Impact of site location and groundwater table depth on the thickness of flexible airfield pavements

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2012 Arizona Pavements/Materials Conference

Tempe, AZ - October 31st, 2012

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Agenda

- Intro
- Objective
- Analysis
- Results
- Summary and Conclusions
- Recommendations

part I: introduction

Environmental effects on pavement design and performance is a fundamental component of any Mechanistic-Empirical Pavement Design procedure.

However, current airfield design procedures do not consider the effects of groundwater table depth and the effect due to environmental conditions.

There is a significant need to incorporate the influence of environmental site factors and the groundwater table depth upon flexible airfield pavement design and performance.

A methodology and computer code has been developed at Arizona State University that allows for this analysis, including special considerations for **unsaturated regions**.

part II: objective

Provide a quantitative assessment of the potential benefits and savings in **pavement design thickness** that occur due to the inclusion of specific environmental site properties

Environmental site properties analyzed included **moisture, temperature** and **groundwater table depth**

The study focuses upon the prediction of pavement thickness to guard against excessive shear deformations or rutting for asphalt pavements.

Analysis is provided for a series of aircraft types, subgrade support values, different geographic locations across the US, and a range of GWT depths.

part III: the analysis

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ZAPMEDACA

Ramadan Salim

Mena Souliman

Daniel Rosenbalm

5 different climatic conditions

6 groundwater table depths

3 subgrade soils

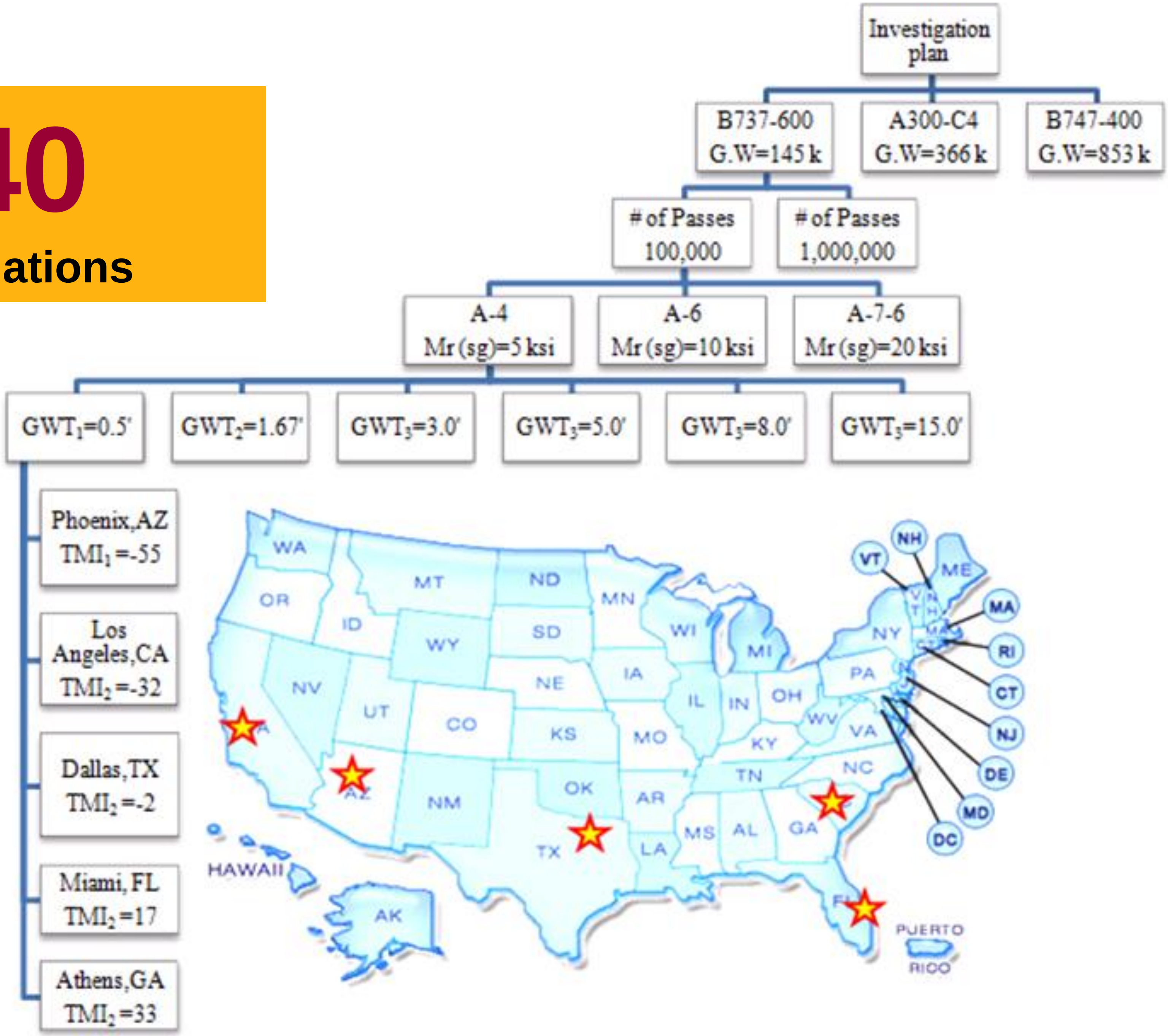
Experimental Matrix

2 levels of design traffic

3 aircraft types

540

simulations



Investigation plan

B737-600 G.W=145 k

A300-C4 G.W=366 k

B747-400 G.W=853 k

\# of Passes 100,000

\# of Passes 1,000,000

A-4 Mr (sg)=5 ksi

A-6 Mr (sg)=10 ksi

A-7-6 Mr (sg)=20 ksi

GWT_1=0.5'

GWT_2=1.67'

GWT_3=3.0'

GWT_3=5.0'

GWT_3=8.0'

GWT_3=15.0'

Phoenix,AZ TMI_1=-55

Los Angeles,CA TMI_2=-32

Dallas,TX TMI_2=-2

Miami, FL TMI_2=17

Athens,GA TMI_2=33

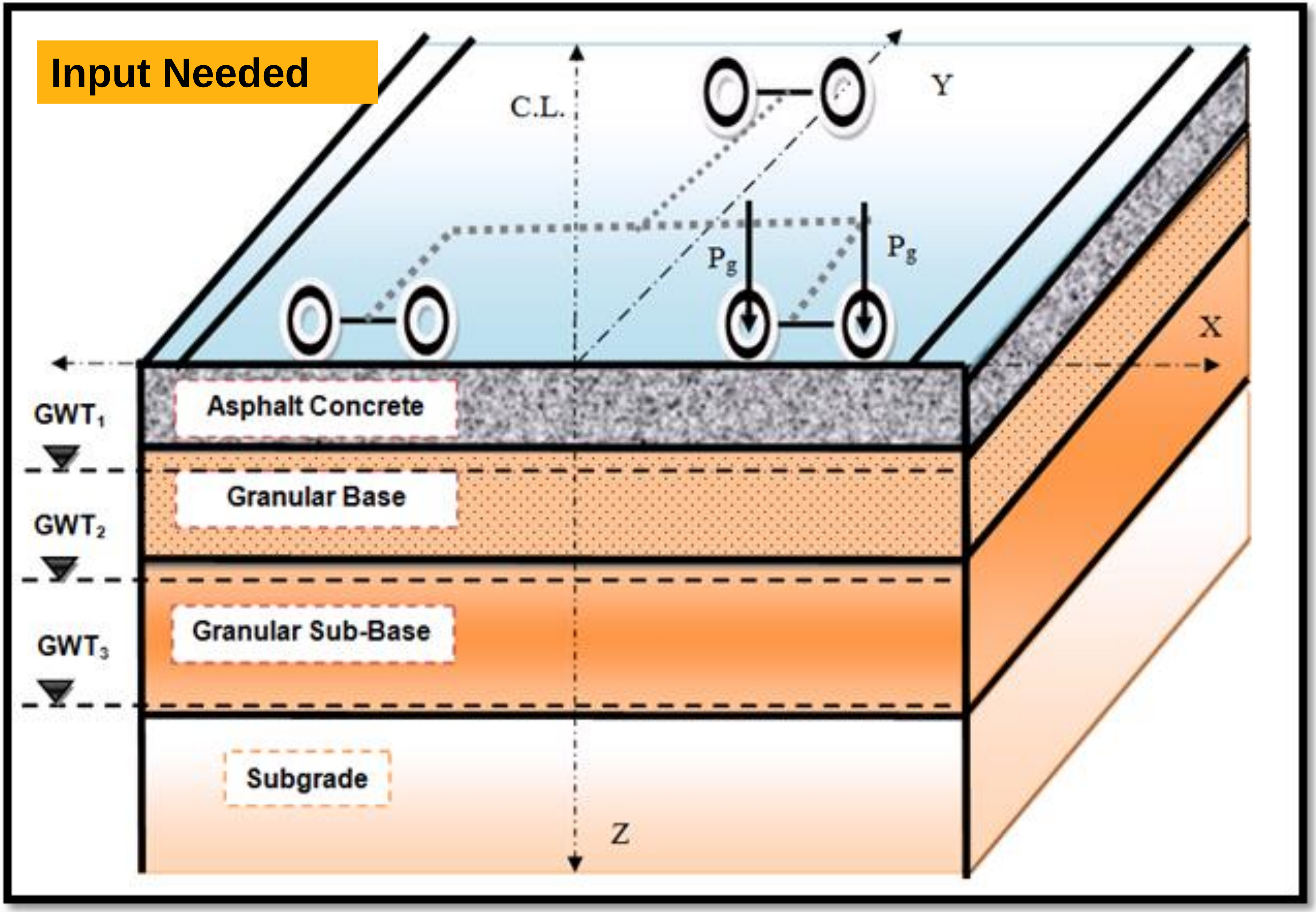
This study used the Limiting Subgrade Strain criteria developed for the newly revised USACE-β approach.

The Limiting Subgrade Strain criteria is a performance criteria applicable to design for excessive shear deformations (rutting) of the pavement.

The USACE limiting strain criteria is expressed as follows:

$$\log\left(\varepsilon_{v_{sg}}\right)=\frac{-2.1582-1.3723\log\left(N_f\right)}{1+0.4115\log\left(N_f\right)}$$

Input Needed

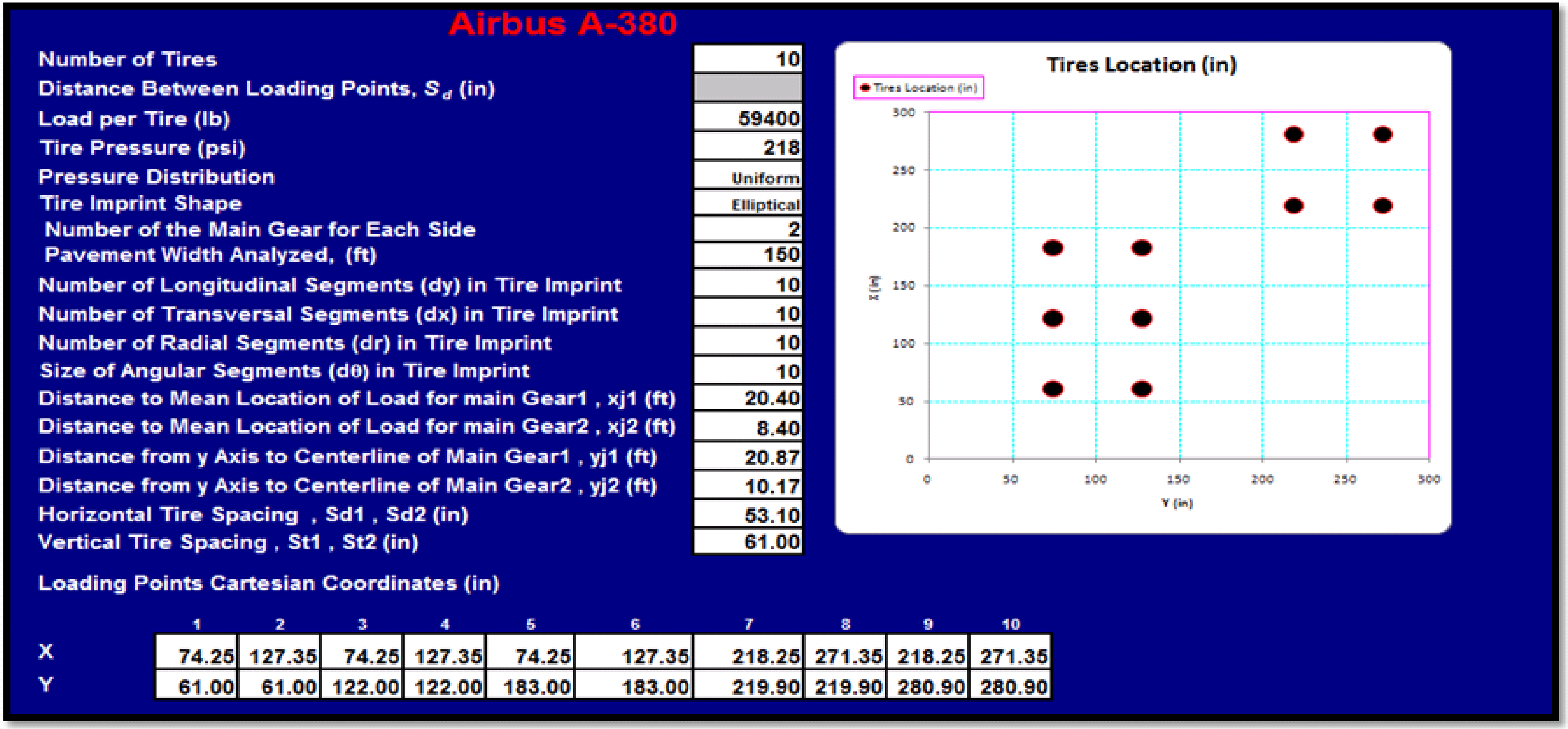


Material Properties and Structure

Layer Number	**1**	**2**	**3**	**4**		
Material Type	Asphalt	Base	Subbase	Subgrade		
Thickness (in)	6.0	14.0	**Variable**	Semi-Infinite		
Poisson Ratio	0.35	0.40	0.45	0.45		
Elastic Modulus (ksi)	300	38	32	20	10	5
AASHTO Classification	--	A-1-b	A-2-4	A-4	A-6	A-7-6
Passing #200 (%)	--	17	22	60	70	80
Plasticity Index , PI	--	1.5	4	6	14	28
Specific Gravity, G_s	--	2.65	2.68	2.68	2.69	2.68
w_{opt} %	--	8	14	12	15	20
$\gamma_{d\,max}$ (pcf)	--	130	115	119	114	102

ZAPMEDACA implementation modules

Load Configuration



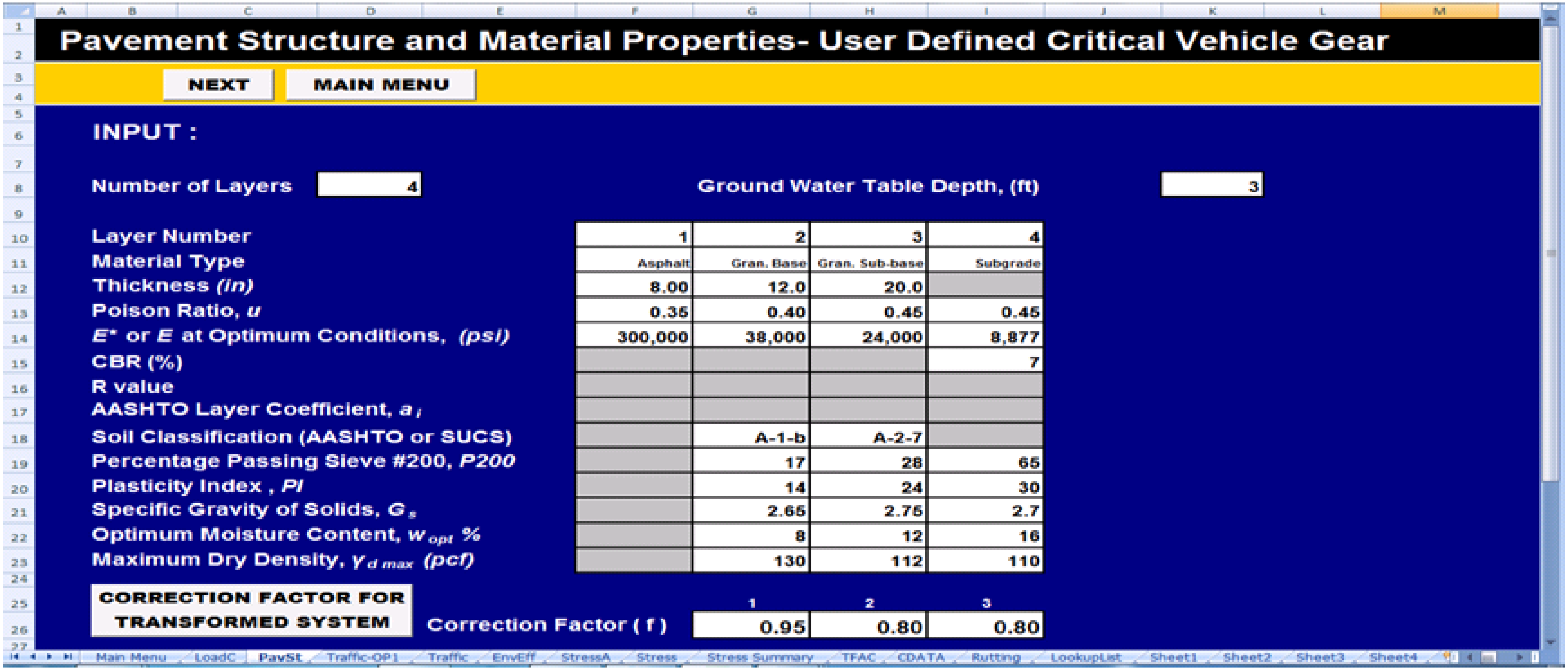
Airbus A-380

Number of Tires	10
Distance Between Loading Points, S_d (in)	
Load per Tire (lb)	59400
Tire Pressure (psi)	218
Pressure Distribution	Uniform
Tire Imprint Shape	Elliptical
Number of the Main Gear for Each Side	2
Pavement Width Analyzed, (ft)	150
Number of Longitudinal Segments (dy) in Tire Imprint	10
Number of Transversal Segments (dx) in Tire Imprint	10
Number of Radial Segments (dr) in Tire Imprint	10
Size of Angular Segments (dθ) in Tire Imprint	10
Distance to Mean Location of Load for main Gear1 , xj1 (ft)	20.40
Distance to Mean Location of Load for main Gear2 , xj2 (ft)	8.40
Distance from y Axis to Centerline of Main Gear1 , yj1 (ft)	20.87
Distance from y Axis to Centerline of Main Gear2 , yj2 (ft)	10.17
Horizontal Tire Spacing , Sd1 , Sd2 (in)	53.10
Vertical Tire Spacing , St1 , St2 (in)	61.00

Loading Points Cartesian Coordinates (in)

	1	2	3	4	5	6	7	8	9	10
X	74.25	127.35	74.25	127.35	74.25	127.35	218.25	271.35	218.25	271.35
Y	61.00	61.00	122.00	122.00	183.00	183.00	219.90	219.90	280.90	280.90

Pavement Structure and Material Properties



Pavement Structure and Material Properties- User Defined Critical Vehicle Gear

INPUT :

Number of Layers: 4

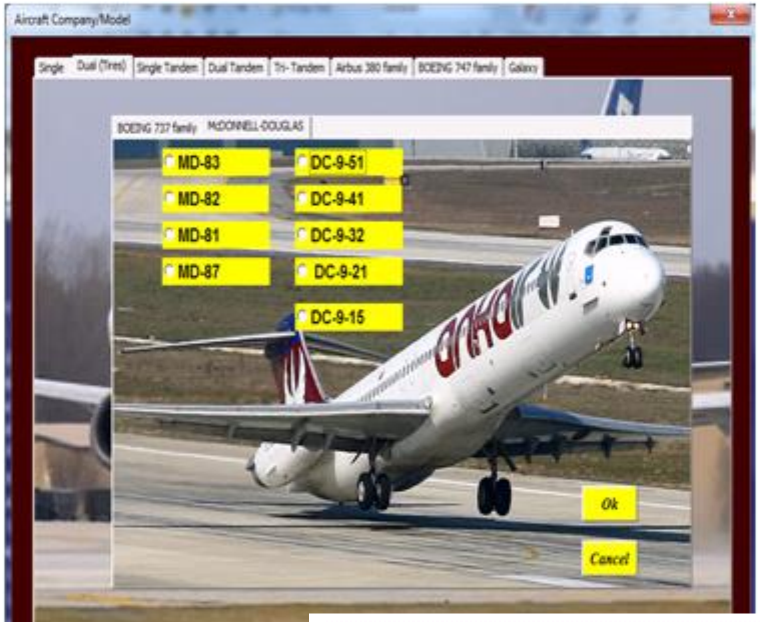
Ground Water Table Depth, (ft): 3

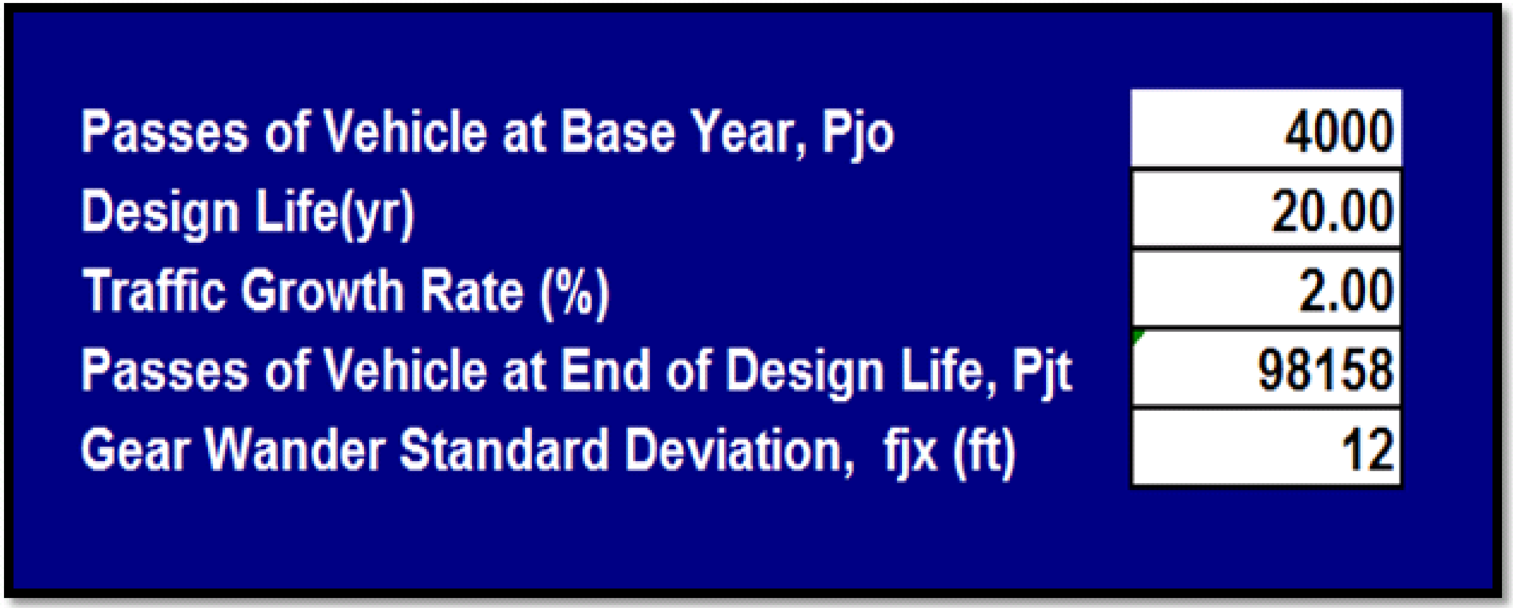
Layer Number	1	2	3	4
Material Type	Asphalt	Gran. Base	Gran. Sub-base	Subgrade
Thickness *(in)*	8.00	12.0	20.0	
Poison Ratio, *u*	0.35	0.40	0.45	0.45
*E** or *E* at Optimum Conditions, *(psi)*	300,000	38,000	24,000	8,877
CBR (%)				7
R value				
AASHTO Layer Coefficient, a_i				
Soil Classification (AASHTO or SUCS)		A-1-b	A-2-7	
Percentage Passing Sieve #200, *P200*		17	28	65
Plasticity Index , *PI*		14	24	30
Specific Gravity of Solids, G_s		2.65	2.75	2.7
Optimum Moisture Content, w_{opt} %		8	12	16
Maximum Dry Density, $\gamma_{d\ max}$ *(pcf)*		130	112	110

CORRECTION FACTOR FOR TRANSFORMED SYSTEM

	1	2	3
Correction Factor (f)	0.95	0.80	0.80

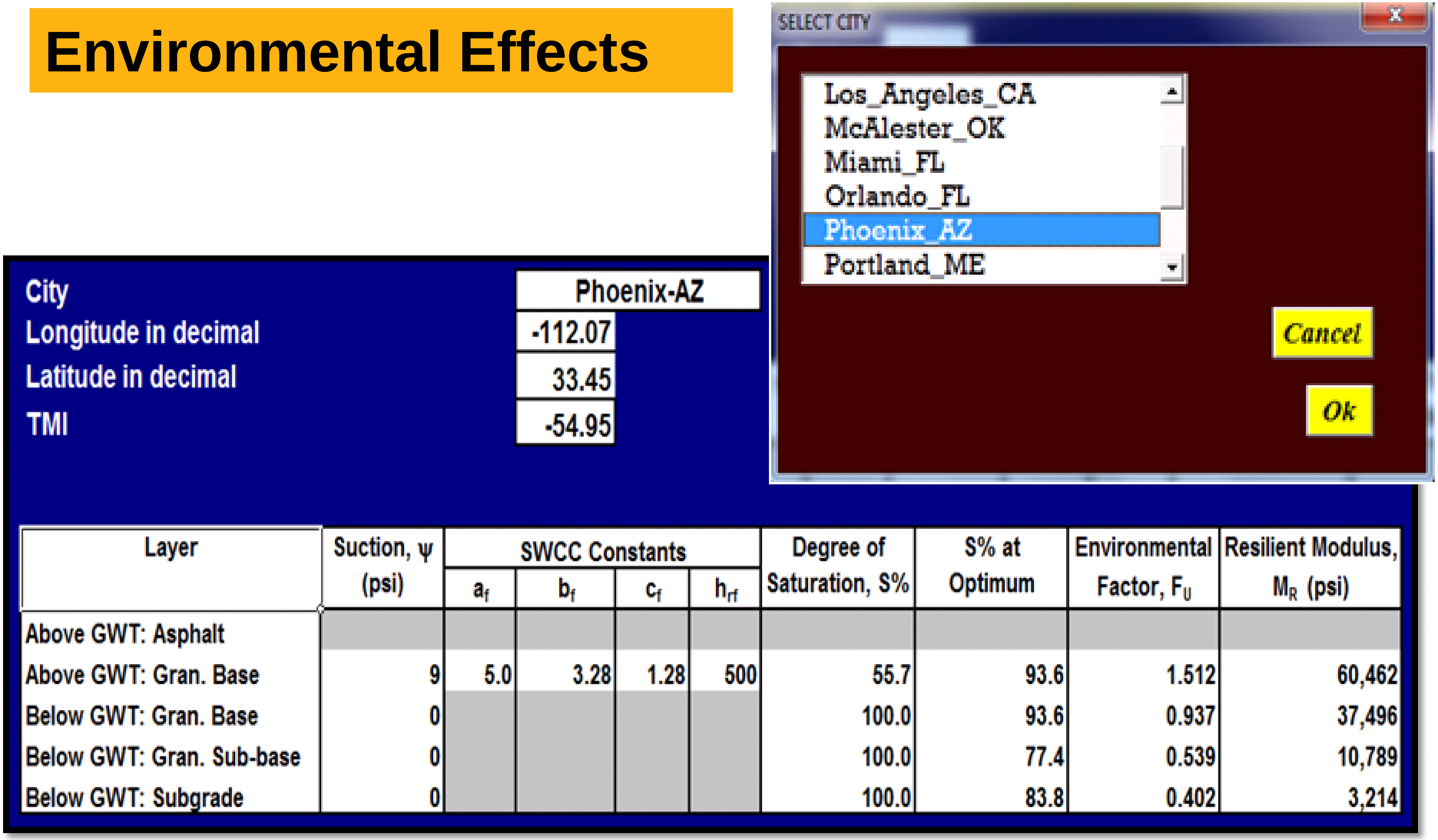
Traffic Input





Passes of Vehicle at Base Year, Pjo	4000
Design Life(yr)	20.00
Traffic Growth Rate (%)	2.00
Passes of Vehicle at End of Design Life, Pjt	98158
Gear Wander Standard Deviation, fjx (ft)	12

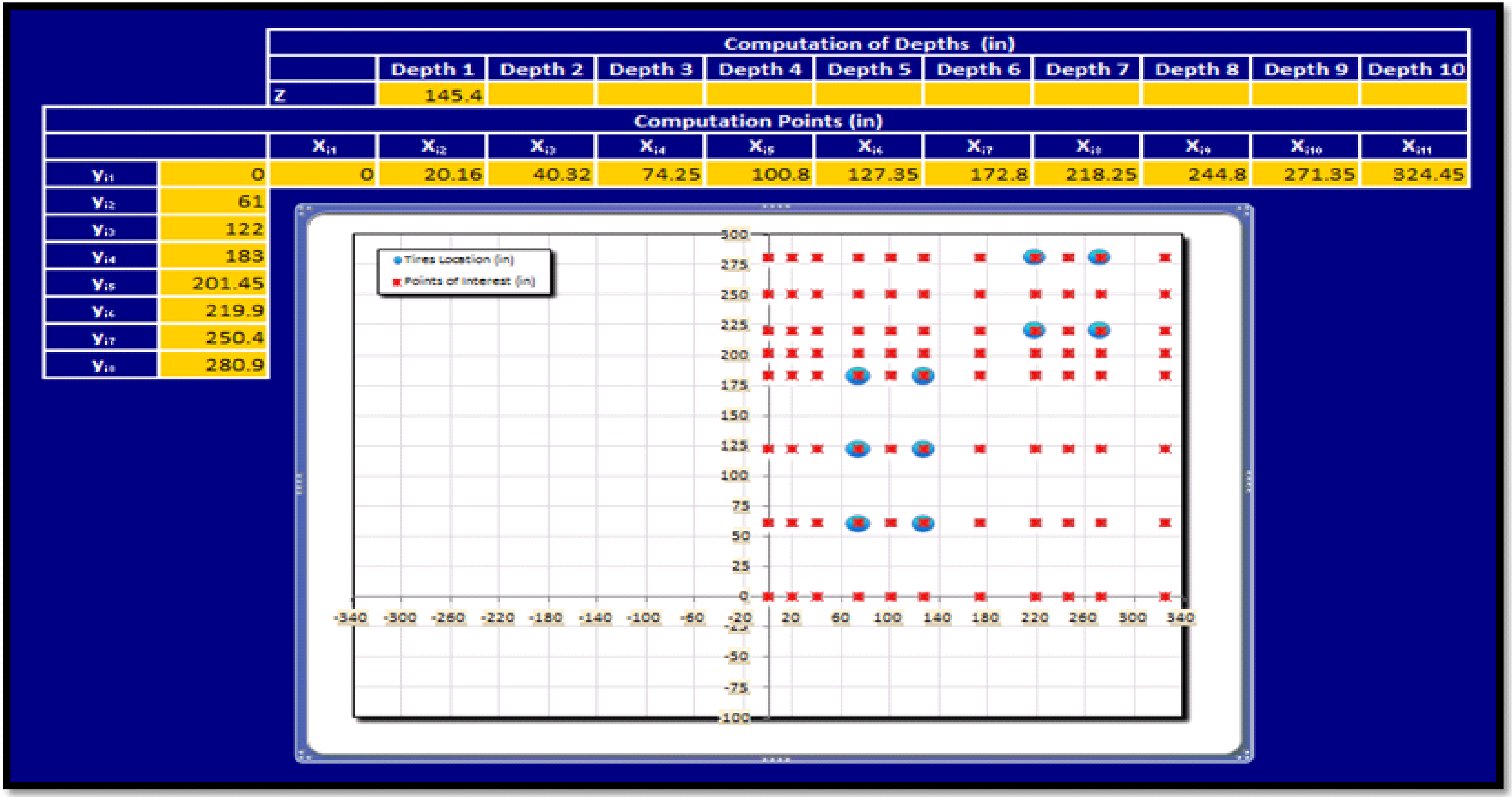
Environmental Effects



City: Phoenix-AZ
Longitude in decimal: -112.07
Latitude in decimal: 33.45
TMI: -54.95

Layer	Suction, ψ (psi)	SWCC Constants				Degree of Saturation, S%	S% at Optimum	Environmental Factor, F_U	Resilient Modulus, M_R (psi)
		a_f	b_f	c_f	h_{rf}				
Above GWT: Asphalt									
Above GWT: Gran. Base	9	5.0	3.28	1.28	500	55.7	93.6	1.512	60,462
Below GWT: Gran. Base	0					100.0	93.6	0.937	37,496
Below GWT: Gran. Sub-base	0					100.0	77.4	0.539	10,789
Below GWT: Subgrade	0					100.0	83.8	0.402	3,214

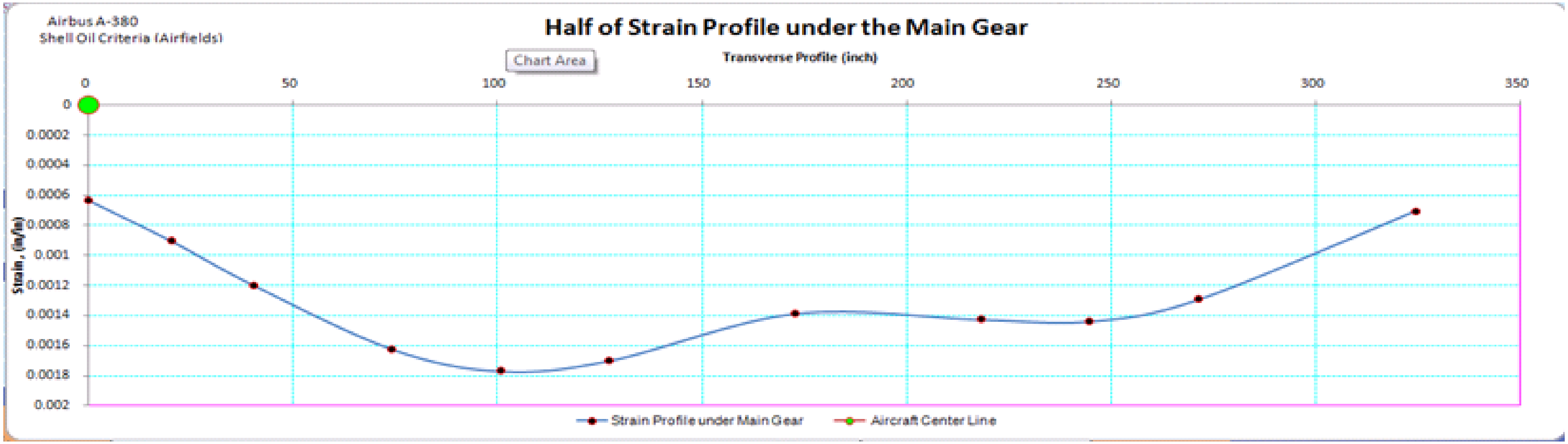
Stress Analysis



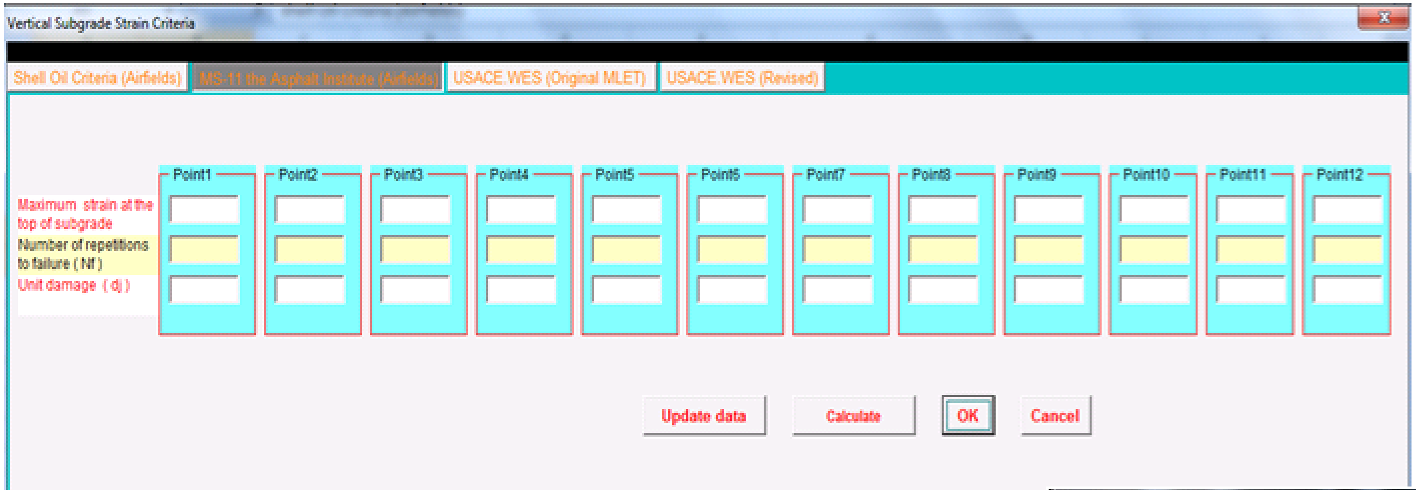
Computation of Depths (in)										
	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5	Depth 6	Depth 7	Depth 8	Depth 9	Depth 10
Z	145.4									

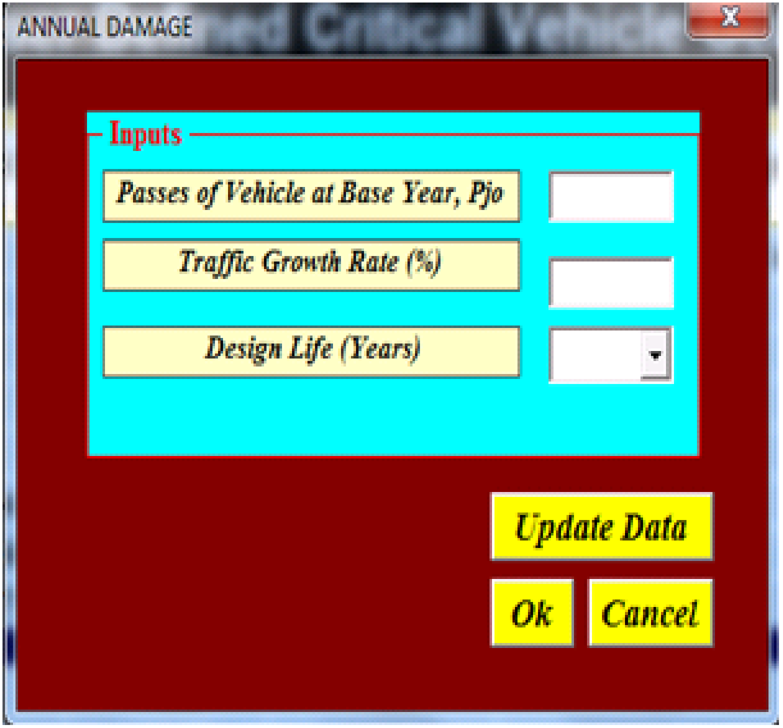
Computation Points (in)												
		x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	x_{i8}	x_{i9}	x_{i10}	x_{i11}
y_{i1}	0	0	20.16	40.32	74.25	100.8	127.35	172.8	218.25	244.8	271.35	324.45
y_{i2}	61											
y_{i3}	122											
y_{i4}	183											
y_{i5}	201.45											
y_{i6}	219.9											
y_{i7}	250.4											
y_{i8}	280.9											

Stress Analysis

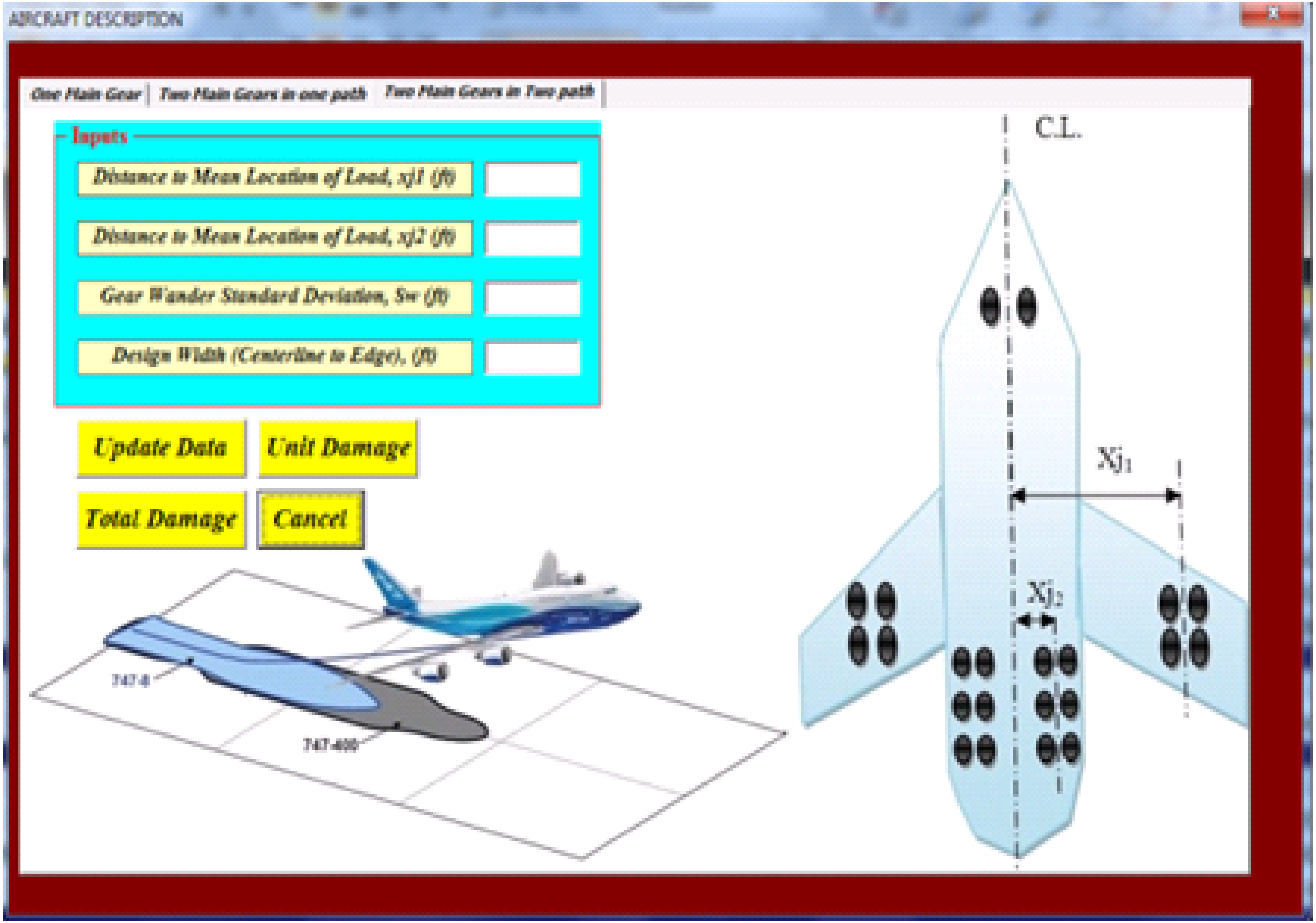


Rutting Design Criteria

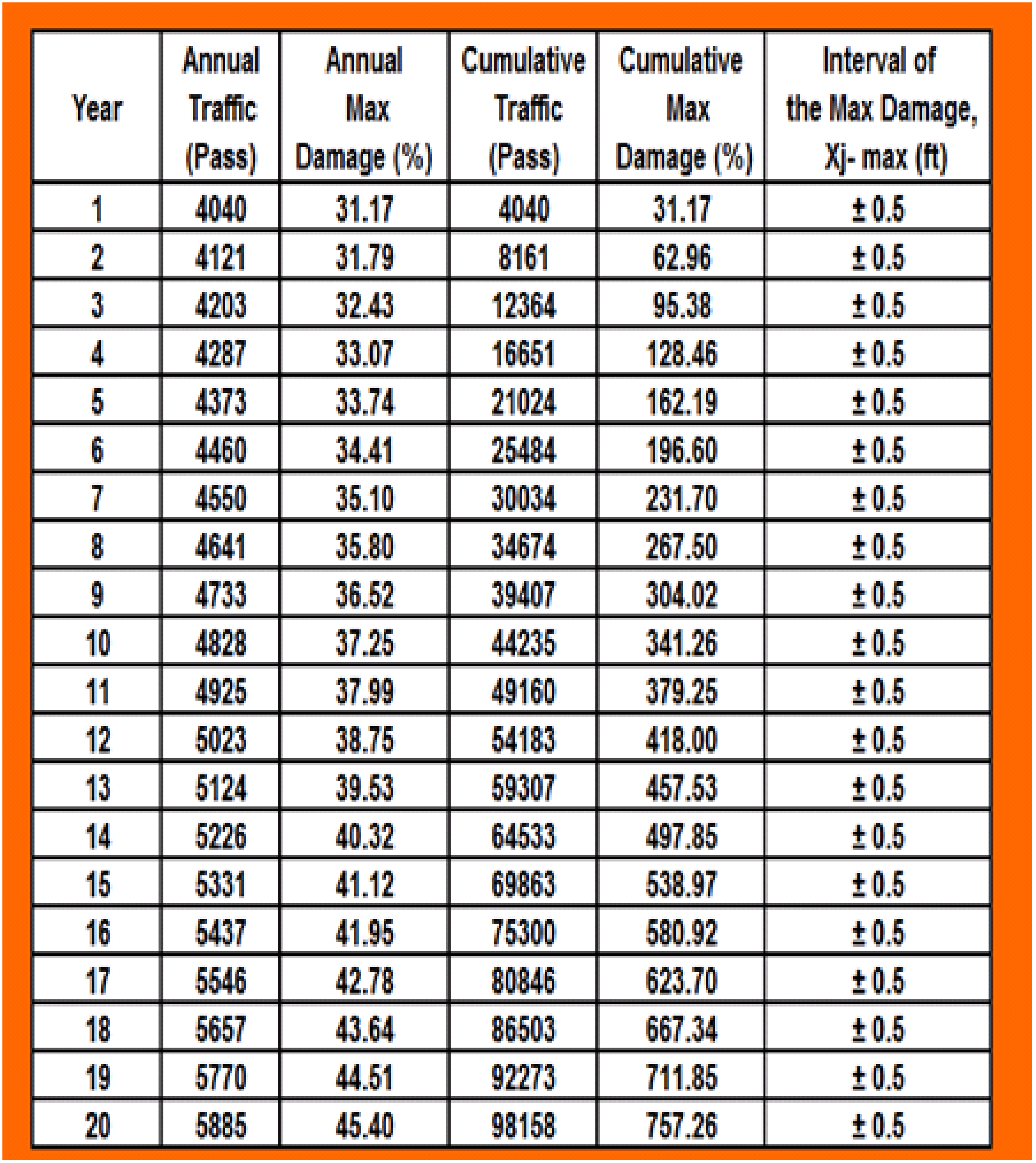




Rutting Design Criteria



Rutting Design Criteria



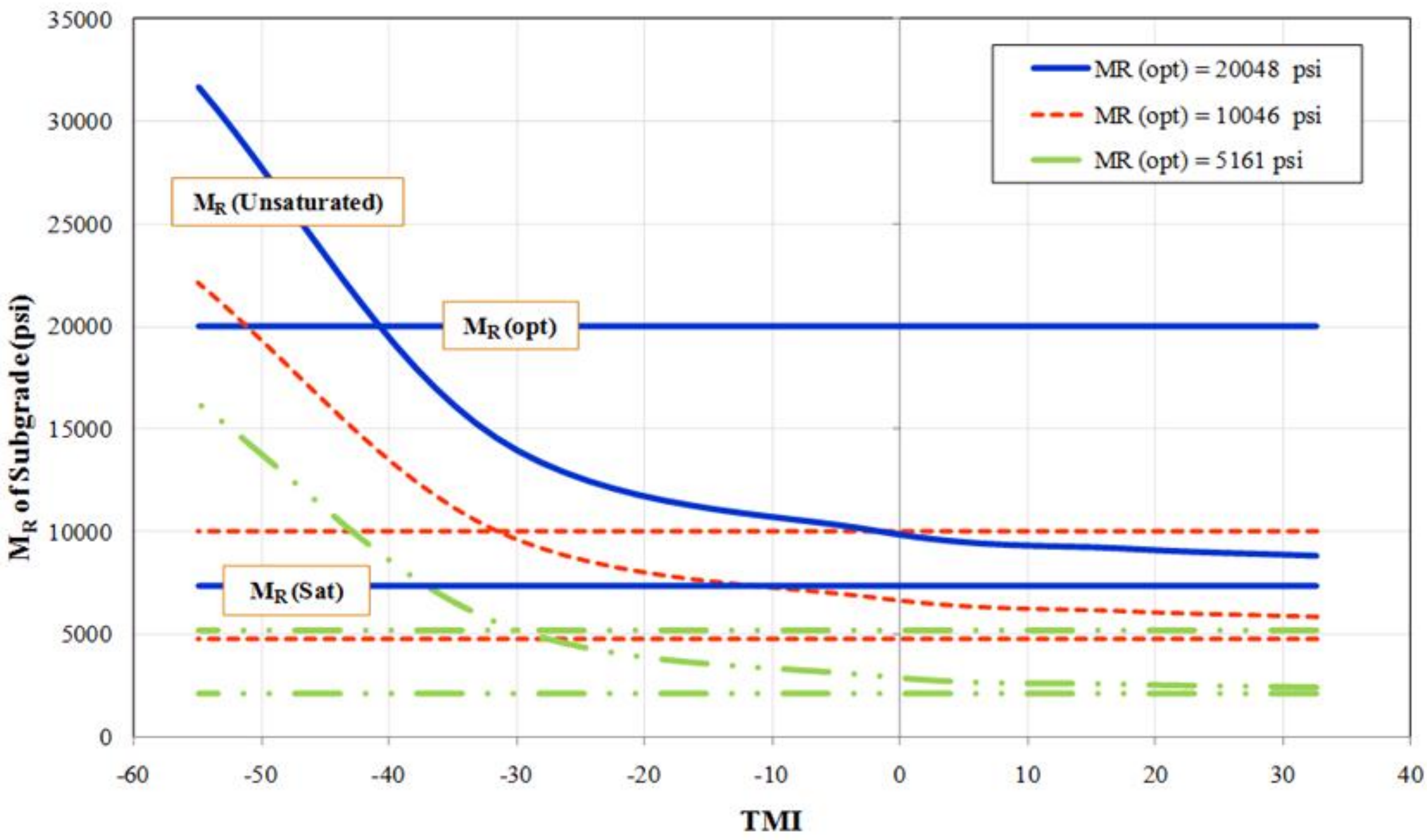
Year	Annual Traffic (Pass)	Annual Max Damage (%)	Cumulative Traffic (Pass)	Cumulative Max Damage (%)	Interval of the Max Damage, Xj- max (ft)
1	4040	31.17	4040	31.17	± 0.5
2	4121	31.79	8161	62.96	± 0.5
3	4203	32.43	12364	95.38	± 0.5
4	4287	33.07	16651	128.46	± 0.5
5	4373	33.74	21024	162.19	± 0.5
6	4460	34.41	25484	196.60	± 0.5
7	4550	35.10	30034	231.70	± 0.5
8	4641	35.80	34674	267.50	± 0.5
9	4733	36.52	39407	304.02	± 0.5
10	4828	37.25	44235	341.26	± 0.5
11	4925	37.99	49160	379.25	± 0.5
12	5023	38.75	54183	418.00	± 0.5
13	5124	39.53	59307	457.53	± 0.5
14	5226	40.32	64533	497.85	± 0.5
15	5331	41.12	69863	538.97	± 0.5
16	5437	41.95	75300	580.92	± 0.5
17	5546	42.78	80846	623.70	± 0.5
18	5657	43.64	86503	667.34	± 0.5
19	5770	44.51	92273	711.85	± 0.5
20	5885	45.40	98158	757.26	± 0.5

part IV: the results

Resulting **subgrade modulus** after considering the environmental effects for 5 cities

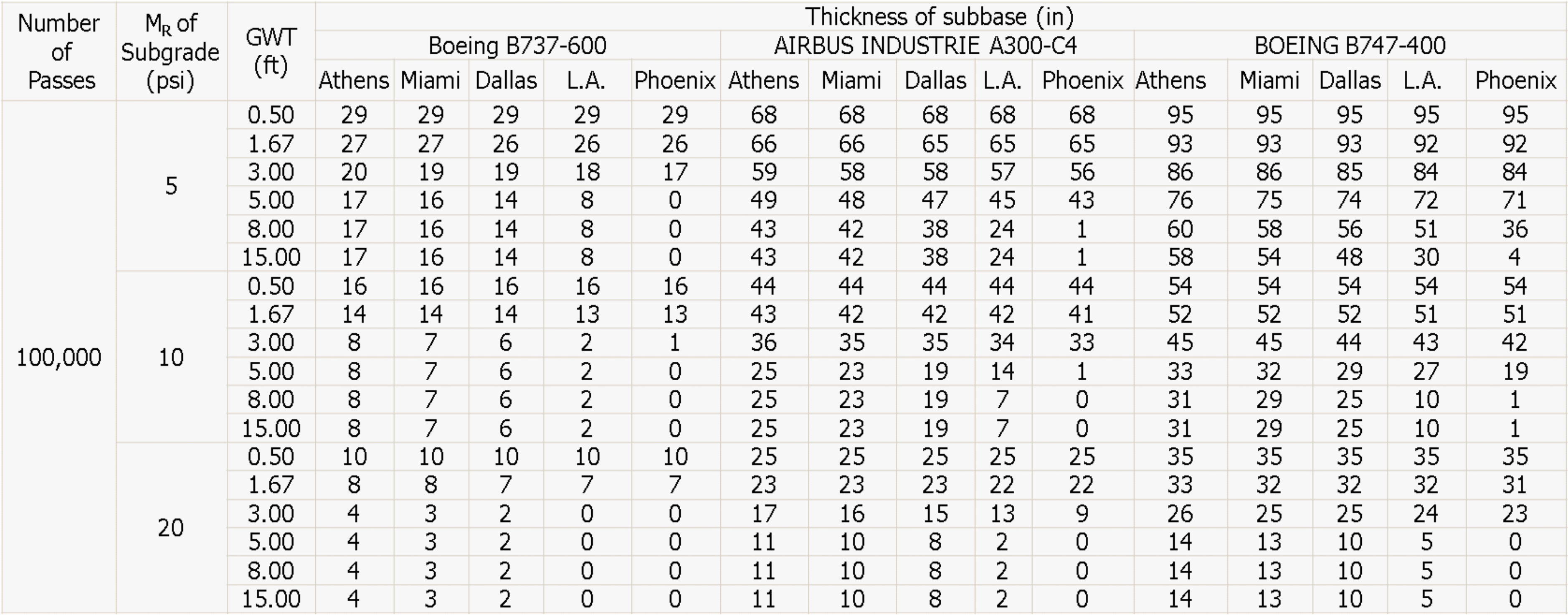
M_R (opt)	M_R (Sat)	M_R for Unsaturated Soil Conditions									
		Athens		Miami		Dallas		L.A.		Phoenix	
		S_r	M_R	S_r	M_R	S_r	M_R	S_r	M_R	S_r	M_R
5161	2073	97.2	2424	96.2	2575	93.6	2984	82.4	5593	60.4	16261
10046	4788	96.4	5834	95.5	6111	93.6	6763	86.1	10046	69.4	22174
20048	7384	96.4	8799	95.6	9158	93.8	10020	86.1	14544	69.0	31637

Resulting subgrade modulus after considering the environmental effects for 5 cities



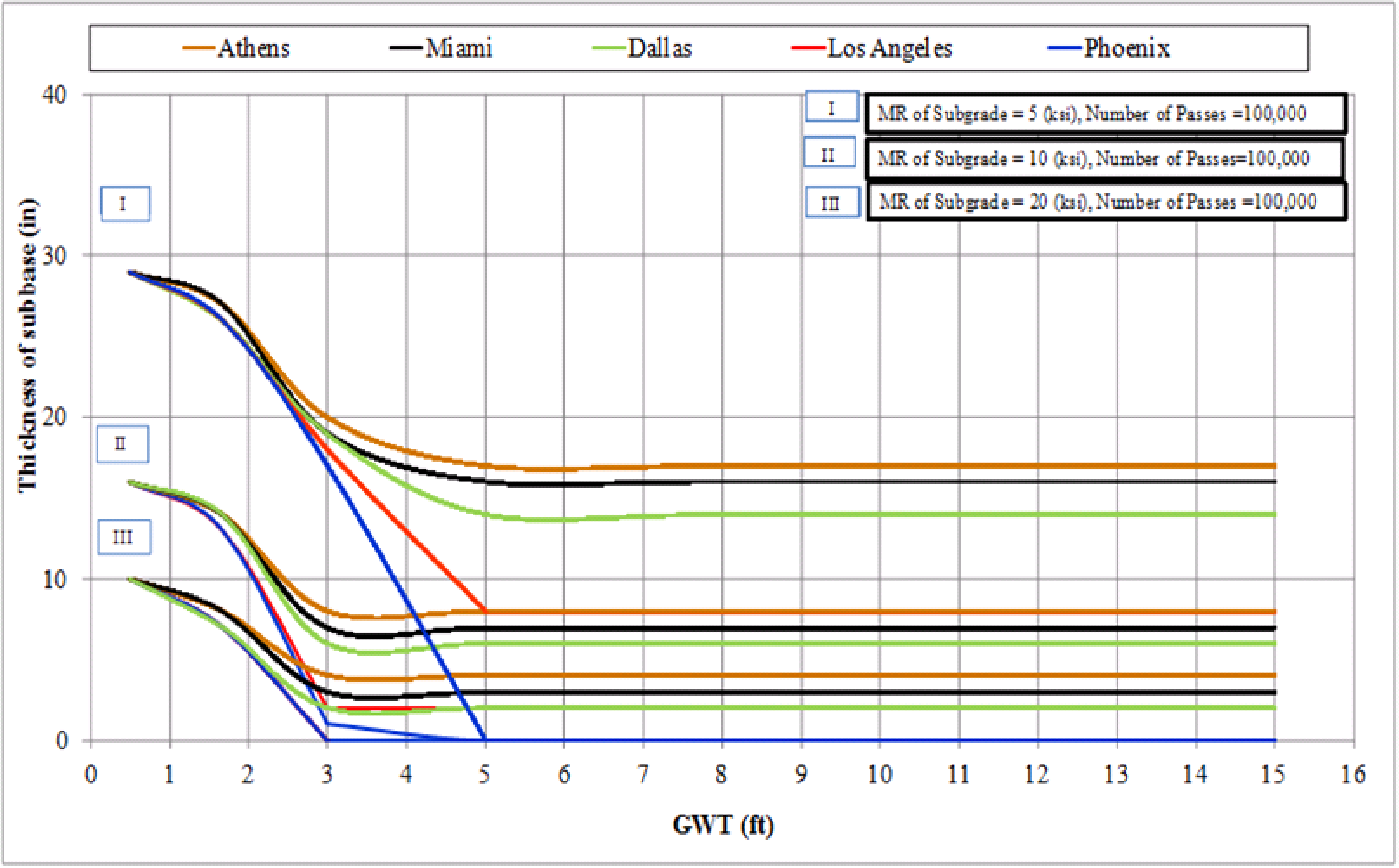
Cost savings are proportional to savings of subbase thickness

Subbase thickness (in) for selected aircrafts

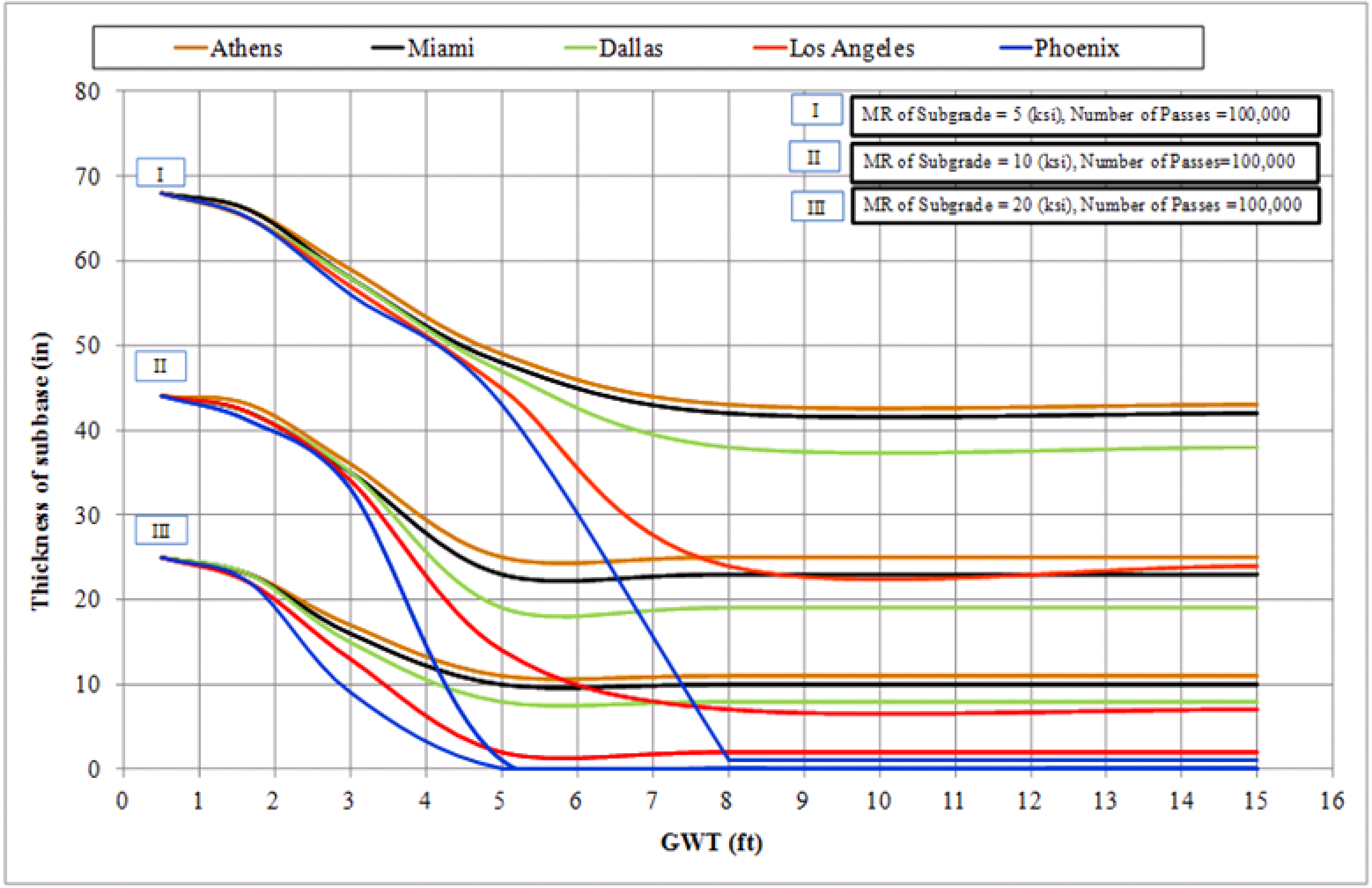


Number of Passes	M_R of Subgrade (psi)	GWT (ft)	Thickness of subbase (in)														
			Boeing B737-600					AIRBUS INDUSTRIE A300-C4					BOEING B747-400				
			Athens	Miami	Dallas	L.A.	Phoenix	Athens	Miami	Dallas	L.A.	Phoenix	Athens	Miami	Dallas	L.A.	Phoenix
100,000	5	0.50	29	29	29	29	29	68	68	68	68	68	95	95	95	95	95
		1.67	27	27	26	26	26	66	66	65	65	65	93	93	93	92	92
		3.00	20	19	19	18	17	59	58	58	57	56	86	86	85	84	84
		5.00	17	16	14	8	0	49	48	47	45	43	76	75	74	72	71
		8.00	17	16	14	8	0	43	42	38	24	1	60	58	56	51	36
		15.00	17	16	14	8	0	43	42	38	24	1	58	54	48	30	4
	10	0.50	16	16	16	16	16	44	44	44	44	44	54	54	54	54	54
		1.67	14	14	14	13	13	43	42	42	42	41	52	52	52	51	51
		3.00	8	7	6	2	1	36	35	35	34	33	45	45	44	43	42
		5.00	8	7	6	2	0	25	23	19	14	1	33	32	29	27	19
		8.00	8	7	6	2	0	25	23	19	7	0	31	29	25	10	1
		15.00	8	7	6	2	0	25	23	19	7	0	31	29	25	10	1
	20	0.50	10	10	10	10	10	25	25	25	25	25	35	35	35	35	35
		1.67	8	8	7	7	7	23	23	23	22	22	33	32	32	32	31
		3.00	4	3	2	0	0	17	16	15	13	9	26	25	25	24	23
		5.00	4	3	2	0	0	11	10	8	2	0	14	13	10	5	0
		8.00	4	3	2	0	0	11	10	8	2	0	14	13	10	5	0
		15.00	4	3	2	0	0	11	10	8	2	0	14	13	10	5	0

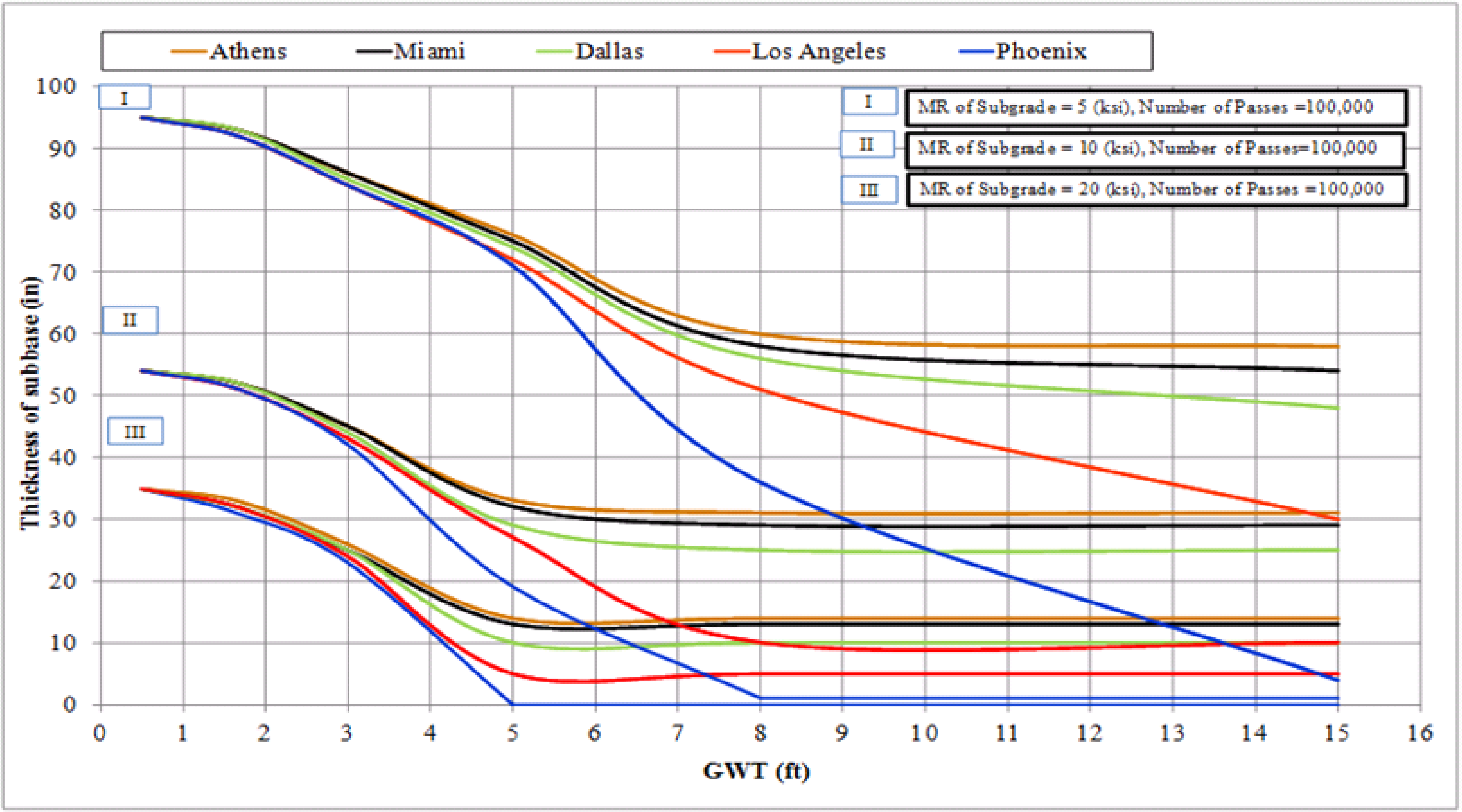
Required subbase thickness (in) for Boeing B737-600



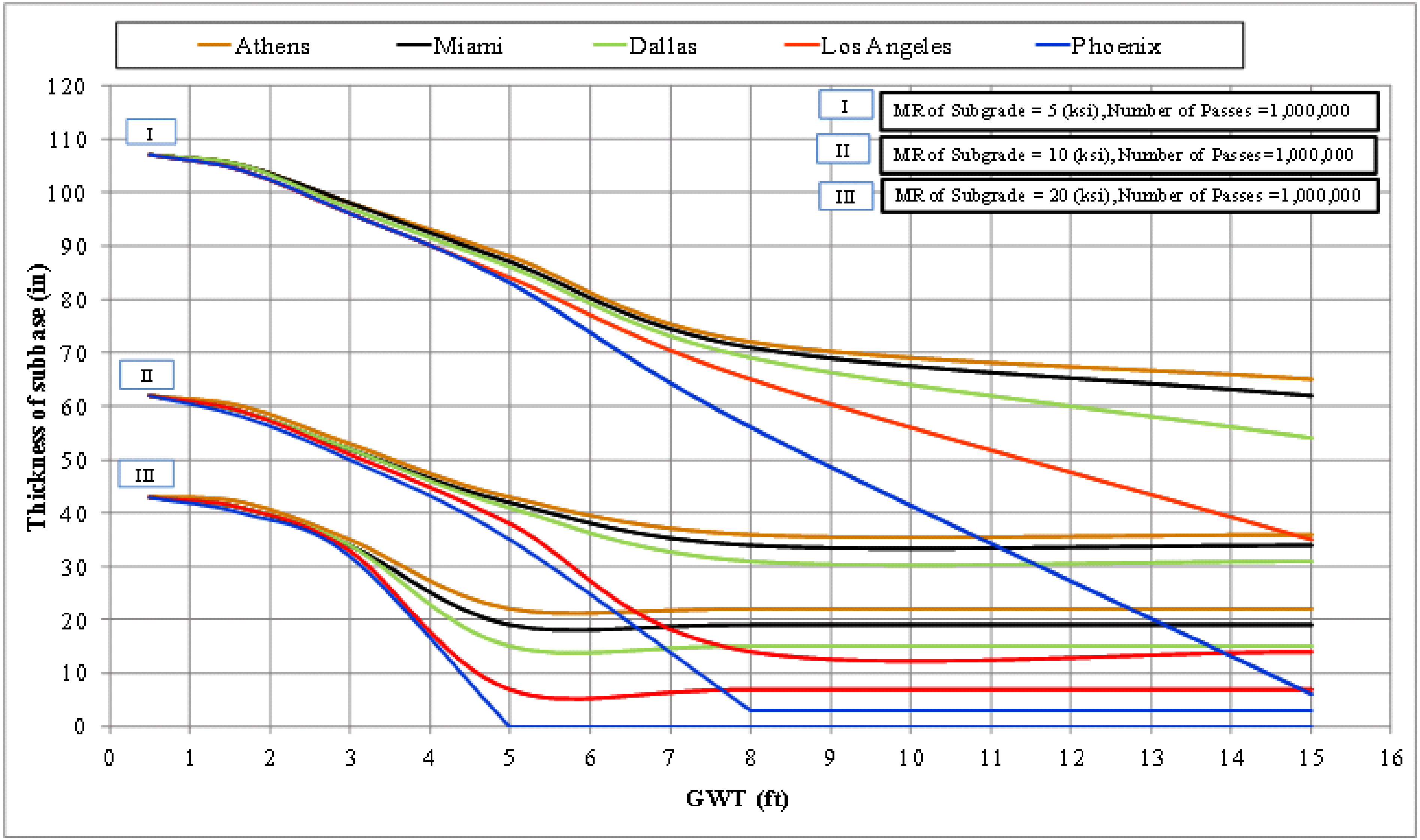
Required subbase thickness (in) for Airbus A300-C4



Required subbase thickness (in) for **Boeing B747-400**
N = 100,000



Required subbase thickness (in) for Boeing B747-400 N = 1'000,000



part V: summary and conclusions

ZAPMEDACA software/program is a powerful analytical tool that incorporates **environmental effects** in airfield design

This has not been accomplished by any other airfield pavement design procedure used in the world!!

Savings of subbase material up to 2.5 feet for lighter B-737 aircraft to as much as 3 to 8 feet for heavier B-747 aircraft may occur when unsaturated soil mechanics / environmental conditions are incorporated in the pavement design process.

Savings are obvious when design thicknesses are compared to those obtained with the classical assumption used in most pavement design methods that rely upon fully saturated evaluation of all unbound material layers.

Results generated from this study provide quantitative evidence of the significant savings that may be accrued in the design, construction and rehabilitation of airfield pavements by using unsaturated soil mechanics principles in the design methodologies

part VI:
recommendations

Several major additions need to be made to enhance ZAPMEDACA to consider a wider range of computational improvements, additional distress types and real time environmental model changes in unbound layers for flexible airfield pavement systems

Controlled full-scale field tests to validate the results of ZAPMEDACA analysis are necessary and highly recommended

Major US and International airfield pavement design agencies responsible for airfield operation should carefully re-evaluate the current state of the practice and move to incorporate more precise and rational theories and methodologies

The authors would like to acknowledge the general guidance, valuable input and recommendations given by Professor **Matthew Witczak**

part VII:
acknowledgments

part VIII: thanks!