5-4.0 DRAINAGE

Highway drainage consists of directing surface and subsurface water away from structural elements of the roadway and toward a safe outfall through the use of ditches, culverts, drains, drainage blankets, etc. The importance of drainage will be discussed in terms of surface and subsurface water flow.

5-4.01 SURFACE DRAINAGE

As one of its most basic characteristics, a roadway must be carefully shaped and graded to remain "high and dry". The combination of: (1) centerline grade (with respect to existing ground), (2) typical section (the shape of the roadway structure including ditches), and (3) vertical alignment (the succession of centerline grades) must be established to prevent inundation of the roadway and its supporting structure.

Various means of roadway surface drainage collection and conveyance are described in the following sections.

5-4.01.01 DITCHES

Ditches are open channels that collect runoff and seepage water from pavements and slopes and convey it to a safe outfall via gravity. Ditches are the least complicated and most cost-effective means of collecting and conveying water from surface and shallow subsurface flows. In granular, free-draining soils ditches are most often used to lower the local water table.

In order to determine the proper design elements of a ditch, it is necessary to define the purpose of the ditch. The following is a discussion of some specific uses of ditches in roadway design:

- **Roadside Ditches** are ditches that parallel roadway edges and conduct water longitudinally. The standard geometry for Mn/DOT's ditches is a rounded trapezoidal configuration with a bottom width of about eight feet, as referenced in Mn/DOT's Road Design Manual Section 4-6.0. Also specified is a desired longitudinal ditch gradient of 0.005 feet per lineal foot to prevent ponding water in localized low areas. Ditches are typically four to six feet in depth, but it should be make certain that the design depth is equal or greater than the depth of subgrade correction necessary to support traffic.

- **Median Ditches** are designed to conduct water longitudinally within median areas to median collection points in much the same manner as roadside ditches. Median ditch grades may vary from the roadway grades as necessary to handle the runoff from lanes between the divided roadway crowns, as well as from the median area itself.

- **Offtake Ditches** are more or less perpendicular to roadway alignments and conduct flows to outfalls that parallel roadways, such as rivers or shorelines.

- **Intercepting Channels** are located at the top of or along intermediate elevations of cut slopes to prevent excessive flows down the slopes. The use of these channels must be approved by the Foundations Unit (Office of Materials) due to the potential for slope instability.

- **Toe-of-fill Channels** are similar to intercepting channels and are used along the toe of fill slopes as control at the base of slopes.

Ditch slopes and bottoms are typically lined with three to twelve inches of topsoil or other surfacing materials. Ditch design should account for the thickness and roughness of the lining materials when sizing for depth of subgrade improvement and maximum slope.

Aside from the initial design and construction of a ditch, the most important element affecting ditch performance is the maintenance of the proper ditch depth. As a part of routine roadway maintenance, inspection for excessive siltation or vegetation that would impair the function of the ditch should be performed.

Additional policy and design information is addressed in Mn/DOT's Road Design Manual, Sections 4-6.02, 4-6.03, 8-3.02, 8-4.01, and 8-5.01.

5-4.01.02 CURB AND GUTTER/STORM DRAINS

Gutters are formed by using a curb to channel pavement surface runoff towards storm-drain systems or other outlets. They are typically used in urban areas where right-of-way is limited and/or roadway channels are undesirable for other reasons. Curb and gutter system design should include a hydraulic analysis to determine the extent of roadway flooding during the design storm event. The presence of free water poses specific installation problems including the potential for buoyancy of the installed pipe. Additional policy and design information is addressed in Mn/DOT's Road Design Manual, Sections 4-4.04, 8-3.04 and 8-4.04.

5-4.01.03 CULVERTS

Culverts are open-ended conduits used to carry surface water under roadways. Culverts are most often placed along natural drainageways to limit grading and disruption of the existing subsurface ground water regime. Culvert system design should include an investigation of the existing ground water levels and soil conditions at the site. Policy has been to investigate proposed culvert sites with at least three soil borings, including one boring near each end of the structure and one boring near the center of the structure. An extension of a satisfactorily performing culvert should utilize bedding material similar to that of the in-place culvert. Additional policy and design information is addressed in Mn/DOT's Road Design Manual, Sections 8-4.02, 8-4.03, 8-6.0, and 9-3.0.

5-4.02 SUBSURFACE DRAINAGE

The damaging effects of excess moisture within pavement structures have long been recognized. This moisture, in combination with heavy traffic loads and freezing temperatures, can accelerate pavement deterioration, resulting in an increased need for maintenance and shortened service life. Most pavement distresses are either caused or aggravated by the presence of excessive subsurface moisture.

5-4.02.01 SOURCES OF MOISTURE

Moisture in the pavement structure and/or subgrade can come from many sources:

1. Surface Infiltration. Surface infiltration is the primary source of excess water for most pavements. Joints, cracks, shoulder edges, and various other defects in the surfacing material are easy access paths for water; one study performed by the Office of Materials concluded that 40 percent of the rainfall landing on the surface of a pavement flows through openings into its lower structure. This percentage rises a pavement ages and its joints, cracks, and defects deteriorate and widen. Various construction practices and treatments are capable of better sealing the surface of the roadway, however, these methods still allow a significant amount of water to seep through the roadway surface.

2. Groundwater. Groundwater levels often fluctuate seasonally due to rainfall events, the spring thaw, etc. This migration of water can present a major problem for pavements, particularly those in low-lying areas. High groundwater levels are also problematic during construction in cut sections.

Capillary Action. The water table represents the line below which soils are completely saturated. Capillary action is the process by which moisture rises into the unsaturated soil above the water table as a result of surface tension and the attraction between water and soil (Peck et al, 1975). This has the potential to pull significant amounts of moisture to the top of the subgrade or even into the pavement structure if the watertable is high or the soil is particularly conducive. Capillary action is responsible for much of the water that contributes to frost heave damage. Very fine-grained soils, such as clays, have the greatest height of capillary rise due to the small spacing between grains.

4. Seepage. Seepage is water that flows into the pavement structure from other locations. One common source of seepage water is high ground near cut sections. Moisture can also flow laterally from pavement edges and ditches, especially on sections with shallow ditches or flat longitudinal grades.

5. Vapor Movement. Water vapor is present in air voids of the subgrade and pavement structure. The volume of free water held in vapor is typically insignificant compared to other sources of moisture.

5-4.02.02 MOISTURE ACCELERATED DAMAGE

Excess moisture in a pavement section is a primary cause of pavement distress. The main types of deterioration caused by excess moisture in the pavement structure are as follows:

1. Erosion. Erosion occurs in pavements when water seeps into the structure (usually through joints or cracks in the surface) and gradually washes out the underlying granular material. When this occurs near joints or cracks, the surfacing material may begin to move vertically as traffic passes over and pushes it into the depression. This movement is known as ‘pumping’, and it accelerates the pavement deterioration by pressurizing the water sitting in the eroded area so that it rushes out (often carrying additional granular material) after each vehicle passes. The loss of structural support that results leads to faulting and corner cracking of jointed concrete pavement, punch-out in CRCP, and fatigue and subgrade rutting in asphalt pavements.
2. Asphalt Stripping. Stripping is a process in which moisture in the asphalt layer slowly separates the aggregate particles from the binder, causing the material to lose much of its stiffness. Extensive stripping can lead to shoving, rutting, fatigue cracking and the settlement of transverse cracks in asphalt pavements.
3. Bond Loss between Asphalt Layers. Moisture in an asphalt structure can, in a process similar to stripping, cause the bond to break between lifts so that they move independently. This may lead to shoving and fatigue cracking.
4. “D” Cracking. D-cracking occurs in concrete pavements when moist aggregates with coarse pore structures go through freeze-thaw cycles. With time, these susceptible aggregates begin to break apart and the pavement cracks and spalls at the joints.
5. Granular Layer Softening. High saturation levels in base and subgrade layers cause them to lose much of their stiffness and provide less structural support. This effect is particularly noticeable during the spring thaw period, and it can lead to rutting, fatigue cracking, and settlement at transverse cracks in asphalt pavements.

5-4.02.03 APPROACHES TO ADDRESS MOISTURE IN PAVEMENTS

To avoid moisture-related pavement distresses, one major objective of pavement design is to prevent the base, subbase, and other susceptible paving materials from becoming exposed to high moisture levels to the greatest extent possible. There are three general approaches for controlling or reducing the problems caused by moisture.

1. Prevent Moisture from Entering the Pavement System

If no water is allowed into a pavement structure, there will obviously be no moisture-related distresses. Therefore, sealing the structure would be the most effective approach to moisture damage mitigation. Unfortunately, it is difficult to completely seal a pavement structure against water; the best that can be done in most cases is to minimize the infiltration. The following are methods for accomplishing this.

a. Pavement Typical Section

- Provide adequate cross and longitudinal slopes to quickly drain moisture from the pavement surface.
- Separate the grade from the water table by a depth roughly similar to the depth of frost penetration to insure that groundwater does not adversely affect the long-term roadway performance. In many cases this depth is approximated to be 5 feet.

These criteria should be followed in every situation unless local conditions make them impossible. Special design considerations will be necessary in cases where the natural groundwater level is located within 5 ft of grade. These water levels can be permanently lowered by the use of deep longitudinal drains (Refer to Figure 5-4.1), blanket drainage layers in the bottom of subcuts, or special drainage arrays. In most cases, these drains require project specific designs that are related to soil type(s), permeability(s), the depth of lowering required, the depth to a confining layer, etc. Permanent lowering of the water table should not be attempted without consideration of the possible adverse consequences, such as construction expense, design life, wells or wetland impacts, and the potential for settlement of any nearby structures. The Geology Unit (Office of Materials) should be contracted to provide assistance with these designs. For the above reasons, it is extremely important that all groundwater data be accurately summarized and tabulated in both the Materials Design Recommendation report and the bid packages.

b. Joint and Crack Sealing. Seal all joints, cracks, and other discontinuities to prevent surface water from entering the pavement system. This approach is only effective if the cracks are sealed soon after they develop and both cracks and joints are cleaned and resealed periodically. This is particularly important for longitudinal joints, especially the lane-shoulder joint in concrete pavements and the cold joints in asphalt.

2. Use Moisture Insensitive Materials

Base and subgrade materials with low fine contents are less susceptible to moisture-related problems than those with high fine contents. In particular, these materials are less susceptible to frost action, less erodable, and not as likely to experience a damaging loss of stiffness. Therefore, as previously discussed in Section 5-3.05.02, bituminous pavements should incorporate select granular material [which has less than 12 percent passing the 0.075 (No. 200) sieve] in the lower portion of the structure. Similarly, concrete pavements should utilize either select granular material or permeable aggregate base (PAB).

3. Quickly Remove Moisture

Even using the best design practices, it is inevitable that some moisture will manage to penetrate the pavement surface and enter the structure. Therefore, it is often beneficial to have drainage features in place that are capable of removing the water before damage is done. Several different types of these features exist. Some, such as underdrains, subcut drains, and ditches, are designed to permanently lower the local water table in areas where it is close enough to the surface to be problematic. Others, such as permeable bases and edge drains, are designed to quickly remove surface infiltration water. These features may be used together or separately depending on the expected moisture conditions.

5-4.02.04 SUBSURFACE DRAIN TYPES AND DESIGN GUIDELINES

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

1) Subcut Drains

Subcut sections are at high risk of holding potentially damaging moisture: they are located below the natural grade and may be nearing the watertable elevation. In addition, they are often surrounded by subgrade soils with high fine contents and corresponding low permeabilities. Therefore, water that flows into the subcut make take a very long time to drain out through the surrounding soil and, given somewhat regular rain events, the subcut may end up holding water indefinitely in the so-called "bathtub" effect.

Subcut drains are designed to remove the water from the "bathtub". They are typically longitudinal perforated pipe located in the bottom, outer-most corners of granular backfilled subcuts: refer to Figure 5-4.1. (Also see Figure 5-297.430 of the Mn/DOT Standard Plans Manual) The use of subcut drains is recommended for most situations, seeing as how low-permeability soils are common and the subcut tends to attract moisture regardless. It is better practice to assume that these drains will be needed and to search for reasons that they may be unnecessary than vice-versa.

Subcut drains may be installed using one of two construction sequences. In most cases the contractor is allowed to choose their preferred method. However, one of the options should be deleted from the plans if it is determined to be undesirable for a particular project or location.

General design concepts for subcut drains are similar to those for pavement edge drains: applicable portions of the guidelines in the next section should be referred to in the design of subcut drains as well. For subcut drains in particular, the following items should be considered:

- One line of pipe should be placed at each local low point on both sides of the subcut. Exceptions would be in "super" sections, or if because of drain depths and median ditch grades it is not possible to outlet subcut drains to the median ditch, then subcut bottoms may be sloped towards the deep ditch as in a "super" section or cross-connections made to the outlet side. Cross-connections may be PE pipe depending on the construction sequence chosen by the contractor and this pipe is also trenched in by machine. Cross-connection pipe should be considered to be "discharge pipe" for the estimated quantities and should be so noted in the Plans.
- Right angle and "T" connections should be avoided wherever possible because they make cleaning impossible. All connections to the discharge pipe should be by short length of non-perforated PE pipe on a 3 ft minimum radius. Where TP pipe connections to manholes are required, maximum connector angles of 22.5 degrees should be used to facilitate clean out.
- Figure 5-297.433 of Mn/DOT's Standard Plans manual illustrates design details of the water collection system including the edge drain, discharge pipe, and headwall.

Special provisions for subcut drains are on file with Mn/DOT's Special Provisions Unit.

2) Pavement Edge Drains

Edge drains are narrow trench and perforated pipe systems that parallel roadway edges to drain water soon after infiltrating the pavement structure. (Refer to Mn/DOT's Standard Plans Manual) As opposed to subcut drains, edge drain trenches are placed in contact with a permeable base layer so as to drain water before it sinks into deeper layers. Therefore, 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 Geology Unit (Office of Materials) should be contacted to address groundwater concerns.

Edge drains are typically used whenever:

- Cracked concrete pavements are given a bituminous overlay so that water trapped in the cracks and joints does not adversely affect the life of the overlay.
- Concrete or bituminous full-depth pavements on plastic soils receive rehabilitation work of any magnitude. On older concrete roads, it may be necessary to remove the existing plastic soil shoulders and replace them with clean, drainable granular material to provide a stable shoulder area. In these cases where the base is “daylighted” it may not seem necessary to include a drain, however, water may become trapped beneath topsoil and vegetation on the in-slope. A drain is always recommended in areas where the pavement has a history of bleeding or pumping.
- An entire pavement section is constructed, whether it is new construction or a complete replacement. Current drainage recommendations for new construction are discussed in Section 5-3.05.02 of Mn/DOT’s Pavement Design Standards and Sections 5-3.05.03 and 5-3.05.04 (for bituminous and concrete design, respectively) of this manual.

On projects where pavement drains are included in the design and subcuts are being used selectively rather than continuously, edge drains should likely be made continuous throughout. On projects <u>other than</u> interstate or high volume roads, edge drains are likely not necessary where pavement sections are almost continuously underlain by subcuts and associated drainage. For interstate or high volume roads, the desirability of using <u>both</u> subcut drains and pavement edge drains should be discussed with the Pavement Design Unit, Office of Materials.

General design guidelines are as follows:

- One line of perforated pipe on each side of the roadway is recommended for all installations except to the “high side of supers” or locations where inplace ramps or other connections prohibit placement. Drains are generally not required on ramps or loops.
- Corrugated polyethylene tubing may be used anywhere within the roadway, provided that a cover of 18 inches is maintained at all times. (A minimum pipe cover of 12 – 15 inches may be used when necessary to minimize trench depths on projects with very flat pavement grades and where very shallow ditches exist.) The pipe flow line should be at least 3 inches below the bottom of the material to be drained (usually the base). The exact pipe depth and location may vary according to local conditions and the pavement structural design.
- Drain grades should ideally be at least 0.5 percent, but flatter grades (as little as 0.2 percent) are occasionally acceptable when there is a need to minimize trench depths or obtain ditch outlets. The plan profiles should show typical trench depths so contractors can anticipate quantities of filter aggregate required. Laser grade control is required by special provision whenever pipe grades do not follow pavement grades at a constant depth. Pipe should be discharged to the ditch or appropriate manholes at distances no greater than 500 or 800 ft), respectively, with outlets to be 1 ft above ditch grade or manhole invert whenever possible. On flat sections where drain grades approach 0.2 percent, the outlets should be spaced at a maximum of 300 ft. Discharge–point trench depths of up to 30 inches should not be considered unusual.
- A minimum of 1 inch of annular space between the pipe and trench wall is required to permit easy placement of the fine filter aggregate, therefore a 3-inch pipe (with a 4-inch outer diameter) requires a trench at least 6-inches wide. The current specifications suggest that trenches be constructed no wider than 10 inches. It is important that the bottom of the trench be shaped to cradle the lower third of the pipe, that the filter aggregate be carefully placed on sides of the pipe, and that the pipe be centered in the trench in order to safely support the pipe. Fine filter aggregate backfill should extend at

least 3 inches into the inplace concrete or other material to be drained. The drainage of this layer will improve as this contact zone lengthens.

- Two inches of Class 5 or a thicker bituminous shoulder should be laid over the fine filter aggregate in the drain to obtain better stability in this area and enhance densification of the filter aggregate.
- It may be necessary to specify the construction sequence for edge drains when it may affect their performance. In particular, drains should be placed before PCC pavement is cracked and after the new pavement or widened section has been placed.
- The discharge pipe running to the outlet structure (including the 3-inch PE connection to the discharge pipe) should be constructed from non-perforated thermoplastic type pipe and paid for as a separate pay item. Thermoplastic (rigid wall) pipe is desirable because it minimizes the potential for crushing under future maintenance or construction traffic. Leakage of water from a perforated discharge pipe may soften the soils around the headwall or lead to piping under the headwall. When two lines of pipe drain to the same low point, only one discharge pipe and headwall are required. The connection should be made with a “Y” at the end of the 1 ft radius where the non-perforated PE pipe connects to the discharge pipe. Figure 5-297.433 of Mn/DOT’s Standard Plate Manual illustrates design details of the collection system.
- A precast concrete headwall is used when the system outlets to a ditch: design details are shown in Mn/DOT Standard Plate No. 3131B. The standard 4-inch TP discharge pipe will fit both 3-inch and 4-inch pipe, so only one headwall item needs to be specified even if both types of pipe are used on a project. Headwalls can be made for 6-inch PE pipe on special order.
- All discharge/headwall locations must be marked to facilitate the future location of the outlets for inspection and maintenance. The marking method to be used depends upon the project geometry and/or District preference. The method selected should be indicated in the plans or special provisions and should be incidental to the headwall. The following methods are currently available:
  a. Thermoplastic pavement markers. These markers consist of 4 inch by 1-foot strips of white marking tape (Specification 3354) that is placed at the outside edge of the bituminous shoulder at right angles to the roadway while the bituminous is still hot.
  b. An orange post. These posts are placed in the back slope near the Right-of-Way line or at another location as approved by maintenance.
  c. A metal plate. In situations where the Right-of-Way is fenced, a 6 in. by 6 in., orange or day-glow-colored metal plate should be fastened to the fence at the appropriate location.
  d. Paint pavement markers. These consist of paint stripes similar in configuration to the white marking tape mentioned above.
- Headwalls should be inspected on an annual basis by Mn/DOT maintenance to verify that they are clean and operational.

Additional drainage design questions, particularly those regarding the need for drainage, should be directed to the Pavement Design Unit at the Office of Materials.

3) Permeable Aggregate Base (PAB) Drainage Systems

A Permeable Aggregate Base drainage system utilizes a highly permeable base layer to quickly remove water that infiltrates a pavement surface. The majority of the water that penetrates the pavement surface drains to the sides of the roadway within the crushed stone Permeable Aggregate Base (PAB) layer because the lower layers are much less permeable. This water is then collected by edge drains and removed from the system. In this manner, the pavement is saturated for the shortest length of time possible following a rain event; current estimates are that the system will drain within two to three hours. This time frame satisfies 1986 / 1993 AASHTO Design Guide criteria for excellent drainage.

Presently, PAB drainage systems are only used as part of concrete pavements. (These elements are discussed in Section 5-3.05.02 and Figure 5-3.6 of this manual, as well as Figures 5-297.431 and 5-297.432 of Mn/DOT's Standard Plans Manual) Mn/DOT's bituminous pavement designs are, in many cases, controlled by the frost-free zone requirements. Subsequently, there has been little opportunity for bituminous PAB designs to be constructed. Table 5-3.7 in Section 5-3.05.04 of this manual provides guidance regarding the use of PAB under mainline concrete pavements.

The use of a PAB drainage system may allow for a reduction in the concrete slab design thickness by one-half of an inch under certain circumstances. This reduction is made possible by the structural contribution of the drainage layer. The concrete design thickness should be determined in accordance with the procedures provided in Section 5-3.05.04.

The use of PAB under ramps, loops, turn and by-pass lanes should be considered on a project-by-project basis. Special consideration should be given to using PAB on ramps on larger interchanges that are of significant length and free flowing.

The basic elements of the PAB drainage system are:
1. PAB Drainage Layer.
2. Filter / Separation Layer.
3. Collector System (Longitudinal Edge and Transverse Drains).
4. Discharge Pipe and Headwall.
5. Adequate Ditch Depth (Rural Situations).

PAB design guidelines for these elements are as follows:
1. PAB Drainage Layer. The drainage layer should be 4inches thick, and it should consist of one of the following materials: open-graded aggregate base (OGAB), permeable asphalt stabilized base (PASB), or permeable cement stabilized base (PCSB). OGAB is the most commonly used of these three.

   The PAB layer is placed beneath the full width of the pavement and extended as illustrated in Section 5-3.05.04so as to provide stability for the paving equipment and ensure that the edge drains intercept the PAB layer.

2. Filter / Separation Layer. This layer <u>must</u> be placed directly beneath the PAB course as it performs several important functions:
   a. It provides a stable working platform for the construction of the PAB course. The layer should not experience any rutting or movement during the paving operation.
   b. It acts as a filter to prevent fines from migrating from the subgrade soils up into the PAB course. An excessive migration of fines could block the pores in the PAB layer, reducing its effectiveness.
   c. It acts as a "shield" to minimize water infiltration through the PAB into the subgrade and, instead, direct it towards the edge drain.

   The filter / separation layer is composed of Class 5 Aggregate Base (Specification 3138) and should be 4 inches thick after compaction. The layer should be constructed in accordance with Specification 2211 (Aggregate Base) and also satisfy the filter criteria discussed in Section 5-4.03.02.

   If other material types are substituted in place of the Class 5, then their compatibility with the PAB and subgrade soils need to be verified with the filter criteria in Section 5-4.02.06. The use of a geotextile filter as a substitute for the granular filter layer is not recommended at this time.

3. Collector System (Longitudinal Edge and Transverse Drains). A longitudinal edge drain collector system is required to collect and discharge the water flowing through the

permeable aggregate base layer. The system consists of a perforated, corrugated, polyethylene (PE) pipe 4 inches in diameter that is placed in a trench that is partially lined with geotextile and backfilled with a permeable aggregate. The 4-inch PE pipe is required.

The geotextile in the trench bottom is intended to prevent the intrusion of fine material from the surrounding subgrade into the permeable aggregate trench backfill (pea rock size). Once again, this fine material would have the potential to reduce the permeability of the aggregate and clog the pipe.

Special design considerations for the collector system include the following:

a. Drainpipe inverts should be placed at least 4 inches below the bottom of the Class 5 filter / separation layer. The Materials Design Recommendation (MDR) letter may recommend greater depths in certain situations.
b. Pipe grades always follow the pavement grades at a constant depth. If the depth of the drains were gradually increased to promote flow (as is often the case with standard edge drains), then the geotextile trench-bottom liner would be required to gradually widen, resulting in the need for a tapered geotextile. The use of a tapered geotextile is impractical from both a supply and construction standpoint, so this practice should be avoided.
c. In situations where the PAB drains are not covered by the surfacing material (such as the outside edge of turn or by-pass lanes or behind curb and gutter sections), the permeable aggregate in the drain trench and PAB paving train extension must be separated from the overlaying grading material or topsoil by at least3 inches of Class 3 or 5 aggregate to prevent the infiltration of fine-grained soils into the permeable material. Refer to Figure 5-297.231 of Mn/DOT's Standard Plans Manual.
d. Cross-drain interceptor trenches, as shown in Figure 5-297.123 of Mn/DOT's Standard Plans Manual, should be provided at the low points in vertical curves when one or both profile grades exceed 1.5 percent. The function of these drains is to prevent an unusual hydrostatic head build-up under the pavement surface. A cross-drain interceptor trench should also be provided when a PAB design abuts a non-PAB design in a location where the non-PAB design is down the grade.

e. The edge drain at the high side of a superelevation cross-slope should be eliminated in situations where all of the water is perceived to drain to the low side. The designer should be careful not to eliminate the drain at the high end of the superelevation in locations where turn lanes (or other design elements) require transverse slopes that are counter to the superelevation, in which case drainage should be included as appropriate.
f. On curvilinear alignments, roadway superelevation may create depressions on the low side of pavement where the collected water cannot be drained away. An adjustment to the profile grade may be necessary to eliminate these depressions.
g. When a PAB design is underlain by a granular-backfilled subcut, two drain placement options are available:
    1. Lower the PAB drain4 inches below the bottom of the subcut. This option requires considerably more permeable aggregate and geotextile to line the full trench below the Class 5. It is generally not economical unless the subcut is less than 18 – 24 inches.
    2. Taper the bottom of the subcut toward the centerline and place one line of pipe as a modified subcut drain with modified options and typical sections. Standard PAB drains should still be installed in their regular locations in order to drain the PAB. Separate outlets should be provided for the centerline subcut drain.
h. Several types of geocomposite / prefabricated drains are currently being marketed. These are often 1-inch wide by 12 to 18-inch high plastic core ("rectangular pipe") that is wrapped with geotextile. The use of such products for PAB drains is not recommended.

i. The following items summarize portions of the construction special provisions:
   1. The trench width should be a minimum of 7 inches and a maximum of 10 inches.
   2. The trench bottom should be shaped to cradle the lower one-third of pipe and should be at least 4 inches below the bottom of the filter layer. It should follow the pavement grade.
   3. The trench bottom is lined with geotextile. This geotextile terminates within the filter layer located below the permeable base on the pavement side. On the opposite side, the geotextile terminates within or above the filter layer.
   4. The aggregates used for trench backfill must meet a specified gradation or have at least 1000 fpd permeability.
   5. Drains constructed in conjunction with PASB should be trenched immediately adjacent to the placed pavement. Drains constructed in conjunction with OGAB are placed 6 inches away from the pavement to minimize undercutting.
   6. Drains constructed in conjunction with:
      a. PCC pavement are placed after the pavement is placed.
      b. HMA pavement are placed after the non-wear and first layer of the wear course are in place, but before the final wear course layer is laid so as to avoid damage to the finished pavement surface.
      c. All drains are constructed before the placement of any shoulder aggregate or mixture.

4) Discharge Pipe and Headwall

Four-inch, non-perforated, rigid thermoplastic (TP) discharge pipes and connections must be provided at specified intervals for the pavement drainage system to be free draining. Precast concrete headwalls with rodent screens are provided at each discharge pipe to protect its ends. Construction details for discharge pipes and headwalls can be found in Mn/DOT's Special Provisions (Standard Plate 3131A), Mn/DOT's Standard Plate Manual, and Figure 5-297.433 in Mn/DOT's Standard Plans Manual. Special design considerations are indicated below:

a. Discharge pipes are constructed concurrently with the edge drain system and are generally laid at right angles to the roadway centerline, although on rare occasions the use of angled / skewed pipes may be necessary with shallow ditches.
b. Discharge pipe grade should be no less than the drainpipe grade and a minimum of two percent.
c. Discharge pipes should be daylighted to the ditch through headwalls or tied into the storm sewer system at distances no greater than 500 ft, although this distance should be no greater than 300 ft where pavement grades are less than 0.2 percent. Outlets should be provided at all low points on the vertical grade using a "Y" coupling to a single discharge pipe and headwall. Figure 5-297.433 of Mn/DOT's Standard Plans Manual illustrates the typical drain design. Separate discharge headwalls should be used in situations where transverse drains are also required at low points.
d. Discharge pipe outlets should be kept 1 ft above ditch grades whenever possible, and at no time should the outlets be permitted to be less than 6 inches above the grade. (Unless the ditches are unusually shallow, it is rarely difficult to keep the PAB drain outlets 1 ft above the ditch grade. This is because the grades for PAB drains follow pavement grades and do not become progressively deeper with length as is the case for standard edge drains. See paragraph c above for recommended outlet spacing.) When drains discharge to a storm sewer rather than to a ditch, the height above the invert should again be 1 ft or a minimum of 6 inches. For projects with storm sewer discharge and no headwalls on the project, the plan should indicate that, "All sewer connections shall be made with thermoplastic (TP) pipe, Mn/DOT 3245, with maximum bends of 22-1/2 degrees. Connection details and construction sequence shall be as approved by the Engineer. Cost of the connection shall be incidental to other work."
e. The following items summarize portions of the construction special provisions:

1. Discharge trenches should be backfilled with mineral soils that have at least 5 percent minus 0.075 mm (No. 200) sieve sized material (less than 5 percent organic matter) and have a moisture content suitable to prevent piping around the discharge pipe and headwall during compaction.
2. The discharge pipe should be fully inserted / coupled to headwall.
3. The headwall's uppermost point should be placed flush with the inslope at a minimum downgrade of two percent to provide easy water exit.
4. The headwall's location should be permanently marked for future reference with a 4 in. by 18 in. strip of white marking tape placed at the outside edge of the bituminous shoulder at right angles to the roadway. An 8-inch painted stripe or standard post may be substituted at the District's request. If this is the case, the Special Provision for Precast Concrete Headwalls (2502) must be modified accordingly.

5) Adequate Ditch Depth (Rural)

While not typically a formal element of the subsurface pavement drainage system, adequate ditch depths play a critical role in long-term pavement performance. Ditches drain both surface and ground water and thus promote a drier roadway from top to bottom. Deep ditches are also essential for providing adequate clearance between the outlet pipe / headwall and the ditch bottom for the formal drainage systems, which is important for the successful long-term operation of the pavement drainage system. With an inadequate ditch depth, the system may back up and do more harm than good.

6) Pavement Widening Drainage System

Permeable aggregate base (PAB) is a strongly recommended option for designs that involve the widening of narrow pavements so as to perpetuate the drainage of any water trapped in the in-place pavement by the widening. The drainage system is illustrated in Figure 5-297.432 of Mn/DOT's Standard Plans Manual. The type of PAB material (OGAB, PASB) utilized 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:

a. Move the drain from the outside edge of PAB to the inside edge (next to in-place pavement).
b. 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 in. diameter) is used with the PAB widening design and <u>not</u> the PAB drain (4 in. diameter) because they are less expensive and will provide adequate drainage for the widened section. Refer to the previous discussion on pavement edge drains for design and construction details relative to the longitudinal collector pipe, discharge pipe and headwall components.

7) Interceptor Drains (Mini Weeps)

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

The design concept is shown in Appendix D of this manual as well as in Figure 5-297.432 of the Standard Plans Manual.

8) Horizontal Drains

Horizontal drains are designed to lower ground water pressures and prevent slope failures in both soil and rock slopes. They consist of perforated pipe sections placed into bored holes in the slopes and are more or less perpendicular to roadway centerline.

9) Special Drains

The drainage systems discussed in this section of the manual have been designed to remove water that has either infiltrated into a pavement structure through construction joints or cracks, or has developed in the structural section due to spring thaw melt. Groundwater, artesian inflow, etc., conditions should be handled by a separate, deeper drainage system. The Geology Unit of the Office of Materials should be contacted if problems with these sources of water are anticipated on a project.

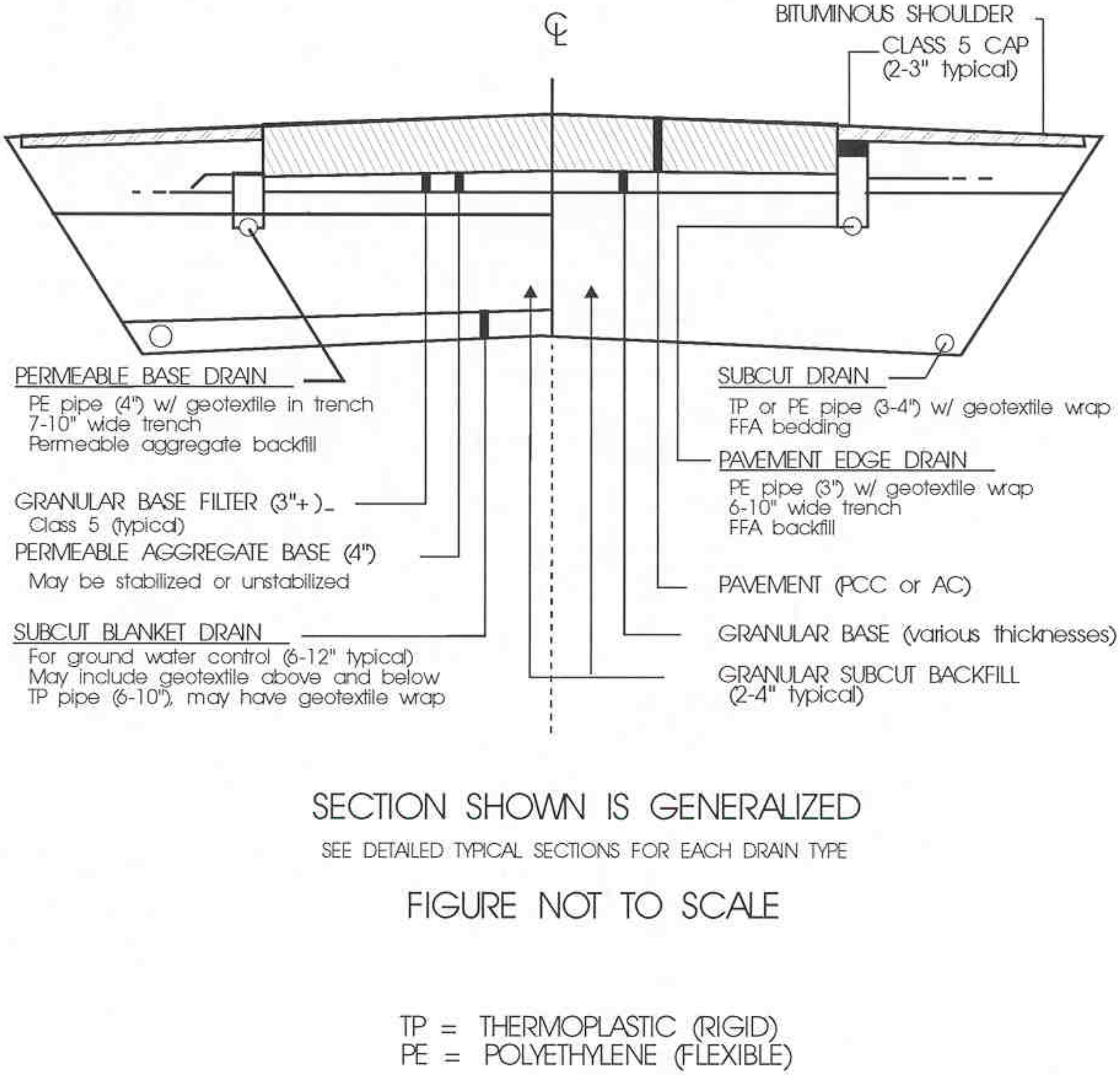
The previously discussed subsurface drain types and associated guidelines may need to be modified slightly to accommodate specific project use. The Pavement Design and Geology Units of the Office of Materials should be contacted with questions relative to the appropriateness of the above guidelines for a specific project.

5-4.0.02.05 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 edge 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 Geology Unit has access to such cameras should they be needed).

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. Regular roadway maintenance, such as crack sealing and joint maintenance, should occur with the same frequency as other roads in the District.

Figure 5-4.1. Typical sections, subsurface drainage.



5-4.03.02 SUBSURFACE DRAIN MATERIALS

1. Pipe. Pipe is used to collect and/or convey subsurface water from the material to be drained to a safe outfall. This pipe may be perforated (to allow infiltration) or non-perforated depending on its placement. If pipes are used only to convey water, such as from a drain to an outlet, the pipes should be non-perforated. Pipe type and size should be as shown in the typical sections in Figure 5-4.1 unless special conditions exist. Standardized pipe sizes and materials are as follows:

   - Plastic.
     - Rigid thermoplastic (TP) (4 to 15 inch diameter) - Mn/DOT 3245.
     - Flexible, corrugated, polyethylene (PE) drain tubing (3 to 10 inch diameter) - Mn/DOT 3278.
   - Clay or Concrete. Only used to extend agricultural drainage (4 to 10 inch diameter) - Mn/DOT 3276.

   As a general rule, 3 and 4-inch diameter pipes are used to collect water infiltrating from rain or snow, while 6-inch and larger diameter pipes are used to control groundwater or provide unusually long pipe runs.

   Both TP and PE pipe may be used anywhere in the roadway system provided they have at least 15 inches of cover. However, due to constructability concerns polyethylene pipe is usually used only when it can be placed in a narrow trench by machine trencher with controlled backfill and compaction operations. Thermoplastic pipe should be used in all other applications, such as wide trenches, bridge approaches, retaining walls, etc. Discharge pipes should always be constructed using thermoplastic pipe.

   Thermoplastic (TP) pipe should be installed with the perforations or slots located on the downward-facing side of the pipe. These perforations and slots must be either compatible with the surrounding filter aggregate or wrapped with an appropriate geotextile to prevent the surrounding material from clogging of the perforations or being lost into the pipe (piping). Specifications govern the hole sizes for perforated pipe.

   Pipe slopes in subsurface drainage applications should be tailored to the design, but a minimum slope of 0.2 percent is recommended and 0.5 percent is preferred. An exception to this guideline is the pipe placed for permeable aggregate base drains, which will always have a grade that matches the pavement grade.

   Drainage pipe is typically paid by the installed length, which includes trenching, pipe, filter, and compaction operations. Therefore, in situations where the pipe is not designed to stay at a uniform depth, the designer should indicate the range of depths by run(s) to enable the contractor to accurately calculate a bid price.

   Many of the problems that drainage systems experience stem from construction issues, therefore, it is important that the contractor uses care during their installation. In particular, the longitudinal grade of pipes should be checked often during installation to ensure that it is kept uniform with continuous positive drainage in the direction of the flow of water. In addition, those working nearby should take care to avoid snapping or collapsing the pipe with heavy machinery; this is particularly critical after the pipe has been covered and is no longer visible. Lastly, care should be taken to prevent intrusion of the surrounding materials into the pipe at all times during installation.

   Following the installation process, the continuity of the drain and discharge pipe should be checked both by visual inspection and through the use of a video probe as required by the special provisions. Mn/DOT's Geology unit owns video cameras that are 2 inches in diameter and able to inspect up to 500 ft of drainage installation (or for other uses as appropriate).

Discharge trenches are typically backfilled with a lower permeability soil, or "plug," which serves to prevent piping and erosion along the outside of the pipe.

Geocomposite drains (which are a combination of a formed plastic core with a geotextile wrap) have been used for edge drains, for drains behind retaining structures, under roads, in landslide repairs, and as vertical drains to increase the rate of consolidation under fills. (However, geocomposite drains are not recommended for use as pavement edge drains at this time) Geocomposites require a specialized design and should be discussed with Foundation and/or Geology Units in the Office of Materials.

2. Granular filters. Granular filters are used to allow the unrestricted drainage of a saturated soil while preventing piping and the intrusion of the drained soil into the filter, perforated pipe, or drainage layer. Therefore, the filter layer must be designed to prevent piping and have adequate permeability. Filter layers are always coarser in grain size than the drained soil that they protect.

Filter design criteria are well established in many references and, as a result, are only briefly discussed below. It should be noted that these same criteria/equations are also widely used to determine the potential for a finer soil to migrate into a coarser soil in other situations (such as when gravity or traffic serves as the infiltration mechanism as opposed to water).

Filter designs should satisfy all of the following criteria, but the most important is Eq. 5-4.1.

Piping $$\frac{D_{15Cr}}{D_{85F}} < 5 \quad \text{(Eq. 5-4.1)}$$

Uniformity $$\frac{D_{50Cr}}{D_{50F}} < 25 \quad \text{(Eq. 5-4.2)}$$

Permeability $$\frac{D_{15Cr}}{D_{15F}} > 5 \quad \text{(Eq. 5-4.3)}$$

The following equations characterize the filter criteria as they relate to pipe perforations.

Round Holes $D_{85m} \geq 1.2$ x hole diameter (Eq. 5-4.4)

Slots $D_{85m} \geq 1.4$ x width of slot (Eq. 5-4.5)

where: D_{85} = the particle diameter (based on percent passing graph of gradation) at which 85% of the soil particles would pass a theoretical sieve. D_{50} and D_{15} are calculated similarly.
Cr = coarsest material.
F = finest material.
m = material next to pipe (typically filter aggregate).

Filter Design Example

Problem:

Design a granular filter to protect a fine sand with the gradation shown in Fig 5-4.2. The filter should be designed so as to prevent the filter material from entering a perforated pipe with either 1/8" round holes or slots.

For the fine sand: D_{85} = 0.012 in
D_{50} = 0.006 in
D_{15} = 0.0033 in

(A filter is always be coarser than the material it protects, therefore the filter is the coarse (Cr) material and the sand is the fine (F) material.)

Solution:

Piping $$\frac{D_{15Cr}}{D_{85F}} < 5,\ \frac{D_{15Cr}}{0.012} < 5, \qquad \text{(Eq. 5-4.1)}$$

$$\therefore\ D_{15Cr} < 0.06''$$

Uniformity $$\frac{D_{50Cr}}{D_{50F}} < 25,\ \frac{D_{50Cr}}{0.006} < 25, \qquad \text{(Eq. 5-4.2)}$$

$$\therefore\ D_{50Cr} < 0.15''$$

Permeability $$\frac{D_{15Cr}}{D_{15F}} > 5,\ \frac{D_{15Cr}}{0.0033} > 5, \qquad \text{(Eq. 5-4.3)}$$

$$\therefore\ D_{15Cr} > 0.0165''$$

Round Hole $$D_{85m} > 1.2\ x\ hole\ diameter\ (0.125''), \qquad \text{(Eq. 5-4.4)}$$

$$\therefore\ D_{85m} > 0.15''$$

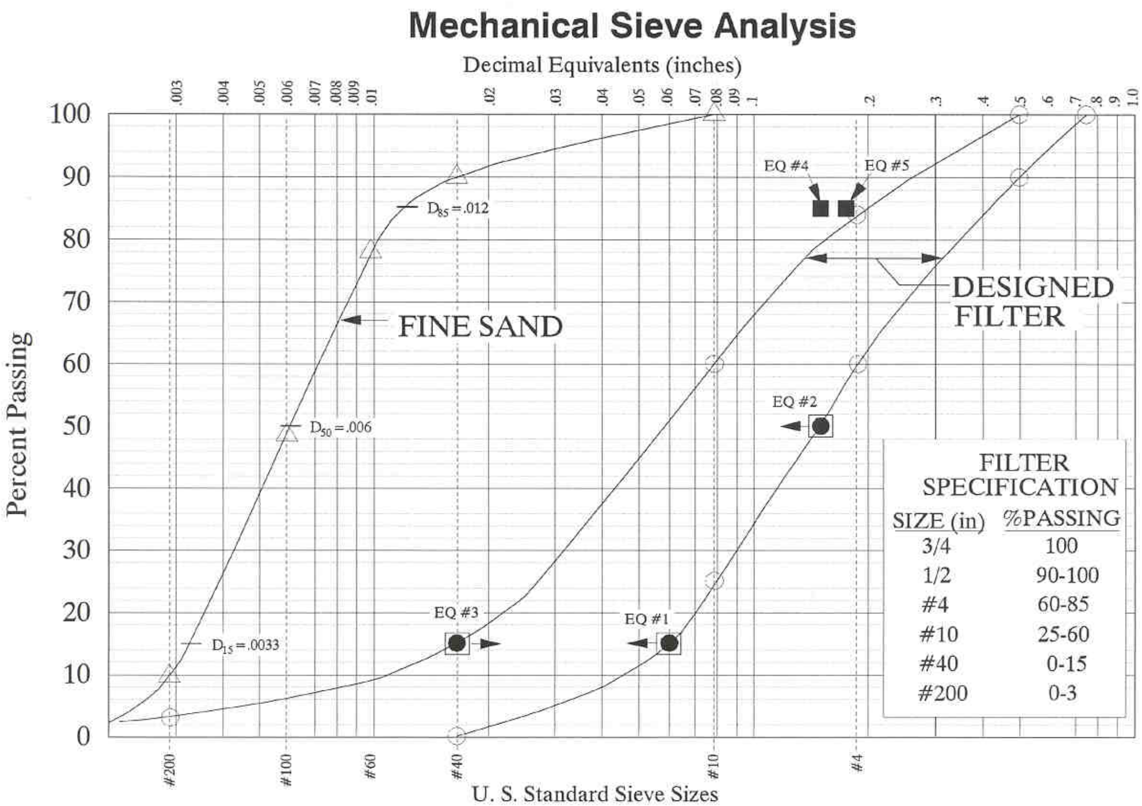
Slot $$D_{85m} > 1.4\ x\ slot\ width\ (0.125''), \qquad \text{(Eq. 5-4.5)}$$

$$\therefore\ D_{85m} > 0.125''$$

The resulting design for the filter envelope is shown on Fig. 5-4.2. Note that there are only four "control" points (there would only be three if pipe were not involved). The coarse and fine sides of the filter envelope should be roughly parallel and should generally be drawn so that specified sieve sizes are in multiples of five (e.g. 60-85 or 25-60 and not 62-81 or 24-58).

It should also be noted that the resultant filter is quite coarse compared to the fine sand that it is protecting and that geotextile is not required around the pipe. Geotextile is necessary if the fine side of the designed filter envelope will not satisfy the perforation criteria, but this situation should be avoided if possible. The designed filter should be specified as either Mn/DOT 3149.2J (Fine Filter Aggregate, Mod.) or 3149.2H (Coarse Filter Aggregate, Mod.) depending on which of the two gradations is closest to the designed gradation.

Figure 5-4.2 Granular Filter Calculations



3. Geotextile Filters. Geotextiles may be used in lieu of an aggregate filter to greatly reduce the amount of time necessary to construct the drainage structure. In addition, they are very thin in comparison to a properly graded aggregate filter, which saves space and allows water to pass through without piping (erosion) adjacent soil fines. Type 1 geotextile (Mn/DOT 3733) is used for most of these subsurface drainage applications. Special purpose geotextile and drainage designs should be discussed with the Geology Unit.

5-5.0 AGGREGATE-SURFACED ROAD DESIGN

The structural requirements for aggregate-surfaced roads are a function of the subgrade soil strength, the expected traffic loading, and the support provided by the various types of surfacing materials.

The design procedure consists of the determination of both the total thickness of aggregate material required above the subgrade as well as the thicknesses of the different aggregate layers required for the given traffic and subgrade conditions. A design guide for determining these thicknesses was developed for the counties, townships, and municipalities that design these roads entitled "Minnesota's Design Guide for Low Volume Aggregate Surfaced Road." This guide can be found in Appendix B.

A reference to an FHWA publication on the use of geotextiles in unpaved roads is included at the end of this chapter.

REFERENCES

Ahlborn, G., ELSYM5, Computer Program for Determining Stresses and Deformations in Five Layer Elastic System, University of California, Berkeley.

American Association of State Highway and Transportation Officials, AASHTO Interim Guide for Design of Pavement Structures, Washington, D.C., 1981.

American Association of State Highway and Transportation Officials, AASHTO Guide for Design of Pavement Structures, Washington, D.C., 1986.

Asphalt Institute, Thickness Design - Asphalt Pavements for Highways and Streets, Manual Series No. 1, Maryland, September 1981.

Cedergren, Harry R., Drainage of Highway and Airfield Pavements, John Wiley and Sons, Inc., New York, 1974.

Dehlen, G. L., The Effects of Non-linear Response on the Behavior of Pavements Subjected to Traffic Loads, Ph.D. Dissertation, University of California, Berkeley, 1969.

De Jong, D. L., M. G. F. Peutz, and A. R. Korswagen, Computer Program BISAR, Layered Systems Under Normal and Tangential Loads, External Report AMSR.0006.73, Koninklijke Shell-Laboratorium, Amsterdam, 1973.

Duluth Technical College, Civil Engineering Technology and Minnesota Department of Transportation, Grading and Base II Course Book, 1992-93.

Duncan, J. M., C. L. Monismith, and E. L. Wilson, "Finite Element Analyses of Pavements," Highway Research Record No. 228, Highway Research Board, Washington, D.C., 1968, pp. 18 - 33.

ERES Consultants Inc., Pavement Design, Principles and Practices, U.S. Department of Transportation, Federal Highway Administration, National Highway Institute, September 1987.

ERES Consultants Inc., Techniques for Pavement Rehabilitation, U.S. Department of Transportation, Federal Highway Administration, National Highway Institute, October 1987.

Ioannides A. M. and J. P. Donnelly, "Three-Dimensional Analysis of Slab on Stress-Dependent Foundation," Transportation Research Record 1196, Transportation Research Board, Washington, D.C., 1988.

Jorenby, B. N. and R. G. Hicks, "Base Course Contamination Limits" Transportation Research Record 1095, Transportation Research Board, Washington, D.C., 1986.

Koerner, Robert M., Designing with Geosynthetics, Prentice Hall, New Jersey, 1990.

NCHRP, Design and Use of Highway Shoulders, NCHRP Synthesis of Highway Practice, Report No. 63, 1979.

United States Army Corps of Engineers, EM 1110-2-1901, "Engineering and Design, Seepage Analysis and Control for Dams," 30 September 1986.

Tayabji, S.D. and P.A. Okamoto, "Thickness Design of Concrete Reinforcing," 3rd International Conference Concrete Pavement Design and Rehabilitation, Purdue Indiana, 1985.

United States Department of Transportation, Federal Highway Administration, Highway Subdrainage Design, Report No. FHWA-TS-80-224, 1980.

United States Department of Transportation, Federal Highway Administration, Geotextile Engineering Manual, Publication No. FHWA-HI-89-050, 1989.

United States Department of Transportation, Federal Highway Administration, Geotextile Design and Construction Guidelines, Report No. FHWA-HI-90-001, 1990. (Edited version of above, with construction-related additions.)

United States Department of Transportation, Federal Highway Administration, Geotextile Selection and Installation Manual for Rural Unpaved Roads, Report No. FHWA-RT-89-050, 1989.