An Introduction to the Principles of Pavement Drainage

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<u>CONTENTS</u>

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1. INTRODUCTION

1.1 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.

1.2 SOURCES OF WATER

1.2.1 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.

1.2.2 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.

1.2.3 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.

1.3 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 1-1 and 1-2 illustrate examples of infiltration and groundwater control systems.

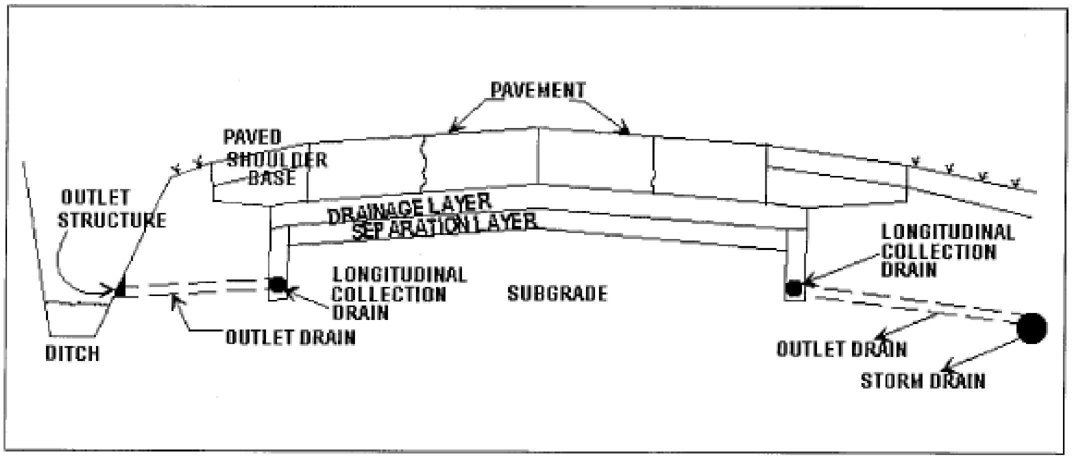

Figure 1-1

Collector Drain Used to Remove Infiltration Water

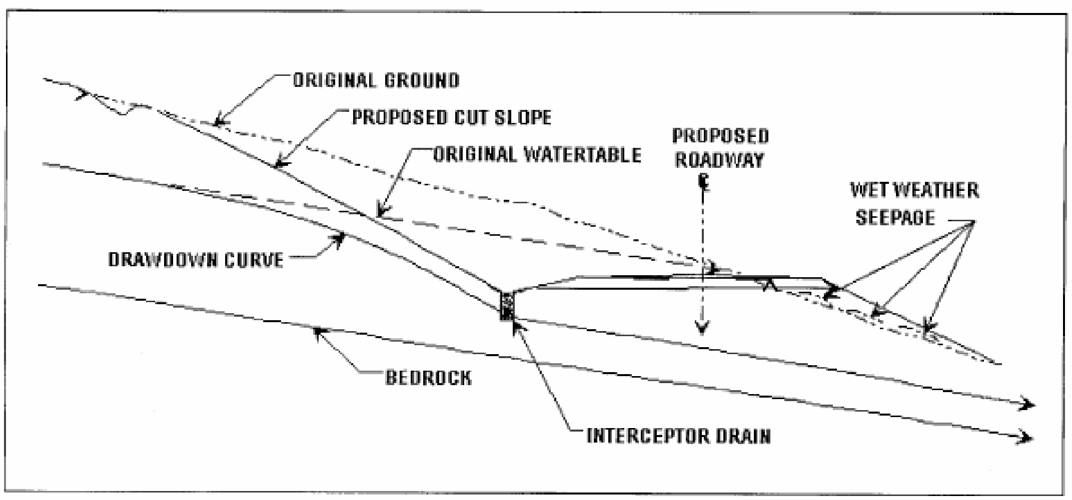

Figure 1-2

Collector Drain Used to Intercept Seepage and

Lower the Groundwater Table

2. 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:

$$v = ki \qquad \text{(Eq. 2-1)}$$

where k is the coefficient of proportionality known as the coefficient of permeability. Equation 2-1 can be expanded to obtain the rate of flow through an area of soil (A). The equation for the rate of flow (Q) is:

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

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.

2.1 FACTORS AFFECTING PERMEABILITY

2.1.1 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 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:

$$k = D_s^2 \frac{\gamma}{\mu} \frac{e^3}{(1-e)} C$$

(Eq. 2-3)

2.1.2 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 discussion, water is assumed to be the pore fluid. Equation 2-3 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.

2.1.3 EFFECT OF GRAIN SIZE. Equation 2-3 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 2-1 provides estimates of the permeability for these materials for various amounts of material finer than the 0.075 mm (No. 200) sieve.

Coefficient of 55

Percent by Weight Passing 0.075 mm (No. 200) Sieve	Permeability for Remolded Samples millimeters/second	feet/minute
3	5 x 10-1	10-1
5	5 x 10-2	10-2
10	5 x 10-3	10-3
15	5 x 10-4	10-4
20	5 x 10-5	10-5

Table 2-1

Coefficient of Permeability for Sand and Gravel Materials.

Coefficient of 55

2.1.4 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. The amount of water that can be 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 (ne) 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:

$$n_e = 1 - \frac{\gamma_d}{G_s \gamma_w}(1 + G_s W_e) \qquad \text{(Eq. 2-4)}$$

where

γd = dry density of the soil

Gs = specific gravity of solids

γw = unit weight of water

We = 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.

2.1.5 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 direction 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:

$$k = (k_1 d_1 + k_2 d_2 + k_3 d_3 + ...)/(d_1 + d_2 + d_3 + ...) \qquad \text{(Eq. 2-5)}$$

where,

k = the effective horizontal permeability

k1,k2,k3, ... = the coefficients of horizontal permeability of individual layers

d1,d2,d3, ... = 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.

3. QUANTITY AND RATE OF SUBSURFACE FLOW

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.

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.

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.

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 (qs) in terms of depth of water per unit area is computed by:

gs = (ne)(h) (Eq. 2-6)

ne = effective porosity

h = the thickness of the drainage layer

In the equation the dimensions of the qs 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 hours; 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 2-6 is modified to be:

gs = 0.85 (ne)(h) (Eq. 2-7)

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

qd = (t) (k) (i) (h) (Eq. 2-8)

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

$$q_d = (t)\,(k)\,(i)\,(h)\ /\ 2$$

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 qs, qd, t, k, and h should be consistent. The total capacity (q) of the drainage layer will be the sum of qs and qd resulting in the following equation for the capacity.

$q = 0.85(ne)\ (h)\ +\ (t)\ (k)\ (i)\ (h) / 2$ g (Eq .2-9)

Knowing the water entering the pavement, Equation 2-9 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 2-7 can be used in estimating the thickness required for the drainage layer.

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:

$$T_{50} = (ne\ D)/2\,kHo \qquad \text{(Eq. 2-10)}$$

where,

T_{50} = time for 50 percent drainage
ne = effective porosity of the soil
k = coefficient of permeability
D and H = base-and subbase geometry dimensions (illustrated in Figure 2-2)

The dimensions of time, k, Ho and D must be consistent. In Figure 2-2 the slope (i) of the drainage path is D/Ho; therefore, Equation 2-10 can be written:

$$T_{50} = (ne)\ (D)/2ik \qquad \text{(Eq. 2-11)}$$

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 hours. The time for 85 percent drainage is approximately twice the time for 50% drainage. The time for 85 percent drainage (T_{85}) is computed by:

$$T_{85} = (ne)(D)/ik \qquad \text{(Eq. 2-12)}$$

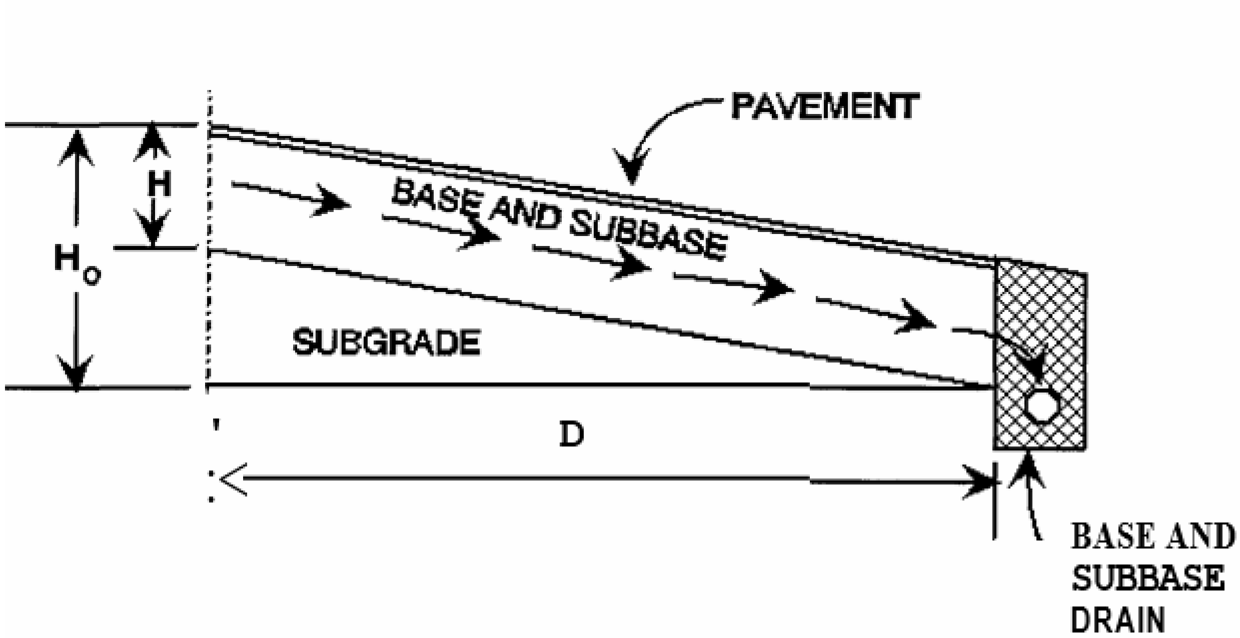

Figure 2-2

Pavement Geometry for Computation of Time for Drainage

3.6 LENGTH AND SLOPE OF THE DRAINAGE PATH. As can be seen in Equation 2-10, 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.

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.

4. USE OF DRAINAGE LAYERS

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.

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.

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 tradeoff 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 meters/day (1,000 feet/day) will provide sufficient drainage.

5. USE OF FILTERS

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 occurs is where water is 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.

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:

15 percent size of drainage or filter material
85 percent size of material to be drained

and

50 percent size of drainage or filter material
50 percent size of material to be drained

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 millimeters and the 50 percent criteria will be disregarded.

5.3 PERMEABILITY REQUIREMENTS. To assure that the filter material is sufficiently permeable to permit passage of water without hydrostatic pressure buildup, the following requirements should be met:

15 percent size of filter material
15 percent size of material to be drained

6 USE OF SEPARATION LAYERS

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 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.

7. USE OF GEOTEXTILES

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.

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 millimeters. 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.

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 .212 millimeters and also equal to or greater than .125 millimeters.

7.3.1 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.

7.3.2 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 drainage system.

7.3.3 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.

7.3.3.1 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. 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 3-1.

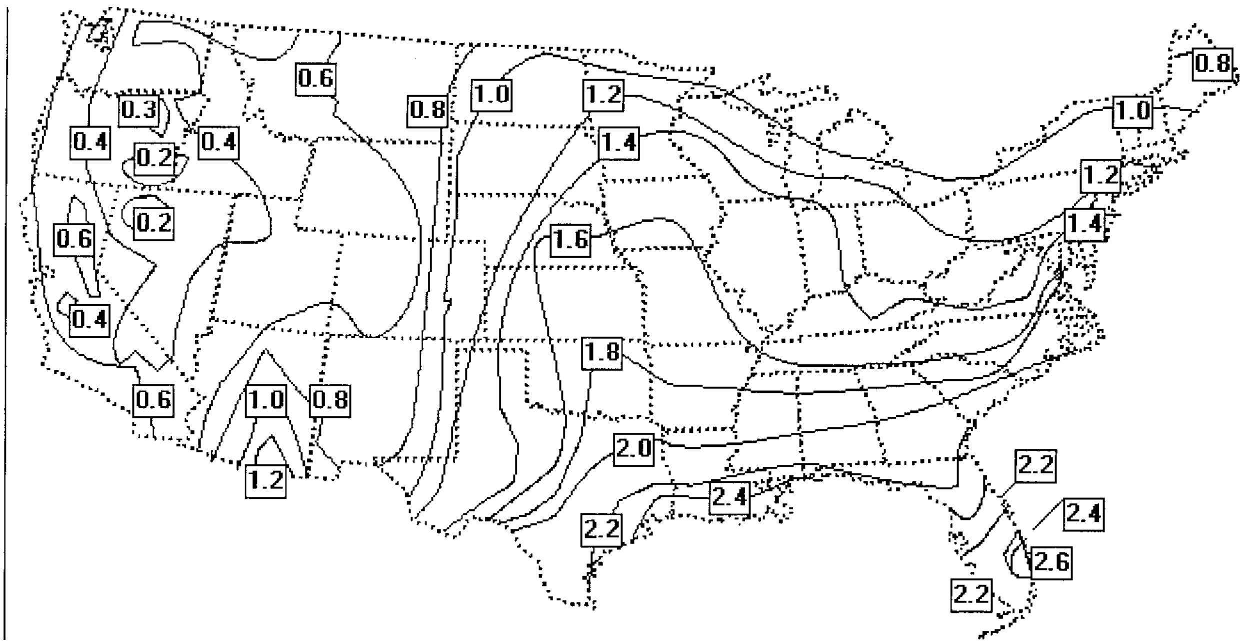

Figure 3-1

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

7.3.3.2 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.

7.3.3.3 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.

7.3.3.4 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 3-1. 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.

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

Table 3-1

Frost susceptible soils

7.3.3.5 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 Table 2-1. Although the value of permeability determined from Table 2-1 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 literature. 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.