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A Comparable Analysis of Civilian and Military Airfield Runway Design Procedures

Jacob Wessel
University of Texas at El Paso

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JACOB WESSEL

Master's Program in Civil Engineering

APPROVED:

Reza Ashtiani, PH.D., P.E., Chair

Joanne Moyer, Ph.D.

Diane Doser, Ph.D.

Stephen L. Crites, Jr., Ph.D.
Dean of the Graduate School

Dedication

I would like to dedicate this thesis to my academic mentor, Reza Ashtiani, PH.D., P.E., I would not have done this without you presenting me with an opportunity to be a research assistant and teaching assistant for these last couple of years. Thank you. To my wife who has supported, encouraged, and motivated me to do this to be more. She believed in me even when I doubted myself at time. I could not have achieved this without you and your love; I love you. To my friends there were there to lend a hand or word of encouragement, thank you for your support and advice along the way.

COMPARABLE ANALYSIS OF CIVILIAN AND MILITARY AIRFIELD RUNWAY DESIGN PROCEDURES

by

JACOB WESSEL, BSCE

THESIS

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Abstract

In the United States there are two primary agencies that regulate, approve, and aid in airfield runway designs. These two agencies are the Federal Aviation Administration (FAA) and the Department of Defense (DOD), and they both have different design procedure for design and construction of their prospective airfield runways. It is important to have a closer look at the design procedures, the reliance of software and how these compare to each other. The primary objective of this research was to conduct a sensitivity analysis of the FAA and the DOD airfield design programs used to aid in the design of civilian and military airfield runways. Particularly in the area of the subgrade modulus and the relationship of how the changes in the modulus of subgrade affect the structural layer design thickness of a pavement design for airfield. A comprehensive study and comparison of the two-design procedure was conducting by comparing air traffic mixes to how each agencies designed their pavement structure to handle these loads over the live cycle of the runway. This analysis of the design process provides a valuable insight into potential variations in results and the importance of not relying solely on design programs in the design process.

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Chapter 1: Introduction

1.1 OBJECTIVE

The Federal Aviation Administration (henceforth referred to as FAA) utilizes a program called *FAA Rigid and Flexible Iterative Elastic Layer Design* (FAARFIELD) while the Department of Defense (henceforth referred to as DOD) utilizes the program *Pavement-Transportation Computer Assisted Structural Engineering* (PCASE). Both programs allow for design of various types of runways ranging from flexible, rigid, overlays, dirt, and so on by using layer elastic design concepts. To date, there are limited data and publications that contain a direct comparison of the two programs. The aim of this thesis is to evaluate the programs with controlling parameters and compare them side by side to highlight their similarities and differences.

Using a *sensitivity analysis* with the objective to identify control points by adjusting the modulus of the subgrade soil in steady increments, focus design inputs that have the greatest effect on pavement design, as well as possible deviations between design models and a real structure are explained in addition to the aforementioned comparison.

Table 1.1: Experiment Matrix

Pavement Structure	Agency	Type of test	Traffic Mix	Layer Thickness Held constant	Number of Test
Rigid Pavement design	FAA	LED	Air Force Medium Mix	Stabilized Base 6" Subbase 18"	4
	DOD	LED Empirical		Stabilized Base 8" Subbase 12"	4
Rigid Pavement design	FAA	LED	Air Force Heavy Mix	Stabilized Base 6" Subbase 12"	4
	DOD	LED Empirical		Stabilized Base 8" Subbase 18"	4
Flexible Pavement design	FAA	LED	Air Force Medium Mix	Surface 4" Stabilized Base 6"	4
	DOD	LED Empirical		Surface 4" Subbase 6"	4
	FAA	LED			4

Flexible Pavement design			Air Force Medium Mix	Surface 4" Stabilized Base 12"	
	DOD	LED		Surface 4" Subbase 18"	4
		Empirical			
		Multi-Layer		Surface 4"	
Flexible Pavement design	FAA	LED	Air Force Heavy Mix	Surface 5" Stabilized Base 6"	4
	DOD	LED		Surface 5" Subbase 12"	4
		Empirical			
		Multi-Layer		Surface 5"	
Flexible Pavement design	FAA	LED	Air Force Heavy Mix	Surface 6" Stabilized Base 12"	4
	DOD	LED		Surface 6" Subbase 18"	4
		Empirical			
		Multi-Layer		Surface 6"	

1.2 ORGANIZATION

This thesis is structured as follows:

Chapter 2 provides a literature review outlining the FAA and DOD design programs and their capabilities/limitations,

Chapter 3 outlines methodologies utilized in this research,

Chapter 4 provides relevant recorded data and has a side by side comparison of the DOD and FAA designs under similar constraints.

Chapter 5 compares the design process of an airfield runway of old with the current design process and the actual air traffic mix from that time.

Chapter 6 concluded this thesis with a summary of the finding and their importance to the design process of airfield runway designs

Chapter 2: Literature Review

2.1 BACKGROUND

Airfield runways, whether meant for civilian use, military use, or a combination of both, are a vital part of today's infrastructure. They serve as one of the primary modes of *transportation* – the movement of people and goods – around the world, thus safe operation is of the utmost importance. The two typical types of pavements used in runway design are rigid and flexible pavements, however there are other types such as overlays and dirt runways. Regardless of the pavement type, a runway needs to be able to provide the necessary load carrying capacity to support aircraft that are expected to use the runway. In order to do so, a list of projected aircraft that would use the runway over the span of its life cycle is also needed. Outside of load capacity, runway design takes components such as sustainability, ride quality, intended life cycle, and potential weather are also taken into consideration while selecting the proper pavement type, layer thickness and configuration, and materials. The cost-effectiveness of the runway can then be determined with safety requirements set forth by either the FAA or DOD; all while meeting the demands of an airport.

With the need to properly design airfield runways in the most cost effective and expedient way all while meeting all the requirement of the airfield there have been several methods developed over the years, not only here in the US but also internationally. Over the many years three methods have emerged as the top methods use for pavement designs, these are empirical methods, analytical solutions, and numerical approaches. With the advancement of technology and continued research and development runways design moved into a more mechanistic design approach. With this more complex method approach the reliance of software programs is greater than before and the two biggest organization in the US have approached this with the development of two different programs.

Airfield runways can be a very complex and unique in the structural pavement design. These pavements have large, concentrated dynamic loads the must support the aircraft while landing, moving along the runway and as it takes off. With the wide range of aircraft each with is own live loads which are characterized as the load magnitude, tire to pavement contact area, speed, frequency of movement, and landing gear configuration. This information all goes into determining the Critical Aircraft Design, or somethings called the Design Aircraft or Critical Design Aircraft with is the most demanding aircraft or group of aircraft that have similar characteristics. The Critical Design Aircraft determines the size and dimensions of the runways, taxiways, and the separations between the two. As for pavement design FAARFIELD uses a cumulative damage factor (CDF) that considers each aircraft in the traffic mix to get the total cumulative damage of all aircraft within the traffic mix, whereas PCASE used as Aircraft Group Index that is broken down into 14 group to determine the controlling aircraft. These dynamic loads are important for analysis tools, how this information is used can vary between different programs. However, the use of dynamic loading calculations is important in determining the behavior of the pavement design over its live cycle. This in turn helps determine the pavement thickness needed to withstand stress exerted by the aircraft.

2.2 FAARFIELD

In the late 1990s, The FAA has started its work on a new Airfield pavement thickness design software to help keep up with the increasing size of aircraft, specifically with the introduction of Boeing B777 6-wheel gear configuration. The FAA's answer to this is their new program called FAA Rigid and Flexible Iterative Elastic Layer Design (FAARFIELD). As a part of this new program, the FAA similarly rewrote the Advisory Circular (AC) that encompasses Airport Pavement Design and Evaluation (AC 150/5320-6D) mutually with the revised AC, FAAFIELD became the standard for FAA airport design, replacing the FAA nomogram-based design program. The FAA has continued to improve and develop the FAAFIELD program as it updates its AC, and today the FAA uses FAARFILED 2.0 and AC 150/5320-6G.

The FAARFIELD Program is a complex program that relies on several subprograms to operate. The main subroutines are LEAF (Layered Elastic Analysis), FAAMesh (three-dimensional mesh generation for finite element analysis), FAASR3D (finite element processing), and ICAO-ACR (International Civil Aviation Organization of Aircraft Classification Rating and Pavement Classification Rating). The FARRFIELD program can operate in four central operational modes, namely Thickness Design, Life Calculations, Compaction Requirements and PCR Calculations, using either the US Customary or Metric system. The FAARFIELD 2.0 incorporates a full 3D finite element response to aircraft loads for new rigid pavements and rigid overlays. The FAA continues to implement both layered elastic-based and three-dimensional finite element-based design procedures for new and overlay design of flexible and rigid pavements. A new 3D finite element computational library, FAASR3D (FAA Structural Response – 3D), written in Visual Basic supports a new (ICAO ACR-PCR) system which replaced the Aircraft Classification Number and Pavement Classification Number (ACN-PCN). FAARFIELD has the ability to work multiple jobs at once however, the 3D finite element models used for rigid pavement designs are computationally intensive and may result in long run times.

Thou FAAFIELD is more advance than previous procedures, a great deal of engineering knowledge remains to produce an effective design. The program doesn't automatically incorporate all requirement to meet the detained requirements and recommendations of AC 1510/5320-6G.

FAAFIELD does not consider any provisions for frost protection and permafrost conditions. FAARFIELD assumes that all pavement layers meet the requirements of AC 150/5370-10 for materials, construction, and quality control. The "design airplane" model has been changed to design for fatigue failure which is expressed as a "cumulative damage factor" (CDF) using Miner's rule. However, the CDF method does detect the aircraft in the design mix that causes the greatest damage to the pavement. The main material properties of pavement layers with in FAARFIELD are uniformly expressed as modulus of elasticity, rather than the California Bearing Ratio (CBR) previously used for flexible pavements or the k-value for rigid pavements.

The FAA requires that for all federally funded projects FAARFIELD must be used for structural design of airfield pavements and the engineer report must include a copy of the results from FAARFIELD for pavement design.

2.3 PCASE

The U.S. Army Engineer Research and Development Center (ERDC) in the late 80's early 90's starting development of a new program called Pavement-Transportation Computer Assisted Structural Engineering (PCASE), This program was designed to help aid in the design for roadways and airfield runways. PCASE has been improved, modified, and update many times over the years with its current version being 7.0.2. In the current version, PCASE runs in Microsoft Windows with code configured in the Flow Module; Design; Evaluation; Dynamic Penetration Evaluation (DCP); Material Characterization using NDT equipment and back calculations.

For designs using flexible pavement design, PCASE allows its users to use either the CBR empirical design method or the Layer Elastic Design (LED) design method. With the CBR method, PCASE designs the layer thickness based on the CBR values for the pavement structure base, subbase, and subgrade that are provided by the users. PCASE will also allow users to include a drainage layer in the pavement design. For the LED method, PCASE uses the elastic modulus and

Poisson’s ratio for the material characteristics. PCASE used default values for design layers, as shown in *Table 2.1*, but allows the user to input other values that they got from other tests and research at their discretion.

Table 2.1: PCASE default values for flexible pavements structure design

Material type	Elastic modulus (psi)	Poisson’s ratio
Asphalt	350,000	0.35
Base Course	30,000	0.35
Drainage Layer	30,000	0.35
Subgrade	15,000	0.40

If the user desires, PCASE allows the user to include the slip at the interface between the layers. For no-slip situations, a user would use a value of 1, for frictionless layer a user would use a value of 1000. In addition, by using the LED method in PCASE, users can account for seasonal changes in the life cycle of the pavement.

For rigid pavement design, PCASE also has two methods for the user to choose from, the empirical method, Layered Elastic, or the *Westergaard solution*: Using the empirical method, PCASE uses the subgrade reaction modulus (k) criterion. The material characteristics included in the PCASE design are the concrete slab flexural strength, the k value for each layer along with the k value for the subgrade. PCASE also calculates the required layer thickness based on the aircraft composition, pavement material and expected design life. The ridged pavement design was modeled as a slab on a liquid foundation using the Westergaard solution PCASE, with critical loads occurring at the edge of the slab. Because of this, the Westergaard solution is applicable for wheel loads at both the slab edge and interior points. The contact surface of the wheel loading is applied in an elliptical area where the tire shape default value is 1.652. The Elastic modulus and Poisson's Ratio have default values of 27,580 MPA (4,000,000 psi) and 0.15, respectively. PCASE also sets a default value of 25% load transfer for airport pavement panel joints, and for road joints, PCASE assumes 0% load transfer. As with the flexible pavement design for rigid pavement designs slip at the layer interface can be included in the analysis using a friction value between 1 (no-slip) and 1000 (frictionless interface).

Chapter 3: Methodology

3.1 FAARFIELD & PCASE COMPARISON

For the comparative analysis of the FAARFIELD and the PCASE software, similar air traffic mix situations were used. The Air Force standard medium mix (Figure 3.1 & 3.2) from PCASE was chosen: this mix consisted of the B-52 Stratofortress, the C-17A Globemaster III, and the F-15E Eagle. To achieve congruency in the total number of aircraft over a twenty-year period, the annual growth rate in the FAARFIELD model was set to zero. This is one of the of the areas where FAARFIELD and PCASE differ. PCASE in its computations uses the number of passes of an aircraft, which refer to the number of aircraft the pass or move by an imaginary transverse line with in 500-ft of the runway end, this does not include touch and go aircraft (ref - UFC 03-260-03). Were as in FAARFIELD the use of annual departing aircraft is used, the use of departing aircraft is used since departing aircraft will weigh more than arriving aircraft because of fuel lose (ref- 150/5320-6G).

Vehicles

Add Delete ACN/ACR Curves

Traffic	Load (lb)		Passes	
	Areas A, B	Areas C, D	Areas A, B, C	Area D
B-52H STRATOFORTRESS	400,000	300,001	400	4
C-17A GLOBEMASTER III	585,000	438,751	400,000	4,000
F-15E EAGLE	81,000	60,751	100,000	1,000

Figure 3.1: PCASE Air Force Medium Traffic Mix.

Airplane Name	Gross Taxi Weight (lbs)	Annual Departures	Annual Growth (%)	Total Departures
B-52	488000	200	0	4000
B-52 Belly	488000	200	0	4000
C-17A	585000	20000	0	400000
F-15C	68000	5000	0	100000

Figure 3.2: FAARFIELD Traffic Mix.

With the choose of aircraft, specifically with the B-52, there is a difference in how the two programs handle the landing gear configuration. The Landing gear configuration for a B-52 has what is referred to as belly gear which is the additional landing gear or gears in the center portion of the aircraft between the main gear. Were as main gear in the primary landing gear that is symmetrical on either side of and aircraft (US Department of Transportation FAA Order_5300_7). In FAARFIELD due to the configuration of the landing gear of the B-52 (Figure 3.3) FAARFIELD calculates this as two different aircraft. Were as in PCASE to simplify calculations aircraft are divided into fourteen groups as shown in (Figure 3.4).

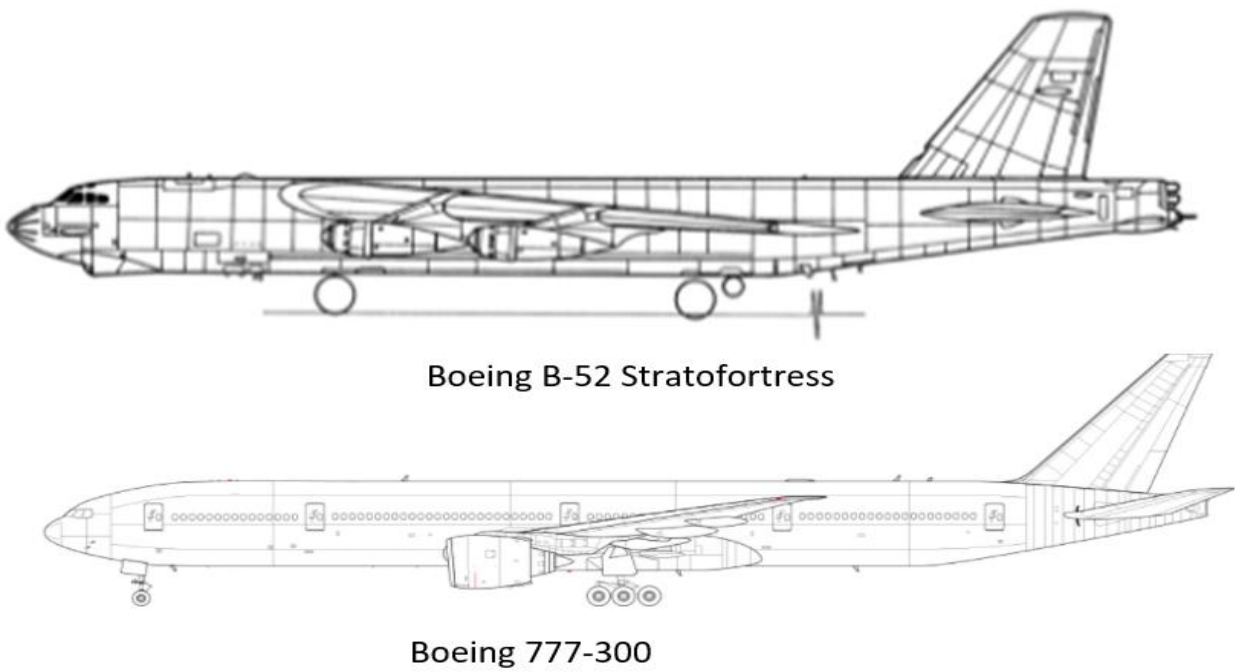


Figure 3.3: Landing gear configuration for Boeing 777 and B-52
(https://drawingdatabase.com/boeing-b-52-stratofortress/)
(https://www.shopnorebbo.com/products/boeing-777-9-line-drawing)

Table 2-1
Air Force Aircraft Group Index

1	2	3	4	5	6	7
C-23[1]	F-15[1]	F-111[1]	C-130[1]	C-9[1]	T-43[1]	B-727[1]
C-12	A-7	F-117		C-7	737	C-22
C-21	A-10			DC-9		P-3
C-27	C-20			C-140		
A-37	F-4					
	F-5					
	F-14					
	F-16					
	F-22					
	F-100					
	F-101					
	F-102					
	F-105					
	F-106					
	T-1A					
	T-33					
	T-38					
	T-39					
8	**9**	**10**	**11**	**12**	**13**	**14**
E-3[1]	C-141[1]	C-17[1]	C-5[1]	KC-10[1]	E-4[1]	B-52[1]
707E-8	B-1			DC-10	747	
C-135	B-757			L-1011	VC-25	
KC-135	B-2					
VC-137						
DC-8						
EC-18						
A-300						
B-767						

[1] Controlling aircraft.

Figure 3.4: Air Force Aircraft Group Index UFC 3-260-03_2001

This grouping of aircraft in PCASE also plays into how the two programs design the various layers of the pavement design. FAARFIELD relies on a Cumulative Damage FACTOR (CDF) using Miner's rule. The theory of CDF is that each individual aircraft within the traffic mix contributes to damage to the airfield, this damage is summed for all the aircraft into a total cumulative damage. Whereas PCASE relies on a critical aircraft within the assign group in its calculations.

3.3 FLEXIBLE PAVEMENT DESIGN

For this comparison of FAARFIELD and PCASE the focus was on two types of pavement designs, new flexible and new rigid designs in the standard three-layer design (Figure 3.5). However, both programs have the option for many other pavement design types and many different variations of layer structure. For the new flexible design, the layer structures were made up of a surface layer with a stabilized base followed by crushed aggregate laid on top of a natural subgrade.

For FAARFIELD the layer design consisted of P-401/P403 HMA surface layer with a P-401/P403 HMA stabilized layer followed by a P-209 crushed aggregate layer on top of the natural subgrade (Figure 3.6). There is a wide range of varying layer property to choose from that can be used for designing the pavement structure to include user defined (Figure 3.7). For all materials used is assumed that all layers were constructed to FAA standards and meet the construction material specifications set in the U.S. Department of Transportation FAA Advisory Circular 150/5370-10. User defined layers can be used when utilizing materials other than FAA standard materials.

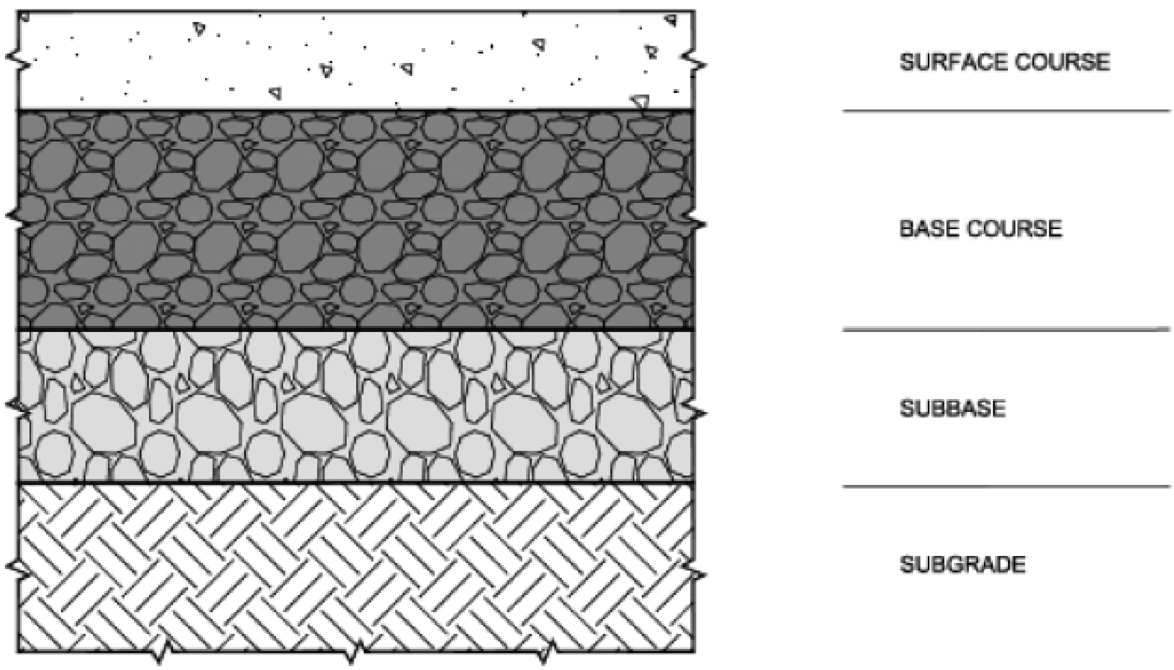


Figure 3.5: Typical Pavement structure (AC150/5320-6F)

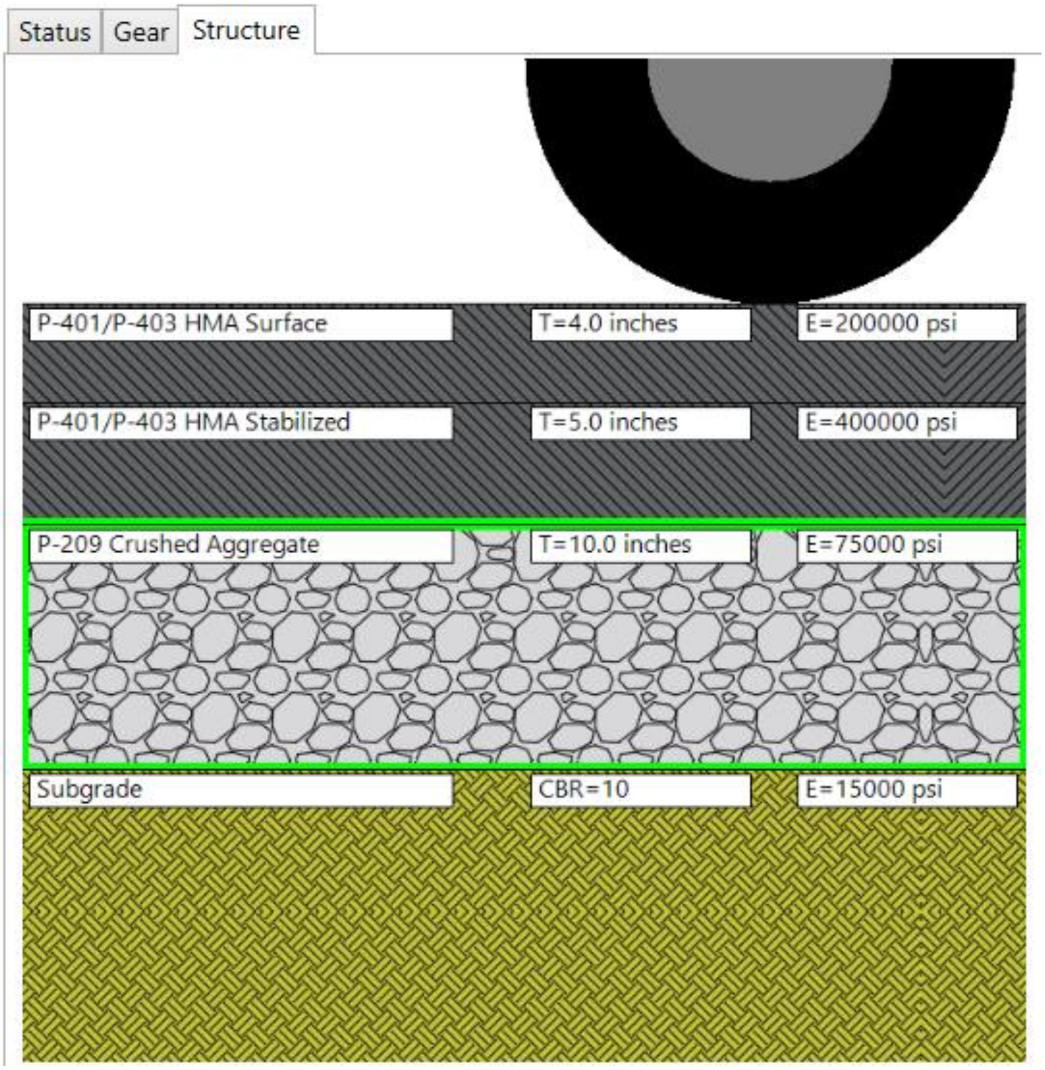


Figure 3.6: FAARFIELD Flexible pavement layer design

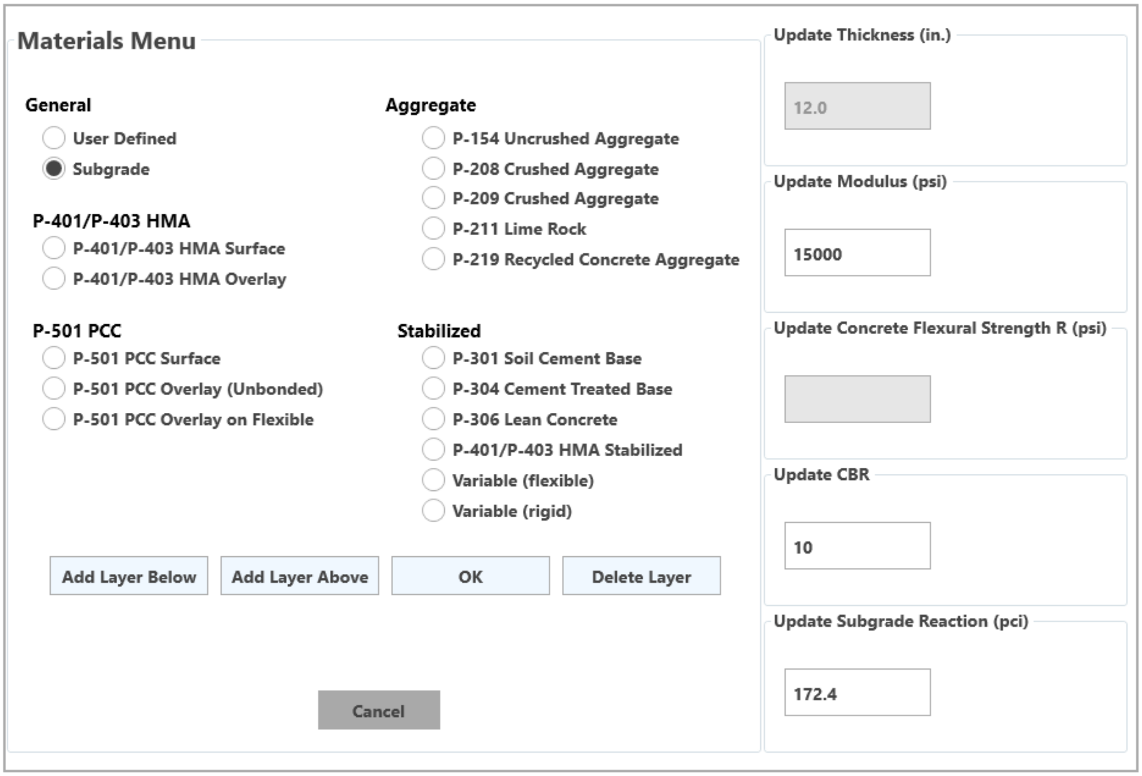


Figure 3.7: FAARFIELD Layer Properties

To select the layer configuration with in PCASE is a little different. The flexible pavement design for PCASE is a surface layer of Asphalt Concrete with a stabilized base of asphalt concrete consisting of all Bituminous, this is followed by a subbase of unbound aggregate on top of the natural subgrade (Figure 3.8). As with FAARFIELD PCASE also has a wide range of layer options and varying property values for this layer (Figure 3.9). Materials and material properties can be found in Unified Facilities Criteria (UFC) 3-260-03 Airfield Pavement Evaluation.

Layer Type	Material Type	Modulus (psi)	Compute	Non-Frost Design Thickness (in)	Min. Thickness (in)	Poisson's Ratio	Bond
Asphalt Concrete	Asphalt Cement	200,000	☑	5	5	0.35	Fully Bonded
Stabilized Base	AC Stab-ALL Bituminous	1,000,000	☐	9	6	0.25	Fully Bonded
Subbase	Unbound Aggregate	24,000	☐	4	4	0.35	Fully Bonded
Natural Subgrade	Cohesionless Cut	15,000	☐			0.4	

Figure 3.8: PCASE Flexible pavement layer design

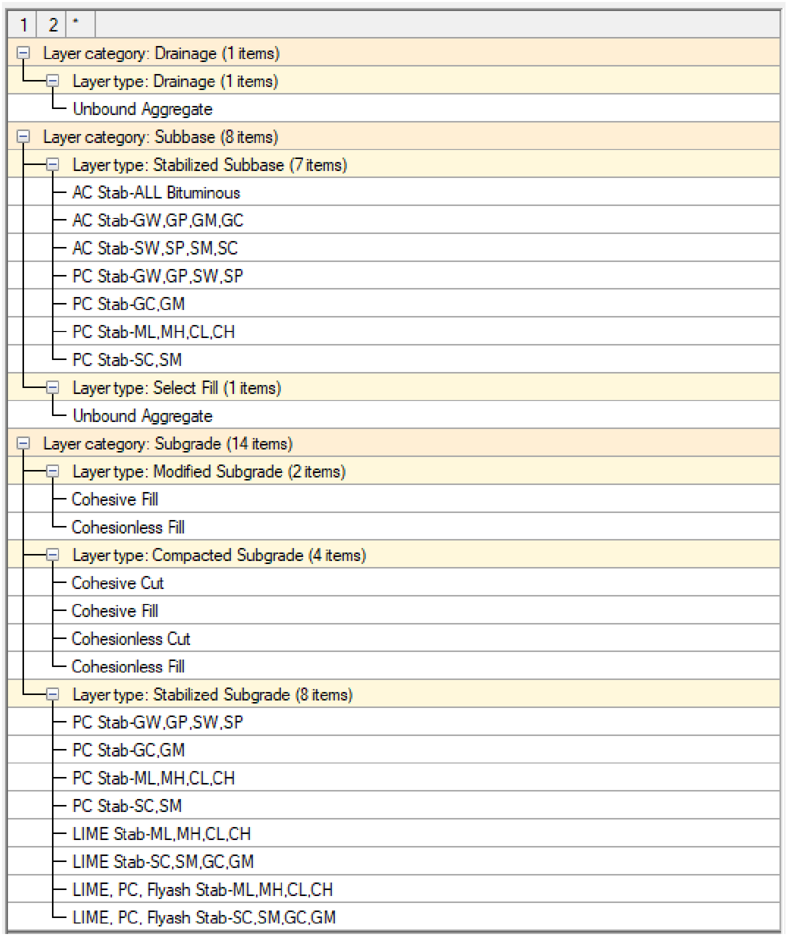


Figure 3.9: PCASE Layer Properties

This simulation for pavement design was centered around how by changing the subgrade soil properties would affect the layer thickness of the layer above. It should be noted that in FAARFIELD for a new flexible pavement design only the base and subbase layers can be chosen as the design layer, also only one layer can be designed at a time, where as in PCASE multiple layers can be design at once or one layer at a time. It should also be noted that the range for the E Modulus in FAARFIELD has a range of 1000 psi to 50000 psi and has a CBR ranging from 0.7 to 33.3, While PCASE has a Modulus range from 5000 psi to 50000 psi and a CBR range from .5 to 100. With these constraints one layer was annualized at a time with a changing subgrade modulus or CBR until the minimum layer thickness was reached. This simulation was run for the subbase and stabilized layers in FAARFIELD and in PCASE. However, in PCASE this simulation was run using the California Bearing Ration (CBR) and Layered Elastic which are the two options for designing a flexible pavement design in PCASE.

3.3 RIGID PAVEMENT DESIGN

For the rigid pavement design the layer structure the three-layer pavement design was again used. The surface layer consisting of Portland Concrete with a stabilized base of bituminous material followed by a subbase of unbound aggregate all on top of a natural subbase (Figure 3.5). As with the flexible pavement design the rigid pavement design centers around how the structural layers change with the changing of the subgrade soil properties. As with the flexible pavement design constraints were put in place to allow for a more equal comparison of the two programs. When designing the rigid pavement structure in PCASE as with FAARFIELD only the surface layer of Portland concrete can be set as the design layer. The Stabilized base and subbase need to be set are set by the user in both programs. PCASE allows for different model type for designing rigid pavement one being the Westergaard Plate Solution which uses the k value (with a range on 25 to 500pci) and by using the Layered Elastic theory which use an elastic module value (with a range from 5000 to 50000).

For the rigid pavement design in FAARFIELD the layer configuration consisted of a surface layer of P-501 PCC, P-401/P-403 HMA Stabilized layer, and P-209 Crush Aggregate subbase (Figure 3.10). The rigid layer property to choose from are the same that can be found in (Figure 3.7). For all materials used it is assumed that all layers were constructed to FAA standards and meet the construction material specifications set in the U.S. Department of Transportation FAA Advisory Circular 150/5370-10. User defined layers can be used when utilizing materials other than FAA standard materials. As stated, before the stabilized layer and the subbase as user defined FAARFIELD does not design these layers in the New Rigid pavement type setting.

As with the flexible pavement design the rigid pavement design was centered around how changes to the subgrade soil properties would affect the layer thickness of the surface layer. For FAARFILED to changing of the subgrade properties is done by adjusting the E modulus which has a range of 1000 psi to 50000 psi or by changing the k (pci) value which has ranging from 20.9 to 440.4 pci. By methodically going through the E modulus or k value range of values a picture form as to how this change in soil properties affect the surface layer thickness.

With PCASE rigid pavement design there are two options to choose from for a rigid design, they are the Westergaard Plate Solution that utilizes the k (pci) value and Layer Elastic design (led) that uses a modulus value. The value range for k is 25-500 pci and the LED values range from 1500-50000 psi for subgrade soil.

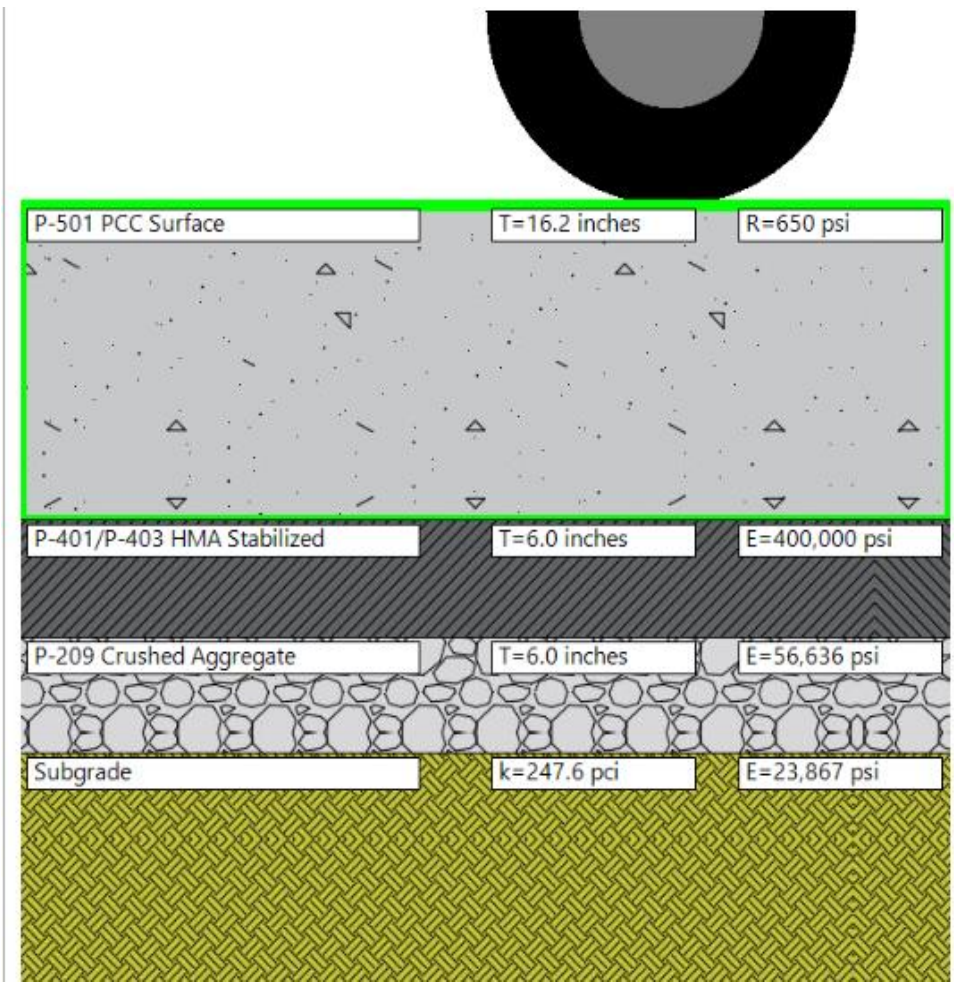


Figure 3.10: FAARFIELD Rigid pavement layer design

3.4 PCASE FROST ANALYSES

Once of the capability that PCASE has over FAARFIELD is that with PCASE you can include frost depth in your pavement design. PCASE pulls weather data from various weather station around the world to help get accurate information for your design. Having accurate information about frost depth is a very important aspect of the design. This will allow for a better design that should save time and money along with improve the longevity of the runway.

The design processes are the same for flexible and rigid design with a couple additional steps. The first additional step is in the mange project tab, here there is a block that can be selected for consideration of frost in the design process. Once consider frost is selected a drop-down menu with appear so that the location of the intended runway can be selected, this is followed by then selection the weather station within that location of the project.

Once the weather information has been selected the frost group needs to be selected for each of the layers of the pavement design (Figure 3.11). PCASE uses the frost group (Figure 3.12) to apply a reduction factor to the moduli during the thawing period of the runway (Figure 3.13). To calculate the frost depth, first the design is process is run that same way as stated before in flexible and rigid design. Once the design is run the calculate frost tab is selected followed then by selecting the calculate thickness tab again.

Frost Group	Degree of Susceptibility	Type of Soil	Percentage Finer than 0.02 mm	Typical Soil Classification (Unified)
NFS	Negligible	Gravels, Sands	0 – 3	GW, GP SW, SP
PFS	Low	Gravels, Sands	1.5 – 10	GW, GP, SW, SP
S1	Very Low to Medium	Gravelly soils	3 – 6	GW, GP, GW-GM, GP-GM
S2	Negligible to Low	Sandy soils	3 – 6	SW, SP, SW-SM, SP-SM
F1	Very Low to Medium	Gravelly soils	6 – 10	GM, GW-GM, GP-GM
F2	Low to Medium	Gravelly soils	10 – 20	GM, GW-GM, GP-GM
		Sands	6 – 15	SM, SW-SM, SP-SM
F3	High	Gravelly soils	> 20	GM, GC
		Sands, except very fine silty sands	> 15	SM, SC
		Clays (PI > 12)	-	CL, CH
F4	Very High	All silts	-	ML, MH
		Very fine silty sands	> 15	SM
		Clays (PI < 12)	-	CL, CL-ML
		Varved clays and other fine-grained, banded sediments	-	CL, ML, CH, SM

NFS = non-frost-susceptible; PFS = possibly frost-susceptible

Figure 3.11: Frost group with soil classification “Designing Base and Subbase to Resist Environmental Effects on Pavements”

Table 7-4
Modulus Reduction Factors for use in Seasonal Frost Areas

Frost Group	Modulus Reduction Factors (RF)
NFS	1.00
PFS	0.90
S1	0.75
S2	0.70
F1	0.60
F2	0.50
F3/F4	0.30

Figure 3.12: PCASE Modulus Reduction Factors for Use in Seasonal Frost Areas

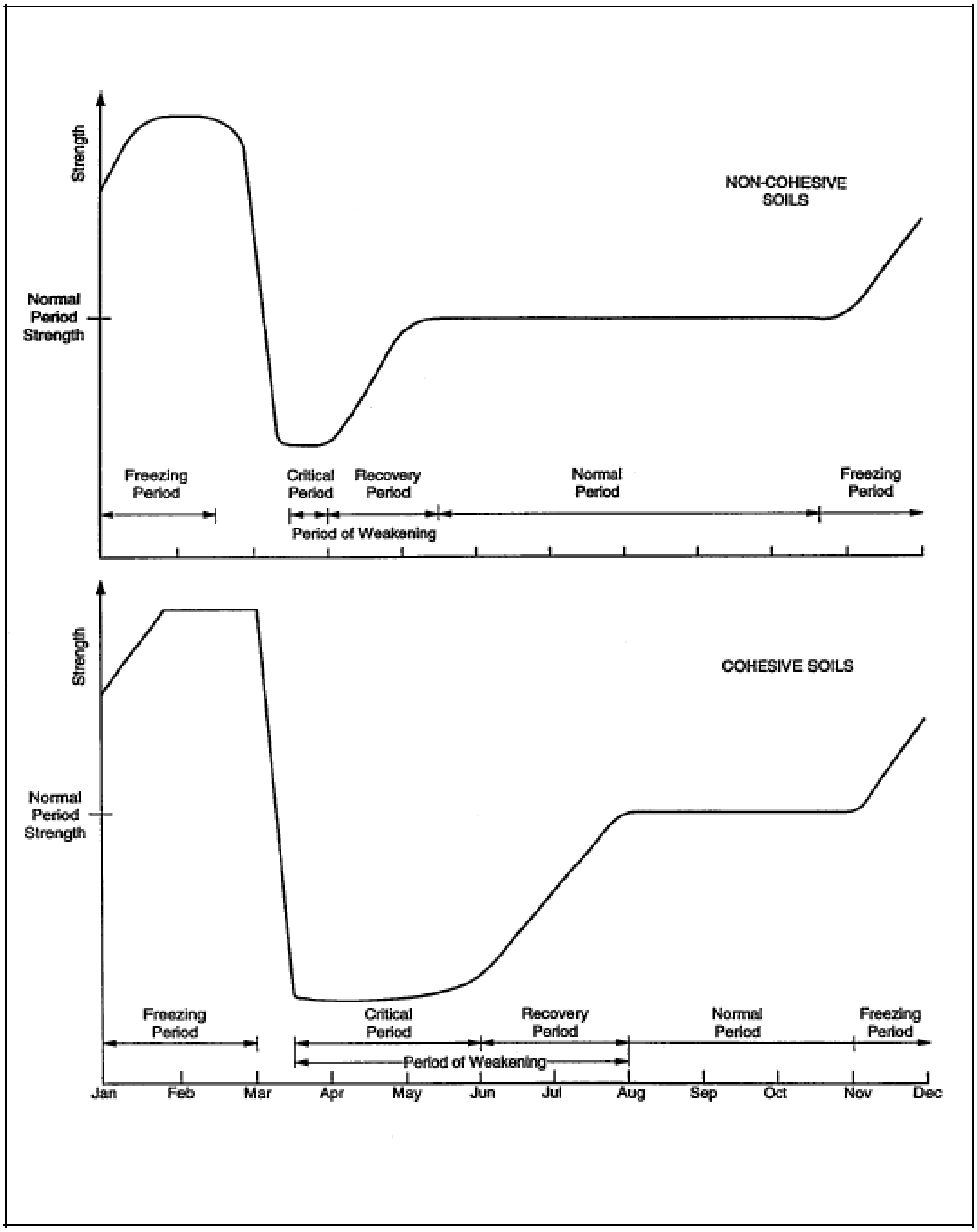


Figure 3.13: example of a thawing weakening period

Chapter 4: Data Collection

4.1 FAARFIELD DATA

Pavement designs for airfield runways can be a complex problem involving the interaction of multiple layers of materials that are needed to support a dynamic load. FAARFIELD does this by using layered elastic theory combined with 3D finite element analysis. For flexible pavement designs FAARFIELD uses the maximum vertical strain at the top of the subgrade soil in conjunction with the maximum horizontal strain at the bottom of the asphalt layer to determine the pavement life cycle. FAARFIELD also can evaluate the surface, base, and subbase layers to provide the required thickness for a pavement design that will support designated air traffic mix over a given subgrade.

For rigid pavement designs FAARFIELD uses the horizontal stress at the bottom of the concrete layer as the predictor and the pavement life cycle. In the design, both edge and interior loading in used to determine the maximum horizontal stress on the pavement. FAARFIELD checks that this minimum thickness of the base, and subbase layers meet the standard set by the FAA but will only design for the surface layer thickness required to meet the designated air traffic load.

4.1.1 Flexible Design

FAARFIELD was evaluated under the various conditions and design requirement to determine how the program computer layer thickness as the modulus of the subgrade soil changed. First as a sample test an example flexible pavement design problem from FAA advisory circular 150/5320-6G was used. For this example, H2, the pavement structure and the aircraft traffic mix as given (figure 4.1 & 4.2). For the subgrade modulus the elastic modulus (E) can be used for the California bearing ratio (CBR) can be used. The E value can be converted to an estimated CBR: E(psi) = 1500 x CBR.

Thickness	Pavement Structure
4 inches	P-401 Asphalt Surface Course
5 inches	P-401/P-403 Stabilized Base Course
6 inches	P-209 Crushed Aggregate Base Course
12 inches	P-154 Aggregate Base Course
	Subgrade, CBR=5 (E = 7500 psi)

Figure 4.1: Pavement Structure

Aircraft	Gross Weight (lbs)	Annual Departures
B737-800	174,700	3000
A321-200 opt	207,014	2500
EMB-195 STD	107,916	4500
CRJ700	72,500	3500

Figure 4.2: Aircraft Traffic Mix

Following the step-by-step instructions for the AC I got the same results and the circular, as expected. Staying with the same pavement structure and traffic mix and by adjusting the Subgrade Modulus I was able to see how the Layer thickness decreased and the modulus of the subgrade increased. The same reaction held true even as I increase the thickness of the Stabilized base layers, and the Crushed Aggregate layer as seen in Figure 4.3.

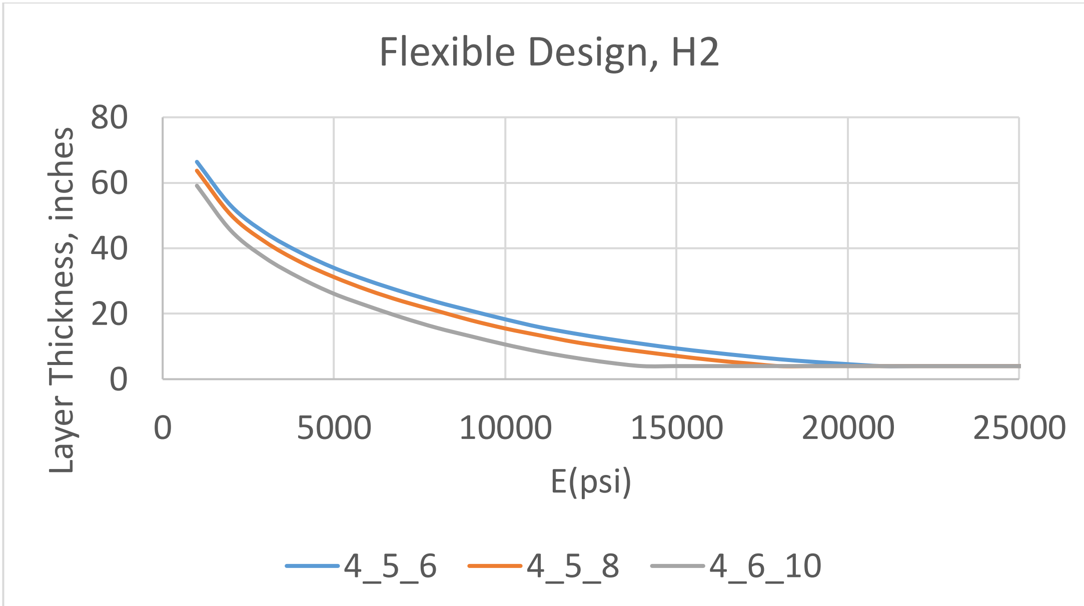


Figure 4.3: Layer Thickness

The results of this simulation again were as expected with the increase of the subgrade modulus and increase of layer thickness the uncrushed aggregate layer decrease layer thickness and reached the minimum layer thickness at a lower modulus value.

To further analyze this pavement structure, I changed the layers to be designed to the stabilized base layer while holding the surface, crushed aggregate, and uncrushed aggregate to their minimum layer thickness of 4in, 6in and 6in respectively. During this analyze as anticipated the layer thickness decrease as the modulus of the subgrade increased, however there was a slight abnormality at about a modulus of 22500 psi (Figure 4.4). According to AC 150/5320-6G the minimum layer thickness for the stabilized base with a maximum aircraft gross weight operating on pavement greater than or equal to 100,000lb (45,360 kg) is 5in. At a modulus greater the 22500 psi the thickness of the stabilized bas layer goes to 4in, which less than the minimum layer thickness.

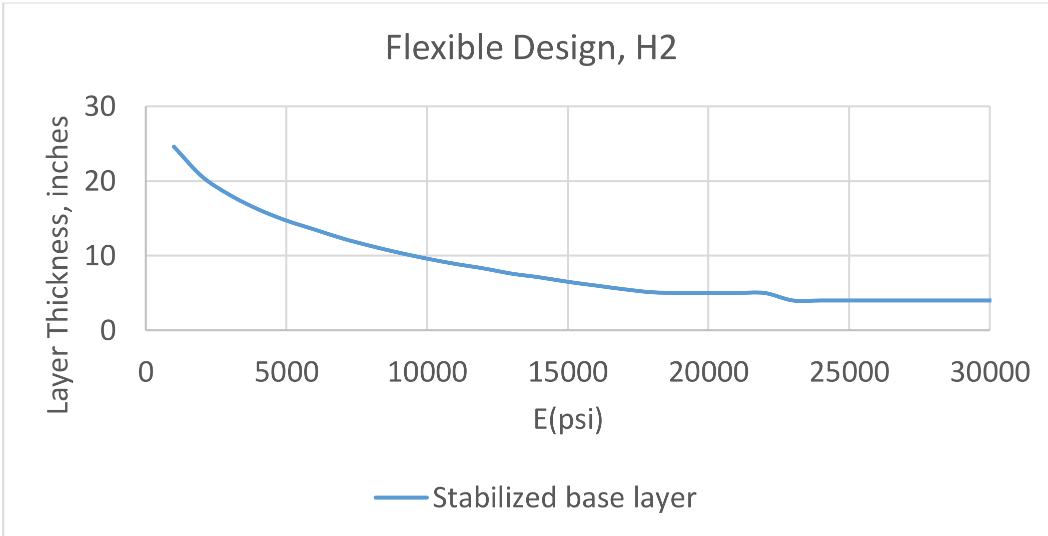


Figure 4.4: Flexible Design, Stabilized Base analyze, Example H2 Air Traffic Mix, 4-layer system

This same abnormality can be seen when changing the pavement structure form a 4-layer system to a 3-layer system (Figure 4.5, 4.6) when analyzing the stabilized base layer.

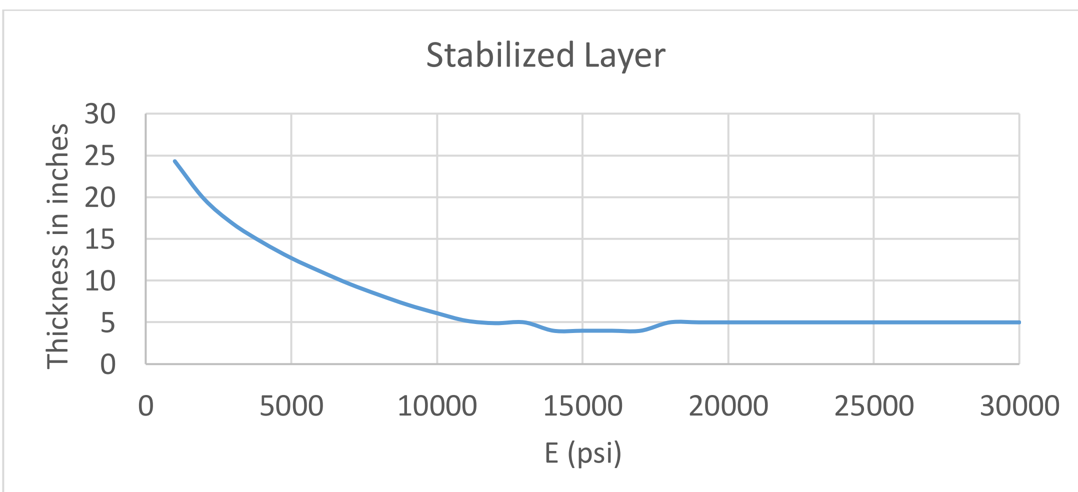


Figure 4.5: Flexible Design, Stabilized Base analyze, Example H2 Air Traffic Mix, 3-layer system

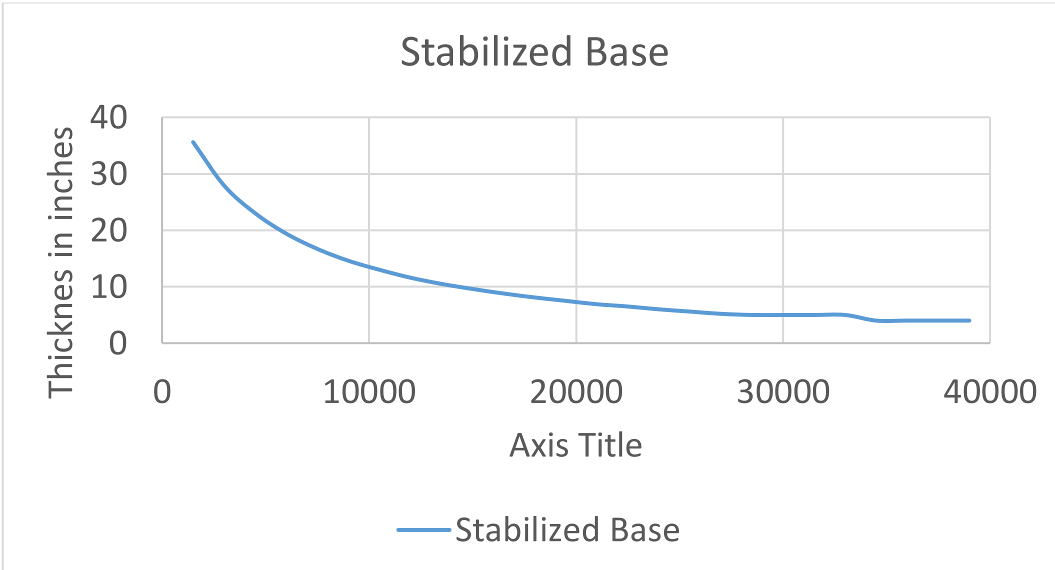


Figure 4.6: Flexible Design, Stabilized Base analyze, Airforce Medium Air Traffic Mix. 3-layer system

There was an additional variation between the two simulations in that when analyzed using the same air traffic mix as the example H2 the layer thickness reached the minimum thickness of 5in then drop to 4in between the subgrade modulus of 14000psi and 17000pai then returned back to the 5in minimum layer thickness at 18000 psi (Figure 4.4). Whereas when using the air traffic mix Air Force medium mix the layer thickness reached the minimum of 5in at a subgrade modulus of 28500psi stayed at 5in until a modulus of 34500psi where the layer thick ness again dropped to 4in, but this time stayed at 4in and did not return back to the 4in minimum (Figure 4.5).

4.1.2 Rigid Design

FAARFIELD was evaluated under the various conditions and design requirement to determine how the program computer layer thickness as the modulus of the subgrade soil changed. First as a sample test an example rigid pavement design problem from FAA advisory circular 150/5320-6G was used. For this example, H3, the pavement structure and the aircraft traffic mix as given (figure 4.7 & 4.8). For the subgrade modulus k (pci) value is used, the k value has the units of pounds per cubic inch (Mega-newton per cubic meter). The k value can be converted to a estimated elastic modulus E: E(psi) = 20.15 x $k^{1.284}$ (k in pci).

Thickness	Pavement Structure
14 inches (thickness to be determined by FAARFIELD)	P-501 Concrete Surface Course (*R* = 600 psi)
5 inches	P-401/P-403 Stabilized Base Course
12 inches	P-209 Crushed Aggregate Base Course
	Subgrade, *k*=100 pci (E = 7452 psi)

Figure 4.7: Pavement Structure

Aircraft	Gross Weight (lbs)	Annual Departures
B737-800	174,700	3000
A321-200 opt	207,014	2500
EMB-195 STD	107,916	4500
CRJ700	72,500	3500

Figure 4.8: Aircraft Traffic Mix

Following the step-by-step instructions for the AC I got the same results and the circular, as expected. With a k of 100pci and the initial layer design of a surface layer, stabilized base, and a crushed aggregate layer of 14in, 5in, and 12in respectfully, the end result is a surface layer thickness of 17.1in. Staying with the same pavement structure and traffic mix and by adjusting the Subgrade Modulus I expected to see that as the subgrade modules increased the surface layer would decrease. This expectation held turn until a subgrade modulus of about 7500 psi where the layer thickness reached 17.1in, from 7500 psi to about 20500 psi the layer thickness stayed at 17.1 in. After a modulus of 20500 the layer thickness starts to increase to a thickness of 18.7in (Figure 4.9).

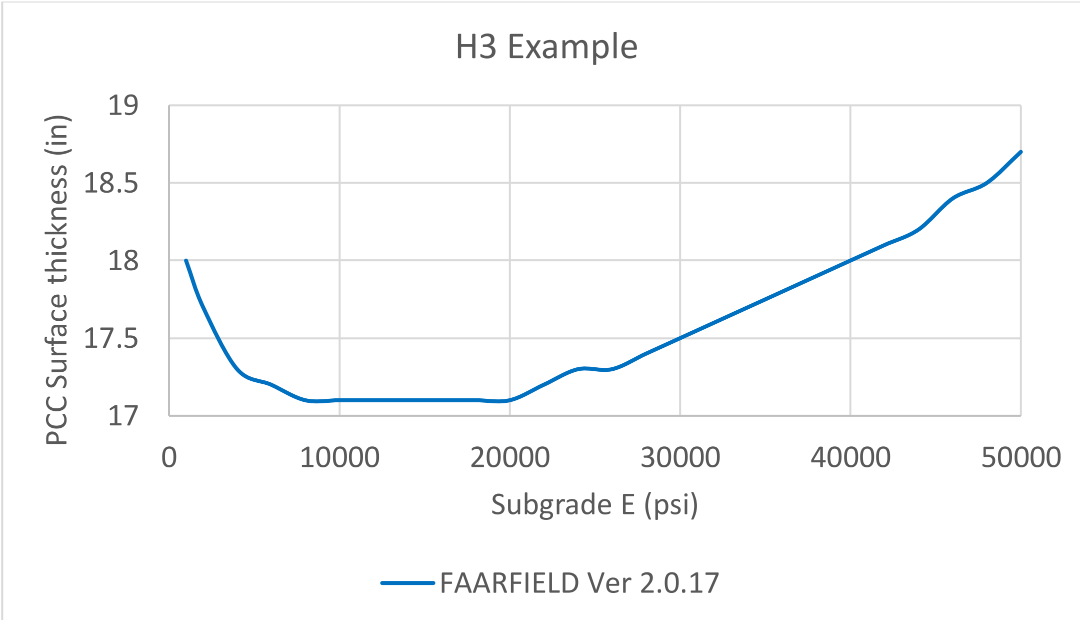


Figure 4.8: Aircraft Traffic Mix

To further analysis this abnormality the simulation was run under varying layer thickness and different air traffic mixes to see if this was a one-off situation or something that was consistent with in the program. The simulations were also run with the previous version (ver 2.07, 09/14/2021) of the software verse the current version (ver 2.0.17, 04/06/2022). For the initial simulation a comparison between version of the software was run while keeping the air traffic mix and the layer thickness and properties the same. In this simulation It can be seen that the surface layer thickness between the two version stays the exact same (Figure 4.9).

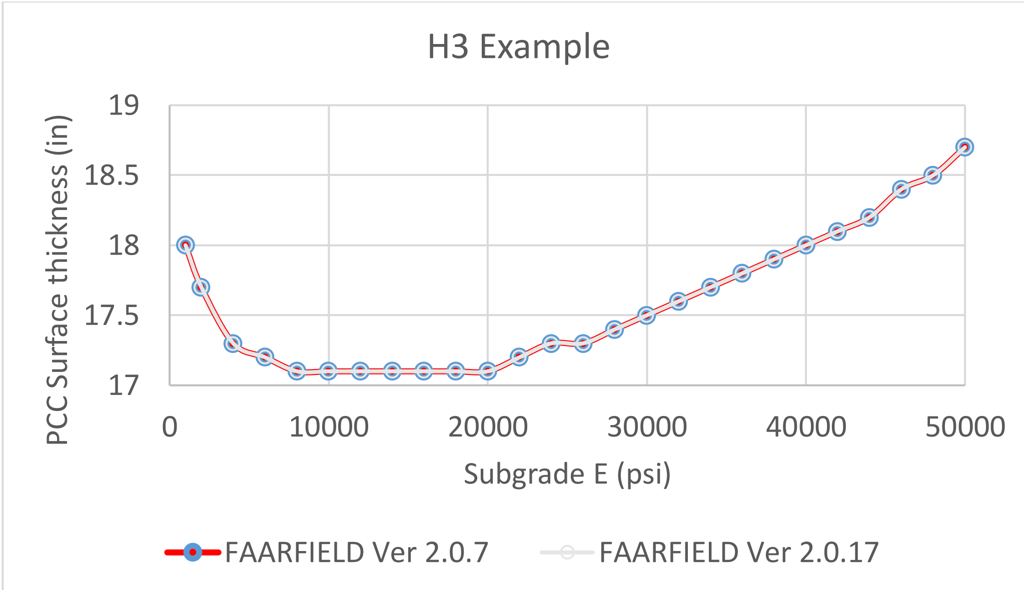
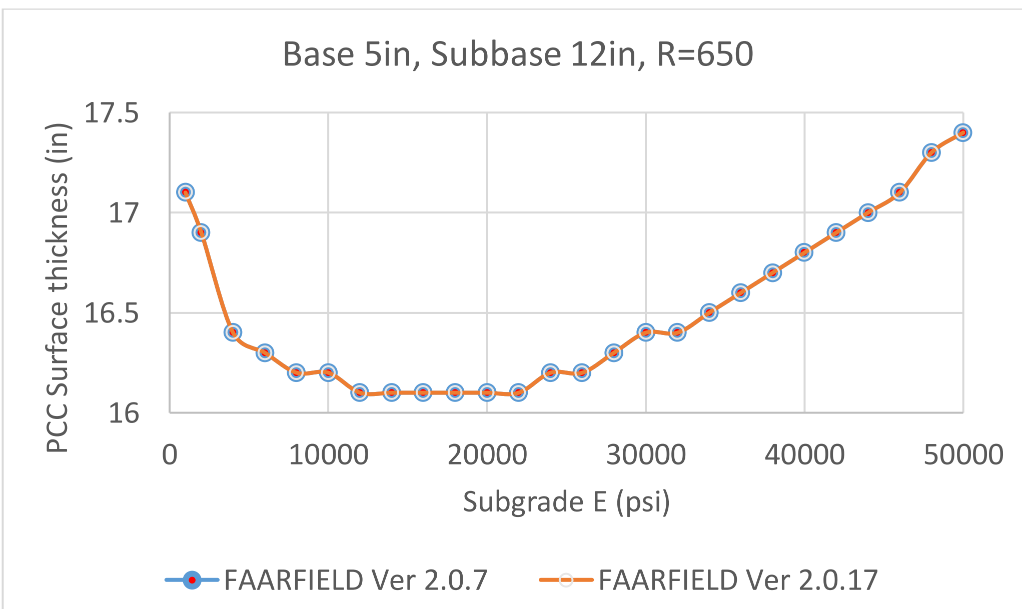


Figure 4.9: FAARFIELD Rigid Surface Layer Design

To verify these finding the simulation was run by changing the concrete flexural strength along with changing the layer thickness of the HMA Stabilized base layer and the crushed aggregate layer thickness. In all these cases that new version and the previous version of the software matched (Figure 4.10).



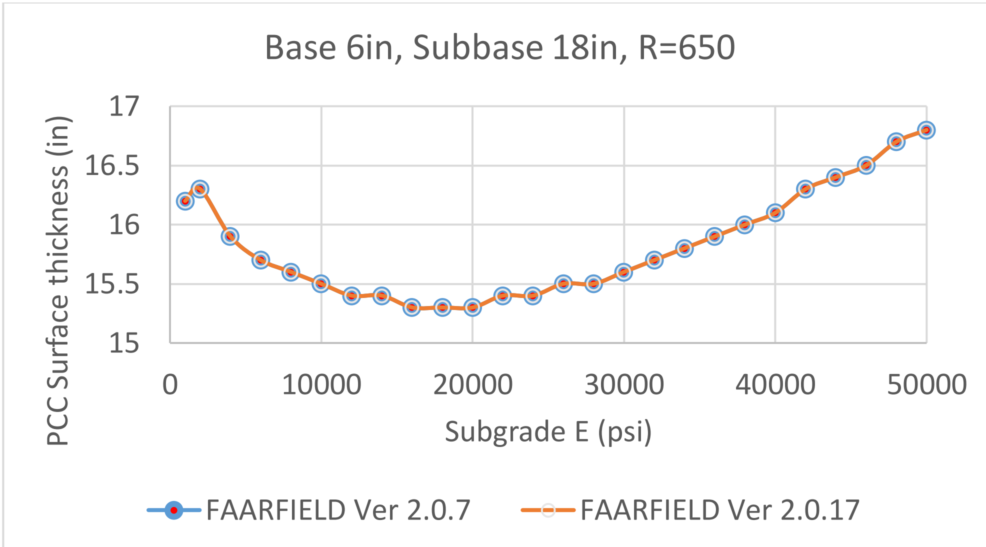


Figure 4.10: FAARFIELD Rigid Surface Layer Design under varying conditions

When the air traffic mix was changes this match between the version starting to vary. As the air traffic mix started to consist of larger and heavier aircraft the two versions of FAARFIELD varied more (Figure 4.11-4.13)

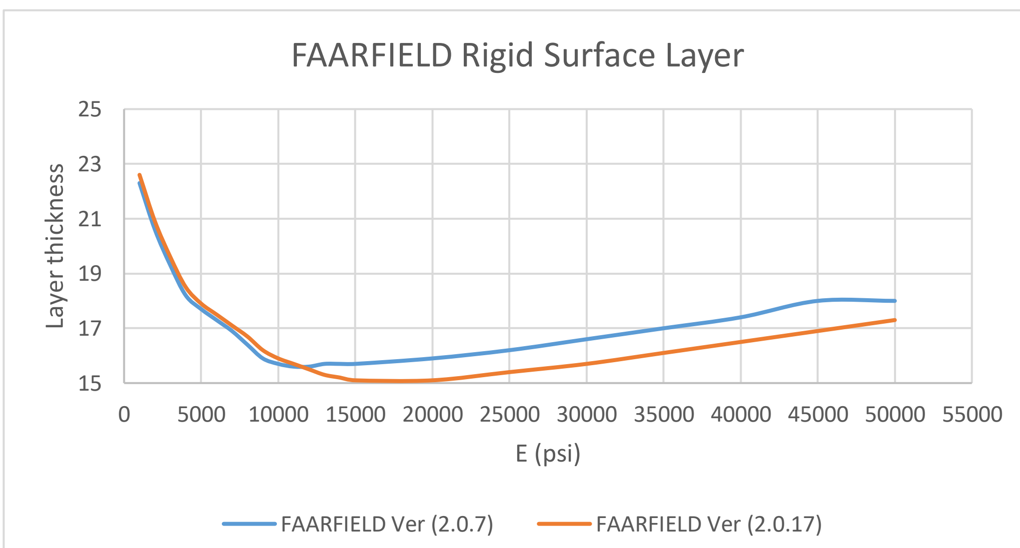


Figure 4.11: FAARFIELD Rigid Air Force Med, Base 6in, Subbase 18in, R=650

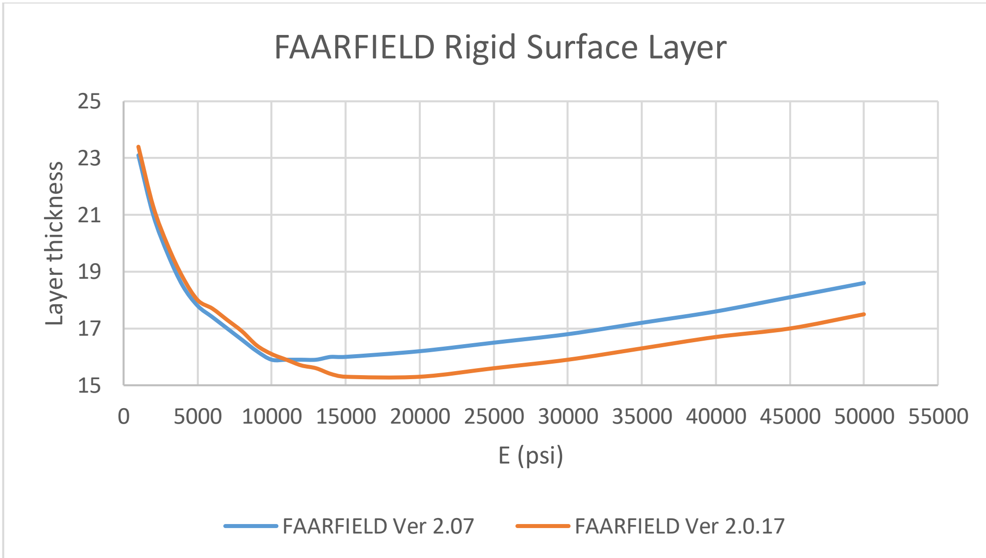


Figure 4.12: FAARFIELD Rigid Air Force Med, Base 8in, Subbase 12in, R=650

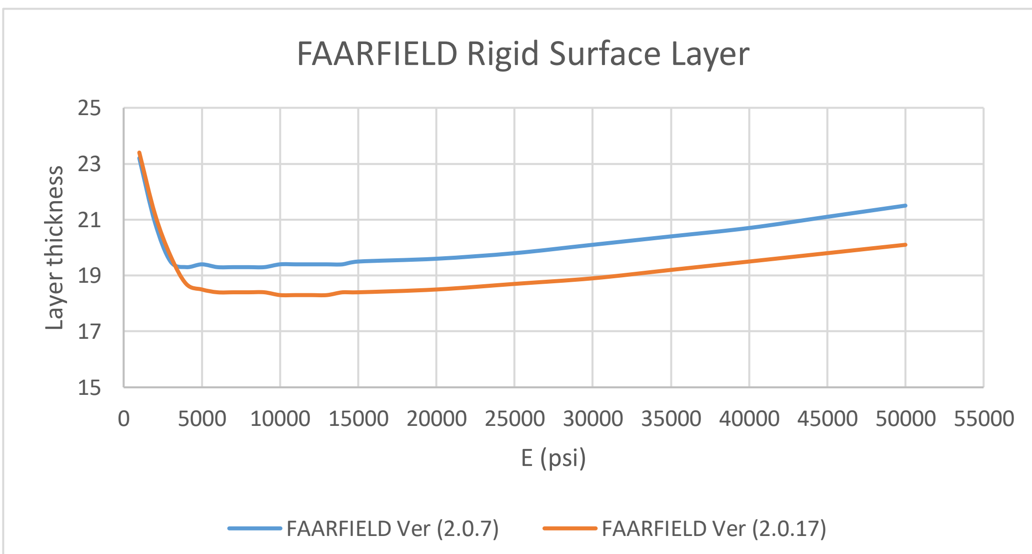


Figure 4.13: FAARFIELD Rigid Air Force Heavy, Base 6in, Subbase 12in, R=650

When the two version deviate from each other there is about a 1-inch difference between the two with the new version being thinner. For all other simulation version 2.0.17 was used.

4.2 PCASE DATA

The complexity of an airfield runway design holds true for any organization that has the undertaking of designing a airfield runway, however with DOD there can be the added complexity of a time constraint that usually not see in civil design planning. The DOD program PCASE achieves this by using layered elastic theory for one design opposition and empirical method for the other. For flexible pavement designs the maximum vertical strain at the top of the subgrade soil in conjunction with the maximum horizontal strain at the bottom of the asphalt layer to determine the pavement life cycle. PCASE allows for evaluate the surface, base, and subbase layers to provide the required thickness for a pavement design that will support designated air traffic mix over a given subgrade. One advantage PCASE has is that the program allows the user to design multiple layers at a time.

For rigid pavement designs PCASE uses the horizontal stress at the bottom of the asphalt concrete layer as the predictor and the pavement life cycle. In the design, both edge and interior loading in used to determine the maximum horizontal stress on the pavement. PCASE used the layered elastic (CBR) and the Westergaard plate solution (k) for rigid pavement designs. As with the FAA the DOD software only designs for the asphalt concrete surface layer when designing for a rigid pavement structure design.

4.2.1 Flexible Design

For evaluated of the DOD design approach under the various conditions to determine how the program computed layer thickness as the modulus of the subgrade soil changed. The procedures and step were followed as laid out in the PCASE 7 User Guide. For these simulations two air traffic mixes were used, Air Force medium (Table 4.1) and Air Force Heavy (Table 4.2)

Table 4.1: PCASE Air Force Medium Traffic Mix

Traffic	Load (lb)		Passes	
	Area A, B	Area C, D	Area A, B, C	Area D
B-52 Stratofortress	400,000	300,001	400	4
C-17A Globemaster III	585,000	438,751	400,000	4,000
F-15E Eagle	81,000	60,751	100,000	1,000

Table 4.2: PCASE Air Force Heavy Traffic Mix

Traffic	Load (lb)		Passes	
	Area A, B	Area C, D	Area A, B, C	Area D
B-52 Stratofortress	480,000	359,999	120,000	1,200
C-17A Globemaster III	585,000	438,751	200,000	2,000
F-15E Eagle	81,000	60,751	100,000	1,000

For the pavement structure a 3-layer system was chosen for evaluation, the layer configuration consisted of a surface layer, stabilized base, and subbase on a natural subgrade (Table 4.3).

Table 4.3: PCASE 3-Layer Pavement Structure

Layer Type	Material Type
Asphalt Concrete	Asphalt Cement
Stabilized Base	AC Stab-All Bituminous
Subbase	Unbound Aggregate
Natural Subgrade	Cohesionless Cut

When designing a flexible pavement system using the DOD design approach, following the same procedure of changing the subgrade modulus to see how this affected the other layers of the system. With using the Air Force medium traffic mix and using the both the layered elastic (Figure 4.13) and California bearing ration design (Figure 4.14) procedures the initial result was as expected when looking at the graphs. As the subgrade modulus increased the selected layer for design decrease at a steady rate, however there was an abnormality with the LED design under a closer look.

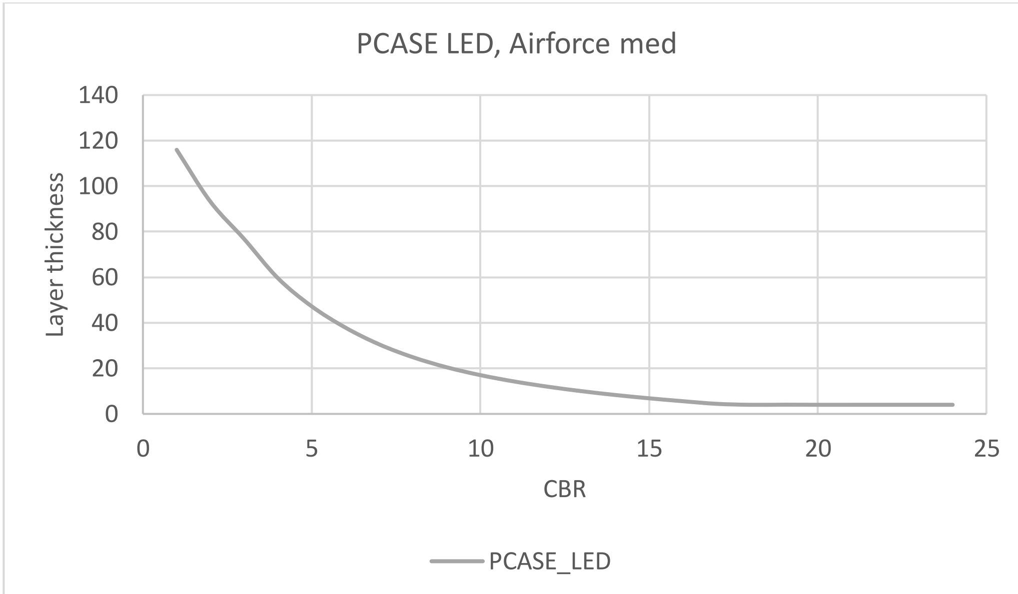


Figure 4.13: PCASE LED Design with Airforce Med mix, Surface 4in, Stabilized base 6in

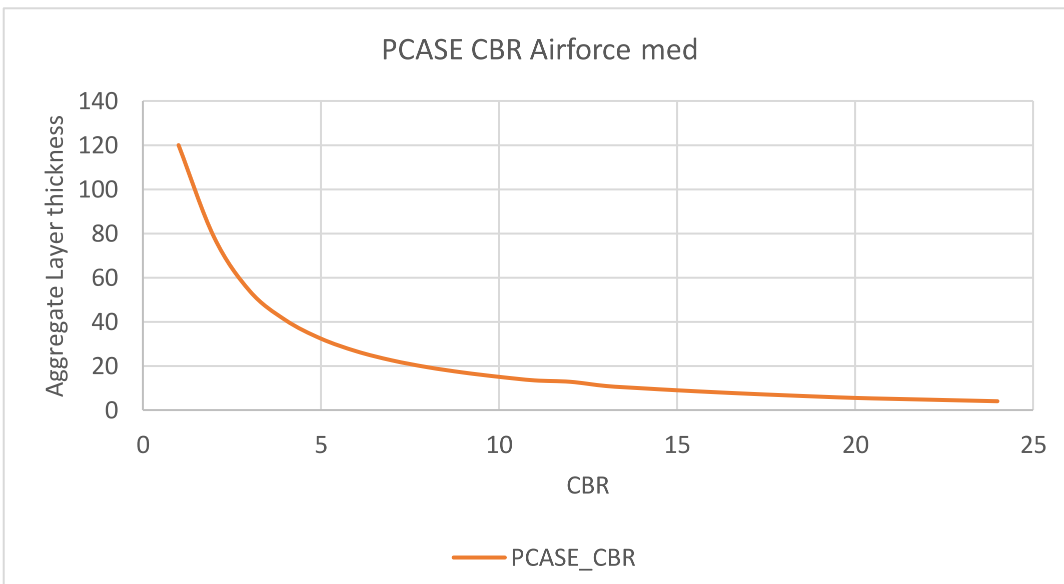


Figure 4.14: PCASE CBR Design with Airforce Med mix, Surface 4in, Stabilized base 6in

When running the initial simulation that was a 0.05 jump in the layer thickness at a modulus of 28500 psi then returning back to the layer minimum thickness of 4in (Table 4.3).

Table 4.4: PCASE LED Air Force Med

Surface Layer	Stabilized Base	Subbase	Subgrade
4	6	6.86	22500
4	6	5.58	24000
4	6	4.43	25500
4	6	4	27000
4	6	4.05	28500
4	6	4	30000
4	6	4	31500
4	6	4	33000
4	6	4	34500
4	6	4	36000

When taking a closer look at the reaction taking place between the subgrade modulus of 27000psi and 30000psi there were found be large variations in of layer thickness with the largest having a thickness of 18.66in (Figure 4.15).

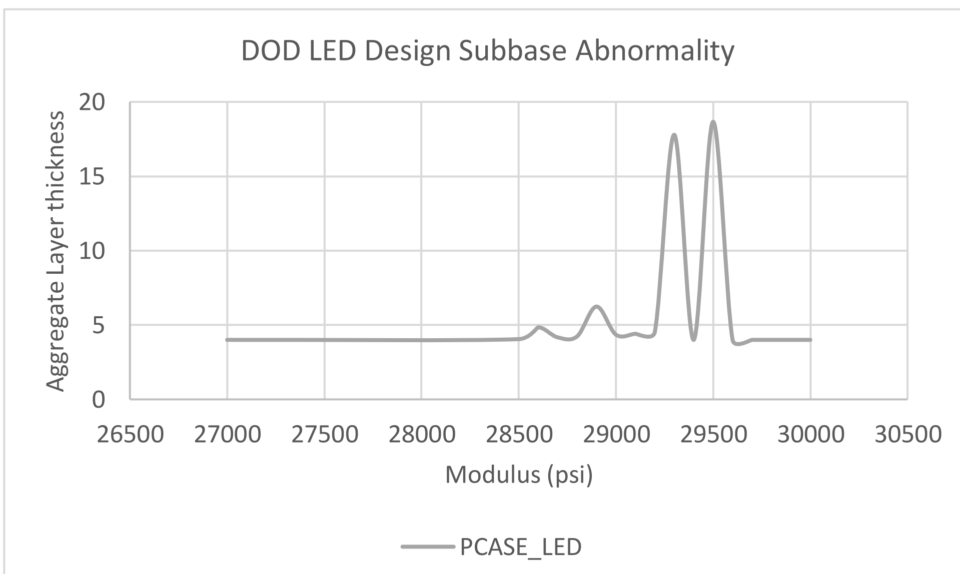


Figure 4.15: PCASE LED Design Abnormality between a modulus of 27000 and 30000 psi

When the air traffic mix is changed from Air Force medium to Air Force Heavy this time around there is a jump from the minimum thickness of 4in a modulus of about 36000psi to a thickness of 17.43in at the modulus of 39000psi (Figure 4.16).

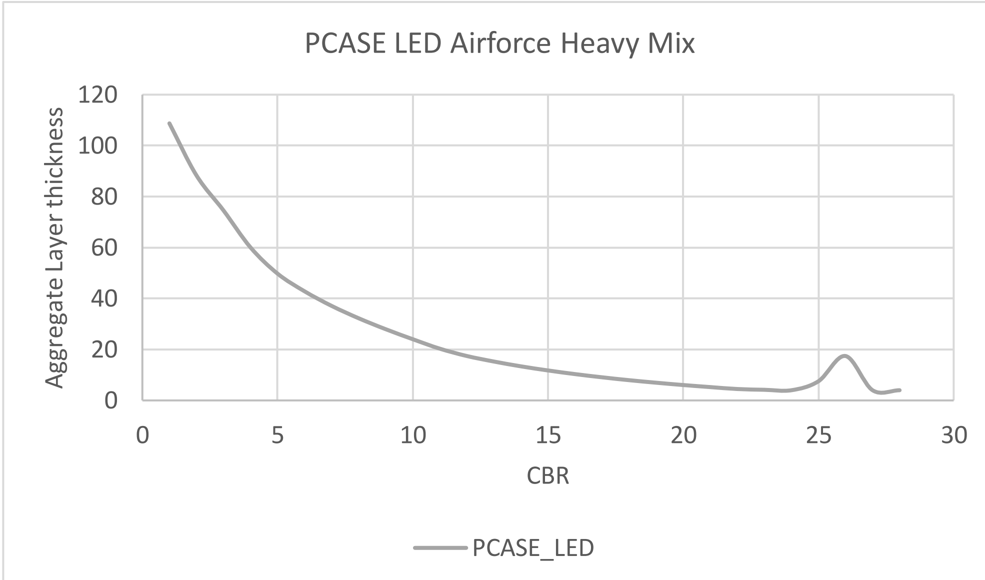


Figure 4.16: PCASE CBR Design with Airforce Med mix, Surface 4in, Stabilized base 6in

When looking closely at the area between a modulus of 36000psi to 42000psi again you see a wide variation of layer thickness for 4in to 17.43in (Figure 4.17).

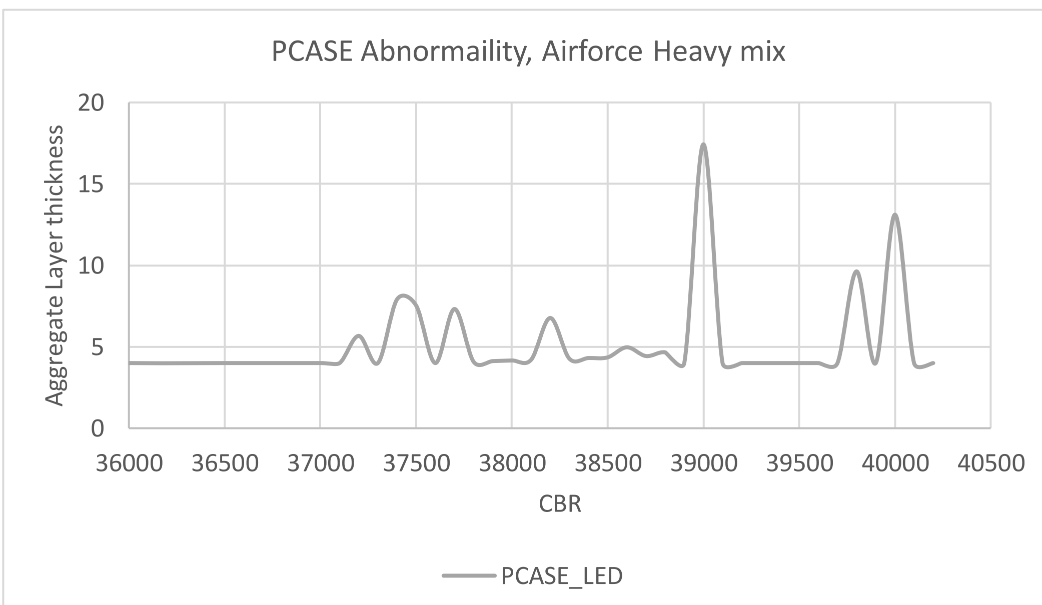


Figure 4.16: PCASE CBR Design with Airforce Heavy mix, Surface 5in, Stabilized base 6in

When looking to see if this abnormality was isolated to the subbase layer test were on how the changing subgrade modulus affected the base layer. For this simulation again the Air Force medium mix design was used with the same 3-layer system but this time the surface layer was held at 4in, and the subbase layer was held at 18in (Figure 4.17).

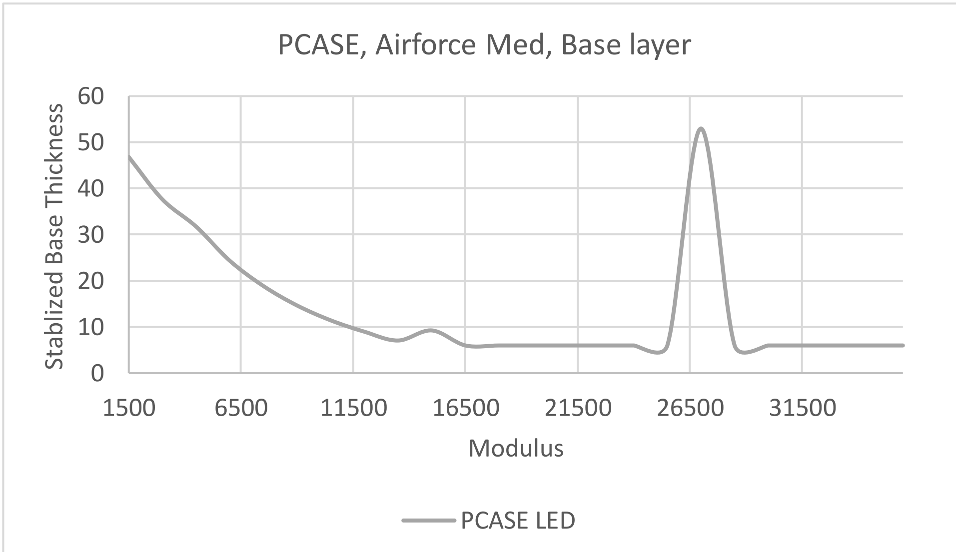


Figure 4.17: PCASE CBR Design with Airforce Med mix, Surface 4in, Subbase 18in

Here you can clearly see that there are two deviations from the expected result, and one is an extreme deviation. Upon closer examination of these two deviations the erratic variation in the layer thickness is clearly seen (Figure 4.18 & 4.19).

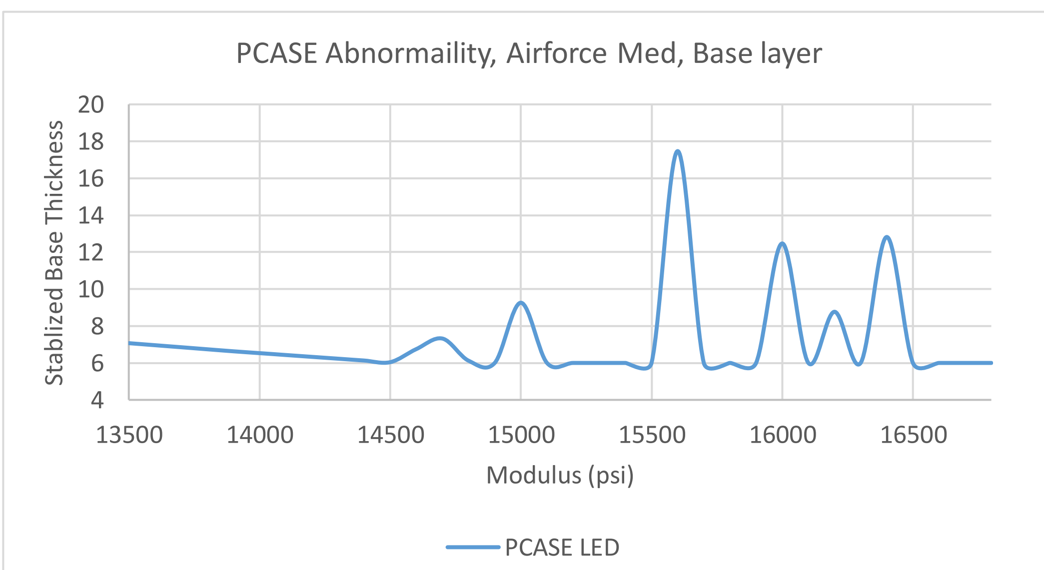


Figure 4.17: PCASE CBR Design Abnormality with Airforce Med mix, Surface 4in, Subbase 18in

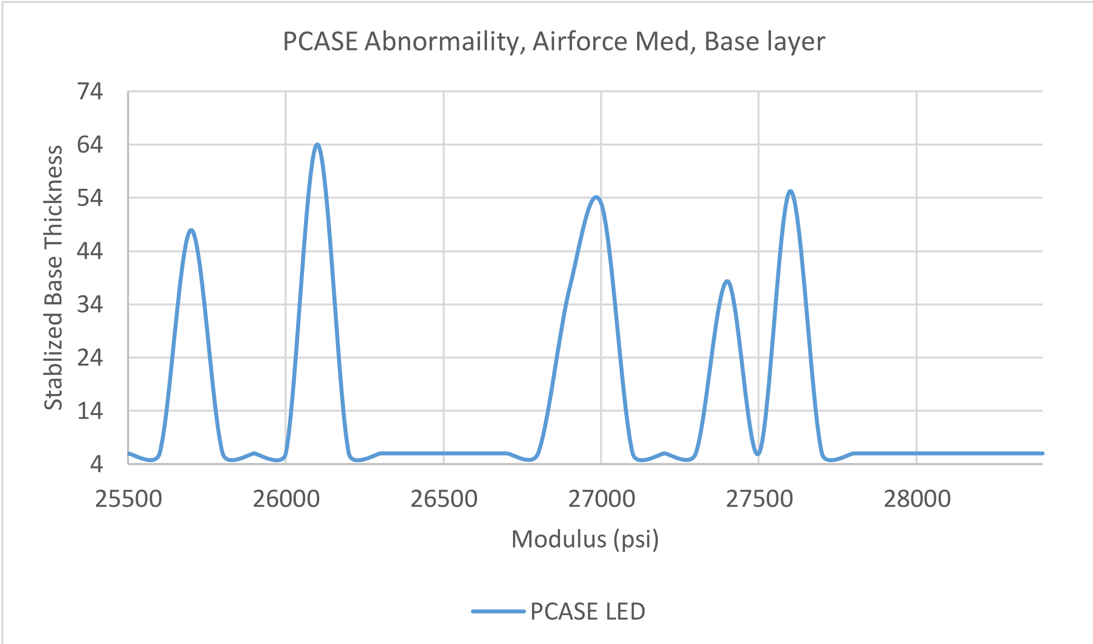


Figure 4.17: PCASE CBR Design Abnormality with Airforce Med mix, Surface 4in, Subbase 18in

One added feature with the DOD design approach is that it allows the user to design multiple layers simultaneously. When running the simulation using the Airforce Med mix and continuing with the 3-layer system, again the results are mostly as expected (Figure 4.18).

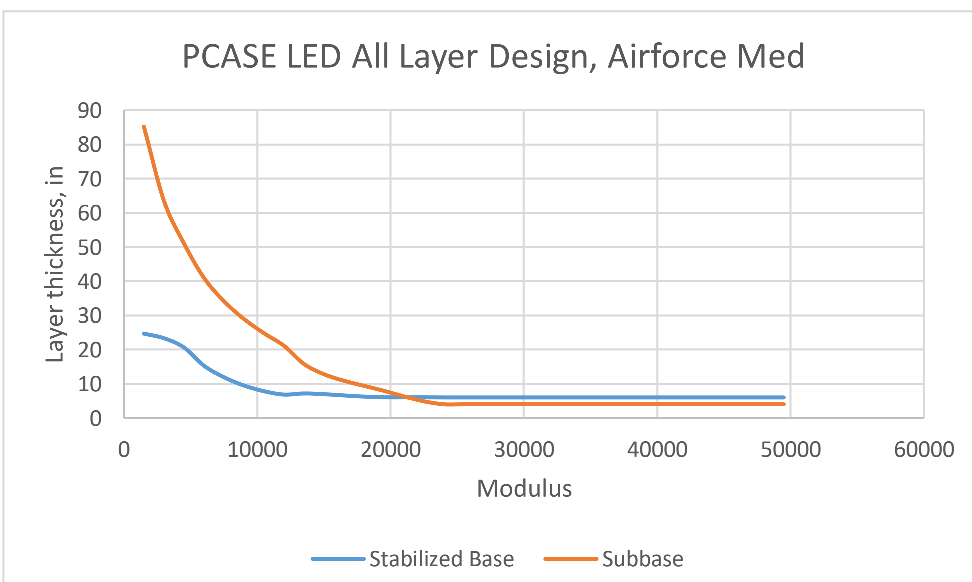


Figure 4.18: PCASE Multiple Layer Design, Airforce Medium Mix

There were a couple of deviation when running this simulation. The first being that when running the simulation one layer at a time the minimum layer thickness for the surface layer was 4in, however then running the simulation for multiple layers the minimum surface layer thickness changes to 5in and would not allow the user to change the layer thickness bad to 4in. This included even if the user selected only one layer to design. According to the UFC 3-260-02 Pavement Design for Airfields table 8-5 the minimum surface thickness for traffic area a is 4in for a medium load (Figure 4.19). For the Air Force Heavy traffic mix the PCASE defaults the minimum surface layer to 5in and stays at 5in for ether signal layer design or multiple layer design.

Table 8-5
Minimum Surface and Aggregate Base-Course Thickness Requirements for Air Force Flexible Pavement Airfields, Inches

		100 CBR Base			80 CBR Base[1,2,3]		
Airfield Type	Traffic Area	Surface	Base	Total	Surface	Base	Total
Light load	A	4	6	10	5	6	11
	B	4	6	10	5	6	11
	C	3	6	9	4	6	10
	Shoulders	2	6	8	2	6	8
Medium load	A	4	6	10	5	6	11
	B	4	6	10	5	6	11
	C	3	6	9	4	6	10
	D	3	6	9	3	6	9
	Shoulders	2	6	8	2	6	8
Heavy load	A	5	10	15	6	9	15
	B	5	9	14	6	8	14
	C	4	9	13	5	8	13
	D	3	6	9	3	6	9
	Shoulders	2	6	8	2	6	8
Modified heavy load	A	5	8	13	6	8	14
	B	5	8	13	6	8	14
	C	4	8	12	5	8	13
	D	3	6	9	3	6	9
	Shoulders	2	6	8	2	6	8
Shortfield	A	4	6	10	5	6	11
Auxiliary	A	3	6	9	3	6	9
	B	3	6	9	3	6	9
	C	3	6	9	3	6	9
	Shoulders	2	6	8	2	6	8

Note: When the underlying subbase has a design CBR of 80, the minimum base-course thickness will be 6 inches.

[1] Restricted to Florida limerock for heavy load pavements and modified heavy load pavements except that graded crushed aggregate (80 CBR) or cement modified or bituminous modified aggregate will be permitted in type D traffic areas.

[2] Florida limerock or graded crushed aggregate (80 CBR) cement modified or bituminous modified aggregates permitted in type B, C, and D traffic areas for medium load pavements.

[3] Florida limerock or graded crushed aggregate (80 CBR), cement modified or bituminous modified permitted for light load, shortfield, and auxiliary pavements.

Conversion Factor: Millimeters = 25.4 × inches.

Figure 4.19: Table 8-5 from UFC 3-260-02 30 June 2001

During this simulation run there was also a deviation in the expected result between the subgrade modulus 10500psi and 13500 psi (Table 4.4). Between these two moduli the layer thickness dropped by about an inch before returning back to the expected layer thickness (Figure 4.20) and continuing of a stayed decrease as the modulus increased.

Table 4.5: PCASE LED Multi-Layer Air Force Med

Surface Layer	Stabilized Base	Subbase	Subgrade
5	11.92	34.16	7500
5	9.49	28.97	9000
5	7.82	24.79	10500
5	6.83	21.13	12000
5	7.16	15.8	13500
5	6.95	12.79	15000
5	6.58	10.88	16500
5	6.24	9.4	18000

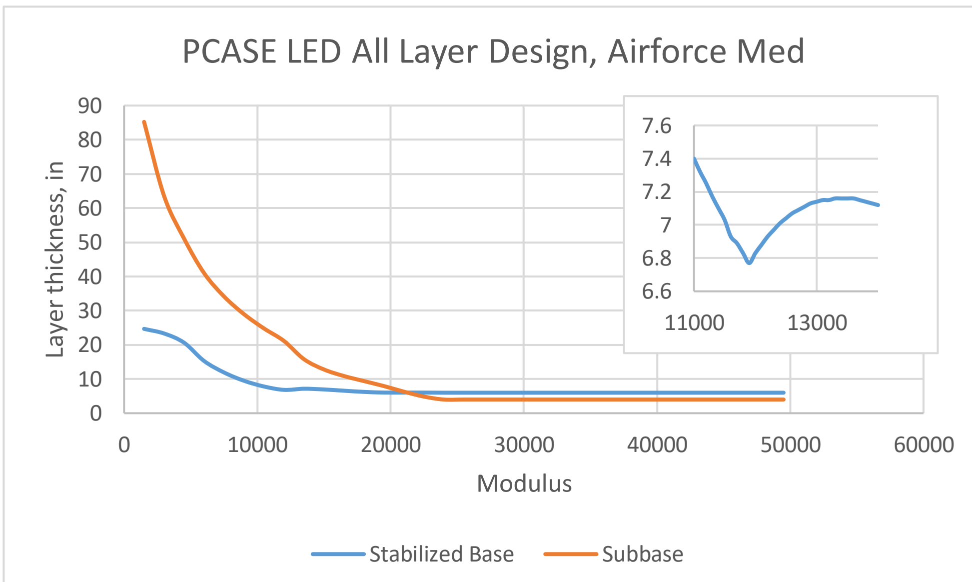


Figure 4.18: PCASE Multiple Layer Design, Airforce Medium Mix Deviation

When running the simulation using the Airforce heavy traffic mix there was a dramatic deviation in the expected results at about the 45000psi range.

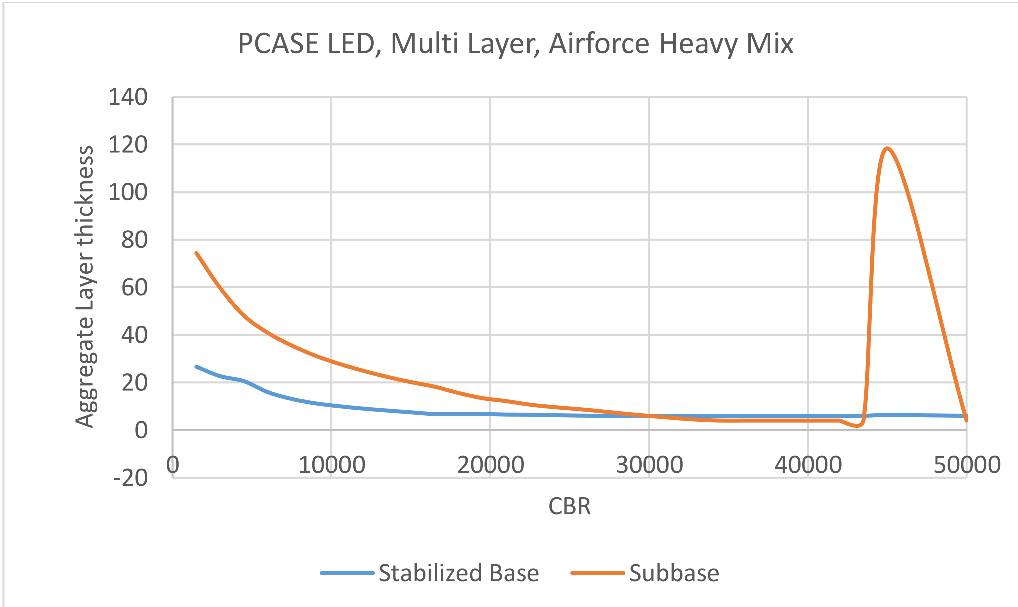


Figure 4.19: PCASE Multiple Layer Design, Airforce Heavy Mix

When looking closer at this deviation for the stabilized base layer this is some varying between 6 to 6.75in in thickness layer between the modulus of 43500psi to 48000psi (Figure 4.20). When looking at the large jump in layer thickness in the subbase layer there are large variations in layer thickness ranging from 4in to 118in between these same moduli (Figure 4.21).

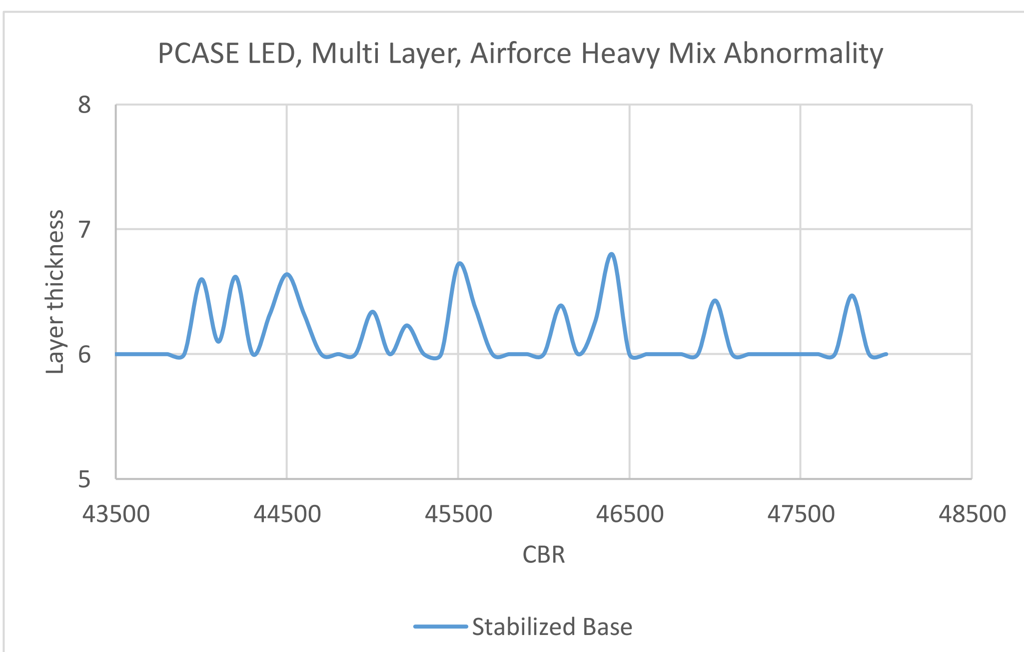


Figure 4.20: PCASE Multiple Layer Design, Airforce Heavy Mix Deviation in Base layer

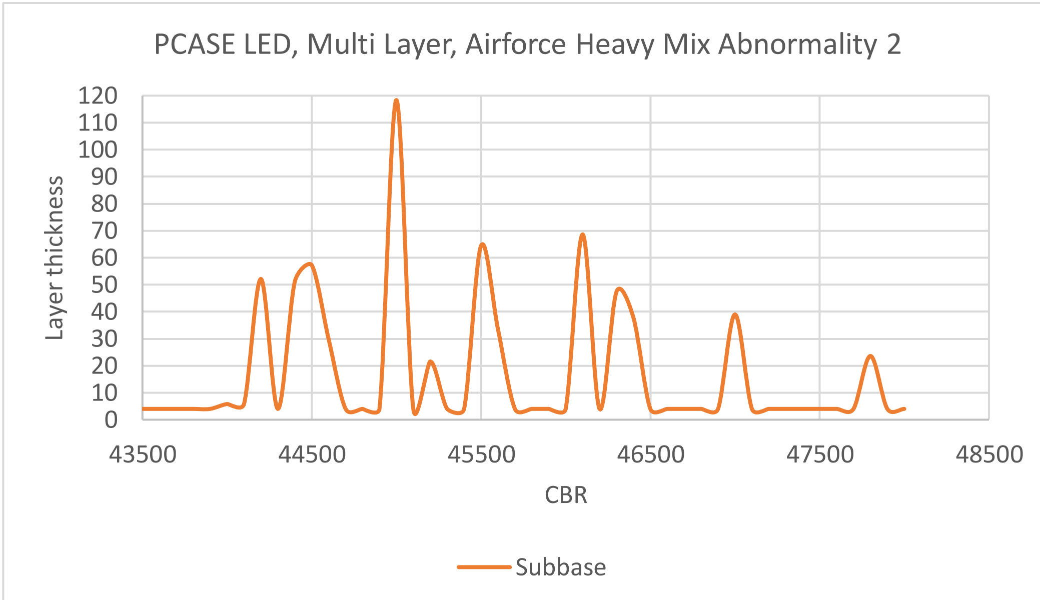


Figure 4.21: PCASE Multiple Layer Design, Airforce Heavy Mix Deviation in Subbase layer

When running the simulation for multiple layers simultaneously using CBR there was not deviation from the expected results to be noted.

4.2.2 Rigid Design

When analyzing the DOD design approach for rigid pavement designs the same air traffic mix of med and heavy were used along with the same 3-layer pavement structure. As stated, before the rigid design process as two different method that can be used in the design process. As with the FAA design approach the DOD design approach only designs for the surface layer in a rigid design. There is also the equation $E(psi) = 20.15 \times k^{1.284}$ that can be used when needing to convert between k values and the modulus E.

For the first simulation with the Air Force medium mix the test was run with a stabilized base of 6in and a subbase thickness of 18in. The initial result whereas expected with the subgrade modulus increasing the surface layer thickness decreases (Figure 4.22).

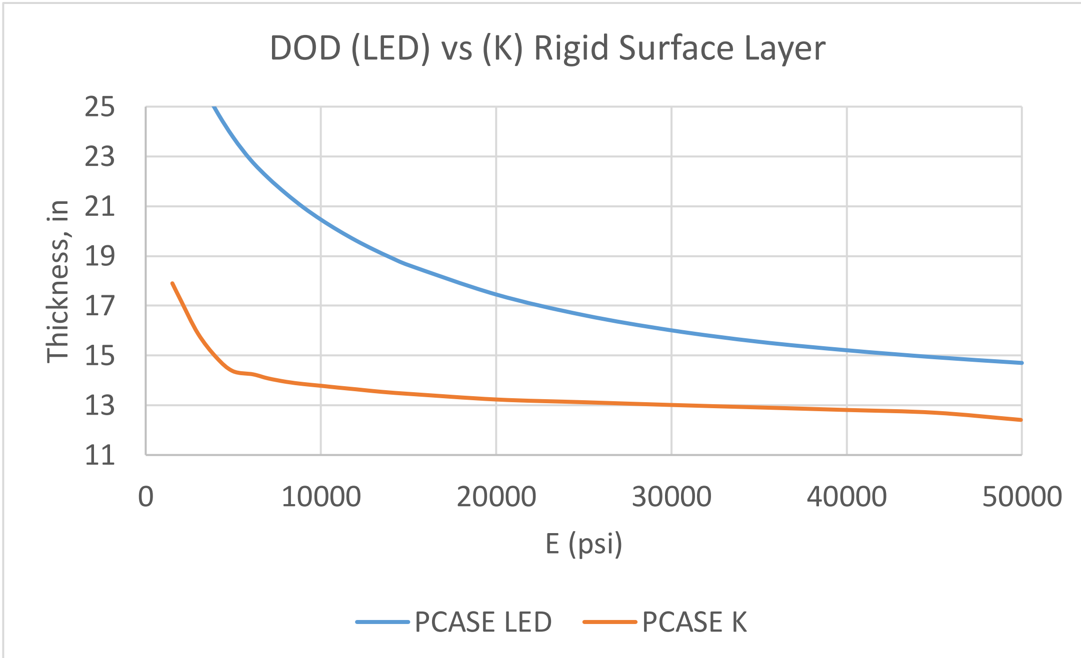


Figure 4.22: DOD LED, k Design Airforce Med, base 6in, subbase 18in

The first difference between the two is the layer thickness, the range of variation runs from 11.26in at 1500psi to 2.29in at 50000psi. The other deviation is a minor 0.5 variation in the DOD k design in the range of 5000psi (Figure 4.23).

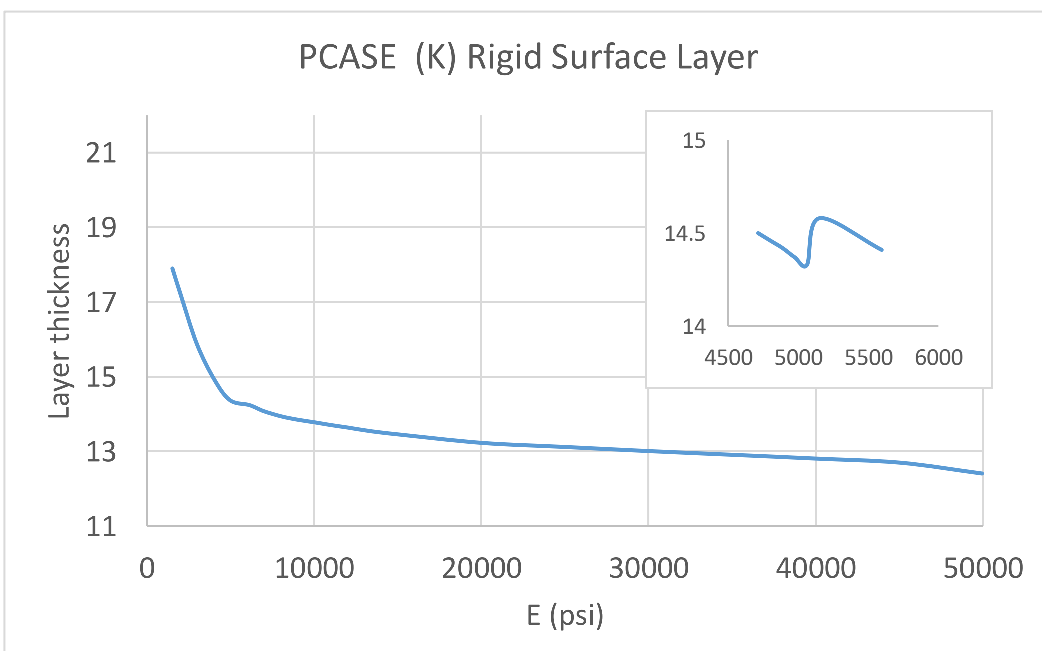


Figure 4.23: DOD k Design Airforce Med, base 6in, subbase 18in deviation

With additional simulation run with the Airforce med traffic mix and Airforce heavy Traffic mix with varying base layer and subbase layer thicknesses the results run similar to the first simulation. The surface layer thickness differs more at a subgrade modulus of 1500psi and close in as the subgrade modulus increase. This can be seen in (Figures24-26).

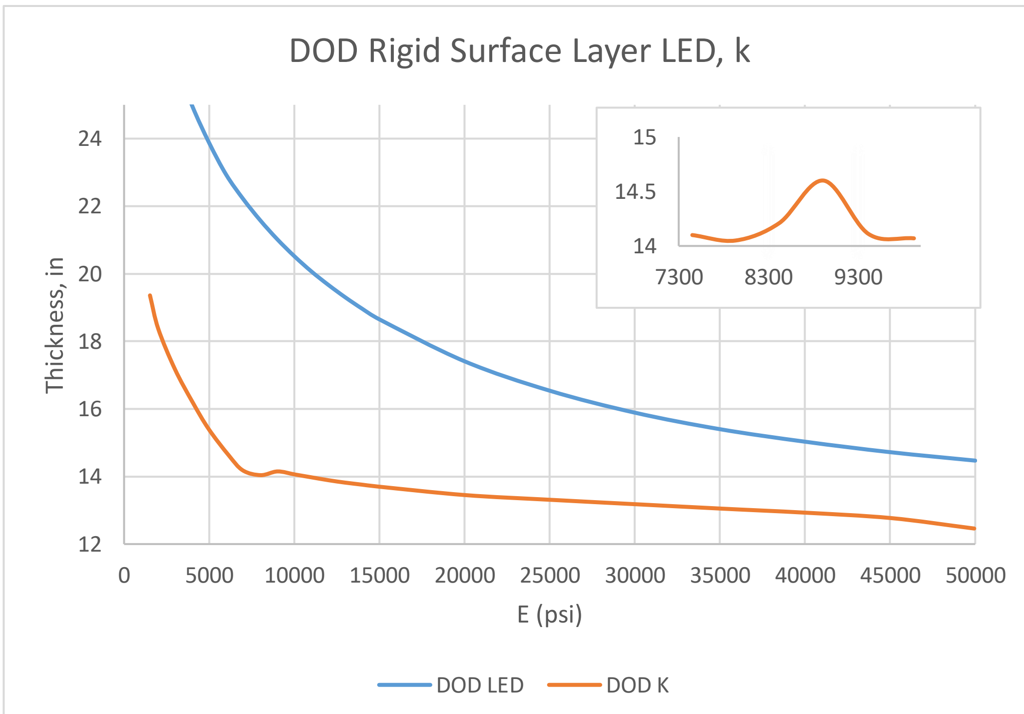


Figure 4.24: DOD LED, k Design Airforce Med, base 8in, subbase 12in

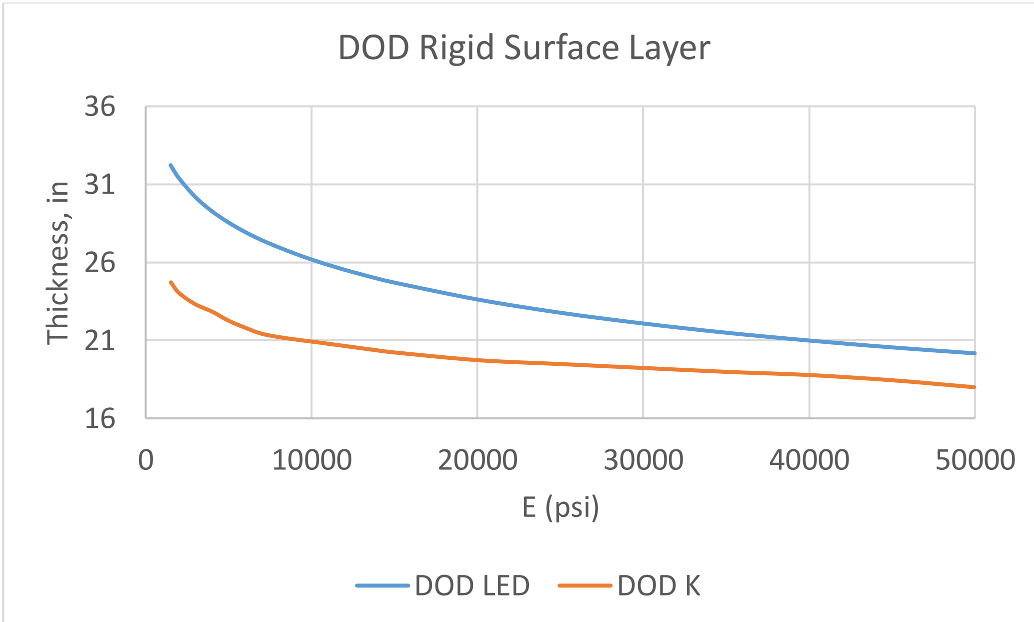


Figure 4.25: DOD LED, k Design Airforce Heavy, base 6in, subbase 12in

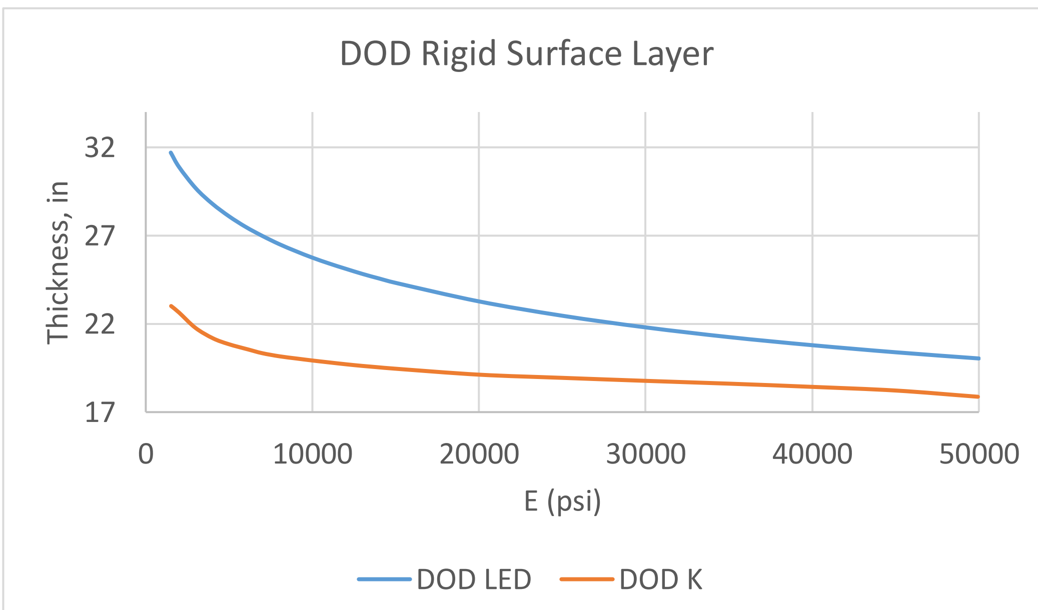


Figure 4.26: DOD LED, k Design Airforce Heavy, base 8in, subbase 18in

As for the deviation that was seen in the first simulation it again showed up in the other simulation using the Airforce medium traffic mix, however with the Airforce heavy traffic mix these is no deviation from the expect curve of the surface layer thickness.

4.3 DOD COMPAIRED TO FAA RIGID DESIGN

When comparing the results of the DOD and FAA it is nearly imposable to do a direct comparison as the two organization use very different programs in their design process. The design approach that is used by the DOD and FAA are geared toward their organization and how a civilian runway is designed and used can differ from how a military runway is designed and used. With this in mind, the use of basic structural design was used along with using common aircraft to both programs was used in this comparison.

When comparing the results, it can be seen that there is a variation between the layer thickness between the two-design process. For example, when looking at the rigid design approach using the layered elastic theory with a medium Air Force Traffic mix, a Stabilized base lay thickness of 8in and a Crush Aggregate layer of 12 in the layer thickness at the lower subgrade modulus has a larger variation between the 2 designs (Table 4.6 & Figure 4.27).

Table 4.6: DOD vs FAA Rigid Design Comparison (thickness in inches)

Subgrade Modulus	DOD vs FAA LED design	DOD k vs FAA LED design
1500	-5.81	4.04
2000	-6.75	2.93
3000	-6.41	2.72
4000	-6.17	2.61
5000	-5.87	2.6
6000	-5.23	3.07
7000	-4.91	3.12
8000	-4.68	2.86
9000	-4.62	2.25
10000	-4.42	2.04
11000	-4.17	1.92
12000	-3.97	1.81
13000	-3.7	1.78
14000	-3.56	1.64
15000	-3.35	1.6
20000	-2.11	1.85
25000	-0.94	2.29
30000	0.01	2.72

35000	0.9	3.25
40000	1.67	3.77
45000	2.28	4.23
50000	3.03	5.04

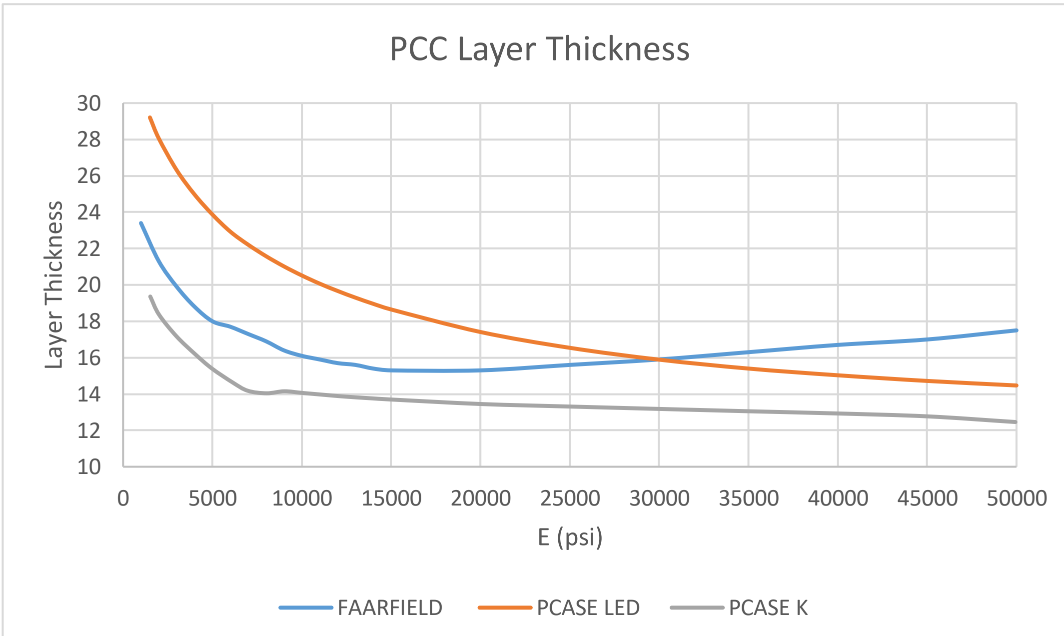


Figure 4.27: DOD vs FAA Rigid Design, Air Force Medium Mix, 8in Stabilized base, 12 Crushed Aggregate

This variation of thickness between the two design approaches decreases as the subgrade modulus increase to the point where they are the same before separating again. This variation between the two design approaches holds true also when comparing DOD empirical design (k value) and Civilian layered elastic approach but to a lesser extent.

When comparing the DOD and FAA using an Air Force heavy mix with 8in Stabilized Base and a Crush Aggregate layer of 18in there is a wider variation between the DOD and FAA LED design and less of a variation between the DOD empirical method and FAA LED design as seen in the table and graph (Table 4.7 & Figure 4.28).

Table 4.7: DOD vs FAA Rigid Design Comparison (thickness in inches)

Subgrade Modulus	DOD vs FAA LED design	DOD k vs FAA LED design
1500	-10.3	-1.61
2000	-10.88	-2.63

3000	-10.68	-2.77
4000	-10.4	-2.78
5000	-10.09	-2.85
6000	-9.59	-2.65
7000	-9.08	-2.44
8000	-8.72	-2.36
9000	-8.32	-2.24
10000	-7.95	-2.12
11000	-7.72	-2.12
12000	-7.42	-2.01
13000	-7.13	-1.92
14000	-6.87	-1.84
15000	-6.62	-1.76
20000	-5.47	-1.32
25000	-4.46	-0.94
30000	-3.6	-0.57
35000	-2.75	-0.11
40000	-1.99	0.37
45000	-1.19	0.98
50000	-0.44	1.73

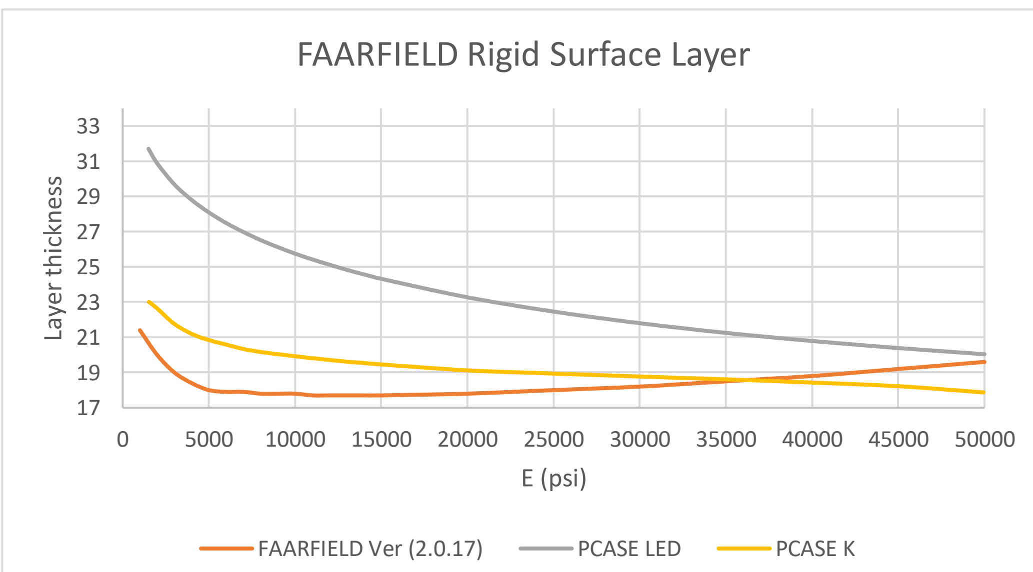


Figure 4.28: DOD vs FAA Rigid Design, Air Force Heavy Mix, 8in Stabilized base, 18 Crushed Aggregate

4.4 DOD COMPAIRED TO FAA FLEXIBLE DESIGN

Has with the rigid pavement design the comparing the results of the DOD and FAA flexible pavement design are not a direct comparison as the two-organization use differ in their design approaches. Staying with the basic structural design and by using common aircraft to both programs was the approached used in order to have the best comparison of the two organizations.

When comparing the results, the variation between the layer thickness of the two-design process with a flexible pavement design the variations still as they converge to the layers minimum thickness. As mentioned before unlike the rigid pavement design the flexible pavement design allow for design nor more than just the surface layer. For this example, looking at the flexible design using a medium Air Force Traffic mix, a Surface lay thickness of 4in and a Stabilized base layer of 6in the layer thickness of the subbase does not vary between the result to the extent as the rigid pavement design, as seen in (Table 4.8 & Figure 4.29).

Table 4.7: DOD vs FAA Flexible Design Comparison, Subbase layer (thickness in inches)

Subgrade Modulus	DOD vs FAA LED design	DOD CBR vs FAA LED design
1500	-53.27	-57.3
3000	-45.39	-30.43
4500	-38.3	-15.41
6000	-27.91	-9.08
7500	-20.46	-5.55
9000	-15.11	-3.8
10500	-10.95	-2.88
12000	-7.5	-1.99
13500	-5.19	-1.69
15000	-3.74	-1.75
16500	-2.65	-1.84
18000	-1.75	-2.6
19500	-1.09	-2.01
21000	-0.41	-1.98
22500	0.04	-2.06
24000	0.42	-2.14
25500	1.57	-1.39
27000	2	-0.71

28500	1.95	-0.08
30000	2	0.51
31500	2	0.9
33000	2	1.27
34500	2	1.64
36000	2	2

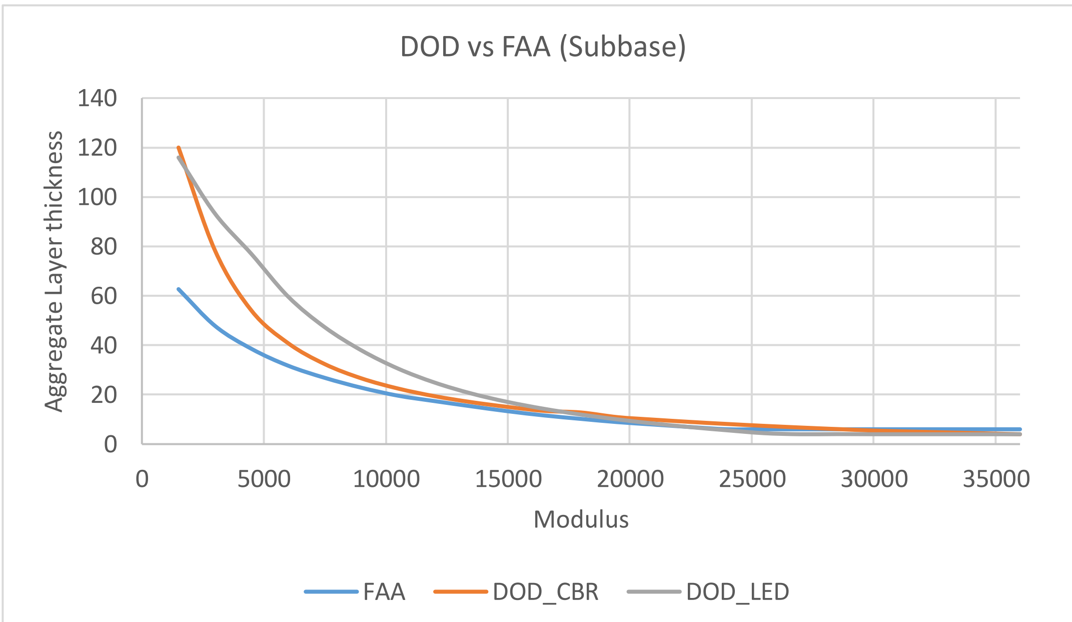


Figure 4.28: DOD vs FAA Flexible Design, Air Force Medium Mix, 4in Surface layer, 6in Stabilized Base layer

There is still a wide variation in the layer thickness at the lower modulus levels but decrease at a steady rate until reach the minimum layer thickness.

When comparing the DOD and FAA using an Air Force heavy mix with 5in Surface thickness and 6in Stabilized the variation between the DOD and FAA designs are similar (Table 4.8 & Figure 4.29). There is a wide variation in layer thickness at the lower modulus levels, but the variation decreases at the higher modulus levels.

Table 4.8: DOD vs FAA Flexible Design Comparison, Subbase layer (thickness in inches)

Subgrade Modulus	DOD vs FAA LED design	DOD CBR vs FAA LED design
1500	-47.64	-57.07
3000	-42.12	-27.24
4500	-37.66	-15.75

6000	-29.22	-9.81
7500	-22.15	-5.32
9000	-18.11	-2.6
10500	-14.79	-0.48
12000	-12.14	1.15
13500	-9.34	2.53
15000	-6.82	3.3
16500	-4.5	3.71
18000	-2.93	3.96
19500	-2.06	3.99
21000	-1.28	4.06
22500	-0.66	4.09
24000	-0.13	4.12
25500	0.33	4.16
27000	0.76	4.22
28500	1.15	4.1
30000	1.36	3.4
31500	1.67	2.9
33000	1.92	2.4
34500	1.82	2
36000	2	2
37500	-1.53	2
39000	-11.43	2
40500	2	2
42000	2	2
43500	2	6
45000	2	6

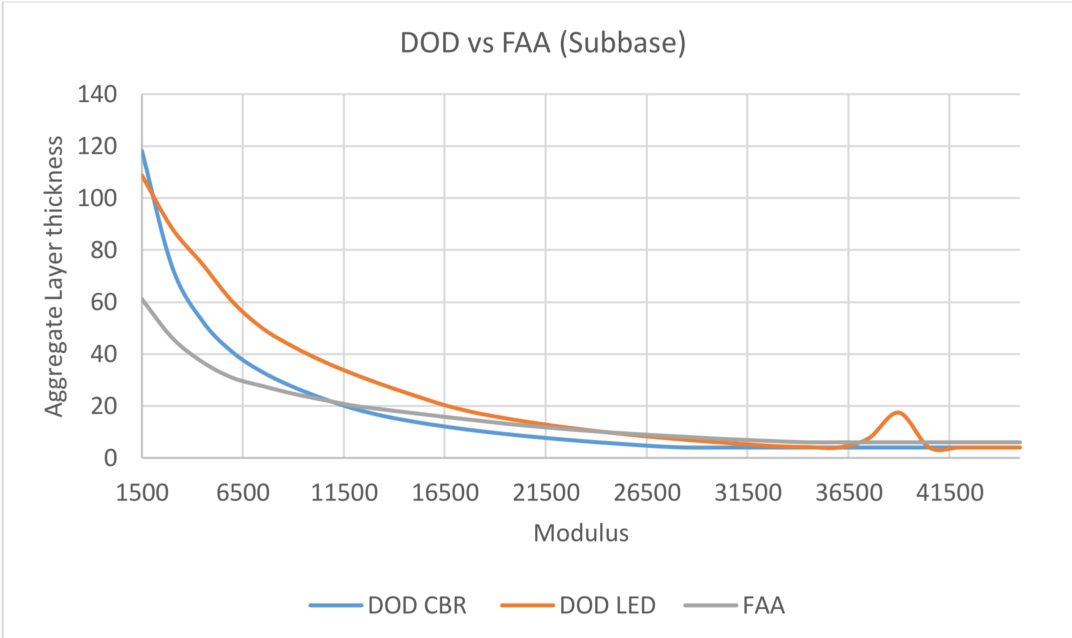


Figure 4.29: DOD vs FAA Flexible Design, Air Force Medium Mix, 4in Surface layer, 6in Stabilized Base layer

With this comparison the abnormality with the DOD LED design shows up with the layer thickness jumping for 2in to 6in at a modulus of 43000psi.

When the comparison was made for the base layer thickness the layered elastic comparison ran similar to the comparison made with the subbase. The layer thickness has a wide variation between the two design approaches at the lower modulus levels but decrease until the minimum layer thickness is reached. With the DOD design using the CBR value this layer thickness decrease to a point and then held steady and not reaching minimum layer thickness (Table 4.9 & Figure 4.30)

Table 4.8: DOD vs FAA Flexible Design Comparison, Subbase layer (thickness in inches)

Subgrade Modulus	DOD vs FAA LED design	DOD CBR vs FAA LED design
1500	-9.88	-21.56
3000	-10.11	-10.46
4500	-10.43	-6.57
6000	-8.58	-5.34
7500	-6.35	-3.89
9000	-4.82	-3.05
10500	-3.58	-2.39
12000	-2.69	-1.92

13500	-2.06	-1.77
15000	-1.5	-2.27
16500	-1.16	-3.17
18000	-0.91	-3.97
19500	-0.69	-4.67
21000	-0.59	-5.37
22500	-0.6	-5.97
24000	-1	-6.37
25500	-1	-6.37
27000	-1	-6.37
28500	-1.39	-6.37
30000	-2	-7.37
31500	-2	-7.37
33000	-2	-7.37
34500	-2	-7.37
36000	-2	-7.37
37500	-2	-7.37
39000	-2	-7.37
40500	-2	-7.37
42000	-2	-7.37

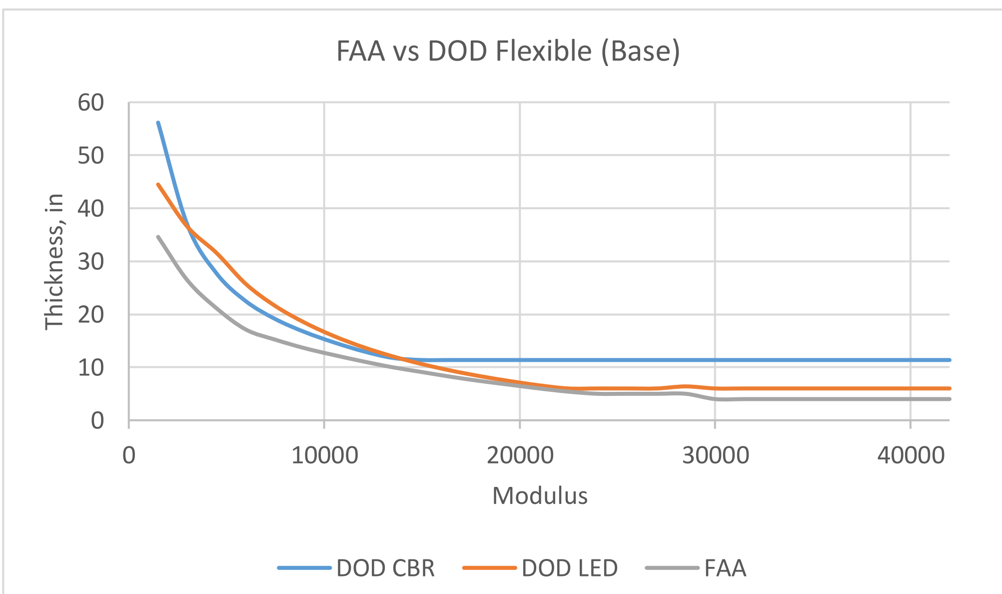


Figure 4.29: DOD vs FAA Flexible Design, Air Force Medium Mix, 5in Surface layer,12 Subbase Base layer

Chapter 5: Airfield Design compairision

5.1 El Paso Airfield

As an experiment a test was run to compare a section of runways design for the El Paso Airport that was designed using the FAA standard of using FAARFIELD. The initial design was conducted in 2014 using FAARFIELD version 1.305, 9/28/10 64-bit and the FAARFIELD version used in the experiment was 2.0.17, 04/06/2022 32-bit. The 32-bit version of the program was used for this experiment because it is recommended for used on personal computers.

Design drawing for the El Paso Airport Runway 4-22 was given by the Engineers at the airport for use in this Thesis. In Figure 4.30 is a typical section of runway 4-22 for STA 12+20.00 to 13+00.00. Here the Surface layer of Portland Cement Concrete (PCC) is 15.5in and Bituminous Stabilized Base layer of 6in and a Crushed Aggregate Subbase of also 6in. The strength R for the PCC was 650psi, it should be noted that for the Crush Aggregate layer the Modulus used by the design team was 48,505psi, In the experiment run the Modulus for Crush Aggregate layer was 56,636, this variation is believed to be due to the upgrade in the versions of the program.

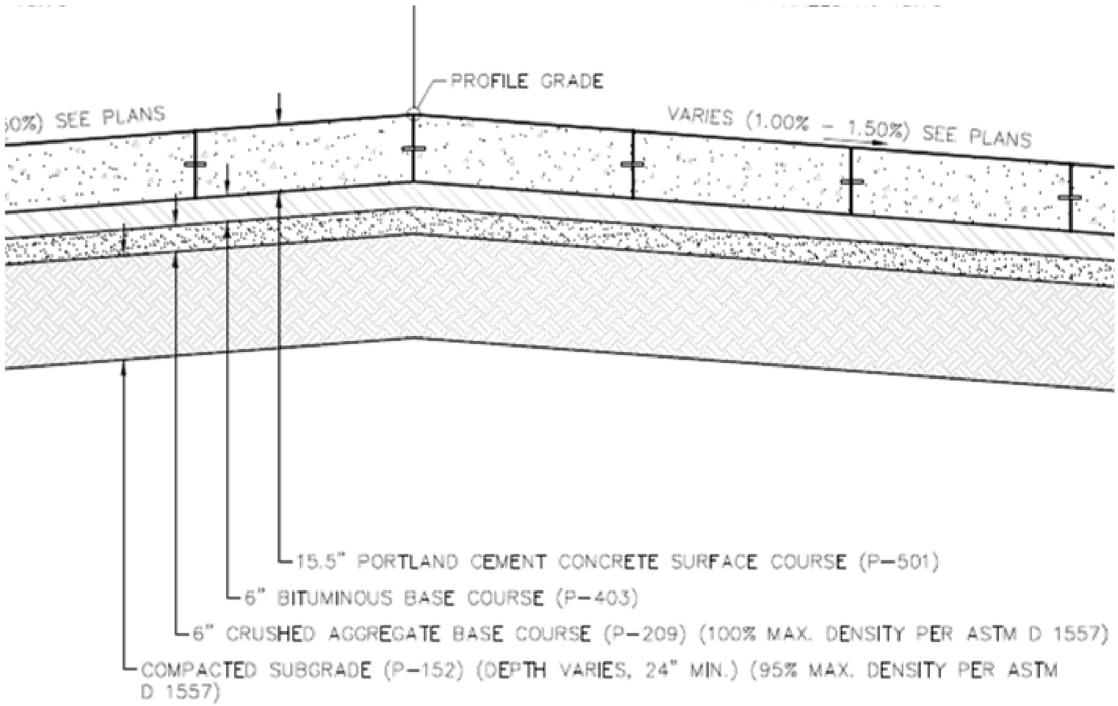


Figure 4.30: EL Paso Airport Typical Section for Runway 4-22 STA 12+20.00 to 13+00.00

From the Engineer's Design Report also provided by the EL Paso Airport the Subgrade modulus was 23,867 psi for this location. The air traffic mix consisted of 22 different aircraft with and annual departure total of just over 16,600 with a growth rate of 2.8% (Table 4.9).

Table 4.9: EL Paso Air Traffic Mix for Runway 4-22 Design

Aircraft	Gross Wt lbs	Annual Departures	% Annual Growth
Sngl Whl-45	48500	2044	2.8
Sngl Whl-45	53000	767	2.8
Dual Whl-75	72750	1022	2.8
Dual Whl-75	82500	767	2.8
Dual Whl-150	140000	767	2.8
MD83	160000	511	2.8
MD90-30 ER	156000	1022	2.8
A319-100 std	166000	1022	2.8
B737-700	154500	2555	2.8
B737-500	133500	2555	2.8
B737-300	124500	1278	2.8
A300-600 std	365745	684	2.8
MD11ER	602555	312	2.8
MD11ER Belly	602555	312	2.8

DC10-10	458000	240	2.8
DC10-30/40	583000	48	2.8
DC10-30/40 Belly	583000	48	2.8
B757-200	240000	216	2.8
B767-300 ER Freighter	400000	48	2.8
DC9-32	121000	288	2.8
B727-100C Alternate	160000	60	2.8
Adv. B727-200 Option	209500	36	2.8

With this data the design team at following the FAA design process got a PCC layer thickness of 14.98in. As seen in the construction drawings the layer thickness used was 15.5in, it is unknown why 0.5in, it could be assumed to be a safety factor or might be related to calculations done for freezing as the FAA program does not calculate for frost depth.

When the simulation was run using the latest version of the FAA design program using the same traffic mix and a subgrade modulus of 23,867psi, the surface PCC layer was calculated to be 15.3in, this is only a 0.4in difference. When this simulation was run using the actual air traffic for the El Paso airport for the year 2014-2015 the results differ. First when looking up the Air Traffic for this time frame it was found that there were about 60,337 departures for the Airport according for the FAA data. However, for this simulation a departure number 44,920 aircraft was used because several the aircraft from the FAA report were not in the FAARFIELD aircraft database. When this simulation was run the FAA program computed that the layer thickness for the PCC surface layer should be 16.2in, this is 1.22in greater than the original design and 0.9 in greater using the same traffic mix but with the updated version of FAARFIELD.

The other thing that stood out when the simulation was run with the original traffic mix from the Engineer's Report is that The CDF is greater than 1, this would indicate a failure (Figure 4.30).

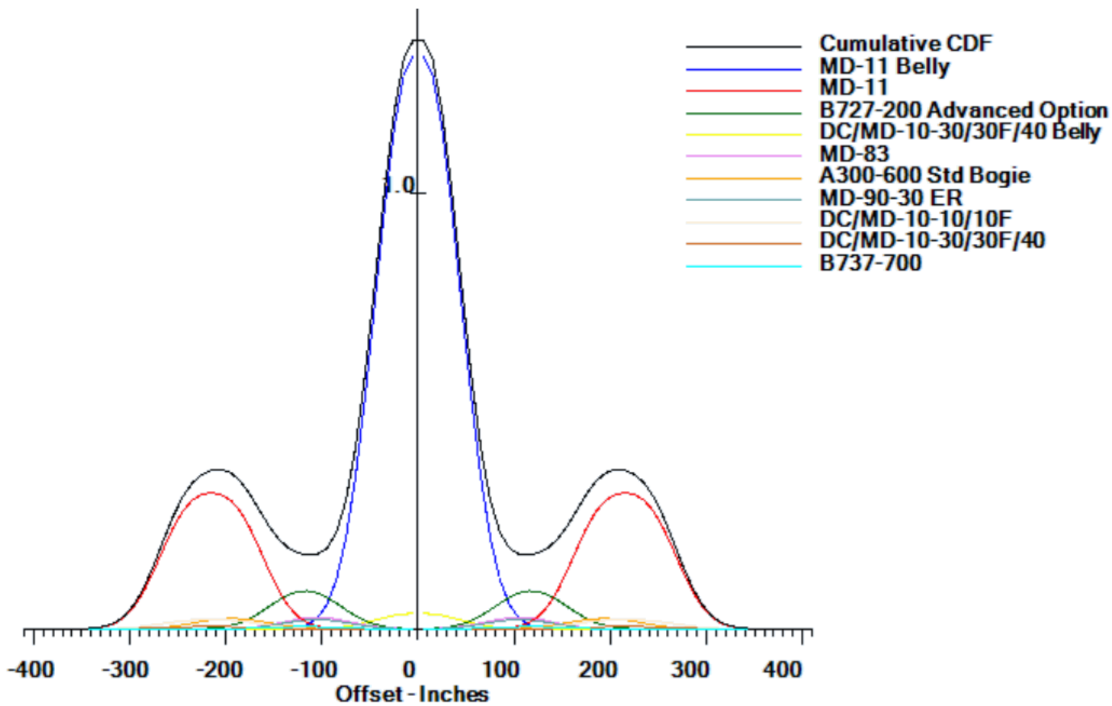


Figure 4.30: FAA CDF for El Paso Airport using Air Traffic mix from Engineer's Report

By increasing the layer thickness of the base and subbase layers a CDF of 1 can be reached. As an example, by changes the stabilized base to 12in and the crushed aggregate subbase to 18in a CDF was achieved (Figure 4.31)

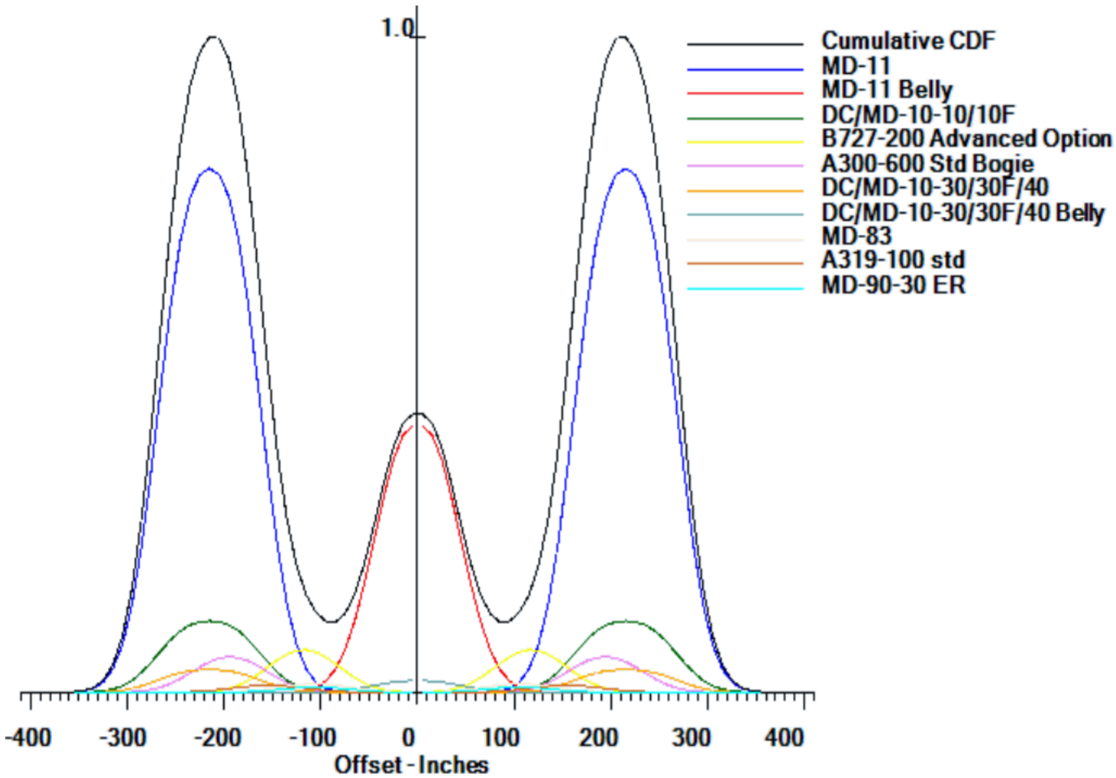


Figure 4.31: FAA CDF for El Paso Airport using Air Traffic mix from Engineer's Report with modified base and subbase

When I same simulation was run using the data from the FAA for the year 2014-2015 the CDF is 1 which indicated a good design (Figure 4.32).

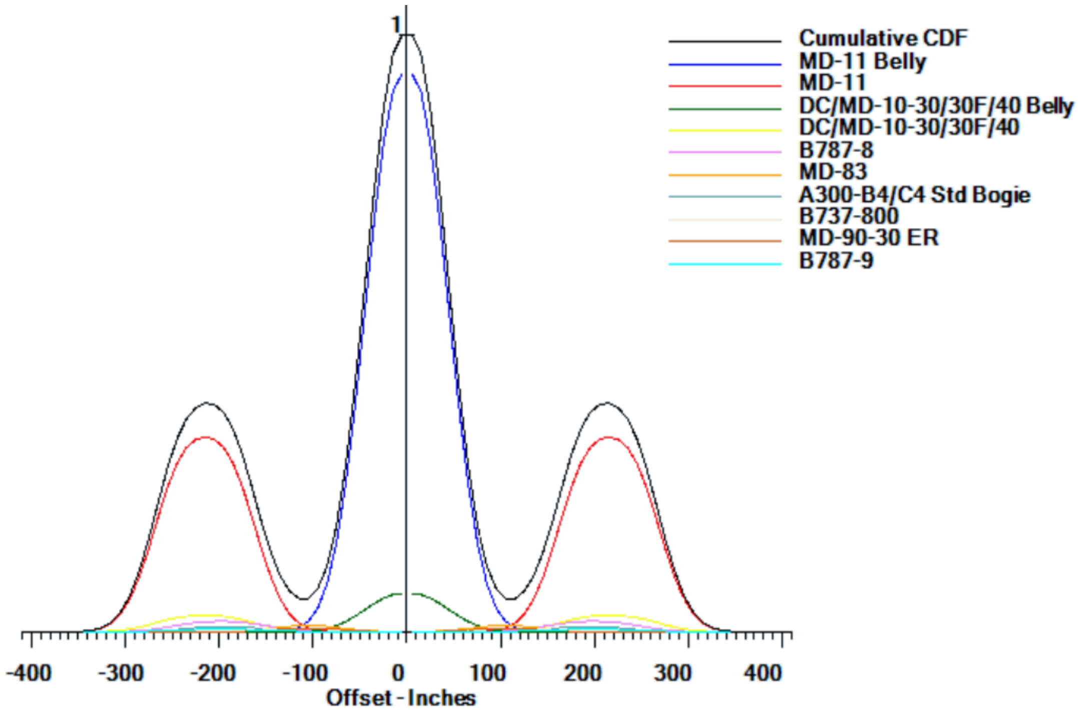


Figure 4.32: FAA CDF for El Paso Airport using Air Traffic mix from FAA for 2014-2015

It is unknow why this happen the simulation was run multiple times to confirm. These was no information about the CDF value in the Engineer's Report for the EL Paso airport.

Chapter 6: Conclusion

The sensitivity analysis conducted for both the FAA and DOD airfield runways design clearly show the benefits of using are either program to aid and expedite the initial design process. However, both programs have visible differences and abnormalities in serviceability. The FAARFIELD program is simpler, with a strict focus on layered elastic theory in runway design processes; this narrower focus shows fewer abnormalities detected. A few of these abnormalities included the increase in surface layer thickness verse a continues decrease in layer thickness with the increase in the subgrade modulus. The DOD program is a much more complex, designing for standard airfield runways, mat or dirt runways, roads, parking lots, landing pads and/or tank trails. This design approach also utilizes weather data to calculate frost depth and drainage with the benefit of the use of possible geotextiles within the designs. This wider range of use relating to the DOD program is believed to be the cause of the detection of a larger number of abnormalities found to have certain areas where the layer thickness increase and, in some cases, a dramatic increase but only within a small range of modulus of subgrade. Additional studies relating to both programs should be considered as they could reveal more deviations and give the necessary data to improve the programs further.

While these programs are useful, it is clear that there is room for improvement. However, there cannot be a sole reliance on software to facilitate structural design - whether it is related to runway design or not. Even with programs as powerful as these, there is a need for knowledgeable individuals to review each step in the design process to check for deviations or abnormalities that may affect the integrity of the project.

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Vita

Jacob Wessel was Born in St Johnsbury, VT where he attended Concord High School for his foraminal years. Upon graduation from High School, He joined the U.S. Army as a Combat Engineer with the intention of completed his original contacted and then getting out and going back to school. As with most plans they tend to change with time, and he stayed until retirement after 21 years of service. During this time, he married, had 2 daughters, lived in 5 different states and 2 different counties. He also deployed to Kosovo, Iraq and Afganistan during his time in the military.

After retirement Jacob was excepted into the University of Texas at El Paso (UTEP) where he obtained his Bachelor of Science in Civil Engineering in the spring of 2020. Prior to graduating he participated in a research project under the guidance of Dr. Reza Ashtiani, who convinced Jacob to further this education by enrolling the master's graduate program in Civil Engineering at UTEP.