Airport Engineering

Houston Airport System Pavement Seminar, Houston Texas (Sept. 14, 2011)

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HOUSTON AIRPORTS

AIRPORT ENGINEERING

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ABSTRACT

Recent developments in computer design software for airfield pavement design, have simplified the design process to a great extent. The Federal Aviation Administration's Rigid and Flexible Iterative Elastic Layered Design software (FAARFIELD) is one of their newly released design programs. FAARFIELD is based on AC 150/5320-6E, which includes Finite Elemental Modeling approaches. For flexible pavement design, FAARFIELD uses the similar structural response and failure models as LEDFAA 1.3. For rigid and overlay pavement design, FAARFIELD combines a three-dimensional finite element analysis with a performance/failure model based on full scale test result from National Airport Pavement Test Facility (NAPTF) and re-analysis of USACE full scale test results. With the application of appropriate calibration factors, FAARFIELD is considered one of the most effective tools in simulating and material modeling. FAARFIELD is also capable of handling New Large Aircrafts (NLA) with complex landing gear configuration including B-777, Airbus A380 and An-225. Other recent developments in pavement management software includes COMFAA 3.0 (as per AC150/5335-5B) and FAAPAVEAIR (Beta Version, expected to release soon). The objective of this paper is to introduce Airport Engineering, some of the innovative pavement technologies in computer design software-Finite Elemental Modeling, Pavement Management Technologies and various Decision making criteria "Decision Matrix" that have been using at Houston Airport Systems for several years. Pavement strength evaluation techniques and reporting criteria based on ACN-PCN evaluation using recent updated version of COMFAA 3.0, and application of NDT for sub-grade modulus evaluation and their implication on ACN-PCN determination are also presented and discussed. Finally, the outcomes of preliminary investigation on "Evaluation of Corrosion Potential of Native Sub-grade Soils though Soils Resistivity Analysis at Houston Airports Systems" are also presented.

Key Words: ***Soil, Pavement Design, FAARFIELD, COMFAA, ACN/PCN, NDT, Corrosion, Resistivity***

Airport Engineering

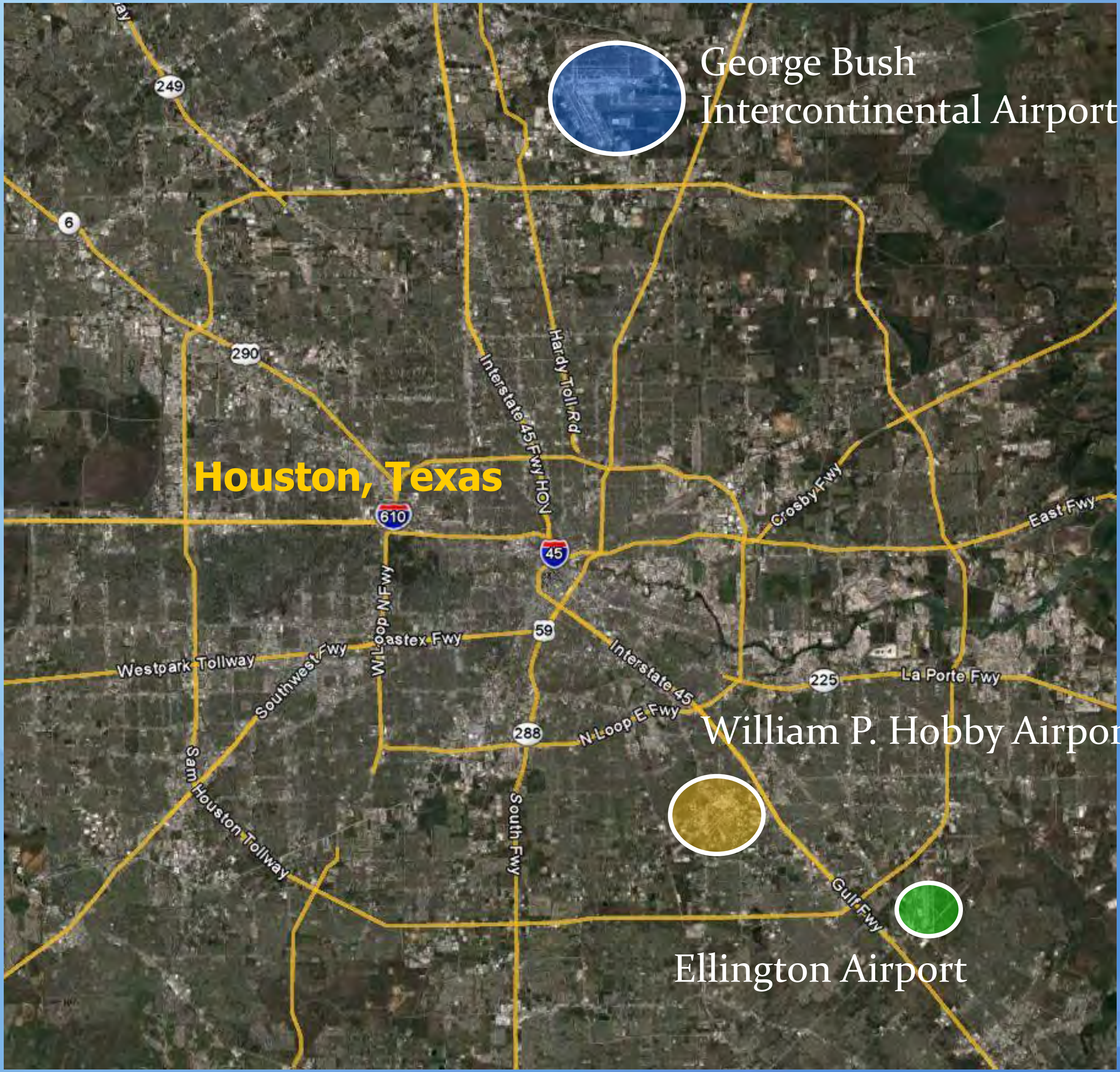
Overview

1. Introduction to Houston Airport Systems
2. Introduction to Pavement Design and Design Software
3. Pavement Management System
4. Soils Resistivity and Corrosion Potential of Native Sub-grade Soils at Houston Airport Systems

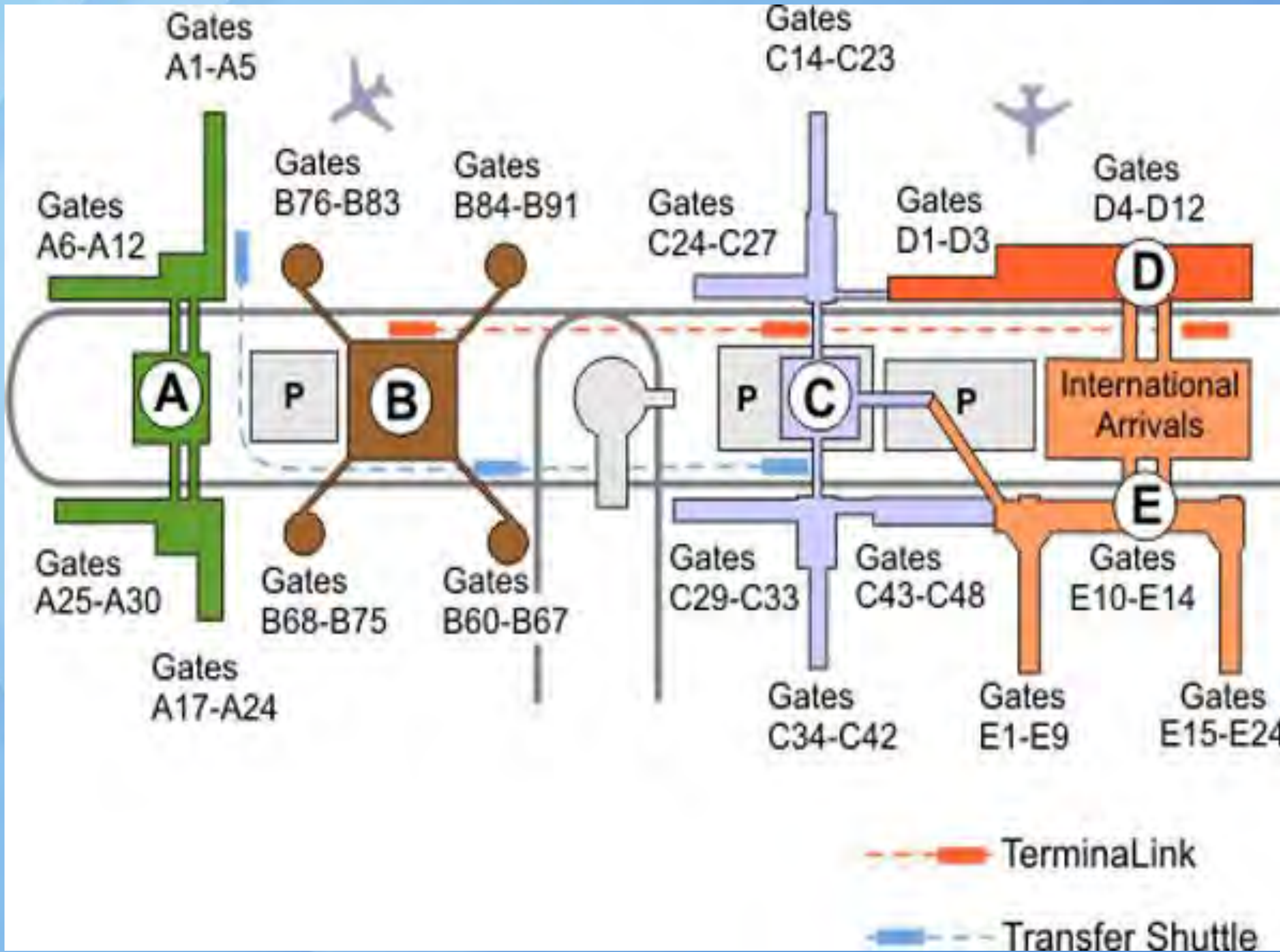
Section-1: Introduction

- Houston Airport System
- General Airport Features
- Instrumentation Landing Systems

LOCATION MAP: HOUSTON AIRPORT SYSTEMS



Aerial Map – George Bush Intercontinental Airport



5 Major Runways

8L/26R=9,000' **8R/26L =9,400'** **9/27=10,000'**

15L/33R=12,000' **15R/33L=10,000**

William P. Hobby Airport


Parking
USO
Entrance
Passenger
Drop off
Entrance
CHECK IN
CHECK IN
Lobby
e-ticket
Ticketing
SouthWest
Customer Service
Concourse
Gate 20
Gate 22
Gate 24
Gate 26
Gate 28
Gate 30
Gate 32
Gate 21
Gate 23
Gate 25
Gate 27
Gate 29
Gate 31
Gate 40
Gate 42
Gate 44
Gate 46
Gate 48
Gate 50
Gate 41
Gate 43
Gate 45
Gate 47
Gate 49
Gate 51

Ellington Airport

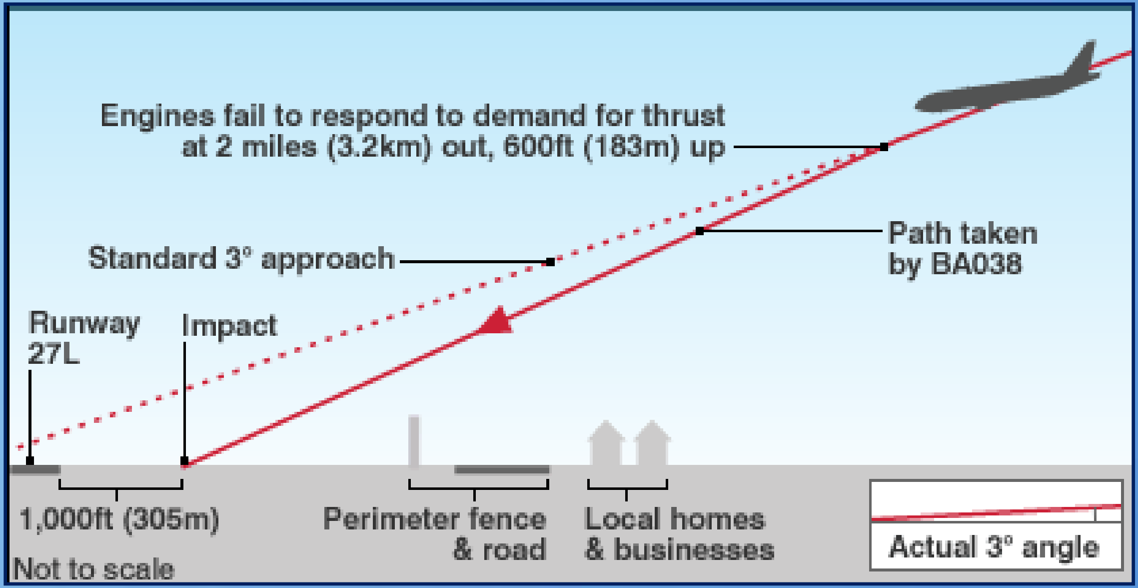
Ellington Airport

This Airport is Currently Operated by Military, NASA , and General Aviation

General Airport Features

- Terminal Buildings/Control Tower
- Runways/Taxiways
- Instrumentation Landing System
- Jet Bridge/ Gates
- Fuel Tank/Pipelines
- Strom Water Management/Sewer Systems
- Detention Pond/ Lift Stations
- Air quality/Noise/Hazardous Material
- Wetland/Biotic Communities

Instrumentation Landing System

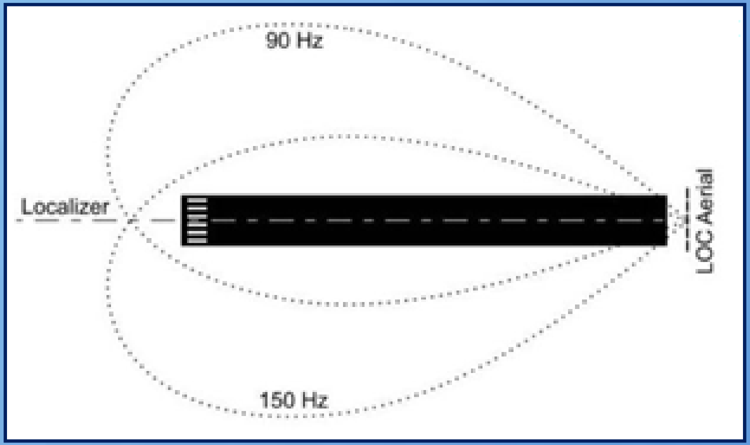


Glide Slope & Antenna

Corrects the Descent Path in V. Direction

- Located Between 750'-1250' From the Approach end of Runway
- Transmits a Glide Path Beam at 1.4 Degree Wide
- Path Projection of 3 Degree

Instrumentation Landing System



Localizer & Marker

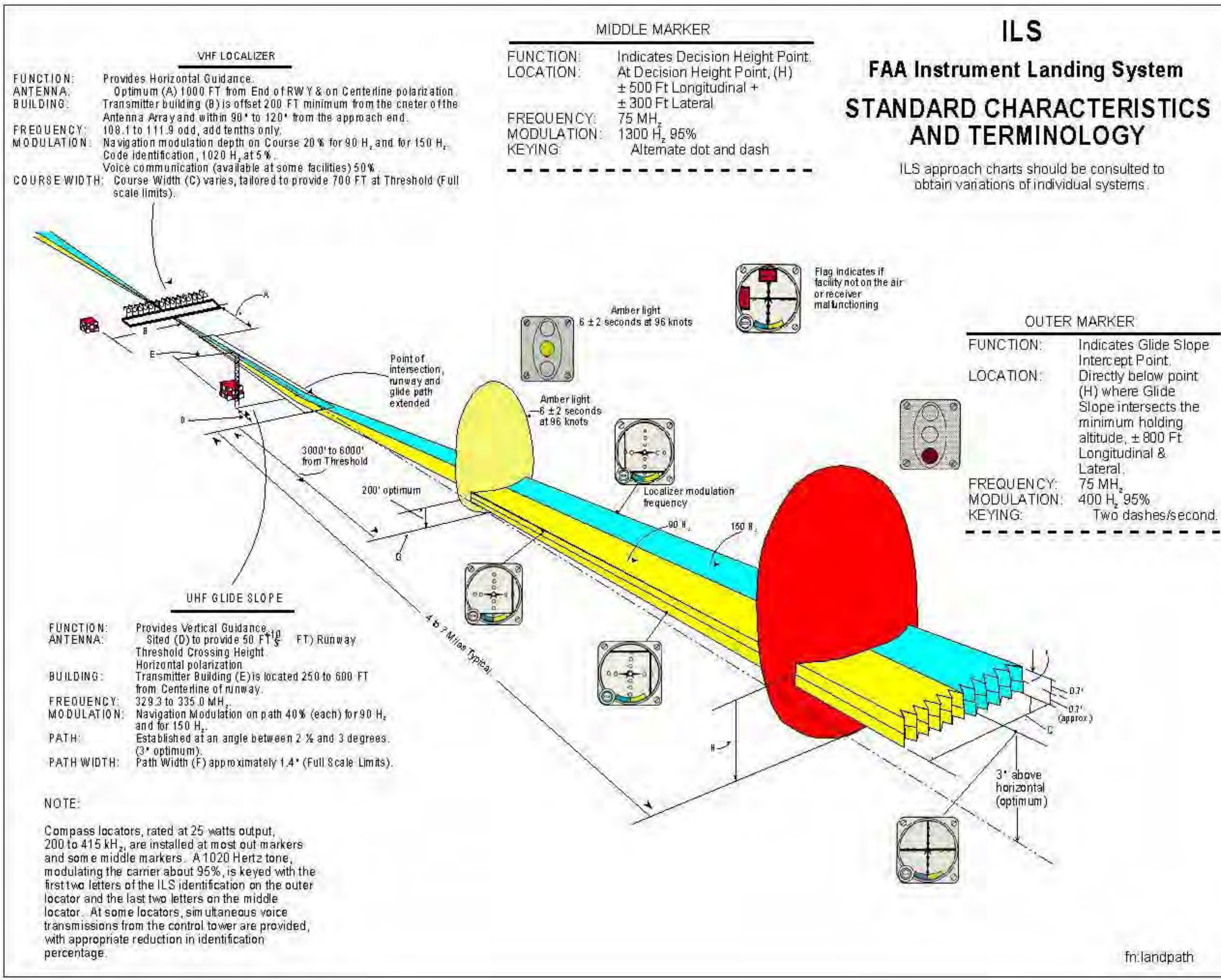
Transmits Signals To The Pilot
Provide Lateral Guidance
Aligns Horizontal Position with Runways

Navigational Aids & Other FAA-Operated Facilities

- Airport Surveillance Radar
- Navigational Aids And Lighting Systems
- Doppler Radar- Enhance Weather Prediction
- Low level Wind Shear System
- Aircraft Rescue And Firefighting Facility

Ground Based Augmentation System to Global Positioning System (GPS) provides a very precise navigation service (low visibility conditions)

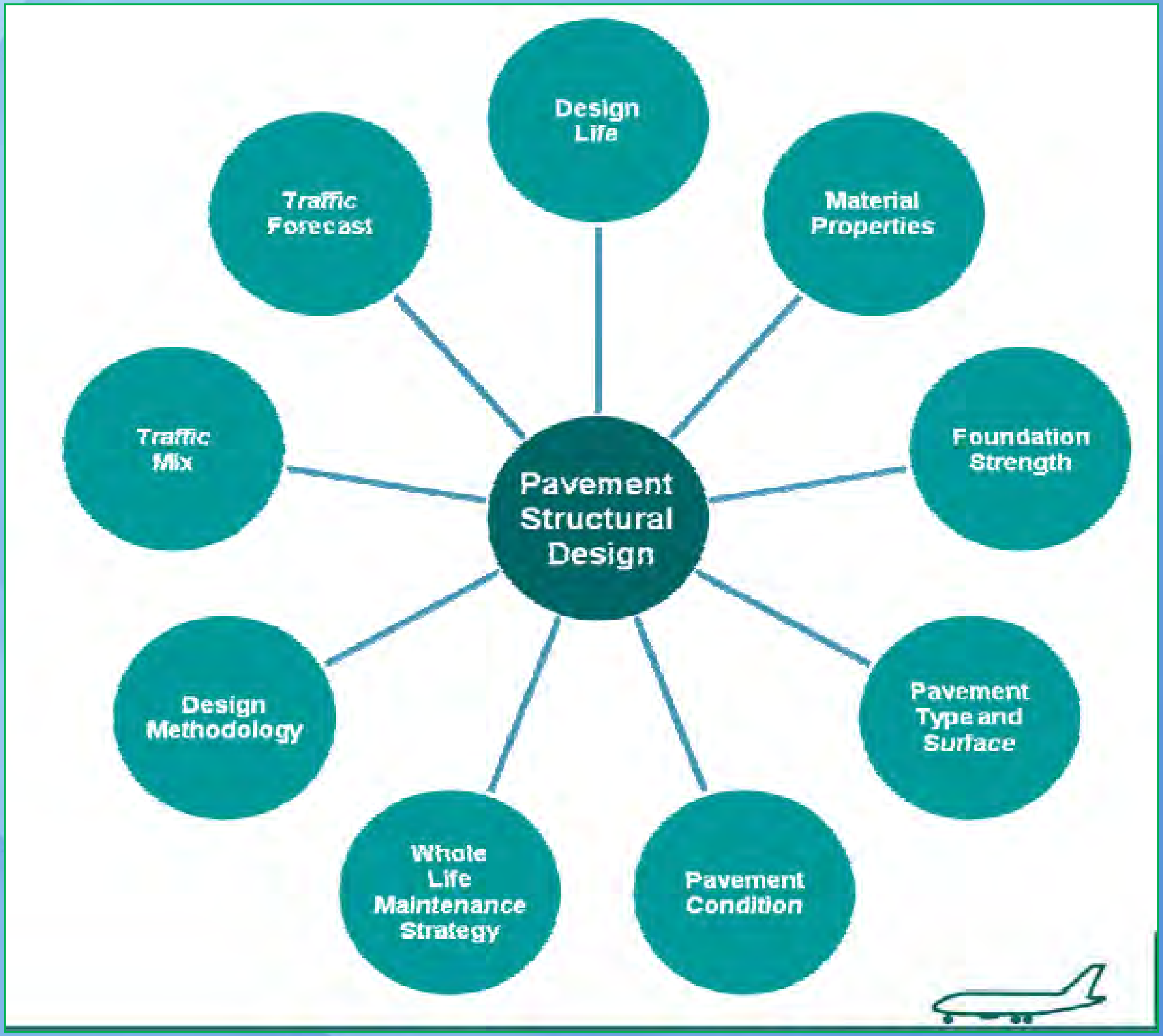
ILS


ILS
FAA Instrument Landing System
STANDARD CHARACTERISTICS AND TERMINOLOGY
ILS approach charts should be consulted to obtain variations of individual systems.
VHF LOCALIZER
FUNCTION: Provides Horizontal Guidance.
ANTENNA: Optimum (A) 1000 FT from End of RWY & on Centerline polarization.
BUILDING: Transmitter building (B) is offset 200 FT minimum from the cneter of the Antenna Array and within 90° to 120° from the approach end.
FREQUENCY: 108.1 to 111.9 odd, add tenths only.
MODULATION: Navigation modulation depth on Course 20% for 90 Hz and for 150 Hz. Code identification, 1020 Hz at 5%. Voice communication (available at some facilities) 50%.
COURSE WIDTH: Course Width (C) varies, tailored to provide 700 FT at Threshold (Full scale limits).
MIDDLE MARKER
FUNCTION: Indicates Decision Height Point.
LOCATION: At Decision Height Point, (H) ± 500 Ft Longitudinal + ± 300 Ft Lateral.
FREQUENCY: 75 MHz
MODULATION: 1300 Hz 95%
KEYING: Alternate dot and dash
OUTER MARKER
FUNCTION: Indicates Glide Slope Intercept Point.
LOCATION: Directly below point (H) where Glide Slope intersects the minimum holding altitude, ± 800 Ft Longitudinal & Lateral.
FREQUENCY: 75 MHz
MODULATION: 400 Hz 95%
KEYING: Two dashes/second.
UHF GLIDE SLOPE
FUNCTION: Provides Vertical Guidance.
ANTENNA: Sited (D) to provide 50 FT (+10 -5 FT) Runway Threshold Crossing Height. Horizontal polarization.
BUILDING: Transmitter Building (E) is located 250 to 600 FT from Centerline of runway.
FREQUENCY: 329.3 to 335.0 MHz.
MODULATION: Navigation Modulation on path 40% (each) for 90 Hz and for 150 Hz.
PATH: Established at an angle between 2 ½ and 3 degrees. (3° optimum).
PATH WIDTH: Path Width (F) approximately 1.4° (Full Scale Limits).
NOTE:
Compass locators, rated at 25 watts output, 200 to 415 kHz, are installed at most out markers and some middle markers. A 1020 Hertz tone, modulating the carrier about 95%, is keyed with the first two letters of the ILS identification on the outer locator and the last two letters on the middle locator. At some locators, simultaneous voice transmissions from the control tower are provided, with appropriate reduction in identification percentage.
Flag indicates if facility not on the air or receiver malfunctioning
Amber light 6 ± 2 seconds at 96 knots
Amber light 6 ± 2 seconds at 96 knots
Point of intersection, runway and glide path extended
3000' to 6000' from Threshold
200' optimum
Localizer modulation frequency
90 Hz
150 Hz
4 to 7 Miles Typical
0.7°
0.7° (approx.)
3° above horizontal (optimum)
A
B
C
D
E
F
G
H
fn:landpath

Section-2

Pavement Design and Design Software

Design- Components



Design Components- Pavement design

Fundamental of Pavement Design

Pavement Types

Rigid PCC

•Jointed Plain Concrete Pavement(JPCP/JCP)

•Jointed Reinforced Concrete Pavement –(JRCP)

•Continuously Reinforced Concrete Pavement-CRCP

•Pre-stressed Concrete Pavement-PCP

Flexible ACP/HMA

Full Depth

Layered

- Granular
- Bound layers

Surface Treatment

Composite

Fundamental of Pavement Design

Pavement Components

Rigid Pavement
Portland Cement Concrete Slab
Base
Sub-grade
Flexible Pavement (Layered System)
Asphaltic Wearing Surface
Base
Sub-base
Sub-grade

Fundamental of Pavement Design

Factors Affecting Pavement Design

Types of Aircraft

- Loads
- Anticipated frequency
- Gear configuration

Type of facility considered

- Runway
- Taxiway
- Apron
- Hangar Floor

Supporting value of the sub-grade

Characteristics of available construction Material

Fundamental of Pavement Design

Wheel Loading

Pavement Thickness
Pavement Stiffness
Environmental Loading – Temperature and Moisture
Joint Spacing
Reinforcement
HMA Stiffness

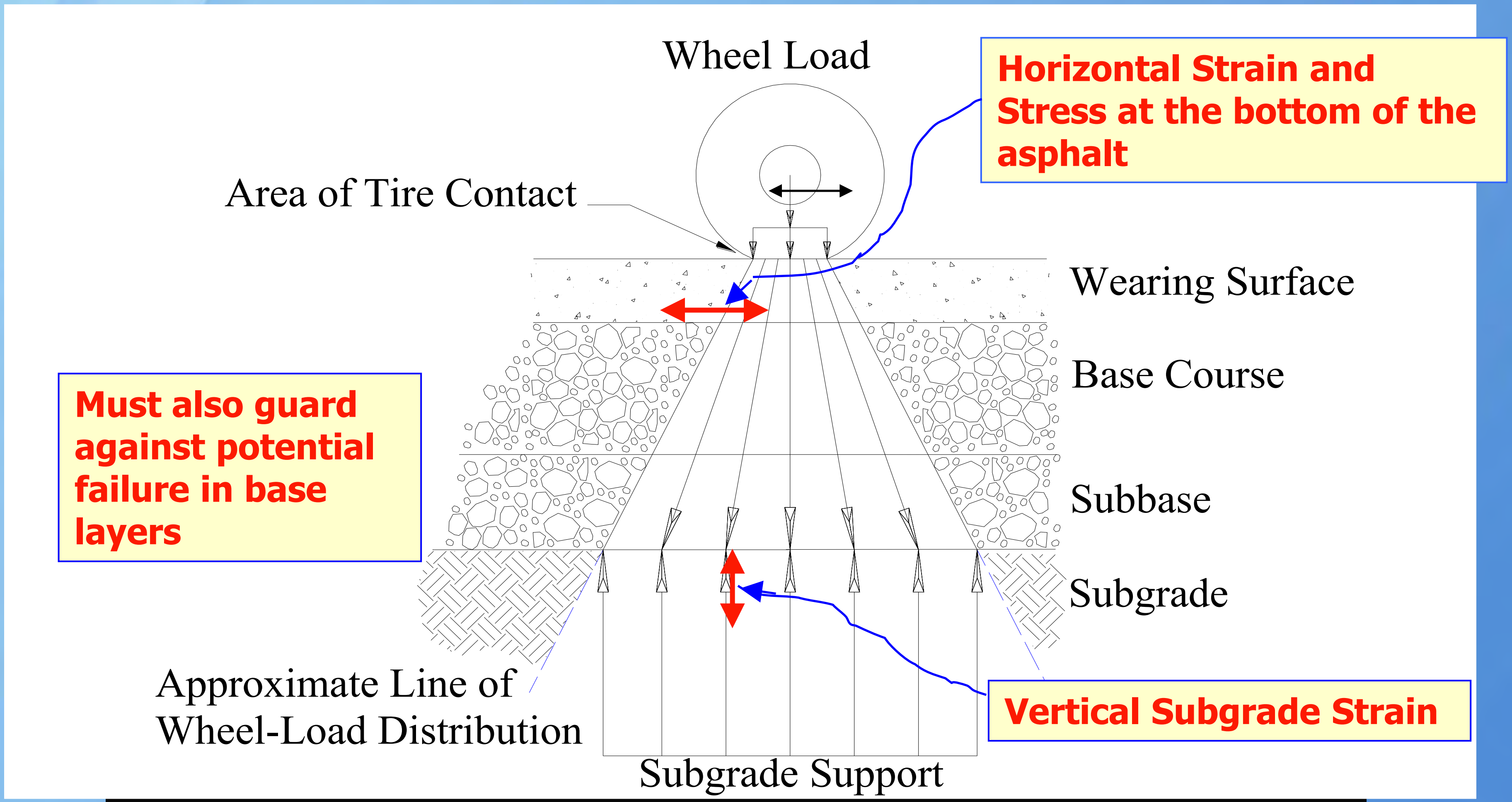
Fundamental of Pavement Design

Fundamental Design Concepts

- Application
- Load and Environment
- Principle of Superposition
- Stress Dependent On:
  - Gear Spacing
  - Magnitude and tire pressure
  - Number of wheels
- Fatigue
- Layered Concept


787
BOEING
DREAMLINER
N787FT

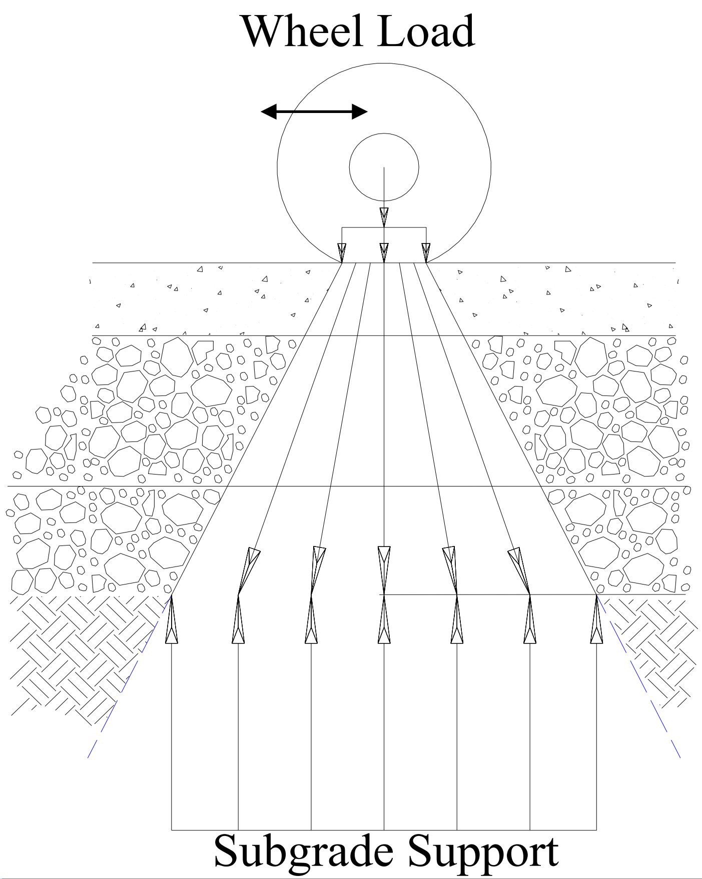
Flexible Pavement Design



Flexible Pavement Layer Parameters- LED vs. CBR

LAYERED ELASTIC METHOD

SURFACE	E_S, μ_S, h	**CBR Method**	
		Not Defined	
BASE	E_B, μ_B, h_B	**CBR**	
SUBBASE	$E_{SB}, \mu_{SB}\ h_{SB}$	**CBR**	
SUBGRADE	$E_{SG}, \mu_{SG}\ h_{SG}$	**CBR**	



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

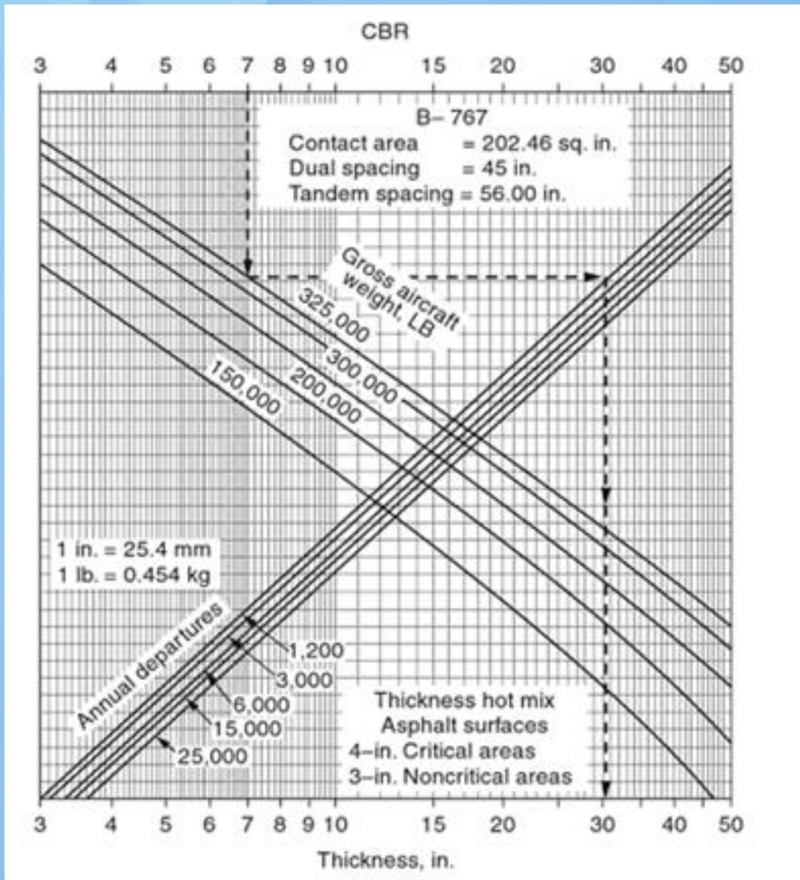
CBR = California Bearing Ratio

- **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

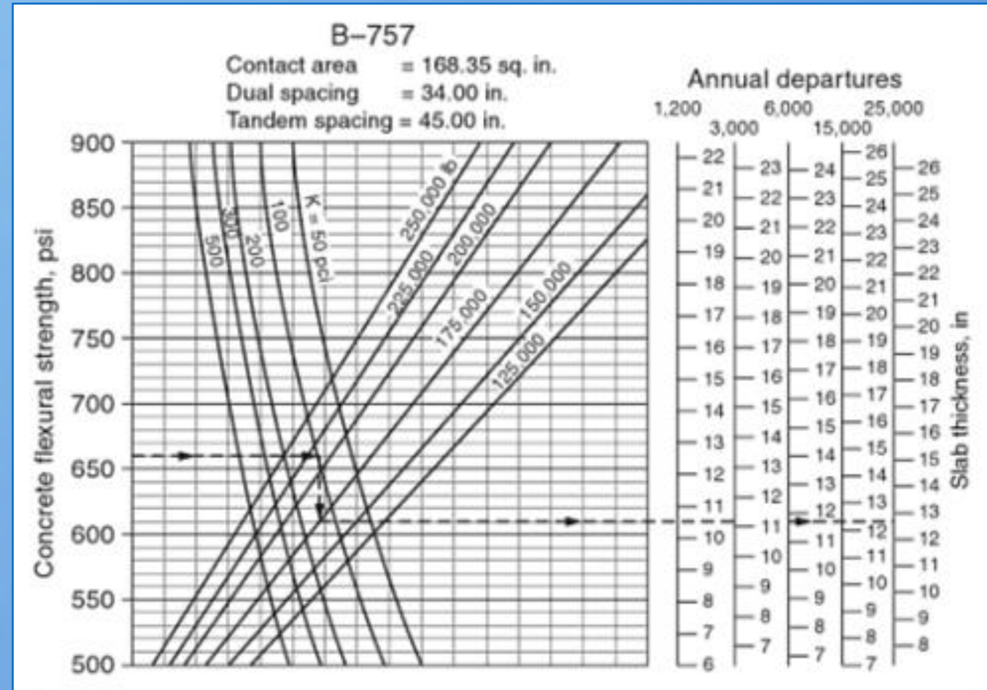
- New procedures require that ALL anticipated traffic be included in the traffic model.
- Concept of "Design Aircraft" is no longer used
- Cumulative Damage Factor (CDF) replaces need for design aircraft procedure.

HISTORICAL DESIGN PROSPECTIVE



Example approximation chart, CBR method of flexible pavement

CBR METHOD: Flexible Pavement



Example design curve for estimating the slab thickness of rigid pavement using Westergaard's analysis.

Westergaard's Approach-(Rigid Pavement)

EQUIVALENT TRAFFIC METHOD (FAA,1975)

Determination of annual aircraft departure by each aircraft and convert them into equivalent annual departure in terms of landing gear configuration

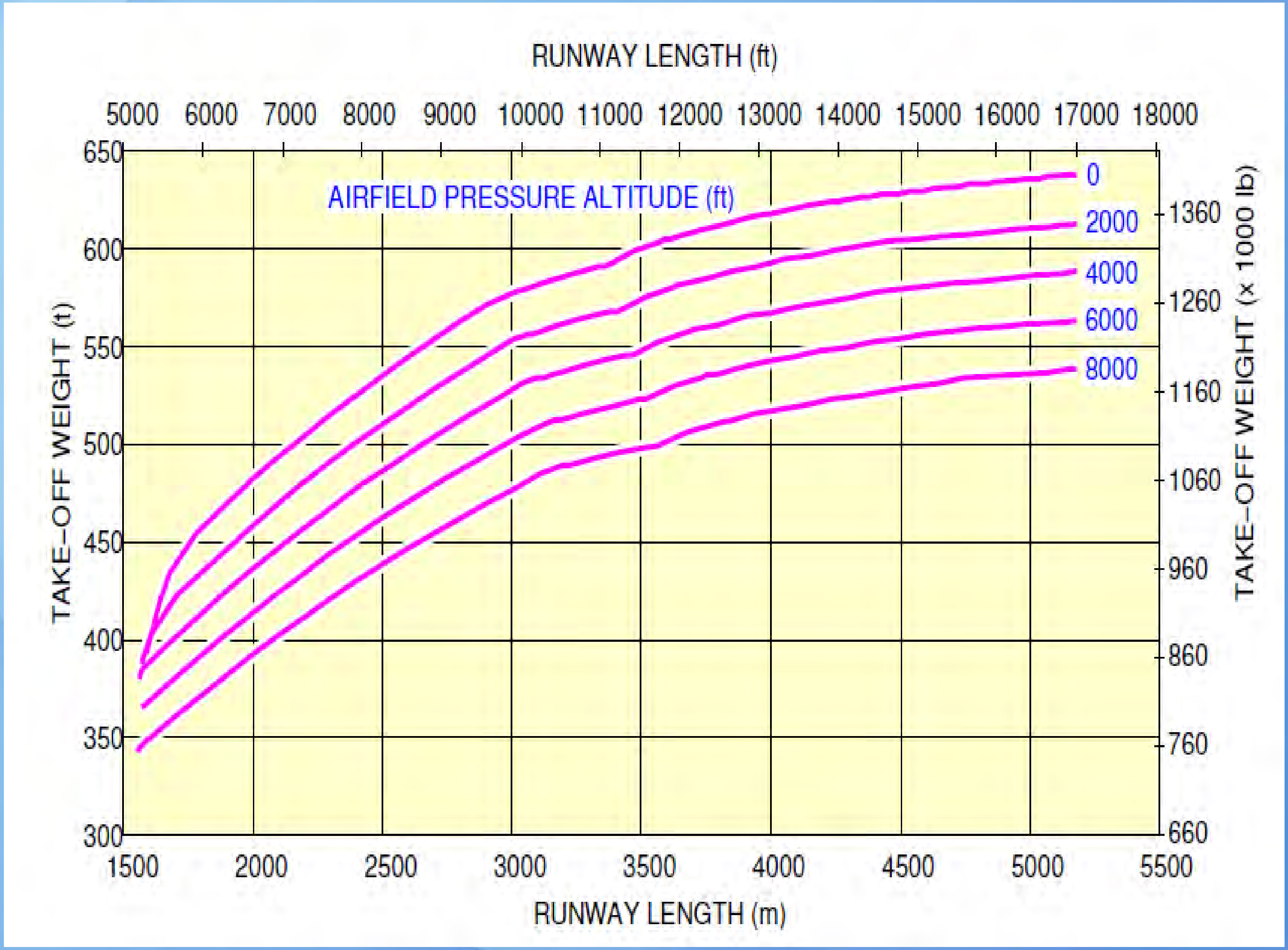
To Convert From	To	Multiply Departures By
Single wheel	Dual wheel	0.8
Single wheel	Dual tandem	0.5
Dual wheel	Dual tandem	0.6
Double dual tandem	Dual tandem	1.0
Dual tandem	Single wheel	2.0
Dual tandem	Dual wheel	1.7
Dual wheel	Single wheel	1.3
Double dual tandem	Dual wheel	1.7

Factors for Converting Annual Departures by Aircraft to Equivalent Annual Departures by Design Aircraft

where R_1 = equivalent annual departures by the design aircraft
R_2 = annual number of departures by an aircraft in terms of design aircraft landing gear configuration
W_1 = wheel load of the design aircraft
W_2 = wheel load of the aircraft being converted

$$\text{Log } R_1 = \log R_2 \times \left(\frac{W_2}{W_1}\right)^{1/2}$$

RUNWAY LENGTH DETERMINATION



FACTORS: ELEVATION, TEMPERATURE, PRESSURE AND MTOW

Selection of Pavement Material and Specification

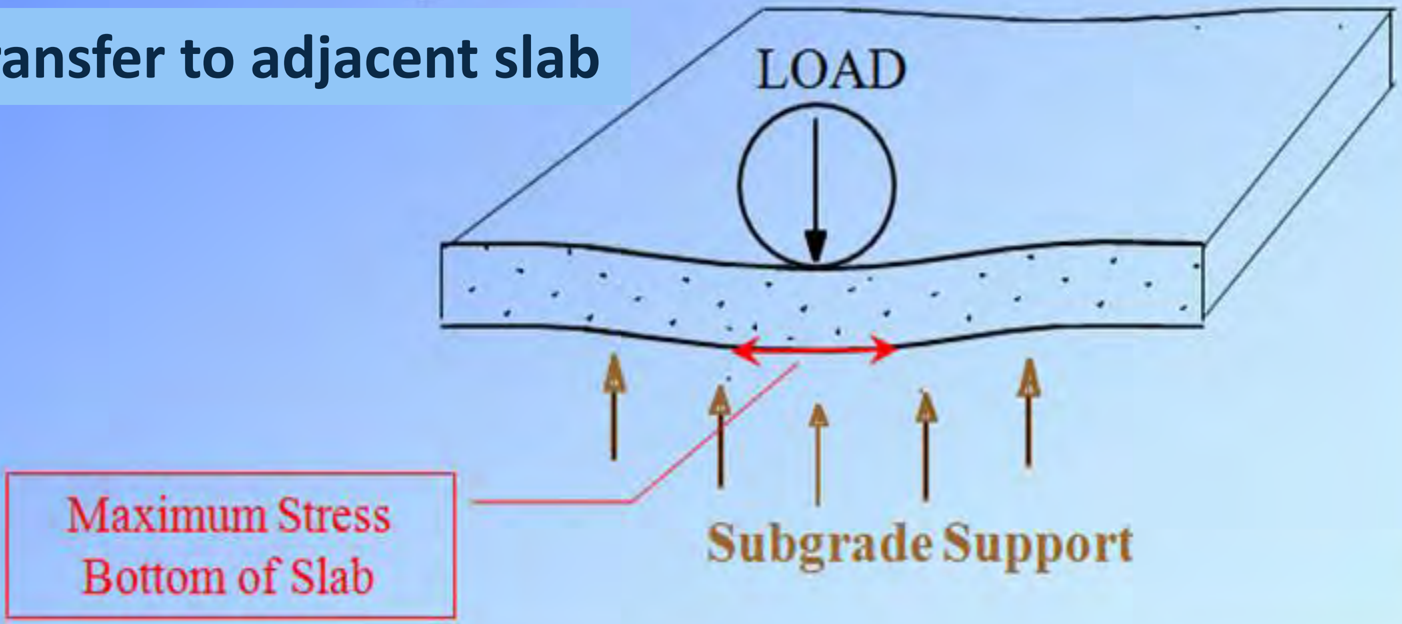
Surface	BASE	SUBBASE	SUBGRADE
P-401	P-209	P-154	P-152
P-403	P-208	P-210	P-155*
P-501	P-211	P-212	P-157*
	P-304*	P-213	P-158*
	P-306*	P-301*	
	P-401*		
	P-403*		
	Rubblized PCC		

* Chemically Stabilized Materials

FEM Model Approach
Rigid Pavement

Critical Load Condition Assumptions

- Maximum stress at pavement edge
- 75% load Transfer to adjacent slab



DEVELOPMENT OF PAVEMENT DESIGN SOFTWARE

LEDFAA 1995

AC 150/5320-6D

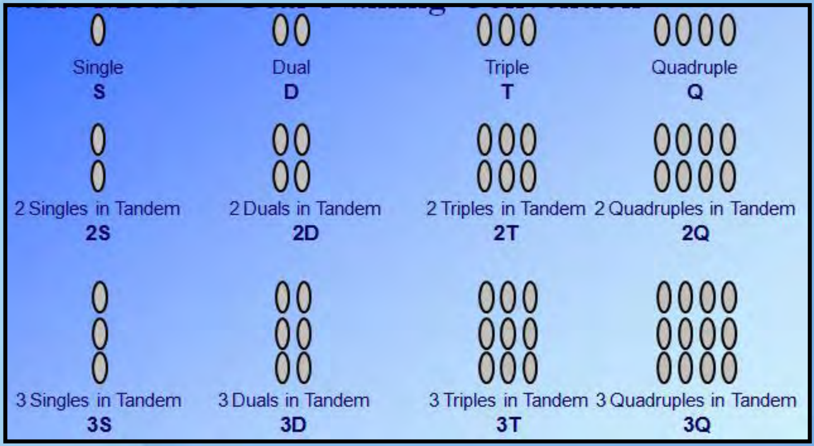
COMFAA

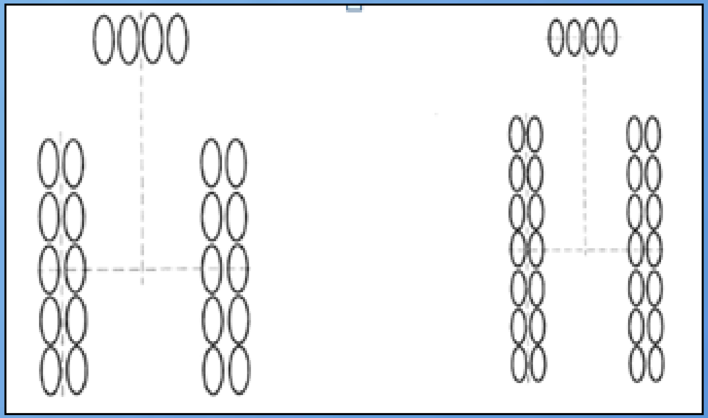
FEAFAA

FAARFIELD 2009

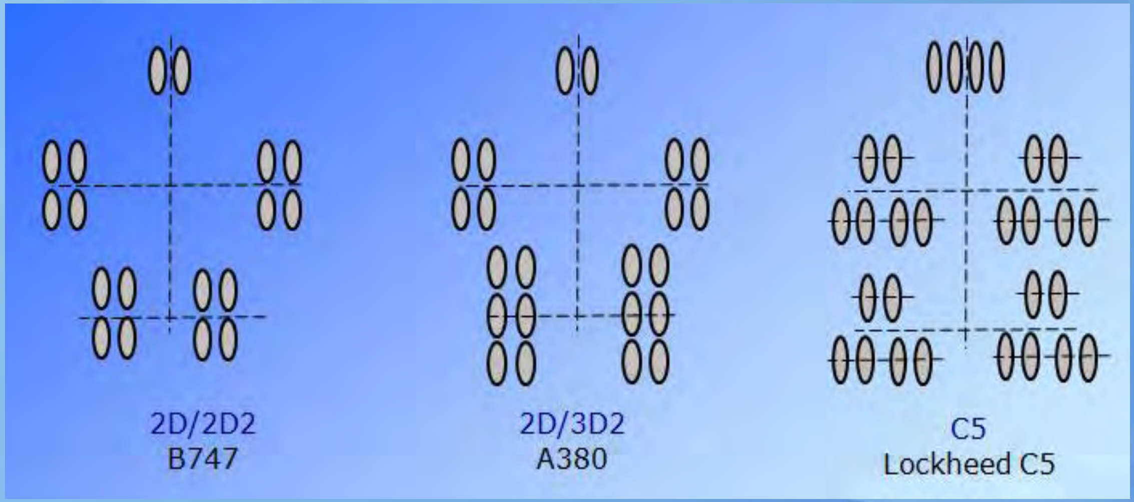
AC 150/5320-6E

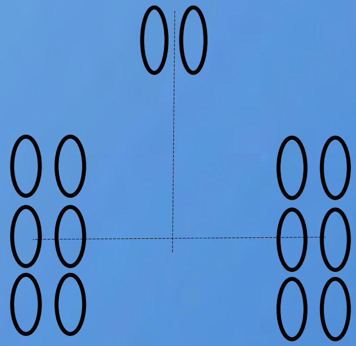
Gear Configuration & Naming Convention- Complex Aircraft





AN-125 **AN 225**





3D

B 777

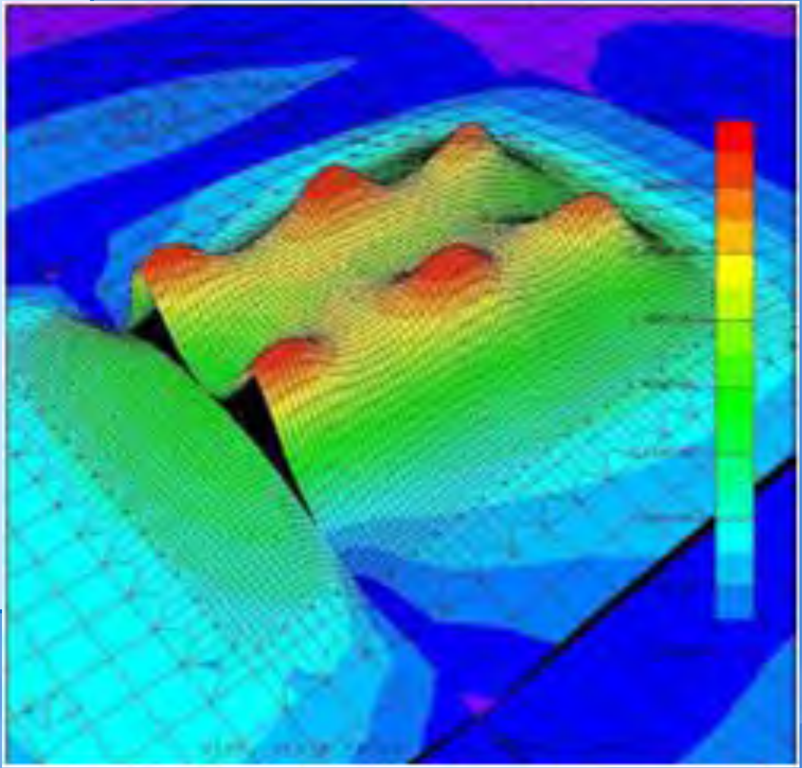
INTRODUCTION-TO FINITE ELEMENTAL MODELING- FAARFIELD

Based on - Layered Elastic and 3D-FE modeling

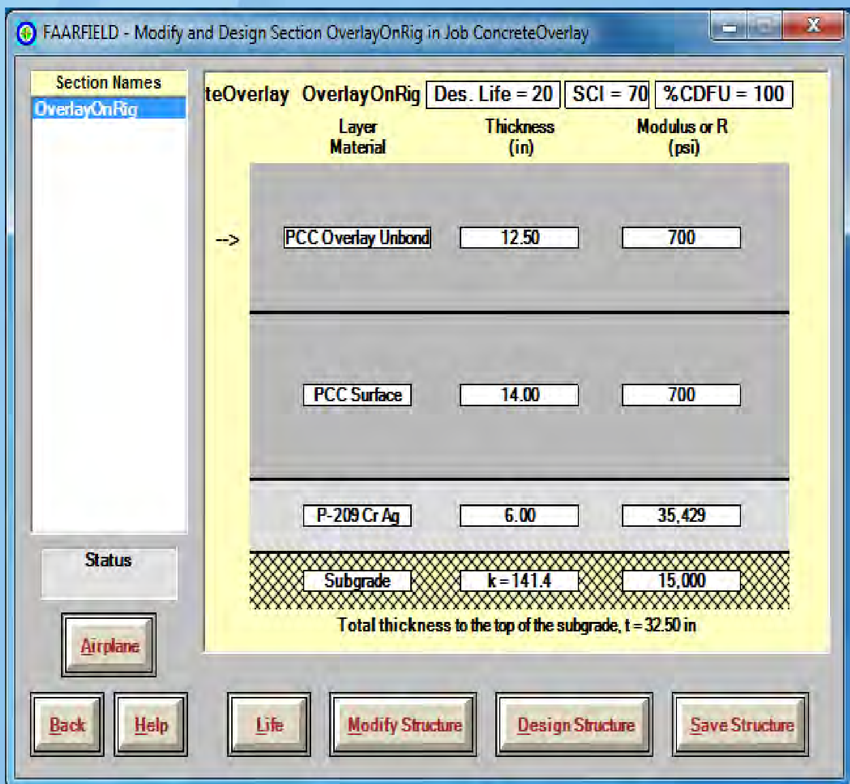
AC 150/5320-6E (Current)

Computer Programs:

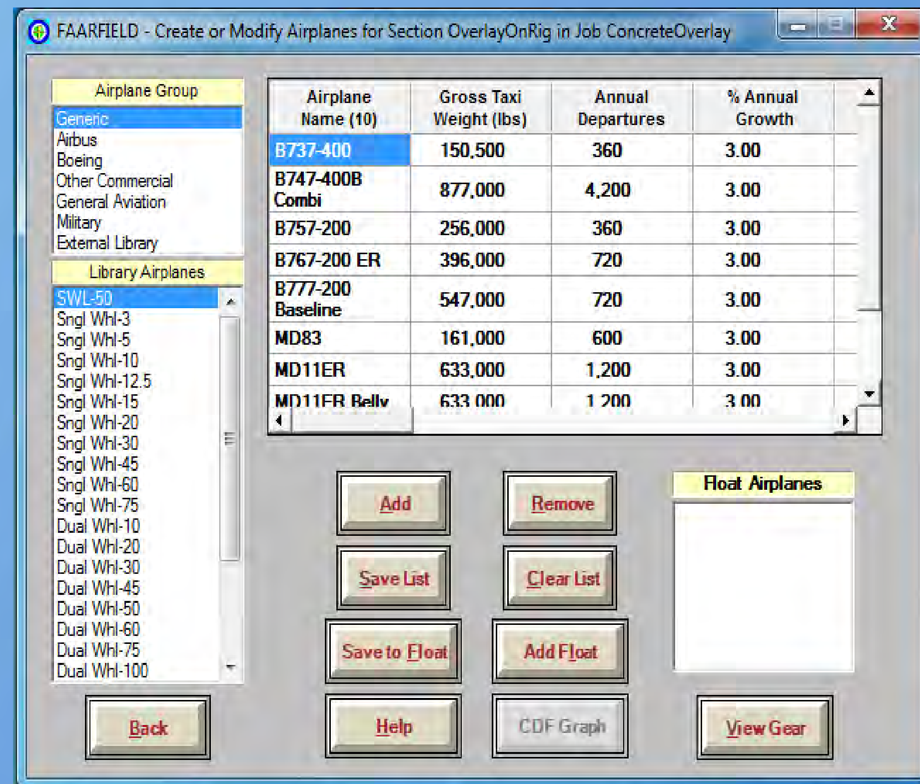
- **LEAF (layered elastic analysis) Visual Basic 2005**
- **NIKE3D (3D finite element analysis)- FORTRAN**
- **INGRID (3D mesh generation)**



INTRODUCTION-TO FINITE ELEMENTAL MODELING

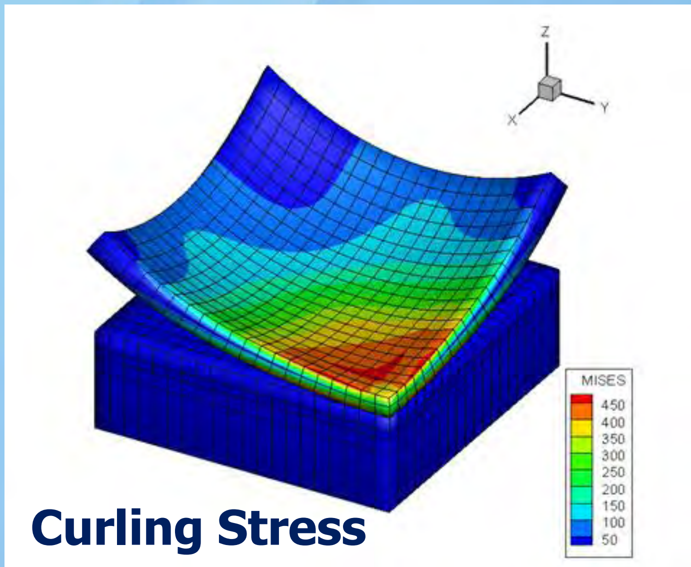


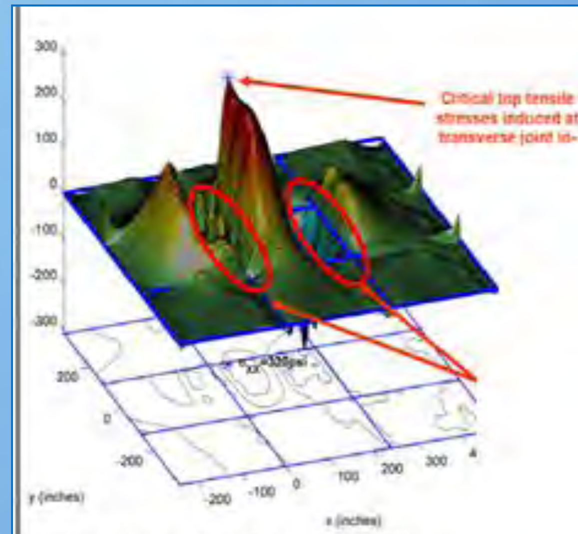
Screen Shot: Structure



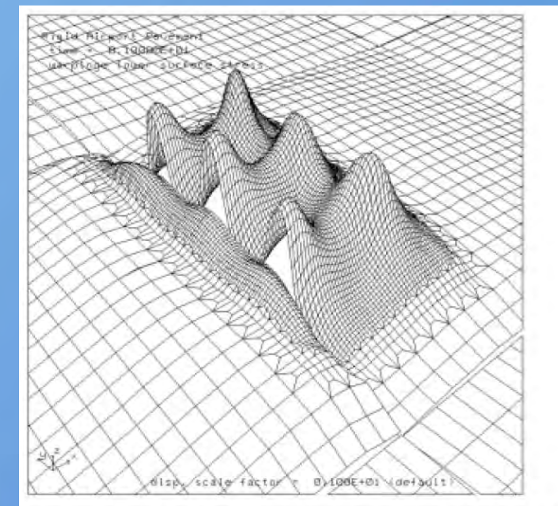
Screen Shot: Traffic

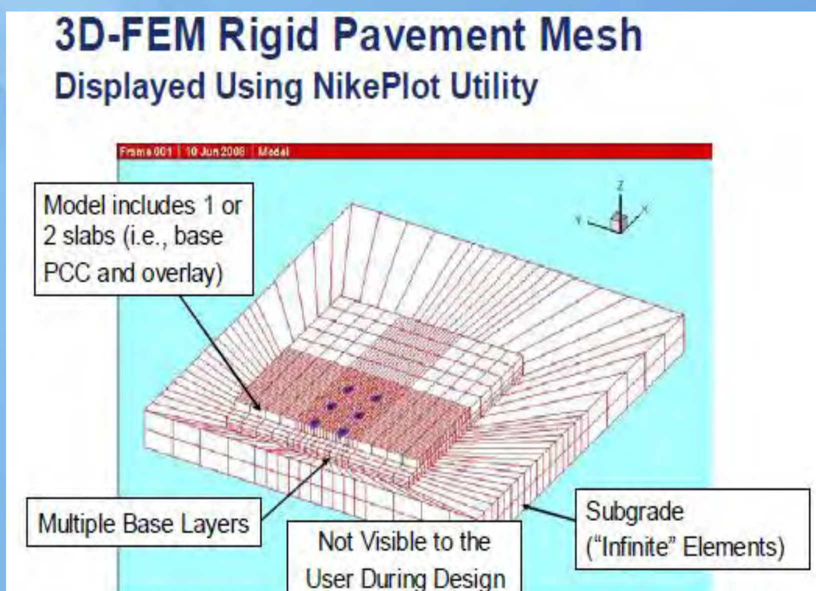
FEM Model Approach

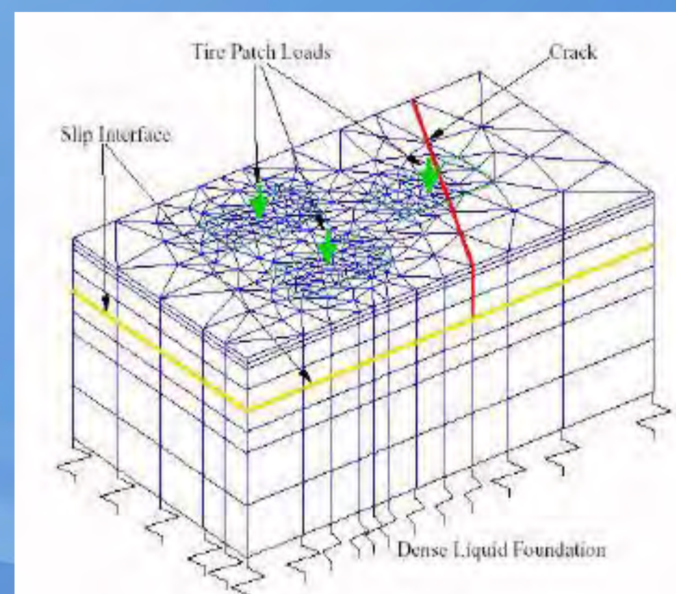




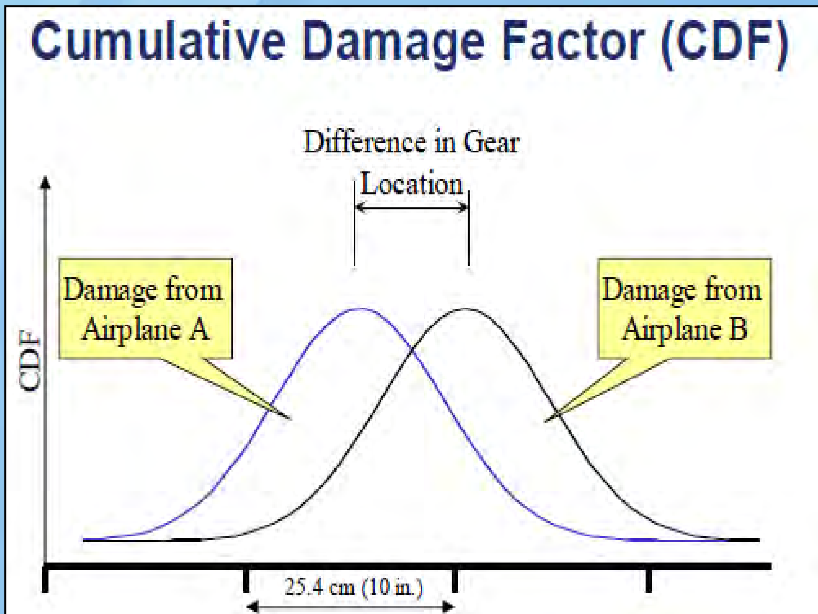
Evangelista Junior and Roesler (2008)

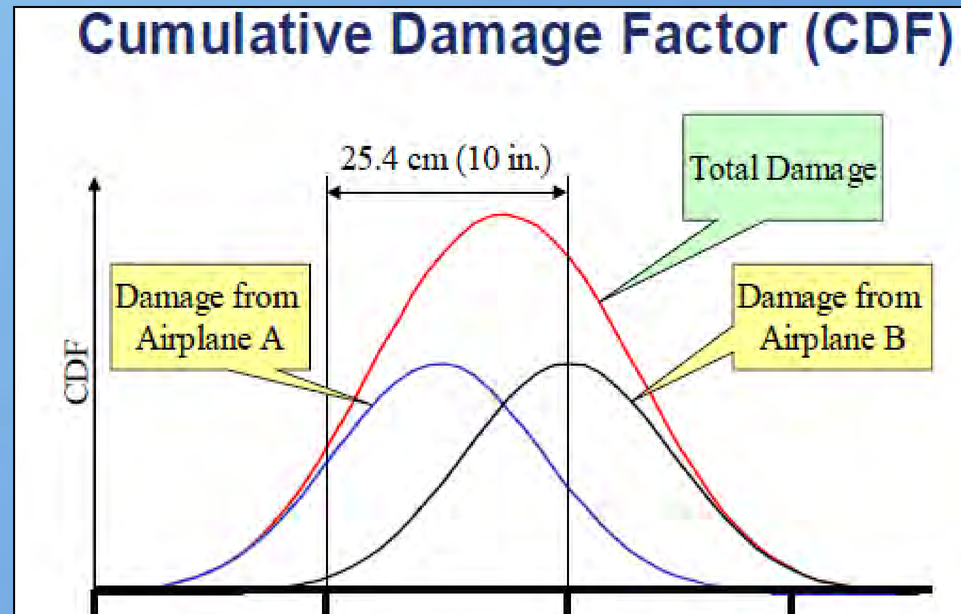

PRINCIPAL BENDING STRESS IN BOTTOM OF PCC SLAB
(B-777 EDGE LOAD)

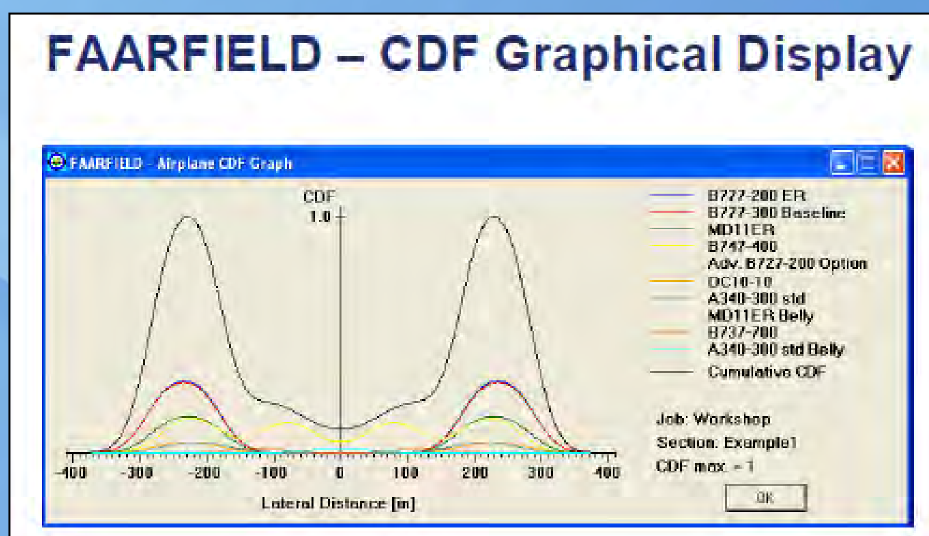




FEM Model Approach







Cumulative Damage Factor (CDF) for Some Aircraft

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

EFFECT OF GEAR POSITION & CRITICAL STRESS LOCATION

Rigid pavement thickness is designed based on critical tensile bending stress at the bottom of the slab. Top-Down cracking may occur under certain combined Loading and pavement geometry configuration

(Full scale test - NAPTF and Airbus PEP)

Guo (2006) reported that tensile stress developed on slab bottom were related primarily to the wheel load, while the tensile stresses on the slab top were related primarily to the gear load at both longitudinal and transverse joint location.

EFFECT OF GEAR POSITION & CRITICAL STRESS LOCATION

2D Simulation on 9 slab (University of Urbana-Champaign)

- Four main landing gear (B-777, A-380, MD-11, & B747)
- Five individual aircraft gear geometry-Dual -B737
  Dual Tandems- B747, B757, B767
  Triple Dual Tandems-B-777

1. **Individual Gear Analysis: (with assumption of no initial curling stresses)**
2. **Main landing Gear Analysis (two load transfer efficiencies (0 and 85%) were assumed across the joint)**

EFFECT OF GEAR POSITION & CRITICAL STRESS LOCATION

1.Individual Gear Analysis: (with assumption of no initial curling stresses)

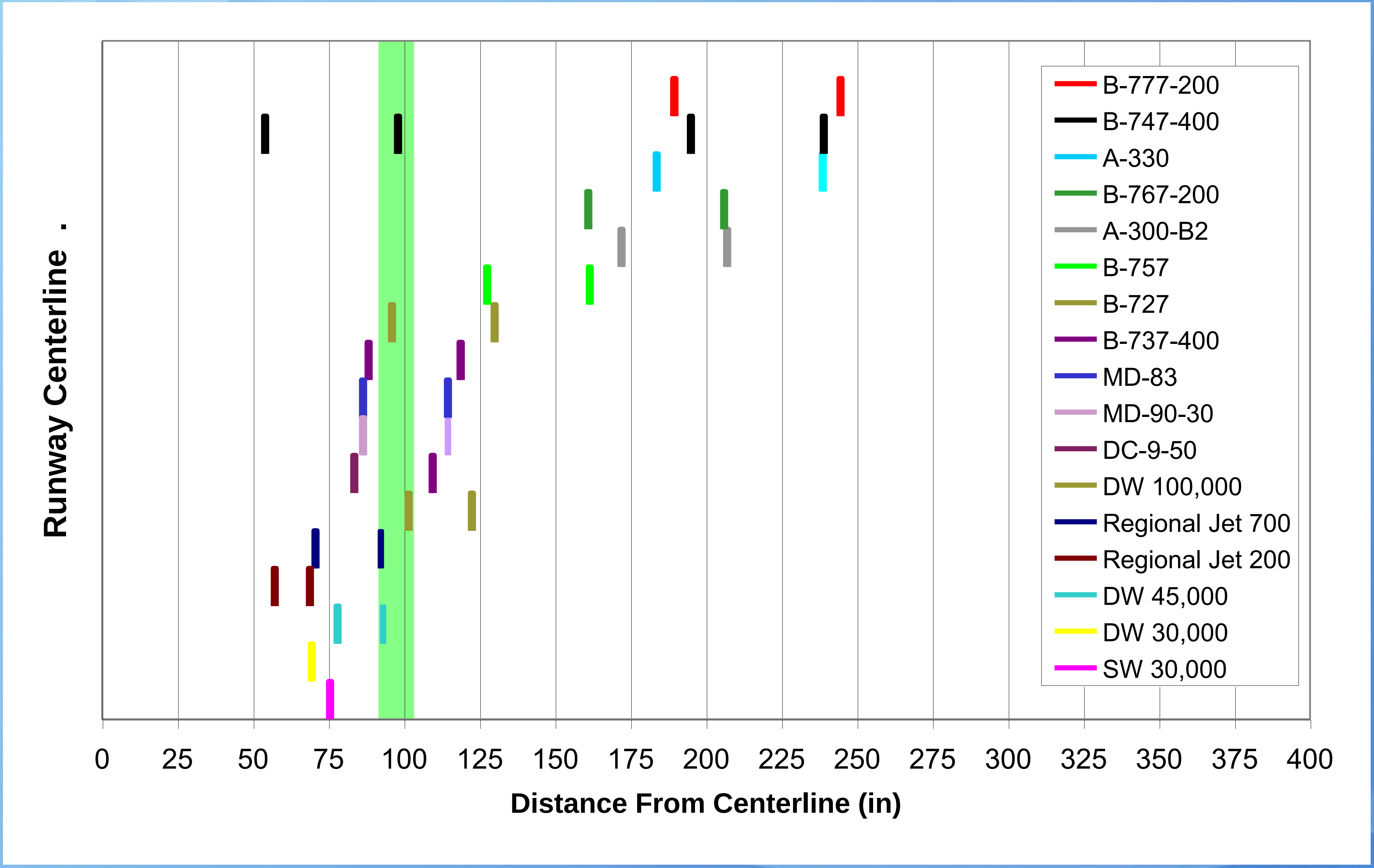
- Due to small wheel spacing, B-737 produced greatest tensile stress at the bottom of the slab in y direction.
- The largest Tensile stress at the top of the slab is came from TDT gear (B-777) in x- direction.
- Max. tensile stress at top was similar in both direction for each gear type.
- Gear load affected the max tensile stress at the top of the slab while wheel affected the max tensile stresses at the bottom of the slab.
- Top-down cracking depends on top to bottom tensile stress ratio.
- B-777 produced the highest tensile stress ratio.

EFFECT OF GEAR POSITION & CRITICAL STRESS LOCATION

2. Main landing Gear Analysis (two load transfer efficiencies (0 and 85%) were assumed across the joint)

- As the load transfer efficiency at the joints decreased for all aircraft, the max. tensile stresses at the top and bottom increased.
- The main landing gear of A-380 resulted in the highest top tensile stress.
- Max tensile stress on the top of the slab was in x-direction, which indicates that longitudinal cracking would be the most likely failure mode.
- MD-11 and A-380 have significantly higher tensile stresses at the bottom of the slab in y-direction compared to the tensile stress in x-direction, which would first lead to bottom –up transverse cracking.
- Due to large spacing between the main landing gear in B-777, produced lower top tensile stress in the main landing gear.

Large Aircraft Traffic Mix Gear Locations



EFFECT OF GEAR POSITION & CRITICAL STRESS LOCATION

- **Tensile stress at the bottom of the slab are more critical.**
- **The main landing gear of A-380 resulted in the largest top tensile stress.**
- **The ratio of top to bottom of the slab tensile stress were significantly higher for full gear analysis relative to the individual gear analysis.**
- **The critical top tensile stress occurred at the transverse joint would promote propagation of longitudinal cracks.**

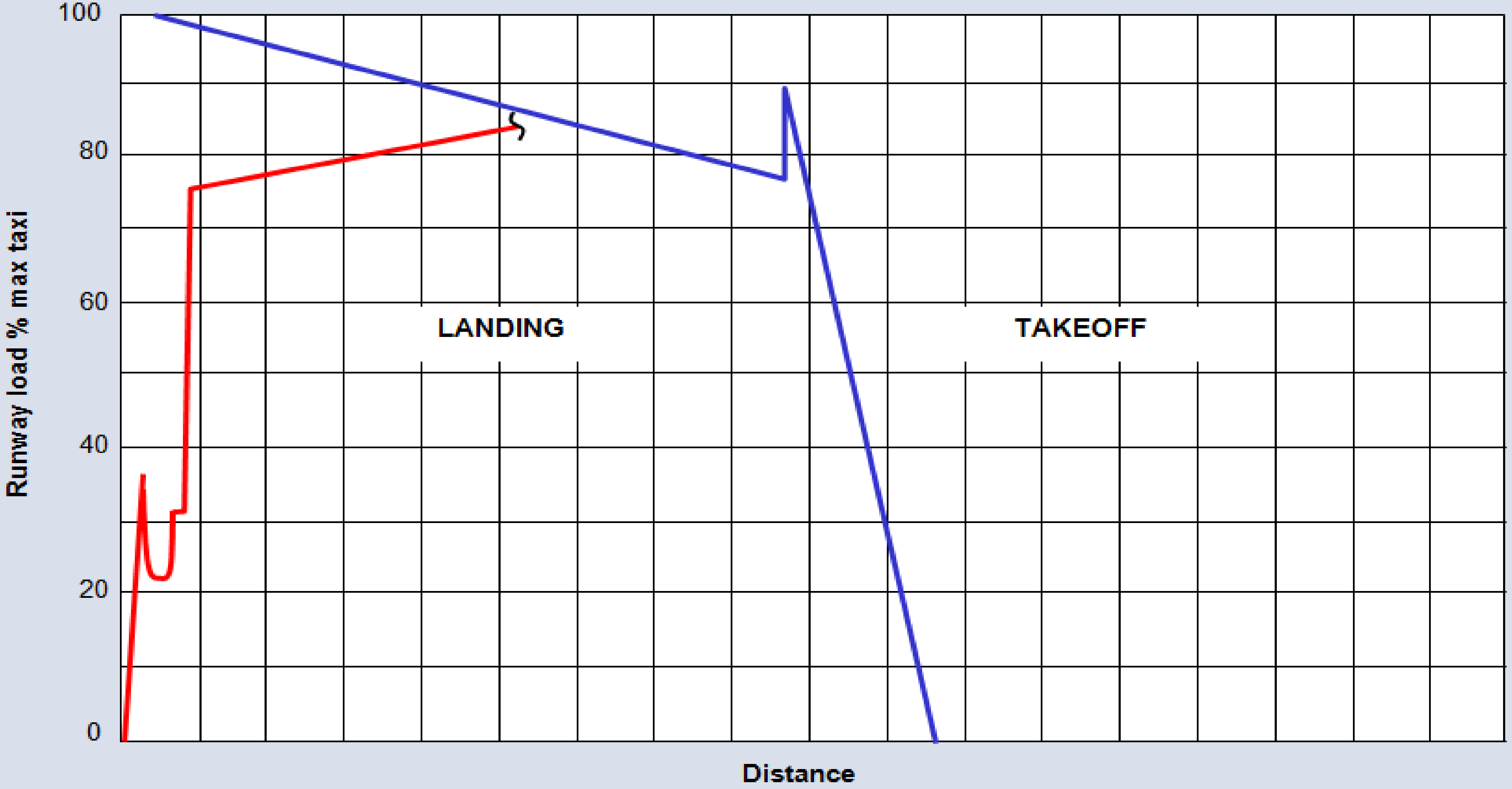
TOUCHDOWN IMPACT AND STRESSES

- During the touch down operation less than 50% of the weight of aircraft impacts on pavement.
- Aircrafts are lighter due to burning of fuel in the flight.

- A partial weight is taken by the flaps (opening of flaps during touchdown)
- Flaps changes horizontal energy to vertical energy which allow to decrease the sink rate prior to touchdown.
- The more flaps available and used, the slower the speed, the slower the touchdown and shorter the rollout.

Runway Loads - Takeoff / Landing

Typical Jet Aircraft



Runway pavements are designed for static load.

The impact of landing is only about 38% of the takeoff static load.

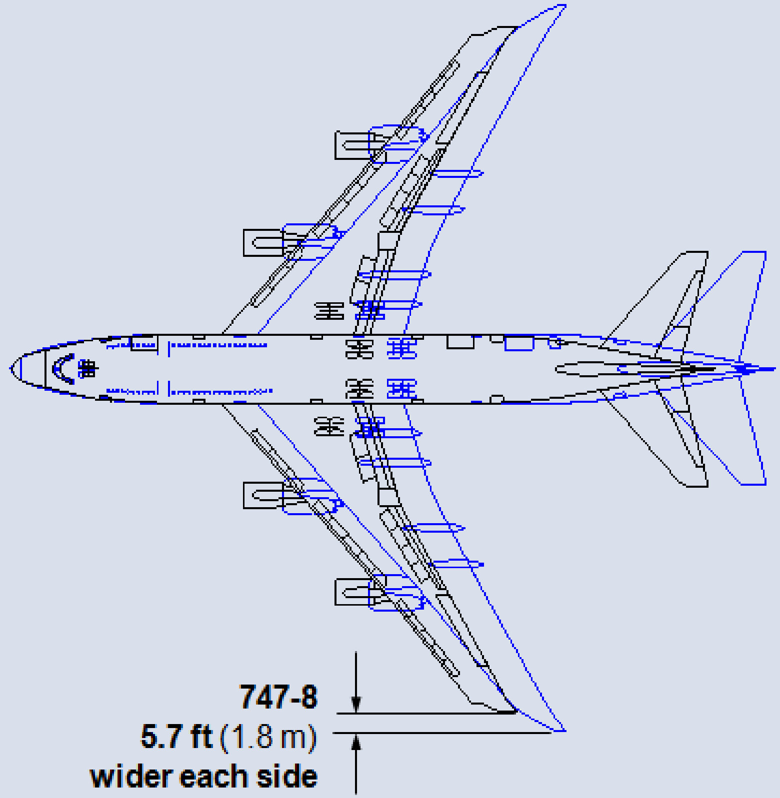
Flap Effects

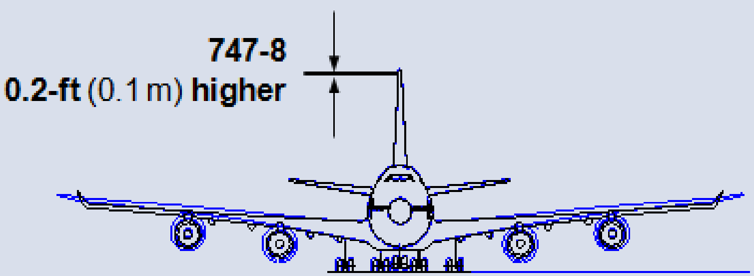
- Increase lift
  Increase drag
  More abrupt stall
  Lower stall speed
- Decrease climb rates
  Change pitch attitude
  Increase approach angle
  Decrease distance to lift-off
  Shorten Takeoff and Landing distance

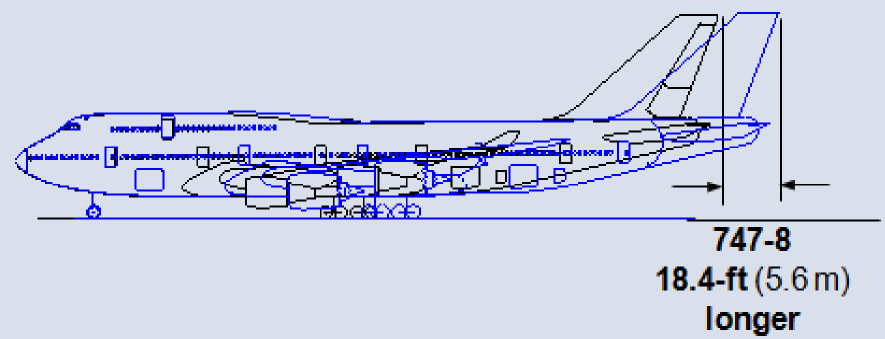
747-8 vs. 747-400 Comparison

	747-8 (ft/m)	747-400 (ft/m)
Span	224.4/68.4	213.0/64.9
Length	250.2/76.3	231.8/70.7
Height	64.2/19.6	64.0/19.5

747-8 (blue)
747-400 (black)

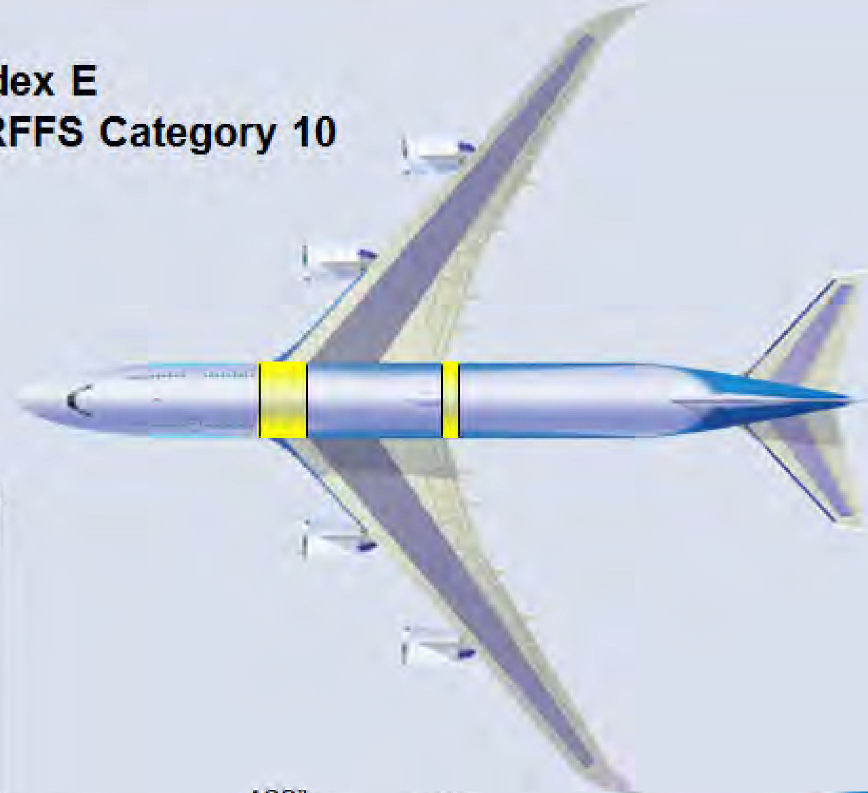


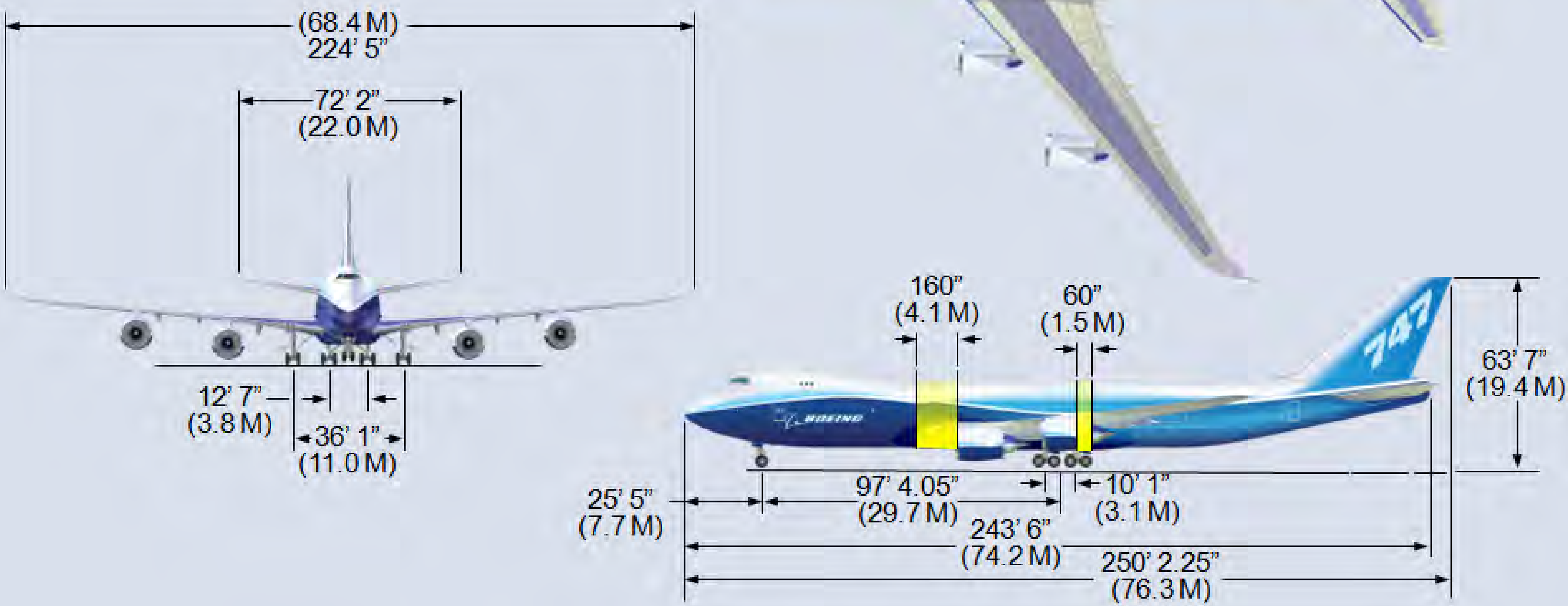




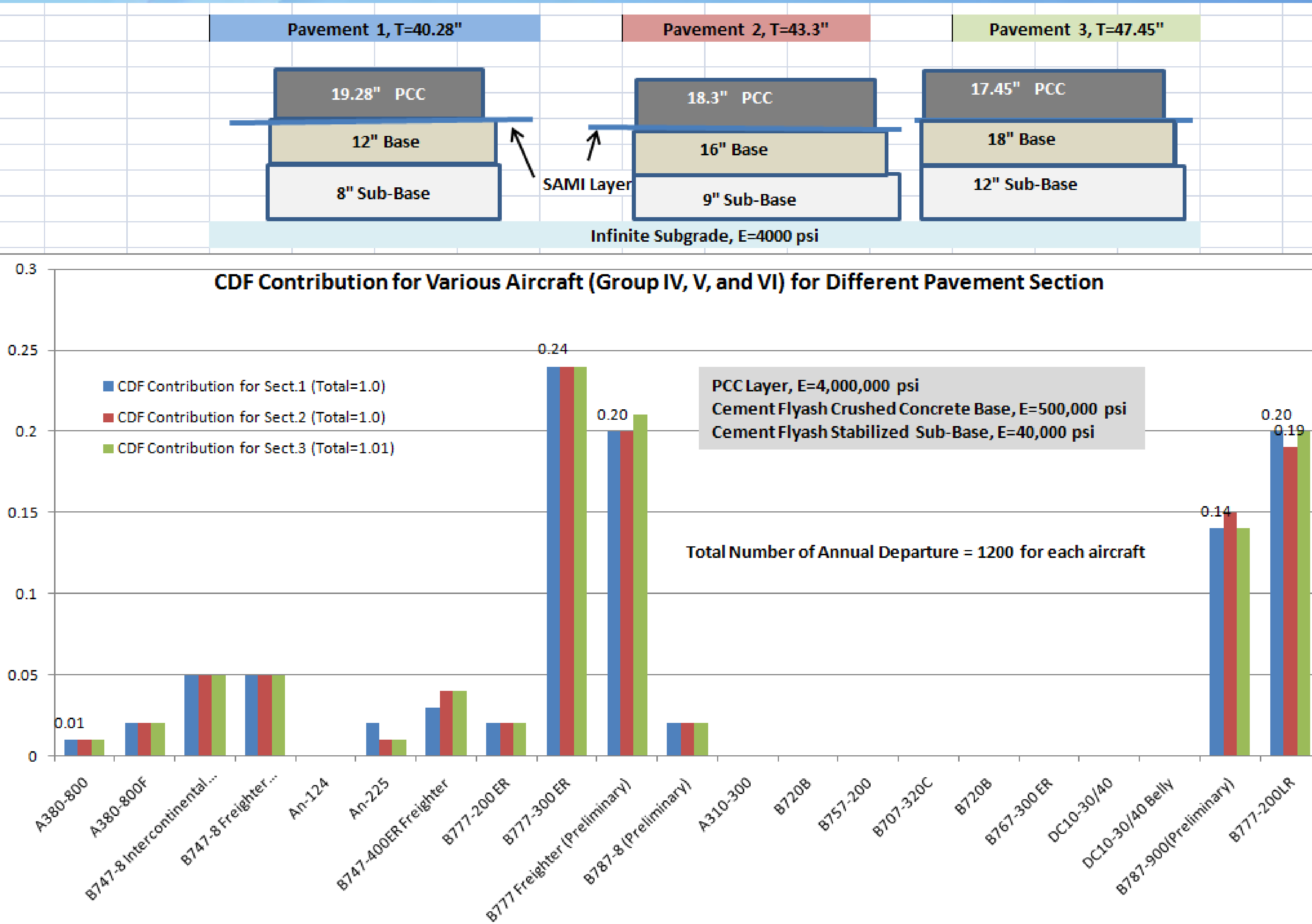
747-8 Freighter - General Arrangement

FAA Airport Design Group 6 – ARFF Index E
ICAO Aerodrome Reference Code F – RFFS Category 10





CDF Comparison for Group IV, V, and VI Aircraft



FAARFIELD DESIGN OUTPUT TW- WB

No.	Type	Thickness in	Modulus psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	19.00	4,000,000	0.15	700
2	Undefined	16.00	500,000	0.35	0
3	Undefined	8.00	40,000	0.35	0
4	Subgrade	0.00	4,000	0.40	0

Total thickness to the top of the sub-grade = 43.26 in

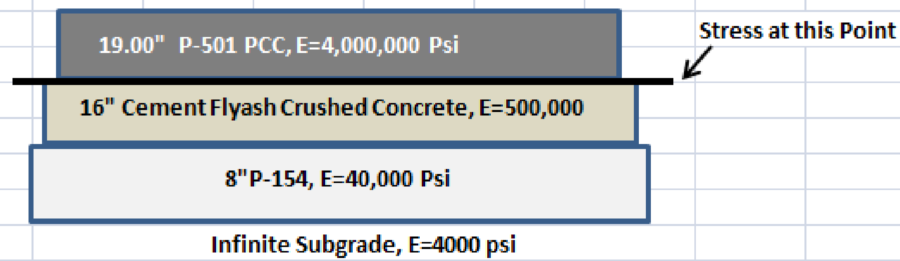
No.	Name	Gross Wt. lbs	Annual Departures	% Annual Growth
1	DC8-43	318,000	227	2.00
2	DC9-32	109,000	69	2.00
3	DC9-51	122,000	100,000	2.00
4	DC9-51	122,000	36,511	2.00
5	DC10-30/40	583,000	2,522	2.00
6	DC10-30/40 Belly	583,000	2,522	2.00
7	Adv. B727-200C Basic	185,200	14,781	2.00
8	B737-300	140,000	82,956	2.00
9	B737-800	174,700	77,036	2.00
10	B747-400B Combi	877,000	103	2.00
11	B747-200B Combi Mixed	836,000	929	2.00
12	B757-200	256,000	478	2.00
13	**B777-200LR**	**768,000**	**10,258**	**2.00**
14	A320-100	150,796	1,964	2.00
15	A340-200 std	568,563	3,647	2.00
16	A340-200 std Belly	568,563	3,647	2.00
17	Fokker-F-28-1000	66,500	272	2.00
18	Dual Tan-400	400,000	171	2.00
19	Dual Tan-400	400,000	46	2.00
20	A380-800	1,239,000	46	2.00
21	B747-8 Freighter (Preliminary)	978,000	100	2.00
22	B787-8 (Preliminary)	486,000	100	2.00
23	**B777-300 ER**	**777,000**	**2,000**	**2.00**
24	B747-400ER Passenger	913,000	100	2.00
25	B787-8 (Preliminary)	545,000	100	2.00

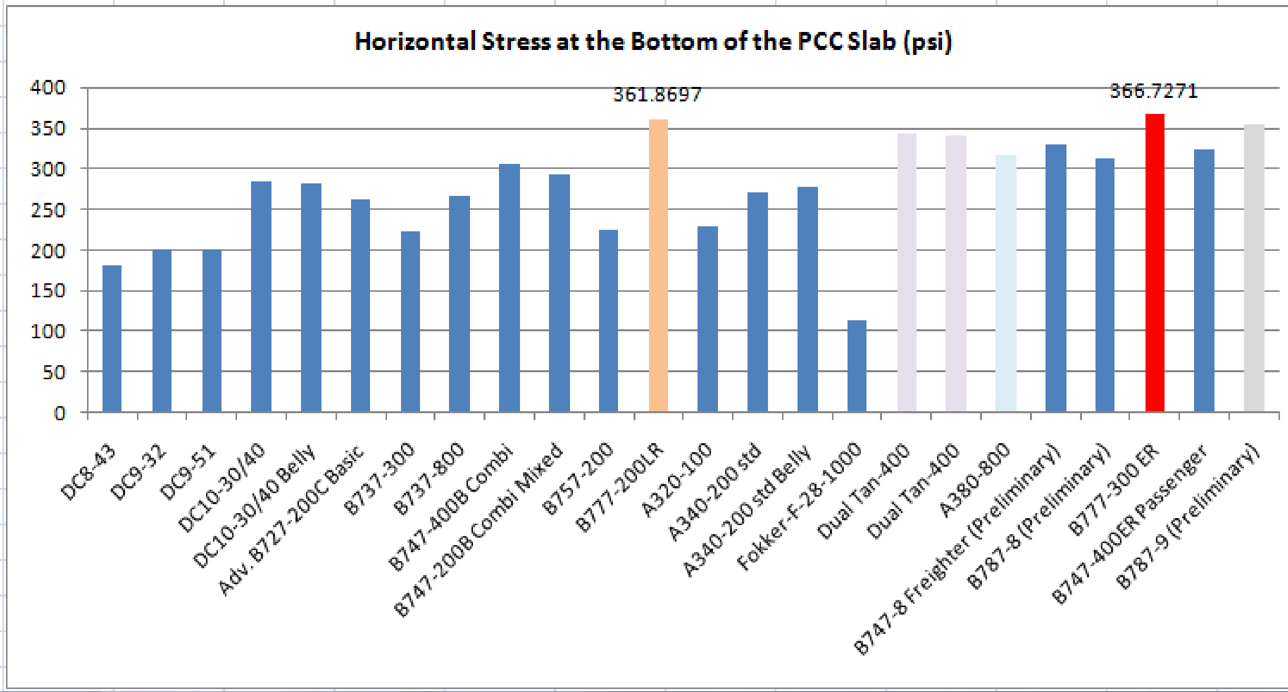
FAARFIELD OUTPUT TW-WB

No.	Name	CDF Contribution	CDF Max for Airplane	P/C Ratio
1	DC8-43	0.00	0.00	3.34
2	DC9-32	0.00	0.00	3.65
3	DC9-51	0.00	0.00	3.64
4	DC9-51	0.00	0.00	3.64
5	DC10-30/40	0.00	0.00	3.55
6	DC10-30/40 Belly	0.00	0.00	2.89
7	Adv. B727-200C Basic	0.00	0.00	2.92
8	B737-300	0.00	0.00	3.79
9	B737-800	0.00	0.01	3.52
10	B747-400B Combi	0.00	0.00	3.46
11	B747-200B Combi Mixed	0.00	0.00	3.46
12	B757-200	0.00	0.00	3.90
13	**B777-200LR**	**0.80**	**0.80**	**3.86**
14	A320-100	0.00	0.00	3.84
15	A340-200 std	0.00	0.00	1.89
16	A340-200 std Belly	0.00	0.00	2.99
17	Fokker-F-28-1000	0.00	0.00	3.60
18	Dual Tan-400	0.00	0.01	3.19
19	Dual Tan-400	0.00	0.00	3.19
20	A380-800	0.00	0.00	3.61
21	B747-8 Freighter (Preliminary)	0.00	0.00	3.56
22	B787-8 (Preliminary)	0.00	0.00	3.78
23	**B777-300 ER**	**0.19**	**0.19**	**3.86**
24	B747-400ER Passenger	0.00	0.00	3.62
25	B787-8 (Preliminary)	0.00	0.01	3.78

FAARFIELD: Horizontal Stress at the Bottom of PCC Slab

Aircraft	Hor. Stress at Bottom of PCC layer
DC8-43	181.378
DC9-32	200.8331
DC9-51	200.89
DC10-30/40	284.8653
DC10-30/40 Belly	283.1896
Adv. B727-200C Basic	261.2953
B737-300	223.4171
B737-800	265.9797
B747-400B Combi	307.3259
B747-200B Combi Mixed	293.1689
B757-200	224.6692
B777-200LR	361.8697
A320-100	229.1269
A340-200 std	270.7625
A340-200 std Belly	278.3226
Fokker-F-28-1000	113.2704
Dual Tan-400	342.996
Dual Tan-400	342.4131
A380-800	317.0354
B747-8 Freighter (Prelimir	330.6996
B787-8 (Preliminary)	313.8884
B777-300 ER	366.7271
B747-400ER Passenger	324.6338
B787-9 (Preliminary)	354.5188

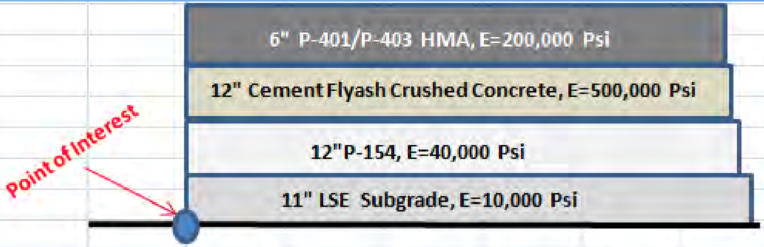


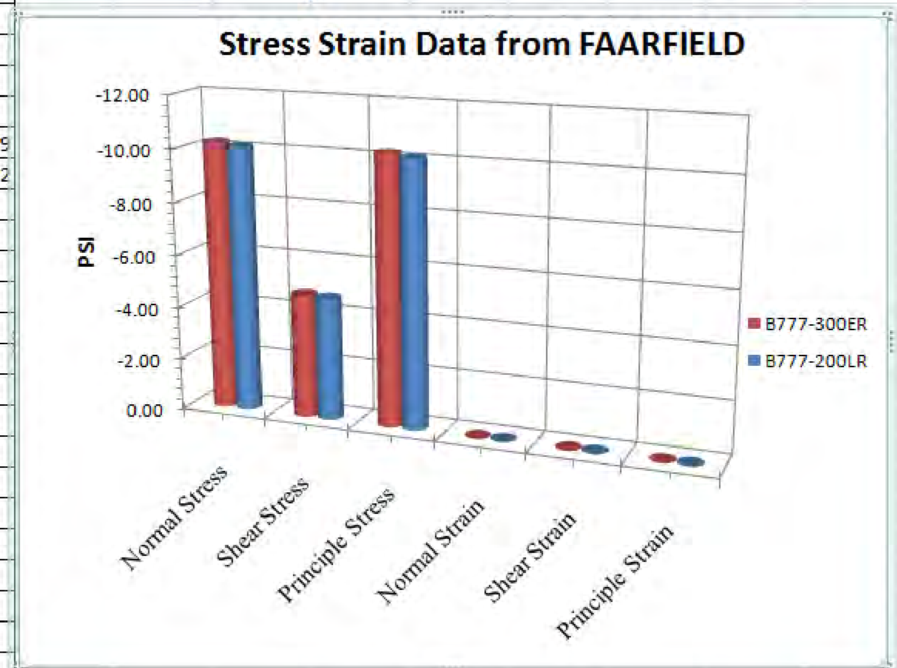


Stress Computation for TW-WB, output from FAARFIELD

FAARFIELD: Stress/Strain Analysis at the Bottom of the Flexible Pavement

B777-200LR						
	v. stress	H. stress(Y)	H. stress(X)	xz shear	yz shear	xy shear
Stress	-1.01E+01	-1.39E+00	-7.75E-01	0.00E+00	0.00E+00	-2.61E-18
Strain	-2.34E-03	6.06E-04	8.15E-04	0.00E+00	0.00E+00	-1.76E-21
Displacement	3.78E-01					
Principle Stress		Principle strain		Max Shear	-4.68E+00	
1	-1.01E+01	1	-2.34E-03			
2	-1.39E+00	2	6.06E-04			
3	-7.75E-01	3	8.15E-04			
B777-300ER						
	v. stress	H. stress(Y)	H. stress(X)	xz shear	yz shear	xy shear
Stress	-1.03E+01	-1.41E+00	-7.84E-01	0.00E+00	0.00E+00	-8.81E-19
Strain	-2.37E-03	6.13E-04	8.24E-04	0.00E+00	0.00E+00	-5.95E-22
Displacement	3.82E-01					
Principle Stress		Principle Strain		Max Shear	-4.73E+00	
1	-1.03E+01	1	-2.37E-03			
2	-1.41E+00	2	6.13E-04			
3	-7.84E-01	3	8.24E-04			
B777-200LR				B777-300ER		
Normal Stress	-1.01E+01	1		-1.03E+01		
Shear Stress	-4.68E+00	2		-4.73E+00		
Principle Stress	-1.01E+01	3		-1.03E+01		
Normal Strain	-2.34E-03	5		-2.37E-03		
Shear Strain	-1.76E-21	6		-5.95E-22		
Principle Strain	-2.34E-03	7		-2.37E-03		
Bending Stress	-7.75E-01	8		-7.84E-01		
Bending Strain	8.15E-04	9		8.24E-04		
Displacement	3.78E-01	4		3.82E-01		



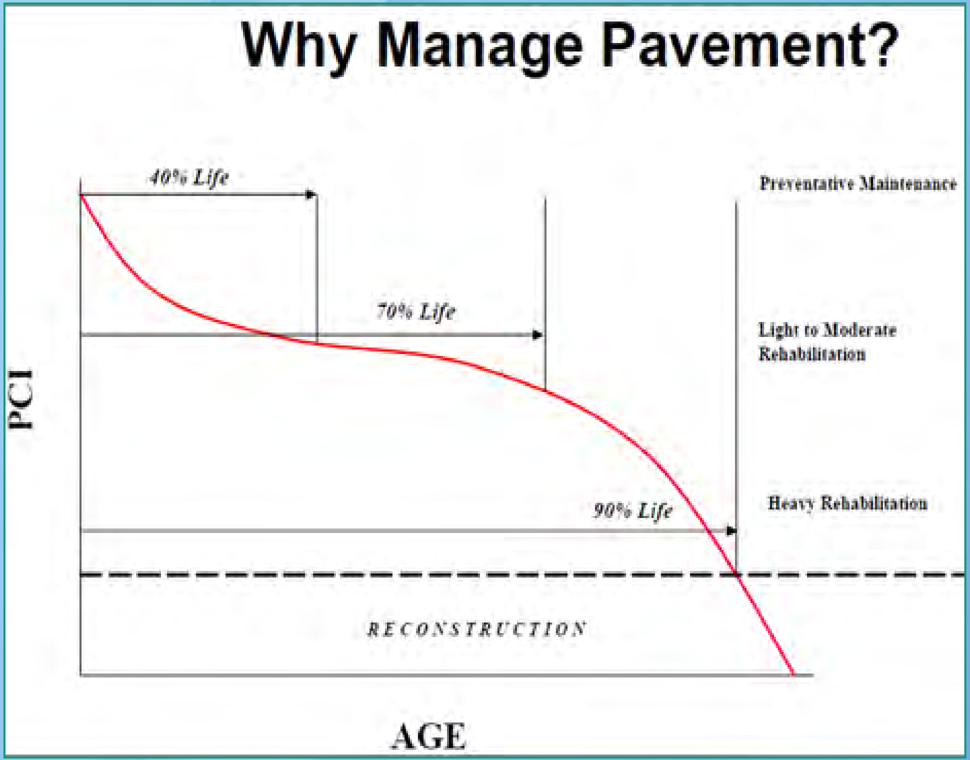


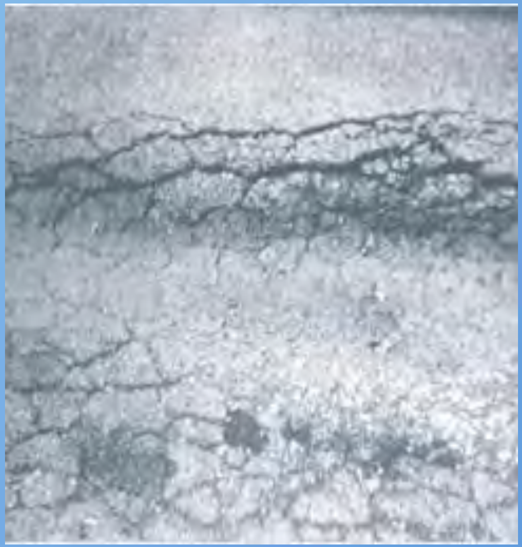
Stress Computation for TW-WB Shoulder, output from FAARFIELD

Section-3

Pavement Evaluation & Management System

- Pavement Strength Evaluation and Rating process
    - PCI Rating
    - NDT
    - ACN-PCN Evaluation
- Life Cycle Modeling
- Decision Matrix
- Pavement Management Software
- Evaluation of Concrete and Metal Structure through Soils Resistivity Analysis





- To Evaluate the current Pavement condition
- Detail Plan for repair (what/When/How..)
- Cost Benefit Analysis
- Justification
- What happens if not repair at this point ?

All these are answered

Pavement Evaluation & Rating Process

Pavement Condition Index (PCI)
Structural Condition Index (SCI)

↓

NDT And Back Calculation for Strength Evaluation, Validate w/Field Testing

↓

Traffic Analysis- AIRPAVE

↓

ACN-PCN Evaluation
Pavement Thickness

↓

COMFAA
BACKFAA
FAARFIELD

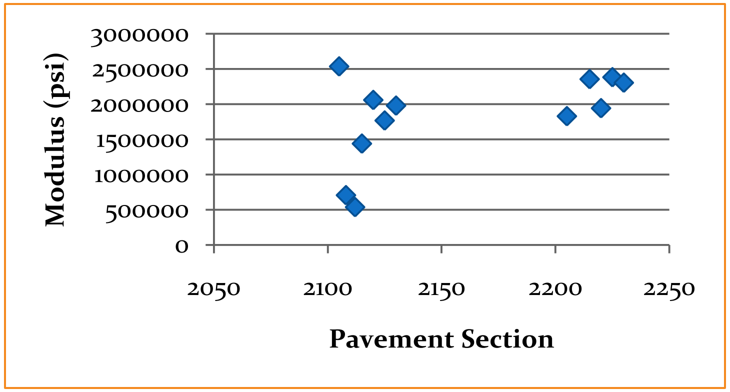
Minimum Service Level	
Runways	75
Taxiways	70
Aprons	65

Pavement Evaluation: Distresses

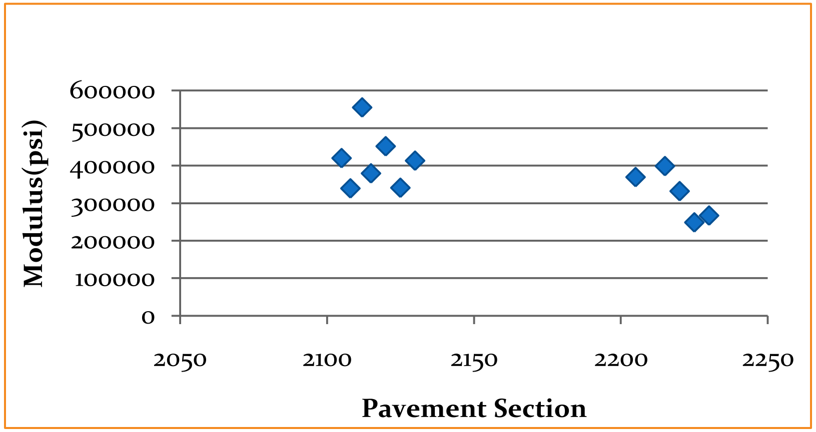
AC 150/5380-6
ASTM D 5340-10
Distress Severity, Qty. & Type

Flexible pavement	**Rigid pavement**
Alligator	Blow Up
Bleeding	Corner Break
Block Cracking	LTD Cracking
Corrugation	D- Cracking
Depression	Joint Seal Damage
Jet Blast Erosion	Large Patch
Long,.& Trans. Cracking	Small Patch
Oil Spill	Pumping
Joint Refl. Cracking	Pop Outs
Polished Agg.	Faulting
Raveling/Weathering	Shattered Slab
Rutting	Shrinkage
Shoving From PCC	Joint Spalling
Slippage	Corner Spalling
Swelling	

Strength Evaluation: NDT Modulus (Back-calculation)



Top layer



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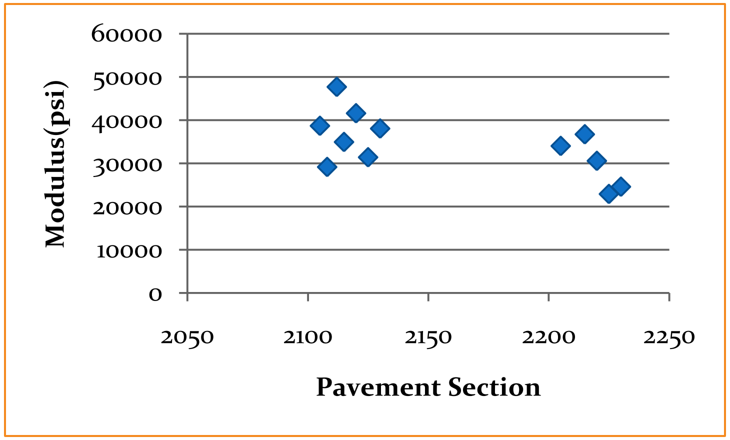
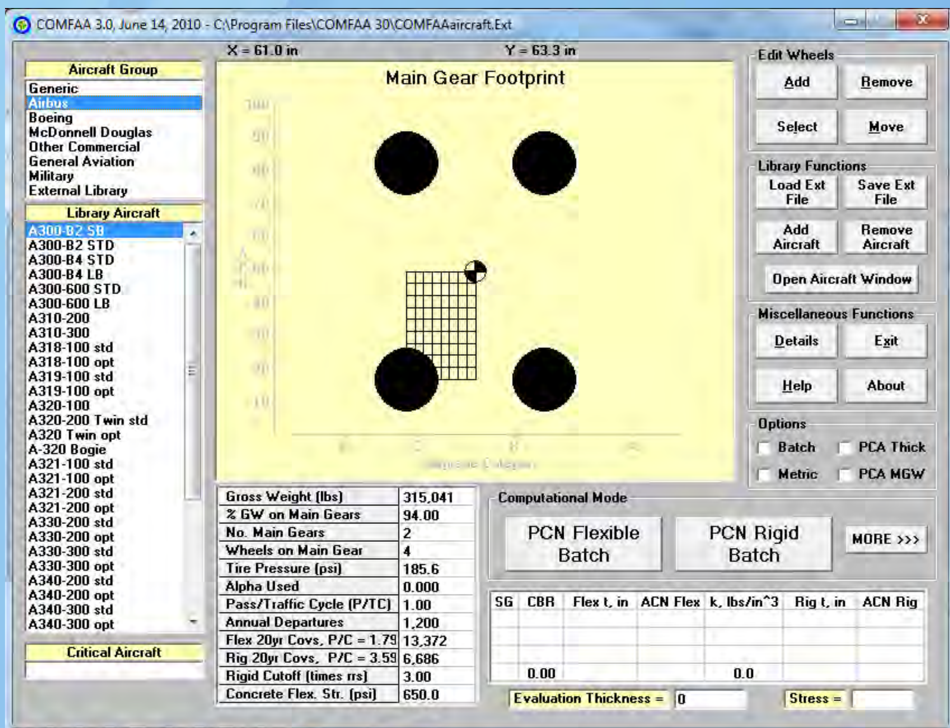
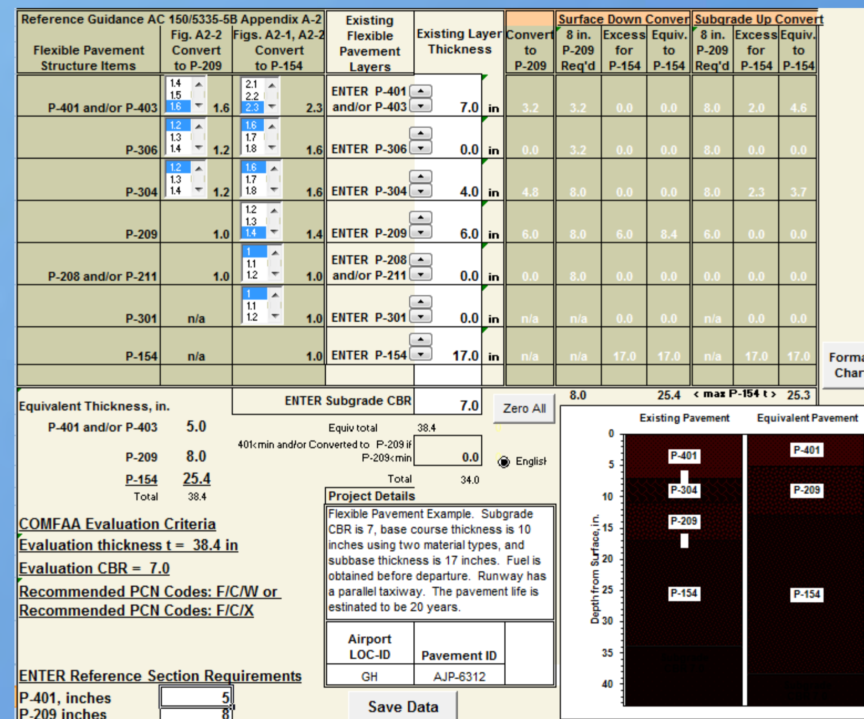


Sub-grade

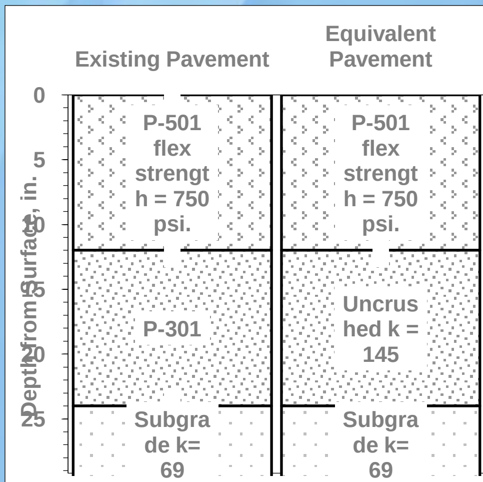
Determination of ACN-PCN Using COMFAA 3.0

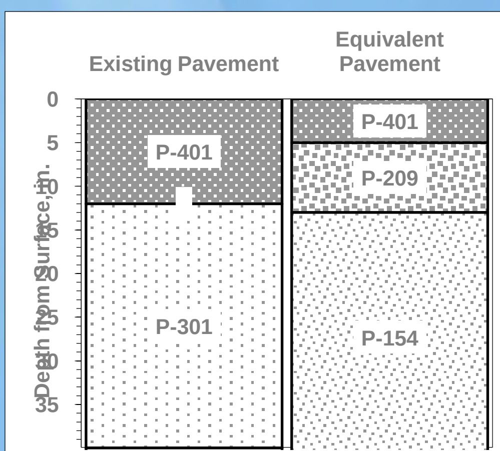


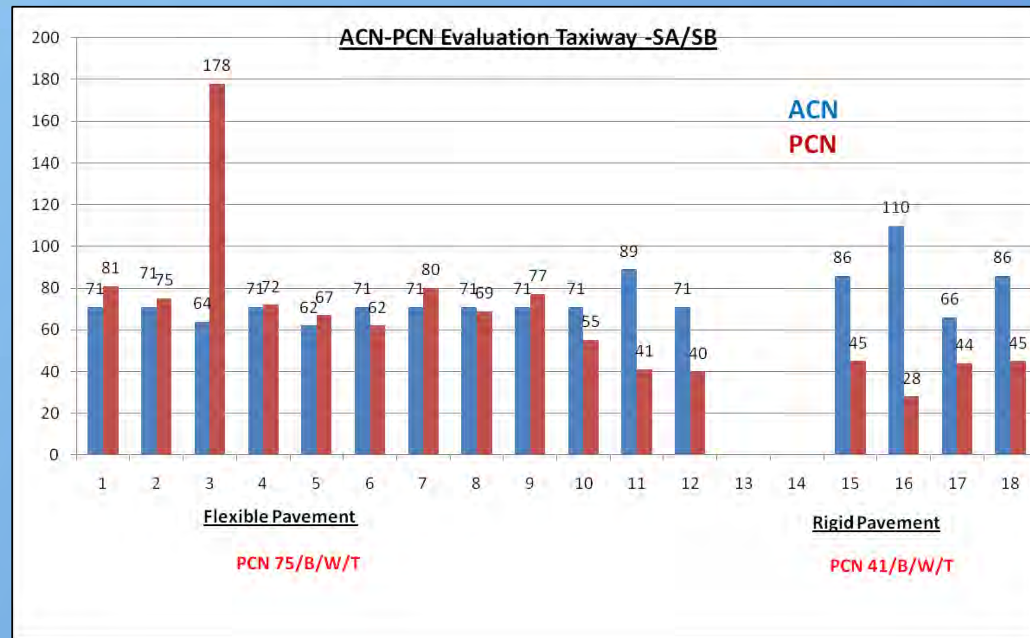


COMFAA 3.0 Screen Shot and Equivalent Section Determination

ACN-PCN Evaluation Using COMFAA 3.0







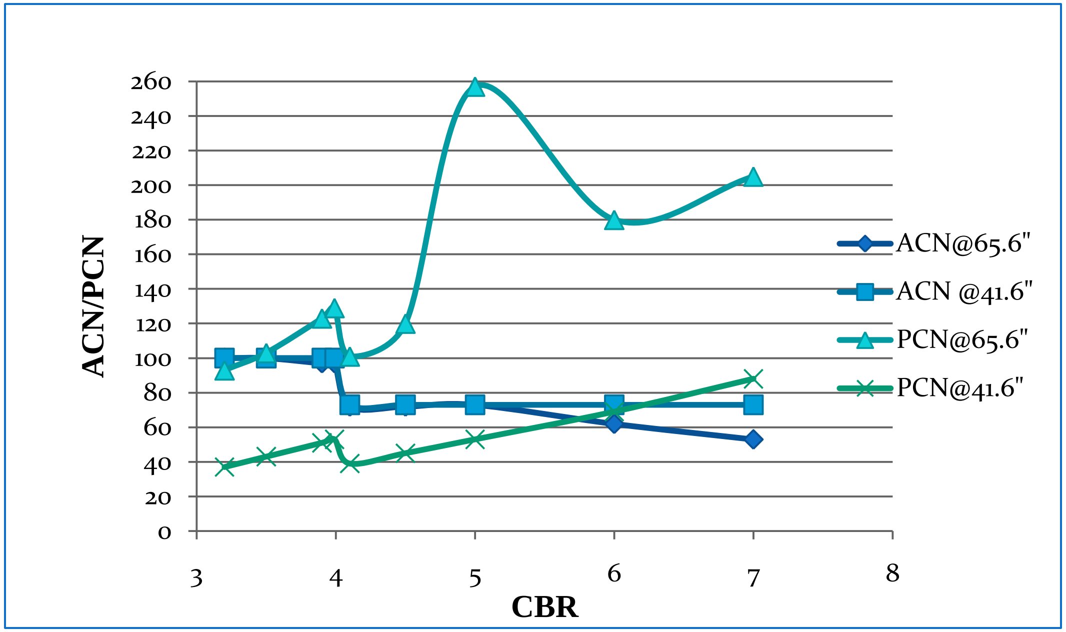
Example Output from COMFAA 3.0 TW SA/SB

PCN Reporting Format:

PCN Number/Pavement Type/Tire Pressure/Method of Calculation (Technical/Using Airplane)

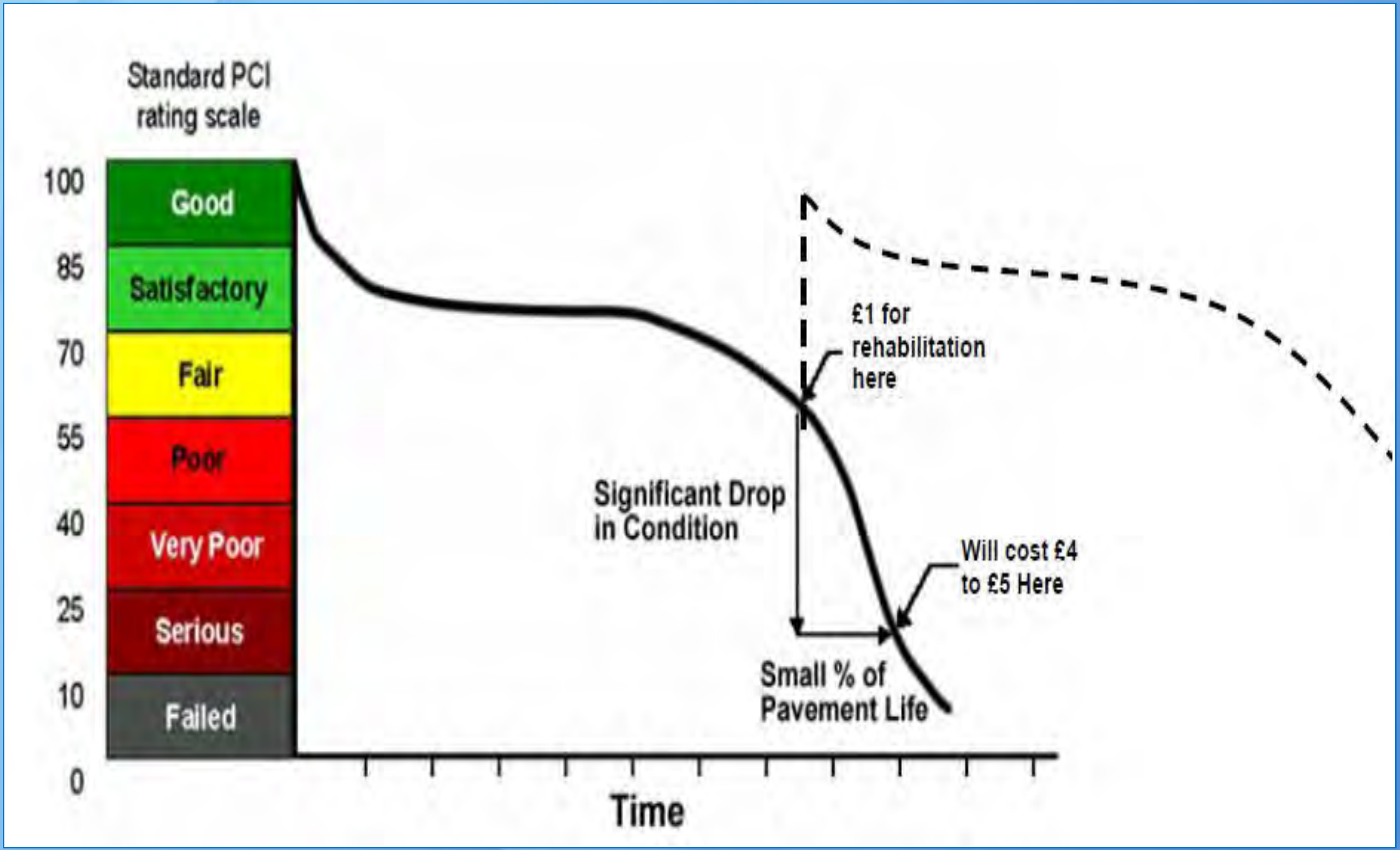
FACTORS AFFECTING ACN-PCN EVALUATION

- **Sub-grade Modulus**
- **Pavement Thickness**
- **Traffic loading/type and Gear**
- **Engineering Judgment (Personal decisions)**



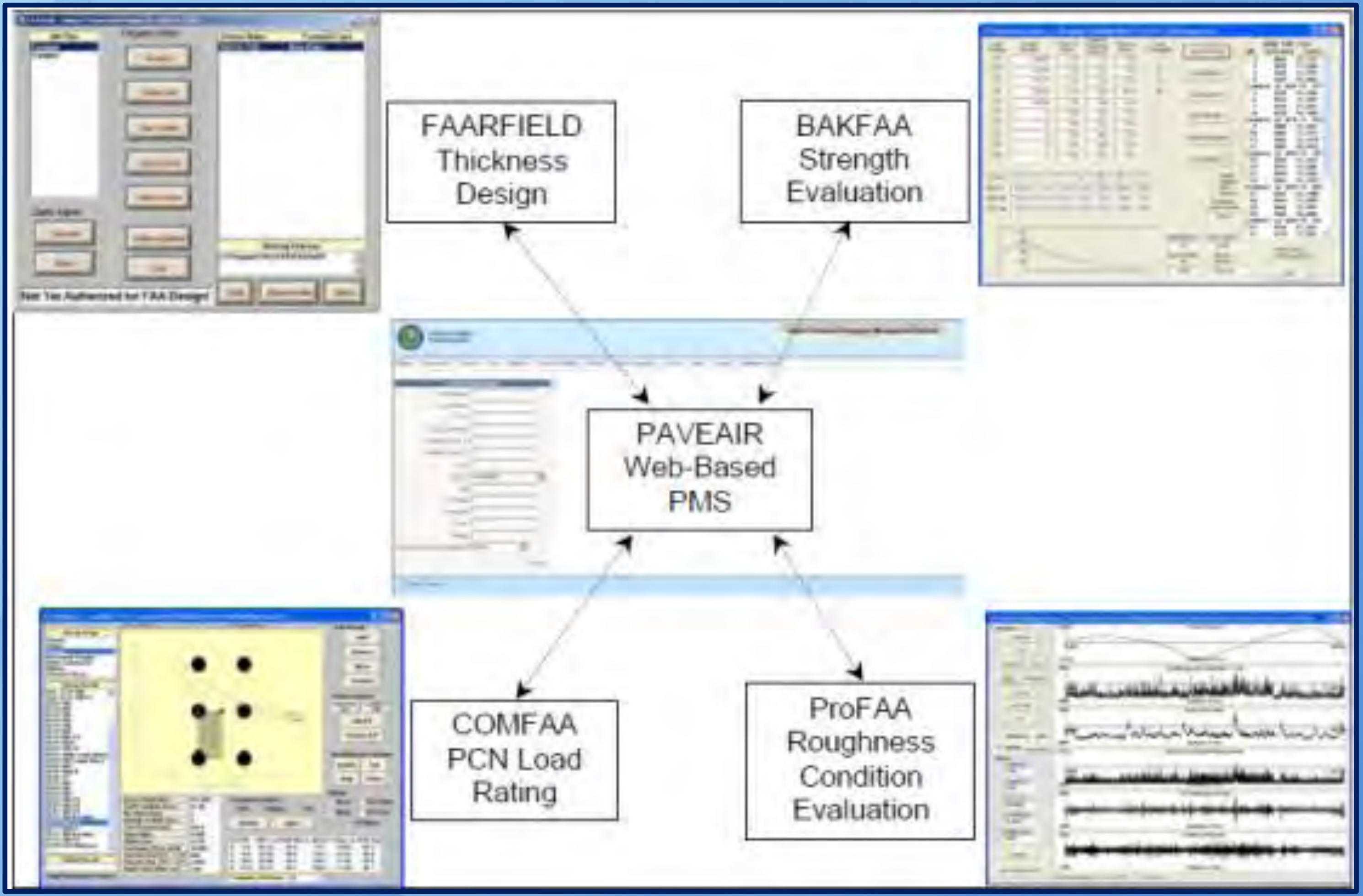
Example: TW SA/SB Section #2108 Evaluation with DMJM Traffic -Projection

Life Cycle Cost Analysis



LCCA Model

PAVEAIR: Web Based Project Management Tool



Pave Air Beta Version

Rehabilitation Alternatives and Decision Making Criteria

Matrix Comparison of PCC Pavement Rehabilitation Alternatives

Pavement Rehabilitation Alternative	Airport Operation Impact		Construction		Performance	Cost		Total Score	Weighted Score
	Runway Closure	Tenant Impact	Sustainability	Time	Smoothness	Initial Construction	Life Cycle		
Weighted Factor	15	15	10	10	10	25	15	100	
Total Reconstruction	2	3	1	2	4	1	4	17	2.30
Partial Reconstruction	3	3	3	3	3	2	3	20	2.75
Un-bonded PCC Overlay	3	3	4	3	4	3	2	22	3.05
Bonded PCC Overlay	4	4	5	4	4	4	4	29	4.1

Rating Scale: 5- Excellent, 4- Very Good, 3- Good, 2- Fair, 1- Poor, 0- Very Poor

Rehabilitation of Taxiways WA-WB and New West Vault

Rehabilitation Alternatives and Decision Making Criteria

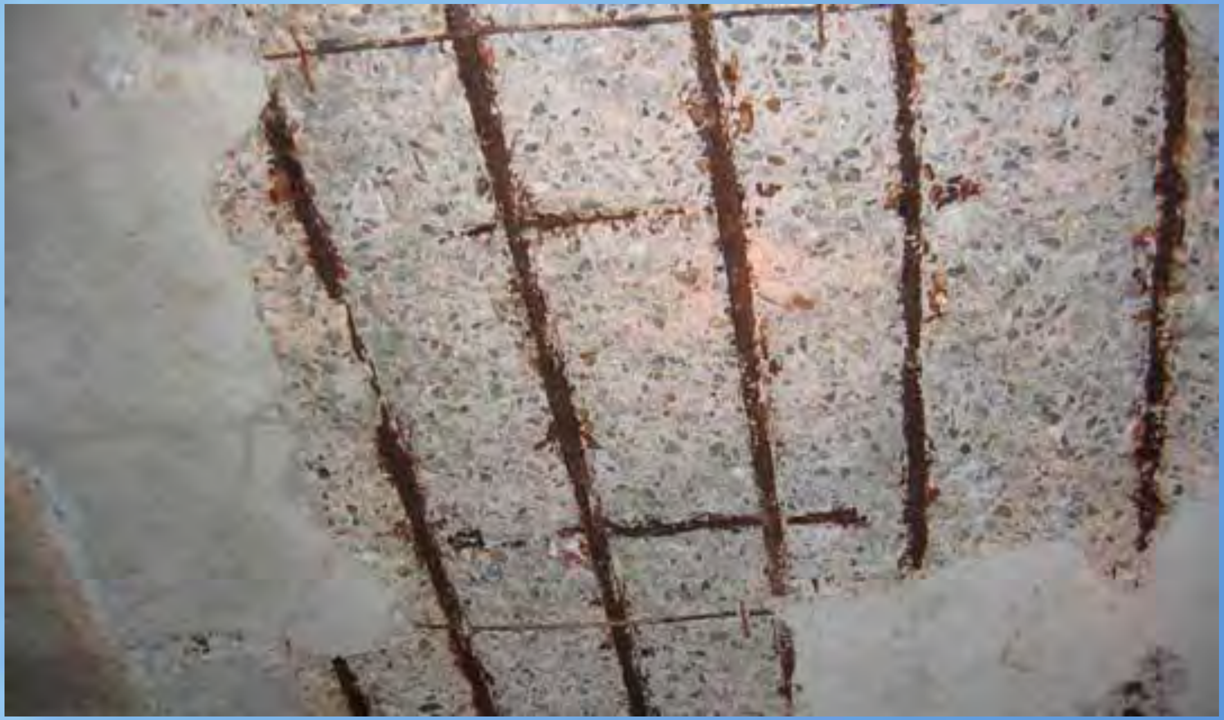
Rating Scale 5 – Excellent 4 – Very Good 3 – Good 2 – Fair 1 – Poor 0 – Very Poor		CONSTRUCTION					DESIGN		PERFORMANCE	COSTS		
Options		Constructability	Contractor Familiarity	Feasibility	Schedule	Schedule Risk	Impacts to Airfield Electrical Infrastructure & ILS	Grade Compatibility	Maintenance Requirements	Initial Capital Cost	Life Cycle Cost	Total Score
1	PC Concrete Jointed Overlay (mill 3" of existing AC)	4	5	5	3	5	3	4	4	5	5	43
2	PC Concrete Jointed Overlay (mill existing AC to LCF base)	3	5	5	3	3	3	4	4	4	4	38
3	Continuously Reinforced Concrete Overlay (Mill 3" of Existing AC)	3	2	5	3	3	3	4	5	3	3	34

Rehabilitation of Runway 9-27
Final Engineering Report

Section-4

Soils Resistivity and Corrosion Potential of Native Sub-grade Soils

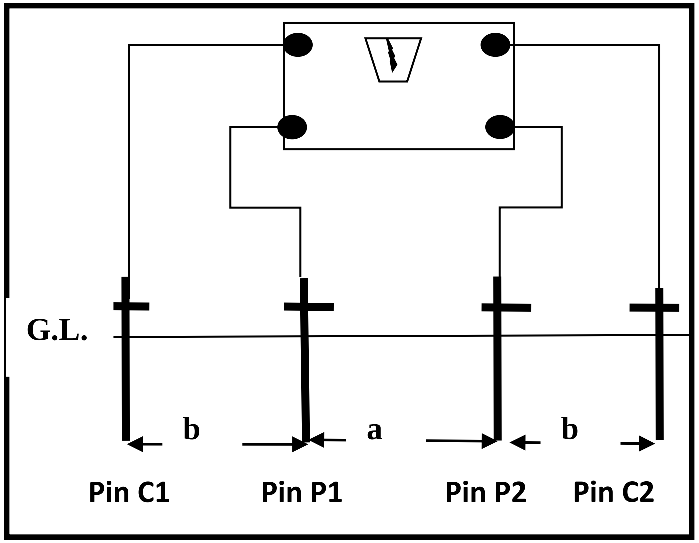
Deterioration of Concrete and Metal Structures



Concrete and metal structures are deteriorated at faster rate with soils corrosion activity. Soils Corrosivity is measured by Soils Resistivity

Soils Resistivity Testing

Method of Soils Resistivity Testing
Field Testing
Lab Testing



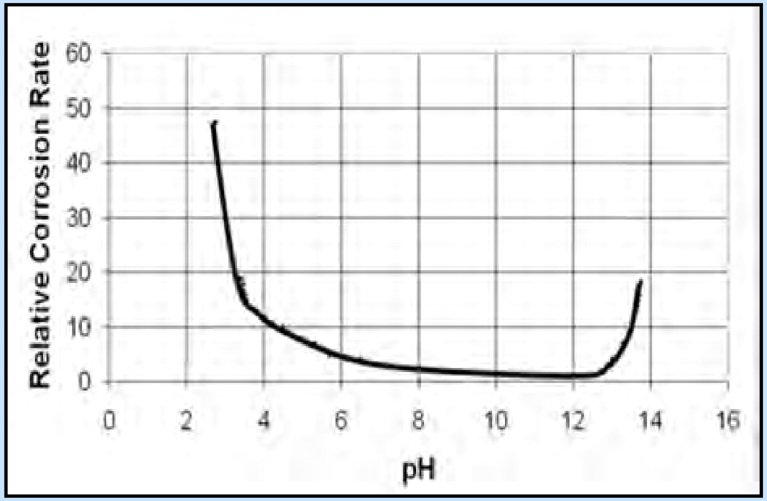
Schematic Diagram For Field Testing Setup

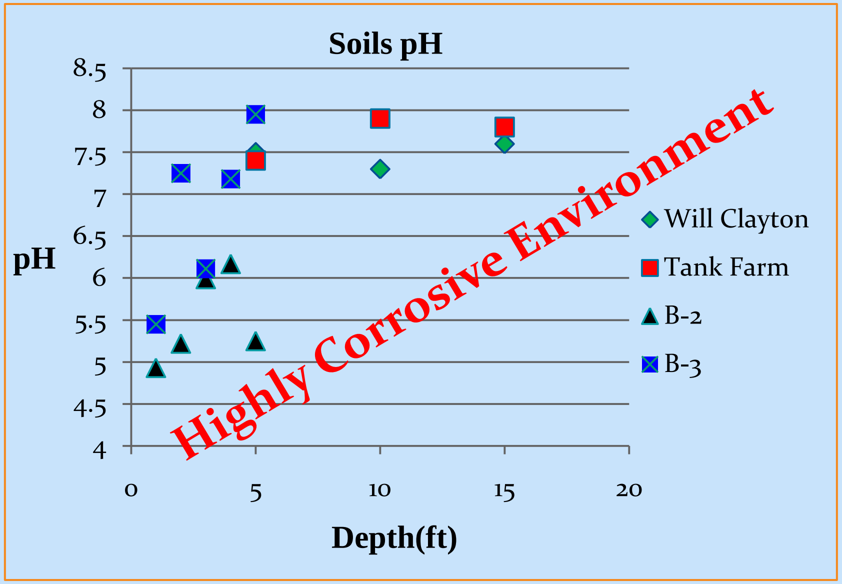
SOILS RESISTIVITY

Factors:

- **Soils PH**
- **Mineral Content (Chloride And Sulfate Ions)**
- **Soils Types**
- **Moisture Content**
- **Temperature and Environment**

pH Concentration and Corrosion Rate





General Trend of Soils pH To Rate of Corrosion

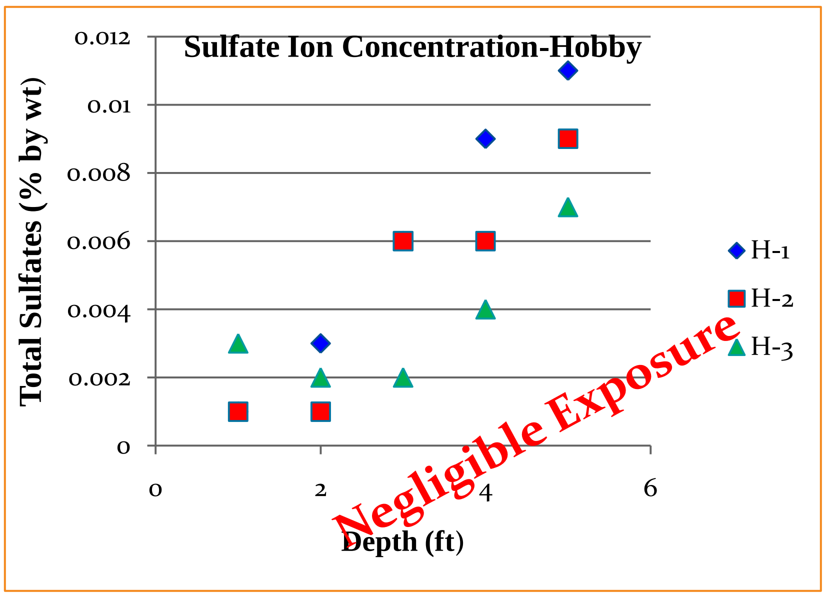
High Moisture Content (Shallow Water Table)
High Temperature
Acidic Environment
Highly Plasticity Soils

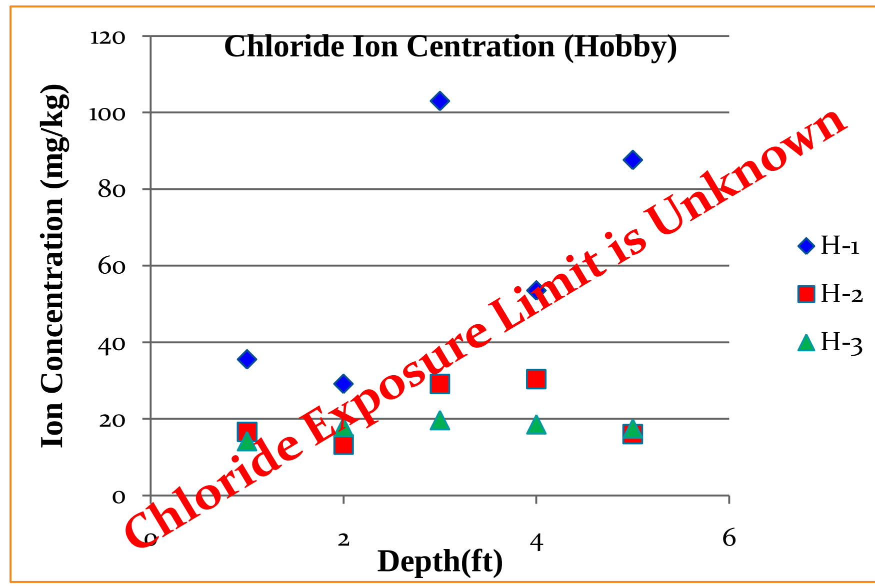
These conditions may accelerate corrosion activity

Sulfate and Chloride Ion Concentration

Sulfate Exposure	Water Soluble Sulphates (So4) (in % by wt.)
Neglibible	0.00≤SO4<0.10
Moderate	0.10≤SO4<2.0
Severe	0.20≤SO4<2.0
Very Severe	SO4>2.0

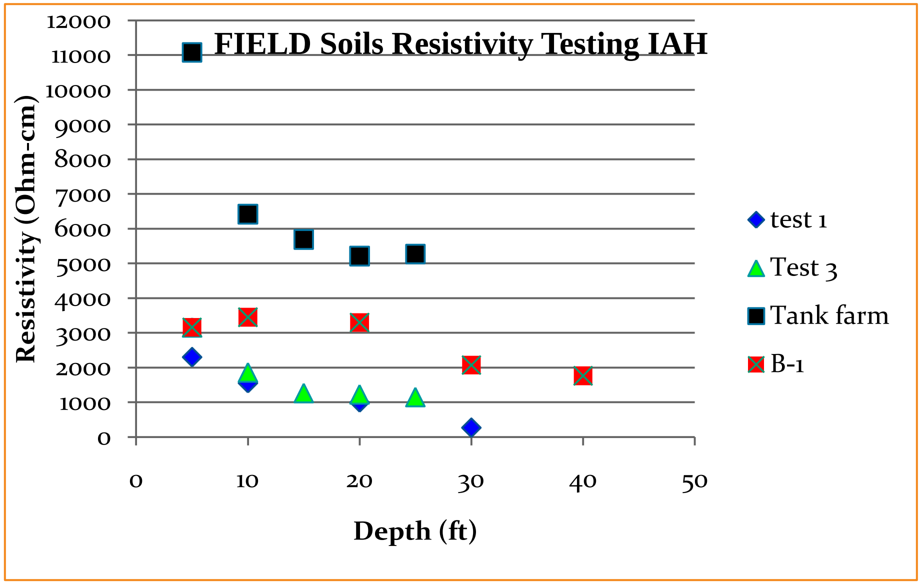
No standard Limit for Chloride exposure

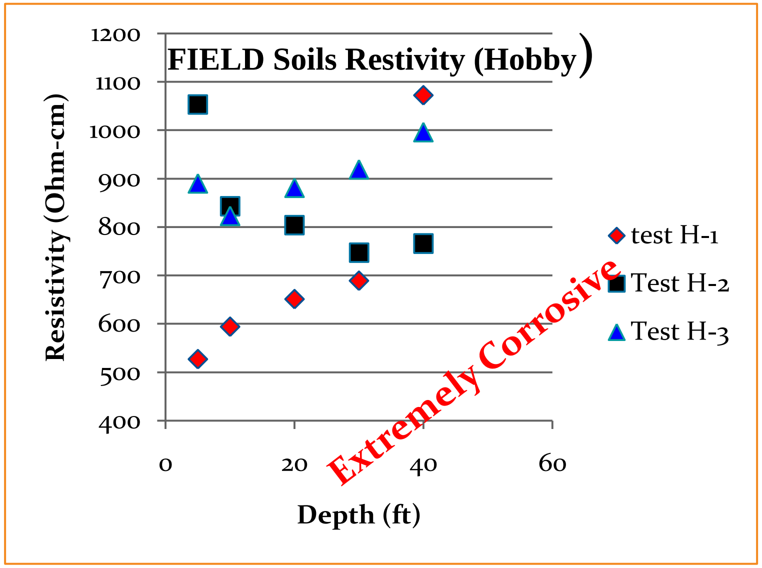


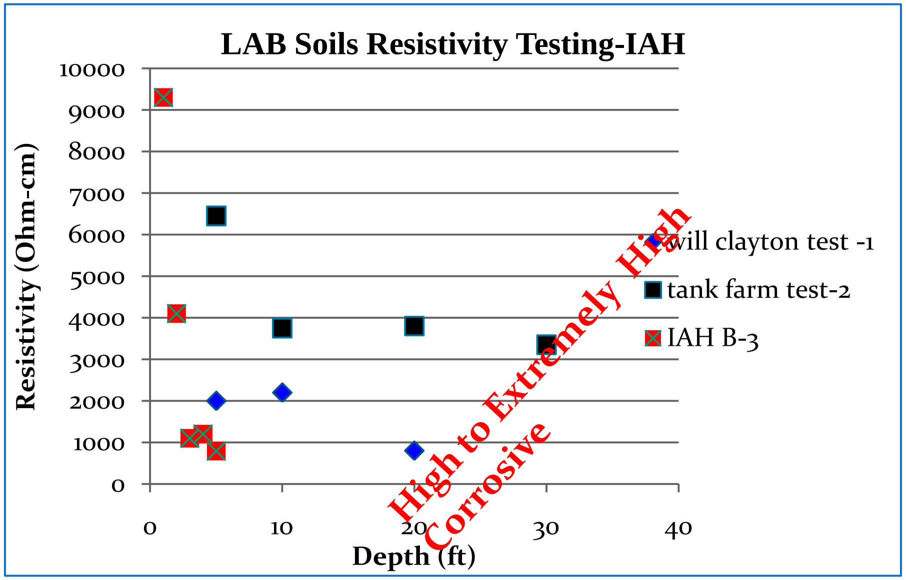


As per AASHTO specification, the maximum acceptable levels for chloride is 100 PPM and for sulfates is 200 PPM for minimum resistivity level of 3000 Ohm-cm

Soils Resistivity Test Results







Soil Corrosion Rating

Resistivity (in Ohm-cm)	Corrosion State
Higher than 20,000	Essentially non corrosive
10,000-20,000	Mild corrosive
5000-10000	**Moderately corrosive**
3000-5000	**Corrosive**
1000-3000	**Highly corrosive**
Less than 1000	**Extremely corrosive**

Research on Soils Resistivity Testing is Going on

References:

•Brill, D.R. (2010). “Calibration of FAARFIELD Rigid Pavement Design Procedure”, Final Report , U.S. Department of Transportation and Federal Aviation Administration, DOT/FAA/AR-09/57, Office of Research and Technology Development, Washington DC.

•Federal Aviation Administration, Advisory Circular AC 150/5320-6E (2009). “Airport pavement Design and Evaluation”, U.S. Department of Transportation and Federal Aviation Administration.

•Federal Aviation Administration, Advisory Circular AC 150/5335-5B (2011). “Standard Method of Reporting Airport Pavement Strength –PCN”, U.S. Department of Transportation and Federal Aviation Administration.

•Godiwalla, A. (2011). “Advanced, Modern and Innovative Technologies Used at Houston Airport Systems, Stabilized Sub-grade and Stabilized Bases Pavement Surfaces”, Airfield Engineering & Asset Maintenance Summit, Singapore Expo & Convention Center, Singapore.

•Guo, E.H. (2006). “Fundamental Modeling of Curling Responses in Concrete Pavements.” 6th International Workshop on Fundamental Modeling of Design and Performance of Concrete Pavements, Belgium.

•Pokhrel, D.R. (2011). “Pavement Design and Management Systems at Houston Airport Systems”, Presented to the 4th Annual Conference of American Society of Nepalese Engineers, July (9-10), Houston TX.

•Pokhrel, D.R. (2011). “Current Status and Issues with the Geotechnical Engineering At Houston Airport System”, PDC Project Status Briefings, Department of Aviation, Houston Airport Systems.

•Roesler, J., Evangelistra , F. Jr., & Domingues, M. (2007). “Effect of Gear Position on Airfield Rigid Pavement Critical Stress Location.” FAA Worldwide Airport Technology Transfer Conference, Atlantic City, New Jersey, USA.

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