ICAO AERODROME PAVEMENT WORKSHOP

Design Examples Using FAARFIELD 2.1

Presented to: ICAO Aerodrome Pavement Workshop
Bangkok, Thailand

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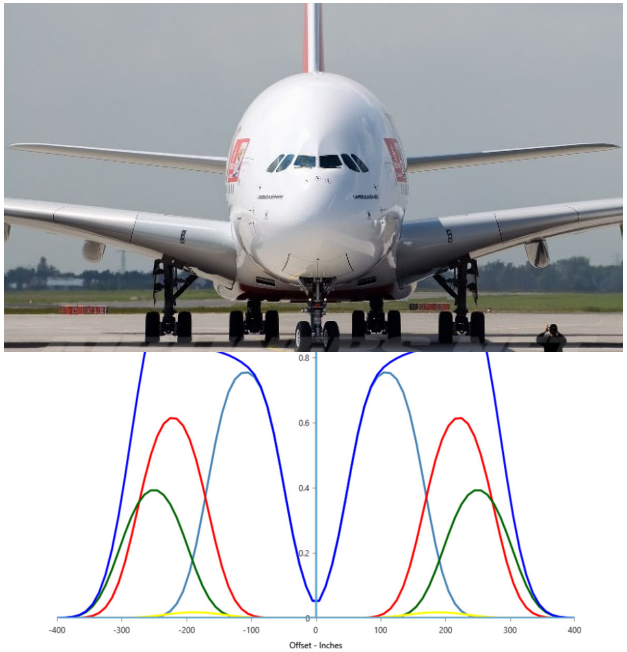
Date: 8 February 2024

Federal Aviation Administration



FAARFIELD 2.1

Flexible Pavement Design Example

Flexible Pavement Design Example

A flexible pavement is being designed for a new runway at a commercial airport in Washington, D.C. Based on the information obtained from the Airport Master Plan, the new runway is expected to handle the traffic mix presented in Table 1. Eight soil borings were performed for this project, the results of which are presented in Table 2.

Table 1. Aircraft traffic mix for flexible pavement design example.

Aircraft	Departure Weight, kg	Arrival Weight, kg	Annual Departures
S-30	13,608	10,206	8000
Fokker F-100	44,452	34,019	6500
B737-300	62,822	52,163	5000
B767-300 ER	158,757	131,541	3200
A380-800	544,310	462,664	400
B777-300	263,083	237,682	1500

Table 2. Soil boring results for flexible pavement design example.

Boring No.	UCSC Soil Type	Moisture Content, %	Optimal MC, %	Dry unit weight, kN/m^3	Water Table Depth, m	CBR, %
B-1	SC	12.2	10.4	20.26	3	10.6
B-2	SC	14.4	12.2	19.57	3	7.2
B-3	SC	16.5	9.6	20.80	2.5	8.4
B-4	CL	15.8	13.5	18.88	2.0	6.3
B-5	CL	17.0	14.5	19.24	2.4	4.8
B-6	CL	16.2	13.8	18.96	1.7	5.9
B-7	CL	16.8	12.6	19.48	1.4	4.2
B-8	CL	14.2	12.8	20.14	1.8	6.4
Average:						
Std. Deviation:						

Flexible Pavement Design Example

1. **What do the soil boring results tell us about the in situ soil properties? What subgrade support value do you recommend for design?**
2. **What type and thickness of base/subbase materials do you recommend? Are positive drainage features required?**
3. **Should the pavement be designed for aircraft arrival or departure weights? What is the required flexible pavement thickness for the runway? What is the most demanding aircraft?**
4. **Perform a sensitivity analysis on the following variables:**
   - Average annual departures of most demanding aircraft (+/- 10 percent of departures).
   - Departure weight of the most demanding aircraft (+/- 10 percent of weight).
   - Subgrade modulus (+/- 10 percent of modulus).

Flexible Pavement Design Example

1. **What do the soil boring results tell us about the in-situ soil properties? What subgrade support value do you recommend for design?**
2. **What type and thickness of base/subbase materials do you recommend? Are positive drainage features required?**
3. **Should the pavement be designed for aircraft arrival or departure weights? What is the required flexible pavement thickness for the runway? What is the most demanding aircraft?**

Boring No.	UCSC Soil Type	Moisture Content, %	Optimal MC, %	Dry unit weight, kN/m^3	Water Table Depth, m	CBR, %
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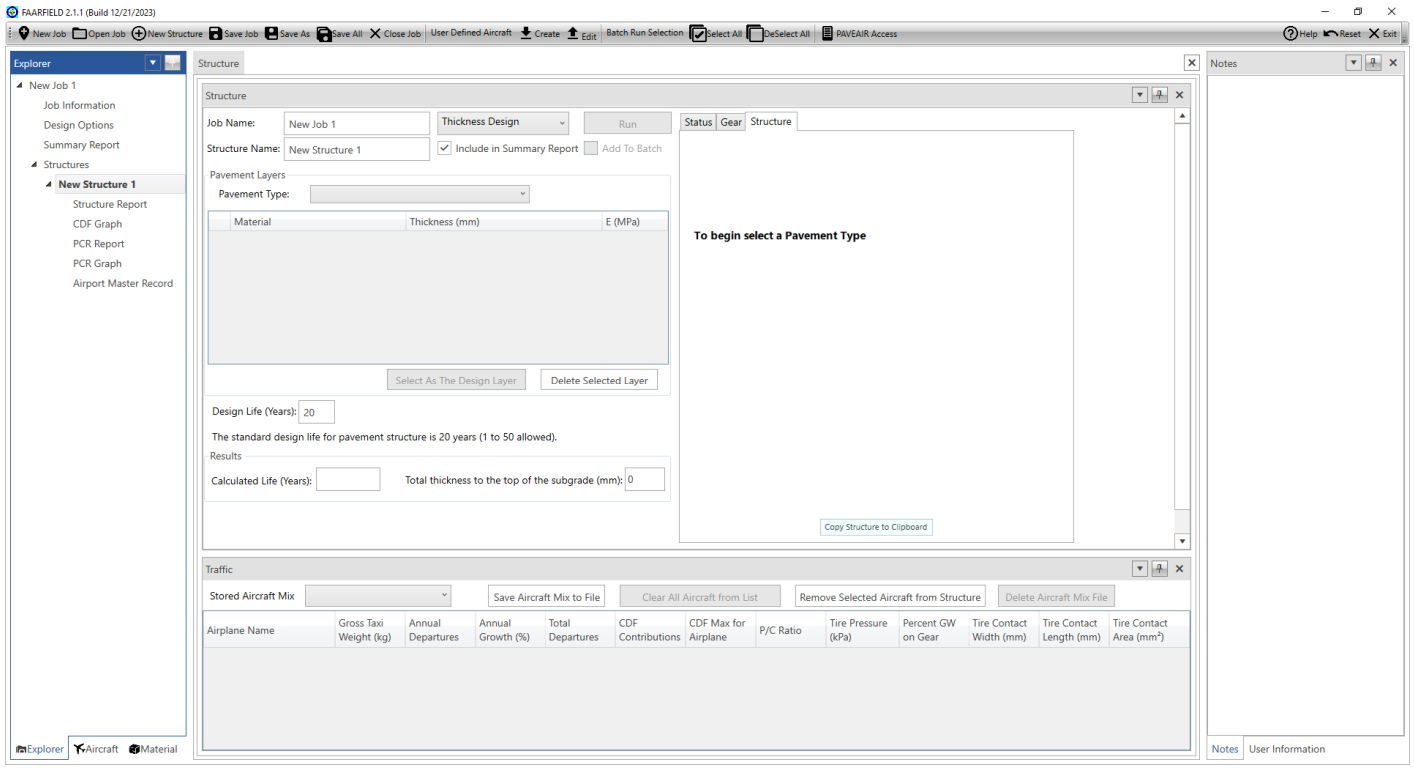
B-7	CL	16.8	12.6	19.48	1.4	4.2
B-8	CL	14.2	12.8	20.14	1.8	6.4
Average:		**15.4**	**12.4**	**19.66**	**2.3**	**6.7**
Std. Deviation:		**1.7**	**1.7**	**0.68**	**0.6**	**2.0**

Starting Screen – No Job Files Created

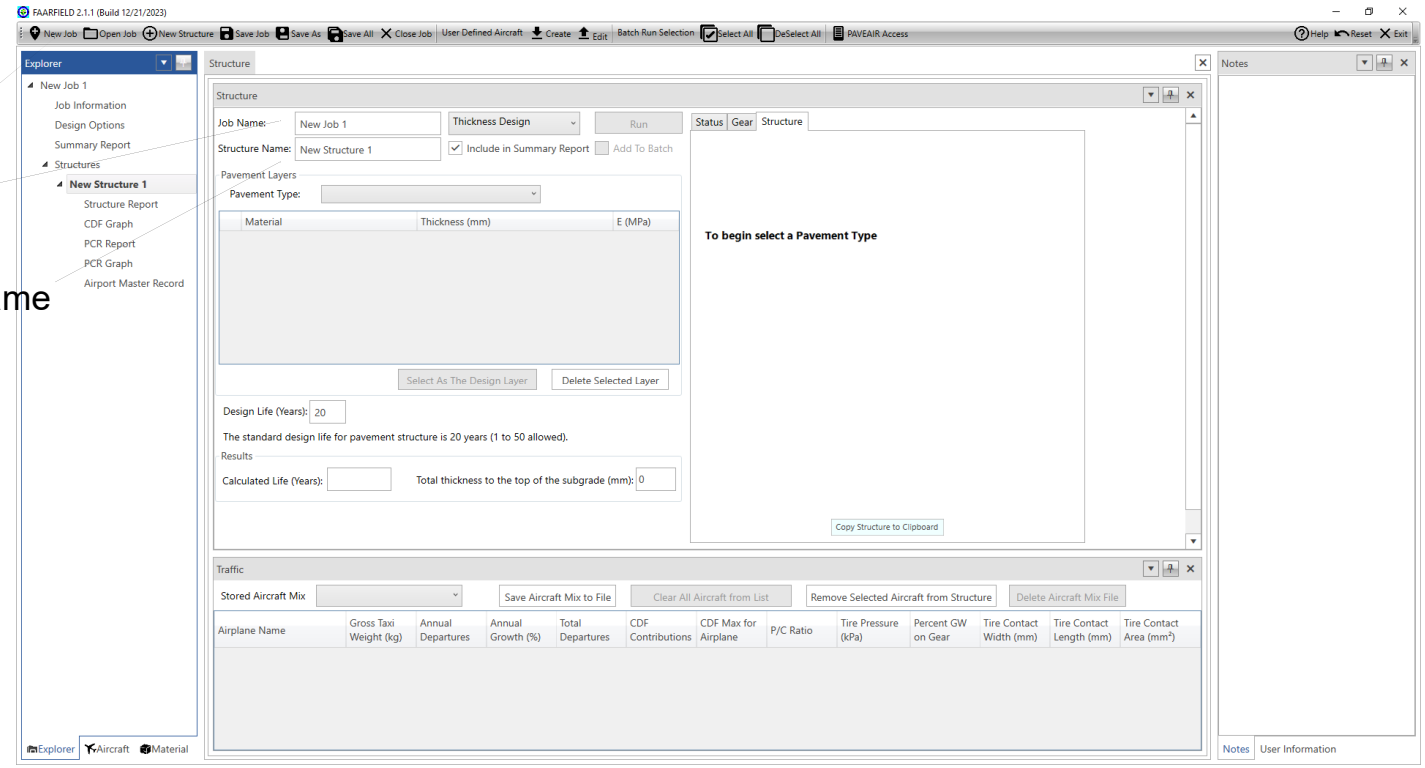


Creating/Naming a Job File

Click “New Job”

Enter Job Name

Enter Section Name



Selecting Structure

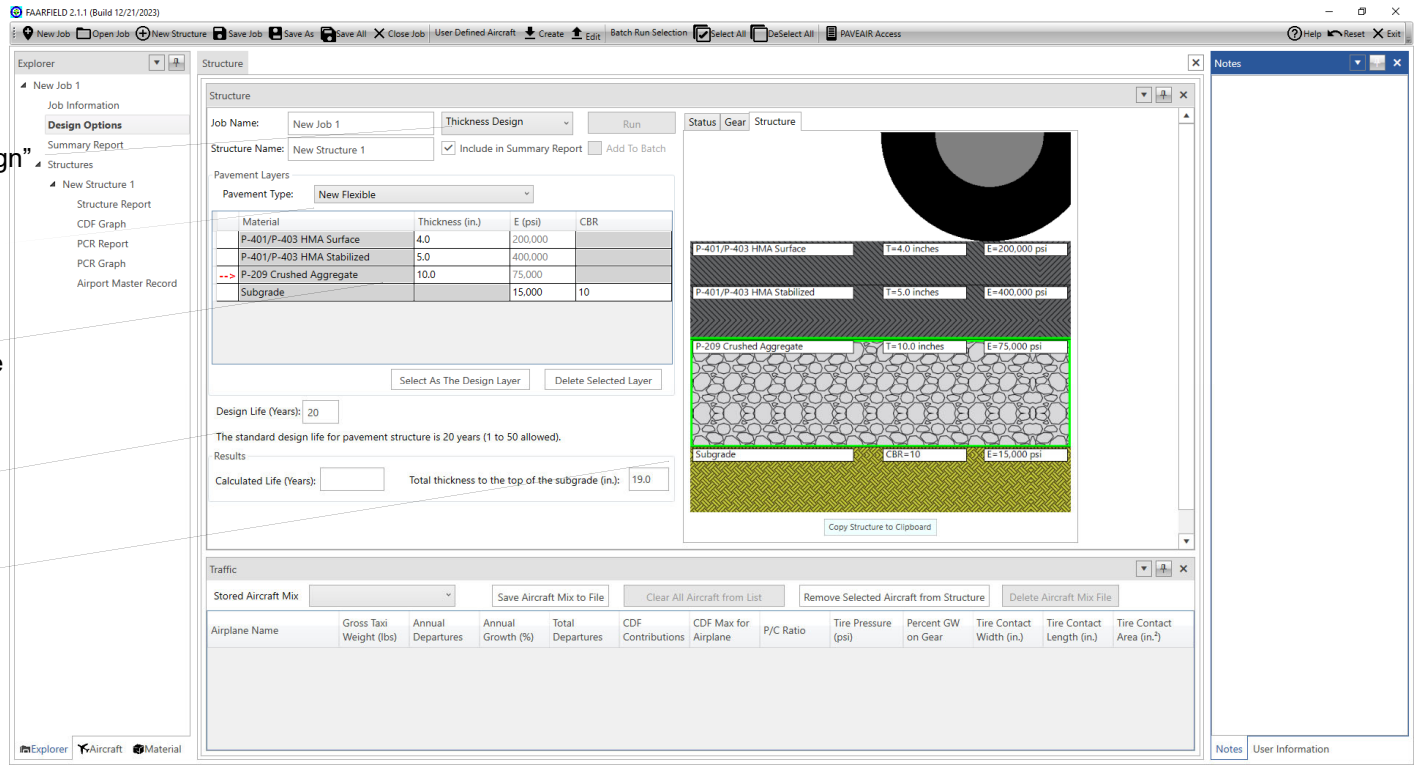
Select “Thickness Design”

Select Pavement Type as “New Flexible”

Default pavement structure details in table

Default pavement Design Life

Default pavement structure for “New Flexible”



Design Options

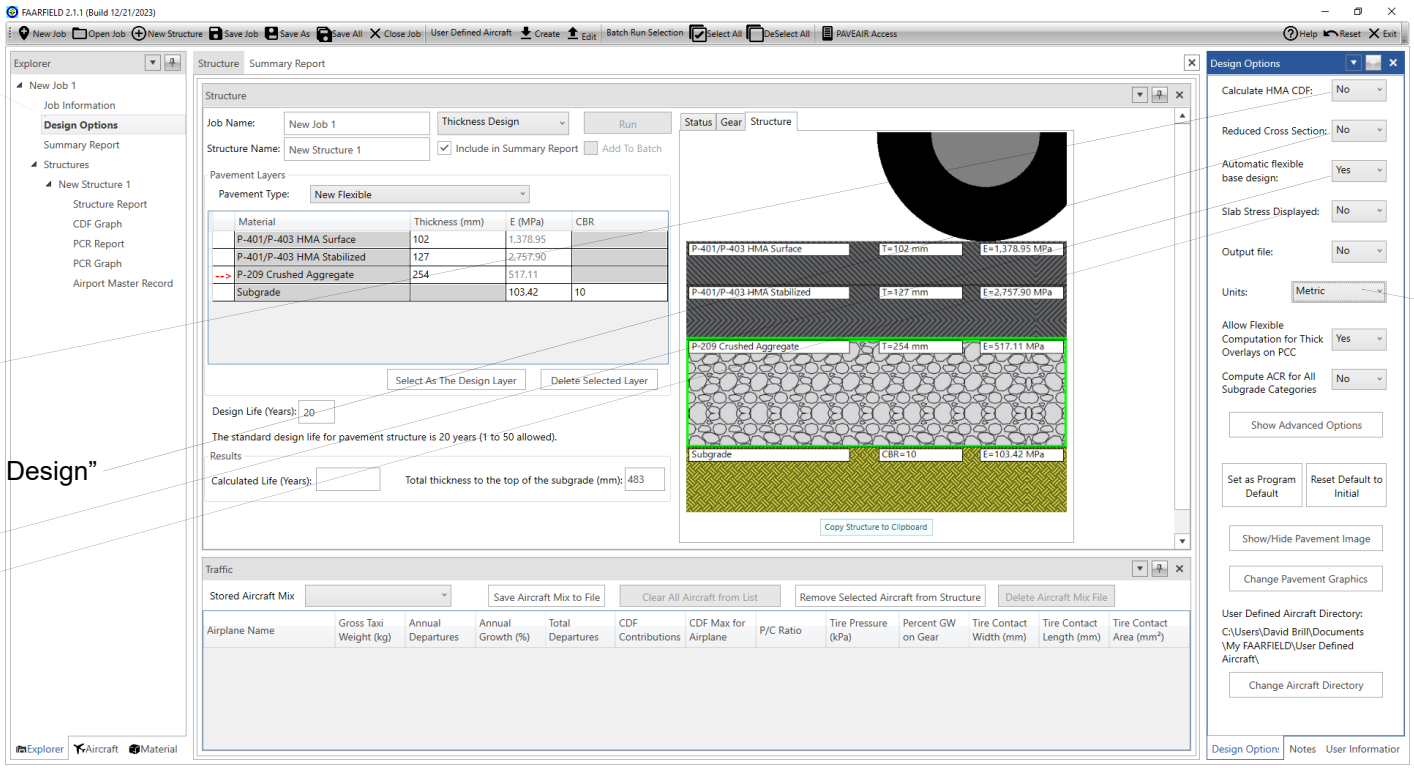
Click “Design Options”

Select Option for “HMA CDF”

“Automatic Flexible Base Design”

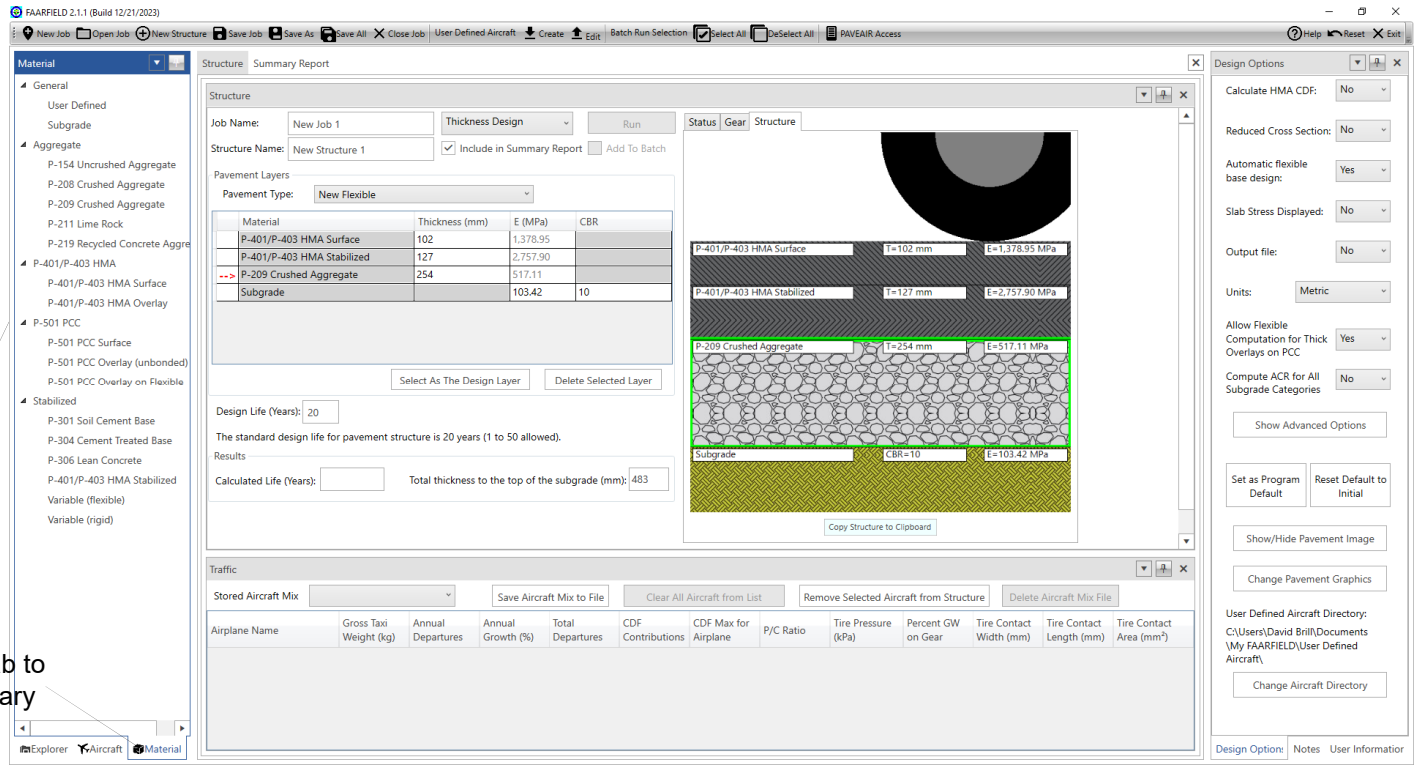
“Output File”

“Units”



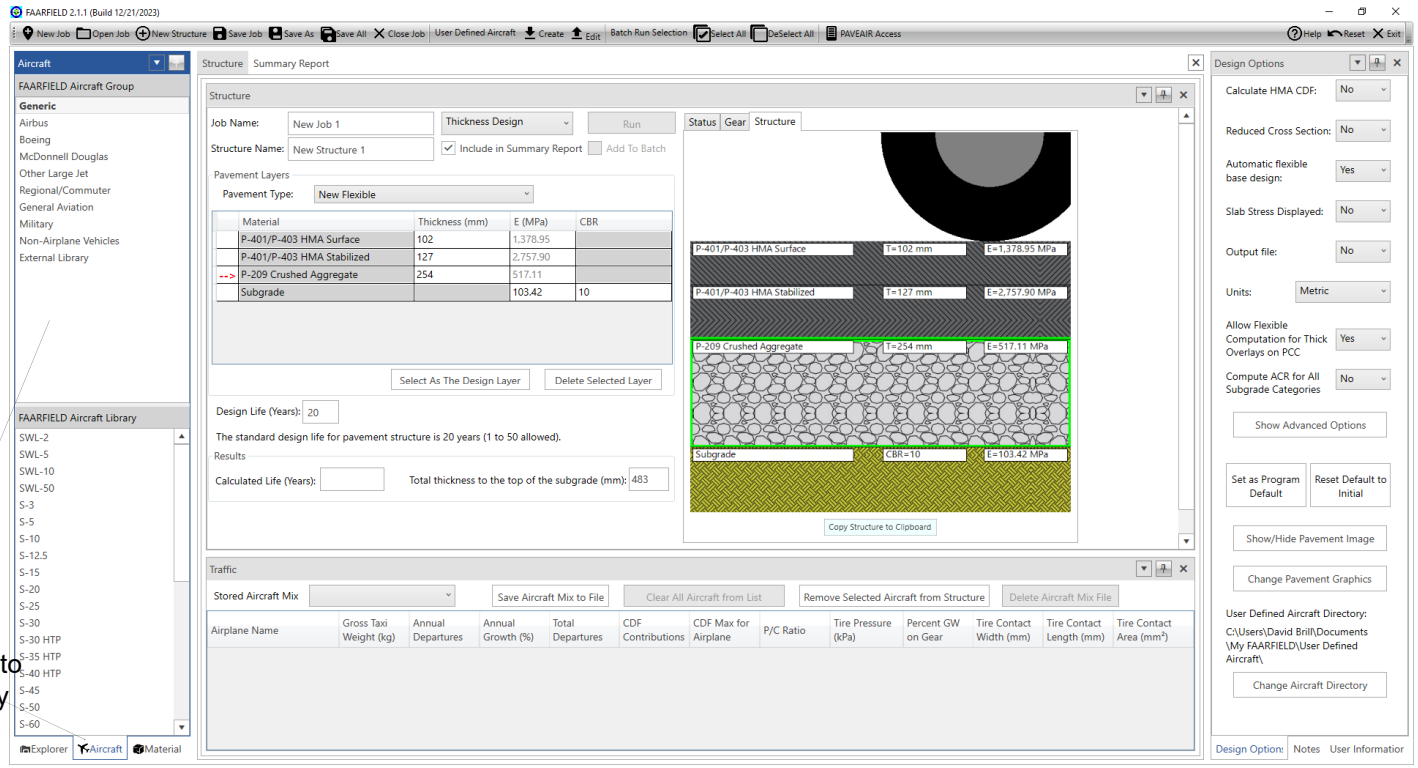
Set Units to “Metric”

Materials Library – Layer Types



Click “Materials” tab to open materials library

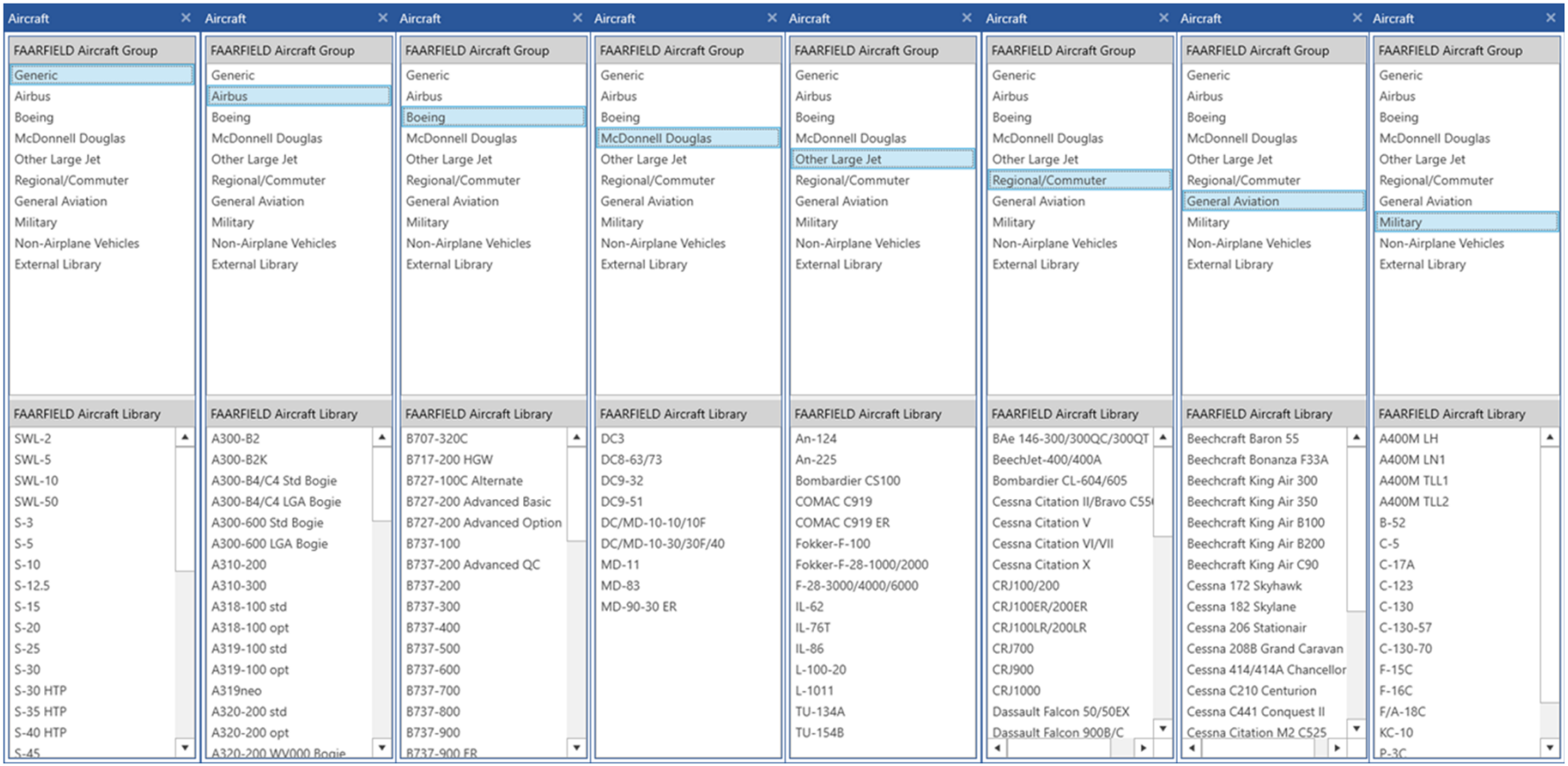
Aircraft Library



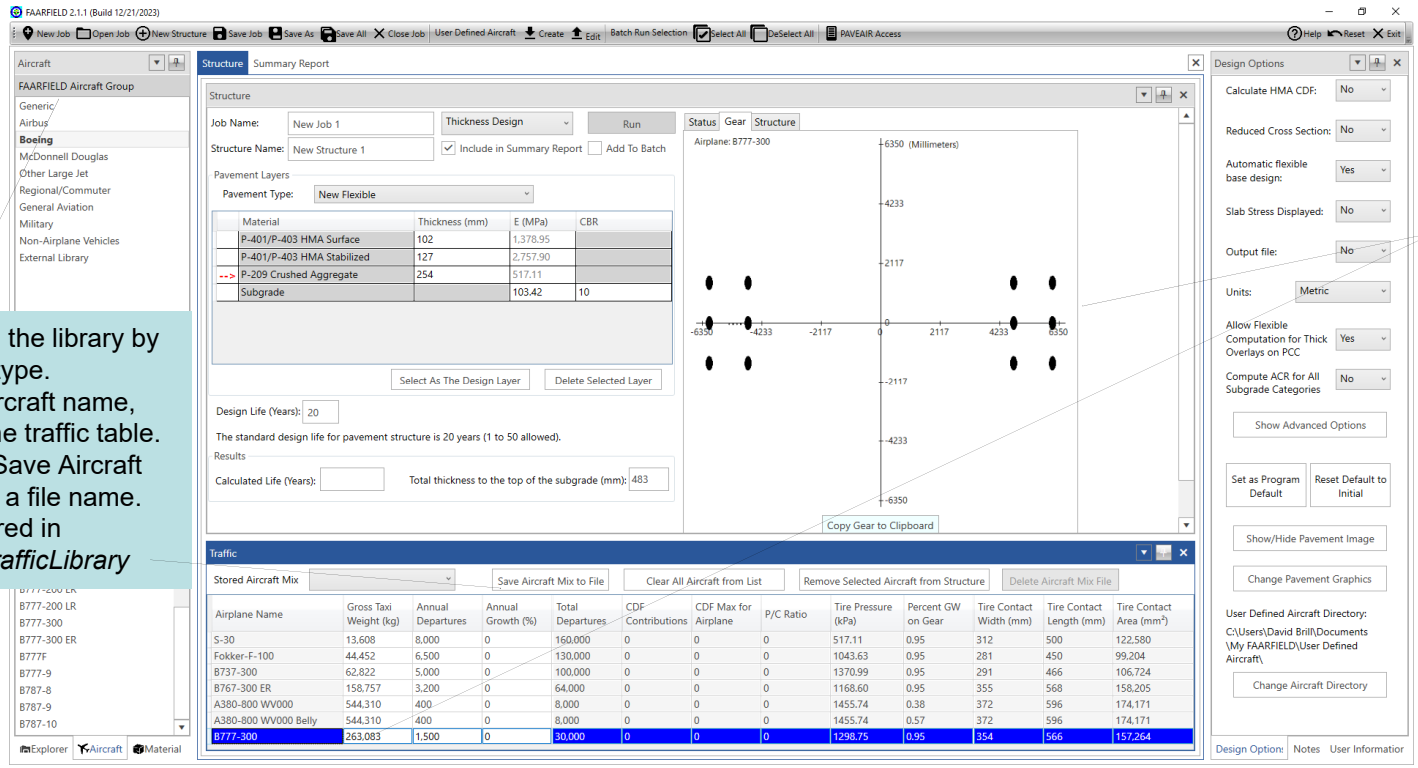
Click “Aircraft” tab to open aircraft library

Aircraft Library –

Completely reorganized and updated for the FAARFIELD 2.0 release



Creating Aircraft Traffic Mix

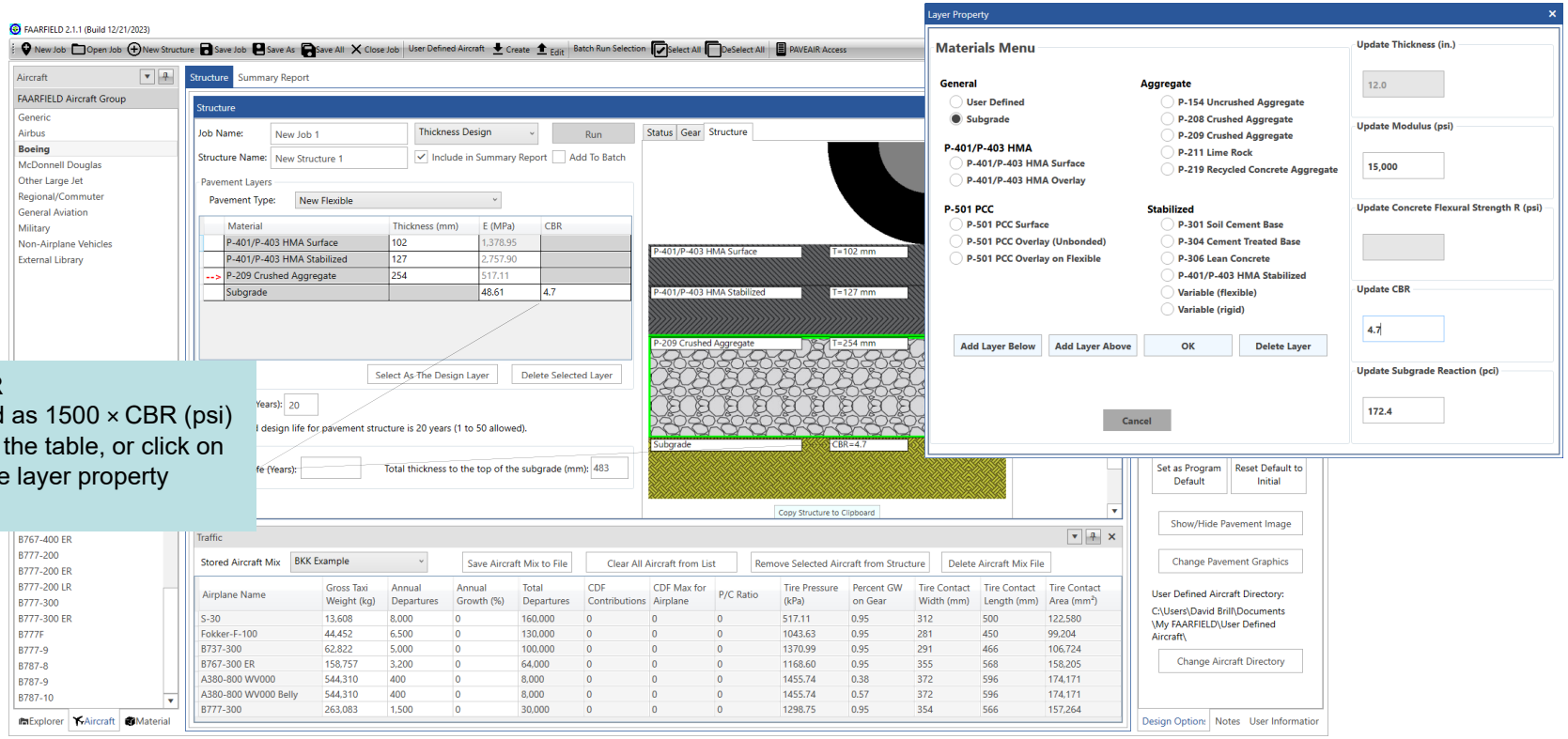


- Select aircraft from the library by aircraft group and type.
- Double-click the aircraft name, or drag/drop into the traffic table.
- Once done, click “Save Aircraft Mix to File.” Give it a file name.
- Traffic files are stored in *My FAARFIELD/TrafficLibrary*

Highlight an aircraft to display gear geometry. (Gear geometry displays in window.)

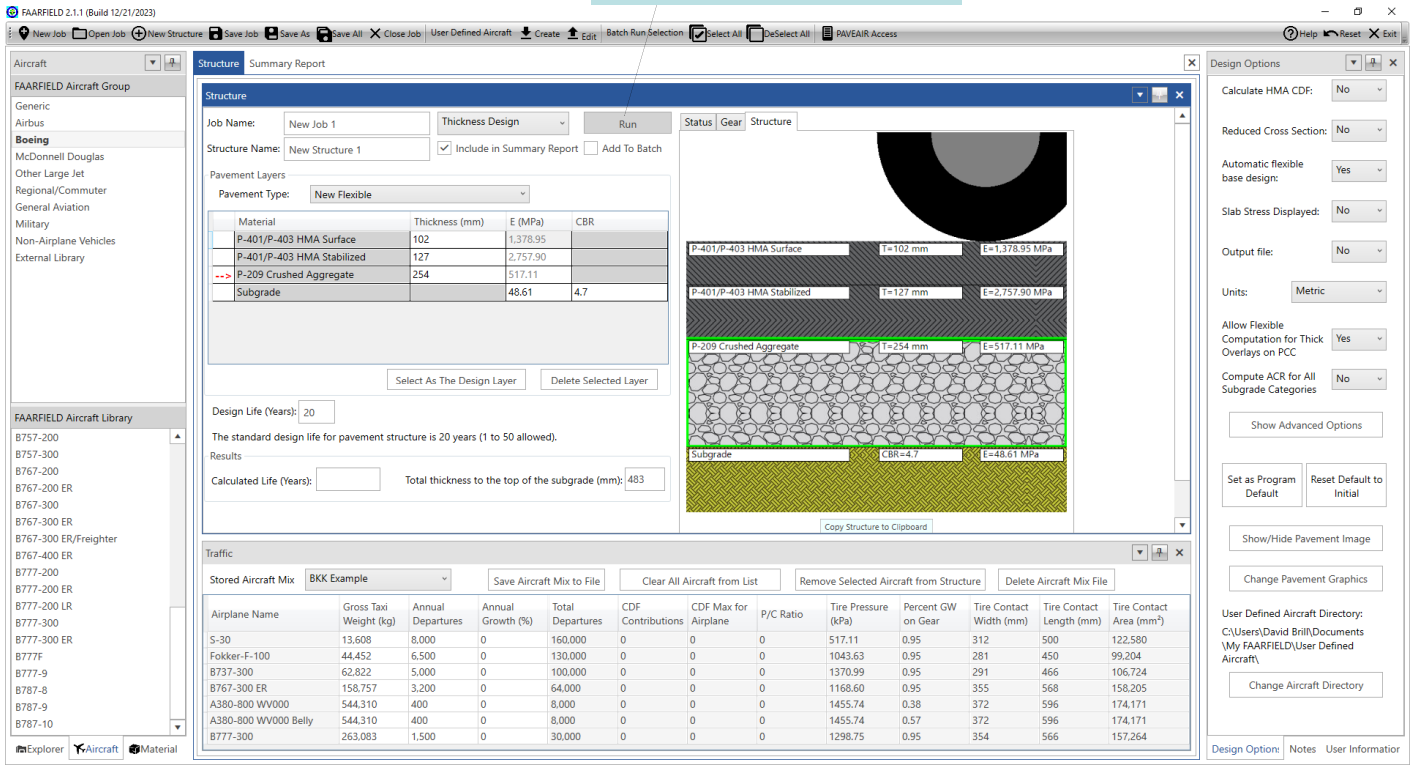
Subgrade CBR

- Enter Subgrade CBR
- Modulus is computed as 1500 × CBR (psi)
- Enter data directly in the table, or click on a layer to bring up the layer property dialog box.



Performing Pavement Thickness Design

Click “Run” to start pavement thickness design



Federal Aviation Administration

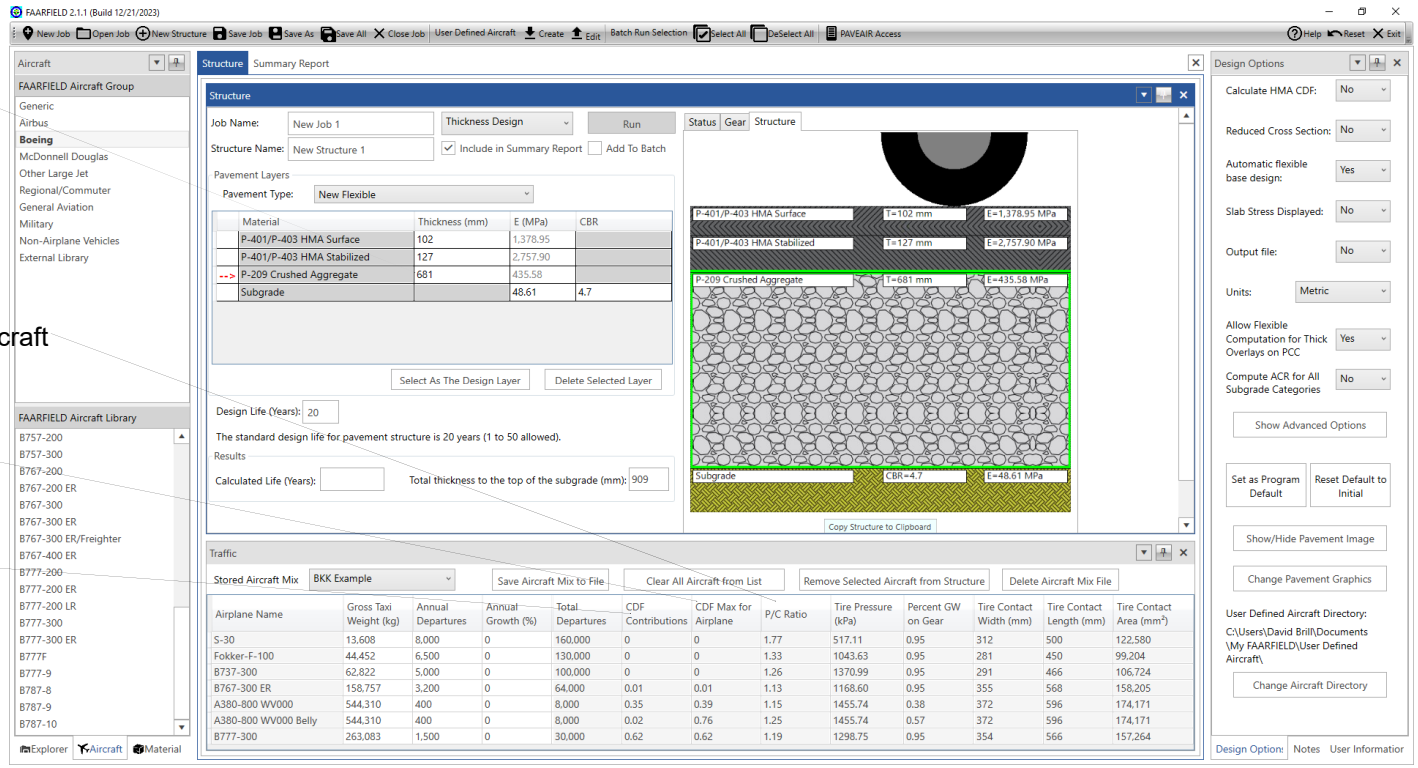
Completed Pavement Thickness Design

P-209 Thickness was designed

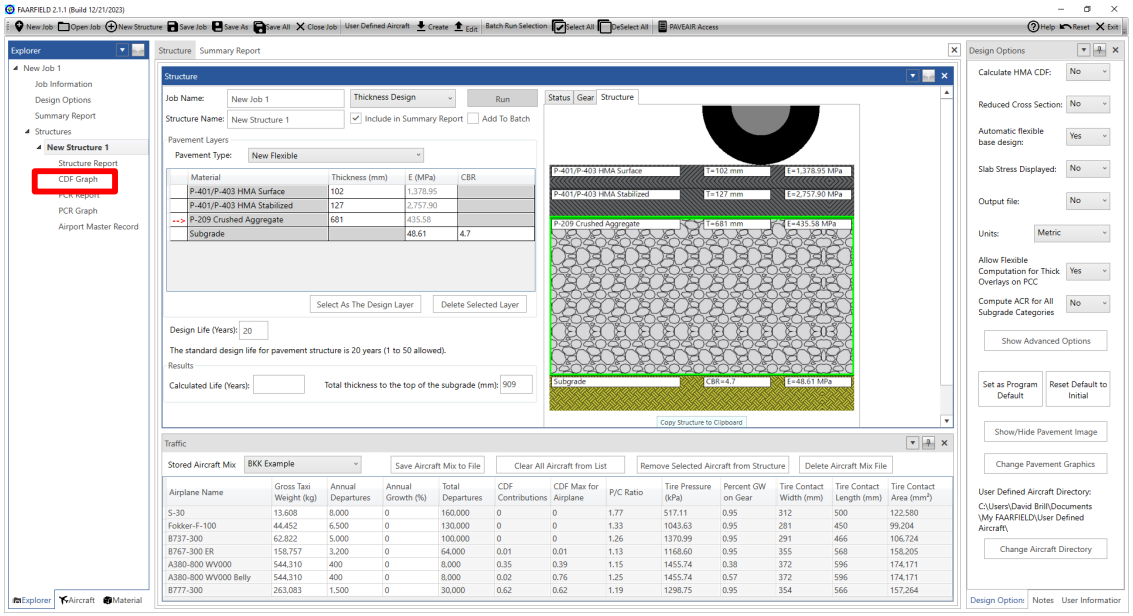
P/C Ratio for each aircraft

CDF max. for aircraft

CDF contribution of each aircraft



CDF Chart



Job Name: New Job 1

Structure: New Structure 1

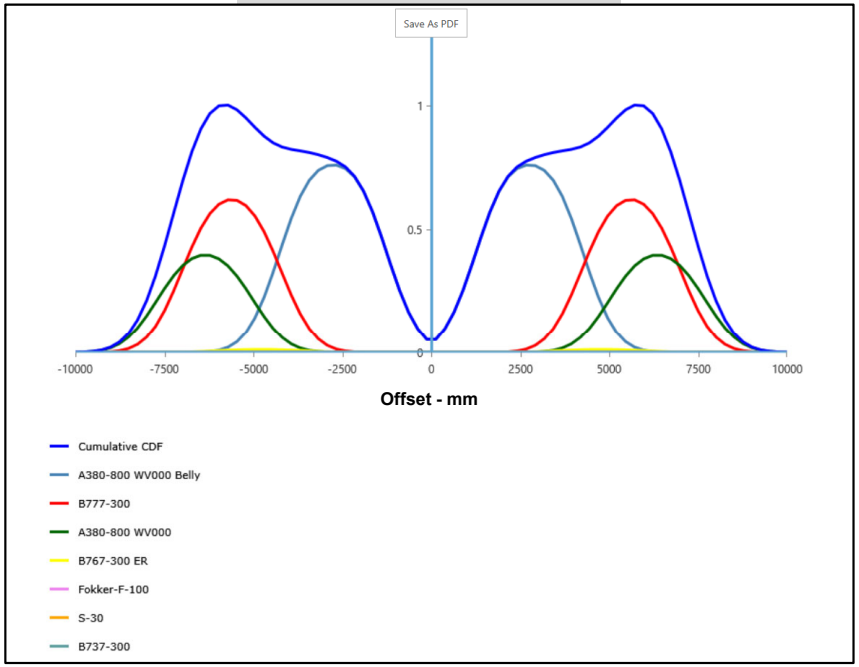
Analysis Type: New Flexible

Analysis Run Time: 2024-01-30 09:15:41

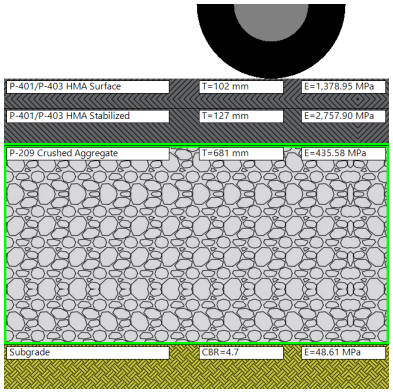
Last Run: Thickness Design

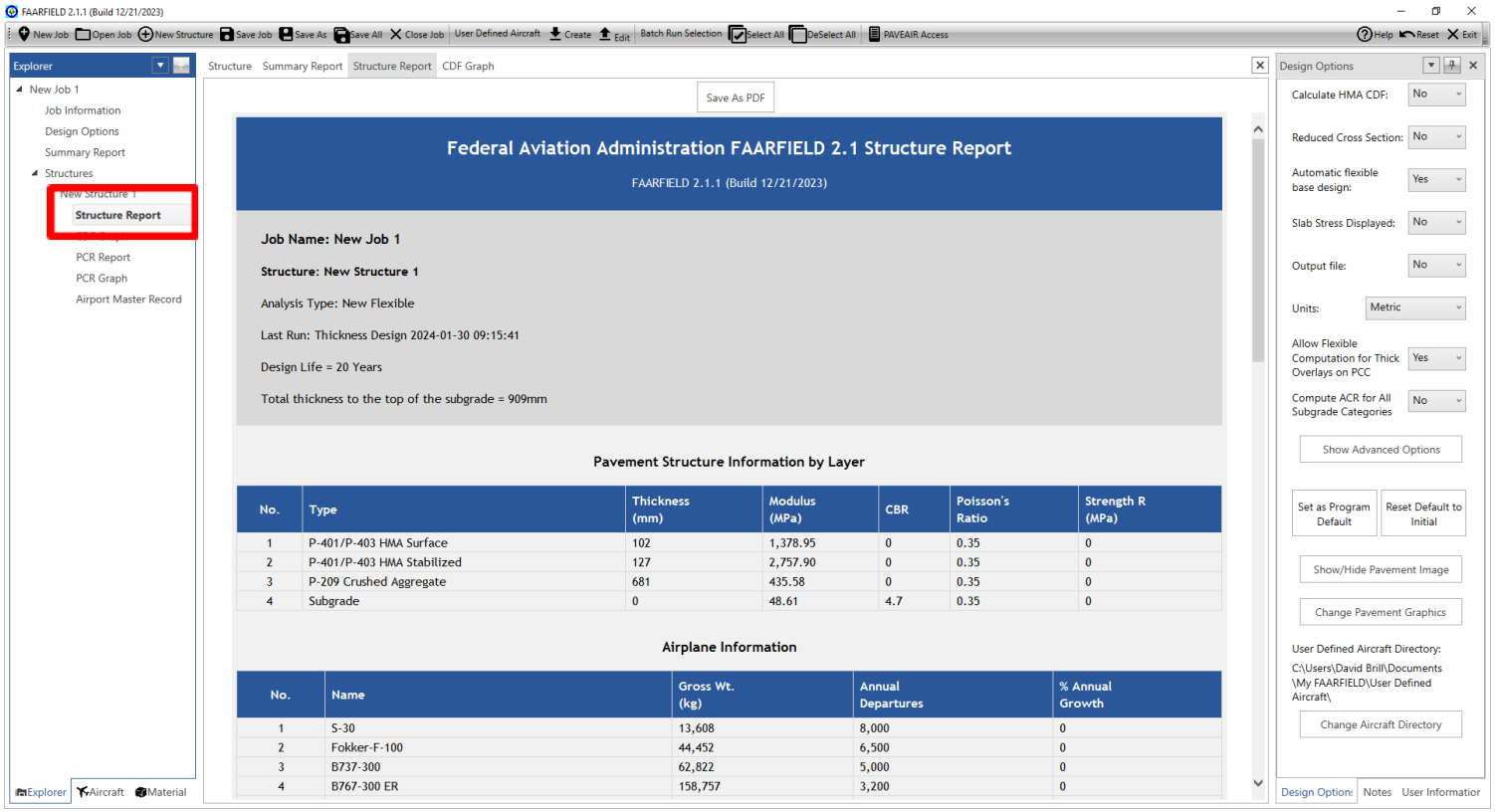
Design Life = 20.0 Years

Total thickness to the top of the subgrade = 909mm



Structure Report

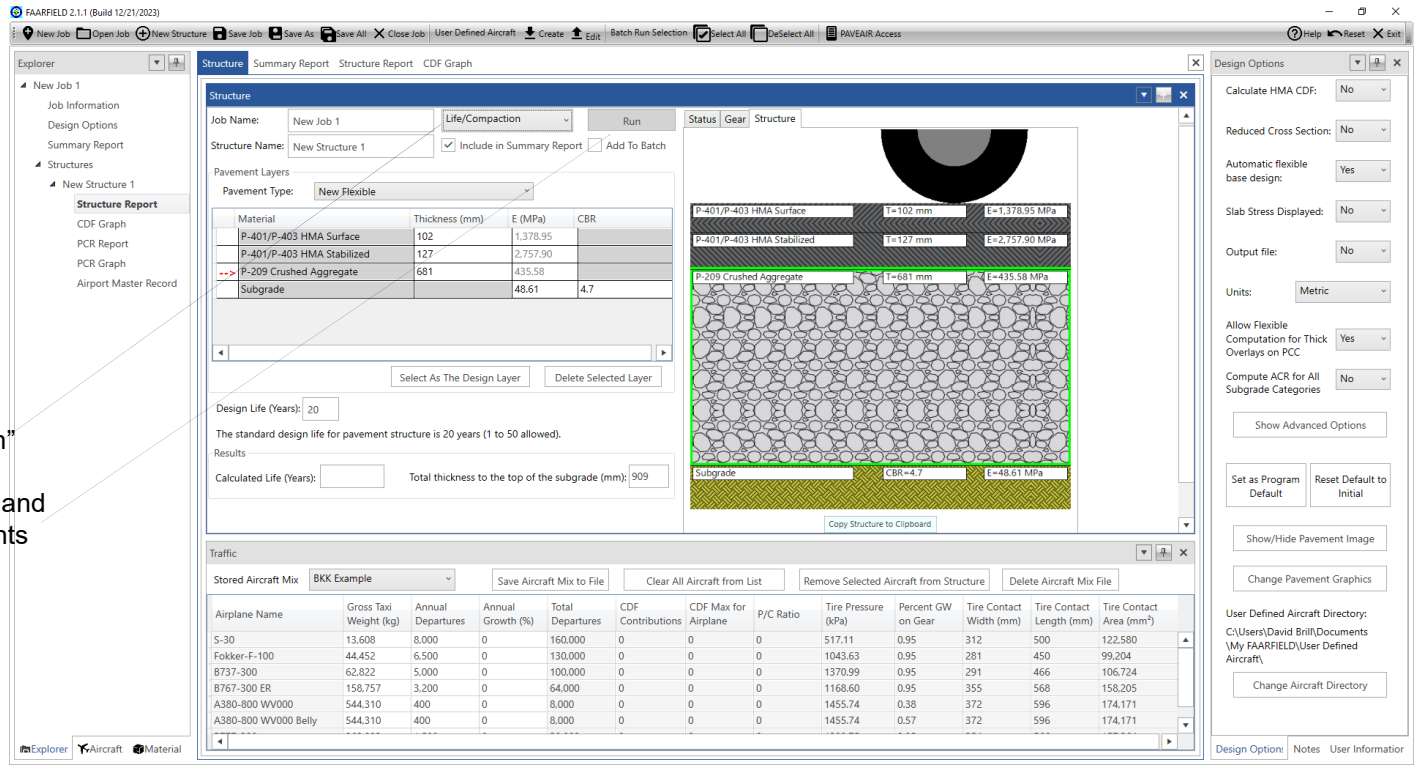




Life/Compaction

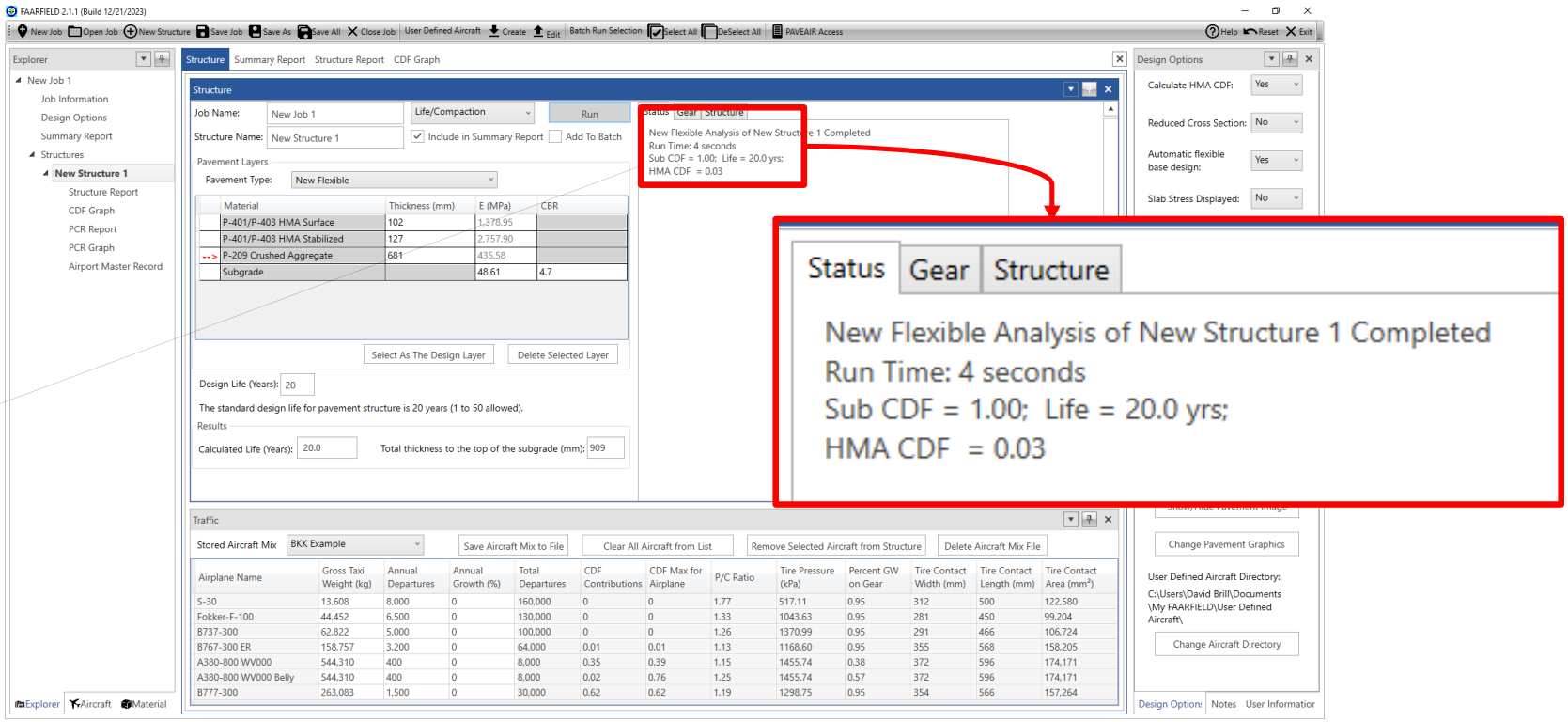
Select “Life/Compaction”

Click “Run” to start Life and Compaction requirements



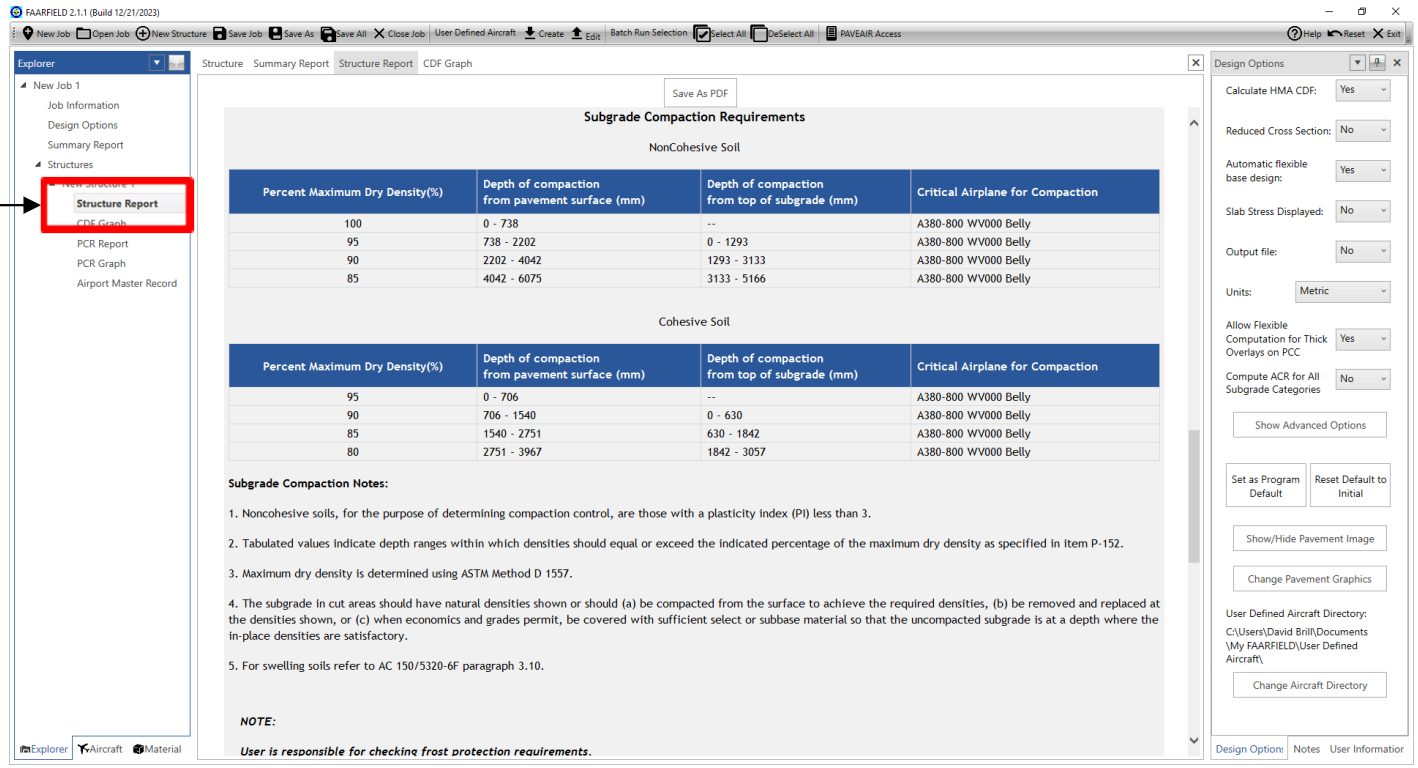
Life/Compaction

Pavement Life results



Compaction Requirements

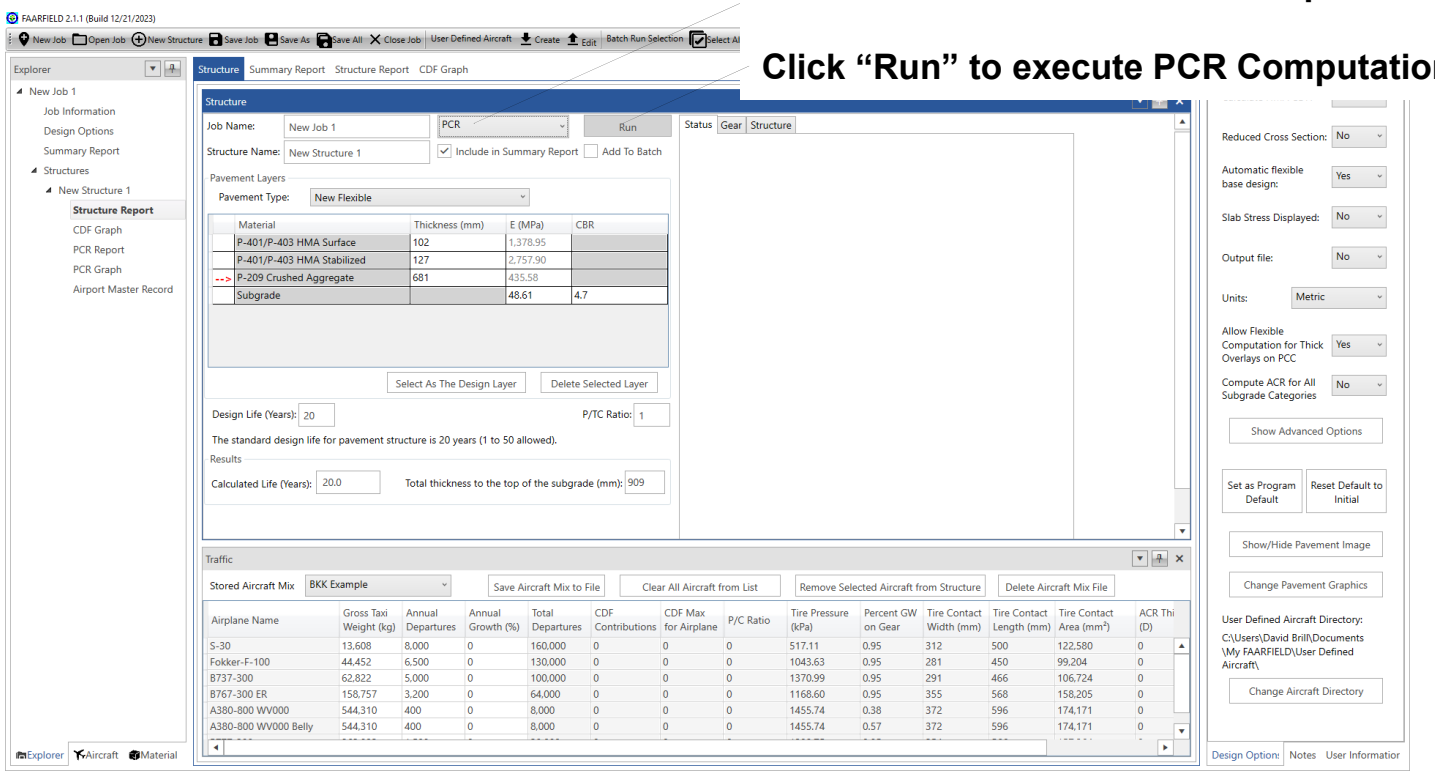
Section Report



PCR

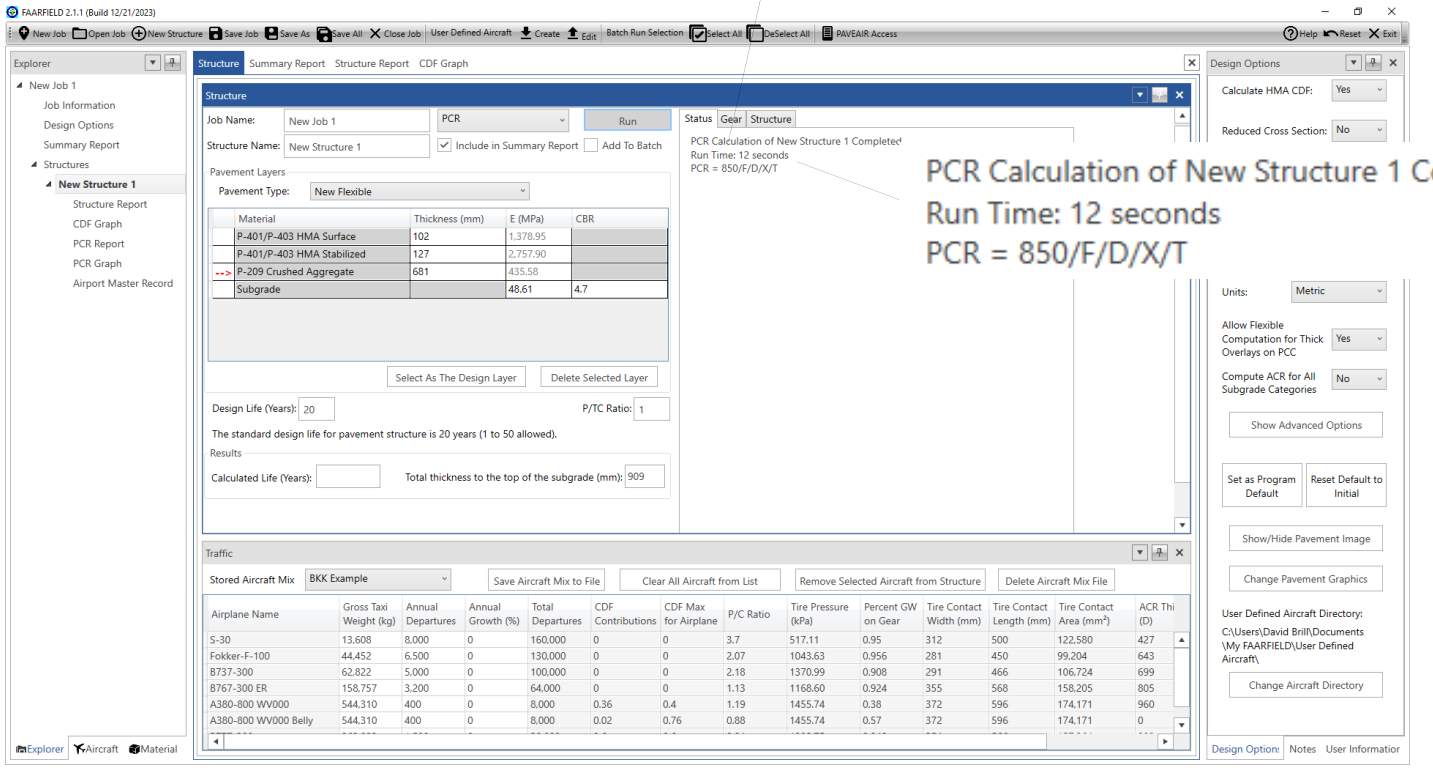
Select “PCR” in the function drop-down box.

Click “Run” to execute PCR Computations

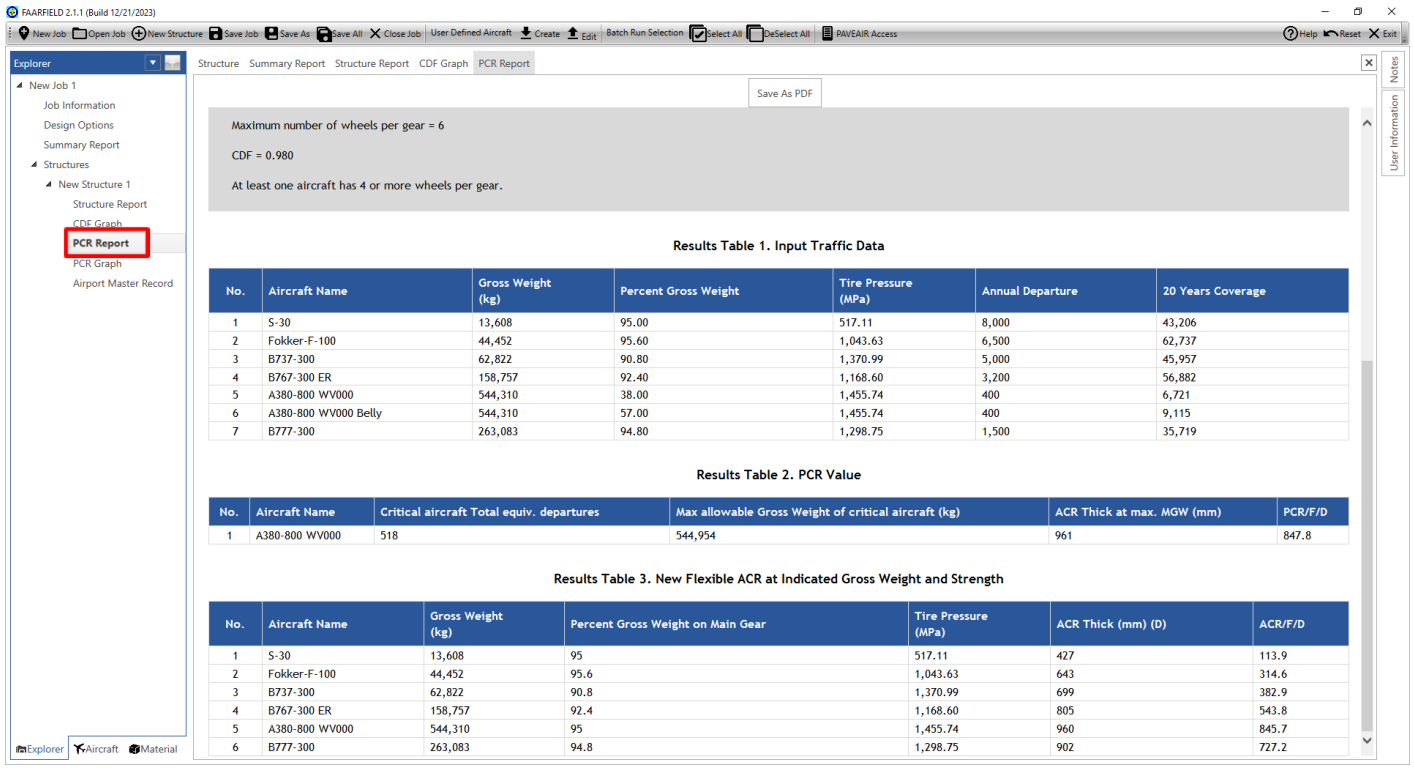


PCR

Results of PCR computations



PCR Report



Results Table 1. Input Traffic Data

No.	Aircraft Name	Gross Weight (kg)	Percent Gross Weight	Tire Pressure (MPa)	Annual Departure	20 Years Coverage
1	S-30	13,608	95.00	517.11	8,000	43,206
2	Fokker-F-100	44,452	95.60	1,043.63	6,500	62,737
3	B737-300	62,822	90.80	1,370.99	5,000	45,957
4	B767-300 ER	158,757	92.40	1,168.60	3,200	56,882
5	A380-800 WV000	544,310	38.00	1,455.74	400	6,721
6	A380-800 WV000 Belly	544,310	57.00	1,455.74	400	9,115
7	B777-300	263,083	94.80	1,298.75	1,500	35,719

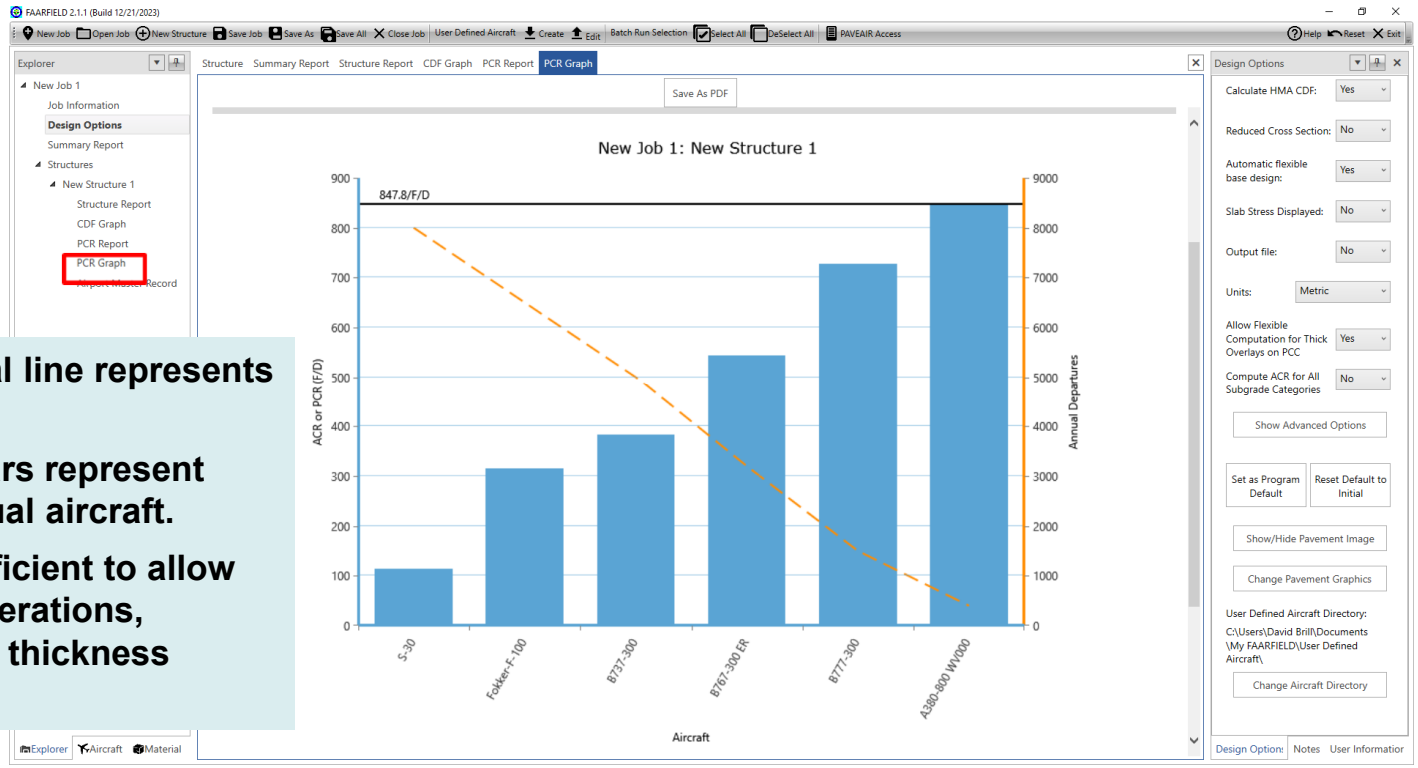
Results Table 2. PCR Value

No.	Aircraft Name	Critical aircraft Total equiv. departures	Max allowable Gross Weight of critical aircraft (kg)	ACR Thick at max. MGW (mm)	PCR/F/D
1	A380-800 WV000	518	544,954	961	847.8

Results Table 3. New Flexible ACR at Indicated Gross Weight and Strength

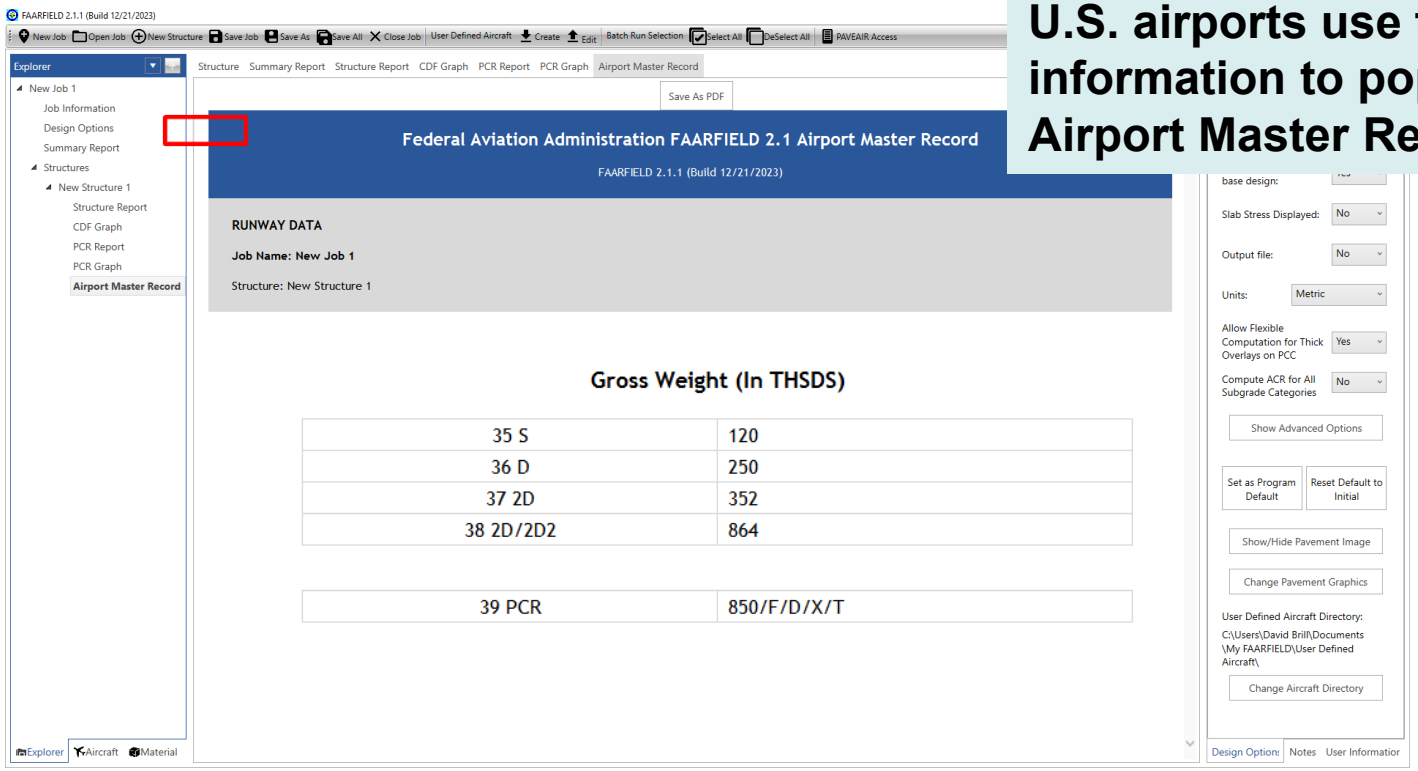
No.	Aircraft Name	Gross Weight (kg)	Percent Gross Weight on Main Gear	Tire Pressure (MPa)	ACR Thick (mm) (D)	ACR/F/D
1	S-30	13,608	95	517.11	427	113.9
2	Fokker-F-100	44,452	95.6	1,043.63	643	314.6
3	B737-300	62,822	90.8	1,370.99	699	382.9
4	B767-300 ER	158,757	92.4	1,168.60	805	543.8
5	A380-800 WV000	544,310	95	1,455.74	960	845.7
6	B777-300	263,083	94.8	1,298.75	902	727.2

PCR Graph

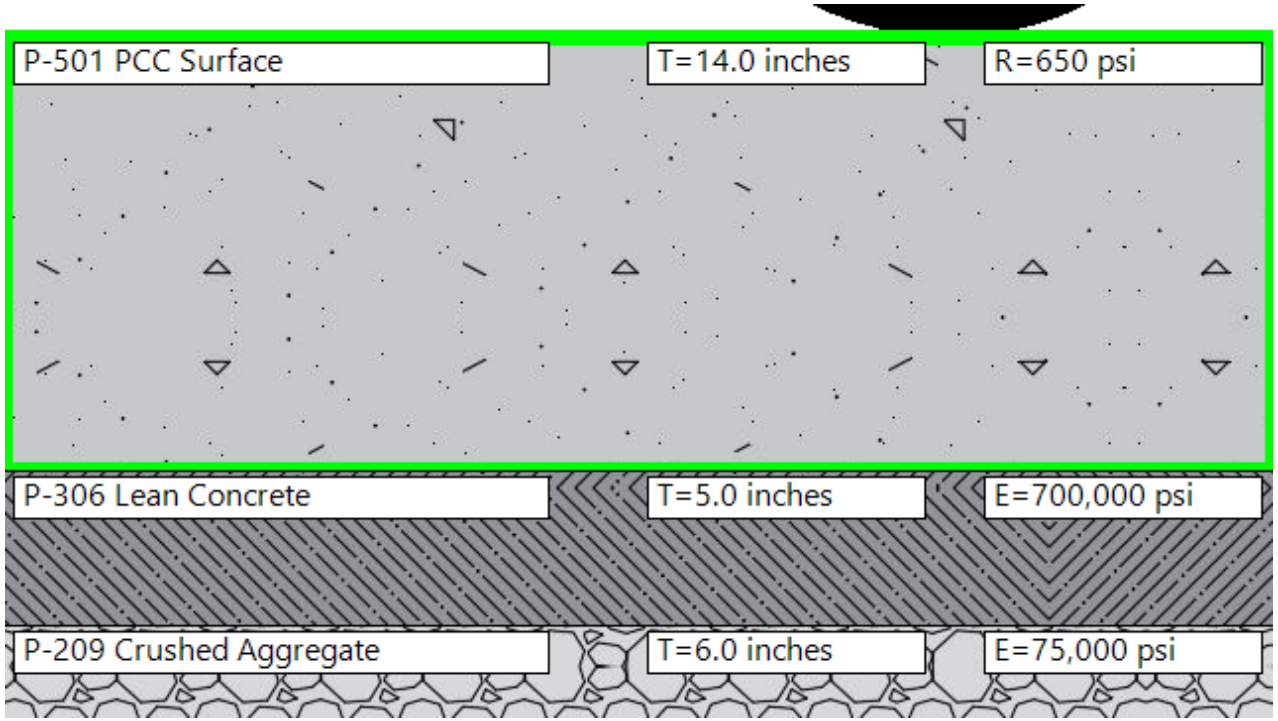


- **Black horizontal line represents PCR.**
- **Blue vertical bars represent ACR of individual aircraft.**
- **PCR is just sufficient to allow unrestricted operations, consistent with thickness design.**

Airport Master Record

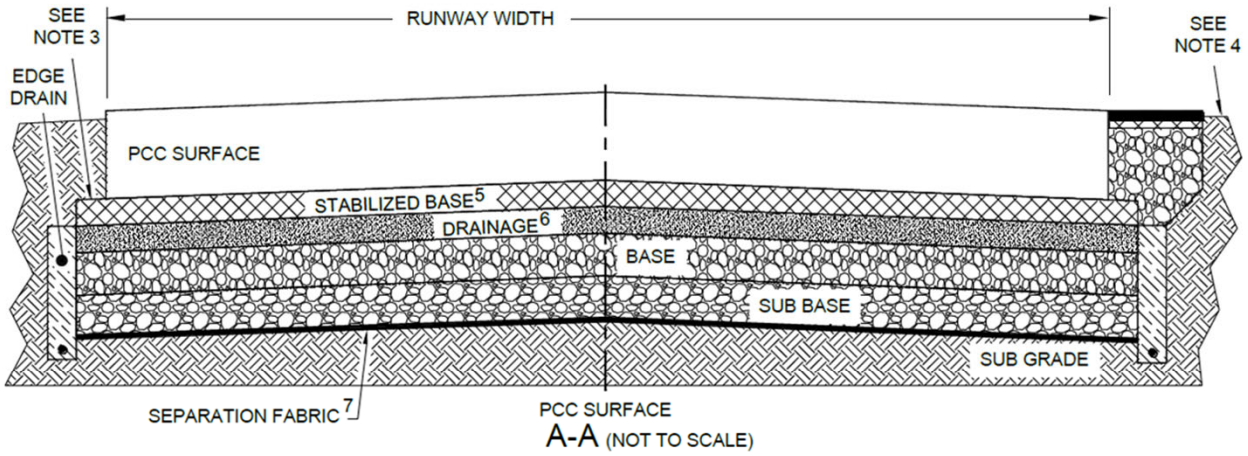


U.S. airports use this information to populate the Airport Master Record (AMR)



Rigid Pavement Design Example Using FAARFIELD 2.1

Typical Rigid Pavement



A-A (NOT TO SCALE)

NOTES:

1. RUNWAY, TAXIWAY AND SHOULDER WIDTHS; TRANSVERSE SLOPES, ETC. PER AC 150/ 5300-13, AIRPORT DESIGN
2. SURFACE, BASE, PCC, ETC. THICKNESS PER AC 150/5320-6.
3. STABILIZED BASE, BASE AND SUBBASE MINIMUM 12 INCHES [30CM] UP TO 36 INCHES [90 CM] BEYOND FULL STRENGTH PAVEMENT.
4. CONSTRUCT A 1.5 INCH [4 CM] DROP BETWEEN PAVED AND UNPAVED SURFACES.
5. WHEN REQUIRED, SEE PARAGRAPH 3.5.
6. LOCATION AND NEED FOR DRAINAGE LAYER AS RECOMMENCED BY GEOTECHNICAL AND PAVEMENT ENGINEER.
7. WHEN RECOMMENDED BY GEOTECHNICAL AND PAVEMENT ENGINEER.

Rigid Pavement Design in FAARFIELD

- **Considers only one mode of failure for rigid pavement, bottom-up cracking of the concrete slab.**
- **Cracking is controlled by limiting the horizontal stress at the bottom of the concrete slab.**
- **The rigid pavement design model does not explicitly consider failure of subbase and subgrade layers.**

Rigid Pavement Failure Model

- **FAARFIELD rigid failure model:**

$$DF = \left[\frac{F_s' bd}{(1-\alpha)(d-b)+F_s' b}\right] \times \log C + \left[\frac{(1-\alpha)(ad-bc)+bc}{(1-\alpha)(d-b)+F_s' b}\right]$$

where:

$SCI = \alpha \times 100 \quad 0 \le \alpha \le 1$

DF = design factor = R/σ

R = concrete flexural strength (ASTM C78)

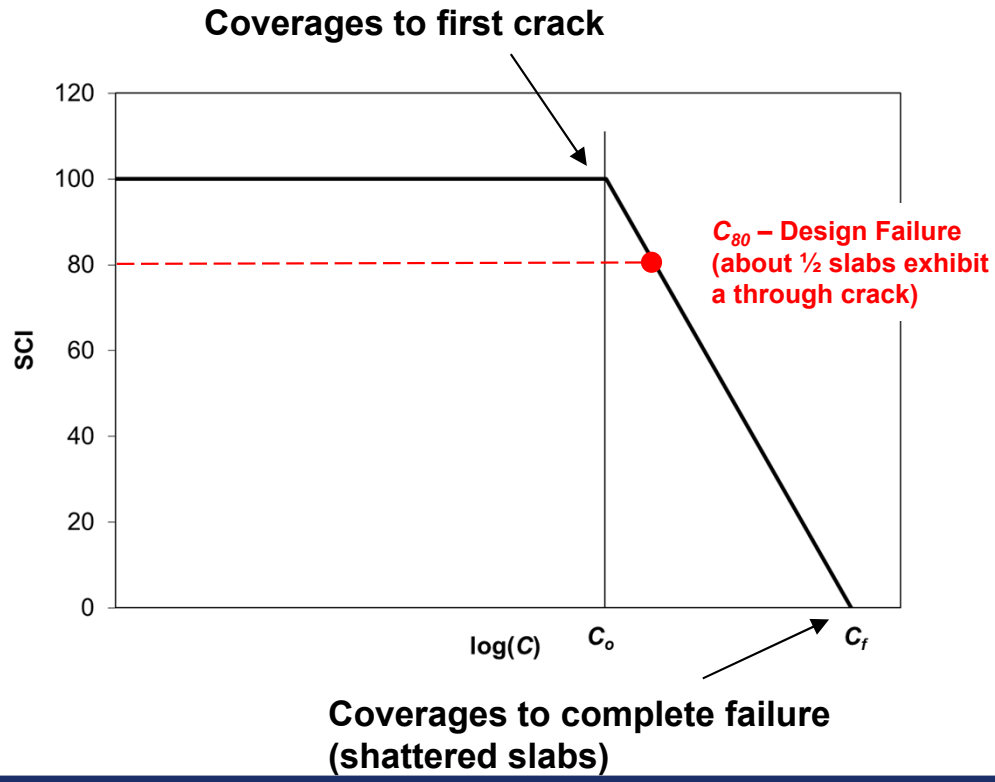
σ = max. computed tensile stress

C = coverages

F_s' = compensation factor for stabilized base

a, b, c, d = parameters determined by full-scale test

- **DF is linear in log(*C*).**



Concrete Flexural Strength

- **Design flexural strength between 600 and 750 psi (4.14 to 5.17 MPa) is recommended for most airfield applications.**
- **Avoid design flexural strengths higher than 750 psi (5.17 MPa), unless it can be shown that higher strength mixes are produced by normal methods using local materials, i.e., without relying on excessive cement contents or additives likely to negatively impact durability.**
- **The strength used in thickness design is different than the strength used for material acceptance in P-501.**
  - Design strength can be 5% higher than specified 28-day strength.

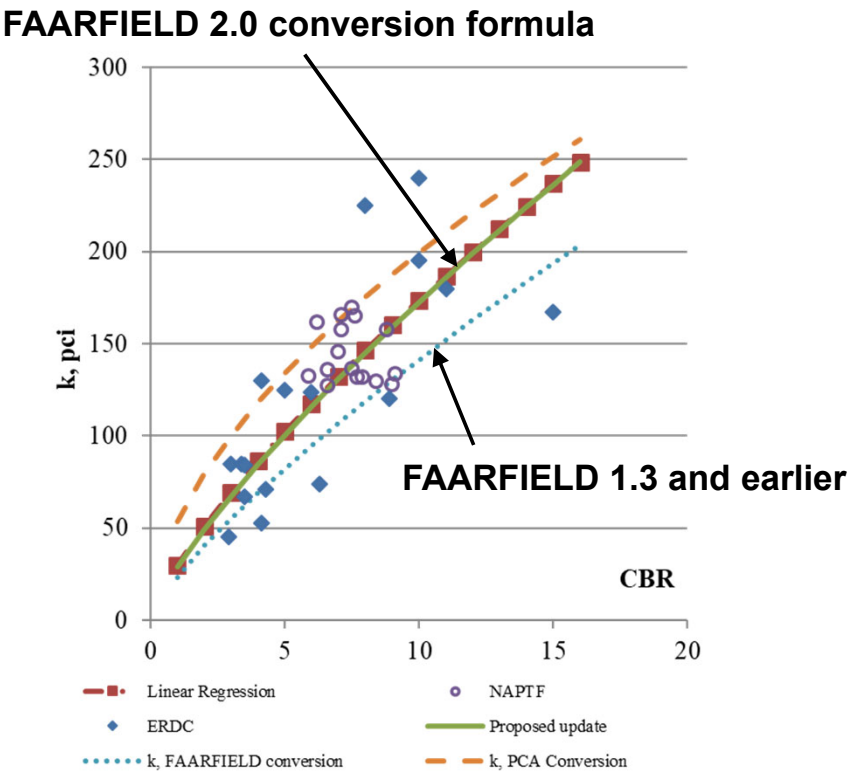
Subgrade Modulus

- **FAARFIELD automatically converts *k* to *E*, and vice-versa.**
- **The conversion formula implemented in FAARFIELD 2.0 is:**

$$k = 28.6926 \times \mathrm{CBR}^{0.7788}$$

where: $\mathrm{CBR} = E / 1500$
(*E* in psi, and *k* in psi/inch).

- **Compared to the earlier formula:**
  - Improved agreement with field correlations
  - less conservative when converting from CBR data.



Rigid Pavement Design Example

A rigid pavement is being designed for a new runway at a commercial airport in Washington, D.C. Based on the information obtained from the Airport Master Plan, the new runway is expected to handle the traffic mix presented in Table 1. Eight soil borings were performed for this project, the results of which are presented in Table 2. The specified 28-day strength (ASTM C78) is 4.6 MPa.

Table 1. Aircraft traffic mix for rigid pavement design example.

Aircraft	Departure Weight, kg	Arrival Weight, kg	Annual Departures
S-30	13,608	10,206	8000
Fokker F-100	44,452	34,019	6500
B737-300	62,822	52,163	5000
B767-300 ER	158,757	131,541	3200
A380-800	544,310	462,664	400
B777-300	263,083	237,682	1500

Same as flexible example!

Table 2. Soil boring results for rigid pavement design example.

Boring No.	UCSC Soil Type	Moisture Content, %	Optimal MC, %	Dry unit weight, kN/m^3	Water Table Depth, m	CBR, %
B-1	SC	12.2	10.4	20.26	3	10.6
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B-3	SC	16.5	9.6	20.80	2.5	8.4
B-4	CL	15.8	13.5	18.88	2.0	6.3
B-5	CL	17.0	14.5	19.24	2.4	4.8
B-6	CL	16.2	13.8	18.96	1.7	5.9
B-7	CL	16.8	12.6	19.48	1.4	4.2
B-8	CL	14.2	12.8	20.14	1.8	6.4
Average:						
Std. Deviation:						

Rigid Pavement Design Example

1. **What do the soil boring results tell us about the in-situ soil properties? What subgrade support value do you recommend for design?**

   Mean CBR – 6.7 Standard Deviation – 2.04

   Design CBR – 4.7 E_{SG} ~ 47 MPa (10 CBR)

1. **What type and thickness of base/subbase materials do you recommend? Are positive drainage features required?**
2. **What flexural strength of concrete would you use for the design?**

   AC 150/5320-6G allows 5 percent above specified 28-day strength for design.

   Given 28-day strength = 4.6 MPa, the allowable design strength is 1.05 × 4.6 = 4.83 MPa.

   Use 4.8 MPa in the FAARFIELD design.

1. **Should the pavement be designed for aircraft arrival or departure weights? What is the required flexible pavement thickness for the runway? What is the most demanding aircraft?**

Boring No.	UCSC Soil Type	Moisture Content, %	Optimal MC, %	Dry unit weight, kN/m³	Water Table Depth, m	CBR, %
B-1	SC	12.2	10.4	20.26	3	10.6
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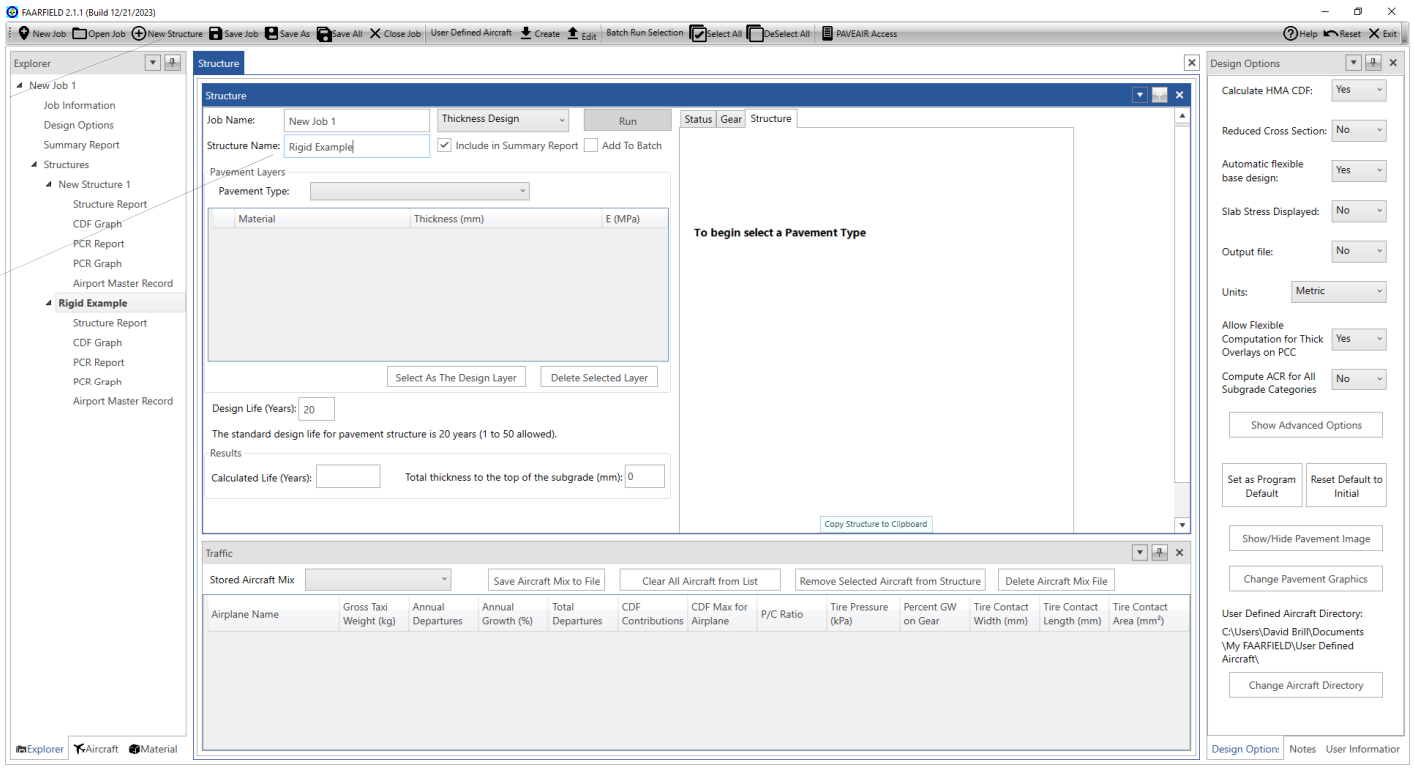
B-4	CL	15.8	13.5	18.88	2.0	6.3
B-5	CL	17.0	14.5	19.24	2.4	4.8
B-6	CL	16.2	13.8	18.96	1.7	5.9
B-7	CL	16.8	12.6	19.48	1.4	4.2
B-8	CL	14.2	12.8	20.14	1.8	6.4
Average:		**15.4**	**12.4**	**19.66**	**2.3**	**6.7**
Std. Deviation:		**1.7**	**1.7**	**0.68**	**0.6**	**2.0**

Creating/Naming a Structure

Click on “New Structure”

Enter Structure Name”



Select Pavement Type

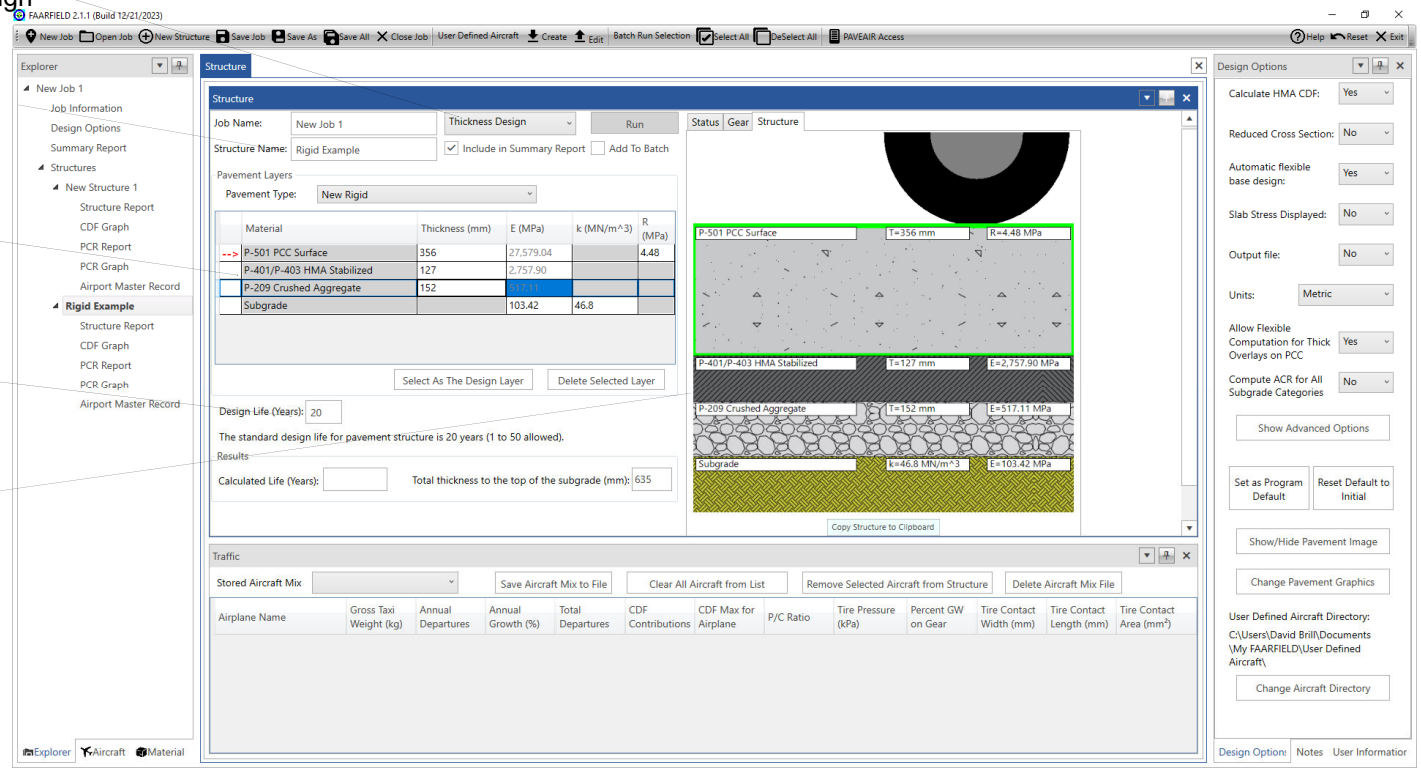
Select “Thickness Design”

Select Pavement Type as “New Rigid”

Default pavement structure details in table

Default pavement life (20 years)

Default pavement structure for “New Rigid” type

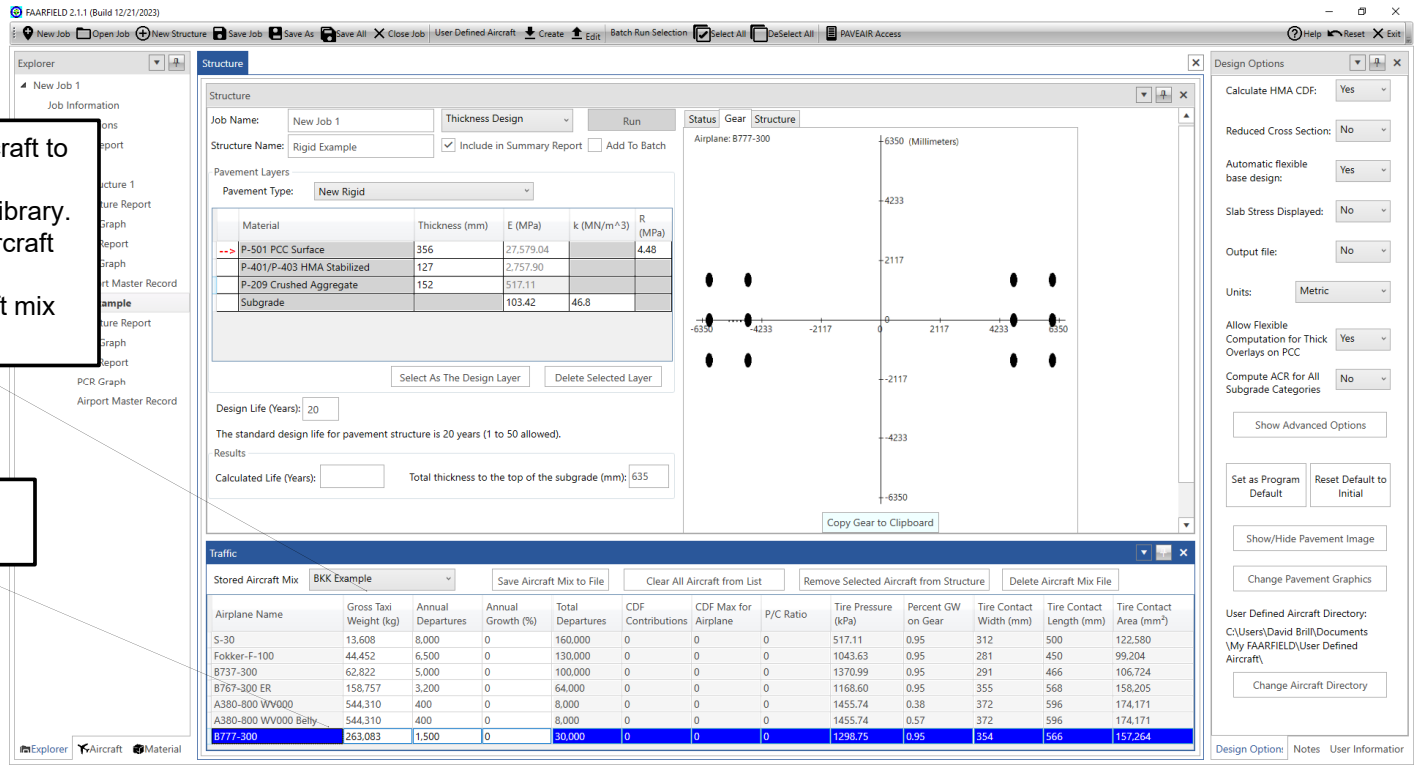


Creating Aircraft Traffic Mix

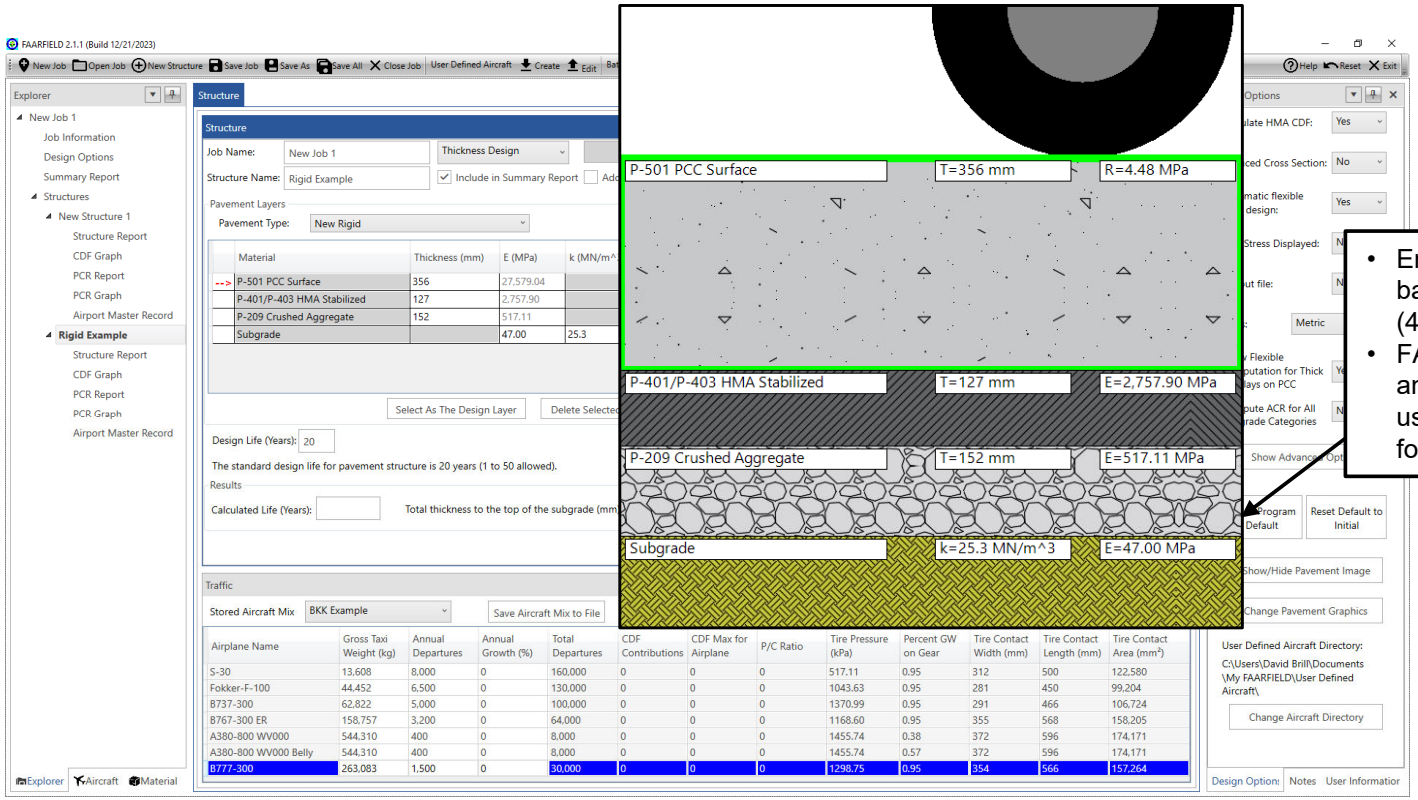
Several ways to add aircraft to the traffic table:

- Pick aircraft from the library. Double click on the aircraft name or drag/drop.
- Select a stored aircraft mix from the drop-down.

Select an aircraft to display gear geometry.

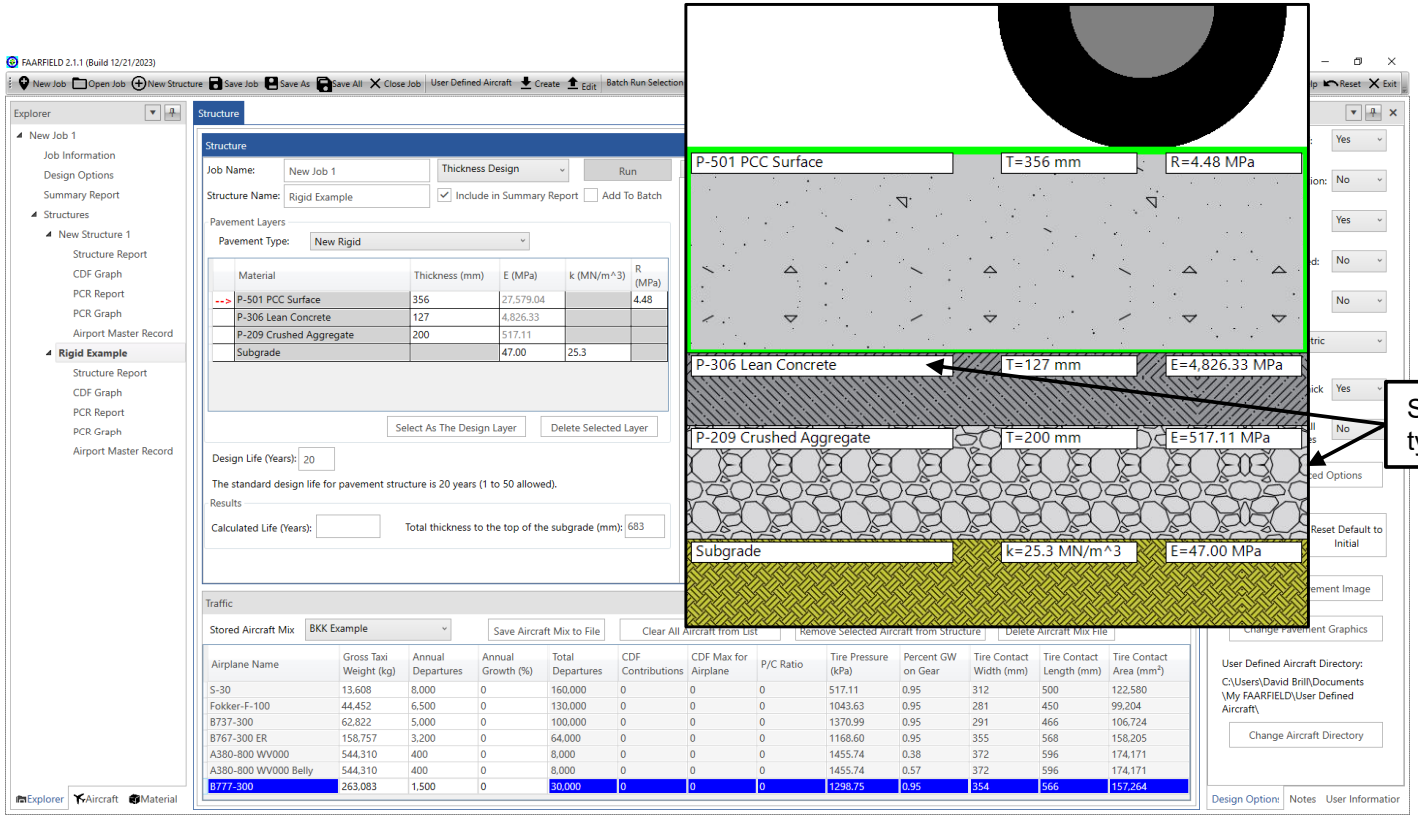


Modify Default Layer Properties

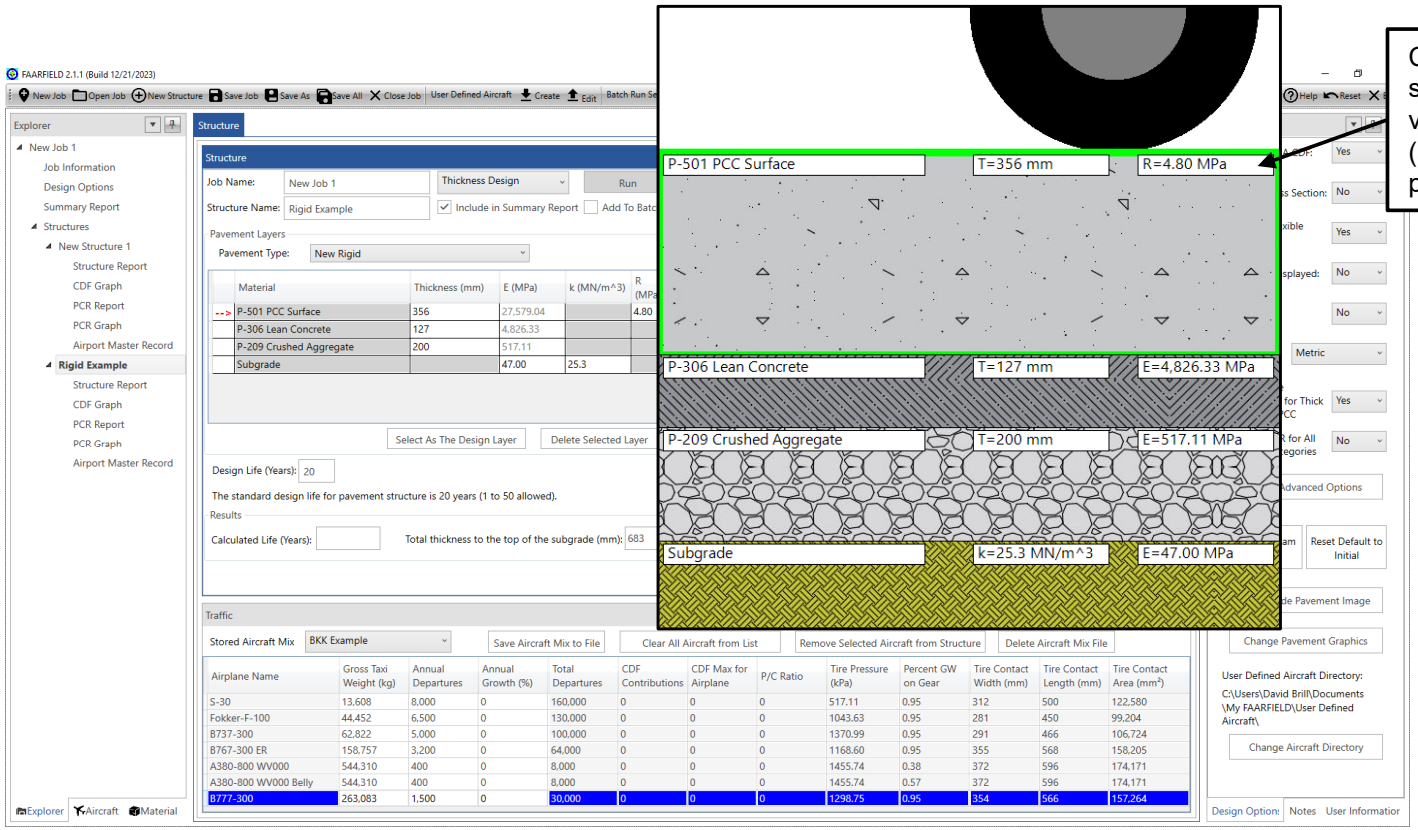


- Enter the modulus value based on design CBR (47 MPa).
- FAARFIELD computes an equivalent k-value using the conversion formula.

Modify Default Layer Properties

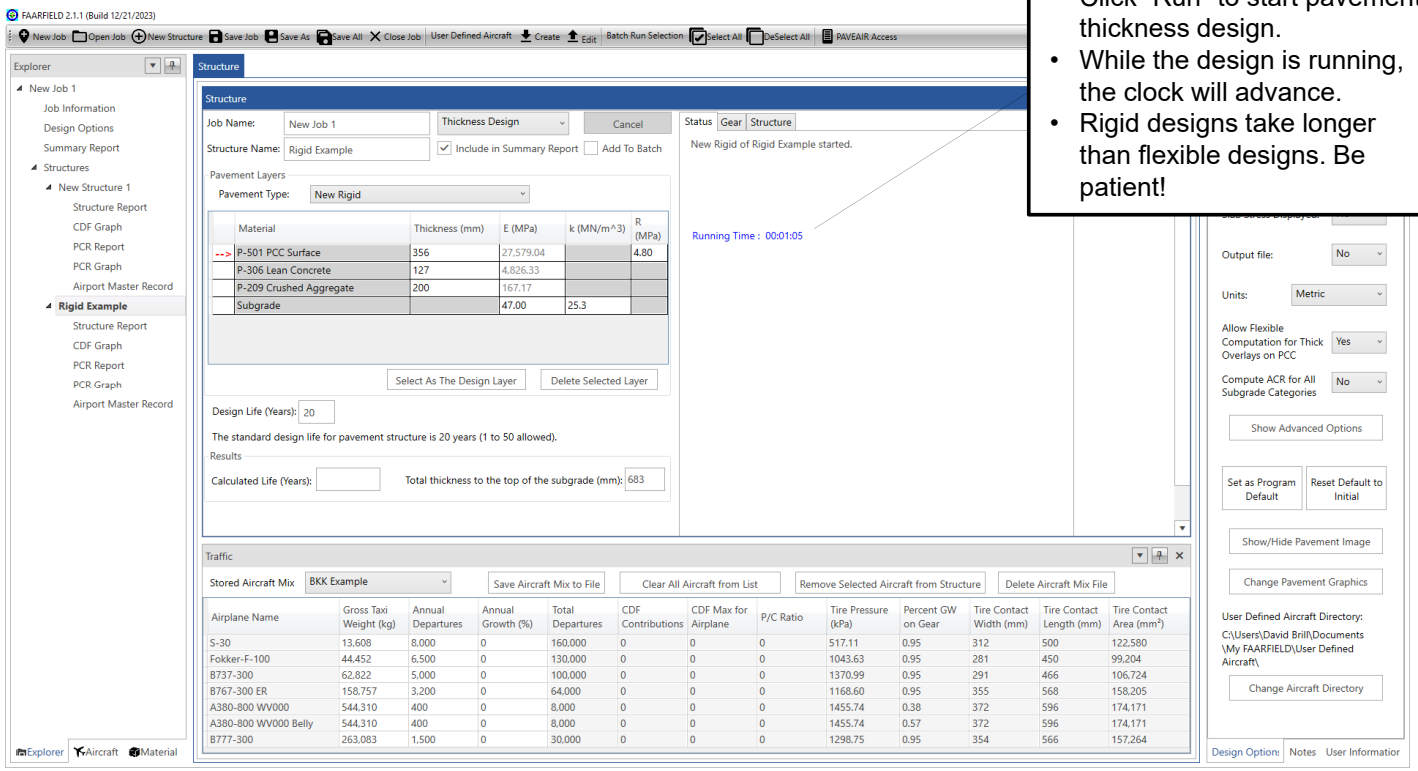


Modify Default Layer Properties



Change flexural strength from default value to R =700 psi (as determined on a previous slide).

Run Pavement Thickness Design



- Click “Run” to start pavement thickness design.
- While the design is running, the clock will advance.
- Rigid designs take longer than flexible designs. Be patient!

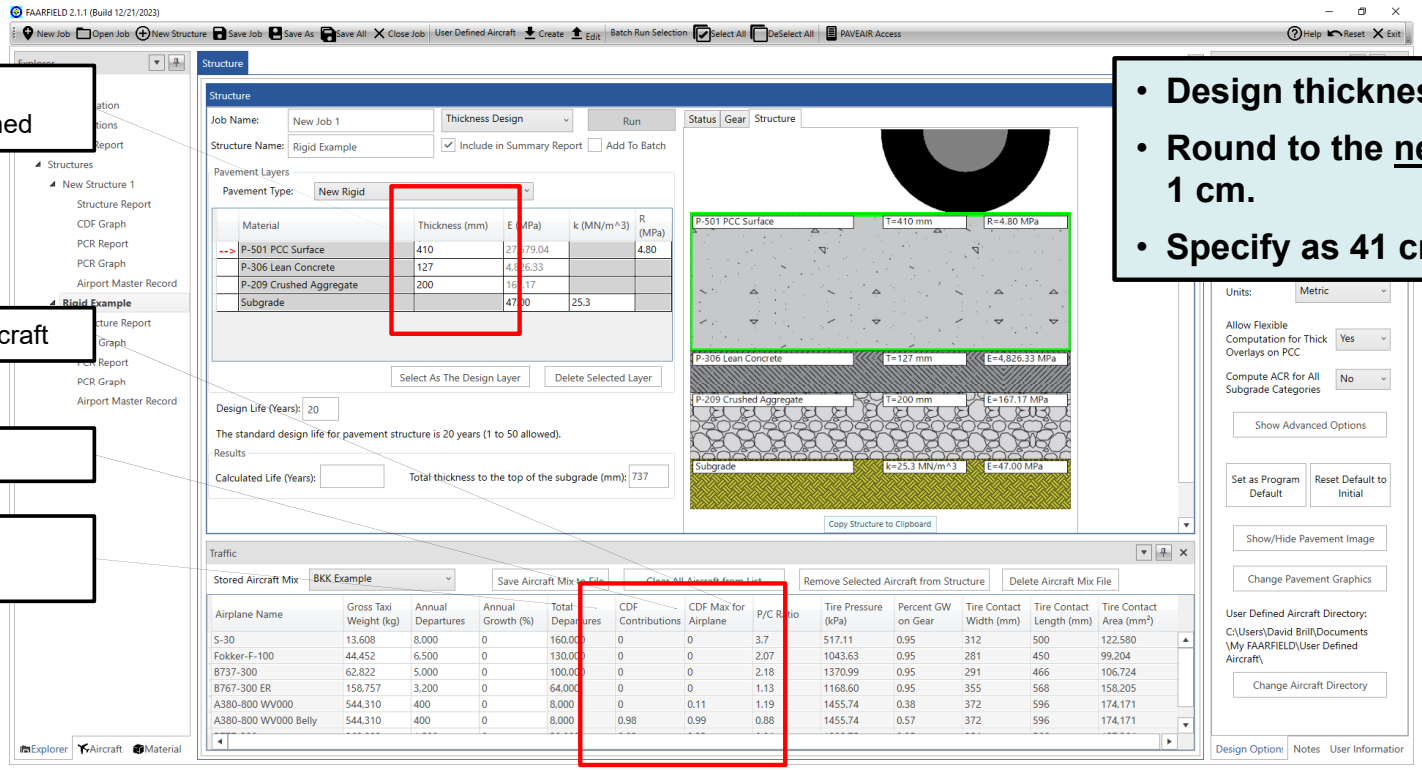
Completed Pavement Thickness Design

P-501 PCC Surface Thickness was designed

P/C Ratio for each aircraft

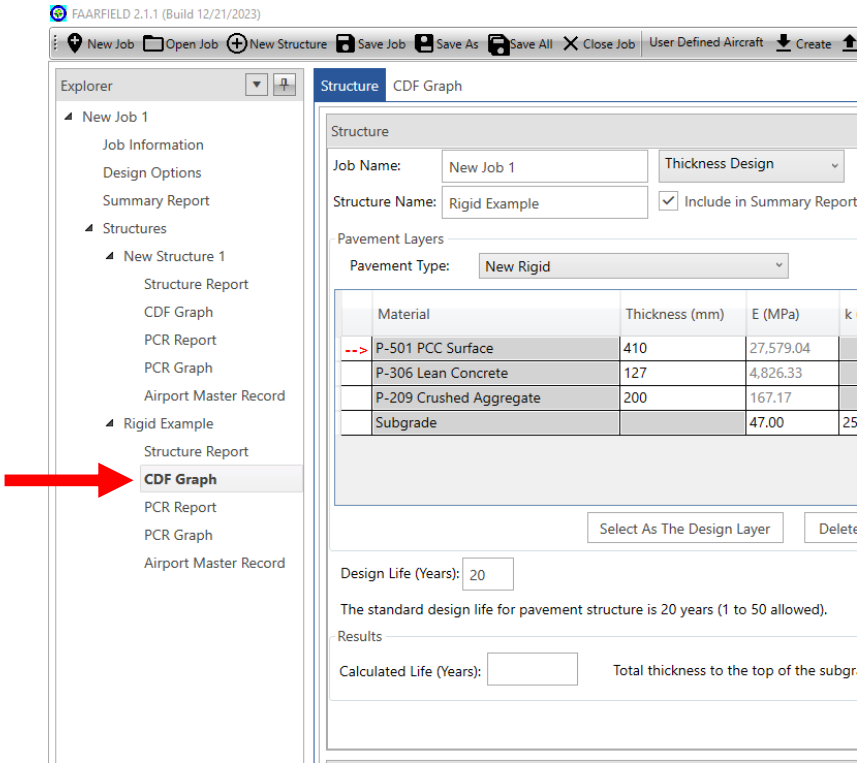
CDF max. for aircraft

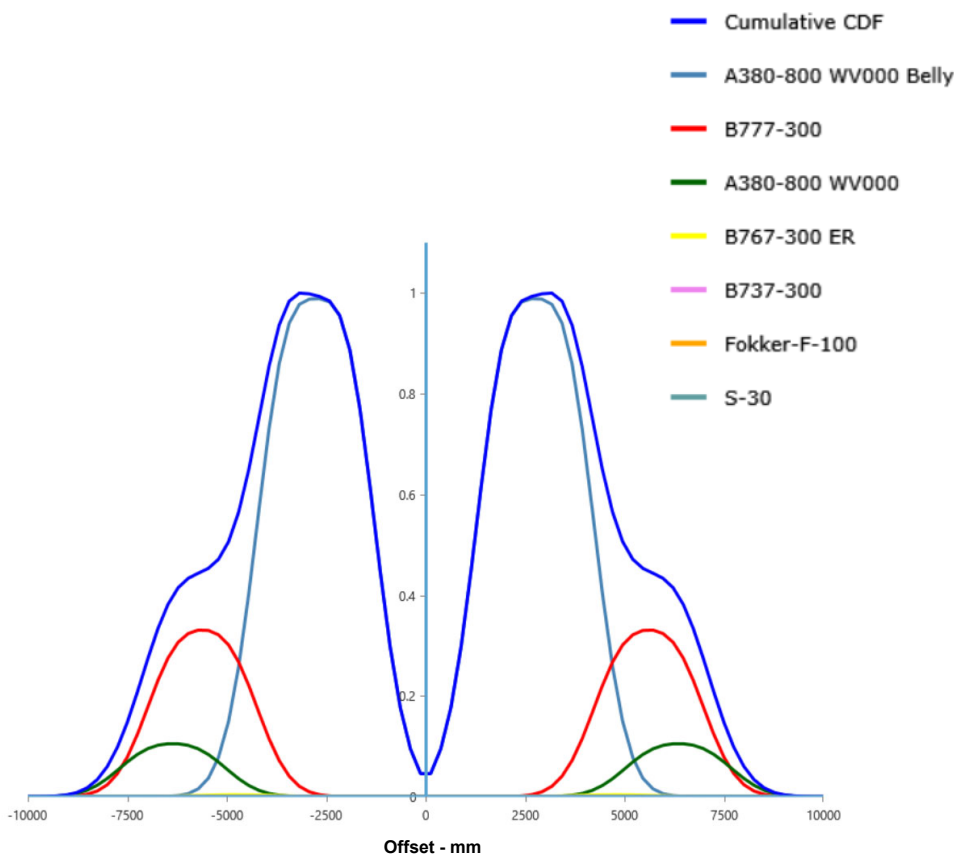
CDF contribution of each aircraft



- **Design thickness is 410 mm**
- **Round to the <u>nearest</u> 0.5 in or 1 cm.**
- **Specify as 41 cm.**

CDF Chart


FAARFIELD 2.1.1 (Build 12/21/2023)
New Job
Open Job
New Structure
Save Job
Save As
Save All
Close Job
User Defined Aircraft
Create
Explorer
New Job 1
Job Information
Design Options
Summary Report
Structures
New Structure 1
Structure Report
CDF Graph
PCR Report
PCR Graph
Airport Master Record
Rigid Example
Structure Report
CDF Graph
PCR Report
PCR Graph
Airport Master Record
Structure
CDF Graph
Structure
Job Name:
New Job 1
Thickness Design
Structure Name:
Rigid Example
Include in Summary Report
Pavement Layers
Pavement Type:
New Rigid
Material
Thickness (mm)
E (MPa)
P-501 PCC Surface
410
27,579.04
P-306 Lean Concrete
127
4,826.33
P-209 Crushed Aggregate
200
167.17
Subgrade
47.00
Select As The Design Layer
Design Life (Years):
20
The standard design life for pavement structure is 20 years (1 to 50 allowed).
Results
Calculated Life (Years):
Total thickness to the top of the subgr


Cumulative CDF
A380-800 WV000 Belly
B777-300
A380-800 WV000
B767-300 ER
B737-300
Fokker-F-100
S-30
1
0.8
0.6
0.4
0.2
0
-10000
-7500
-5000
-2500
0
2500
5000
7500
10000
Offset - mm

Rigid Pavement Example – Results

1. **What do the soil boring results tell us about the in situ soil properties? What subgrade support value do you recommend for design?**

   Mean CBR = 6.7 Standard Deviation = 2.04 Design CBR = 4.7 E_{SG} = 47 MPa

2. **What type and thickness of base/subbase materials do you recommend? Are positive drainage features required?**

3. **What flexural strength of concrete would you use for the design?**

   AC 150/5320-6G allows 5 percent above specified 28-day strength for design.

   Given 28-day strength = 4.6 MPa, the allowable design strength = 1.05 × 4.6 = 4.83 MPa.

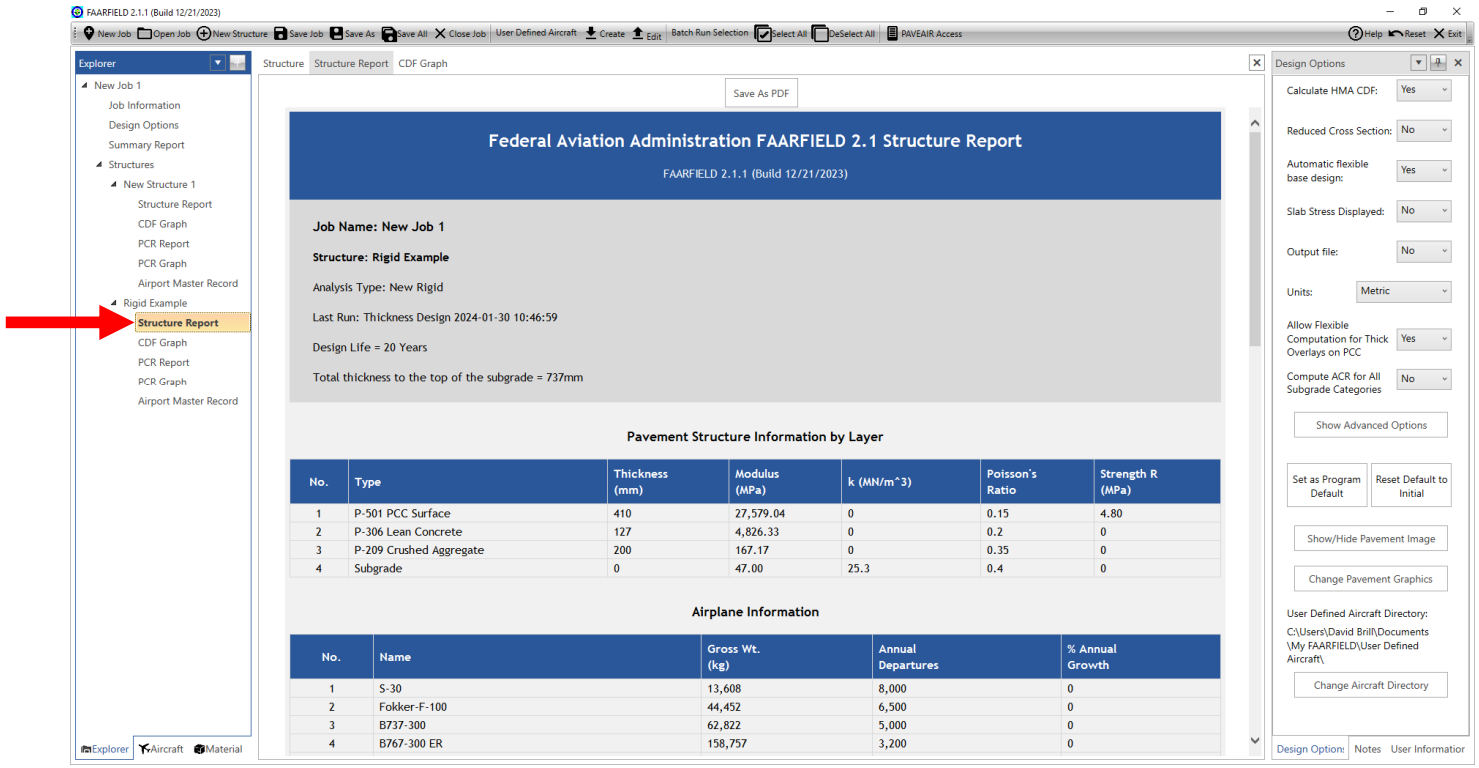
   Use *R* = 4.8 Mpa in the FAARFIELD design.

4. **Should the pavement be designed for aircraft arrival or departure weights? What is the required PCC slab thickness for the runway? What is the most demanding aircraft?**

   For the given inputs, FAARFIELD 2.0 gives a slab thickness 41 cm.

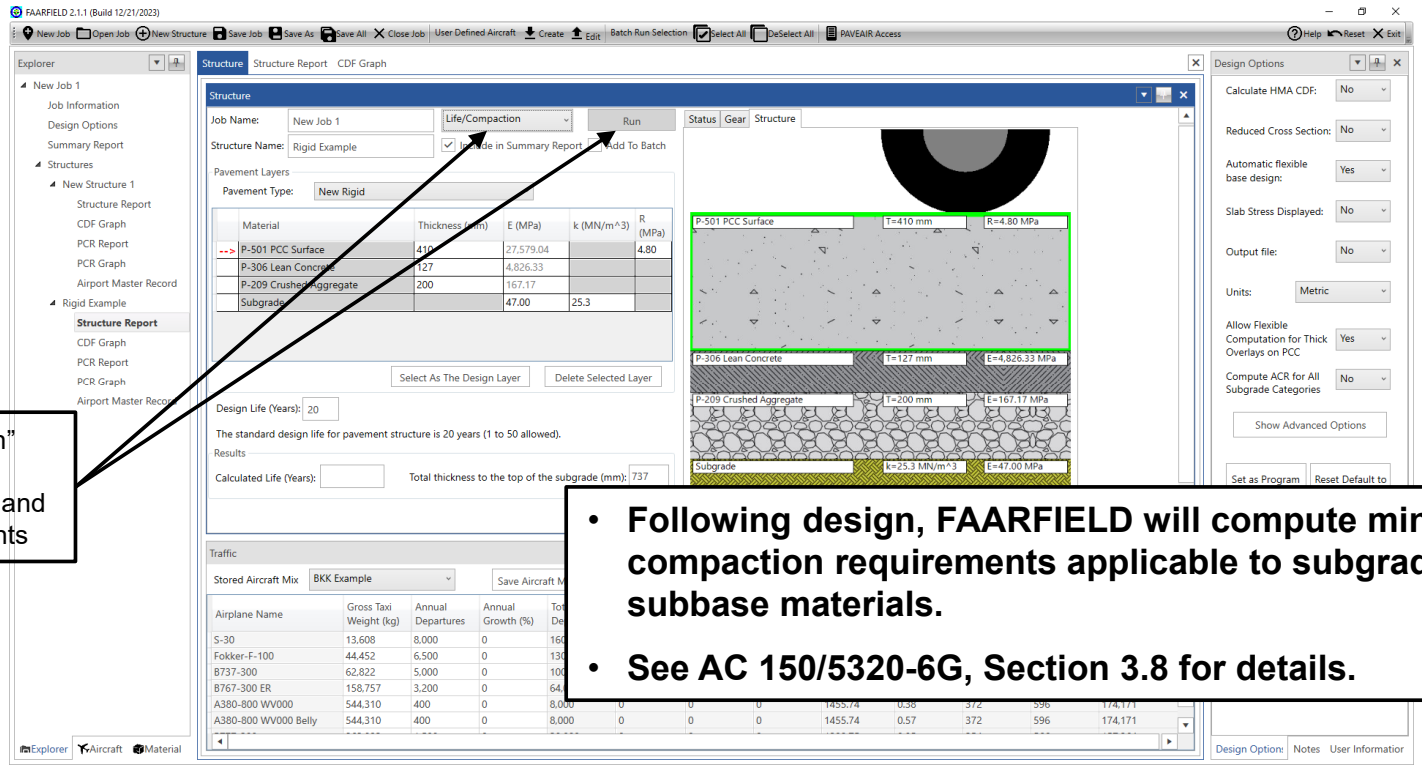
   The most demanding aircraft is the Airbus 380-800, for which the belly gear (6-wheels) contributes 98% of the CDF on the critical strip.

Structure Report



Federal Aviation Administration

Life/Compaction

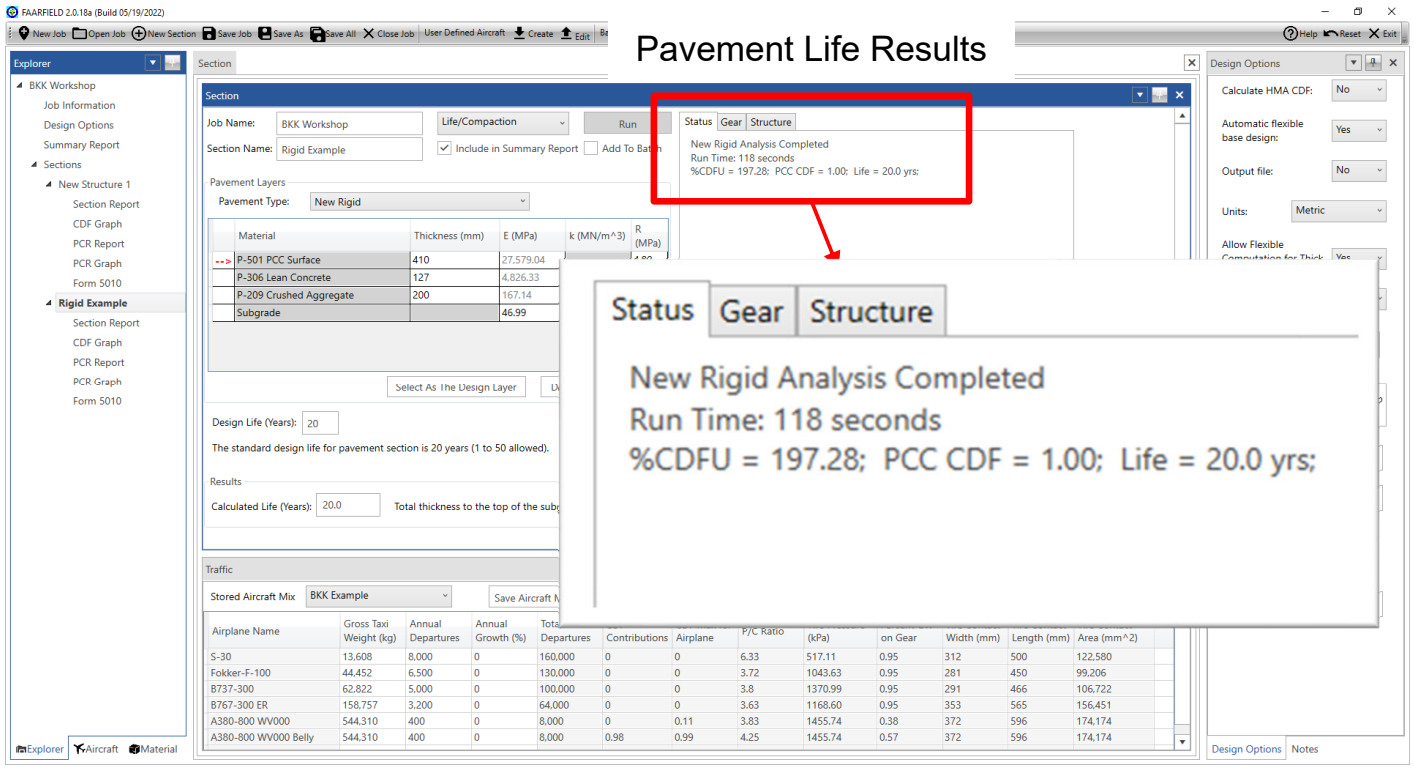


Select “Life/Compaction”

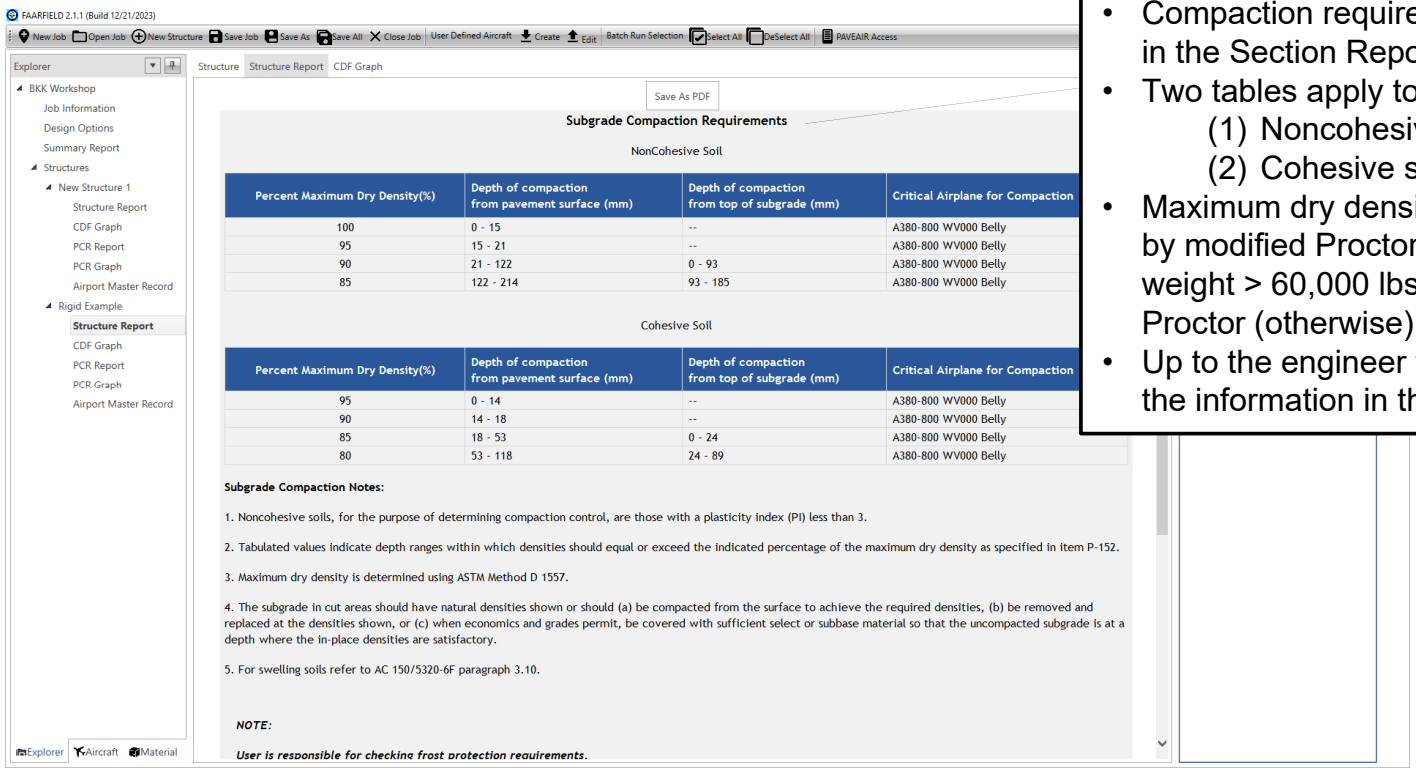
Click “Run” to start Life and Compaction requirements

- **Following design, FAARFIELD will compute minimum compaction requirements applicable to subgrade and subbase materials.**
- **See AC 150/5320-6G, Section 3.8 for details.**

Life/Compaction



Compaction Requirements



- Compaction requirements are available in the Section Report.
- Two tables apply to:
  - (1) Noncohesive soils (PI < 3)
  - (2) Cohesive soils
- Maximum dry density determined either by modified Proctor (if aircraft gross weight > 60,000 lbs.), or standard Proctor (otherwise).
- Up to the engineer to correctly apply the information in these tables.

Rigid Pavement Design Example - Sensitivities

Perform a sensitivity analysis on the following variables:

- **Average annual departures of most demanding aircraft (+/- 20 percent of departures).**
  A380-800 annual departures: 480 / 320
- **Departure weight of the most demanding aircraft (+/- 10 percent of weight).**
  A380-800 GW: 598740 / 489880 kg.
- **Subgrade modulus (+/- 10 percent of modulus).**
  ***E* = 42.3 / 51.7 MPa**
- **Concrete Flexural Strength (+/- 10 percent of *R*).**
  ***R* = 4.32 / 5.28 MPa**

Sensitivity Analysis:

Condition	*Design Thickness, in*	*Sensitivity*
Basic Design	*15.9*	
+20% A380 Departures	*16.1*	$S_{Dep,t} = \frac{0.3}{160} \times \frac{400}{15.9} = 0.047$
-20% A380 Departures	*15.8*	
+10% A380 Gross Weight	*17.4*	$S_{GW,t} = \frac{2.1}{240000} \times \frac{1200000}{15.9} = 0.660$
-10% A380 Gross Weight	*15.3*	
+10% Subgrade E	*15.7*	$S_{E,t} = \frac{-0.50}{1410} \times \frac{7050}{15.9} = -0.157$
-10% Subgrade E	*16.2*	
+10% R	*14.5*	$S_{R,t} = \frac{-3.1}{140} \times \frac{700}{15.9} = -0.975$
-10% R	*17.6*	

The thickness design is most sensitive to concrete strength, followed by gross weight of the controlling aircraft. The FAARFIELD rigid design is insensitive to small changes in the number of aircraft departures.

Overlay Design Example Using FAARFIELD 2.1

FAARFIELD Overlay Design

- **HMA Overlays on Flexible Pavement**
  - Same as designing a new flexible pavement, except the design layer is the HMA overlay.
- **PCC Overlays on Flexible Pavement**
  - Same principle as new rigid design.
- **HMA Overlays on Rigid Pavement**
- **PCC Overlays on Rigid Pavement**
  - More complex than new rigid pavement design.
  - Both slabs (base PCC and overlay) deteriorate with applied traffic. Stresses are computed for both slabs.
  - E-modulus of the base slab is a function of reduced SCI.

FAARFIELD Overlay Design –
PCC on Rigid Overlays

- **Fully bonded overlays**
  - Treat as a new rigid pavement design.
  - Thickness of overlay slab is $h_{overlay} = h_{design} - h_{exist}$.
- **Unbonded overlay**
  - Bond breaker or leveling course is used.
- **Partially bonded overlay**
  - Not a standard design in AC 150/5320-6F.
  - Default in FAARFIELD is off.
  - May be enabled from the Options window, but displays a “Non Standard Structure” message.

FAARFIELD Overlay Design –
HMA on Rigid Overlays

- **See AC 150/5320-6G, Paragraphs 4.7.5.5 & 4.7.5.6**
- **Current design procedure does not address reflection cracking.**
- **Default model assumes base concrete pavement continues to deteriorate under traffic, reaching a terminal SCI at end of life.**
- **Thick asphalt overlays on existing rigid pavements.**
  - Applies only when the overlay thickness exceeds the concrete thickness.
  - Can treat as a flexible design where the existing concrete acts as a high-quality base material.
  - Program performs both designs - reports the one that gives the thinner overlay.

FAARFIELD Overlay Design

Required Inputs

- **Existing rigid pavement condition is characterized by the Structural Condition Index (SCI).**
  - SCI derived from PCI as determined by ASTM D 5340, Airport Pavement Condition Index Surveys. AC 150/5320-6G, par. 4.7.5.3, gives guidance on SCI.
  - SCI is computed using only structural components from the PCI survey.
- **SCI = 80 is the FAA definition of structural failure. This is equivalent to 50% of the slabs in a section exhibiting a full-width structural crack)**
- **For existing pavements with structural damage (SCI < 100)**
  - The user inputs a value of SCI for the existing pavement.
  - The range of allowable values is SCI 67 – 100.
  - The Help file also gives approximate formulas for relating SCI to C_r and C_b factors in earlier FAA design methods.

FAARFIELD – PCC Unbonded Overlay Design Structural Condition Index (SCI)

Rigid Pavement Distress Types Used to Calculate SCI

Distress	Severity Level
Corner Break	Low, Medium, High
Longitudinal/Transverse/Diagonal Cracking	Low, Medium, High
Shattered Slab	Low, Medium, High
Shrinkage Cracks (cracking partial width of slab)*	Low
Spalling–Joint	Low, Medium, High

*** Used only to describe a load-induced crack that extends only part of the way across a slab. The SCI does not include conventional shrinkage cracks due to curing or other non load-related problems.**

Cumulative Damage Factor Used (CDFU)

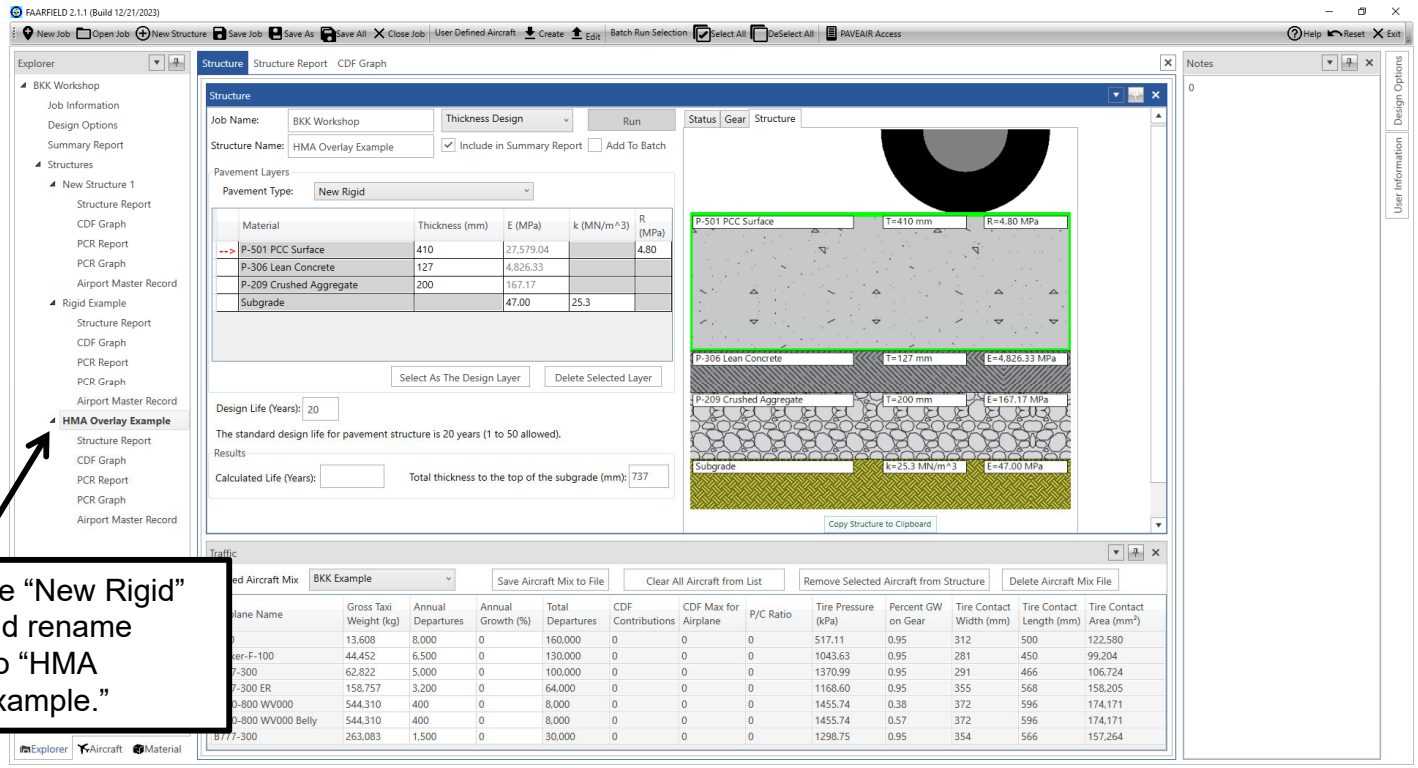
For existing pavements where SCI=100 (no structural distress):

- **There is no visible distress contributing to reduction in SCI (no structural distress types). However, some pavement life has been consumed by the applied traffic.**
- **The amount of pavement life consumed before the onset of cracking is the percent CDF Used (%CDFU).**
- **Need to estimate a value of %CDFU.**
- **The Help file gives guidance on estimating %CDFU using the Life key.**

HMA on Rigid Overlay Example

- **PCC overlay will be placed on an existing PCC slab.**
- **Assume the previous traffic mix.**
- **Existing PCC slab:**
  - 360 mm P-501, *R* = 4.8 MPa.
  - Assume SCI = 80 for existing slab.
- **All other design inputs same as previous example.**

Create a New Structure



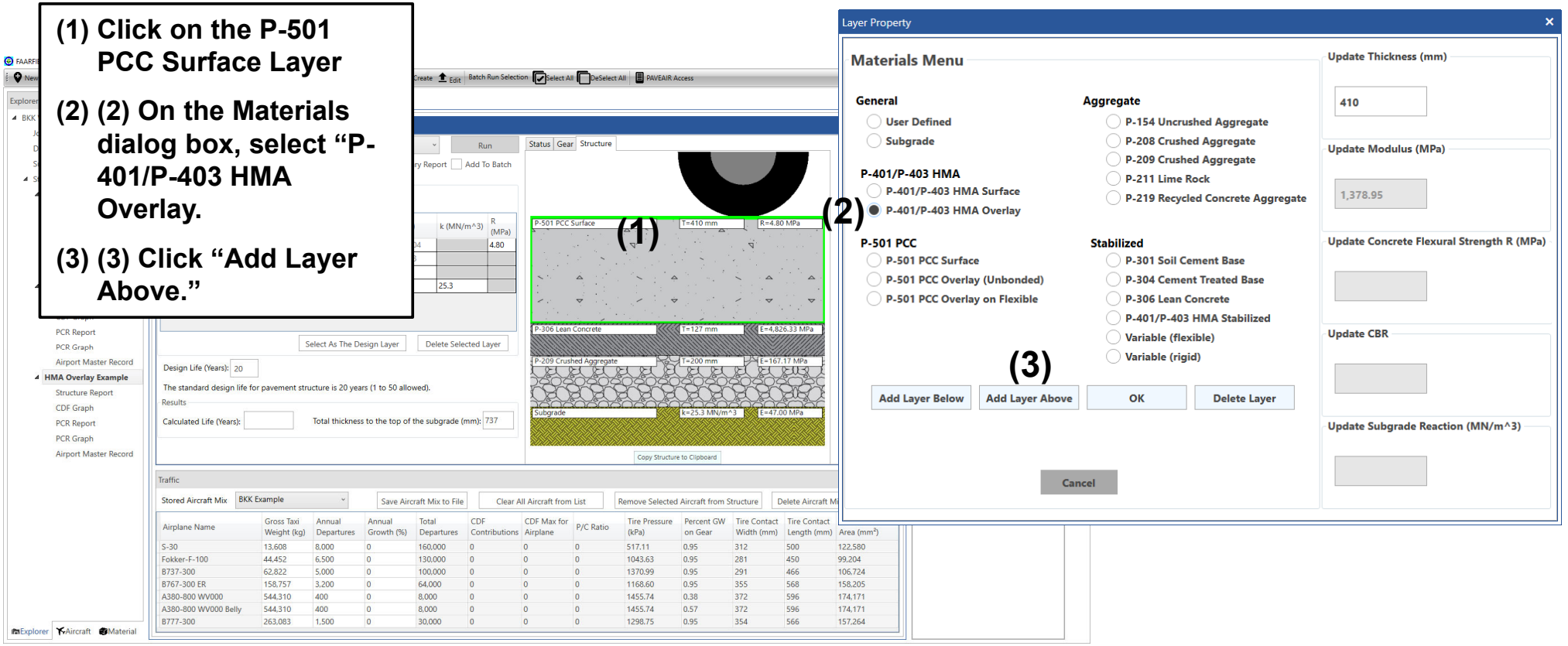
Copy/Paste “New Rigid” Section and rename structure to “HMA Overlay Example.”

Modify the Structure

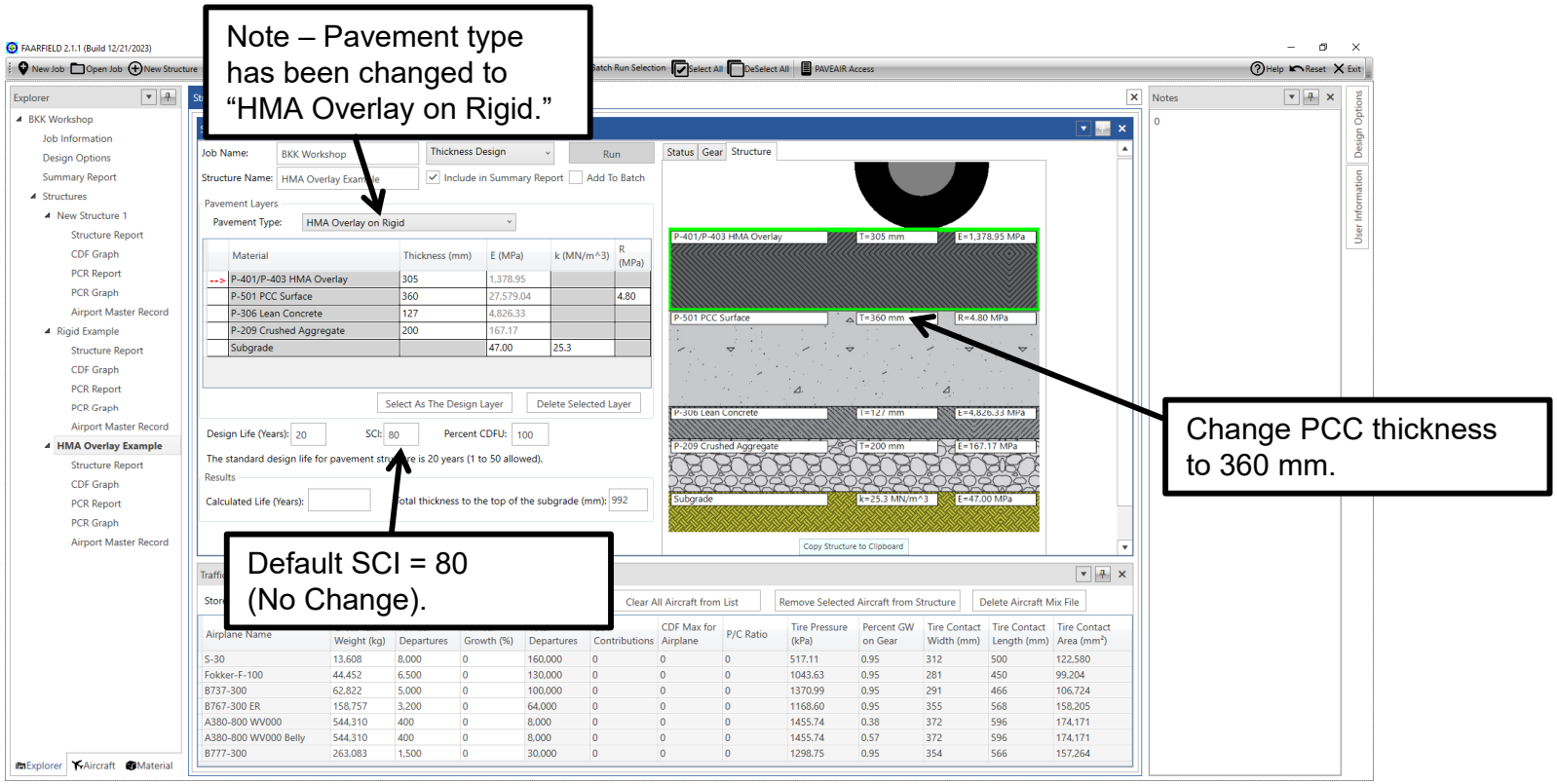
(1) Click on the P-501 PCC Surface Layer

(2) (2) On the Materials dialog box, select “P-401/P-403 HMA Overlay.

(3) (3) Click “Add Layer Above.”

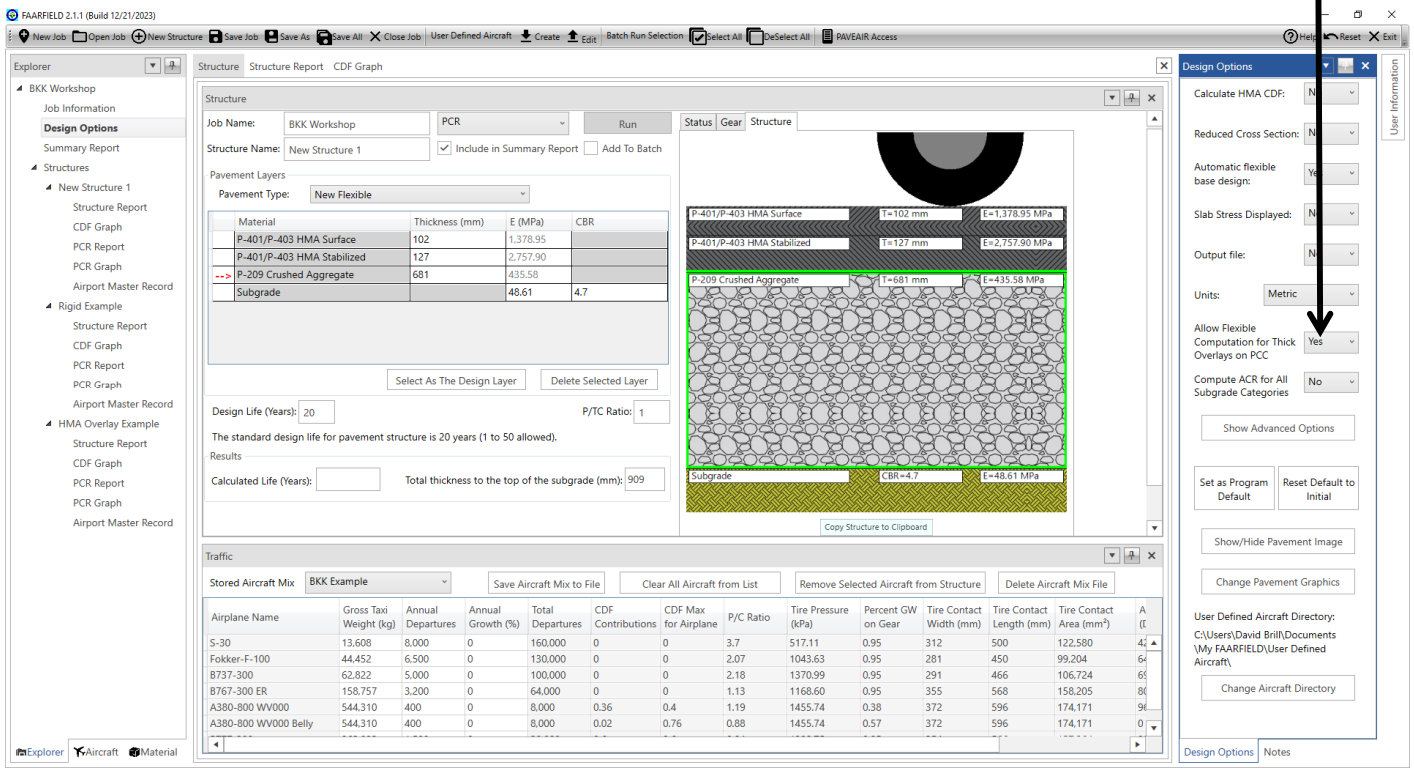


Modify the Structure

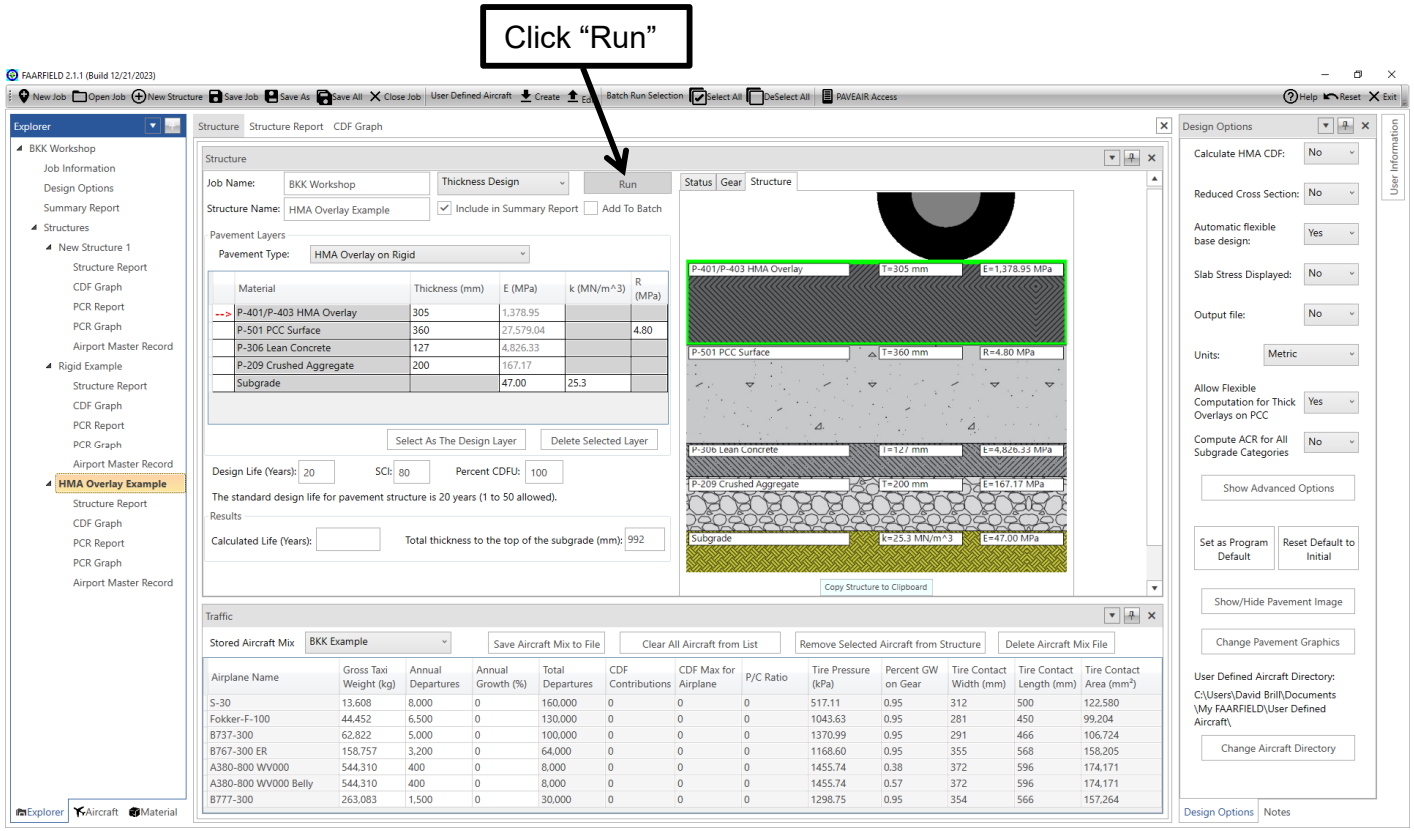


Design Options

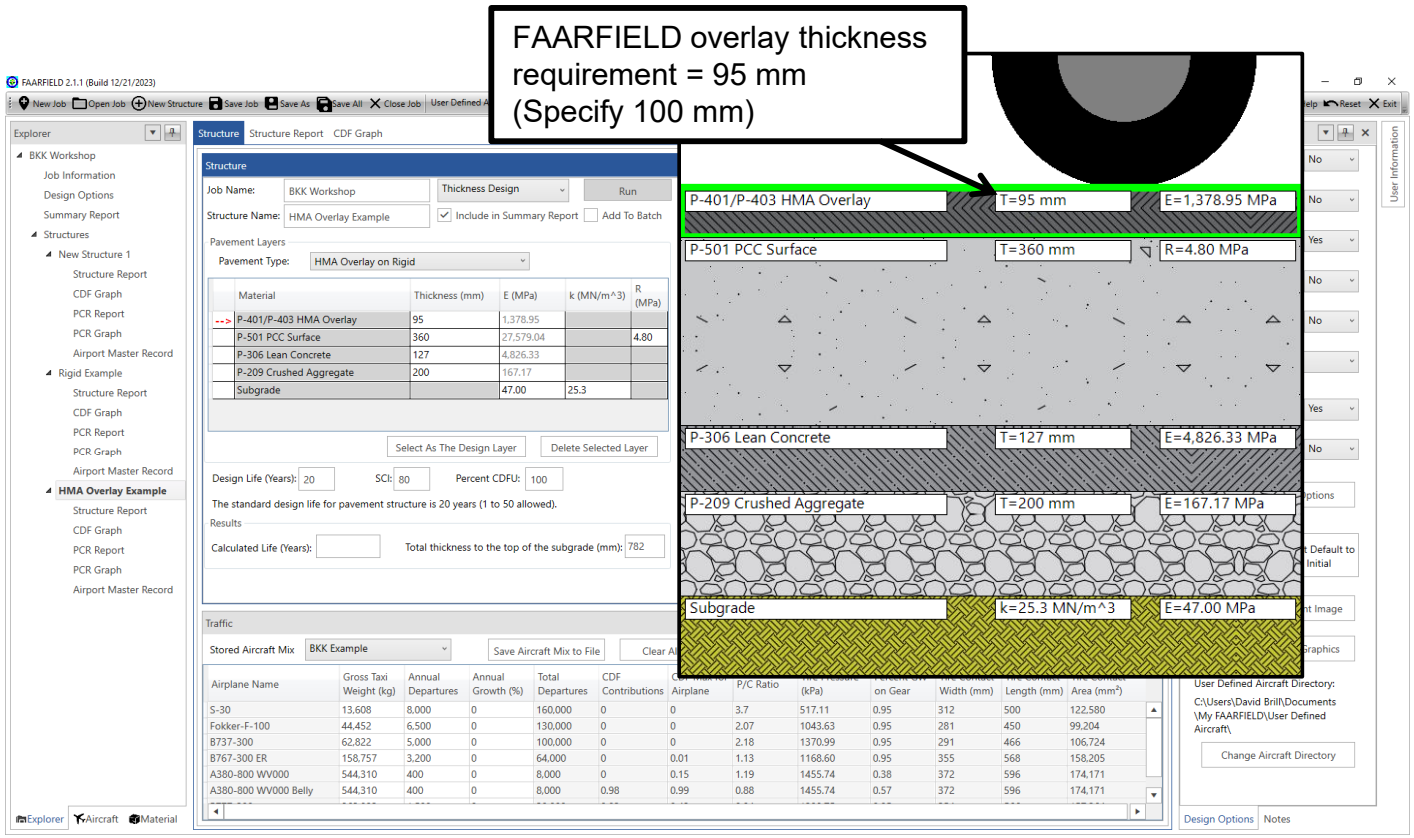
Design Options – Make sure “Allow Flexible Computation for Thick Overlays on PCC” is set to “Yes.”



Run Overlay Thickness Design



Design Complete



Thank You!

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