DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

28 AUG 2008

FROM: AFCESA/CEO
139 Barnes Drive, Suite 1
Tyndall AFB FL 32403-5319

SUBJECT: **Engineering Technical Letter (ETL) 08-14: Structural Evaluation Procedure for Stabilized Soil-Surfaced Airfields**

1. Purpose. This ETL outlines an approach for determining the remaining operational capacity of stabilized soil-surfaced airfields. A proven technique for modeling the complex mechanical behavior of stabilized soils does not currently exist. The successful development of a stabilized soil performance model will require additional research, but a promising approach has been established. This guidance presents a method for evaluating stabilized soil-surfaced airfields in situ using a linear elastic modeling approach commonly used for rigid and flexible pavements. Portland cement stabilized soil airfields were evaluated to develop this approach and the applicability to other stabilization methods is not yet known. In this method, portable, lightweight strength-measuring devices are used to evaluate the surface and subgrade, providing a rapid and easily deployable method for assessing the current condition of stabilized soil-surfaced airfields.

2. Application: All Department of Defense (DOD) organizations responsible for the evaluation of stabilized soil-surfaced airfields.

2.1. Authority: Air Force policy directive (AFPD) 32-10, *Air Force Installations and Facilities*.

2.2. Coordination: Major command (MAJCOM) pavement engineers.

2.3. Effective Date: Immediately.

2.4. Intended Users:

- Air Force Prime BEEF and RED HORSE units.
- Army Corps of Engineers.
- Navy and Marine Corps.
- Organizations performing DOD airfield pavement evaluations and/or others responsible for airfield maintenance.

3. Referenced Publications.

3.1. Air Force.

- AFPD 32-10, *Air Force Installations and Facilities*, available at http://www.e-publishing.af.mil/

3.2. DOD:

- United Facilities Criteria (UFC) 3-260-03, *Airfield Pavement* Evaluation, available at http://www.wbdg.org/ccb/DOD/UFC/ufc_3_260_03.pdf
- UFC 3-260-02, *Pavement Design for Airfields*, available at http://www.wbdg.org/ccb/DOD/UFC/ufc_3_260_02.pdf

3.3. Army:

- Bell, Haley P. (2006). *Operating the Portable Seismic Pavement Analyzer*. Special Report ERDC/GSL SR-06-9. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS, available at https://transportation.wes.army.mil/triservice/default.aspx

3.4. American Society for Testing and Materials (ASTM):

- *Annual Book of ASTM Standards*, available at http://www.astm.org
- ASTM D 1635, *Standard Test Method for Flexural Strength of Soil-Cement Using Simple Beam with Third-Point Loading*
- ASTM D 4694, *Standard Test Method for Deflections with a Falling-Weight-Type Impulse Load Device*
- ASTM D 6951, *Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications*

4. Acronyms and Terms:

AC	– asphalt concrete
ALRS	– alternate launch and recovery surface
ASTM	– American Society for Testing and Materials
CBR	– California bearing ratio
DCP	– dynamic cone penetrometer
DOD	– Department of Defense
E	– elastic (Young's) modulus
E_{PSPA}	– elastic modulus reported by PSPA
ERDC	– Engineer Research and Development Center
ETL	– Engineering Technical Letter
FOD	– foreign object damage
FWD	– falling weight deflectometer
ksi	– kilograms per square inch
lbs	– pounds
LEEP	– linear elastic evaluation program
mm	– millimeter
M_R	– resilient modulus
PCASE	– Pavement-Transportation Computer Assisted Structural Evaluation
PCC	– Portland cement concrete
Prime BEEF	– Priority Improved Management Effort - Base Engineer Emergency Force
psi	– pounds per square inch
PSPA	– Portable Seismic Property Analyzer
R	– modulus of rupture

RED HORSE– Rapid Engineers Deployable Heavy Operations Repair Squadron Engineers
SCI – structural condition index
T – layer thickness
UFC – Unified Facilities Criteria
USW – ultrasonic surface waves
ν – Poisson's ratio
WESLEA – Waterways Experiment Station Linear Elastic Analysis

5. Preface. The U.S. Army Corps of Engineers' Engineer Research and Development Center (ERDC) was tasked to develop a method for assessing the remaining operational capacity of stabilized soil-surfaced airfields. Stabilized soil airfields are commonly used as alternative launch and recovery surfaces (ALRS) and contingency training facilities. Stabilized soil-surfacing is a cost-effective alternative to Portland cement concrete (PCC) and asphalt concrete (AC) surfaces and should be more durable than plain aggregate-surfaced airfields. The mechanical behavior of stabilized materials is non-uniform and the performance is stress- and time-dependent. Fresh stabilized materials perform similarly to weak rigid pavement layers. However, after cracking occurs, the performance characteristics more closely resemble firm, flexible pavement layers. Therefore, this guidance assesses the stabilized surface layer using a combination of rigid and flexible pavement evaluation approaches. Determination of the failure limits of stabilized materials is equally complex. The stabilized materials maintain a considerable amount of the original strength after cracking. However, delamination of thin surface layers may occur much earlier than structural failure characterized by severe cracking and rutting, creating a potential for foreign object damage (FOD).

6. Background.

6.1. Soil Stabilization. Soil stabilization is accomplished by blending natural soils with supplementary materials to improve the engineering properties of the natural soils. Commonly used additive materials include PCC, lime, fly ash, asphalt cement, polymers, and fibers. The long-term performance of stabilized soils is influenced by the characteristics of the parent soil, type and quantity of stabilization additive, construction practices, frequency and magnitude of loading, and placement environment.

6.2. Multilayer Linear Elastic Analysis. Multilayer linear elastic analysis is an analytical method of calculating the mechanistic responses (stress, strain, and deflection) of a pavement as the result of the application of an external load. Burmister's solutions are used to determine the stresses and strains in the pavement system. Using an empirical approach, the magnitudes of the responses are used to determine the occurrence and severity of distresses in the pavement. A number of assumptions are made in the modeling of the pavement system to conduct multilayer elastic analysis, including the following: the material properties of each layer are isotropic and homogeneous; the layers are characterized by elastic modulus (E) and Poisson's ratio (ν); each layer has a finite thickness, with the exception of the subgrade which is assumed to be infinite; each layer extends infinitely in the horizontal direction; and the loading is static and applied uniformly over a circular area. The mechanical responses are determined for the critical locations within the pavement system and the controlling location and responses are identified. Using established failure conditions, the maximum allowable aircraft coverages and loading are determined in the analysis.

6.3. Pavement - Transportation Computer Assisted Structural Engineering (PCASE). PCASE is a pavement design and evaluation computer application. The software was developed to provide engineers with a tool capable of handling all of the processes of pavement design and evaluation in a single interface. The evaluation protocol used in the program is based upon the standards set forth in UFC 3-260-02 and UFC 3-260-03 for airfield pavement design and evaluation, respectively. The PCASE program contains the WESLEA linear elastic modeling subroutine. WESLEA is a five-layer linear elastic model used to conduct the mechanistic analysis. The modes of failure and indicating responses are different for rigid and flexible pavements when analyzed using multilayer elastic methods.

6.3.1. Rigid Pavements. A uniform circular vertical load is applied to the surface of a rigid pavement with known flexural strength (R) and thickness (T). A rigid pavement slab responds to perpendicular loading by curling; that is, the top of the slab goes into compression and the bottom of the slab goes into tension. Rigid pavements are strong in compression but relatively weak in tension. Therefore, failure occurs in rigid pavements at the bottom of the slab when the load-induced tensile stress is in excess of the flexural strength of the stabilized material. PCASE calculates the tensile stress at the bottom of the rigid pavement layer due to a defined loading using the WESLEA subroutine. The number of allowable coverages is then determined when the tensile stress is not in excess of the flexural strength for a given surface condition index (SCI). Failure in rigid pavements is defined by cracking. Cracking occurs first at the bottom of the slab and then propagates upward toward the surface.

6.3.2. Flexible Pavements**.** When modeling flexible pavements, a uniform perpendicular circular load is applied to the pavement surface. All of the layers in the flexible pavement system are characterized by “E”, “ν”, and “T”, except for the subgrade, which is modeled with an infinite thickness. The flexible pavement layers respond to loading by undergoing shear deformation. The WESLEA subroutine calculates the load-induced strain within the critical locations of the pavement layers. Failure in flexible pavements is defined by the permanent deformation of the pavement layers known as rutting. Rutting occurs when the load-induced deformation in a pavement layer is in excess of the recoverable deformation of the material. PCASE uses the critical strain determined using WESLEA to establish the maximum allowable coverages at a given loading when the load-induced strain is not in excess of the recoverable strain of the material. Rutting can occur in any of the pavement layers but is primarily found in the subgrade layer.

6.4. Field Determination of Pavement Properties*.* Determining the material properties of stabilized soil materials is possible by sampling and returning the material to the laboratory for testing. Transporting and testing the samples is time-consuming and not cost-effective—a method of determining the properties of the material in situ is preferred.

6.4.1. Material Properties.

6.4.1.1. The ability of a material to resist deflection due to an imparted force defines the elastic modulus (E). When considering pavement layers, the stiffness of the material determines the magnitudes of displacement and strain experienced as a result of being loaded. Stiffness is used interchangeably with the terms elastic modulus, Young's modulus, and resilient modulus (M_R). The elastic modulus is used to describe the stiffness of the pavement layer, although it is more accurately a description of the resistance to deflection of the constituent materials within the layer.

6.4.1.2. The ratio of horizontal strain to axial strain in a material as it is loaded is known as the Poisson's ratio (ν). The Poisson's ratio defines the magnitude of deformation normal to the load. The deformation occurs as a result of inherent resistance to change in volume. The Poisson's ratio is a material property and commonly ranges from 0.0 to 0.5, although some materials, such as foams, possess negative "ν" values.

6.4.1.3. The ability of a solid to resist fracture in bending is the flexural strength of the material and is also known as the modulus of rupture (R). With respect to pavements, particularly rigid pavements, the flexural strength determines the amount of bending stress the slab can endure before cracking develops.

6.4.1.4. The physical depth or the distance from the surface to the bottom of a pavement layer is defined as the thickness (T) of that layer. The thickness of the stabilized pavement layer bears great influence on the exhibited performance characteristics.

6.4.2. In Situ Testing Devices.

6.4.2.1. The properties of the stabilized surface layer may be determined using the Portable Seismic Property Analyzer (PSPA). The PSPA was developed by Geomedia Research & Development as a portable device with the ability to nondestructively evaluate concrete, asphalt, 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 Young's modulus.

Figure 1. Portable Seismic Property Analyzer (PSPA)

6.4.2.2. The strength of the subgrade is determined using the dynamic cone penetrometer (DCP) (see Figures 2 and 3). The DCP is used extensively in both military and civilian applications. The DCP is a portable device capable of determining the in situ strength of soils. The DCP is intended for use on horizontal construction applications, including fine- and coarse-grained soils, granular construction materials, and weak stabilized or modified materials. Materials underlying a bound surface layer can be tested by first drilling or coring an access hole. The DCP is composed of a handle, two rods, either a 10.1-pound (4.58-kilogram) or 17.6-pound (7.98-kilogram) hammer, an anvil, and a conical tip. The data output of the DCP is the DCP index. The DCP index is a measure of the penetration rate, or the depth of penetration, of the conical tip with each blow of the hammer. A number of published correlations exist relating the DCP index to California bearing ratio (CBR) and resilient modulus (M_R).

Figure 2. Drilling Through the Overlying Stabilized Surface

Figure 3. Using a DCP to Determine Subgrade Soil Strength

7. Evaluation Procedure*.*

7.1. Assessing a Test Site. The evaluation of a stabilized soil airfield should include critical locations such as the runway ends and taxiways in addition to any parking aprons involved in the proposed operations. A minimum of 10 test locations should be established and focused on areas within the expected wheel path of the evaluation aircraft. An example of a typical test location layout for a stabilized airfield runway is shown in Figure 4. The PSPA should be used to evaluate the stabilized material surface layer and the DCP should be used to determine the level of subgrade support. Several factors should be noted and taken into consideration when evaluating the airfield. Of particular importance are the surface condition (current distress levels) and environment (moisture conditions). The influence of the conditions at the time of testing should be considered when reviewing the results of the analysis.

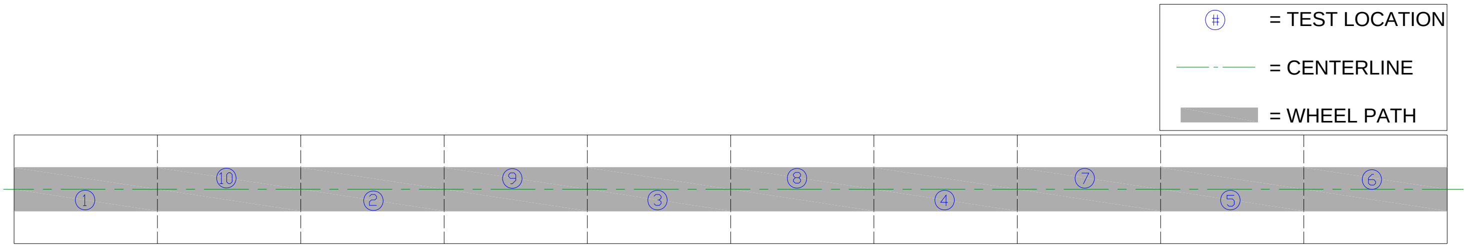

Figure 4. Test Location Layout for Stabilized Runway

7.2. Measurement of Properties.

7.2.1. The PSPA should be used in accordance with the procedures outlined in the guidance developed by the ERDC and available in ERDC/GSL SR-06-9. Three tests should be run at each test location and used to determine the average PSPA modulus (E_{PSPA}) of that location. Testing with the PSPA should not be conducted on segments of the surface layer that are heavily cracked. If the width of cracks in the surface is in excess of 0.25 inch (6.3 millimeters), the "E" value determined for the subgrade should also be used for the evaluation of the stabilized surface. When assessment using the PSPA is possible, Equation 1 should be used to modify "E_{PSPA}" to yield the elastic modulus of the stabilized material. Equation 1 was developed by conducting a regression analysis using PSPA measurements in the field and backcalculated elastic modulus (E) values determined using a falling weight deflectometer (FWD) in accordance with ASTM D 4694. The coefficient of determination for the regression relationship is 0.72. The correlation shown in Equation 2 should be used to establish the modulus of rupture of the surface layer. Equation 2 was developed by conducting a regression analysis using PSPA measurements in the field and samples returned to ERDC for laboratory testing. The testing was conducted in accordance with ASTM D 1635 and the coefficient of determination of the relationship is 0.77. It should be noted that "E_{PSPA}" is reported in ksi (kilograms per square inch) or 1.0 x 10^3 psi (pounds per square inch). The elastic modulus reported using the PSPA should be converted to psi before being used to calculate Young's modulus.

$$E\left(psi\right) = 353{,}753 \times \ln\left(E_{PSPA}\right) - 4{,}237{,}000 \qquad (1)$$

$$R\left(psi\right) = 0.14 \times 10^{-3}\left(E_{PSPA}\right) + 21.00 \qquad (2)$$

7.2.2. A hammer drill or other boring device will be needed to penetrate the stabilized surface to access the subgrade material. Upon complete penetration of the surface layer, a measurement of the thickness (T) of the surface layer should be made. Care should be taken to accurately measure the thickness to ± 0.25 inch (6.3 millimeters). The DCP should then be run in accordance with the standard procedures outlined in ASTM D 6951 to determine the DCP index of the subgrade. The established correlation provided in Equation 3 will be used to determine the in situ CBR of all subgrade soils except CL (low-plasticity clay) soils with a CBR less than 10 and CH (high-plasticity clay) soils. The in situ CBR of the exception soils should be determined using Equations 4 and 5. The relationship presented in Equation 6 should be used to establish the elastic modulus (E) of the subgrade based upon the calculated CBR.

$$CBR(\%) = 292 \big/ (DCPIndex)^{1.12} \tag{3}$$

$$CL\ Soils\ CBR < 10 : CBR(\%) = 1 \big/ (0.017019 \times DCPIndex)^{2} \tag{4}$$

$$CH\ Soils : CBR(\%) = 1 \big/ (0.002871 \times DCPIndex) \tag{5}$$

$$E(psi) = 1500 \times CBR \tag{6}$$

7.2.3. Poisson's ratio (ν) is a material property that cannot be measured in the field and therefore a common value for PCC-stabilized soils, 0.20, should be used for evaluation.

7.3. Determining Operational Limits. The evaluation module of the PCASE 2.08 software package may be used to determine the operational capacity of the stabilized soil-surfaced airfield using the material characterization data collected in situ. Due to the complex performance characteristics of stabilized materials, a combination of rigid and flexible analyses should be run to evaluate the stabilized surface. Users should note that the airfield and test locations must be established using the inventory module and the projected traffic input using the traffic module of the software before any analysis can be conducted. More information is available in the PCASE Help utility.

7.3.1. New stabilized soil pavement layers and those exhibiting no structural cracking should be evaluated using both the rigid and flexible approaches. The occurrence of shrinkage cracking is expected in stabilized soil layers and should not be interpreted as structural cracking. Cracked pavements should be evaluated with the flexible approach only. For the evaluation, the stabilized surface will be modeled as either weak PCC or stiff AC in the rigid and flexible analyses, respectively.

7.3.2. Rigid Analysis. For the rigid analysis, the "R" and "E" for the surface layer will have to be entered, in addition to the "E" for the subgrade layer. Common values of Poisson's ratio should be used for the surface and subgrade if the true values are unknown—0.20 and 0.40, respectively. Due to the lack of joints capable of transferring loads in a stabilized surface, the load transfer should be set to 0.0 percent. The SCI should be set to 50, which is related to the appearance of 50 percent shattered slabs in a rigid pavement. A shattered slab is a rigid pavement unit broken into four or more pieces by intersecting cracks. This is defined as the failure point of rigid pavements. It should be noted that a level of shrinkage cracking is expected in stabilized materials and should not be interpreted as failure of the surface. The analysis should be run and the allowable loading and passes to failure determined for the surface.

Example: An uncracked PCC-stabilized surface on a contingency airfield is comprised of 9.0 inches of stabilized surface over compacted silty-sand subgrade at the runway ends. Evaluation yields E_{PSPA} = 1,350,000 psi for the surface and a DCP Index = 18 mm/blow for the subgrade. How many passes of a C-17 Globemaster, at a weight of 486,000 pounds, should be allowed on the pavement?

From the equations:

$$E\left(psi\right) = 353{,}753 \times \ln\left(E_{PSPA}\right) - 4{,}237{,}000$$
$$= 353{,}753 \times \ln\left(1{,}350{,}000\right) - 4{,}237{,}000 = 756{,}441\ psi \rightarrow 756{,}400\, psi$$

$$R\left(psi\right) = 0.14 \times 10^{-3}\left(E_{PSPA}\right) + 21.00 = 0.14 \times 10^{-3}\left(1{,}350{,}000\right) + 21.00 = 210\ psi$$

$$CBR\left(\%\right) = 292 \Big/ \left(DCPIndex\right)^{1.12} = 292 \Big/ \left(18.0\right)^{1.12} = 11.5\%$$

$$E\left(psi\right) = 1500 \times CBR = 1500\left(11.5\right) = 17{,}250\, psi$$

- Open the PCASE 2.08 program.
- Select the Traffic tab, select Create Pattern, name the pattern “C-17,” and click “Ok.”
- Set the Analysis Type to “Individual.”
- Select the Add Vehicle tab, click the box for the C-17 on the dropdown menu, click Add, set the Traffic Area Weight (lbs) to “486,000” for “Areas A/B,” and click Apply.
- Select the Evaluation Module tab (Figure 5), click Create/Retrieve Feature, fill in the information, and click Assign.
- Set the Evaluation Type to “Airfield,” set the Traffic Area to “A” for the runway ends, and set the Condition to “Good.”
- Set the Analysis Type to “LEEP” and select the Traffic Pattern “C-17” from the dropdown menu.
- Select the Layer Manager tab (Figure 6) and enter the properties for the stabilized layer: set the surface to “PCC” from the dropdown menu, enter the thickness as “9.0,” set the Analysis E to “Manual,” and enter the Flex Strength as “210.”
- Select “Compacted Subgrade” from the dropdown menu for the next layer, enter the thickness as “231.0,” set the Analysis E to “Manual,” and click Save.

- Select the Edit Settings tab (Figure 7), click Backcalculation, click Edit, set the PCC Strength value to “756,400” (rounded off calculated value of E), set the Poisson’s ratios (PR) equal to “0.20” and “0.40” for the PCC and Compacted Subgrade respectively, set the Slip to “1.0” for both layers, and click Save.
- Click Analysis, click Edit, enter the modulus value for each layer (756,400 psi for the PCC and 17,250 psi for the Compacted Subgrade), and click Save.
- Set the SCI to “50” and Load Transfer equal to “0.0%.”
- Return to the Layer Manager tab (Figure 6) and click Run Analysis.
- Computations indicate that three passes of a C-17 at the specified load of 486,000 pounds are allowable.

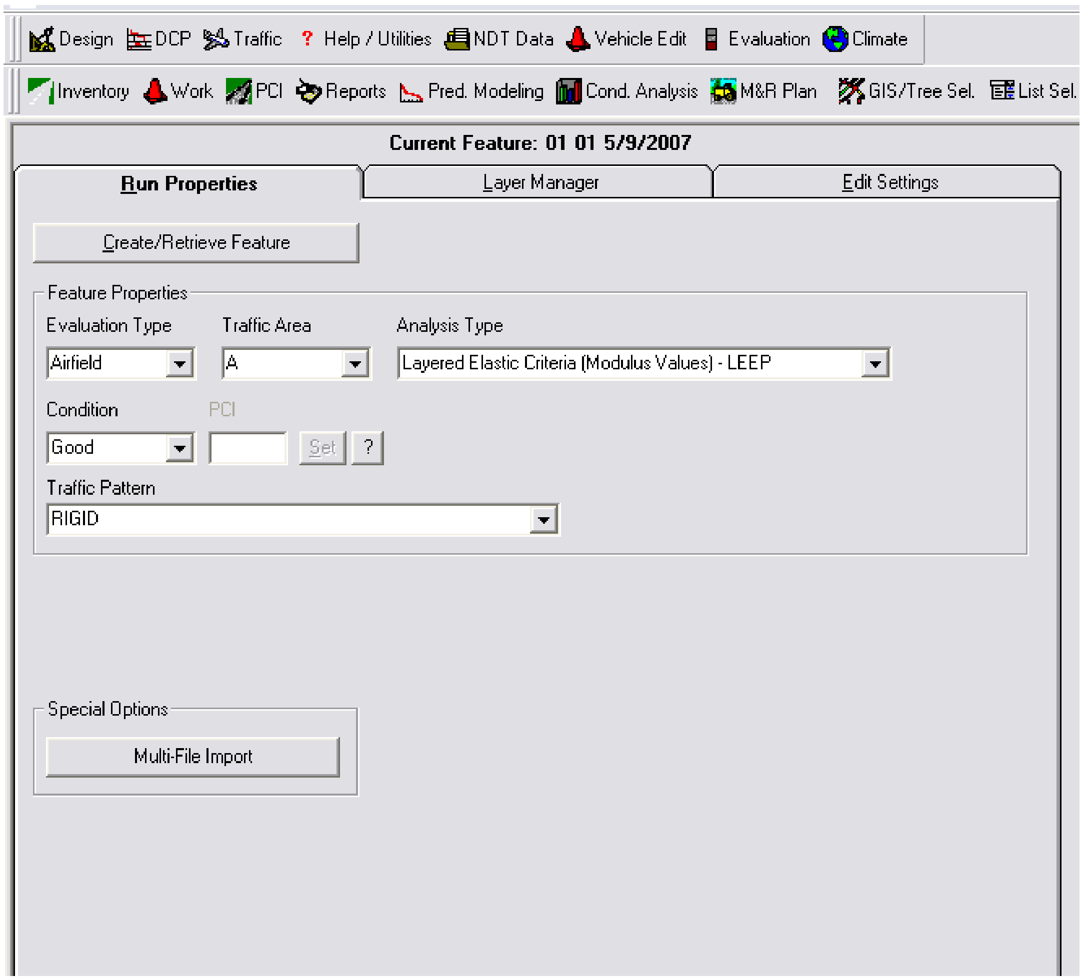

Figure 5. Evaluation Module Run Properties Tab in PCASE 2.08

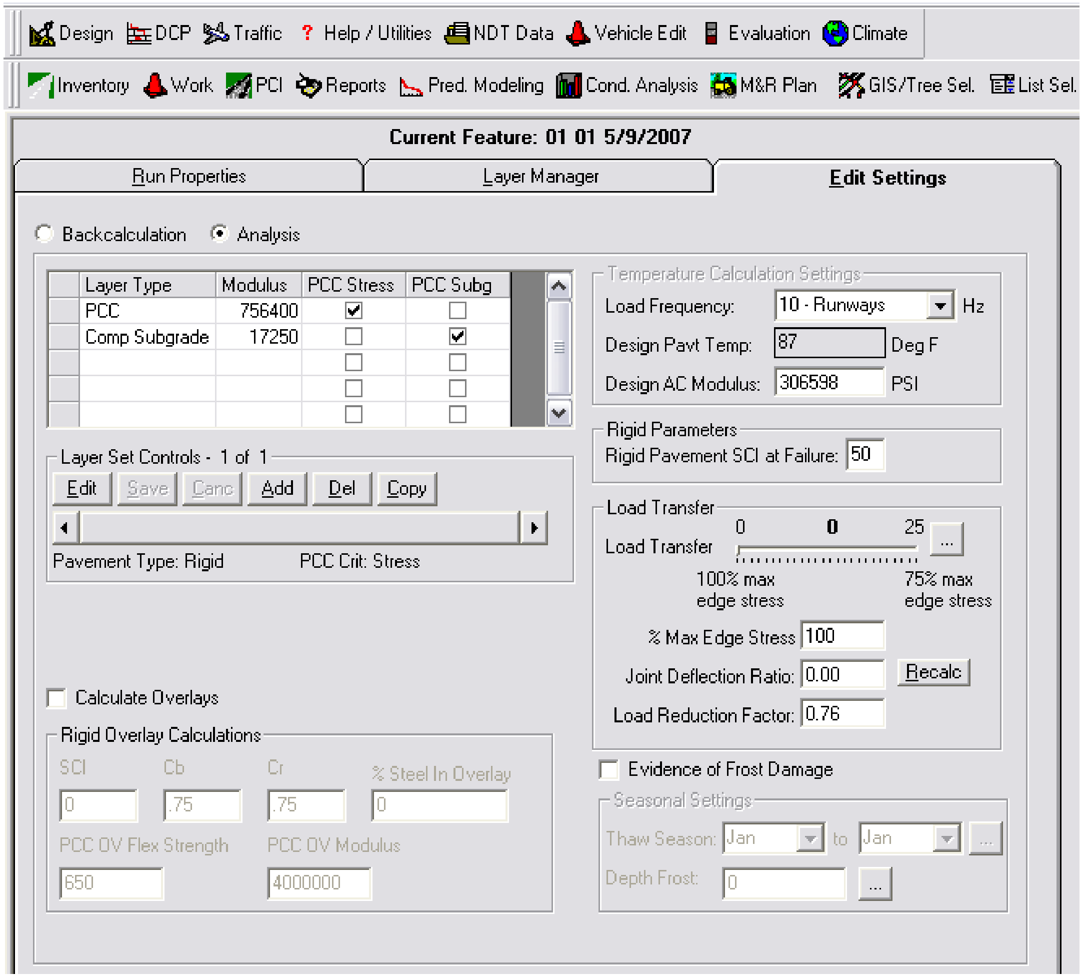

Figure 6. Evaluation Module Edit Settings Tab in PCASE 2.08

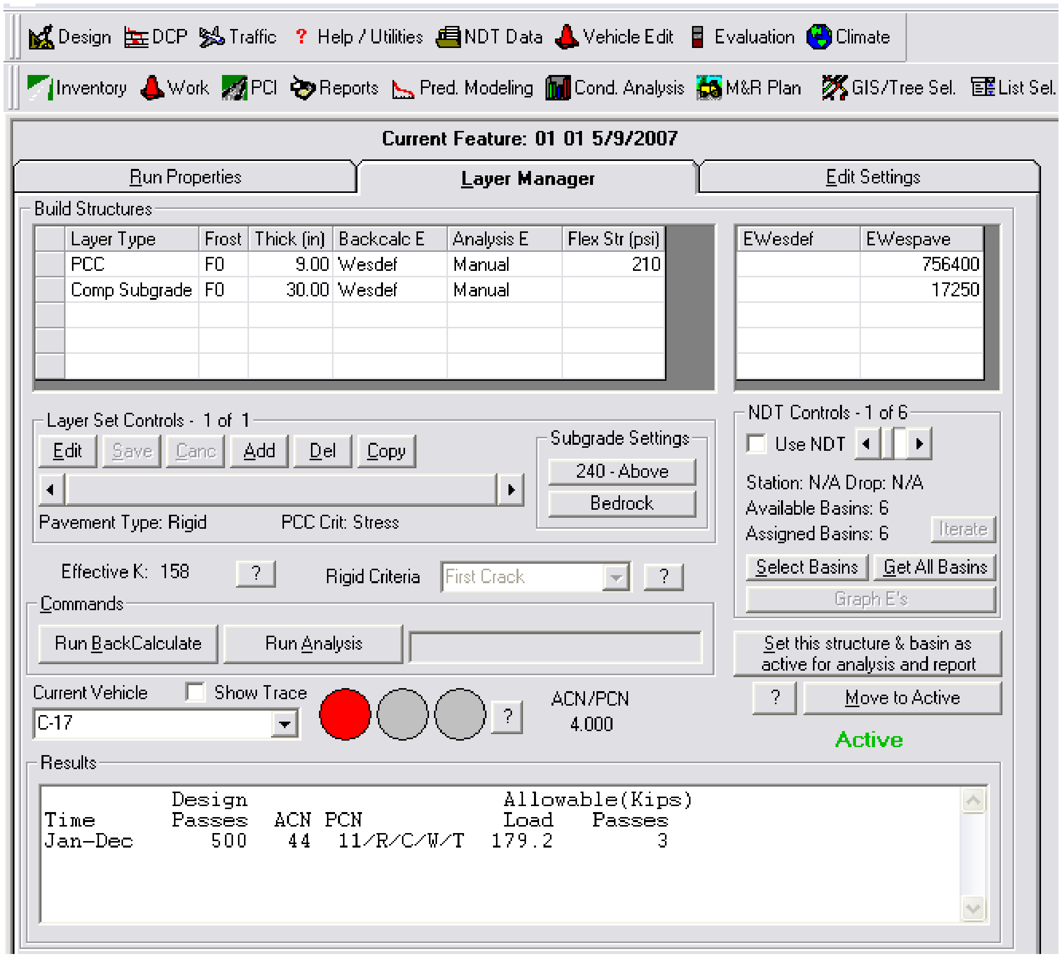

Figure 7. Evaluation Module Layer Manager Tab (Rigid Analysis) in PCASE 2.08

7.3.3. Flexible Analysis. The flexible analysis is run similarly to the rigid analysis. The top layer type should be set to asphalt and the "E" values used for analysis set to manual. The elastic modulus values calculated using the PSPA measurements should be input into the analysis settings and the allowable passes to failure determined again.

Example: Same pavement structure and operations scenario as the previous example.

- Within the Layer Manager tab (Figure 8), enter the layer properties for the flexible analysis: click Edit, set the surface layer to "Asphalt," enter the thickness as "9.0," and set the Analysis E to "Manual."
- Select "Compacted Subgrade" for next layer, enter the thickness as "231.0," set the Analysis E to "Manual," and click Save.
- Select the Edit Settings tab, click Backcalculation, set the Asphalt Strength value to "756,400," set the Poisson's ratios (PR) equal to

"0.20" and "0.40" for the Asphalt and Compacted Subgrade respectively, set the Slip to "1.0" for both layers, and click Save.

- Click Analysis, enter the modulus value for each layer (756,400 psi for the Asphalt, 17,250 psi for the Compacted Subgrade), and click Save.
- Return to the Layer Manager tab and click Run Analysis.
- Computations indicate that 25,799 passes of a C-17 at the specified load of 486,000 pounds are allowable.

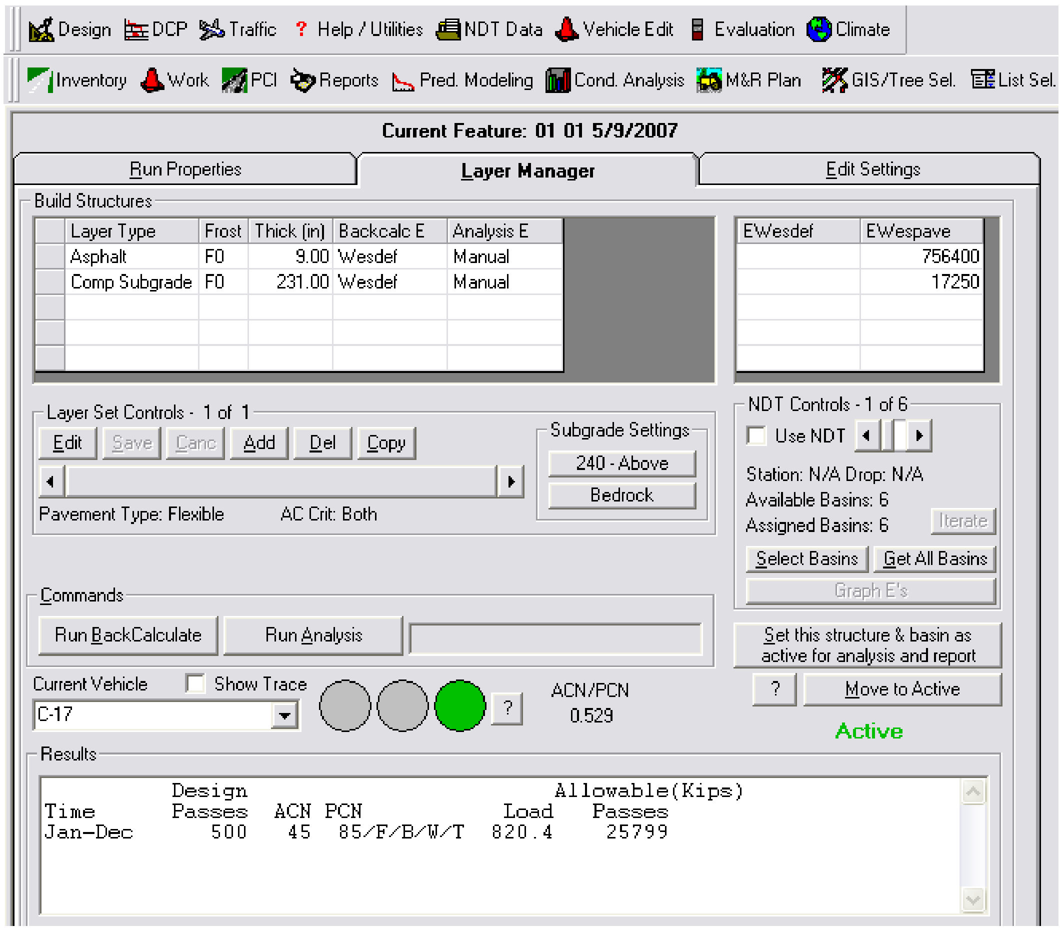

Figure 8. Evaluation Module Layer Manager Tab (Flexible Analysis) in PCASE 2.08

7.3.4. For new and uncracked stabilized layers, the rigid analysis will indicate the number of passes and allowable loading before structural cracking occurs. Once the initial cracking has occurred, the material performance transitions from that resembling a weak rigid layer to that of a stiff, flexible layer. The flexible analysis will give an estimate of the number of passes and allowable loading before the complete failure of the stabilized soil-surfaced layer. All test locations of interest on the airfield should be evaluated using the procedures outlined above. The lowest number of passes, or the maximum loading for a given number of passes, determined for all airfield features, should be used to establish the controlling condition for the airfield. See UFC 3-260-03 or the PCASE Help utility for further guidance on using the software.

Example: Using the previous rigid and flexible pavement analysis examples, only three passes of a C-17 at 486,000 pounds should be allowed to prevent structural cracking, while 25,799 passes may be allowed before complete failure of the stabilized soil surface occurs.

8. Further Research. The development of a stabilized soil performance model is required to accurately predict the operational capacity of stabilized soil-surfaced airfields. Current linear elastic models can be used to provide an estimate of the performance capacity of stabilized soil pavement layers. However, due to the complex performance characteristics of stabilized materials, additional research is needed to determine the ultimate load-bearing capacity, strength deterioration rate after initial cracking, and material durability under wheel-loading of stabilized soil materials. This research should be incorporated into the development of a finite element model which can be used to accurately predict the performance of stabilized soil pavement layers.

9. Point of Contact. Questions or comments regarding this ETL are encouraged and should be submitted to the Pavements Engineer, HQ AFCESA/CEOA, 139 Barnes Drive, Suite 1, Tyndall AFB, FL 32408-5319, DSN 523-6439, commercial (850) 283-6439, e-mail AFCESAReachbackCenter@tyndall.af.mil

LESLIE C. MARTIN, Colonel, USAF
Director, Operations and Programs Support

Atch
1. Distribution List

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

Defense Commissary Agency (1)
Design and Construction Division
2250 Foulois St., Suite 2
Lackland AFB, TX 78236

AAFES (1)
ATTN: RE-C
PO Box 660202
Dallas, TX 75266-0202

SPECIAL INTEREST ORGANIZATIONS

Information Handling Services (1)
15 Inverness Way East
Englewood, CO 80150

Construction Criteria Base (1)
National Institute of Bldg Sciences
Washington, DC 20005