FAA Pavement Design

AC 150/5320-6E and FAARFIELD

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Federal Aviation Administration

FAA Pavement Design

AC 150/5320-6E, Airport Pavement Design and Evaluation

Note that this presentation will address significant changes to FAA pavement design procedures and is not intended to convey a complete overview of the pavement design procedure

FAA Pavement Design

AC 150/5320-6E, Airport Pavement Design and Evaluation

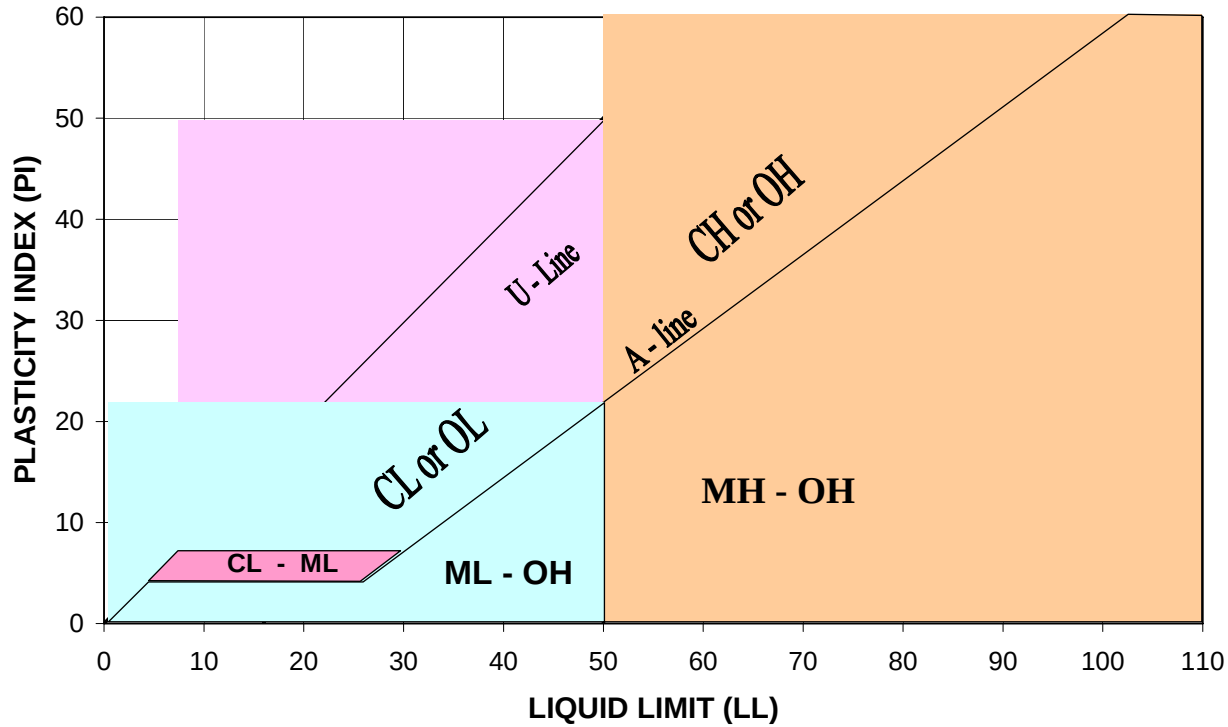
- Completely revised in 2008
- New design methodologies for Rigid and Flexible pavements
- Software dependent design procedures
- Addresses modern airplane parameters

Chapter 2
Soil Investigations and Evaluation

Chapter 2
Soil Investigations and Evaluation

- **Very few significant changes**
- **Still uses Unified Soil Classification (USC) system**
  - Reference to ASTM 2487

GW	CL
GP	ML
GM	OL
GC	CH
SW	MH
SP	OH
SM	PT
SC	



Chapter 2
Soil Investigations and Evaluation

Same minimum subsurface boring recommendations

Same soil testing recommendations

AREA	Minimum spacing	Minimum depth
RWY/TWY	200 ft interval	10 ft
Other areas	1 per 10,000 sq ft	10 ft
Borrow areas	As necessary	As necessary

Chapter 2
Soil Investigations and Evaluation

Continues to split soil compaction requirements based upon 60,000 lb gross weight airplane

< 60,000 ASTM D 698 Standard Proctor

> 60,000 ASTM D 1557 Modified Proctor

Soil Strength Parameter for FLEXIBLE pavement

Subgrade Modulus (E psi) or CBR

CBR

- Design value – One Standard Deviation below the Mean
- Lowest practical value CBR = 3

  Otherwise stabilize or replace

Soil Strength Parameter for RIGID pavement

Resilient Modulus E (psi) or

Modulus of Subgrade Reaction – k-value (pci)

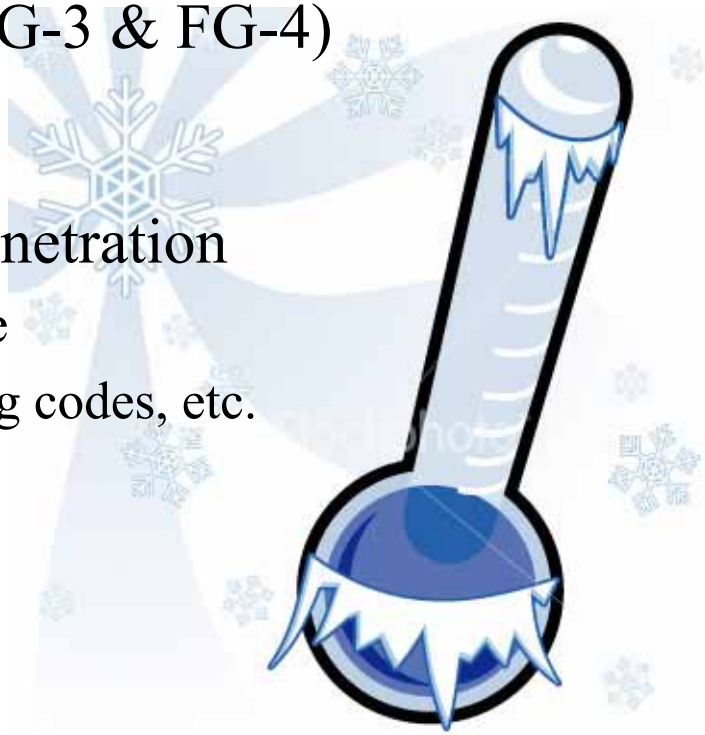
- Design value – "conservative selection"
- K-value can be estimated from CBR

$$k = \left[\frac{1500 \times \mathrm{CBR}}{26} \right]^{0.7788} \qquad (k \text{ in pci})$$

Seasonal Frost

- Same Frost Groups (FG-1, FG-2, FG-3 & FG-4)

- Determination of Depth of Frost Penetration
  - Based on local Engineering experience
  - i.e. local construction practice, building codes, etc.
  - No nomographs or programs provided



Chapter 3
Pavement Design

Chapter 3 - Pavement Design

- Completely New Chapter
- Covers standard pavement design procedures for both flexible and rigid pavement
- Applies to pavement designed for airplanes with gross weights exceeding 30,000 lbs
- Design procedure requires the use of computer program, i.e. FAARFIELD

Chapter 3 - Pavement Design

- **Flexible Pavement Design based on Layered Elastic design procedure**
  - US Corp of Engineers CBR Method no longer used
- **Rigid Pavement Design based on 3-Dimensional Finite Element model**
  - Westergaard design procedure no longer used.

Traffic Models

- New procedures require that ALL anticipated traffic be included in the traffic model.
- Concept of “design aircraft” is no longer used
- Cumulative Damage Factor (CDF) replaces need for design aircraft procedure.

Traffic Model - Cumulative Damage Factor

- Sums Damage From ***Each*** Aircraft
  - Based upon its unique pavement loading characteristics and
  - Location of the main gear from centerline

- DOES NOT use the "design aircraft" method of condensing all aircraft into one design model

Traffic Model - Cumulative Damage Factor

- Sums Damage From ***Each*** Aircraft - Not From "Design Aircraft"

$$\text{CDF} = \frac{\text{number of applied load repetitions}}{\text{number of allowable repetitions to failure}}$$

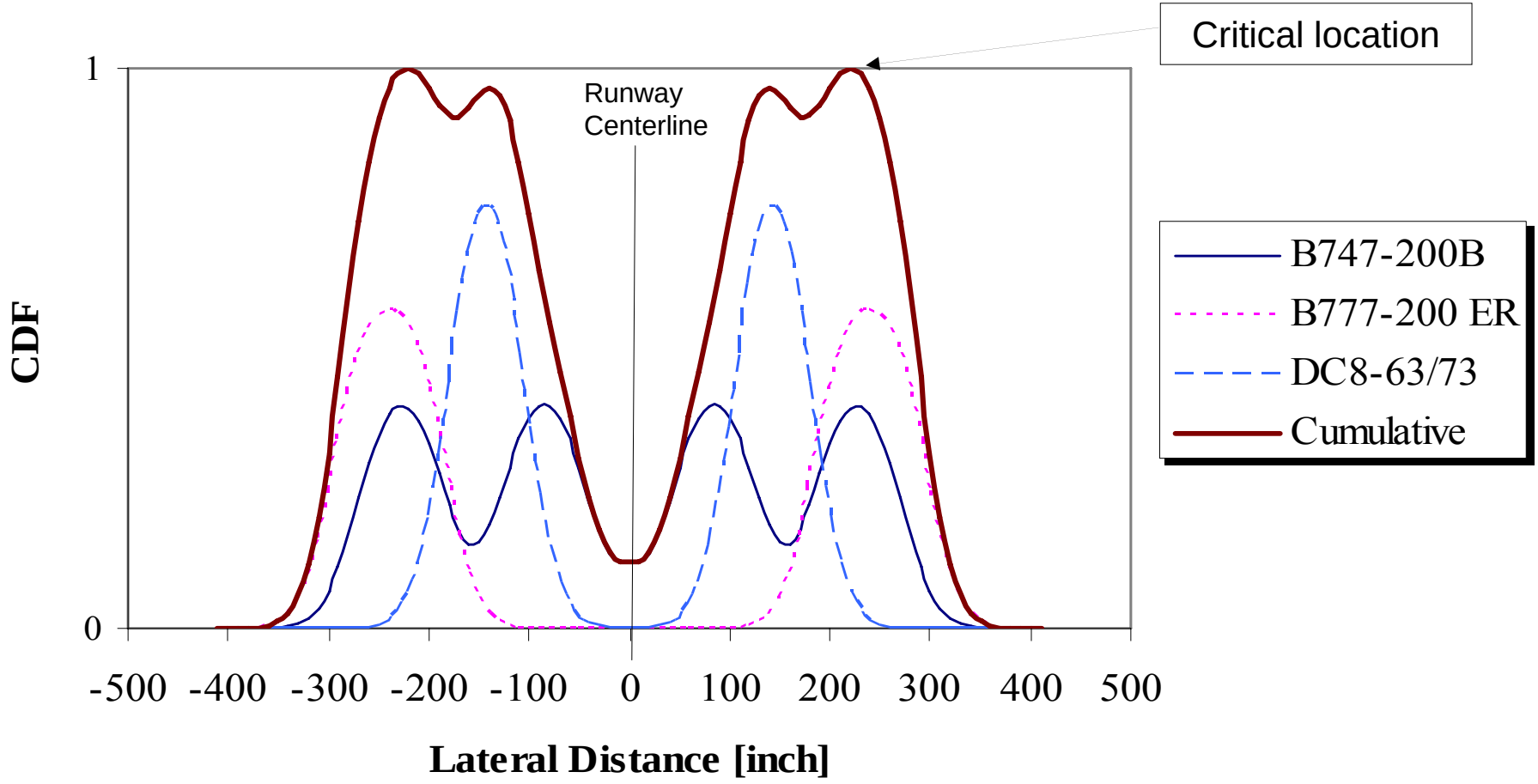
- When CDF = 1, Design Life is Exhausted

Traffic Model - Cumulative Damage Factor

- CDF is Calculated for each 10 inch wide strip over a total 820 inch width.
- Gear location and wander considered for each aircraft
- Use Minor's rule to sum damage for each strip

➢ **Must Input Traffic Mix, NOT "Design Aircraft"**

Traffic Model - Cumulative Damage Factor

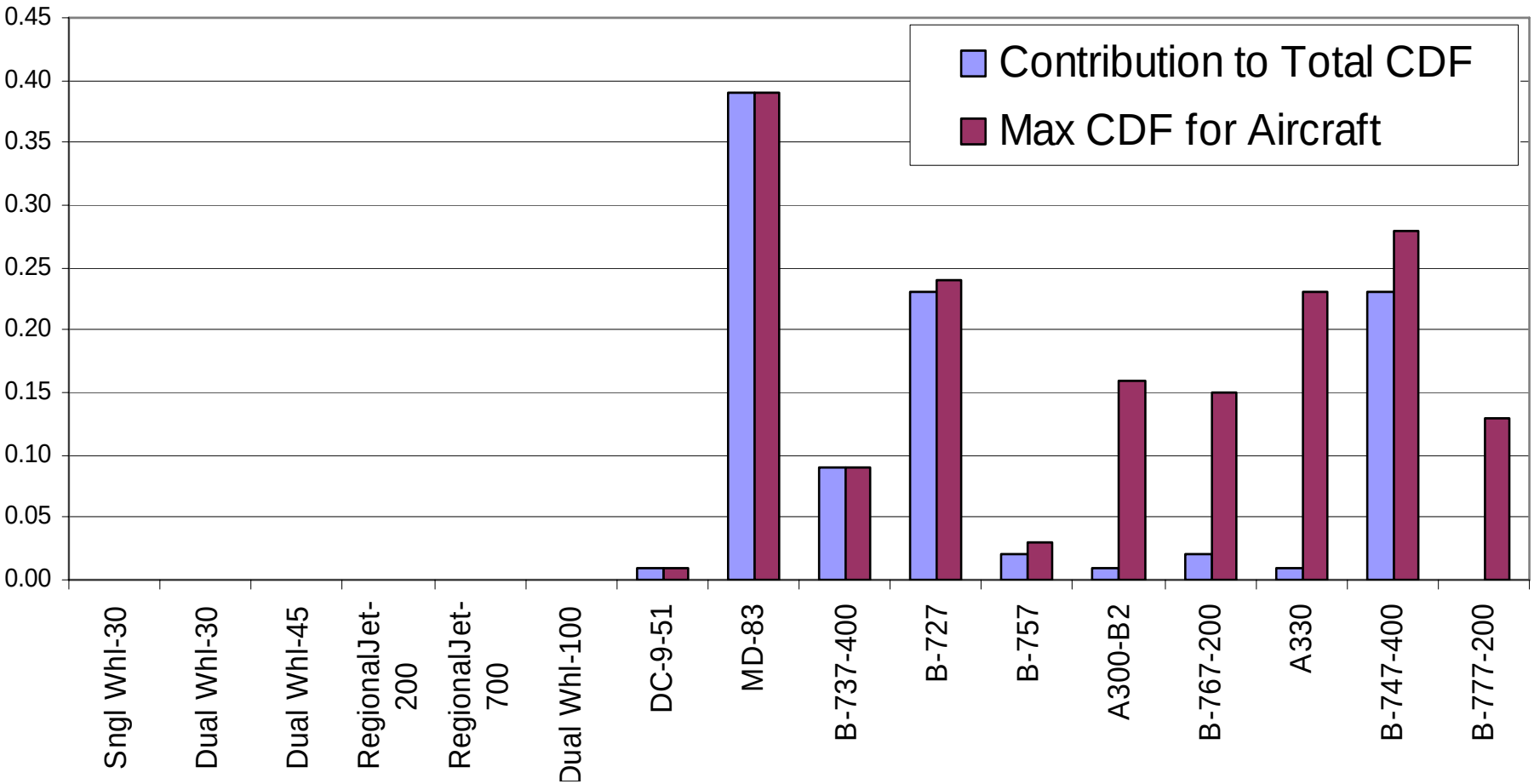


Sample Aircraft Traffic Mix CDF Contribution

Aircraft Name	Gross Weight	Annual Departures	CDF Contribution	CDF Max For Aircraft
Sngl Whl-30	30,000	1,200	0.00	0.00
Dual Whl-30	30,000	1,200	0.00	0.00
Dual Whl-45	45,000	1,200	0.00	0.00
RegionalJet-200	47,450	1,200	0.00	0.00
RegionalJet-700	72,500	1,200	0.00	0.00
Dual Whl-100	100,000	1,200	0.00	0.00
DC-9-51	122,000	1,200	0.01	0.01
MD-83	161,000	1,200	0.39	0.39
B-737-400	150,500	1,200	0.09	0.09
B-727	172,000	1,200	0.23	0.24
B-757	250,000	1,200	0.02	0.03
A300-B2	304,000	1,200	0.01	0.16
B-767-200	335,000	1,200	0.02	0.15
A330	469,000	100	0.01	0.23
B-747-400	873,000	100	0.23	0.28
B-777-200	537,000	500	0.00	0.13

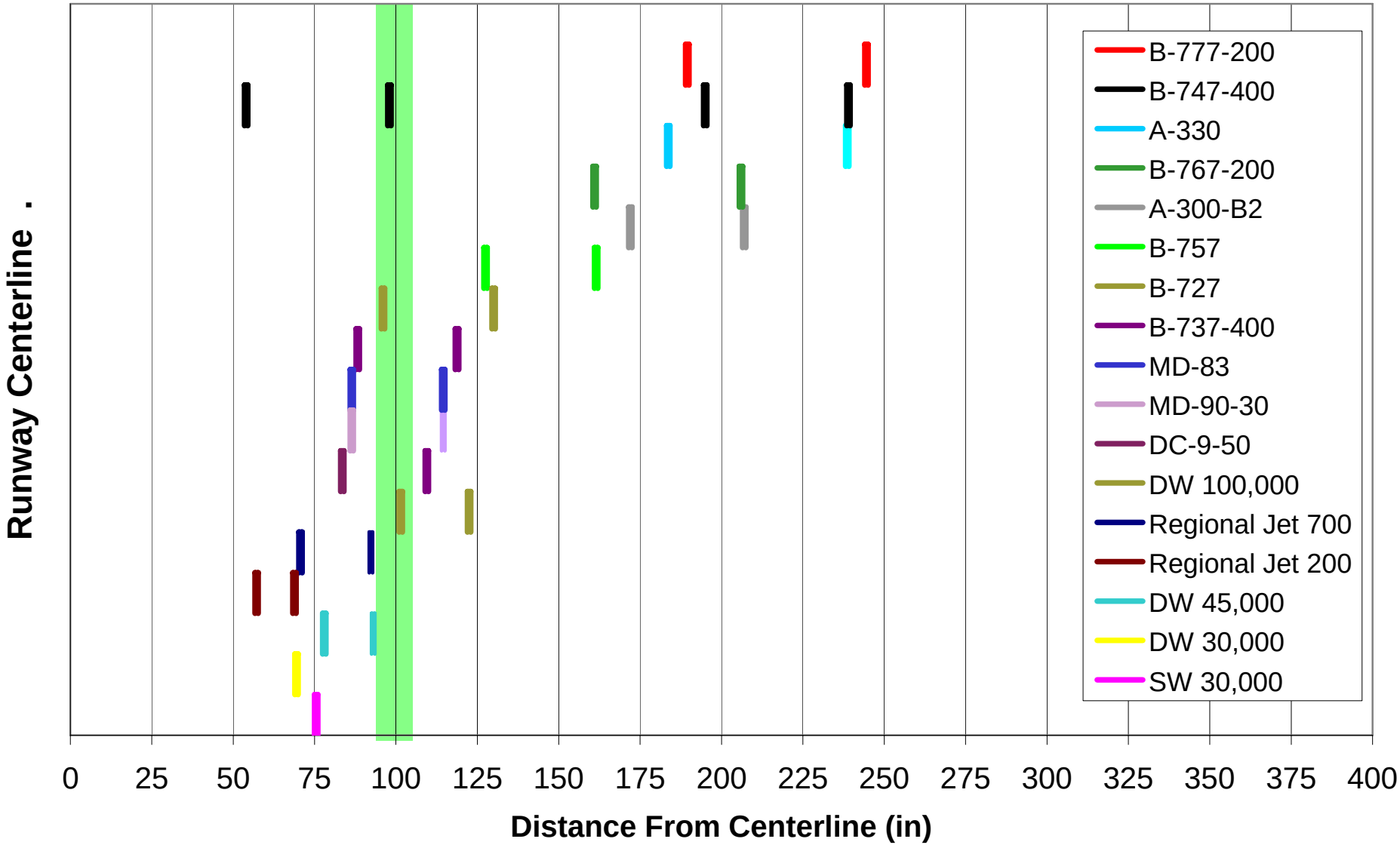
Condition specific and not a general representation of noted aircraft

Sample Aircraft Traffic Mix CDF Contribution

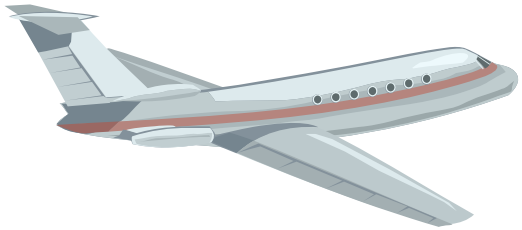


Condition specific and not a general representation of noted aircraft

Large Aircraft Traffic Mix Gear Locations



Remember



Must use the entire traffic mixture

No more "Design Aircraft"

Comparisons between new and previous design procedures using "design aircraft" for the traffic model will result in significant errors

Traffic Model – Airplane Characteristics

- FAARFIELD program currently provides 198 different aircraft models
- Each model is unique with respect to gross load, load distribution, wheel spacing, and tire pressure
- Gear types identified in accordance with FAA Order 5300.7
  - Eliminates “widebody” terminology

Traffic Model – Gear Naming Convention

Main Gear Designation **Body/Belly Gear Designation**

 # X # / # X #

# of gear types in tandem
(A value of 1 is omitted for simplicity.)

Gear type, e.g. S, D, T, or Q

# of main gears in line on one side of the aircraft
(Assumes gear is present on both sides. The value indicates number of gears on one side. A value of 1 is omitted for simplicity.)

Total # of body/belly gears
(Because body/belly gear may not be symmetrical, the gear must identify the total number of gears present and a value of 1 is not omitted if only one gear exists.)

Gear type, e.g. S, D, T, or Q

# of gear types in tandem
(A value of 1 is omitted for simplicity.)

Traffic Model – Gear Naming Convention

Single	Dual	Triple	Quadruple
S	**D**	**T**	**Q**

Traffic Model – Gear Naming Convention

Single
S

Dual
D

Triple
T

Quadruple
Q

2 Singles in Tandem
2S

2 Duals in Tandem
2D

2 Triples in Tandem
2T

2 Quadruples in Tandem
2Q

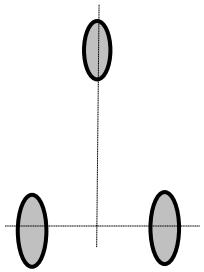
3 Singles in Tandem
3S

3 Duals in Tandem
3D

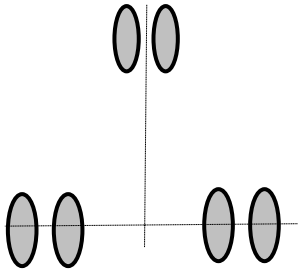
3 Triples in Tandem
3T

3 Quadruples in Tandem
3Q

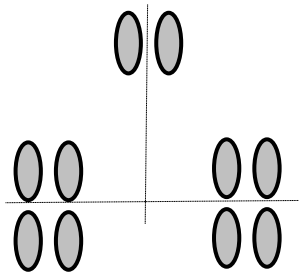
Chapter 3 - Pavement Design -- Examples



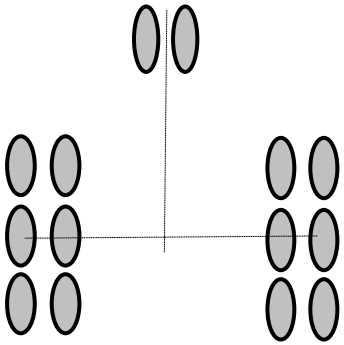
S
Single Wheel



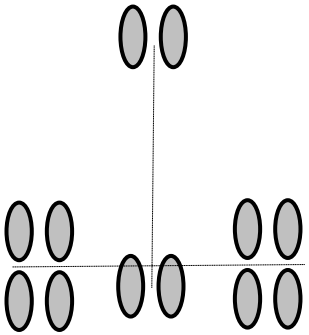
D
Dual Wheel



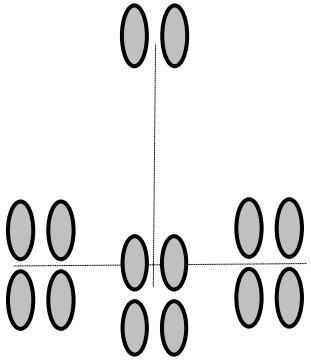
2D
Dual Tandem



3D
B777

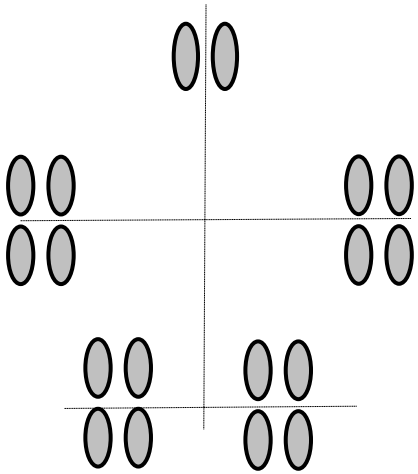


2D/D1
DC-10

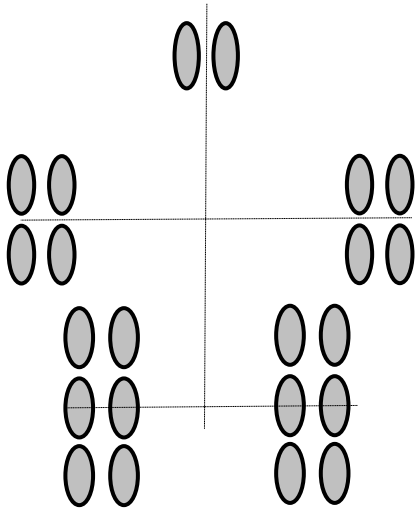


2D/2D1
A340-600

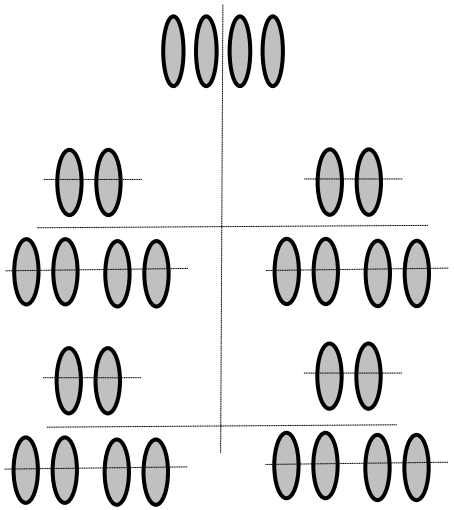
Chapter 3 - Pavement Design -- Examples



2D/2D2
B747



2D/3D2
A380



C5
Lockheed C5

Traffic Model – Pass to Coverage (P/C) Ratio

- Lateral movement is known as airplane wander and is model by statistically normal distribution.
  - Standard Deviation = 30.435 inches (773 mm)
- (P/C) -The ratio of the number of trips (or passes) along the pavement for a specific point on the pavement to receive one full-load application.
- -6E utilizes new procedure for determining P/C

Traffic Model – Pass to Coverage (P/C) Ratio

- Rigid Pavement

  One Coverage = One full stress application to the bottom of the PCC layer

- Flexible Pavement

  One Coverage = One repetition of maximum strain at the top of the subgrade layer

Traffic Model – Pass to Coverage (P/C) Ratio

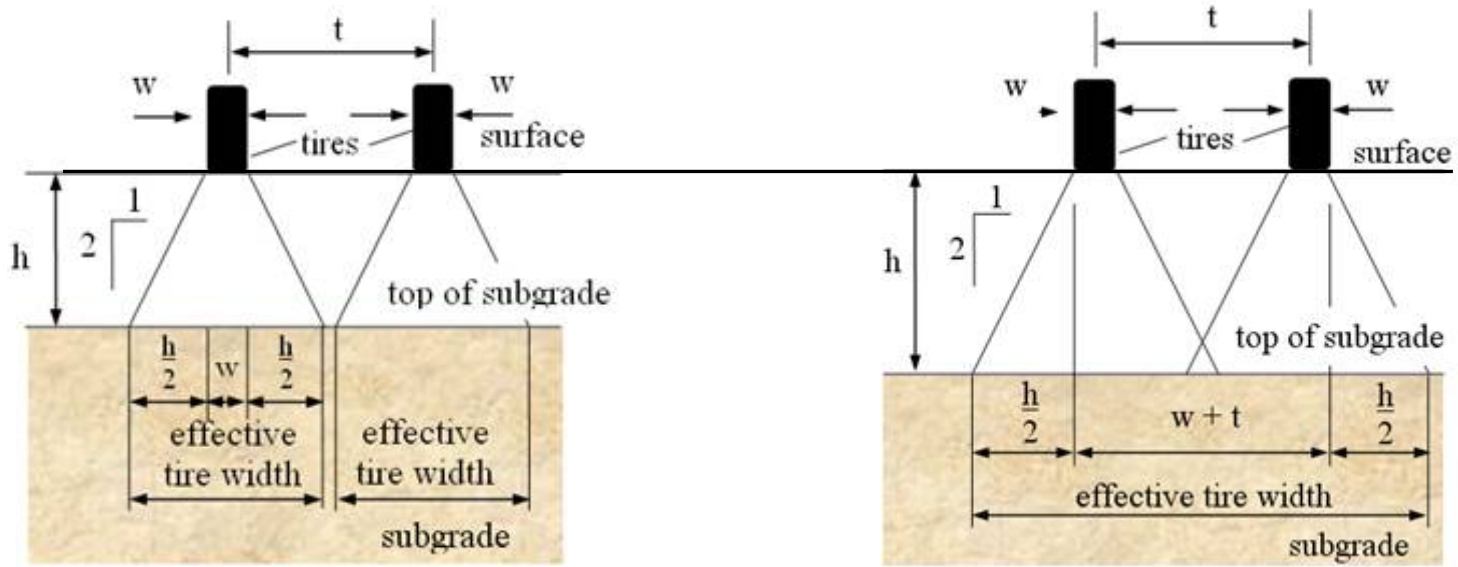
- -6E (FAARFIELD) uses the concept of "Effective Tire Width"
- Rigid Pavement – Effective width is defined at the surface of the pavement (equal to tire contact patch)

  (same as previous P/C procedures)

- Flexible Pavement – Effective width is defined at the surface of the subgrade layer

Traffic Model – Pass to Coverage (P/C) Ratio

Flexible pavement P/C ratio vary with depth of pavement



Chapter 3 - Pavement Design – Frost Design

FROST DESIGN - 3 options

- Complete Frost Protection
  - Remove frost susceptible materials to below frost depth
- Limited Frost Protection
  - Remove frost-susceptible material to 65% frost depth
  - Limits frost heave to tolerable level
- Reduced Subgrade Strength
  - Reduce subgrade support value
  - Design adequate load carrying capacity for weakened condition

Chapter 3 - Pavement Design – Typical Sections

- **Airport pavements are generally constructed in uniform, full width sections**

- **Variable sections are permitted on runway pavements**

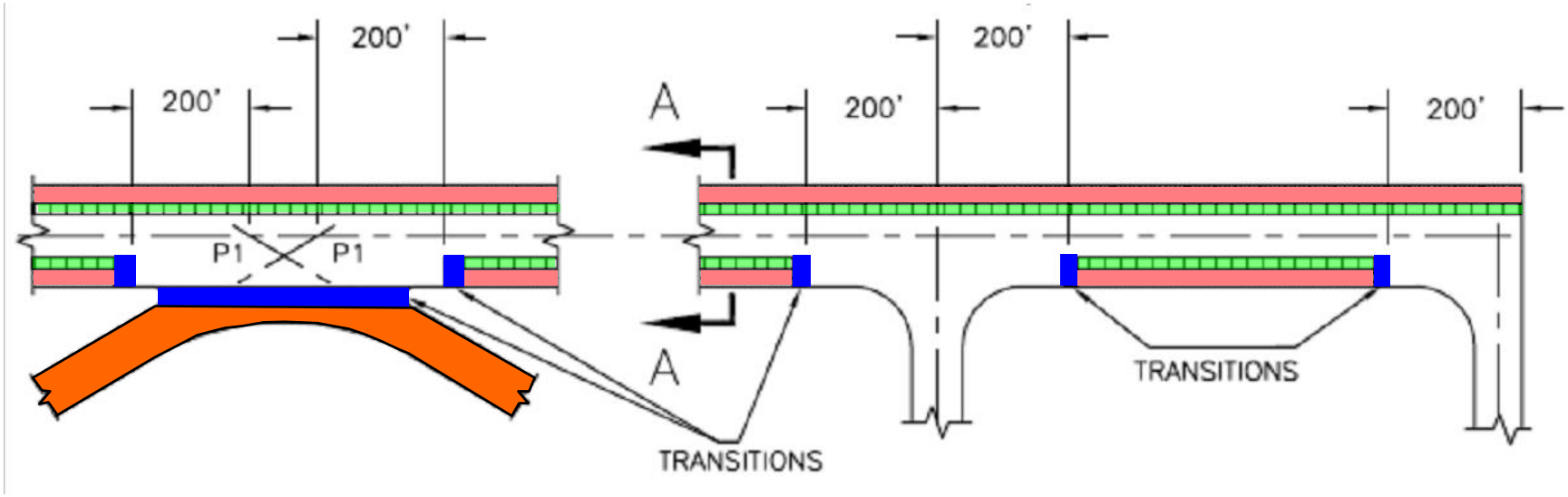
  Designer should consider:

  Practical feasibility – complex construction operations

  Economical feasibility – cost of complex construction

Chapter 3 - Pavement Design – Typical Sections

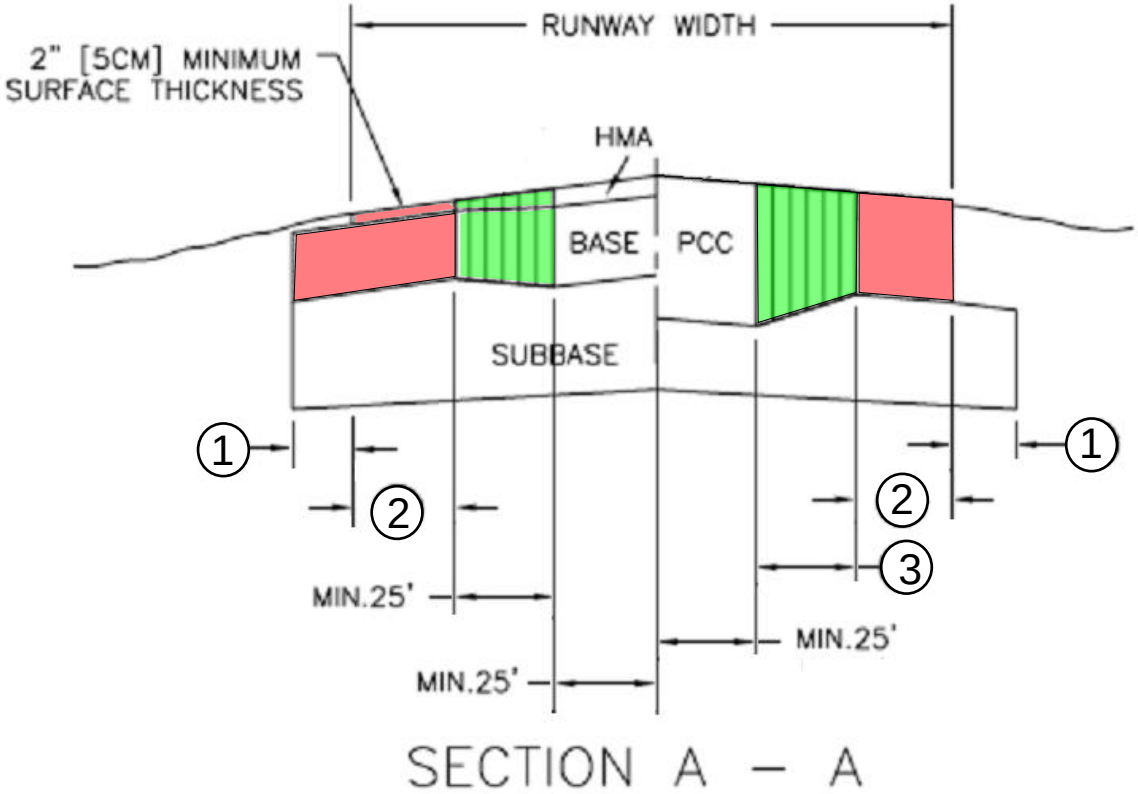
Variable sections permitted on runway pavements



- Full pavement thickness
- Outer edge thickness (based on 1% of normal traffic)
- Pavement thickness tapers to outer edge thickness
- Transitions
- Design using arrival traffic only

Chapter 3 - Pavement Design – Typical Sections

Variable sections permitted on runway pavements



1. Minimum 12” up to 36”
2. For runways wider than 150’, this dimension will increase.
3. Width of tapers and transitions on rigid pavements must be an even multiple of slabs, minimum one slab width.

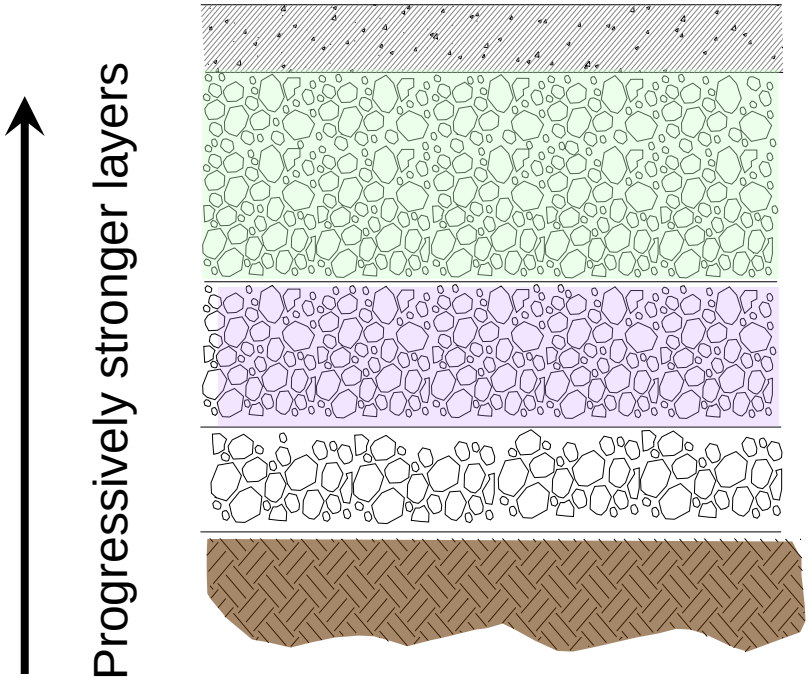
- Full pavement thickness
- Outer edge thickness (1% traffic)
- Pavement thickness tapers to outer edge thickness

FLEXIBLE PAVEMENT DESIGN

AC 150/5320-6E, Airport Pavement Design and Evaluation

CHAPTER 3, Section 2 – Flexible Pavement Design

Typical Flexible Pavement



Hot-Mix Asphalt Surface

Base Course (Minimum CBR=80)
(May Require Stabilization)

Subbase (Minimum CBR=20)
(May Require Stabilization)

Frost Protection (As Appropriate)

Subgrade

Chapter 3 Section 2 – Flexible Pavement Design

Surface	BASE	SUBBASE	SUBGRADE
P-401	P-209	P-154	P-152
P-403	P-208	P-210	P-155*
	P-211	P-212	P-157*
	P-304*	P-213	P-158*
	P-306*	P-301*	
	P-401*		
	P-403*		
	Rubblized PCC		

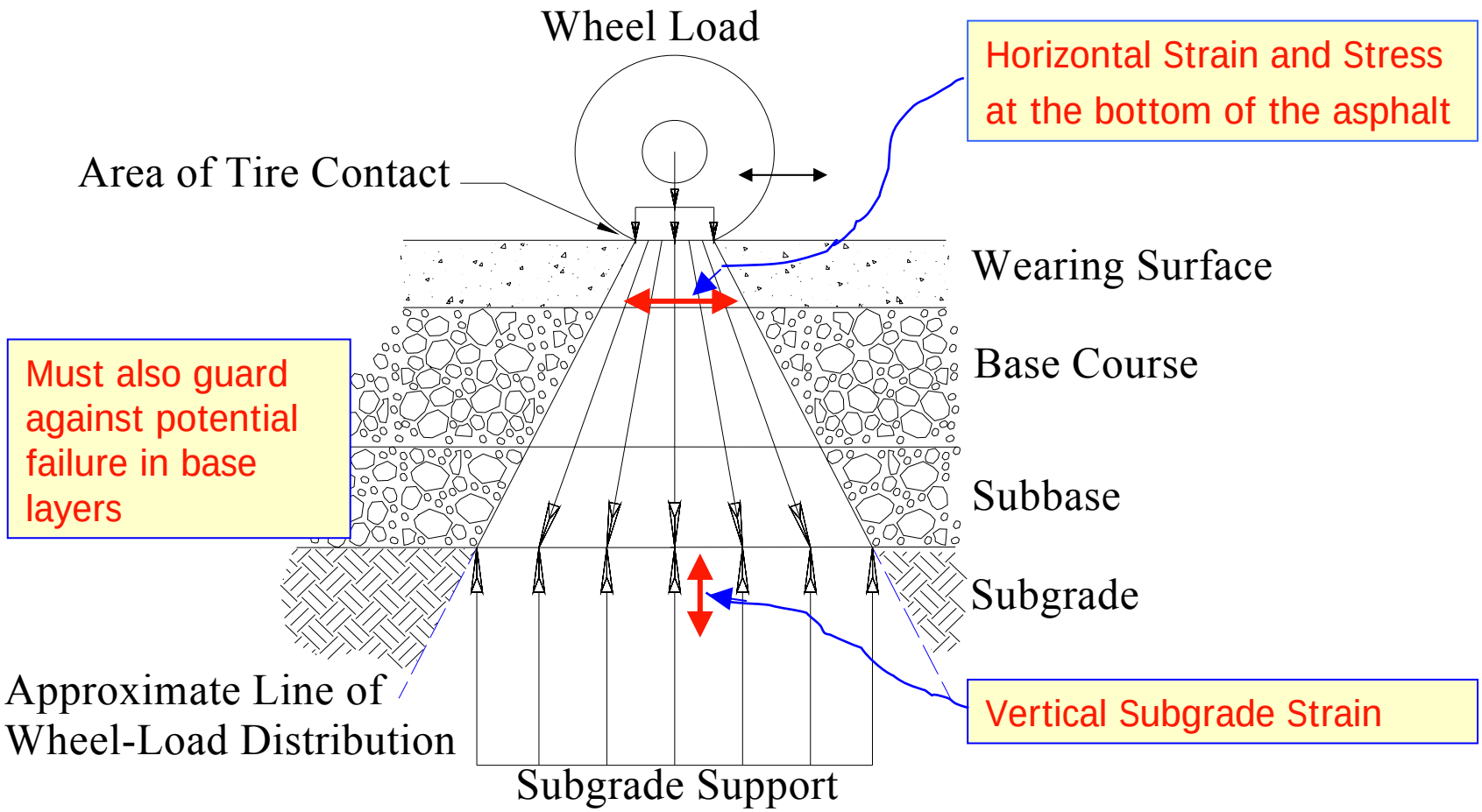
* Chemically Stabilized Materials

Flexible Pavement Design based on Layered Elastic Design (LED)

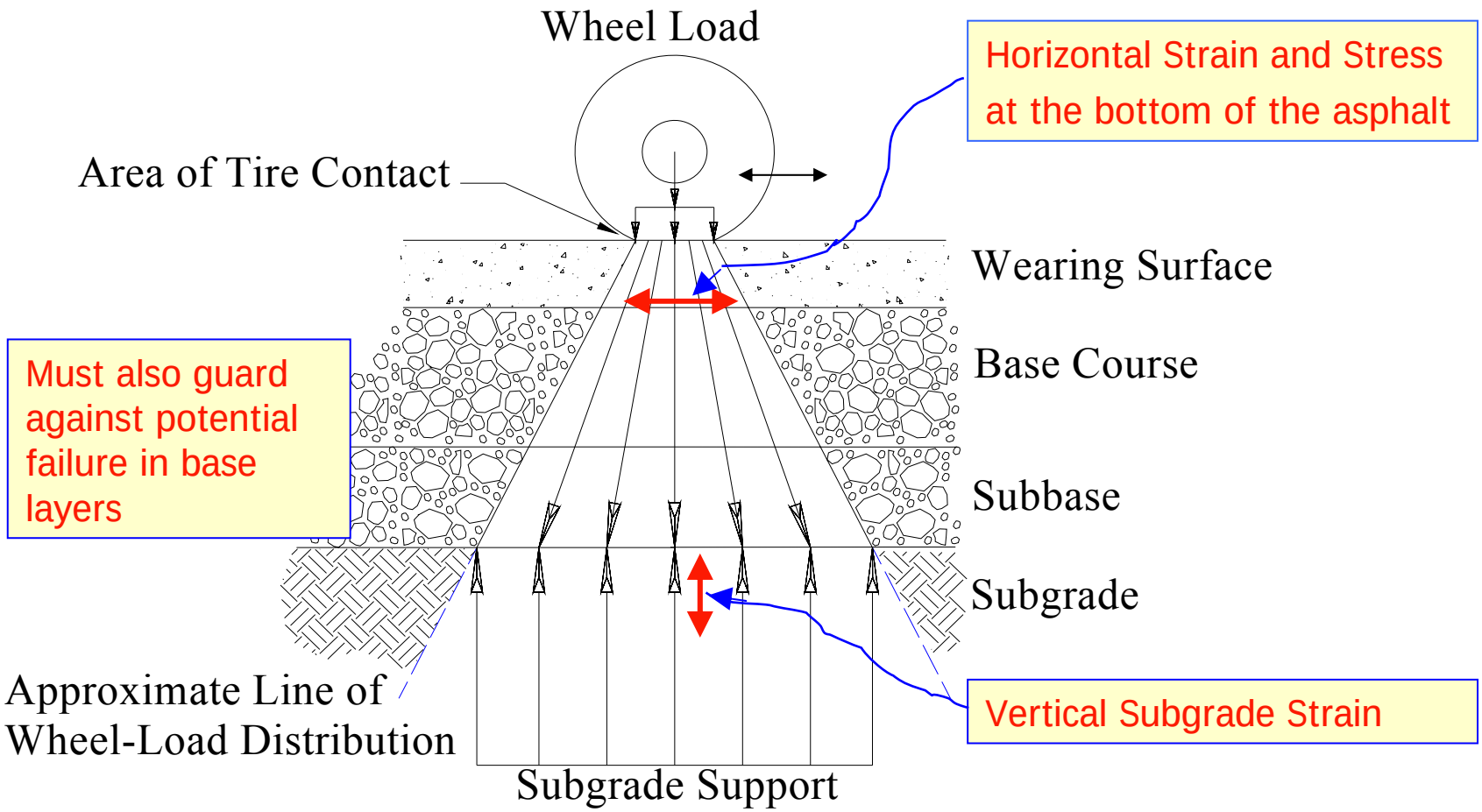
- Same as previously permitted in Chp 7 of -6D
  - Predictors of pavement life (FAARFIELD)
    - Maximum vertical strain at the top of subgrade and
    - Maximum horizontal strain at bottom of asphalt surface layer

      **By default, FAARFIELD does not automatically check horizontal stain in asphalt surface layer. Users can select this manually

Chapter 3 Section 2 – Flexible Pavement Design



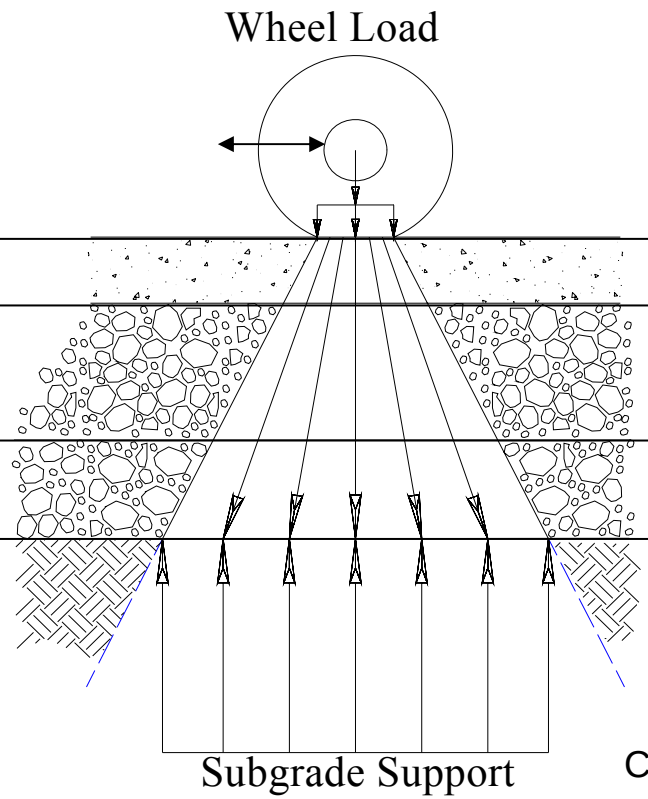
Chapter 3 Section 2 – Flexible Pavement Design



Chapter 3 Section 2 – Flexible Pavement Design

Flexible Pavement Layer Parameters- LED vs CBR

LAYERED ELASTIC METHOD		CBR Method
SURFACE	E_S, μ_S, h	*Not Defined*
BASE	E_B, μ_B, h_B	*CBR*
SUBBASE	E_{SB}, μ_{SB} h_{SB}	*CBR*
SUBGRADE	E_{SG}, μ_{SG} h_{SG}	*CBR*



E = Elastic Modulus
h = thickness
μ = Poisson's Ratio

CBR = California Bearing Ratio

FAARFIELD Default Values

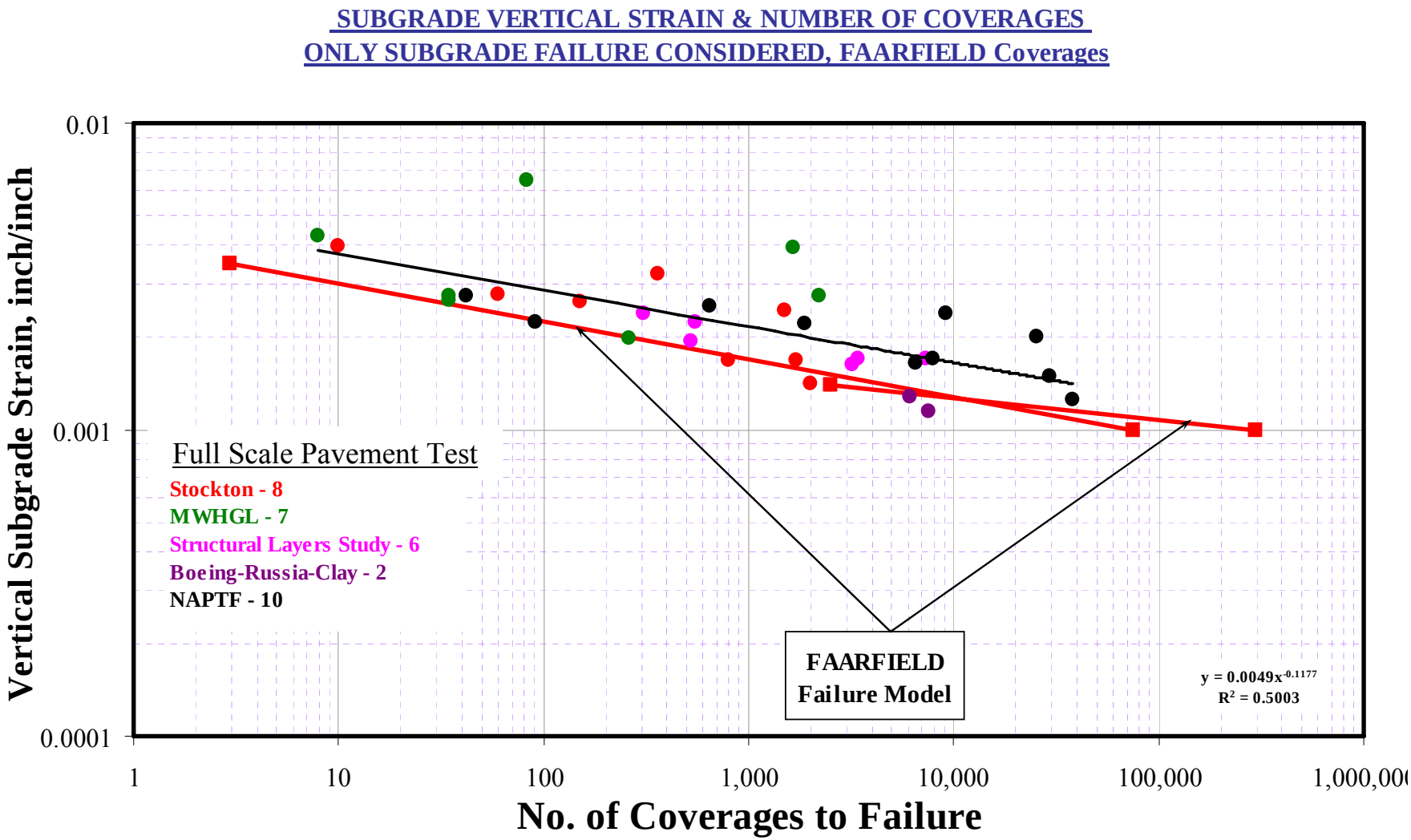
LAYER	ITEM	E (psi)	POISSON'S	FAA EQUIV
AC Surface	P401/403	200,000	0.35	NA
PCC Surface	P501	4,000,000	0.15	NA
Aggregate Base	P209	MODULUS	0.35	NA
Aggregate Subbase	P154	MODULUS	0.35	NA
AC Base	P401/403	400,000	0.35	1.6
AC Base (min)	Variable	150,000	0.35	1.2
AC Base (max)	Variable	400,000	0.35	1.6
CTB (min)	P301	250,000	0.20	NA
CTB	P304	500,000	0.20	NA
CTB (max)	P306	700,000	0.20	NA
Undefined (min)		1,000	0.35	NA
Undefined (max)		4,000,000	0.35	NA
Rubblized PCC (min)	EB66	200,000*	0.35	NA
Rubblized PCC (max)	EB66	400,000*	0.35	NA

** Still subject to change

Pavement Structural Design Life

- Default "design life" is for 20 years
- Structural design life indicates pavement performance in terms of allowable load repetitions before subgrade failure is expected.
- Structural life is determined based upon annual departures multiplied by 20 (yrs). This value may or may not correlate with calendar years depending upon actual pavement use.
- Pavement performance in terms of surface condition and other distresses which might affect the use of the pavement by airplanes is not directly reflected in the structural design life.

Chapter 3 Section 2 – Flexible Pavement Design



Chapter 3 Section 2 – Flexible Pavement Design

Vertical Strain at top of subgrade

$$C = \left(\frac{0.004}{\varepsilon_v} \right)^{8.1}$$

When C ≤ 12,100

$$C = \left(\frac{0.002428}{\varepsilon_v} \right)^{14.21}$$

When C > 12,100

Horizontal Strain at Bottom of Surface Layer

$$Log_{10}(C) = 2.68 - 5 \times Log_{10}(\varepsilon_h) - 2.665 \times Log_{10}(E_A)$$

REQUIRED INPUT VARIABLES

- Subgrade support conditions
  - CBR or Modulus
- Material properties of each layer
  - Modulus
  - Thickness for most layers
  - Poisson's Ratio -- fixed in FAARFIELD
- Traffic
  - Frequency of load application
  - Airplane characteristics
    - Wheel load, wheel locations, & tire pressure

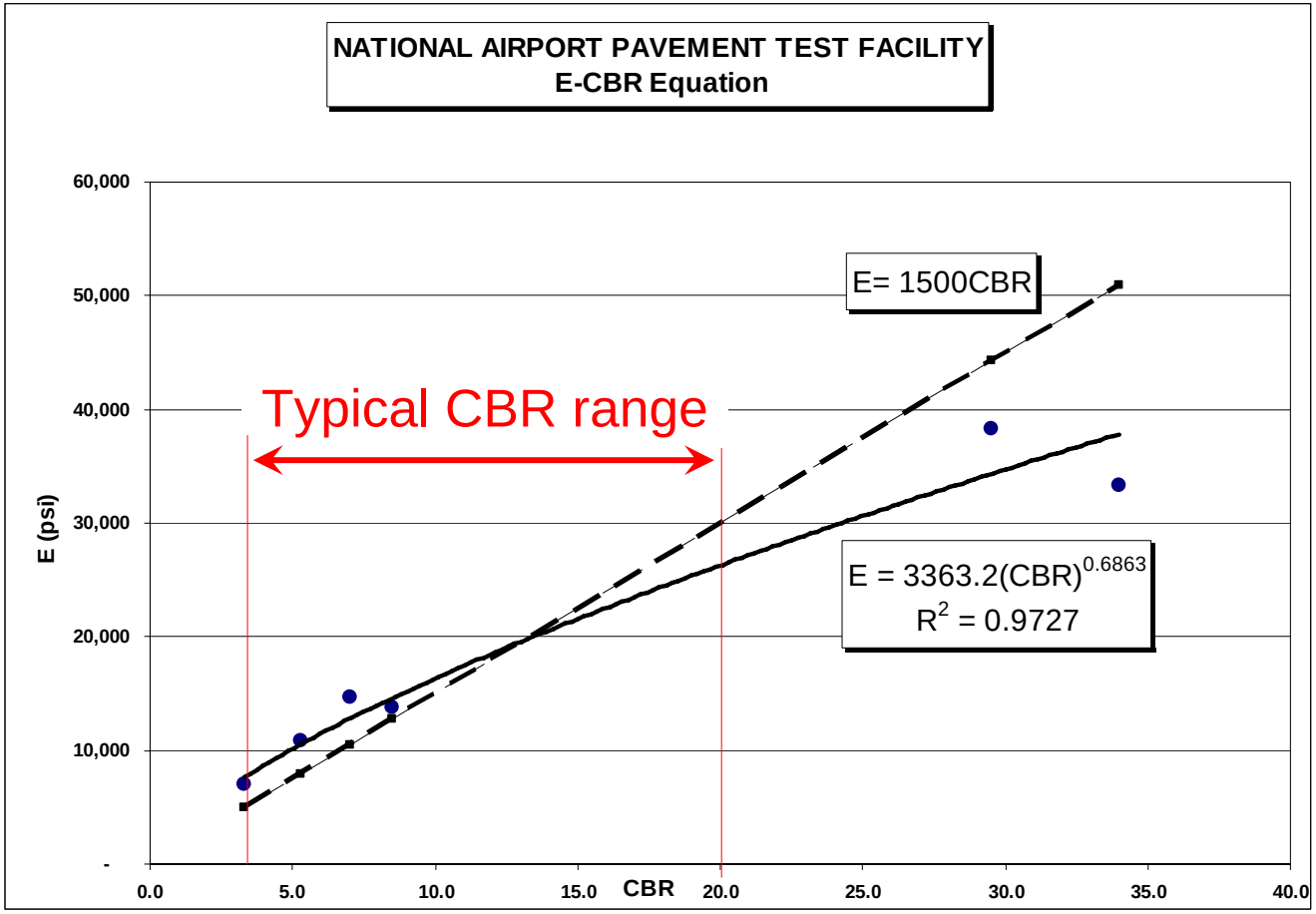
Subgrade Characteristics

- Subgrade assumed to have infinite thickness
- FAARFIELD will accept Elastic Modulus E (psi) or CBR values
- CBR is widely accepted and used by the industry
  - Relationship between E and CBR

E = 1500 X CBR (E in psi)

Subgrade Characteristics

E = 1500 X CBR



Subgrade Compaction Requirements – Table 3-4

Determined by airplane (in the traffic mix) with greatest demand

Indicates depth of compaction below subgrade

CRITICAL AIRCRAFT	Gross Weight Lb.	NON-COHESIVE SOILS Depth of Compaction, inch				COHESIVE SOILS Depth of Compaction, inch			
		100%	95%	90%	85%	95%	90%	85%	80%
S	30,000	8	8-18	18-32	32-44	6	6-9	9-12	12-17
	50,000	10	10-24	24-36	36-48	6	6-9	9-16	16-20
	75,000	12	12-30	30-40	40-52	6	6-12	12-19	19-25
D (incls. 2S)	50,000	12	12-28	28-38	38-50	6	6-10	10-17	17-22
	100,000	17	17-30	30-42	42-55	6	6-12	12-19	19-25
	150,000	19	19-32	32-46	46-60	7	7-14	14-21	21-28
	200,000	21	21-37	37-53	53-69	9	8-16	16-24	24-32
2D/D1, 2D/2D1 (incls. B757, B767, A-300, DC-10, L1011,A-340)	100,000	14	14-26	26-38	38-49	5	6-10	10-17	17-22
	200,000	17	17-30	30-43	43-56	5	6-12	12-18	18-26
	300,000	20	20-34	34-48	48-63	7	7-14	14-22	22-29
	400,000 – 600,000	23	23-41	41-59	59-76	9	9-18	18-27	27-36
2D/2D2 (incls. B747 series)	800,000	23	23-41	41-59	59-76	9	9-18	18-27	27-36
	975,000	24	24-44	44-62	62-78	10	10-20	20-28	28-37
3D (incls. B777 series)	550,000	20	20-36	36-52	52-67	6	6-14	14-21	21-29
	650,000	22	22-39	39-56	56-70	7	7-16	16-22	22-30
	750,000	24	24-42	42-57	57-71	8	8-17	17-23	23-30
2D/3D2 (incls. A380 series)	1,250,000	24	24-42	42-61	61-78	9	9-18	18-27	27-36
	1,350,000	25	25-44	44-64	64-81	10	10-20	20-29	29-38

Subgrade Compaction Requirements –Example

Cohesive soil,

Given the following traffic mixture

Airplane	Gross Weight (lbs)	Annual Departures
Sngl Whl-45	50,000	1000
A318-100 std	122,000	2000
B737-400	150,500	3000
B747-400	877,000	1600
B777-300 Baseline	662,000	1750
A330-300 opt	515.661	1500

Subgrade Compaction Requirements –Example

Cohesive soil,

Required depth of compaction from Table 3-4

Airplane	Gross Weight (lbs)	Annual Departures	95%	90%	85%	80%
Sngl Whl-45	50,000	1000	6	6-9	9-16	12-17
A318-100 std	122,000	2000	6	6-12	12-19	19-25
B737-400	150,500	3000	7	7-14	14-21	21-28
B747-400	877,000	1600	10	10-20	20-28	28-37
B777-300 Baseline	662,000	1750	7	7-16	16-22	22-30
A330-300 opt	515.661	1500	9	9-18	18-27	27-36

Asphalt Surface Layer Characteristics

- Minimum material requirements
  - P-401 or P-403
- Modulus fixed at 200,000 psi in FAARFIELD
  - Conservatively chosen to correspond to pavement surface temperature of 90° F
- 4 inch minimum thickness
- Asphalt as overlay has the same properties except for minimum thickness

Base Layer Characteristics

- Minimum material requirements
  - P-209, P-208, P-211, P-304, P-306, P-401, P-403, & rubblized PCC
- Design assumes minimum strength – CBR $\geq$ 80
- Aggregate layer modulus dependent on thickness
  - Modulus calculated by FAARFIELD is dependent on thickness
- Stabilization required - airplane gross weight > 100,000 lbs
- Minimum thickness requirements – by airplane

Chapter 3 Section 2 – Flexible Pavement Design

Minimum Aggregate Base Layer Thickness Requirements

Determined by the airplane in the traffic mix with greatest demand

Determination of minimum base layer thickness is automated in FAARFIELD

TABLE 3-9. Minimum Aggregate Base Course Thickness

Gear Type	Design Load Range lbs	Minimum Base Course (P-209) Thickness in.
S	30,000 - 50,000	4
	50,000 - 75,000	6
D	50,000 - 100,000	6
	100,000 - 200,000*	8
2D	100,000 - 250,000*	6
	250,000 - 400,000*	8
2D (B757, B767)	200,000 - 400,000*	6
2D/D1 (DC10, L1011)	400,000 - 600,000*	8
2D/2D2 (B747)	400,000 - 600,000*	6
	600,000 - 850,000*	8
2D/2D1 (A340)	568,000 – 840,400	10
2S (C130)	75,000 - 125,000	4
	125,000 - 175,000*	6
3D (B777)	537,000 – 777,000*	10
3D (A380)	1,239,000 – 1,305,125*	9

*Values are listed for reference. When traffic mixture contains airplanes exceeding 100,000 lbs gross weight, a stabilized base is required.

Base Layer Characteristics –When stabilization is required

FAARFIELD automates this process

- Changes section to P-401 on P-209 over CBR=20
- Determines P-209 thickness requirement
- Converts P-209 to stabilized material using 1.6 conversion factor
- Reconstructs section with minimum base and finishes design

User can disable this feature of FAARFIELD and do this process manually if desired.

Subbase Layer Characteristics

- Minimum material requirements
  - P-210, P-212, P-213, P-301,
- Design assumes minimum strength – CBR > 20
- Aggregate layer modulus dependent on thickness
  - Modulus calculated by FAARFIELD is dependent on thickness
- Thickness requirement determined as design solution

Subbase Layer Characteristics – When Stabilization is required

- Minimum material requirements
  - P-208 or P-209, or any stabilized base material
- Thickness requirement determined as design solution

Traffic Input for Flexible Pavement Design

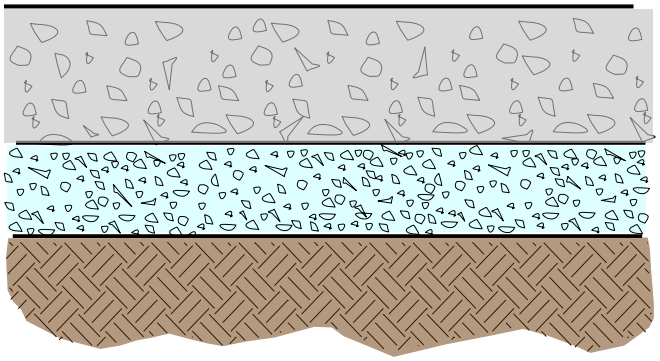
- Airplane characteristics
  - 198 Airplane models currently available in FAARFIELD
  - Wheel load – determined automatically based on gross weight
  - wheel locations – Internal to FAARFIELD aircraft library
  - tire pressure – Internal to FAARFIELD aircraft library
- Frequency of load application
  - Entered as annual departures
    - Arrival traffic ignored

RIGID PAVEMENT DESIGN

AC 150/5320-6E, Airport Pavement Design and Evaluation

CHAPTER 3, Section 3 – Rigid Pavement Design

Typical Rigid Pavement



Portland Cement Concrete (PCC)

Subbase Course **

Subgrade

** Stabilization required when airplanes exceeding 100,000 lbs are in the traffic mixture.

Chapter 3 Section 3 – Rigid Pavement Design

Surface	SUBBASE	SUBGRADE
P-501	P-154	P-152
	P-208	P-155*
	P-209	P-157*
	P-211	
	P-301	
	P-304*	
	P-306*	
	P-401*	
	P-403*	
	Rubblized PCC	

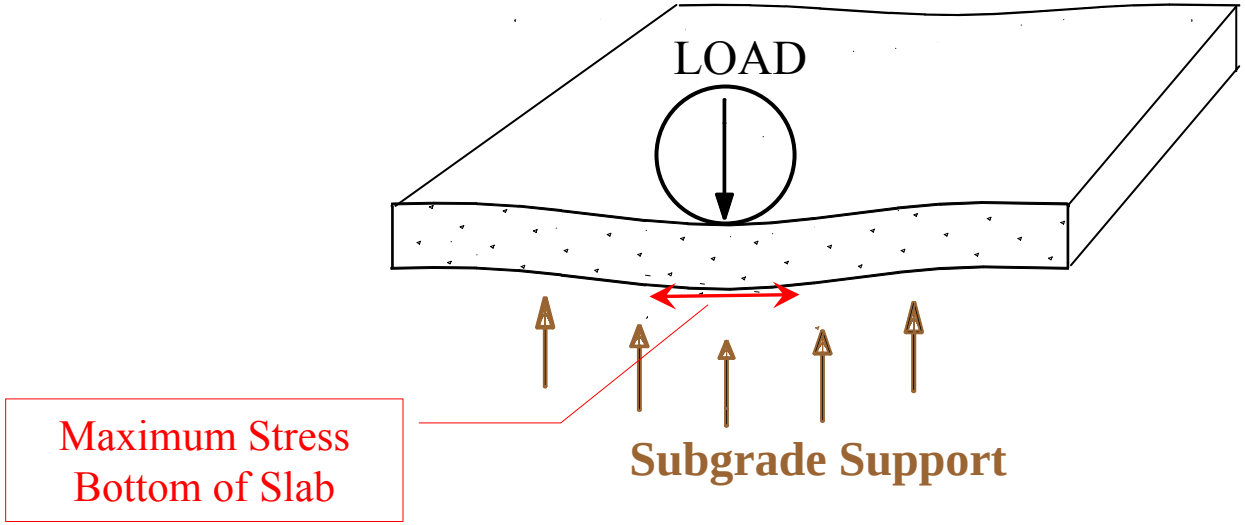
* Chemically Stabilized Materials

3-Dimensional Finite Element Design

- NEW procedure
- Rigid design uses 3-D finite element method (3D-FEM) for direct calculation of stress at the edge of a concrete slab.
- Predictor of pavement life
  - Maximum Stress at pavement edge
  - Assumed position – bottom at slab edge

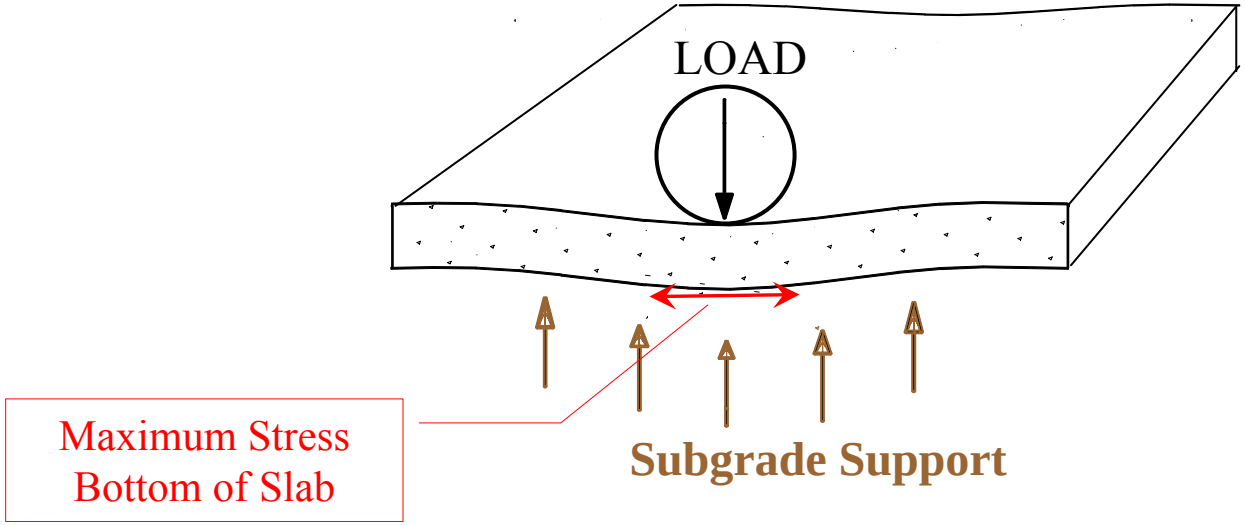
CRITICAL LOAD CONDITION ASSUMPTIONS

- Maximum stress at pavement edge
- 25% Load Transfer to adjacent slab



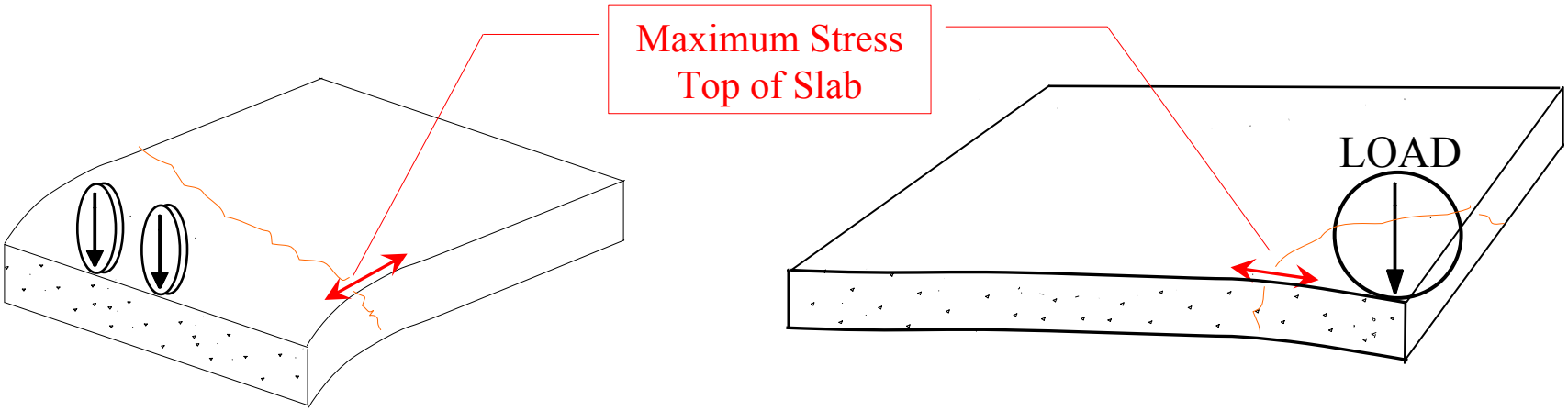
CRITICAL LOAD CONDITION ASSUMPTIONS

- Maximum stress at pavement edge
- 25% Load Transfer to adjacent slab



TOP DOWN CRACKING DUE TO EDGE OR CORNER LOADING NOT INCLUDED IN DESIGN

- Maximum stress due to corner or edge loading condition
- Risk increases with large multi-wheel gear configurations
- These conditions may need to be addressed in future procedures



Pavement Structural Design Life

- Default "design life" is for 20 years
- Structural design life indicates pavement performance in terms of allowable load repetitions before "First Crack" i.e. SCI = 80.
- Structural life is determined based upon annual departures multiplied by 20 (yrs). This value may or may not correlate with calendar years depending upon actual pavement use.
- Pavement performance in terms of surface condition and other distresses which might affect the use of the pavement by airplanes is not directly reflected in the structural design life.

Rigid pavement failure model in FAARFIELD

$$\frac{DF}{F_c} = \left[\frac{F_s' bd}{\left(1 - \frac{SCI}{100}\right)(d - b) + F_s' b} \right] \times \log C + \left[\frac{\left(1 - \frac{SCI}{100}\right)(ad - bc) + F_s' bc}{\left(1 - \frac{SCI}{100}\right)(d - b) + F_s' b} \right]$$

DF **= design factor, defined as the ratio of concrete strength *R* to computed stress**

C **= coverages**

SCI **= structural condition index, defined as a subset of the pavement condition index (PCI) excluding all non-load related distresses from the computation**

a, b, c, d **= parameters**

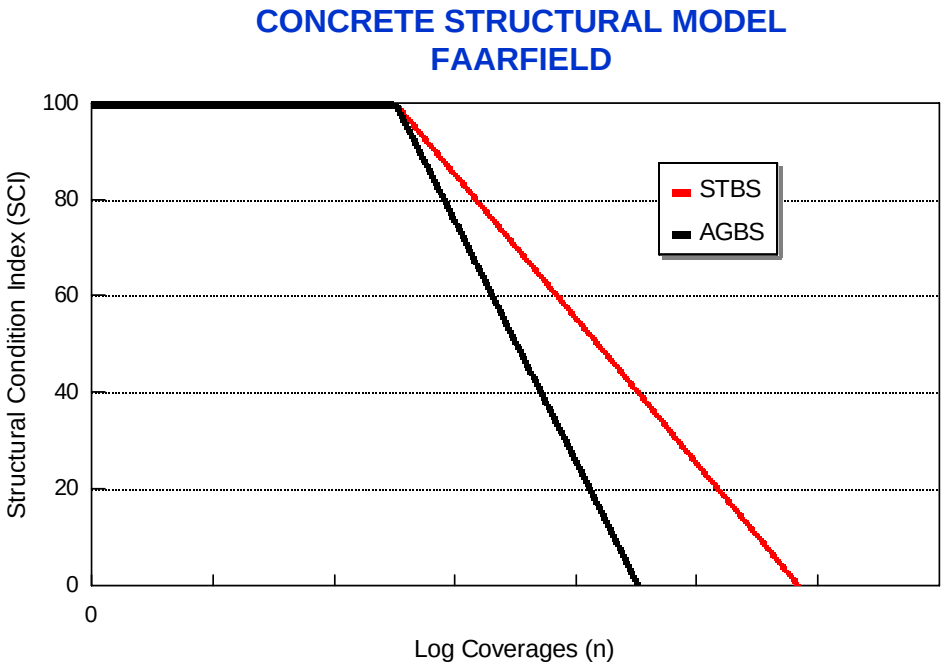
F'_s = compensation factor for high quality and stabilized base

F_c = calibration factor

Rigid pavement failure model in FAARFIELD

Initial cracking occurs at the same time for aggregate and stabilized subbase

Stabilized section performs better (longer life) after initial cracking



REQUIRED INPUT VARIABLES

- Subgrade support conditions
  - k-value or Modulus
- Material properties of each layer
  - Modulus for all layers (flexural strength for PCC)
  - Thickness for all layers except surface PCC
  - Poisson's Ratio – fixed in FAARFIELD
- Traffic
  - Frequency of load application
  - Airplane characteristics
    - Wheel load, wheel locations, & tire pressure

Subgrade Characteristics

- Subgrade assumed to have infinite thickness
- FAARFIELD accepts Resilient Modulus E_{SG} or k-value (only necessary to enter one value)
  - Converts k-value to modulus

$$E_{SG} = 26k^{1.284}$$

E_{SG} = Resilient modulus of subgrade, in psi

k = Foundation modulus of the subgrade, in pci

AASHTO T 222, Nonrepetitive Static Plate Load Test of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements

Subgrade Characteristics

k-value can be estimated from CBR value

$$k = \left[\frac{1500 \times CBR}{26} \right]^{0.7788}$$

k = Foundation modulus of the subgrade, in pci

Subbase Layer Characteristics

- Minimum material requirements
  - P-154, P-208, P-209, P-211, P-301, P-304, P-306, P-401, P-403, & rubblized PCC
- Up to three subbase layers allowed in FAARFIELD
- Aggregate layer modulus dependent on thickness
  - Modulus calculated by FAARFIELD based on thickness
- 4 inch minimum thickness requirement

Portland Cement Concrete Layer Characteristics

- Minimum material requirements
  - P-501
- Flexural Strength as design variable
  - FAA recommends 600 – 700 psi for design purposes
  - FAARFIELD will allow 500 – 800 psi
  - ASTM C 78 Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
  - Modulus fixed at 4,000,000 psi
- 6 Inch minimum thickness requirements
- Thickness rounded to the nearest 0.5 inch

Design Flexural Strength versus P-501 Specification

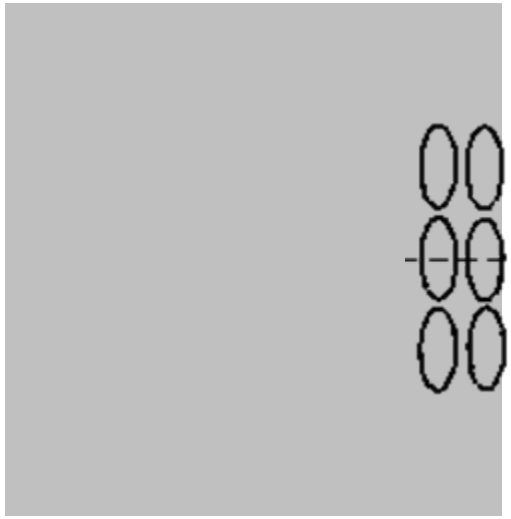
- Design Strength can be 5% greater than P-501 28-day strength
- e.g. P-501 = 650 psi then design at 680 psi
- Factors to Consider:
  - Capability of the industry in a particular area to produce desired strength
  - Flexural strength vs. cement content data from prior projects at the airport
  - Need to avoid high cement contents, which can affect concrete durability
  - Whether early opening requirements necessitate using a lower strength than 28-day

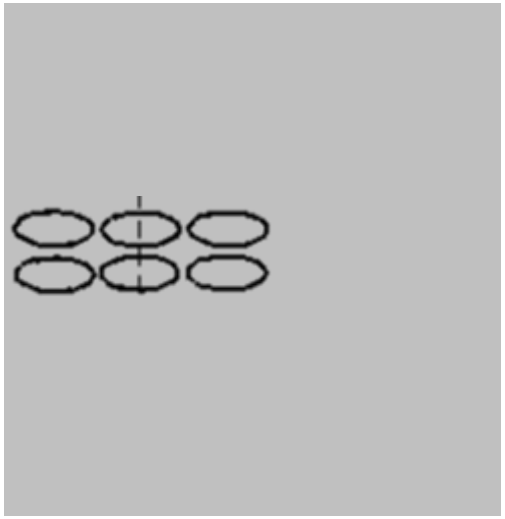
Traffic Input for Rigid Pavement Design

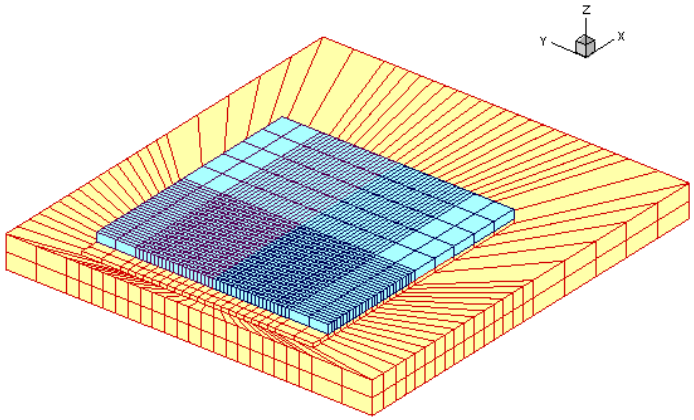
- Airplane characteristics
  - 198 Airplane models currently available in FAARFIELD
  - Wheel load – determined automatically based on gross weight
  - wheel locations – Internal to FAARFIELD aircraft library
  - tire pressure – Internal to FAARFIELD aircraft library
- Frequency of load application
  - Entered as annual departures
    - Arrival traffic ignored
    - User determines percent of total airport volume

FAArfield – Gear Alignment on slab edge

- FAARFIELD either places the gear perpendicular or parallel to the edge of a slab.
- FAARFIELD makes this determination.







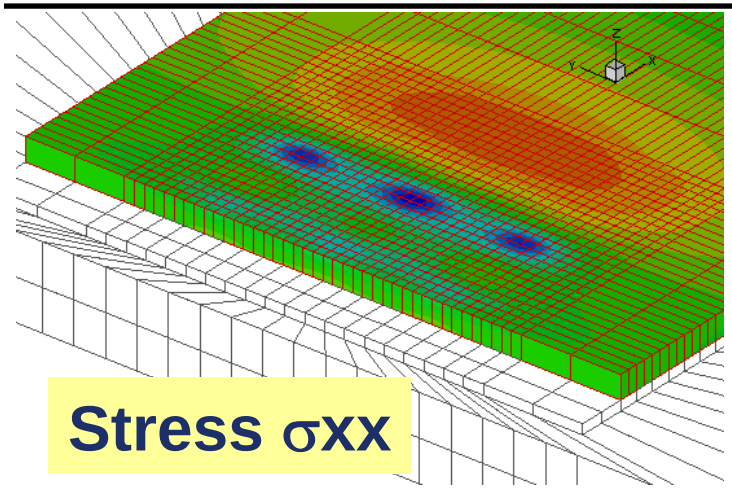
Key Advantages of 3-D Model

- Correctly models rigid pavement features - slab edges and joints.
- Provides the complete stress and displacement fields for the analyzed domain.
- Handles complex load configurations easily.
- No inherent limitation on number of structural layers or material types.
- Not limited to linear elastic analysis.

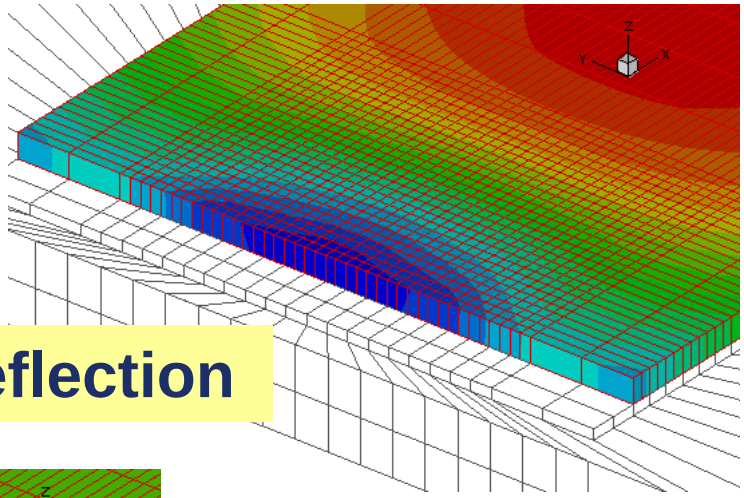
Disadvantages of 3D-FEM

- May require long computation times.
- Pre-processing and post-processing requirements.
- Solution are mesh-dependent.
  - In theory, the solution can always be improved by refining the 3D mesh.
  - Improvement comes at the expense of time.

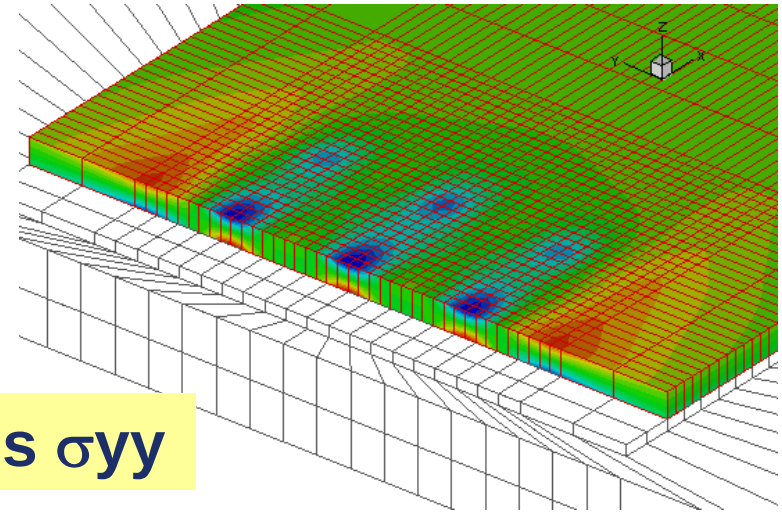
Chapter 3 Section 3 – Rigid Pavement Design
3D-FEM Solution



Stress σxx



Deflection



Stress σyy

3D Finite Element is:

A method of structural analysis.

Applicable to a wide range of physical structures, boundary and loading conditions.

3D Finite Element is <u>not</u>:

A design method or procedure.

An exact mathematical solution.

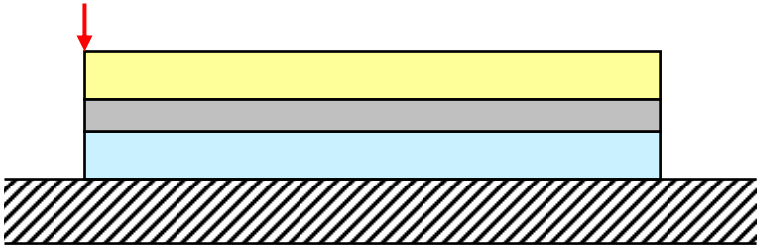
Always preferable to other analysis models.

Structures and Models

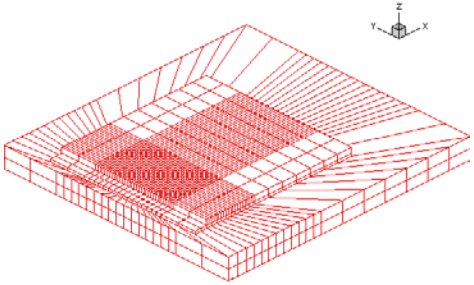
In finite element analysis, it is important to distinguish:

The physical structure

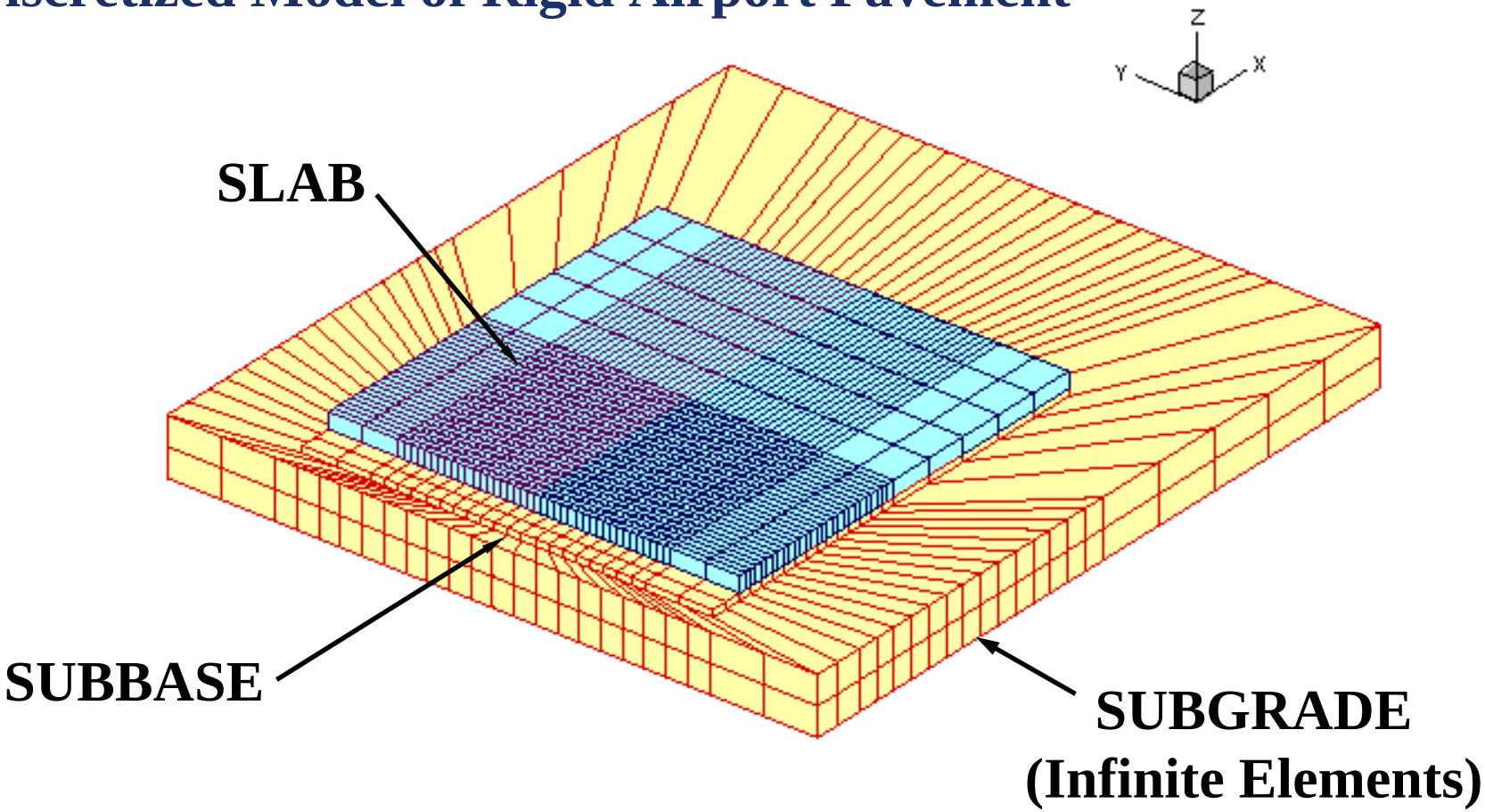
The idealized model



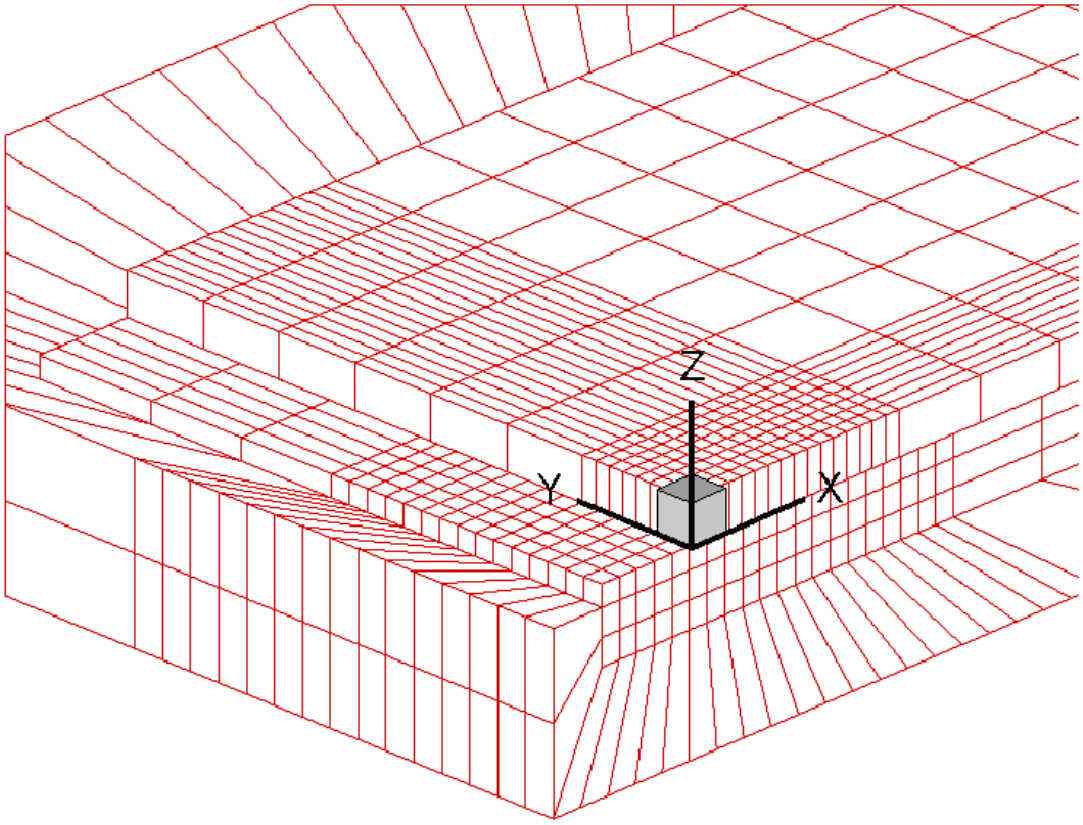
The discretized (approximate) model



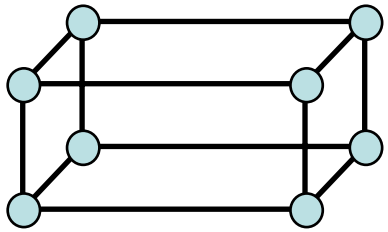
Discretized Model of Rigid Airport Pavement



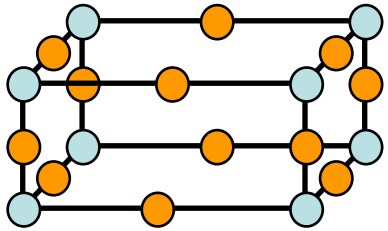
Discretized Model of Rigid Airport Pavement



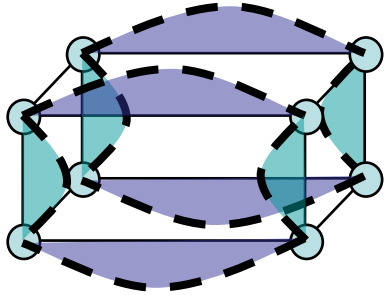
Types of 3D Elements



Linear (8-Node) Brick

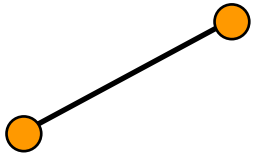


Quadratic (20 -Node) Brick

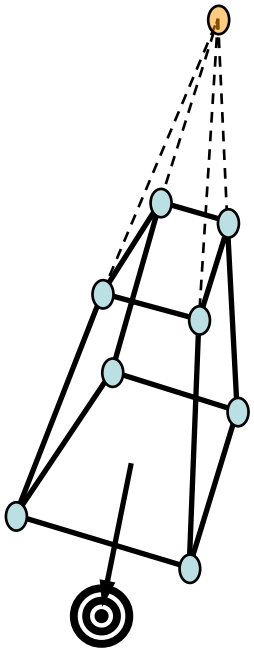


Nonconforming (Incompatible Modes)

Equal to 6-8 layers of ordinary 8-node element

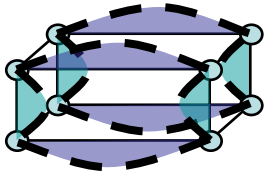


Axial (1-D)



Focal Point

Infinite Element



8-node Incompatible solid element

Horizontal Mesh Size

6” X 6” mesh size selected for FAARFIELD

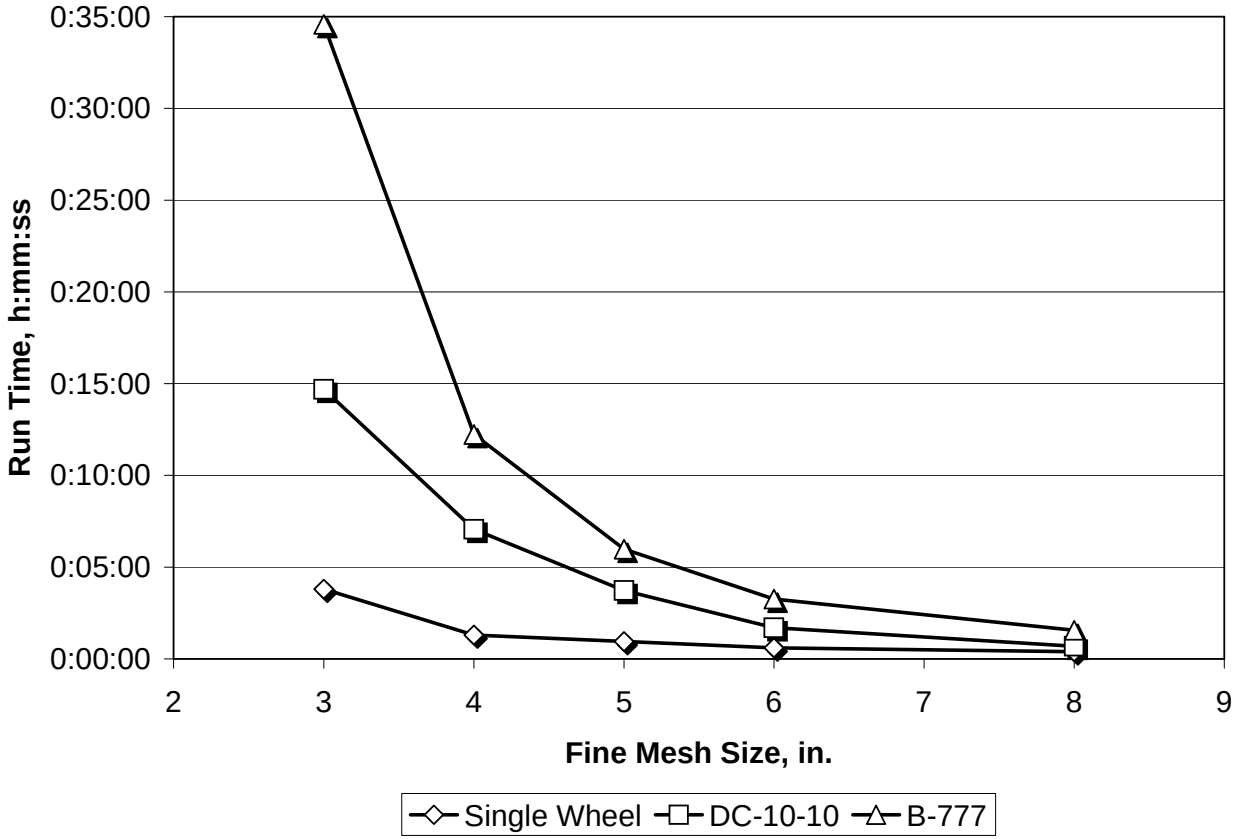
- 96-99% accuracy
- 3 - 6 time faster solution than 4X4 (multiple wheel gear analysis)
- 20 – 55 times faster solution the 2X2 (multiple wheel gear analysis)

Vertical Mesh Size

Single element selected for FAARFIELD (slab thickness)

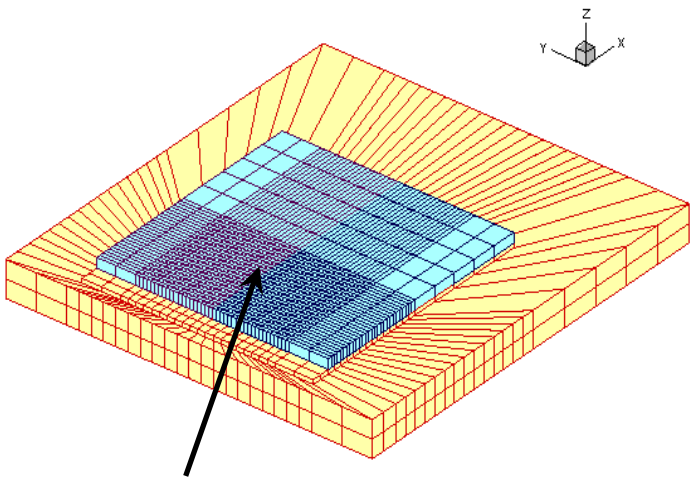
- Produced similar results when compared to 6 element (3”) mesh

Effect of Mesh Size on Run Time (Using Windows XP, Pentium-4, 512MB)

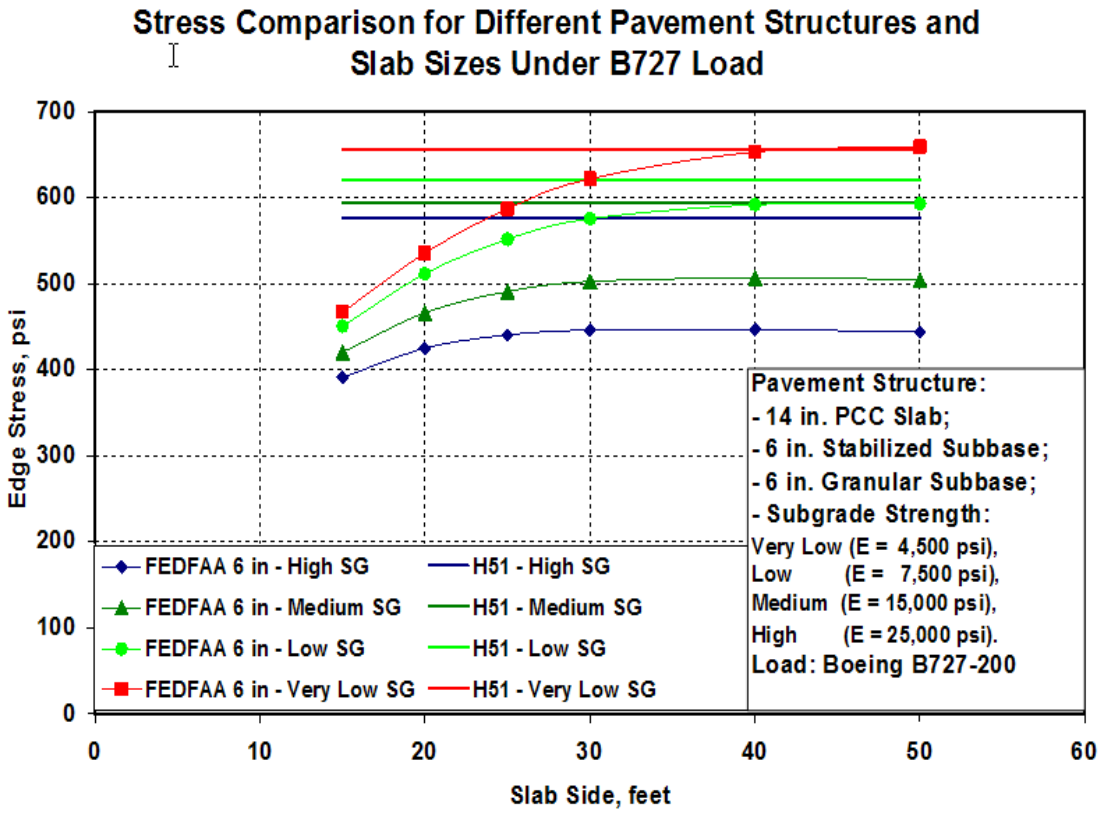


Discretized Model – Slab Size

30ft X 30ft slab size selected for FAARFIELD

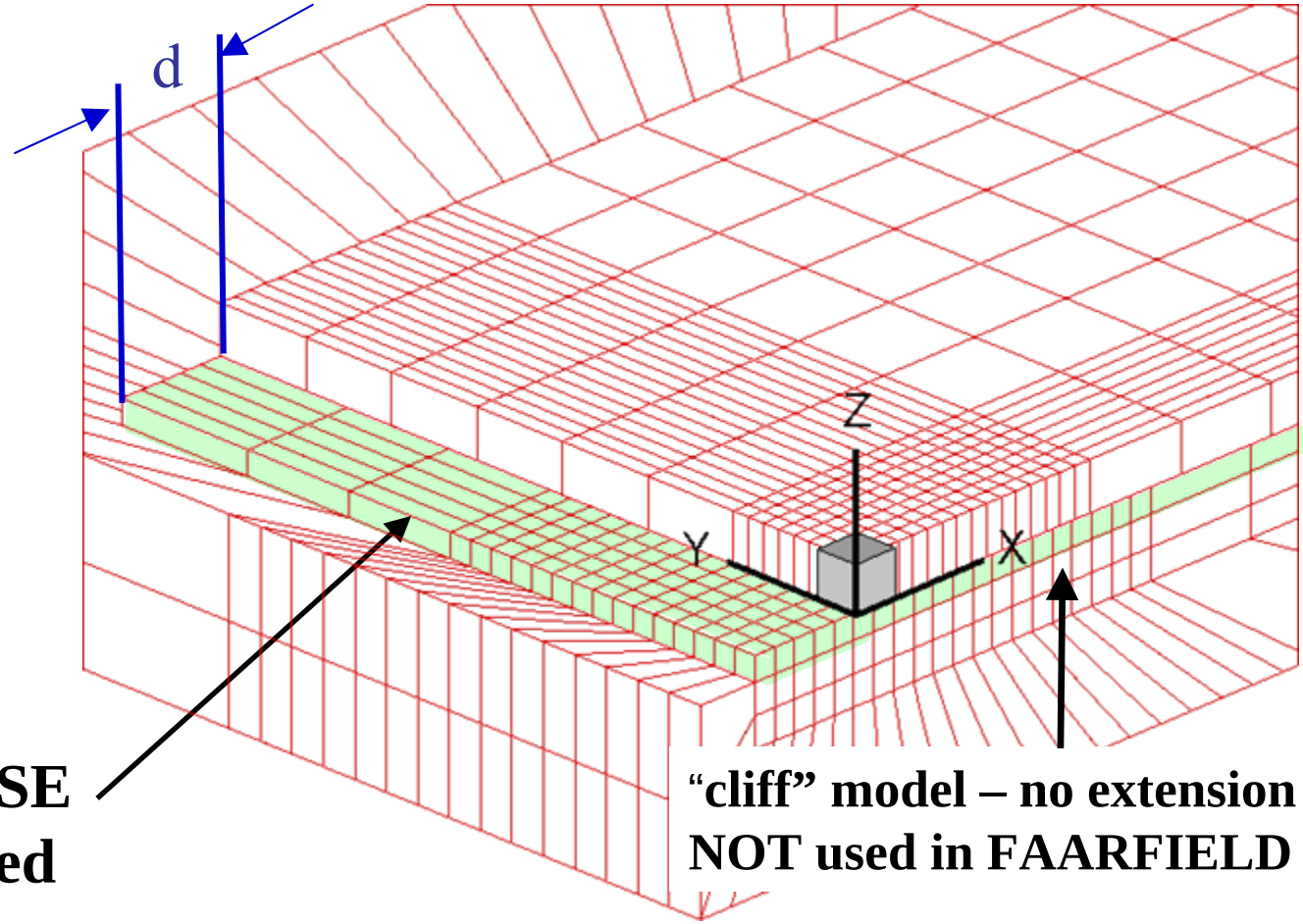


SLAB Size for model



Discretized Model – Subbase Extension

To provide a more realistic model of the edge-loaded slab response, all pavement layers below the slab are extended some distance "d"

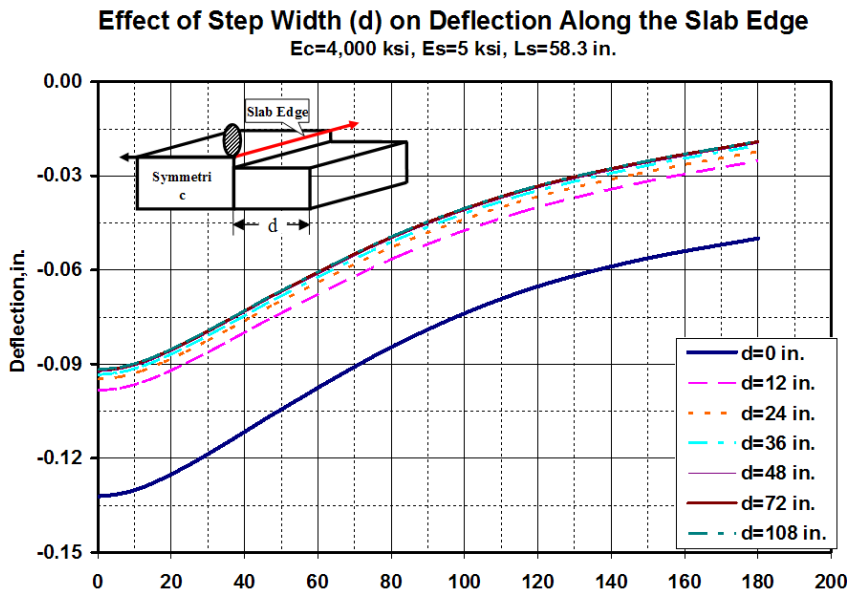


SUBBASE Extended

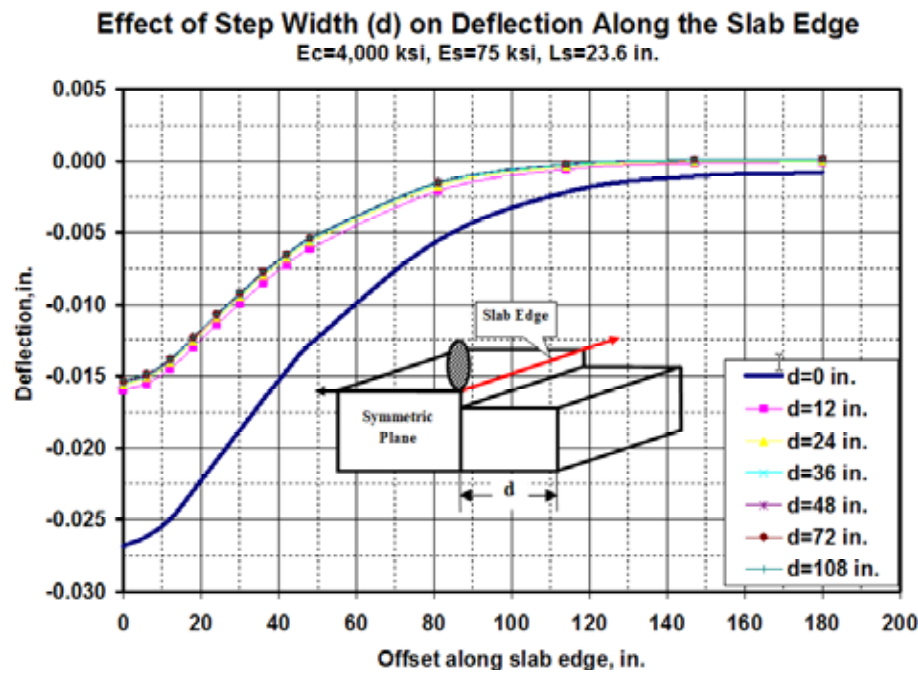
"cliff" model – no extension NOT used in FAARFIELD

Discretized Model – Subbase Extension
Deflection along the Slab Edge

Low Strength subgrade

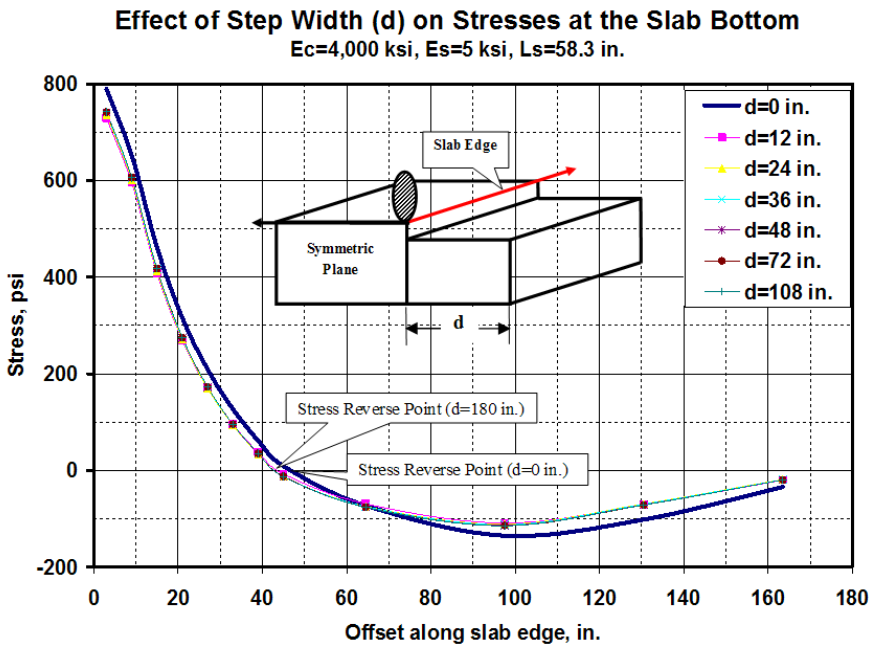


High Strength subgrade

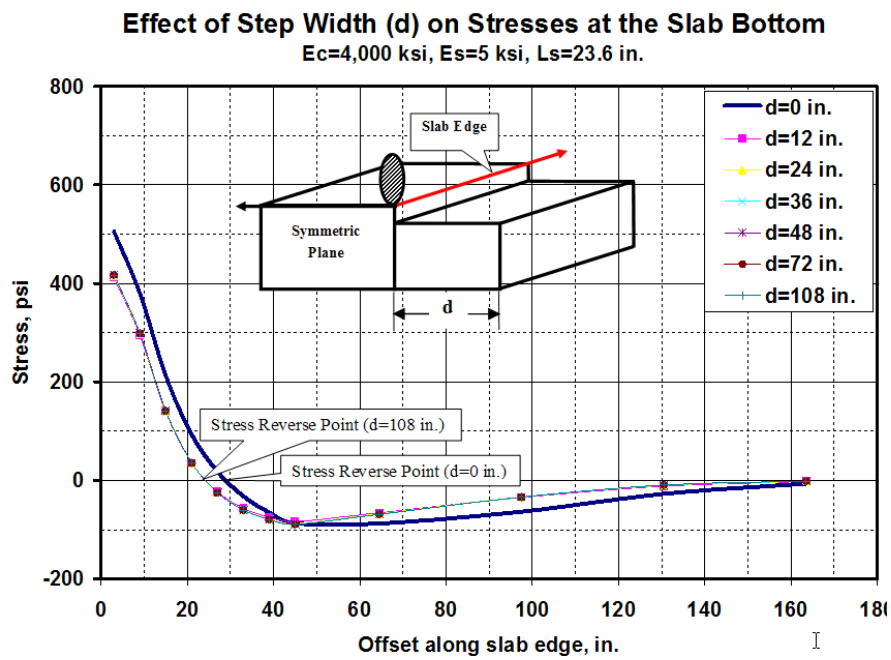


Discretized Model – Subbase Extension
Stress at the Slab Bottom

Low Strength subgrade



High Strength subgrade



Discretized Model – Subbase Extension

The width "d" of the extended step foundation used in FAArfield is 24 inches

The Stress difference using 24 inches or longer is negligible

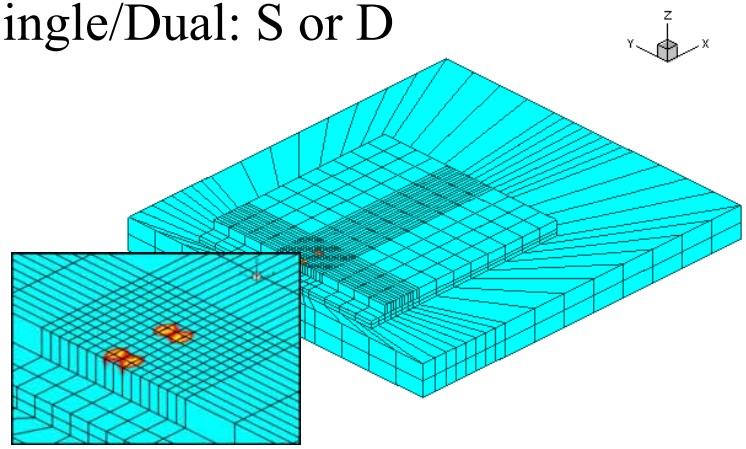
	Step width, *d*		Diff. in %
Responses	***d* = 24 inches**	***d* = 108 inches**	
Critical Stress at the Bottom, l_S = 58.3 inches (psi)	**736.2**	**741.8**	**0.8**
Critical Stress at the Bottom, l_S = 23.6 inches (psi)	**415.6**	**417.0**	**0.3**
Maximum Deflection, l_S = 58.3 inches (inches)	**94.8**	**91.8**	**3.2**
Maximum Deflection, l_S = 23.6 inches (inches)	**15.6**	**15.3**	**2.0**

Handling Mixed Aircraft Traffic in FAARFIELD

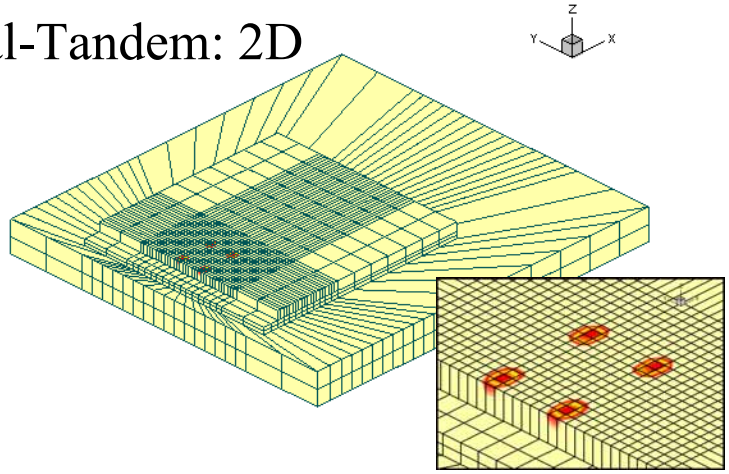
- FAARFIELD groups airplanes into 4 categories:
  - Single wheel, dual wheel (e.g., B-737).
  - Dual tandem (e.g., B-767, B-747).
  - Triple dual tandem (e.g., B-777).
  - Complex gear configuration (C-5, C-17A).
- All airplanes in a category are analyzed with one call to calculation subroutine (NIKE3D), using the same mesh.
- Results in significant savings in computation time.

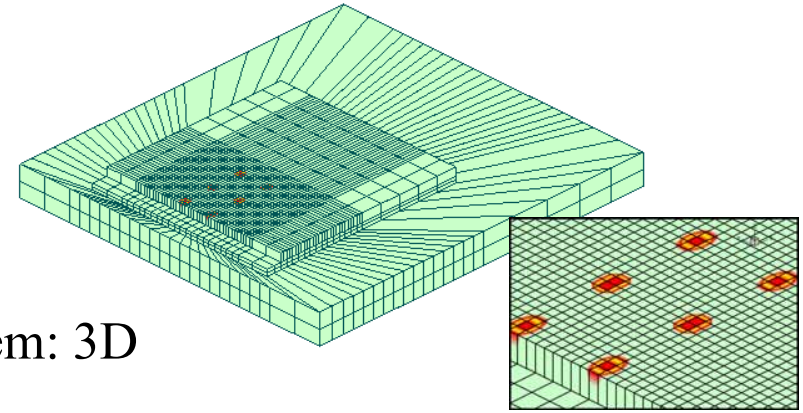
3D FEM Mesh Optimization

Single/Dual: S or D



Dual-Tandem: 2D





Triple Dual Tandem: 3D

Improvement in Solution Time

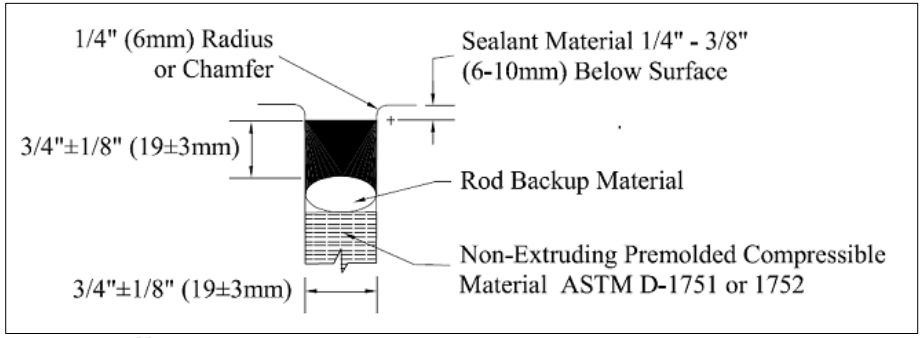
- **Approximate time for B-777 stress solution:**
  - July 2000: 4 - 5 hours
  - July 2001: 30 minutes
    (single slab with infinite element foundation)
  - May 2002: 2 - 3 minutes
    (implement new incompatible modes elements)
  - Current version implemented in FAARFIELD:
    10 seconds or less

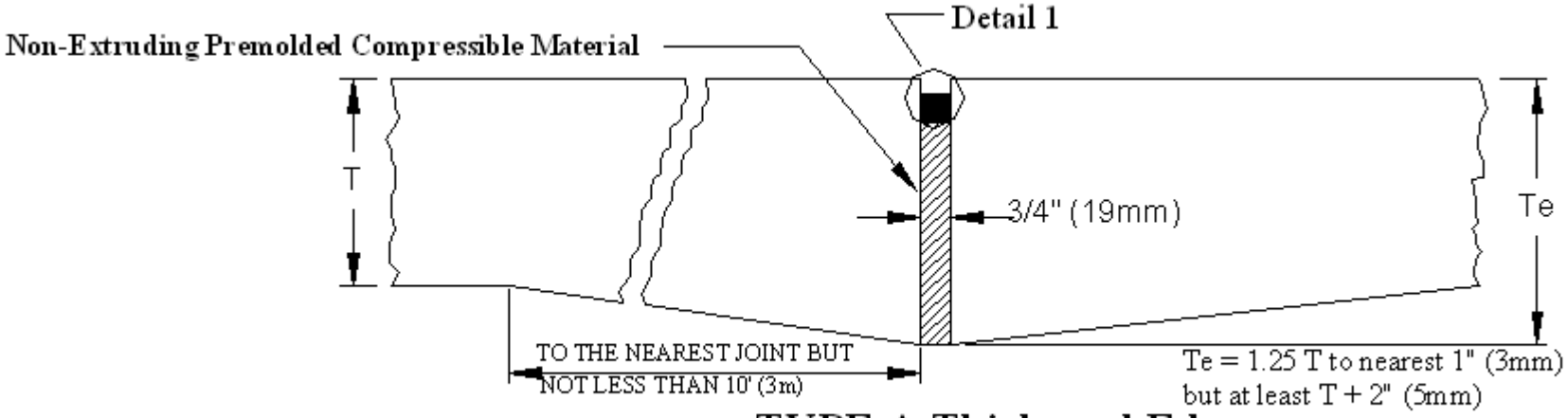
Rigid Pavement Joint Types and Details

- **5 joint types provided in 5320-6E**
  - Isolation Joints
    - Type A – Thickened Edge
  - Contraction Joints
    - Type B – Hinged
    - Type C – Doweled
    - Type D – Dummy
  - Construction Joints
    - Type E – Doweled

Rigid Pavement Joint Types and Details

- **Isolation Joints**
  - Type A – Thickened Edge

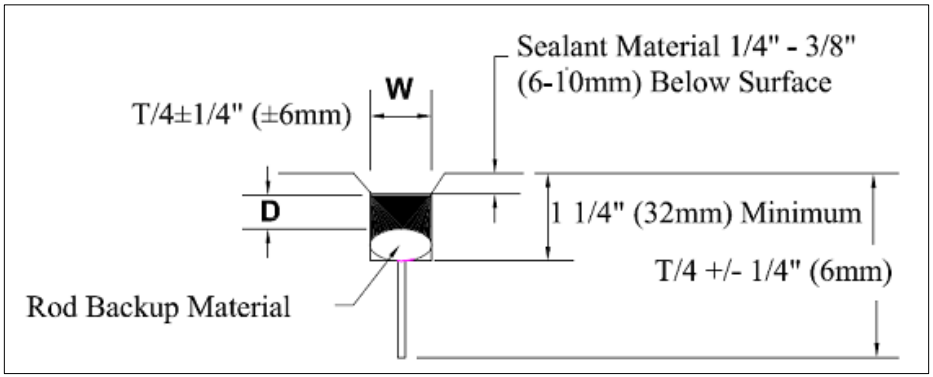


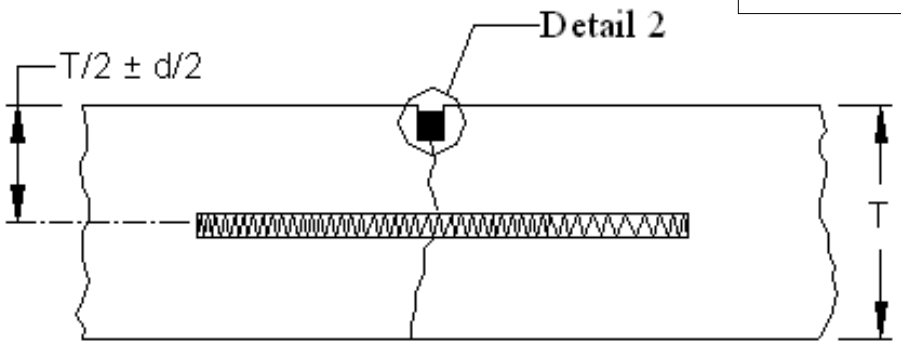


TYPE A Thickened Edge

Rigid Pavement Joint Types and Details

- **Contraction Joints**
  - Type B – Hinged



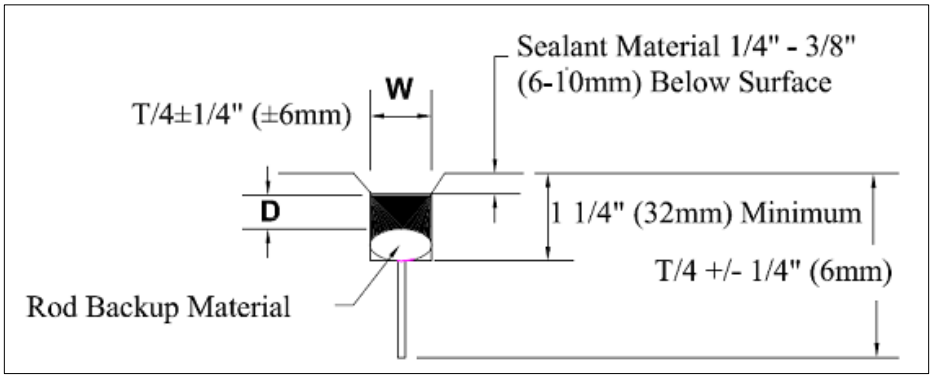


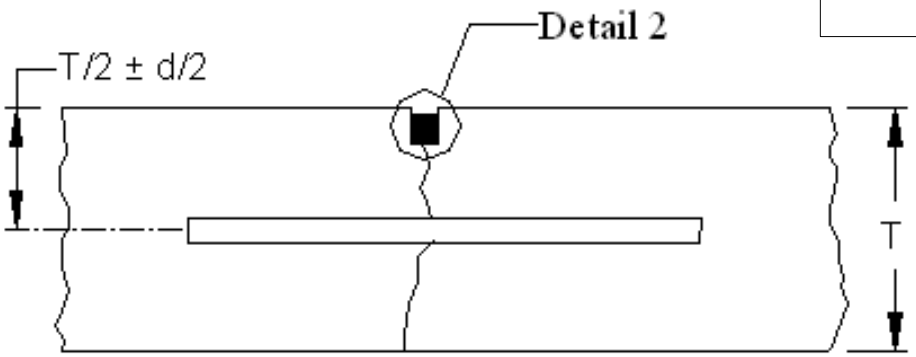
Tie Bar 30" (76 cm) Long on 30" (76cm) Centers

TYPE B Hinged

Rigid Pavement Joint Types and Details

- **Contraction Joints**
  - Type C – Doweled



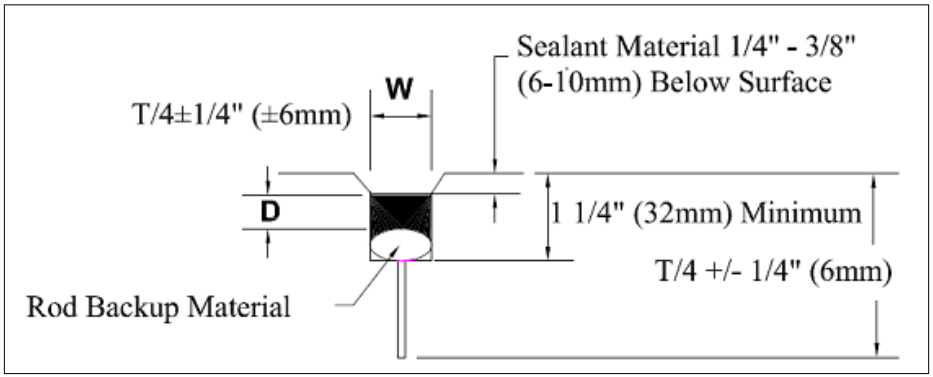


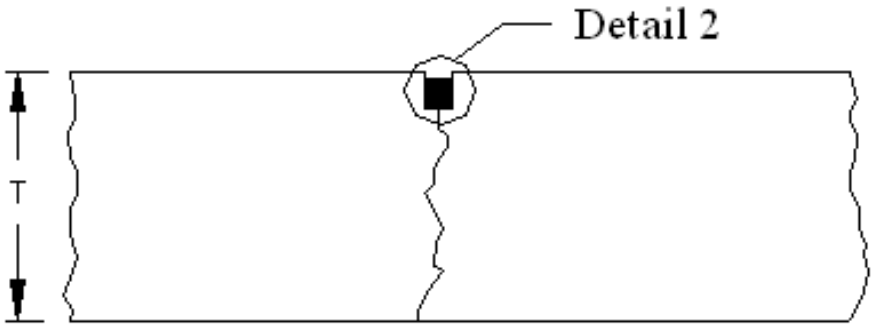
Paint and Oil One End of Dowel

TYPE C Doweled

Rigid Pavement Joint Types and Details

- **Contraction Joints**
  - Type D – Dummy



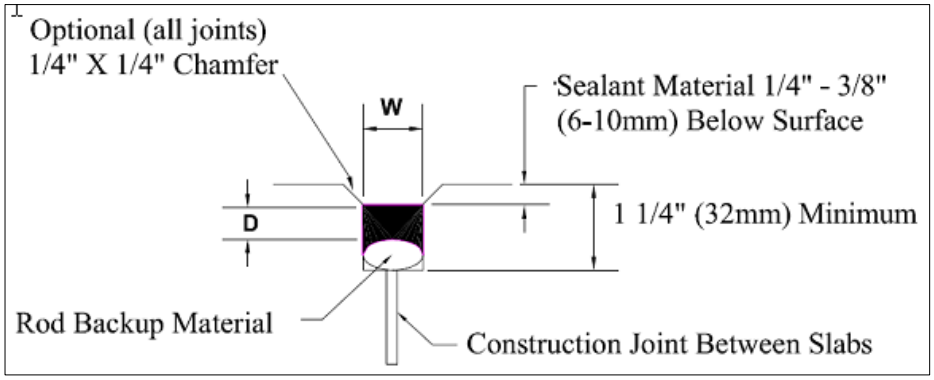


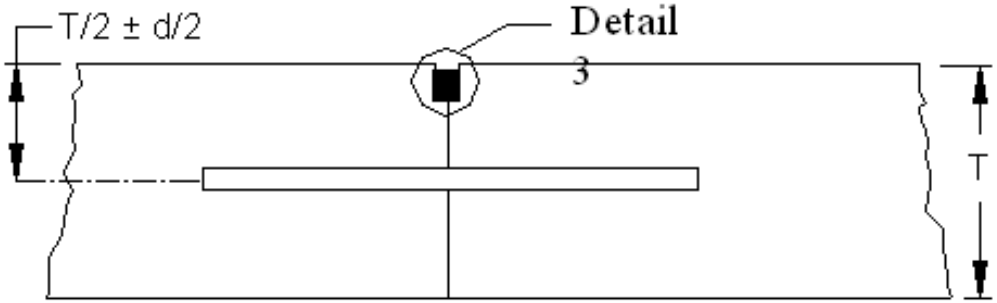
TYPE D Dummy

Rigid Pavement Joint Types and Details

➢ Construction Joints

- Type E – Doweled



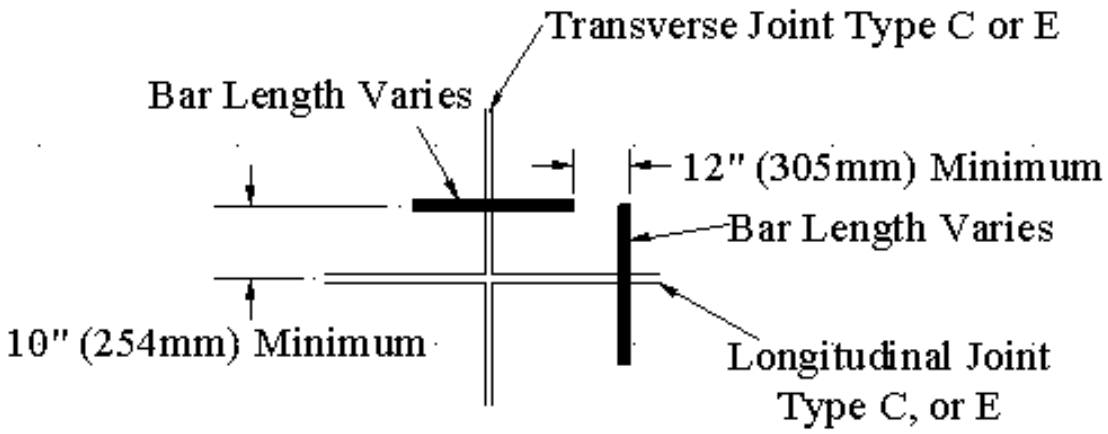


Paint and Oil One End of Dowel

TYPE E Doweled

Rigid Pavement Joint Types and Details

- **Dowel Bar Spacing at Slab Corner**



Rigid Pavement Joint Spacing

TABLE 3-16. RECOMMENDED MAXIMUM JOINT SPACINGS - RIGID PAVEMENT WITH OR WITHOUT STABILIZED SUBBASE

Part I, without Stabilized Subbase			
Slab Thickness		Joint Spacing[1]	
Inches	Millimeters	Feet	Meters
6	150	12.5	3.8
7-9	175-230	15	4.6
>9	>230	20	6.1

Part II, with Stabilized Subbase			
Slab Thickness		Joint Spacing[1]	
Inches	Millimeters	Feet	Meters
8–10	203-254	12.5	3.8
11-13	279-330	15	4.6
14-16	356-406	17.5[2]	5.3[2]
>16	>406	20	6.1

CHAPTER 4

AIRPORT PAVEMENT OVERLAYS AND RECONSTRUCTION

Chapter 4 – Airport Pavement Overlays.

OVERLAY TYPES

- **Flexible**

  Hot Mix Asphalt over existing flexible pavement

  Hot Mix Asphalt over existing rigid pavement

- **Rigid**

  PCC over existing flexible pavement (whitetopping)

  PCC bonded to existing PCC

  PCC unbonded to existing PCC

Deleted partially bonded PCC

Chapter 4 – Airport Pavement Overlays.

Overlay design requires the FAARFIELD program

Input variables include:

- Existing pavement structure
  - Including material properties and traffic requirements
- Existing pavement condition
  - Flexible – requires engineering judgment
  - Rigid – use Structural Condition Index (SCI)

Structural Condition Index (SCI)

- Derived from the Pavement Condition Index as determined by ASTM D 5340 Airport Pavement Condition Index Surveys
- SCI is computed using only structural components from the PCI survey (6 of 15 distress types)
  - SCI will always be greater than or equal to the PCI
- SCI = 80 – FAA definition of structural failure
  - 50% of slabs with structural crack

Structural Condition Index (SCI)

TABLE 4-1. RIGID PAVEMENT DISTRESS TYPES USED TO CALCULATE THE STRUCTURAL CONDITION INDEX, (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
Spalling–Corner	Low, Medium, High

Cumulative Damage Factor Used (CDFU)

- SCI = 100 when there is no visible distress contributing to reduction in SCI (no structural distress types)
- Condition of existing pavement described by CDFU

Cumulative Damage Factor Used (CDFU)

- **CDFU defines amount of structural life used**

  For structures with aggregate base

$$CDFU = \frac{L_U}{0.75\,L_D} \quad \text{when } L_U < 0.75\,L_D$$
$$= \quad 1 \quad \text{when } L_U \geq 0.75\,L_D$$

LU = number of years of operation of the existing pavement until overlay
LD = design life of the existing pavement in years

- **FAARFIELD modifies this relationship for stabilized subbase to reflect improved performance**

Overlay on Rubblized Concrete Pavement

- Design process is similar to HMA over existing flexible
- Rubblized PCC layer is available in FAARFIELD
  - Recommended modulus values 200,000 to 400,000 psi
  - Thinner PCC layers warrant lower modulus values
  - Final values may change with AAPTP report

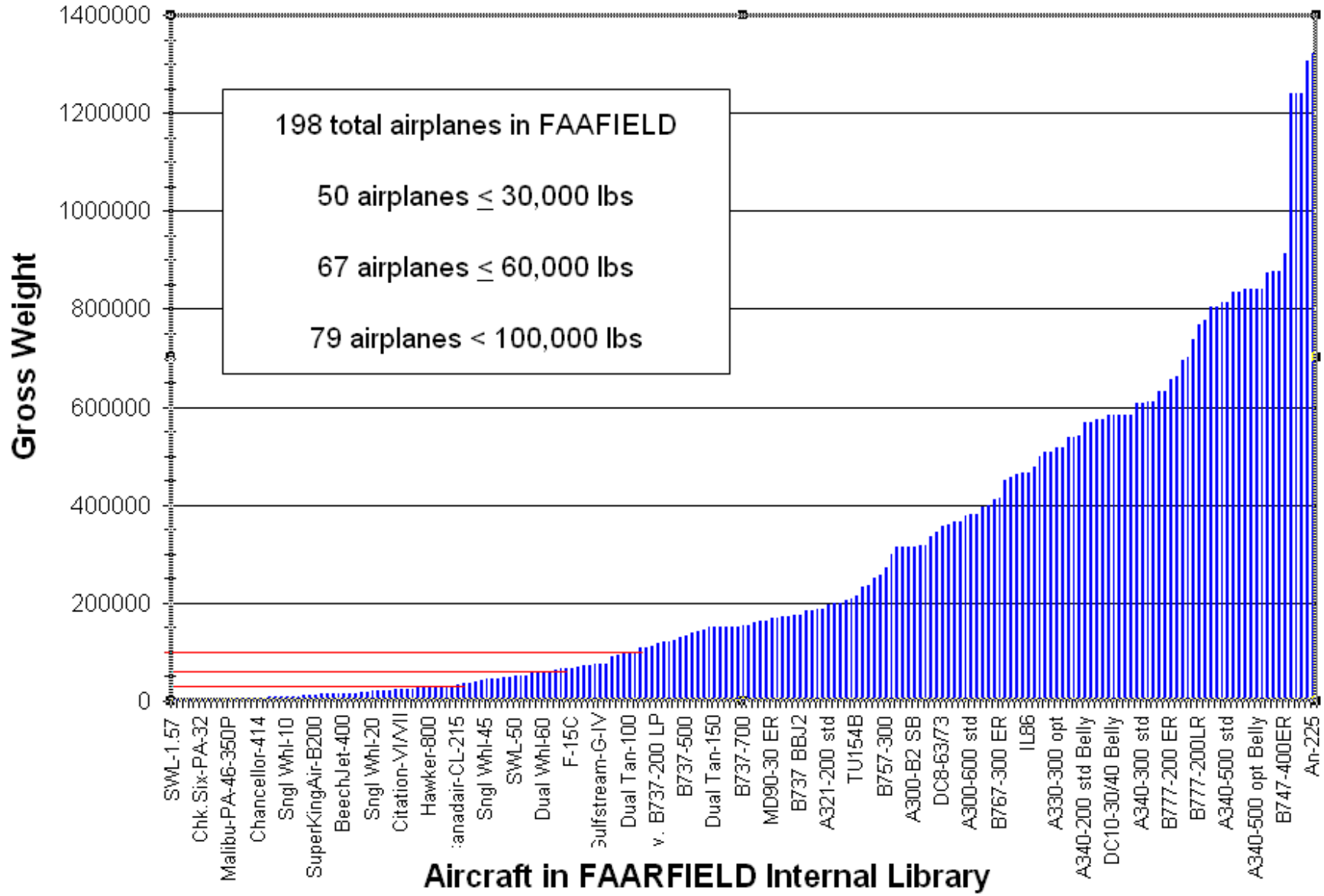
Chapter 5
Pavements for Light Aircraft

Chapter 5 –Pavements For Light Aircraft

Pavement design for airplanes weighing less than 30,000 lbs

- Flexible pavement design procedure requires FAARFIELD
- Rigid pavement design procedure – fixed thickness
- Aggregate -Turf pavement

Chapter 5 –Pavements For Light Aircraft



Chapter 5 –Pavements For Light Aircraft

Flexible Pavement -- airplanes weighing less than 30,000 lbs

- Hot Mix Asphalt surface course requirements
  - P-401 or P-403
  - State Standards permitted for < 12,500 lbs
- Minimum thickness = 2 inches over aggregate base

Chapter 5 –Pavements For Light Aircraft

Flexible Pavement -- airplanes weighing less than 30,000 lbs

Base Layer Requirements

- Minimum material requirements
  - P-208, P-209, P-210, P-211, P-212, P-213, P-301, P-304, P-306, P-401, & P-403 (some local materials)
- Design assumes minimum strength – CBR $\geq$ 80
- Minimum thickness of aggregate = 3 inches
- Aggregate layer modulus dependent on thickness
  - Modulus calculated by FAARFIELD is dependent on thickness

Chapter 5 –Pavements For Light Aircraft

Flexible Pavement -- airplanes weighing less than 30,000 lbs

Subbase Layer Requirements

- Suitable material requirements
  - P-154, P-208, P-209, P-210, P-211, P-212, P-213, P-301, P-304, P-306, P-401, & P-403 (some local materials)
- Design assumes minimum strength – CBR $\geq$ 20
- No minimum thickness
- Aggregate layer modulus dependent on thickness
  - Modulus calculated by FAARFIELD is dependent on thickness

Chapter 5 –Pavements For Light Aircraft

Flexible Pavement -- airplanes weighing less than 30,000 lbs

Subgrade Compaction Requirements

TABLE 5-1. SUBGRADE COMPACTION REQUIREMENTS FOR LIGHT LOAD FLEXIBLE PAVEMENTS

Design Aircraft Gross Weight lbs	Noncohesive Soils Depth of Compaction (in.)				Cohesive Soils Depth of Compaction (in.)			
	100%	95%	90%	85%	95%	90%	85%	80%
12,500 or less	6	6-9	9-18	18-24	4	4-8	8-12	12-15
12,501 or more	8	8-12	12-24	24-36	6	6-9	9-12	12-15

Chapter 5 –Pavements For Light Aircraft

Rigid Pavement -- airplanes weighing less than 30,000 lbs

- Portland Cement Concrete surface course requirements
  - P-501
  - State Standards permitted for < 30,000 lbs
- Minimum thickness = 5 inches < 12,500 lb
  6 inches 12,501 to 30,000 lbs

Chapter 5 –Pavements For Light Aircraft

Aggregate-Turf – Non-Jet airplanes weighing less than 12,500 lbs

- Material requirements – P-217
- Procedure in 5320-6E to use FAARFIELD to determine thickness requirement of P-217 layer.

CHAPTER 7

PAVEMENT DESIGN FOR AIRFIELD SHOULDERS

Chapter 7 – Pavement Design For Airfield Shoulders

- **Shoulders are primarily intended to provide**
  - Protection from erosion and generation of debris from jet blast
  - Support for airplanes running off the primary pavement
  - Enhanced drainage

Chapter 7 – Pavement Design For Airfield Shoulders

Shoulder must provide sufficient support for unintentional or emergency operation of any airplane in the traffic mix.

Must also provide support for emergency and maintenance vehicle operations

Chapter 7 – Pavement Design For Airfield Shoulders

- **Minimum section provided by Chapter 7 will not perform in the same fashion as full strength pavement**
  - Expect considerable movement and possible rutting with single operations
  - Shoulder pavement should be inspected after every operation.

Chapter 7 – Pavement Design For Airfield Shoulders

Shoulder Design Procedure

- Uses FAARFIELD to determine “most demanding airplane”
- Evaluate proposed shoulder section for each airplane based on 10 operations
- Does not use composite traffic mixture

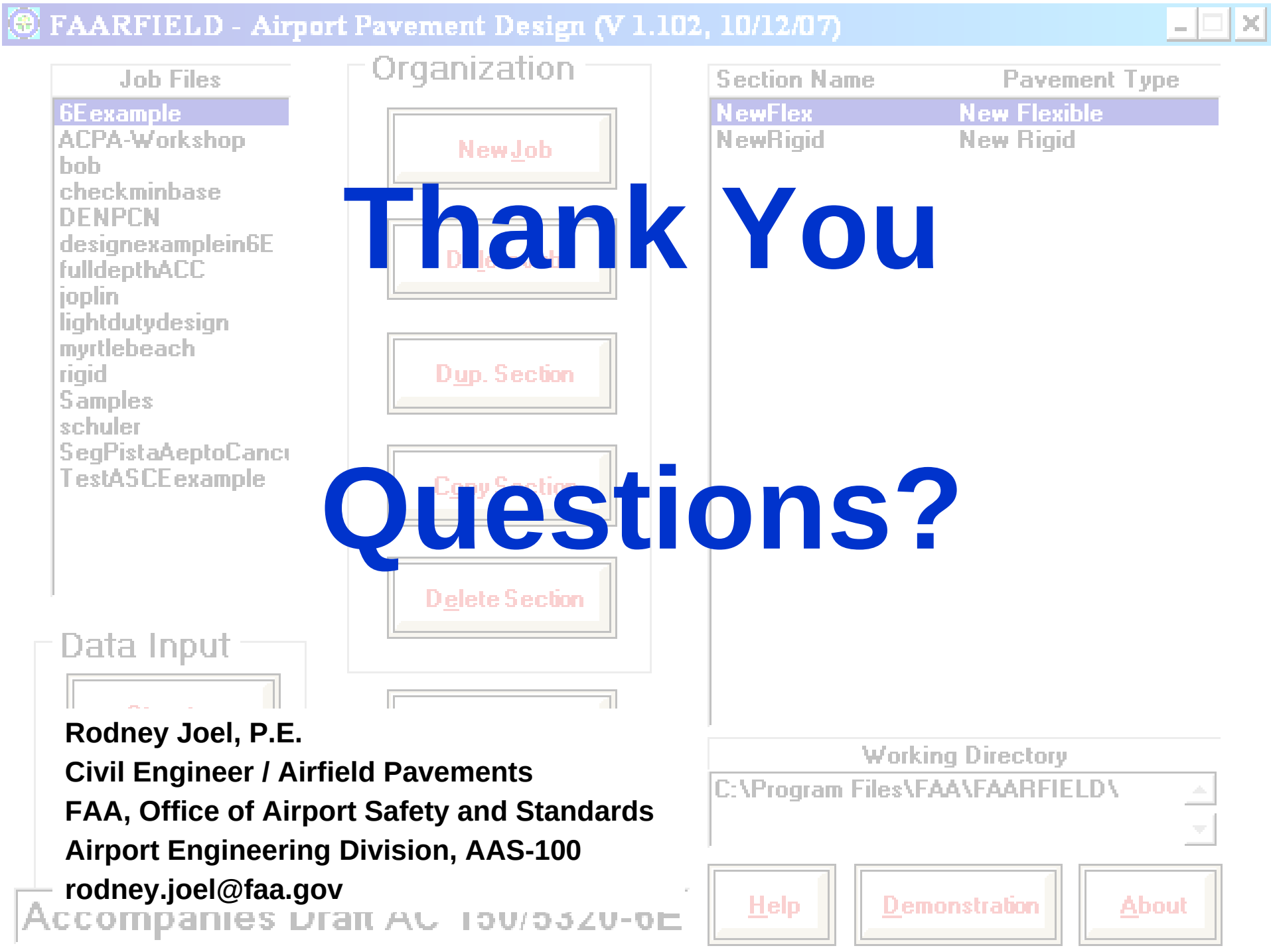
Shoulder Design Procedure – Material Requirements

- Asphalt
  - P-401/403 or similar local material specifications
  - Minimum compaction target density – 93% max theo. density
  - Minimum thickness = 3 inches
- Portland Cement Concrete
  - P-501 or similar local material specifications
  - Minimum flexural strength = 600 psi
  - Minimum thickness = 6 inches

Chapter 7 – Pavement Design For Airfield Shoulders

Shoulder Design Procedure – Material Requirements

- Base Material
  - FAA specifications or similar local material specifications
  - Expect CBR $\geq$ 80
  - Minimum thickness = 6 inches
    - May be reduced to 4 inch minimum if asphalt surface increased by 1 inch
- Subbase Material
  - FAA specifications or similar local material specifications
  - Expect CBR $\geq$ 20
  - Minimum thickness = 4 inches (practical construction limit)



Thank You

Questions?

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