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*Drainage Retrofit and Repair*

## **A Review of Airfield Pavement Drainage Guidance**

Rachel L. Hastings, Meghan C. L. Quinn,  
Andrew P. Bernier, and Craig A. Rutland

October 2022



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# **A Review of Airfield Pavement Drainage Guidance**

Rachel L. Hastings, Meghan C. L. Quinn, Andrew P. Bernier, and Craig A. Rutland

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## Abstract

Inadequate drainage conditions may lead to airfield pavement deterioration. A thorough review of existing pavement drainage guidance and literature was necessary to identify key drainage considerations such as surface drainage infrastructure, pavement drainage layer thickness, use of geotextiles, and performance in freeze–thaw climates. Existing airport drainage guidance is provided by the Unified Facilities Criteria (UFC), the Federal Aviation Administration (FAA), and the Tri-Service Pavements Working Group (TSPWG).

Pavement drainage guidance is buried within regulations for pavement design and can, at times, be split awkwardly to accommodate pavement guidance that is split between rigid and flexible designs. Most airfield pavement guidance has been adapted from guidance for highway design. Most guidance is also strength based, with little to no attention paid to material erodibility (a potential cause of pavement deterioration). This review also found very little reference to repairing, rather than completely replacing, damaged subsurface drainage layers. Further research is needed to assess the use of geofabrics and moisture in freeze–thaw conditions on drainage layers and surface structures. With further research, the retrofit and repair of existing subpavement systems might become a more economical solution to drainage-caused pavement deterioration issues than complete reconstruction.

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## Preface

This study was conducted for the US Air Force Civil Engineer Center (AFCEC) under Project Number 488431, “Drainage Repair and Retrofit Design Criteria,” with funding provided by MIPR F4ATA40307JW05. The technical monitor was Mr. Jeb Tingle (GSL).

The work was performed by the Terrain and Ice Engineering group of the Remote Sensing GIS Center of Expertise (RS/GIS CX), US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Dr. Meghan Quinn was group lead, and Mr. David Finnegan was director, RS/GIS CX. The deputy director of ERDC-CRREL was Mr. Bryan E. Baker, and the director was Dr. Joseph L. Corriveau.

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The commander of ERDC was COL Christian Patterson, and the director was Dr. David W. Pittman.

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# 1 Introduction

The deterioration of airfield pavement may be caused by a lack of adequate drainage layers or the degradation of existing pavement drainage layers. Drainage layer deterioration of airfield pavement occurs for a variety of reasons, such as defects in materials, issues during construction, or environment or aircraft-related degradation. Mechanisms of drainage layer degradation include moisture trapped within the drainage layer, which reduces system strength; particle movement due to environmental or loading effects; and strength failure in the native soil.

## 1.1 Background

Airfield pavement deterioration is often presumed to be caused by inadequate drainage conditions. Options for the repair and retrofit of existing pavement drainage and subdrainage systems (and components) are of special interest. Repair and retrofit costs are typically less than those for total replacement or reconstruction of an airfield.

Current guidance related to pavement drainage layers is provided in a Unified Facilities Criteria (UFC) document, *Pavement Design for Airfields* (UFC 3-260-02, USACE 2001b). A published, but not yet adopted, update to this document is available from the US Army Corps of Engineers (USACE), Tri-Service Transportation (UFC 3-260-02, USACE 2014), as is a published, but not yet adopted, update to the currently inactive UFC *Surface and Subsurface Drainage Design* (UFC 3-230-01, USACE 2006). The Tri-Service Pavements Working Group's (TSPWG) *Manual for Airfield Pavement Drainage Layers* (TSPWG 3-260-02.11-4, USACE 2019c), the Unified Facilities Guide Specifications' (UFGS) *Base Course Drainage Layers* (UFGS 32 11 23.23, USACE 2017), and the National Cooperative Highway Research Program also provide guidance. Additional guidance is available from the FAA advisory circular (AC) *Airport Drainage Design* (AC 150/5320-5D, FAA 2013).

## 1.2 Objective

The objective of this report was to provide a thorough literature review of existing guidance and research related to airfield pavement drainage layers. This report documents and summarizes several pavement drainage

layer variables, such as the recommended number of and materials for drainage layers. Other considerations discussed herein include drainage layer thickness, varying precipitation, transient groundwater elevation, use of geotextiles (i.e., engineered fabrics), and performance in freeze–thaw climates.

### **1.3 Approach**

An Engineer Research and Development Center (ERDC) team composed of personnel from ERDC’s Cold Regions Research and Engineering Laboratory (CRREL) gathered to review and summarize the available pavement drainage layer guidance presented in this report.

### **1.4 Scope**

The scope of this report was to summarize existing general guidance on airfield pavement drainage layers and to discuss drainage layer guidance for a few areas of interest (Section 1.2). We examined drainage below flexible (e.g., bituminous) and rigid (e.g., cement-based) pavement and reviewed guidance on groundwater, freeze–thaw, and geological conditions. This literature review will lead to small-scale testing of drainage layer options with water flow and freeze–thaw cycles.

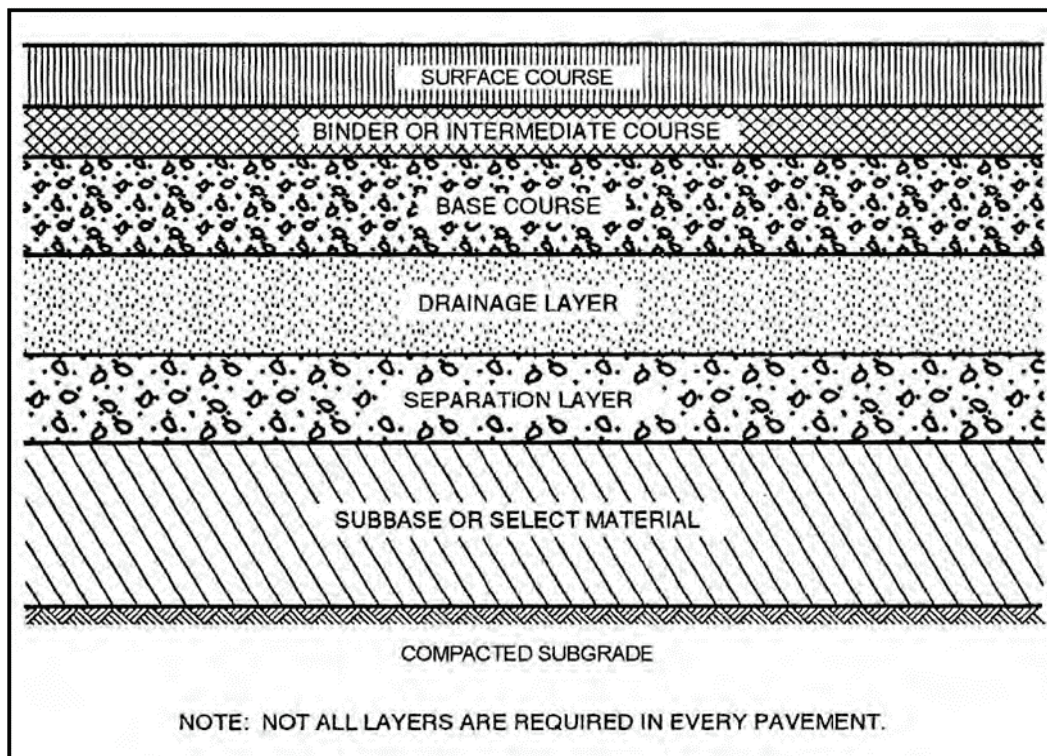
## 2 Pavement and Drainage

Both the UFC and the FAA provide guidance documents on pavement drainage for airfields. A full list of this drainage guidance material is provided in the Bibliography. The TSPWG also provides information about pavement drainage (TSPWG 3-260-02.11-4, USACE 2019c).

### 2.1 Flexible pavements

Flexible pavements are surfaces such as bituminous pavement and hot-mix asphaltic concretes (UFC 3-260-02, USACE 2001b). Flexible pavements are designed so that each structural layer is supported by the layer below it, with the final layer being the subgrade. Figure 1 shows a sectional view of a typical flexible pavement.

Figure 1. Typical flexible pavement structure. Image reproduced from Unified Facilities Criteria (UFC) 3-260-02 (USACE 2001b, 1-4).



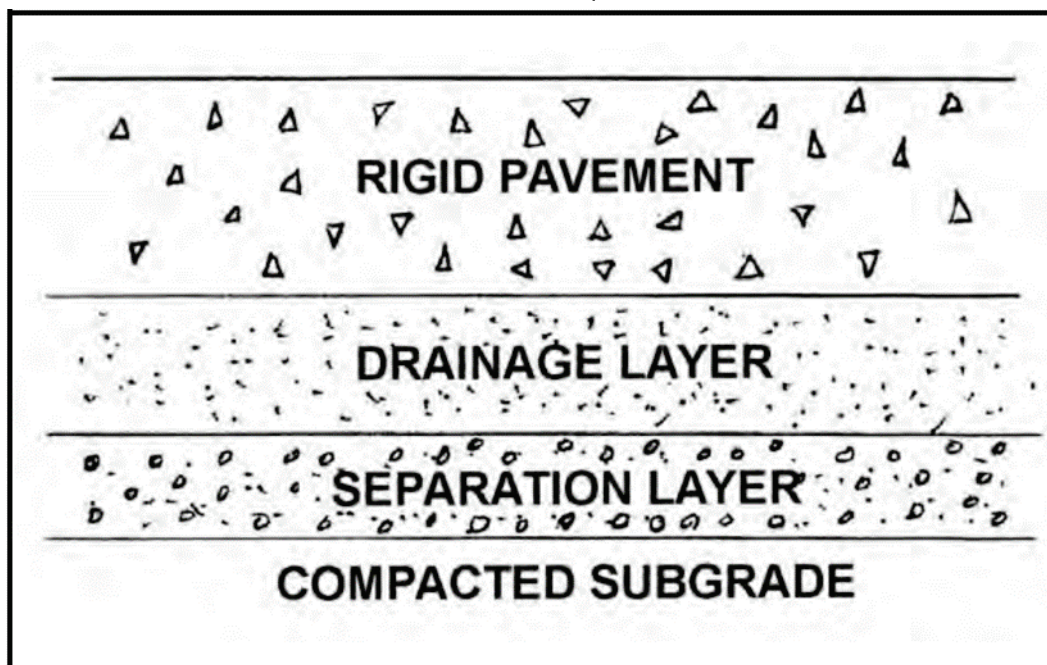
### 2.2 Rigid pavements

Rigid pavements are surfaces that draw principal load resistance from a surface concrete layer (AC 150/5320-6G, FAA 2021) containing Portland cement concrete. Figure 2 shows that rigid pavement typically consists of a

compacted subgrade, a separation layer, a drainage layer, and the rigid pavement layer. A stabilized layer may also be included. Examples of rigid pavement include plain concrete, reinforced concrete, fibrous concrete, prestressed concrete, rigid overlay, and nonrigid overlay (UFC 3-260-02, USACE 2001b).

Rigid pavements are used in paved areas where aircraft are regularly parked (e.g., servicing areas, hangar floors, and runway ends), on runway ends, or in any other area, such as pavement intersections, where flexible pavement would not suit (UFC 3-260-02, USACE 2001b).

Figure 2. Typical rigid pavement structure. Image reproduced from UFC 3-260-02 (USACE 2001b, 1-5).



Rigid pavements require specific soil characteristics and compaction tests, as provided in *Pavement Design for Airfields* (UFC 3-260-02, USACE 2001b). Minimum base courses require at least 100 mm (4 in.) subgrade thickness for many soil types. Fine-grained materials (e.g., silt and clay) are not recommended for use with rigid pavements (UFC 3-250-01, USACE 2016).

### 2.3 Water within the pavement and drainage layer system

Water within pavement subgrades can come from two sources: groundwater and surface runoff. In pavement subgrade layers, groundwater can

infiltrate from elevating groundwater tables, capillary forces, artesian conditions, or freeze–thaw conditions. Groundwater can increase or decrease seasonally depending on soil infiltration and absorption. Seasonal conditions may include drought, evaporation, unseasonal rain, or water flow through the drainage layer. Surface runoff from precipitation or flood events can infiltrate pavement and percolate through the subgrade. Water below pavement and areas in which water may accumulate below pavement must be identified and managed in the exploration and design process (UFC 3-250-01, USACE 2016).

Drainage layers in the pavement help protect pavements from moisture-related failures in the subgrade, subbase, and base because they facilitate the removal of excess water from the pavement structure. The FAA (2021) recommends that airfields have drainage layers if they serve aircraft weighing more than 60,000 lb. and if the local soil permeability is less than 20 ft/day. The FAA also requires drainage layers to achieve 85% drainage in 24 hours for all runways and taxiways. All other low-speed traffic areas must achieve 85% drainage within 10 days. Soils used in the subgrades for these drainage layers must meet the specifications presented in Tables 1 and 2. As specified in Table 3, the drainage layer should be segregated from native soils by a separation layer.

The specifications for a separation layer (Table 3) are provided by the FAA (2013) in the document *Airport Drainage Design* (AC 150/5320-5D). Specifications for separation layers are not provided by the US Army or Air Force at this time. UFC documents (e.g., USACE 2001b) reference a document titled *Subsurface Drainage* (EI 02C202), but this is an inactive UFC document from 1995 with no updates or active replacing documents.

Tables 2 and 3 contain criteria for the California Bearing Ratio (CBR), a measure of soil strength. UFC 3-260-02 (USACE 2001b) requires the CBR to be calculated using the procedures in UFC document CRD-C654-95 (*Standard Test Method for Determining the California Bearing Ratio of Soils*).

**Table 1. Drainage layer material gradation. Adapted from Unified Facilities Guide Specifications (UFGS) 32 11 23.23 (USACE 2017).**

Percentage by Weight Passing Square-Mesh Sieve		
Sieve Designation	Rapid Draining Material (RDM)	Open Graded Material (OGM)
1 1/2 in. (37.50 mm)	100	100
1 in. (25.00 mm)	70–100	95–100
3/4 in. (19.00 mm)	55–100	---
1/2 in. (12.50 mm)	40–80	25–80
3/8 in. (9.50 mm)	30–65	---
No. 4 (4.75 mm)	10–50	0–10
No. 8 (2.36 mm)	0–25	0–5
No. 16 (1.18 mm)	0–5	---

**Table 2. Drainage layer material specifications. Adapted from UFC 3-260-02 (USACE 2001b).**

Property	Rapid Draining Material (RDM)	Open Graded Material (OGM)
Coefficient of permeability (ft/day)	1,000–5,000	>5,000
Effective porosity	0.25	0.32
Percent fractured faces (COE method)	90% for 80 CBR	90% for 80 CBR
	75% for 50 CBR	75% for 50 CBR
Cv	>3.5	--
LA abrasion	<40	<40

Note: Cv is the uniformity coefficient = D60/D10.

**Table 3. Criteria for granular separation layer. Reproduced from Advisory Circular (AC) 150/5320-5D (FAA 2013, 428).**

Criteria for Granular Separation Layer	
Maximum aggregate size	Lesser of 50 mm (2 in.) or 0.25 of layer thickness
Maximum CBR	50
Maximum percent passing 2.00 mm (No. 10)	50
Maximum percent passing 0.075 mm (No. 200)	15
Maximum liquid limit	25
Maximum plasticity index	5
D <sub>15</sub> of separation layer to D <sub>85</sub> of subgrade	≤ 5

## 2.4 Drainage structures

Draining water off, out of, and away from a paved area is an essential component of any pavement system. Water on pavement can disrupt

traffic, decrease road friction, cause hydroplaning, and reduce visibility and steering capabilities (FAA 2013). According to the FAA (2013), the DoD requires that all airfields and heliports design drainage structures to manage, at minimum, a two-year storm event such that there will be no loss of useable surface and less than 4 in. of ponding around a drainage apron inlet. In addition, the drainage spillways should be constructed to direct water volumes up to those produced by the ten-year storm away from the interior 50% of all taxiways, runways, and helipads such that they have no standing water. UFC 3-201-01 *Civil Engineering* (USACE 2018a) provides further guidance for airfields in Section 3-1.2.1, which states, “[For] runways, taxiways, heliports, and aprons, use the minimum [storm event] required by the local governing authority for airfields and heliports or a minimum 5-year storm frequency. Retrofit projects on existing runways, taxiways, heliports, and aprons should be designed using a 5-year storm. Where an engineering and cost analysis indicates that it is advantageous to the project, a minimum 2-year storm frequency may be used for retrofit projects.” UFC 3-201-01 (2018a) provides further guidance regarding drainage inlet design, pipe material selection, storm structure material selection, and acceptable stormwater facilities on airfields.

Drainage structures are designed to control water infiltration, groundwater, or both. Pavement infiltration surface drains collect and remove precipitated or surface flow water. Subdrains control for groundwater by diverting water around the pavement or lowering the water table (UFC 3-250-01, USACE 2016). Surface drainage systems (i.e., catch basins and gutter systems) are designed to collect runoff from pavement in a gutter (or swale) and to convey it to an infiltration or treatment area. These systems typically feed into infiltration trenches, dry ponds, or wet ponds (FAA 2013).

Subsurface drainage structures depend on local soil properties and the proximity of the system to the groundwater table. Soil properties, such as porosity and permeability, are used to evaluate potential drainage system solutions (UFC 3-250-01, USACE 2016). These subsurface structures may include geotextiles acting as a drainage liner between soil layers, subsurface storm drains, or drainage layers.

Geotextiles are sometimes considered to aid pavement drainage. Geotextiles are often used to filter slotted pipes used in edge drains so that

finer particles can be kept out of the edge drain system. Regulations allow geotextiles to be applied as filter membrane strips or using a full-width application (UFC 3-250-01, USACE 2016). Geotextiles used as a separation layer or as part of the drainage layer should comply with the standards listed in Table 4.

**Table 4. Criteria for filter fabric to be used as a separation layer. Reproduced from AC 150/5320-5D (FAA 2013, 429).**

Soil Type	Criteria	ASTM Test Method
Soil with 50% or less passing No. 200 sieve	AOS (mm) < 0.6 mm	D-4751
	Greater than No. 30 sieve	
Soil with greater than 50% passing No. 200 sieve	AOS (mm) < 0.297	D-4751
	Greater than No. 50 sieve	

## **3 Airfield Pavement Drainage Guidance**

### **3.1 Soils**

To design an effective drainage system, the engineer must know soil characteristics and properties, such as density, strength, void ratio, grain size distribution, and plasticity. Soil fines are typically cohesionless (e.g., fine sand and silt) or cohesive (e.g., some silt and clays). When saturated, cohesionless soil can liquefy and lose stability. Loss of stability can result in particle movement or surface-system collapse. If these cohesionless fines cannot be kept at or below optimum moisture content, the base and pavement should be made thicker so that the subgrade will not become overstressed (UFC 3-260-02, USACE 2001b). Cohesive soils should be evaluated for differences in undisturbed soil layers versus disturbed soil layers (i.e., residual) to determine which provides greater strength. If the undisturbed soil displays greater strength, construction operations should be mindful to cause minimal disturbance to the soil (UFC 3-260-02, USACE 2001b).

### **3.2 Flexible pavements**

Flexible pavement systems are used on airfields as a lower-cost, easier-to-maintain alternative to rigid pavements. Flexible pavements are used on airfields only in those areas without potential for fuel spillage, severe jet blast, or parked aircraft, which are commonly runway interiors, secondary taxiways, shoulders, and other areas not specifically required to have rigid pavement (UFC 3-260-02, USACE 2001b). Tables 5 and 6 list the compaction requirements for subgrades under flexible pavements. For flexible pavements, the drainage layer should be placed immediately above the subgrade (AC 150/5320-6G, FAA 2021). Minimum layer thicknesses for the flexible pavement are listed in Table 7.

**Table 5. Compaction requirements for cohesive subgrades and select materials under flexible pavements—Air Force pavements (LL > 25, PI > 5). Adapted from UFC 3-260-02 (USACE 2001b).**

Airfield Type	Depth of Compaction Below the Pavement Surface (in.)							
	85%				90%			
	A	B	C	D or Overruns	A	B	C	D or Overruns
Light	34	32	28	16	27	25	22	12.5
Medium	62	60	50	33	46	45	36	24
Heavy	69	68	57	36	53	52	41	27
Modified heavy	68	66	55	35	51	49	40	26
Shortfield	42	--	--	21	31	--	--	16
Auxiliary	14	13	11	8	11	10	9	6
Airfield type	Depth of Compaction Below the Pavement Surface (in.)							
	95%				100%			
	A	B	C	D or Overruns	A	B	C	D or Overruns
Light	20	19	16	9.5	13	12	10	4
Medium	31	30	24	16	17	16	13	9
Heavy	34	34	28	19	21	20	17	11
Modified heavy	35	33	26	17	21	19	15	10
Shortfield	22	--	--	12	12	--	--	6
Auxiliary	8	7	6	4	4	4	3	3

Note: Conversion factor: millimeters = 25.4 x inches

**Table 6. Compaction requirements for cohesionless subgrades and select materials under flexible pavements—Air Force pavements (LL < 25, PI < 5). Adapted from UFC 3-260-02 (USACE 2001b).**

Airfield Type	Depth of Compaction Below the Pavement Surface (in.)							
	85%				90%			
	A	B	C	D or Overruns	A	B	C	D or Overruns
Light	64	60	52	27	50	44	37	21
Medium	109	106	91	65	85	82	70	48
Heavy	149	145	105	73	95	94	79	55
Modified heavy	123	119	102	70	96	93	78	52
Shortfield	79	--	--	39	59	--	--	29
Auxiliary	24	23	20	11	19	18	15	9

**Table 6 (cont.). Compaction requirements for cohesionless subgrades and select materials under flexible pavements—Air Force pavements (LL < 25, PI < 5). Adapted from UFC 3-260-02 (USACE 2001b).**

Airfield type	Depth of Compaction Below the Pavement Surface (in.)							
	95%				100%			
	A	B	C	D or Overruns	A	B	C	D or Overruns
Light	33	31	26	15	20	19	16	10
Medium	58	56	47	31	31	30	24	16
Heavy	65	64	55	34	35	34	28	19
Modified heavy	65	62	51	33	35	33	26	17
Shortfield	39	--	--	--	22	--	--	11
Auxiliary	14	13	11	--	8	7	6	3

Note: Conversion factor: millimeters = 25.4 x inches

**Table 7. Minimum layer thickness for flexible pavement structures. Reproduced from AC 150/5320-6G (FAA 2021, 3-20).**

Layer Type	FAA Specification Item	Maximum Aircraft Gross Weight Operating on Pavement, lbs. (kg)		
		< 60,000	< 100,000	≥ 100,000
		(27,215)	(45,360)	(45,360)
Asphalt Surface <sup>2</sup>	P-401/P-403	3 in (75 mm)	4 in (100 mm)	4 in (100 mm)
Stabilized Base <sup>3</sup>	P-401 or P-403; P-304; P-306 <sup>3</sup>	Not Required	Not Required	5 in (125 mm)
Crushed Aggregate Base <sup>5,6</sup>	P-209, P-211	Not Required	6 in (150 mm)	6 in (150 mm)
Aggregate Base <sup>5,6</sup>	P-207, P-208, P-210, P-212, P-213, P-219	6 in (75 mm)	n/a	n/a
Drainable Base (When Used)	P-307, P-407 <sup>7</sup>	Not Required	6 in (150 mm) when used	6 in (150 mm) when used
Subbase <sup>6,8</sup>	P-154	6 in (150mm) (if required)	6 in (150mm) (if required)	6 in (150mm) (if required)

Notes:

- Structural design must be completed to determine layer thicknesses required to support actual traffic.
- P-403 as surface course when all aircraft less than 60,000 lbs. (27,215 kg). P-404-Fuel Resistant Hot Mix Asphalt may be used to replace the top 1 1/2 in (75 mm) to 3 in (150 mm) of P-401 or P-403 where a fuel resistant surface is needed; structurally, P-404 considered same as P-401.
- See [FAA 2021] paragraph 3.5, Stabilized Base Course, for requirements and limitations.
- Use of P-304 or P-306 requires measures to control potential for reflective cracking.
- P-208, P-210, P-212, P-213, limited to pavements designed for gross loads of 60,000 pounds (27,215 kg) or less or for use as subbase.
- P-207, P-219 require laboratory testing to establish if it will perform as a base or subbase. If CBR > 100 may be used as a stabilized base, If CBR > 80 may be used in place of P-209, CBR > 60 in place of P-208. Both may be used as a subbase under stabilized base.
- See EB 102, Asphalt Treated Permeable Base.
- P-154, when structural thickness of subbase required by FAARFIELD is less than 6 in, eliminate subbase in FAARFIELD and calculate thickness of base.

### 3.3 Rigid pavements

Rigid pavements are used for all airfield surfaces for which flexible pavements are not considered appropriate. The layers under US Army and Air Force rigid pavement must meet certain minimum thickness requirements based on pavement layer type (i.e., rigid surface, stabilized base, subbase) and maximum expected loading (FAA 2021). The minimum requirements are listed in Table 8. Engineers should use their best judgement to design aggregate base-course drainage that does not trap water beneath the pavement. If using cohesionless sands or similar aggregates, it may be beneficial to increase the aggregate base-course footprint further outside the edge of the pavement (UFC 3-260-02, USACE 2001b).

**Table 8. Minimum layer thickness for rigid pavement structures. Reproduced from AC 150/5320-6G (FAA 2021, 3-21).**

Layer Type	FAA Specification Item	Maximum Aircraft Gross Weight Operating on Pavement, lbs. (kg)		
		<60,000	<100,000	≥100,000
		(27,215)	(45,360)	(45,360)
Rigid Surface	P-501, Cement Concrete Pavement	6 in (150 mm)	6 in (150 mm) <sup>2</sup>	6 in (150 mm) <sup>2</sup>
Drainable Base (When Used)	P-407 <sup>5</sup> , P-307		6 in (150 mm) when used	6 in (150 mm) when used
Stabilized Base <sup>3</sup>	P-401 or P-403; P-304; P-306	Not Required	Not Required	5 in (125 mm)
Base <sup>4</sup>	P-209, P-207, P-208, P-210, P-211, P-212, P-213, P-219, P-220	Not Required	6 in (150 mm)	6 in (150 mm)
Subbase <sup>5</sup>	P-154	6 in (100 mm)	As needed for frost or to create working platform	As needed for frost or to create working platform

*Notes:*

1. Complete structural design to determine rigid surface layer thickness required to support actual traffic.
2. Use greater of FAARFIELD thickness to the nearest 0.5 inch (10 mm), or minimum layer thickness, if all aircraft <30,000 lbs. (11,520 kg) 5 in (125 mm) minimum thickness.
3. See [FAA 2021] paragraph 3.5, Stabilized Base Course, for requirements and limitations. P-220 may be used under concrete with minimum thickness of 12" and when concrete thickness is increased by 3"
4. P-207, P-219 require laboratory testing to establish if it will perform as a base or subbase. If CBR > 80 may be used in place of P-209, CBR > 60 in place of P-208. Both may be used as a subbase under stabilized base.
5. Any base material may be used as a subbase.
6. See EB 102, *Asphalt Treated Permeable Base*.

A thorough investigation into the source, quantity, and characteristics of all materials used to make the rigid pavement layer and sublayers is required for US Army and Air Force rigid pavements. This investigation and verification must confirm the rigid pavement and sublayers are highly

stable and meet all requirements specified by EI 02C202 (as cited in USACE 2001b) and ASTM E 11-20 (*Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves*; ASTM International 2020). The aggregate base courses for US Navy and Marine Corps rigid pavement properties must be in accordance with ASTM D 2940 (*Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports*; ASTM 2003).

Local practices should be evaluated and considered during the material selection process, and local materials should be given preference for all design decisions. There should be minimal fines content in the soil used for the base course. The gradation of the soil used in the base course must meet requirements for stability and drainage. Geotextiles may be used to reinforce the subgrade by providing a buffer to separate the subgrade and base layers in accordance with UFC 3-220-10 (*Soil Mechanics*; USACE 2022) and the minimum thickness requirements stated in Table 9 (UFC 3-260-02, USACE 2001b).

**Table 9. Aggregate base course minimum thickness requirements for US Navy and Marine Corps rigid pavements. Adapted from UFC 3-260-02 (USACE 2001b).**

Base Material	Minimum Thickness
Granular material	152 mm (6 in.)
Cement stabilized	152 mm (6 in.)
Asphalt stabilized	152 mm (6 in.)
Asphalt concrete	102 mm (4 in.)
Lean concrete mixture	102 mm (4 in.)

Note: For subgrades classified as CH, CL, MH, ML, or OL, the minimum granular base course thickness shall be 203 mm (8 in.).

### 3.4 Drainage layer requirements

There might be airfield sites where the native material (i.e., the subgrade) drains adequately and a drain system is not required. According to the FAA (2013) and UFC (USACE 2016), if the permeability exceeds 20 ft/day (6 m/day), no pavement drainage layer is needed. The UFC also allows flexible pavements with 8 in. or less of thickness above the subgrade to not have a drainage layer. For conditions not meeting the criteria, a full drainage analysis should be performed (UFC 3-250-01, USACE 2016).

Though regulations state that drainage systems may not be required, it is usually prudent to install drainage systems below pavement to account for potential site heterogeneity. Per UFC requirements, pavement drainage

systems are designed to handle storms lasting one hour with a probability of occurring once every two years. Drainage pipes must be in accordance with AC 150/5370-10H (*Standards for Specifying Construction of Airports*; FAA 2018).

The first step to designing a subsurface drainage system is measuring the subsurface soil properties and water table conditions. Data collected through field explorations (i.e., drilling borings and excavating test pits) are used in subsurface characterization and topographic mapping to evaluate native site conditions. To get a holistic picture of site conditions, these maps should include details related to water, such as local streams, wells, and reservoirs, along with any topographic changes that affect water movement, such as ditches and channels. Prudent site characterizations should include features, such as vegetation (e.g., type, maturity, and density), slopes, soil exposure, agricultural use, flooding and drainage, erosion, and structures such as bridges or roads, that are observed in aerial photos. Along with a site assessment, information (e.g., related to typical drainage and water table behavior) from local experts can be meaningful (UFC 3-250-01, USACE 2016). It is vitally important to have a holistic understanding of the site conditions and expected drainage system loadings and requirements before starting the design process. Once the initial site conditions are understood, the drainage layer design phase may begin. This design phase will include topographic changes and drainage layer thickness calculations.

### **3.5 Frost considerations**

In frost-susceptible areas, pavement drainage that uses underdrains and culverts should be minimized because soil heave from freezing can cause significant damage, including joint failures and even pipe breakage (FAA 2013). If subpavement drainage utilities are necessary, the drainage pipes should be installed before the base courses to ensure maximum system and soil uniformity. To avoid frost effects, pipe inlets must be placed at or below the depth of maximum frost penetration (FAA 2013), which must be discovered through field study or local data. Soils used in frost conditions are categorized into frost groups based on their ability to drain water even in frozen conditions. These frost groups range from non-frost susceptible (NFS) soils, such as gravel and crushed stone, to highly freezable (F-4) soils, such as silts and clays. Subsurface drainage layers may help control moisture in frost areas constructed on freeze-resistant (i.e., FG-2 or higher) subgrade soils (FAA 2021). Table 10 lists frost design

classifications. Generally, uniform subgrade material must be used to prevent differential heave.

Table 10. Frost design classification. Reproduced from UFC 3-260-02 (USACE 2001b, 3-8).

Frost Group		Kind of Soil	Percentage Finer than 0.02 mm by Weight	Unified Soil Classification Soil Types
NFS*	(a)	Gravels Crushed Stone Crushed Rock	0–1.5	GW, GP
	(b)	Sands	0–3	SW, SP
PFS**	(a)	Gravels Crushed Stone Crushed Rock	1.5–3	GW, GP
	(b)	Sands	3–10	SW, SP
S1		Gravelly Soils	3–6	GW, GP, GW-GM, GP-GM
S2		Sandy Soils	3–6	SW, SP, SW-SM, SP-SM
F1		Gravelly Soils	6–10	GM, GW-GM, GP-GM
F2	(a)	Gravelly Soils	10–20	GM, GW-GM, GP-GM
	(b)	Sands	6–15	SM, SW-SM, SP-SM
F3	(a)	Gravelly Soils	Over 20	GM, GC
	(b)	Sands, except very fine silty sands	Over 15	SM
	(c)	Clays, PI 12	--	CL, CH
F4	(a)	Gravelly soils	--	ML, MH
	(b)	Sands, except very fine silty sands	Over 15	SM
	(c)	Clays, PI 12	--	CL, CL-ML
	(d)	Versed clays and other fine grained banded sediments		CL, ML, SM, CH

\* Nonfrost-susceptible

\*\* Possibly frost-susceptible, but requires laboratory test to determine frost design soil classification

Frost conditions affect the drainage layers below pavement. Pavement can be designed for complete frost protection, limited frost protection, or reduced subgrade strength (FAA 2021). Complete frost protection works to control pavement deformation caused by frost action with a combination of pavement and NFS material thickness. The combined thickness should exceed the total depth of frost penetration for the airfield, thus minimizing disruptions caused by frost. This type of frost prevention is only used for runways and taxiways at very large airports or in areas with low frost penetration (FAA 2021). Limited frost penetration works to keep total

pavement heave to less than 1 in. This requires the combination of pavement and NFS thickness to be 65% of the total frost penetration depth. The final method, accepting reduced subgrade strength, requires increasing the design subgrade strength by about 50% and then allowing frost action to occur. This method is only used for FG-1, FG-2, and FG-3 soils, which are horizontally uniform. It is typically used at low-traffic airports serving smaller aircraft (FAA 2021).

More information on frost-susceptible areas is provided in Chapter 5 of this report.

## 4 Air Force–Specific Drainage Guidance

Drainage layers are required on all Air Force mission-essential pavements, such as runways, taxiways, arm-disarm pads, and overruns, though a few exceptions exist. Exceptions might be permitted in nonfrost areas where the subgrade is shallow and highly permeable and flexible pavements are being used. All other exceptions require a written waiver from the supervising authority (UFC 3-250-01, USACE 2016).

Some soils are unacceptable subgrade materials and must be either removed and replaced with suitable alternatives or treated to allow for use. For example, alternatives and controls should be considered for highly expansive soils to prevent excessive swell. The choice between placing suitable fill and stabilizing native soils is a design and project-cost consideration.

However, it is possible that some highly compacted soils will swell when soil moisture increases. This swelling can generate significant uplift pressures and potentially cause differential upheaving of pavements. This condition may be controlled by compacting the soil at a moisture content and density suited for minimal uplift pressure, by providing overburden pressure that counteracts the swelling, or by placing a permeable layer over the soil to keep it in a saturated condition (UFC 3-260-02, USACE 2001b). Table 11 lists the recommended treatments for swelling soils.

Table 11. Recommended treatment of swelling soils. Reproduced from AC 150/5320-6G (FAA 2021, 3-7).

Swell Potential (Based on Experience)	Percent Swell Measured (ASTM D1883)	Potential for Moisture Fluctuation <sup>2</sup>	Treatment
Low	3-5	Low	Compact soil on wet side of optimum (+2% to +3%) to not greater than 90% of maximum density per ASTM D698. <sup>2</sup>
		High	Lime or cement stabilize soil to a depth of at least 6 in (150 mm)
Medium	6-10	Low	Lime or cement stabilize soil to a depth of at least 12 in (300 mm)
		High	Lime or cement stabilize soil to a depth of at least 12 in (300 mm)
High	Over 10	Low	Lime or cement stabilize soil to a depth of at least 12 in (300 mm)
		High	For uniform soils, i.e., redeposited clays, stabilize soil to a depth of at least 36 in (900 mm) or raise grade to bury swelling soil at least 36 in (900) mm below pavement section or remove and replace with non-swelling soil. Increase to 60 in (1,500 mm) when variable soil deposits are present.

Notes:

1. Soluble sulfate in either soil or mixing water above 3,000 ppm may cause expansion, above 5,000 ppm require special treatment to avoid expansive reactions. Generally, cement stabilization recommended for soils with soluble sulfates greater than 3,000 ppm.
2. Potential for moisture fluctuation is a judgment determination. Consider proximity of water table, likelihood of variations in water table, as well as other sources of moisture, and thickness of the swelling soil layer.
3. Base the design subgrade strength on the moisture content and density used to control swelling.
4. Generally, lime stabilization works best on clay soils and cement on coarser soils with low clay/silt content. However, cement stabilization works on almost all soil types.
5. For lime stabilization, utilize 1-2% more lime than amount needed to increase the soil pH to > 12. Sufficient lime to increase the unconfined compressive strength of the soil at least 50 psi.
6. For cement stabilization, utilize 1-2% more than determined following the PCA method. See *PCA Soil Cement Construction Handbook* or UFC 3-250-1.1, *Soil Stabilization*

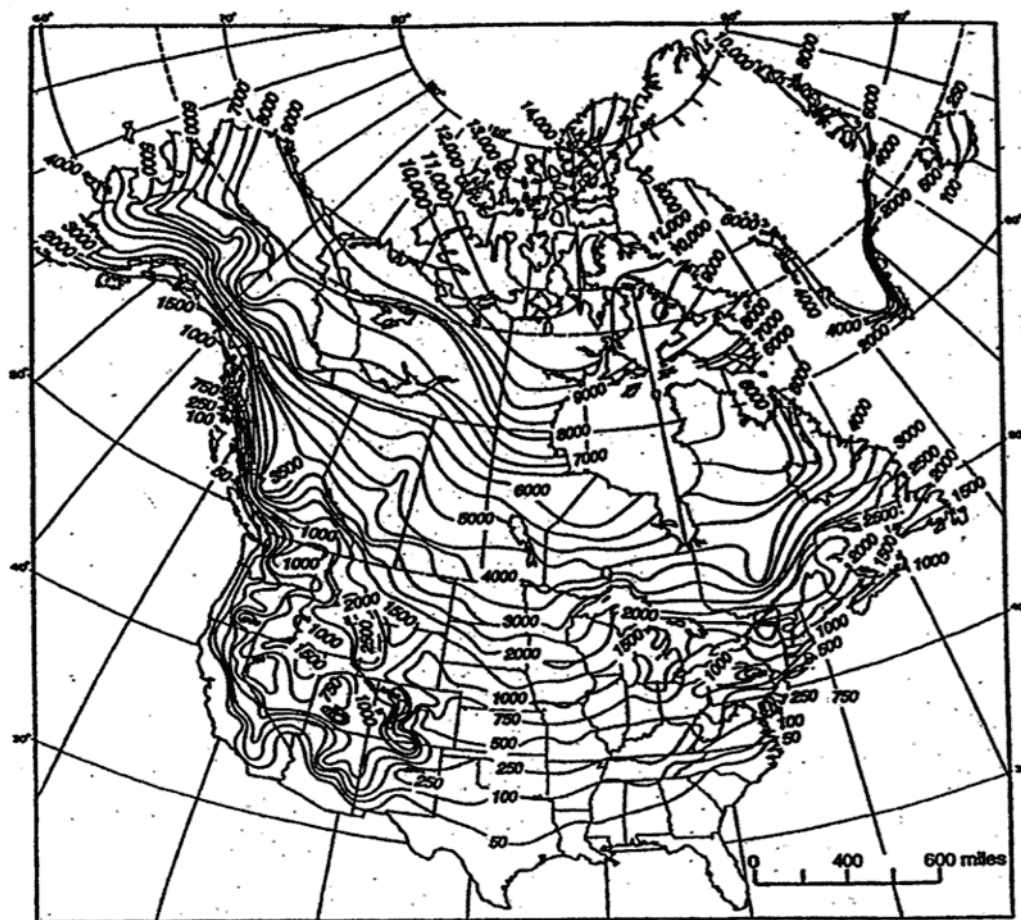
## 5 Drainage Guidance in Frost-Susceptible Areas

Areas subject to seasonal frost conditions, such as freeze–thaw, require special consideration. In base course material, frost action results in differential heave, decreases in soil strength during the thaw-weakened months, and premature failure of the pavement. Frost can also cause loss of compaction, increased pavement roughness, restrictions of draining, and asphalt cracking. Subbase materials that are less susceptible to mobility of fines in wet conditions should be selected. Pavements (indoor or outdoor) must be robust enough to reach the design life through expected freeze–thaw cycles (UFC 3-260-02, USACE 2001b).

For the evaluation of frost considerations, soils are divided into eight groups based on frost susceptibility and bearing capacity (as determined by laboratory tests). Table 10 lists soils in order of most to least useful (based on decreasing soil strength and increasing frost susceptibility). The most useful categories for frost-risk designs are NFS material, possibly frost-susceptible (PFS) material, gravelly soils (S1), and sandy soils (S2; UFC 3-260-02, USACE 2001b).

Figure 3 shows the design freezing index by geographic region, which can be used to determine the total pavement, base, and subbase thickness needed at a given location. The freezing index is based on the three coldest years in a 30-year record (UFC 3-250-01, USACE 2016). The map can be read by interpolating between freezing index contours, or the design freezing index can be determined for a specific location.

Figure 3. Distribution of design freezing indexes in North America. Image reproduced from UFC 3-250-01 (USACE 2016, 73).



CONVERSION FACTORS

$$^{\circ}\text{C} - \text{HOURS} = 13.33 \times ^{\circ}\text{F} \text{ DAYS}$$

NFS material must be used to construct the shoulder base and subbase courses of small structures in the shoulder pavements, such as drain inlets, to prevent differential frost heave. The NFS material should extend at least 1.5 m (5 ft) away from the small structure, with gradual transitions beyond that distance. Synthetic insulation could be used instead to prevent the subgrade from freezing. The UFC documents require that drainage in flexible pavements must comply with EI 02C202, but as mentioned previously, this document has been removed from active use and not replaced (UFC 3-260-02, USACE 2001b).

Base course material for areas with seasonal frost must have the following characteristics:

- The top 50% of the total base thickness must be NFS.
- The bottom 50% of the total base thickness must be NFS, S1, or S2 material.
- Materials of lower accepted quality must be tested frequently after compaction to demonstrate compliance with standards.
- There must be no mixing of the base and subbase course materials with frost-susceptible subgrade soils (UFC 3-260-02, USACE 2001b).

Cement- or lime-bound base should not be used under frost conditions beneath bituminous pavement without prior approval, nor should an unbound course go between two impervious layers. A drainage layer may be required if the subcourse materials do not meet minimum requirements (i.e., drainage of 20ft/day) under testing (UFC 3-250-01, USACE 2016). Asphalt concrete layers must have a 100 mm (4 in.) NFS drainage layer just below the asphalt. The same is required below rigid pavement layers and beneath the bound base for all pavements in frost-susceptible areas. The drainage layer is treated as a structural component and serves as part of the base course (UFC 3-260-02, USACE 2001b).

Areas with subgrade freezing also require a 100 mm NFS separation layer between the subgrade and the base course. A deeper thickness may be required over weak subgrades. A geotextile fabric may be used as a substitute for the separation layer (i.e., filter) if the foundation is already stable (UFC 3-260-02, USACE 2001b).

Subgrades in frost areas that will encounter freezing should be made as uniform as possible by mixing all soils into a single homogeneous layer. This minimizes differential frost heave across the pavement surface. The least frost-susceptible soils should be placed as the upper subgrades of fill sections (UFC 3-260-02, USACE 2001b). Wet, fine-grained subgrades must be treated for frost conditions using fill material by either raising the grade or excavating and replacing the wet, fine-grained material. NFS material should be used. Any areas with wet subgrade will require further care and drainage considerations (UFC 3-250-01, USACE 2016).

Drains, culverts, ducts, and other such structures (sometimes referred to as *utilities*) should not be placed under frost-susceptible pavements unless there is no other option. If they are placed under pavement, they must be designed in accordance with the correct methods, as stated in *Pavement Design for Airfields* (UFC 3-260-02, USACE 2001b). The utilities should

be placed prior to the subbase and base course. Back-excavating completed course layers to lay out the facilities causes differing support strength and is not permitted.

Drain inlets, hydrants, and pavement lighting systems can cause abrupt differential frost heaves because they possess different thermal properties than the surrounding soils. The pavement sections within 1.5 m (5 ft) of the structures should therefore be designed using NFS base course and insulation to prevent freezing. Anchoring the footings with spread bases should also be considered (UFC 3-260-02, USACE 2001b).

During replacement or reconstruction of existing airfield pavements, using different base or subbase materials or thicknesses can cause noticeable differential frost heave that can result in problems with snow removal, surface ponding, and icing, leading to the loss of control of aircraft. The differences can be longitudinal or transverse, depending on the nature of the reconstruction. Differential heave must be minimized by conducting summer and winter surface elevation surveys prior to designing a new facility. The differential heave can be negated or minimized by using material transitions or by using the same material from the previous build. Experienced design engineers should consider whether to reuse a material that performed poorly in the previous design (UFC 3-260-02, USACE 2001b).

Compacted subgrade thicknesses can be designed to negate the potentially severe losses in soil strength caused by seasonal thaw. Compacting the subgrade can make a lower thickness than otherwise required and is useful for both rigid and flexible pavements with uniform subgrades. This method may require further justification (UFC 3-250-01, USACE 2016).

Freeze–thaw cycles can cause groundwater to penetrate pavement sections. Freezing groundwater can cause significant damage, such as frost heaves, loss of material density, and loss of pavement strength, to the pavement structure. Frost heave may be reduced using proper soil material, insulation, steel reinforcement, soil layer transitions, or drainage. Soils with high capillary potential and low cohesion are particularly susceptible to frost (UFC 3-250-01, USACE 2016).

## 6 Existing Research

### 6.1 ERDC research

Over the past 20 years, ERDC has studied the airfield pavement drainage layers at Elmendorf Air Force Base, Alaska; Tinker Air Force Base, Oklahoma; Fort Bliss, Texas; and Cannon Air Force Base, New Mexico. These studies analyzed overall performance and, in some cases, evaluated defects and investigated their causes. Elmendorf, Tinker, and Fort Bliss were examined in 2008 to assess the long-term effectiveness of the drainage layers and provide recommendations for future drainage-layer design (Rushing and Mejias-Santiago 2009).

Rushing and Mejias-Santiago (2009) tested drainage layer performance by drilling a hole through the pavement to the top of the drainage layer and then placing PVC pipe into the hole. The pipe was sealed using polyurethane foam, and a 2 in. hose connected to a flow meter was placed in the pipe. Water from a water truck was forced through the hose down into the drainage layer until reaching the maximum drainage layer capacity without overflowing. Total flow and time to infiltrate that flow was recorded. GPR was used to determine moisture profiles below the pavement.

Rushing and Mejias-Santiago's (2009) assessments of the drainage layers at Elmendorf, Tinker, and Fort Bliss found that the proper design and construction of pavement drainage layers on airfields was vital to a successfully performing system. They also found that the soil permeability rates were all still acceptable, but there was little evidence of routine maintenance, which in turn had caused systems to clog to the point that there was no difference between the performance of pavements with or without drainage layers. The authors recommended closely monitoring systems during and after construction, considering alternate drainage systems that do not require subsurface maintenance, and conducting the required routine maintenance to keep systems functioning. These recommendations, in part, inspired this study.

In 2019, ERDC researchers Lein et al. (2019) measured soil thermal conductivity and temperature through multiple freeze–thaw cycles for frost-susceptible soil types. The researchers determined that moisture migration was the most significant cause of frost heave and penetration in soils. The experimental results were used to develop a thermodynamic finite element

model that could eventually be used to more accurately predict frost depth and deflection for airfield runway and general pavements.

## 6.2 Other research

In 2004, Al-Qadi et al. studied pavement drainage layers and examined the effectiveness of a geocomposite membrane with geotextile layers as a moisture barrier in flexible pavements. The study was conducted on a roadway pavement using GPR to monitor and detect moisture content. The authors found that using the geocomposite membrane (between two geotextile layers) reduced water infiltration into the aggregate base layer by up to 30%. They also found that the area with a geocomposite layer showed less pavement deflection than uninsulated areas.

In 2008, drainage layer performance was evaluated at three US Air Force bases. The study, authored by Mejias and Rushing (2011), considered the overall usefulness of a required drainage layer on the pavement. The researchers evaluated the layers by introducing water into the pavement and observing how it flowed through the layers. The layers were evaluated using permeability and current drainage design criteria. The researchers found that while drainage layers must be well maintained to remain effective, the drainage layers themselves were useful but should be required only where there is potential for water entering the pavement and causing problems.

Li et al. (2018) analyzed the performance of an asphaltic drainable base course layer for flexible airport pavements. They found that the addition of the asphaltic drainable base layer increased structural capacity, pavement performance, and pavement longevity. They recommended that the FAA continue using additional treated drainable base materials with the goal of considering saturated conditions.

## **7 Conclusions: Knowledge Gaps**

### **7.1 Conclusions and knowledge gaps**

Based on this review, most drainage layer and soil guidance is related to strength rather than material erosion. In some cases, this has led to erosion problems and soil movement (i.e., piping). This area needs further research and recommendations for solutions.

More research needs to be performed on how rapid-draining material (RDM) and open-graded material (OGM) drainage layers compare to straightforward graded material or geotextiles.

More research should also be performed, and more guidance should be written on, using stabilizers in drainage layers. More research is also needed on using geotextiles in drainage layers.

Most drainage infrastructure is designed for standard roads and has been adapted to airports. Additional study into what is effective for airfields would allow for more detailed recommendations.

Very little research has been conducted on how to repair a drainage layer once it has been clogged or damaged. Most maintenance is focused on monitoring and identifying problems and is followed by pavement replacement, not repair. The UFC and FAA both provide guidance on how to build a drainage layer, but there is little on the maintenance or repair of existing drainage layers. Because monitoring and maintenance are two of the most important activities in prolonging the life of a pavement, further research into accomplishing these tasks with the drainage layer is necessary.

### **7.2 Recommendations**

A research study should be conducted on scaled drainage systems with multiple conditions. This study should include the use of geofabrics, differing beginning moisture contents and densities, and different soil types. The study should measure the moisture content of the soil as rain events occur and should capture the water and materials that leave the drainage layer.

Guidance should be created on simple field tests to quickly determine native soil permeability and drainage repair methodologies.

Finally, a further study should be conducted on potential airfield pavement retrofit or repair options for drainage. Potential studies could include surface drainage retrofits for a damaged or missing drainage layer, drainage layer repair, and drainage layer replacement.

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## Abbreviations

AC	Advisory Circular
ERDC	Engineer Research and Development Center
DoD	Department of Defense
CBR	California Bearing Ratio
CRREL	Cold Regions Research and Engineering Laboratory
GPR	Ground penetrating radar
NFS	Non-frost susceptible
OGM	Open-graded material
PFS	Possibly frost susceptible
RDM	Rapid draining material
S1	Gravelly soils
S2	Sandy soils
TSPWG	Tri-Service Pavements Working Group
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
USACE	US Army Corps of Engineers

# REPORT DOCUMENTATION PAGE

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<b>14. ABSTRACT</b> Inadequate drainage conditions may lead to airfield pavement deterioration. A thorough review of existing pavement drainage guidance and literature was necessary to identify key drainage considerations such as surface drainage infrastructure, pavement drainage layer thickness, use of geotextiles, and performance in freeze-thaw climates. Existing airport drainage guidance is provided by the Unified Facilities Criteria (UFC), the Federal Aviation Administration (FAA), and the Tri-Service Pavements Working Group (TSPWG).  Pavement drainage guidance is buried within regulations for pavement design and can, at times, be split awkwardly to accommodate pavement guidance that is split between rigid and flexible designs. Most airfield pavement guidance has been adapted from guidance for highway design. Most guidance is also strength based, with little to no attention paid to material erodibility (a potential cause of pavement deterioration). This review also found very little reference to repairing, rather than completely replacing, damaged subsurface drainage layers. Further research is needed to assess the use of geofabrics and moisture in freeze-thaw conditions on drainage layers and surface structures. With further research, the retrofit and repair of existing subpavement systems might become a more economical solution to drainage-caused pavement deterioration issues than complete reconstruction.						
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