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Introduction

Pavement subsurface includes the base, subbase, engineered soil and embankment. The pavement structural design and minimum pavement sections are contained in Chapter 4: HMA and Chapter 5: PCC. This chapter contains requirements and guidance for the design of the pavement subsurface to address concerns such as weak or unstable soils, differential frost heave, and subsurface moisture.

Section 300: Definitions

This section contains several definitions of pavement subsurface components that are used in this chapter. Examples of these terms are illustrated in Figure 300.1.

Figure 300.1 – Example of new rural pavement sections.
Aggregate Base is the layer of aggregate placed below the HMA or PCC pavement. Typically, it is made of a layer of class 5 or class 6 dense-graded aggregates (Specification 3138.2E), but it may also contain a drainable layer. This layer provides; a construction platform for paving, a portion of the pavement structure, a filter layer, and resistance to differential frost heave. This layer also is resistant to the effects of moisture such as; maintaining strength when saturated, resistant to moisture damage, and will not draw water up through capillary action (important for frost resistance). Class 5 and class 6 aggregate base also provide some limited drainage capability. It drains better than non-granular soils, but its drainage capability is much less than designated drainable materials.

Grading Grade is defined by the MnDOT Standard Specifications for Construction as the bottom of the aggregate base.

Subbase is the layer of granular material below the aggregate base. Typically, it is select granular or granular (Specification 3149.2B), but it may also contain layers of class 3 or class 4 aggregates (Specification 3138.2E). Subbase provides resistance to differential frost heave, improved moisture properties as compared to non-granular soils and may provide part of the pavement structure. Subbase must have drains below its outside edges unless it is daylighted to the in-slope.

Top of Subgrade is the surface of material immediately beneath the granular material. If there is no granular material, then the top of subgrade is the grading grade.

Engineered Soil is often referred to as “subcut”, “compaction subcut”, or “uniformity subcut”. It is the layer of select grading material (Specification 2106.1A6) immediately beneath the subbase. This layer provides a uniform, compacted layer for the pavement structure and improves resistance to differential frost heave as compared to the existing soil.

Select Grading Materials are all mineral soils found in the Triaxial Chart in the Grading and Base Manual, excluding silt. Silt is defined as soils containing 80% or more silt-sized particles. Marl and organic soils are also excluded (Specification 2106.1A.6).
Section 310: Aggregate Base and Subbase

This chapter only applies to the materials and specifications of aggregate base and subbase; for thickness and structural requirements see Chapter 4: HMA or Chapter 5: PCC.

1. Aggregate base

Specify the following materials to be used as aggregate base.

A. Dense-graded aggregate base (Specification 3138)

- Class 5 (Specification 3138) – This material is the most commonly used and is applicable in most situations.

- Class 5Q (by Special Provision) – This material may be used where class 5 may be specified. It is a special gradation that is intended to be more convenient to produce when the source aggregate is a quarry or recycled concrete pavement. It is recommended to specify class 5Q only for quantities of at least 10,000 CY and for projects that have a source of aggregate within 20 miles.

- Class 6 (Specification 3138) – This material is generally regarded as a somewhat higher quality material than class 5 because it has fewer fines (improves drainage), more crushed material (improves stability), and a stricter requirement for aggregate properties.

B. Drainable bases (Specification 3136) - There are two types of drainable bases: open graded aggregate base (OGAB) and drainable stable base (DSB).

- OGAB may only be specified with PCC pavements and it must be accompanied by edge-drains. Its use is limited to PCC pavements because its excellent drainability comes at the expense of its stability. The minimum layer thickness is 4.0 inches (see Figure 500.1) and must be placed on dense-graded aggregate base to prevent intrusion of fine materials into the OGAB. The typical installation of OGAB is shown in MnDOT Standard Plan Sheet 5-297.432.

- DSB is a more stable material than OGAB. DSB has less drainability than OGAB but it is still very drainable. It may be used where dense-graded aggregate base is used, but a drainage path must be provided. The drainage path may be provided by either edge-drains or by daylighting the layer to the in-slope.
2. Subbase

The following materials are suitable for use as pavement subbase:

A. Select granular material (Specification 3149.2B.2): This is the most commonly specified material.

B. Select granular material (super sand) (Specification 3149.2B.3): This is select granular material with stricter gradation requirements for material passing the No. 40 and No. 200 sieves, which are intended to improve this materials drainage and frost performance as compare to select granular material. Specifying this material is dependent on its availability, cost, and district preference or experience.

C. Select granular material – modified: Select granular material with the specifications modified by Special Provision or plan note may be specified due to district preference or experience.

D. Class 3 or class 4 aggregate (Specification 3138): For the design of pavements, these materials have a greater structural contribution than the same thickness of select granular. These materials are specified at the discretion of the District Materials/Soils Engineer (see Chapter 4: HMA).

If the subbase is placed in an excavation of non-granular soil (percent passing ratio [No. 200 (75 μm)/1 inch (25 mm)] sieve > 20)) that is not daylighted, then provide longitudinal subcut drains on each side of the subbase (see Section 370: Subsurface Design).
Section 320: Below the Subbase

Any construction beneath the aggregate base and subbase is at the discretion of the District Materials/Soils Engineer. This section contains subgrade treatments and corrections commonly used on MnDOT projects.

1. Subgrade preparation/engineered soil

   The existing soil is normally prepared with the following:

   A. Subgrade preparation (Specification 2112) consists of shaping, mixing, and compacting the top 6.0 inches of existing soil before placing the next layer.

   B. Engineered soil is often referred to as a “subcut”, “compaction subcut”, or “uniformity subcut”. This is a layer of select grading material (Specification 2106.1A6) immediately beneath the subbase. Typically, this layer is constructed by excavating the existing soil to the depth of the engineered soil layer, removing any silt or unsuitable material from the excavated soil, then blending, backfilling, and compacting the excavated soil (specified as select grading material) into the excavation. The source of the select grading material for the backfill does not need to be from the excavation but if it meets materials specifications it may be used. This provides a uniform, compacted layer for the pavement structure and improves resistance to differential frost heave as compared to the existing, undisturbed soil. Engineered soil is typically specified from 1 to 4 feet deep, depending on district preference and experience.

2. Special treatments

   A. Swamp areas

   Swamps are areas where poor foundation soils and/or wet materials are excavated and replaced with a suitable backfill or a floated embankment is used. Poor foundation soils contain >5% organic material by weight, peat, marl, or other soils. Wet material is any material where the soils are described as “wet” in the boring logs. Suitable backfill is typically either granular material or plastic material (select grading material).

   Determine the depth and limits of required excavation by using soil borings (see Section 220: Borings). The MnDOT Foundations Unit (Office of Materials and Road Research) may also be contacted for recommendations.

   (1) Excavation and backfill. In this method, swamp materials are excavated and replaced with suitable backfill. For fills of intermediate height (5 to 20 feet), the typical section shown in Figure 320.1 should be used as a guide.

   a. In general, swamp materials should be excavated outward (from the road centerline) and down from the point of intersection of the proposed side slopes and roadway surface (P.I.) to a depth of about two thirds the swamp thickness. From that point, the swamp materials should be excavated on a slope of 1(V) to ½(H) outward and up to the existing grade and in and down to the bottom of the swamp.
b. For shallow fills of less than about 5 feet, a floated embankment may be used; or the excavation may be made on a steeper slope of 1(V) to \(\frac{1}{2}(H)\), but must extend outward and all of the way down to the bottom of the swamp.

c. For high fills of more than about 20 feet in height, where more excavation is required to maintain stability, the typical section (1(V) to 1\(\frac{1}{2}(H)\) slope), or even flatter, should be maintained and extend outward and all the way down to the swamp bottom. These fills must be designed by a geotechnical engineer.

d. Poor foundation soils may be disposed of outside the completed toe of the roadway embankment. In general, disposal areas for swamp materials should have 1(V) to 10(H) or flatter slopes, unless otherwise specified by the MnDOT Foundations Unit (Office of Materials and Road Research).

e. Backfill material should consist of either granular or select grading. If the excavation is performed underwater, the excavation should be backfilled with granular material to a level at least two feet higher than the local water level. If the excavation is performed in the dry (due to natural causes or the water having been removed from the excavation by sumps and pumping) it may be backfilled with either select grading or granular soils. However, granular soils are generally the preferred swamp backfill material.

f. Caution should be exercised if sumps and surface pumping are used, as such methods may decrease overall stability and result in flowing material or slides and damage to adjacent structures. In some swamp excavations it may be necessary to maintain the natural water level, even by pumping in water, to keep the sides of the excavation stable or to minimize possible settlement of adjacent structures.

g. The proximity of adjacent structures to the excavation should be a carefully considered. The damage that would result from flowing material or slides should be addressed. Installation and monitoring of settlement plates or other instrumentation may be necessary, and should be coordinated with the MnDOT Foundations Unit (Office of Materials and Road Research).
Figure 320.1 - Typical swamp sections.

@SOIL BORINGS
SLOPE RATIOS SHOWN AS H:V
NOT TO SCALE

NOTES:
THIS TYPICAL SECTION MAY BE USED IF ALL OF THE FOLLOWING APPLY:

A. EMBANKMENT FILL IS 20 FT. OR LESS
B. POOR FOUNDATION SOILS DEPTHS (AS MEASURED BY DMAX) ARE 20 FT. OR LESS
C. POOR FOUNDATION SOIL BOTTOM SLOPES TOWARDS CENTERLINE OR IF THE BOTTOM SLOPES AWAY FROM CENTERLINE AT A 6:1 SLOPE OR FLATTER

FOR HIGHER EMBANKMENTS, DEEPER POOR FOUNDATION SOILS AND STEEPER SLOPING BOTTOMS, CONSULT THE GOTECHNICAL ENGINEERING SECTION (OFFICE OF MATERIALS).

1. EXCAVATE POOR FOUNDATION SOILS AND BACKFILL WITH SUITABLE MATERIAL (TO BE DETERMINED BY SOILS ENGINEER). POOR FOUNDATION SOILS CONSIST OF ORGANIC AND MINERAL SOILS WITH GREATER THAN 5% ORGANIC CONTENT BY WEIGHT AND MAY INCLUDE FERT. MARL, OR OTHER SOILS AS DIRECTED BY THE SOILS ENGINEER

2. DISPOSAL AREA AND SLOPE DRESSING. PLACE SUITABLE OR UNSUITABLE BACKFILL MATERIAL AS DIRECTED BY THE SOILS ENGINEER. PLACE A MAXIMUM OF 5 FT. OF EXCAVATED POOR FOUNDATION SOIL. DO NOT PLACE SUITABLE GRADING MATERIAL ON TOP OF ORGANIC SOILS.

3. ADDITIONAL DISPOSAL AREA. PLACE ADDITIONAL UNSUITABLE MATERIAL AND EXCAVATED POOR FOUNDATION SOILS. SPECIFICATION 2105 FURTHER DISCUSSES THE CONSTRUCTION REQUIREMENTS FOR EXCAVATED MATERIAL.

4. FOR DESIGN PURPOSES, USE 10:1 (H:V) SLOPE UNLESS OTHERWISE RECOMMENDED BY THE SOILS ENGINEER

5. EXCAVATION SLOPE COMING UP OUT OF BOTTOM SHALL BE 1/2:1 TO 2:1 AS RECOMMENDED BY THE SOILS ENGINEER. AS A MINIMUM, THE EXCAVATION SHOULD REMOVE POOR FOUNDATION SOILS TO THE FULL WIDTH OF THE EMBANKMENT.
(2) Floated embankment. In the placement of a floated embankment, existing trees, brush, and other surface vegetation is clear cut with only minimal disturbance to the existing vegetative mat. The embankment is placed directly over the existing swamp, proceeding from the toes in toward the road centerline, with the slope width, including berms, exceeding twice the depth of the swamp. Typically, this method requires less fill material because the swamp material is not removed. Placement of geosynthetics (geotextiles or geogrids) between the swamp and placed embankment materials is recommended in order to minimize ruts, expedite work, increase allowable stresses on the swamp subgrade and to allow the floated embankment to act as a cohesive whole. It should be noted that the use of geosynthetics will not eliminate settlement, but will tend to make it more uniform.

It may also be desirable to use light weight fill (e.g., geofoam, wood chips, shredded tires, etc.) for floating the embankment.

Note: The use of geosynthetics for earth reinforcement (MnDOT Specification 3733, type VI), or the use of light weight fill, should be coordinated with and studied by the MnDOT Foundations Unit (Office of Materials and Road Research).

(3) Embankment widening on weak soils. The placement of additional fill adjacent to an existing roadway may be accomplished by either excavation and backfill or use of a floated embankment. In either case, particularly if excavation and backfill is used, the stability of the old road core should be considered. Figure 320.2 depicts embankment widening over weak soils. This type of work should be studied and coordinated with the MnDOT Foundations Unit and/or MnDOT Pavement Design Unit (Office of Materials and Road Research).
Figure 320.2 – Cross-section of an embankment over an existing roadway in swamp area.
B. Subgrade correction

Subgrade Corrections are used to eliminate specific unstable conditions in the subgrade of an existing road (e.g., frost heaves and subgrade failures). These areas may be visually apparent and may appear as weak areas in Falling-Weight Deflectometer (FWD) data (see Section 200: Falling-Weight Deflectometer (FWD)). Take borings to identify if poor/wet foundation soils are present and to determine the depth and limits of the subgrade correction (see Section 220.2.D. (2: Subgrade corrections)).

Remove any poor/wet foundation soils and backfill with uniform soils. Poor foundation soils contain peat, marl, >5% organic material by weight, or other soils as directed by the District Materials/Soils Engineer. Wet materials are any soils that are described as “wet” in the boring logs. Backfill is typically either granular material or select grading material (if the excavation is dry). Wet areas may be drained with subsurface drains or by daylighting the granular material to the ditch.

C. Shadow treatment

Differential heave may occur at the limits of the shadow cast by an overhead bridge. In locations where this may occur, excavate 2 feet deeper than the subbase and backfill with granular material. This treatment should extend for at least 150 feet, plus tapers, on either side of the bridge.

D. Rock excavation

(1) Preliminary designs for rock excavation must be based on MnDOT's Road Design Manual, Section 4-6.02. Final designs should be established only after completion of a detailed geological investigation.

(2) Roadway excavations require the determination of the rock excavation method (mechanical or explosive) and transitions into and out of rock sections. Both transverse and longitudinal transitions should be provided in the design to minimize differential cracking. (Generally, rock designs provide for 6.0 inches of paid overbreak below the bottom of the rock subcut).

E. Muck excavation with automated machine guidance (AMG)

Specify the use of AMG for muck excavations when quantities are greater than or equal to 50,000 cubic yards, when muck excavation activities are anticipated to be under water (consider the size and/or depth of excavation activities), or if conditions make it difficult to use conventional survey methods for creation of the as-built surface and calculation of volumes.
3. Embankments

A. Any embankment in the road core must be either select grading or granular material. Non-structural grading materials (Specification 2105.1A8) may be used as embankment outside the road core (as described in the standard specifications).

The road core (2105.1A1) is defined as the area below the grading grade to the bottom of the excavation and between the following:

- For embankment heights ≤ 30 ft., from the grading grade point of intersections (P.I.s) with a 1(V) to 1(H) slope and
- For embankment heights > 30 ft., from the grading grade point of intersections (P.I.s) with a 1(V) to 1½(H) slope.

B. Slope preparation. Embankments which are to be widened and have in-slopes steeper than 1(V) to 4(H) require that the slopes be flattened to this slope, or flatter; or that steps (benches) be cut into the slope (See MnDOT's Specification 2105.3C). The material used for the embankment widening should substantially match the existing embankment material in terms of textural classification, color, moisture and performance characteristics.

C. Controlled rate/surcharge. Compressible silts, clays, and organic deposits may be improved by surcharging. A surcharge is applied in controlled lifts to the area to be treated and allowed to remain while the foundation soils consolidate sufficiently to increase their strength or reduce compressibility. After sufficient time for the required compression has occurred, either the surcharge is removed or additional fill may be placed. Surcharging has proven to be a relatively inexpensive method of treating deep compressible deposits.

D. Monitoring of embankment settlements and movements is done through the installation of settlement plates, control points or other instrumentation. Installation and location of settlement plates on, and control points outside of, the embankment should be coordinated with the MnDOT Foundations Unit (Office of Materials and Road Research).
4. Transitions

Transitions between different materials and depths should be tapered to avoid differential movement (e.g., frost heaving) of the pavement. The following transitions should be provided:

A. When connecting new surfacing, cut vertically to the bottom of the existing aggregate base (or to the bottom of the new aggregate base, whichever is deeper) then diagonally at a 1(V) to 1(H) slope to the bottom of the recommended subgrade excavation.

B. When connecting to existing roadways at the termini of proposed new construction, cut vertically to the bottom of the existing aggregate base (or to the bottom of the new aggregate base, whichever is deeper); then at a 1(V) to 20(H) taper to the bottom of the recommended subgrade excavation.

C. When matching into existing crossroads, cut vertically to the bottom of the existing surfacing (or to the bottom of the new surfacing design, whichever is deeper) then at a 1(V) to 4(H) slope to the bottom of the recommended subgrade excavation.

D. Provide 1(V) to 20(H) tapers when transitioning between subsurface layer depths. Tapers between non-granular and granular must should be constructed so that the granular soil overlays the plastic soil.

5. Topsoil removal

Provide a depth of existing topsoil to be removed and reused in areas that will be disturbed by construction.
Section 330: Compaction

Compaction is the process of increasing the density of aggregate or soil by reducing its air voids using mechanical means, such as rolling or tamping. It is carried out to improve the material’s engineering properties such as load-bearing capacity, stability, stiffness, volume change characteristics, and resistance to settlement and frost damage. The inspection of compaction activities and their results is necessary to ensure that the materials compaction is sufficient.

Specify, in the MDR, the appropriate method of compaction testing of aggregates and embankment. In most instances more than one method is available and which method to specify will be based on district experience/preference and available resources.

1. Aggregate

   A. Specified density (Specification 2211.3.D.2.a)

      Specified density is used only for virgin aggregate base material. The specified density method compares the density of the compacted material to a reference value determined in the laboratory from a proctor test.

   B. Quality compaction (Specification 2211.3.D.2.b)

      Quality compaction is the compaction of each lift until there is no further evidence of consolidation. It is the default compaction requirement for aggregate surfacing.

   C. Penetration index (Specification 2211.3.D.2.c)

      Penetration index (PI) is the default method of compaction testing for aggregate base. The penetration index method is based on testing the compacted material with a dynamic cone penetrometer (DCP). A DCP consists of two 5/8 inch shafts coupled near mid-point. The lower shaft contains an anvil and a pointed tip which is driven into the ground by dropping a sliding hammer contained on the upper shaft onto the anvil. The amount that the shaft penetrates into the soil (recorded in millimeters) per blow is known as the DCP penetration index (DPI). The allowable DPI for different materials and moisture contents is given in Table 2211-3 of the MnDOT Standard Specifications for Construction.
2. Embankment (soils and granular materials)

A. Compaction testing not required

Mechanical compaction is not required on portions of the embankment that are constructed with predominantly stone or rock fragments or placed in conjunction with topsoil covering or roadside grading. Compaction testing should not be used on waste materials or non-rock material (topsoil, etc.) utilized for incidental drainage or landscaping outside the roadbed embankment. However, it is the responsibility of the project field inspector to approve that the placed material is a compact mass that is acceptably consolidated.

B. Specified density (Specification 2106.3.F.1)

Specified density is used for embankment material that doesn’t meet the definition of granular. The Specified density method compares the density of the compacted material to a reference value determined from a proctor test. The requirement for the percentage of the reference density for the existing material is found in specification 2105.3.F.1.

C. Quality compaction (Specification 2106.3.F.2)

Quality compaction is the compaction of each lift until there is no further evidence of consolidation.

D. Penetration index (Specification 2106.3.F.3)

The Penetration index (PI) is used when the material that is being compacted meets the definition of granular.

The penetration index method is based on testing the compacted material with a dynamic cone penetrometer (DCP). A DCP consists of two 5/8 inch shafts coupled near mid-point. The lower shaft contains an anvil and a pointed tip which is driven into the ground by dropping a sliding hammer contained on the upper shaft onto the anvil. The amount that the shaft penetrates into the soil (recorded in millimeters) per blow is known as the DCP Penetration Index (DPI). The allowable DPI for different materials and different moisture contents is given in Table 2105-6 of the MnDOT standard specifications for Construction.

E. Test rolling (Specification 2111)

Test rolling is an evaluation of a subgrade or subbase with a heavy roller to evaluate the adequacy of the roadbed construction relative to uniformity and consistency of the subgrade support in terms of strength, stiffness, stability, density and moisture content. The test roller will detect weak/unstable subgrade areas due to inadequate compaction (both in terms of moisture content and density), and/or unstable soils to a depth of about 5 feet. The failed areas will require corrective measures. These measures may include removing the unstable/unsuitable soils, reducing the moisture content by aeration, or the re-compaction of the soil.

Test rolling in accordance with MnDOT 2111 is not, generally, recommended for the following situations.
(1) Embankments or backfills thinner than 30.0 inches. Test rolling these shallow areas probably will not pass the 2111 requirements.

(2) Roadbed construction where shallow underground utilities are present.

(3) Roadway segments with numerous, closely spaced, shallow, underground structure (culvert, storm sewers, other utilities, etc.). In all situations where test rolling is used, shallow structures must be protected against damage from the test roller. Structures should have at least 30.0 inches of soil cover prior to testing the subgrade. This depth may require the temporary increase in soil cover over the structure (construction of a blister).

(4) Roadway segments with relatively closely spaced bridge overpasses.

(5) Areas where geo-synthetics are placed within the upper 5 feet of the embankment.

F. Proof rolling (special provision)

Proof rolling is a method, similar to test rolling, to evaluate the adequacy of subgrade compaction. The weight of the testing equipment (a loaded truck) is substantially lower with proof rolling and therefor the depth that is being tested is less. Contact the MnDOT Grading and Base Unit (Office of Materials and Road Research) for available Proof Rolling Special Provisions.
Section 340: Shrinkage Calculation

Provide soil shrink/swell factors if the project uses Specification 2105 for excavation and embankment. Shrinkage factors are not required when Specification 2106 is used for excavation and embankment. In this instance, the contractor is responsible for their own shrinkage calculations.

Shrink/swell factors are determined by locating the material source and then estimating their volume change from their undisturbed condition to their reworked and compacted condition (although, MnDOT, typically, does not specify the borrow sources to use for a project). This change is referred to as the shrink (if the compacted density is greater than the in situ density) or swell (if the compacted density is less than the in situ density) of the material. The factor is particularly important when haul distances are long.

A shrinkage factor of 100 percent means that a material will occupy the same volume when placed and compacted in the roadway as it did in the ground prior to excavation. A factor greater than 100 means that the natural material will shrink and more borrow or excavation material will be needed to build the planned embankment. A factor less than 100 percent indicates that the natural material will swell (i.e., its density at the borrow source is greater than its expected density in the roadway embankment).

One complication to be considered when determining shrinkage factors is the consolidation of the underlying foundation soils during construction. This consolidation can induce roadbed settlement in tilled fields, which would have a dramatic effect on the amount of fill needed on the project. The shrinkage factor is therefore the sum of the compaction factor plus other factors. If varying conditions are encountered, more than one shrinkage factor may be required.

The preferred method to determine the shrinkage/swell factor is to obtain undisturbed soil samples from the borrow pit and measure their in situ density and moisture content. These undisturbed soil samples may be taken either at the surface or in shallow excavations. In the case of non-granular soils, MnDOT Foundation Unit (Office of Materials and Road Research) drill rigs can obtain undisturbed thin-wall tube samples at depth. Densities of deep granular soils are most commonly estimated from N$_{60}$ values (the SPT N value corrected for field procedures).

The existing density values should be compared against the Proctor density/moisture curves to arrive at a compaction factor. Although MnDOT's specifications may call for 95 or 100 percent of AASHTO T99 (Method C) density, the as-built density may be greater than the specification density. Investigation 183, “Application of AASHO Road Test results to Design of Flexible Pavements in Minnesota”, concluded that non-granular fills are generally placed about 3 percent above specification density, while granular fills are generally about 4 percent higher.

After the compaction factor is calculated, it should be adjusted for foundation consolidation to arrive at an estimated shrinkage factor (Shrinkage Factor = Compaction Factor plus other factors).

Shrinkage factors have, in the past, included the disposal of unsuitable material: this practice is misleading and should be discontinued. A separate calculation should be made to determine the amount of unsuitable materials (primarily organic soils) that cannot be utilized on the job. Likewise, estimates of swamp shrinkage should be made separately due to complicating factors such as vertical subsidence and lateral compression. Guidance in this area may be obtained from the MnDOT Foundations Unit (Office of Materials and Road Research).

The MnDOT Geology Unit (Office of Materials and Road Research) should be contacted for an estimate of swell when rock cuts are being considered. Generally, rock shrinkage factors will be less than 100 percent.
It may not be necessary to make an estimate of the shrinkage factor for particularly small projects where exploratory resources are not available. In these situations, it is acceptable to use prior experience and outside sources to estimate factors. One such source of existing engineering properties of Minnesota soils is the Natural Resources Conservation Service’s [Web Soil Survey](#).

Another source of published shrinkage factors is an MHD study performed by W.W. Dreveskracht. A regression analysis of some 70 compaction versus depth of excavation calculations resulted in the values presented in Table 340.1.

**Table 340.1 - Compaction Factor vs Depth**

<table>
<thead>
<tr>
<th>Depth Feet</th>
<th>Compaction (Shrinkage) Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>122</td>
</tr>
<tr>
<td>2</td>
<td>116</td>
</tr>
<tr>
<td>5</td>
<td>108</td>
</tr>
<tr>
<td>10</td>
<td>102</td>
</tr>
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<td>15</td>
<td>98</td>
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<tr>
<td>20</td>
<td>96</td>
</tr>
<tr>
<td>25</td>
<td>94</td>
</tr>
<tr>
<td>30</td>
<td>92</td>
</tr>
</tbody>
</table>

The values given are compaction factors only and do not include other factors, such as equipment shrinkage, which must be considered to arrive at an estimated shrinkage factor.

An additional adjustment may be made to account for accidental loss or waste during hauling. This adjustment should change the final factor by no more than five percent.

Lastly, past MnDOT experience indicates that field conditions (e.g., depth, overburden and material type) impact the shrinkage or swell as shown in Table 340.2.
<table>
<thead>
<tr>
<th>Type</th>
<th>Material/Area</th>
<th>Shrinkage Factor (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock</td>
<td>Sandstone</td>
<td>90 - 100</td>
</tr>
<tr>
<td>Rock</td>
<td>Limestone, granite, basalt, etc.</td>
<td>70 - 90</td>
</tr>
<tr>
<td>Rock</td>
<td>Shale</td>
<td>90 - 110</td>
</tr>
<tr>
<td>Soil</td>
<td>Deep cuts and high fills</td>
<td>100 - 130</td>
</tr>
<tr>
<td>Soil</td>
<td>Normal cuts and fills</td>
<td>130 - 140</td>
</tr>
<tr>
<td>Soil</td>
<td>Ditch cuts and shallow fills</td>
<td>135 - 150</td>
</tr>
<tr>
<td>Soil</td>
<td>Shoulder grading</td>
<td>140 - 150</td>
</tr>
<tr>
<td>Soil</td>
<td>Light shoulder grading</td>
<td>150 – 165</td>
</tr>
<tr>
<td>Swamp Backfill</td>
<td>Removing small amount of topsoil</td>
<td>130</td>
</tr>
<tr>
<td>Swamp Backfill</td>
<td>5 ft. below natural ground</td>
<td>135</td>
</tr>
<tr>
<td>Swamp Backfill</td>
<td>10 ft. below natural ground</td>
<td>140</td>
</tr>
<tr>
<td>Swamp Backfill</td>
<td>15 to 20 ft. below natural ground, irregular bottom</td>
<td>145</td>
</tr>
<tr>
<td>Swamp Backfill</td>
<td>About 30 ft. below natural ground, very irregular bottom</td>
<td>150</td>
</tr>
</tbody>
</table>
Section 350: Infiltration

Infiltration of water into the ground is a practice used to reduce the amount of water that would normally drain as a surface flow. However, water can be damaging to pavement structures and areas used for infiltration should be limited to areas where the water will not degrade the pavement. Follow these guidelines for the location of infiltration with regard to pavement sections.

On state highways, do not introduce water into any area that may increase moisture in the base, subbase, or existing soil above the groundwater table.

- In rural cross-sections, this area extends from shoulder PI to PI and downward and outward at 1(V) to 2 (H) slopes (see Figure 350.1) to the top of the groundwater table.

- For urban cross-sections, the width of this area is 12 feet beyond the back-side of the curb to the depth of the base and subbase, and from the back of the curb down to the top of the groundwater table (see Figure 350.2). Infiltration may be allowed within 1 foot of the back of the curb if an impermeable barrier is used to protect the base, subbase, and existing soil (see Figure 350.2).

Non-highway pavements, such as sidewalks, driveways, parking lots, utility roads, and some low-speed low-volume city streets may be designed to allow infiltration under their structure. A minimum of 6.0 inches of aggregate material should be placed under the pavement and above the depth of any infiltration. This will act to drain the pavement material and keep moisture from being introduced to the pavement from below. Although, the minimum aggregate depth is not sufficient to reduce frost heaving and will have a minimal effect on loss of pavement section strength from saturation.

Note: These guidelines only address concerns related to the pavement section. There may be additional considerations related to slope stability, maintenance, and other factors that must be addressed.
Figure 350.1 - Rural roadway section.

Figure 350.2 - Urban roadway section.
Section 360: Culvert and Storm Drain Bedding and Backfill

This section covers the bedding and backfill treatments of culverts, storm drains, and concrete box culverts with less than a 20-foot deep excavation. Treatments for excavations greater than 20 feet must be designed by a registered Geotechnical Engineer.

For the purposes of this manual, culverts are defined as structures that are open on each end to convey surface water under a highway, railroad or embankment. Since culverts are open on each end, air is generally allowed to flow through, resulting in frozen ground conditions in the area immediately surrounding the culvert. For this reason culverts generally have more rigorous bedding and backfill requirements than storm drains.

Per MnDOT Standard Specification 2501, entrance culvert designs are reviewed on a case-by-case basis. Only use the bedding details shown in this section if specifically requested by the District Hydraulics or Materials Engineer.

Storm drain is defined as part of the drainage system that receives runoff from one or more inlets and conveys the runoff through a closed-conduit to a discharge point. Since free air flow through the system is generally limited, storm drain typically does not experience the same freezing conditions as culverts, and has lesser requirements for bedding and backfill.

The following details and recommendations for bedding pipes and box culverts are based upon successful past practice. However, the District Materials and/or Soils Engineer is free to use engineering judgement to modify them to suit the unique conditions (frost depth, material properties, etc.), or construction requirements that may exist at a particular site.

1. Bedding and backfill of rigid pipe culverts

Rigid pipe culverts are made from reinforced concrete and should be bedded as shown in Figure 360.1. Rigid centerline pipe culverts (culverts that cross the roadway centerline) will generally be designed with special backfill treatment and granular backfill tapers as shown below (Figures 360.2 - 360.4) to help to reduce the differential heave at the roadway surface caused by frost penetration into the soil around the pipe, particularly if the in situ soils are non-granular. These treatments are in addition to using the aforementioned bedding detail (Figure 360.1). Hence, for rigid pipe culverts the project Materials Design Recommendation (MDR) should specify which backfill treatment and frost depth to use, any modifications to the standard backfill treatment, and whether to use a plastic soils cap (refer to Figure 360.15).
A. Backfill treatments for rigid centerline pipe culverts

The treatments are shown below and are available as electronic dgn files on the MnDOT Design Standards Unit website under “Design Details” (PDF of same drawings, says dgn on projectwise).

**Treatment # 1** - Applies to all rigid culverts with granular existing soil (**Figure 360.2**).

**Treatment # 2** - Applies to rigid culverts with existing non-granular soils where the frost depth* is *above* the center of the pipe (**Figure 360.3**).

**Treatment # 3** - Applies to rigid culverts with existing non-granular soils where the frost depth* is *below* the center of the pipe (**Figure 360.4**).

*Districts have developed standard frost depth for the specification of culvert treatments.

The notes in **Figure 360.1** include provisions for allowing coarse filter aggregate beneath the pipe when installing in wet conditions.

**Figures 360.5 through 360.7** provide additional information and details regarding the lateral and longitudinal extent of the culvert treatments. The area noted as "Zone A" depicts the slopes and details in the immediate vicinity of the pipe. "Zone B" depicts the details further away from the pipe. The sketches shown portray the taper slopes and details for rigid centerline culvert treatment #2, treatments 1 & 3 and those for flexible pipes are similar, but vary slightly. These sketches are shown for general reference and are not intended to be included in the roadway plans.

Refer to the MnDOT Drainage Manual for information regarding maximum & minimum fill height for culverts and storm drains. The MnDOT Drainage Manual is available at the hydraulics website.

B. Geotextile

A geotextile (MnDOT Standard Specification 3733, type V) is often specified for use below the aggregate bedding for separation and stabilization if the existing soils are soft and/or unstable. If a geotextile is required it should be included in the MDR.
CONSTRUCTION SEQUENCE

1. Place and compact 6" of fine aggregate bedding to the requirements of Spec. 2105.
2. Compact 6" of fine aggregate bedding material to grade. Do not compact prior to pipe placement.
3. For pipes with bell, remove material in bell area prior to placement.
4. Furnish and install pipe to grade.
5. After placement of the pipe, place additional bedding and compact the full length on both sides of the pipe underneath the launch area by first shoveling gravel, then applying the pipe end of a shovel at an angle down the entire length of the launch area. Compact the pipe in two increments: 6" and 6". Compact the remaining material outside the launch area to the requirements of the applicable material type ensuring that the entire length of pipe is supported uniformly by bedding.
6. Place and compact backfill evenly and simultaneously in 6" lifts on each side of the pipe up to the mid-height when compacted.
7. Complete remaining backfill per the appropriate treatment requirements.

NOTES

Excavate & construct all trenches and slopes per OSHA requirements.
All slopes shown are nominal.

PIPE SIZE IS BASED ON THE NOMINAL INSIDE DIAMETER.

1. (If approved by the engineer) in wet conditions, the contractor may substitute 18" of coarse filter aggregate per 3149.2-4 compacted to the quality compaction requirements of Spec. 2105, wrap with geotextile fabric Type IV per Spec. 3735, seam all fabric sides and ends per Spec. Table 3735-1, including footnote "A." or overlap a minimum of 5 ft. All at no additional cost.

2. For fill heights less than 3 ft., omit h/2 taper.
3. For installations on intact bedrock, omit this layer.
4. Over excavation beneath tapers is not permitted unless required by OSHA Type IV.
5. Maximum embankment particle size within 2 ft. of pipe is 3" per Spec. Table 2105-4.

PROJECT ALL PIPE DURING CONSTRUCTION PER Spec. 2501 or 2503.
PLACE MULTIPLE PIPE CULVERTS WITH A MINIMUM CLEARANCE OF 24 INCHES OR GREATER BETWEEN STRINGS OF PIPE.

LEGEND

- Nominal inside diameter or span of pipe
- Outside diameter of round pipe, or outside span of pipe-arch
- Fill cover height over pipe (feet)
- Unmodified soil
- Span

NO TRENCHES ARE REQUIRED. NOTES SHOULD BE REMOVED BEFORE PREPARING FINAL PLAN.
Figure 360.2 – Treatment # 1: rigid culverts with existing granular soil.

Figure 360.3 – Treatment # 2: rigid culverts with existing non-granular soils where the frost depth is above the center of the pipe.
Figure 360.4 – Treatment #3: rigid culverts with non-granular existing soils where the frost depth is below the center of the pipe.

Figure 360.5 – Longitudinal section view
Figure 360.6 – Cross section view

Figure 360.7 – Isometric view
2. Bedding and backfill of rigid pipe storm drain

The main purpose for bedding and backfilling storm drain with granular materials is to provide for good compaction and support around the pipe, as shown in Figure 360.8.

Figure 360.8 – Rigid pipe storm drain bedding

CONSTRUCTION SEQUENCE

1. Loosely place 6" of fine aggregate bedding material to grade, do not compact prior to pipe placement.
2. For pipes with bell, remove material in bell area prior to placement.
3. Finish and install pipe to grade.
4. After installation of pipe, place additional fine aggregate bedding and compact the full length on both sides of the pipe underneath the launch area by first shoveling manually and then compacting the sides using a powered mechanical or pneumatic device such as a pole tamper, jumping jack, or similar. Compact the remaining material outside the launch area to the requirements of Spec. 2105 ensuring that the entire length of pipe is supported uniformly by bedding.
5. Place and compact backfill evenly and simultaneously in 6" lifts on each side of the pipe up to the mid-height when compacted.
6. Complete remaining backfill.

NOTES

Excavate & construct all trenches and slopes per OSMA requirements.
Pipe size is based on the nominal inside diameter.
Protect all pipe during construction per Spec. 2500 or 2503.

Granular backfill above storm drain may result in a granular block wholly within the frost zone of plastic soils, which can cause frost heave. In addition, on urban highways with numerous small diameter shallow storm drain lines crossing at close intervals, backfilling with granular materials becomes quite costly and may create construction difficulties. Therefore, it is recommended that all storm drain be backfilled with the same or similar material found in the excavation that meets "Selected Grading Material" as defined under MnDOT Standard Specification 2106.1.A.6 unless otherwise recommended by the District Materials and/or Soils Engineer. The Select Grading Material may be either plastic or granular soil as long as it meets 2106.1.A.6 and is free of clods, stones over 3 inches, sod and roots.

Do not use the culvert backfill treatments shown above for closed-end storm drainage systems. However, they may be used on open-end (i.e. outlet apron) storm drain pipe located under roadway pavements if recommended by the District Materials and/or Soils Engineer. If a special granular backfill is required, consider using a treatment type similar to those shown above (Figures 360.2-360.4).
3. Bedding and backfill of flexible pipe culverts

Flexible pipe culverts include those made from high density polyethylene (HDPE), polypropylene (PP), polyvinyl chloride (PVC), or metal and should be bedded as shown in Figure 360.9. Refer to chapter 2 of the MnDOT Drainage Manual for information regarding restrictions on pipe material types. Similar to rigid pipe culverts, centerline flexible pipe culverts may also need to be constructed with special backfill treatments and granular backfill tapers to help to reduce the differential heave at the roadway surface caused by frost penetration into the soil around the pipe, particularly if the in situ soils are non-granular. These treatments are in addition to using the aforementioned bedding detail (Figure 360.9). Hence, for flexible pipe culverts the project MDR should specify which backfill treatment and frost depth to use, any modifications to the standard backfill treatment, and whether to use a plastic soils cap.

A. There are three different backfill treatments for flexible pipe culverts. The treatments are shown below and are available as electronic dgn files on the MnDOT Design Standards Unit website under “Design Details”.

**Treatment # 1** - Applies to all flexible culverts with granular existing soil (Figure 360.10).

**Treatment # 2** - Applies to flexible culverts with existing non-granular soils where the frost depth* is above the center of the pipe (Figure 360.11).

**Treatment # 3** - Applies to flexible culverts with existing non-granular soils where the frost depth* is below the center of the pipe (Figure 360.12).

*Districts have developed standard frost depth for the specification of culvert treatments.

The notes in Figure 360.9 include provisions for allowing coarse filter aggregate beneath the pipe when installing in wet conditions.

Details regarding the lateral and longitudinal extent of culvert treatments are similar to those for rigid culverts as shown in Figures 360.5 through 360.7. These sketches are shown for general reference and are not intended to be included in the roadway plans.
CONSTRUCTION SEQUENCE

1. Place and compact 18" of fine aggregate bedding to the requirements of SPEC 2105.
2. Place additional bedding and compact the full length on both sides of the pipe level with the final bed surface. The full length of the pipe is supported uniformly by bedding.
3. Pipe installation may require the use of restraints,asd by approved methods in order to keep maintain grade and alignment.

NOTES

EXCAVATE & CONSTRUCT ALL TRENCHES AND SLOPES PER OSHA REQUIREMENTS.
ALL SLOPES SHOWN AS 1:1.0ND PIPE SIZE IS BASED ON THE NOMINAL INSIDE DIAMETER.
OF APPROVED BY THE CONTRACTOR MAY SUBSTITUTE 18" OF COARSE FILTER AGGREGATE PER 3149.2H COMPLIANT TO THE QUALITY COMPACTION REQUIREMENTS OF SPEC 2105, WRAP WITH GRID TILTED PAPER TYPE IV PER SPEC 3733, SEAM ALL FABRIC SIDES AND ENDS PER SPEC TABLE 3733-1 INCLUDING FOOTNOTE (A) OR OVERLAP A MINIMUM OF 3 FT. ALL AT NO ADDITIONAL COST.
FOR FULL HEIGTHS LESS THAN 3 FT. OMIT 1/2" TAPER.
TREND WIDTHS FOR TRENCH WIDTHS FOR THERMOPLASTIC PIPE WITH MORE THAN 30 FT. OF FILL OVER THE PIPE.
MAXIMUM EMANEMENT PRIORITY SIZE WITHIN 3 FT. OF PIPE IS 3" FOR METAL PIPE AND 1" FOR PLASTIC PIPES.
PROTECT ALL PIPE DURING CONSTRUCTION PER SPEC 2502 OR 2503.
PLACING MULTIPLE PIPE CULVERTS WITH A MINIMUM CLEARANCE OF 24 INCHES OR GREATER BETWEEN SPRINGS OF PIPE.
DESIGNER NOTE:
DESIGN AND SPECIFY FOR EXCAVATIONS GREATER THAN 30 FT. DEEP SHALL BE DESIGNED BY A REGISTERED ENGINEER.

LEGEND

Dn: Nominal Inside Diameter or Span of Pipe
Dn: Outside Diameter of Round Pipe or Outside Span of Pipe-Arc,
H: Fill Over Height Over Pipe (Feet)
* Uncoated Soil

NOTES: PIPE SHALL BE DESIGNED MODIFIED OR REVISN BEFORE SOIL SHEET PER FINIAL PLAN.
Figure 360.10 – Treatment #1: flexible pipe culverts with existing granular soil.

Figure 360.11 – Treatment #2: flexible pipe culverts with existing non-granular soils where the frost depth is above the center of the pipe.
Figure 360.12 – Treatment #3: flexible Culverts with non-granular existing soils where the frost depth is below the center of the pipe.

Trench width tables for the various types of flexible pipe are included in the electronic dgn files on the MnDOT Design Standards Unit website under “Design Details” and are also published in the MnDOT Drainage Manual. In general, they are equal to or wider than the trench width required for rigid pipe.

Refer to the MnDOT Drainage Manual for information regarding maximum & minimum fill height for flexible culverts and storm drains.

B. Geotextile

If the existing soils are soft and/or unstable consider requiring a geotextile (MnDOT Standard Specification 3733, type V) below the aggregate bedding for separation and stabilization. If a geotextile is required include it in the MDR.
4. Bedding and backfill of flexible storm drain

The main purpose for bedding and backfilling storm drain with granular materials is to provide for good compaction and support around the pipe, as shown in Figure 360.13.

**Figure 360.13 – Flexible pipe storm drain bedding**

<table>
<thead>
<tr>
<th>TRENCH WIDTH + B</th>
<th>TRENCH BASE WIDTH</th>
<th>( \Delta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5&quot; to 48&quot;</td>
<td>0.5&quot; to 48&quot;</td>
<td>( \Delta )</td>
</tr>
<tr>
<td>35° or less</td>
<td>0.5&quot; x 0.5&quot;</td>
<td>( \Delta )</td>
</tr>
<tr>
<td>42&quot; or more</td>
<td></td>
<td>( \Delta )</td>
</tr>
</tbody>
</table>

**CONSTRUCTION SEQUENCE**

1. Loosely place 6" of fine aggregate bedding material to grade, do not compact prior to pipe placement.
2. For pipes with bell, remove material in bell area prior to placement.
3. Furnish and install pipe to grade.
4. After installation of pipe, place additional fine aggregate bedding and compact the full length on both sides of the pipe underneath the backfill area by first shoveling manually shoveling the blade of shovel at an angle down the entire length of backfill and then compact the backfill at an angle using a powered mechanical or pneumatic device (i.e., pole tamper, jumping jack, or similar), compact the remaining material outside the backfill area to the requirements of Spec. 2105, ensuring that the entire length of pipe is supported uniformly by bedding.
5. Place and compact backfill evenly and simultaneously in 6" lifts on each side of the pipe up to 12" above the pipe when compacted.
6. Complete remaining backfill.

**NOTES**

Excavate & construct all trenches and slopes per OSHA requirements.
Pipe size is based on the nominal inside diameter.
Protect all pipe during construction per Spec. 2501 or 2503.

Similar to rigid storm drain, backfilling a flexible storm drain with granular material within the frost zone and within plastic soils, may cause a frost heave. Therefore, it is recommended to backfill with the same or similar material found in the excavation that meets Selected Grading Material as defined under Specification 2106.1.A.6, unless modified by the District Materials and/or Soils Engineer. The Select Grading Material may be either plastic or granular soil as long as it meets 2106.1.A.6, and is free of clods, stones over 3 inches for metal pipes (1" for material within 2 ft. of plastic pipe), sod and roots.

Do not use the culvert backfill treatments shown above for closed-ended storm drainage systems. However, they may be used on open-end (i.e. outlet apron) storm drain pipe located under roadway pavements, if recommended by the District Materials and/or Soils Engineer. If a special granular backfill is required, consider using a treatment type similar to those shown above (Figures 360.2-360.4).
5. Bedding and backfill of concrete box culverts

Bed concrete box culverts in accordance with Figure 360.14. Include in the MDR the depth at which the 1:20 taper begins. Similar to pipe culverts, one may use coarse aggregate bedding to bed culverts in wet locations.

Figure 360.14 – Box culvert bedding and treatment
6. Plastic soils cap at the end of drainage structures

Erosion and piping may occur in the granular bedding and/or the backfill of drainage structures on either the inlet or outlet ends, although, the problem is generally more prevalent at the inlet. Scour is generally less of a problem when flare-type aprons are provided for the structure.

Large pipe and precast box culverts normally have concrete aprons and drop walls to protect the bedding from erosion. However, this may not be sufficient to prevent erosion around the structure, especially with flooding conditions and granular embankments.

**Figure 360.15 – Plastic soil cap treatment at culverts**

To alleviate this potential problem, a plastic soil cap as shown in **Figure 360.15** should be recommended in the MDR when erosion of a pipe or box culvert is a concern or for any other structures identified by the District Hydraulics Engineer. The end treatment normally will only be required at the inlet end of the structure; however, when deemed necessary it may also be used at the outlet end. The end treatment may be recommended for use with either granular embankments or plastic soil embankments when granular backfill treatments are provided.
Section 370: Subsurface Drainage

Excess subsurface water has a detrimental effect on both HMA and PCC pavements and the lower pavement layers. It reduces the strength of the aggregate base, subbase, and soil which may cause pavement cracking or rutting, deterioration of existing pavement cracks and joints, and promotes frost heave. To address the problem of subsurface water, base and subbase layers may be daylighted to the ditch or subsurface drains may be installed. The following discuss alternatives for removing subsurface water.

1. Subsurface drain types and design guidelines.

MnDOT uses several types of drains to remove water from pavement structures. The following is a list of these types, including recommendations for their use.

A. Subcut drains (specification 2502.3.f).

Subcut sections are at high risk for collecting potentially damaging subsurface water because these sections may create a “bathtub” by extending relatively permeable material below the natural, less permeable grade. Subcut drains are designed to remove the water from this “bathtub”. They are typically a longitudinal perforated pipe located in the bottom of each of the outer-most corners of granular backfilled subcuts (see MnDOT Standard Plan 5-297.430 and 5-297.433). The use of subcut drains is recommended for most situations.

B. Edge-drains

Edge-drains are installed along each side of the mainline pavement and are intended to drain a portion of the pavement structure. There are two types of edge-drains, pavement edge-drain type (specification 2502.3.g) and permeable aggregate base type (Specification 2502.3.e).

(1) Pavement edge-drain type drains (Specification 2502.3.g)

Pavement edge-drains type drains may be installed during the construction of a new pavement structure or (more typically) retrofitted into an existing pavement structure. These drains consist of a perforated pipe, wrapped in a geotextile fabric, which is placed in the bottom of a trench filled with fine filter aggregate (Specification 3149.2.J.2) (see MnDOT Standard Plan 5-297.432). They are used to collect and discharge water infiltrating into the pavement system from rain, snow melt, and spring-thaw seepage. While these drains are effective in mitigating water that infiltrates through the pavement surface, they are located too high in the structure to be able to correct groundwater problems. The MnDOT Geology Unit (Office of Materials and Road Research) should be contacted to address any groundwater concerns.

Pavement edge-drain type (Specification 2502.3.g) is recommended to be used in these situations:

• With rubblized or crack and seat projects.
• With unbonded PCC overlay (UBOL) projects that use a geotextile fabric as an interlayer (if the fabric cannot be drained by a daylighted aggregate base layer).
• When PCC or HMA full-depth pavements on plastic soils receive rehabilitation work of any magnitude.
• In any areas where the pavement has a history of pumping.
(2) Permeable aggregate base (PAB) type drains (specification 2502.3.e)

Permeable aggregate base (PAB) type drains consist of a perforated pipe, not-wrapped in a geotextile fabric, which is placed in the bottom of a trench filled with permeable aggregate (see MnDOT Standard Plan 5-297.431 & 5-297.432). This type of drain provides a relative high-rate of flow and is required when a pavement is constructed with a highly permeable drainage layers such as:

- Open-graded aggregate base (OGAB)
- Drainable stable base (DSB)
- Permeable asphalt stabilized stress relief course (PASSRC)
- Permeable asphalt stabilized base (PASB)

2. Discharge pipe and headwall

Subsurface drains are drained by 4.0 inch non-perforated, rigid thermoplastic (TP) discharge pipes and connections at specified intervals. Precast concrete headwalls with rodent screens are provided at each discharge pipe to protect its ends.

Discharge pipes should be daylighted to the ditch through headwalls or tied into the storm sewer system at distances no greater than 500 feet, although this distance should be no greater than 300 feet where pavement grades are less than 0.2 percent. MnDOT Standard Plan 5-297.433 illustrates the typical drain design.

3. Pavement widening drainage system

Permeable aggregate base (PAB) is a recommended option for designs that involve the widening of narrow pavements to facilitate the drainage of any water trapped in the existing pavement by the widening. The drainage system is shown in MnDOT Standard Plan 5-297.432. The type of PAB material (OGAB, PASB) used for this widened section is optional.

Where PAB is used under a widened section on the high side of a superelevated roadway, two drain options are available:

- Move the drain from the outside edge of PAB to the inside edge (next to existing pavement).
- Eliminate the PAB in these areas and substitute either class 5 base or, as appropriate, deep-strength bituminous or concrete.

The standard pavement edge-drain (3-inch diameter) is used with the PAB widening design and not the PAB drain (4-inch diameter) because they are less expensive and will provide adequate drainage for the widened section.

4. Interceptor drains (mini weeps)

Interceptor drains are incorporated into unbonded concrete pavement overlay designs to collect water from the existing PCC joints and major cracks. These drains typically connect into a standard permeable base drain for discharge.

The design concept is shown in MnDOT Standard Plan 5-297.432.
5. Subsurface drain maintenance

Proper maintenance of subsurface drain systems is critical to the performance of pavement systems, with the lateral outlet pipes being the primary area of concern. Vegetation growth, roadside slope debris, and topsoil are notorious for obstructing and plugging these outlet pipes. If the drain system becomes blocked it can severely harm the pavement structure by reversing its normal function and allowing more water to build up than would normally exist in the pavement. Therefore, inspection, cleaning, and repairing of the subsurface drains and lateral outlets should be regularly scheduled every two years or less to avoid damage. A simple mandrel can be used to check the discharge pipes and connections, which are the locations where most problems occur. The use of 2-inch diameter video equipment for inspection of the edge-drain system after, and even during, construction is recommended (The MnDOT Geology Unit has access to such cameras should they be needed).

**Note:** Drainage systems should not be incorporated into the pavement system unless a commitment to regularly inspect and maintain them has been made by the district.
Section 380: Frost Effects

This section discusses frost heaving, thaw weakening, and estimating frost depth.

1. Detrimental effects of frost

   A. Frost heaving

   Frost heaving is caused by frost lenses growing in a frost susceptible soil. Frost lenses begin as ice crystalizing within the larger soil voids. As freezing temperatures continue and advance deeper into the soil, water may remain unfrozen in the soil’s pore structure despite freezing temperatures. This unfrozen water, augmented by any source of unfrozen water from below, is transported upwards by capillary rise, to crystalize and add to the mass of the frost lenses. As the frost lenses grow, the overlying soil and pavement will heave up, potentially resulting in pavement roughness and cracking. The frost lenses will grow until the water source is used up, or until temperatures are low enough to freeze the capillary water, in which case a secondary layer of frost lenses may form at a lower depth. The frost heaving process is diagramed in Figure 370.1.

   Three conditions are necessary for frost lenses to form and cause frost heave. These are:

   • Freezing temperatures
   • Water
   • Frost susceptible soil – Any material with more than 3% material finer than 0.02 mm is considered to be likely frost susceptible (see Figure 370.2).

   Removal of any of these conditions will eliminate or minimize frost heaving. If these conditions occur uniformly, heaving will occur uniformly which normally is not detrimental to pavement performance. However, if these conditions are non-uniform, heaving will also be non-uniform which will cause pavement roughness and possible cracking.

   Figure 370.1 - Diagram of Frost Heaving
Figure 370.2 - Frost susceptibility of various soil types tested by the Corps of Engineers, 1950-1970 (from FHWA-TS-80-224, "Highway Subdrainage Design," August 1980).

B. Thaw weakening

Thaw weakening occurs during spring melting when ice contained in the pavement subsurface melts. Because thawing typically proceeds from the top down, this water is trapped by the remaining frozen soil beneath. The increase in moisture from this trapped water reduces the stiffness of the pavement subsurface layers and more fatigue will occur to the pavement structure than during normal conditions.
2. To reduce frost effects

A. Replace frost-susceptible material with frost resistant material

Frost susceptible soils have pore sizes that promote capillary rise which facilitates the growth of frost lenses. Therefore, the degree of a soil’s frost susceptibility is related to the amount of fines that it contains. Materials with less than 10% finer than no. 200 (75 µm) sieve are considered to be frost resistant and will likely experience little frost heaving. Materials with greater amounts of fines are considered frost susceptible to some degree with soils containing silts regarded as the most frost susceptible. Clays also contain fine material but their permeability may be so low as to inhibit capillary rise and the growth of frost lenses.

Generally, it is impractical and not-cost effective to replace all of the pavement structure with frost resistant material. MnDOT’s standard pavement structure requirements are a compromise between cost and anticipated benefits. For new HMA pavements on non-granular soils, MnDOT requires a minimum total pavement structure of 30.0 inches for roads with less than 7 million 20-year BESALs and 36.0 inches for roads with more than 7 million 20-year BESALs. This thickness includes pavement, base, and subbase. This depth is approximately one-half the average frost depth for Minnesota overall. Higher trafficked roads require thicker frost resistant because the increase in reliability and performance are considered worth the expense. For new PCC pavements on non-granular soils, MnDOT requires a minimum of 4.0 inches of base on 12.0 inches of subbase.

B. Provide good roadway drainage

Water in the pavement subsurface is a necessary condition for both frost heaving and thaw weakening and minimizing it will minimize both frost effects. Provide surface drainage and seal any cracks or joints to keep surface water from entering the pavement subsurface. Use aggregate and granular materials under the pavement and provide a path for these layers to drain. The drainage path may include drains or daylighting the layer, which is extending the width of a pavement layer to near the in-slopes (only covered by topsoil) so that the layer may directly drain to the ditch.

C. Uniform soil

Uniform soil will tend to heave uniformly which typically isn’t detrimental to a pavement.

D. Match materials and use transitions

Uniform frost heave is typically not a problem but any abrupt differences in heave will be experienced as a bump or roughness. It is important to match the thickness and materials of adjacent sections and to use appropriate transitions when differences are necessary.

3. More information on frost