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Guide for Mechanistic-Empirical Design

OF NEW AND REHABILITATED PAVEMENT STRUCTURES

FINAL REPORT

PART 3. DESIGN ANALYSIS

CHAPTER 1. DRAINAGE

NCHRP

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PART 3—DESIGN ANALYSIS

CHAPTER 1
DRAINAGE

3.1.1 INTRODUCTION

As early as 1820, John McAdam noted that, regardless of the thickness of the structure, many roads in Great Britain deteriorated rapidly when the subgrade was saturated (*1*). It is widely recognized today that excess moisture in pavement layers, when combined with heavy truck traffic and moisture-susceptible materials, can reduce service life. Temperatures below freezing can also contribute to durability problems of saturated materials.

Moisture in the subgrade and the pavement structure can come from many different sources, as indicated in figure 3.1.1. Water may seep upward from a high groundwater table due to capillary suction or vapor movements, or it may flow laterally from the pavement edges and side ditches. Another source of water in pavements is surface infiltration of rain and meltwater through joints, cracks, shoulder edges, and various other defects, especially in older deteriorated pavements. Some studies have indicated that up to 40 percent of rainfall enters the pavement structure (*2, 3, 4*).

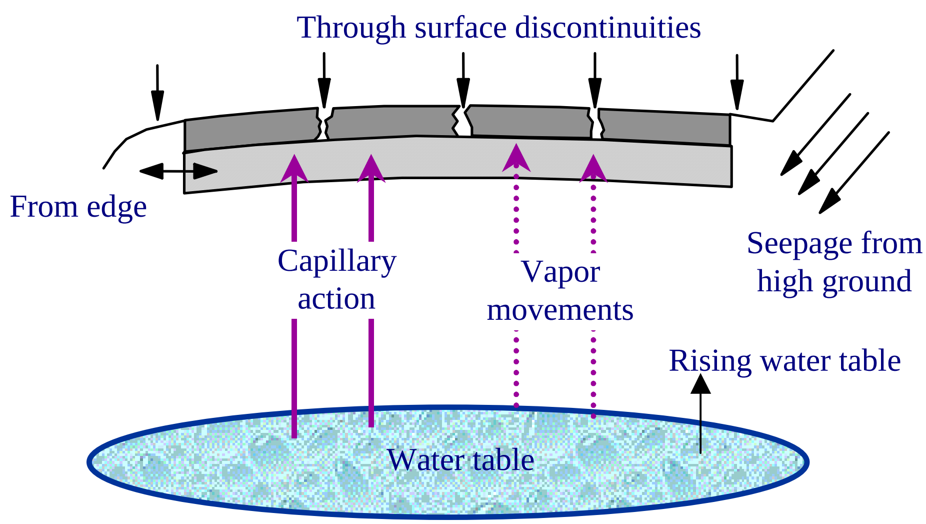


Figure 3.1.1. Sources of moisture in pavement systems.

Problems caused by prolonged exposure to excess moisture fall into three broad categories:

- Softening of pavement layers and subgrade as they become saturated and remain saturated for lengthy periods of time.
- Degradation of material quality from interaction with moisture.
- Loss of bond between pavement layers from saturation with moisture.

Moisture damage in pavements manifests itself in the form of moisture-caused and moisture-accelerated distresses. Moisture-caused distresses are those that are induced primarily by moisture, such as stripping of asphalt in flexible pavements and D-cracking in rigid pavements. Moisture-accelerated distresses are those that are initiated primarily by factors other than moisture (e.g., by wheel loads) but whose rate of deterioration is accelerated in the presence of moisture. Most pavement distresses worsen in the presence of moisture. Therefore, by corollary, if the entry of water into the structure is addressed adequately, it may be possible to extend pavement life by reducing the rate of progression of distress.

In recognition of the impact moisture can have on pavement performance, the AASHTO Design Guide incorporated an empirical drainage coefficient into the 1986 design equations. This coefficient increased awareness and encouraged design of pavements with permeable drainage layers.

In the design process presented in this Guide, the impact of moisture on the stiffness properties of unbound granular and subgrade materials is considered directly through the modeling of the interactions between climatic factors (rainfall and temperatures), groundwater fluctuations, and material characteristics of paving layers. In addition, the effect of moisture on base erodibility is considered for rigid pavement analysis and design (empirically). Further, for both flexible and rigid pavements, the effects of moisture on frost penetration and its subsequent impact on unbound base/subbase and subgrade structural properties are considered. Unlike previous versions of the AASHTO Guide, drainage coefficients such as m_i (for flexible pavements) and C_d (for rigid pavements) will not be used. The changes to the layer strength and stiffness in the Guide procedure are predicted directly by the Enhanced Integrated Climatic Model (EICM) (PART 2, Chapter 3) based on the climatic, materials, and foundation inputs (including water table depth) for the design project under consideration. The incremental damage accumulation process described in PART 1, Chapter 1 makes it possible to consider seasonal changes in unbound layer and subgrade properties due to moisture and coupled moisture-temperature effects in predicting pavement distress. Therefore, using this approach, the benefits of incorporating drainage layers should be apparent in terms of the distresses predicted.

A point to note, however, is that the sensitivity of the distress prediction models to drainage considerations is limited to the performance data available for calibrating the distress models included in the Guide procedure. Considering that only a limited amount of performance data was available for sections incorporating permeable layers and edgedrains, additional work is needed to document the effect of positive drainage on pavement life.

3.1.2 GENERAL DESIGN CONSIDERATIONS FOR COMBATING MOISTURE

A major objective in pavement design should be to keep the base, subbase, subgrade, and other susceptible paving materials from becoming saturated or even being exposed to constant high moisture levels over time. Many engineers would also add hot mix asphalt (HMA) and portland cement concrete (PCC) to this list, as saturation and freezing have caused problems in the past with these materials. Four approaches commonly employed to control or reduce moisture problems are listed below:

- Prevent moisture from entering the pavement system.
- Use materials that are insensitive to the effects of moisture.
- Incorporate design features to minimize moisture damage.
- Quickly remove moisture that enters the pavement system.

It is important to recognize that no approach can completely negate the effects of moisture on the pavement system under heavy traffic loads over many years. Thus, it is often necessary to employ a combination of approaches, particularly for heavy traffic loading conditions. Salient aspects of each of these approaches are discussed below.

3.1.2.1 Prevent Moisture from Entering the Pavement System

Conceptually, the best approach for reducing the detrimental effects of moisture is to prevent moisture from entering the pavement system; however, moisture enters the pavement system from a variety of sources, and nothing can prevent it completely. Nevertheless, designers can *minimize* the amount of moisture entering the pavement system.

<u>Pavement Geometry—Surface Drainage</u>

An effective means for minimizing surface infiltration is to provide adequate cross-slopes and longitudinal slopes to drain water from the pavement surface quickly. The selection of appropriate pavement slopes is based on considerations such as user safety, profile economics, level of service, terrain, and vehicle operating characteristics. In general, the less time the water is allowed to stay on the pavement surface, the less moisture can infiltrate through joints and cracks. Minimum cross-slopes and longitudinal grades must be maintained to achieve this objective. The AASHTO geometric design manual, *A Policy on Geometric Design of Highways and Streets*, is the governing document on highway geometric design (*5*). A recent study, "Improved Surface Drainage of Pavements," proposed several changes to the current AASHTO geometric design policy to further reduce the risk of hydroplaning on new and rehabilitated pavements (*6*). According to this study, the risk of hydroplaning in pavements with design speeds exceeding 60 mph can be offset by adopting alternative pavement finishing techniques (grooving, tining, texture depth), using drainage appurtenances (slotted drains), or using alternative pavement materials (porous asphalt) in addition to maximizing the pavement slopes within feasible limits.

<u>Joint and Crack Sealing</u>

Another common approach to limit surface water in the pavement system is to seal all joints, cracks, and other discontinuities. Many agencies seal the joints on rigid pavements during initial construction. However, with time, the seal becomes damaged due to the opening and closing of the joints and other climatic effects. In addition, some cracks in all types of pavements may never be sealed, including the lane/shoulder longitudinal joint or crack. For this approach to be effective, all cracks must be sealed soon after they develop, and joints and cracks must be cleaned and resealed as often as necessary. Special attention must be paid to lane-lane and lane-shoulder longitudinal joints, as these are significant moisture entry points. Although HMA pavements do not contain joints, they do develop cracks over time that should be sealed properly to prevent moisture intrusion.

3.1.2.2 Provide Moisture-Insensitive (Nonerodible) Materials

Another means of preventing moisture-accelerated damage is to use moisture-insensitive or nonerodible base materials that are less affected by the detrimental effects of moisture. However, although some materials can reduce or delay the detrimental effects of moisture, moisture-insensitive materials by themselves may not fully address moisture-related problems in pavements that are heavily loaded. A discussion on materials that are used often to reduce moisture-related damage is presented in this section.

Lean Concrete Base and Cement-Treated Base

Strong and nonerodible cement-stabilized materials can be effective in minimizing problems with pumping and faulting in PCC pavements. In addition to the conventional strength testing for durability, such materials should also be checked for resistance to moisture erosion. In general, the higher the cement content and compressive strength, the more resistant the material is to moisture damage. Obviously, high-quality crushed aggregates are also needed to ensure long-term durability.

When using cement stabilized base layers under jointed plain concrete pavements (JPCP), two construction options are available. If bonding between the slab and base is allowed, notches should be cut in the base to match the joints in the JPCP to prevent reflection cracking. If bonding is not allowed, an asphalt seal coat should be used between the slab and the base to serve as a shear-relief layer. Further, an aggregate subbase is recommended to prevent pumping and loss of fines from beneath the treated base on JPCP in areas with adverse site conditions (e.g., high design traffic, wet climates, and high amounts of pumpable fines in the subgrade). The use of pavement design features such as widened lanes and dowel bars can sometimes obviate this requirement.

The erodibility class definitions of lean concrete base (LCB) and cement-treated base (CTB) materials for use in design can be found in PART 2, Chapter 2 of the Guide.

Asphalt-Treated Base

Hot-mix asphalt base materials can also be effective in minimizing moisture problems in HMA and PCC pavements. The stripping of asphalt binder, caused by many factors but particularly aggregate characteristics and inadequate film thicknesses, has been the biggest problem with asphalt-treated base (ATB) under PCC pavements. Therefore, just as with CTB, adequate film thickness of asphalt cement around the aggregates and quality aggregates are required in ATBs to ensure long-term durability. The treated asphalt layers should be constructed using high-quality aggregates, and the design should be consistent with that of a dense graded HMA base course layers defined in PART 2, Chapter 2 of the Guide. In general, high asphalt content ensures adequate film thicknesses around the aggregates, thereby increasing resistance to moisture. Laboratory testing should be conducted to ensure that the mix design and testing for stripping is adequate to withstand the effects of moisture.

The erodibility class definitions of various asphalt-treated layers for use in design can be found in PART 1, Chapter 2 of the Guide.

Granular Base with Limited Fines

Granular materials with a high amount of crushed materials, low fines contents, and low plasticity may also be used to combat the effects of moisture. These open-graded materials provide better resistance to the effects of moisture than dense-graded materials with high fines contents. First, open-graded materials allow easier movement of moisture through the material, so the layer remains saturated for less time. Second, the reduction of fines means there is less material that can be ejected through joints and cracks. However, stability of these untreated permeable base layers is a major concern because settlement can lead to serious problems and needs to be addressed adequately. Permeable base layers are discussed in more detail later in this chapter.

The erodibility class definitions of permeable granular layers for use in design can be found in PART 1, Chapter 2 of the Guide.

3.1.2.3 Incorporate Design Features to Minimize Moisture Damage

Apart from using moisture-insensitive materials, several other design features can be used to minimize moisture damage. The following design options could be used with jointed PCC pavements:

- Dowel bars at transverse joints of sufficient size and spacing. This is typically the most cost-effective solution to joint faulting problems and the only effective means of preventing excessive faulting on pavements subjected to high volumes of heavy trucks.
- Widened slabs 2 ft to reduce deflections, faulting, and cracking.
- Tied concrete shoulders to keep the lane/shoulder joint tight and reduce the potential for pumping by reducing the edge deflections.
- Provision of a granular layer between the subgrade and stabilized base course to reduce erosion beneath the base course, to allow bottom seepage, and to minimize frost susceptibility, which could increase pavement roughness.
- Provision of adequate side ditches with flow lines beneath the pavement structure.

For conventional and deep-strength HMA pavements, the following design options can be used:

- Full-width paving to eliminate the lane/shoulder cold joint, which is a major source of water infiltration in the pavement structure.
- Provision of a granular layer between the subgrade and base course to reduce erosion and to allow bottom seepage and minimize frost susceptibility that could increase pavement roughness.
- Provision of adequate side ditches with flow lines beneath the pavement structure.

3.1.2.4 Removal of Free Moisture through Subsurface Drainage

To obtain adequate pavement drainage, the designer should consider providing three types of drainage systems: surface drainage, groundwater drainage, and subsurface drainage (also called subdrainage). Such systems, however, are only effective for "free water." Water held by capillary forces in soils and in fine aggregates cannot be drained. The effects of this "bound" moisture are considered in the EICM through adjustments to pavement materials properties.

Of the three types of drainage mentioned, surface drainage considerations have already been discussed. Groundwater seepage is usually considered a geotechnical problem which needs to be addressed during embankment design and will not be discussed in this Guide.

The final approach to remove free water through the provision of subdrainage is addressed in this chapter. It should be recognized, however, that all three forms of drainage share a symbiotic relationship and should be considered together in the overall drainage design for a project.

The use of subsurface drainage has gained popularity over the past two decades, and many agencies now routinely specify drainable pavement structures to reduce moisture-related problems in pavements. The focus of the remainder of this chapter is to explain the basic subsurface drainage terminology, present some commonly used drainage alternatives, provide guidance on the hydraulic design of subdrainage components, and explain how the incorporation of drainage relates to the overall pavement structural design process. The subdrainage systems described here primarily address moisture infiltration occurring through cracks and discontinuities in the pavement surface. Occasionally, these systems may also help relieve moisture from spring-thaw bleeding.

3.1.3 SUBSURFACE DRAINAGE TERMINOLOGY

This section introduces some of the subdrainage components referred to throughout this chapter, along with short discussions of their functions, materials issues, hydraulic and structural design considerations, and other salient characteristics.

3.1.3.1 Permeable Base

A permeable base is an open-graded drainage layer with a typical laboratory permeability value of 1,000 ft/day or greater. The primary function of the permeable base is to dissipate water infiltrating the pavement surface by moving it laterally towards the edge of the pavement within an acceptable timeframe. The drainage path and the hydraulic gradient are determined by the pavement geometry. Therefore, by definition, these layers are viable where the vertical drainage through the subgrade is inhibited by materials with low hydraulic conductivities.

The recommended minimum and maximum thickness of permeable base layers is 4 inches. This recommendation ensures an adequate hydraulic channel for the free flow of water and places an upper limit on the thickness of this relatively unstable layer. Permeable bases could be asphalt-treated, cement-treated, or untreated, depending on structural requirements. Where structural requirements demand a higher strength and stiffness, treated permeable layers are warranted. A separator layer should always be placed below a permeable base to ensure that any fines from the subgrade or other underlying layers do not contaminate it, which could result in serious pavement deterioration over time.

The recommended approach for hydraulic design of permeable base layers is the time-to-drain approach described in Appendix SS. In this approach, the time required to drain the base from an initial flooded condition to an acceptable level of saturation (or degree of drainage) is the main parameter of interest. The quality of the permeable base layer is judged based on this parameter. Most Interstate pavements and primary arterials are designed to have permeable bases that can drain 50 percent of the drainable water from an initially saturated condition in approximately 2 hours.

While drainabilty is important, the permeability of this layer should always be balanced with stability. Stability of the layer is vital for both construction purposes and long-term performance of the pavement. Stabilization with asphalt or cement can help provide adequate stability.

Materials Considerations for Unstabilized Permeable Bases

The aggregate used for this type of permeable base must be hard, durable material. As a minimum, the aggregate should have at least two fractured faces; preferably, it should consist of 98 percent crushed stone. The L.A. abrasion wear should not exceed 45 percent as determined by AASHTO T 96, "Resistance to Abrasion of Small Size Coarse Aggregate by Use of Los Angeles Machine." The soundness loss percent should not exceed 12 or 18 percent as determined by the sodium sulfate or magnesium sulfate tests, respectively. The test shall be in accordance with AASHTO T 104, "Soundness of Aggregate by the Use of Sodium Sulfate or Magnesium Sulfate." The gradation of this layer should enable free movement of water with a minimum permeability value around 1,000 ft/day. Material passing the No. 40 sieve shall be non-plastic in accordance with AASHTO T 90, "Determining the Plastic Limit and Plasticity Index of Soils."

This information was excerpted from the guide specification for materials selection and construction of unstabilized permeable base layers, which is available through the FHWA (*7*). Agencies may consult this specification on an as-needed basis.

Materials Considerations for Asphalt-Treated Permeable Bases (ATPB)

The aggregate material used for ATPB must be hard and durable with the same requirements for angularity, L.A. abrasion, and soundness as specified for unstabilized permeable bases. Asphalt binders that minimize draindown and that permit thorough coating of aggregates must be used. The asphalt content should be 3 percent plus (+) or minus (-) ½ percent by weight of dry aggregate. Adequate asphalt cement and film thickness are important for the long-term durability of ATPB layers. Asphalt cement as described in AASHTO M320, "Performance Graded Asphalt Binder," PG 76-22, 70-22, or 64-22 or equivalent viscosity, AR, or penetration grades for a given region may be used as conditions warrant. It is recommended that an additive to prevent stripping of the asphalt cement be used where appropriate. The gradation of this layer should enable free movement of water with a minimum permeability value around 1,000 ft/day.

This information was excerpted from the guide specification for materials selection and construction of ATPB layers, which is available through the FHWA (*7*). Agencies may consult this specification on an as-needed basis.

<u>Materials Considerations for Cement-Treated Permeable Bases (CTPB)</u>

The aggregate material used for CTPB must be hard and durable with the same requirements for angularity, L.A. abrasion, and soundness as specified for unstabilized permeable bases. Cement shall be Type I, Type I-P, or Type II conforming to the appropriate sections of the State highway agencies' standard specifications for AASHTO M 85, "Specification for Portland Cements." The minimum cement content shall be 235 lbs/yd^3 or 2.5 bags/yd^3. The water-cement ratio used should provide for the minimum amount of water consistent with the required workability to provide a uniform material (with well coated aggregates) and surface texture as determined through visual inspection. The gradation of this layer should enable free movement of water with a minimum permeability value around 1,000 ft/day.

This information was excerpted from the guide specification for materials selection and construction of CTPB layers, which is available through the FHWA (*7*). Agencies may consult this specification on an as-needed basis.

3.1.3.2 Separator Layer

A separator layer is an impermeable layer of aggregate material (treated or untreated) or a geotextile layer placed between the permeable base and the subgrade or other underlying layers. The separator layer has three main functions: (a) to maintain separation between permeable base and subgrade and prevent them from intermixing, (b) to form an impermeable barrier that deflects water from the permeable base horizontally toward the pavement edge, and (c) to support construction traffic.

If dense-graded aggregate separator layers are used, the aggregate must be a hard, durable material. As a minimum, the aggregate should have at least two fractured faces as determined by the material retained on the No. 4 sieve; preferably, it should consist of 98 percent crushed stone. The L.A. abrasion wear should not exceed 50 percent as determined by AASHTO T 96, "Resistance to Abrasion of Small Size Coarse Aggregate by Use of Los Angeles Machine." The soundness loss percent should not exceed 12 or 18 percent as determined by the sodium sulfate or magnesium sulfate tests, respectively. The test shall be in accordance with AASHTO T 104, "Soundness of Aggregate by the Use of Sodium Sulfate or Magnesium Sulfate." The gradation of this layer should such that it allows a maximum permeability of approximately 15 ft/day with less than 12 percent of the material passing the No. 200 sieve, by weight. Material passing the No. 40 sieve shall be nonplastic in accordance with AASHTO T 90, "Determining the Plastic Limit and Plasticity Index of Soils." This information was excerpted from the FHWA guide specification for materials selection and construction of aggregate separation layers.

Geotextile separator layers are used primarily to prevent intermixing of permeable base layers with subgrade soil. Typically, they are used when an adequate construction platform already exists. Both woven and non-woven geotextiles have been used for the separation application. Just as with aggregate separator layers, the geotextile layers will have to satisfy filtration criteria. In addition, they need to satisfy survivability and endurance criteria.

The design of aggregate and geotextile separator layers is discussed in Appendix SS. Guide specifications for materials selection and construction of aggregate and geotextile separator layers are available through the FHWA (*7*).

3.1.3.3 Edgedrains

Edgedrains consist of longitudinal pipes that run alongside the pavement. They are placed 2-in from the bottom of a trench dug on the side of the pavement adjacent to the lane-shoulder joint. They collect water discharged from the pavement structure and transfer it to the outlets. Pipe edgedrains and prefabricated geocomposite edgedrains (PGEDs) are the two types of commonly available edgedrains. Pipe edgedrains should have adequate strength to withstand crushing. If the pipe can withstand loads during construction, it will serve out its design life without crushing. Edgedrains should conform to the appropriate State or AASHTO specification.

Edgedrain pipes should have a minimum diameter of 4 inches for maintenance purposes and should be designed to handle the inflow from the pavement cross-section. The hydraulic design of edgedrains for cross-sections with and without a permeable base is discussed in Appendix SS. The appendix also covers materials selection and construction aspects of highway edgedrains.

3.1.3.4 Outlets

Outlets are short pipes that carry the water from the edgedrains to the side ditches. Non-perforated metal or smooth, rigid pipes are recommended for outlets. This pipe must be strong enough to resist construction and maintenance traffic. A minimum pipe diameter of 4 inches is recommended for maintenance purposes. The connections between the longitudinal edgedrains and outlet pipes should be designed to facilitate easy movement of water and should amenable for inspection and maintenance. The preferred layout of the edgedrain-outlet system is presented in Appendix SS.

3.1.3.5 Headwall

Headwalls made of PCC are used to house drainage outlets to prevent them from potential damage by routine roadside maintenance activities. They also help prevent slope erosion and aid in locating outlet pipes. Headwalls should be placed flush with the slope of the embankment so that routine maintenance activities are not impaired. Removable rodent screens are recommended with headwalls to prevent small animals from entering the outlets.

The outlet pipes carrying water to the headwall normally rest on porous backfill bedding material. While this is good practice, there is concern that the water conducted by this material, drains down the grade and logs up against and around headwall creating maintenance problems. One way to address this issue is to provide small weep holes in the headwall on either side of the outlet pipe at the outflow end. This can be accommodated relatively easily in precast headwalls.

3.1.3.6 Side Ditches

Ditches are dug to carry the water collected from the outlets away from the pavement. This feature is common to both surface and subsurface drainage. The side ditches should have a minimum longitudinal grade of 0.005 ft/ft and an adequate freeboard to be effective.

3.1.3.7 Storm Drains

In urban locations where ditches cannot be dug on the side of the highway, storm drains are installed to carry the surface and subsurface runoff.

3.1.3.8 Daylighting

In a daylighted pavement section, the edges of the base and subbase layers are exposed to allow water trapped in these layers to flow directly into the side ditch. Such a design is the conceptual opposite of a “bathtub” section.

3.1.4 SUBSURFACE DRAINAGE ALTERNATIVES

Various subdrainage alternatives are available for different design situations. Subdrainage alternatives vary in complexity and cost, ranging from the provision of open-graded drainage layers tied into longitudinal edgedrains and outlet pipes to simply daylighting dense-graded bases. However, not all alternatives are applicable for all pavement design situations. Some of the more commonly employed drainage alternatives and their applicability in different situations are explained below.

3.1.4.1 Permeable Base System with Pipe Edgedrains: Type Ia

A permeable base system is the most complete subsurface drainage alternative, as it incorporates most of the drainage-related components. It consists of a permeable base layer, separator layer, edgedrains, outlets, headwall, and a side ditch or storm drain, arranged as shown in figure 3.1.2. In this design, water infiltrating the pavement surface is deflected at the permeable base/separator layer interface and flows horizontally through the permeable base into the edgedrains and outlets instead of flowing vertically into the subgrade. This design is associated primarily with new construction or reconstruction projects. Note that pipe edgedrains are used in this design because they have sufficient hydraulic capacity to handle the high outflow of water from the permeable base and can be inspected with video equipment and maintained. The edgedrains are placed in a trench partially wrapped with a geotextile to prevent fines from the surrounding materials from entering the pipes. The separator layer could be an aggregate layer, a geotextile layer, or a combination thereof. The backfill material should have a permeability equal to or greater than the permeable base. The material could be untreated or stabilized with asphalt or cement. All components of this system should be designed adequately for hydraulic capacity as described in Appendix SS. The layering arrangement and cross-section that emerge from hydraulic considerations will then become an input for the structural design.

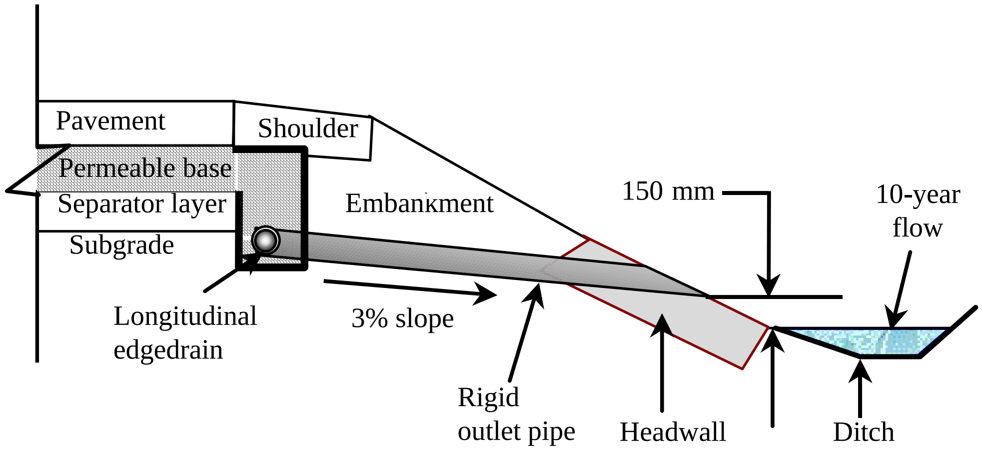


Figure 3.1.2. Permeable base system with edgedrains (*4*).

3.1.4.2 Daylighted Permeable Base System: Type Ib

This design is similar to Type Ia except that the permeable base is extended and daylighted to the side ditch. This design is illustrated in figure 3.1.3. This design may be applicable where pavement longitudinal grades are flat so the cross slope controls subsurface drainage. The function of the fabric separator in the figure is to keep the embankment soil from contaminating the permeable base. The key to good performance of such sections is maintenance of the daylighted edge of the base.

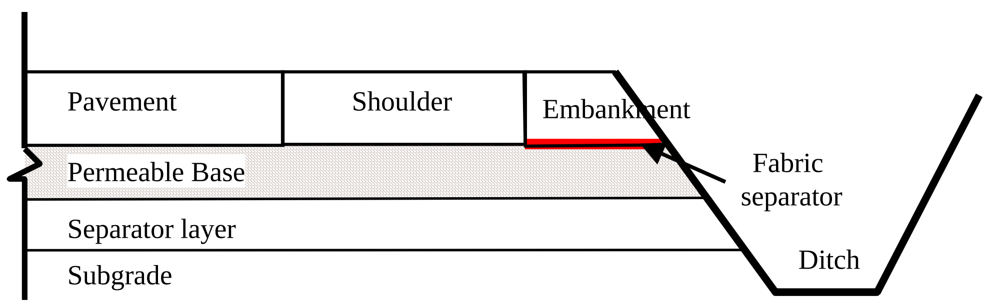


Figure 3.1.3. Daylighted permeable base system (*4*).

When constructing daylighted permeable base systems, care should be taken to prevent reverse flows (i.e., flow of the water from the side ditch into the pavement structure). This can be accomplished by ensuring that the bottom of the permeable base is at least 6 in above the 10-year design flow of the ditch.

3.1.4.3 Nonerodible Base with Pipe Edgedrains: Type IIa

When a pavement section with a nonerodible base (e.g., a hot mix asphalt base or an LCB) is fitted with longitudinal pipe edgedrains, it represents a partial drainage system. The edgedrains are located in a trench filled with open-graded backfill material. Figure 3.1.4 presents a sketch of the design.

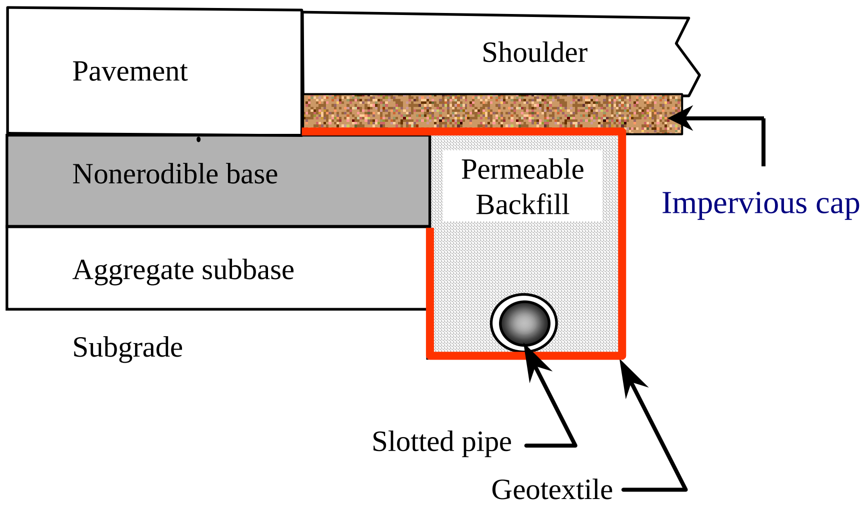


Figure 3.1.4. Nonerodible base with pipe edgedrains.

The aggregate subbase is an integral part of this design, as it greatly reduces erosion beneath a treated base. The term “nonerodible base” refers to durable asphalt-treated or cement-treated bases. The function of the edgedrains is to collect water entering the pavement through the lane/shoulder joint and surface cracks and to move it to the outlets and side ditch. The backfill material should be free-draining. This design is a viable option for new construction, reconstruction, or rehabilitation where moisture-related distress has reduced (or is expected to reduce) the pavement's service life.

A modification to the design shown in figure 3.1.4, practiced by many agencies, is the provision of a nonerodible base without the edgedrain pipes and trench. Although this design does not qualify as a subdrainage option (because it does not include any drainage component), it is a viable alternative for combating the detrimental effects of moisture and has been used successfully.

3.1.4.4 Nonerodible Base with Edgedrains and Porous Concrete Shoulder: Type IIb

This design consists of a nonerodible base under the traffic lanes and a cement-treated permeable base under the shoulder fitted with edgedrains is illustrated in figure 3.1.5. The difference between this design and the Type IIa design is in the backfill material used in the edgedrain trench. The cement-stabilized material used for the trench backfill in this design provides stronger support under the shoulder and alleviates shoulder settlement problems. However, it also increases the cost of construction.

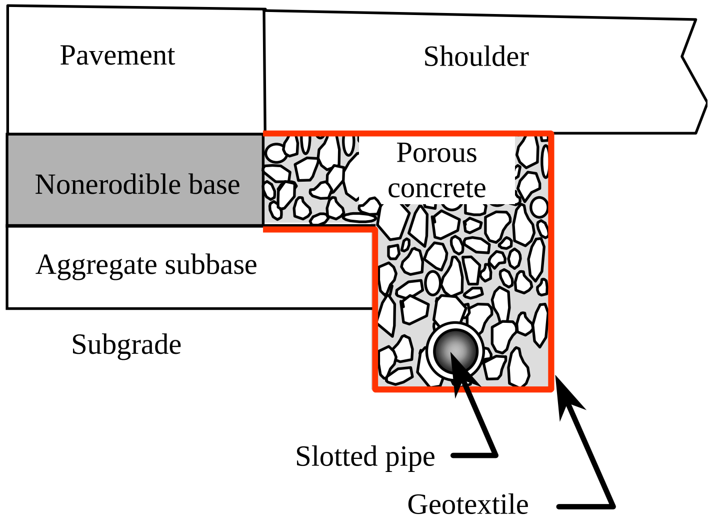


Figure 3.1.5. Nonerodible base with porous concrete shoulder.

3.1.4.5 Daylighted Dense-Graded Aggregate Base: Type III

This design consists of a pavement (typically a rigid pavement) on a dense-graded aggregate base (DGAB). The DGAB is directly daylighted to the side ditch. Although this is not a highly recommended alternative, it is better than constructing a "bathtub" section because it provides some drainage relief from seepage along the granular base/subgrade interface. Daylighted dense-graded bases were provided under PCC pavements in the AASHO Road Test. These bases have been used successfully under HMA pavements as well *(8)*.

3.1.5 SYSTEMATIC APPROACH FOR SUBSURFACE DRAINAGE DESIGN: CONSIDERATIONS IN NEW OR RECONSTRUCTED PAVEMENTS

This section discusses the design considerations for providing subsurface drainage in new or reconstructed pavements. First, the agency must maintain the subsurface drainage system. If such a commitment cannot be made, then it would not be logical to construct a subsurface drainage system. If such a commitment is made, then the decision to provide subsurface drainage should be based primarily on cost-effectiveness. In general, positive subsurface drainage should increase pavement life and decrease the probability of failure, but it will also increase the cost of initial construction. Therefore, as a first step, the need for drainage should be assessed to determine whether drainage will be cost-effective for the given site conditions and proposed design features. If drainage is not deemed cost-effective from this analysis, it need not be considered in the structural design. On the other hand, if it is felt that provision of subdrainage is important, viable drainage alternatives should be selected and properly designed from a hydraulic and structural standpoint. Proper attention to materials selection, construction, and maintenance of the drainage systems is also important for long-term success of drainage systems. Subdrainage is not a substitute for poor design; adequate structure should be present in order for these systems to function effectively.

Figure 3.1.6 presents a systematic approach to consider the need for drainage and to perform drainage design, ultimately leading to the preparation of cross-sections with adequate drainage features that can be evaluated for structural distresses using the mechanistic-empirical approach presented in the Guide. A discussion of the various steps outlined in the figure is presented below. The practical considerations of subsurface drainage design discussed in this chapter help augment the Guide's design approach by addressing factors that cannot be directly input into the design equations.

3.1.5.1 Step 1: Assessing the Need for Drainage

Identifying the need for subdrainage for a given project situation is an important step in the pavement design process. As previously stated, subsurface drainage is cost-effective only when there is an anticipated problem with moisture. There are no universal criteria for assessing the need for subsurface drainage; however, answering the following basic questions can help guide the decision making process:

- What is the anticipated heavy traffic level? (Truck traffic is a prime factor in determining the need for subdrainage.)
- Are climatic conditions such that significant water could infiltrate the pavement and keep it saturated for long periods?
- Does the natural subgrade allow free vertical drainage or does it have high amount of plastic fines that inhibit flow?
- Are the pavement materials susceptible to moisture-related damage? Are there any features in the pavement design that could alleviate some moisture-related problems?
- Is a subsurface drainage system the most effective method of minimizing moisture-related distress in the pavement?
- Will the subsurface drainage system be maintained periodically?

Ideally, the need for subdrainage should be based on a cost/benefit analysis in that the benefit (extended life, reduced maintenance) should be greater than the added cost of installing and maintaining such systems. In the absence of a universally acceptable procedure to perform such an analysis, the practical approach outlined in table 3.1.1 may be used. The procedure is based primarily on site conditions that affect the decision making process the most. In the table, heavy trucks were defined as higher than FHWA Class 4 vehicles. Further, similar to the Long Term Pavement Performance (LTPP) program, the following criteria were used in defining the four climatic regions shown:

Wet Climate:	Annual precipitation > 508 mm (20 in)
Dry Climate:	Annual precipitation $\leq$ 508 mm (20 in.)
Freeze:	Annual freezing index > 83 ^{o}C-days (150 ^{o}F-days)
No-Freeze:	Annual freezing index $\leq$ 83 ^{o}C-days (150 ^{o}F-days)

The climatic zones are represented pictorially in figure 3.1.7.

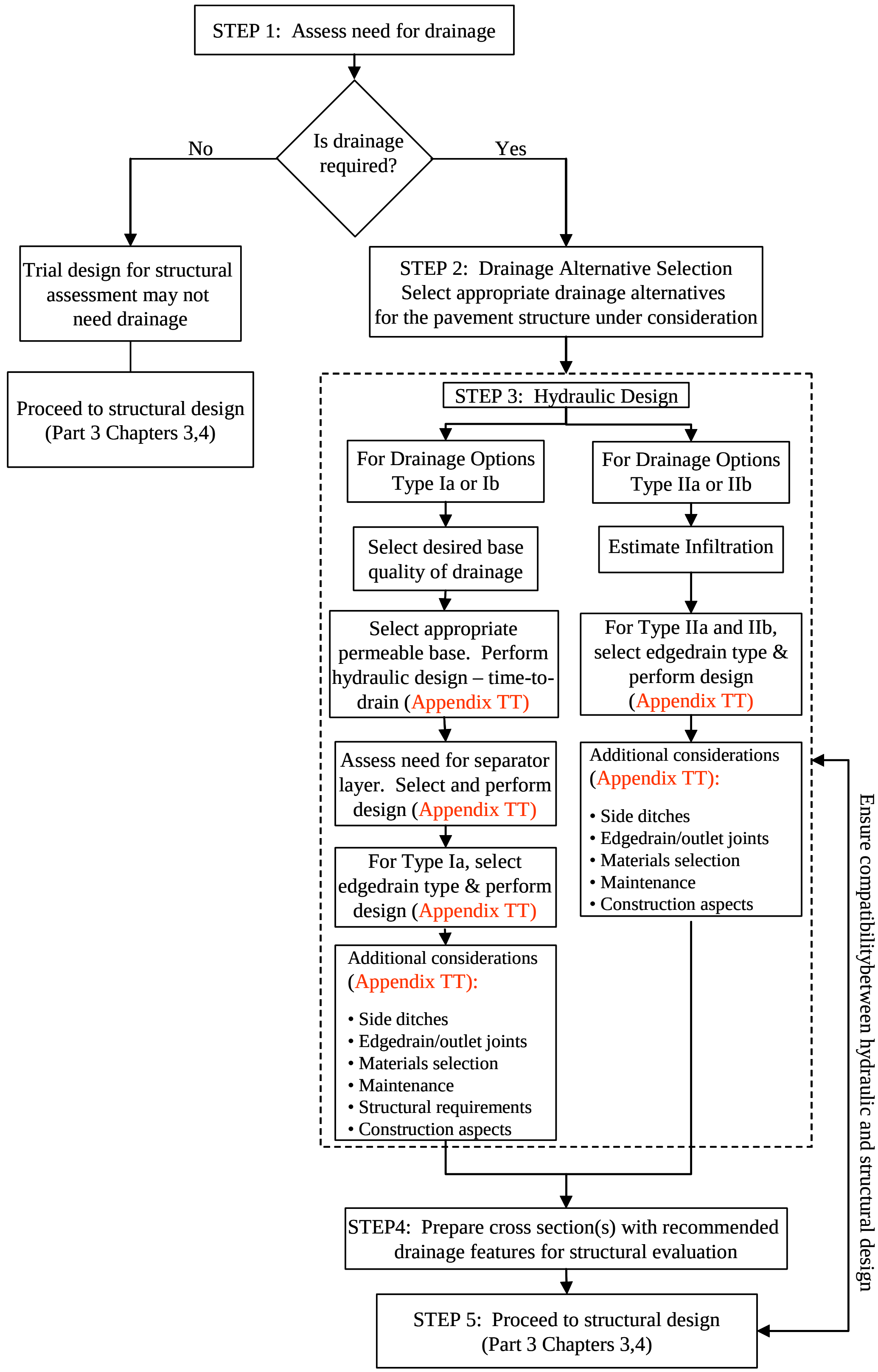


Figure 3.1.6. Systematic approach for subsurface drainage considerations in new or reconstructed pavements.

Table 3.1.1. Assessment of need for subsurface drainage in new or reconstructed pavements (adapted after [*4*]).

Climatic Condition	**Greater than 12 million 20-year design lane heavy trucks**			**Between 2.5 and 12 million 20-year design lane heavy trucks**			**Less than 2.5 million 20-year design lane heavy trucks**		
	$k_{subgrade}$ < 3 m/day	**$k_{subgrade}$ 3 to 30 m/day**	**$k_{subgrade}$ > 30 m/day**	**$k_{subgrade}$ < 3 m/day**	**$k_{subgrade}$ 3 to 30 m/day**	**$k_{subgrade}$ > 30 m/day**	**$k_{subgrade}$ < 3 m/day**	**$k_{subgrade}$ 3 to 30 m/day**	**$k_{subgrade}$ > 30 m/day**
Wet-Freeze	R	R	F	R	R	F	F	NR	NR
Wet-No Freeze	R	R	F	R	F	F	F	NR	NR
Dry-Freeze	F	F	NR	F	F	NR	NR	NR	NR
Dry-No Freeze	F	NR	NR	NR	NR	NR	NR	NR	NR

LEGEND

$k_{subgrade}$ = Subgrade permeability (this term is used as a surrogate for soil type) as determined using:

(a) AASHTO T 215, "Permeability of Granular Soils (Constant Head)," for coarse-grained soils (clean sands and gravels).

(b) U.S. Army Corps of Engineers' Engineering Manual (EM-1110-2-1906) procedure for permeability determination of fine grained soils (Falling Head) (clays and silts) recorded in Appendix VII.

R = Some form of subdrainage or other design features are recommended to combat potential moisture problems.

F = Providing subdrainage is feasible. The following additional factors need to be considered in the decision making:

(1) Past pavement performance and experience in similar conditions, if any.

(2) Cost differential and anticipated increase in service life through the use of various drainage alternatives.

(3) Anticipated durability and/or erodibility of paving materials.

NR = Subsurface drainage is not required in these situations.

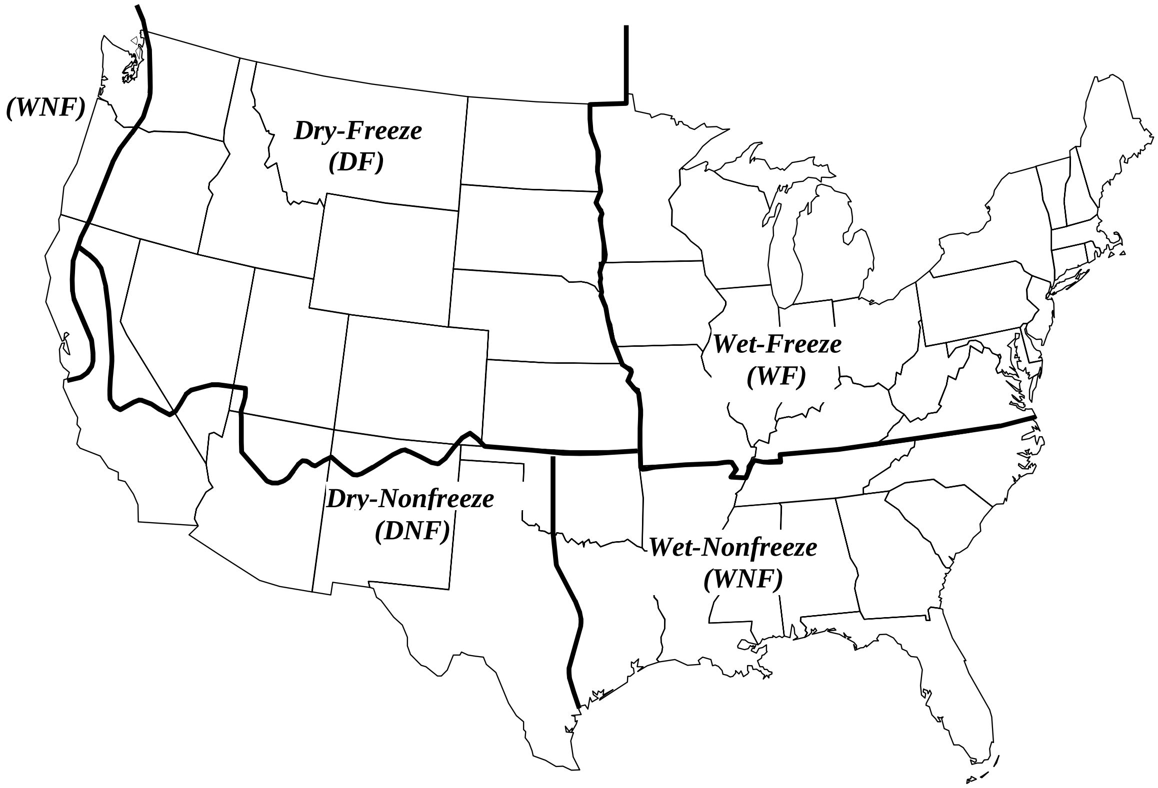


Figure 3.1.7. Four climatic zones as identified in the Long-Term Pavement Performance program.

Where drainage is "recommended" in table 3.1.1, moisture-related problems are anticipated. Incorporation of subsurface drainage features to alleviate these problems should be carefully considered in such situations along with other options.

When drainage is "feasible" in table 3.1.1, there is a chance that moisture problems could affect pavement performance. However, the use of any form of subdrainage in these situations should be governed by cost considerations, past performance history, anticipated materials quality, and the economy of other non- drainage options. For example, in the design of jointed plain concrete pavements, the provision of subdrainage is generally more cost-effective when the pavement is undoweled, or if it is doweled, when the volume of truck traffic is high. Other non-drainage options that help minimize the effect of moisture in JPCP include widened lanes and tied shoulders. For asphalt pavements, monolithic paving of mainline and shoulder to eliminate cold joints can help mitigate moisture distresses to some extent by preventing the entry of water.

When drainage is "not recommended" in table 3.1.1, it implies that the addition of drainage probably will not be cost-effective. In this case, the trial designs for structural evaluation will not require any drainage considerations. However, even in these cases, special situations along a given project such as cut sections, flat grades, sag curves, or poor construction materials should be evaluated on a case-by-case basis.

Overall, adjusting the recommendations in table 3.1.1 to local experience is very important.

3.1.5.2 Step 2: Selection of Drainage Alternatives

After determining that subsurface drainage is needed, the designer must select the drainage type that will be most effective for a given pavement design. The type of subsurface drainage required should be based on the weighted need for a given design situation. Some feasible subdrainage options for various pavement types are discussed.

Conventional and Deep Strength HMA Pavements (see PART 3, Chapter 3 for definitions)

When site conditions are such that drainage is "recommended" in table 3.1.1, the following options are available for this pavement type:

- A permeable base system with pipe edgedrains (Type Ia). The permeable base could be an ATPB or a CTPB layer. A separator layer must also be provided. A daylighted permeable base (Type Ib) could be considered for flat grades (with less than 0.5 percent longitudinal grade) or at the bottom of sag curves when maintenance of the daylighted edge can be assured.
- A partial drainage system with a nonerodible base and pipe edgedrains (Type IIa).

When site conditions are such that drainage is "feasible," the provision of a thick, daylighted dense aggregate base can be considered in addition to the two options listed above.

Full-Depth HMA Pavements

When site conditions are such that drainage is "recommended" in table 3.1.1, the following options are available for this pavement type:

- A permeable base system with pipe edgedrains (Type Ia). The permeable base must be an ATPB, and the aggregate separator layer an asphalt treated layer in order to satisfy the definition of a full-depth HMA pavement. A daylighted permeable base (Type Ib) could be considered for flat grades (with less than 0.5 percent longitudinal grade) or at the bottom of sag curves when maintenance of the daylighted edge can be assured.
- Installation of pipe edgedrains along with the HMA full-depth section (Type IIa). The nonerodibility of the dense HMA layer should be assured for the success of this design.

When site conditions are such that the provision of drainage is "feasible," either of the options listed could be chosen.

Jointed Plain Concrete Pavements

When site conditions are such that drainage is "recommended" in table 3.1.1, the following options are available for this pavement type:

- A permeable base system with pipe edgedrains (Type Ia). The permeable base could be an ATPB or a CTPB when the heavy truck traffic level is high (> 12 million 20-year design lane applications). A daylighted permeable base (Type Ib) could be considered for flat grades (with less than 0.5 percent longitudinal grade) or at the bottom of sag curves when maintenance of the daylighted edge can be assured.

- A partial drainage system with a nonerodible base and pipe edgedrains.
- A partial drainage system with a nonerodible base, pipe edgedrains, and a porous concrete shoulder.

When site conditions are such that the provision of drainage is "feasible," a thick, daylighted dense graded aggregate base could be considered along with the options listed above.

Continuously Reinforced Concrete Pavements

When site conditions are such that drainage is "recommended" in table 3.1.1, the following options are available for this pavement type:

- A partial drainage system with a nonerodible base and pipe edgedrains (Type IIa).
- A partial drainage system with a nonerodible base, pipe edgedrains, and a porous concrete shoulder (Type IIb).

Permeable bases are not recommended with continuously reinforced concrete pavements (CRCP) until further performance data becomes available. Stability is more critical than permeability in these types of pavements as there are no transverse joints that allow water to enter.

When the drainage assessment is "feasible," a thick, daylighted dense graded aggregate base could be considered along with the options listed above.

3.1.5.3 Step 3: Hydraulic Design

The issues involved in designing the main components of a permeable base system are presented in the following sections. The main topics of discussion are permeable base design, separator layer design, and edgedrain design. Salient aspects of the hydraulic design for each of these drainage components are discussed here. Appendix SS presents the design equations and approach in detail. The FHWA microcomputer program DRIP (*9*), available as part of the software accompanying the Guide, can perform the hydraulic design of these components rapidly and accurately. Appendix TT presents the DRIP User's Guide (*10*).

Hydraulic Design of Permeable Bases

The recommended approach for performing hydraulic design of permeable bases is the time-to-drain procedure. This procedure is based on the following assumptions:

- Water infiltrates the pavement until the permeable base is saturated.
- Excess runoff will not enter the pavement section after it is saturated.
- After the rainfall event ceases, water is drained to the side ditches or storm drains through edgedrains or by daylighting.

The main parameter of interest in the time-to-drain procedure is the time required to drain the permeable base to a pre-established moisture level. The AASHTO design standard based on this parameter rates the permeable base quality of drainage from "Excellent" to "Poor." Table 3.1.2 presents guidance for selecting permeable base quality of drainage based on this method.

Table 3.1.2. Permeable base quality of drainage rating based on time taken to drain 50 percent of the drainable water.

Quality of Drainage	**Time to Drain**
Excellent	2 hours
Good	1 day
Fair	7 days
Poor	1 month
Very Poor	Does not drain

The objective of drainage is to remove all drainable water within a short period of time. For most Interstate highways and freeways, draining 50 percent of the drainable water in approximately 2 hours is desired (*4*).

The inputs to the time-to-drain design procedure include basic pavement design and material properties such as roadway geometry (cross-slope, longitudinal slope, lane width), thickness of the permeable base, porosity and effective porosity of permeable base aggregate, and permeability of the permeable base material. Using these inputs, the time-to-drain parameter is calculated for a given degree of drainage (U). The final design is then chosen on the basis of this information. Appendix SS provides a step-by-step procedure for completing the time-to-drain design, and Appendix TT contains guidance on how to use the DRIP program to perform permeable base design. The roadway geometry and materials inputs used here should be noted for further use in structural design (PART 3, Chapter 3 and 4).

Sensitivity of the Time-to-Drain Procedure and Permeable Base Design Recommendations

Of all the inputs that go into the calculations, permeability has the greatest influence and permeable base thickness the least influence on the time-to-drain parameter. The time required to drain a permeable base decreases exponentially with an increase in permeability. Therefore, to cost-effectively reduce the time to drain, it is recommended that the permeability be increased by a reduction in fines (a minimum of 1000 ft/day is required for permeable bases). However, care must be taken to maintain adequate stability in the permeable base while effecting a reduction in fines. To guarantee reasonable stability, a minimum coefficient of uniformity value, C_U, of 3.5 is required for an untreated permeable base. If this cannot be achieved, the base should be treated with either asphalt or portland cement. Further, higher in-service traffic levels also warrant a treated permeable base.

Since the thickness does not have a significant effect on the time-to-drain parameter, a value of 4 in is recommended for permeable bases. This thickness should provide an adequate hydraulic conduit and lend itself to compaction without segregation.

Separator Layer Design

The issues involved in designing the two types of separator layers—dense-aggregate and geotextile—will be discussed in this section.

Design of Aggregate Separator Layers

The aggregate separator layer must satisfy the separation and uniformity requirements at the separator layer/subgrade interface and the separator layer/permeable base interface. The first criterion ensures that the separator layer, acting as a filter, prevents the intermixing of dissimilar materials, and the second provides guidance for developing a well-graded aggregate base. A detailed discussion of the uniformity and separation requirements is presented in Appendix SS. The separator layer should also serve as an impermeable barrier to prevent the water in the permeable base from entering the subgrade (permeability less than 15 ft/day is desired).

The following additional requirements are necessary to ensure that the dense-graded aggregate separator layer does not have too many fines and is well-graded:

- Maximum percentage of material passing the No. 200 sieve should not exceed 12 percent.
- Coefficient of uniformity should be greater than 20, preferably greater than 40.

The results of these checks are typically plotted on a gradation chart to develop a design envelope through which the gradation of the aggregate separator layer must pass. In addition, some States prime the dense graded separator layer to reduce erosion of fines at its surface. A detailed aggregate separator layer design can be accomplished using the DRIP program available as part of the software accompanying the Guide. Appendix TT presents the User's Guide for the DRIP program.

When stabilized separator layers are used, the gradation checks noted above will not be necessary. However, it should be noted that, when high strength stabilized layers are used (e.g., cement treated layers), any shrinkage cracks that appear in these layers could result in piping of the subgrade material into the permeable bases. Care should be taken to avoid this situation.

Design of Geotextile Separator Layers

Designing geotextiles for filtration is essentially the same as designing dense-graded aggregate separator layers. A geotextile is similar to soil in that it has voids (pores) and particles (filaments and fibers). However, because of the shape and arrangement of the filaments and the compressibility of the structure with geotextiles, the geometric relationships between filaments and voids is more complex than in soils. Three simple filtration concepts are used in the design process (*11*):

1. If the size of the largest pore in the geotextile filter is smaller than the larger particles of soil, the soil will be retained by the filter.
2. If the smaller openings in the geotextile are sufficiently large enough to allow smaller particles of soil to pass through the filter, then the geotextile will not *blind* or *clog*.
3. A large number of openings should be present in the geotextile so proper flow can be maintained even if some pore openings later become plugged.

The important design criteria to be considered in specifying the properties of geotextile as a separator layer are divided into four categories, namely:

- Soil retention.
- Permeability.
- Clogging.
- Survivability and endurance.

The soil retention and clogging criteria are satisfied in geotextile design by selecting an appropriate Apparent Opening Size (AOS) value for the geotextile fabric and by selecting a minimum number of pore openings. It is also necessary to ensure that the geotextile will survive the construction process and will perform adequately over the design life by checking it against certain strength and endurance standards.

The engineering design guidelines for the soil retention, permeability, clogging, survivability, and endurance criteria are summarized in Appendix SS. The geotextile separator layer design can be accomplished using the DRIP program available as part of the software accompanying the Guide. Appendix TT presents the User's Guide for the DRIP program. In the absence of the detailed design, AASHTO M 288, "Standard Specification for Geotextiles," may be used (*12*). This specification provided maximum AOS values in relation to percent of in situ soil passing the No. 200 sieve and lists minimum desirable strength and endurance properties.

Edgedrain Design

The hydraulic design of edgedrains is basically a four-step process, as outlined below.

1. Determine pavement discharge rate.
    a. Pavement infiltration approach (based on estimated infiltration).
    b. Permeable base approach (based on depth-of-flow approach).
    c. Time-to-drain approach (based on the time required for a specific amount of the water to drain from a saturated permeable base).
2. Determine edgedrain flow capacity.
    a. Pipe edgedrain.
    b. Geocomposite edgedrain.
3. Determine outlet spacing.
    a. For pipe edgedrains, maximum outlet spacing should not exceed 75 m for maintenance purposes.
4. Determine the trench width.

The ultimate objective of the edgedrain design is to determine the outlet spacing based on the anticipated discharge from the pavement and the edgedrain flow capacity.

There are three options for determining the pavement discharge, as indicated. When designing Type Ia drainage systems, the recommendation is to use the time-to-drain approach to determine pavement discharge rate. When designing Type IIa or IIb systems, the pavement infiltration approach could be used for estimating pavement discharge rate. Details of the step-by-step hydraulic design process are presented in Appendix SS.

Pipes with a minimum diameter of 4 in are required for longitudinal pipe edgedrains and outlets. This allows easy access of monitoring and maintenance equipment to the pipe interiors. Further, a maximum outlet spacing of 250 ft is also recommended for ease of maintenance activities such as flushing and rodding or removal and replacement. Dual outlets with headwalls are also recommended. The maintenance requirements for pipe diameter and outlet spacing often satisfy the hydraulic design requirements.

Trench widths, location of the drains within the trench, trench line and grade, backfill, and lining are all important details in edgedrain construction. These details along with the recommended pipe edgedrain/outlet layout are presented in Appendix SS.

3.1.5.4. Step 4: Prepare Pavement Cross-Sections with Appropriate Drainage Features

In this step, all viable drainage options for the given site and design constraints are summarized for structural evaluation. It may be that multiple drainage options may be available for any given situation. The designer could select the most viable option or options based on materials availability, economic analysis, construction experience, projected maintenance efforts, or other local experience for structural evaluation. Preparing detailed cross-sections of the pavement structure—which includes various assumptions made in the hydraulic design process with regard to layer types, thicknesses, and relative arrangement, pavement geometry, pipe slopes and elevations above the ditch line, etc.—will aid the structural analysis process.

3.1.5.5 Step 5: Perform Structural Design

The pavement cross-section details from step 4 will help in preparing inputs for configuring a trial design for structural evaluation. Design of new and reconstructed flexible pavements and rigid pavements is covered in PART 3, Chapters 3 and 4. Care must be taken during the structural design process to ensure that the final design solution matches the assumptions made in the hydraulic design process particularly with regard to the following items:

- Assumed thicknesses of permeable and aggregate separator layers.
- Design feature assumptions (e.g., tied shoulders or dowel bars for JPCP) used in the drainage needs assessment (these play an important role in determining the extent of moisture infiltration into the pavement structure during structural design).
- Materials selected for open-graded drainage layers and separator layers during hydraulic design (these play an important role in determining seasonal stiffness adjustments to the pavement layers).
- Pavement geometry assumptions (coupled with the material properties they are used in calculating the drainage time estimation).

3.1.6 SYSTEMATIC APPROACH FOR SUBSURFACE DRAINAGE DESIGN: CONSIDERATIONS FOR REHABILITATION PROJECTS

Figure 3.1.8 presents the approach for subdrainage consideration in rehabilitation projects. It can be noted that the procedure is similar to the approach for new and reconstruction design. The significant differences are in the way the drainage needs are assessed and the type of drainage options available. These differences will be apparent in the discussion below. As with new design, the incorporation of subsurface drainage in rehabilitation projects should be based on needs analysis and cost-effectiveness.

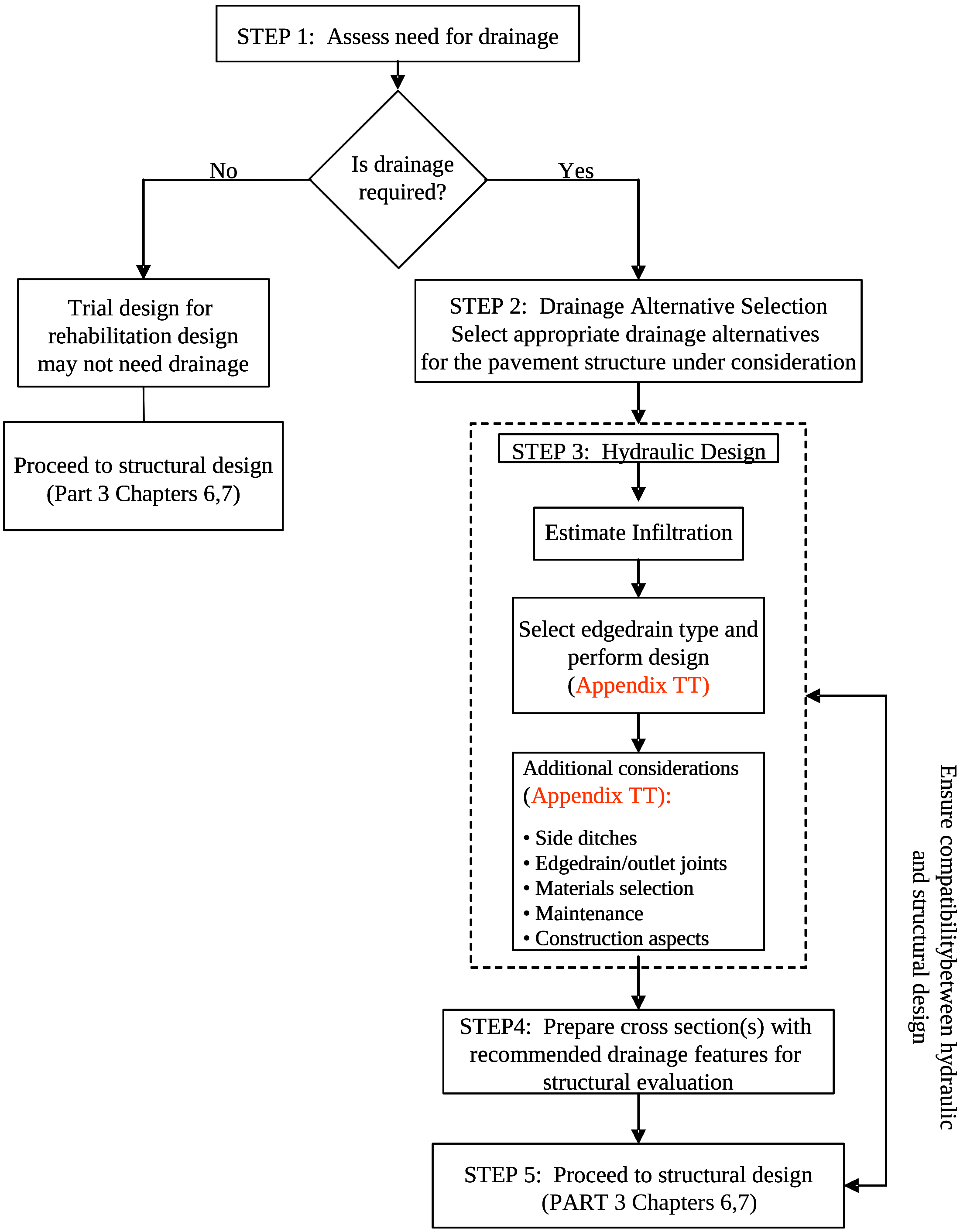


Figure 3.1.8. Systematic approach for subsurface drainage considerations for rehabilitation.

3.1.6.1 Step 1: Assessing the Need for Drainage

For existing pavements, a drainage evaluation can be performed in conjunction with other pavement evaluation procedures, such as a distress survey, to assess subsurface drainage needs. If a project has significant moisture-accelerated distress and factors that will contribute to further distress acceleration, some type of improvement is recommended in subdrainage. Routine use of subdrainage everywhere is not likely to be cost-effective.

Drainage Evaluation

A drainage evaluation includes an examination of the critical factors that influence the moisture-accelerated damage in a pavement. Some of the questions requiring answers during the evaluation are listed below:

- How deep are the ditches?
- Is the flow-line beneath the top of the subgrade?
- Are the ditchlines clear of standing water?
- Are the ditchlines and pavement edges free of vegetation that would clog the drainage path?
- After rainfall, does moisture stand in the joints or cracks? Is there evidence of pumping? Does water stand at the outer edge of the shoulder, or is there evidence that the water may pond on the shoulder?
- Are inlets clear and set at proper elevations, with adequate cross-slope to get water to the pavement edge?
- Are joint or crack sealants in good condition, and do they prevent water from entering the pavement?
- If subsurface drainage is present, check for the following:
    - Are the outlets clearly marked and easily found?
    - Are the outlets clear of debris and set at the proper elevation above the ditchline?
    - Are the drainage components properly installed or constructed?
    - Are the drainage components functional?

Figure 3.1.9 shows a form that can be used to conduct drainage surveys.

Distress Survey

Pavement distresses are caused by loads, materials, environmental factors, or a combination of the three. Moisture will accelerate the deterioration of any distress, regardless of its cause. During a distress survey it is therefore important to record any signs of moisture-caused or moisture-accelerated damage. Procedures for conducting a distress survey of pavements are described in several references (*13*,*14*).

3.1.6.2 Step 2: Drainage Improvement Alternatives

Where it is perceived that the moisture is backing up into the pavement system because of inadequate side slopes and ditches, or due to the presence of debris and cattails in the side ditches, deepening of the side ditches and regrading the slopes and ditch lines should be adequate. In other situations, retrofitting subsurface drainage systems is a viable option if conditions favorable to the functioning of these drains exist. For example, retrofitting edgedrains is not suitable when the base or subbase material has excessive fines, as these materials could clog the drains.

Field Survey: *Drainage Information* Project ID: ________________
Date of survey (mm/dd/yy): Surveyor's initials: __________

Slope Measurements:

	Station	Slope	
		Outer	Inner
Longitudinal Slope (m/m) 3 measurements equally spaced along the project	+	/	/
	+	/	/
	+	/	/
Cross-slope (m/m) 3 measurements equally spaced along project	+	/	/
	+	/	/
	+	/	/
Shoulder Slope (m/m) 3 measurements equally spaced along project	+	/	/
	+	/	/
	+	/	/

Cut/Fill and Ditch Line Depth:

Circle if Cut/Fill Depth Uniform	Cut/Fill Depth	Station		Depth of Ditch Line
1	Fill > 13.3 m	+	+	Meters
2	Fill 4.85 – 13.3 m	+	+	Meters
3	Fill 1.82 – 4.85 m	+	+	Meters
4	At Grade (1.5-m fill to 1.5-m cut)	+	+	Meters
5	Cut 1.82 – 4.85 m	+	+	Meters
6	Cut 4.85 – 13.3 m	+	+	Meters
7	Cut > 13.3 m	+	+	Meters

Lane/Shoulder Joint Integrity:

	Outer Shoulder	Inner Shoulder
Sealant Damage	N L M H	/
Blow Holes	N L M H	/
Sealant Type	None HP SI Preform Other	

Subsurface Drainage (visual): Type of drainage system present: ________________________
(1 = none; 2 = longitudinal drains; 3 = transverse drains; 4 = other)

Condition of Drainage Outlets: ____

Indicators of Poor Drainage:

Cattails or willows growing in ditch: Y / N
Drainage outlets clogged: Y / N
Drainage outlets below ditch line: Y / N
Non-continuous cross-section, crown to drainage ditch: Y / N
Pumping: N L M H
Other: __________________________

Figure 3.1.9. Example of drainage survey form (after [*4*]).

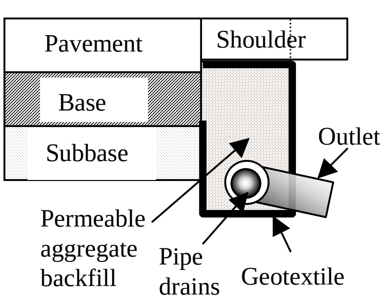
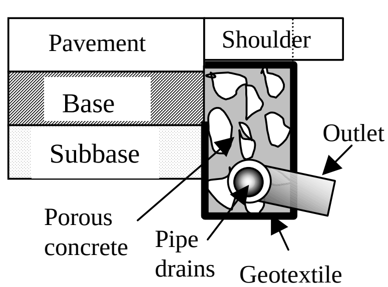
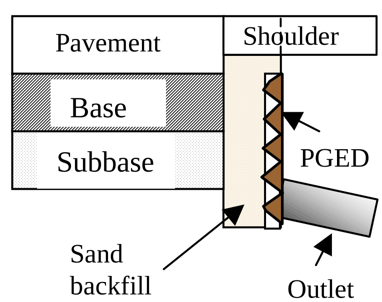
Examples of viable candidates for retrofitting drainage are listed below:

- A specific moisture-related problem, such as bleeding water from spring thaw
- Moisture-related distresses such as stripping for HMA pavements and pumping and D-cracking for PCC pavements
- Pavement is in a cut section located in a wet climate
- Other obvious signs of poor drainage, such as standing water in pavement cracks, joints, and ditches

On extensively deteriorated pavements, installation of retrofit drainage accompanied by appropriate rehabilitation measures is required to ensure that the rehabilitation is effective. It is also important to note that other rehabilitation measures may be more effective for addressing the existing problems. For example, dowel bar retrofitting is obviously more effective for eliminating joint and crack faulting problems in jointed concrete pavements than installation of edgedrains. For fatigue cracking, an overlay is more effective. However, drainage improvement may be important for material durability considerations and for minimizing moisture-accelerated damage.

Table 3.1.3 presents the subdrainage alternatives available for rehabilitation projects. All three alternatives involve retrofitting existing pavements with edgedrains. When selecting one alternative over another, tradeoffs between cost, design, and maintenance must be analyzed carefully. The difference between Type A and B design is the type of trench backfill used. Type B design lends more support under the shoulder but is more expensive. The difference between Type A and Type C design is the type of edgedrain used. Although PGEDs have a smaller initial cost compared to pipe edgedrains, they cannot be maintained if clogged. Therefore, they should only be used when the potential for clogging is minimal over the anticipated design period. The presence of erodible fines and the potential for their migration need to be investigated before this edgedrain system is selected. The geocomposite filter in the PGED must be selected carefully to ensure compatibility with these conditions.

Table 3.1.3. Subdrainage alternatives for rehabilitation projects.

Type A	**Type B**	**Type C**
		

With one exception, all three alternatives are suitable for flexible and rigid pavements. Pavements with dense-graded aggregate bases containing more than 15 percent fines (fraction passing the No. 200 sieve) should not be retrofit with edgedrains. Excessive fines can clog the drains, and the loss of fines through the pipes can lead to significant base erosion.

3.1.6.3 Step 3: Hydraulic Design

The hydraulic design considerations for retrofit drainage are limited to designing the edgedrains, backfill trenches, and the side ditches. The same basic four-step process described for new and reconstruction projects are applicable for retrofit edgedrain design with the following qualification – the pavement discharge is computed using the *Pavement Infiltration* approach. The *Time-to-Drain* and *Permeable Base* approaches previously discussed for new or reconstruction design will not applicable in a majority of the cases since drainage retrofitting is usually performed on pavements with bases that are not free-draining. Hydraulic design details are provided in Appendix SS.

All other aspects of edgedrain installation such as trench design, backfill, lining, construction, and materials selection remain the same as for new pavements as explained in Appendix SS. For projects with retrofit with pipe edgedrains, the minimum edgedrain and outlet pipe diameters, edgedrain/outlet connections, and outlet spacing also remain the same.

3.1.6.4 Step 4: Prepare Pavement Cross-Sections with Appropriate Drainage Features

In this step, all viable drainage options for the given site and design factors are summarized for structural evaluation. It may be that multiple drainage options may be available for any given situation. The designer could select the most viable option or options based on materials availability, economic analysis, construction experience, projected maintenance efforts, or other local experiences for structural evaluation. Preparing detailed cross-sections of the pavement structure, which includes various assumptions made in the hydraulic design process, will aid the structural analysis process.

3.1.6.5 Step 5: Perform Structural Design

The pavement cross-section details from step 4 will help develop inputs for configuring a trial design for rehabilitation. Care must be taken during the structural design process to ensure that the final design solution matches the assumptions made in the hydraulic design process. Rehabilitation design of flexible and rigid pavements is discussed in PART 3, Chapters 6 and 7. It must be noted here that, although there are no direct inputs specific to retrofit drainage in the performance models considered in rehabilitation design, the addition of drains will nonetheless improve the reliability of the rehabilitation options chosen.

3.1.7 EDGEDRAIN MAINTENANCE

As noted in previous sections, the primary components of a typical subsurface drainage system include well-prepared subgrades, separator layers, permeable bases, longitudinal edgedrains, outlet drains, and ditches. The success of permeable bases and separator layers is dictated primarily by proper design, material selection, and construction. Very little, if anything, can be done to separator layers and permeable bases once they are constructed. In contrast, post-construction maintenance is of paramount importance for proper functioning of the pipe drains, outlets, and roadside ditches. Maintenance of the exposed periphery of daylighted bases is also critical.

For subsurface drainage systems with edgedrains, inadequate longitudinal edgedrain, outlet, and ditch maintenance is a universal problem. The combination of vegetative growth, roadside slope debris, and fines discharging from the edgedrains will eventually plug the outlet pipe. Often, outlets cannot even be found because they are completely covered with vegetative growth or roadside slope debris. Periodic inspection, as well as routine flushing and rodding of the edgedrain system are essential. In addition, outlets should be free of vegetation and debris and should be clearly marked. Rodent screens must be removable to allow maintenance and inspection of the outlets and longitudinal edgedrains.

On the basis of agency experience, some agencies disallow the use of drainage layers until they are assured that the necessary maintenance will be performed. This requires video inspections just after construction and at periodic intervals. Such considerations during the design phase will be very helpful in the long-term success of subsurface drainage systems. More discussion on edgedrain maintenance is provided in Appendix SS. NCHRP Synthesis 285 (*15*) also provides an excellent summary of current practice on the tools and methods used for maintenance of edgedrains.

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