INCH-POUND

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DEPARTMENT OF DEFENSE
HANDBOOK

AIRFIELD PAVEMENT DESIGN FOR FROST CONDITIONS AND SUBSURFACE DRAINAGE

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ABSTRACT

Design criteria for use by qualified engineers are presented for the subsurface drainage and frost aspects of airfield pavements. The contents include the procedures and requirements for investigations of subsoils for both frost protection and subsurface drainage along with specific design criteria requirements for each.

FOREWORD

This handbook on airfield pavement design for frost conditions and subsurface drainage was developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command (NAVFACENGCOM), other Government agencies, and the private sector. It uses, to the maximum extent feasible, national professional society, association, and institute standards in accordance with NAVFACENGCOM policy. Do not deviate from these criteria without prior approval of NAVFACENGCOM Criteria Office.

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AIRFIELD PAVEMENT DESIGN FOR FROST CONDITIONS AND SUBSURFACE DRAINAGE

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Section 1: INTRODUCTION

1.1 **Scope**. This handbook presents criteria for the design of subsurface drainage systems and frost protection for airfield pavements. Included in this handbook are criteria for subsurface exploration as it relates to frost and drainage, frost protection, design alternatives for subsurface drainage, and suggested details for subsurface drainage design.

1.2 **Cancellation**. This handbook, MIL-HDBK-1021/6, dated 15 April 2000, cancels and supersedes NAVFAC design manual (DM)-21.06, dated April 1986.

1.3 **Related Criteria**

Subject	**Source**
Pavements	NAVFAC DM-5.04
Soil Mechanics	NAVFAC DM-7.01
Foundations and Earth Structures	NAVFAC DM-7.02
Pavement Design for Airfields	NAVFAC DM-21.10
Airfield Pavement Design	MIL-HDBK-1021 (Series)
Airfield and Heliport Planning and Design	NAVFAC P-971

1.4 **Definitions**. Refer to the *Glossary* for definitions of the key terms used in this handbook.

1.4.1 **Frost**. Within the context of this handbook, frost is the condition of free water freezing within the pavement structure or in the subgrade. The action of frost includes expansion or heaving, as well as the loss of support during the melt period. The frost action may result in the formation of ice crystals in any frost-susceptible material within or below the pavement structure to which freezing temperatures penetrate.

1.4.2 **Subsurface Drainage**. Subsurface drainage refers to the collection and removal of water from a pavement structure or subgrade. Subsurface drainage systems are categorized into two functional categories: one for draining surface infiltration water and the other for controlling groundwater.

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

1.5 **Sources of Water**. Free water in a pavement structure and subgrade can come from many different sources, as illustrated in Figure 1. Water may seep upward from the groundwater table through capillary suction or vapor movements, or it may flow in laterally from high grounds and shoulder ditches. Surface infiltration through joints and cracks is another major source of water, especially in older deteriorated pavements. On rigid pavements, 25 to 67 percent of rainfall may infiltrate the pavement structure through joints and cracks, depending on pavement condition. On flexible pavements, water can infiltrate through surface cracks, longitudinal cold joints that crack, and pavement edges. Depending on pavement condition, 25 to 50 percent of rainfall can enter flexible pavements through surface infiltration. Pavement subsurface drainage systems are designed primarily to handle surface infiltration water, but in cut areas or areas with high groundwater, drainage of groundwater can also be an important design consideration.

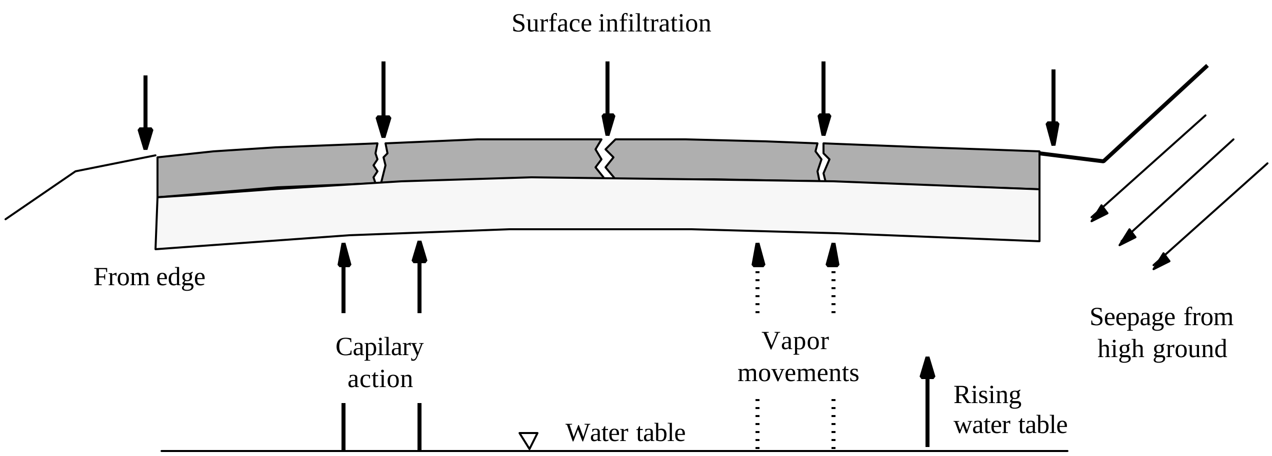
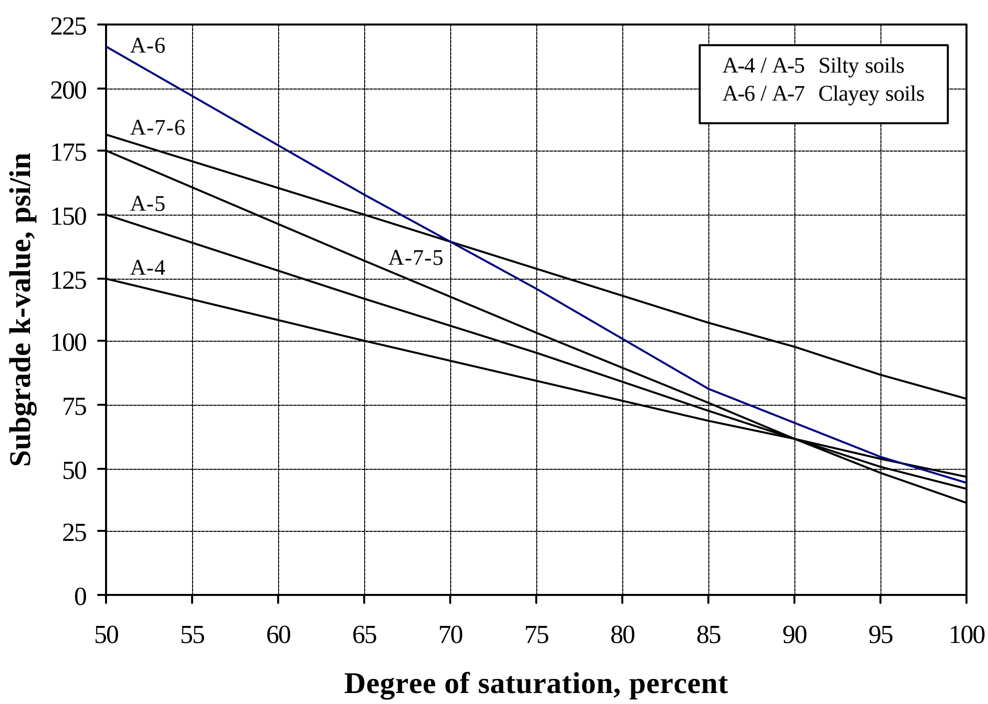


Figure 1
Source of Water in Pavement Structures

1.6 **Effects of Subsurface Water**. Many pavement distresses are either caused by water or greatly aggravated in the presence of excess free water. For flexible pavements, softening of the base, subbase, or subgrade upon saturation is one of the main causes of pavement failures. The stiffness of silty and clayey soils can drop by a factor of two or more upon saturation (see Figure 2). Such a drop in subgrade stiffness is accompanied by a corresponding increase in pavement deflection. The increased pavement deflections lead to accelerated deterioration of cracks and other distresses. The deflection and performance of rigid pavements are similarly affected by the subgrade softening. For rigid pavements, pumping and loss of support under joints and cracks can also be a significant problem. Under saturated conditions, moving wheel loads can cause movement of free water under very high pressure within the pavement layers. This movement of water can cause erosion of the base and subgrade materials, as well as deterioration of the interface between pavement layers. The increased deflections and the presence of excess free water during saturated conditions can also cause pumping of the subgrade fines into the base layers, resulting in significant loss of stability. In frost areas, excess free water can aid frost activity if susceptible material is present, aggravating the frost-heave problem. Poor subsurface drainage can also aggravate material problems such as D-cracking and reactive aggregate problems in rigid pavements and stripping in flexible pavements.

1.7 **Effects of Frost Action**. Frost action can cause differential heaving, cracking, surface roughness, blocked drainage, and a reduction in bearing capacity during thaw periods. The extent of these problems ranges from slight to severe, depending on the type and uniformity of the subgrade soil and availability of water. The most effective method of addressing the effects of frost action is taking measures to avoid this problem. This is typically accomplished by either removing and replacing all frost-susceptible material within frost penetration depth, or providing sufficient cover over the susceptible material with non-frost susceptible material.



1 psi/in = 0.271 MPa/m

Figure 2
Effects of Moisture Level on Stiffness of Silty and Clayey Soils (Hall et al. 1996)

1.7.1 **Frost Heaving**. Upon freezing, the volume of water expands by about 9 percent; however, this volume expansion alone is not sufficient to account for the heaving of several inches or more that occurs in some pavements. Frost heaving results from the growth of ice lenses in susceptible subgrade or unbound materials in the pavement structure. Uniform heave is generally not troublesome, but nonuniform heave can result in serious surface irregularities in flexible pavements and cracking in rigid pavements. Differential heave is usually the result of variations in subgrade soils, soil moisture, and transitions from cut to fill with high groundwater level.

1.7.2 **Formation of Ice Lenses**. Ice lenses form in soils that are highly susceptible to capillary action. As the soil is slowly cooled, the water in the voids begins to freeze to form ice crystals. If the soil is susceptible to capillary action, water is drawn to these ice crystals, which grow to form ice lenses. The ice lenses continue to grow as long as the freezing conditions remain and the supply of water is present. To have serious formation of ice lenses, three conditions must exist:

a) Presence of frost-susceptible materials.

b) Penetration of freezing temperatures into the susceptible material.

c) Available supply of water.

The potential for significant frost heaving is the greatest when the groundwater table is relatively close to the surface and just below the freezing zone. Surface infiltration and lateral flow are other potential sources of water; however, when freezing starts and a layer of ice develops, the water supply from above will be cut off by the ice layer itself.

1.7.3 **Thawing and Reduction in Bearing Capacity**. During thawing periods, the upper ice lenses melt, releasing water into the base course (see Figure 3). If the pavement structure is inadequately drained, or if the drains are blocked with ice, the base course becomes saturated and weakened. Traffic during this period causes large pavement deflections and the development of high pore pressures. The resulting problems are the same as those associated with excess free water in the pavement structure discussed under par. 1.6.

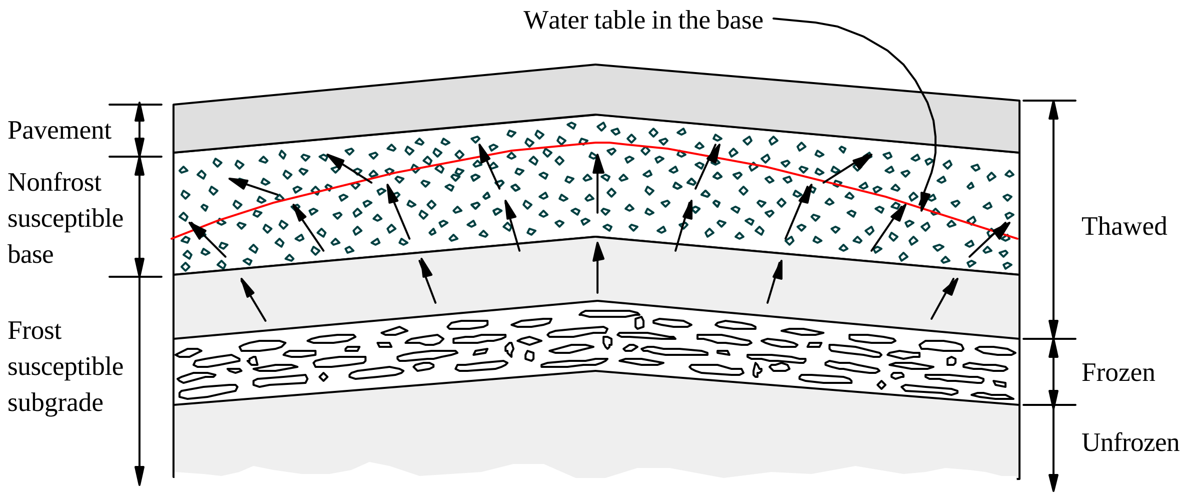


Figure 3
Upward Movement of Moisture into Base Course During Thaw Period

1.8 **Benefits of Subsurface Drainage**. If properly designed, installed, and maintained, subsurface drainage systems can be highly effective in providing longer pavement service life. Moisture-related problems such as pumping, frost heaving, and material problems can drastically reduce the service life of pavements. The effects of poor drainage are particularly detrimental on pavements that have developed distresses. Cracks and deteriorated joints provide entry points for water into the pavement structure, and loads placed over cracks cause substantially higher deflections. The combination of the excess free water and increased pavement deflections leads to accelerated deterioration of cracks under wet conditions. A properly functioning drainage system can prevent or greatly reduce exposure to adverse moisture conditions, thereby improving pavement performance. Good subsurface drainage is important for both flexible and rigid pavements.

Section 2: PRELIMINARY DESIGN DATA

2.1 **General**. The need for subsurface drainage and frost protection must be identified during the design stage to enable incorporation of appropriate features into the pavement design. Verification of design assumptions is important to obtain reliable designs. If during construction any of the site conditions were found different than those assumed in the design, the design may have to be modified. Various site-related factors affect the need for frost protection and the need for subsurface drainage. In this section, investigation of those site factors is discussed.

2.2 **Investigation for Frost Design**. The key factors that determine the need for frost protection include type and gradation of subgrade, climate, and depth of groundwater table. Frost heaving will occur only if the following three conditions exist:

a) Presence of frost-susceptible material.

b) Penetration of freezing temperatures into the susceptible material.

c) Available supply of water.

The investigation for frost design involves evaluating site conditions for the determination of the presence of these conditions.

2.2.1 **Subsoil Investigations**. Frost action is detrimental if it results in differential heaving, which is caused by variations in subsurface conditions. Variability of subsurface conditions, therefore, is an important consideration for frost design. Subsoil investigation should include assessment of horizontal and vertical variations in subgrade soil type, natural moisture content, and water table elevations. In some situations, variable pavement sections may be needed for different parts of the project to accommodate the differences in subsurface conditions along the project. These conditions must be identified during the subsoil investigation. Consider removing isolated pockets or sections of frost-susceptible soil to eliminate abrupt changes in subgrade conditions.

2.2.2 **Classification of Soils for Frost Susceptibility**. Frost susceptibility of a soil is the potential for the formation of ice lenses in the soil under freezing conditions. Because the water needed for formation and growth of ice lenses is supplied through capillary action, severe frost heave occurs in soils with a high capillary rate. As the freezing temperatures penetrate deeper into the ground, a heavy formation of ice lenses takes place at each successive level, resulting in severe frost heave. All inorganic soils that contain more than 3 percent by weight of particles finer than 0.02 mm in diameter are generally frost-susceptible. Some uniform sandy soils that contain as much as 10 percent finer than 0.02 mm may remain non-susceptible. These sands are usually interbedded with other soils and, in general, cannot be considered separately. Frost-susceptible soils have been classified into four groups (F1, F2, F3, and F4) according to the degree of susceptibility, as shown in Table 1. The following are additional comments on the frost susceptibility of various types of soils:

2.2.2.1 **Sands and Gravels**. Little or no frost action is likely to occur under normal freezing conditions in sands, gravels, crushed rock, cinders, and similar granular materials when they are clean and free draining. The large voids permit water to freeze in place without segregation into ice lenses.

2.2.2.2 **Silts**. Typical silts, such as rock flour, are highly frost-susceptible because of the combination of relatively small voids, high capillary, and relatively good permeability of these soils.

2.2.2.3 **Clays**. Clays are usually cohesive and have high potential capillary, but their capillary rate is low. Frost heaving may occur in clays, but not as severely as in silts because of the impervious nature of the clays, which makes passage of water slow. Although significant heaving does not occur in clays, clayey soils are not necessarily free of the adverse effects of frost action. Moisture introduced into the soil during thaw periods because of melting ice can cause a drastic reduction in stiffness of clayey soils. Thawing usually takes place from the top-down, leaving very high moisture content in the upper strata. Upon saturation, the stiffness of clayey soils can drop by a factor of two or more, compared to that under dry conditions.

2.2.2.4 **Varved Clays**. Varved clays consist of alternating layers of medium gray inorganic silt and darker silty clay. The thickness of the layers rarely exceeds 0.5 in. (13 mm). Where subgrade conditions are uniform and there is local evidence that the degree of heave is not exceptional, the varved clay may be assigned to Group F3 for frost susceptibility. Nonuniform varved clays are considered to have very high frost susceptibility.

2.2.3 **Temperature Design Values**. For frost considerations, the design freezing index is the basic value for measuring temperature effects. Freezing index is proportional to the magnitude and duration of subfreezing temperatures during the winter season. For airfield pavement design, the design freezing index is the freezing index for the coldest year in a 10-year cycle or the average of the three coldest winters in the latest 30 years on record. Figure 4 shows design freezing index values for the continental United States. Values for locations not shown in Figure 4 should be determined using the following terms and the procedure illustrated in Figure 5.

2.2.3.1 **Average Daily Temperature**. The average of the maximum and minimum temperatures for one day, or the average of several temperature readings taken at equal time intervals (typically on an hourly basis) during one day.

2.2.3.2 **Mean Daily Temperature**. The average of the average daily temperatures for a given day for several years.

2.2.3.3 **Degree-Days**. The degree-days for any one day is the difference between the average daily air temperature and 32 degrees F (0 degrees C). The degree days are negative when the average daily temperature is below 32 degrees F (freezing degree-days) and positive when it is above 32 degrees F (thawing degree-days). Figure 5 shows curves obtained by plotting cumulative degree-days against time.

Table 1
Frost Susceptibility Classification of Soils

Frost group	Degree of frost susceptibility	Type of soil	Percent finer than 0.02 mm by weight	Typical Soil Classification*
F1	Negligible to low	Gravelly soils	3 to 10	GW, GP, GW-GM GP-GM
F2	Low to Medium	Gravelly soils	10 to 20	GM, GW-GM GP-GM
		Sands	3 to 15	SW, SP, SM, SW-SM SP-SM
F3	High	Gravelly soils	> 20	GM, GC
		Sands, except very fine silty sands	> 15	SM, SC
		Clays, PI > 12 Varved clays existing with uniform subgrade		CL, CH
F4	Very high	All silts		ML, MH
		Very fine, silty sands	> 15	SM, SC
		Clays, PI < 12		CL, CL-ML
		Nonuniform varved clays and other fine grained, banded sediments		CL, ML, SM, CH

*Unified Soil Classification System

2.2.3.4 **Freezing Index**. The number of degree-days between the highest and lowest points on a cumulative degree-days versus time curve (e.g., Figure 5) for one freezing season. Freezing index is a measure of the combined duration and magnitude of below-freezing temperatures occurring during any given freezing season. The index determined for air temperatures at 4.5 ft (1.35 m) above the ground is commonly designated as the air freezing index, while that determined for temperatures immediately below the surface is know as the surface freezing index.

2.2.3.5 **Design Freezing Index**. The average air freezing index of the three coldest winters in the latest 30 years of record. If 30 years of record are not available, the index for the coldest year in the latest 10-year period may be used. The design freezing index at a site with continuing construction need not be changed more often than once in 5 years unless recent temperature records indicate a significant change in thickness design requirements for frost. Design freezing index is illustrated in Figure 5.

2.2.3.6 **Mean Freezing Index**. The freezing index determined based on mean temperatures. The period over which temperatures are averaged is usually at least 10 years (a period of 30 years is preferred). The latest available data should be used. Mean freezing index is illustrated in Figure 5.

2.2.4 **Local Frost Data**. Local history of frost heaving may be a strong indication that careful evaluation of site conditions for frost activities is needed. Study all locally available records of maximum and differential frost heaving of airfield and highway pavement in the area. Local public utility companies may be a good source of information for depth of soil freezing.

2.2.5 **Water Source for Ice Formation**. A groundwater level within 5 ft (1.5 m) of the proposed subgrade elevation is an indication that sufficient water is available for ice lens formation, if the subgrade is frost-susceptible. Other conditions that warrant special attention include the following:

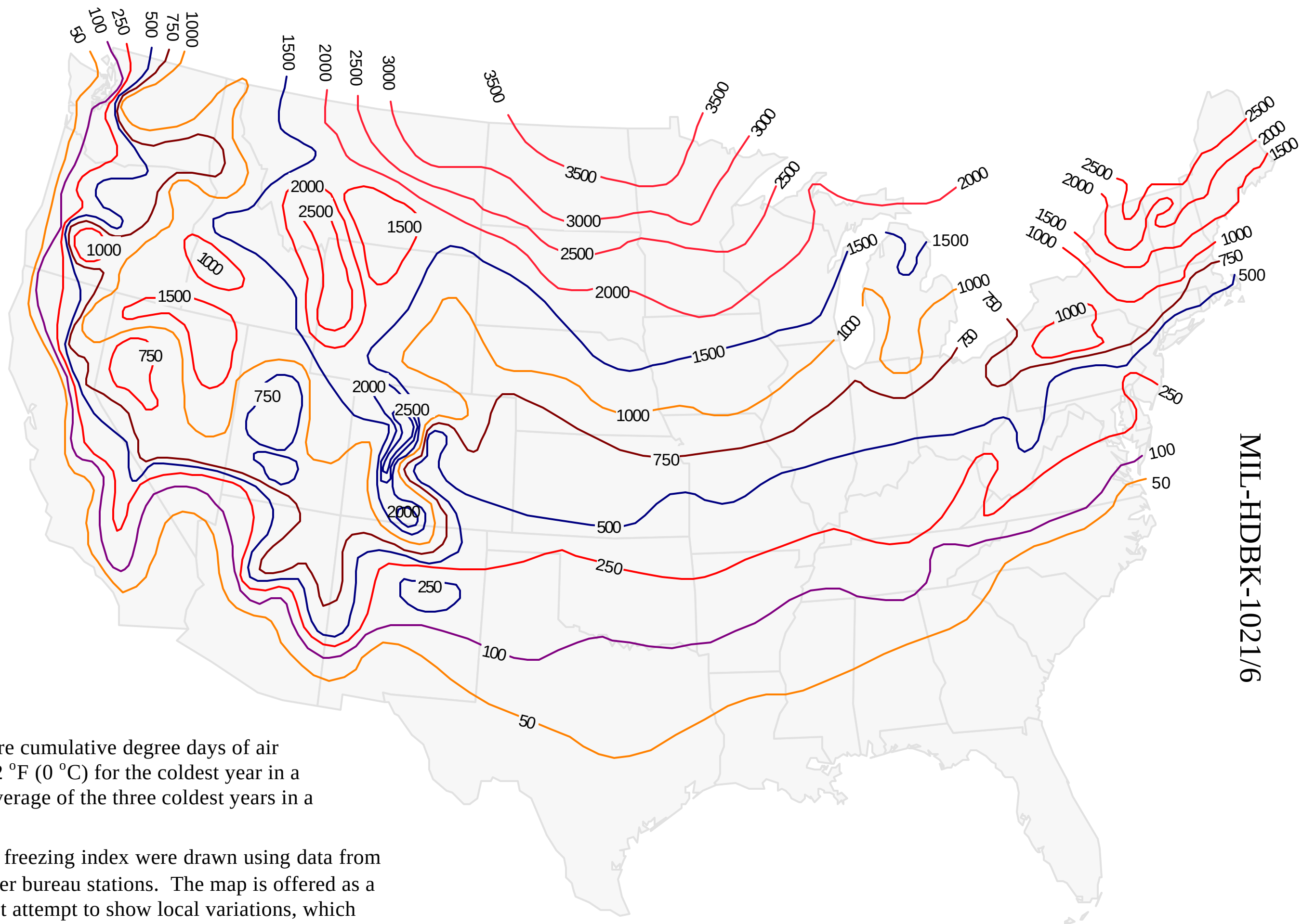
a) Homogeneous clay subgrade soils contain sufficient moisture for ice formation, even with the depth to ground water in excess of 10 ft (3.0 m).

b) Unsealed joints and cracks in pavement surface, poorly drained pavements, and shoulder surfaces are common sources of trapped water.

Identification of all potential sources of water for frost activity is an important aspect of site investigations. The pavement design should incorporate appropriate joint details and grades to minimize surface infiltration water.

2.3 **Investigation for Subsurface Drainage Design**. The analysis and design of subsurface drainage requires information on prevailing subsurface conditions, as well as information on local climatic conditions. Fundamental material properties are an important aid to classifying materials and determining their ability to transmit water. The climatic factors are an important consideration in identifying the need for subsurface drainage. The information needed for subsurface drainage design includes surface geometry, subsurface geometry, and material properties.

2.3.1 **Airfield Surface Geometry**. The subsurface investigations should begin with an examination of the planned profiles and cross-sections. Information on the planned grades relative to original ground level is needed. The topographical map of the area should also be examined to establish the boundaries of the flow domain.

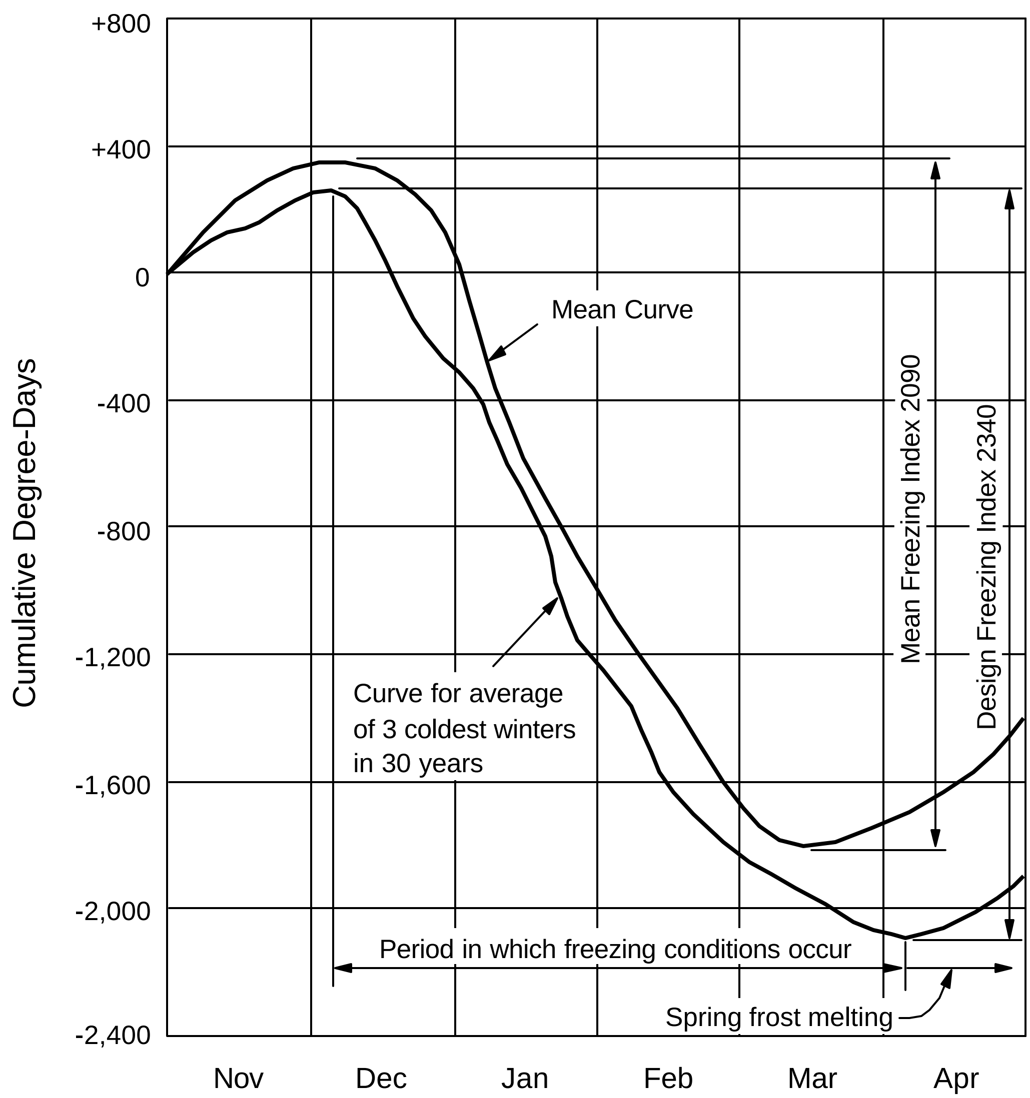


Design index values are cumulative degree days of air temperatures below 32 °F (0 °C) for the coldest year in a 10 year cycle or the average of the three coldest years in a 30 year cycle.

The isolines of design freezing index were drawn using data from nearly 400 U.S. weather bureau stations. The map is offered as a guide only. It does not attempt to show local variations, which may be substantial, particularly in mountainous areas.

The actual design freezing index used should be computed for the specific project using temperature data from station nearest site.

Figure 4
Distribution of Design Freezing Index Values in the Continental United States



1 degree-day F = 0.556 degree-days C

Figure 5
Example Determination of Freezing Index

2.3.2 **Subsurface Geometry**. An accurate assessment of the prevailing subsurface conditions is very important for drainage analysis and design. The information needed includes subsurface soil and rock profiles, natural drainage characteristics, and prevailing groundwater conditions. In general, a thorough program of subsurface exploration and geologic evaluation is needed to obtain this information. A good subsurface exploration is an essential part of airfield pavement design for various purposes. The work needed for the drainage considerations should be incorporated in the overall subsurface exploration program for the project. In many parts of the nation, agricultural or geological maps are available that are very useful in planning the subsurface exploration.

2.3.2.1 **Site Visits**. Valuable information pertaining to the existing subsurface drainage conditions can be obtained by careful examination of the site in the field, especially if the visits were made during or immediately following a wet period. It may be possible to observe wet-weather springs or other evidence of intermittent seepage that might not show up during drier periods. The type and condition of the vegetation in the area can also offer some clues on the soil and groundwater conditions. Lush green foliage and the presence of certain types of plants and trees that require a high water table (such as cattails and willows) may be significant indications of potential groundwater problems.

2.3.2.2 **Exploration**. Subsurface exploration should be conducted using the techniques described in MIL-HDBK-1021 Series, NAVFAC P-971, and NAVFAC DM-7.01. During explorations, field crews should obtain all possible data that might relate to subsurface drainage in any way. Any evidence of artesian pressures or loss of wash water during drilling should be noted, and any unusual stratification (e.g., granular layers or lenses within a more cohesive stratum) should be recorded. The sampling should be coordinated so that representative samples are obtained for laboratory testing from all strata that may be involved in the seepage phenomenon. This includes cut materials that will later be placed in fills. When significant seasonal fluctuations in the water table are either known or suspected, installation of groundwater observation wells is highly recommended. Plastic tubing placed in bore holes can be used to monitor changes in groundwater levels over time. Such installations are inexpensive and can provide valuable information.

2.3.3 Material Properties

2.3.3.1 **Index Properties**. The index properties of materials are those properties that help to identify and classify the material. Index properties can also be an important indicator of material performance. The pertinent index properties for the analysis and design of subsurface drainage are those that influence seepage. The properties in this category include the following:

a) Grain size characteristics: ASTM C117, Testing Methods for Materials Finer Than 75-Micrometers (No. 200) Sieve in Mineral Aggregates by Washing.

b) Atterberg Limits: ASTM D 4318, Soils, Liquid Limit, Plastic Limit, and Plasticity

Together, these test results lead to the soil classifications. Refer to NAVFAC DM-7.01 for additional information on soil testing and soil properties.

2.3.3.2 **Engineering Properties**. Two properties in this category are important for subsurface drainage considerations: coefficient of permeability and frost susceptibility. The frost susceptibility of materials is discussed earlier in this section, under par. 2.2. Ideally, the coefficient of permeability should be determined by in-situ measurements; however, laboratory determinations are more common (ASTM D 2434, Test Methods for Permeability of Granular Soils). Although field- or laboratory-measured coefficient of permeability is desirable, in practice it is often necessary to use empirically estimated values. Table 2 lists the ranges of values of coefficient of permeability as related to the Unified Soil Classification System. For typical values of coefficients of permeability of compacted soils, refer to NAVFAC DM-7.02.

Table 2
Approximate Correlation Between Permeability and Unified Soil Classification (FHWA 1980)

Unified Soil Classification	Relative permeability	Coefficient of permeability, k*	
		ft/day	m/day
GW	Pervious	2.7 to 274	0.82 to 84
GP	Pervious to very pervious	13.7 to 27,400	4.2 to 8,350
GM	Semipervious	2.7×10^{-4} to 27	8.2×10^{-5} to 8.2
GC	Impervious	2.7×10^{-5} to 2.7×10^{-2}	8.2×10^{-6} to 8.2×10^{-3}
SW	Pervious	1.4 to 137	0.43 to 41.8
SP	Semipervious to pervious	0.14 to 1.4	0.043 to 0.43
SM	Impervious to semipervious	2.7×10^{-4} to 1.4	8.2×10^{-5} to 0.43
SC	Impervious	2.7×10^{-5} to 0.14	8.2×10^{-6} to 0.043
ML	Impervious	2.7×10^{-5} to 0.14	8.2×10^{-6} to 0.043
CL	Impervious	2.7×10^{-5} to 2.7×10^{-3}	8.2×10^{-6} to 8.2×10^{-4}
OL	Impervious	2.7×10^{-5} to 2.7×10^{-2}	8.2×10^{-6} to 8.2×10^{-3}
MH	Very impervious	2.7×10^{-6} to 2.7×10^{-4}	8.2×10^{-7} to 8.2×10^{-5}
CH	Very impervious	2.7×10^{-7} to 2.7×10^{-5}	8.2×10^{-8} to 8.2×10^{-6}

*When placed as well-constructed rolled-earth embankment with moisture-density control.

2.3.4 **Climatic Conditions**. The climatic information of interest to subsurface drainage analysis and design include annual precipitation and freezing index. In general, precise information on frequency, intensity, and duration of precipitation in an area is not needed. The recommended procedure for hydraulic design does not require any of these factors as an input; however, climatic condition is an important factor for consideration in determining the need for drainage. The climatic zones established under the Federal Highway Administration (FHWA) Long-Term Pavement Performance (LTPP) program are a good indicator of the relative need for drainage. In the LTPP program, the continental United States is divided into four climatic regions based on annual precipitation and freezing index, as shown in Figure 6. The wet climate is defined as areas receiving more than 20 in. (508 mm) of rainfall per year, and the freeze climate is defined as areas with a design freezing index greater than 150 degree-days F (83.3 degree-days C). In general, good subsurface drainage is most critical for the wet-freeze region and the least critical for the dry-nonfreeze region. Good drainage is also important in all areas where subgrade freezing can occur.

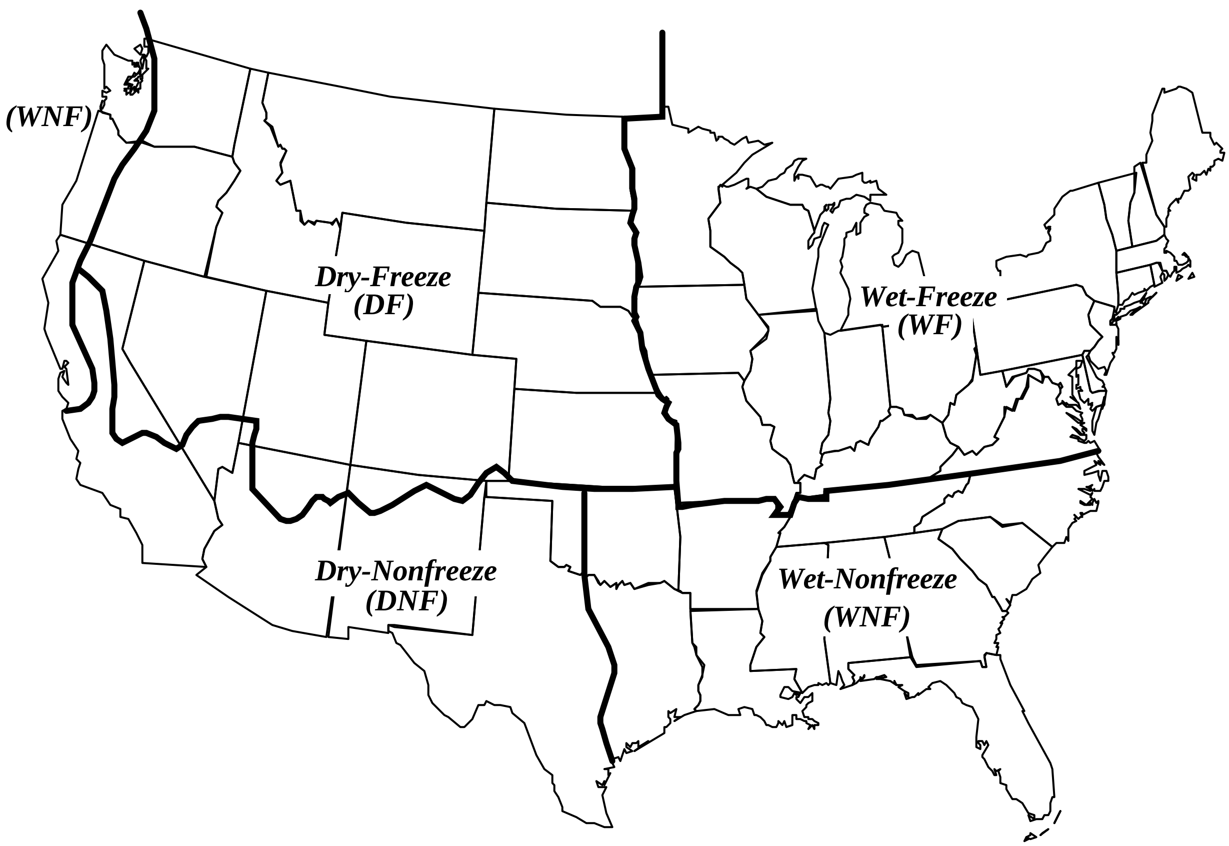


Figure 6
The Climatic Zones as Defined in the FHWA Long-Term Pavement Performance (LTPP) Program

Section 3: FROST PROTECTION DESIGN

3.1 **Need for Frost Protection**. Differential frost heaving can cause pavement cracking, significant roughness, and a drastic reduction in pavement service life. If prevented from free movement, frost heaving can exert enormous forces on pavements, structures, or utilities. The forces involved are so great that any attempt to accommodate frost heaving by providing a more substantial pavement structure is not practical. The only practical solution is prevention. Even if frost action does not result in significant heaving, the excess free water during thaw periods, and consequent softening of the subgrade and base material, can also be detrimental to pavement performance. If the investigation for frost design (refer to Section 2) reveals that frost action is possible at the project site, frost protection design must be considered. In general, the following combination of conditions denotes a potential for frost action and the need for frost protection:

a) Presence of frost-susceptible soil.

b) Groundwater level within 5 ft (1.5 m) of the proposed subgrade elevation.

c) Frost penetration depth greater than the planned overall thickness of the pavement structure (typically, design freezing index greater than 150 degrees F [83.3 degrees C]).

3.2 **Design Approach**. There are two basic approaches to frost protection: (a) complete prevention of subgrade freezing and (b) limiting frost penetration into the subgrade. The first method involves providing a sufficient cover over the frost-susceptible material to prevent penetration of freezing temperatures into the subgrade. This may require removing and replacing a certain thickness of frost-susceptible material or providing a layer of non-susceptible fill, if the combined thickness of the pavement structure and any fills needed for geometric requirements are not sufficient to provide adequate cover. The second approach allows limited frost penetration into the subgrade. The applicability and details of each of these design approaches are discussed in the following.

3.3 **Design to Prevent Subgrade Freezing**. In this method, the adverse effects of frost action are eliminated by preventing the freezing temperatures from reaching the frost-susceptible subgrade. This is accomplished by providing a cover of sufficient thickness of nonfrost-susceptible material over the susceptible subgrade.

3.3.1 **Criteria for Application**. This is the only acceptable method of frost protection in all areas where freezing of the subgrade beneath the pavement structure is possible, if accompanied by any of the following conditions:

a) Subgrade soil and moisture conditions are extremely variable.

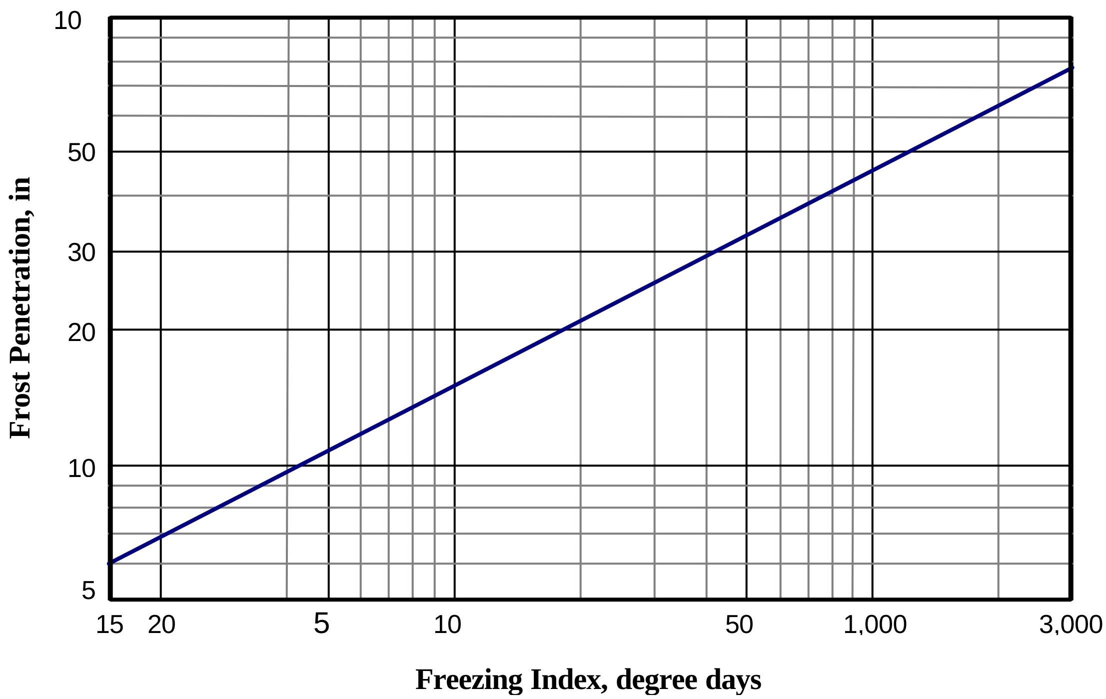
b) The subgrade soil belongs to the frost group F3 or F4.

c) Limited differential heave can present severe operational problems.

3.3.2 Design Procedure

(1) Determine the design freezing index and depth of frost penetration from Figures 4 and 7, respectively. Adjust these values based on local experience, if reliable information is available.

(2) The frost penetration depth determined in step (1) above is the required overall pavement thickness, which includes asphalt or concrete surface, base, subbase, and any additional nonfrost-susceptible material courses. The additional depth of material required for frost protection must consist of nonfrost-susceptible material. Refer to MIL-HDBK-1021 Series and NAVFAC P-971 to determine the minimum required base and subbase thicknesses.



1 degree-day F = 0.556 degree-days C
1 in = 25.4 mm

Figure 7
Empirical Relationship Between Freezing Index and Frost Penetration Beneath Snow-Free Pavement Surfaces (From Corps Of Engineers)

3.4 Design to Limit Frost Penetration in Subgrade

3.4.1 Criteria for Application. Use this method for all but the situations described in par. 3.3 a) above.

3.4.2 **Design Procedure**

a) Determine the design freezing index and depth of frost penetration from Figures 4 and 7, respectively. Adjust these values based on local experience, if reliable information is available.

b) From the frost penetration depth determined in step (1) above, subtract the proposed thickness of asphalt or concrete surface course, and multiply the remaining thickness by 2/3. This value is the thickness of limited frost penetration into the subgrade. Provide the required base, subbase, and any additional fill to equal the thickness of limited frost penetration into the subgrade. The material in each of these courses must be nonfrost susceptible.

3.5 **Base and Subbase Requirements**

3.5.1 **Nonfrost-Susceptible Materials**. Base and subbase courses in areas subjected to frost action must consist of nonfrost-susceptible materials. A conservative general requirement for such materials is that they have less than 3 percent by weight of particles smaller than 0.02 mm. In some cases, laboratory tests may be desirable to determine frost susceptibility of economically available materials that do not meet the general requirements. Currently, a simple and reliable test or criteria for frost susceptibility, which are suitable for general use, are not available. Additional discussion of frost susceptibility of different types of soils is presented in par. 2.2.2 and Table 1. The data in Table 1 are based on extensive testing conducted by the U.S. Army Corps of Engineers.

3.5.2 **Layer Separation**. When designing pavements by the limited frost penetration method, a filter/separator layer should be provided between the base (or subbase) and subgrade to prevent infiltration of subgrade fines into the base layers during the thaw periods. A separator layer also prevents mixing of the frost-susceptible subgrade and overlying nonfrost-susceptible materials, thereby minimizing the effects of freezing and preserving the strength of the aggregate base. Either a dense-graded aggregate meeting certain gradation requirements or a geotextile may be used for this purpose.

3.5.2.1 **Aggregate Separator Layer**. A dense-graded aggregate base material meeting the following criteria can be used as a separator layer:

$$D_{15\,Filter} \leq 5\,D_{85\,Subgrade} \quad (1)$$

$$D_{50\,Filter} \leq 25\,D_{50\,Subgrade} \quad (2)$$

$$D_{15\,Subbase} \leq 5\,D_{85\,Filter} \quad (3)$$

$$D_{50\,Subbase} \leq 25\,D_{50\,Filter} \quad (4)$$

The D_x in the above equations is the particle size at which x percent of the particles are smaller than that size. For example, if 15 percent of the particles in the filter material are finer than 0.08 in. (2.0 mm), D_{15} = 0.08 in. (2.0 mm) for the filter material. The following additional requirements are specified to avoid excessive fines in the filter/separator layer and to obtain a well-graded material:

a) The filter material should contain less than 12 percent fines passing the No. 200 sieve (0.075 mm).

b) The filter material should have a coefficient of uniformity (CU), as defined below, greater than 20 (preferably greater than 40):

$$CU = \frac{D_{60}}{D_{10}} \qquad (5)$$

These checks are automated in the computer program DRIP, which is a Windows® program for pavement subsurface drainage design developed by the FHWA.

The top 6 in. (152 mm) of base or subbase can double as the separator layer, if the material satisfies the gradation requirements. Sand, gravelly sand, and screenings that meet the above requirements for aggregate separator layer may also be used. The minimum recommended thickness of an aggregate separator layer is 6 in. (152 mm). However, on soft subgrade (CBR less than 4), 6 in. (152 mm) of aggregate separator may not be sufficient to prevent some pumping of subgrade fines into the base. For soft subgrade, the use of a geotextile separator layer is recommended. Alternatively, the subgrade soil may be stabilized to improve subgrade strength (refer to par. 3.5.3).

3.5.2.2 **Geotextile Separator Layer**. When readily available aggregate base material does not meet the requirements for separator layer, a synthetic fiber fabric may be used to serve as the separator layer. The use of geotextile separator layer is also recommended if the subgrade at the project site is very soft (CBR less than 4). There are two basic types of fabrics: woven and nonwoven. The types of fibers used in geotextiles include polypropylene, polyethylene, polyester, polyamides, nylon, and glass. Numerous tests are available for evaluating geotextiles. The majority of these tests had been developed for measuring properties of fabrics that were originally designed for applications other than reinforcement or separation of soil layers. Those properties that are considered important for the performance of the fabrics over clay soils are shown in Table 3, along with a listing of the applicable standard testing procedures. Table 9 (Section 4) provides a listing of representative geotextile fabrics.

Table 3
Specifications for Fabrics Used in Pavement Layer Separation and Filtration
(AASHTO-ABC-ARBTA Joint Committee Recommendation)[1]

Fabric Property	Test Method	Fabric Requirements (Minimum Values)[2]	
		Class A[3]	Class B[4]
Grab tensile strength	ASTM D4632	180 lb (801 N)	80 lb (356 N)
Elongation	ASTM D4632	n/a	n/a
Seam strength[5]	ASTM D4632	160 lb (712 N)	70 lb (311 N)
Puncture strength	ASTM D4833	80 lb (356 N)	25 lb (111 N)
Trapezoid tear strength	ASTM D4533	50 lb (222 N)	5 lb (22 N)

1. Acceptance of geotextile material should be based on ASTM D4759. Contracting agency may require a letter from the supplier certifying that its geotextile meets specification requirements.
2. Minimum requirements for value in weaker principal direction. All numerical values represent minimum average roll value (i.e., test results from any sampled roll in a lot shell be or exceed the minimum specified values in the table). Stated values are for noncritical, nonsevere applications. Lot samples according to ASTM D4354.
3. Applications where very coarse, sharp or angular aggregate is used, a heavy degree of compaction (greater than 95 percent AASHTO T99) is specified, or depth of trench is greater than 10 ft (3.0 m).
4. Applications where geotextile is used with smooth graded surfaces having no sharp angular projections, no sharp angular aggregate is used, compaction requirements are light (less than 95 percent AASHTO T99), and trench depth is less than 10 ft (3.0 m).
5. Values apply to both field and manufactured seams.

The properties listed in Tables 3 and 9 relate to the survivability and endurance of geotextiles. Geotextiles used in the separator layer application must also satisfy the filter and permeability criteria. A product with the appropriate size pore opening must be used to prevent pumping of fines through the geotextile and to avoid clogging. The geotextile must have permeability several times greater than the subgrade to ensure free drainage of the water out of the subgrade. In general, the permeability requirement is not a problem because most subgrades have relatively poor permeability. The requirements for the geotextile pore opening are as follows:

Woven geotextile: $O_{95} \leq D_{85}$ (6)

Nonwoven geotextile: $O_{95} \leq 1.8\ D_{85}$ (7)

$O_{50} \leq 0.5\ D_{85}$ (8)

$O_{95} \leq$ No. 50 sieve (9)

$O_{95} \geq 3\ D_{15}$ (10)

The O_x is the opening size at which "x" percent of the single-size glass beads pass the geotextile, when tested in accordance with ASTM D 4751, Determining Apparent Opening Size (AOS) of a Geotextile. The sieve number that corresponds to O_{95} is also known as the AOS. The Equations (6) through (9) above are the soil retention and filter criteria. Equation (10) is to prevent clogging. Also for clogging considerations, the percentage of open area for woven fabric must be greater than 4, and the porosity of nonwoven fabric must be greater than 50 percent.

3.5.3 **Stabilization**

3.5.3.1 **Subgrade Soil**. Subgrade soil may be stabilized with lime, fly ash, or portland cement to improve strength or to mitigate frost susceptibility. For soft subgrade (CBR less than 4), stabilization or a deep granular fill may be needed to ensure desirable pavement performance. However, soil stabilization must be used with care in frost areas because some soils may become frost susceptible when stabilized and perform more poorly. Few quantitative data are available on suitability and durability of stabilized materials in seasonal frost areas. Thus, testing of the stabilized material is essential to avoid any frost-related problems.

3.5.3.2 **Base**. Reflection cracking is a frequent problem for asphalt concrete surfaces constructed on a cement-treated or lean concrete base. The cause of the problem is shrinkage cracks in these bases. The random cracks in these bases can also reflect through concrete surfaces, but reflection cracking is a less frequent problem on rigid pavements. A similar problem is possible on full-depth asphalt pavements placed directly on stabilized soil without an aggregate base. In seasonal frost areas, random cracking is particularly undesirable because of the increased potential for surface infiltration through the cracks. To avoid random reflection cracking, a cement-treated or lean concrete base should not be used on flexible pavements. On rigid pavements, reflection cracking can be avoided by notching the base at the proposed joint locations and sawing joints on the concrete surface directly above the notches.

3.6 **Overruns and Shoulder Pavements**. Overrun, blast protection, and shoulder pavements should be designed for frost action. These pavement areas will normally be designed in accordance with NAVFAC DM-21.10. In frost-susceptible areas, the thickness should also comply with the requirements of this handbook.

3.7 **Permafrost**. Permafrost areas do not occur within the continental United States, except Alaska.

Section 4: SUBSURFACE DRAINAGE DESIGN

4.1 **Need for Subsurface Drainage**. Subsurface drainage systems are needed most often to address the water infiltrating the pavement structure through joints and cracks. The need for this type of drainage system depends on site conditions, including annual precipitation, freezing index, traffic level, and subgrade type. Subsurface drainage may also be needed in seasonal frost areas to minimize the potential for frost damage, as well as damage due to melt water during thaw periods. In some cases, high groundwater or seepage from high grounds may require the installation of a groundwater drainage system to lower the groundwater level beneath the pavement to an acceptable level.

4.1.1 **Frost Action in the Subgrade**. Subsurface drainage is required when subgrade freezing can occur beneath the pavement structure. Subgrade freezing is possible if the frost penetration depth is greater than the total thickness of the proposed pavement structure and any non-susceptible fill that will be placed beneath the pavement structure (refer to Section 3). If the pavement is designed to prevent or limit frost penetration into the subgrade in accordance with Section 3, subsurface drainage is not required.

4.1.2 **Surface Infiltration**

4.1.2.1 **Base Course Drainage**

a) Base course drainage is needed to remove water infiltrating the pavement structure through joints and cracks, unless the subgrade has sufficient permeability to allow vertical drainage. Provide base course drainage for all airfield pavements, except under the following conditions:

(1) When the natural subgrade has a permeability of at least 1 ft/day (0.3 m/day). Table 2 lists the range of permeability of different types of soils. To allow vertical drainage through subgrade, the unbound base material must also have a minimum permeability of 1 ft/day (0.3 m/day).

(2) In dry regions (as defined in par. 2.3.4), if the aggregate base (or subbase) has a permeability of at least 2 ft/day (0.6 m/day) and is daylighted. In seasonal frost areas, subsurface drainage may still be needed for frost considerations.

(3) The drainage requirement may be waived for pavements in nonfrost areas designed for light traffic.

b) Where base course drainage is required, the use of a rapid-draining, permeable base will often be necessary to satisfy the drainage requirements. On airfield pavements (especially runways), the drainage path is typically too long for a dense-graded base to provide sufficient drainage in an acceptable time. If satisfactory drainage cannot be achieved within an acceptable time, the use of a permeable base is necessary. Provide a permeable base for the following conditions:

(1) When 50 percent drainage of the base layer cannot be achieved within 10 days after the end of a rain event.

(2) Consider using a permeable base in wet regions (more than 20 in. [254 mm] of rain per year; see Figure 6) if the airfield will be subjected to heavy traffic volumes.

c) Use either Equation (17) (shown in Figure 10) or DRIP to determine the time to 50 percent drainage. For typical design conditions, a base permeability of 20 ft/day (6.1 m/day) or more for runways and 10 ft/day (3.0 m/day) or more for taxiways is required to satisfy the time-to-drain requirement.

4.1.2.2 **Surface Drainage**. Good surface drainage is very important to minimize the amount of water infiltrating the pavement structure. It is far easier and faster to remove surface water than the water that has infiltrated the pavement structure. Adequate cross slope must be provided to prevent ponding of water on the pavement surface. The cross slope requirements for drainage considerations are as follows:

a) Longitudinal Slope. The longitudinal slope is a concern only for the removal of water from collector drains. Longitudinal slope is not required for good surface drainage. Refer to par. 4.4.1.3 for discussion of the longitudinal slope requirements for collector drains.

b) Transverse Slope. Adequate transverse slope is very important for good surface drainage. Provide the maximum slope allowed by the geometric military handbook (MIL-HDBK-1021 Series) and NAVFAC P-971. A minimum transverse slope of 1.5 percent (0.015 ft/ft or m/m) is required. For shoulders and the turf area along the pavement edge, the minimum recommended transverse slope is 3 percent (5 percent preferred) to promote rapid drainage of surface runoff into the drainage ditch.

The surface runoff must be directed into drainage ditches or storm drains to prevent infiltration into the pavement structure. Inlets and storm drains should be provided at low points on the pavement to drain away the water that may otherwise pond at those locations. Maintaining joints and cracks well sealed is also important for minimizing surface infiltration.

4.1.3 **High Groundwater**. Subsurface drainage may be needed to address high groundwater or seepage from high grounds. In general, cut areas are particularly prone to high groundwater problems and, therefore, warrant special attention. Consider the effects of seasonal variation in groundwater levels in determining the need for both subgrade and interceptor drains.

4.1.3.1 **Subgrade Drains**. Provide subgrade drainage when the groundwater level will rise to within 1 ft below the bottom of the base course.

4.1.3.2 **Interceptor Drains**. Identifying the need for interceptor drains requires careful investigation of local conditions. Where seepage from high grounds can raise the groundwater level to within 1 ft (0.3 m) of the bottom of the base course, provide interceptor drains to cut off seepage and lower the groundwater level beneath the pavement structure (see Figure 8).

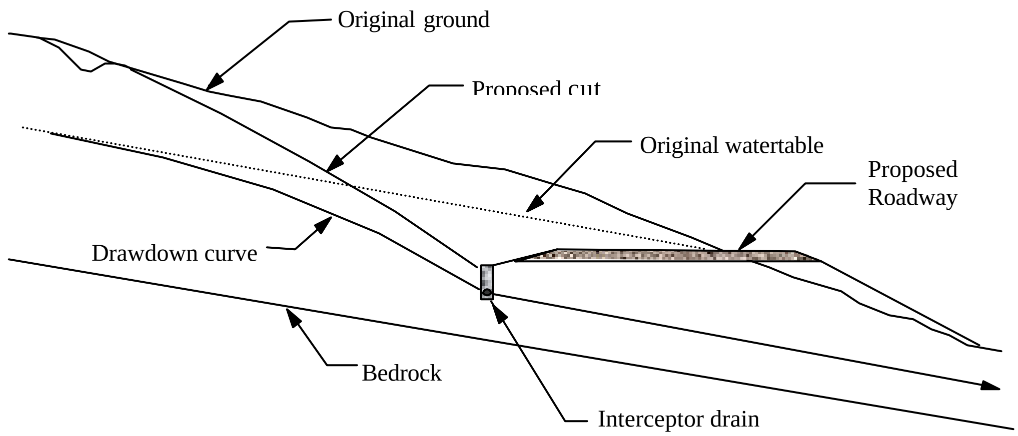


Figure 8
Interceptor Drain Used to Cut Off Seepage From High Grounds and Lower Groundwater Table

4.2 **Hydraulic Design**. This section provides the procedure for calculating drainage capacity requirements. Before proceeding with this section, the need for drainage should have already been established in accordance with par. 4.1. The design equations presented in this section are automated in DRIP.

4.2.1 **Base Course Drainage**. The basic approach to drainage design for the base course in this handbook is to minimize its exposure to saturated conditions. This is accomplished by ensuring that a certain level of drainage is achieved within a specified time after the rain has ended.

4.2.1.1 **Time to Drain**. Use either Equation (17) (Figure 10) or DRIP to determine the time required to drain the base course for the trial design. The drainage requirements are as follows:

a) Dense-graded base: 50 percent drainage in 10 days or less. For typical design conditions, a base permeability of 20 ft/day (6.1 m/day) or more for runways and 10 ft/day (3.0 m/day) or more for taxiways is required to satisfy this requirement.

b) Permeable base: 50 percent drainage in 1 day or less. Use 6-in. (152-mm) thick treated base when using a permeable base. For typical design conditions, a base material with permeability about 1,000 ft/day (300 m/day) will provide adequate drainage.

Achieving the target level of drainage following a rain event is less time-critical for airfield pavements than highways, because airfield pavements are typically subjected to far less traffic volume. However, adequate drainage must be achieved within a reasonable time to prevent constant high levels of moisture in the pavement structure. The guidelines for quality of drainage are given in Table 4.

Table 4
Quality of Drainage Rating for Highways and Airfield Pavements

Quality of Drainage	Time to Drain	
	Highways	Airfields
Excellent	2 hr	1 day
Good	1 day	7 days
Fair	7 days	15 days
Poor	30 days	30 days

The time-to-drain calculation requires the following input (automated in DRIP):

- S_R — Resultant slope of the roadway. Most pavements have slope in both transverse and longitudinal directions, as shown in Figure 9. If longitudinal slope is less than 0.5 percent S_R may be approximated as S_T.

$$S_R = \sqrt{S_T^2 + S_L^2} \tag{11}$$

where

S_R =Resultant slope, ft/ft (m/m).

S_T =Transverse slope, ft/ft (m/m).

S_L =Longitudinal slope, ft/ft (m/m).

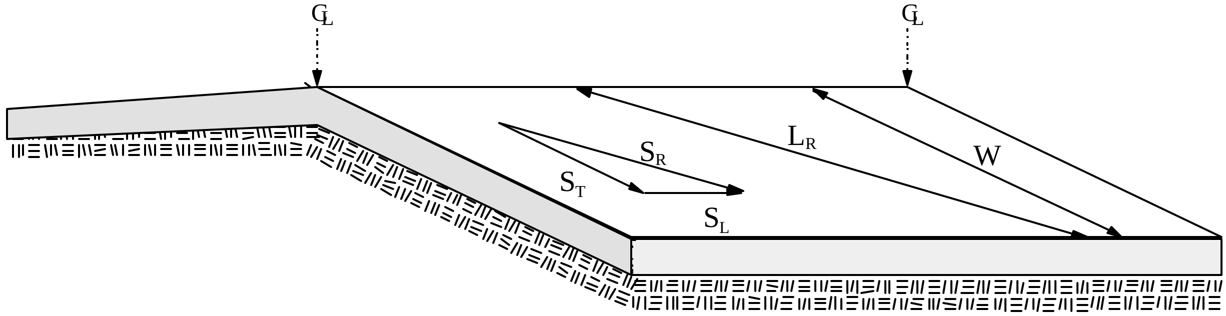


Figure 9
Illustration of Resultant Slope and Drainage Path

L_R — Resultant drainage path (see Figure 9). The drainage path will follow the resultant slope. For longitudinal slope less than 0.5 percent, L_R may be approximated as W.

$$L_R = W \frac{S_R}{S_T} \tag{12}$$

where

L_R =Resultant drainage path, ft (m).

W =Transverse drainage path, ft (m) (see Figure 9).

S_R =Resultant slope, ft/ft (m/m).

S_T =Transverse slope, ft/ft (m/m).

n_e — Effective porosity. Use either Equation (13) or (14) to determine n_e. For base materials, Equation (14) is recommended.

$$n_e = n - w_e \frac{g_d}{g_w} \tag{13}$$

$$n_e = n\,WL \tag{14}$$

where

n_e =Effective porosity

n =Porosity

$$n = 1 - \frac{g_d}{G_s g_w} \tag{15}$$

g_d =Dry density of the material, pcf

g_w =Unit weight of water, pcf (62.4 pcf [1.0 Mg/m^3])

Gs =Specific gravity of solids (2.65 to 2.70 for typical aggregate material)

w_e = Effective water content (water content after the specimen has drained to a constant weight), decimal fraction of dry unit weight

WL = Water loss. The amount of water that can be drained, decimal fraction of total voids (see Table 5 for WL values).

Table 5
Typical Water Loss Values for n_e Determination (FHWA 1994)

		Type and Amount of Fines								
		Filler			Silt			Clay		
		2.5%	5%	10%	2.5%	5%	10%	2.5%	5%	10%
Material Type	Gravel	70	60	40	60	40	20	40	30	10
	Sand	57	50	35	50	35	15	25	18	8

Notes: Fines are defined as the material passing the No. 200 sieve.
For gravel with 0 percent fines, water loss is equal to 80 percent.
For sand with 0 percent fines, water loss is equal to 65 percent.

k — Coefficient of permeability. Estimate coefficient of permeability of all base material using the guidelines given in NAVFAC DM-7.01. Table 6 shows approximate values of coefficient of permeability of remolded samples of sand and gravel base materials.

a) Dense Graded Base. If more than one aggregate base layer will be used, determine the average coefficient of permeability using Equation (16).

$$k_a = \frac{k_1 d_1 + k_2 d_2 + k_3 d_3 + \ldots + k_n d_n}{d_1 + d_2 + d_3 + \ldots + d_n} \tag{16}$$

where:

k_a =Average coefficient of permeability of all base layers, ft/day (m/day).

$k_1, k_2, k_3, \ldots$=Coefficient of permeability of individual base layers, ft/day (m/day).

$d_1, d_2, d_3, \ldots$=Thickness of individual base layers, in. (mm).

b) Permeable Base. If a permeable base is used, the permeability of dense-graded base layers can be ignored because the permeability of a permeable base is several orders of magnitude greater than that of a dense-graded base.

Table 6
Approximate Values of Coefficient of Permeability of Remolded Sand and Gravel Base Material

Percent by Weight Passing No. 200 Sieve	Coefficient of Permeability, *k*	
	ft/day	m/day
3	140	43
5	14	4.3
10	1.4	0.43
15	0.14	0.043
25	0.014	0.0043

4.2.1.2 **Base Course Discharge**. The maximum rate of discharge from the base course is needed in determining the required outlet spacing for the collector drains. Determine the maximum discharge from the base layer using Equation (19).

$$q_b = k S_T h \qquad (19)$$

where:

q_b =Maximum rate of discharge from base course, ft^3/day/ft (m^3/day/m)

k =Permeability of the base material, ft/day (m/day)

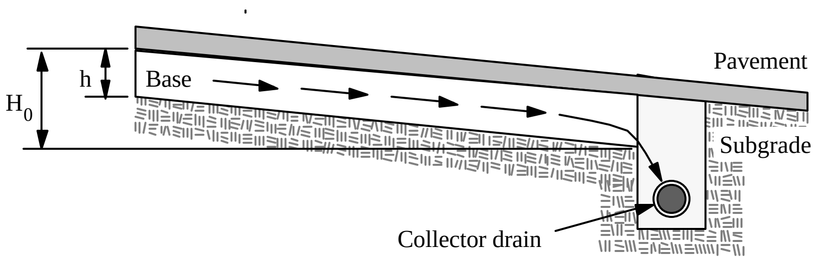
S_T =Transverse slope, ft/ft (m/m)

h =Base thickness, ft (m)

4.2.2 **Subgrade Drains**. The assumptions for the subgrade drainage and the equation for determining the rate of discharge for the subgrade drains are shown in Figure 11.

a) Use Equation (20) to determine the maximum rate of discharge for subgrade drainage. Modify method of analysis where local information indicates that a more precise analysis is possible. Consider infiltration from the shoulder areas in any modified analyses. Where subgrade drains are being considered, good surface drainage is particularly important to minimize the amount of water that must be removed through a subsurface drainage system.

b) The subgrade drains may be combined with base course drains. The collector drains for the base course drainage can be designed to handle the water from both sources. For the combined drainage system, if the subgrade permeability is less than 1 ft/day (0.3 m/day), the discharge from the groundwater source is small compared to the base course discharge and may be ignored.



Assumptions: 1. Base course is saturated.
2. No inflow occurs during drainage of base course.
3. Subgrade is impervious.
4. Base course has unimpeded flow into the collector drain.

Time for 50 Percent Drainage:

$$t_{50} = \frac{n_e \, L_R^{\,2}}{2.08 \, k \, H_0} \qquad (17)$$

where:

t_{50} =Time required to drain 50 percent of drainable water from the aggregate base, days.

n_e =Effective porosity (Equation (14))

L_R =Resultant drainage path, ft (m) (Equation (12))

k =Coefficient of permeability of the base material, ft/day (m/day)

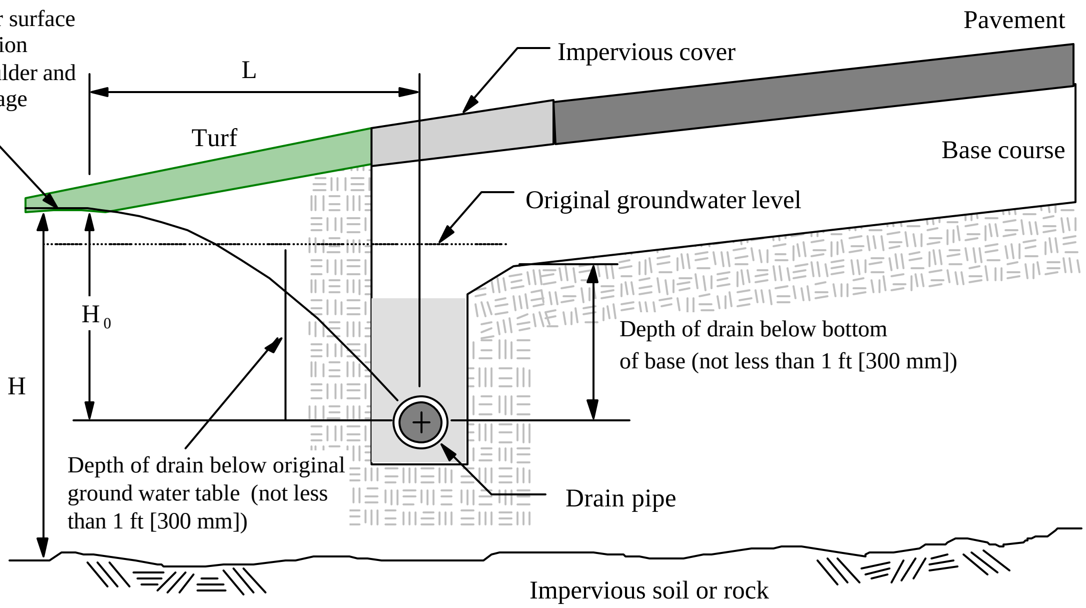
H_0 =Head difference as shown in above figure, ft (m)

$$H_0 = S_R \, L_R + h \qquad (18)$$

S_R =Resultant slope, ft/ft (m/m) (Equation (11))

h =Base thickness, ft (m)

Figure 10
Time-to-Drain Calculation for Airfield Pavements



<u>Assumptions</u>:

1. Subgrade below groundwater level is saturated.
2. Groundwater level beneath shoulder is raised by infiltration.
3. Subgrade is not under artesian pressure.
4. Drains have adequate capacity
5. Steady flow conditions.

<u>Maximum Rate of Discharge</u>:

$$q_s = k\,H_0\,c \tag{20}$$

where:

q_s = Maximum discharge for subgrade drainage, ft^3/day/ft (m^3/day/m)

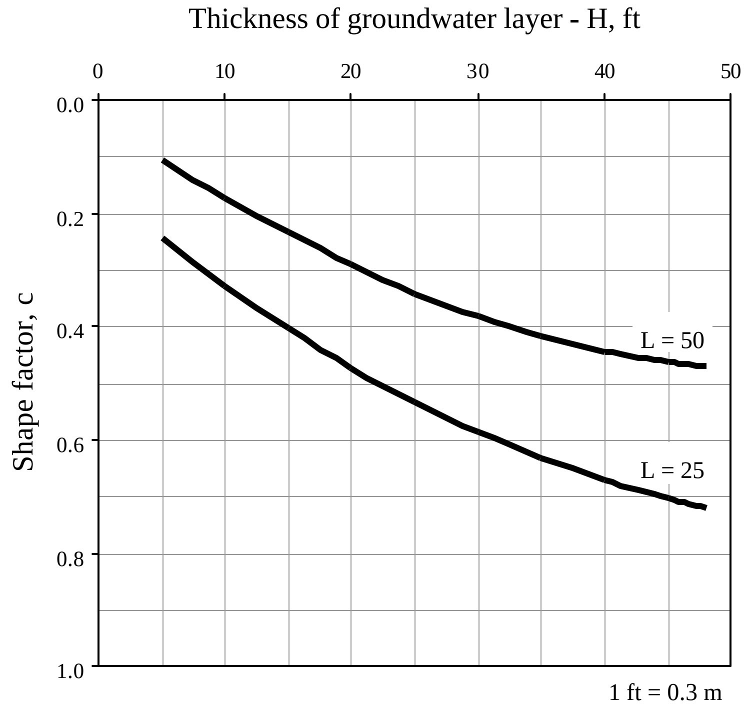
k = Subgrade coefficient of permeability, ft/day (m/day)

H_0 = Elevation difference between midpoint of the drain pipe and groundwater surface at distance L from the drain as shown above, ft (m)

L = Horizontal distance from center of the drain pipe to the edge of water draw down, ft (m)

c =Shape factor for groundwater drainage (from Figure 12)

Figure 11
Maximum Discharge Calculation for Subgrade Drains



Notes:

H = Thickness of the groundwater layer, as shown in Figure 10.

Use L = 50 curve if subgrade permeability is greater than 1.4 ft/day (0.43 m/day).

Use L = 25 curve if subgrade permeability is less than or equal to 1.4 ft/day (0.43 m/day).

Figure 12
Shape Factor for Subgrade Drainage

4.2.3 **Interceptor Drains**. Use Equation (21) to estimate the discharge from interceptor drains. The parameters used in the calculation are illustrated in Figure 13, along with the chart for shape factor.

$$q_i = c' k S H \qquad (21)$$

where:

q_i = Maximum discharge from interceptor drain, ft^3/day/ft (m^3/day/m)

c' = Shape factor for interceptor drain (Figure 13)

k = Subgrade coefficient of permeability, ft/day (m/day)

S = Slope of the impervious layer, ft/ft (m/m) (Figure 13)

H = Thickness of the groundwater layer, ft (m) (Figure 13)

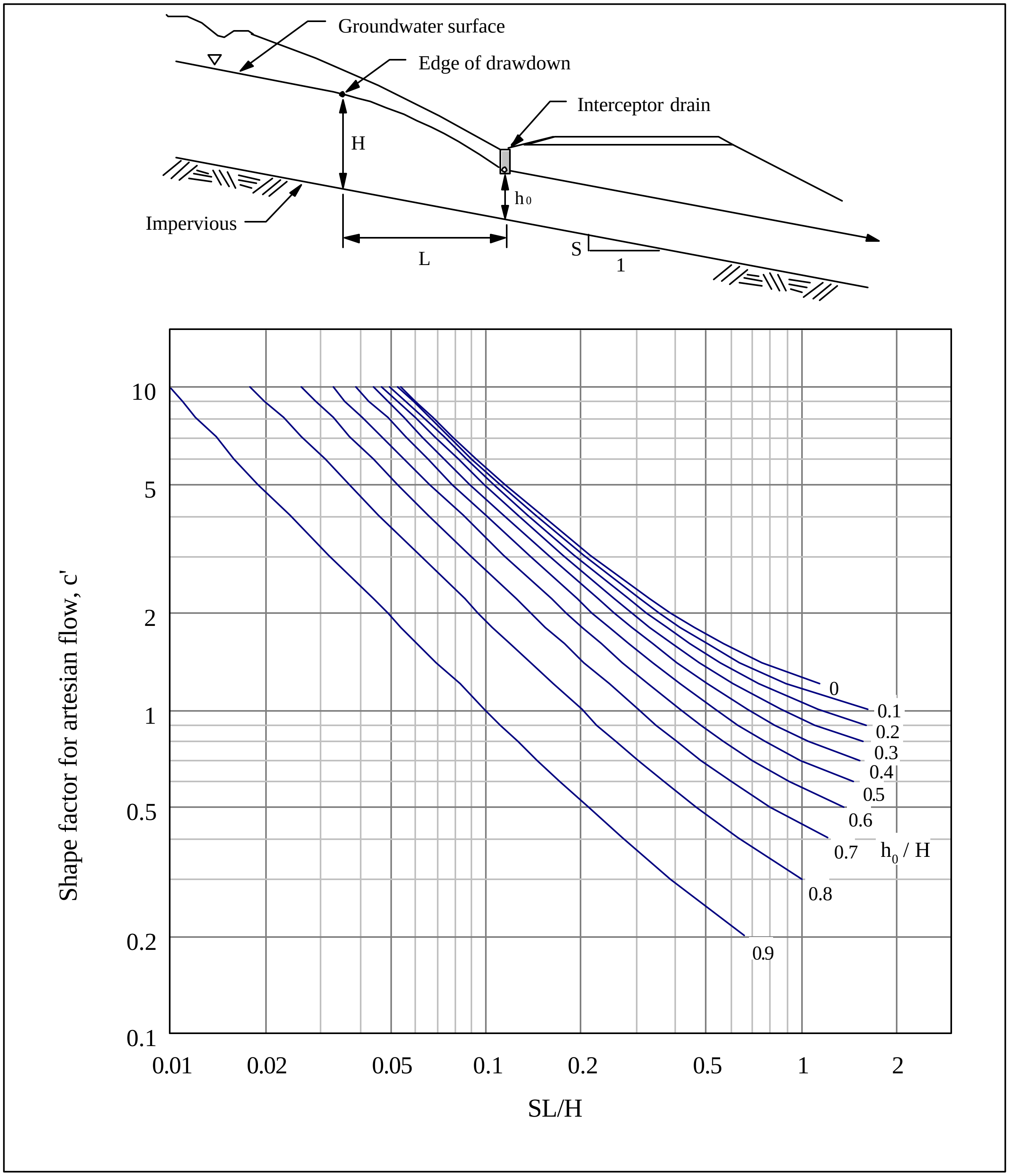


Figure 13
Shape Factor for Interceptor Drain

a) The minimum requirement for a subsurface drainage system is to place a 6-in. (152-mm) pipe drain with the maximum outlet spacing of 500 ft (150 m). In general, this design will provide ample drainage capacity for interceptor drains.

b) The interceptor drains may be combined with base course drains. For the combined drainage system, if the subgrade permeability is less than 0.01 ft/day (0.003 m/day), the discharge from the groundwater source is small compared to the base course discharge and may be ignored.

4.2.4 **Collector Drain Capacity**. The collector drain capacity can be estimated using the Manning's equation:

$$Q = \frac{1.486}{n} A \left(\frac{d}{4} \right)^{2/3} S^{1/2} \qquad (22)$$

where:

Q =Pipe capacity, ft^3/sec

n =Manning's roughness coefficient

A =Cross sectional area of the drainage pipe, ft^2

d =Pipe diameter, ft

S =Slope of the pipe drain (longitudinal slope), ft/ft

For circular pipes, equation 21 reduces to the following:

$$Q = \frac{40{,}000}{n} d^{8/3} S^{1/2} \qquad (23)$$

where:

Q =Pipe capacity, ft^3/day

n =Manning's roughness coefficient

n = 0.012 for smooth pipe

n = 0.024 for corrugated pipe

d =Pipe diameter, ft

S =Slope of the pipe drain (longitudinal slope), ft/ft

Note the unit conversion incorporated in Equation (23), which gives the flow capacity of the pipe in terms of ft^3/day. In SI units, Equation (23) is as follows:

$$Q = \frac{26{,}920}{n} d^{8/3} S^{1/2} \qquad (24)$$

where:

Q =Pipe capacity, m^3/day

n =Manning's roughness coefficient (same values as Equation (23))

d =Pipe diameter, m

S =Slope of the pipe drain (longitudinal slope), m/m

4.2.5 **Outlet Spacing**. For maintenance considerations, long outlet spacing is not desirable. The shorter outlet spacing is especially important in areas with flat grades. The maximum allowable outlet spacing for collector drains are as follows:

Smooth pipes: 500 ft (150 m)

Corrugated pipes: 250 ft (75 m)

In general, the outlet spacing requirements based on maintenance considerations are much more stringent than those based on hydraulic requirements. Nevertheless, hydraulic requirements must be checked to ensure that the subsurface drainage system provides unimpeded flow of infiltrated water out of the pavement structure. The maximum outlet spacing based on the hydraulic requirement is given by Equation (25).

$$L = \frac{Q}{q} \tag{25}$$

where:

L =Outlet spacing, ft (m)

Q =Flow capacity of the drain pipe, ft^3/day (m^3/day)

q =Maximum discharge from all contributing sources of water, ft^3/day/ft (m^3/day/m)

Include the discharge from all sources that the collector drain is designed to handle:

Base course drainage only: $q = q_b$ (26)

Base course and subgrade drainage: $q = q_b + q_s$. (27)

Base course, subgrade, and intercept drainage: $q = q_b + q_s + q_i$. (28)

where:

q_b = Base course discharge (Equation (19)).

q_s = Subgrade discharge (Equation (20)).

q_i = Interceptor drain discharge (Equation (21)).

For interior drains (Figure 17), the collector drain must handle discharge from both sides of the drain. For interior drains,

$$q = 2\,q_b \tag{28}$$

The base course discharge (q_b) given by Equation (19) is the peak flow from the base layer. The outlet spacing based on Equation (19), therefore, is the most conservative value. For most design situations, the conservative outlet spacing based on Equation (19) is desirable. However, the outlet spacing based on Equation (19) can be overly conservative when a very highly permeable base (k greater than 3,000 ft/day [1,000 m/day]) is used. Where a very highly permeable base is used, the following equation may be used to obtain more realistic estimate of the required outlet spacing:

$$q_b = W\,h\,n_e U\,24/t \tag{29}$$

where:

q_b =Base course discharge from based on time-to-drain, ft^3/day/ft (m^3/day/m)

W = Base width (half of the total pavement width for crowned sections), ft (m)

h =Base thickness, ft (m)

n_e =Effective porosity of the permeable base (Equation (14))

U =Degree of drainage, fraction

t =Time to drain, hours

According to Table 4, 50 percent drainage achieved in 12 hours is excellent drainage for airfield pavements. Substituting these values in Equation (29) gives Equation (30):

$$q_b = W\,h\,n_e \tag{30}$$

4.3 **Design Alternatives**. Three different types of subsurface drains are considered in this handbook: base course drains, subgrade drains, and interceptor drains.

4.3.1 **Base Course Drains**. The base course drains consist of collector drains placed along the outer edges of the pavement. The drains may be provided with or without a permeable base, depending on site conditions (refer to par. 4.4 for design details). Figure 14 shows the typical design for the base course drains on pavements with a dense-graded base. The typical design for a permeable base system is shown in Figure 15.

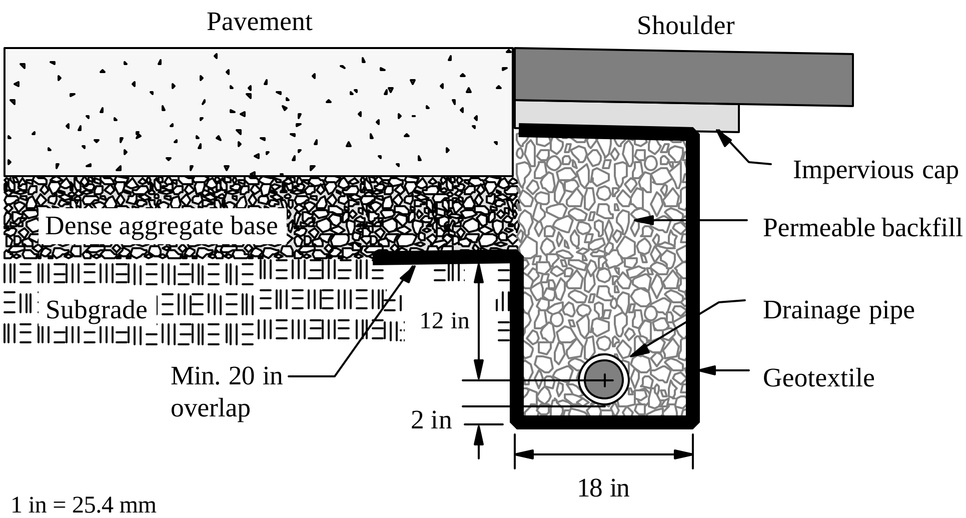


Figure 14
Typical Design for Base Course Collector Drains for a Pavement With a Dense-Graded Base

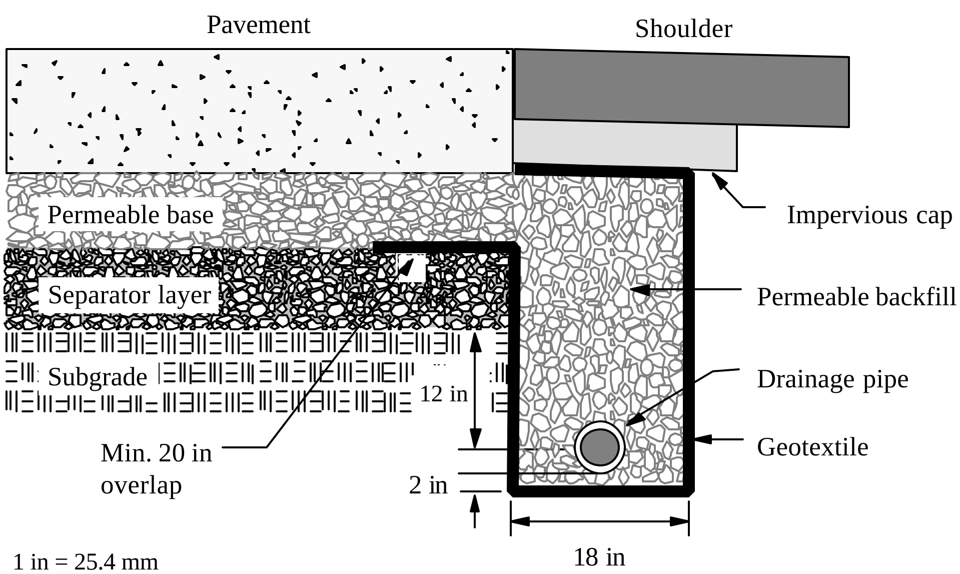


Figure 15
Typical Design for Base Course Collector Drains for a Pavement With a Permeable Base

4.3.1.1 **Collector Drains**. The design of the collector drain is the same for both systems, with a minor difference in the placement of geotextile. The key design features of the collector drains include the following :

a) Perforated drainage pipe placed a drainage trench (refer to par. 4.4 for details).

b) Geotextile around the perimeter of the drainage trench. The geotextile is needed to prevent loss of fines from the surrounding soil through the collector drain and to prevent clogging of the drainage pipes. Note that the drainage trench is open to the base being drained for both dense-graded aggregate and permeable base systems to allow unimpeded flow of water into the drainage trench.

c) Permeable backfill.

d) Impervious cap. The impervious cap is a very important design detail to prevent infiltration of surface runoff into the collector drain. If an asphalt shoulder is provided, there is no need for a separate cap. If the pavement will have a turf area at the pavement edge rather than a paved shoulder, the impervious cap must consist of a minimum 3 in. (76 mm) of cohesive backfill.

The use of prefabricated geocomposite edgedrains is not recommended for base course drainage because they cannot be maintained.

4.3.1.2 **Permeable Base System**. A permeable base system consists of the following components (refer to par. 4.4 for design details):

a) A permeable base layer for rapid removal of infiltrated water out of the pavement structure.

b) A separator layer to prevent infiltration of subgrade fines into the permeable base.

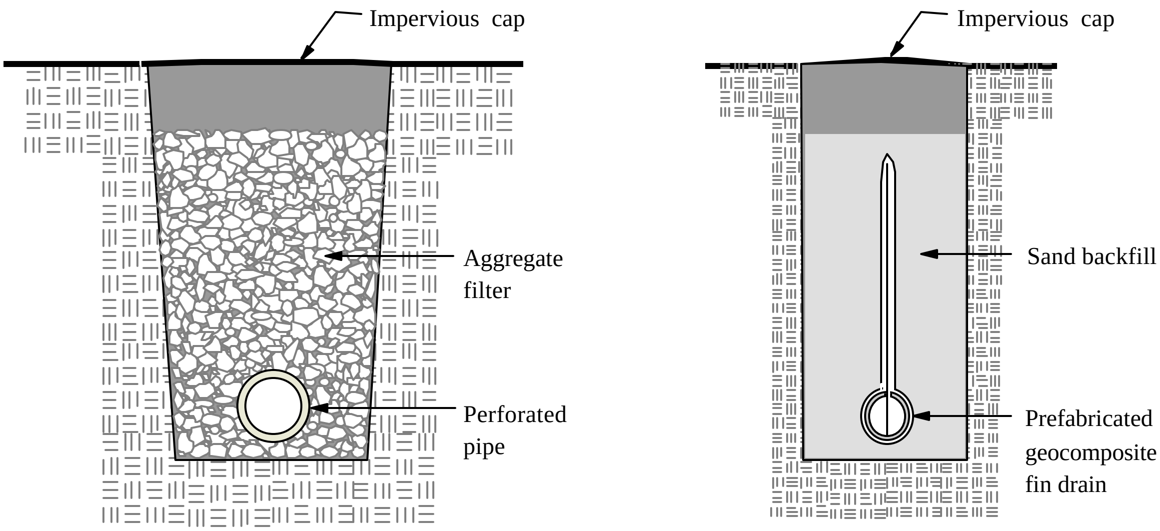
c) Collector drains to direct water draining out of the pavement structure to drainage outlets.

d) Regularly spaced outlets.

4.3.2 **Subgrade Drains**. A subgrade drain may consist of an open ditch or subsurface collector drains similar to those for base course drainage. In general, it should be possible to design base course drains to handle subgrade drainage. Where separate subgrade drains are needed, the designs shown in Figure 16 may be used. For both designs shown in Figure 16, the permeability of the aggregate filter backfill must be greater than that of the subgrade being drained.

4.3.3 **Interceptor Drains**. Interceptor drains may be combined with base course drains. Where separate interceptor drains are needed, the designs shown in Figure 16 may be used.

4.3.4 **Combination of Surface and Subsurface Drainage**. The surface runoff should never be allowed to drain into the collector drains for subsurface drainage. Provide entirely separate system of collector drains for surface runoff and subsurface water. It is, however, permissible to outlet subsurface water into storm drain inlet structures when the collector drains for subsurface drainage cannot be easily outlet into open drainage ditches. Refer to par. 4.4 for design details.



(a) (b)

Figure 16
Design Alternatives for Subgrade and Interceptor Drains

4.4 **Design Details**

4.4.1 **Collector Drains for Base Course Drainage**. The recommended design details for the collector drains are shown in Figures 14 and 15.

4.4.1.1 **Location of Collector Drains**. Place the drains only at runway and taxiway edges, except under unusual circumstances where this is not possible. Large paved areas, such as parking aprons, will generally require intermediate drains. The design details for interior drains are shown in Figure 17.

4.4.1.2 **Trench Dimensions**. See Figures 15 and 16 for trench details. The requirements are as follows:

a) A minimum clearance of 6 in. (152 mm) on either side of the drainage pipe.

b) Adequate depth to place the center of the drainage pipe a minimum of 12 in. (305 mm) below the bottom of the base or separator layer, with room for 2 in. (51 mm) of bedding beneath the drainage pipes. Interior drains (Figure 17) in flexible pavements may require a deeper trench to satisfy the cover requirements. In seasonal frost areas, the drainage pipes must be placed below the frost depth; however, drainage pipes need not be placed deeper than 48 in. (1.2 m) below the bottom of the base layer.

4.4.1.3 **Slopes**. The recommended minimum slope for collector drains is 0.15 percent (0.0015 ft/ft [m/m]). If this minimum slope cannot be achieved, provide outlets at 250-ft (75-m) intervals.

4.4.1.4 **Geotextile Placement**. Line the drainage trench with geotextile as shown in Figure 14, 15, or 17 to prevent contamination of the collector drains by fines from surrounding subgrade. Use a nonwoven needle punched fabric meeting the criteria given in par. 3.5.2.2.

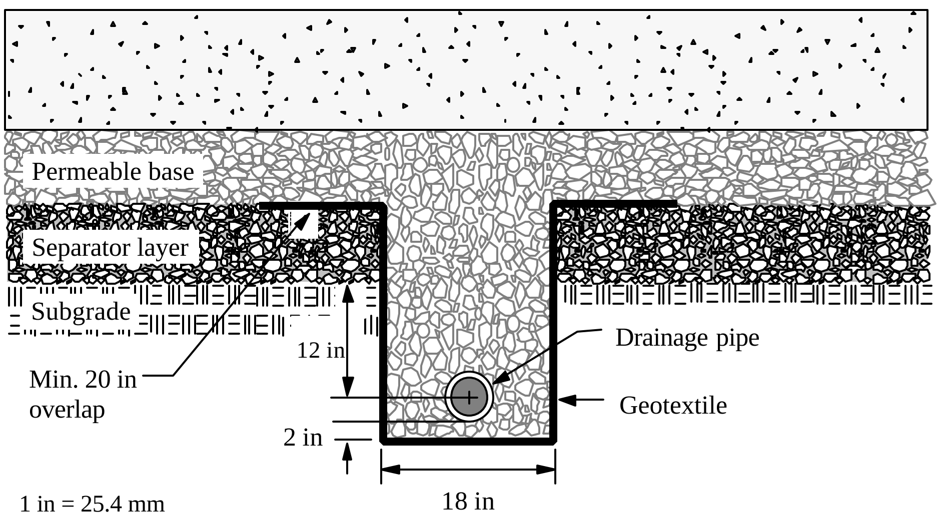


Figure 17
Typical Design Detail for Interior Collector Drains

4.4.1.5 **Drainage Pipe**. Use either corrugated polyethylene (CPE) or smooth rigid polyvinyl chloride (PVC) pipes with perforations. Use 6-in. minimum diameter pipe. In general, 6-in. (152-mm) diameter pipe will provide adequate hydraulic capacity and satisfy maintenance requirements. The applicable specifications for drainage pipes are as follows:

a) CPE pipes — AASHTO M252M, Corrugated Polyethylene Drainage Pipe.

b) Smooth rigid PVC pipes — AASHTO M278, Class PS46 Polyvinyl Chloride (PVC) Pipe, Class PC50.

c) Corrugated pipes with smooth interior — ASTM F 949 for PVC and AASHTO M252M for CPE pipes.

If an asphalt-treated permeable material will be used to backfill the drainage trench, the drainage pipe must be capable of withstanding high temperatures. Use PVC electric conduit EPC 40 or EPC 80 that meets National Electrical Manufacturers Association (NEMA) Specification TC 2, Electrical Plastic Tubing (EPT) and Conduit.

4.4.1.6 **Pipe Cover**. Pipe cover is a concern for the drains located in trafficked areas. In general, the collector drains placed along the pavement edges are located beyond the traffic area and only the interior drains (Figure 17) will be subjected to live loads. For loads up to 100,000-lb (45-kN) dual-wheel, the detail shown in Figure 17 provides adequate cover for pipe drains under rigid pavements. For flexible pavements, additional cover may be required if the total pavement thickness over the drainage trench (excluding the trench backfill) is less than 2 ft (0.6 m). Cover requirements for different design wheel loads are indicated in Army Technical Manual (TM) 5-820-3/AFM 885, Drainage and Erosion-Control Structures for Airfields and Heliports, Chapter 3.

4.4.1.7 **Backfill Material**. The trench backfill material must be stable and at least as permeable as the base being drained. In general, the same material used in the permeable base should be used.

4.4.2 Dense-Graded Base System

4.4.2.1 **Dense-Graded Base**. A dense-graded aggregate base with a moderately high permeability may be used as a drainage layer. For typical design conditions, a base permeability of at least 20 ft/day (6.1 m/day) for runways and 10 ft/day (3.0 m/day) for taxiways is required to satisfy the time-to-drain requirement. An aggregate base used as the drainage layer must contain no more than 15 percent of fines passing the No. 200 sieve (0.075 mm) to prevent clogging of the edgedrains or loss of fines through the edgedrains. In general, an aggregate material that satisfies the permeability requirement will satisfy the fines-content requirement. To ensure good stability, use only 100 percent crushed stone.

4.4.2.2 **Protection of the Drainage Layer**. A dense-graded aggregate that meets the permeability requirements of a drainage layer will generally contain fewer fines (material passing No. 200 sieve [0.075 mm]) than a typical dense-graded base. To prevent contamination and loss of permeability, the drainage layer must be adequately protected from the underlying materials. If the filter criteria (Equations (1) and (2)) are not satisfied, a geotextile separator layer should be used to protect the drainage layer. The use of a geotextile separator layer is also recommended for projects in wet or freeze climate, if either of the following conditions exist:

a) Silty or clayey subgrade (A-4 or A-6)

b) Subgrade CBR less than 4

4.4.3 **Permeable Base System**

4.4.3.1 **Permeable Base**

a) In general, a gradation that has permeability of about 1,000 ft/day (300 m/day) will provide adequate drainage capacity and stability. To ensure good stability, use only 100 percent crushed stone, and the aggregate should be graded to provide coefficient of uniformity (Equation (5)) greater than 4.0. Example permeable base gradations are given in Table 7. Only a stabilized permeable base should be used on airfield pavements.

(1) Asphalt-treated permeable base — A minimum AC content of 2.5 percent by weight is recommended. Use a harder grade of asphalt cement (e.g., AC 40 or AR 8000).

(2) Cement-treated permeable base — Application rate of 2 to 3 bags/yd^3 (112 to 167 kg/m^3) is recommended.

Table 7
Example Permeable Base Gradations

Sieve Size		Rapid Draining Material (RDM)	New Jersey
1 in	25 mm	70 – 100	95 – 100
¾ in	19 mm	55 – 100	
½ in	12.5 mm	40 – 80	60 – 80
3/8 in	9.5 mm	30 – 65	
No. 4	4.75 mm	10 – 50	40 – 55
No. 8	2.36 mm	0 – 25	5 – 25
No. 16	1.18 mm	0 – 5	0 – 8
No. 50	300 µm		0 – 5
CU		> 3.5	> 4
Coefficient of Permeability, *k*		1,000 to 5,000 ft/day 300 to 1,500 m/day	1,000 ft/day 300 m/day

b) Use 6-in. (152-mm) thick asphalt- or cement-treated permeable base for airfield pavement applications. The permeable base should be placed directly below the pavement slabs in rigid pavements and immediately below the last stabilized layer in flexible pavements. An unbound aggregate layer may be placed above the permeable base layer in flexible pavements if the aggregate material satisfies the following requirements:

(1) Contains less than 8 percent of fines passing the No. 200 (0.075 mm) sieve.

(2) Satisfies the filter criteria specified in par. 3.5.2.

(3) Has a coefficient of permeability greater than 2 ft/day (0.6 m/day).

4.4.3.2 **Separator Layer**. The separator layer is an essential component of a permeable base system. Provide a minimum 6-in. thick unbound aggregate separator layer. The requirements for the aggregate separator layer are as follows:

a) Satisfies the filter criteria specified in par. 3.5.2

b) Contains less than 12 percent of fines passing the No. 200 sieve (0.075 mm).

c) Has a coefficient of uniformity of at least 20 (preferably greater than 40).

In general, typical dense-graded aggregate base material will satisfy these requirements. Table 8 provides an example gradation that satisfies these requirements. Table 9 lists geotextiles that may be used as a separator layer. A geotextile may be placed between the aggregate separator layer and the permeable base to provide the most positive protection of the permeable base, but the use of the geotextile by itself as a separator layer is not recommended. The use of both geotextile and aggregate separator layers may be appropriate if the subgrade at the project site is very soft (e.g., CBR less than 4). A geotextile separator layer must satisfy the filter criteria specified in par. 3.5.2.

Table 8
Example Aggregate Separator Layer Gradation

Sieve Size		Aggregate Separator Layer Material
1 in.	25 mm	100
3/4 in.	19 mm	95 – 100
No. 4	4.75 mm	50 – 80
No. 40	425 µm	20 – 35
No. 200	75 µm	5 – 12
CU		40

4.4.4 **Subgrade and Interceptor Drains**. The subgrade and interceptor drains can be combined with the base course drains. If separate drains are needed, the designs shown in Figure 16 can be used. In general, the pipe drain is preferred because of maintenance considerations.

4.4.4.1 **Pipe Drains**. The trench detail for the pipe drain is the same as that for the base course drains. The backfill material for the pipe drain must have permeability greater than the subgrade being drained and satisfy the filter criteria specified in par. 3.5.2. In addition, the backfill material must satisfy the following criteria to prevent loss of fines through the drainage pipes:

Slotted pipes: D_{85} of backfill > 1.2 slot width.

Pipes with circular holes: D_{85} of backfill > 1.0 hole diameter.

These requirements need not be checked for permeable backfill. If permeable backfill is used, the drainage trench must be wrapped with geotextile. In general, because of low permeability requirements, a permeable backfill will not be required for subgrade or interceptor drains.

4.4.4.2 **Geocomposite Drains**. The trench detail for prefabricated geocomposite collector drains is similar to that for pipe drains, except the recommended trench width is 8 in. to 12 in. (203 mm to 305 mm). Excessive compaction can crush geocomposite drains. Backfill the drainage trench with coarse sand that satisfies the filter criteria (par. 3.5.2) and compact by flushing with water.

4.4.5 **Outlet Design**. Dual outlets are recommended for maintenance considerations, as shown in Figure 18. The dual outlet system allows sections of collector drains to be flushed out to clear any debris or material blocking the free flow of water. The recommended design details for drainage outlets are as follows:

a) Provide dual outlet with large-radius bends, as shown in Figure 19.

b) Use rigid-walled, non-perforated pipes. For pipe drains, use the same diameter pipe as the collector drains. For prefabricated geocomposite drains, 4-in. to 6-in (102-mm to 152-mm) 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.

c) A minimum 3-percent slope is recommended for outlet pipes.

d) The discharge end of the outlet pipe should be placed at least 6 in. (152 mm) above the 10-year design flow in the drainage ditch (Figure 20). The same requirement applies even if the outlet is discharging into storm drain inlets.

e) Provide headwalls as shown in Figure 21. Headwalls and clear marking of outlets is very important for proper maintenance.

4.4.6 **Manholes and Observation Basins**. Where collector drains do not outlet into an open drainage ditch, provide manholes, observation basins, and risers for access to the drainage system for inspection and maintenance.

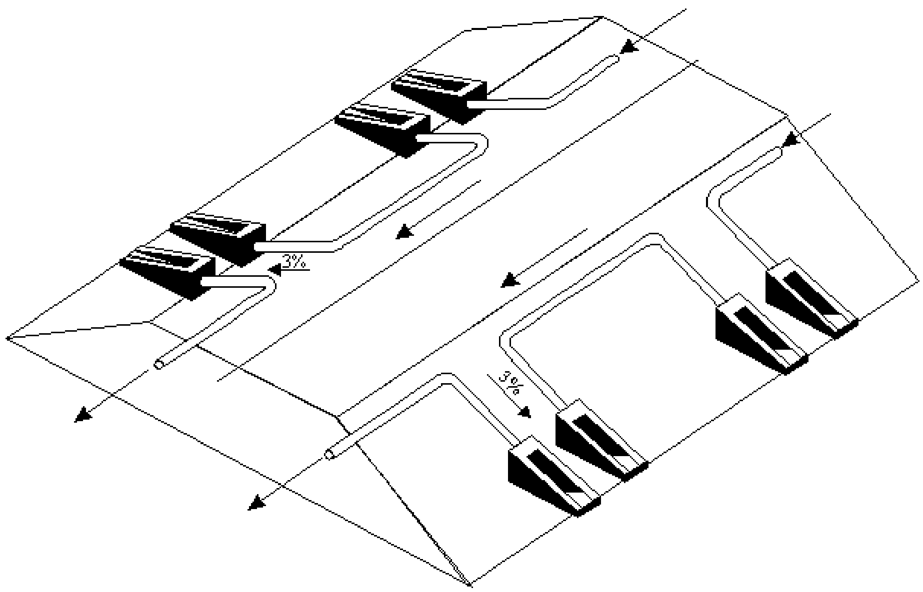


Figure 18
Schematic of Dual Outlet System Layout (Baumgardner 1998)

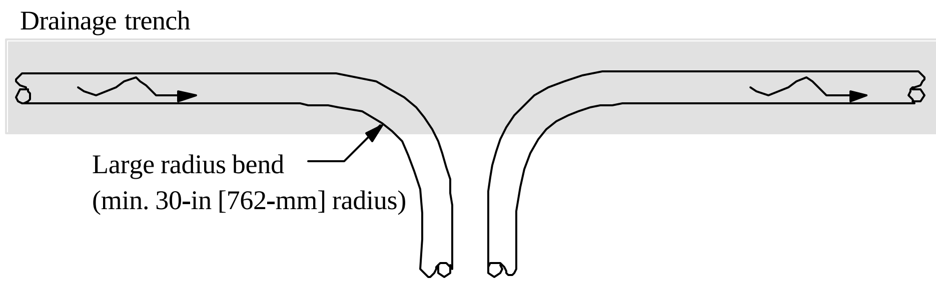


Figure 19
Illustration of Large-Radius Bends Recommended for Drainage Outlet

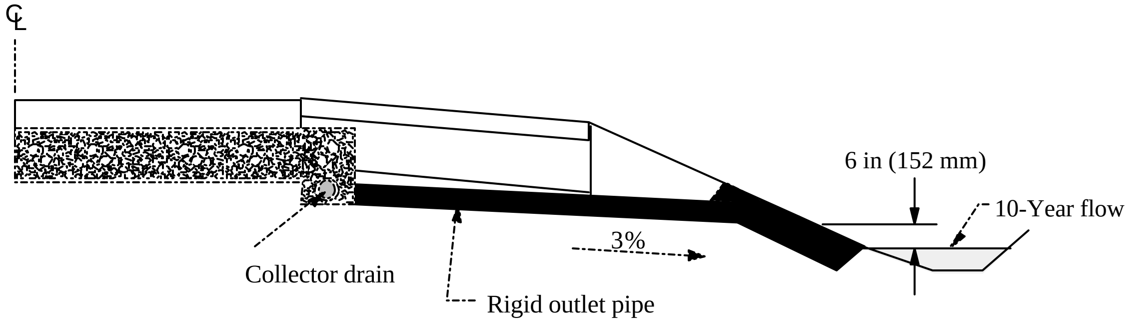
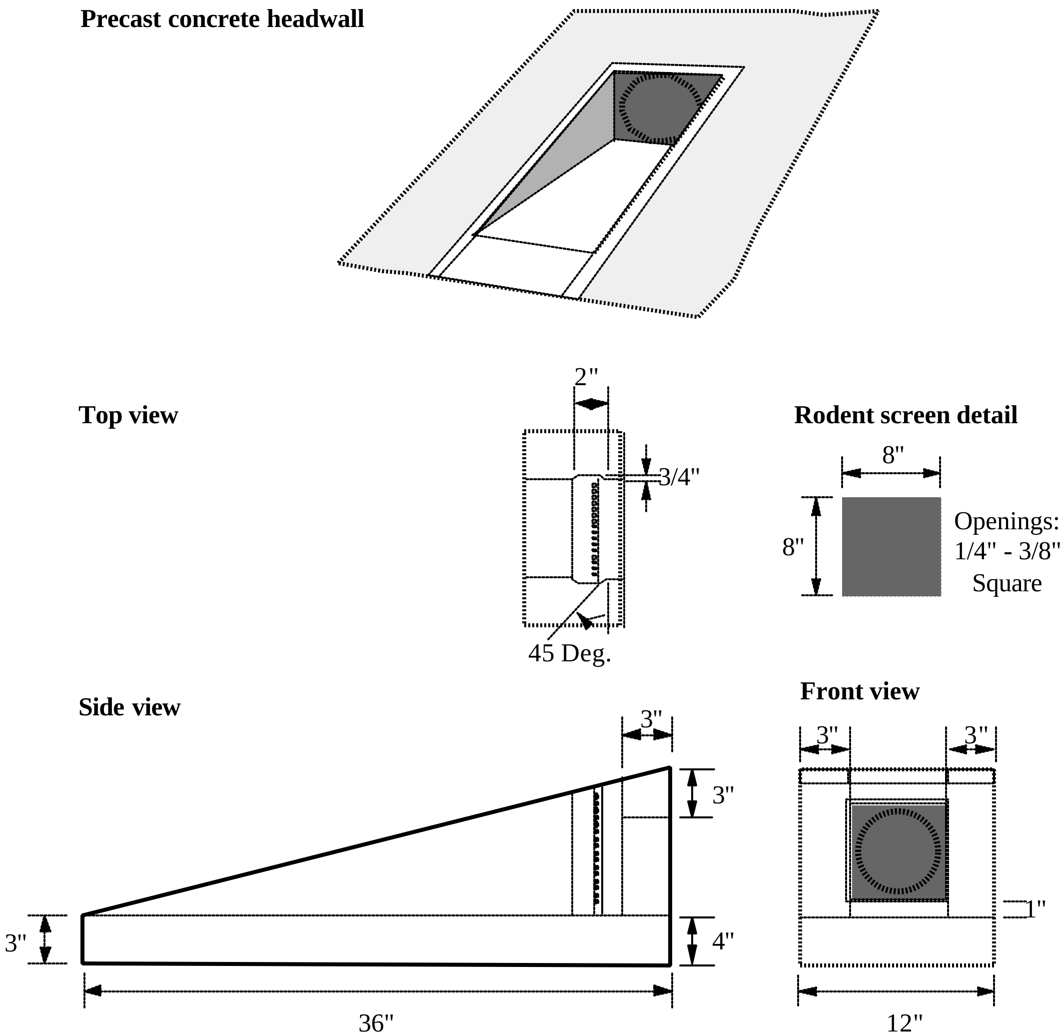


Figure 20
Recommended Outlet Design Detail



1 in = 25.4 mm

Figure 21
Recommended Headwall Design for Drainage Outlets

Table 9
Properties and Applications of Representative Fabrics (IFAI 1997)

Product	Structure[1]	AOS, Sieve No. (mm)	Grab tensile strength, lb (kN)	Puncture strength, lb (kN)	Burst strength, psi (MPa)	Trapezoid tearing strength, lb (kN)	Manufacturer suggested application[2]
ACF Environmental							
ACF-200	W-PP	50 (0.3)	200 (0.890)	90 (0.40)	400 (2.75)	75 (0.330)	F, D, S/S, R
ACF SB 102	NW-PP	70 (0.21)	130 (0.579)	40 (178)	140 (0.965)	60 (0.267)	S/S, F, D
Advanced Drainage Systems, Inc.							
4000	NW-PP	70 (0.212)	90 (0.400)	55 (0.245)	185 (1.276)	35 (0.156)	F, D, S/S
4420	NW-PP	70 (0.212)	105 (0.467)	65 (0.289)	225 (1.551)	45 (0.202)	F, D, S/S
6600	NW-PP	70 (0.212)	160 (0.712)	95 (0.423)	325 (2.241)	60 (0.267)	F, D, E, P, R, S/S
8800	NW-PP	80 (0.180)	205 (0.912)	130 (0.578)	400 (2.758)	85 (0.378)	F, D, E, P, R, S/S
1020	NW-PP	100 (0.150)	255 (1.134)	160 (0.712)	510 (3.516)	100 (0.445)	P, E, S/S
1220	NW-PP	100 (0.150)	300 (1.334)	180 (0.801)	600 (4.137)	114 (0.507)	R, P, E, S/S
Amoco Fabrics & Fibers Co.							
AMOCO 2002	W-PP	50 (0.300)	200 (0.890)	90 (0.400)	400 (2.758)	75 (0.330)	S/S, R
AMOCO 4504	NW-PP	70 (0.212)	95 (0.423)	65 (0.289)	225 (1.551)	35 (0.156)	F, D, S/S
AMOCO 4506	NW-PP	70 (0.212)	160 (0.712)	90 (0.400)	350 (2.413)	65 (0.289)	F, D, P, E, S/S
AMOCO 4508	NW-PP	100 (0.150)	203 (0.903)	130 (0.578)	450 (3.103)	80 (0.356)	F, D, P, E, S/S
AMOCO 4510	NW-PP	100 (0.150)	250 (1.112)	165 (0.734)	550 (3.792)	100 (0.445)	P, F, D, S/S, E
AMOCO 4512	NW-PP	100 (0.150)	300 (1.334)	195 (0.867)	650 (4.482)	115 (0.512)	P, F, D, S/S, E
AMOCO 4514	NW-PP	100 (0.150)	360 (1.601)	230 (1.023)	750 (5.171)	130 (0.578)	F, D, S/S, E
AMOCO 4516	NW-PP	100 (0.150)	400 (1.779)	250 (1.112)	800 (5.516)	145 (0.645)	F, D, S/S, E

[1] W = Woven; NW = Nonwoven
PP = Polypropylene
PET = Polyester

[2] D = Drainage
E = Erosion control
F = Filtration
P = Protection
R = Reinforcement
S/S = Separation/stabilization

Table 9 (Continued)
Properties and Applications of Representative Fabrics (IFAI 1997)

Product	Structure[1]	AOS, Sieve No. (mm)	Grab tensile strength, lb (kN)	Puncture strength, lb (kN)	Burst strength, psi (MPa)	Trapezoid tearing strength, lb (kN)	Manufacturer suggested application[2]
Amoco Fabrics & Fibers Co. (continued)							
AMOCO 4546	NW-PP	70 (0.212)	100 (0.445)	65 (0.289)	225 (1.551)	45 (0.200)	F, D, S/S
AMOCO 4547	NW-PP	70 (0.212)	120 (0.534)	70 (0.311)	240 (1.655)	50 (0.222)	F, D, S/S, E
AMOCO 4550	NW-PP	70 (0.212)	135 (0.601)	80 (0.356)	265 (1.827)	56 (0.249)	F, D, S/S, E
AMOCO 4551	NW-PP	100 (0.150)	160 (0.712)	90 (0.400)	315 (2.172)	65 (0.289)	F, D, S/S, E
AMOCO 4552	NW-PP	100 (0.150)	180 (0.801)	105 (0.467)	350 (2.413)	75 (0.334)	F, D, S/S, E
AMOCO 4553	NW-PP	100 (0.150)	203 (0.903)	130 (0.578)	400 (2.758)	80 (0.356)	F, D, S/S, E
Bradley Industrial Textiles Inc.							
Phoenix SCS-I	NW-PET	70 (0.212)	180 (0.801)	90 (0.400)	350 (2.413)	70 (0.311)	S/S, D, E, R, F
Carthage Mills							
FX-22	W-PP	50 (0.300)	100 (0.445)	60 (0.267)	225 (1.551)	40 (178)	S/S
FX-33	W-PP	50 (0.300)	120 (0.534)	65 (0.289)	270 (1.862)	50 (0.222)	S/S
FX-66	W-PP	70 (0.212)	300 (1.334)	125 (0.556)	650 (4.482)	120 (0.534)	S/S, D
FX-60HS	NW-PP	80 (0.180)	170 (0.757)	95 (0.423)	300 (2.068)	65 (0.289)	S/S, D
FX-80HS	NW-PP	80 (0.180)	210 (0.934)	110 (0.489)	370 (2.551)	85 (0.378)	S/S, D
FX-100HS	NW-PP	100 (0.150)	270 (1.201)	160 (0.712)	490 (3.378)	100 (0.445)	S/S, P, D
FX-160HS	NW-PP	100 (0.150)	395 (1.757)	245 (1.090)	790 (5.447)	155 (0.689)	S/S, P, D

[1] W = Woven; NW = Nonwoven
PP = Polypropylene
PET = Polyester

[2] D = Drainage
E = Erosion control
F = Filtration
P = Protection
R = Reinforcement
S/S = Separation/stabilization

Table 9 (Continued)
Properties and Applications of Representative Fabrics (IFAI 1997)

Product	Structure[1]	AOS, Sieve No. (mm)	Grab tensile strength, lb (kN)	Puncture strength, lb (kN)	Burst strength, psi (MPa)	Trapezoid tearing strength, lb (kN)	Manufacturer suggested application[2]
Contech Construction Products Inc.							
Contech C-50 NW	NW-PP	70 (0.212)	150 (0.667)	85 (0.378)	280 (1.931)	60 (0.267)	F, D, E, S/S
Contech C-60 NW	NW-PP	70 (0.212)	160 (0.712)	85 (0.378)	280 (1.931)	60 (0.267)	F, D, E, S/S
Contech C-70 NW	NW-PP	70 (0.212)	180 (0.801)	100 (0.445)	330 (2.275)	75 (0.334)	F, D, E, S/S
Contech C-80 NW	NW-PP	80 (0.180)	205 (0.912)	105 (0.467)	350 (2.413)	85 (0.378)	F, D, E, S/S
Contech C-100 NW	NW-PP	100 (0.150)	250 (1.112)	150 (0.667)	460 (3.572)	100 (0.445)	F, D, P, S/S
Contech C-120 NW	NW-PP	100 (0.150)	300 (1.334)	175 (0.778)	580 (3.999)	115 (0.512)	F, D, P, S/S
Contech C-160 NW	NW-PP	100 (0.150)	380 (1.690)	240 (1.068)	750 (5.171)	145 (0.645)	F, D, P, S/S
Contech C-175 NW	NW-PP	100 (0.150)	395 (1.757)	260 (1.157)	850 (5.861)	150 (0.667)	F, D, P, S/S
Evergreen Technologies Inc.							
TG 500	NW-PP	50 (0.300)	120 (0.534)	60 (0.267)	215 (1.482)	45 (0.200)	S/S
TG 550	NW-PP	50 (0.300)	140 (0.623)	70 (0.311)	245 (1.689)	55 (0.245)	S/S
TG 600	NW-PP	70 (0.212)	160 (0.712)	80 (0.356)	285 (1.965)	65 (0.289)	S/S, D
TG 650	NW-PP	70 (0.212)	200 (0.890)	95 (0.423)	325 (2.241)	75 (0.334)	S/S, D
Geo-Group International							
ST153NW	NW-PP	70 (0.212)	120 (0.534)	70 (0.311)	240 (1.655)	50 (0.222)	D, F, S/S
ST200NW	NW-PP	70 (0.212)	150 (0.667)	95 (0.423)	325 (2.241)	60 (0.267)	D, F, S/S
ST270NW	NW-PP	80 (0.180)	205 (0.912)	125 (0.556)	400 (2.758)	80 (0.356)	D, F, S/S

[1] W = Woven; NW = Nonwoven
PP = Polypropylene
PET = Polyester

[2] D = Drainage
E = Erosion control
F = Filtration
P = Protection
R = Reinforcement
S/S = Separation/stabilization

Table 9 (Continued)
Properties and Applications of Representative Fabrics (IFAI 1997)

Product	Structure[1]	AOS, Sieve No. (mm)	Grab tensile strength, lb (kN)	Puncture strength, lb (kN)	Burst strength, psi (MPa)	Trapezoid tearing strength, lb (kN)	Manufacturer suggested application[2]
LINQ Industrial Fabrics Inc.							
GTF 200S	W-PP	50 (0.300)	180 (0.801)	80 (0.356)	305 (2.103)	70 (0.311)	S/S
Typar 3301	NW-PP	50 (0.300)	120 (0.534)	25 (0.111)	90 (0.621)	35 (0.156)	S/S, F, D
Typar 3401	NW-PP	70 (0.212)	130 (0.579)	40 (0.178)	140 (0.965)	60 (0.267)	S/S, F, D
Typar 3501	NW-PP	70 (0.212)	160 (0.710)	56 (0.250)	190 (1.300)	60 (0.267)	S/S, F, D
Typar 3601	NW-PP	140 (0.106)	240 (1.067)	65 (0.289)	210 (1.448)	90 (0.401)	S/S, F, D
Typar 3631	NW-PP	140 (0.106)	250 (1.113)	80 (0.356)	210 (1.448)	90 (0.401)	S/S, F, D
140 EX	NW-PP	70 (0.212)	120 (0.534)	65 (0.289)	230 (1.586)	50 (0.222)	S/S, F, D
150 EX	NW-PP	80 (0.180)	165 (0.734)	90 (0.401)	310 (2.137)	65 (0.289)	S/S, F, D, A/O
160 EX	NW-PP	80 (0.180)	180 (0.801)	90 (0.401)	320 (2.206)	70 (0.311)	S/S, F, D
180 EX	NW-PP	80 (0.180)	200 (0.890)	100 (0.445)	330 (2.275)	75 (0.334)	S/S, F, D, E, P
225 EX	NW-PP	80 (0.180)	215 (0.957)	115 (0.512)	360 (2.482)	85 (0.378)	S/S, F, D, E, P
250 EX	NW-PP	100 (0.150)	270 (1.201)	150 (0.668)	450 (3.102)	100 (0.445)	S/S, E, P
275 EX	NW-PP	100 (0.150)	300 (1.334)	170 (0.757)	550 (3.792)	115 (0.512)	S/S, E, P
350 EX	NW-PP	100 (0.150)	380 (1.690)	240 (1.068)	750 (5.171)	145 (0.645)	S/S, E, P

[1] W = Woven; NW = Nonwoven
PP = Polypropylene
PET = Polyester

[2] D = Drainage
E = Erosion control
F = Filtration
P = Protection
R = Reinforcement
S/S = Separation/stabilization

Table 9 (Continued)
Properties and Applications of Representative Fabrics (IFAI 1997)

Product	Structure[1]	AOS, Sieve No. (mm)	Grab tensile strength, lb (kN)	Puncture strength, lb (kN)	Burst strength, psi (MPa)	Trapezoid tearing strength, lb (kN)	Manufacturer suggested application[2]
Mirafi							
500X	W-PP	50 (0.300)	200 (0.890)	90 (0.401)	400 (2.758)	75 (0.334)	S/S
140N	NW-PP	70 (0.212)	120 (0.534)	70 (0.311)	240 (1.655)	50 (0.222)	S/S, F, D, E
160N	NW-PP	70 (0.212)	160 (0.710)	95 (0.423)	325 (2.241)	60 (0.267)	S/S, F, D, E
180N	NW-PP	80 (0.180)	205 (0.912)	130 (0.579)	400 (3.102)	80 (0.356)	S/S, F, D, E, P
1100N	NW-PP	100 (0.150)	250 (1.113)	155 (0.689)	510 (3.516)	100 (0.445)	S/S, F, D, E, P
1120N	NW-PP	100 (0.150)	300 (1.334)	175 (0.778)	600 (4.137)	115 (0.512)	S/S, F, D, E, P
1160N	NW-PP	100 (0.150)	380 (1.690)	235 (1.045)	750 (5.171)	140 (0.623)	S/S, F, D, E, P
National Seal Co../Fluid Systems							
Trevira 011/200	NW-PET	70 (0.212)	160 (0.710)	80 (0.356)	285 (1.965)	60 (0.267)	F, D, E, S/S
Trevira 011/250	NW-PET	70 (0.212)	210 (0.934)	95 (0.423)	360 (2.484)	75 (0.334)	F, D, E, S/S
Trevira 011/280	NW-PET	70 (0.212)	230 (1.023)	100 (0.445)	380 (2.622)	80 (0.356)	F, D, E, S/S, R
Trevira 011/350	NW-PET	70 (0.212)	305 (1.356)	130 (0.579)	510 (3.519)	100 (0.445)	F, P, R, E, S/S
Trevira 011/420	NW-PET	70 (0.212)	350 (1.556)	150 (0.668)	550 (3.795)	120 (0.534)	R, P, S/S
Trevira 011/550	NW-PET	100 (0.150)	500 (2.224)	195 (0.867)	780 (5.382)	150 (0.668)	R, P, S/S
Synthetic Industries Inc.							
Geotex 501	NW-PP	70 (0.212)	150 (0.667)	85 (0.378)	280 (1.931)	60 (0.267)	F, D, E, S/S
Geotex 601	NW-PP	70 (0.212)	160 (0.710)	85 (0.378)	280 (1.931)	60 (0.267)	F, D, E, S/S
Geotex 701	NW-PP	70 (0.212)	180 (0.801)	100 (0.445)	330 (2.275)	75 (0.334)	F, D, E, S/S
Geotex 801	NW-PP	80 (0.180)	205 (0.912)	105 (0.467)	350 (2.413)	85 (0.378)	F, D, E, S/S
Geotex 1001	NW-PP	100 (0.150)	250 (1.113)	150 (0.667)	460 (3.172)	100 (0.445)	F, D, P, S/S

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S/S = Separation/stabilization
A/O = asphalt overlay

Table 9 (Continued)
Properties and Applications of Representative Fabrics (IFAI 1997)

Product	Structure[1]	AOS, Sieve No. (mm)	Grab tensile strength, lb (kN)	Puncture strength, lb (kN)	Burst strength, psi (MPa)	Trapezoid tearing strength, lb (kN)	Manufacturer suggested application[2]
Synthetic Industries Inc., (continued)							
Geotex 1201	NW-PP	100 (0.150)	300 (1.334)	175 (0.778)	580 (3.999)	115 (0.512)	F, D, P, S/S
Geotex 1601	NW-PP	100 (0.150)	380 (1.690)	240 (1.068)	750 (5.171)	145 (0.645)	F, D, P, S/S
Geotex 1751	NW-PP	100 (0.150)	395 (1.757)	260 (1.157)	850 (5.861)	150 (0.667)	F, D, P, S/S
TNS Advanced Technologies							
E040	NW-PP	70 (0.212)	105 (0.467)	65 (0.289)	230 (1.586)	45 (0.200)	S/S, F, D, E
E060	NW-PP	80 (0.180)	160 (0.710)	95 (0.423)	350 (2.413)	55 (0.245)	S/S, F, D, E
E070	NW-PP	80 (0.180)	200 (0.890)	115 (0.512)	400 (2.75)	75 (0.334)	S/S, F, D, E
E080	NW-PP	80 (0.180)	225 (1.001)	130 (0.579)	450 (3.103)	90 (0.401)	S/S, F, D, E, P
E100	NW-PP	100 (0.150)	270 (1.201)	165 (0.734)	560 (3.861)	100 (0.445)	S/S, F, D, E, P
E120	NW-PP	100 (0.150)	350 (1.556)	190 (0.845)	650 (4.482)	125 (0.556)	S/S, F, D, E, P
E140	NW-PP	100 (0.150)	390 (1.735)	210 (0.934)	725 (4.999)	135 (0.601)	S/S, F, D, E, P
E160	NW-PP	100 (0.150)	425 (1.890)	240 (1.068)	800 (5.516)	150 (0.667)	S/S, F, D, E, P
R060	NW-PP	80 (0.180)	160 (0.710)	90 (0.401)	315 (2.172)	65 (0.289)	F, D, E, S/S
R070	NW-PP	80 (0.180)	180 (0.801)	105 (0.467)	350 (2.413)	75 (0.334)	F, D, E, S/S
R080	NW-PP	80 (0.180)	200 (0.890)	130 (0.579)	400 (2.75)	85 (0.378)	F, D, E, S/S
R100	NW-PP	80 (0.180)	250 (1.113)	160 (0.710)	520 (3.585)	100 (0.445)	F, D, P, S/S
R120	NW-PP	100 (0.150)	300 (1.334)	180 (0.801)	600 (4.137)	115 (0.512)	F, D, P, S/S
R160	NW-PP	100 (0.150)	380 (1.690)	240 (1.068)	800 (5.516)	145 (0.645)	F, D, P, S/S

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PET = Polyester

[2] D = Drainage
E = Erosion control
F = Filtration
P = Protection
R = Reinforcement
S/S = Separation/stabilization

Table 9 (Continued)
Properties and Applications of Representative Fabrics (IFAI 1997)

Product	Structure[1]	AOS, Sieve No. (mm)	Grab tensile strength, lb (kN)	Puncture strength, lb (kN)	Burst strength, psi (MPa)	Trapezoid tearing strength, lb (kN)	Manufacturer suggested application[2]
WEBTECH Inc.							
Tera Tex NO3	NW-PP	70 (0.212)	80 (0.356)	50 (0.222)	170 (1.172)	25 (0.111)	D, S/S, F
Tera Tex NO4	NW-PP	70 (0.212)	95 (0.423)	55 (0.245)	200 (1.379)	40 (0.178)	D, S/S, F
Tera Tex OL	NW-PP	70 (0.212)	90 (0.401)	60 (0.267)	200 (1.379)	35 (0.156)	A/O, D, S/S, F
Tera Tex SD	NW-PP	70 (0.212)	105 (0.467)	65 (0.289)	215 (1.482)	45 (0.200)	D, S/S, F
Tera Tex SO4	NW-PP	70 (0.212)	130 (0.579)	40 (0.178)	140 (0.965)	60 (0.267)	D, S/S, F
Tera Tex NO5	NW-PP	70 (0.212)	135 (0.601)	80 (0.356)	270 (1.862)	55 (0.245)	S/S, D, E, F
Tera Tex NO6	NW-PP	80 (0.180)	165 (0.734)	95 (0.423)	325 (2.241)	65 (0.289)	S/S, D, P, E
Tera Tex NO7	NW-PP	80 (0.180)	200 (0.890)	110 (0.489)	380 (2.620)	75 (0.334)	S/S, F, P, E
Tera Tex NO8	NW-PP	80 (0.180)	215 (0.956)	130 (0.578)	400 (2.75)	85 (0.378)	S/S, F, P, E
Tera Tex N10	NW-PP	100 (0.150)	285 (1.268)	160 (0.710)	525 (3.620)	100 (0.445)	S/S, R, F, P, E
Tera Tex N12	NW-PP	100 (0.150)	325 (1.446)	180 (0.801)	625 (4.309)	115 (0.512)	S/S, R, F, P, E
Tera Tex N16	NW-PP	120 (0.120)	425 (1.890)	250 (1.113)	800 (5.516)	165 (0.734)	S/S, R, F, P, E

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PP = Polypropylene
PET = Polyester

[2] D = Drainage
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S/S = Separation/stabilization
A/O = asphalt overlay

Section 5: CONSTRUCTION OF SUBSURFACE DRAINAGE SYSTEMS

5.1 **General.** The construction of a drainage system includes handling and placement of a variety of materials, including permeable drainage layers, dense-graded separator layers, geotextiles, and plastic or metallic pipes. Drainage systems can be constructed without undue difficulties if a few precautionary measures are taken. The key to successful construction lies in training of the personnel involved to ensure that special requirements of drainage systems are properly addressed.

5.2 **Considerations for Subgrade Soil Treatments.** A stable foundation is essential to a permeable base system for both construction and long-term performance considerations. Soft subgrades do not provide adequate support for construction traffic and for the compaction of the overlying layers. Moreover, a poor subgrade promotes pumping of the subgrade fines into the permeable base, as well as intermixing at the permeable base–separator layer and separator layer–subgrade interfaces. The intermixing results in contamination of the permeable base and significant loss of permeability. A minimum California bearing ratio (CBR) of 4 is recommended for pavements provided with a permeable base. If the CBR requirement cannot be met, placement of a thick granular fill or subgrade improvement through either mechanical or chemical (lime or cement) stabilization is highly recommended.

5.3 **Placement of Permeable Base.** Permeable base materials are susceptible to segregation due to their open-graded nature. Therefore, special care should be taken to avoid this problem while stockpiling or placing these materials. Hauling on permeable bases should be a kept to a minimum, and care should be taken to avoid excessive rutting and shoving of materials under construction traffic. When a permeable base is being placed over a geotextile separation layer, sharp turns of the construction equipment should be avoided to prevent wear and tear of the geotextile. After placement, the drainage layer should be protected to prevent contamination with fines or other foreign materials. Any contaminated area should be completely removed and replaced with new material. Minimal construction traffic should be allowed on the completed permeable base. Only tracked pavers should be used to pave over the permeable base. The following are additional considerations for placement and compaction of permeable bases:

5.3.1 **Asphalt-Treated Permeable Base**

a) The aggregates should be preheated to between 275 and 325 degrees F (135 and 163 degrees C).

b) The temperature-viscosity relationship of the asphalt binder should be used to determine the mixing temperatures. For AC-40 (or equivalent 280 degrees F performance-grade asphalt), the recommended mixing temperatures are between 230 and 280 degrees F (110 and 138 degrees C).

c) The compaction process should begin and end when the asphalt temperature is between 150 and 100 degrees F (66 and 38 degrees C) for AC-40 or equivalent binder.

d) Conventional asphalt paving machines can be used to place the permeable base materials.

e) One to three passes of a 5- to 10-ton (4.5 to 9.1 Mg) steel-wheeled static roller are adequate to seat and compact the aggregate.

5.3.2 **Cement-Treated Permeable Base**

a) The cement-treated permeable base can be placed using a spreading machine or a subgrade planer. A paver should follow the spreader.

b) Vibratory plates and screeds on the paving machine can be used for compacting.

c) Polyethylene sheeting, water mist curing, and chemical curing have all been used to cure the cement-treated permeable bases. A test strip should be constructed to determine the curing method that works best for the given situation.

5.4 **Construction of Collector Drains**

5.4.1 **Edgedrain Location.** The location of the edgedrain relative to the pavement is a function of the construction sequence. In pre-pave installations, the edgedrain trench should be located far enough away from the pavement edge so that the paver tracks do not run directly over the trench. In post-pave installations, the edgedrains are installed after the pavement is constructed. In this case, the edgedrains should be placed far enough away from the pavement edge to prevent loss of support underneath the pavement. The pre-pave or post-pave decision may be left with the contractor.

5.4.2 **Trenching.** The trench should be cut at a constant depth so that the bottom of the trench follows the pavement grade. A 2-in. (51-mm) layer of bedding material is recommended beneath the drainage pipe. To obtain proper line and grade, the bottom of the trench should be grooved to cradle the lower one-third of the pipe. The bedding groove helps in holding the pipe in place during installation. The shape of the groove should closely match the shape of the pipe.

5.4.3 **Geotextile Lining.** The trench should be lined with a geotextile to prevent the migration of fines from the surrounding soil. The lining should be such that the portion of the trench adjacent to the permeable base should be open in order to allow free access for the water percolating through the base.

5.4.4 **Pipe Placement.** When placing CPE pipes, care should be taken to prevent overstretching. A maximum tolerance of 5 percent is allowed for overstretching.

5.4.5 **Trench Backfill.** Prior to backfilling the trench, the connections between the pipes and the outlets must be secured. The material used for trench backfill should be stable and at least as permeable as the permeable base material. The backfill material should be gently placed into the trench using chutes in order to avoid damaging the edgedrain pipe. The pipes should not be compacted until a cover of 6 in. (152 mm) is established over the pipes. A high energy

Vermeer vibratory wheel can be used to compact the trench backfill in two lifts. A minimum target density of 95 percent standard Proctor (AASHTO T99) is recommended for the trench backfill.

5.5 **Construction Quality Monitoring**. Proper construction of the subsurface drainage system involves continual monitoring of all its components during the construction phase. This is especially true for the collector drains and drainage outlets. Several studies have documented that a significant percentage of edgedrains and outlets are rendered nonfunctional by the time construction is complete.

5.5.1 **Visual Inspection**. Visual inspection during construction is extremely important to achieve properly functioning drainage system. The following items warrant special attention:

a) Drainage trench dimensions and slope — Ensure that collector drain trenches are excavated to proper depth and slope.

b) Geotextile placement — Ensure that geotextiles are placed as specified and kept clear of contaminants (e.g., fines from surrounding soil). To prevent contamination, the geotextile should be placed just prior to installing drainage pipes. Ensure that the collector drain is open to the base being drained as shown in Figures 14, 15, and 17.

c) Pipe installation — Ensure that the drainage pipes are installed with proper slope and that the pipes are properly connected. Sagging and lateral undulations can be a problem for CPE pipes. Check all connections (between sections of collector drain pipes, collector drain to outlet pipe connection, and connection between outlet pipes and headwalls).

5.5.2 **Acceptance.** Video inspection of the completed drainage systems is highly recommended as an acceptance tool. A detailed list of equipment used in an FHWA study (Daleiden 1998) is given in Table 10. 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 10
Equipment Description for 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 3 to 6 in. (76 to 152 mm) in diameter. The flexiprobe lighthead and camera has a physical size of 2.8 in. (71 mm) and is capable of negotiating 4 in. x 4 in. (102 mm x 102 mm) 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 8-in. (203-mm) 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 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.

Section 6: MAINTENANCE OF SUBSURFACE DRAINAGE SYSTEMS

6.1 **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.

6.1.1 **Visual Inspection.** The visual inspection process includes the following items:

a) 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.

b) 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.

6.1.2 **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. The equipment for video inspection is described in par. 5.5.2.

6.2 **Maintenance Guidelines**

6.2.1 **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 suggested in Section 4. 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.

6.2.2 **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.

6.2.3 **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.

Section 7: NOTES

7.1 Subject Term (Key Word) Listing

Backfill, permeable
Cap, impervious
Drainage, subsurface
Drain, collector
DRIP
Freezing Index
Frost
Geotextile
Manning's roughness
Pavement
Permafrost
Permeability
Pipe, drainage
Porosity
Shoulder
Slope
Structure, pavement
Subgrade

APPENDIX A
DRIP USER'S GUIDE AND EXAMPLE PROBLEMS

A.1 **Introduction**. The microcomputer program *Drainage Requirements in Pavements (DRIP)*, developed under an FHWA contract (Wyatt et al. 1998a), is designed to assist engineers in designing subsurface drainage systems for highway pavements. The modular framework of DRIP is illustrated in Figure A-1. Each of these modules can be accessed either individually to perform a specific design task or sequentially as part of an overall design process. The Design and Analysis node is central to the program and controls the flow of information between modules.

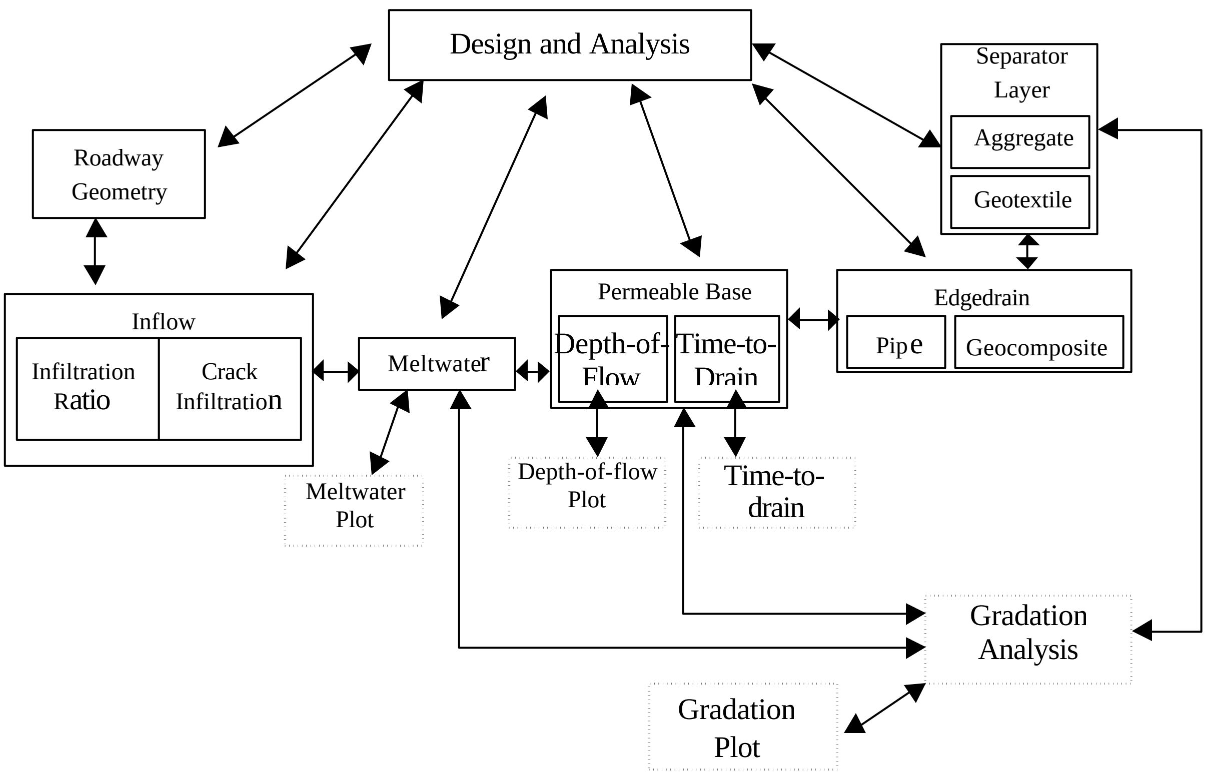

Figure A-1
Modular Framework of the DRIP Program (Wyatt et al. 1998b)

Not all of the modules presented in Figure A-1 is required to perform the design of the drainage systems recommended in this handbook. Therefore, only the relevant modules and their design windows are presented in this appendix.

APPENDIX A (Continued)

A.2 **System Requirements**. DRIP was developed to run under Windows 3.1. The program has been fully tested and verified to run error-free under Windows 95 and NT. Other than the Windows operating system, DRIP does not have any special requirements. However, a 16-color display with small fonts and at least 800x600 resolution is recommended because of the graphical nature of the program.

A.3 **Getting Started**. The opening screen of DRIP is shown in Figure A-2. From this screen you can either start a DRIP session by clicking on the *Begin* button or quit the program by clicking on the *Close* button.

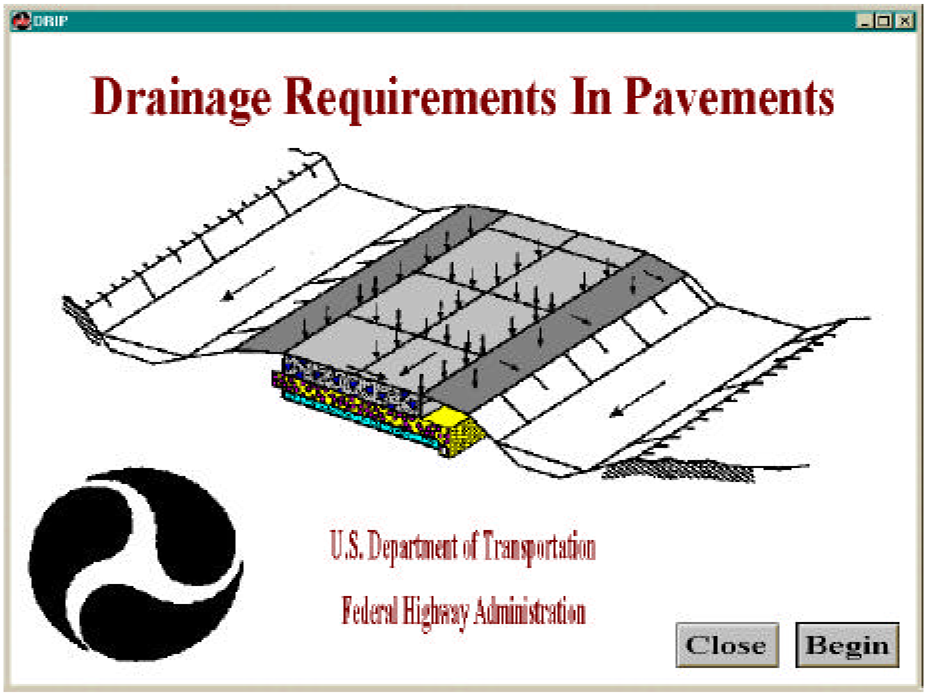

Figure A-2
The Opening Screen of DRIP

APPENDIX A (Continued)

A.4 **Design and Analysis Window**. The *Design and Analysis* window is shown in Figure A-3. This window is the central node of the program. The items listed on the left side of the window — *Roadway Geometry*, *Inflow*, *Permeable Base*, *Separator*, and *Edgedrain* — each correspond to a specific design module. The DRIP design modules may be accessed either by clicking on the respective icons or using the *Go To* list box. Prior to accessing the design modules, however, you need to suitably configure the design options by clicking on the check boxes located on the left side of the window.

A.4.1 **Permeable Base**: Select *Time-to-Drain Method* for the design of permeable base. This is the analysis method used in the guide.

A.4.2 **Separator**: Check *Use Separator Layer* to evaluate separator layer materials.

A.4.3 **Edgedrain**: Select *Pipe* edgedrain. For airfield applications, the guide recommends pipe edgedrains.

A.4.4 **Units**: Select the desired unit system. You have the option to set unit system for each module, but the unit system selected on the *Design and Analysis* window will be the default.

APPENDIX A (Continued)

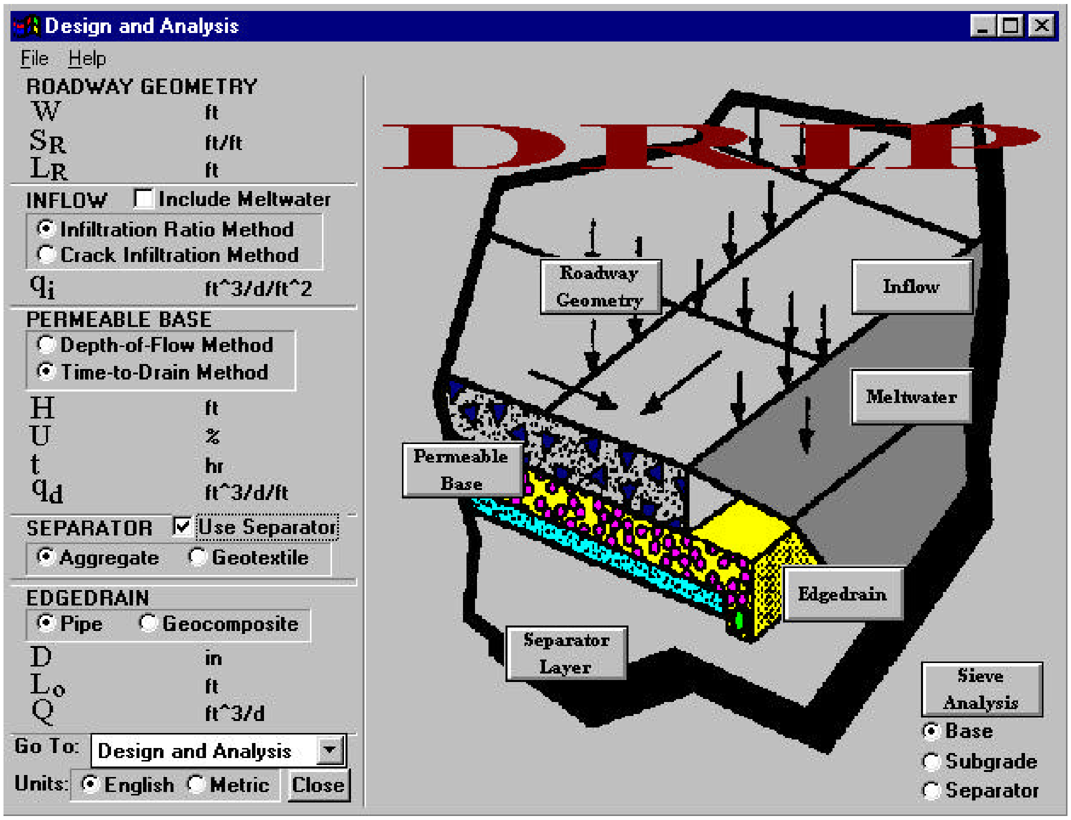

Figure A-3
The Design and Analysis Window

A.5 **Drip Modules**. In this section, the DRIP modules that are relevant to hydraulic design of airfield pavements are explained in detail. Example problems are included to demonstrate the usage of DRIP. DRIP uses the following general convention:

a) When several design modules are executed under the same DRIP session, relevant data are automatically shared between modules.

b) Any window can be closed using the *Close* button at the bottom of the window or by selecting *Exit* from the File menu.

c) Every design window displays a number of inputs and outputs. Also displayed are the equations that relate the inputs to the respective outputs. Once all the input data values for a given equation are entered, a calculator icon next to the output is activated, indicating that the particular output is ready to be computed. Click on the calculator icon to process the input data.

APPENDIX A (Continued)

d) If any of the DRIP-calculated fields are entered manually, DRIP issues a warning message. For example, the resultant slope and drainage path is needed for time-to-drain calculation in the *Permeable Base* module. DRIP includes *Roadway Geometry* module for calculating these values. Therefore, DRIP will issue a warning message if these values are entered manually.

A.5.1 **Sequence of Operation**. DRIP is modular and the sequence of execution of the modules need not follow any particular order. However, the following sequence is recommended:

A.5.1.1 **Roadway Geometry**: Use this module to determine the resultant slope and drainage path. To access *Roadway Geometry* module click on the *Roadway Geometry* button or select *Roadway Geometry* from the *Go To* drop-down menu.

A.5.1.2 **Sieve Analysis**: This module is used to calculate the gradation parameters required in various modules. To access this module, click on the *Sieve Analysis* button or select *Sieve Analysis* from the *Go To* drop-down menu.

A.5.1.3 **Permeable Base**: Perform hydraulic design of permeable base using the time-to-drain method. Choose *Time-to-Drain Method* of analysis under *Permeable Base*, and click on the *Permeable Base* button on the *Design and Analysis* window to access this module. This window requires inputs from the *Sieve Analysis* module for permeable base gradation.

A.5.1.4 **Edgedrain**: Perform pipe edgedrain design using the *Edgedrain* module.

A.5.1.5 **Separator Layer**: Use this module to perform separator layer design. There are two selections for separator layers. Based on the project requirements, the appropriate layer type must be chosen. This module also requires inputs from the *Sieve Analysis* module for subgrade and separator layer gradations (in the case of aggregate separators).

As the design progresses from one step to another, the inputs and outputs of a given module are made available to all modules that are subsequently invoked. However, if a step is inadvertently missed, you need to go back to the module in question and perform the necessary calculations.

A.5.2 **Roadway Geometry Calculations**. The resultant slope, S_R, and the resultant length, L_R, of the flowpath are needed for time-to-drain calculations. The resultant slope is the resultant of the longitudinal slope, S, and cross-slope, S_x, of the pavement; the resultant length is the distance over which water flows within the pavement structure in the direction of the resultant slope. These quantities can be computed using the *Roadway Geometry* module in DRIP.

APPENDIX A (Continued)

A.5.2.1 Roadway Geometry Inputs

a) Roadway cross-section (crowned or superelevated)

b) Lane and shoulder widths

c) Longitudinal grade of roadway (S).

d) Cross-slope of roadway (S_x).

A.5.2.2 Roadway Geometry Outputs

a) Resultant slope (S_R).

b) Resultant drainage path (L_R).

<u>Example A-1: Roadway Geometry Design</u>

Determine the resultant slope, S_R, and the resultant length, L_R, for the following crowned runway section:

Cross-slope, S_x: 0.015 ft/ft
Longitudinal slope, S: 0.0015 ft/ft
Pavement width: 150 ft
Shoulder width: 0 ft

Solution

1. Click on *Roadway Geometry* button from the *Design and Analysis* window to access *Roadway Geometry* module.
2. Enter the lane width, b, and the shoulder width, c. The shoulder width, c, is the distance from the pavement edge to the edgedrain. Typically, edgedrain is located at least 1 or 2 ft away from the pavement edge. Assume c = 2 ft.
3. Choose *Geometry A*.
4. The calculator icon next to “W” should now turn blue. Click on the calculator icon to compute the width of the drainage path, “W.”
5. Enter values of the slopes S and S_x.
6. The calculator icons next to the quantities S_R and L_R should now turn blue, indicating that the solutions are ready to be computed. Compute L_R and S_R by clicking on the respective icons.

Figure A-4 shows the *Roadway Geometry* design window with the inputs and outputs for this example. The resultant slope is 0.01507 ft/ft, and the drainage path is 77.38 ft.

APPENDIX A (Continued)

A.5.3 **Sieve Analysis**. The *Sieve Analysis* module is used to determine gradation parameters for base, separator layer, and subgrade. Three selection buttons are provided under the *Sieve Analysis* button on the *Design and Analysis* window for the selection of the analysis for base, separator layer, and subgrade. Note that the *Separator* button becomes active only if the *Use Separator* check box is checked in the *Design and Analysis* window. The VASDAM (Visual Analysis of Sieve Data for Aggregate Materials) program window corresponding to each of these three layers can be accessed by first selecting the desired layer and then clicking on the *Sieve Analysis* button.

A.5.3.1 **Inputs to the Sieve Analysis Module**

a) Material Name: The name supplied here is used to identify the gradation data being analyzed. The drop-down list box attached to this input can be used to retrieve any gradations saved in the DRIP library. The default DRIP library includes a number of permeable base gradations, including AASHTO # 57, AASHTO # 67, Iowa, Minnesota, New Jersey, Pennsylvania, and Wisconsin. You can save the gradation data that you entered from a DRIP session by clicking on *File* from the *Sieve Analysis* module and then selecting *Save As*. To retrieve previously saved gradation data, click on *File*, then select *Open*.

b) Sieve Data: Select either the *Range* or *Value* selection button. When the *Range* is specified, the gradation parameters are computed for the midpoint of the gradation band.

APPENDIX A (Continued)

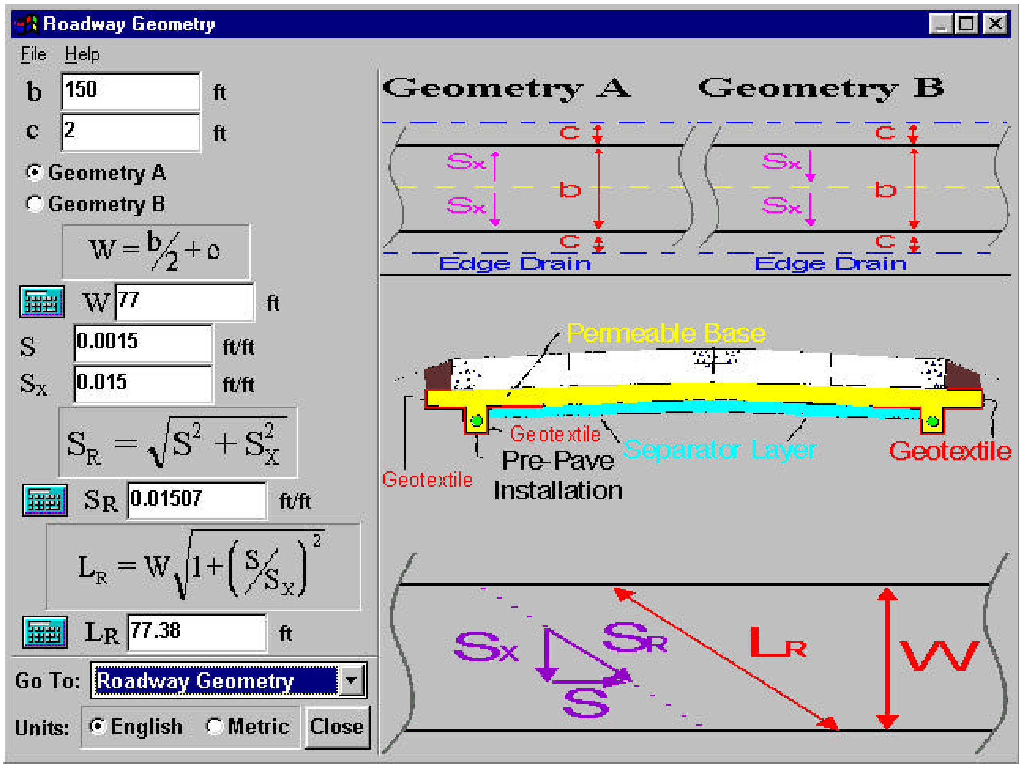

Figure A-4
Roadway Geometry Design Window for Example A-1

c) Sieve Number: A sieve size can be entered with the help of the drop-down menu attached to this input. The drop-down menu is activated by clicking on the *Sieve Number* input field. Click on the desired sieve to make the selection.

d) **%**-Passing: A numeric value indicating the percent of material passing the current sieve number. Enter the appropriate values and click on *Add to Table* button to add the information to the table. To modify the previously entered %-Passing data, select the row to be modified, enter the appropriate values, and click on *Add to Table* button to update the table.

e) Unit Wt: Laboratory determined unit weight of the base material. Guidance for determining unit weight can be accessed by clicking on the *?* button located to the left of this input.

APPENDIX A (Continued)

f) Spec. Gravity: Laboratory-determined specific gravity of the base material. Guidance for determining specific gravity can be accessed by clicking the *?* button located to the left of this input.`

g) Effective Porosity Calculation: Effective porosity can be calculated using either the *Water Loss Method* or the *Water Content Method*. Select the desired method by clicking on the appropriate selection button.

h) W: The water loss coefficient, W. DRIP provides a table of recommended water loss values based on the type and amount of fines (material passing No. 200 Sieve (0.075-mm) material) present in the material. This table is accessed by clicking on the *?* button located next to the symbol *W*.

The sieve analysis window for permeable bases is shown in Figure A-5. As with other DRIP modules, the calculator icon becomes enabled as the required data are provided. Click on the calculator icon to perform the required calculation.

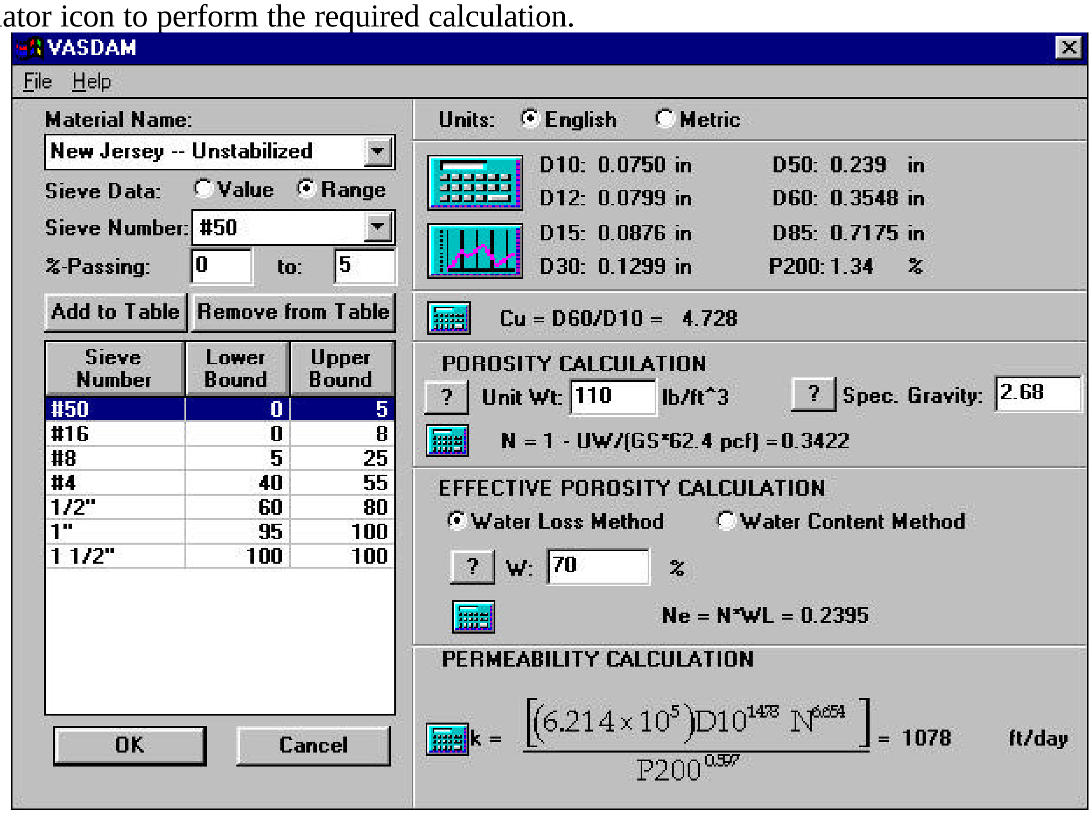

Figure A-5
Sieve Analysis Window for Permeable Bases

APPENDIX A (Continued)

A.5.3.2 **Outputs of the Sieve Analysis Module**. The sieve analysis module provides the following output:

a) D_{10}, D_{12}, D_{15}, D_{30}, D_{50}, D_{60}, and D_{85}. These values are needed for checking filter criteria for the separator layer.

b) P_{200} (percent passing the 0.075-mm sieve).

c) Coefficient of uniformity, C_U.

d) Porosity, N.

e) Effective porosity, N_e.

f) Permeability, k. The permeability estimated in this module is based on empirical correlation for fine-grained soils. The permeability of aggregate materials can deviate significantly from this value. Therefore, this value is not recommended for use; a laboratory-estimated value should be used.

A.5.4 **Permeable Base Design**. The *Permeable Base* module can be accessed from the *Design and Analysis* window by clicking the *Permeable Base* button. Ensure that *Time-to-Drain Method* is selected under *Permeable Base* on the *Design and Analysis* window before entering this module. The design inputs and outputs for this module are as follows:

A.5.4.1 **Inputs for Permeable Base Design Based on the Time-to-Drain Method**

a) n_e: The effective porosity of the base material. The effective porosity can be determined using the *Sieve Analysis* module. If you completed the sieve analysis using DRIP, the value determined from the sieve analysis module should already be shown on the time-to-drain analysis window. Clicking on the calculator icon next to the edit box for n_e will take you to the *Sieve Analysis* module where n_e for the selected gradation can be calculated. Alternatively, n_e determined from laboratory testing can be entered manually.

b) k: The coefficient of permeability of the base material. The value determined by laboratory testing should be used, although the *Sieve Analysis* module can also be used to determine a rough estimate. As with n_e, clicking on the calculator icon next to the edit box for *k* will take you to the *Sieve Analysis* module for estimating *k* using the formula shown on that window.

d) S_R: The resultant slope of the permeable base. This parameter is an output of the *Roadway Geometry* module and automatically appears on this window if that module was previously executed. Otherwise, S_R can be entered manually.

APPENDIX A (Continued)

e) L_R: The resultant length of the drainage path. This parameter is also an output of the *Roadway Geometry* module and automatically appears on this window if that module was previously executed in the same DRIP session. Otherwise, L_R can be entered manually.

f) H: Thickness of the permeable base. A fixed value of 6 in. (150 mm) is recommended for airfield pavements.

g) Either the target percent saturation, S, or percent drained, U is needed to determine time-to-drain. The drainage criteria used in DM 21.06 is the based on time to 50 percent drainage (i.e., U = 50). The relationship between S and U are shown on *Permeable Base – Time to Drain* window. Once either S or U is entered, the other value can be determined by clicking on the calculator icon next to the input parameter.

A.5.4.2 **Outputs of the Time-to-Drain Method for Permeable Base Design**

a) The time required to drain the base to the target percent saturation or percent drained.

b) The drainage history plot. A plot of the percent-drained or percent-saturation of the base with time can be viewed by clicking on the plot icon located immediately below the calculator icon for the time-to-drain calculation (see Figure A-6).

Located on the lower right of the *Permeable Base – Time to Drain* window is the quality of drainage assessment table for highway pavements. Note that the time-to-drain requirements for airfield pavements, as specified in this handbook, are less stringent than those for highways. See Table 4 for the assessment of the quality of drainage for airfield pavements.

Example A-2: Time-to-Drain Determination and Permeable Base Design

Determine the time required for 50 percent drainage for the pavement section given in Example A-1. The permeable base should satisfy the requirements for an *Excellent* quality of drainage as defined in Table 4 (50 percent drainage in 12 hours or less). New Jersey permeable base gradation with a laboratory coefficient of permeability (*k*) of 1,000 ft/day is proposed as the base material. Assume a unit weight of 110 pcf, specific gravity of 2.68, and a water loss coefficient of 70 percent. Assume a permeable base thickness of 6 in.

APPENDIX A (Continued)

Solution

1. Click on *Permeable Base* button from *Design and Analysis* window to access *Permeable Base* module. Be sure that the *Time-to-Drain Method* is selected under *Permeable Base* on the *Design and Analysis* window. If you completed Example A-1, the *Permeable Base--Time-to-Drain* window should already display the values of the resultant slope (S_R) and resultant length (L_R) calculated from the *Roadway Geometry* window.
2. Click on the calculator icon next to the n_e input box. This opens the VASDAM window (Figure A-5). From the *Material Name* drop-down box, select “New Jersey–Unstabilized.” The gradation for this parameter appears and the D_X calculator icon is activated. Click on this icon to compute D_X. Enter the given unit weight, specific gravity, and water loss coefficient in the respective boxes of the VASDAM window. Click on appropriate calculator buttons to calculate the coefficient of uniformity (C_u), porosity (N), and effective porosity (N_e). Click on the *OK* button to close the VASDAM window and return to the *Permeable Base -- Time-to-Drain* window.
3. Enter the base permeability (k) and base thickness (0.5 ft).
4. Enter the target percentage drained value, U(%) = 50 percent. Click on the calculator icon next to percent saturation, *S*, to see what degree of saturation 50 percent drainage represents.
5. Click on the calculator icon next to *t* (time-to-drain) to determine the time required to drain 50 percent of the drainable water. The plot icon below *t* should also become active when all inputs are entered. Click on this button to view the drainage history plot.
6. Check to see if the chosen gradation meets the design standard.

APPENDIX A (Continued)

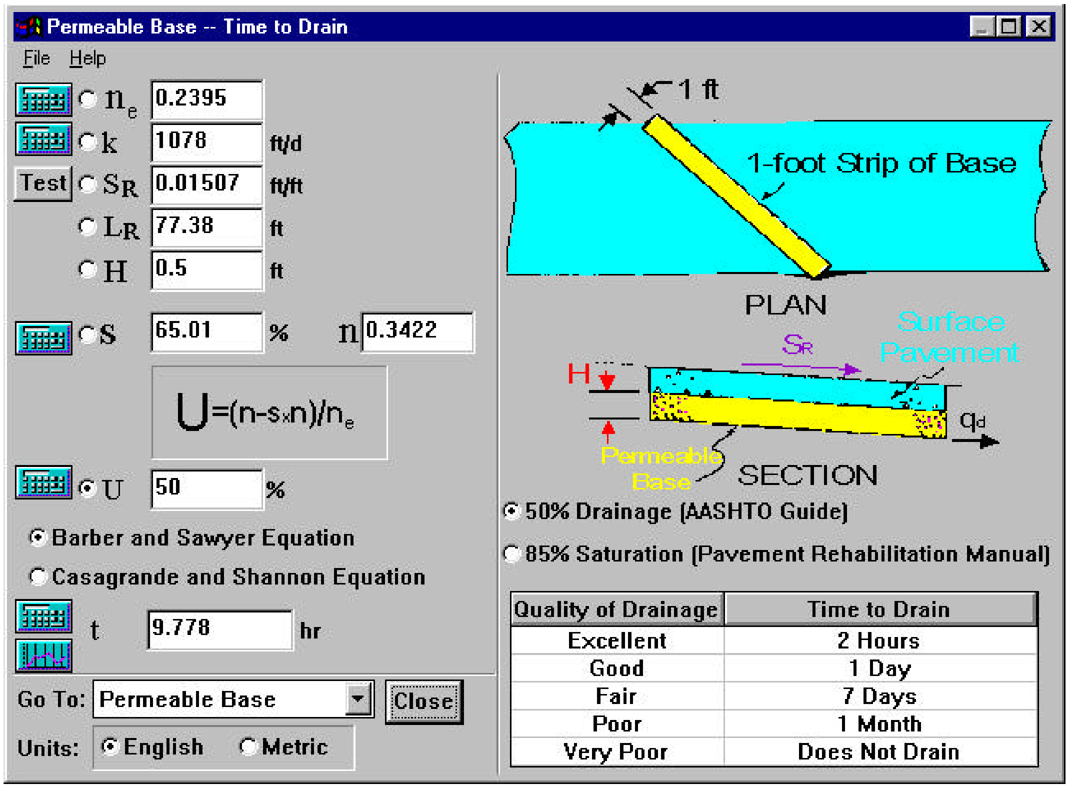

Figure A-6
Time-to-Drain Design Window for Example A-2

Figure A-6 shows the DRIP window with all inputs and outputs for this example. The calculated time-to-drain for this example is 9.778 hours. Therefore, the selected permeable base material meets the design standard.

A.5.5 **Separator Layer Design**. The DRIP *Separator Layer* module performs the automated checking of the filter criteria for aggregate and geotextile separator layers. However, the filter criteria for geotextile separator layer incorporated in DRIP is slightly different than the recommendations given in this handbook. Therefore, DRIP should be used for checking the filter criteria for aggregate separator layer only.

A.5.5.1 **Aggregate Separator Layer Design**. The DRIP window for aggregate separator layer design is shown in Figure A-7. The criteria that need to be satisfied for the design are listed on the right side of the window. The inputs required to compute these criteria are listed to the left of the window.

APPENDIX A (Continued)

a) Inputs for Aggregate Separator Layer Design

(1) Permeable base inputs (D_{15} and D_{50}).

(2) Subgrade inputs (D_{50} and D_{85}).

(3) Separator layer inputs (D_{12}, D_{15}, D_{50}, and D_{85}).

Click on the calculator icon for each layer to determine these values using the *Sieve Analysis* module. Once the required input values are provided, the balance icon on the *Separator Layer* window becomes active. Click on this icon to see if the selected separator layer material satisfies the required criteria. The results are also shown graphically.

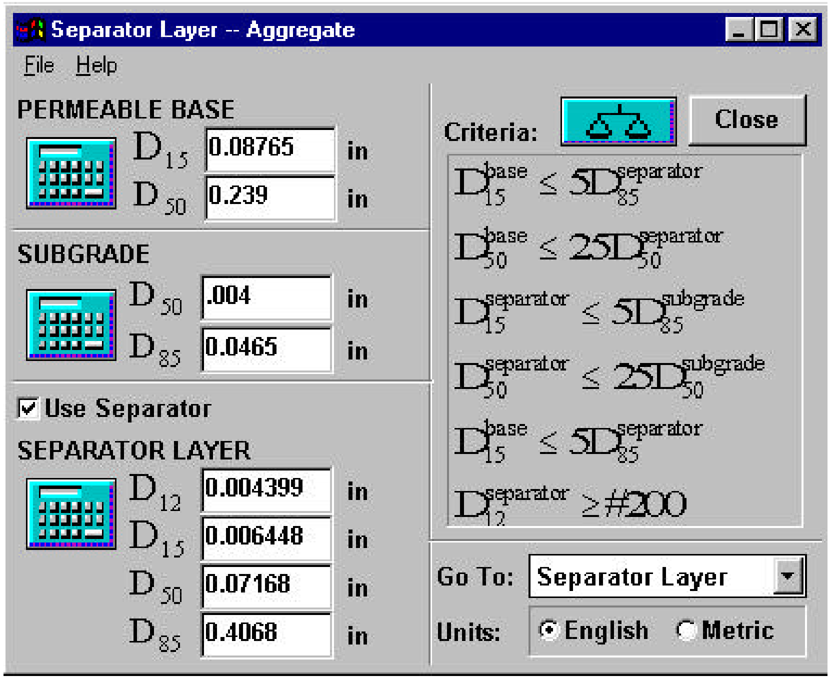

Figure A-7
DRIP Window for Aggregate Separator Layer Design

APPENDIX A (Continued)

A.5.6 **Edgedrain Design**. Pipe edge drains are recommended for use in this handbook. Ensure that *Pipe* radio button is selected under *Edgedrain* on *Design and Analysis* window and click on the *Edgedrain* button to access the *Pipe Edgedrain* window.

Pipe edgedrain design is a two-step process involving the calculation of the pipe capacity, Q, and the outlet spacing, L_o. The output of the first step is an input to the second. Three different options are available for determining the pavement discharge rate: *Pavement Infiltration*, *Permeable Base*, and *Time-to-Drain*. As explained in this handbook, the permeable base discharge option provides the maximum possible discharge from the base layer, but if the base material is extremely highly permeable, the results may be overly conservative. For very highly permeable base, the *Time-to-Drain* method should be used, with the time-to-drain manually entered to achieve the desired quality of drainage (e.g., enter 12 hr for *Excellent* or 168 hr for *Good* drainage). The inputs and outputs for this module are as follows:

A.5.6.1 **Input**. The pipe edgedrain design inputs are the following:

Longitudinal grade, S
Pipe diameter, D
Manning's roughness coefficient (= 0.012 for smooth pipes or 0.024 for rough pipes)

For permeable base discharge calculation, the following are required:

Base thickness, H
Transverse slope, S_T
Base permeability, *k*

For time-to-drain discharge calculation, the following are required:

Base thickness, H
Base width, W
Time-to-drain
Effective porosity, n_e
Percent drained, U (50 percent)

If the *Roadway Geometry* module was used to determine resultant slope and drainage path, the values from that module will automatically be copied to the appropriate input boxes in this module. Similarly, if *Sieve Analysis* module was used to determine gradation parameters, the effective porosity calculated from that module will be automatically imported to this module.

<u>Example A-3. Pipe Edgedrain Design</u>

Design a pipe edgedrain for the permeable base in Example A-2. Assume corrugated pipe drain with 6-in. diameter.

APPENDIX A (Continued)

Solution

1. From the *Design and Analysis* window, ensure that the *Pipe* radio button is selected and click on the *Edgedrain* button to open the *Pipe Edgedrain* window.
2. Enter the values for the longitudinal slope, S, and the pipe diameter, D. Click the *Corrugated Pipe* checkbox to enter the appropriate Manning's roughness coefficient, n. The longitudinal slope, S, will automatically be imported into this window if the *Roadway Geometry* module was previously used in the same session.
3. Click on the calculator button next to pipe capacity, *Q*, to calculate the flow capacity of the edgedrains.
4. Select the *Permeable Base* discharge rate approach and enter the base thickness (*H*), transverse slope (S_T), and base permeability (*k*). If you completed Example A-2, the values from the *Permeable Base* module will be automatically imported into the appropriate input boxes.
5. Click on the calculator icon next to the outlet spacing, L_o, to determine the maximum outlet spacing based on hydraulic considerations.

The inputs and outputs for this example are illustrated in Figure A-8. The maximum outlet spacing determined based on hydraulic consideration for this example is 1,356 ft. However, this value far exceeds the recommended maximum outlet spacing of 250 ft (500 ft for smooth pipes), based on maintenance consideration.

APPENDIX A (Continued)

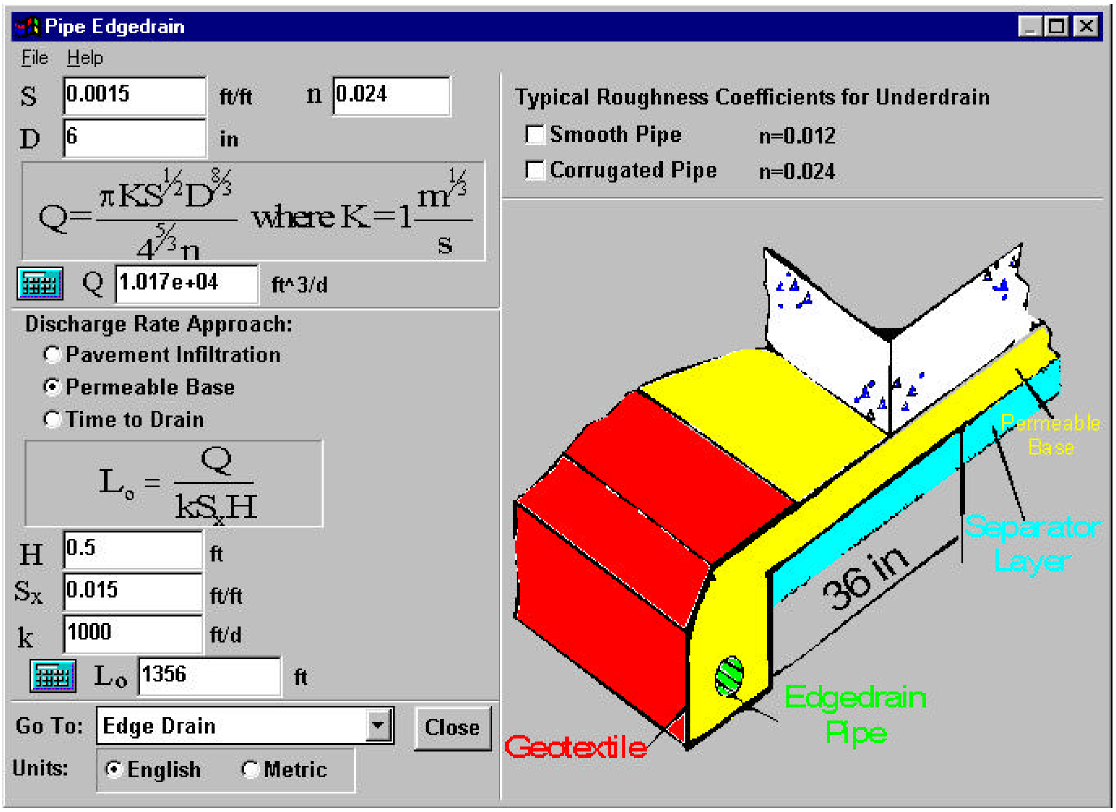

Figure A-8

Pipe Edgedrain Design Window for Example A-4

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REFERENCES

NOTE: THE FOLLOWING REFERENCED DOCUMENTS FORM A PART OF THIS HANDBOOK TO THE EXTENT SPECIFIED HEREIN. USERS OF THIS HANDBOOK SHOULD REFER TO THE LATEST REVISIONS OF CITED DOCUMENTS UNLESS OTHERWISE DIRECTED.

MILITARY HANDBOOKS:

Unless otherwise indicated, copies are available from Defense Standardization Program, Standardization Documents Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.

HANDBOOKS

MIL-HDBK-1021 Series	Airfield Pavement Design

NAVFAC P-PUBLICATIONS:

P-971	Airfield and Heliport Planning and Design

OTHER GOVERNMENT DOCUMENTS AND PUBLICATIONS:

DESIGN MANUALS

DM-5.04	Pavements
DM-7.01	Soil Mechanics
DM-7.02	Foundations and Earth Structures

(Unless otherwise indicated, copies are available from the NAVFAC Web Site: http://criteria.navfac.navy.mil/criteria or National Technology Information Service (NTIS), 5825 Port Royal Road, Springfield, VA 22161.)

DM-21.10	Pavement Design for Airfields

(Unless otherwise indicated, copies are available from the following web site: http://www.pcase.com/.)

ARMY TECHNICAL MANUAL

TM 5-820-3/ AFM885	Drainage and Erosion-Control Structures for Airfields and Heliports

(Unless otherwise indicated, copies are available from the U.S. Army Publishing Agency web site: http://www.usapa.army.mil or National Technology Information Service (NTIS), 5825 Port Royal Road, Springfield, VA 22161.)

NON-GOVERNMENT PUBLICATIONS:

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

AASHTO M252M	Corrugated Polyethylene Drainage Pipe
AASHTO M278	Class PS46 Polyvinyl Chloride (PVC) Pipe
AASHTO T99	Moisture-Density Relations of Soils Using a 2.5kg (5.5 lb) Rammer and a 305 mm (12 in.) Drop

(Unless otherwise indicated, copies are available from the American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol Street, NW, Suite 249, Washington, DC 20001.)

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM C117	Test Methods for Materials Finer Than 75-Micrometers (No. 200) Sieve in Mineral Aggregates by Washing
ASTM D2434	Permeability of Granular Soils (Constant Head)
ASTM D4318	Soils, Liquid Limit, Plastic Limit, and Plasticity
ASTM D4354	Sampling of Geosynthetics for Testing
ASTM D4533	Trapezoid Tearing Strength of Geotextiles
ASTM D4632	Grab Breaking Load and Elongation of Geotextiles
ASTM D4751	Determining Apparent Opening Size of a Geotextile
ASTM D4759	Determining the Specification Conformance of Geosynthetics
ASTM D4833	Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products
ASTM F949	Poly(Vinyl Chloride) (PVC) Corrugated Sewer Pipe with a Smooth Interior and Fittings

(Unless otherwise indicated, copies are available from the American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.)

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION (NEMA)

NEMA TC 2	Electrical Plastic Tubing (EPT) and Conduit (EPC-40 and EPC-80)

(Unless otherwise indicated, copies are available from the National Electrical Manufacturers Association (NEMA), 1300 N. 17th Street, Suite 1847, Rosslyn, VA 22209.)

GLOSSARY

AASHTO - American Association of State Highway and Transportation Officials.

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.

ASTM - American Society for Testing and Materials.

Average Daily Temperature — The average of the maximum and minimum temperatures for one day, or the average of several temperature readings taken at equal time intervals (typically on an hourly basis) during one day.

CBR - California bearing ratio.

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.

CPE - Corrugated polyethylene.

CU - Coefficient of uniformity.

Degree-Days — The degree-days for any one day is the difference between the average daily air temperature and 32 degrees F. The degree days are negative when the average daily temperature is below 32 degrees F (freezing degree-days) and positive when it is above 32 degrees F (thawing degree-days). Figure 5 shows curves obtained by plotting cumulative degree-days against time.

Design Freezing Index — The average air freezing index of the three coldest winters in the latest 30 years of record. If 30 years of record are not available, the index for the latest 10-year period may be used. Design freezing index is illustrated in Figure 5.

DM - Design manual.

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 a part of the base.

DRIP - Drainage requirements in pavements.

Effective Porosity — The effective porosity is 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.

FHWA — Federal Highway Administration.

Freezing Index — The number of degree-days between the highest and lowest points on a cumulative degree-days versus time curve for one freezing season. Freezing Index is a measure of the combined duration and magnitude of below-freezing temperatures occurring during any given freezing season. The index determined for air temperatures at 4.5 ft (1.35 m) above the ground is commonly designated as the air freezing index, while that determined for temperatures immediately below the surface is know as the surface freezing index.

Frost — As it relates to pavements, frost is the condition of free water freezing within the pavement structure or in the subgrade. The action of frost includes expansion or heaving, as well as the loss of support during the melt period. The frost action may result in the formation of ice crystals in any frost-susceptible material within or below the pavement structure to which freezing temperatures penetrate.

Geotextile — A permeable textile used in geotechnical projects. In this handbook, geotextile refers to a nonwoven needle punch fabric that meets the requirements of the apparent opening size, grab strength, and puncture strength specified for the particular application.

Geocomposite Edgedrain — A prefabricated product using geotextiles, geogrids, geonets, or geomembranes in laminated or composite form, which can be used as an edgedrain in place of trench-pipe construction.

LTPP - Long term pavement performance.

Mean Daily Temperature — The average of the average daily temperatures for a given day for several years.

Mean Freezing Index — The freezing index determined based on mean temperatures. The period of record over which temperatures are averaged is usually a minimum of 10 years, the preferred being 30 years. The latest available data should be used. Mean freezing index is illustrated in Figure 5.

MIL-HDBK - Military handbook.

NAVFAC - Naval Facilities Engineering Command.

NEMA - National Electrical Manufacturers Association.

Pavement Structure — Pavement structure is the combination of subbase, base, and surface layers constructed on a subgrade.

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.

Porosity — The amount of voids in a material, expressed as the ratio of the volume of voids to the total volume.

Pumping — Ejection of free water in the pavement layers under the action of moving wheel loads. The water being ejected carries out with it any erodible fines in the pavement layers or from the top of the subgrade, creating voids and loss of support. Under saturated conditions, the combination of the presence of excess free water and large deflections caused by moving wheel loads can also cause migration of subgrade fines into the base or subbase layers.

PVC - Polyvinyl chloride.

Separator Layer — A layer provided directly beneath the drainage layer to prevent fines from infiltrating or pumping into the drainage layer and to provide a stable foundation for the drainage layer.

Stabilization — Use of either portland cement or asphalt to increase stability of the base material to withstand construction traffic or to provide additional structural support for the surface layer. Subgrade soil may also be stabilized with either lime or portland cement to provide a good working platform for construction purposes, as well as to improve foundation support for the pavement structure.

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

CUSTODIAN:
NAVY - YD

PREPARING ACTIVITY:
NAVY - YD

PROJECT NUMBER:
FACR-5023

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.

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I RECOMMEND A CHANGE:	1. DOCUMENT NUMBER MIL-HDBK-1021/6	2. DOCUMENT DATE (YYMMDD): 000415

DOCUMENT TITLE : AIRFIELD PAVEMENT DESIGN FOR FROST CONDITIONS AND SUBSURFACE DRAINAGE

4. NATURE OF CHANGE (identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME *(Last, First, Middle Initial)*	b. ORGANIZATION	
c. ADDRESS *(Include Zip Code)*	d. TELEPHONE *(Include Area Code)* (1) Commercial (2) DSN *(If applicable)*	7. DATE SUBMITTED: *(YYMMDD)*

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c. ADDRESS *(Include Zip Code)* CRITERIA OFFICE 1510 GILBERT STREET NORFOLK, VA 23511-2699	**IF YOU DO NOT RECEIVE A REPLY WITHIN 45 DAYS, CONTACT:** Defense Standardization Program Office (DLSC-LM) 8725 John J. Kingman Road, Suite 2533 Fort Belvoir, Virginia 22060-6221 Telephone (703) 767-6888 DSN 427-6888