Subsurface Drainage Systems

A. General Information

Subsurface drainage is a key element in the design of pavement systems. Indiscriminate exclusion of this element will assuredly lead to the premature failure of pavement systems, thereby resulting in high life-cycle costs. Faulting and associated pumping in rigid pavements systems, extensive cracking from loss of subgrade support in flexible pavements, and distress from frost heave are clear signs of inadequate drainage. The two basic design strategies promoted are to (1) prevent water from entering in the first place and (2) quickly remove any water that does infiltrate. After years of unsuccessful sealing attempts, the profession has learned that we cannot prevent water from entering a pavement and that removal of water is essential for the pavement elements to perform as desired (Christopher and McGuffey 1997).

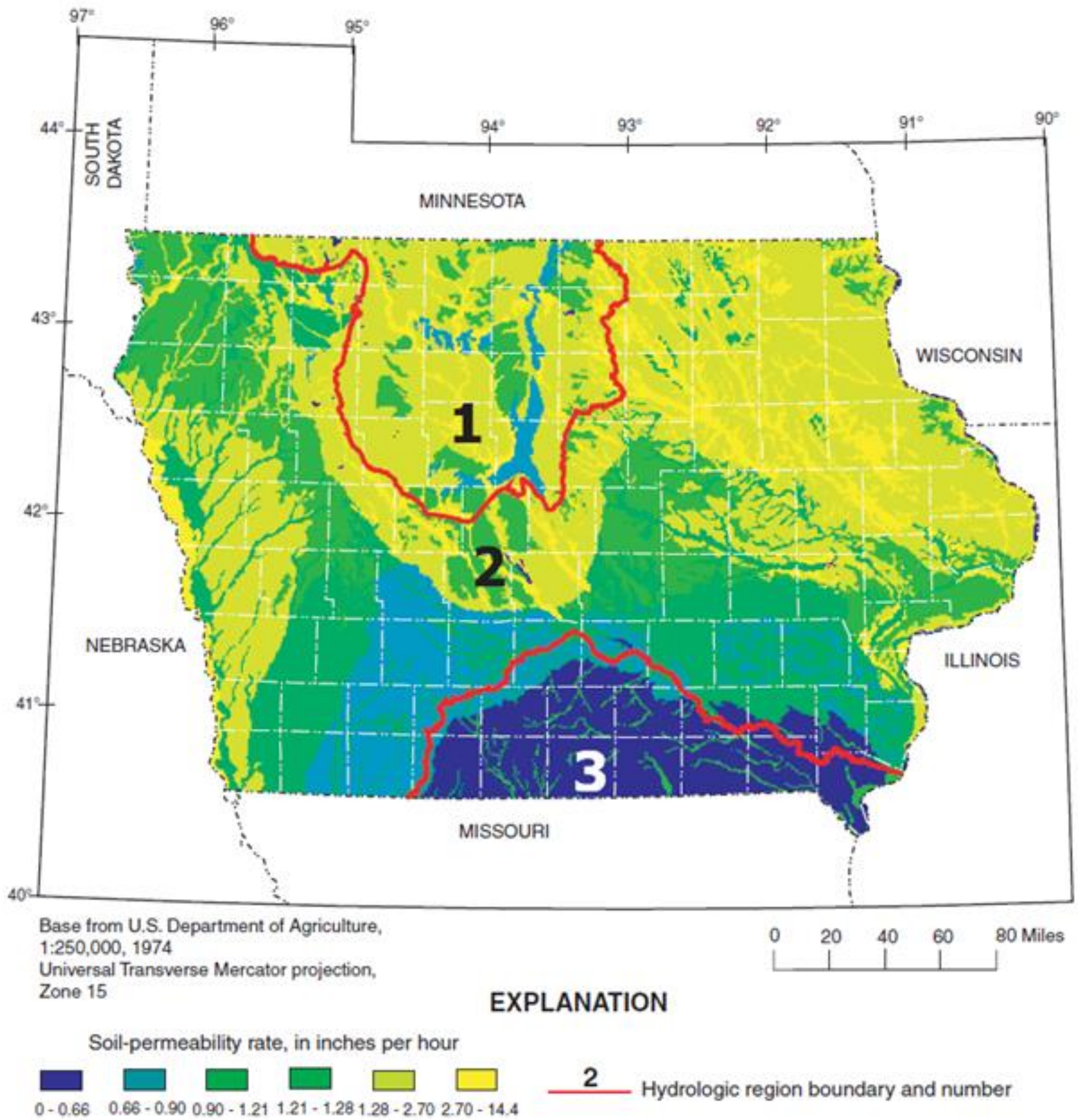
Proper drainage cannot be overstressed in road construction. Water affects the entire serviceability of a road. In general, Iowa soils are fine-grained with low permeability. Coupled with a wet climate, if there is no subsurface drainage in pavement construction, the subgrade and subbase can be saturated for long periods. Starting from the bottom up, subsurface drainage may be the most important factor contributing to the longevity of a pavement section. Water in the subgrade and subbase weakens the support provided to the pavement. Maintaining the integrity of the subgrade and subbase can be accomplished through subsurface drainage and separation of the subbase from the subgrade using geotextiles.

Urban pavements with curbs are generally designed to direct surface stormwater within the right-of-way and adjacent property toward the pavement, where it is intercepted and transported by a system of stormwater intakes and pipes. This encourages the introduction of additional subsurface and surface water to the pavement system. Footing drains for adjacent structures may drain to this storm sewer system, a specially-constructed footing drain collector, or a combination subdrain/footing drain collector.

Proper surface drainage can reduce the amount of water infiltrating through the pavement and is a strategy that goes hand in hand with proper subsurface drainage. Most free water will enter the pavement through joints, cracks, and pores in the surface of the pavement. Water also will enter from backup in ditches and groundwater sources. Drainage prevents the buildup of free water in the pavement section, thereby reducing the damaging effects of load and environment. Based on documented case histories, studies have shown that pavement life can be extended up to three times if adequate subsurface drainage systems are installed and maintained (Cedergren 1989).

The importance and design of subgrade and subbase drainage is discussed in Section 6E-1 - Subgrade Design and Construction, and Section 6F-1 - Pavement Subbase Design and Construction. Generally, Iowa's soils are fine-grained and will have low permeability as indicated in the state permeability map shown in Figure 6G-1.01. Most subgrade soils in Iowa have poor drainage quality by AASHTO standards, less than 10 feet per day (< 5 inches/hour). Coupled with the fact that Iowa receives over 20 inches of precipitation a year and is considered a wet climate, subgrades and subbases can be saturated for long periods if subsurface drainage is not accommodated in pavement system construction. Subdrain systems, specifically designed to drain subsurface water, are a solution to remove water from permeable subbases and drainable subgrades. The advantage of a functional subsurface pavement drainage system will vary based on climate, subgrade soils, and the design of overall pavement system.

Figure 6G-1.01: Permeability of Iowa Soils



Source: Eash 2001

Unless a subsurface exploration determines subsurface drainage systems are not necessary, they should be installed for most paving projects in Iowa. A successful drainage design process must adequately and consistently address the following:

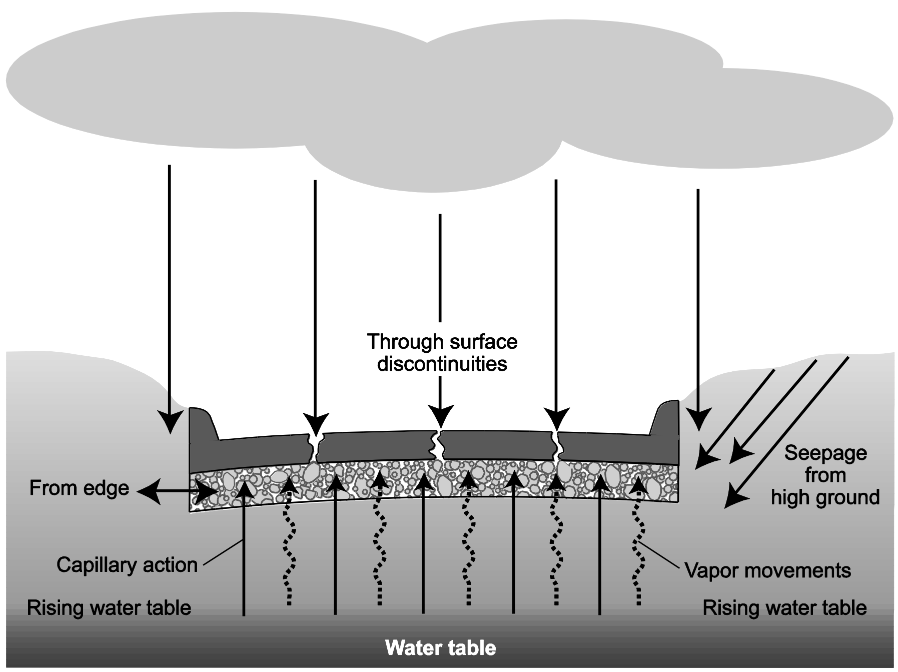
- Evaluation of the need for subdrainage.
- Determination of the necessary subdrainage components for the given situation.
- The hydraulic and structural design of subsurface drainage systems and their integration into the overall pavement design process.
- Property specifications of drainage materials for achieving long-term performance.
- Documentation of special construction and maintenance considerations.

B. Need for Subsurface Drainage

The damaging effects of excess moisture on pavement have long been recognized. Moisture from a variety of sources can enter a pavement structure. Figure 6G-1.02 shows that moisture in the subgrade and pavement structure can come from many different sources. Water may seep upward from a high ground water table, or it may flow laterally from the pavement edges. Knowledge of ground water and its movement are critical to the performance of pavement as well as the stability of adjacent sideslopes. Ground water can be particularly troublesome for pavements in low-lying areas. When pavements are constructed below the permanent or a seasonally high water table, drainage systems must perform or rapid pavement failure will occur. This moisture, when combined with traffics loads, voids in pavement sections, and freezing temperatures, can have a negative effect on both material properties and overall performance of a pavement system.

The most significant source of excess water in pavements is typically infiltration through the surface through joints, cracks, and other defects in the surface that provide an easy path for water. The problem only worsens with time. As pavements age and deteriorate, cracks become wider and more abundant and joints and edges deteriorate into channels through which water is free to flow. The result is more water being allowed into the pavement structure with increasing age, which leads to accelerated development of moisture-related distresses and pavement deterioration. Excess moisture in a pavement structure can adversely affect pavement performance. While a pavement structure can be stable at given moisture contents, the pavement structure may become unstable if the materials become saturated. High water pressures can develop under traffic loads. Water in the pavement structure can freeze and expand, developing high internal pressures on the pavement structure. Flowing water can carry soil particles and lead to clogging of drains and, in combination with traffic, lead to pumping of fines from the subbase or the subgrade.

Figure 6G-1.02: Sources of Moisture in Pavement Systems



Source: Based on FHWA-NHI 2004

C. Types of Drainage Systems

To avoid moisture-related problems, a major objective in pavement design should be to keep the subgrade, subbase, and pavement structure from becoming saturated or exposed to high moisture levels. Three approaches exist for controlling or reducing the problems caused by moisture:

1. Prevent moisture from entering the pavement system
2. Use materials and design features that are insensitive to the effects of moisture
3. Quickly remove moisture that enters the pavement system.

No single approach can completely negate the effects of moisture on the pavement system over a period of many years. It is practically impossible to effectively seal the pavement from water intrusion. While materials that resist moisture can be incorporated, this is often not cost effective and in many cases such materials are simply not available locally. Indeed, subgrades that are susceptible to moisture deterioration cannot easily or cost effectively be replaced. Thus, the need for drainage systems that can quickly and effectively remove water from the pavement system is necessary.

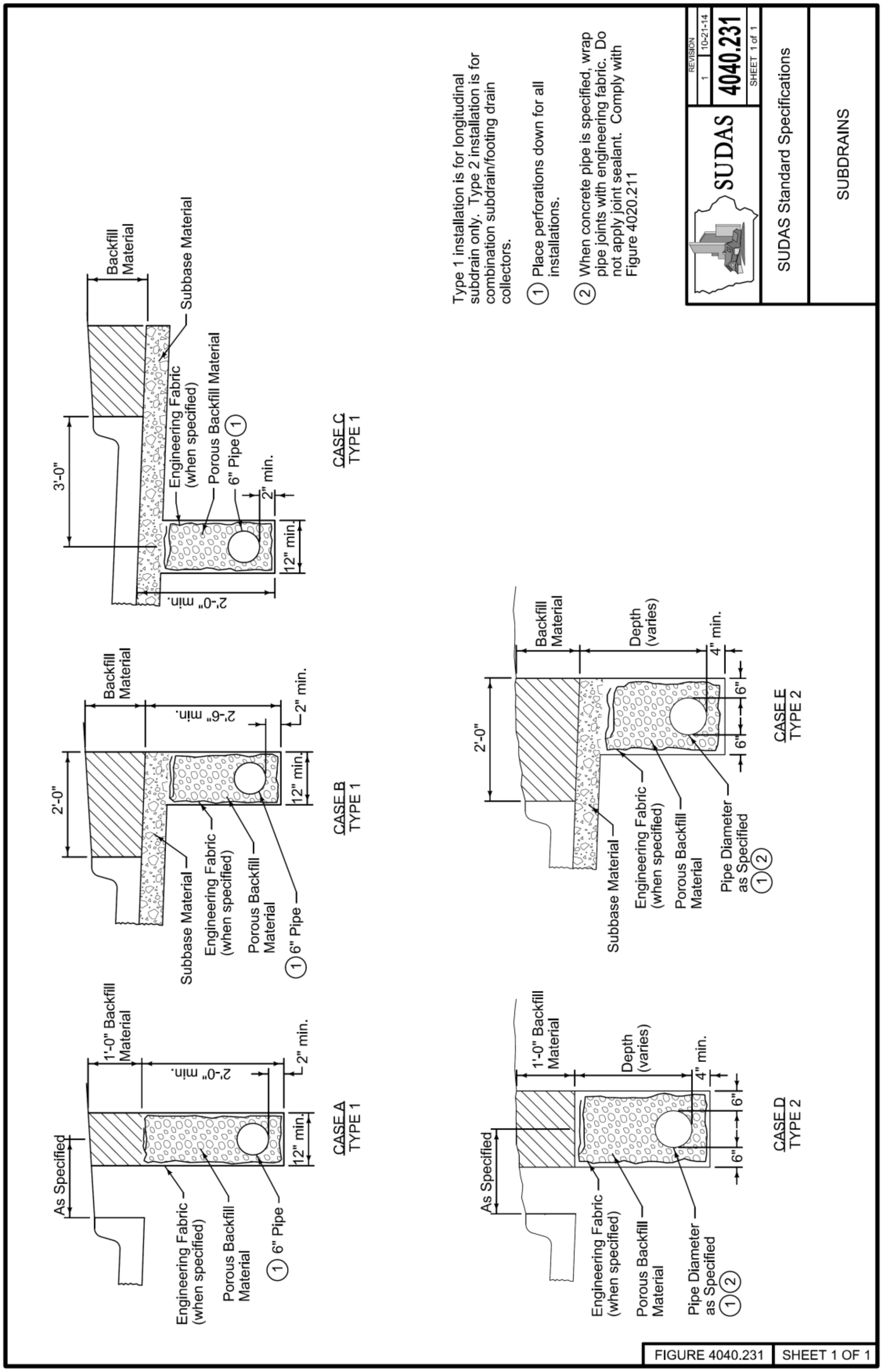
Positive drainage can be affected with three elements:

1. Subbase to provide rapid drainage of free water that may enter the pavement structure.
2. Longitudinal subdrain collector system to convey accumulated water from the subbase.
3. Filter-separator layer to prevent the migration of fines (minus 200 sieve material) into the subbase from the subgrade (see Figure 6G-1.03, Cases A and C).

Unrestricted flow to the subbase must be ensured. The filter-separator layer, whether aggregate or geotextile, must be properly designed to prevent migration of fines and possible base contamination. Since many existing pavements have been designed and constructed with impermeable subgrades, rapid lateral drainage from the base of these rehabilitated pavement sections is not feasible. Here, retrofit with longitudinal subdrains can affect drainage of water that has infiltrated the pavement structure and migrated to the slab/subgrade interface. Subdrains placed adjacent to the pavement can intercept this water and shorten the time it is present at the interface, thereby minimizing the potential degradation effects (see Figure 6G-1.03, Case B).

Generally, footing drains for adjacent structures may drain to a storm sewer system or a combination subdrain/footing drain collector. However, a combination subdrain/footing drain collector, as shown in Figure 6G-1.03, Cases D and E, may be installed to serve both purposes. See Chapter 2 - Stormwater, for guidance on sizing of footing drain collectors; normally pipe sizes range from 8 to 12 inches in diameter.

Figure 6G-1.03: Subdrains
(SUDAS Specifications Figure 4040.231)



D. Design

Design of subsurface pavement drainage systems consists of balancing permeability and stability and removing collected water rapidly. Important components consist of subbase material, a separating layer to prevent infiltration of subgrade materials into the subbase, and a collection and removal system. Design approaches for each of the components are summarized below.

1. **Subbase:** For the design of subbases, see Section 6F-1 - Pavement Subbase Design and Construction. One of the purposes of the subbase is to remove infiltration water. The subbase should consist of durable, crushed, angular aggregate with the best porosity so that it will release the maximum amount of water. However, the structural requirements for the overall pavement section must be met using appropriate pavement design practices. The subbase can be stabilized or unstabilized. Effective subbase design must address structural, hydraulic, material durability and quality, constructability, and maintenance requirements.

   Hydraulic requirements must be addressed for specific project conditions; however, the time period that free water is present within the pavement structure should be minimized, preferably less than 2 hours following end of precipitation. To maintain positive flow through the base, the road section should be sloped as much as possible, with a minimum cross slope of 2%. The highest permeability materials are unstable under construction traffic; therefore, it is desirable to use a more stable material with a lower permeability, such as 150 to 350 feet per day (75 to 175 inches per hour).

   FHWA (1992) guidelines indicate that the quality of crushed aggregates is the single most important factor for the stability of a subbase. Breakdown of the aggregate could cause both loss of support and a decrease in permeability. Los Angeles Abrasion Wear should not exceed 50%, and aggregate soundness loss should not exceed the requirements for a Class B aggregate as specified by AASHTO M 283 (i.e., 12% for sodium sulfate test or 18% for magnesium sulfate test).

   To enable proper construction of subbases, several construction guidelines have been proposed (Christopher and McGuffey 1997). Unstabilized materials generally are used in thicknesses of 4 inches or more. Asphalt and cement stabilized materials can be built as thin as 2 inches, however, 4 inches is recommended as a minimum. Material gradations vary widely; see White et al. (2004) for a review.

   Of the subbase materials included in SUDAS Specifications Section 2010, only granular subbase and modified subbase will provide adequate permeability. Granular subbase provides the highest permeability, however it is generally unstable under construction traffic. Modified subbase provides both stability and good permeability.

2. **Separator/Filter Layers:** There is usually a need for a separator/filter layer between the subbase and the subgrade. Filtration compatibility of the subbase must be evaluated with respect to both the subgrade and the subbase to prevent migration of the subgrade into the subbase.

   Geotextiles are commonly used as separators/filters. The FHWA geosynthetics manual (Holtz et al. 1995) provides guidelines on design procedures. Care must be exercised in the amount of cover material over geotextiles as there is potential for damage from equipment. Normally, 6 inches is considered the minimum thickness when earthmoving equipment is used for placement.

   Dense-graded (low permeability) subbase can be placed below the permeable subbase and provide adequate separation. Filter criteria need to be checked for impermeable subbase materials that will be adjacent to the permeable subbase.

3. Subdrains:

a. New Construction: Subdrains for new construction generally consist of pipe in a trench lined with non-woven geotextile (engineering fabric) and filled with aggregate. Typical installation sections are shown in Figure 6G-1.03, Cases B, C, and E. Design of subdrains for new construction and major reconstruction projects consists of ensuring that the trench backfill and subdrain pipe have the capacity to handle the design flow from the subbase.

The size of pipe is often based on maintenance requirements for cleaning capabilities and reasonable distance between outlets. Although FHWA recommends a minimum pipe diameter of four inches, the SUDAS Specifications require a minimum of 6 inch diameter pipe for Type 1 subdrain installations and a minimum of eight inch diameter pipe for Type 2 combination subdrain/footing drain collectors. The larger diameter subdrain pipe allows for additional capacity, easier cleaning, and inspection. Cleanouts are required for all Type 2 subdrains, at the end of line or at 300 feet spacings. For exceptionally long Type 1 installations, greater than 300 feet from an outlet, consideration should be given to providing cleanouts as required for Type 2 subdrains.

Trench backfill aggregate could be the same as the subbase or a material with greater permeability. AASHTO No. 57 stone, Iowa DOT Gradation No. 3 has been used for trench backfill. The SUDAS Specifications Section 3010 requires porous backfill to comply with Iowa DOT Gradation No. 29 or the use of commercially available pea gravel. The non-woven geotextile used to line the subdrain trench must be designed as a filter, considering both the subbase and subgrade soils. The geotextile should not be extended between the interface of the subbase and the trench backfill aggregate because it may form a barrier. Also, geotextile should not be wrapped around the perforated drainage pipe.

One of the most critical items for subdrains is the grade of the invert. Construction control of very flat grades usually is not possible, leaving ponding areas that result in subgrade weakening and premature failures. It may be necessary to raise the pavement grade to develop adequate drain slopes for the subsurface drainage facilities. To achieve a desirable drainage capacity, a minimum slope that is greater than the slope of the road may be required for the subdrain, although this is often not practical and the pipe will mostly be sloped the same as the roadway. When adequate slopes cannot be achieved, rigorous maintenance should be anticipated.

The outlet for the subdrain must be low and large enough so that flow from the subdrain does not back up. FHWA recommends that the outlet pipe be at least 6 inches above the 10-year storm flow line of the ditch or hydraulic structure into which the outlet is flowing.

The designed drain trench and backfill must be constructible with normal construction equipment. Construction of subdrains is time-consuming. Care must be taken so that the trench backfill does not become contaminated with adjacent soil that might clog the drainage capacity.

b. Retrofit Subdrains: A majority of pavement distress problems are related to excess moisture in the pavement structure. Retrofit subdrains can be used in rehabilitation projects to remove water. The design of retrofit subdrains is substantially different than new construction. Subdrains should be just one of the methods to consider to correct water problems. The principles for the design of retrofit subdrains apply to both HMA and PCC pavements. For the design of retrofit subdrains, the designer is referred to the Concrete Pavement Preservation Guide, 2nd Edition (National Concrete Pavement Technology Center, September 2014) and the Material Subsurface Pavement Drainage Manual (Idaho Transportation Department, 2007).

c. **Geocomposite Subdrains:** Prefabricated, geocomposite subdrains (PGEDs) have recently been in high use and have been found to be very effective in removing water, with drainage rates equal to or better than pipe drains. Although many states have found PGEDs to be cost effective for retrofit applications, problems of clogging and intrusion of fines and buckling during construction have somewhat limited their use. Design considerations for PGEDs are detailed in NCHRP Report 367 (Koerner et al. 1994).

E. Construction Issues

Construction decisions and actions can have a significant impact on the performance of the pavement section. The design and construction groups must consider (1) each phase of construction, including subgrade preparation, placement of separation/filtration layers, construction of drains, placement of subbase, and construction of the pavement section; and (2) how the decisions of one group will affect the actions and decisions of the other group.

In the design phase, the designer must be concerned with how construction details, sequencing of work, site accessibility, and protection of drainage components will integrate with both the methods and equipment that can be used for pavement and drainage facility construction. Design decisions such as location of collector pipes and outlets, temporary and permanent surface drainage, and aesthetic treatments will influence how construction can be conducted. Such decisions will affect the right-of-way required for construction of the drainage systems.

Sequencing is best left to the contractor unless there is a significant impact on the performance of the drainage system. An important construction related design consideration is pipe access at the upstream end of a segment so that inspection and maintenance flushing activities can take place.

One of the primary reasons for bringing construction personnel in at the design phase is to acquaint them with the impact of construction on design. Care exercised during construction of the designed section without compromising the effectiveness of the design is essential to the pavement’s long-term performance. Key performance elements for construction personnel include the following (Christopher and McGuffey 1997).

- Good pavement starts with a good foundation. A stable platform is required for construction of the subbase.
- Quality of aggregate and its ability to meet gradation requirements is essential for meeting expected design performance levels.
- Awareness is needed concerning the fact that the introduction of fines into the subbase during construction could result in premature failure of the pavement.
- Unstabilized base tends to displace under traffic loadings.
- Too much compaction or fine grading can significantly reduce the expected permeability of the subbase.

1. **Subgrade Preparation:** The foundation/subgrade surfaces are required to be level, somewhat smooth, and constructed to required grades. On drainable pavement sections, constructing and maintaining required subsurface grades is essential to maintain positive drainage until the pavement is constructed. Local depressions resulting from soft areas or depressions from equipment trafficking can lead to ponding of water below the pavement structure and subsequent loss of foundation support.

2. **Separator/Filter Layers:** For granular subbase separator/filter layers, the gradation of materials needs to be checked carefully against the design specifications. Materials that are more openly-graded than specified requirements may allow migration of fines through or from the subbase, which can contaminate the permeable layer. Good compaction of the separator/filter layer is

essential for placement of the subbase. The subbase should be observed for rutting during compaction and subsequent trafficking; surface rutting may be an indication of subgrade rutting, which requires immediate attention. Increasingly, geotextile separation/filter layers are being used. For these, material and certification should be checked against the design requirements to ensure that the proper materials have been received and are being use. In constructing geotextile separation or filter layer, a smooth subgrade surface is essential. Therefore, sharp rock protrusion and loose rocks should be removed to avoid damage to the geotextile.

3. **Subdrains:** Proper grade control is required for subdrains to be effective. Undulating lines are not acceptable because water will accumulate in depressed portions of the pipe. Good practice dictates that subdrains be properly connected to the subbase and the outlets. For maintenance purposes, outlet spacing is limited to 300 feet. Subdrains need to be properly connected to the permeable subbase and outlets. Outlets are required to be set at the proper grades, and ditch lines are graded according to drainage requirements. Subdrain lines should be carefully marked to avoid damage due to construction equipment. Therefore, subdrains can sometimes be constructed after pavement construction. In this case, temporary subdrains are required for the permeable subbase.

4. **Permeable Subbase Materials:** Unstabilized subbase material requires close control of material gradation and activities that might produce segregation of the material during placement.

   Subbase materials are very susceptible to segregation during placement. Special care is needed to prevent fines from migrating into the material and clogging the system. The addition of 2% to 3% water by weight reduces the potential for segregation during hauling and placement.

   Excessive compaction with heavy vibratory compactors is not recommended on subbases because of the potential for damage and reduced permeability. Adequate compaction may be achieved with lightweight vibratory compactors or smooth drum rollers because of the relatively narrow gradation range of subbase.

   Care is required to protect the subbase from contamination from dirty equipment, adjacent backfilling operations, or erosion sediment. The subbase should not be allowed to be used as a haul road. Good practice dictates that traffic be minimized and restricted to low speeds with minimal turning. No equipment should be allowed on the permeable materials until the complete drainage of the base and subbase has been confirmed.

F. Maintenance

Maintenance of pavement subsurface drainage systems has been identified as essential to the long-term success of drainage systems and, subsequently, pavements. The most effective maintenance programs use a five-phase approach:

- Routine inspection and monitoring
- Routine preventive maintenance
- Spot detection of problems (occurrences)
- Repair
- Continued monitoring and feedback

Budget constraints have resulted in usually only two phases being conducted: spot detection and repair. Studies show that inspection in conjunction with preventative maintenance can be very cost effective with $3 to $4 return in benefits for every $1 invested (Christopher and McGuffey 1997).

1. **Inspection and Monitoring:** The inspection phase of maintenance provides important data on the effectiveness of drainage elements and the need for further maintenance. Inspection practices include visual inspection and effectiveness testing. Visual inspection consists of inventorying outflow during storm events and assessing outlet condition. Outflow inventories are generally qualitative (e.g., high, moderate, low, or no flow). Visual inspection can be enhanced through the use of video cameras. Effectiveness testing can provide a more quantitative assessment of performance through the use of post-storm event monitoring with bucket sampling or direct upstream inflow coupled with downstream outflow measurements.

2. **Preventative Maintenance:** Preventative maintenance actions that promote good subsurface drainage system performance include: clean and seal joints and cracks, clean and verify the grade of outlet ditches, clean catch basins and other discharge points, and clean outlet screens and area around headwalls. Based on the results of the outlet inspection program, a routine outlet cleaning program should be implemented.

3. **Repair:** It is generally accepted that once pavement damage from blocked subsurface drainage is visible, the damage is irreversible, and that pavement life has been shortened. For this reason, any problems observed, no matter how minor in appearance, should be addressed immediately to confine the problems to a localized area.

4. **Continuous Monitoring and Feedback:** Monitoring is a continuous improvement process and improvements are achieved only through providing feedback to the design and construction groups. Thus maintenance should provide inspection results long with performance indicators to design and construction groups for review. Pavement management methodologies and maintenance strategies are reviewed in NCHRP Syntheses 222 and 223 (Zimmerman and ERES Consultants 1995 and Geoffroy 1996).

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