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Evaluation of Nontraditional Airfield Pavement Surfaces for Contingency Operations

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Abstract

During the period November 2012 through September 2013, research was conducted at the US Army Engineer Research and Development Center (ERDC) in Vicksburg, Mississippi, to develop pavement evaluation guidance to improve the field performance prediction for nontraditional airfield pavements used during contingency operations. Nontraditional airfield pavements investigated included wearing surfaces comprised of sand asphalt, macadam, bituminous surface treatments, or stabilized soils/aggregates. These pavement types may be encountered during contingency operations or in remote regions where traditional airfield construction materials such as asphalt or portland cement concrete are not readily available or are too cost-, labor-, or equipment-intensive to use. This report presents a review of the literature pertaining to the mechanical properties of these nontraditional materials and the development of an interim evaluation procedure for predicting the performance of these pavement types for the C-17 and C-130 aircraft. Recommendations for improving the interim evaluation procedure through field verification tests are also presented.

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Preface

This study was conducted for the US Air Force Civil Engineer Center (AFCEC) under the project “Nontraditional Pavement Evaluation.” The Technical Monitor was Dr. Craig Rutland, AFCEC.

The work was performed by the Airfields and Pavements Branch (GM-A) of the Engineering Systems and Materials Division (GM), US Army Engineer Research and Development Center, Geotechnical and Structures Laboratory (ERDC-GSL). At the time of publication, Dr. Gary L. Anderton was Chief, CEERD-GM-A; Dr. Larry N. Lynch was Chief, CEERD-GM; and Dr. David A. Horner, CEERD-GV-T, was the Technical Director for Force Projection and Maneuver Support. The Deputy Director of ERDC-GSL was Dr. William P. Grogan, and the Director was Dr. David W. Pittman.

COL Jeffrey R. Eckstein was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (US liquid)	3.785412 E-03	cubic meters
Inches	0.0254	meters
pounds (force)	4.448222	newtons
pounds (force) per foot	14.59390	newtons per meter
pounds (force) per inch	175.1268	newtons per meter
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6.894757	kilopascals
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
tons (force)	8,896.443	newtons

1 Introduction

1.1 Problem

In the Global War on Terrorism (GWOT), the United States has conducted major military operations in the Middle East for more than 10 years. However, in recent years, attention has shifted to Africa and the Asia-Pacific region due to increased political tensions, revolutions, humanitarian aid, and terrorist expansion in those areas. If military operations, humanitarian relief missions, or civilian or military personnel evacuations are required in these areas in the future, there may be little to no airfield pavement infrastructure to support contingency airlift operations, particularly in developing nations or in remote regions of developed nations. Access to paved airfield infrastructure would be especially problematic on the African continent, which has more than 4,000 airports and airfields of which only 20% are paved (UNEC 2007). In contrast, in the Asia-Pacific area, there are an estimated 3,500 airports or airfields of which at least 60% are paved (CIA 2013). While there are a tremendous number of airfields in existence, only a fraction of them meet International Civil Aviation Organization (ICAO) standards, and even those may not be compatible with US military cargo aircraft such as the C-17 and C-130. These aircraft have supported the worldwide, rapid transport of personnel and supplies for decades, and it is anticipated they will continue to be utilized for years to come.

In the United States and other developed countries, airfield surfaces (or surfaced courses) are generally constructed using hot mix asphalt (HMA) or portland cement concrete (PCC), both of which are suitable for C-17 and C-130 aircraft operations when constructed according to airfield specifications. These types of materials may not be employed in the areas under consideration due to greater variability in, or possibly lack of, suitable pavement construction materials, quality of construction (skill, availability of heavy equipment, and standard procedures), and differences in the number of aircraft operations and the weights of the aircraft in these locations. As a result, the United States may encounter airfields with “non-traditional” surfaces better suited for road construction, airfield pavement base materials, or temporary pavements. Examples of surfaces that could be encountered include macadam, sand asphalt, bituminous surface treatments, or stabilized soil/aggregate. A thorough review of these nontraditional airfield pavements is needed to determine how to evaluate these pavements and how to determine their in situ performance under C-17 and C-130 traffic.

While well-established methodologies exist for evaluating the in situ performance of traditional airfield pavements using equipment such as the heavy weight deflectometer (HWD) or falling weight deflectometer (FWD), applying these methods to nontraditional airfield pavements may over- or under-predict the pavement performance. Deflections measured with these devices are used in conjunction with evaluation software to determine what load and pass levels of the critical aircraft can be supported by the pavements through back-calculation analyses. For the HWD/FWD, without a clear understanding of the classification of the materials or properties and a general understanding of the as-constructed pavement structure, back-calculation analyses cannot be conducted with any degree of certainty. Thus, if an inspection team is tasked with evaluating these non-traditional airfield pavements for opening and operating a contingency airfield, a refined evaluation procedure is required. The procedure will have to include site assessment guidelines, equipment recommendations, and an improved evaluation procedure using current software.

1.2 Objectives and scope of the current investigation

The objective of the research presented in this report was to provide recommendations for establishing a methodology for evaluating non-traditional airfield pavements. While the areas of interest are Africa and the Asia-Pacific region, these methods could be applied for any contingency airfield evaluation where nontraditional pavements are encountered. To achieve the objective, information was gathered on various pavements including macadam, sand asphalt, bituminous surface treatments, and stabilized pavements. The information was used to gain a better understanding of each pavement's construction procedures and material properties. Current Air Force and Army pavement evaluation procedures were also reviewed to determine what modifications would be required for evaluating nontraditional pavements. Following these steps, preliminary contingency pavement evaluation processes for each pavement were developed.

This report describes the various nontraditional pavements in Chapter 2. The visual inspection procedures for each nontraditional pavement and methods of distinguishing between pavement surfaces are presented in Chapter 3. Chapter 4 presents procedures for conducting structural evaluations of the pavements, while pertinent conclusions and recommendations are noted in Chapter 5.

2 Investigated Pavements

When evaluating a potential contingency airfield site in Africa or remote locations in the Asia-Pacific region, a number of different nontraditional pavements could be encountered. As mentioned in Chapter 1, traditional PCC or HMA may be the exception in these locations rather than the general rule due to lack of access to materials, expertise, or equipment in developing countries or in remote regions of developed nations. Existing pavements are likely to have either been constructed primarily by hand labor, possibly with some limited use of heavy construction equipment, and small batch plants (if available), or they may have been constructed using older methods of pavement construction during periods of colonization by European nations. These conclusions regarding construction methods are based upon historic facts.

The first reason is that, after World War II, there was a large push on the African continent to employ as many laborers as possible to construct roads and other infrastructure assets (SABITA 1993a). Prevalent construction methods during this time included macadam, sand asphalt, surface treatments, and unsurfaced pavements. These construction methods were suitable to the region, because they could be accomplished using local materials, minimal heavy equipment, and with small or temporary batch plants. After World War II, developed countries on the African continent (including South Africa and Egypt), as well as developed portions of Asia, moved away from these construction techniques to HMA and PCC construction for roads and airfield pavements. In colonized countries, these techniques would have most likely been applied to airfield and road construction. However, with the departure of European colonists from nations gaining independence and through extended periods of civil war and political strife, expertise in these techniques was lost. It is not unreasonable to assume that in locations without quality materials, expertise, or heavy equipment, there would have been no other option than to continue to rely on nontraditional airfield construction methods to the present day.

The second reason is that, in 1971, the World Bank initiated a labor-intensive/enhanced road construction study (International Bank for Reconstruction and Development 1971). Since that time, several national programs and pilot projects were established in African countries, including Kenya, Botswana, Lesotho, Malawi, Mozambique, Ethiopia, Gambia, Ghana, and Tanzania (SABITA 1993a). These programs and projects were aimed at not only improving or providing roadway infrastructure for the first time, but also for social and political objectives such as reducing unemployment rates and developing employable skills. Labor-intensive methods explored included unsurfaced construction, macadams, and surface treatments. While intended for roadway construction, these techniques may have also been applied to airfield construction, particularly for smaller airfields that have few aircraft operations with generally low tire pressures.

The third reason is that, in 1993, South Africa initiated a program to shift its reliance on plant-based paving efforts to more labor-based methods for the same sociopolitical reasons described previously. The Southern African Bitumen and Tar Association (SABITA) published manuals describing these techniques, which have been adopted by other countries in Africa due to their wide availability on the Internet (SABITA 1993a,b). Surfacing techniques explored since this program's initiation include surface treatments, dust palliatives or stabilization efforts, and macadam pavements (Emery et al. 1994a,b). One of most highly investigated techniques was macadam due to its labor-based construction suitability (Visser and Hattingh 1999). For high traffic areas for roads, both HMA and sand asphalt were still recommended but required access to plant-mixed materials, construction expertise, and heavy construction equipment.

Another reason is the prevalence of using thin surface treatments over strong base construction in Australia, New Zealand, and surrounding territories. According to Emery and Caplehorn (1993), while traditional airfield construction techniques such as HMA are generally used in Australia and its neighboring territories, surface treatments on a strong base course (also called a bitumen seal) have been used successfully in remote areas without access to an HMA batch plant for aircraft up to the size of the Boeing 767, for occasional operations. Several types of surface treatments including single, double, triple seals, and cape seals have been used in various airports in the Australian territories (such as Cocos Island) with triple seals and cape seals recommended for high stress areas. These construction methods may have been applied in countries in Asia due to the ease of access to construction guidance documents published by Australian authorities on the Internet.

Because of the historical and reported types of pavements among the countries located on the African and Australian continents and the above information, the following pavement surface construction techniques were selected to be explored in more detail: macadam, sand asphalt, stabilized soils/aggregates, and bituminous surface treatments. The following sections describe each of these pavement types.

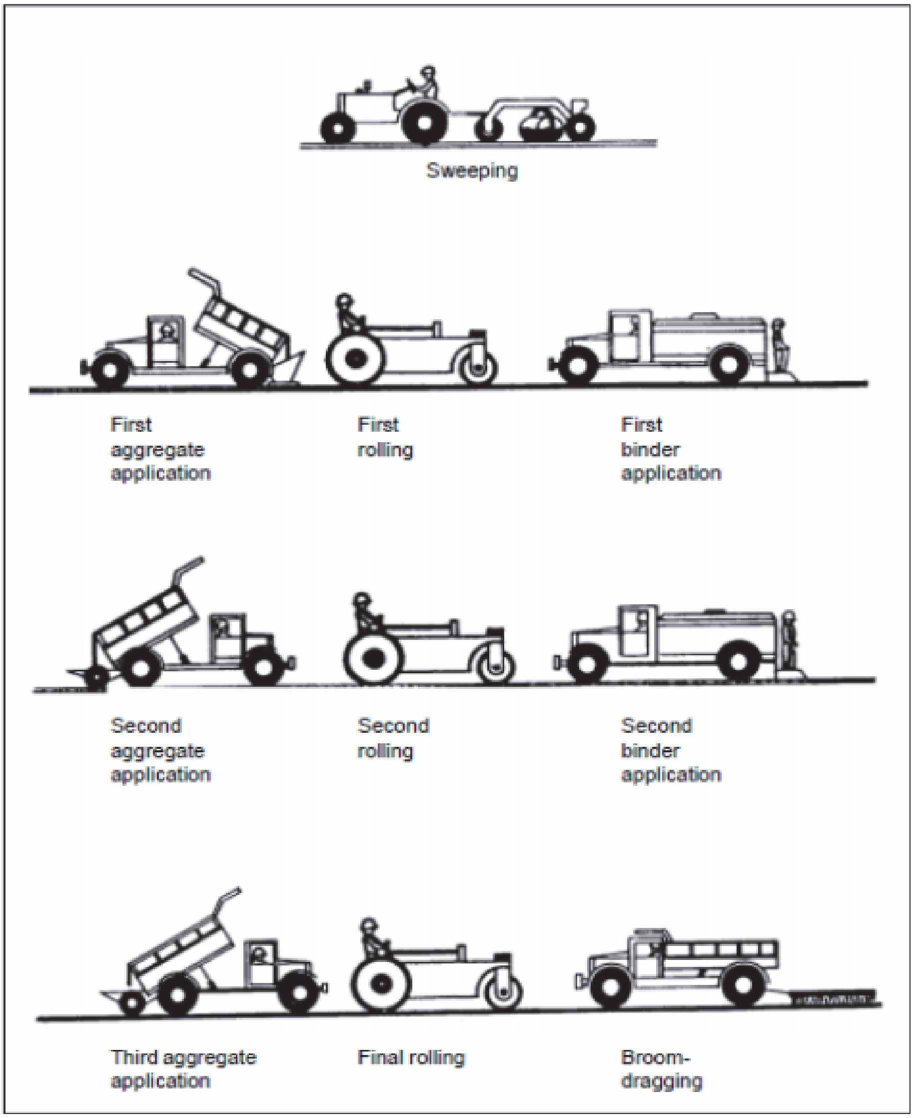
2.1 Macadam pavements

Macadam is one of the oldest forms of pavement construction, dating back to the 1820s, and relies on stone-on-stone contact to support vehicle loads (Visser and Hattingh 1999). The construction consists of placing a layer of single-sized coarse aggregate, followed by vibrating fine aggregates, into the voids (dry-bound macadam) or using water to flush the fines into the voids (water-bound macadam). These fines provide stability and help reduce dislodging of the coarse aggregate under traffic.

In some early versions of this construction, coal tar was poured over the finished aggregates to waterproof the surface and provide additional stability. This variation was called tarmacadam. The process was improved during the first half of the 20th century with the use of a separate macadam-wearing surface on a prepared base called penetration macadam, asphalt penetration macadam, or asphalt macadam. In this process, penetrating coats of asphalt binder were applied to a compacted layer of uniform-graded, coarse, angular, crushed-rock aggregate. This was then covered with smaller, fine aggregates called key stone or key aggregates; another application of asphalt binder; and an application of stone chips. The entire surface was then rolled and broomed to fill surface voids. This process is similar to chip seals used on low-volume roads. Figure 1 presents the construction procedure for a penetration macadam surface course placement as presented in Army Field Manual 5-436 “Paving and Surfacing Operations” (Headquarters, Department of the Army 2000). Figure 2 shows schematics of various macadam pavements. As can be seen in the figure, the voids in the water- or dry-bound macadams are mostly filled but, in the penetration macadam, the voids are not completely filled.

Macadam pavement construction waned in popularity after 1960 with the adoption of HMA or PCC, which were better suited to support higher traffic volumes and tire pressures in modern aircraft. Penetration macadam surfaces are no longer recommended for US military airfield pavements with the exception of overruns not subjected to blast (Headquarters,

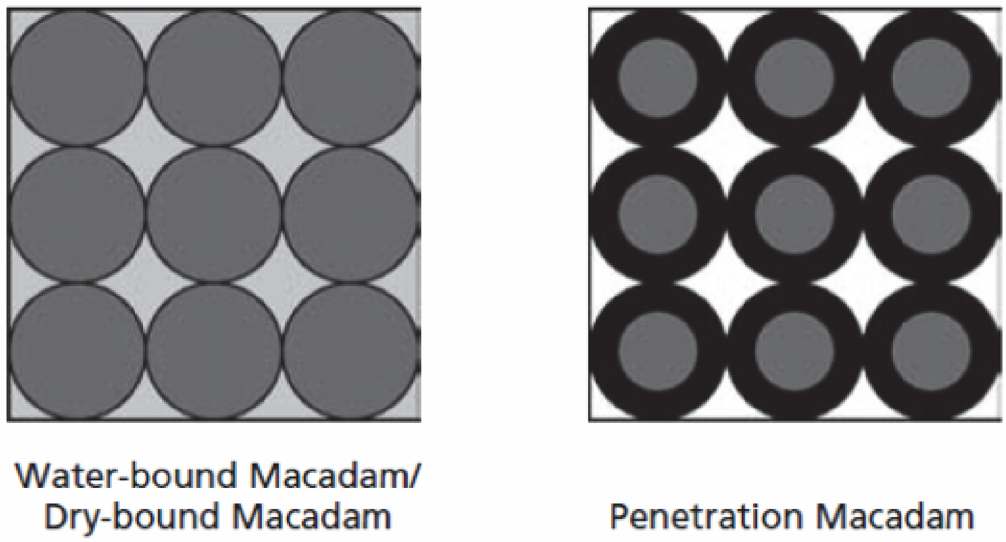
Figure 1. Procedure for placing a penetration macadam surface course (Headquarters, Department of the Army 2000).



Department of the Army 2000). The biggest concern for using macadam for airfields is foreign object damage (FOD) due to dislodged aggregates. Also, the asphalt does not entirely fill the voids, resulting in a wearing surface that is less dense than HMA (Ellis 1979). Because of this, when the pavement is relatively new, the surface may rut and shove (Headquarters, Department of the Army 1951). When the pavement ages, it tends to crack and ravel, exposing aggregates and leading to high FOD potential.

Despite abandonment by many countries, this method is still employed today in locations where expertise or access to modern construction materials is not available or not economically feasible. While labor intensive, this construction method has low relative equipment and material costs

Figure 2. Schematics of macadam pavements (Construction Industry Development Board (CIDB) 2005).



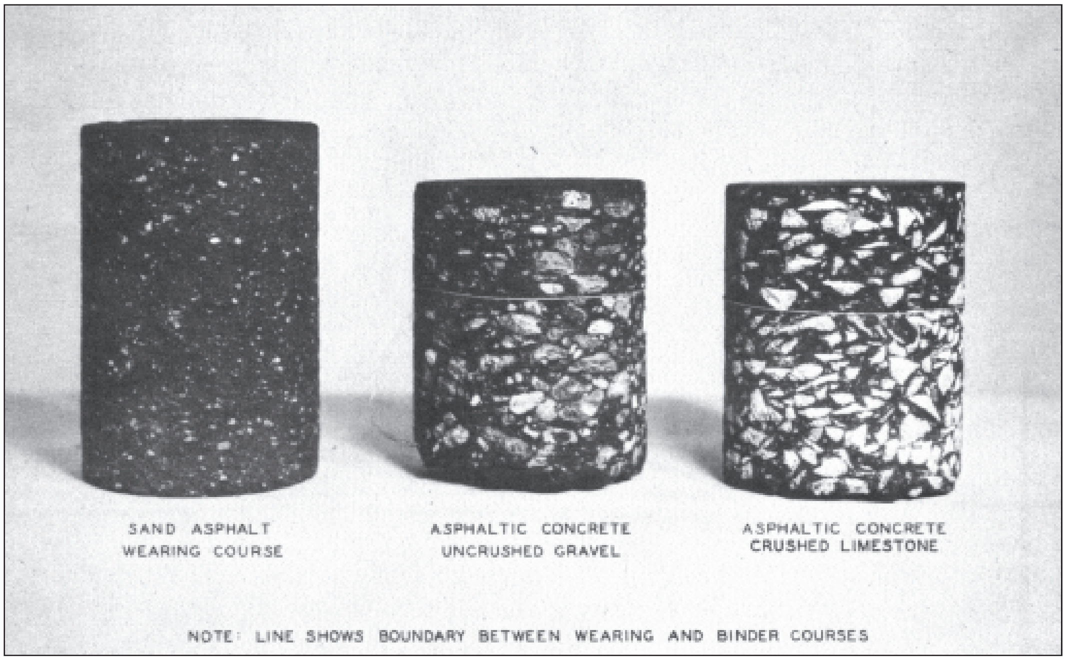
and can support low-volume road and street traffic. This method may also have been applied to airfields in developing countries during the labor-intensive construction initiatives from the 1970s to 1990s and continued to the present day. Finally, in some countries, older pavements constructed out of macadam may also be encountered in abandoned areas or at remote airfields utilizing lighter aircraft traffic.

2.2 Sand asphalt

Sand asphalt is an asphalt paving mixture composed of sand and asphalt binder prepared without the careful grading used for traditional HMA. Sand asphalts are used as the wearing surface for street or road construction in regions where sand is of a good quality and is abundant or is the only available aggregate (Headquarters, Department of the Army 2000). While sand asphalt mixtures are fine-textured, dense, and relatively impermeable, they are not generally recommended for airfield surfaces because they lack the strength and durability needed for high tire pressures (Headquarters, Department of the Army 1957). Figure 3 presents cores taken from sand asphalt and traditional HMA, showing the difference in composition.

The use of sand asphalt in Africa was reported as early as the 1930s with a road constructed from Cairo to Alexandria in Egypt. It was also used in the United States from 1870 until the 1960s. As with macadam, sand asphalt pavement construction waned in popularity after 1960 in most developed countries. Sand asphalt use, however, has continued in developing countries and in parts of South Africa and the Middle East for roads and parking lots due to its ability to incorporate under-utilized deposits of sands in regions where coarse aggregates are unavailable or expensive to transport (SABITA 1996).

Figure 3. Cores from sand asphalt and HMA (Headquarters, Department of the Army 1948).



Sand asphalt is not recommended for pavements with tire pressures above 100 psi due to rutting concerns (Headquarters, Department of the Army 2000). In addition, sand asphalt surfaces can oxidize and become brittle with age or crack and ravel if constructed without sufficient asphalt binder. They are generally more susceptible than HMA to cracking from temperature, load, and aging and perform best when subjected to continuous, all-over traffic providing kneading action not typically experienced with airfield pavements (Headquarters, Department of the Army 1957). Even if well constructed, new sand asphalt surfaces may be soft, leading to rutting or shoving (Headquarters, Department of the Army 1951).

As with macadam pavements, this type pavement may still be used for airfield construction in remote regions where either HMA or PCC is not available or the well-graded aggregates typically used for these materials are unavailable. The literature shows that sand asphalt was used successfully as a surfacing material in Southern Africa (in Mozambique and Zimbabwe) for road construction up until the 1970s (Horak and Makundila 2011) and in other countries in Africa and in South America for airfield surfacing until the 1970s (Morgan et al. 2003; Harris et al. 1995). The technology may have been applied to airfield construction during and since this time. Sand asphalt was used extensively in Mozambique and Zimbabwe for road construction; however, the expertise in its use was lost during periods of social unrest and wars in the 1970s. Recently, efforts have been made to apply cold emulsion mixing techniques to re-create sand asphalt pavements in Mozambique (Horak and Makundila 2011). These pavements may still be used for low-volume airfields supporting aircraft with low tire pressures or may be encountered as abandoned pavements.

2.3 Stabilized soil/aggregate

Stabilization of soil/aggregate is a construction method used in unsurfaced pavement construction. The process improves the properties of the native soil by adding supplementary materials. Stabilizing the surface of the soil improves its bearing capacity and durability (compared to untreated surfaces) and may be employed to reduce costs associated with PCC or HMA surfacing. Stabilization can be accomplished by blending additives such as portland cement, lime, fly ash, asphalt binder, polymers, or fibers with the natural soil. In stabilizing soil, strength, durability, cohesion, and reduced swelling properties may be improved (UFC 2004).

Cement is the most widely used stabilizing agent, as it enhances tensile and compressive strength, which contribute to increased bearing strength. In addition, cement is generally available throughout the world and is relatively inexpensive to use. High percentage cement additions can greatly increase the bearing strength of the material but can result in brittle pavement behavior, leading to cracking and reduced structural performance. In addition to cracking, other common distresses that may be encountered in cement- or lime-stabilized surfaces include crushing of the cemented surface, rutting, and delaminations.

Lime stabilization reduces plasticity and is desirable when the material being stabilized has a plasticity index greater than 10%; for a plasticity index less than 10%, cement is generally recommended. Often a combination of lime and cement may be used (UFC 2004). Similar distresses to those previously described for cement-stabilized materials may be experienced.

In addition to these methods, asphalt stabilization has gained much interest in recent years for base and subbase construction. While asphalt stabilization does not typically provide as great an increase in strength as cement-stabilized pavements, this stabilization technique is often employed to provide water resistance, increased cohesion, and flexibility to the stabilized layer when compacted (Asphalt Academy 2009). The increased cohesion can decrease rutting under traffic when the asphalt-stabilized material is used as a base course; however, rutting is still a common distress that may be encountered when asphalt-stabilized material is used as a surface course. For ideal stabilization, materials with a CBR less than 20% and/or with a plasticity index greater than 15 are not recommended for asphalt stabilization.

Due to the speed of construction and low costs, unsurfaced stabilized soil airfields are commonly used in many areas of the world for contingency military operations (Griffin and Tingle 2009). This form of construction is also less costly compared to PCC or HMA surfacing, and may be used in developing countries for both road and airfield construction. The stabilization technique most likely to be encountered in a contingency environment is cement stabilization due to its worldwide availability. Additionally, this material does not require mechanical distribution. Because the cement can be spread by hand, cement stabilization is the most likely method in austere environments and in labor-intensive construction regions. While gaining acceptance worldwide for base treatments, particularly in South Africa, asphalt stabilization is more expensive than cement stabilization, and it requires mechanical distributors to apply the asphalt binder. While asphalt-stabilized material may be encountered as a surface course, cement-stabilized materials are more likely to be used for that application.

2.4 Bituminous surface treatments

A bituminous surface treatment, also known as a surface seal, is a method of pavement construction in which asphalt binder is sprayed onto an existing substrate, which is then covered with a layer of aggregate (either stone or sand). The substrate may be an existing HMA surface, an old surface treatment, or a prepared aggregate base. However, in the area of interest presented in this document, surface treatments are expected to have been applied to a prepared aggregate base for weatherproofing. The aggregate is rolled into the binder either by direct compaction or by trafficking of vehicles to ensure good adhesion between the binder and the aggregate and to work the binder into the voids between the aggregate particles.

Following compaction or during trafficking, the surface treatment densifies and becomes relatively impermeable. For road construction, generally only a fraction of the densification is achieved by rolling with a compactor; the remaining compaction is provided by vehicle traffic. Additional applications of binder and aggregate may then be applied (Emery 2008).

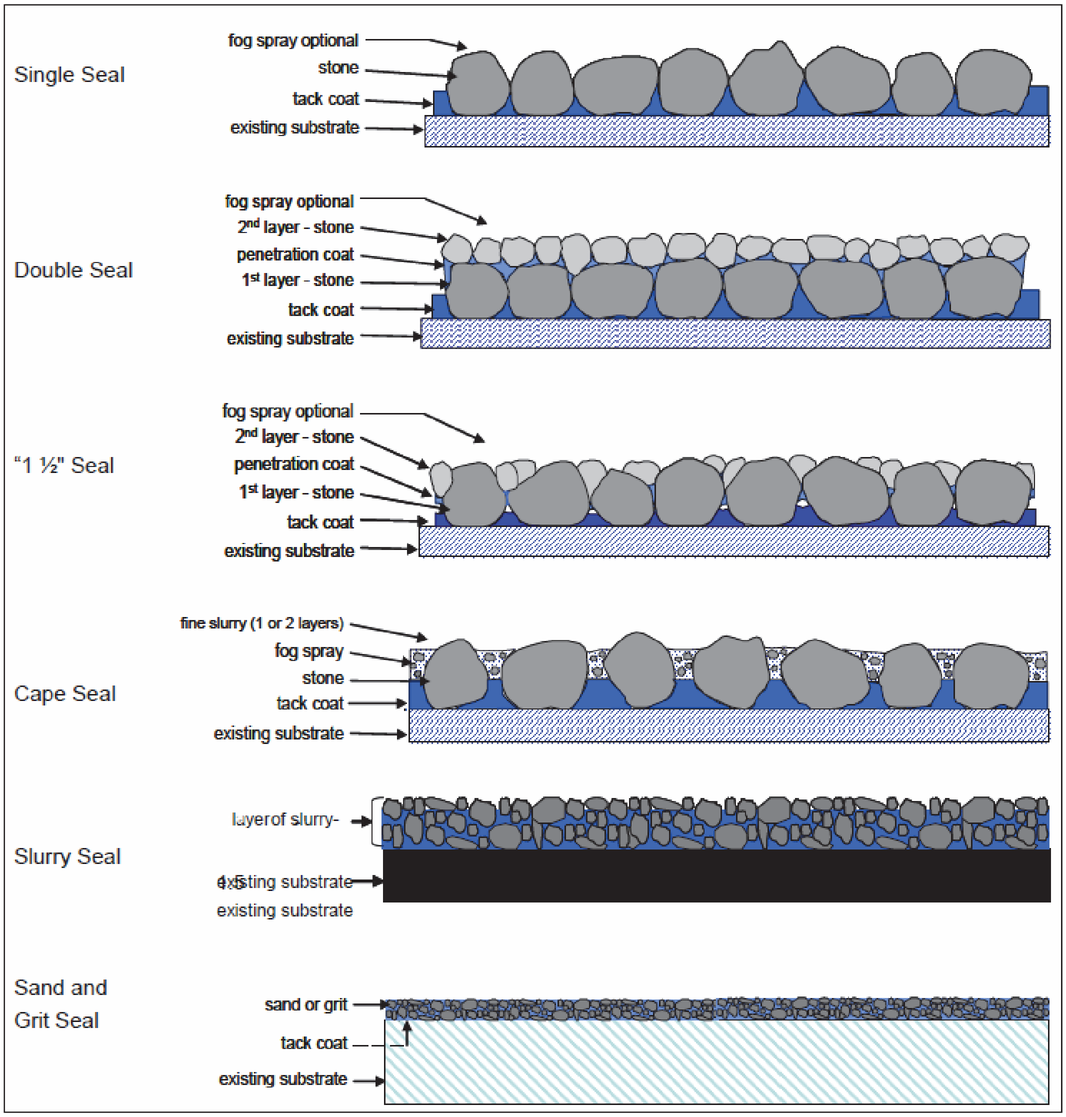
A number of surface treatments/seals are commonly used in Africa and in the Asia-Pacific region as shown in Figures 4 and 5 by the South African National Roads Agency (2007). Knowledge sharing between road and pavement authorities in South Africa and Australia is common and, while the surface treatments have different names, the procedures between countries are similar. The Otta seal shown in Figure 5 is also commonly used in Botswana (South African National Roads Agency 2007) and other countries, including Australia and New Zealand. Because of the availability of design standards and documentation in these two countries, it is expected that other countries in these regions may have adopted similar methods. Ethiopia, for example, has similar procedures for surface treatments (Ethiopian Roads Authority 2013).

It is important to point out that a surface treatment does not contribute appreciably to the structural capacity of the pavement and is simply a wearing surface to protect the base from moisture and traffic abrasion. While multiple treatments may be more than 1 in. thick, they are not normally taken into account when determining the structural thickness of the pavement (Headquarters, Department of the Army 2000).

In the United States, surface treatments are generally recommended only for road applications, airfield overruns, and shoulders due to FOD potential, but surface treatments have been used successfully for airfields in Australia and its territories, and their design guidance may have been adopted for use in other countries. Photographs of a surface-treated runway in New Zealand (Hawke's Bay) are presented in Figure 6.

A single surface treatment application is called a single bituminous surface treatment or chip seal and, when two or more successive layers of single surface treatments are placed, they are called multiple surface treatments.

Figure 4. Schematics of various bituminous surface treatments/seals (South African National Roads Agency 2007).



Additional surface seals such as cape seals, slurry seals, or fog sprays may then be applied to reduce stone loss and to provide a smooth, HMA-like texture. These additional seals can cause reduced friction and, in Australia and its territories, it is recommended that cape or slurry seals not be applied to the center portions of the runways, and lighter fog seals be applied in areas where there is less macrostructure to reduce skidding (Emery 2008).

Design of surface treatments for airports is generally adapted from low-volume road construction designs, which can be a problem because there is not adequate binder to hold the stone in place, leading to a high

Figure 5. Additional schematics of various bituminous surface treatments/ seals (South African National Roads Agency 2007).

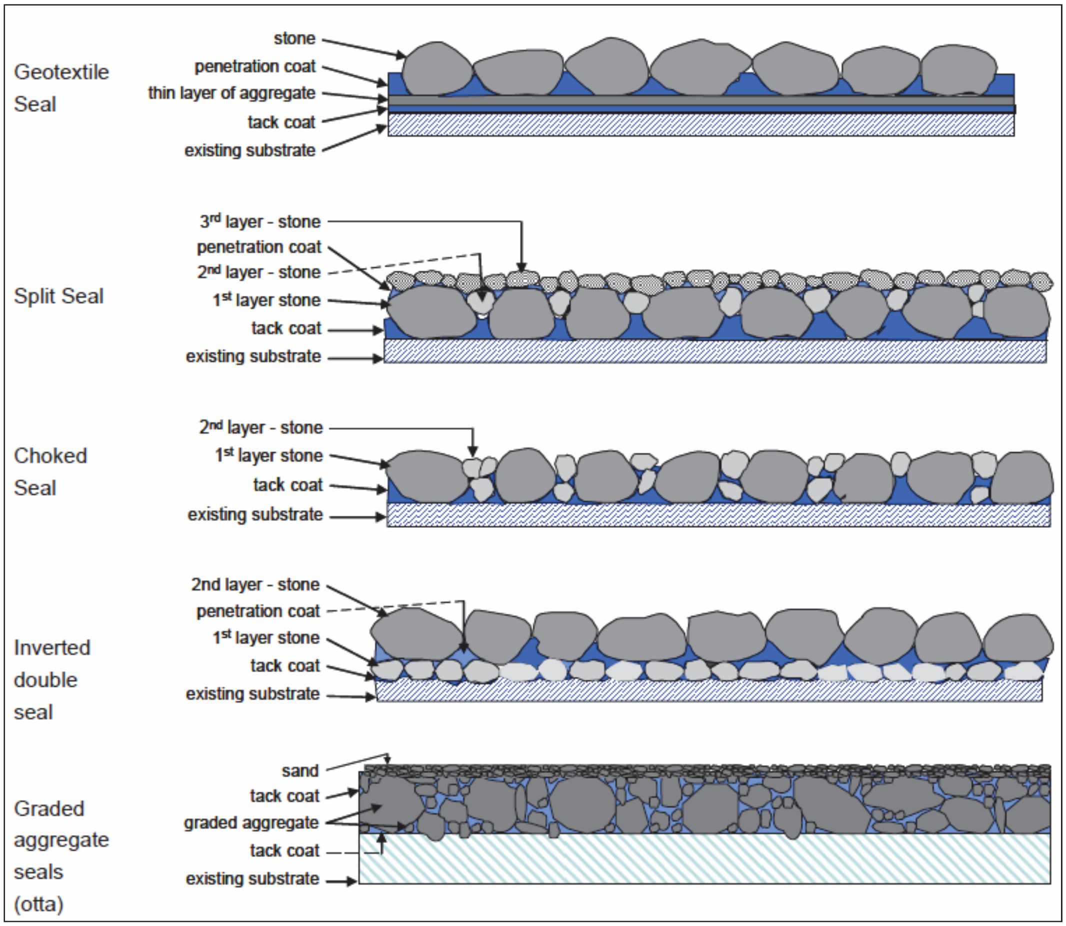


Figure 6. Double bituminous surface-treated runway in New Zealand (Marsh and Cairns 2010).

potential for FOD. Both smaller aggregates and a heavier asphalt binder application rate are recommended for the top treatment when used for airfield construction to reduce FOD potential. However, contractors who are not familiar with airfield construction may cause problems by simply applying road methods of construction.

Despite these concerns, research has indicated that surface treatments can provide relatively satisfactory performance for light aircraft when placed over a high-quality base course, but these pavements require more maintenance than HMA because of loss of aggregate (Emery 2008). In roads, the aggregates are trafficked with some regularity by vehicular traffic to densify the layers of aggregate and binder; but for airfields, there would be limited traffic, and not all areas would be trafficked, particularly small airfields. As a result, dedicated compaction during construction is required prior to opening the airfield to aircraft traffic to prevent FOD damage, and periodic maintenance compaction is also necessary.

Even with maintenance, surface treatments may need resealing every 7 to 10 years. Maintenance may include patching, compaction, sweeping, fog sprays, and reseals. Emery and Caplehorn (1993) concluded that if maintenance cannot be accomplished, surface treatments are not recommended, particularly for airfield construction in developing countries that may not have the resources, expertise, or equipment to conduct proper maintenance. Additionally, in these environments, adequate control of the surface treatment process including binder application rate and maintaining adequate aggregate size, shape, and cleanliness standards may not be achieved, resulting in a shorter treatment life (Ellis 1979).

According to Emery and Caplehorn (1993), who have monitored treatments on Australian and New Zealand airfields for a number of years, surface treatments are not suitable for parking helicopters and are marginally suitable for military jet aircraft due to the high tire pressures and potential for FOD. Problems encountered with using surface treatments include deterioration caused by hardening of the asphalt binder as it ages and loss of aggregate leading to potential FOD damage. High pavement temperatures accelerate this hardening. Surface treatments may also rut, crack, delaminate, wear through in spots (causing potholes), or ravel (causing loose aggregate). Delaminated surface treatments and loose aggregate can cause high FOD potential, and delaminated and rutted areas can cause damage to landing gear.

While in developed countries, surface treatments are generally only used for low-volume roads, remote airfields, or parking applications; in developing countries, surface treatments may be the only surfacing option available (Ellis 1979). Due to the speed of construction and low costs, it is not unreasonable to assume that this type surface would be encountered in remote regions with no other means of paving, in abandoned airfield areas, or on low-volume airfields supporting aircraft with low tire pressures.

3 Visual Condition Assessment

Airfield pavement evaluation includes both the visual assessment of the pavement's surface condition and its structural capacity (strength) to compute the remaining operational capacity of a pavement. This chapter presents recommended procedures to evaluate the pavement's surface through visual condition assessment.

3.1 Inspection procedures

A visual condition assessment is the inspection of a pavement's surface. This assessment provides information on the pavement's structural integrity, operational condition, and projected performance and is necessary to identify any potential problems that would restrict aircraft operations. For contingency airfields, severely rutted or raveled pavement could lead to landing-gear damage of aircraft. Additionally, poorly rated HMA or PCC pavements have historically required that the allowable load for critical aircraft using the pavement be reduced by 25% (UFC 2001b). In conducting visual inspections, photographs of the distresses should be taken to help assess the baseline condition of the pavement prior to aircraft use, particularly if remediation efforts are required following use.

3.1.1 Surfaced pavements- sand asphalt

For visual condition inspection purposes, a sand asphalt pavement should be considered a "surfaced pavement" along with HMA and PCC. Because sand asphalt surfaces will experience deterioration similar to HMA surfaces, sand asphalt should be visually inspected following the traditional pavement condition index (PCI) procedures defined in ASTM Standard D5340-12 (ASTM International 2012) for flexible pavements. The PCI is a numerical score on a scale from 100 (new) to 0 (unsafe for aircraft operations) and is understood among pavement professionals. The index is computed based on the extent and severity of specific pavement distresses, which result in numerical deductions from a pavement score of 100 (new pavement).

Sand asphalts will oxidize and crack like HMA pavements and tend to rut and shove under traffic loads; thus, particular attention should be paid to identify the extent and severity of distresses including cracking, rutting, shoving, weathering, and raveling.

The PCI values for traditional pavement evaluations have narrow rating scales based on their numerical scores and require a more detailed inspection. For contingency evaluation of surfaced pavements, simplified PCI ratings with wider PCI bands are proposed as shown in Table 1 to allow the inspection team to determine a simplified Green, Amber, or Red rating of the pavement surfaces concluded through either a full PCI evaluation or a cursory inspection.

Table 1. Definition of surfaced pavement ratings (after ETL 02-19).

Traditional Rating	Traditional Definition	Simplified Rating	Simplified Definition
86-100	Good: Pavement has minor or no distresses and will require only routine maintenance.	71-100	Good: Pavement should only require routine maintenance and have few, scattered low-severity distresses.
71-85	Satisfactory: Pavement has scattered low-severity distresses, which should require routine maintenance.		
56-70	Fair: Pavement has a combination of generally low- and medium-severity distresses. Near-term maintenance and repair needs should be routine to major.	56-70	Fair: Pavement has a combination of generally low- and medium-severity distresses. Near-term maintenance and repair needs should be routine to major.
41-55	Poor: Pavement has low-, medium-, and high-severity distresses, which probably cause some operational problems. Near-term maintenance and repair needs should range from routine to reconstruction.	55-0	Poor: Pavement has a number of low-, medium-, and high-severity distresses that may require intensive maintenance and frequent repairs to support aircraft operations.
26-40	Very Poor: Pavement has predominantly medium- and high-severity distresses causing considerable maintenance and operational problems. Near-term maintenance and repair needs will be intensive in nature.		
11-25	Serious: Pavement has mainly high-severity distresses, which cause operational restrictions; immediate repairs are needed.		
0-10	Failed: Pavement deterioration has progressed to the point that safe aircraft operations are no longer possible; complete reconstruction is required.		

If time permits, a full surface inspection following ASTM Standard D5340-12 guidance with computation of the PCI for all features is recommended. The computed PCI should then be used to determine the simplified PCI rating (Green, Amber, or Red). If time does not allow a full PCI inspection, then a cursory inspection may be conducted.

To conduct a cursory inspection, for each feature, pavement surface distresses following ASTM Standard D 5340-12 distress descriptions should be identified along with their rating (low-, medium-, or high-severity) (ASTM International 2012). However, in this type inspection, the extent is not measured or recorded, just the distresses and their severities. When this is complete, the distresses should be compared with the simplified rating definitions. If the pavement feature is in relatively good condition with only low-severity distresses scattered across the feature, which would not require more than routine maintenance to maintain aircraft operations, the pavement would be considered in Green (good) condition. However, if medium-severity distresses were present in addition to the low-severity distresses, or the feature would require routine to major repair to maintain operations, then the feature should be rated Amber (fair). If high-severity distresses are prevalent, and the pavement would require constant maintenance and repairs to maintain operations, then the pavement should be considered Red (poor).

A pavement in Green (good) condition should be monitored periodically. A pavement in Amber (fair) condition should be monitored regularly. Pavements in Red (poor) condition should be used with caution with inspections of the surface after every operation. Also, a 25% reduction in the allowable load should be applied when conducting the structural evaluation of surfaced pavements. This reduction is also recommended for sand asphalt pavements.

3.1.2 Unsurfaced pavements- including macadam, stabilized, or surface-treated pavements

For visual condition inspection purposes, macadam, stabilized, and surface-treated pavements should be considered "unsurfaced pavements." Unsurfaced pavements differ from paved surfaces in that unsurfaced pavements do not have a surface-wearing course capable of resisting the abrasive action of the wheel loads. Stabilized soil surfaces have historically been evaluated as "semi-prepared" surfaces, which also include unsurfaced (soil) and aggregate-surfaced pavements. While penetration macadam and surface-treated pavements have thin-wearing surfaces (usually less than 1.5 in. thick), these thin coverings are not capable of resisting the shearing actions of the aircraft gears expected for contingency airfield operations. These pavement surfaces are expected to experience deterioration similar to semi-prepared surfaces.

Unsurfaced pavements are inspected following the semi-prepared airfield condition index (SPACI) procedure detailed in ETL 97-9: *Criteria and Guidance for C-17 Contingency and Training Operations on Semi-prepared Airfields* (AFCESA 1997). The SPACI (similar to PCI with a scale of 100 to 0) is calculated using deduct values assigned based on the severity of the unsurfaced pavement distresses. Distresses should be measured in accordance with ETL 97-9 procedures. The distresses established for unsurfaced pavements include:

- Potholes
- Loose aggregate
- Rutting
- Rolling resistant material
- Dust
- Jet blast erosion
- Stabilized layer failure

In evaluating a macadam or surface-treated pavement, if the binder no longer holds the aggregate in place (usually due to oxidation of the binder), then “loose aggregate” should be recorded as the distress. Loose aggregate should be identified separately from rolling resistant material. Rolling resistant material is also loose material that has separated from the top surface but is usually the result of severe rutting and is located between and in rut locations. Rolling resistant material is usually attributed to unsurfaced soil or aggregate airfields; however, this material could be produced through severe rutting of stabilized, surface-treated, or penetration macadam surfaces. A photograph of loose aggregate on an aged macadam surface is shown in Figure 7.

Stabilized layer failure is recorded for stabilized surfaces when delamination of the surface layer occurs due to aging, cracking, and the loss of bond with the underlying layer. Over time, pieces of the surface (not just aggregates) are dislodged and can cause FOD damage. Delamination due to aging and cracking of penetration macadam and surface-treated surface courses have

Figure 7. Loose aggregate on a penetration macadam taxiway (Morgan et al. 2003).

been identified as problems with these materials and should be recorded as "stabilized layer failure." It is recommended that this distress be changed to "delamination" in the future to avoid confusion. Rutting, delamination, and loose aggregate distresses for a double bituminous surface-treated pavement are shown in Figure 8. Figure 9 shows the beginning of delamination on a surface-treated pavement.

The SPACI simplified rating system includes Green, Amber, and Red ratings as shown in Table 2. If a full inspection cannot be conducted, a cursory inspection noting distress levels shown in Table 3 may be used to establish the simplified rating. Table 3 also provides distress level criteria for each non-traditional pavement type. These severity levels are proposed based on those established in ETL 02-19 for C-17 operations in arid soil environments (AFCESA 1997). Lower tolerance limits are recommended for macadam or treated surface courses than for soil or stabilized soil pavements, as the coarse aggregates may cause higher FOD potential than an arid soil for which the distresses were originally determined.

Figure 8. Examples of bituminous surface treatment distresses.

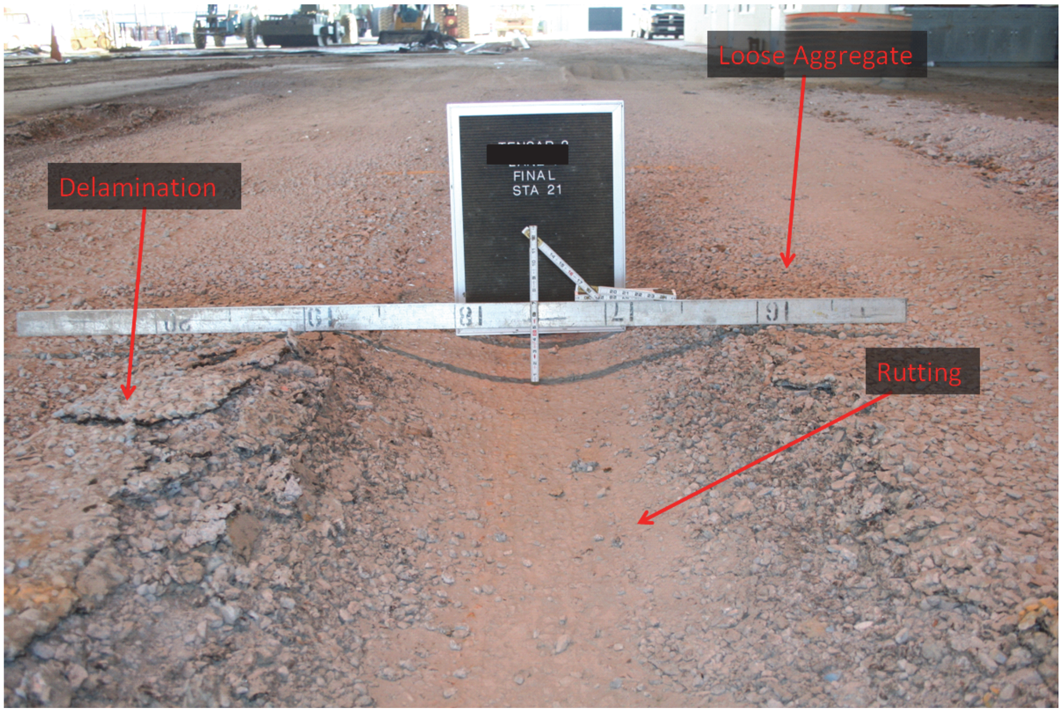


Figure 9. Cracking and delamination of a surface-treated airfield pavement (Edwards 2012).

Table 2. Definition of semi-prepared or unsurfaced pavement ratings.

SPACI	Simplified Definition
75-100	Green: Airfield in generally suitable condition for low-risk operations; however the airfield requires routine monitoring.
25-74	Amber: Airfield in marginal condition for medium-risk operations and requires more frequent monitoring than a green-rated pavement.
24-0	Red: Airfield is dangerous and must be repaired and is only suitable for high-risk operations; monitoring before and after each aircraft operation is required.

Table 3. Proposed distress severity levels for unsurfaced, stabilized, surface-treated, and macadam surfaces after ETL 02-19 (AFCESA 2002).

Distress Type	Green	Amber	Red
Potholes	Unsurfaced or stabilized soils in arid environments (C-17 only): < 4 in. deep and/or < 15 in. in diameter Surface-treated and macadam surfaces in all environments, or unsurfaced or stabilized soils in humid environments: < 1 in. deep and/or < 15 in. in diameter	Unsurfaced or stabilized soils in arid environments (C-17 only): 4-9 in. in depth and > 15 in. in diameter Surface-treated and macadam surfaces in all environments, or unsurfaced or stabilized soils in humid environments: 1-3 in. in depth and > 15 in. in diameter	Unsurfaced or stabilized soils in arid environments (C-17 only): > 9 in. in depth and > 15 in. in diameter Surface-treated and macadam surfaces in all environments, or unsurfaced or stabilized soils in humid environments: > 3 in. in depth and > 15 in. in diameter
Loose aggregate	Unsurfaced or stabilized: Covers <10% of the surface area; surface mostly intact. For surface-treated pavements or macadam surfaces: binder is wearing away causing low FOD potential over <10% the surface; surface mostly intact.	Unsurfaced or stabilized: Covers between 10 and 50% of the surface area. For surface-treated pavements or macadam surfaces: fine aggregate is missing and larger pieces are dislodged. Moderate FOD potential. Surface is rough and pitted with loose aggregates between 10 and 50% the surface.	Unsurfaced or stabilized: Covers >50% of the surface area. Surface mostly loose stone or aggregate. For surface-treated pavements or macadam surfaces: surface texture is very rough and pitted. Loose aggregates cover >50% the surface area. High FOD potential.
Rutting	Unsurfaced or stabilized soils in arid environments (C-17 only): <4 in. deep Surface-treated pavements, macadam surfaces, or unsurfaced or stabilized soils in humid environments: < 1 in. deep	Unsurfaced or stabilized soils in arid environments (C-17 only): 4-9 in. deep Surface-treated pavements, macadam surfaces, or unsurfaced or stabilized soils in humid environments: 1-3 in. deep	Unsurfaced or stabilized soils in arid environments (C-17 only): > 9 in. deep Surface-treated pavements, macadam surfaces, or unsurfaced or stabilized soils in humid environments: > 3 in. deep
Rolling resistant material	Unsurfaced or stabilized soils in arid environments (C-17 only): <3.5 in. deep Surface-treated pavements, macadam surfaces, or unsurfaced or stabilized soils in humid environments: < 1 in. deep	Unsurfaced or stabilized soils in arid environments (C-17 only): 3.5-7.75 in. deep Surface-treated pavements, macadam surfaces, or unsurfaced or stabilized soils in humid environments: < 3 in. deep	Unsurfaced or stabilized soils in arid environments (C-17 only): >7.75 in. deep Surface-treated pavements, macadam surfaces, or unsurfaced or stabilized soils in humid environments: > 3 in. deep
Dust	Does not obstruct visibility	Partially obstructs visibility	Thick; obstructs visibility
Jet blast erosion	< 1 in. deep	1-3 in. deep	> 3 in. deep
Delamination	< 1 in. deep	1-2 in. deep	> 2 in. deep

If the pavement feature is in relatively good condition with only low-severity distresses scattered across the feature, which would not require more than routine maintenance to maintain aircraft operations, the pavement would be considered in Green (good) condition. However, if medium-severity distresses were present in addition to the low-severity distresses, or the feature would require routine to major repair to maintain operations, then the feature should be rated Amber (fair). If high-severity distresses are prevalent, and the pavement would require constant maintenance and repairs to maintain operations, then the pavement should be considered Red (poor). When the condition of the airfield approaches Red, it must be inspected before and after each aircraft operation.

3.2 Identification of nontraditional pavement types

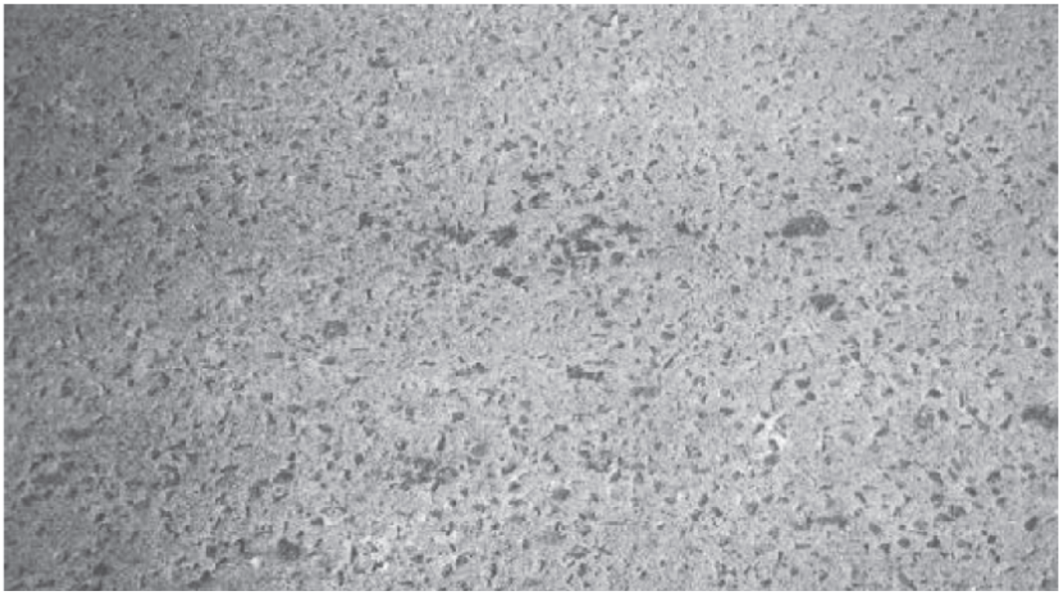
If construction records are not available to define the surface materials and their thicknesses, then these must be determined in the field during the condition assessment. Accurately identifying what type of surface or wearing course is present is necessary to properly evaluate the structural capacity of the pavement and determine the correct condition inspection procedure. Upon cursory examination, surface-treated pavements, penetration macadam, and sand asphalt may appear to be HMA. Closer examination is needed to distinguish between pavement types.

Surface treatments can be distinguished from HMA based on their surface, which should have small, similar-sized aggregates with binder between aggregates as shown in Figure 10. The pavement thickness should also be checked. If the surface course is less than 1.5 in. thick, it can be assumed to be a surface treatment for the purposes of a contingency airfield evaluation. The thickness can be determined by drilling, collecting a piece of delaminated surface course (Figure 11), or digging a small trench off the side of the pavement. Sand asphalts can be distinguished from HMA by coring the pavement to look at the aggregate structure, or by a small test pit. The sand asphalt should have minimal coarse aggregates as shown in Figure 12. Penetration macadam may be more difficult to identify from the surface, however; under the penetrating asphalt layer(s), the base material should be gap-graded with layers of larger aggregate filled with small aggregates. This pavement may also be difficult to penetrate with testing equipment due to the use of large stones or aggregates in its construction (possibly wider than 2 in. in diameter). Thus, the pavement type and thickness should be determined for each pavement section.

Figure 10. Surface of a triple-bituminous sealed runway (Edwards 2012).

Figure 11. Small sample of a triple-bituminous sealed runway (Edwards 2012).

Figure 12. Surface of a sand asphalt pavement (SABITA 1996).



3.3 Material properties

The literature was reviewed to determine ranges of material properties such as elastic modulus or CBR values of the various surface types (macadam, sand asphalt, stabilized soil, and surface treatments). Modulus values may be converted to CBR values using standard correlations. According to United Facilities Criteria (UFC) 3-260-03 *Airfield Pavement Evaluation*, CBR may be calculated by dividing the modulus by 1,500 (UFC 2001b). Because these materials are not generally used for airfield construction in the United States, studies prior to the 1960s and from other countries were reviewed. Another source of information included Army and Air Force airfield pavement inspections. Reports from these inspections provided material properties for these pavements either as the surface pavement or as base materials, where the original pavement surface was overlaid with HMA. Elastic modulus values reported in the literature are provided in Table 4, and evaluation CBR values reported in UFC 3-260-03 are provided in Table 5. Evaluation CBR values can be used during the pavement evaluation process in lieu of in-place data and are based on their historical service behavior; however, these values look high compared to the values reported in the literature.

Table 4. Moduli for various materials.

Material	Modulus	Estimated CBR	Source	Reference
Macadam	145,040 psi	97	*Danish Road Institute Report 138*	Danish Road Directorate (2004)
Penetration Macadam	125,000 psi (over cemented stone or gravel base)	83	*South Africa Low Volume Design Guidelines for Macadam Pavements*	Visser and Hattingh (1999)
Penetration Macadam	84,000 psi (over cemented gravel base)	56	*South Africa Low Volume Design Guidelines for Macadam Pavements*	Visser and Hattingh (1999)
Penetration Macadam	71,000 psi (over gravel soil base)	47	*South Africa Low Volume Design Guidelines for Macadam Pavements*	Visser and Hattingh (1999)
Dry Bound Macadam	102,000 psi	68	*Equivalence Between Dry Bound Macadam and Other Types of Base Layers for Flexible Pavements*	Mateos and Rotger (2008)
Water Bound Macadam Airfield Base	87,000 psi (Poisson's ratio=0.35)	58	*Analysis of the Structural Bearing Capacity of an Airport using Rudimentary Test Results as Input into the SAMDM*	de Bruin et al. (2004)
High-Quality Crushed Stone	22,000-87,000	15-58	*Analysis of the Structural Bearing Capacity of an Airport using Rudimentary Test Results as Input into the SAMDM*	de Bruin et al. (2004)
Sand Asphalt Base	70,000-75,000 psi	47-50	Back-calculated from Duke Field, FL 1988	Bongioanni et al. (2012)
Sand Asphalt Base (overlaid with HMA)	100,000-400,000 psi	67-100	Back-calculated from Duke Field, FL in 2012	Bongioanni et al. (2012)
Sand Asphalt Base (overlaid with HMA)	100,000-170,000 psi	67-100	Back-calculated from Hurlburt Field, FL in 1998	Brown et al. (1998)
Double Bituminous Surface Treatment	61,300 (initial)	41	Back-calculated, ERDC Test Section	Norwood and Tingle (2013)
	40,000 (after 15,000 passes)	27	Back-calculated, ERDC Test Section	Norwood and Tingle (2013)
Double Bituminous Surface-treated Base	900,000-1,400,000 psi	100	*Improved Roadbase Macadams, Road Trials and Design Considerations*	Nunn, Rant, and Schoepe (1987)
Asphalt-Stabilized Base	350,000-1,000,000 psi	100	*AASHTO Guides for Design of Pavement Structures*	AASHTO (1993)
Asphalt-Stabilized Material	40,000-300,000 psi	27-100	*AASHTO Guides for Design of Pavement Structures*	AASHTO (1993)
Lime-Stabilized Base	20,000-70,000 psi	13-47	*AASHTO Guides for Design of Pavement Structures*	AASHTO (1993)
Lime-Stabilized Base	30,500-510,000 psi	20-100	*Evaluation of Structural Properties of Lime- Stabilized Soils and Aggregates*	Little (1999)
Cement-Stabilized Material	29,179-493,008 psi	19-100	*In Situ Evaluation of Unsurfaced Portland Cement-Stabilized Soil Airfields*	Griffin and Tingle (2009)

Table 5. Evaluation CBR values for various materials listed in UFC 3-260-03 (UFC 2001b).

Base Material	Evaluation CBR
Graded Crushed Aggregate (100 CBR)	100
Water-Bound Macadam	100
Dry-Bound Macadam	100
Bituminous Macadam	80
HMA	100
Limerock	80
Graded Crushed Aggregate (80 CBR)	80
Soil Cement	80
Sand Asphalt	80
Sand Shell or Shell	80
Open-Graded (Stabilized or Unstabilized)	80

Based on a review of the literature presented in Tables 4 and 5, the following ranges were identified for the potential surfacing types:

- Penetration/bituminous macadam: 50-100 CBR (80 current UFC recommendation)
- Macadam: 67-100 CBR (80 current UFC recommendation)
- Sand asphalt: 70,000-400,000 psi (47-100 CBR)
- Lime-stabilized: 13-100 CBR
- Cement-stabilized: 20-100 CBR
- Asphalt-stabilized: 26-100 CBR
- Bituminous surface treatments: 26-100 CBR

3.4 Equivalency factors

Equivalency factors used by the United States for design and evaluation of airfield pavements are described in UFC 3-360-02 and UFC 3-260-03 (UFC 2001a,b). These and other equivalency factors were reviewed to determine if they could be used to manually convert the thickness of various surfacing approaches to an equivalent thickness of HMA or high-quality aggregate base course during the evaluation process. A summary of equivalency factors identified in the literature are provided in Table 6. These factors were obtained from UFC 3-260-03 (UFC 2001b) and Canada's *Manual of Pavement Structural Design* (Public Works Canada 1992). Equivalency factors to 1 in. of HMA developed by the American Association of State Highway Officials (AASHO) are provided in Table 7 (AASHO 1972). Based upon the equivalency factors in Tables 6 and 7, the following equivalency factor ranges were recommended for further exploration:

- Penetration/bituminous macadam: 1.5 (to base)
- Macadam: 1.5 (to base)
- Sand asphalt: 0.5-0.91 (to HMA) (0.5 assuming that a poor sand asphalt would be similar to a low stability road mix)
- Lime-stabilized: 1.2 (to subbase); 0.35-0.67 (to HMA)
- Cement-stabilized: 2.0 (to base) and 0.35-1.0 (to HMA)
- Asphalt-stabilized: 1.0-1.5 (to base) and 0.5 to 0.77 (to HMA)
- Bituminous surface treatments: none

Table 6. Equivalency factors for base materials.

	Equivalency Factors		
Material	Base/Surface Course, in.	Subbase, in.	Reference
Unbound Crushed Stone	1.00	2.00	UFC (2001b)
Unbound Subbase	Not to be used as base or surface course	1.00	
Bituminous-Stabilized	1.15	2.30	
Asphalt-Stabilized GW, GP, GM, GC	1.00	2.00	
Asphalt-Stabilized SW, SP, SM, SC	Not to be used as base or surface course	1.50	
Cement-Stabilized GW, GP, SW, SP	1.15	2.30	
Cement-Stabilized GC, GM	1.00	2.00	
Cement-Stabilized ML, MH, CL, CH	Not to be used as base or surface course	1.70	
Cement-Stabilized SC, SM	Not to be used as base or surface course	1.50	
Lime-Stabilized ML, MH, CL, CH	Not to be used as base or surface course	1.00	
Lime-Stabilized SC, SM, GC, GM	Not to be used as base or surface course	1.10	
Lime-, Cement-, Fly Ash-Stabilized ML, MH, CL, CH	Not to be used as base or surface course	1.30	
Lime-, Cement-, Fly Ash-Stabilized SC, SM, GC, GM	Not to be used as base or surface course	1.40	
Cement-Stabilized (Navy)	1.5	1.2	
Lime-Stabilized (Navy)	Not to be used as a base or surface course	1.2	

Material	Equivalency Factors		Reference
	Base/Surface Course, in.	Subbase, in.	
Bituminous-Stabilized (Navy)	1.5	–	
Bituminous-Stabilized	1.5	–	Public Works Canada (1992)
Water-Bound Macadam or Penetration Macadam	1.5	–	
Cement-Stabilized	2.0	–	
HMA Good Condition	2.0	–	
HMA Poor Condition	1.5	–	

Table 7. Equivalency factors for surface materials (to 1 in. HMA).

Material	Equivalency Factor, in.	Source	Reference
Road Mix (Low Stability)	0.45	AASHO Interim Guide for Design of Pavement Structures	AASHO (1972)
Plant Mix (High Stability) (HMA)	1.0		
Sand Asphalt	0.91		
Sandy Gravel	0.15		
Crushed Stone	0.32		
Cement-Treated Base	0.35-0.52		
Bituminous-Treated Aggregate Base	0.77		
Bituminous-Treated Sand Asphalt Base	0.67		
Lime-Treated Base	0.35-0.67		

4 Structural Evaluation

As mentioned in Chapter 3, airfield pavement evaluation includes the visual assessment of the pavement's surface condition and its structural capacity (strength) to compute the remaining operational capacity of a pavement for a set period of time (UFC 2001b). This chapter presents the procedures used to assess a pavement's strength. Specific guidance for determining the load-carrying capacity using evaluation software for each nontraditional pavement will be provided in later sections of this chapter.

4.1 Procedures

Unified Facilities Criteria (UFC) 3-260-03 *Airfield Pavement Evaluation* provides the current military guidance for conducting airfield pavement evaluations (UFC 2001b). Air Force specific guidance for conducting pavement evaluations is provided in Engineering Technical Letter (ETL) 02-19 *Airfield Pavement Evaluation Standards and Procedures* (AFCESA 2002). This document also contains minimal information for conducting contingency airfield evaluations. In addition to these documents, ETL 97-9 *Criteria and Guidance for C-17 Contingency and Training Operations on Semi-Prepared Airfields* provides guidance for unsurfaced or mat-surfaced airfields for contingency airfield pavement design, construction, maintenance, and evaluation (AFCESA 1997). Further guidance for evaluating stabilized soil airfields are provided in ETL 08-14 *Structural Evaluation Procedures for Stabilized Soil-Surfaced Airfields* (AFCESA 2008). The evaluation methods provided in these documents were reviewed to develop nontraditional airfield pavement evaluation procedures.

4.2 Equipment

4.2.1 FWD/HWD

An FWD/HWD is a non-destructive test device used to measure a pavement's response to applied, dynamic loading. The pavement response data collected with this device are commonly used for traditional pavement (PCC and HMA) evaluation by the US military through linear elastic analyses. The device is used to apply loading to the pavement surface by dropping weights from different heights onto a standard load plate. By varying the drop height, the impact force can be increased up to 50,000 lb (for the HWD).

The device uses velocity transducers to measure the pavement's response (deflection) under the applied load. Deflections measured at spacings of 12 in. are used to produce deflection basins. The deflection basins are, in turn, used to back-calculate the strength of each pavement layer and to predict the remaining life and allowable loads of the pavement based on the critical aircraft. Computer programs are used for this purpose and include the US military's Pavement-Transportation Computer Assisted Structural Evaluation (PCASE) software. The test procedure for using the FWD/HWD is provided in UFC-3-260-03 (UFC 2001b). The PCASE software will be described in later sections of this chapter.

While traditional pavement evaluations rely heavily on the use of the FWD or HWD, this equipment is often not compatible with contingency airfield surfaces, such as an unsurfaced airfield, due to the sensitivity of the load plate and deflection sensors to loose material causing erroneous sensor measurements. Additionally, due to the expedient nature of contingency airfield evaluations (regardless of the pavement surface type), neither an FWD nor HWD may be available.

4.2.2 Dynamic cone penetrometer (DCP)

As a result of these compatibility and availability limitations with the FWD/HWD, contingency airfield pavement evaluation teams generally rely on the use of the dynamic cone penetrometer (DCP) or estimated material strengths (CBR or modulus values) from historical data if in situ testing is not possible. Actual in situ measurements are much preferred over using representative values from the historical data. The DCP is generally accepted as adequate for evaluating most pavement structures and is considerably easier to deploy and implement compared to other evaluation equipment. If possible, this device should be used for contingency evaluation purposes.

The DCP is a hand-held portable penetrometer device designed to penetrate pavement layers to depths between 26 and 50 in. with a 0.79-in.-diam cone. Testing with this device is conducted in accordance with ASTM Standard D6951-09, *Standard test method for the use of the dynamic cone penetrometer in shallow pavement applications* (ASTM International 2009). The cone is attached to a 5/8-in.-diam steel rod driven into the ground using a 17.6- or 10.1-lb hammer that is raised and lowered by hand. The device measures the penetration readings at selected drop intervals such as 1, 2, 5, 7, or 10 blows per reading with a minimum penetration of roughly 0.8 in. (20 mm) between recorded measurements.

Once the test is completed, the drop intervals (blow counts) and corresponding penetration measurements are used to estimate the CBR, which is an empirical measure of strength. Cone penetration-per-hammer-blow data are translated into a DCP index value (mm/blow). Equations have been developed to correlate this value to the CBR, and PCASE has a built-in system that allows the DCP data to be directly entered and stored for evaluation purposes. Changes in the CBR index can be used to estimate the sublayer thicknesses by examining a plot of CBR index with depth. The average CBR for each layer can then be used for evaluation purposes.

For the nontraditional pavements, the DCP may be used directly on the pavement surface unless the aggregates are larger than 2.0 in., or there is a relatively new, hardened stabilized soil layer. These large aggregates and stabilized layers can result in refusal of the device. Refusal is defined as no change in penetration after 50 blows of the DCP using the large (17.6-lb) hammer. If impenetrable layers are encountered (or DCP tests could not be conducted), estimated CBR may be used for these layers presented in the previous chapter.

4.2.3 Portable seismic property analyzer (PSPA)

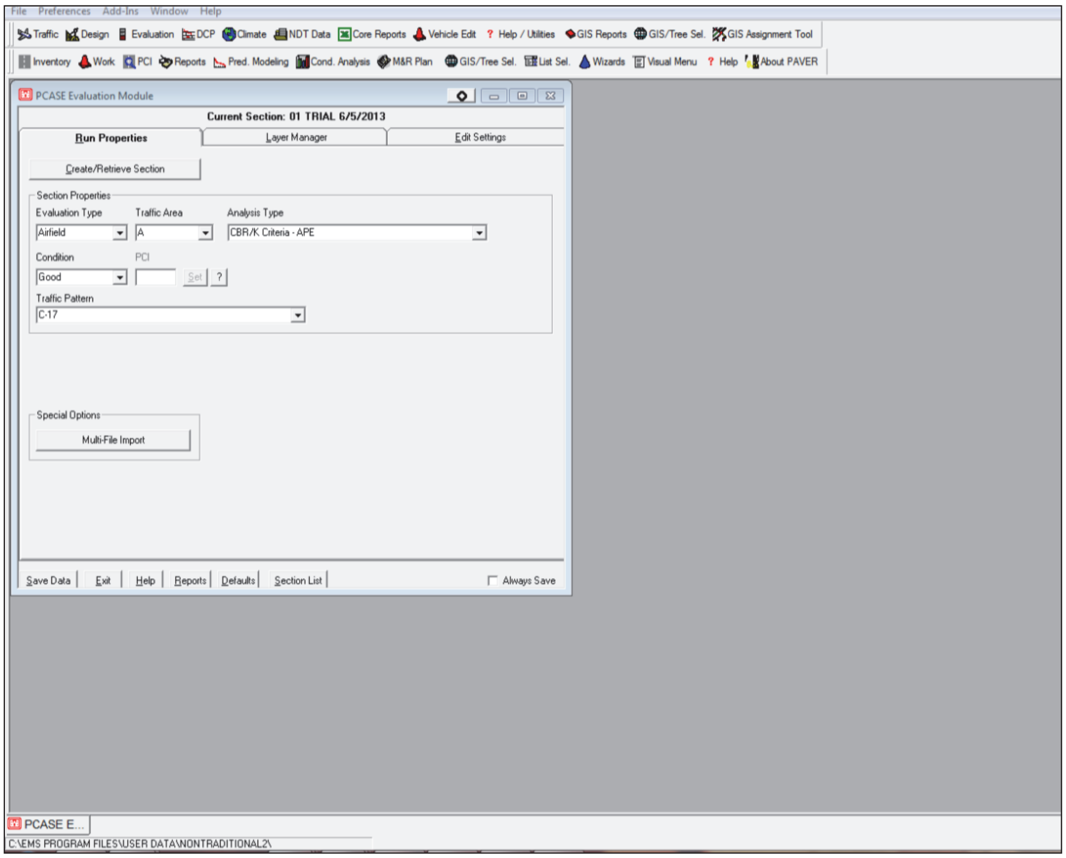
The PSPA is a portable device that nondestructively evaluates PCC, AC, and prepared subgrade materials. The device consists of an electronics box, extension rods, a wave generation source, and two receivers. The system is controlled by a laptop computer, which also records the data. The PSPA generates ultrasonic surface waves (USW), the speeds of which are measured by the two receivers. The velocity of the USW, along with the Poisson's ratio and mass density of the tested material, are used to calculate the modulus of the material. This device has been recommended for the evaluation of cement-stabilized surface layers in ETL 08-14 (AFCESA 2008).

4.3 Pavement evaluation software

PCASE is a pavement design and evaluation computer software application currently employed by the DoD. The evaluation protocol used in the program is based upon the standards set forth in UFC 260-03 (UFC 2001b) for airfield pavement evaluation.

The PCASE evaluation program allows the user to use either modulus values (layered elastic criteria) or CBR values (empirical criteria) to determine the maximum allowable aircraft coverages and loading using established failure criteria. The evaluation module of the PCASE pavement evaluation and design software is shown in Figure 13.

Figure 13. PCASE evaluation module.



The PCASE software application allows the user to design and evaluate a variety of pavement types. For this report, PCASE was used to predict the performance of nontraditional pavements, although it was designed for traditional PCC (rigid), HMA (flexible), and unsurfaced analyses. For general PCASE use, if non-destructive testing data from an FWD or HWD is available, then the layered elastic evaluation program (LEEP) module is used. If non-destructive data are not available, and the pavement is evaluated based on DCP or estimated CBR values, then the airfield pavement evaluation (APE) program module is used.

Currently, no specific evaluation criteria exist for macadam, sand asphalt, lime- or asphalt-stabilized, or surface-treated pavements. Specific evaluation criteria have been established using LEEP for cement-stabilized soil, including a combination of rigid and flexible pavement analyses and, if possible, these criteria should be followed as detailed in ETL 08-14 (AFCESA 2008). Because sand asphalt provides a surface-wearing course that can resist the shearing action of low tire pressures, it should be evaluated as a flexible pavement. The remaining pavement types do not generally have a surface-wearing course of adequate thickness to resist shearing action. Thus, macadam (including penetration macadam), surface-treated, and lime- or asphalt-stabilized pavements should be evaluated as unsurfaced pavements. For unsurfaced pavement analyses in PCASE (with the exception of cement-stabilized surfaces), only the APE program can be used. Because it is easy to deploy and implement and is compatible with uneven surfaces, the DCP should be used to estimate the CBR of each pavement layer for evaluating the nontraditional airfield pavements.

The material properties required for using flexible pavement analysis include layer thicknesses, an estimate of each layer's material type, Poisson's ratio, and each layer's CBR (determined using the DCP or standard estimates). Failure for flexible pavement analysis is rutting of the pavement layers with failure defined as rutting of 1.0 in. Rutting occurs when the load-induced deformation exceeds the recoverable deformation for the material. In traditional pavements, rutting is primarily found in the subgrade layer, but it may occur in any layer.

The material properties required for unsurfaced analysis are the same as those for flexible pavement analysis, and failure is also defined by rutting in the pavement layers. However, the allowable rutting for unsurfaced pavements may be greater than for flexible pavement analyses depending on aircraft type.

4.4 Contingency airfield evaluation procedures using PCASE

General recommendations for using PCASE software to estimate the allowable loads and passes for the design aircraft are provided in the following sections for each pavement surface type. For clarity, the allowable load is the load that can be sustained by the pavement for the anticipated number of passes by the design aircraft, and the allowable passes are the number of passes that the pavement can sustain at the design aircraft load.

4.4.1 Macadam

Macadam pavements with or without a penetrating asphalt layer should be evaluated as unsurfaced pavements. However, if the macadam has been overlaid with an HMA-wearing course more than 2 in. in thickness, then the macadam becomes the base, and the entire structure should be evaluated as a flexible pavement following traditional airfield evaluation procedures detailed in UFC 3-260-03 (UFC 2001b).

If no HMA surface exists, then treat the structure as an unsurfaced pavement. As mentioned previously, unsurfaced pavements may only be evaluated using the APE/CBR analysis method in PCASE. This method allows selection of several material types for the surface course. For conservative purposes, when evaluating macadam as the surface course, the material type should be set to “unbound aggregate” in the PCASE layer manager. Setting it to “unbound crushed stone” may over-predict the allowable passes.

As mentioned previously, in addition to material type and thickness, CBR values for each layer are required as inputs to use the APE/CBR analysis method. As presented in Chapter 3, a range of CBR values have been measured or assumed for a variety of macadam pavements (50-100 CBR), and a recommendation of 80 CBR is the current UFC 3-260-03 guidance for penetration/bituminous macadam if the CBR of the layer cannot be determined with the DCP (UFC 2001b). It is recommended that CBR values be based on pavement condition as shown in Table 8 due to the range of CBR values reported in the literature. Also, an equivalency factor of 1.5 has been suggested for macadam to HMA and was recommended for further investigation. Both of these were evaluated in the following examples to determine their impact on the number of allowable loads and passes of the C-17 and C-130 aircraft for contingency airfield missions. For contingency operations, 100 passes was defined as the design pass level.

Table 8. Recommended CBR values for macadam pavement based on pavement condition.

CBR Value	Pavement Condition
80	Good
70	Satisfactory
60	Fair
50	Poor

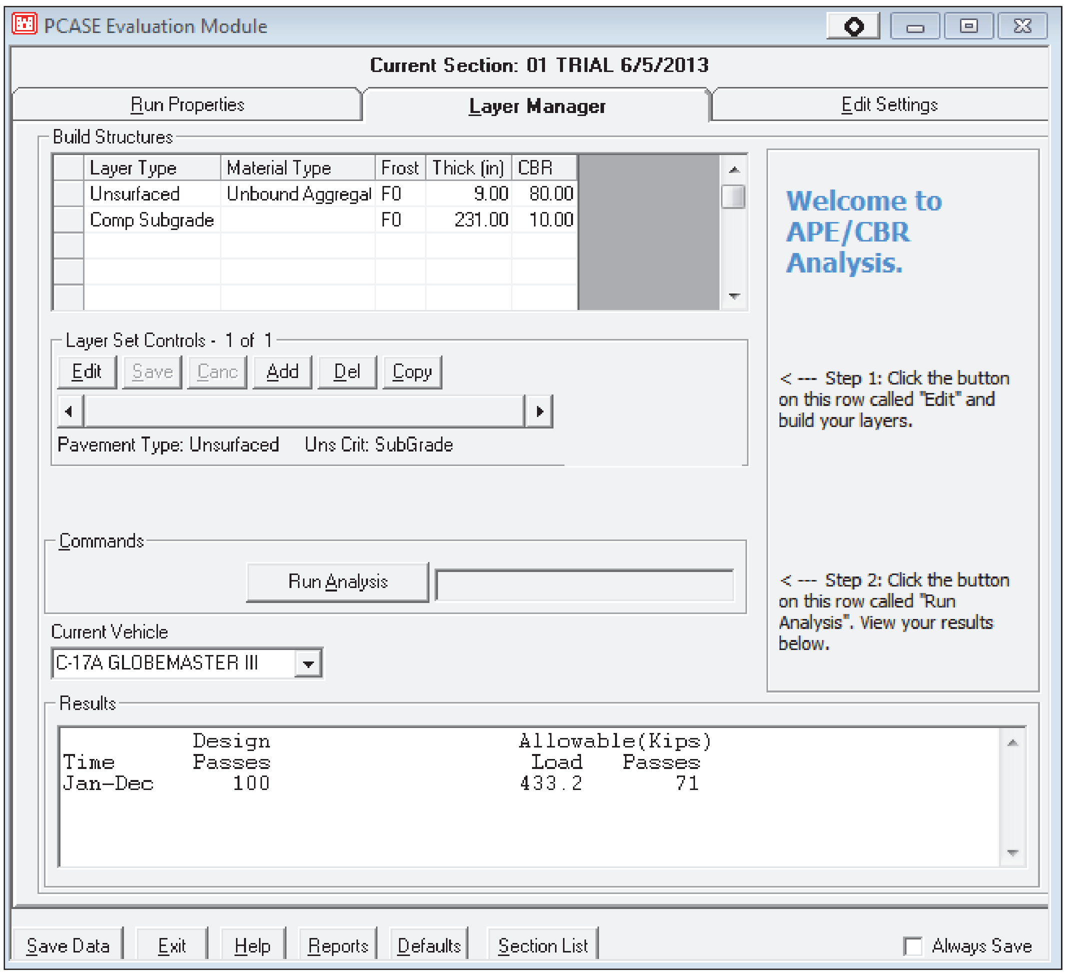
4.4.1.1 Macadam example 1

A penetration macadam surface on a contingency airfield is comprised of 9 in. of penetration macadam over a compacted silty subgrade. DCP evaluation indicates the macadam layer caused refusal of the DCP, and the subgrade has a CBR of 10. The overall surface condition is Green (Good) based on a cursory inspection. How many passes of a C-17 Globemaster, at a weight of 486,000 lb, should be allowed on the pavement? How many C-130 passes, at maximum weight of 155,000 lb, should be allowed on the pavement?

1. Open the PCASE program.
2. Select the Traffic tab, select Create Pattern, name the pattern “C-17,” and click “Ok.”
3. Set the Analysis Type to “Individual.”
4. Select the Add Vehicle tab, click the box for the C-17 on the dropdown menu, click Add, set the Traffic Area Weight (lb) to “486,000” for “Areas A/B,” and click Apply. A design pass level of 100 for traffic areas A, B, and C is the default setting, so no changes are necessary.
5. Repeat the procedure for another pattern named “C-130” (using its maximum weight), and click Apply. Again, a design pass level of 100 for traffic areas A, B, and C is the default setting, so no changes are necessary.
6. Select the Evaluation Module tab (Figure 13); click Create/Retrieve Feature, fill in the information, and click Assign.
7. Set the Evaluation Type to “Airfield,” set the Traffic Area to “A” for the runway ends; for unsurfaced evaluation, load reduction is not applied in PCASE, so leave the default setting “Good.” **Note: For surfaced pavement evaluation, this must be changed if the pavement has a PCI less than 40.**
8. Set the Analysis Type to “CBR/K Criteria - APE” and select the Traffic Pattern “C-17” from the dropdown menu.
9. Select the Layer Manager tab (Figure 14) and enter the properties for the macadam layer: set the surface to “Unsurfaced” from the dropdown menu, enter the material type as “Unbound aggregate” thickness as “9.0,” and set the CBR to “80” based on the current UFC recommendation and the good condition of the pavement surface.
10. Select “Compacted Subgrade” from the dropdown menu for the next layer, enter the thickness as “231.0” and set the CBR to “10,” and click Save.
11. Click Run Analysis.

12. **Computations indicate that 71 passes of a C-17 may be conducted at the maximum weight of 486,000 lb. With a reduced weight of 433,200 lb, 100 passes are allowable.**
13. Select the Run Properties tab, and change the Traffic Pattern to "C-130" from the dropdown menu.
14. Select the Layer Manager tab, and click Save.
15. Click Run Analysis.
16. **Computations indicate that 614 passes of the C-130 at the maximum weight of 155,000 lb are allowable.**

Figure 14. PCASE layer manager tab.



4.4.1.2 Macadam example 2

Repeat macadam example 1 with CBR values of 50 and 100 instead of 80 for the surface layer (based on the ranges of measured CBR for macadam pavements presented in Chapter 3).

The same general steps as presented in macadam example 1 were conducted, but the CBR of the unsurfaced layer was first changed to 50 and then to 100. Neither of these changes resulted in changes to the number of allowable passes or allowable loads because the limiting factor was the strength of the subgrade material (10 CBR or higher) and the thickness of the layer above the subgrade on the number of allowable passes. Reducing both the thickness of the base layer and its CBR would result in fewer passes to failure. Thus, the measurement of each layer's thickness and CBR are important in the analysis of unsurfaced pavements. If the CBR of the macadam pavement cannot be measured with a DCP, it is recommended that the values based on condition be used as shown in Table 8. However, if the DCP test can be conducted, then the DCP-estimated CBR value should be used.

4.4.1.3 Macadam example 3

Repeat macadam example 1 but apply an equivalency factor of 1.5 for the macadam surface (based on proposed equivalency factors from Chapter 3).

1-9. Repeat steps 1-9 from macadam example 1.
10. Select the Layer Manager tab and enter the properties for the macadam layer: set the surface to "Unsurfaced" from the dropdown menu, enter the material type as "Unbound aggregate" thickness as "13.5" (9.0 in. × 1.5 = 13.5 in.), and set the CBR to "80" based on the "Good" condition and current UFC recommendation.
11. Select "Compacted Subgrade" from the dropdown menu for the next layer, enter the thickness as "226.5" and set the CBR to "10," and click Save.
12. Click Run Analysis.
13. **Computations indicate that 2,281 passes of a C-17 at maximum weight of 486,000 lb are allowable.**
14. Select the Run Properties tab, and change the Traffic Pattern to "C-130" from the dropdown menu.
15. Select the Layer Manager tab, and click Save.
16. Click Run Analysis.
17. **Computations indicate that 37,305 passes of the C-130 at the maximum weight of 155,000 lb are allowable.**

Based on these example problems, using an equivalency factor greater than 1 will result in large increases in both the allowable load and number of passes. Because no pass to failure rates exist for macadam pavements under modern aircraft loads, the use of equivalency factors are not recommended. No recommendations for using LEEP are provided because, currently, only APE can be used for unsurfaced pavement evaluation.

4.4.2 Sand asphalt

Sand asphalt should be evaluated as a flexible pavement (with modifications.) This material is not as dense as HMA, and equivalent thickness concepts or reduced modulus values should be applied. Chapter 3 presented equivalency factors ranging from 0.5 to 0.91 for sand asphalt to traditional HMA. Additionally, manually input modulus values ranging from 70,000-400,000 psi may be applied for LEEP analysis. Both of these were evaluated in the following examples to determine their impact on the number of allowable loads and passes of the C-17 and C-130 aircraft for contingency airfield missions. As with macadam pavements, 100 passes was defined as the design pass level.

4.4.2.1 Sand asphalt example 1

A sand asphalt pavement on a contingency airfield is comprised of 8 in. of sand asphalt over 12 in. of crushed aggregate base over a compacted silty subgrade. DCP evaluation indicates the base layer caused refusal of the DCP, and the subgrade has a CBR of 4. The overall surface condition is Green (Good) based on a cursory inspection. How many passes of a C-17 Globemaster, at a weight of 486,000 lb, should be allowed on the pavement? How many C-130 passes, at maximum weight of 155,000 lb, should be allowed on the pavement?

1. Open the PCASE program.
2. Select the Traffic tab, select Create Pattern, name the pattern “C-17,” and click “Ok.”
3. Set the Analysis Type to “Individual.”
4. Select the Add Vehicle tab, click the box for the C-17 on the dropdown menu, click Add, set the Traffic Area Weight (lb) to “486,000” for “Areas A/B,” and click Apply. Use the default setting of 100 passes for traffic areas A/B.
5. Repeat the procedure for another pattern named “C-130” (using its maximum weight), and click Apply. Use the default setting of 100 passes for traffic areas A/B.
6. Select the Evaluation Module tab; click Create/Retrieve Feature, fill in the information, and click Assign.

7. Set the Evaluation Type to “Airfield,” set the Traffic Area to “A” for the runway ends, and set the Condition to “Good.”
8. Set the Analysis Type to “CBR/K Criteria - APE” and select the Traffic Pattern “C-17” from the dropdown menu.
9. Select the Layer Manager tab and enter the properties for the sand asphalt layer: set the surface to “Asphalt” from the dropdown menu and the thickness as “8.0.” Click on Edit Settings tab and select “Analysis.” The default modulus should be 350,000 psi. Use this unless modulus values are known.
10. Select “Base” from the dropdown menu for the next layer, enter “Unbound aggregate” as the material type and enter the thickness as “12.0,” set the CBR to “100” based on refusal for an aggregate base, and click Save.
11. Select “Compacted Subgrade” from the dropdown menu for the next layer, enter the thickness as “220.0” and set the CBR to “4,” and click Save.
12. Click Run Analysis.
13. **Computations indicate that 123 passes of a C-17 at the maximum weight of 486,000 lb are allowable.**
14. Select the Run Properties tab, and change the Traffic Pattern to “C-130” from the dropdown menu.
15. Select the Layer Manager tab, and click Save.
16. Click Run Analysis.
17. **Computations indicate that 1,554 passes of the C-130 at the maximum weight of 155,000 lb are allowable.**

4.4.2.2 Sand asphalt example 2

Repeat sand asphalt example 1, but with a red “Poor” surface condition.

1. Open the PCASE program.
2. Select the Traffic tab, select Create Pattern, name the pattern “C-17,” and click “Ok.”
3. Set the Analysis Type to “Individual.”
4. Select the Add Vehicle tab, click the box for the C-17 on the dropdown menu, click Add, set the Traffic Area Weight (lb) to “486,000” for “Areas A/B,” and click Apply. Use the default setting of 100 passes for traffic areas A/B.
5. Repeat the procedure for another pattern named “C-130” (using its maximum weight), and click Apply. Use the default setting of 100 passes for traffic areas A/B.
6. Select the Evaluation Module tab; click Create/Retrieve Feature, fill in the information, and click Assign.

7. Set the Evaluation Type to "Airfield," set the Traffic Area to "A" for the runway ends, and set the Condition to "Poor." "Load Reduction in Effect" should appear beside Condition.
8. Set the Analysis Type to "CBR/K Criteria - APE" and select the Traffic Pattern "C-17" from the dropdown menu.
9. Select the Layer Manager tab and enter the properties for the sand asphalt layer: set the surface to "Asphalt" from the dropdown menu, and the thickness as "8.0." Check the Edit Settings tab and "Analysis." Leave the default value of 350,000 psi for the asphalt modulus.
10. Select "Base" from the dropdown menu for the next layer, enter "Unbound aggregate" as the material type, enter the thickness as "12.0" and set the CBR to "100," and click Save.
11. Select "Compacted Subgrade" from the dropdown menu for the next layer, enter the thickness as "220.0" and set the CBR to "4," and click Save.
12. Click Run Analysis.
13. **Computations indicate that 23 passes of a C-17 at the maximum weight of 486,000 lb are allowable and that 100 passes at a reduced weight of 376,200 lb are allowable.**
14. Select the Run Properties tab, and change the Traffic Pattern to "C-130" from the dropdown menu.
15. Select the Layer Manager tab, and click Save.
16. Click Run Analysis.
17. **Computations indicate that 203 passes of the C-130 at the maximum weight of 155,000 lb are allowable.**

4.4.2.3 Sand asphalt example 3

Repeat sand asphalt example 1, but use LEEP.

1-7. Repeat steps 1-7 from sand asphalt example 1.
8. Set the Analysis Type to "LEEP" and select the Traffic Pattern "C-17" from the dropdown menu.
9. Select the Layer Manager tab and enter the properties for the sand asphalt layer: set the surface to "Asphalt" from the dropdown menu and the thickness as "8.0." Set Analysis E to "Manual."
10. Select "Base" from the dropdown menu for the next layer, enter the thickness as "12.0," set Analysis E to "Manual."
11. Select "Compacted Subgrade" from the dropdown menu for the next layer, enter the thickness as "220.0," set Analysis E to "Manual," and click Save.
12. Click on the Edit Setting Tab and click "Analysis" button.

13. Click Edit under Layer Set Controls; change the Asphalt Modulus to "70,000" based on the lowest modulus for sand asphalt presented in Chapter 3, Base Modulus to "150,000" (100 CBR converted to modulus using relationship CBR × 1,500=Modulus), and Comp Subgrade to "6,000" (CBR=4; 4 × 1,500= 6,000 psi). Click Save.
14. Click on the Layer Manager Tab.
15. Click Run Analysis.
16. **Computations indicate that 593 passes of a C-17 at the maximum weight of 486,000 lb are allowable.**
17. Select the Run Properties tab, and change the Traffic Pattern to "C-130" from the dropdown menu.
18. Select the Layer Manager tab, and click Save.
19. Click Run Analysis.
20. **Computations indicate that 4,562 passes of the C-130 at the maximum weight of 155,000 lb are allowable.**

4.4.2.4 Sand asphalt example 4

Repeat sand asphalt example 1, but apply a 0.5 equivalency factor for the sand asphalt layer.

1-8. Repeat steps 1-8 from sand asphalt example 1.

9. Select the Layer Manager tab and enter the properties for the sand asphalt layer: set the surface to "Asphalt" from the dropdown menu, and the thickness as "4.0" (applying 0.5 equivalency factor, 0.5 × 8.0 in. =4.0 in.).
10. Select "Base" from the dropdown menu for the next layer, enter "Unbound aggregate" as the material type and enter the thickness as "12.0," and set the CBR to "100."
11. Select "Compacted Subgrade" from the dropdown menu for the next layer, enter the thickness as "220.0," set the CBR to "4," and click Save.
12. Click Run Analysis.
13. **Computations indicate that 4 passes of a C-17 at the maximum weight of 486,000 lb are allowable and that 100 passes at a reduced weight of 234,500 lb are allowable.**
14. Select the Run Properties tab, and change the Traffic Pattern to "C-130" from the dropdown menu.
15. Select the Layer Manager tab, and click Save.
16. Click Run Analysis.
17. **Computations indicate that 14 passes of the C-130 at the maximum weight of 155,000 lb are allowable and that 100 passes at a reduced weight of 97,600 lb are allowable.**

4.4.2.5 Sand asphalt example 5

Repeat sand example 1 but apply a 0.5 equivalency factor for the sand asphalt layer using LEEP.

1-8. Repeat steps 1-8 from sand asphalt example 3.

9. Select the Layer Manager tab and enter the properties for the sand asphalt layer: set the surface to "Asphalt" from the dropdown menu and the thickness as "4.0." Set Analysis E to "Manual."
10. Select "Base" from the dropdown menu for the next layer, enter the thickness as "12.0," set Analysis E to "Manual," and click Save.
11. Select "Compacted Subgrade" from the dropdown menu for the next layer, enter the thickness as "224.0," set Analysis E to "Manual," and click Save.
12. Click on the Edit Setting Tab and click "Analysis" button.
13. Click Edit under Layer Set Controls; change the Asphalt Modulus to "70,000" based on the lowest modulus for sand asphalt presented in Chapter 3, Base Modulus to "150,000" (100 CBR converted to modulus using equation CBR × 1,500 = Modulus), and Comp Subgrade to "6,000" (CBR = 4; 4 × 1,500 = 6,000 psi). Click Save.
14. Click on the Layer Manager Tab.
15. Click Run Analysis.
16. **Computations indicate that 116 passes of a C-17 at the maximum weight of 486,000 lb are allowable.**
17. Select the Run Properties tab, and change the Traffic Pattern to "C-130" from the dropdown menu.
18. Select the Layer Manager tab, and click Save.
19. Click Run Analysis.
20. **Computations indicate that 579 passes of the C-130 at the maximum weight of 155,000 lb are allowable.**

Based on these example problems, load reduction greatly reduces the number of allowable passes and the allowable loads (for the C-17). It is recommended that if the PCI of the surface is below 40, then the load reduction function in PCASE should be applied. Also, LEEP predicts much higher pass levels than APE. Because of the large differences in allowable passes and loads and the lack of aged moduli values for sand asphalt surfaces in the literature, LEEP analysis is not recommended using estimated modulus values. Recommendations for using LEEP need to be developed based on HWD back-calculated moduli for new and aged sand asphalt pavements. For conservative estimates, it is recommended that APE be used for analyzing sand asphalt pavements. Additionally, it is recommended to use an equivalency factor of 0.5 for sand asphalt to HMA thickness until pass to failure rates for sand asphalt pavements under modern aircraft loads can be determined through field experiments.

4.4.3 Stabilized soil/aggregate

Many stabilization methods may be encountered, including cement, lime, or asphalt stabilization. As mentioned previously, these pavements should be evaluated as unsurfaced pavements using APE, with the exception of cement-stabilized soil. If cement-stabilized surface layers are encountered and both a DCP and a PSPA are available for conducting the structural evaluation, then the process for using LEEP described in ETL 08-14 (AFCESA 2008) should be used. These procedures are not repeated in this report. If, however, the PSPA is not available for evaluation purposes, or the condition of the cement-stabilized surface is “Poor/Red,” then LEEP should not be used, and the APE procedure detailed herein for stabilized soil/aggregate should be utilized for conservative predictions of performance. If possible, evaluate the pavement as an unsurfaced pavement using field-measured DCP values for each layer.

Equivalency factors presented in Chapter 3 included 2.0 for cement-stabilized surface (to base) and 0.35 to 1.0 (to HMA). Additionally, CBR values between 20 and 100 have been measured and may be used if DCP-estimated CBR values cannot be determined. Equivalency factors in Chapter 3 ranging from 1.15 to 1.5 have been suggested for asphalt-stabilized material (to base) or 0.5 to 0.77 (to HMA). Additionally, CBR values between 26 and 100 have been measured and may be used if DCP-estimated CBR values cannot be determined. Chapter 3 also provides equivalency factors for lime-stabilized material (to HMA) between 0.35 and 0.67 and CBR values between 13 and 100. The recommendation of 80 CBR is the current UFC 3-260-03 guidance for cement-stabilized soil if the CBR of the layer cannot be determined with the DCP (UFC 2001b). No UFC recommendations exist for asphalt- or lime-stabilized materials. Based on the historically measured values presented in Chapter 3, the following CBR values based on pavement condition as shown in Table 9 should be used.

Both equivalency factors and CBR values for stabilized materials were evaluated in the following examples to determine their impact on the allowable loads and the numbers of passes of the C-17 and C-130 aircraft for contingency airfield missions with 100 passes defined as the design pass level.

Table 9. Recommended CBR values for stabilized materials based on pavement condition.

CBR Value	Pavement Condition
80	Good
70	Satisfactory
50	Fair
20	Poor

4.4.3.1 Cement-stabilized aggregate example 1

A contingency airfield is comprised of 9 in. of cement-stabilized gravel over a compacted silty subgrade. DCP evaluation indicates the surface layer had a CBR of 60, and the subgrade has a CBR of 10. PSPA tests were not conducted. The overall surface condition is Green (Good) based on a cursory inspection. How many passes of a C-17 Globemaster, at a weight of 486,000 lb, should be allowed on the pavement? How many C-130 passes, at maximum weight of 155,000 lb, should be allowed on the pavement?

1. Open the PCASE program.
2. Select the Traffic tab, select Create Pattern, name the pattern “C-17” and click “Ok.”
3. Set the Analysis Type to “Individual.”
4. Select the Add Vehicle tab, click the box for the C-17 on the dropdown menu, click Add, set the Traffic Area Weight (lb) to “486,000” for “Areas A/B,” and click Apply. Use the default setting of 100 passes for traffic areas A/B.
5. Repeat the procedure for another pattern named “C-130” (using its maximum weight), and click Apply. Use the default setting of 100 passes for traffic areas A/B.
6. Select the Evaluation Module tab; click Create/Retrieve Feature, fill in the information, and click Assign.
7. Set the Evaluation Type to “Airfield,” set the Traffic Area to “A” for the runway ends; for unsurfaced evaluation, load reduction is not applied in PCASE, so leave the default setting “Good.”
8. Set the Analysis Type to “CBR/K Criteria - APE” and select the Traffic Pattern “C-17” from the dropdown menu.
9. Select the Layer Manager tab and enter the properties for the stabilized aggregate layer: set the surface to “Unsurfaced” from the dropdown menu, enter the material type as “Unbound aggregate” thickness as “9.0,” and set the CBR to “60” based on the DCP-estimated CBR. (You may also select

the type of cement-stabilized material based on its soil classification; however, this does not change the results of the analyses unless a base or subbase is present.)

10. Select "Compacted Subgrade" from the dropdown menu for the next layer, enter the thickness as "232.0" and set the CBR to "10," and click Save.
11. Click Run Analysis.
12. **Computations indicate that 71 passes of a C-17 at the maximum weight of 486,000 lb are allowable and that 100 passes at a reduced weight of 433,200 lb are allowable.**
13. Select the Run Properties tab, and change the Traffic Pattern to "C-130" from the dropdown menu.
14. Select the Layer Manager tab, and click Save.
15. Click Run Analysis.
16. **Computations indicate that 614 passes of the C-130 at the maximum weight of 155,000 lb are allowable.**

4.4.3.2 Cement-stabilized aggregate example 2

A contingency airfield is comprised of 9 in. of cement-stabilized gravel over a compacted silty subgrade. DCP evaluation resulted in refusal in the stabilized layer and the subgrade having a CBR of 6. PSPA tests were not conducted. The overall surface condition is Red (Poor) based on a cursory inspection. How many passes of a C-17 Globemaster, at a weight of 486,000 lb, should be allowed on the pavement? How many C-130 passes, at maximum weight of 155,000 lb, should be allowed on the pavement?

1-8. Repeat steps 1-8 from previous example.

9. Select the Layer Manager tab and enter the properties for the stabilized aggregate layer: set the surface to "Unsurfaced" from the dropdown menu, enter the material type as "Unbound aggregate" thickness as "9.0," and set the CBR to "20" based on poor condition of the surface layer and value reported in Table 9.
10. Select "Compacted Subgrade" from the dropdown menu for the next layer, enter the thickness as "232.0" and set the CBR to "6," and click Save.
11. Click Run Analysis.
12. **Computations indicate that 10 passes of a C-17 at the maximum weight of 486,000 lb are allowable and that 100 passes at a reduced weight of 224,100 lb are allowable.**
13. Select the Run Properties tab, and change the Traffic Pattern to "C-130" from the dropdown menu.
14. Select the Layer Manager tab, and click Save.

15. Click Run Analysis.
16. **Computations indicate that 46 passes of the C-130 at the maximum weight of 155,000 lb are allowable and that 100 passes at a reduced weight of 113,400 lb are allowable.**

4.4.3.3 Asphalt-stabilized aggregate example 1

A contingency airfield is comprised of 8 in. of asphalt-stabilized gravel over a compacted silty subgrade. DCP evaluation indicates the surface layer had a CBR of 60 and the subgrade has a CBR of 10. The overall surface condition is Amber (Fair) based on a cursory inspection. How many passes of a C-17 Globemaster, at a weight of 486,000 lb, should be allowed on the pavement? How many C-130 passes, at maximum weight of 155,000 lb, should be allowed on the pavement?

1. Open the PCASE program.
2. Select the Traffic tab, select Create Pattern, name the pattern “C-17” and click “Ok.”
3. Set the Analysis Type to “Individual.”
4. Select the Add Vehicle tab, click the box for the C-17 on the dropdown menu, click Add, set the Traffic Area Weight (lb) to “486,000” for “Areas A/B,” and click Apply. Use the default setting of 100 passes for traffic areas A/B.
5. Repeat the procedure for another pattern named “C-130” (using its maximum weight), and click Apply. Use the default setting of 100 passes for traffic areas A/B.
6. Select the Evaluation Module tab; click Create/Retrieve Feature, fill in the information, and click Assign.
7. Set the Evaluation Type to “Airfield,” set the Traffic Area to “A” for the runway ends; for unsurfaced evaluation, load reduction is not applied in PCASE, so leave the default setting “Good.”
8. Set the Analysis Type to “CBR/K Criteria - APE” and select the Traffic Pattern “C-17” from the dropdown menu.
9. Select the Layer Manager tab and enter the properties for the stabilized aggregate layer: set the surface to “Unsurfaced” from the dropdown menu, enter the material type as “Unbound aggregate” thickness as “8.0,” and set the CBR to “60” based on the DCP-estimated CBR.
10. Select “Compacted Subgrade” from the dropdown menu for the next layer, enter the thickness as “232.0” and set the CBR to “10,” and click Save.
11. Click Run Analysis.

12. **Computations indicate that 40 passes of a C-17 at the maximum weight of 486,000 lb are allowable and that 100 passes at a reduced weight of 343,600 lb are allowable.**
13. Select the Run Properties tab, and change the Traffic Pattern to “C-130” from the dropdown menu.
14. Select the Layer Manager tab, and click Save.
15. Click Run Analysis.
16. **Computations indicate that 327 passes of the C-130 at the maximum weight of 155,000 lb are allowable.**

4.4.3.4 Lime-stabilized aggregate example 1

Repeat asphalt-stabilized aggregate example 1 with CBR values of 13 and 100 for a lime-stabilized aggregate layer instead of the measured CBR of 60 for the surface layer (based on the ranges of measured CBR for lime-stabilized layers presented in Chapter 3 of 13-100 CBR).

The same general steps as presented in asphalt-stabilized aggregate example 1 were conducted, but the CBR of the unsurfaced layer was changed to 13 and then to 100. Changing the surfaced layer CBR to 13 resulted in only 10 allowable passes of the C-17 at the maximum weight of 486,000 lb and 46 passes of the C-130 at its maximum weight of 155,000 lb (same as in using a CBR of 20 in cement-stabilized aggregate example 2). The design pass level could not be met with a surface layer this weak by reducing the allowable load for the C-17. For the C-130, reducing the weight to 113,400 lb would allow 100 passes. For 100 CBR, the increase from 60 to 100 CBR did not result in changes to the number of allowable passes or amount of allowable load compared to a CBR of 60, because the limiting factor in the unsurfaced analysis was the strength of the subgrade material and the thickness above the subgrade on the number of allowable passes. As mentioned previously, the measurement of each layer’s thickness and CBR are important in the analysis of unsurfaced pavements. If the CBR of the stabilized aggregate cannot be measured with a DCP, it is recommended that a conservative estimate presented in Table 9 be used. However, if the DCP can be conducted, then the DCP-estimated CBR value should be used.

4.4.4.4 Asphalt-stabilized aggregate example 2

Repeat asphalt-stabilized aggregate example 1 using an equivalency factor of 1.5.

1-8. Repeat steps 1-8 from asphalt-stabilized aggregate example 1.

9. Select the Layer Manager tab and enter the properties for the stabilized aggregate layer: set the surface to “Unsurfaced” from the dropdown menu, enter the material type as “Unbound aggregate” thickness as “12.0” (8.0 in. × 1.5 = 12.0 in.), and set the CBR to “60” based on the DCP-estimated CBR.
10. Select “Compacted Subgrade” from the dropdown menu for the next layer, enter the thickness as “232.0” and set the CBR to “10,” and click Save.
11. Click Run Analysis.
12. **Computations indicate that 598 passes of a C-17 at the maximum weight of 486,000 lb are allowable.**
13. Select the Run Properties tab, and change the Traffic Pattern to “C-130” from the dropdown menu.
14. Select the Layer Manager tab, and click Save.
15. Click Run Analysis.
16. **Computations indicate that 7,279 passes of the C-130 at the maximum weight of 155,000 lb are allowable.**

4.4.4.5 Asphalt-stabilized aggregate example 3

Repeat asphalt-stabilized aggregate example 1, but apply a 0.5 equivalency factor for the asphalt-stabilized layer to asphalt using LEEP.

1-7. Repeat steps 1-7 from asphalt-stabilized aggregate example 1.

8. Set the Analysis Type to “LEEP” and select the Traffic Pattern “C-17” from the dropdown menu.
9. Select the Layer Manager tab and enter the properties for the stabilized layer: set the surface to “Asphalt” from the dropdown menu and the thickness as “4.0” (0.5 × 8.0 in. = 4.0 in.). Set Analysis E to “Manual.”
10. Select “Compacted Subgrade” from the dropdown menu for the next layer, enter the thickness as “236.0,” set Analysis E to “Manual,” and click Save.
11. Click on the Edit Setting Tab and click “Analysis” button.
12. Click Edit under Layer Set Controls; change the Asphalt Modulus to “350,000” assuming regular quality asphalt for the equivalency and Comp Subgrade to “15,000” (CBR = 10, 10 × 1,500 = 15,000 psi). Click Save.
13. Click on the Layer Manager Tab.
14. Click Run Analysis.
15. **Computations indicate that 3 passes of a C-17 at the maximum weight of 486,000 lb are allowable and that 100 passes at a reduced weight of 304,300 lb are allowable.**

16. Select the Run Properties tab, and change the Traffic Pattern to "C-130" from the dropdown menu.
17. Select the Layer Manager tab, and click Save.
18. Click Run Analysis.
19. **Computations indicate that 9 passes of the C-130 at the maximum weight of 155,000 lb are allowable and that 100 passes at a reduced weight of 110,400 lb are allowable.**

The use of the asphalt equivalencies in LEEP resulted in either far fewer or far more predicted passes of the C-17 and C-130. Unless back-calculated moduli are available, using LEEP for evaluating asphalt- or lime-stabilized materials is not recommended. Because no data could be found for these layers as surfaces for airfields, it is also recommended that no equivalency factors be used for either bituminous- or lime-stabilized surface courses. These materials should be evaluated as unsurfaced layers in APE until pass to failure rates under modern aircraft have been determined through field testing. LEEP should be used for cement-stabilized surfaces if both PSPA and DCP data are available. If not, then either in situ DCP measurements or recommended values for CBR listed in Table 9 should be used.

4.4.5 Surface-treated pavements

As mentioned previously, these pavements should be evaluated as unsurfaced pavements using APE. If a surface treatment has been applied to HMA, then the pavement should be evaluated using conventional HMA evaluation procedures. Chapter 3 indicated that no equivalency factors have been suggested for bituminous surface treatments. Measured CBR values from the literature indicated that surface-treated surface courses had measured CBR ranges between 21 and 100. Both of these were evaluated in the following examples to determine their impact on the number of allowable loads and passes of the C-17 and C-130 aircraft for contingency airfield missions with design pass levels of 100.

4.4.5.1 Surface-treated example 1

A surface-treated pavement on a contingency airfield is comprised of 12 in. of crushed aggregate base overlaid with a double-bituminous surface treatment placed over a compacted silty subgrade. DCP evaluation indicates the base layer caused refusal of the DCP, and the subgrade has a CBR of 4. The overall surface condition is Green (Good) based on a cursory inspection. How many passes of a C-17 Globemaster, at a weight of 486,000 lb, should be allowed on the pavement? How many C-130 passes, at maximum weight of 155,000 lb, should be allowed on the pavement?

1. Open the PCASE program.
2. Select the Traffic tab, select Create Pattern, name the pattern “C-17,” and click “Ok.”
3. Set the Analysis Type to “Individual.”
4. Select the Add Vehicle tab, click the box for the C-17 on the dropdown menu, click Add, set the Traffic Area Weight (lb) to “486,000” for “Areas A/B,” and click Apply. Use the default setting of 100 passes for traffic areas A/B.
5. Repeat the procedure for another pattern named “C-130” (using its maximum weight), and click Apply. Use the default setting of 100 passes for traffic areas A/B.
6. Select the Evaluation Module tab; click Create/Retrieve Feature, fill in the information, and click Assign.
7. Set the Evaluation Type to “Airfield,” set the Traffic Area to “A” for the runway ends, and set the Condition to “Good.”
8. Set the Analysis Type to “CBR/K Criteria - APE” and select the Traffic Pattern “C-17” from the dropdown menu.
9. Select the Layer Manager tab and enter the properties for the aggregate base layer: set the surface to “Unsurfaced” from the dropdown menu and the thickness as “12.0,” set the CBR to 100 based on refusal for an aggregate base and the upper range for measured surface-treated bases, and click Save.
10. Select “Compacted Subgrade” from the dropdown menu for the next layer, enter the thickness as “228.0” and set the CBR to “4,” and click Save.
11. Click Run Analysis.
12. **Computations indicate that 10 passes of a C-17 at the maximum weight of 486,000 lb are allowable and that 100 passes are allowable if the weight is reduced to 262,100 lb.**
13. Select the Run Properties tab, and change the Traffic Pattern to “C-130” from the dropdown menu.
14. Select the Layer Manager tab, and click Save.
15. Click Run Analysis.
16. **Computations indicate that 40 passes of a C-130 at the maximum weight of 155,000 lb are allowable and that 100 passes are allowable if the weight is reduced to 118,000 lb.**

4.4.5.2 Surface-treated example 2

Repeat surface-treated example 1 with CBRs of 20 and 50 for the surface-treated layer.

The same general steps as presented in surface-treated example 1 were conducted, but the CBR of the unsurfaced layer was changed to 20 and then to 50. Changing the CBR to 20 or 50 did not result in changes to the number of allowable passes or amount of allowable load compared to a CBR of 100. As mentioned previously, the measurement of each layer's thickness and CBR are important in the analysis of unsurfaced pavements. If the CBR of the surface-treated aggregate cannot be measured with a DCP, it is recommended that the condition based recommendations presented in Table 9 be used. However, if the DCP can be conducted, then the DCP-estimated CBR value should be used (for surface treatment plus the underlying base). Because only APE can be used for unsurfaced pavement evaluation, no recommendations for using LEEP are provided. Finally, because no equivalency factors were found for surface-treated pavements, no recommendations for their use are provided.

4.5 Design curve evaluation procedures

In addition to using computer software, design curves may also be used to estimate the allowable loads and passes for the design aircraft. General recommendations for using design curves are provided in ETL 02-19 (AFCESA 2002). The procedures detailed in this ETL should be followed with specific recommendations provided in the following sections for the nontraditional pavement surface types.

4.5.1 Macadam

Macadam pavements with or without a penetrating asphalt layer should be evaluated as a semi-prepared, aggregate-surfaced pavement using DCP-estimated CBR data for each pavement layer. However, if the macadam has been overlaid with an HMA-wearing course more than 2 in. in thickness, then the macadam becomes the base, and the entire structure should be evaluated as an HMA pavement.

4.5.2 Sand asphalt

Sand asphalt should be evaluated as an HMA-surfaced pavement (with modifications). Reduce the HMA thickness by half for conservative estimates of the pavement performance based on the equivalency factors presented previously. Use the DCP-estimated CBR for each underlying layer.

4.5.3 Stabilized soil/aggregate

If the PCASE evaluation cannot be accomplished, then stabilized surfaces should be evaluated as semi-prepared, unsurfaced, or aggregate-surfaced pavements using the DCP-estimated CBR for each layer.

4.5.4 Surface-treated pavements

Surface-treated bases should be evaluated as a semi-prepared, aggregate-surfaced pavement. If a surface treatment has been applied to HMA, then the pavement should be evaluated using conventional HMA procedures.

5 Conclusions and Recommendations

During the research period, several nontraditional surface types were identified that may be encountered during contingency airfield operations. These include macadam, sand asphalt, stabilized-layer, and surface-treated courses.

A review of the literature on relevant pavement construction techniques was completed in this investigation to determine material properties that could be used to assess the suitability of a pavement for C-17 or C-130 aircraft traffic. Additionally, methods for assessing the condition of the pavements' surfaces and methods for evaluating their structural adequacy were developed and presented. Table 10 provides a summary of both of these methods for each pavement's surface type. Conclusions and recommendations for inspecting and evaluating nontraditional airfield pavements are presented in the following sections.

Table 10. Summary of interim evaluation procedures for nontraditional airfield surfaces.

Item	Surface Type					
	Macadam	Sand Asphalt	Cement-Stabilized	Lime-Stabilized	Asphalt-Stabilized	Surface-Treated
Condition rating procedure	Full SPACI procedures if time permits using distress modifications presented in Table 3. Simplified SPACI using simplified rating system detailed in Table 2 and if time does not permit.	Full PCI procedures for HMA pavements if time permits. Simplified rating system defined in Table 1 if time does not permit.	Full SPACI procedures if time permits using distress modifications presented in Table 3. Simplified SPACI using simplified rating system detailed in Table 2 and if time does not permit.	Full SPACI procedures if time permits using distress modifications presented in Table 3. Simplified SPACI using simplified rating system detailed in Table 2 and if time does not permit.	Full SPACI procedures if time permits using distress modifications presented in Table 3. Simplified SPACI using simplified rating system detailed in Table 2 and if time does not permit.	Full SPACI procedures if time permits using distress modifications presented in Table 3. Simplified SPACI using simplified rating system detailed in Table 2 and if time does not permit.
Evaluation equipment	DCP	DCP	DCP for APE/CBR analyses	DCP	DCP	DCP
PCASE evaluation module	APE/CBR	APE/CBR	LEEP if PSPA and DCP equipment are used. APE/CBR	APE/CBR	APE/CBR	APE/CBR

Item	Surface Type					
	Macadam	Sand Asphalt	Cement-Stabilized	Lime-Stabilized	Asphalt-Stabilized	Surface-Treated
Evaluation surface type	Unsurfaced if wearing surface <2.0 in. Surfaced if wearing surface > 2.0 in.	Surfaced (AC)	Unsurfaced	Unsurfaced	Unsurfaced	Unsurfaced
Equivalency factor for surface layer?	No	Yes: multiply sand asphalt thickness by 0.50 to determine equivalent HMA thickness.	No	No	No	No
Recommended CBR values if no surface layer data are available based on surface condition rating	80-"Good" condition 70- "Satisfactory" condition 60- "Fair" condition 50- "Poor" condition	N/A. Use default asphalt modulus.	80-"Good" condition 70- "Satisfactory" condition 50- "Fair" condition 20- "Poor" condition	80-"Good" condition 70- "Satisfactory" condition 50- "Fair" condition 20- "Poor" condition	80-"Good" condition 70- "Satisfactory" condition 50- "Fair" condition 20- "Poor" condition	80-"Good" condition 70- "Satisfactory" condition 60- "Fair" condition 20- "Poor" condition
Load reduction?	No	Yes: 25% for pavement in "Red" condition.	No	No	No	No
Design curve guidance	Use semi-prepared, aggregate surfaced pavement curve procedures if wearing surface <2.0 in. Use AC/HMA-surfaced evaluation procedures if wearing surface >2.0 in.	Use AC/HMA surfaced evaluation procedures; reduce the thickness by one half.	Use semi-prepared, aggregate-surfaced pavement curve procedures.	Use semi-prepared, aggregate-surfaced pavement curve procedures.	Use semi-prepared, aggregate-surfaced pavement curve procedures.	Use semi-prepared, aggregate-surfaced pavement curve procedures.

5.1 Conclusions

- The primary distresses that may be encountered with each pavement type are
  - Macadam-surfaced pavements: loose aggregate, rutting, potholes, and shoving
  - Sand asphalt-surfaced pavements: rutting, shoving, weathering, raveling, and cracking
  - Stabilized-surface pavements: rutting, loose aggregate, potholes, delaminations, dust, rolling resistant material, and jet-blast erosion
  - Surface-treated pavements: weathering, raveling, potholes, rutting, loose aggregate, and delaminations
- The interim structural evaluation procedures detailed in this report and summarized in Table 10 should be used for conservative estimates of flight operations. The pavement should be inspected after every aircraft pass, as these procedures have not been validated through field testing.
- Based on the limited analyses of this report, as long as there is a relatively strong base adequately thick to protect the subgrade, minimum C-17 and C-130 aircraft operations may be conducted on the nontraditional pavements described in this report. It may be required to reduce the allowable load to conduct operations, however.

5.2 Recommendations

- Due to the limited test data available and no long-term exposure data for sand asphalt, surface-treated, or macadam pavements, very conservative estimates of CBR and equivalency factors are recommended.
- Fighter aircraft are not recommended on sand asphalt-surfaced pavements due to their high tire pressures. Also due to high FOD potential, operation of fighter aircraft is not recommended on macadam surfaces, stabilized surfaces, or surface-treated pavements.
- Due to their limited use in the United States, full-scale field testing, including construction of macadam, surface-treated, and sand asphalt pavements, is recommended to validate the interim evaluation guidance presented in this report.

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14. ABSTRACT

During the period November 2012 through September 2013, research was conducted at the US Army Engineer Research and Development Center (ERDC) in Vicksburg, Mississippi, to develop pavement evaluation guidance to improve the field performance prediction for nontraditional airfield pavements used during contingency operations. Nontraditional airfield pavements investigated included wearing surfaces comprised of sand asphalt, macadam, bituminous surface treatments, or stabilized soils/aggregates. These pavement types may be encountered during contingency operations or in remote regions where traditional airfield construction materials such as asphalt or portland cement concrete are not readily available or are too cost-, labor-, or equipment-intensive to use. This report presents a review of the literature pertaining to the mechanical properties of these nontraditional materials and the development of an interim evaluation procedure for predicting the performance of these pavement types for the C-17 and C-130 aircraft. Recommendations for improving the interim evaluation procedure through field verification tests are also presented.

15. SUBJECT TERMS

Pavement evaluation	Macadam	Stabilized
Surface treatments	Sand asphalt	C-17
	Unsurfaced	

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