CHAPTER 6

DESIGN OF SUBSURFACE DRAINAGE SYSTEMS

6-1 INTRODUCTION

6-1.1 **Purpose.** This chapter provides guidance for the design and construction of subsurface drainage facilities for airfields, roads, streets, parking lots and other paved areas.

6-1.2 **Scope.** The criteria within this chapter applies to paved areas such as airfields, roads, streets and parking lots having a relatively impervious surface such as asphalt concrete or Portland cement concrete. The criteria is limited to situations where the surface water can be drained by gravity flow and is mainly concerned with elimination of water which enters the pavement through the surface.

6-1.3 **Definitions.** This chapter uses a number of terms that have unique usage within the chapter or which may not be in common usage. The definitions of these terms are described below.

6-1.3.1 **Apparent Opening Size (AOS).** A measure of the opening size of a geotextile. AOS is the sieve number corresponding to the sieve size at which 95 percent of the single-size glass beads pass the geotextile (O_{95}) when tested in accordance with ASTM D 4751, Determining Apparent Opening Size (AOS) of a Geotextile.

6-1.3.2 **Coefficient of permeability (k).** A measure of the rate at which water passes through a unit area of material in a given amount of time under a unit hydraulic gradient.

6-1.3.3 **Choke Stone.** A small size stone used to stabilize the surface of an OGM. For a choke stone to be effective, the ratio of d_{15} of the coarse aggregate to the d_{15} of the choke stone must be less than 5, and the ratio of the d_{50} of the coarse aggregate to d_{50} of the choke stone must be greater than 2.

6-1.3.4 **Drainage Layer.** A layer in the pavement structure that is specifically designed to allow rapid horizontal drainage of water from the pavement structure. The layer is also considered to be a structural component of the pavement and may serve as part of the base or subbase.

6-1.3.5 **Effective Porosity.** The effective porosity is defined as the ratio of the volume of voids that will drain under the influence of gravity to the total volume of a unit of aggregate. The difference between the porosity and the effective porosity is the amount of water that will be held by the aggregate. For materials such as the RDM and OGM, the water held by the aggregate will be small; thus, the difference between the porosity and effective porosity will be small (less than 10 percent). The effective porosity may be estimated by computing the porosity from the unit dry weight of the aggregate and the specific gravity of the solids which then should be reduced by 5 percent to allow for water retention on the aggregate.

6-1.3.6 **Geocomposite Edge Drain.** A manufactured product using geotextiles, geogrids, geonets, and/or geomembranes in laminated or composite form, which can be used as an edge drain in place of trench-pipe construction.

6-1.3.7 **Geotextile.** A permeable textile used in geotechnical projects. For this manual geotextile will refer to a nonwoven needle punch fabric that meets the requirements of the apparent opening size (AOS), grab strength and puncture strength specified for the particular application.

6-1.3.8 **Open Graded Material (OGM).** A granular material having a very high permeability (greater than 1,500 m/day (5,000 ft/day)) which may be used for a drainage layer. Such a material will normally require stabilization for construction stability or for structural strength to serve as a base in a flexible pavement.

6-1.3.9 **Pavement Structure**. Pavement structure is the combination of subbase, base, and surface layers constructed on a subgrade.

6-1.3.10 **Permeable Base**. An open-graded granular material with most of the fines removed (e.g., less than 10 percent passing the No. 8 sieve) to provide high permeability (1,000 ft/day or more) for use in a drainage layer.

6-1.3.11 **Porosity**. The amount of voids in a material, expressed as the ratio of the volume of voids to the total volume.

6-1.3.12 **Rapid Draining Material (RDM).** A granular material having a sufficiently high permeability (300 to 1,500 m/day (1,000 to 5,000 ft/day)) to serve as a drainage layer and also having the stability to support construction equipment and the structural strength to serve as a base and/or a subbase.

6-1.3.13 **Separation Layer.** A layer provided directly beneath the drainage layer to prevent fines from infiltration or pumping into the drainage layer and to provide a working platform for construction and compaction of the drainage layer.

6-1.3.14 **Stabilization.** Stabilization refers to either mechanically or chemically stabilizing the drainage layer to increase the stability and strength to withstand construction traffic and/or design traffic. Mechanical stabilization is accomplished by the use of a choke stone and compaction. Chemical stabilization is accomplished by the use of either portland cement or asphalt.

6-1.3.15 **Subsurface Drainage**. Collection and removal of water from a pavement surface or subgrade. Subsurface drainage systems are categorized into two functional categories: one for draining surface infiltration water, and the other for controlling groundwater.

6-1.4 **Bibliography.** In recent years subsurface drainage has received increasing attention, particularly in the area of highway design. A number of studies have been conducted by State Highway Agencies and by the Federal Highway Administration that have resulted in a large number of publications on the subject of subsurface drainage. Appendix B contains a list of publications which contain information pertaining to the design of subsurface drainage for pavements.

6-1.5 **Effects of Subsurface Water.** Water has a detrimental effect on pavement performance, primarily by either weakening subsurface materials or erosion of material by free water movement. For flexible pavements the weakening of the base, subbase or subgrade when saturated with water is one of the main causes of pavement failures. In rigid pavement free water, trapped between the rigid concrete surface and an impermeable layer directly beneath the concrete, moves due to pressure caused by loadings. This movement of water (referred to as pumping) erodes the subsurface material creating voids under the concrete surface. In frost areas subsurface water will contribute to frost damage by heaving during freezing and loss of subgrade support during thawing. Poor subsurface drainage can also contribute to secondary damage such as 'D' cracking or swelling of subsurface materials. Water is contained above an impervious stratum and hence the infiltration water is prevented from reaching a groundwater table at a lower elevation. The upper body of water is called perched groundwater and its free surface is called a perched water table.

6-1.6 **Sources of Water**

6-1.6.1 **General.** The two sources of water to be considered are from infiltration and subterranean water. Infiltration is the most important source of water and is the source of most concern in this document. Subterranean water is important in frost areas and areas of very high water table or areas of artesian water. In many areas perched water may develop under pavements due to a reduced rate of evaporation of the water from the surface. In frost areas free water collects under the surface by freeze/thaw action.

6-1.6.2 **Infiltration.** Infiltration is surface water which enters the pavement from the surface through cracks or joints in the pavement, through the joint between the pavement and shoulder, through pores in the pavement, by movement from ditches and surface channels near the pavement, and through shoulders and adjacent areas. Since surface infiltration is the principal source of water, it is the source needing greatest control measures. Groundwater tables rise and fall depending upon the relation between infiltration, absorption, evaporation and groundwater flow. Seasonal fluctuations are normal because of differences in the amount of precipitation and maybe relatively large in some localities. Prolonged drought or wet periods will cause large fluctuations in the groundwater level.

6-1.6.3 **Subterranean water.** Subterranean water can be a source of water from a high water table, capillary forces, artesian pressure, and freeze-thaw action. This source of water is particularly important in areas of frost action when large volumes of water can be drawn into the pavement structure during the formation of ice lenses. For large paved areas the evaporation from the surface is greatly reduced which causes saturation of the subgrade by capillary forces. Also, if impervious layers exist beneath the pavement, perched water can be present or develop from water entering the pavement through infiltration. This perched water then becomes a subterranean source of water.

6-1.6.4 **Classification of subdrainage facilities.** Subdrainage facilities can be categorized into two functional categories, one to control infiltration, and one to control groundwater. An infiltration control system is designed to intercept and remove water that enters the pavement from precipitation or surface flow. An important function of this system is to keep water from being trapped between impermeable layers. A groundwater control system is designed to reduce water movement into subgrades and pavement sections by controlling the flow of groundwater or by lowering the water table. Often, subdrainage is required to perform both functions, and the two subdrainage functions can be combined into a single subdrainage system. Figures 6-1 and 6-2 illustrate examples of infiltration and groundwater control systems.

Figure 6-1. Collector Drain Used to Remove Infiltration Water

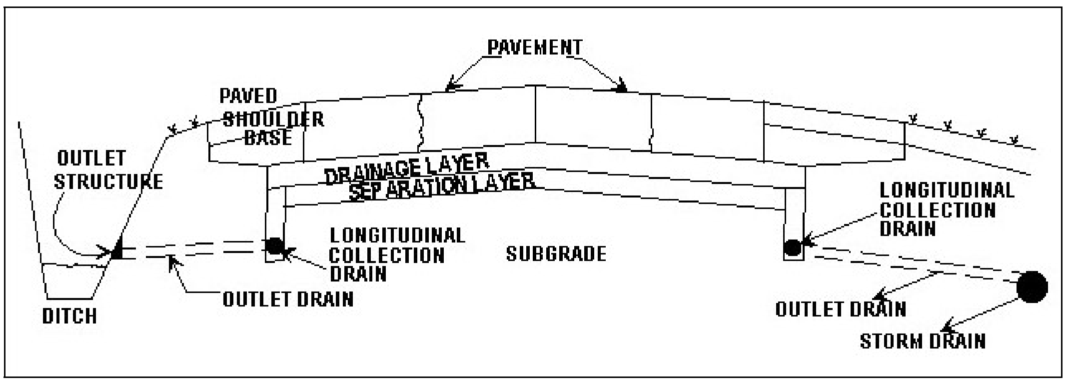
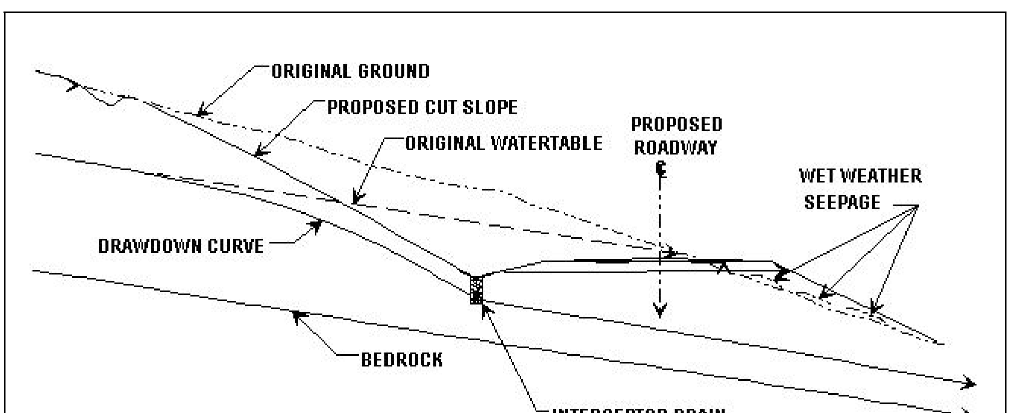


Figure 6-2. Collector Drain to Intercept Seepage and Lower the Ground-Water Table



6-1.7 **Subsurface Drainage Requirements.** The determination of the subsurface soil properties and water condition is a prerequisite for the satisfactory design of a subsurface drainage system. Field explorations and borings made in connection with the project design should include the following investigations pertinent to subsurface drainage. A topographic map of the proposed area and the surrounding vicinity should be prepared indicating all streams, ditches, wells, and natural reservoirs. The analysis of aerial photographs of the areas selected for construction may furnish valuable information on general soil and groundwater conditions. An aerial photograph presents a graphic record of the extent, boundaries, and surface features of soil patterns occurring at the surface of the ground. The presence of vegetation, the slopes of a valley, the colorless monotony of sand plains, the farming patterns, the drainage pattern, gullies, eroded lands, and evidences of the works of man are revealed in detail by aerial photographs. The use of aerial photographs may supplement both the detail and knowledge gained in topographic survey and ground explorations. The sampling and exploratory work can be made more rapid and effective after analysis of aerial photographs has developed the general soil features. The location and depth of permanent and perched groundwater tables may be sufficiently shallow to influence the design. The season of the year and rainfall cycle will measurably affect the depth to the water table. In many locations, information may be obtained from residents of the surrounding areas regarding the behavior of wells and springs and other evidences of subsurface water. The soil properties investigated for other purposes in connection with the design will supply information that can be used for the design of the drainage system. It may be necessary to supplement these explorations at locations of subsurface drainage structures and in areas where soil information is incomplete for design of the drainage system.

6-1.8 **Laboratory Tests.** The design of subsurface drainage structures requires knowledge of the following soil properties of the principal soils encountered: strength, compressibility, swell and dispersion characteristics, the in situ and compacted unit dry weights, the coefficient of permeability, the in situ water content, specific gravity, grain-size distribution, and the effective void ratio. These soil properties may be satisfactorily determined by experienced soil technicians through laboratory tests. The final selected soil properties for design purposes may be expressed as a range, one extreme representing a maximum value and the other a minimum value. The true value should be between these two extremes, but it may approach or equal one or the other, depending upon the variation within a soil stratum.

6-1.9 **Drainage of Water from Soil.** The quantity of water removed by a drain will vary depending on the type of soil and location of the drain with respect to the groundwater table. All of the water contained in a given specimen cannot be removed by gravity flow since water retained as thin films adhering to the soil particles and held in the voids by capillarity will not drain. Consequently, to determine the volume of water that can be removed from a soil in a given time, the effective porosity as well as the permeability must be known. The effective porosity is defined as the ratio of the volume of the voids that can be drained under gravity flow to the total volume of soil. Limited effective porosity test data for well-graded base course materials, such as bank-run sands and gravels, indicate a value for effective porosity of not more than 0.15. Uniformly graded soils such as medium coarse sands, may have an effective porosity of not more than 0.25.

6-2 PRINCIPLES OF PAVEMENT DRAINAGE

6-2.1 **Flow of Water Through Soils.** The flow of water through soils is expressed by Darcy's empirical law which states that the velocity of flow (v) is directly proportional to the hydraulic gradient (i). This law can be expressed as:

$$v = ki_1 \qquad \text{(eq. 6-1)}$$

where k is the coefficient of proportionality known as the coefficient of permeability. Equation 6-1 can be expanded to obtain the rate of flow through an area of soil (A). The equation for the rate of flow (Q) is:

$$Q = kiA_2 \qquad \text{(eq. 6-2)}$$

According to Darcy's law, the velocity of flow and the quantity of discharge through a porous media are directly proportional to the hydraulic gradient. For this condition to be true, flow must be laminar or nonturbulent. Investigations have indicated that Darcy's law is valid for a wide range of soils and hydraulic gradients. However, in developing criteria for subsurface drainage, liberal margins have been applied to allow for turbulent flow. The criteria and uncertainty depend heavily on the permeability of the soils involved in the pavement structure. It is therefore useful to examine the influence of various factors on the permeability of soils. In examining permeability of soils in regard to pavement drainage, the materials of most concern are base and subbase aggregate and aggregate used as drainage layers.

6-2.2 Factors Affecting Permeability

6-2.2.1 **Coefficient of permeability.** The value of permeability depends primarily on the characteristics of the permeable materials, but it is also a function of the properties of the fluid. An equation (after Taylor) demonstrating the influence of the soil and pore fluid properties on permeability was developed based on flow through porous media similar to flow through a bundle of capillary tubes. This equation is as follows:

$$k = D_s^2 \frac{\gamma \ e^3}{\mu (1-e)} C \qquad \text{(eq. 6-3)}$$

where

k = the coefficient of permeability
D_s = some effective particle diameter
(= unit weight of pore fluid
: = viscosity of pore fluid

e = void ratio
C = shape factor

6-2.2.2 **Effect of pore fluid and temperature.** In the design of subsurface drainage systems for pavements, the primary pore fluid of concern is water. Therefore, when permeability is mentioned in this chapter, water is assumed to be the pore fluid. Equation 6-3 indicates that the permeability is directly proportional to the unit weight of water and inversely proportional to the viscosity. The unit weight of water is essentially constant, but the viscosity of water will vary with temperature. Over the widest range in temperatures ordinarily encountered in seepage problems, viscosity varies about 100 percent. Although this variation seems large, it can be insignificant when considered in the context of the variations which can occur with changes in material properties.

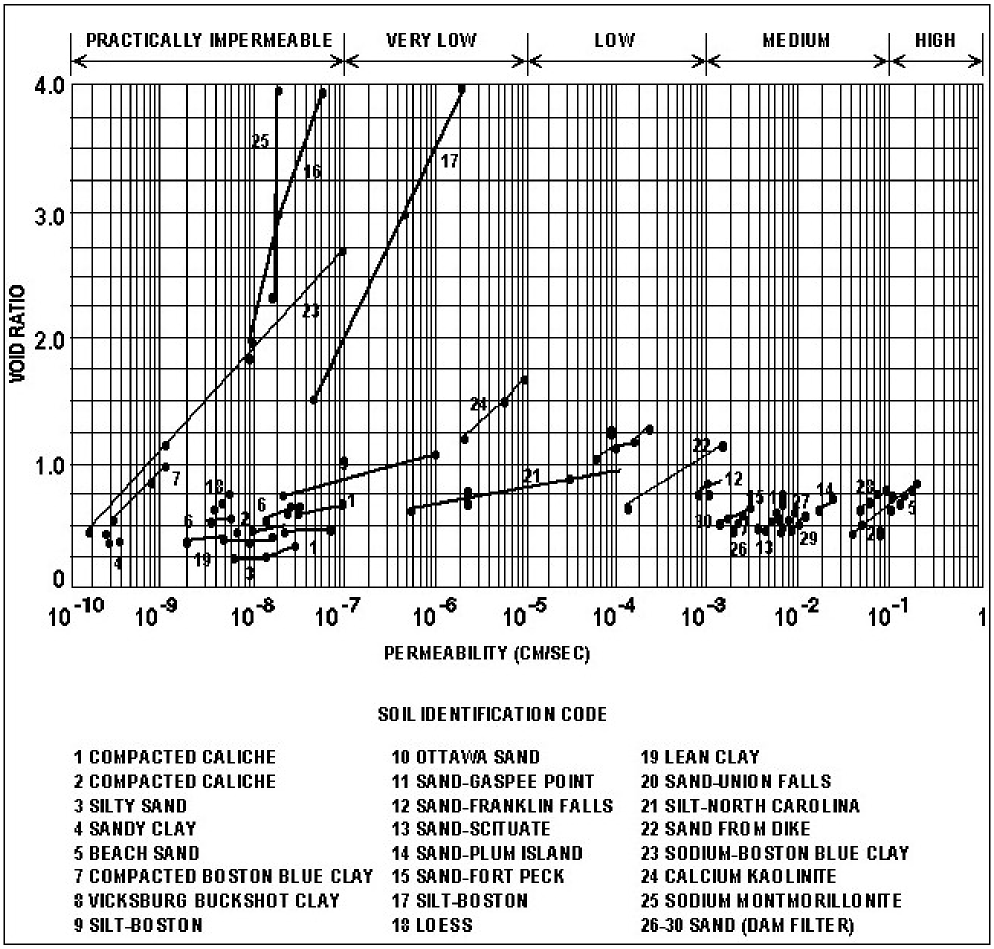
6-2.2.3 **Effect of grain size.** Equation 6-3 suggests that permeability varies with the square of the particle diameter. It is logical that the smaller the grain size the smaller the voids that constitute the flow channels, and hence the lower the permeability. Also, the shape of the void spaces has a marked influence on the permeability. As a consequence, the relationships between grain size and permeability are complex. Intuition and experimental test data suggest that the finer particles in a soil have the most influence on permeability. The coefficient of permeability of sand and gravel materials, graded between limits usually specified for pavement bases and subbases, depends principally upon the percentage by weight of particles passing the 0.075 mm (No. 200) sieve. Table 6-1 provides estimates of the permeability for these materials for various amounts of material finer than the 0.075 mm (No. 200) sieve.

Table 6-1. Coefficient of Permeability for Sand and Gravel Materials. Coefficient of 55

Percent by Weight Passing 0.075 mm (No. 200) Sieve	Permeability for Remolded Samples	
	mm/sec	ft/min
3	5 H 10^{-1}	10^{-1}
5	5 H 10^{-2}	10^{-2}
10	5 H 10^{-3}	10^{-3}
15	5 H 10^{-4}	10^{-4}
20	5 H 10^{-5}	10^{-5}

6-2.2.4 **Effect of void ratio.** The void ratio or porosity of soils, though less important than grain size and soil structure, often has a substantial influence on permeability. The void ratio of a soil will also dictate the amount of fluid that can be held within the soil. The more dense a soil, the lower the soil permeability and the lesser the amount of water that can be retained in the soil. Figure 6-3 presents the permeability for different soils as a function of the void ratio. The amount of water that can be

Figure 6-3. Permeability Test Data (from Lambe and Whitman, with permission)



contained in a soil will directly relate to the void ratio. Not all water contained in a soil can be drained by gravity flow since water retained as thin films adhering to the soil particles and held by capillarity will not drain. Consequently, to determine the volume of water that can be removed from a soil the effective porosity (n_e) must be known. The effective porosity is defined as the ratio of the volume of the voids that can be drained under gravity flow to the total volume of soil, and can be expressed mathematically as

$$n_e = 1 - \frac{\gamma_d}{G_s \gamma_w}(1 + G_s W_e) \qquad \text{(eq. 6-4)}$$

where

γ_d = dry density of the soil
G_s = specific gravity of solids
γ_w = unit weight of water
W_e = effective water content (after the soil has drained) expressed as a decimal fraction relative to dry weight

Limited effective porosity test data for well-graded base-course materials, such as bank-run sands and gravels, indicate a value for effective porosity of not more than 0.15. Uniformly graded medium or coarse sands, may have an effective porosity of not more than 0.25 while for a uniformly graded aggregate, such as would be used in a drainage layer, the effective porosity may be above 0.30.

6-2.2.5 **Effect of structure and stratification.** Generally, in situ soils show a certain amount of stratification or a heterogeneous structure. Water deposited soils usually exhibit a series of horizontal layers that vary in grain-size distribution and permeability, and generally these deposits are more permeable in the horizontal than in the vertical direction. In pavement construction the subgrade, subbase, and base materials are placed and compacted in horizontal layers which result in having a different permeability in the vertical direction than in the horizontal direction. The vertical drainage of water from a pavement can be disrupted by a single relatively impermeable layer. For most pavements the subgrades have a very low permeability compared to the base and subbase materials. Therefore, water in the pavement structure can best be removed by horizontal flow. For a layered pavement system the effective horizontal permeability is obtained from a weighted average of the layer permeability by the formula

$$k = (k_1 d_1 + k_2 d_2 + k_3 d_3 + \ldots)/(d_1 + d_2 + d_3 + \ldots) \qquad \text{(eq. 6-5)}$$

where

k	=	the effective horizontal permeability
$k_1, k_2, k_3, \ldots$	=	the coefficients of horizontal permeability of individual layers
$d_1, d_2, d_3, \ldots$	=	thicknesses of the individual layers

When a drainage layer is employed in the pavement section, the permeability of the drainage material will likely be several orders of magnitude greater than the other materials in the section. Since water flow is proportional to permeability, the flow of water from the pavement section can be computed based only on the characteristics of the drainage layer.

6-2.3 Quantity and Rate of Subsurface Flow

6-2.3.1 **General.** Water flowing from the pavement section may come from infiltration through the pavement surface and groundwater. Normally groundwater flows into collector drains from the subgrade and will be an insufficient flow compared to the flow coming from infiltration. The computation of the groundwater flow is beyond the scope of this manual and should it be necessary to compute the groundwater flow, a textbook on groundwater flow should be consulted. The volume of infiltration water flow from the pavement will depend on factors such as type and condition of surface, length and intensity of rainfall, properties of the drainage layer, hydraulic gradient, time allowed for drainage and the drained area. In the design of the subsurface drainage system all of these factors must be considered.

6-2.3.2 **Effects of pavement surface.** The type and condition of the pavement surface will have considerable influence on the volume of water entering the pavement structure. In the design of surface drainage facilities all rain falling on paved surfaces is assumed to be runoff. For new well designed and constructed pavements, the assumption of 100 percent runoff is probably a good conservative assumption for the design of surface drainage facilities. For design of the subsurface drainage facilities, the design should be based on the infiltration rate for a deteriorated pavement. Studies have shown that for badly deteriorated pavements well over 50 percent of the rainfall can flow through the pavement surface.

6-2.3.3 **Effects of rainfall.** It is only logical that the volume of water entering the pavement will be directly proportional to the intensity and length of the rainfall. Relatively low intensity rainfalls can be used for designing the subsurface drainage facilities because high intensity rainfalls do not greatly increase the adverse effect of water on pavement performance. The excess rainfall would, once the base and subbase are saturated, run off as surface drainage. For this reason a seemingly unconservative design rainfall can be selected.

6-2.3.4 **Capacity of drainage layers.** If water enters the pavement structure at a greater rate than the discharge rate, the pavement structure becomes saturated. The design of horizontal drainage layers for the pavement structure is based, in part, on the drainage layer serving as a reservoir for the excess water entering the pavement. The capacity of the drainage layer as a reservoir is a function of the storage capacity of the drainage layer plus the amount of water which drains from the layer during a rain event. The storage capacity of the drainage layer will be a function of the effective porosity of the drainage material and the thickness of the drainage layer. The storage capacity of the drainage layer (q_s) in terms of depth of water per unit area is computed by:

$$q_S = (n_e)(h) \qquad \text{(eq. 6-6)}$$

where

n_e = the effective porosity
h = the thickness of the drainage layer

In the equation the dimensions of the q_s will be the same as the dimensions of the h. If it is considered that not all the water will be drained from the drainage layer, then the storage capacity will be reduced by the amount of water in the layer at the start of the rain event. The criterion for design of the drainage layer calls for 85 percent of the water to be drained from the drainage layer within 24 hr; therefore it is conservatively assumed that only 85 percent of the storage volume will be available at the beginning of a rain event. To account for the possibility of water in the layer at the beginning of a rain event, equation 6-6 is modified to be:

$$q_S = 0.85(n_e)(h) \qquad \text{(eq. 6-7)}$$

The amount of water (q_d) which will drain from the drainage layer during the rain event may be estimated using the equation

$$q_d = \frac{(t)(k)(i)(h)}{2} \qquad \text{(eq. 6-8)}$$

where

- t = duration of the rain event
- k = permeability of the drainage layer
- i = slope of the drainage layer
- h = thickness of the drainage layer

In these equations the dimensions of q_s, q_d, t, k, and h should be consistent. The total capacity (q) of the drainage layer will be the sum of q_s and q_d resulting in the following equation for the capacity

$$q = 0.85(n_e)(h) + \frac{(t)(k)(i)(h)}{2} \qquad \text{(eq. 6-9)}$$

Knowing the water entering the pavement, equation 6-9 can be used to estimate the thickness of the drainage layer such that the drainage layer will have the capacity for a given design rain event. For most situations the amount of water draining from the drainage layer will be small compared to the storage capacity. Therefore, in most cases, equation 6-7 can be used in estimating the thickness required for the drainage layer.

6-2.3.5 **Time for drainage.** It is desirable that the water be drained from the base and subbase layers as rapidly as possible. The time for drainage of these layers is a function of the effective porosity, length of the drainage path, thickness of the layers, slope of the drainage path, and permeability of the layers. Past criterion has specified that the base and subbase obtain a degree of 50 percent drainage within 10 days. The equation for computing time for 50 percent drainage is:

$$T_{50} = \frac{(n_e D)}{2kH_o} \qquad \text{(eq. 6-10)}$$

where

- T_{50} = time for 50 percent drainage
- n_e = effective porosity of the soil
- k = coefficient of permeability
- D and H = base- and subbase geometry dimensions (illustrated in Figure 6-4)

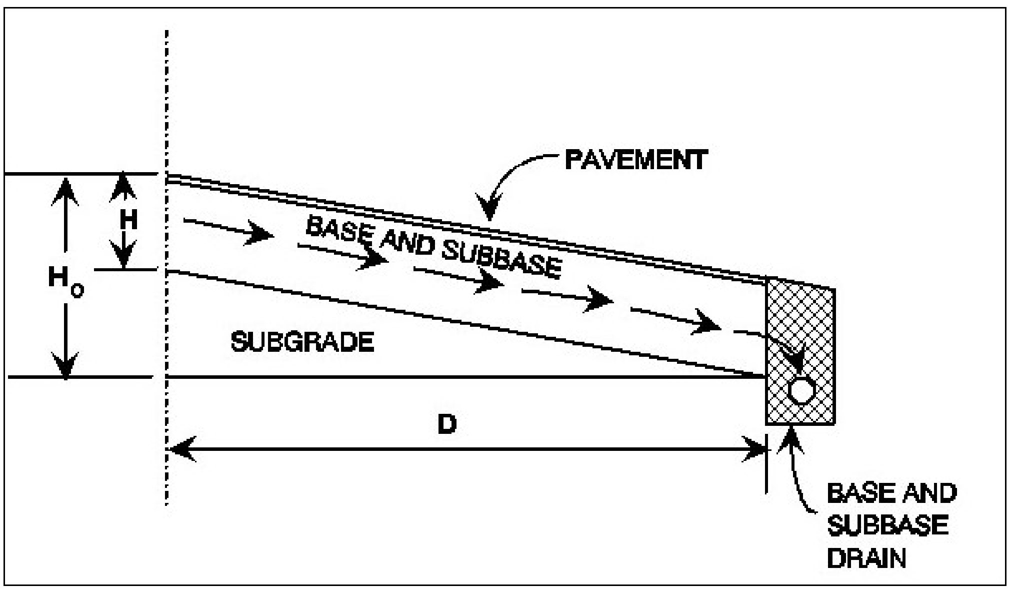
The dimensions of time, k, H_o, and D must be consistent. In Figure 6-4 the slope (i) of the drainage path is D/H_o; therefore equation 6-10 can be written

$$T_{50} = (n_e)(D)/2ik \qquad \text{(eq. 6-11)}$$

Experience has shown that base and subbase materials, when compacted to densities required in pavement construction, seldom have sufficient permeability to meet the 10 day drainage criterion. In such pavements the base and subbase materials become saturated causing a reduced pavement life. When a drainage layer is incorporated into the pavement structure to improve pavement drainage, the criterion for design of the drainage layer shall be that the drainage layer shall reach a degree of drainage of 85 percent within 24 hr. The time for 85 percent drainage is approximately twice the time for 50 percent drainage. The time for 85 percent drainage (T_{85}) is computed by

$$T_{85} = (n_e)(D)/ik \qquad \text{(eq. 6-12)}$$

Figure 6-4. Pavement Geometry for Computation of Time for Drainage



6-2.3.6 **Length and slope of the drainage path.** As can be seen in equation 6-10, the time for drainage is a function of the square of the length of drainage path. For this reason and the fact that for most pavement designs the length of the drainage path can be controlled, the drainage path length is an important parameter in the design of the drainage system. The length of the drainage path (L) may be computed from the following equation

$$L = \frac{L_t \sqrt{i_t^2 + i_e^2}}{i_t} \qquad \text{(eq. 6-13)}$$

where

L_t = the length of the transverse slope of the drainage layer

i_t = the transverse slope of the drainage layer
i_e = the longitudinal slope of the drainage layer

The slope of the drainage path (i) is a function of the transverse slope and longitudinal slope of the drainage layer and is computed by the equation

$$i = \sqrt{i_t^2 + i_e^2} \qquad \text{(eq. 6-14)}$$

6-2.3.7 **Rate of flow.** The edge drains for pavements having drainage layers shall be designed to handle the maximum rate of flow from the drainage layer. This maximum rate of flow will be obtained when the drainage layer is flowing full and may be estimated using equation 6-2.

6-2.4 **Use of Drainage Layers**

6-2.4.1 **Purpose of drainage layers.** Special drainage layers may be used to promote horizontal drainage of water from pavements, prevent the buildup of hydrostatic water pressure, and facilitate the drainage of water generated by cycles of freeze-thaw.

6-2.4.2 **Placement of drainage layers.** In rigid pavements the drainage layer will generally be placed directly beneath the concrete slab. In this location the drainage layer will intercept water entering through cracks and joints, and permit rapid drainage of the water away from the bottom of the concrete slab. In flexible pavements the drainage layer will normally be placed beneath the base. In placing the drainage layer beneath the base the stresses on the drainage layer will be reduced to an acceptable level and drainage will be provided for the base course.

6-2.4.3 **Permeability requirements for the drainage layer.** The material for drainage layers in pavements must be of sufficient permeability to provide rapid drainage and rapidly dissipate water pressure and yet provide sufficient strength and stability to withstand load induced stresses. There is a trade off between strength or stability and permeability; therefore the material for the drainage layers should have the minimum permeability for the required drainage application. For most applications a material with a permeability of 300 m/day (1,000 ft/day) will provide sufficient drainage.

6-2.5 **Use of Filters**

6-2.5.1 **Purpose of filters in pavement structures.** The purpose of filters in pavement structures is to prevent the movement of soil (piping) yet allow the flow of water from one material to another. The need for a filter is dictated by the existence of water flow from a fine grain material to a coarse gain material generating a potential for piping of the fine grain material. The principal location in the pavement structure where a flow from a fine grain material into a coarse grain material is water flowing from the base, subbase, or subgrade into the coarse aggregate surrounding the drain pipe. Thus, the principal use of a filter in a pavement system will be in preventing piping into the drain pipe. Although rare, the possibility exists for hydrostatic head forcing a flow of water upward from the subbase or subgrade into the pavement drainage layer. For such a condition it would be necessary to design a filter to separate the drainage layer from the finer material.

6-2.5.2 **Piping criteria.** The criteria for preventing movement of particles from the soil or granular material to be drained into the drainage material are:

$$\frac{\text{15 percent size of drainage or filter material}}{\text{85 percent size of material to be drained}} \leq 5$$

and

$$\frac{\text{50 percent size of drainage or filter material}}{\text{50 percent size of material to be drained}} \leq 25$$

The criteria given above will be used when protecting all soils except clays without sand or silt particles. For these soils, the 15 percent size of drainage or filter material may be as great as 0.4 mm and the d_{50} criteria will be disregarded.

6-2.5.3 **Permeability requirements.** To assure that the filter material is sufficiently permeable to permit passage of water without hydrostatic pressure buildup, the following requirement should be met:

$$\frac{\text{15 percent size of filter material}}{\text{15 percent size of material to be drained}} \geq 5$$

6-2.6 **Use of Separation Layers**

6-2.6.1 **Purpose of separation layers.** When drainage layers are used in pavement systems, the drainage layers must be separated from fine grain subgrade materials to prevent penetration of the drainage material into the subgrade or pumping of fines from the subgrade into the drainage layer. The separation layer is different from a filter in that there is no requirement, except during frost thaw, to protect against water flow through the layer.

6-2.6.2 **Requirements for separation layers.** The main requirements of the separation layer are that the material for the separation layer have sufficient strength to prevent the coarse aggregate of the drainage layer from being pushed into the fine material of the subgrade and that the material have sufficient permeability to prevent buildup of hydrostatic pressure in the subgrade. To satisfy the strength requirements the material of the separation layer should have a minimum CBR of 50. To allow for release of hydrostatic pressure in the subgrade, the permeability of the separation layer should have a permeability greater than that of the subgrade. This would not normally be a problem because the permeability of subgrades are orders of magnitude less than the permeability of a 50 CBR material but to ensure sufficient permeability the permeability requirements of a filter would apply.

6-2.7 Use of Geotextiles

6-2.7.1 **Purpose of geotextiles.** Geotextiles (engineering fabrics) may be used to replace either the filter or the separation layer. The principal use of geotextiles is the filter around the pipe for the edge drain. Although geotextiles can be used as a replacement for the separation layer, geotextile adds no structure strength to the pavement; therefore this practice is not recommended.

6-2.7.2 **Requirements of the geotextiles for filters.** When geotextiles are to serve as a filter lining the edge drain trench, the most important function of the filter is to keep fines from entering the edge drain system. For pavement systems having drainage layers there is little requirement for water flow through the fabric; therefore for most applications, it is better to have a heavier fabric than would normally be used as a filter. Since drainage layers have a very high permeability, geotextile fabric should never be placed between the drainage layer and the edge drain. The permeability of geotextiles is governed by the size of the openings in the fabric which is specified in terms of the apparent opening size (AOS) in millimeters. For use as a filter for the trench of the edge drain the AOS of the geotextile should always be equal to or less than 0.212 mm. For geotextiles used as filters with drains installed to intercept groundwater flow in subsurface aquifers the geotextile should be selected based on criteria similar to the criteria used to design a granular filter.

6-2.7.3 **Requirements for geotextiles used for separation.** Geotextiles used as separation layers beneath drainage layers should be selected based primarily on survivability of the geotextiles with somewhat less emphasis placed on the AOS. When used as a separation layer the geotextile survivability should be rated very high by the rating scheme given by AASHTO M 28890 “Standard Specification for Geotextiles, Asphalt Retention, and Area Change of Paving Engineering Fabrics.” This would ensure survival of the geotextiles under the stress of traffic during the life of the pavement. To ensure that fines will not pump into the drainage layer yet allow water flow to prevent hydrostatic pressure the AOS of the geotextile must be equal to or less than 0.212 mm and also equal to or greater than 0.125 mm.

6-3 DESIGN OF THE PAVEMENT SUBSURFACE DRAINAGE SYSTEM

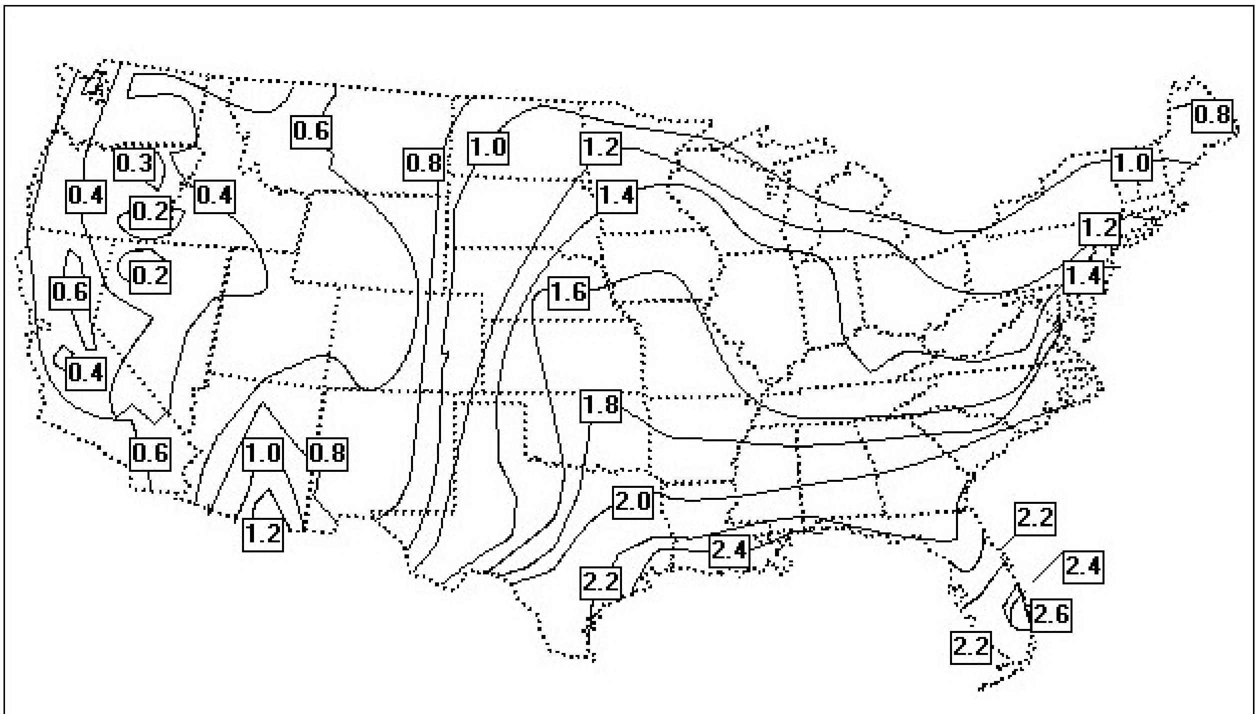
6-3.1 **General.** The design methodology contained herein is for the design of a pavement subsurface drainage system for the rapid removal of surface infiltration water and water generated by freeze-thaw action. Although the primary emphasis will be on removing water from under the pavement, there may be occasions when the system will also serve as interceptor drain for groundwater.

6-3.2 **Methods.** For most pavement structures water is to be removed by the use of a special drainage layer which allows the rapid horizontal drainage of water. The drainage layer must be designed to handle surface infiltration from a design storm and withstand the stress of traffic. A separation layer must be provided to prevent intrusion of fines from the subgrade or subbase into the drainage layer and facilitate construction of the drainage layer. The drainage layers should feed into a collection system consisting of trenches with a drain pipe, backfill, and filter. The collection system must be designed to maintain progressively greater outflow capabilities in the direction of flow. The outlet for the subsurface drains should be properly located or protected to prevent backflow from the surface drainage system. Some pavements may not require a drainage system in that the subgrade may have sufficient permeability for the water to drain vertically into the subgrade. In addition, some pavements designed for very light traffic may not justify the expense of a subsurface drain system.

6-3.3 **Design Prerequisites.** For the satisfactory design of a subsurface drainage system, the designer must have an understanding of environmental conditions, subsurface soil properties and groundwater conditions.

6-3.3.1 **Environmental conditions.** Temperature and rainfall data applicable to the local area should be obtained and studied. The depth of frost penetration is an important factor in the design of a subsurface drainage. For most areas the approximate depth of frost penetration can be determined by referring to TM 5-825-2/ AFMAN 32-8008, Vol. 2 or by using the computer program for frost analysis. Rainfall data are used to determine the volume of water to be handled by the subsurface drainage system. The data can be obtained from local weather stations or by the use of Figure 6-5.

Figure 6-5. Design Storm Index, 1-hr Rainfall Intensity-Frequency Data for Continental United States Excluding Alaska



6-3.3.2 **Subsurface soil properties.** In most cases the soil properties investigated for other purposes in connection with the pavement design will supply information that can be used for the design of the subsurface drainage system. The two properties of most interest are the coefficient of permeability and the frost susceptibility of the pavement materials.

6-3.3.3 **Coefficient of permeability.** The coefficient of permeability of the existing subsurface soils is needed to determine the need of special horizontal drainage layers in the pavement. For pavements having subgrades with a high coefficient of permeability the water entering the pavement will drain vertically and therefore horizontal drainage layers will not be required. For pavements having subgrades with a low coefficient of permeability the water entering the pavement must be drained horizontally to the collector system or to edge drains.

6-3.3.4 **Frost susceptible soils.** Soils susceptible to frost action are those that have the potential of ice formation occurring when that soil is subjected to freezing conditions with water available. Ice formation takes place at successive levels as freezing temperatures penetrate into the ground. Soils possessing a high capillary rate and low cohesive nature act as a wick in feeding water to ice lenses. Soils are placed into groups according to the degree of frost susceptibility as shown in Table 6-2. Because a large volume of free water is generated during thaw of ice lenses, horizontal drainage layers are required to permit the escape of the water from the pavement structure and thus facilitate the restoration of the pavement strength.

Table 6-2. Frost Susceptible Soils

Typical Soil			
Frost Group	**Type of Soil**	**Percent Finer than 0.02 mm by Weight**	**Types Under Unified Soil Classification System**
F1	Gravely Soils	6-10	GW-GM, GP-GM, GW-GC, GP-GC
F2	(a) Gravely Soils (b) Sands	10-20 6-15	GM, GC, GM-GC SM, SC, SW-SM, SP-SM, SW-SC, SP-SC, SM-SC
F3	(a) Gravely Soils (b) Sands, except very fine silty sands (c) Clays (PI > 12)	> 20 > 15 --	GM, GC, GM-GC SM, SC, SM-SC CL, CH, ML-CL
F4	(a) Silts (b) Very fine sands (c) Clays (PI < 12) (d) Varved clays and other fine grained, with banded sediments	-- > 15 -- --	ML, MH, ML-CL SM, SC, SM-SC CL, ML-CL CL or CH layered ML, MH, SM, SC SM-SC or ML-CL

6-3.3.5 **Sources for data.** The field explorations made in connection with the project design should include a topographic map of the proposed pavement facility and surrounding vicinity indicating all streams, ditches, wells, and natural reservoirs. An analysis of aerial photographs should be conducted for information on general soil and groundwater conditions. Borings taken during the soil exploration should provide depth to water tables and subgrade soil types. Typical values of permeability for subgrade soils can be obtained from Figure 6-3. Although the value of permeability determined from Figure 6-3 must be considered only an estimate, the value should be sufficiently accurate to determine if subsurface drainage is required for the pavement. For the permeability of granular materials, estimates of the permeability may be determined from the following equations:

$$k = \frac{217.5\,(D_{10})^{1.478}\,(n)^{6.654}}{(P_{200})^{0.597}} \text{ in mm/sec} \qquad \text{(eq 6-15)}$$

or

$$k = \frac{6.214 \times 10^{5}\,(D_{10})^{1.478}\,(n)^{6.654}}{(P_{200})^{0.597}} \text{ in ft/day} \qquad \text{(eq 6-16)}$$

where

n = porosity = $1 - \frac{\gamma_d}{\gamma_w G}$

G = specific gravity (assumed 2.7)

$(_d$ = density of water, $\frac{gm}{mm^3}, \frac{lb}{ft^3}$

$(_w$ = dry density of material

D_{10} = effective grain size at 10 percent passing in mm

P_{200} = percent passing 0.075 mm (No. 200) sieve

For the most part the permeability needed for design of the drainage layer will be assigned based on the gradation of the drainage material. In some cases, laboratory permeability tests may be necessary, but it is cautioned that the permeability of very open granular materials is very sensitive to test methods, methods of compaction and gradation of the sample. Therefore, conservative drainage layer permeability values should be used for design.

6-3.4 Criteria for Subsurface Drain Systems

6-3.4.1 **Criteria for requiring a subsurface drain system.** Not all pavements will require a subsurface drain system either because the subgrade is sufficiently permeable to allow vertical drainage of water into the subgrade or the pavement structure does not justify the expense of a subsurface drain system. For pavements in nonfrost areas and having a subgrade with a permeability greater than 6 m/day (20 ft/day), one can assume that the vertical drainage will be sufficient such that no drainage system is required. In addition to the above exemption for the requirement for drainage systems, flexible pavements which are in nonfrost areas and having total thickness of structure above the subgrade of 200 mm (8 in.) or less are not required to have a drainage system. All pavements not meeting the above criteria are required to have a subsurface drainage system. Even if a pavement meets the exemption requirements, a drainage analysis should be conducted for possible benefits for including the drainage system. For rigid pavements in particular, care should be taken to ensure water is drained rapidly from the bottom of the slab and that the material directly beneath the concrete slab is not susceptible to pumping.

6-3.4.2 **Design water inflow.** The subsurface drainage of the pavement is to be designed to handle infiltrated water from a design storm of 1 hr duration at an expected return frequency of 2 yr. The design storm index for different parts of the world can be obtained from Figure 6-5 or from Figure 2-2. The inflow is determined by multiplying the design storm index (R) times an infiltration coefficient (F). The infiltration coefficient will vary over the life of the pavement depending on the type of pavement, surface drainage, pavement maintenance, and structural condition of the pavement. Since the determination of a precise value of the infiltration coefficient for a particular pavement is very difficult, a value of 0.5 may be assumed for design.

6-3.4.3 **Length and slope of drainage path.** The length of drainage path is measured along the slope of the drainage layer from the crest of the slope to where the water will exit the drainage layer. In simple terms, the length of the drainage path is the maximum distance water will travel in the drainage layer. The length of drainage path (L) in meters (feet) may be computed by equation 6-13, and the slope (i) of the drainage path may be computed by equation 6-14.

6-3.4.4 **Thickness of drainage layer.** The thickness of the drainage layer is computed such that the capacity of the drainage layer will be equal to or greater than the infiltration from the design storm. When the length of the drainage path (L) is in meters (feet), the design storm index (R) is in meters/hour (feet/hour), the permeability of the drainage layer (k) is in meters/hour (feet/hour), and the length of the design storm (t) is in hours, the equation for computing the thickness (H) in meters (feet) is

$$H = 2(F)(R)(L)(t)/[1.7 n_e L + k i t] \qquad \text{(eq. 6-17)}$$

The effective porosity (n_e), the infiltration coefficient (F) and the slope of the drainage path (i) are nondimensional. If the term (k i t) is small compared to the term 1.7 n_e L, which would be the case for long drainage paths, i.e., for drainage paths longer than 6 m (20 ft), then the required thickness of the drainage layer can be estimated by deleting the term (k i t) from equation 6-17 or

$$H = (F)(R)/0.85n_e \quad \text{(eq. 6-18)}$$

where the units are the same as in equation 6-17.

6-3.4.5 **Required permeability, slope, and length.** The subsurface drainage criteria require that from the end of the design storm, the drainage layer should attain 85 percent drainage within 24 hr. The time for 85 percent drainage is computed by the equation

$$T_{85} = n_e * L/(i * k) \quad \text{(eq. 6-19)}$$

where the dimensions of T_{85} will be in days when L is in meters (feet) and k is in meters/day (feet/day). The time of drainage may be adjusted by changing the drainage material, the length of the drainage path or the slope of the drainage path. Changing the drainage material will change both the effective porosity and the permeability but the effective porosity will change, at the most, by a factor of 3, whereas the permeability may change by several orders of magnitude. Thus, providing a more open drainage material would decrease the time for drainage but more open materials are less stable and more susceptible to rutting. It is therefore desirable to keep the drainage material as dense as possible. The drainage layer of a pavement is usually placed parallel to the surface; therefore the slope of the drainage path is governed by the geometry of the pavement surface. For large paved areas such as parking lots, airfield aprons, and storage areas, the time for drainage is best controlled by designing the collection system to minimize the length of the drainage path. For edge drains along roads, streets, and airfield taxiways and runways, it may be difficult to reduce the length of the drainage path without resorting to placing drains under the pavement. Pavements having long longitudinal slopes may require transverse collector drains to prevent long drainage paths. Thus, designing the subsurface drainage system to meet the criteria for time of drainage involves matching the type of drainage material with the drainage path length and slope.

6-3.5 Placement of Subsurface Drainage System

6-3.5.1 **Rigid pavements.** In the case of rigid pavements the drainage layer, if required, shall be placed as shown in Figure 6-6 directly beneath the concrete slab. In the structural design of the concrete slab the drainage layer along with any granular separation layer shall be considered a base layer, and structural benefit may be realized from the layers.

6-3.5.2 **Flexible pavements.** In the case of flexible pavements the drainage layer should be placed either directly beneath the surface layer as shown in Figure 6-7 or beneath a graded crushed aggregate base course as shown in Figure 6-6. If the required thickness of granular subbase is equal to or greater than the thickness of the drainage layer plus the thickness of the separation layer, the drainage layer is placed beneath the graded crushed aggregate base (Figure 6-6). Where the total thickness of pavement structure is less than 300 mm (12 in.), the drainage layer may be placed directly beneath the surface layer (Figure 6-6) and the drainage layer used as a base. When the drainage layer is placed beneath an unbound aggregate base, care must be taken to limit the material passing the 0.075 mm (No. 200) sieve in the aggregate base to 8 percent or less.

Figure 6-6. Drainage Layer Placed Beneath Base Course

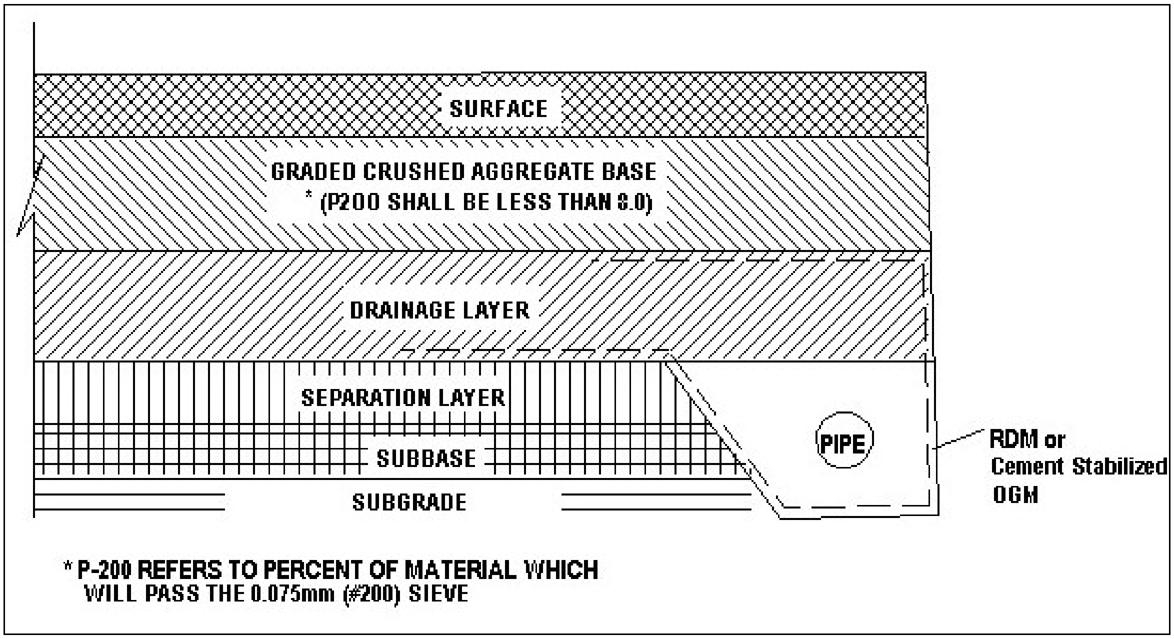
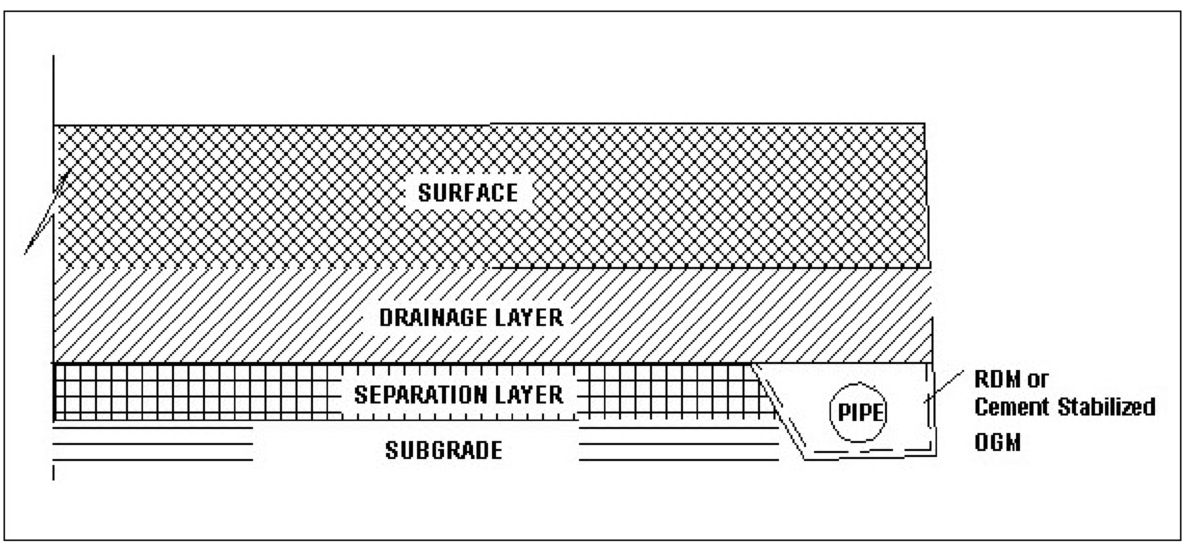


Figure 6-7. Drainage Layer Placed Directly Below Surface Layer



6-3.5.3 **Separation layer.** The drainage layer must be protected from contamination of fines from the underlying layers by a separation layer to be placed directly beneath the drainage layer. In most cases the separation layer should be a graded aggregate material meeting the requirements of a 50 CBR subbase and, in fact, can be considered as part of the subbase. For design situations where a firm foundation already exists and thickness of the separation layer is not needed in the structure for protection of the subgrade, a filter fabric may be substituted for the granular separation layer.

6-3.6 Material Properties

6-3.6.1 **For drainage layers.** The material for a drainage layer should be a hard, durable crushed aggregate to withstand degradation under construction traffic as well as in-service traffic. The gradation of the material should be such that the material has sufficient stability for the operation of construction equipment. While it is desirable for strength and stability to have the well-graded aggregate, the permeability of the material must be maintained. For most drainage layers, the drainage materials should have a minimum permeability of 300 m/day (1,000 ft/day). Two materials, a rapid draining material (RDM) and an open graded material (OGM), have been identified for use in drainage layers. The RDM is a material having a sufficiently high permeability (300 m/day (1,000 ft/day) to 1,500 m/day (5,000 ft/day)) to serve as a drainage layer and will also have the stability to support construction equipment and the structural strength to serve as a base and/or a subbase. The OGM is a material having a very high permeability (greater than 1,500 m/day (5,000 ft/day)) which can be used for a drainage layer. The OGM will normally require stabilization for construction stability and/or for structural strength to serve as a base in a flexible pavement. Gradation limits for the two materials are given in Table 6-3 and the design properties are given in Table 6-4.

Table 6-3. Gradations of Materials for Drainage Layers and Choke Stone

Drainage Layer Material			
Sieve Designation (mm)	Rapid Draining Material	Open Graded Material	Choke Stone
38.0 (1-1/2 in.)	100	100	100
25.0 (1 in.)	70-100	95-100	100
19.0 (3/4 in.)	55-100	--	100
12.5 (1/2 in.)	40-80	25-80	100
9.5 (3/8 in.)	30-65	--	80-100
4.75 (No. 4)	10-50	0-10	10-100
2.4 (No. 8)	0-25	0-5	5-40
1.2 (No. 16)	0-5	--	0-10

Table 6-4. Properties of Materials for Drainage Layers

Property	Rapid Draining Material	Open Graded Material
Permeability in m/sec (feet/day)	300-1,500 (1,000-5,000)	> 1,500 (> 5,000)
Effective Porosity	0.25	0.32
Percent Fractured Faces (COE method)	90% for 80 CBR 75% for 50 CBR	90% for 80 CBR 75% for 50 CBR
C_v	> 3.5	--
LA Abrasion	< 40	< 40
Note: C_v is the uniformity coefficient = D60/D10.		

6-3.6.2 **Aggregate for separation layer.** The separation layer serves to prevent fines from infiltrating or pumping into the drainage layer and to provide a working platform for construction and compaction of the drainage layer. The material for the separation layer should be a graded aggregate meeting the requirements of a 50 CBR subbase as given in TM 5-825-2/AFM 88-6, Chap. 2 except that the maximum aggregate size should not be greater than 1/4 the thickness of the separation layer. The permeability of the separation layer should be greater than the permeability of the subgrade, but the material should not be so open as to permit pumping of fines into the separation layer. To prevent pumping of fines the ratio of d_{15} of the separation layer to d_{85} of the subgrade must be equal to or less than 5. The material property requirements for the separation layer are given in Table 6-5.

Table 6-5. Criteria For Granular Separation Layer

Maximum Aggregate Size	Lesser of 50 mm (2 in.) or 1/4 of layer thickness
Maximum CBR	50
Maximum Percent Passing 2.00 mm (No. 10)	50
Maximum Percent Passing 0.075 mm (No. 200)	15
Maximum Liquid Limit	25
Maximum Plasticity Index	5
d_{15} of Separation Layer to d_{85} of Subgrade	≤ 5

6-3.6.3 **Filter fabric for separation layer.** Filter fabric provides protection against pumping, but does not provide extra stability for compaction of the drainage layer. Therefore, fabric should be selected only when the subgrade provides adequate support for compaction of the drainage layer. The important characteristics of the fabric are strength for surviving construction and traffic loads, and apparent opening size (AOS) to prevent pumping of fines into the drainage layer. Filter fabric for separation shall be a nonwoven needle punched fabric meeting the criteria given in Table 6-6.

Table 6-6. Criteria for Filter Fabric to be Used as a Separation Layer

	Criteria	ASTM Test Method
50 Percent or Less Passing No. 200 Sieve	AOS (mm) < 0.6 mm Greater than No. 30 sieve	D-4751
Greater Than 50 Percent Passing No. 200 Sieve	AOS (mm) < 0.297 Greater than No. 50 sieve	D-4751
Minimum Grab Strength in kN(lbs) at 50% Elongation	0.8 (180)	D-4632
Minimum Puncture Strength in kN(lbs)	0.35 (80)	D-4833

6-4 STABILIZATION OF DRAINAGE LAYER

6-4.1 **General.** Stabilization of OGM is normally required for stability and strength, and for preventing degradation of the aggregate in handling and compaction. Stabilization may also be used when high quality crushed aggregate is not available and there may even be occasions when stabilization of RDM is necessary. Stabilization may be accomplished mechanically by use of a choke stone or by the use of a binder such as asphalt or portland cement.

6-4.2 **Choke Stone Stabilization.** A choke stone is a small size stone used to stabilize the surface of an OGM. The choke stone should be a hard, durable, crushed aggregate having 90 percent fractured faces. The ratio of d_{15} of the coarse aggregate to the d_{15} of the choke stone must be less than 5, and the ratio of the d_{50} of the coarse aggregate to d_{50} of the choke stone must be greater than 2. The gradation range for acceptable choke stone is given in Table 6-3. Normally ASTM No. 8 or No. 9 stone will meet the requirements of a choke stone for the OGM.

6-4.3 **Asphalt Stabilization.** Stabilization of the drainage material is accomplished by using only enough asphalt required to coat the aggregate. Care should be taken so that the voids are not filled by excess asphalt. Asphalt grade used for stabilization should be AC20 or higher. For stabilization of OGM, 2 to 2-1/2 percent asphalt by weight should be sufficient to coat the aggregate. Higher rates of application may be necessary when stabilization of less open aggregate such as RDM is necessary.

6-4.4 **Cement Stabilization.** As with asphalt stabilization, portland cement stabilization is accomplished by using only enough cement paste to coat the aggregate, and care should be taken so that the voids are not filled by excess paste. The amount of portland cement required should be approximately 170 kilograms per cubic meter (2 bags/yd^3) depending on the gradation of the aggregate. The water-cement ratio should be just sufficient to provide a paste which will adequately coat the aggregate.

6-5 CONSTRUCTION OF THE DRAINAGE LAYER

6-5.1 **Experience.** Construction of drainage layers can present problems in handling, placement, and compaction. If the drainage material does not have adequate stability, major problems can develop in the placement of the surface layer above the drainage layer. Experience with highly permeable bases (drainage layers) both by the Corps of Engineers and various State Departments of Transportation indicates that pavements containing such layers can be constructed without undue difficulties provided due precautions are taken. The real key to successful construction of the drainage layers is the training and experience of the construction personnel. Prior to start of construction, the construction personnel should be indoctrinated in the handling and placing of the drainage material. The placement of test strips is recommended for training of the construction personnel.

6-5.2 **Placement of Drainage Layer.** The material for the drainage layer must be placed in a manner to prevent segregation and to obtain a layer of uniform thickness. The materials for the drainage layer will require extra care in stockpiling and handling. Placement of the RDM and OGM is best accomplished using an asphalt concrete paver. To ensure good compaction, the maximum lift thickness should be no greater than 150 mm (6 in.). If choke stone is used to stabilize the surface of OGM, the choke stone is placed after compaction of the final lift of OGM. The choke stone is spread in a thin layer no thicker than 10 mm (1/2 in.) using a spreader box or paver. The choke stone is worked into the surface of the OGM by the use of a vibratory roller and by wetting. The choke stone remaining on the surface should not migrate into the OGM by the action of water or traffic.

6-5.3 **Compaction.** Compaction is a key element in the successful construction of the drainage layer. Compaction control normally used in pavement construction is not appropriate for materials such as the RDM and OGM. It is therefore, necessary to specify compaction techniques and level of effort instead of the properties of the end product. It will be important to place the drainage material in relatively thin lifts of 150 mm (6 in.) or less and to have a good firm foundation beneath the drainage material. The recommended method of determining the required compaction effort is to construct a test section and closely monitor the aggregate during compaction to determine when crushing of the aggregate appears excessive. Experience has indicated that sufficient compaction can be obtained by six passes or less of a vibratory roller loaded at approximately 9 metric tons (10 short tons). Material not being stabilized with asphalt or cement should be kept moist during compaction. Asphalt stabilized material for drainage layers must be compacted at a somewhat lower temperature than a dense-graded asphalt material. In most cases, it will be necessary to allow an asphalt stabilized material to cool to less than 93 degrees C (200 degrees F) before beginning compaction.

6-5.4 **Protection After Compaction.** After compaction, the drainage layer should be protected from contamination by fines from construction traffic or from flow of surface water. It is recommended that the surface layer be placed as soon as possible after placement of the drainage layer. Precautions must also be taken to protect the drainage layer from disturbance by construction equipment. Only tracked asphalt pavers should be allowed for paving over any RDM or OGM that has not been stabilized. Drivers should avoid rapid acceleration, hard braking, or sharp turning on the completed drainage layer. Although curing of cement stabilized drainage layers is not critical, efforts should be made at curing until the surface layer is placed.

6-5.5 **Proof Rolling.** For Army Class IV airfield with runways over 1,524 m (5,000 ft) and Air Force heavy, modified heavy, and medium load flexible airfield pavements, proof rolling as per TM 5-825-2/AFM 88-6, Chap. 2, is required on the graded crushed aggregate base even when used over a drainage layer. Proof rolling the separation layer prior to placement of the drainage layer for other airfield pavements is recommended. For other Air Force flexible airfield pavements and Army Class IV flexible airfield pavements with runways less than 1,524 m (5,000 ft), it is recommended that the proof rolling be accomplished using a rubber-tired roller load to provide a minimum tire force of 89 kN (20,000 lb) and inflated to at least 620 kPa (90 lb/in.^{2}). A minimum of six coverages should be applied, where a coverage is the application of one tire print over each point in the surface of the designated area. For rigid pavements and flexible pavements for roads, streets, parking areas and Class I, II, and III Army airfields, proof rolling of the separation layer may be accomplished using the rubber-tired roller described above or by using a truck having tandem axles with either dual tires or super single tires. The truck should be loaded to provide 89 kN (20,000 lb) per axle. During proof rolling, action of the separation layer must be monitored for any sign of excessive movement or pumping that would indicate soft spots in the separation layer or the subgrade. Since the successful placement of the drainage layer depends on the stability of the separation layer, all weak spots must be removed and replaced with stable material. All replaced material must be proof rolled as specified above.

6-6 COLLECTOR DRAINS

6-6.1 **Design Flow.** Collector drains are to be provided to collect and transport water from under the pavement. For pavements having drainage layers, it is mandatory that collector drains be provided. The collector system should have the capacity to handle the water from the drainage layer plus water from other sources. The water entering the collector system from the drainage layer is computed assuming the drainage layer is flowing full. Thus, the volume of water (Q_o) in cubic millimeters per second per meter (cubic feet per day per foot) of length of collector pipe (assuming the drainage layer is only on one side of the collector) would be

$$Q = (H)*(i)*(k)*(1000) \text{ in cubic mm per second per meter} \qquad \text{(eq. 6-20)}$$

or

$$Q = (H)*(i)*(k) \text{ in cubic ft per day per foot} \qquad \text{(eq. 6-21)}$$

where

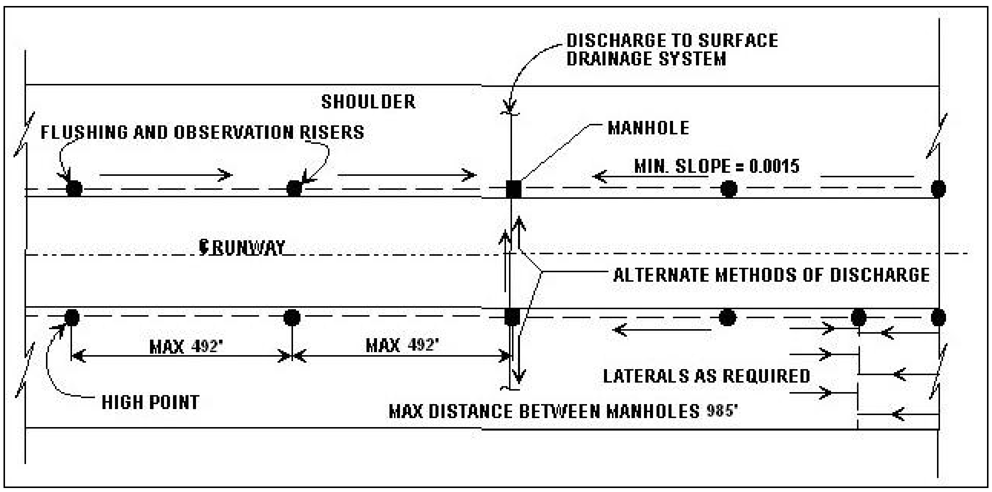
H = thickness of the drainage layer, mm (ft)
i = slope of the drainage layer
k = permeability of the material in the drainage layer, mm/sec (ft/day)

If the collector system has water entering from both sides, the volume of water entering the collector would be double that given by equation 6-20.

6-6.2 **Design of Collector Drains**

6-6.2.1 **Drain system layout**. The collector drains are normally placed along the shoulder of the pavement as illustrated in Figure 6-8. The system will consist of the drain pipe, flushing and observation risers, manholes, discharge laterals, filter fabric, and trench backfill. The drainage system for large areas of pavement may require placement of subsurface drains under the pavement. Typical designs for the collector drains are given in Figures 6-9, 6-10, 6-11, and 6-12.

Figure 6-8. Plan View of Subsurface Drainage System



6-6.2.2 **Collector pipe**. The collector pipe may be perforated flexible, ABS, corrugated polyethylene (CPE) or smooth rigid polyvinyl chloride pipe (PVC). Pipe should conform to the appropriate AASHTO Specification. Most State Highway Agencies use either CPE or PVC. For CPE pipe, AASHTO specification M 252 “Corrugated Polyethylene Drainage Tubing” is suggested, while for PVC pipe, AASHTO Specification M 278, “Class PC 50 Polyvinyl Chloride (PVC) Pipe,” is recommended. It is recommended that asphalt stabilized material not be used as backfill around pipe, but, if it is to be used, then the pipe should be PVC 90 degrees C electric plastic conduct, EPC40 or EPC80 conforming to the requirements of National Electrical Manufacturers Association Specification TC2. Geocomposite edge drains (strip drains) may be used in special situations but only with the approval of HQUSACE (CEMPET) or the appropriate Air Force major command. Geocomposite edge drains should only be considered for pavements not having a drainage layer.

Figure 6-9. Typical Concrete Pavement Interior Subdrain Detail

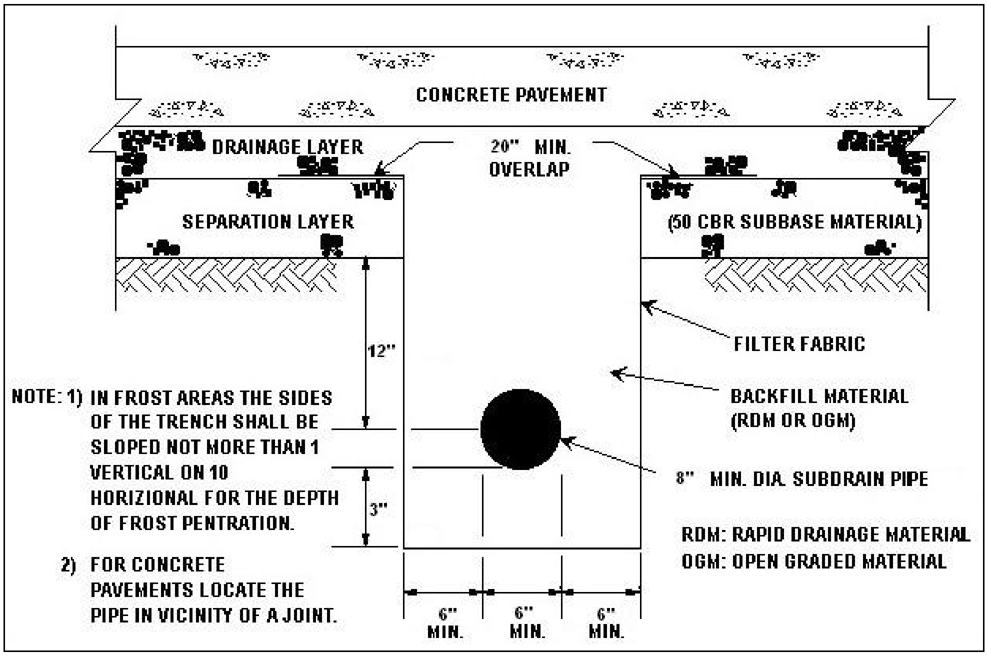


Figure 6-10. Typical Edge Subdrain Detail for Flexible Pavements

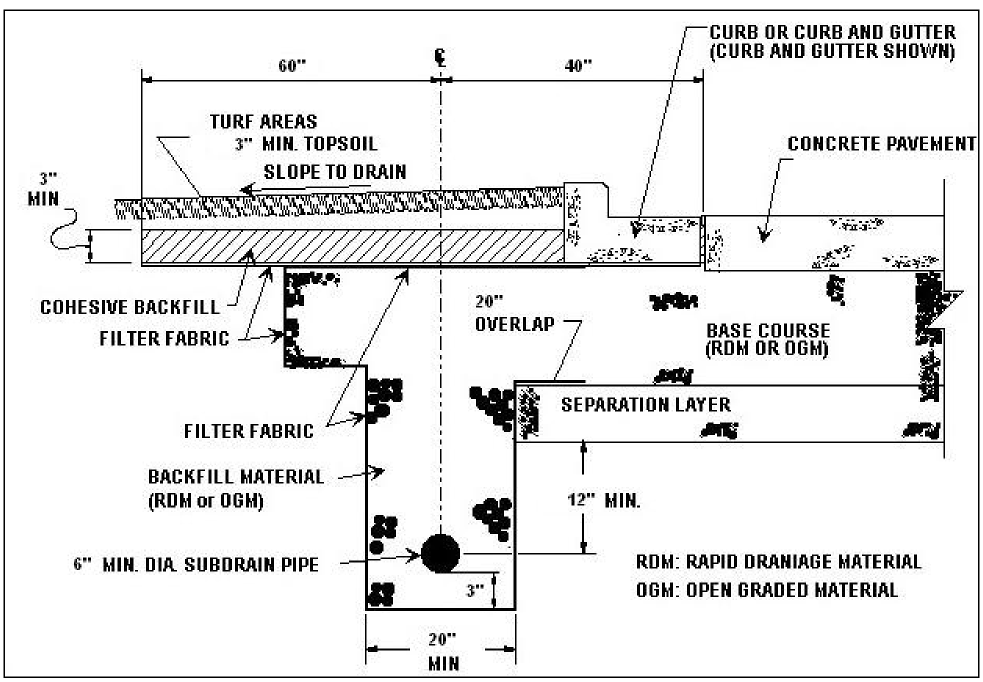


Figure 6-11. Typical Flexible Pavement Interior Subdrain Detail

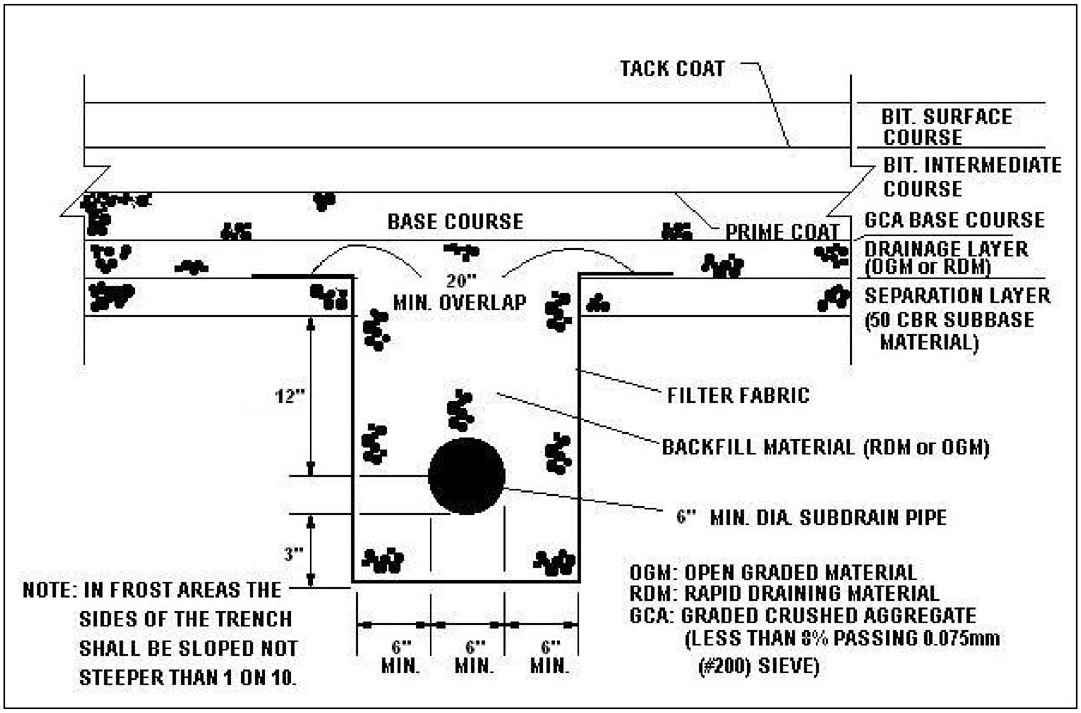
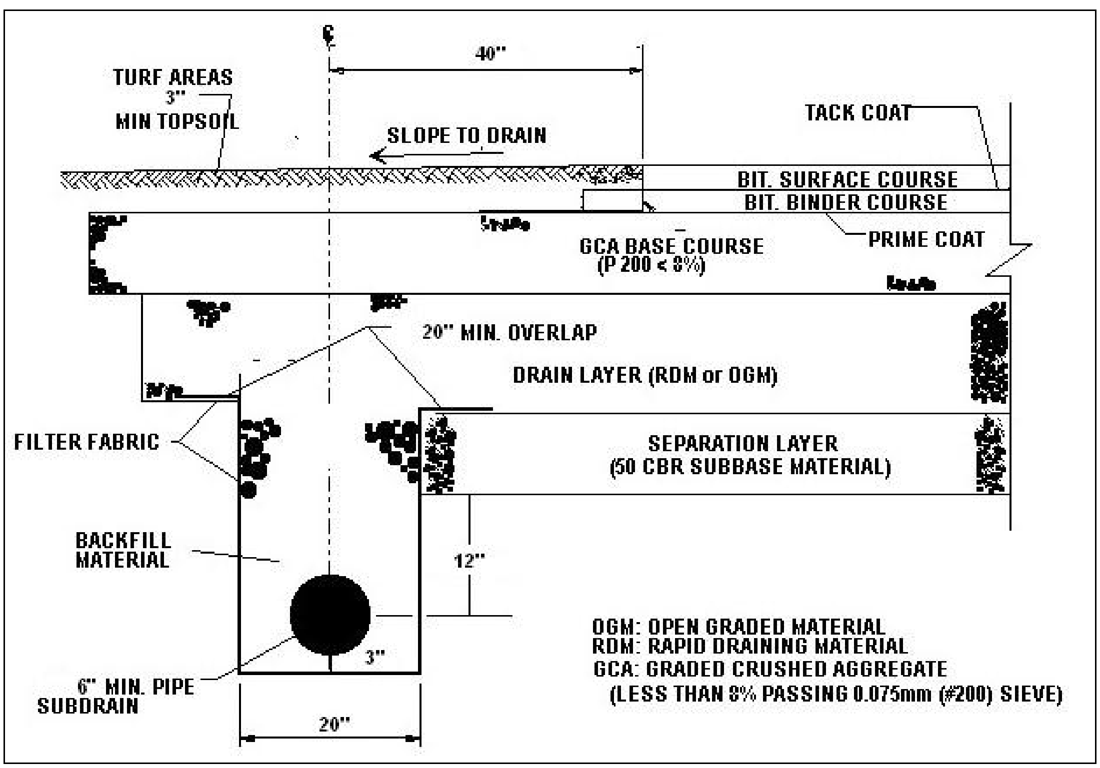


Figure 6-12. Typical Edge Subdrain Detail for Flexible Pavements



6-6.2.3 **Pipe size and slopes**. The pipe must be sized, according to equations 6-22 or 6-23, to have a capacity sufficient to collect the peak flow from under the pavement. Equations 6-22 and 6-23 are Manning equations for computing the capacity of a full flowing circular drain. The equation for flow (Q) in cubic feet per second is:

$$Q = \frac{1.486}{n}(A)\left(\frac{d}{4}\right)^{2/3}(s^{1/2}) \quad \text{(eq. 6-22)}$$

where

n = coefficient of roughness for the pipe
A = area of the pipe, ft^2
d = pipe diameter, ft
S = slope of the pipe invert

For metric units the equation for flow in cubic meters per second is:

$$Q = \frac{1.0}{n}(A)\left(\frac{d}{4}\right)^{2/3}(s^{1/2}) \quad \text{(eq. 6-23)}$$

where

n and s are as defined in equation 6-22
A = pipe area, m^2
d = pipe diameter, m

The coefficient of roughness for different pipe types can be obtained from Table 6-7. Except for long intercepting lines and extremely severe groundwater conditions, 150 mm (6 in.) diameter drains should be satisfactory for most subsurface drainage installations. The minimum size pipe recommended for all collector drains is a 150 mm (6 in.) diameter pipe. The recommended minimum slope for subdrains is 0.15 percent.

Table 6-7. Coefficient of Roughness for Different Types of Pipe

Type of Pipe	Coefficient of Roughness, n
Clay, concrete, smooth-wall plastic, and Asbestos-cement	0.013
Bituminous-coated, non-coated corrugated metal pipe or corrugated metal pipe	0.024

6-6.3 **Trench Construction**

6-6.3.1 **Design.** The trench for the collector drains should be constructed of sufficient width to provide 150 mm (6 in.) clearance on each side of the pipe. The depth of the trench must be sufficient to provide a minimum 300 mm (12 in.) from the top of the pavement subgrade to the center of the pipe plus 80 mm (3 in.) clearance beneath the pipe. The minimum cover requirements for pipe is dependent upon loading and frost requirements. Cover requirements for different design wheel loads are indicated in Appendix D. In frost areas the center of the pipe should be placed below the depth of frost penetration. In areas where the depth of frost penetration is greater than 1.2 m (4 ft) below the bottom of the drainage layer, the pipe need not be located deeper than 1.2 m (4 ft) from the bottom of the drainage layer. Also in frost areas and when differential heave will cause pavement problems, the sides of the trench shall be sloped not steeper than 1 vertical on 10 horizontal for the depth of frost penetration. The sloping of the trench sides is not required for the parts of the trench in nonfrost susceptible materials nor for F1 or S1 soils unless the pavement over the trench is subjected to high speed traffic.

6-6.3.2 **Backfill.** The trench should be backfilled with a permeable material to rapidly convey water to the drainage pipe. The backfill material may be either a OGM, RDM, or other uniform graded aggregate. A minimum of 80 mm (3 in.) of aggregate should be placed beneath the drainage pipe. Proper compaction or chemical stabilization of the backfill is necessary to prevent settlement of the fill. In placing the backfill, the backfill should be compacted in lifts not exceeding 300 mm (12 in.). When geocomposites are used in place of pipe, the geocomposites are placed against the material to be drained and thus the backfill is not expected to convey water. For this reason the backfill for the geocomposites will not require the high permeability required for the backfill around the pipe drains. However, since the backfill for the geocomposites will be against the side of the trench, the backfill should meet the requirements of a granular filter.

6-6.3.3 **Geotextiles in the trench.** The trench should be provided with a geotextile filter fabric as shown in Figures 6-9 through 6-12 for the typical details. The filter fabric should be placed to separate the permeable backfill of the trench from the subgrade or subbase materials. The filter fabric must not be placed so as to impede the flow of water from the drainage layer to the drain pipe. The filter fabric must also protect from the infiltration of fines from any surface layers. This is particularly important for drains placed outside the pavement area where surface water can enter the drain through a soil surface. The filter fabric for the trench shall be a nonwoven needle punched fabric meeting the criteria given in Table 6-8.

Table 6-8. Criteria for Fabrics Used in Trench Construction

	ASTM Test Method	Criteria
Soil With 50 Percent or Less Passing No. 200 Sieve	D 4751	AOS < 0.6 mm (Sieve No. 30)
Soil With Greater Than 50 Percent Passing No. 200 Sieve	D 4751	AOS < 0.297 mm (Sieve No. 50)
Minimum Grab Strength in kN (lb) at 50% Elongation	D 4632	0.6 (130)
Minimum Puncture Strength in kN (lb)	D 4833	0.25 (55)

6-6.3.4 **Trench cap.** Edge drains placed outside of a paved area should be capped with a layer of low permeability material to reduce the infiltration of surface water into subsurface drainage system.

6-6.4 **Lateral Outlet Pipe**

6-6.4.1 **Design.** The lateral outlet pipe provides both a means of getting water out of the edge drains, and for cleaning and inspecting the system. Edge drains should be provided with lateral outlet pipes spaced at intervals (90 to 150 m) (300 to 500 ft) along the edge drains and at the low point of all vertical curves. To facilitate drain cleanout, the outlet pipes should be placed at about a 45 degree angle from the direction of flow in the collector drain. The lateral pipe should be a metal or rigid solid-walled pipe and should be equipped with an outlet structure. A 3 percent slope from the edge drain to the outlet structure is recommended. To reduce outlet maintenance, outlet pipes should, where possible, be connected to existing storm drains or inlets. For lateral pipe flowing to a ditch, the invert of the outlet pipe should be a minimum of 150 mm (6 in.) above the 2-yr design flow in the ditch. To prevent piping, the trench for the outlet pipes must be backfilled with a material of low permeability, or provided with a cutoff wall or diaphragm. Dual outlets are recommended for maintenance considerations, as shown in Figure 6-13. The dual outlet system allows sections of collector drains to be flushed out to clear any debris material blocking the free flow of water. Other recommended design details for drainage outlets are as follows:

6-6.4.1.1 Provide dual outlet with large radius bend, as shown in Figure 6-14.

6-6.4.1.2 Use rigid walls, not perforated pipes. For pipe drains use the same diameter pipe as the collector drains. For prefabricated geocomposite drains, 102-mm to 152-mm (4-in. to 6-in.) diameter pipe should provide adequate hydraulic capacity. The flow capacity of the outlets must be greater than that of the collector drains. In general, because of the greater slope provided for outlet pipes, the hydraulic capacity is not a problem.

6-6.4.1.3 The discharge end of the outlet pipe should be placed at least 152 mm (6 in.) above the 10-yr design flow in the drainage ditch (Figure 6-15). The same requirement applies even if the outlet is discharging into storm drain inlets.

6-6.4.2 **Outfall for outlet pipe.** The outfall for the outlet pipe should be provided with a headwall to protect the outlet pipe from damage, prevent slope erosion, and facilitate the location of outlet pipes. Headwalls should be placed flush with the slope so that mowing operations are not impaired. Easily removed rodent screens should be installed at the pipe outlet. The headwall may be precast or cast-in-place. An example for a design for a headwall is given in Figure 6-16.

6-6.4.3 **Reference markers.** Although not a requirement, reference markers are recommended for the outlets to facilitate maintenance and/or observation. A simple flexible marker post or marking on the shoulder will suffice to mark the outlet.

Figure 6-13. Schematic of Dual Outlet System Layout (Baumgardner 1998)

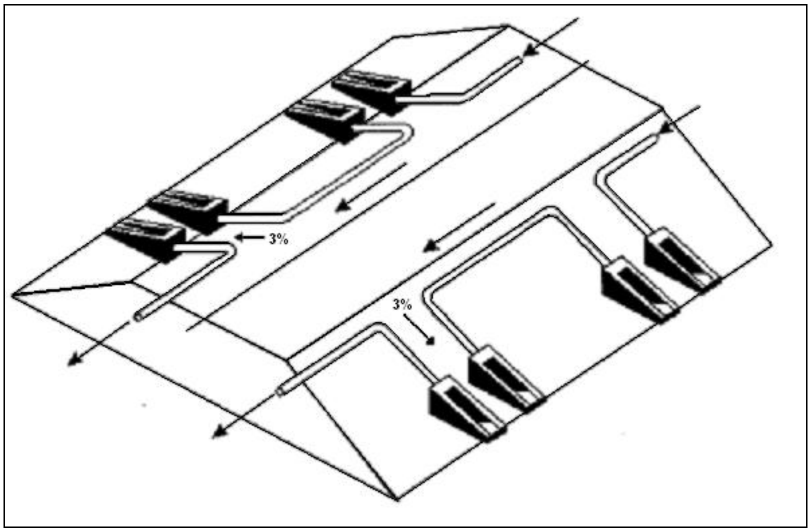


Figure 6-14. Illustration of Large-Radius Bends Recommended for Drainage Outlet

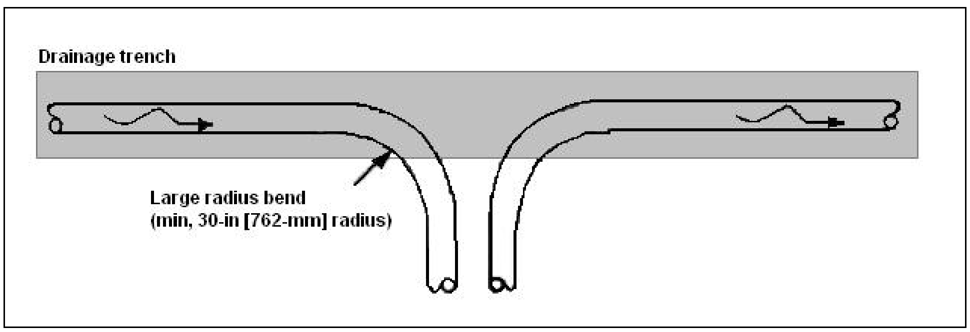


Figure 6-15. Recommended Outlet Design Detail

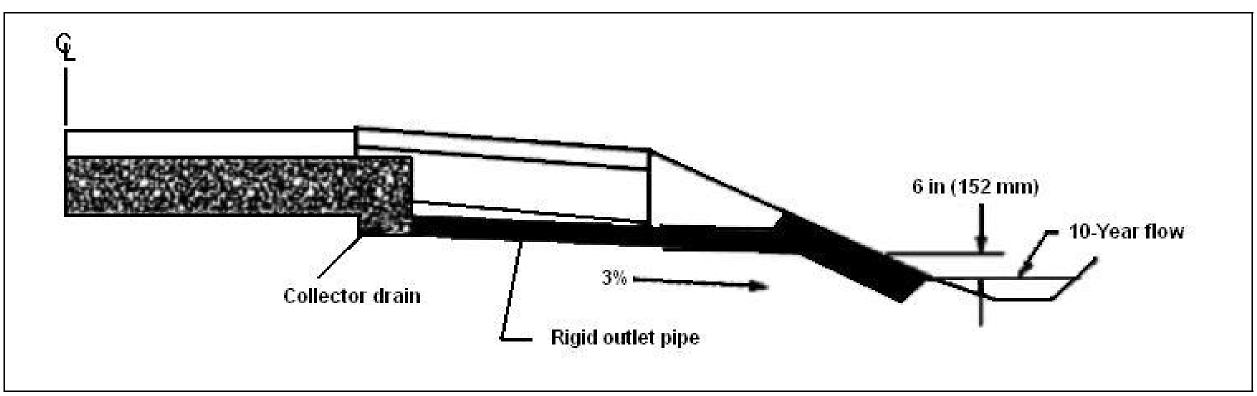
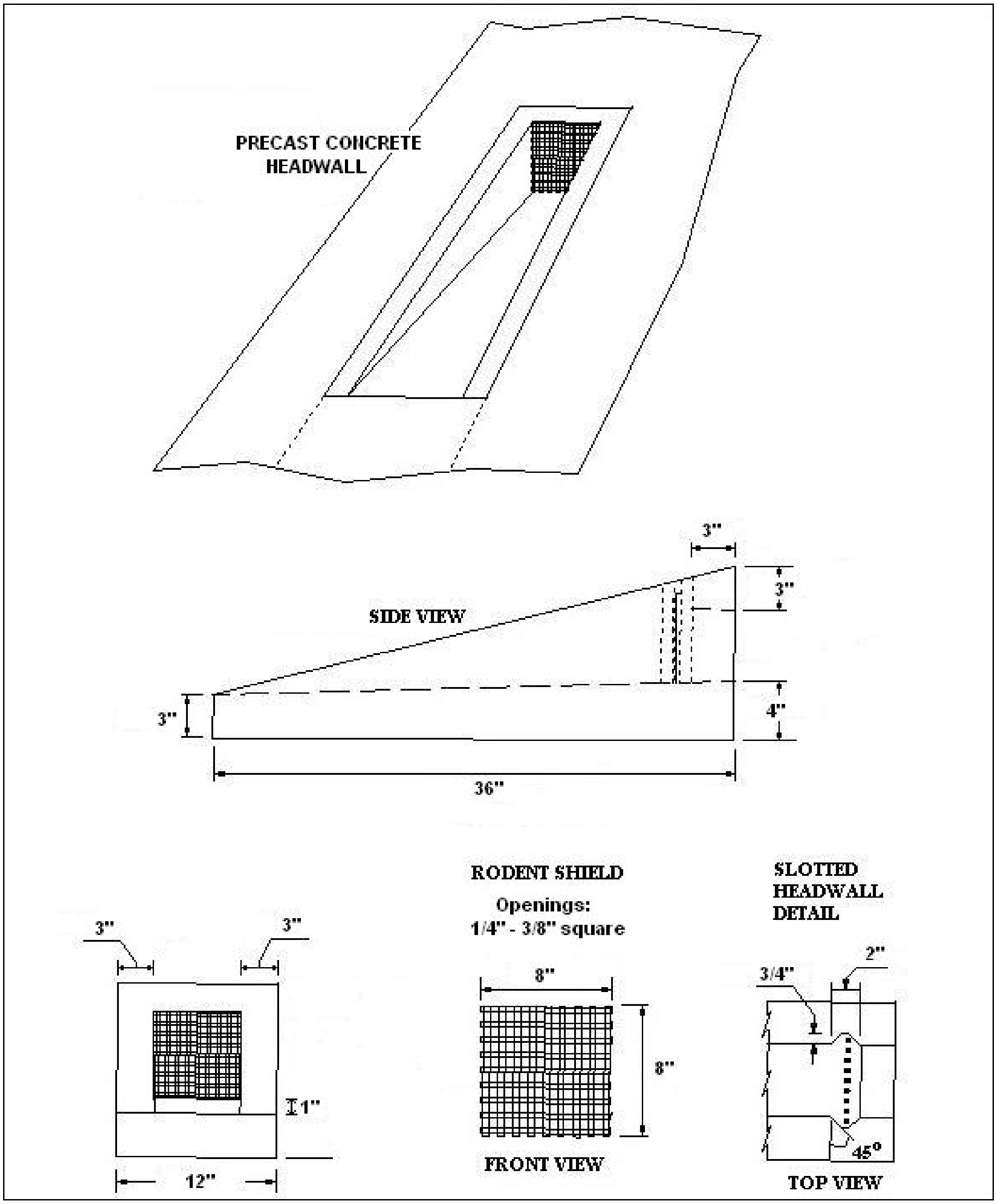


Figure 6-16. Example Design for a Headwall



6-6.5 **Cross Drains.** Cross drains may be required at locations where flow in the drainage layer is blocked, for steep longitudinal grades, or at the bottom of vertical curves. For example, cross drains may be required where pavements abut building foundations, at bridge approach slabs, or where drainage layers abut impermeable bases.

6-6.6 **Manholes and Observation.** Manholes, observation basins, and risers are installed on subsurface drainage systems for access to the system to observe its operation and to flush or rod the pipe for cleaning. When required, manholes on subgrade pipe drains should be located at intervals of not over 300 meters (1,000 feet) with one flushing riser located between manholes and at dead ends. Manholes should be provided at principal junction points of several drains. Typical details of construction are given in Chapter 4.

6-7 MAINTENANCE OF SUBSURFACE DRAINAGE SYSTEMS

6-7.1 **Monitoring Program**. Commitment to maintenance is as important as providing subsurface drainage systems. In fact, an improperly maintained drainage system can cause more damage to the pavement structure than if no drainage were provided at all. Poor maintenance leads to clogged or silted outlets and edgedrain pipes, missing rodent screens, excessive growth of vegetation blocking outlet pipes and openings on daylighted bases, and growth of vegetation in side ditches. These problems can potentially cause backing up of water within the pavement system, thereby defeating the purpose of providing the drainage system. Therefore, inspections and maintenance of subsurface drainage systems should be made an integral part of the policy of any agency installing these systems. The inspection process comprises of two parts: (a) visual inspection and (b) video inspection.

6-7.1.1 **Visual inspection**. The visual inspection process includes the following items:

6-7.1.1.1 Evaluation of external drainage-related features, including measurement of ditch depths and checking for crushed outlets, excessive vegetative growth, clogged and debris-filled daylighted openings, condition of headwalls, presence of erosion, and missing rodent screens. This operation should be performed at least once a year.

6-7.1.1.2 Pavement condition evaluation to check for moisture-related pavement distresses such as pumping, faulting, and D-cracking in PCC pavements and fatigue cracking and AC stripping in AC pavements. This operation could be either a full-scale PCI survey or a brief overview survey, depending on agency needs. The recommended frequency for this activity is once every 2 years.

6-7.1.2 **Video inspection**. Video inspections play a vital role in monitoring in-service drainage systems. The video inspection process can be used to check for clogged drains due to silting and intrusion of surrounding soil, as well as any problems with the drainage system, such as ruptured pipes and broken connections. Video inspections should be carried out on an as-needed basis whenever there is evidence of drainage-related problems. A detailed list of equipment used in an FHWA Study (Daleiden 1998) is given in Table 6-9. A video inspection system typically consists of a camera head, long flexible probe mounted on a frame for inserting the camera head into the pipe, and a data acquisition unit fitted with a video screen and a video recorder. This system can be used to detect and correct any construction problems before a project is accepted. The construction-related problems that are easily detected using the video equipment include crushed or ruptured drainage pipes and improper connections between drainage pipes, as well as the connection between the outlet pipe and headwall.

Table 6-9. Equipment Description or FHWA Video Inspection Study (Daleiden 1998)

Camera: The camera is a Pearpoint flexiprobe high-resolution, high-sensitivity, waterproof color video camera engineered to inspect pipes 76 to 152 mm (3 to 6 in.) in diameter. The flexiprobe lighthead and camera has a physical size of 71 mm (2.8 in.) and is capable of negotiating 102 mm × 102 mm (4 in. × 4 in.) plastic tees. The lighthead incorporates six high-intensity lights. This lighting provides the ability to obtain a “true” color picture of the entire surface periphery of a pipe. The camera includes a detachable hard plastic ball that centers the camera during pipe inspections.
Camera Control Unit The portable color control unit includes a built-in 203-mm (8-in.) color monitor and controls including remote iris, focus, video input/output, audio in with built-in speaker, and light level intensity control. Two VCR input/output jacks are provided for video recording as well as tape playback verification through the built-in monitor.
Metal Coiler and Push Rod With Counter: The portable coiler contains 150 m (6 in.) of integrated semi-rigid push rod, gold and rhodium slip rings, electro-mechanical cable counter, and electrical cable. The integrated push rod/electrical cable consists of a special epoxy glass reinforced rod with polypropylene sheathing material, which will allow for lengthy inspections due to the semi-rigid nature of this system.
Video Cassette Recorder: The video cassette recorder is a high-quality four-head industrial grade VHS recorder with audio dubbing, still frame, and slow speed capabilities.
Generator: A compact portable generator capable of providing 650 watts at 115 V to power the inspection equipment.
Molded Transportation Case: A molded transportation case, specifically built for air transportation, encases the control unit, camera, and videocassette recorder.
Color Video Printer: A video printer is incorporated into the system to allow the technician to obtain color prints of pipe anomalies or areas of interest.

6-7.2 Maintenance Guidelines

6-7.2.1 **Collector drains and outlets**. The collector drains and outlets should be flushed periodically with high-pressure water jets to loosen and remove any sediment that has built up within the system. The key to this operation is having the appropriate outlet details that facilitate the process, such as the dual headwall system shown in Figure 6-13. The area around the outlet pipes should be kept mowed to prevent any buildup of water. Missing rodent screens and outlet markers, damaged pipes and headwalls need to be either repaired or replaced.

6-7.2.2 **Daylighted systems**. Routine removal of roadside debris and vegetation clogging the daylighted openings of a permeable or dense-graded base is very important for maintaining the functionality of these systems.

6-7.2.3 **Drainage ditches**. The drainage ditches should be kept mowed to prevent excessive vegetative growth. Debris and silt deposited at the bottom of the ditch should be cleaned periodically to maintain the ditch line and to prevent water from backing up into the pavement system.