ICAO Seminar on Aerodrome Physical Characteristics and Pavements

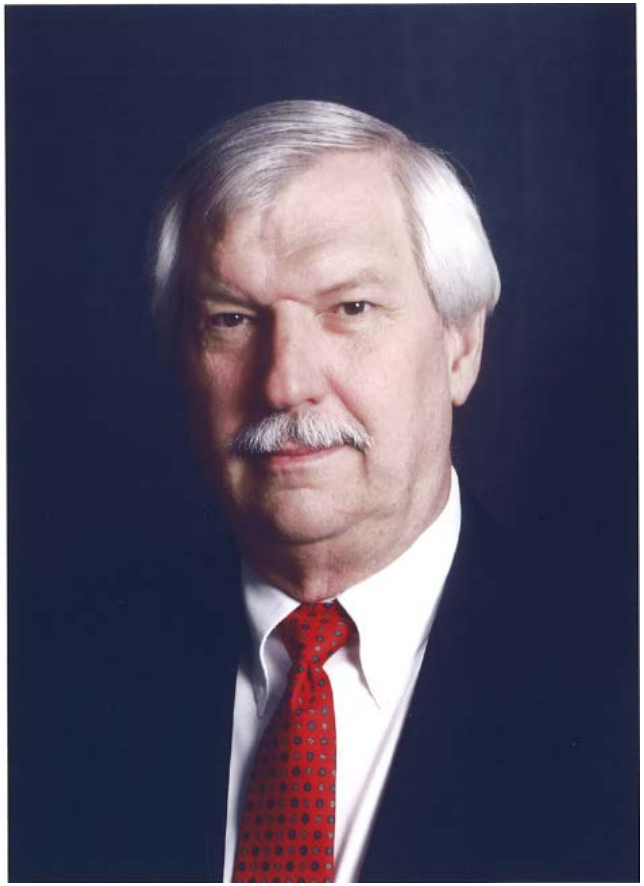
By
Dr.M.W.Witczak
Invited Speaker

Held at
ICAO South American Regional Office
Lima, Peru
6 – 9 August 2013

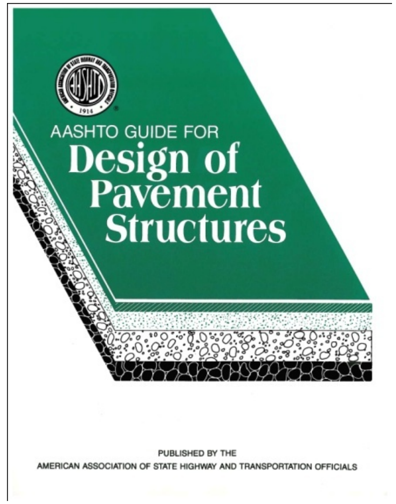
Speaker Introduction

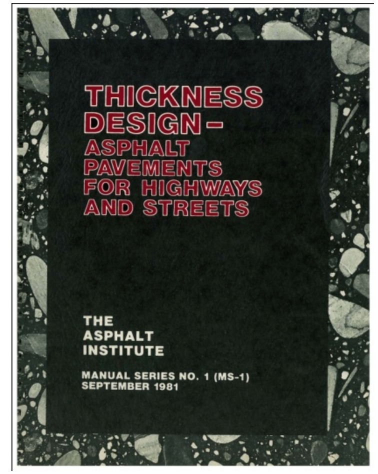
Invited Seminar Speaker – Pavement Systems

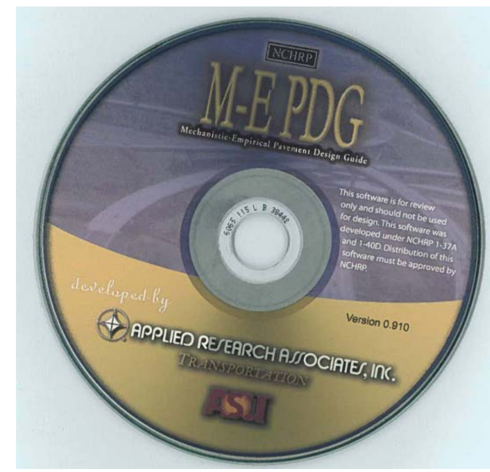
Dr.M.W.Witczak

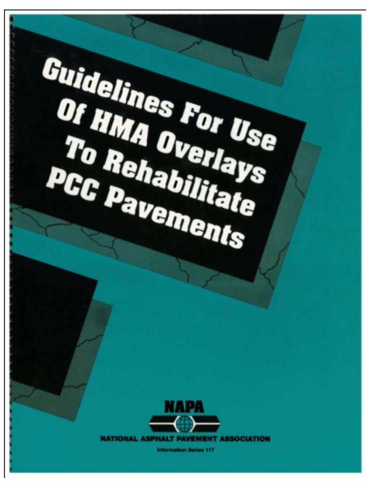


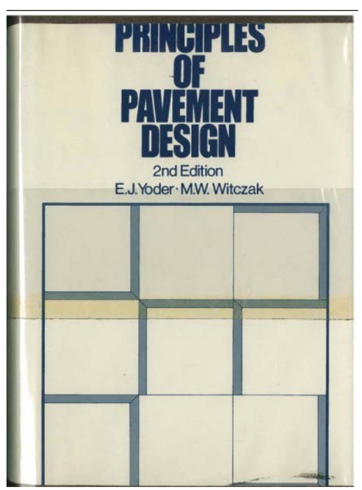
Dr. M.W. Witczak

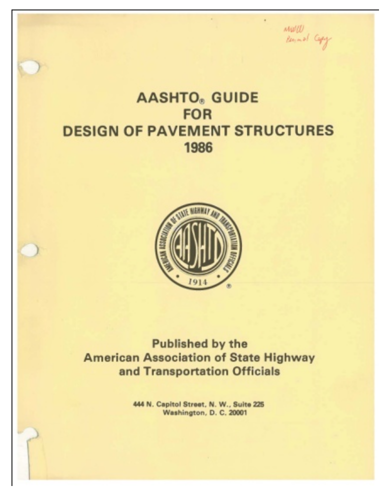












Dr. M. W. Witczak

- ***Consultant to Hundreds of Pavement Agencies-Countries***
  - *US Military (Airfields and Design Manuals)*
  - *FAA, FHWA, NAS, The Asphalt Institute, National Asphalt Pavement Assn, State DOTS, Law Firms, Countries, Private Industry*
- ***Awarded 18 Career Engineering/Construction Honors***
  - *Asphalt Institute Hall of Fame*
  - *AAPT Honorary Member*
  - *NAPA Kenyon Research Implementation Award*
  - *ENR Construction Men of the Year*
  - *USACE US Army Commendation Medal – Military Construction*
  - *TRB DIstinquished T. Deen Transportation Lecture*
  - *Best Technical Papers - TRB (2), AAPT, ASCE*
  - *University of Maryland- Witczak Graduate Scholarship Award*

Dr. M. W. Witczak

- ***National Academy of Sciences/National Cooperative Highway Research Program (NCHRP)***
  - ***Unbound Materials Resilient Modulus Protocol***
  - ***Strategic Highway Research Program***
    - ***Original STRS Committee, Overview of SHRP Program; Asphalt, Models and Long Term Pavement Performance***
  - ***Superpave Models Mgt***
  - ***AC Simple Performance Test***
  - ***Develop AASHTO MEPDG (Asphalt Pavement Design)***
  - ***PI for Development of New Rational Performance Based Specifications (ongoing)***

Speaker Introduction

Invited Seminar Speaker- Pavement Environmental Specialist

Dr. Claudia Zapata

Dr. Claudia Zapata

- ***International Expert in the area of Unsaturated Soil Mechanics; Interaction of Site Environmental Conditions /Pavement Cross section to Real Time Variation of Unbound Base/ Subbase/ Subgrade Resilient Moduli Behavior***

- ***Played Key Role in Developing and Implementing EICM (Enhanced Integrated Climatic Model) into the New AASHTO MEPDG***
  - *Overviewed Final development of In-Situ Volumetric Moisture Module in MEPDG (EICM)*
  - *Linked Subsurface Temp / Moisture Changes to Unbound Mr by Environmental factor (Fenv)*
  - *Prediction of Long Term Anticipated Equilibrium Moisture Conditions at Site (Compared to Assumption of always having Soaked / Saturated Site Conditions)*

Dr. Claudia Zapata

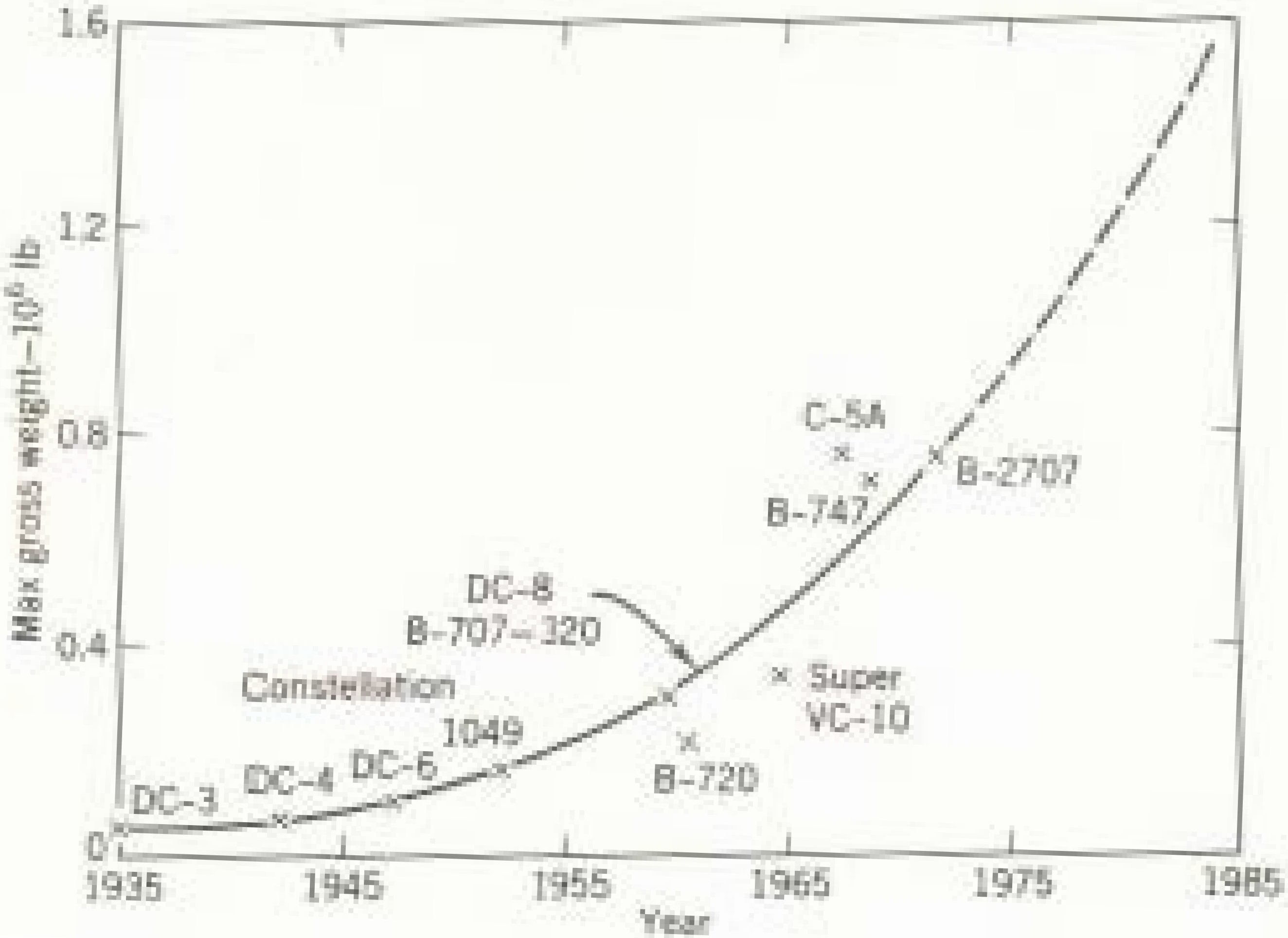
- *Expert in Advanced Laboratory Characterization of Unbound Materials*
  - *Soil Water Characteristic Curves (SWCC)*
  - *Matric Suction*
  - *Non-Linear Mr Incorporating Stress States and Soil Suction*
- *Developer of Most Comprehensive Data Base in the World of SWCC Parameters*
  - *US – NAS Study Based upon Historic USDA and BPR (FHWA) Studies*
  - *31,000+ Soils in US (Entire Country)*
  - *Categorizes Fredlund / Xing SWCC Regression Coefficients of SWCC Equation*

Pavement Evaluation

Aircraft Traffic Considerations

Pavement Evaluation

Historic Growth Projections in Aircraft Gross Weight



1.6
1.2
0.8
0.4
0
Max gross weight—10⁶ lb
C-5A
B-2707
B-747
DC-8
B-707–320
Constellation
1049
Super
VC-10
DC-3
DC-4
DC-6
B-720
1935
1945
1955
1965
1975
1985
Year

Mixed Aircraft Traffic Analysis

Actual Design Future Aircraft MGTOW Used for Several Pavement Design Scenarios

New Dallas Ft Worth Regional Airport

1970 Design Report ***Dr.M.W.Witczak; TAI; TAMS***

Traffic Data from TAMS Simulation Software

Future Heavy Aircraft		1975	1985	1995
P1A	2000 kips	0	2208	18615
P1B	1500 kips	0	6625	26061
P1C	1250 kips	0	17666	48399
P1D	1000 kips	0	22082	74460
Total Annual Departures:		157490	303260	597343
% Future Heavy Aircraft:		0.00%	16.00%	28.10%

Mixed Aircraft Traffic Analysis

Actual Design Future Aircraft MGTOW Used for Several Pavement Design Scenarios

New Dallas Ft Worth Regional Airport (Cont'd)

Fjh Analysis : 1985 Traffic Analysis

Fjh Damage Factor (Theoretically Computed)

		Pavement Thickness		
		20"	30"	40"
P1A	2000 kips	28.6	56.2	67.0
P1B	1500 kips	8.3	15.8	20.2
P1C	1250 kips	4.9	8.5	10.7
P1D	1000 kips	2.4	3.8	5.0
	Predicted Damage:	65.30%	81.50%	85.90%

Mixed Aircraft Traffic Analysis

Actual Design Future Aircraft MGTOW Used for Several Pavement Design Scenarios

New Honolulu Reef Runway, Honolulu International Airport

1971 Design Report ***Dr.M.W.Witczak; TAI; Parsons***

Critical Design Aircraft for Pavement design: ***1500.0 kips (MGTOW)***

(Aircraft resulted in Critical Shear layer being Ocean Bay Mud;

Located some 15' to 17' below New As Constructed Pavement Grade)

Pavement Evaluation

New Very Large Air Carrier Aircraft

Historic Comparisons- Aircraft Gross Weight Trends			
MGTOW	1989 FAA AC 150/5300	2009 FAA FAARFIELD	% Diff
< 100 k	61.3%	38.4%	-22.9%
100-300 k	21.1%	26.0%	4.9%
300-500 k	12.4%	15.1%	2.7%
500-700 k	3.4%	9.6%	6.2%
700-1300 k	1.9%	11.0%	9.1%

Very Large Conventional Aircraft (MGTOW > 700.0Kips)

Aircraft Mfg	Model	Weight (kips)
Boeing	B-747-SP	703.0 k
Boeing	B-747-100 SP	738.0 k
Boeing	B-777-200 ER	768.8 k
Boeing	B-777-300 ER	777.0 k
Airbus	A-340-500	805.1 k
Airbus	A-340-500	813.9 k
Boeing	B-747-200 B	836.0 k
Boeing	B-747-300 CM	836.0 k
Airbus	A-340-500	840.4 k
Boeing	B-747-400	877.0 k
Antonov	An 124	877.4 k
Boeing	B-747-400 ER	913.0 k
Boeing	B-747-8	978.0 k
Boeing	B-747-8F	990.0 k
Airbus	A-380-800	1239.0 k
Airbus	A-380-800 F	1305.1 k
Antonov	An 224	1322.8 k

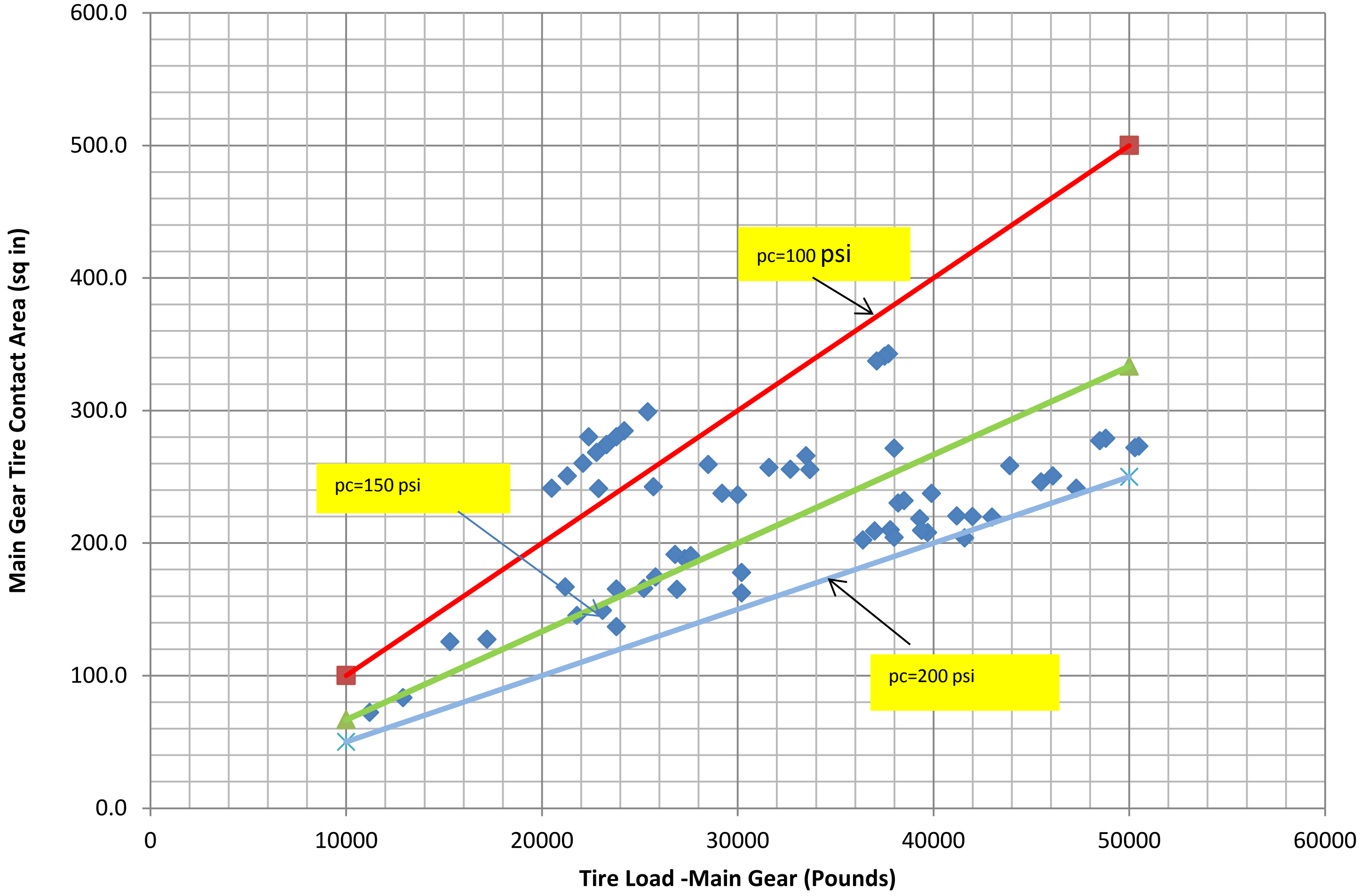
Single
Dual (Tires)
Single Tandem
Dual Tandem
Tri- Tandem
Airbus 380 family
BOEING 747 family
Galaxy
B747-8
B747-400
B747-200
B747-200/300
B747-100B/300
B747-SP
B747-100B/300SR
BOEING
Ok
Cancel


Single
Dual (Tires)
Single Tandem
Dual Tandem
Tri- Tandem
Airbus 380 family
BOEING 747 family
Galaxy
A-380
A-380F
Emirates
Ok
Cancel

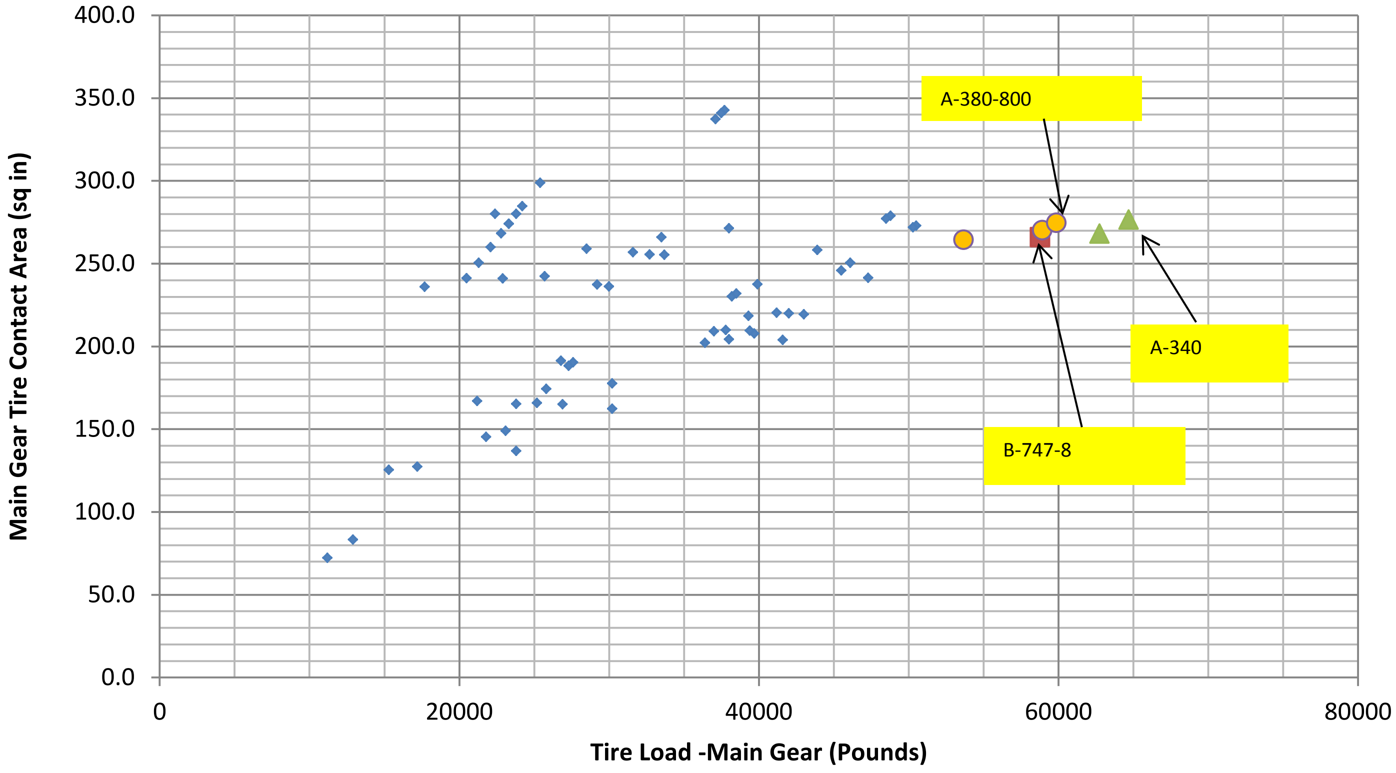
Pavement Evaluation

Tire Load and Tire Contact Pressure Pavement Considerations

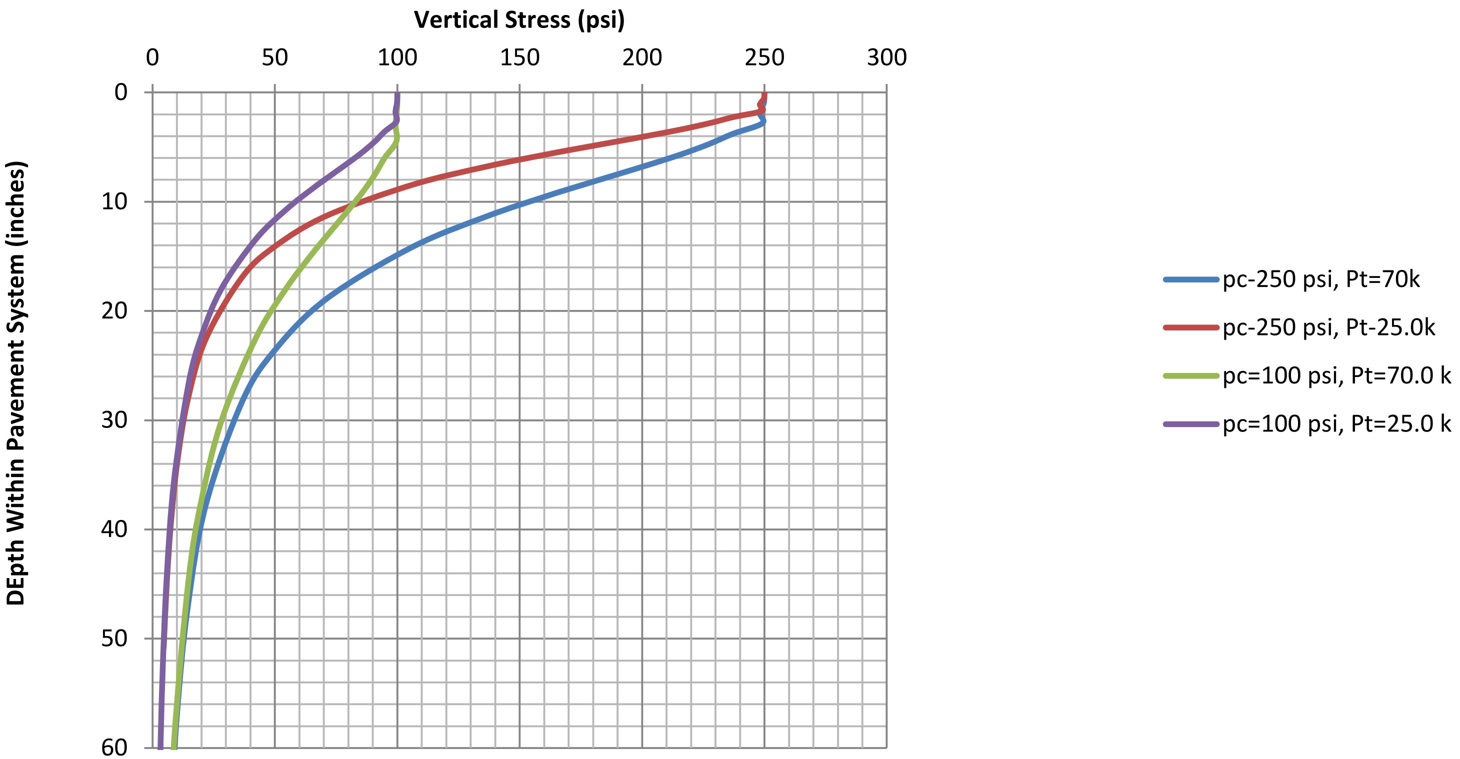
Relationship of Tire Load versus Tire Contact Area



Tire Load versus Tire Contact Area for Very Heavy Aircraft



Influence of Tire Load and Tire Pressure With Depth



Important Conclusions

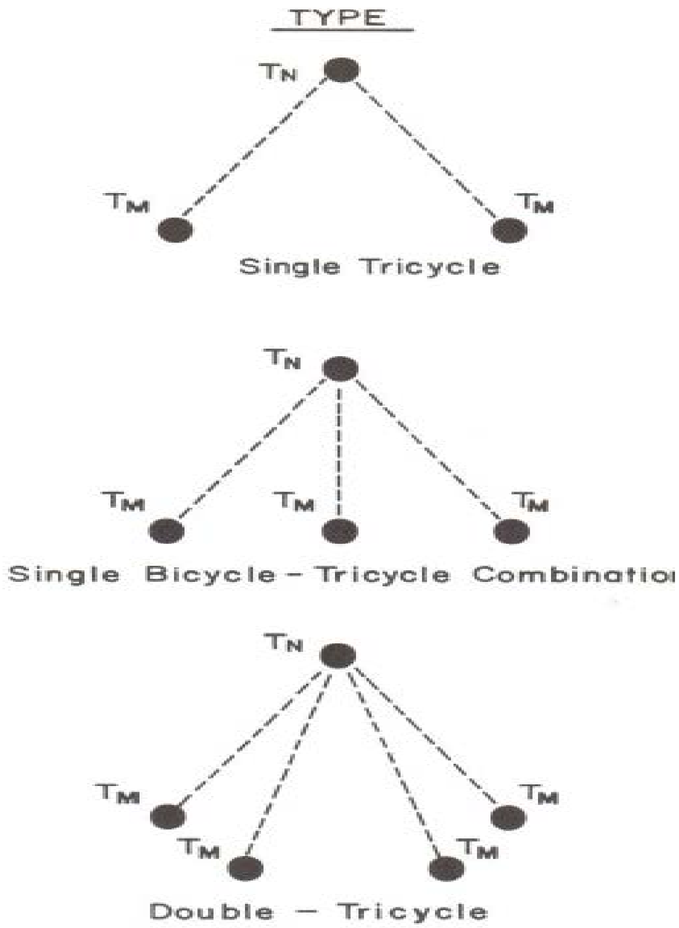
* *Tire Pressure greatly influences the quality of the of the pavement layer material found in the upper zone of the pavement*

* *Tire load greatly influences the total thickness of pavement required to eliminate repetitive shear deformations of the subgrade*

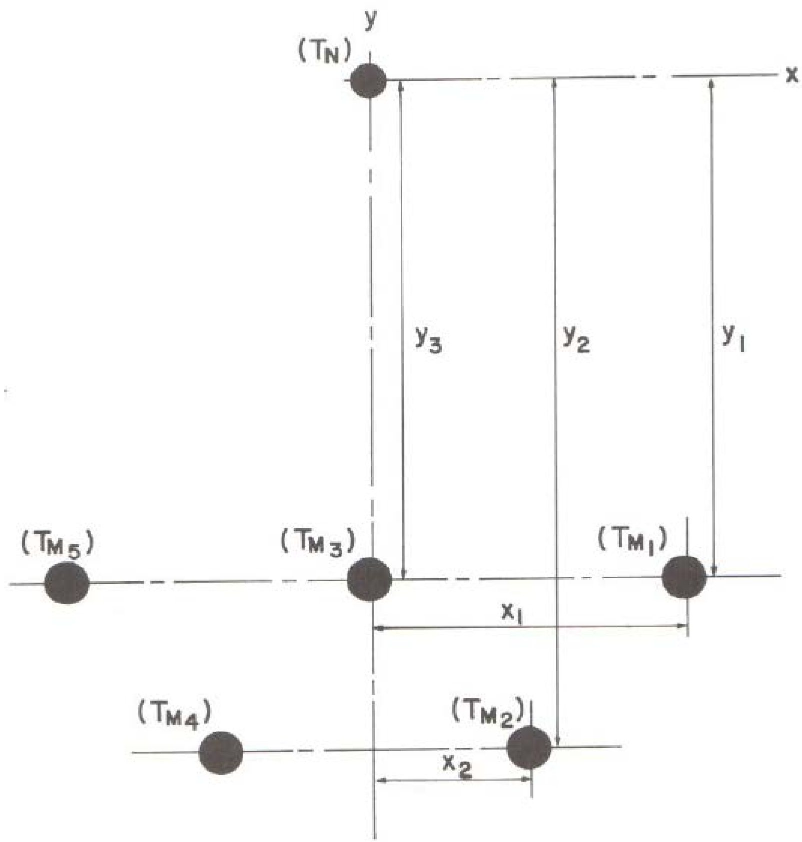
Pavement Evaluation

Types of Aircraft Gear Arrangements and Tire Configurations

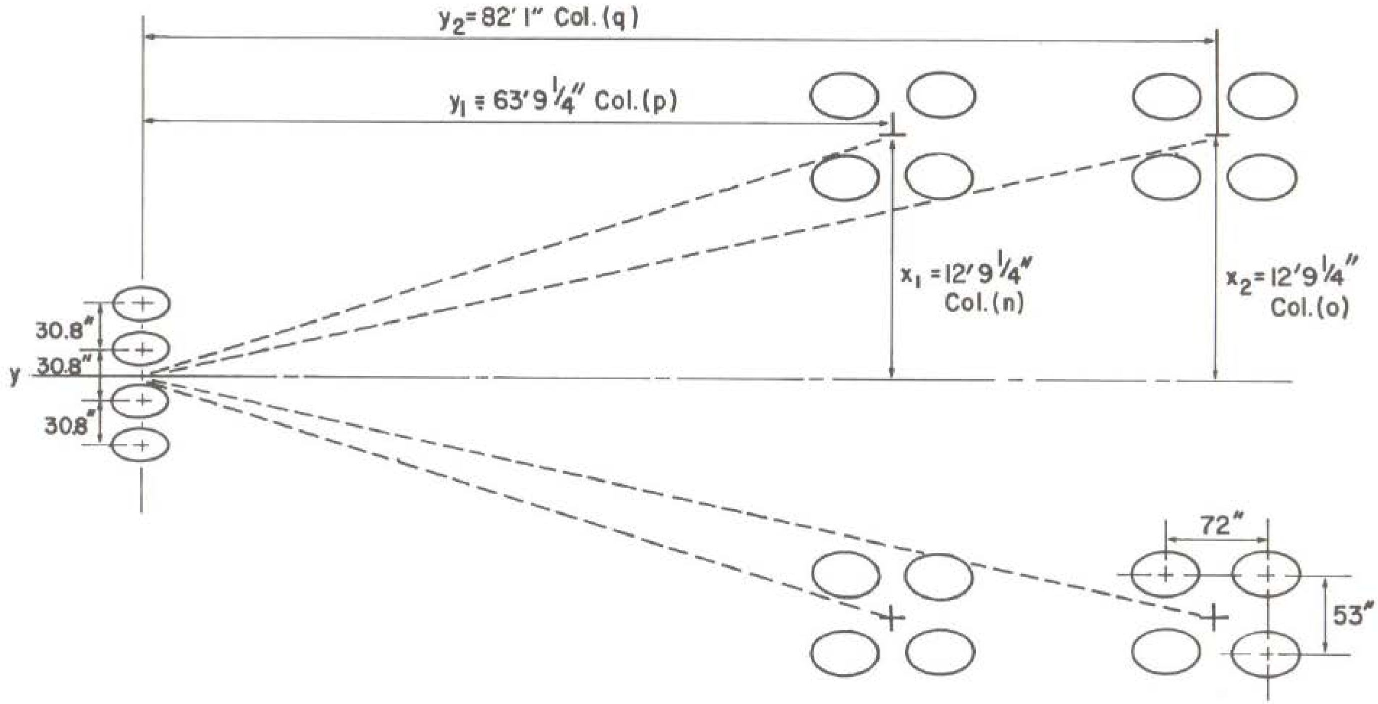
Various Types of Aircraft Gear Assemblies



Geometric Coordinates for Locating Bogey (Truck) Gears



L-500 Aircraft Characteristic Summary



AIRCRAFT CHARACTERISTICS		NOSE GEAR ASSEMBLY	MAIN TRUCK ASSEMBLY
Type: L-500 Col. (a)	Assembly Type:	(4) Col. (d)	(2) Col. (i)
Assembly Type: (C) Col. (b)	Tire Spacing:	30.8" x 30.8" x 30.8" Col. (e)	53" x 72" Col. (j)
Max. Gr. Wt.: 861,500 lb. Col. (c)	Max. Gear Wt.:	53,500 lb. Col. (f)	202,000 lb. Col. (k)
	Max. Wt. per Tire:	13,400 lb. Col. (g)	50,500 lb. Col. (l)
	Tire Pressure:	130 psi Col. (h)	185 psi Col. (m)

NOTE: See Table IX-1 for Column references.
See "Notes", Table IX-1 for metric unit conversion functions.

Pavement Evaluation

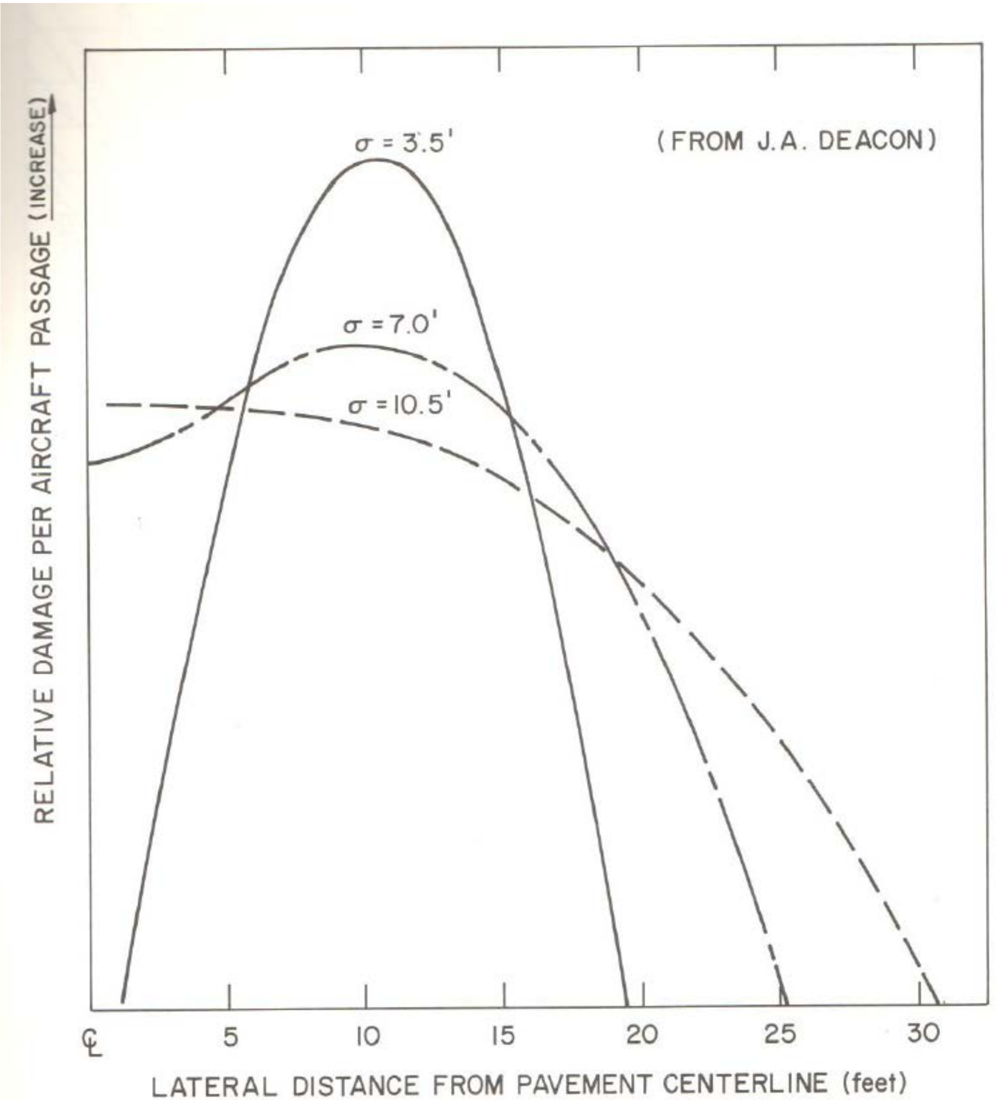
Mixed Traffic Damage Analysis

(Technology has bypassed "Design Critical Aircraft" and has been replaced by Cumulative Damage due to entire Traffic Mix)

Mixed Aircraft Traffic Analysis

Selection of Standard Aircraft (Use of Aircraft Fjh Damage Factor)

pj:	***Design Number of Passes of the "j" th Aircraft in Design Life on*** ***Specific TW / RW segment in Question***
fjx:	***Transverse Frequency Factor at Lateral Points (+/- From RW / TW CL)*** ***Caused by Lateral Aircraft Wander during Operations***



Lateral Pavement Damage as a Function of Aircraft Wander Deviation

Mixed Aircraft Traffic Analysis

Selection of Standard Aircraft (Use of Aircraft Fjh Damage Factor)

Damage Repetitions of the "j th" Aircraft

$$Dj = pj*fjx*dj$$

j:	***"j th " Aircraft in Question***
s:	***"s- Standard" Aircraft in Question***
x:	***Lateral Distance (+/-) from TW / RW CL***

$$Fjh = (dj) / (ds) \quad \text{or} \quad dj = Fjh * ds$$

$$Dtj = \Sigma\, (pj*fjx*Fjh*ds) \qquad (Dtj)/(ds) = Nes = \Sigma(pj*fjx*Fjh)$$

Mixed Aircraft Traffic Analysis

Selection of Standard Aircraft (Use of Aircraft Fjh Damage Factor)

Fjh Damage Factor

dj= (Unit Damage- Damage per Pass of "j" Aircraft)

ds= (Unit Damage- Damage per Pass of "s- standard" Aircraft)

Fjh = (dj) / (ds)

dj=(1/Nfj   ***ds= (1/Nfs)***

Fjh=(Nfs)/(Nfj)

Fj=1 ***"j"th aircraft identical in damage to "standard"***

Fj >= 1 ***"j"th aircraft is more damaging than "s-standard"***

Fj <= 1 ***"j"th aircraft is less damaging than "s-standard"***

Selection of Standard Aircraft (Use of Aircraft Fjh Damage Factor)

Computational Example of Fjh for AC Fatigue Fracture

$$Nf = 10^{c} * k1 * (i/et)^{k2} * (1/Eac)^{k3}$$

$$c = f(Va\% \ \& \ Vbeff\%)$$

For "jth" Aircraft $$dtj = \{10^{c} * k1 * (1/etj)^{k2} * (1/Eac)^{k3}\}^{-1}$$

For "s - standard" Aircraft $$dts = \{10^{c} * k1 * (1/ets)^{k2} * (1/Eac)^{k3}\}^{-1}$$

$$Fjh = (dj)/(ds) = [\{10^{c} * k1 * (1/etj)^{k2} * (1/Eac)^{k3}\}^{-1}] / [\{10^{c} * k1 * (1/ets)^{k2} * (1/Eac)^{k3}\}^{-1}]$$

or:

$$Fjh = [(etj)/(ets)]^{c}$$

with:

Typical Values of "c" for HMA Fatigue

$c = 3.0$ ***to*** 5.0

Mixed Aircraft Traffic Analysis

Selection of Standard Aircraft (Use of Aircraft Fjh Damage Factor)

Computational Example of Fjh for AC Fatigue Fracture (Assume c=4.0)

Hac - HMA (Thickness)	etj(με)	ets(με)	(etj)/(ets)	Fjh
5	450	315	1.43	4.16
10	325	232	1.40	3.85
15	250	200	1.25	2.44
25	200	180	1.11	1.52

MIXED AIRCRAFT TRAFFIC ANALYSIS

Selection of Standard Aircraft (Use of Aircraft Fjh Damage Factors)

Computational Example of Fjh for PCC Slab Fracture

For the USACE; USAF; FAA …….Westergaard Slab fracture

In computing the Fjh for Aircraft "j" to the standard "s", we will always use the same :

kc, hpcc, Epcc, upcc, MR, l, αt

For both the "j" and "s" aircraft

MIXED AIRCRAFT TRAFFIC ANALYSIS

Selection of Standard Aircraft (Use of Aircraft Fjh Damage Factors)

Computational Example of Fjh for PCC Slab Fracture

Definition of the Design Factor (DF)

$DF = (MR/\alpha t * \sigma fe)$ **and** $DF = a + \beta \log Cf$

This leads to equation that:

$$Cf = 10 \wedge((DF - a)/\beta)$$

MIXED AIRCRAFT TRAFFIC ANALYSIS

Selection of Standard Aircraft (Use of Aircraft Fjh Damage Factors)

Computational Example of Fjh for PCC Slab Fracture

Recall that:

Fj=(dj/ds) = (Cfs/Cfj) ; it can be directly derived that:

$$F_j = 10^{\left(\frac{MR}{\alpha_T \beta}\right)\left(\frac{1}{\sigma_{ej}} - \frac{1}{\sigma_{es}}\right)}$$

MIXED AIRCRAFT TRAFFIC ANALYSIS

Selection of Standard Aircraft (Use of Aircraft Fjh Damage Factors)

Computational Example of Fjh for PCC Slab Fracture

Example:

P(MGTOW) B-727: 173.2 kips

P(MGTOW) B-747: 788.2 kips

Epcc=4,000,000 psi

upcc=0.15

MR= 600 psi

Kc=50 pci

αt = 0.75 (Load Transfer)

MIXED AIRCRAFT TRAFFIC ANALYSIS

Selection of Standard Aircraft (Use of Aircraft Fjh Damage Factors)

Computational Example of Fjh for PCC Slab Fracture

Example:

Hpcc	l value	727 edge stress	747 edge stress	Fjh
15”	69.27	737.5 psi	837.5 psi	0.73
18”	79.41	549.4 psi	656.6 psi	0.58
22”	92.31	398.7 psi	498.8 psi	0.40
27”	107.64	286.2 psi	374.1 psi	0.22
30”	116.49	241.0 psi	321.8 psi	0.15

Mixed Aircraft Traffic Analysis

Selection of Standard Aircraft (Use of Aircraft Fjh Damage Factor)

Summary Conclusions:

- ** ***Fjh Values can be Computed for each Pavement Type (Flexible and Rigid) and for each Load Distress Type***

- ** ***Distresses are:***

Flexible	***Rigid***
Subgrade Deformation	***PCC Cracking***
AC Fatigue Fracture	

- ** ***All Fjh values will be DIFFERENT as a Function of Depth and Specific Distress Criterion Used***

- ** ***There is No Unique Single Value of Fjh for a Particular Aircraft***

- ** ***Major Advantage is that this Approach is Computationally Quick, Easy and Can be computed one time for all Designs***

Mixed Aircraft Traffic Analysis

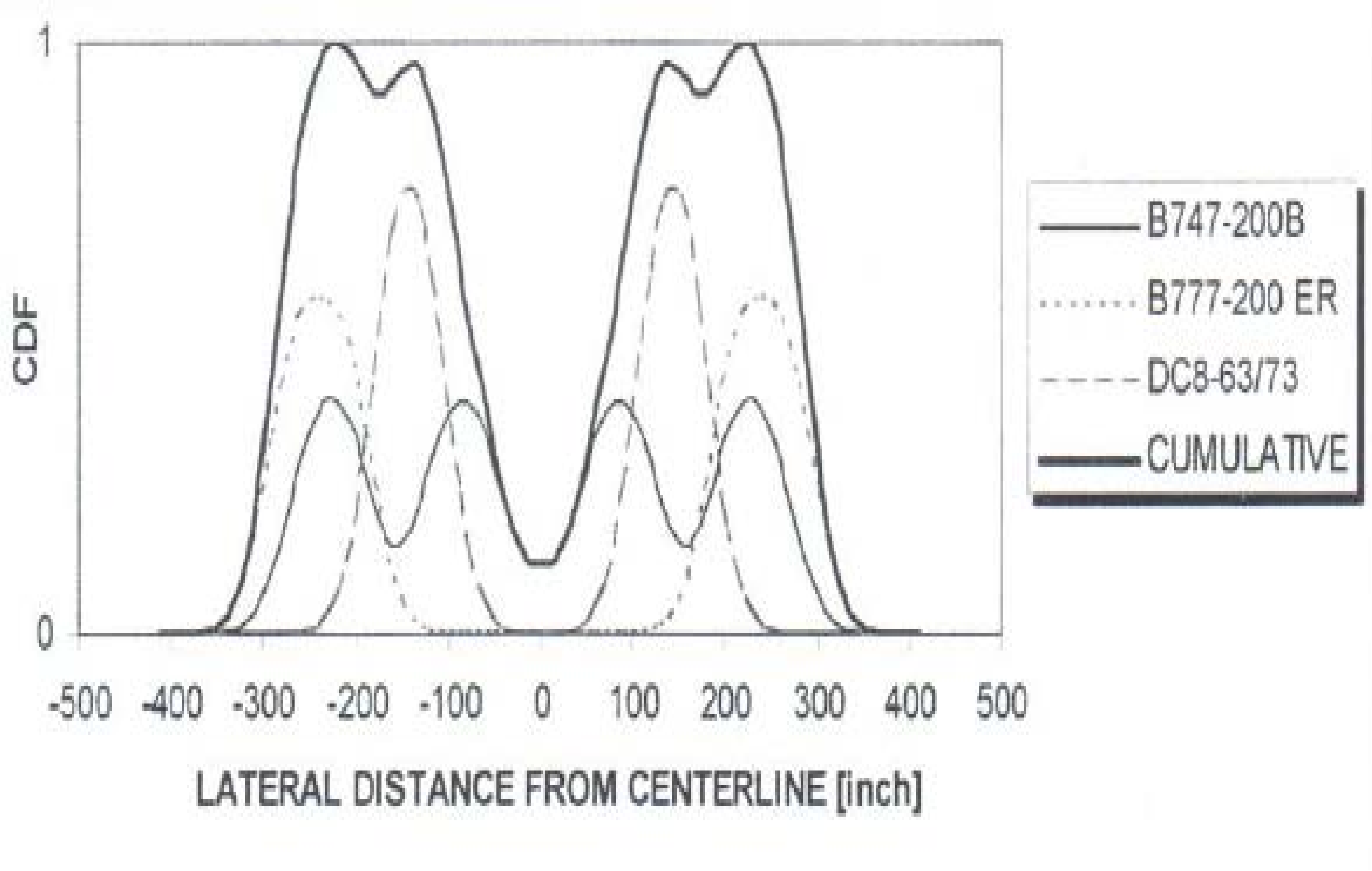
Direct Damage Computation for All Aircraft in Mix (No Use of Fjh Damage Factor)

** *Directly Use Computation of Dj =f(x) for each Aircraft in the Mix*

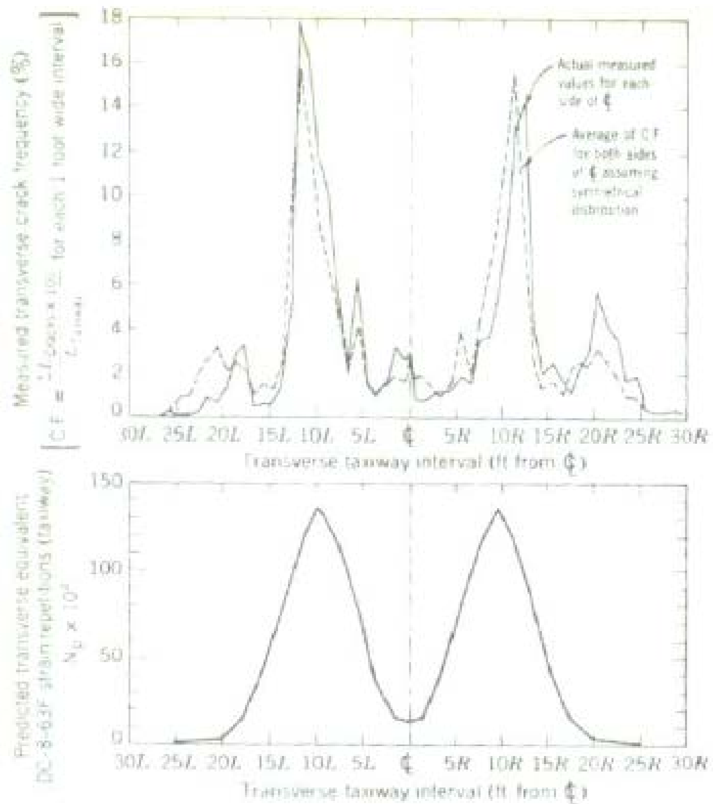
** *Computationally Very Extensive; but Solvable through Computerized Solution Methodology*

** *Each Damage Computation will be a Function of Specific Aircraft Type, Pavement Structure, Lateral Wander Effect, Failure Distress Criterion and Pavement Type*

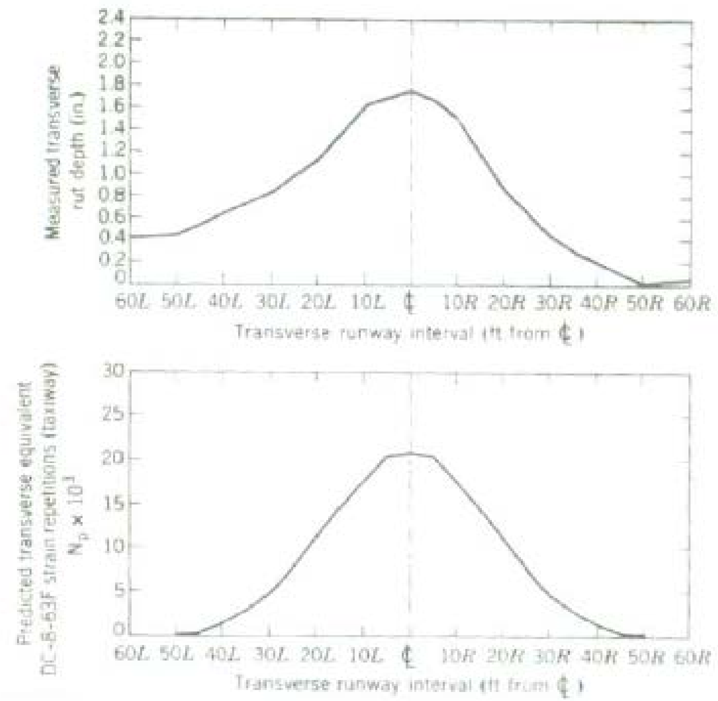
Cumulative Damage Analysis Laterally Along Pavement System



Comparison of Theoretical Aircraft Traffic Mix Damage to Actual Damage



Baltimore International Airport
Taxiway Cracking Distress



Washington (Reagan National) Airport
RW 18-36 Rut Deformations

Field Studies at Both Airports Conducted by Dr.M.W.Witczak

Summary Points : Aircraft Traffic Considerations

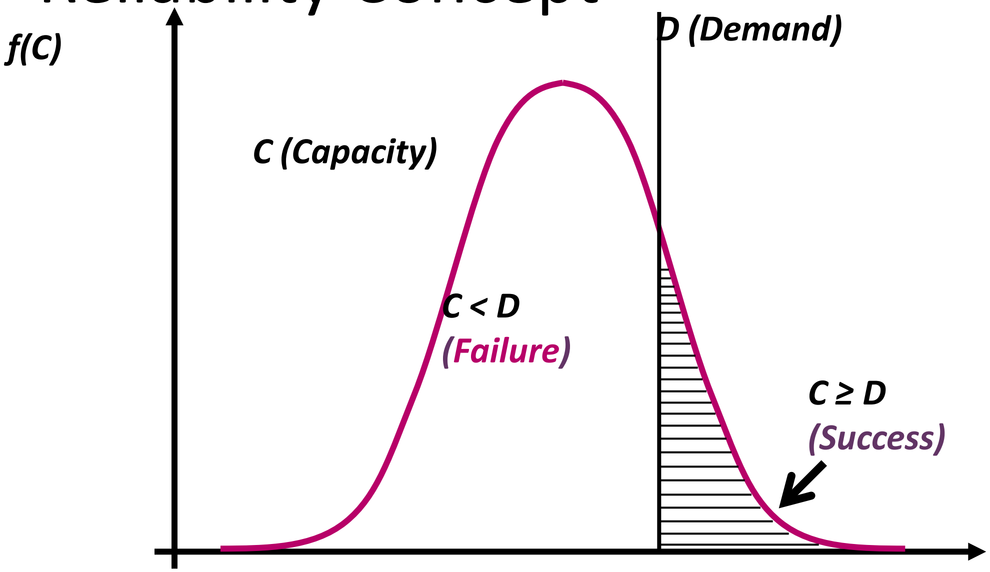
- *Very Large "New" Aircraft (> 1000 kips) have entered Commercial Service around the World*
- *Tire Loads and Bogey Arrangements may Radically differ from Historic Systems*
- *Design, Rehabilitation and Structural Capacity Evaluation should now account for all aircraft in traffic mix*
  - *Aircraft Types*
  - *Loading %*
  - *Operating Routes*
    - *Terminal to Take-off*
    - *Landing to Terminal*
- *Must account for aircraft Wander and Xj of Aircraft*
- *Fj Aircraft Damage Factor or CDF (Cumulative Damage Function) must be a Function of Pavement Type, Load Distress, Pavement Structure*

Variability and its Impact Upon Reliability

The Critical Importance of Using Statistics and Probability in Pavement Engineering Decisions

Significance & Use of Different Reliabilities for Given Model's Use

- Reliability Concept



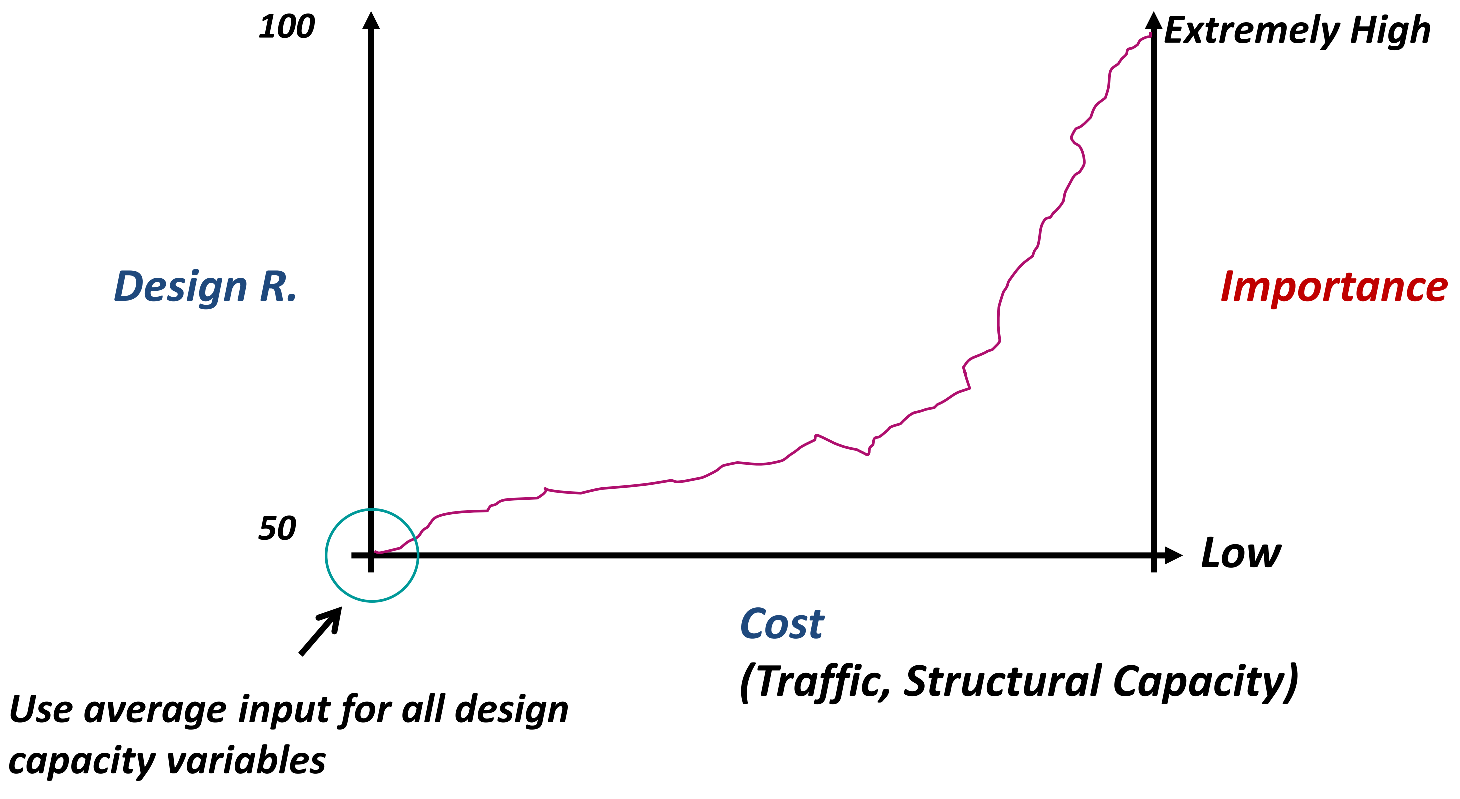
Failure:	***C < D***	***Pr{F}***
Success:	***C ≥ D***	***Pr{S} = Relia.***

Where, Pr{F}+Pr{S} = 100% or 1.0

Reliability = 1 – Pr{F}

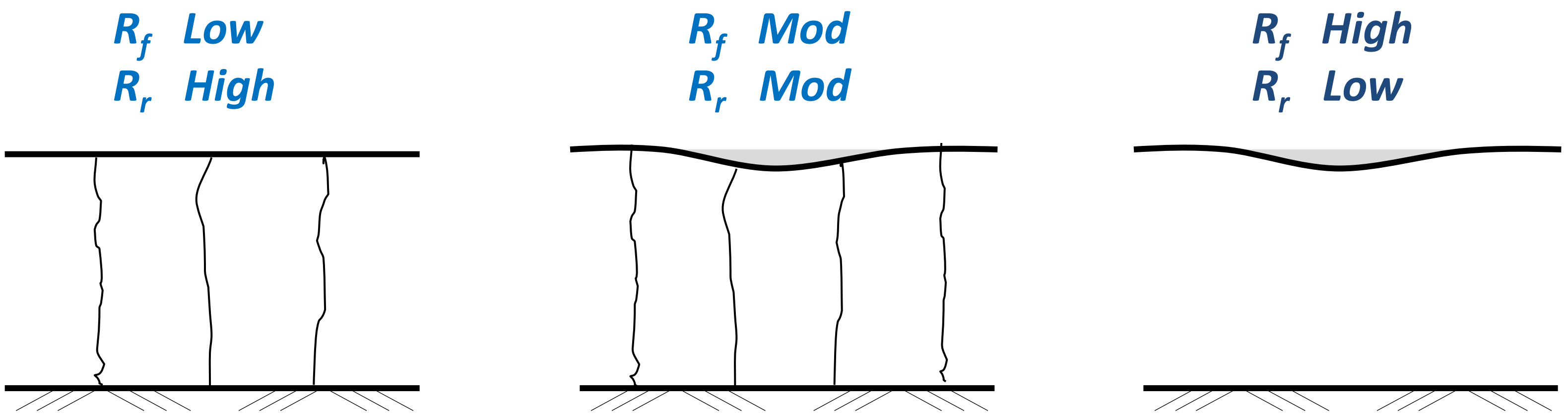
Significance & Use of Different Reliabilities for Given Model's Use

- ***Reliability and Cost***



Significance & Use of Different Reliabilities for Given Model's Use

- ***Multi Distress Condition***
  - R_f — ***Fatigue***
  - R_r — ***Rutting***
  - R_{tc} — ***Thermal Cracking***

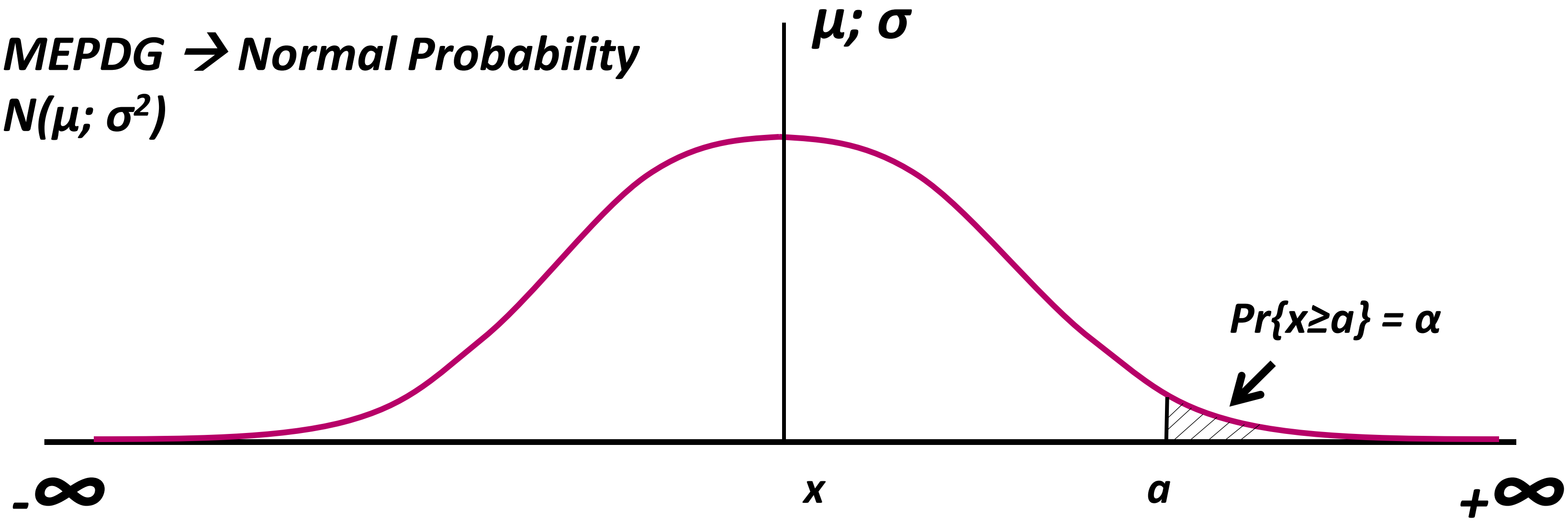


What would be your preference for design?

Significance & Use of Different Reliabilities for Given Model's Use

- ***Some Mathematical Considerations***

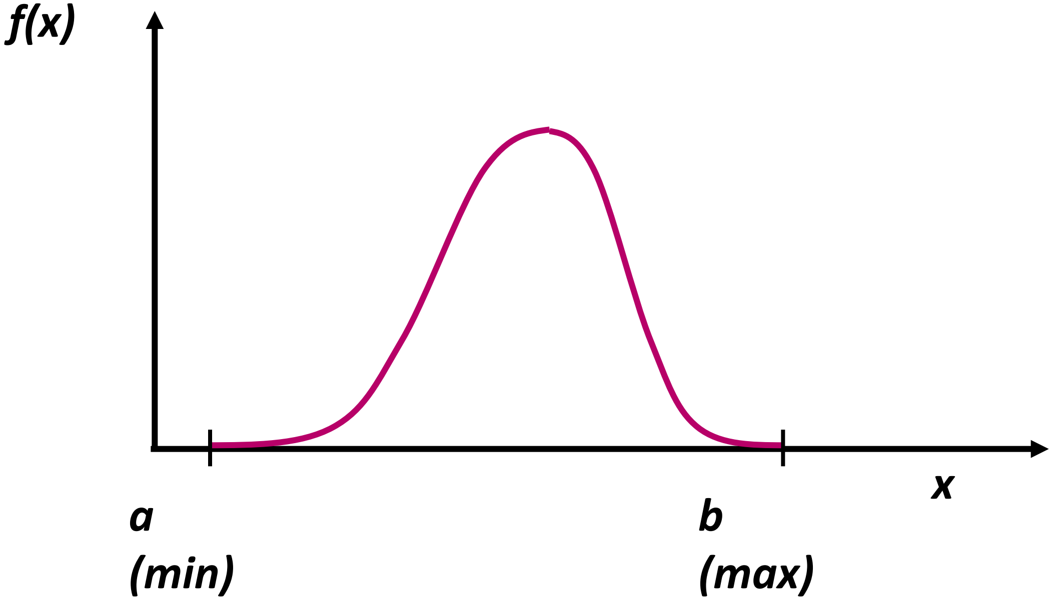
MEPDG → Normal Probability
N(μ; σ²)



Problem we run into:
-AC%; -w%;%P_{200}>100%
Thus, all physically impossible
Caused by limits of N(μ; σ) being ±∞

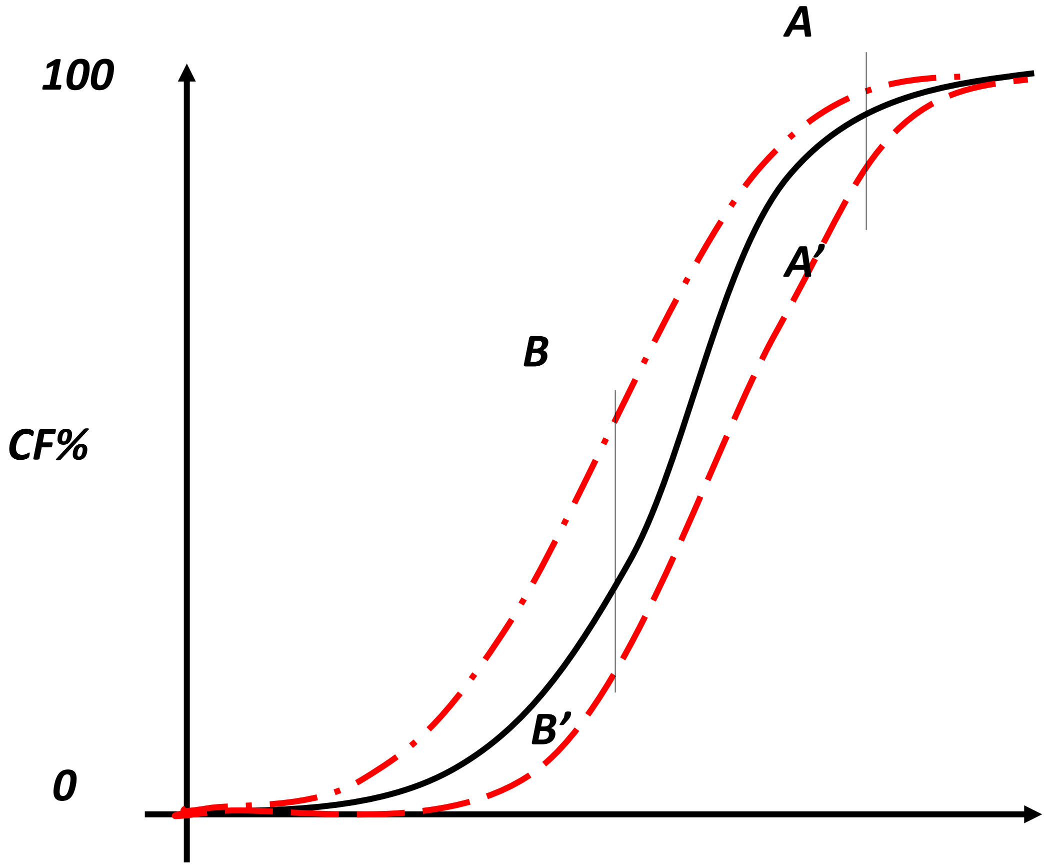
Significance & Use of Different Reliabilities for Given Model's Use

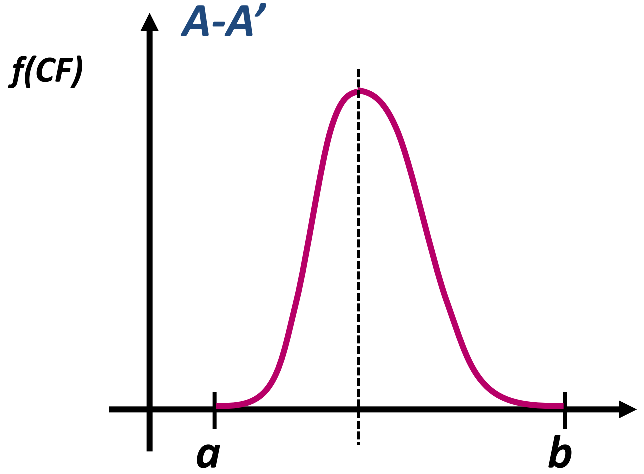
- ***Beta Frequency Distribution***

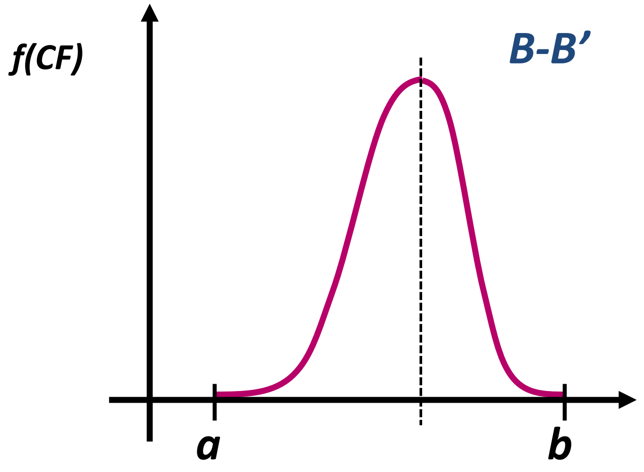


Beta (μ, σ^2, a, b)

Significance & Use of Different Reliabilities for Given Model's Use



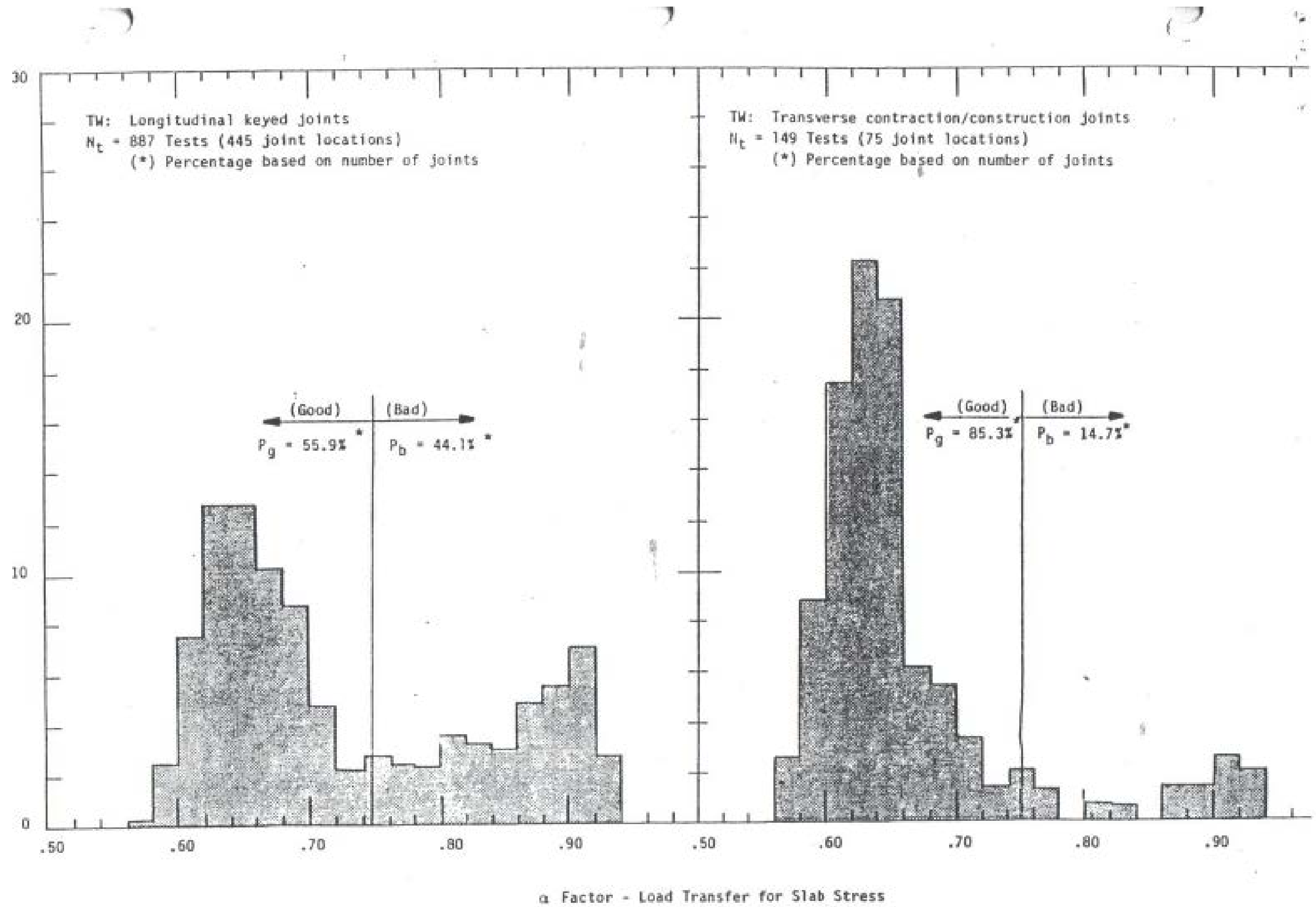




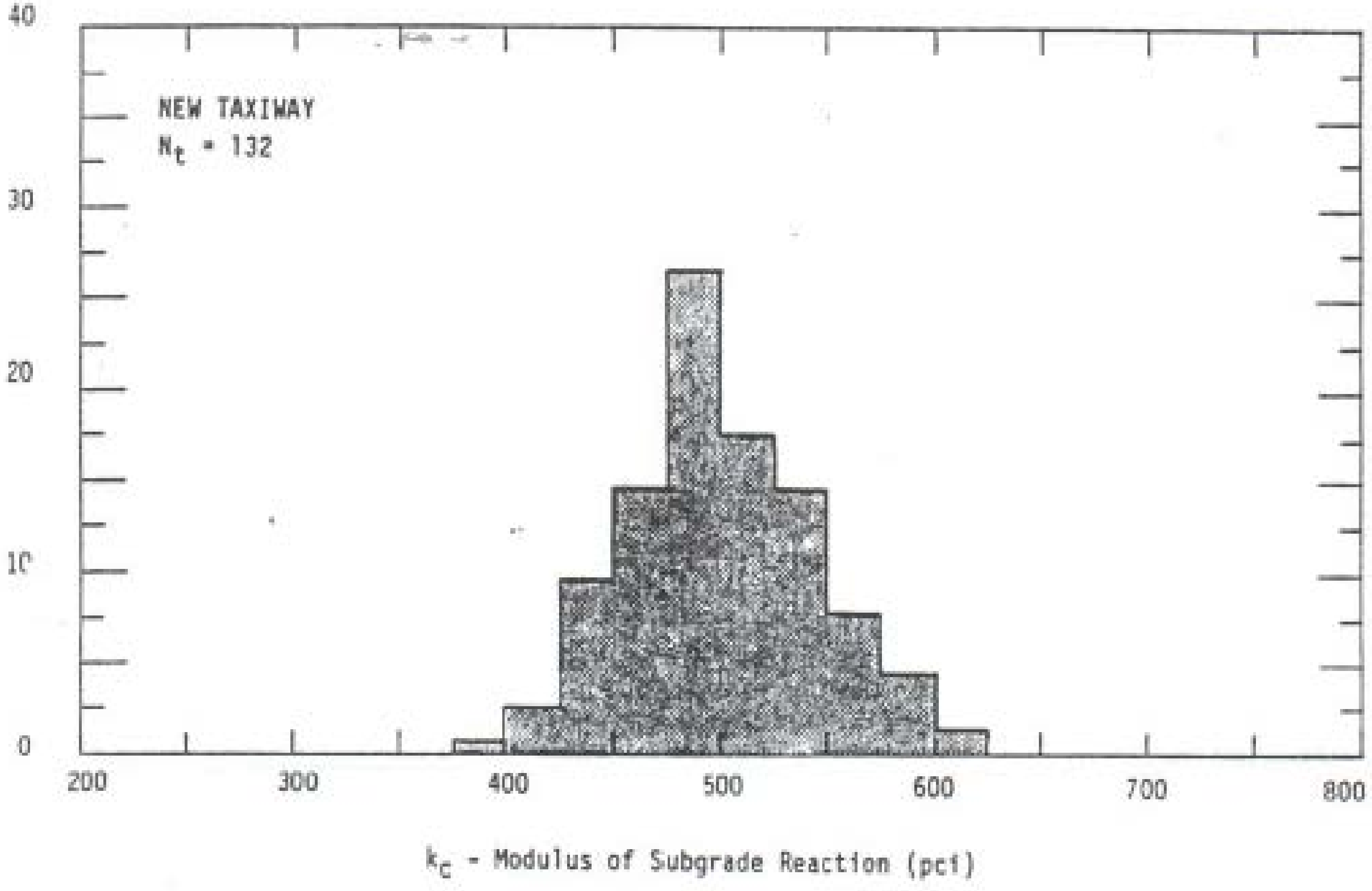
When you use Normal Probability; around R ≥ 95%

A Major Example of Using Reliability in Evaluating if an Aircraft Could Operate on an Existing Airfield

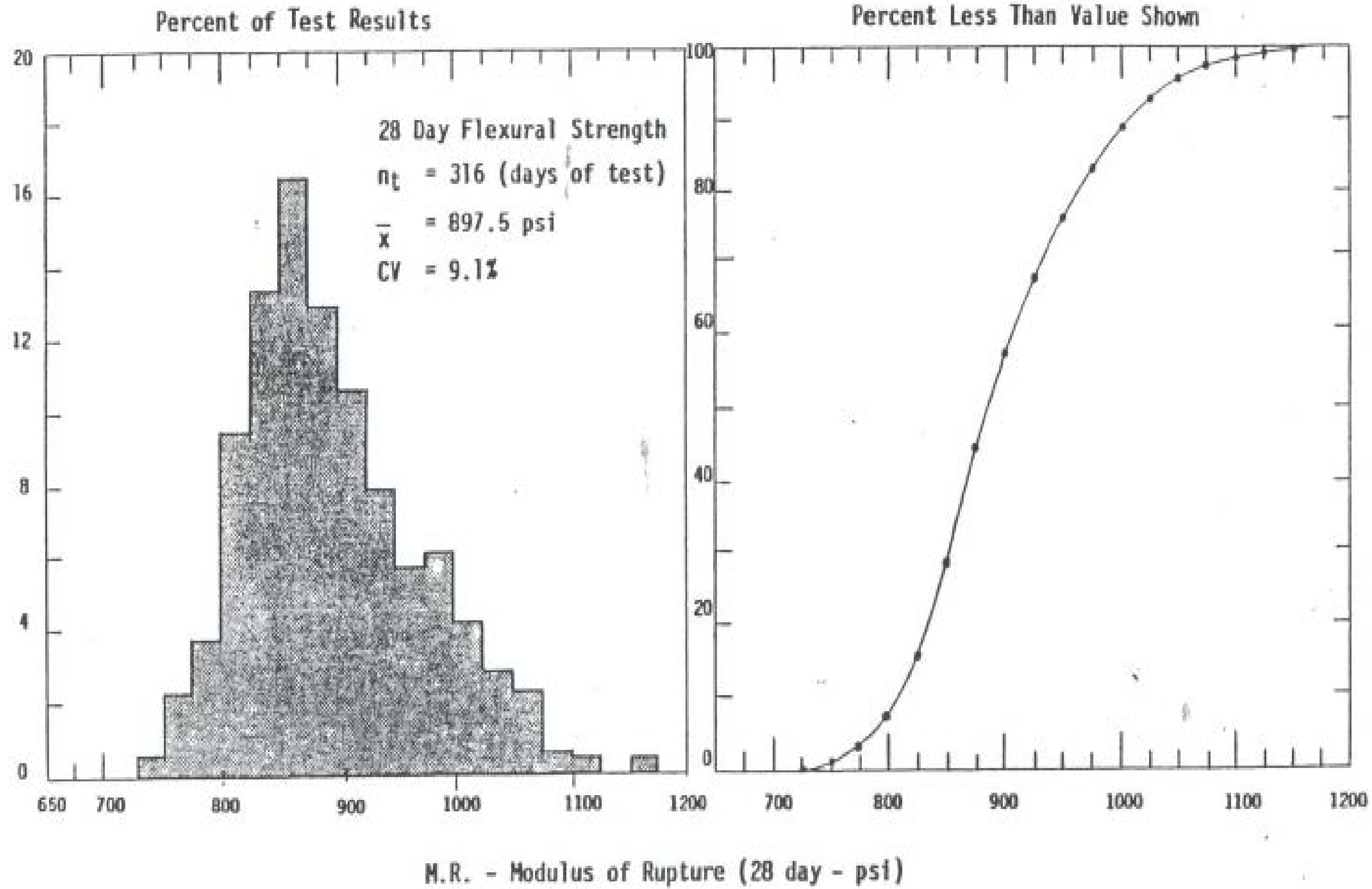
- *Diego Garcia B-52 USAF Airbase*
- *Major Construction / Rehabilitation for First Gulf War*
- *Middle of Indian Ocean (Near Equator)*
- *Coral Atoll Island (4 mi wide by 7 mi)*
- *New 21-24" JPC TW (15,000 '); to be used as temp RW; while existing RW rehabilitated with 14 – 16" JRC*
- *Earthquake hit Island weeks before Aircraft were to be Deployed*
- *Destroyed Load transfer of PCC Slabs with possible reduction in Design Life from 10,000 Cf to only a few hundred coverages*
- *Another very significant problem at site was the fact that new TW construction used Slip form paving but vertical faces not controlled well*
- *Dr.M.W.Witczak requested by US Military to conduct technical study to Advise them if B-52 Aircraft could still be deployed*



Actual in-Situ Distribution of Slab Load Transfer Values as Obtained from NDT Analysis



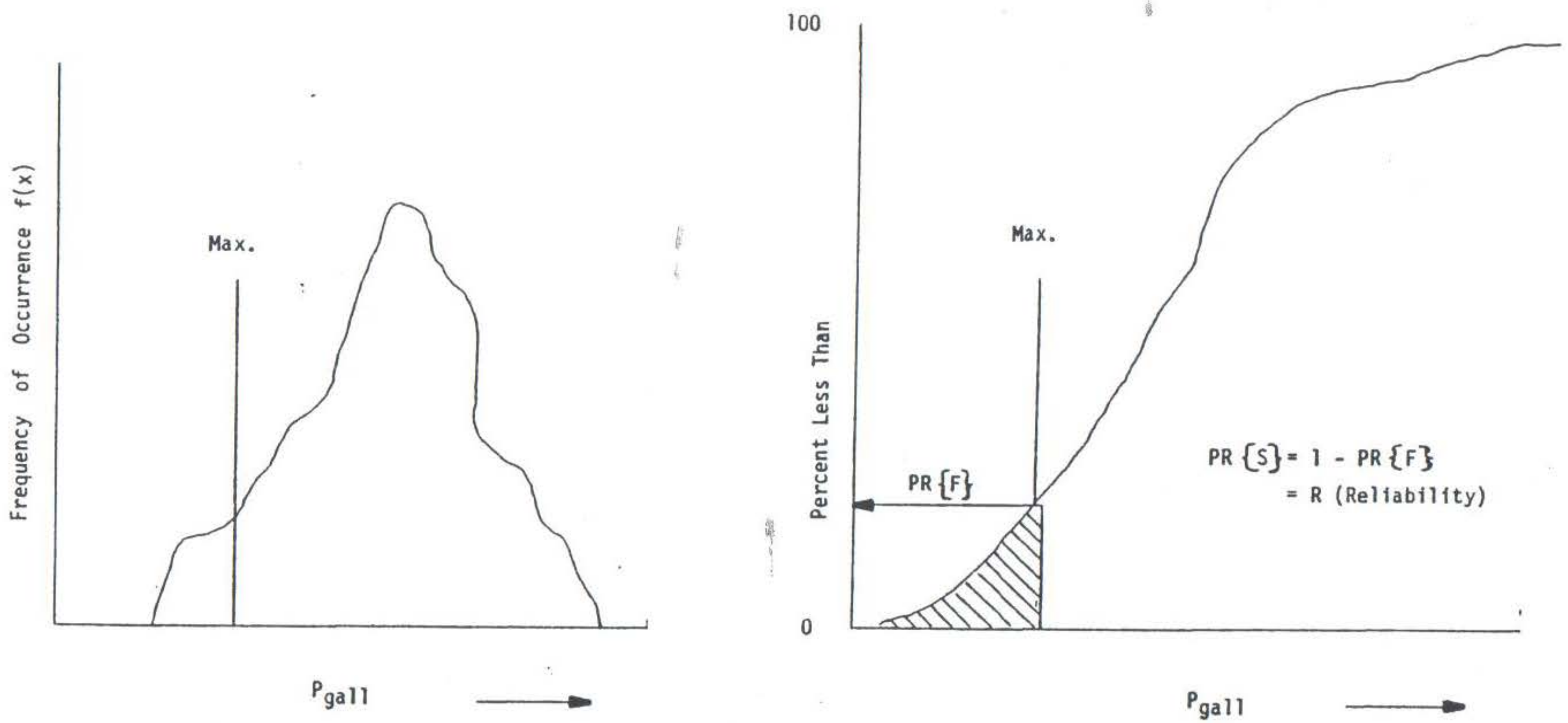
Frequency Distribution of Westergaard's kc – Composite Foundation Modulus



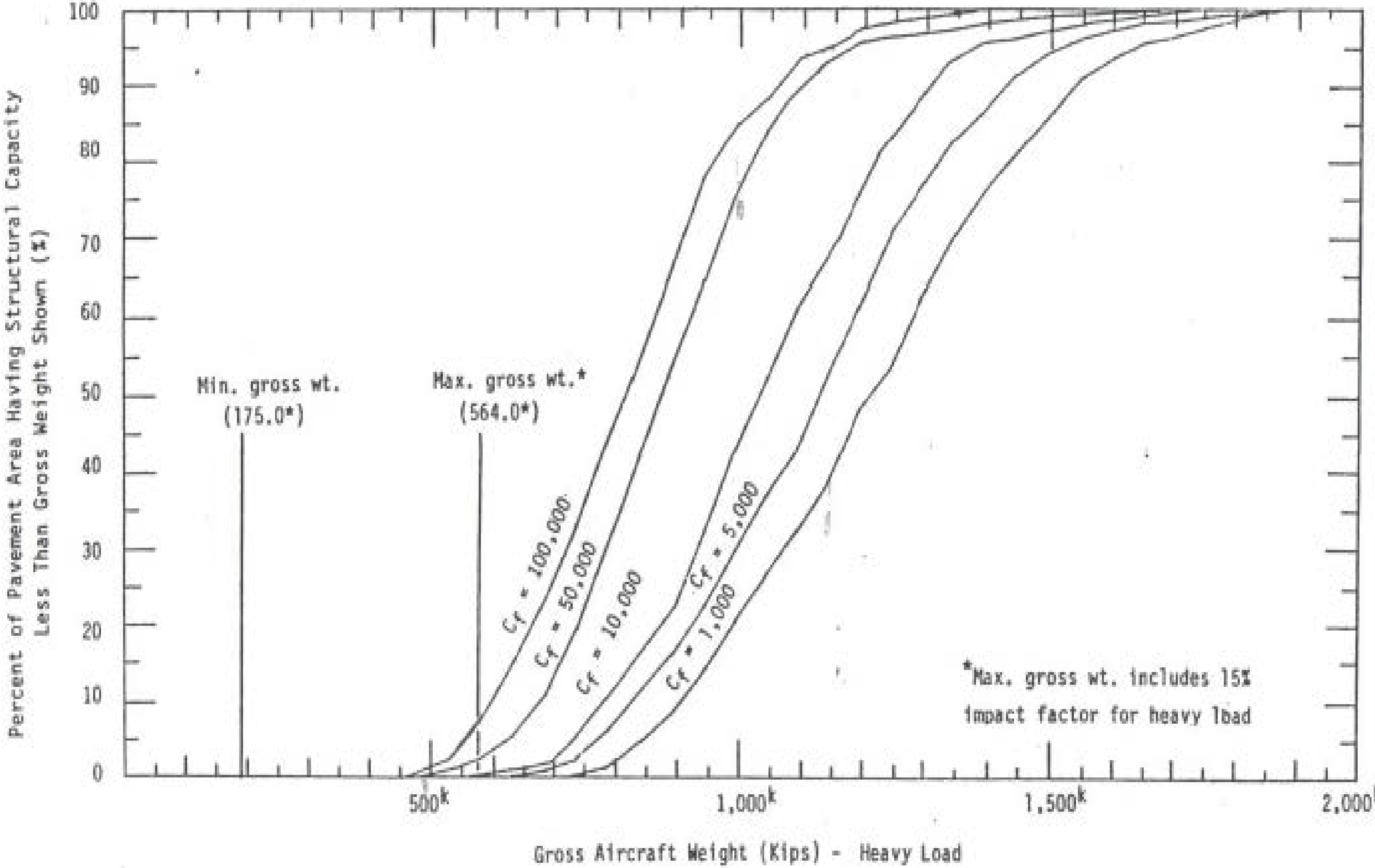
Frequency Distribution of 28 Day Flexural Strength

	Input Values				Output
Run Number	Load Transfer Value	Flexural Strength	Modulus of Reaction	PCC Thickness	Allowable Aircraft Load
N = 1	α_1	MR_1	kc_1	tr_1	P_{gall} 1
N = 2	α_2	MR_2	kc_2	tr_1	P_{gall} 2
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
N = N	α_n	MR_n	kc_n	tr_n	P_{galln}

Concept of Monte Carlo Simulation (Random Number Generator) for Diego Garcia B-52 Air Base



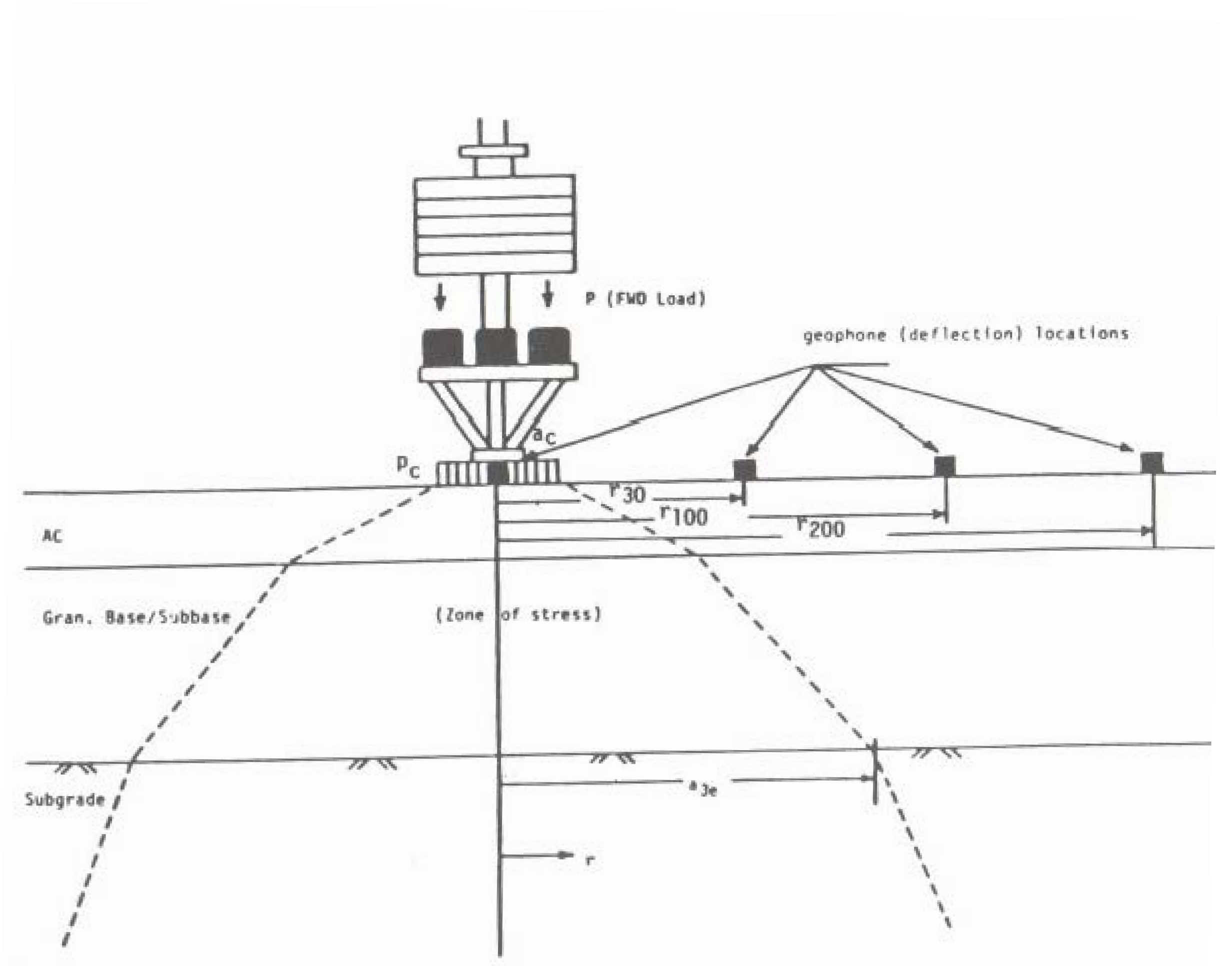
Analysis of Pg Allowable Load Distribution and Determination of Design Reliability



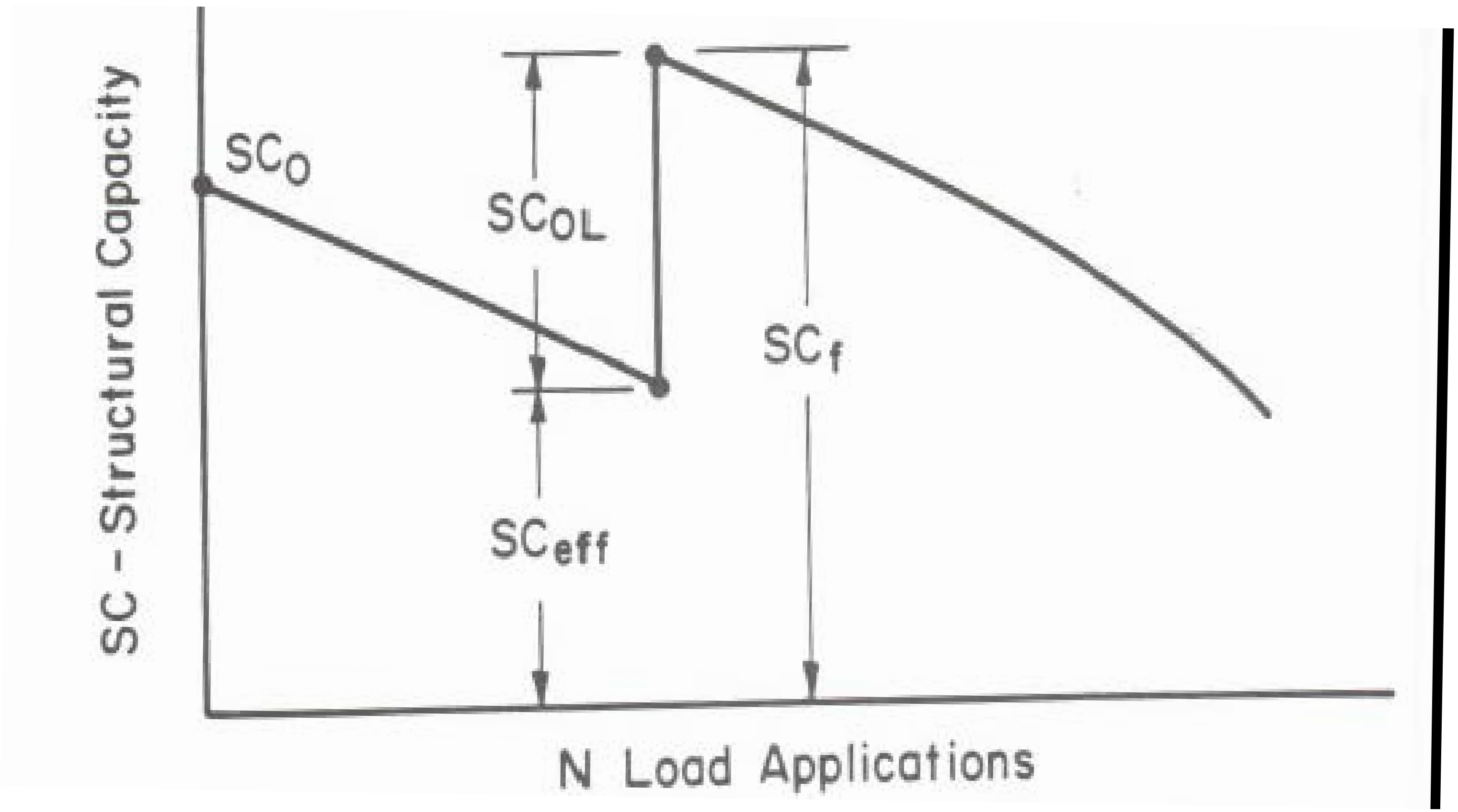
Probabilistic Based Evaluation Decision Regarding Authorization to Utilize Earthquake Damaged Pavement System for B-52 Aircraft

The Selection of the Design Reliability

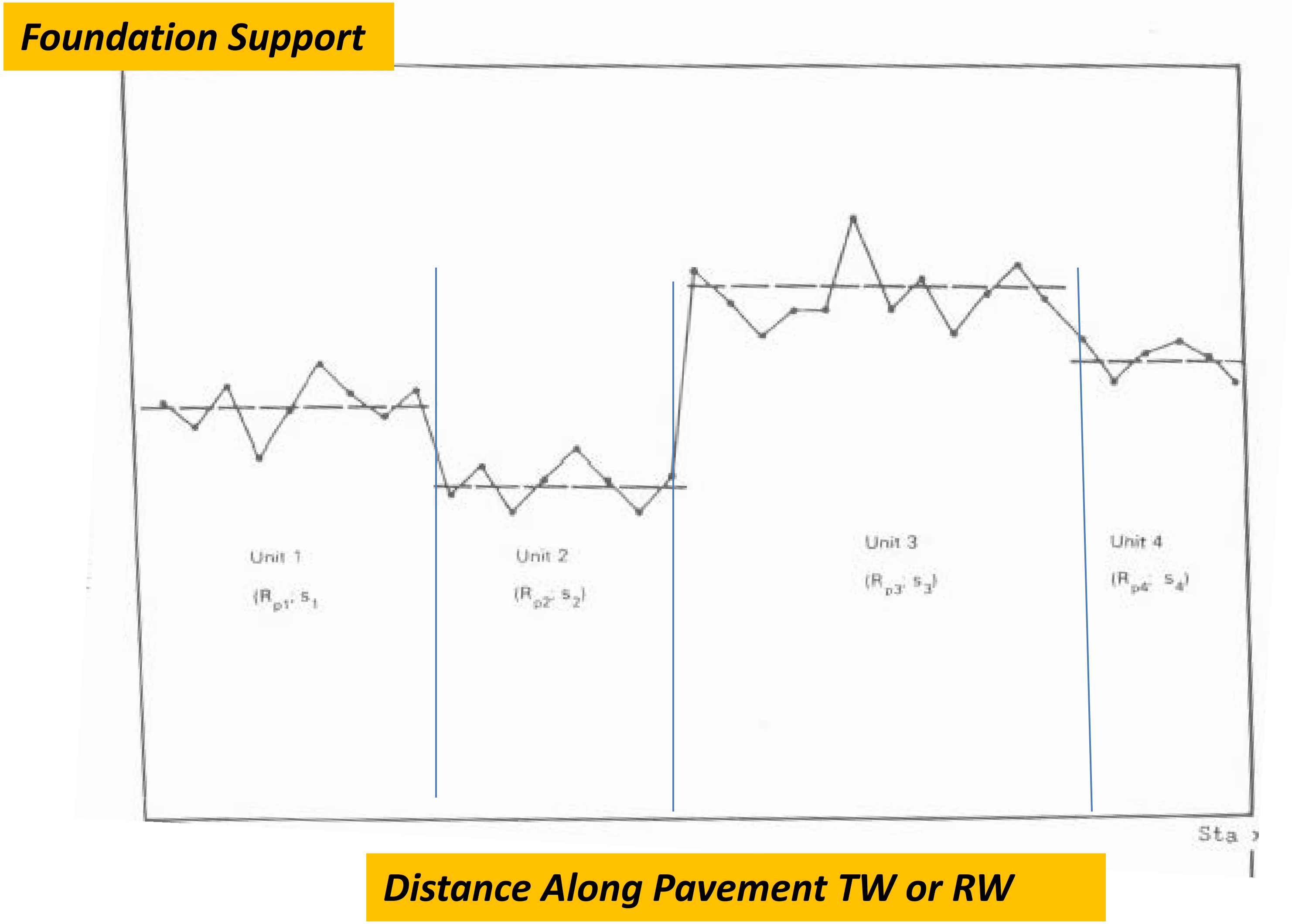
Its Immense Sensitivity in Airfield Pavement Design / Evaluation



Necessity to Conduct NDT Structural Capacity at Time of Evaluation

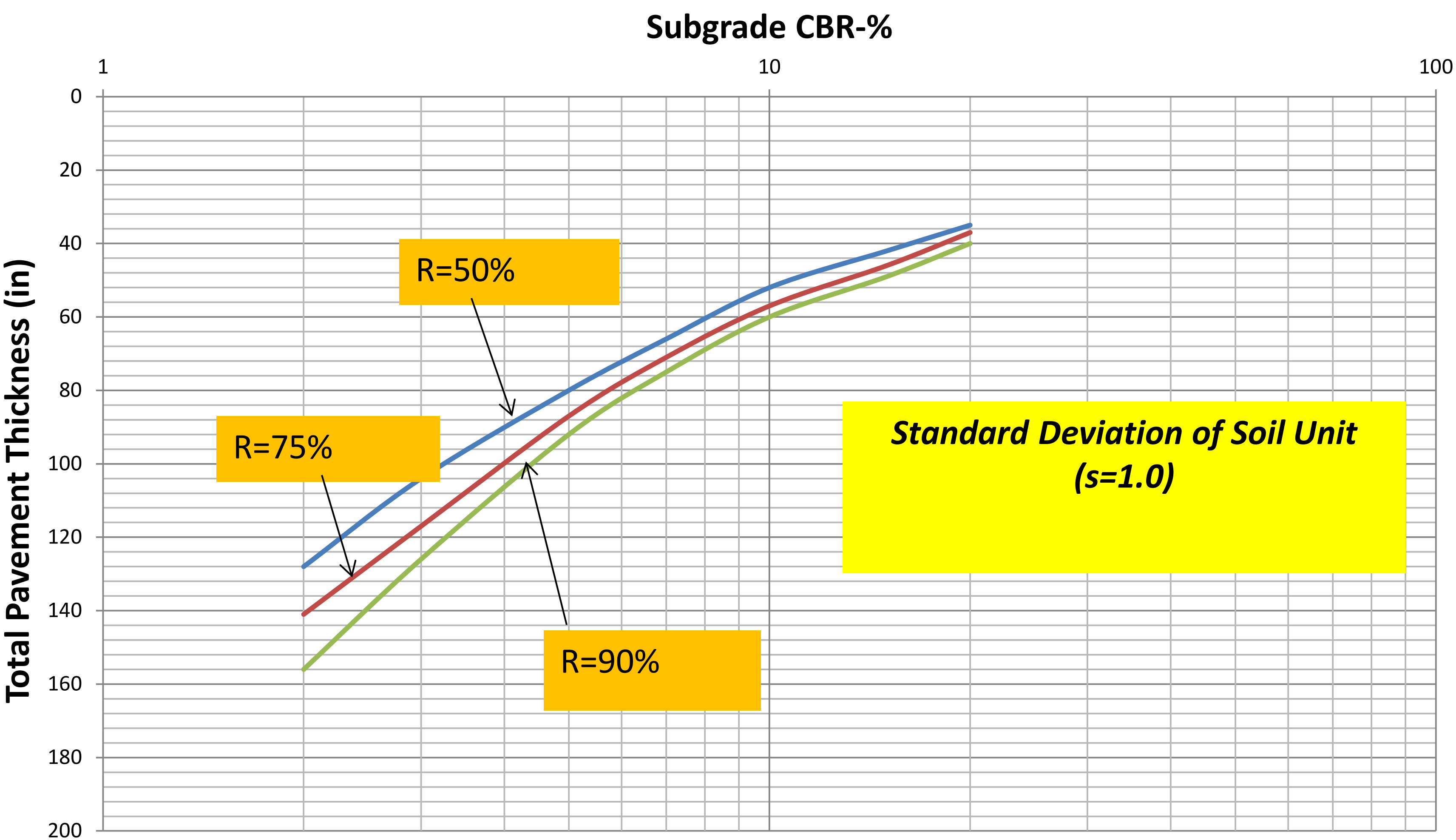


Degradation in Structural Capacity with Time due to Load Damage

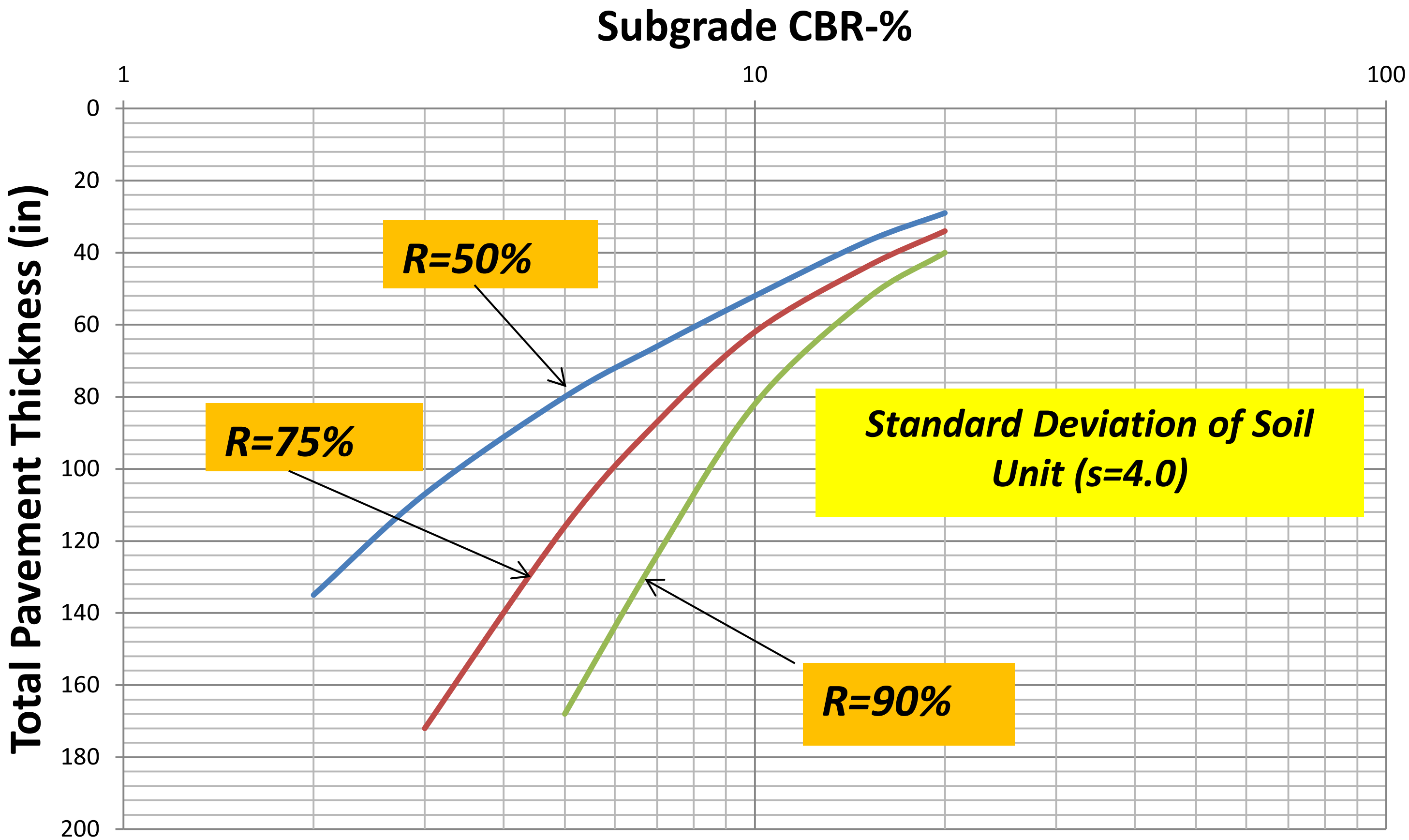


Delineation of Unique Design / Analysis Areas

Reliability Based B-52 Flexible Pavement Based On Subgrade Unit Variability



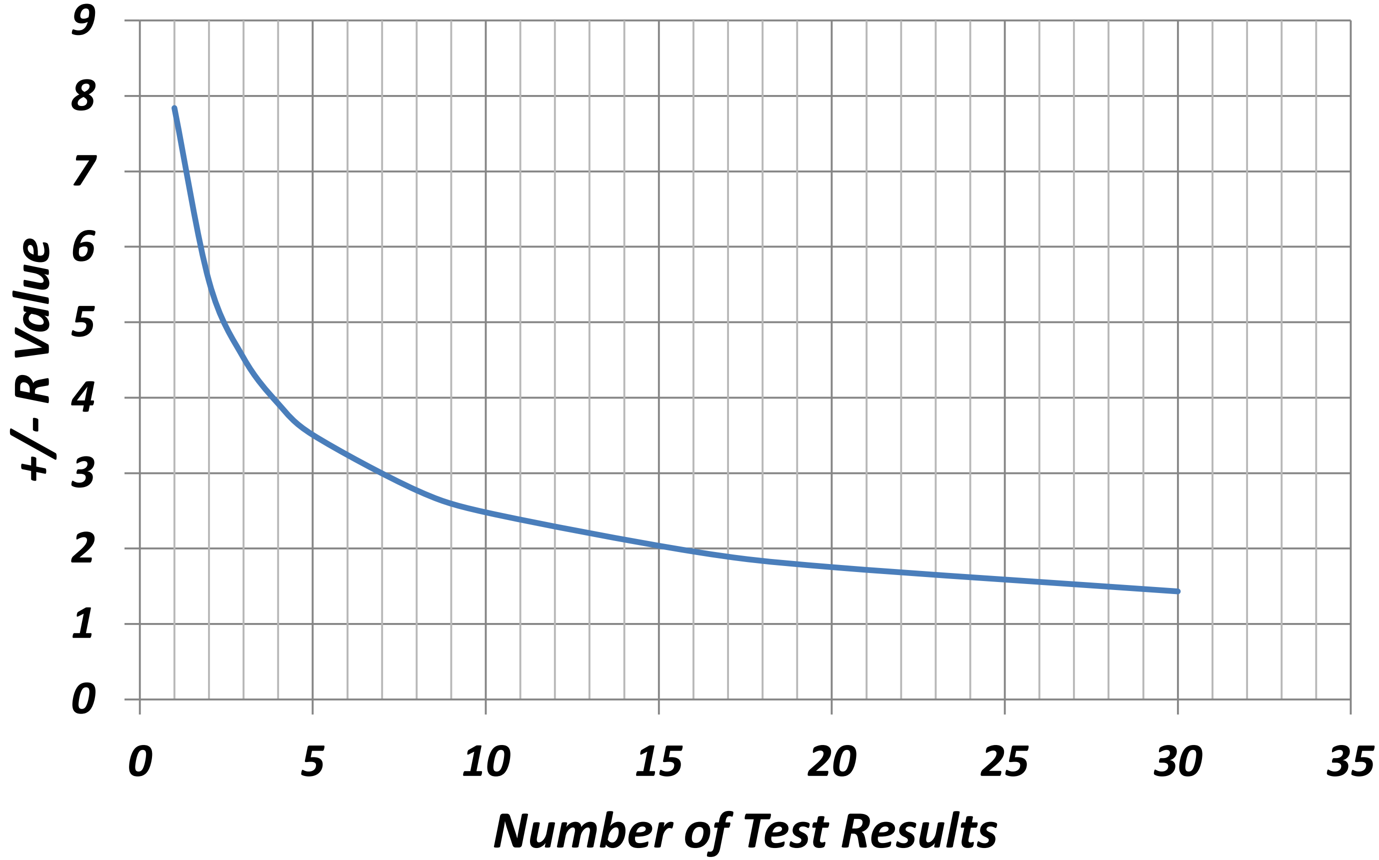
Reliability Based B-52 Flexible Pavement Based On Subgrade Unit Variability

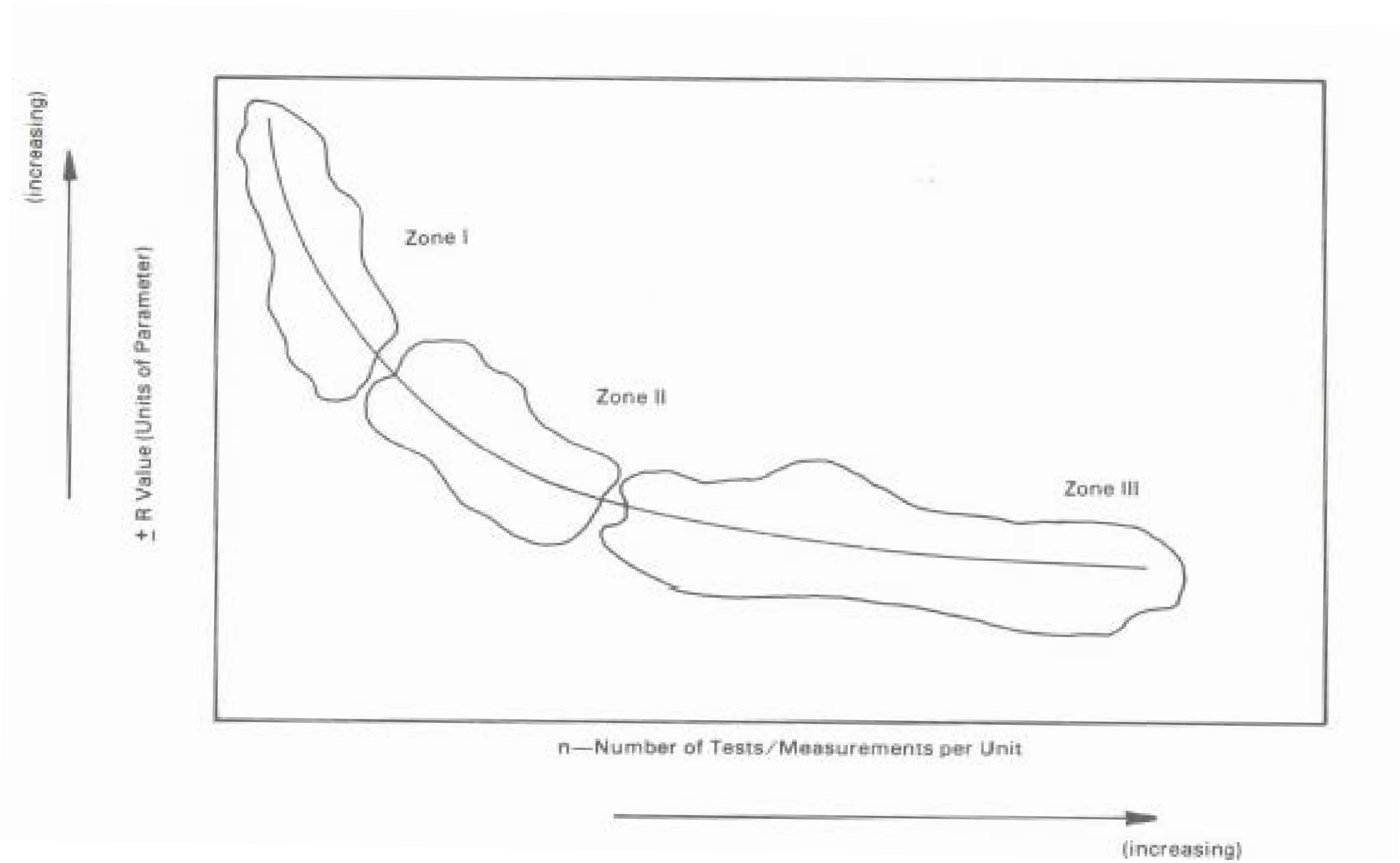


Selection of the Appropriate Number of Test Results Within the Pavement Unit

Limit of Accuracy and the Presumptive Number

Limit of Accuracy Curve for CBR Soil Unit (Standard Deviation = 4)





Typical Limit of Accuracy Curve with Presumptive Number of Test Samples

Types of Tire / Gear Arrangements


A-380
A-380F
OK
Cancel

X	0	0.2x_{j1}	0.4x_{j1}	0.6x_{j1}	0.8x_{j1}	x_{j1}
Y	Y_{j1}	Y_{j1}	Y_{j1}	Y_{j1}	Y_{j1}	Y_{j1}
X	0	0.2x_{j1}	0.4x_{j1}	0.6x_{j1}	0.8x_{j1}	x_{j1}
Y	Y_{j1}-0.2X_{j2}	Y_{j1}-0.2X_{j2}	Y_{j1}-0.2X_{j2}	Y_{j1}-0.2X_{j2}	Y_{j1}-0.2X_{j2}	Y_{j1}-0.2X_{j2}

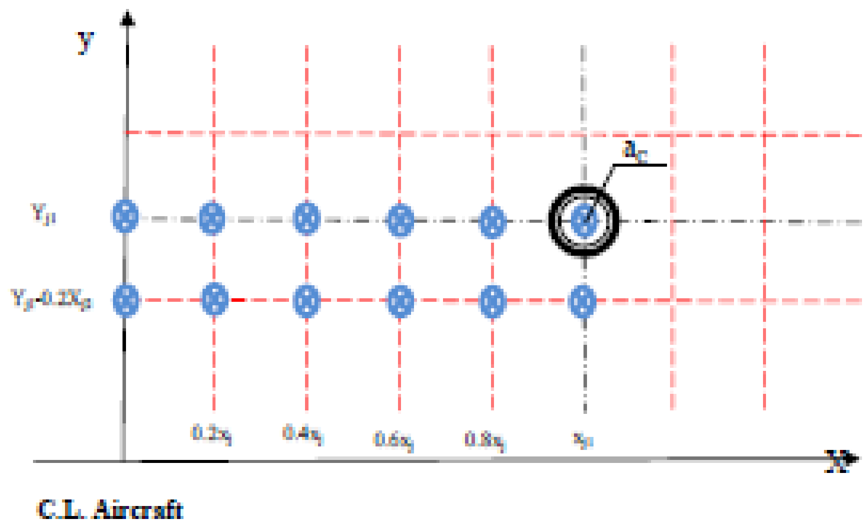


FIGURE 3-1 Type gear single tire.

X	0	0.2xjl	0.4xjl	0.6xjl	xjl - Sdl/2	xjl
Y	Yjl	Yjl	Yjl	Yjl	Yjl	Yjl
X	0	0.2xjl	0.4xjl	0.6xjl	xjl - Sdl/2	xjl
Y	Yjl - 2 ac	Yjl - 2 ac	Yjl - 2 ac	Yjl - 2 ac	Yjl - 2 ac	Yjl - 2 ac

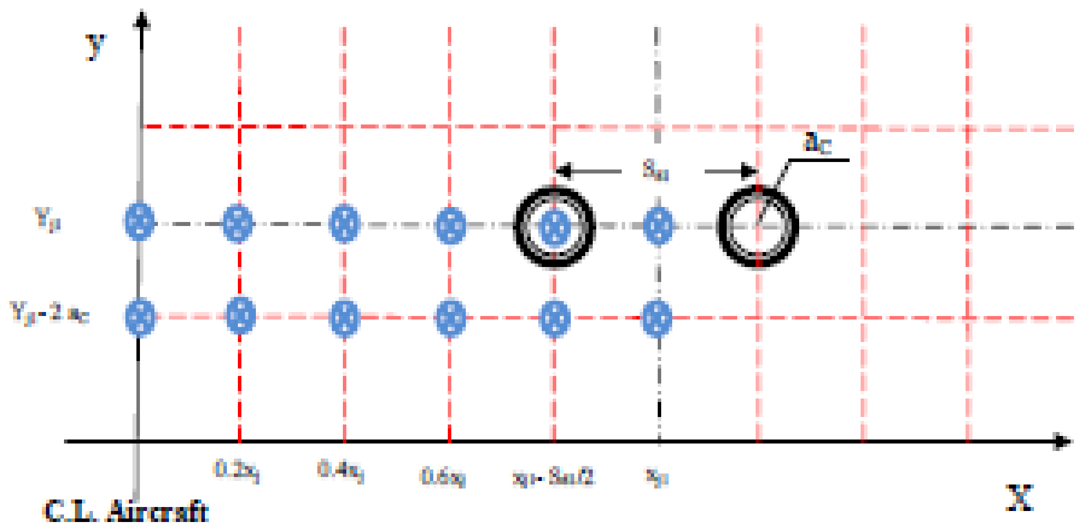
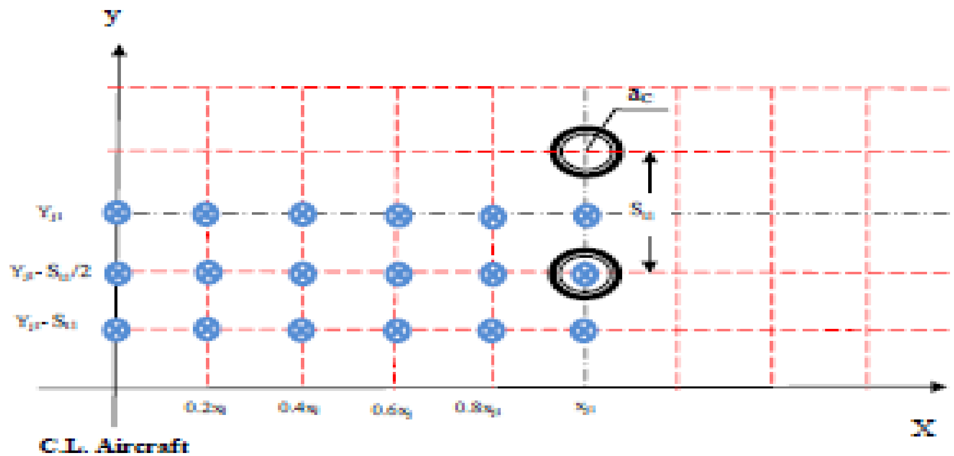


FIGURE 3-2 Type gear dual tire.

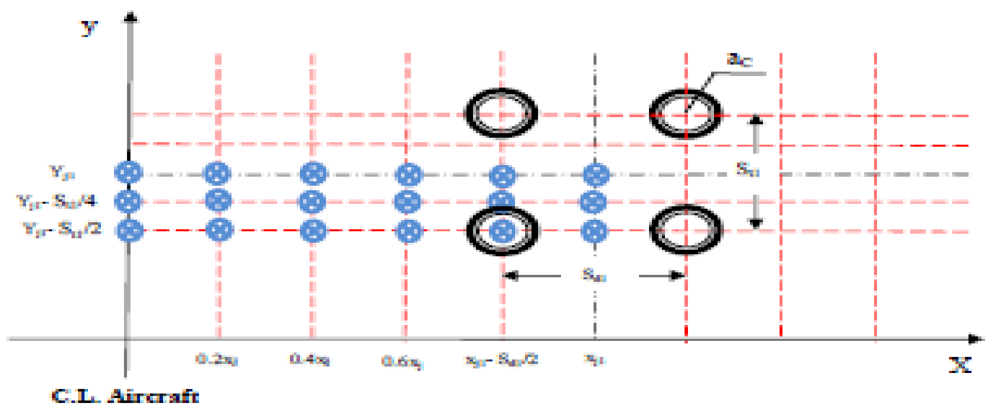
B 737 (Dual-Twin)

X	0	0.2xj1	0.4xj1	0.6xj1	0.8xj1	xj1
Y	Yj1	Yj1	Yj1	Yj1	Yj1	Yj1
X	0	0.2xj1	0.4xj1	0.6xj1	0.8xj1	xj1
Y	Yj1- St1/2	Yj1- St1/2	Yj1- St1/2	Yj1- St1/2	Yj1- St1/2	Yj1- St1/2
X	0	0.2xj1	0.4xj1	0.6xj1	0.8xj1	xj1
Y	Yj1- St1	Yj1- St1	Yj1- St1	Yj1- St1	Yj1- St1	Yj1- St1



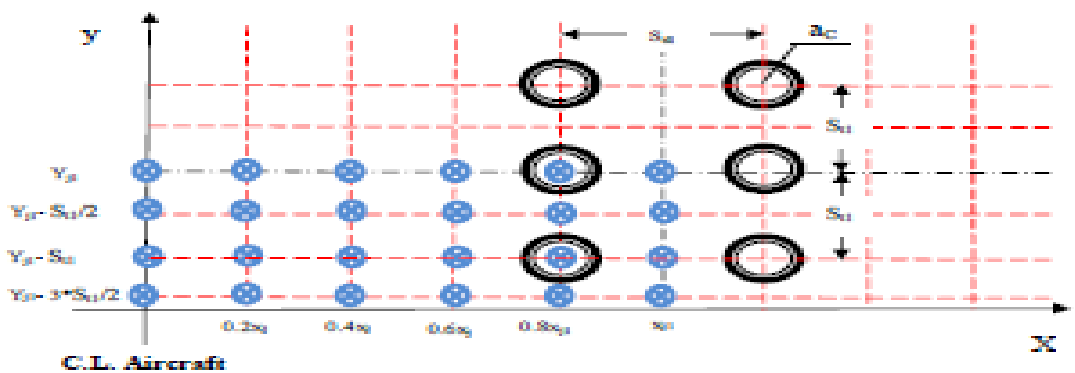
C-130 Hercules (Single Tandem)

X	0	0.2xj1	0.4xj1	0.6xj1	xj1 - Sd1/2	xj1
Y	Yj1	Yj1	Yj1	Yj1	Yj1	Yj1
X	0	0.2xj1	0.4xj1	0.6xj1	xj1 - Sd1/2	xj1
Y	Yj1 - St1/4	Yj1 - St1/4	Yj1 - St1/4	Yj1 - St1/4	Yj1 - St1/4	Yj1 - St1/4
X	0	0.2xj1	0.4xj1	0.6xj1	xj1 - Sd1/2	xj1
Y	Yj1 - St1/2	Yj1 - St1/2	Yj1 - St1/2	Yj1 - St1/2	Yj1 - St1/2	Yj1 - St1/2



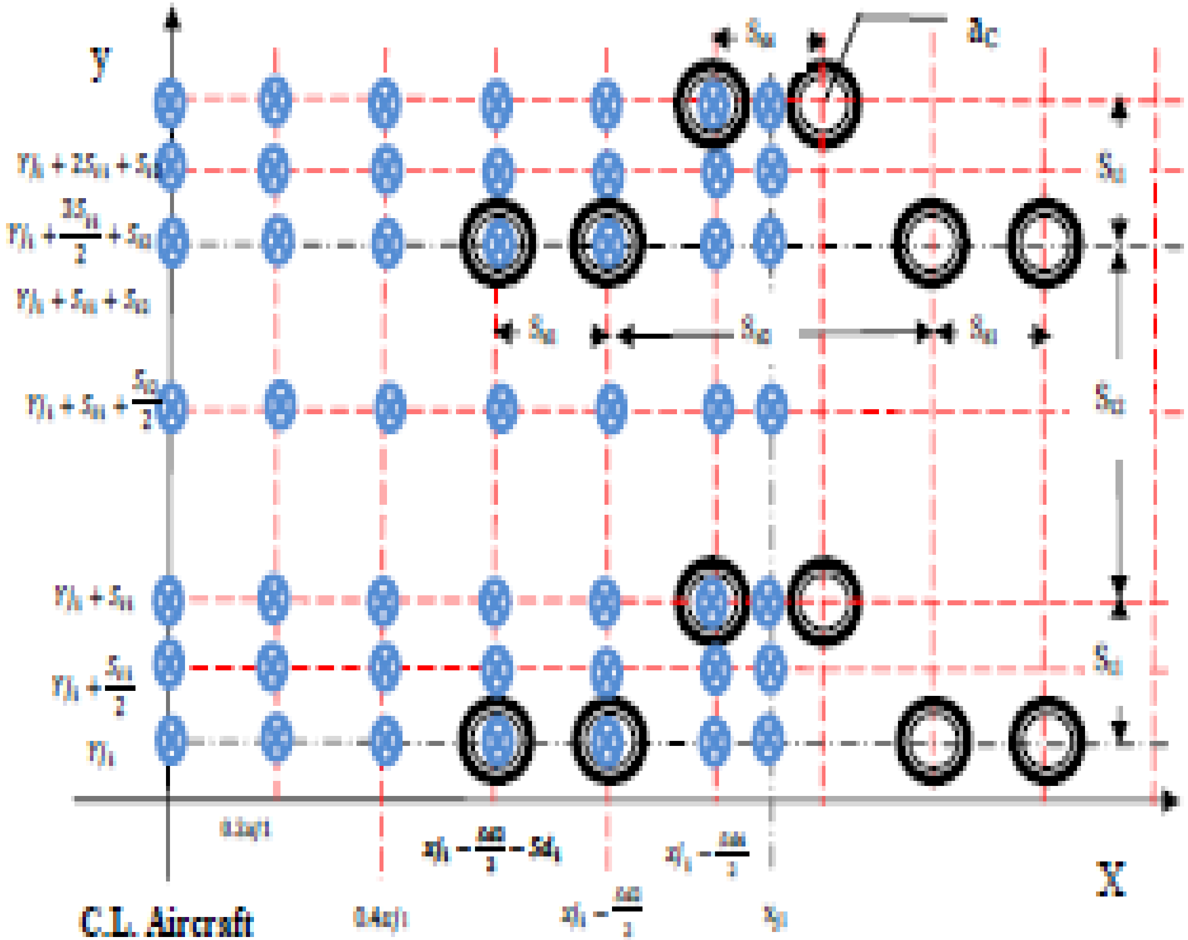
A-320 (Dual / Twin Tandem)

X	0	0.2xj1	0.4xj1	0.6xj1	0.8xj1	xj1
Y	Yj1	Yj1	Yj1	Yj1	Yj1	Yj1
X	0	0.2xj1	0.4xj1	0.6xj1	0.8xj1	xj1
Y	Yj1- St1/2	Yj1- St1/2	Yj1- St1/2	Yj1- St1/2	Yj1- St1/2	Yj1- St1/2
X	0	0.2xj1	0.4xj1	0.6xj1	0.8xj1	xj1
Y	Yj1- St1	Yj1- St1	Yj1- St1	Yj1- St1	Yj1- St1	Yj1- St1
X	0	0.2xj1	0.4xj1	0.6xj1	0.8xj1	xj1
Y	Yj1- 3*St1/2	Yj1-3* St1/2	Yj1- 3* St1/2	Yj1- 3* St1/2	Yj1- 3* St1/2	Yj1- 3* St1/2



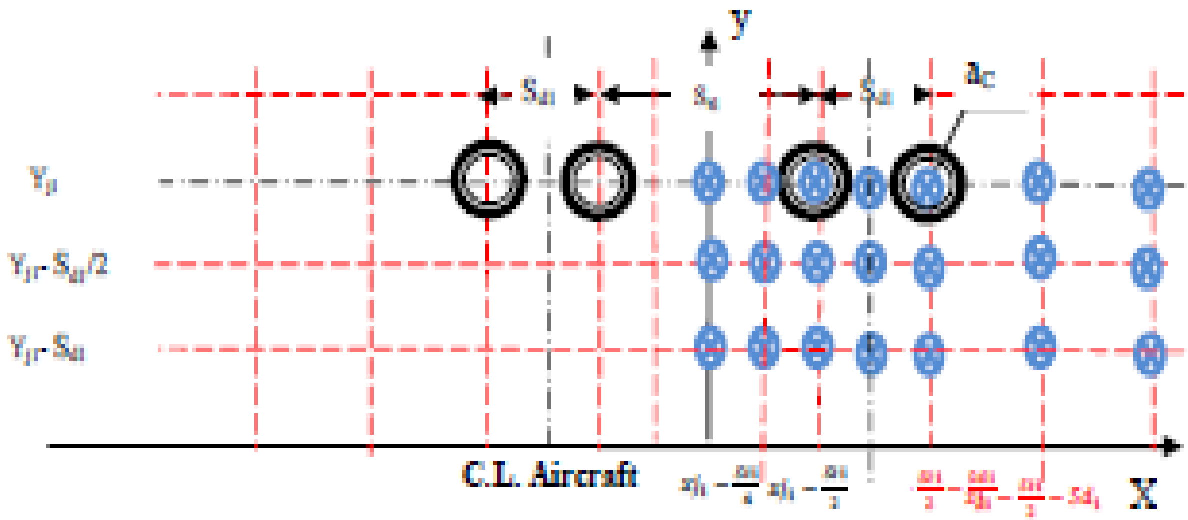
B-777 (Tri – Tandem)

X	0	0.2xj1	0.4xj1	$xj_1 - \frac{Sd2}{2} - Sd_1$	$xj_1 - \frac{Sd2}{2}$	$xj_1 - \frac{Sd4}{2}$	xj1
Y	$Yj_1 + 2S_{t1} + S_{t2}$	$Yj_1 + 2S_{t1} + S_{t2}$	$Yj_1 + 2S_{t1} + S_{t2}$	$Yj_1 + 2S_{t1} + S_{t2}$	$Yj_1 + 2S_{t1} + S_{t2}$	$Yj_1 + 2S_{t1} + S_{t2}$	$Yj_1 + 2S_{t1} + S_{t2}$
X	0	0.2xj1	0.4xj1	$xj_1 - \frac{Sd2}{2} - Sd_1$	$xj_1 - \frac{Sd2}{2}$	$xj_1 - \frac{Sd4}{2}$	xj1
Y	$Yj_1 + \frac{3S_{t1}}{2} + S_{t2}$	$Yj_1 + \frac{3S_{t1}}{2} + S_{t2}$	$Yj_1 + \frac{3S_{t1}}{2} + S_{t2}$	$Yj_1 + \frac{3S_{t1}}{2} + S_{t2}$	$Yj_1 + \frac{3S_{t1}}{2} + S_{t2}$	$Yj_1 + \frac{3S_{t1}}{2} + S_{t2}$	$Yj_1 + \frac{3S_{t1}}{2} + S_{t2}$
X	0	0.2xj1	0.4xj1	$xj_1 - \frac{Sd2}{2} - Sd_1$	$xj_1 - \frac{Sd2}{2}$	$xj_1 - \frac{Sd4}{2}$	xj1
Y	$Yj_1 + S_{t1} + S_{t2}$	$Yj_1 + S_{t1} + S_{t2}$	$Yj_1 + S_{t1} + S_{t2}$	$Yj_1 + S_{t1} + S_{t2}$	$Yj_1 + S_{t1} + S_{t2}$	$Yj_1 + S_{t1} + S_{t2}$	$Yj_1 + S_{t1} + S_{t2}$
X	0	0.2xj1	0.4xj1	$xj_1 - \frac{Sd2}{2} - Sd_1$	$xj_1 - \frac{Sd2}{2}$	$xj_1 - \frac{Sd4}{2}$	xj1
Y	$Yj_1 + S_{t1} + \frac{S_{t2}}{2}$	$Yj_1 + S_{t1} + \frac{S_{t2}}{2}$	$Yj_1 + S_{t1} + \frac{S_{t2}}{2}$	$Yj_1 + S_{t1} + \frac{S_{t2}}{2}$	$Yj_1 + S_{t1} + \frac{S_{t2}}{2}$	$Yj_1 + S_{t1} + \frac{S_{t2}}{2}$	$Yj_1 + S_{t1} + \frac{S_{t2}}{2}$
X	0	0.2xj1	0.4xj1	$xj_1 - \frac{Sd2}{2} - Sd_1$	$xj_1 - \frac{Sd2}{2}$	$xj_1 - \frac{Sd4}{2}$	xj1
Y	$Yj_1 + S_{t1}$	$Yj_1 + S_{t1}$	$Yj_1 + S_{t1}$	$Yj_1 + S_{t1}$	$Yj_1 + S_{t1}$	$Yj_1 + S_{t1}$	$Yj_1 + S_{t1}$
X	0	0.2xj1	0.4xj1	$xj_1 - \frac{Sd2}{2} - Sd_1$	$xj_1 - \frac{Sd2}{2}$	$xj_1 - \frac{Sd4}{2}$	xj1
Y	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$
X	0	0.2xj1	0.4xj1	$xj_1 - \frac{Sd2}{2} - Sd_1$	$xj_1 - \frac{Sd2}{2}$	$xj_1 - \frac{Sd4}{2}$	xj1
Y	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1



C-5A Galaxy

X	$xj_1 - \frac{St1}{2} - 3Sd_1$	$xj_1 - \frac{St1}{2} - 2Sd_1$	$xj_1 - \frac{St1}{2} - Sd_1$	$xj_1 - \frac{St1}{2} - \frac{Sd1}{2}$	$xj_1 - \frac{St1}{2}$	$xj_1 - \frac{St1}{4}$	xj1
Y	Yj1	Yj1	Yj1	Yj1	Yj1	Yj1	Yj1
X	$xj_1 - \frac{St1}{2} - 3Sd_1$	$xj_1 - \frac{St1}{2} - 2Sd_1$	$xj_1 - \frac{St1}{2} - Sd_1$	$xj_1 - \frac{St1}{2} - \frac{Sd1}{2}$	$xj_1 - \frac{St1}{2}$	$xj_1 - \frac{St1}{4}$	xj1
Y	Yj1- Sd1/2	Yj1- Sd1/2	Yj1- Sd1/2	Yj1- Sd1/2	Yj1- Sd1/2	Yj1- Sd1/2	Yj1- Sd1/2
X	$xj_1 - \frac{St1}{2} - 3Sd_1$	$xj_1 - \frac{St1}{2} - 2Sd_1$	$xj_1 - \frac{St1}{2} - Sd_1$	$xj_1 - \frac{St1}{2} - \frac{Sd1}{2}$	$xj_1 - \frac{St1}{2}$	$xj_1 - \frac{St1}{4}$	xj1
Y	Yj1- Sd1	Yj1- Sd1	Yj1- Sd1	Yj1- Sd1	Yj1- Sd1	Yj1- Sd1	Yj1- Sd1



B-52 (Twin-Twin)

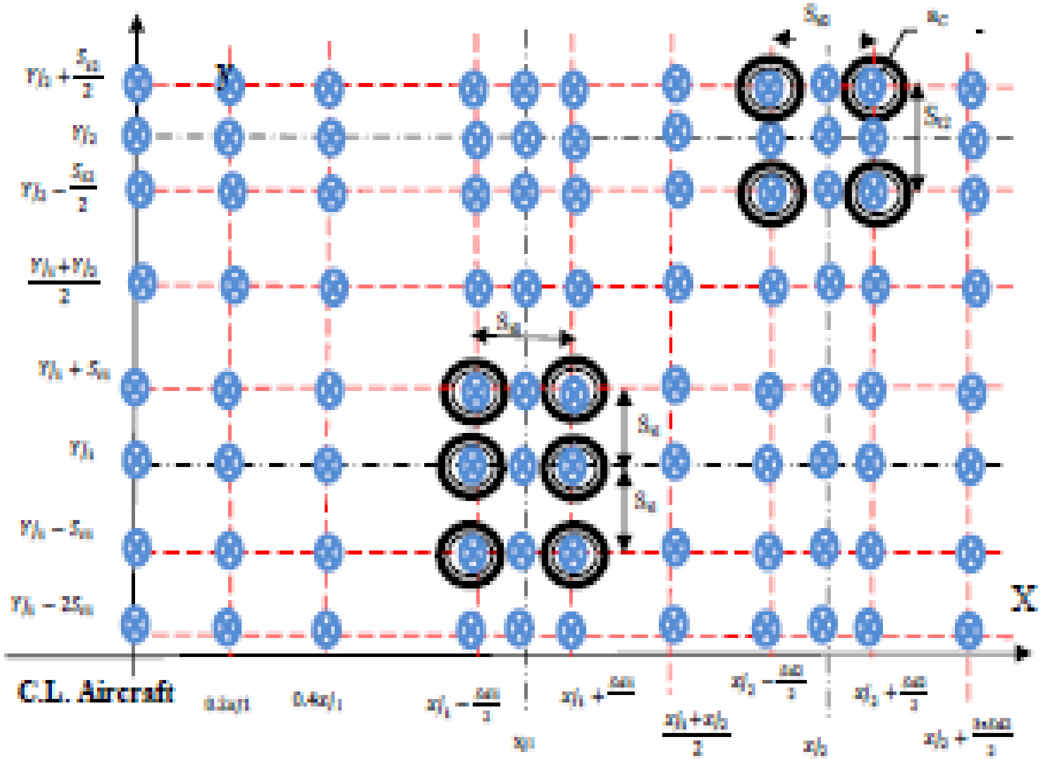
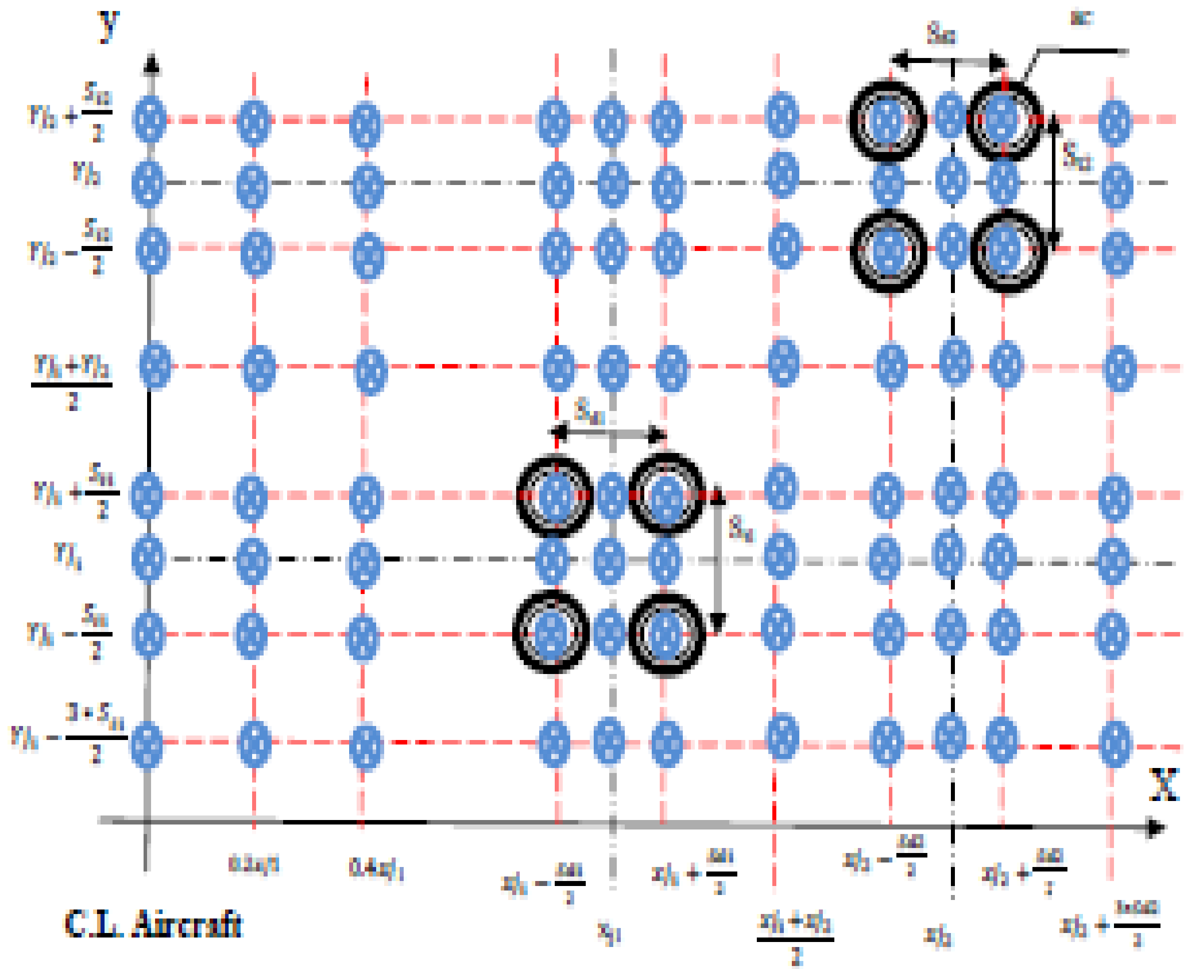


FIGURE 3-8 Type gear for A-380.

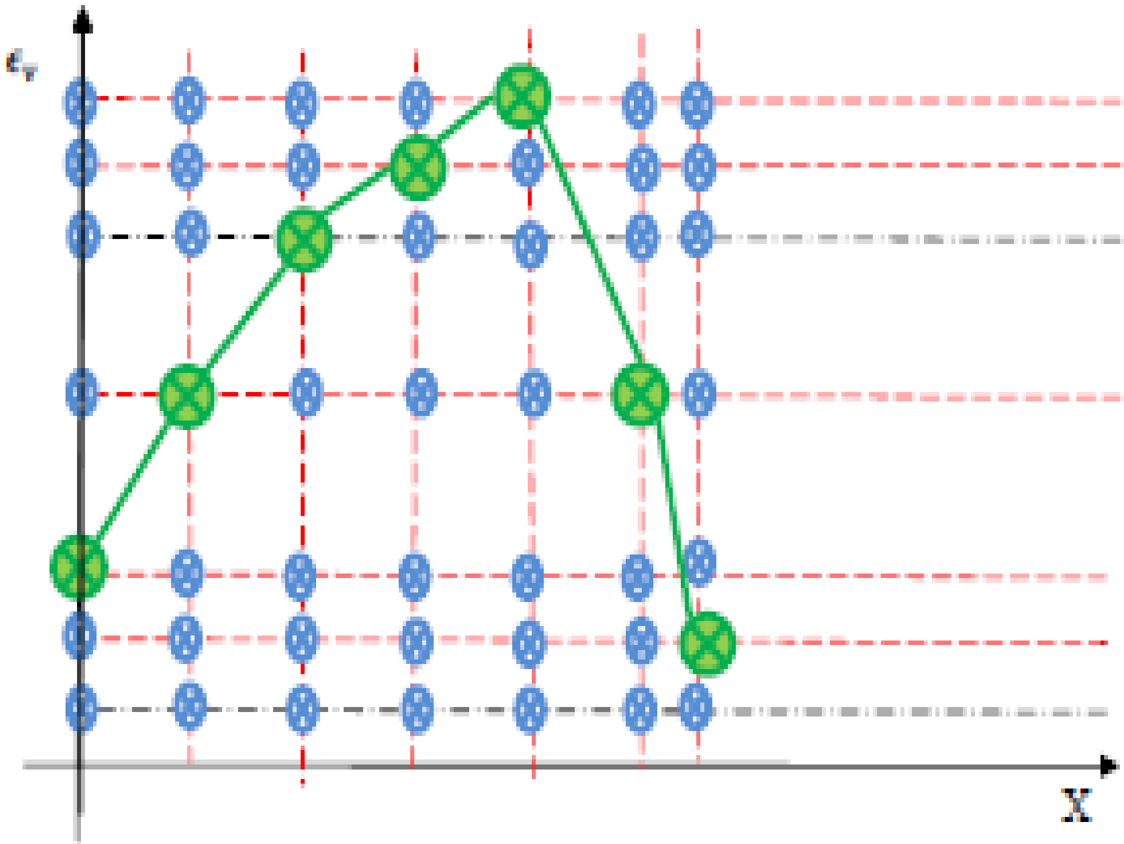
A-380 (Twin Tandem & Tri Tandem)

X	0	0.2xj1	0.4xj1	$xj_1-\frac{Sd1}{2}$	xj1	$xj_1+\frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2-\frac{Sd2}{2}$	xj_2	$xj_2+\frac{Sd2}{2}$	$xj_2+\frac{3*Sd2}{2}$
Y	$Yj_2+\frac{S_{t2}}{2}$	$Yj_2+\frac{S_{t2}}{2}$	$Yj_2+\frac{S_{t2}}{2}$	$Yj_2+\frac{S_{t2}}{2}$	$Yj_2+\frac{S_{t2}}{2}$	$Yj_2+\frac{S_{t2}}{2}$	$Yj_2+\frac{S_{t2}}{2}$	$Yj_2+\frac{S_{t2}}{2}$	$Yj_2+\frac{S_{t2}}{2}$	$Yj_2+\frac{S_{t2}}{2}$	$Yj_2+\frac{S_{t2}}{2}$
X	0	0.2xj1	0.4xj1	$xj_1-\frac{Sd1}{2}$	xj1	$xj_1+\frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2-\frac{Sd2}{2}$	xj_2	$xj_2+\frac{Sd2}{2}$	$xj_2+\frac{3*Sd2}{2}$
Y	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2
X	0	0.2xj1	0.4xj1	$xj_1-\frac{Sd1}{2}$	xj1	$xj_1+\frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2-\frac{Sd2}{2}$	xj_2	$xj_2+\frac{Sd2}{2}$	$xj_2+\frac{3*Sd2}{2}$
Y	$Yj_2-\frac{S_{t2}}{2}$	$Yj_2-\frac{S_{t2}}{2}$	$Yj_2-\frac{S_{t2}}{2}$	$Yj_2-\frac{S_{t2}}{2}$	$Yj_2-\frac{S_{t2}}{2}$	$Yj_2-\frac{S_{t2}}{2}$	$Yj_2-\frac{S_{t2}}{2}$	$Yj_2-\frac{S_{t2}}{2}$	$Yj_2-\frac{S_{t2}}{2}$	$Yj_2-\frac{S_{t2}}{2}$	$Yj_2-\frac{S_{t2}}{2}$
X	0	0.2xj1	0.4xj1	$xj_1-\frac{Sd1}{2}$	xj1	$xj_1+\frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2-\frac{Sd2}{2}$	xj_2	$xj_2+\frac{Sd2}{2}$	$xj_2+\frac{3*Sd2}{2}$
Y	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$
X	0	0.2xj1	0.4xj1	$xj_1-\frac{Sd1}{2}$	xj1	$xj_1+\frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2-\frac{Sd2}{2}$	xj_2	$xj_2+\frac{Sd2}{2}$	$xj_2+\frac{3*Sd2}{2}$
Y	Yj_1+S_{t1}	Yj_1+S_{t1}	Yj_1+S_{t1}	Yj_1+S_{t1}	Yj_1+S_{t1}	Yj_1+S_{t1}	Yj_1+S_{t1}	Yj_1+S_{t1}	Yj_1+S_{t1}	Yj_1+S_{t1}	Yj_1+S_{t1}
X	0	0.2xj1	0.4xj1	$xj_1-\frac{Sd1}{2}$	xj1	$xj_1+\frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2-\frac{Sd2}{2}$	xj_2	$xj_2+\frac{Sd2}{2}$	$xj_2+\frac{3*Sd2}{2}$
Y	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1
X	0	0.2xj1	0.4xj1	$xj_1-\frac{Sd1}{2}$	xj1	$xj_1+\frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2-\frac{Sd2}{2}$	xj_2	$xj_2+\frac{Sd2}{2}$	$xj_2+\frac{3*Sd2}{2}$
Y	Yj_1-S_{t1}	Yj_1-S_{t1}	Yj_1-S_{t1}	Yj_1-S_{t1}	Yj_1-S_{t1}	Yj_1-S_{t1}	Yj_1-S_{t1}	Yj_1-S_{t1}	Yj_1-S_{t1}	Yj_1-S_{t1}	Yj_1-S_{t1}
X	0	0.2xj1	0.4xj1	$xj_1-\frac{Sd1}{2}$	xj1	$xj_1+\frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2-\frac{Sd2}{2}$	xj_2	$xj_2+\frac{Sd2}{2}$	$xj_2+\frac{3*Sd2}{2}$
Y	Yj_1-2S_{t1}	Yj_1-2S_{t1}	Yj_1-2S_{t1}	Yj_1-2S_{t1}	Yj_1-2S_{t1}	Yj_1-2S_{t1}	Yj_1-2S_{t1}	Yj_1-2S_{t1}	Yj_1-2S_{t1}	Yj_1-2S_{t1}	Yj_1-2S_{t1}



B-747 (Offset Twin Tandems)

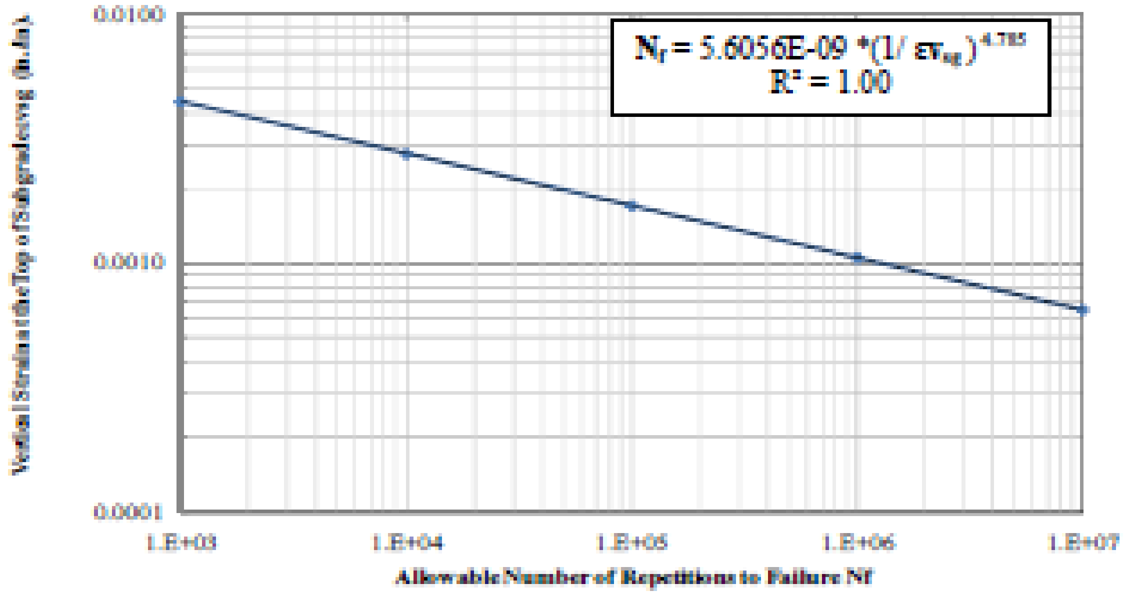
X	0	$0.2xj1$	$0.4xj1$	$xj_1 - \frac{Sd1}{2}$	$xj1$	$xj_1 + \frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2 - \frac{Sd2}{2}$	xj_2	$xj_2 + \frac{Sd2}{2}$	$xj_2 + \frac{3 * Sd2}{2}$
Y	$Yj_2 + \frac{S_{t2}}{2}$	$Yj_2 + \frac{S_{t2}}{2}$	$Yj_2 + \frac{S_{t2}}{2}$	$Yj_2 + \frac{S_{t2}}{2}$	$Yj_2 + \frac{S_{t2}}{2}$	$Yj_2 + \frac{S_{t2}}{2}$	$Yj_2 + \frac{S_{t2}}{2}$	$Yj_2 + \frac{S_{t2}}{2}$	$Yj_2 + \frac{S_{t2}}{2}$	$Yj_2 + \frac{S_{t2}}{2}$	$Yj_2 + \frac{S_{t2}}{2}$
X	0	$0.2xj1$	$0.4xj1$	$xj_1 - \frac{Sd1}{2}$	$xj1$	$xj_1 + \frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2 - \frac{Sd2}{2}$	xj_2	$xj_2 + \frac{Sd2}{2}$	$xj_2 + \frac{3 * Sd2}{2}$
Y	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2	Yj_2
X	0	$0.2xj1$	$0.4xj1$	$xj_1 - \frac{Sd1}{2}$	$xj1$	$xj_1 + \frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2 - \frac{Sd2}{2}$	xj_2	$xj_2 + \frac{Sd2}{2}$	$xj_2 + \frac{3 * Sd2}{2}$
Y	$Yj_2 - \frac{S_{t2}}{2}$	$Yj_2 - \frac{S_{t2}}{2}$	$Yj_2 - \frac{S_{t2}}{2}$	$Yj_2 - \frac{S_{t2}}{2}$	$Yj_2 - \frac{S_{t2}}{2}$	$Yj_2 - \frac{S_{t2}}{2}$	$Yj_2 - \frac{S_{t2}}{2}$	$Yj_2 - \frac{S_{t2}}{2}$	$Yj_2 - \frac{S_{t2}}{2}$	$Yj_2 - \frac{S_{t2}}{2}$	$Yj_2 - \frac{S_{t2}}{2}$
X	0	$0.2xj1$	$0.4xj1$	$xj_1 - \frac{Sd1}{2}$	$xj1$	$xj_1 + \frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2 - \frac{Sd2}{2}$	xj_2	$xj_2 + \frac{Sd2}{2}$	$xj_2 + \frac{3 * Sd2}{2}$
Y	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$	$\frac{Yj_1+Yj_2}{2}$
X	0	$0.2xj1$	$0.4xj1$	$xj_1 - \frac{Sd1}{2}$	$xj1$	$xj_1 + \frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2 - \frac{Sd2}{2}$	xj_2	$xj_2 + \frac{Sd2}{2}$	$xj_2 + \frac{3 * Sd2}{2}$
Y	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$	$Yj_1 + \frac{S_{t1}}{2}$
X	0	$0.2xj1$	$0.4xj1$	$xj_1 - \frac{Sd1}{2}$	$xj1$	$xj_1 + \frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2 - \frac{Sd2}{2}$	xj_2	$xj_2 + \frac{Sd2}{2}$	$xj_2 + \frac{3 * Sd2}{2}$
Y	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1	Yj_1
X	0	$0.2xj1$	$0.4xj1$	$xj_1 - \frac{Sd1}{2}$	$xj1$	$xj_1 + \frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2 - \frac{Sd2}{2}$	xj_2	$xj_2 + \frac{Sd2}{2}$	$xj_2 + \frac{3 * Sd2}{2}$
Y	$Yj_1 - \frac{S_{t1}}{2}$	$Yj_1 - \frac{S_{t1}}{2}$	$Yj_1 - \frac{S_{t1}}{2}$	$Yj_1 - \frac{S_{t1}}{2}$	$Yj_1 - \frac{S_{t1}}{2}$	$Yj_1 - \frac{S_{t1}}{2}$	$Yj_1 - \frac{S_{t1}}{2}$	$Yj_1 - \frac{S_{t1}}{2}$	$Yj_1 - \frac{S_{t1}}{2}$	$Yj_1 - \frac{S_{t1}}{2}$	$Yj_1 - \frac{S_{t1}}{2}$
X	0	$0.2xj1$	$0.4xj1$	$xj_1 - \frac{Sd1}{2}$	$xj1$	$xj_1 + \frac{Sd1}{2}$	$\frac{xj_1+xj_2}{2}$	$xj_2 - \frac{Sd2}{2}$	xj_2	$xj_2 + \frac{Sd2}{2}$	$xj_2 + \frac{3 * Sd2}{2}$
Y	$Yj_1 - \frac{3 * S_{t1}}{2}$	$Yj_1 - \frac{3 * S_{t1}}{2}$	$Yj_1 \frac{3 * S_{t1}}{2}$	$Yj_1 - \frac{3 * S_{t1}}{2}$	$Yj_1 - \frac{3 * S_{t1}}{2}$	$Yj_1 - \frac{3 * S_{t1}}{2}$	$Yj_1 - \frac{3 * S_{t1}}{2}$	$Yj_1 - \frac{3 * S_{t1}}{2}$	$Yj_1 - \frac{3 * S_{t1}}{2}$	$Yj_1 - \frac{3 * S_{t1}}{2}$	$Yj_1 - \frac{3 * S_{t1}}{2}$



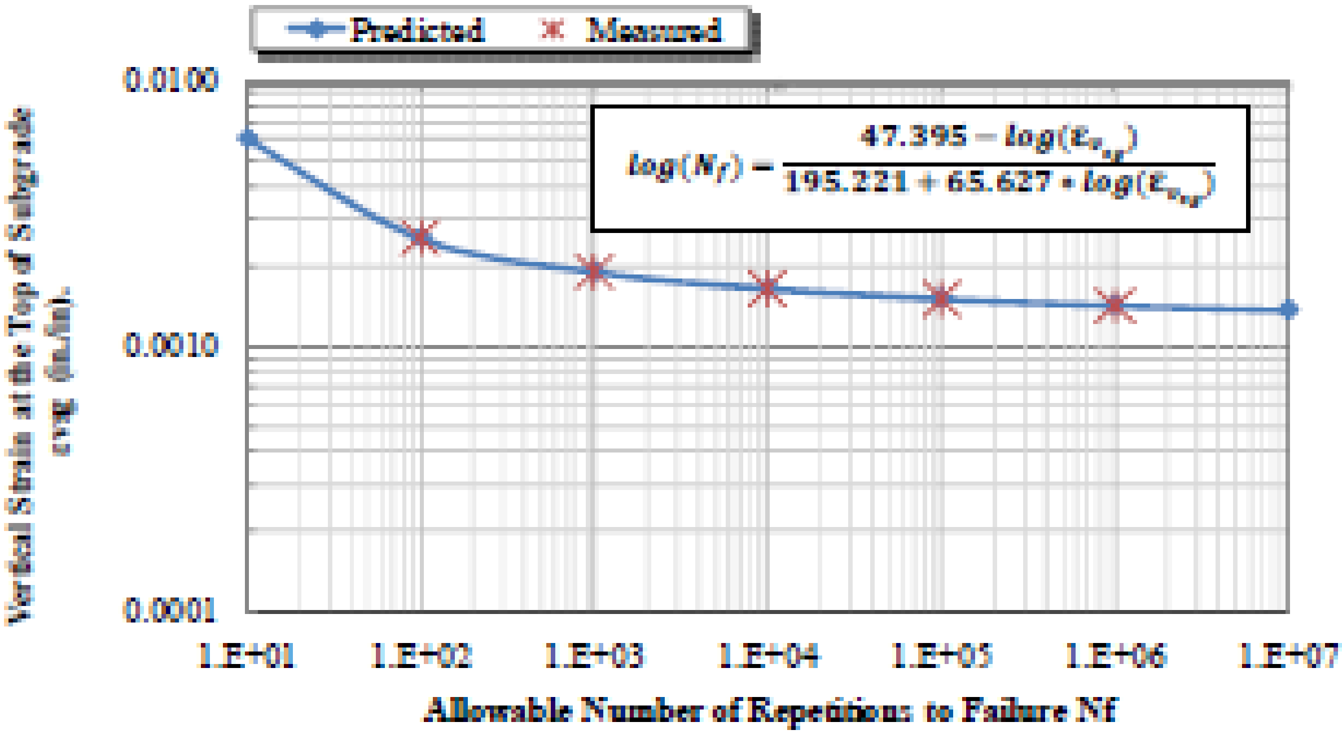
Typical Maximum Strain Results Along X Axis (Transverse Axis)

Some Limiting Vertical Subgrade Strain Criterion for AC Flexible Pavements

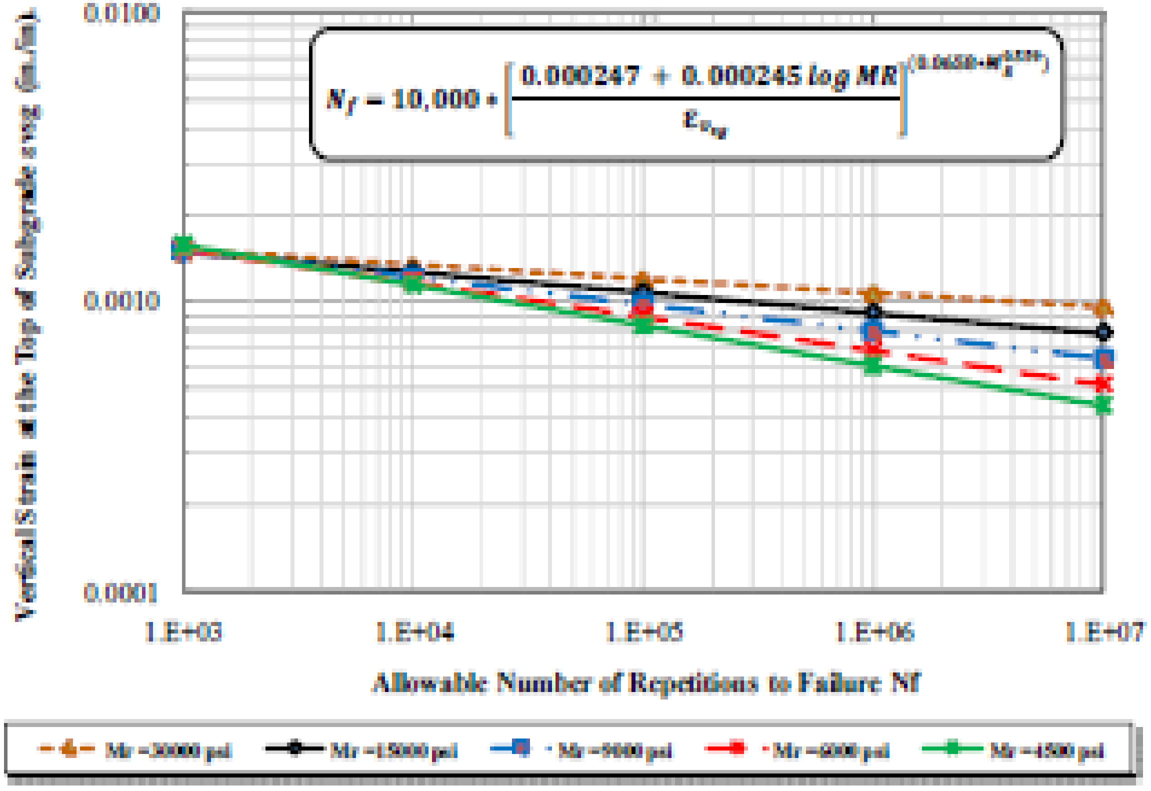
It is critically important for the user to note that the Shell Oil criterion *must use* an effective AC modulus (E1) of 150,000 psi when applying it to analysis/design of airfield pavement structures for permanent deformation. FIGURE 3-12 illustrates the limiting vertical subgrade strain criteria for Shell Oil criterion.



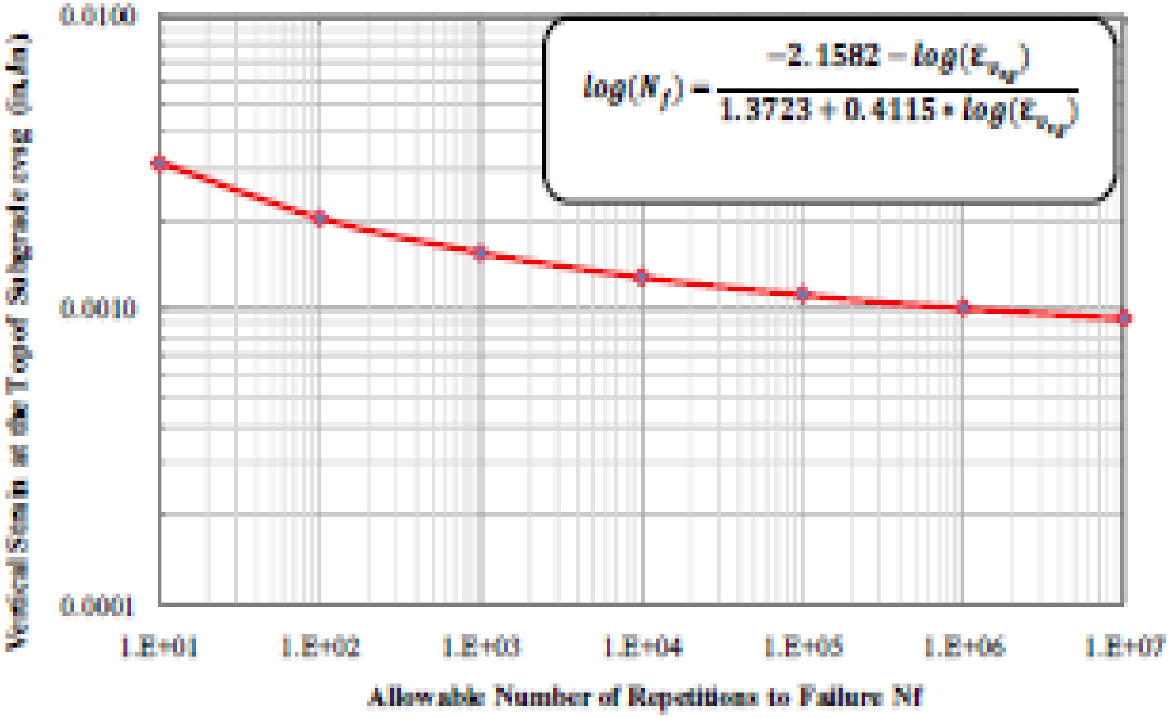
Shell Airfield Criteria (Early 1970's)



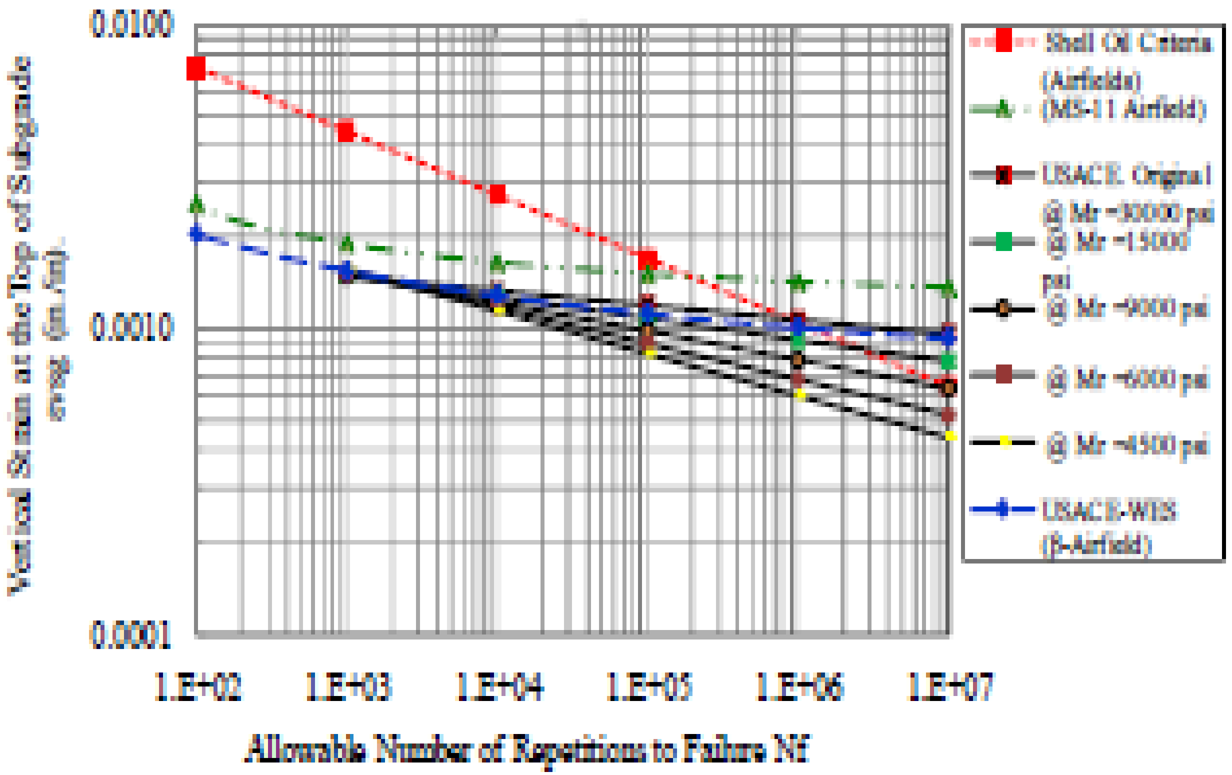
The Asphalt Institute MS-11 (Early 1970's)



USACE-WES (Mid 1980's)



USACE – WES (Beta CBR Approach) (Late 2010's)



Comparison Between Agency Approaches

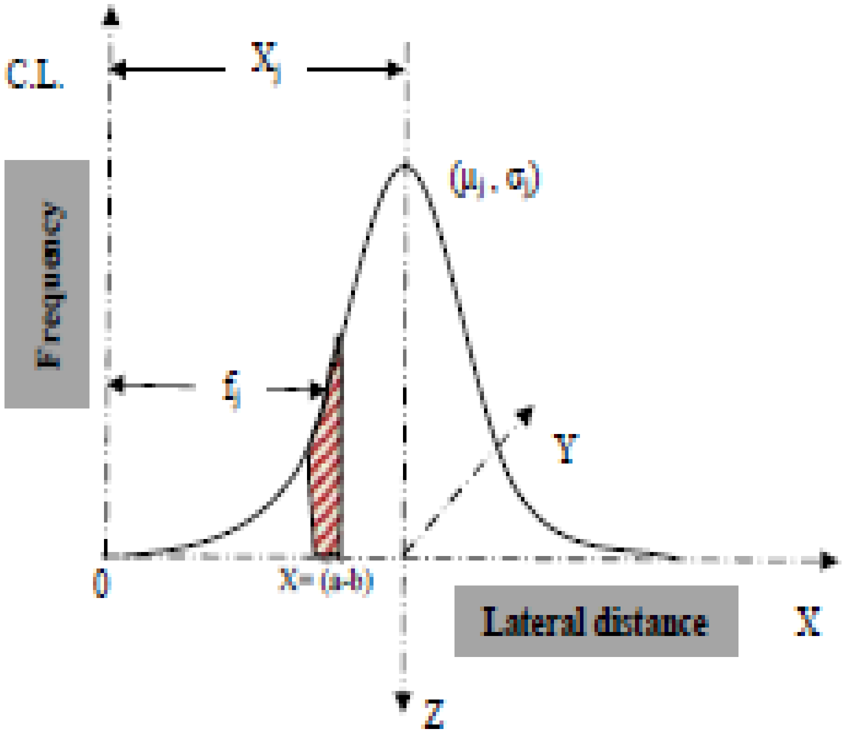


FIGURE 3-24 Distribution of wander laterally of the vehicle.

Speaker Assessment of Aircraft – Pavement Evaluation

Some Thoughts and Considerations About Pavement Aircraft Evaluations

- *One of the most complex technical computations in airfiekd pavement engineering which is very difficult to accurately evaluate*
- *The use of the ACN / PCN approach is not the most accurate methodology to use to formulate this decision as it neglects to consider several important factors affecting pavement performance (such as the current distress condition, actual traffic mixture etc..) although it is an excellent first screening methodology that should be employed*
- *Airfields should have a history of periodic Condition Surveys in order to know the condition and distress categories present when a new heavy aircraft is introduced*

Some Thoughts and Considerations About Pavement Aircraft Evaluations

- ***It is absolutely imperative to accurately know the historic traffic mixtures by type; weight; number of historic passes on each unique traffic (RW / TW) segment***
- ***Historic availability of NDT Back Calculation Studies are necessary to establish the Soil / Pavement Units at the Airfield (For example there are well over 200 pavement "design" units at J.F.Kennedy Airport in New York) and the variability of the unit for reliability analysis***
- ***Need to have precise pavement structural compositions of each unit (material type, thickness and material property)***
- ***Airport Owner must use Cumulative Damage Principles in his decision and not rely on"Critical Design Aircraft Concepts".***

Some Thoughts and Considerations About Pavement Aircraft Evaluations

- ***Flexible Pavement Aircraft – Pavement decisions must be based upon the most accurate available Design Methodologies available today***
  - ***CBR Design Procedures should be Avoided***
  - ***Use of MLET pavement approaches are much more preferred***
  - ***However, future improvements in the MLET airfield design method, currently used by airfield agencies (TAI; USMilitary UFC and FAARFIELD) should be immediately pursued by ICAO to greatly enhance the predictability of the approach***

  -- ***Cumulative Damage Effects of the Aircraft Traffic mixture must be used and one should not rely on a "critical aircraft " approach***

Some Thoughts and Considerations About Pavement Aircraft Evaluations

- ***Rigid Pavement Aircraft – Pavement decisions must be based upon the most accurate design methodologies available today***
  - ***Theoretical solutions that can model slab boundary effects caused by joints, dowels etc must be utilized***
  - ***The finite element FAARFIELD methodology is the most currently preferred approach***
  - ***However, there are still some limitations in this methodology which should be enhanced to make it a powerful aircraft – pavement evaluation / design procedure for rigid PCC systems***
  - ***Cumulative Damage effects of the aircraft traffic mixture must be used and one should not rely upon a "critical aircraft" approach***

Areas of Enhancement Needed in Current Airfield Design Models

- *Total Lack of Real Time Environmental Site Conditions of Airfields*
- *Actual Frequency (load rate) to model Material response behavior for Moving Aircraft must be Considered*
- *Non Linear Response of all Unbound subgrades, subbases and Base Courses must be considered in the analsis*
- *Eliminate 1500 *CBR to estimate Modulus of unbound materials…..it is totally incorrect*
- *Eliminate Ei/Ei+1 Approach of USACE*
- *Completely remove the "Pass to Coverage" Concept developed nearly 50 years ago*
- *Pursue interaction of AC Mix Design Properties with Structural Performance and Distress*

Areas of Enhancement Needed in Current Airfield Design Models

- *Develop a true set of Field calibrated Fatigue criterion for Asphalt Mixtures as well as Cement (pozzolanic) stabilized Layers*
- *Develop accurate models for crack propagation and reflective cracking for Airfield Pavements*
- *Replace Limiting Strain Criteria for Flexible Pavements with mechanistic models that predict estimates of later perrmanent deformation for any given material type, real time climatic conditions and aircraft movements*
- *Conduct a critical re-evaluation to see if changes are warranted in Airfield Pavement Failure Criterion*

Critical Review of “Failure Criteria”

- ***Rigid Pavement Slab Fracture***
  - ***Highways:***
    - ***25% - 50% of Slabs Cracked***
  - ***Airfields***
    - ***Same Criteria for Aprons, Taxiways and Runways ?***
    - ***FOD Problem***
    - ***USACE “Initial Crack Condition” : 50% Slabs with Single Crack***
    - ***Utilization of Various SCI Levels by Pavement Unit ?***

Critical Review of "Failure Criteria"

- ***Rigid / Flexible Pavement Roughness***
  - ***Highways:***
    - ***PSI (PSR) and (IRI) functions of the Highway type***
  - ***Airfields***
    - ***Most Critical area will undoubtedly occur on Runways***
    - ***USAF Developed (in 1970's)advanced model to predict real time (travel speed) vertical accelerations for a given set of aircraft characteristics***
    - ***Was also powerful tool for rehabilitation***
    - ***Focused on Cockpit Instrumentation readings and passenger discomfort during takeoff***
    - ***Analysis system faded from use within a decade***

Critical Review of “Failure Criteria”

- ***Flexible Pavement Rutting***
  - ***Highways:***
    - ***Failure Rut of approximately 0.5”***
    - ***Critical Safety Issue due to Hydroplaning***
  - ***Airfields:***
    - ***Same Criteria for Aprons, Taxiways and Runways***
    - ***Typical Failure Rut 0f ¾”***
    - ***Airfield Hydroplaning seldom a primary concern***
    - ***Very Significant differences between Radii of Curvature between :***
      - » ***Highways Rc = 1/36***
      - » ***Taxiways Rc = 1/ 160***
      - » ***Runways Rc = 1/ 480***

Critical Review of "Failure Criteria"

- ***Flexible Pavement Fatigue Fracture***
  - ***Highways:***
    - *40% - 60% of Total Wheel Path Cracked*
  - ***Airfields***
    - *Same Criteria for Aprons, Taxiways and Runways ?*
    - *FOD Problem*
    - *Presenter is very unsure if he has ever seen a "failure distress criterion level" for Fatigue Cracking Level*
    - *Possible Criterion would logically be at Cumulative Fatigue Damage to be Dt=1.0 (Onset of cracking)*