AUBURN

SAMUEL GINN
COLLEGE OF ENGINEERING

Final Report
ALDOT Project 930-792

INTRODUCTION TO MECHANISTIC-EMPIRICAL (M-E) DESIGN SHORT COURSE

Prepared by

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www.eng.auburn.edu/research/centers/hrc.html

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1.0 BACKGROUND AND PROBLEM STATEMENT

The Mechanistic-Empirical Pavement Design Guide (MEPDG) that will become the new AASHTO design standard for flexible and rigid pavement design represents a significant shift in design philosophy and complexity over existing procedures. As state agencies look toward full implementation of the new design system, there are a number of critical needs that must be addressed. In an earlier research study (Timm et al., 2010) for the Alabama Department of Transportation (ALDOT), five key areas were identified for implementation of the MEPDG. The areas were:

1. Training in the MEPDG.
2. Executing parallel designs using the existing and new methodologies.
3. Development of a material reference library for MEPDG.
4. Development of monthly, vehicle class, and axle load distributions.
5. Local calibration.

While each of these areas is critical to successful implementation, training was identified as an important first step to help transition between the existing methodology (AASHTO 1993 Design Guide) and the MEPDG. It was originally conceived that training would focus on the MEPDG program itself. However, the full AASHTO Ware version (DARWin-ME V2.0,) was not expected to be available until April 2011. In the meantime, it was important to begin the transition process by providing training to pavement design engineers in the new design philosophy. This is critical since it is expected that DARWin-ME V2.0 will be very much a "black box." This is certainly the case for the existing form of the software (MEPDG V1.0). Though a "black box" is needed to expedite design on a day-to-day basis, it is critical that pavement designers fully understand the new design approach, its capabilities and limitations. This will lead to a much better understanding and more efficient use of the new design system once it is released. To that end, it was proposed that a "Introduction to M-E Design" short course be developed and delivered to ALDOT.

2.0 OBJECTIVES AND SCOPE OF WORK

The objective of this project was to develop a short course that covers fundamentals of M-E design. The course presented the generic M-E design framework, provided technical information relating to each component of the framework and featured hands-on applications in working with relevant computer programs and data sets.

3.0 COURSE DESIGN

The course was designed to cover a broad spectrum of topics relevant to M-E design. Discussions with ALDOT concluded in planning for eight hours of classroom instruction. Table 1 provides the course overview. The full set of course notes, developed in PowerPoint format and provided to each participant as a spiral-bound notebook, are provided in Appendix A of this report. It should be emphasized that a number of hands-on computer activities were included in this course. These included using pavement design software (WESLEA, KENSLABs and MEPDG) in addition to web-based applications (Alabama Traffic Data GIS website) and Excel. Additional instructors were present during the hands-on activities to facilitate interaction with the computer programs by participants.

TABLE 1. M-E Design Course Modules

Module	Hours	Topics
1 – Current State of Practice	0.5	Current AASHTO Method Current ALDOT Procedures Limitations of Current Procedures
2 – M-E Design Overview	0.5	Advantages Framework and Key Components Overview of Existing Procedures
3 – Stresses in Pavements	2	General Theory Flexible – WESLEA (computer activity) Rigid – KENSLABs (computer activity)
4 – Material Characterization	1	Soil and Unbound Materials HMA PCC
5 – Traffic Characterization	1	Load Spectra Data Sources and Data Handling ALDOT Traffic (computer activity)
6 – Transfer Function and Damage Accumulation	1	Role of Transfer Functions in M-E Miner's Hypothesis Common Transfer Functions Need for Local Calibration Local Calibration Procedures
7 – Introduction to the MEPDG	2	MEPDG Software and Examples (computer activity)

4.0 COURSE DELIVERY AND REVIEW

Based upon mutual agreement, the course was held in the Auburn University *Brasfield and Gorrie* classroom (Figure 1) in Harbert Engineering Center on December 2-3, 2010. There were 32 course participants. These included staff members from the ALDOT Materials and Tests Bureau, Construction Bureau, Maintenance Bureau, Traffic Management, Research and Development Bureau and engineers from each of the nine ALDOT divisions. Additionally, two representatives from the asphalt and concrete industry attended.

At the conclusion of the course, participants completed a review form. The results are summarized in Figure 2 while a copy of the form is provided in Appendix B. Based on the average scores, it appears that the educational objectives of the course were met. The two lowest scores were obtained in the areas of understanding the material and how it applies to their work. It is not surprising these scores would be lower as this was the first offering of this introductory course. Better understanding and application will come with further exposure to M-E design. Future training opportunities using the DARWin-ME program that focuses on ALDOT policies toward using this software should reinforce the foundational understanding developed by this course. Though these scores were the lowest, they were on average above the "neutral" rating. The remaining average scores were all between "agree" and "strongly agree".

Participants were also given the opportunity to provide written feedback on the course evaluation form. Comments regarding course duration were common. It was suggested that it be extended to perhaps a 12 or 16 hour course. Additional commentary pertained to providing future training once DARWin-ME is released and perhaps providing module-specific training (i.e., traffic, materials, design, etc.)

Figure 1 MEPDG Short Course in Brasfield and Gorrie Classroom.

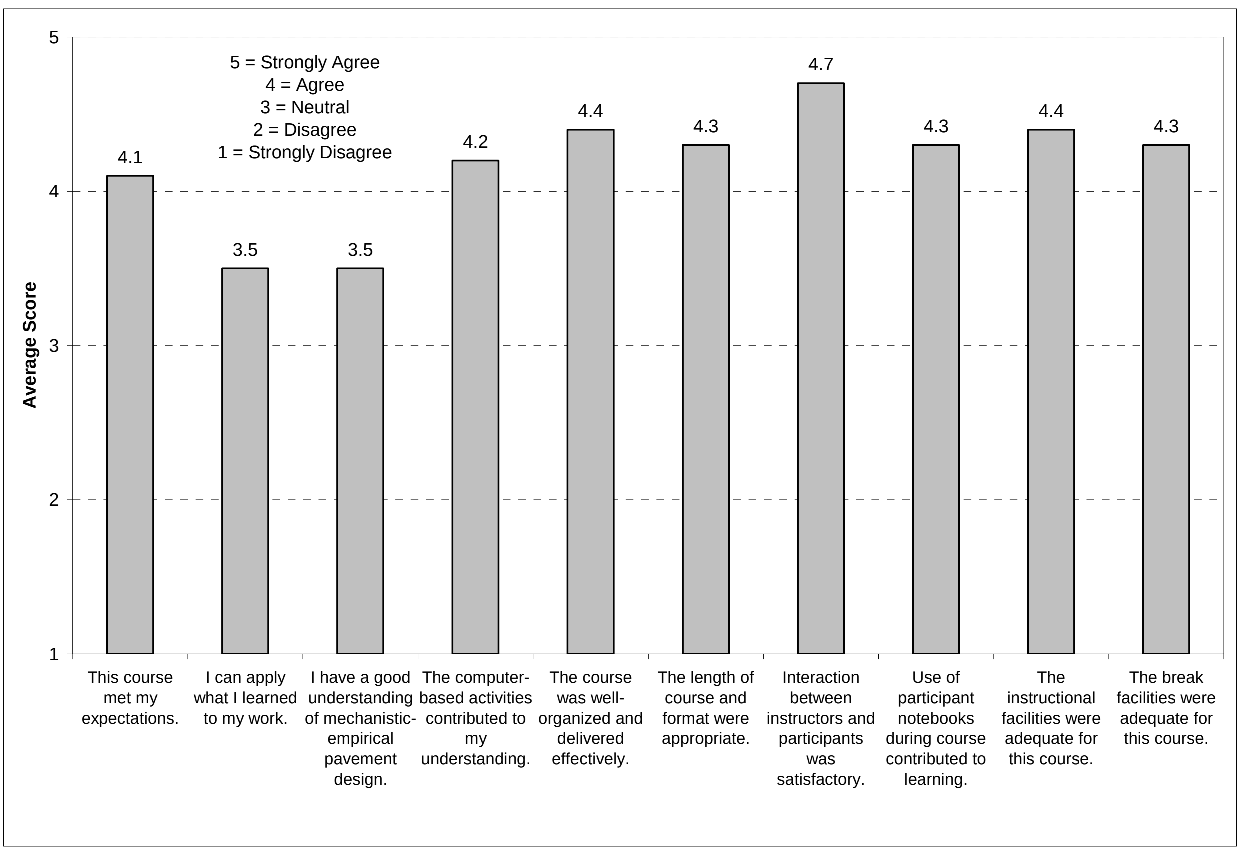


FIGURE 2 Course Review Summary Scores.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based upon feedback received from course participants, the educational objectives of this M-E short course were achieved. It is recommended that future offerings be extended to a 1.5 day format. These offerings could be managed through the Auburn University T^2 center with attendance open to ALDOT, consultants and contractors. Future courses should be developed, in cooperation with ALDOT, related to DARWin-ME when it becomes available. These may be module-specific courses, or comprehensive training in the entire computer program.

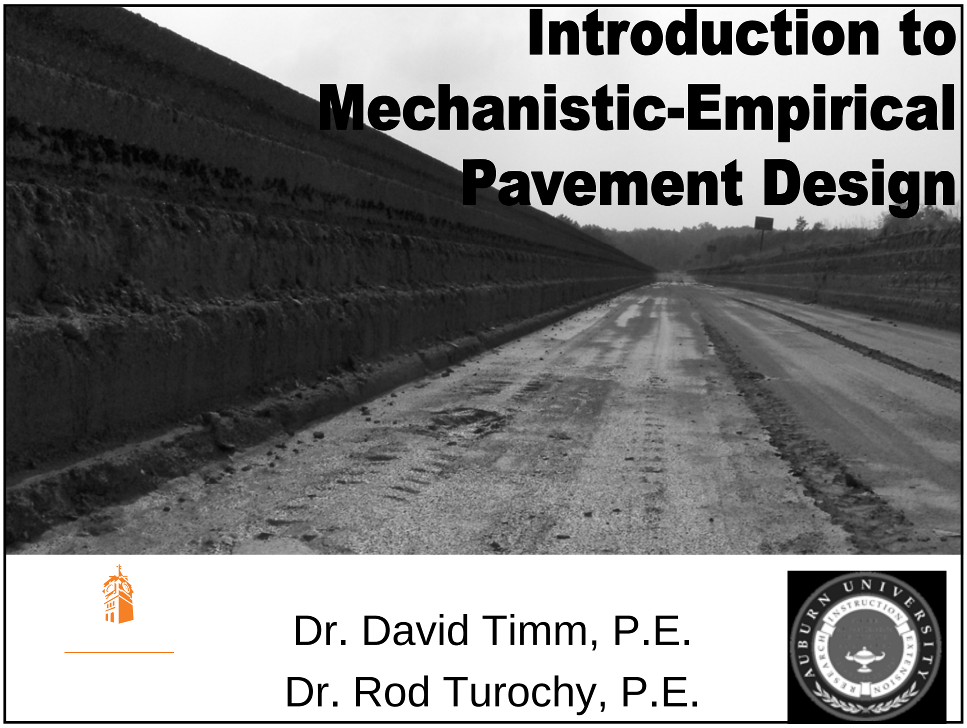
ACKNOWLEDGEMENTS

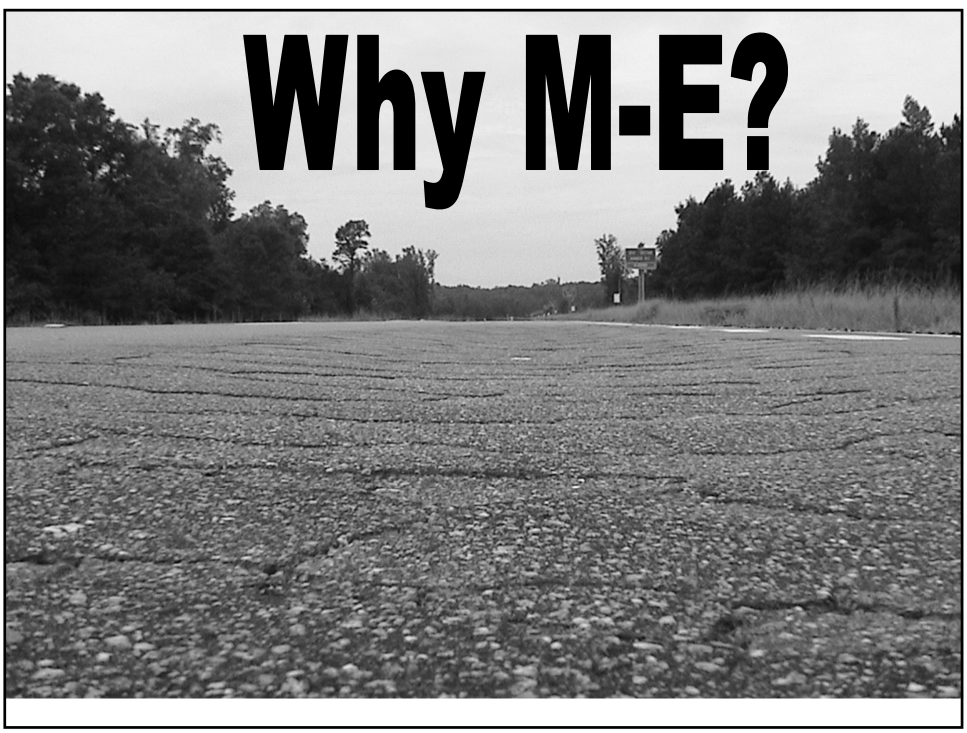
The authors wish to thank the Alabama Department of Transportation for their support and participation in the M-E short course.

REFERENCES

Timm, D.H., R.E. Turochy and K.P. Davis, "Guidance for M-E Pavement Design Implementation," Final Report, ALDOT Project 930-685, Highway Research Center, Auburn University, 2010.

APPENDIX A – PARTICIPANT NOTEBOOK MATERIALS

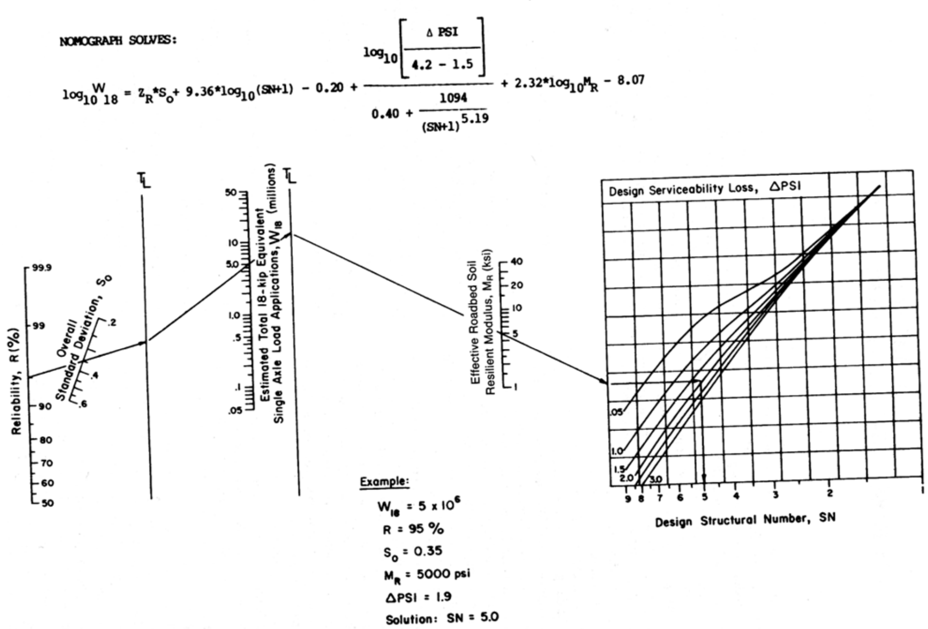

Introduction to
Mechanistic-Empirical
Pavement Design
Dr. David Timm, P.E.
Dr. Rod Turochy, P.E.
AUBURN UNIVERSITY
INSTRUCTION
RESEARCH
EXTENSION


Why M-E?

Current Flexible Pavement Design Method

$$\log W_{18} = Z_R S_0 + 9.36\log(SN+1) - 0.20 + \frac{\log\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.4+\frac{1094}{(SN+1)^{5.19}}} + 2.32\log M_R - 8.07$$

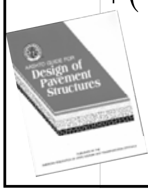
Flexible Design Equation



Current Rigid Pavement Design Method

$$\log W_{18} = Z_R S_o + 7.35\log(D+1) - 0.06 + \left(\frac{\log\left[\frac{\Delta PSI}{4.5-1.5}\right]}{1+\frac{1.624\times 10^{7}}{(D+1)^{8.46}}} \right)$$

$$+ (4.22 - 0.32\,p_t)\log\left[\frac{S_c C_d \left(D^{0.75} - 1.132\right)}{215.63\left[\frac{D^{0.75} - 18.42}{\left(\frac{E_c}{k}\right)^{0.25}}\right]} \right]$$



Current Method Based on AASHO Road Test

HRB, 1962 **Figure 1. Looking east, Loops 5 and 2 in foreground.**

Figure 16. Embankment construction, loop 1, using rotary speed mixers to process and adjust moisture content of soil. Area in foreground is long transition between construction blocks where turning movements of equipment were made. Note step-over pattern used by rollers.

HRB, 1962

Figure 92. Automatic batch-type plant used to produce binder course mixture; dryers in tandem.

HRB, 1962

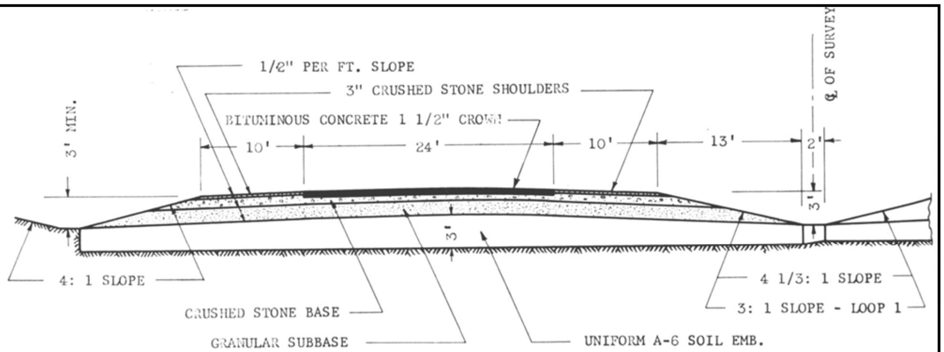


Figure 30. Typical flexible pavement cross-section in test tangents.

HRB, 1962

TABLE 6

DETAILS OF BITUMINOUS SURFACING

Surfacing Thickness (in.)	Binder Course (in.)	Surface Course (in.)
1	0	1
2	0	2
3	1½	1½
4	1¼, 1¼	1½
5	2, 1½	1½
6	1½, 1½, 1½	1½

Max Thickness
6 inches

AASHO Rigid Pavements

- Concrete Mix Design
  - 564 lb/yd^3
  - 0.47 w/c ratio

Parameter	Maximum Aggregate Size	
	1.5 inch	2.5 inch
Mean slump (inches)	2.7	2.5
Mean air content (%)	4.2	3.7
Mean cement content	571	572

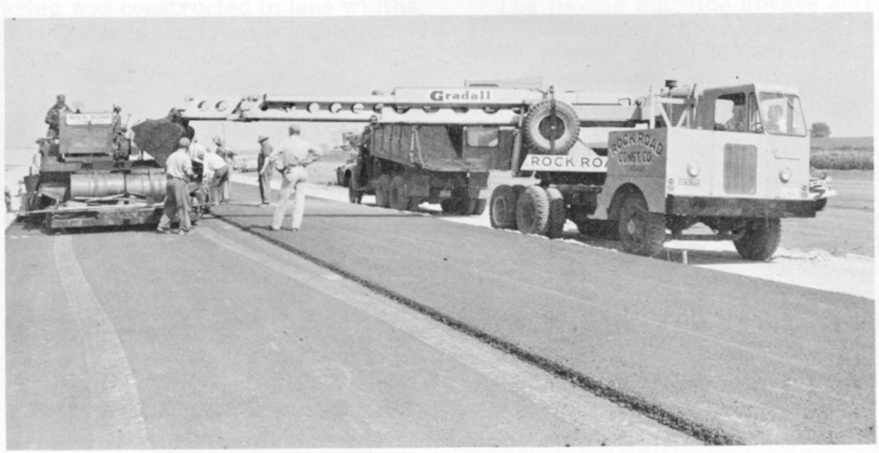
http://training.ce.washington.edu/wsdot/

Age	Maximum Aggregate Size			
	1.5 inch		2.5 inch	
	Compressive Strength (psi)	Flexural Strength (psi)	Compressive Strength (psi)	Flexural Strength (psi)
3 days	2860	550	2670	510
7 days	3780	630	3560	620
14 days	4004	668	3966	636
21 days	4250	710	4130	660
1 year	5990	880	5580	790
2 years	6155	873	5818	787

AASHO Rigid Pavements

- Jointed Plain and Jointed Reinforced
- 15 ft joint spacing
- With Dowels

Loop No.	PCC Slab Thickness (in.)	Subbase Thickness (in.)	Transverse Dowel Bars (Diameter x Length)
1	2.5	0, 6.0	3/8" x 12"
	5.0	0, 6.0	5/8" x 12"
	9.5	0, 6.0	1 1/4" x 18"
	12.5	0, 6.0	1 5/8" x 18"
2	2.5	0, 3.0, 6.0	3/8" x 12"
	3.5	0, 3.0, 6.0	1/2" x 12"
	5.0	0, 3.0, 6.0	5/8" x 12"
3	3.5	3.0, 6.0, 9.0	1/2" x 12"
	5.0	3.0, 6.0, 9.0	5/8" x 12"
	6.5	3.0, 6.0, 9.0	7/8" x 18"
	8.0	3.0, 6.0, 9.0	1" x 18"
4	5.0	3.0, 6.0, 9.0	5/8" x 12"
	6.5	3.0, 6.0, 9.0	7/8" x 18"
	8.0	3.0, 6.0, 9.0	1" x 18"
	9.5	3.0, 6.0, 9.0	1 1/4" x 18"
5	6.5	3.0, 6.0, 9.0	7/8" x 18"
	8.0	3.0, 6.0, 9.0	1" x 18"
	9.5	3.0, 6.0, 9.0	1 1/4" x 18"
	11.0	3.0, 6.0, 9.0	1 3/8" x 18"
6	8.0	3.0, 6.0, 9.0	1" x 18"
	9.5	3.0, 6.0, 9.0	1 1/4" x 18"
	11.0	3.0, 6.0, 9.0	1 3/8" x 18"
	12.5	3.0, 6.0, 9.0	1 5/8" x 18"



HRB, 1962 **Figure 95. Depositing mixture in paver from outside shoulder.**

HRB, 1962 **Figure 108. Placing straw for curing concrete.**

Figure 23. Test vehicles, showing typical axle arrangements and loadings.

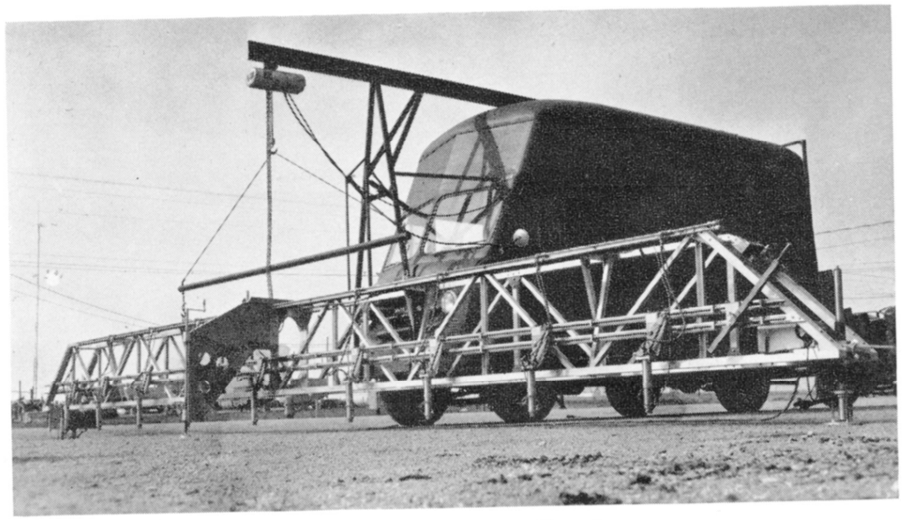
HRB, 1962

Figure 26. During periods of adverse weather traffic operations were governed by safety considerations. Snow and ice conditions usually resulted in operating at reduced speeds.

HRB, 1962

Figure 43. Nuclear density measuring device, used primarily on crushed stone base course.

HRB, 1962



HRB, 1962

Figure 31. Transverse profilometer.

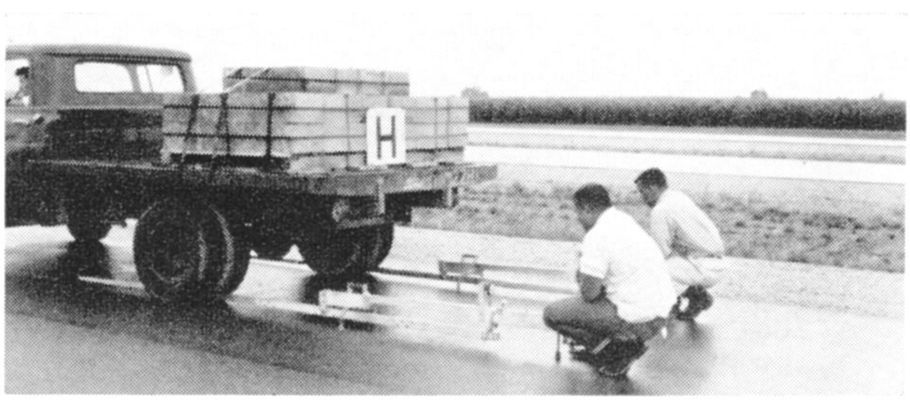
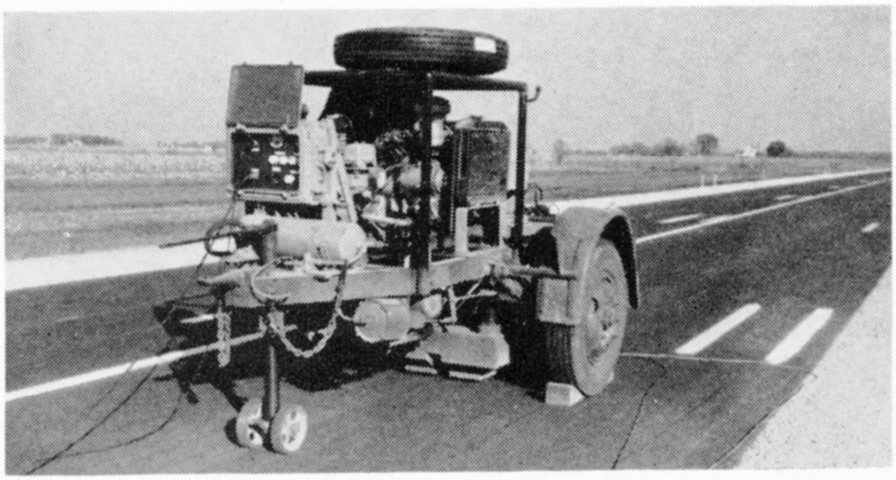


Figure 32. Measuring pavement deflection with Benkelman beam.

HRB, 1962



HRB, 1962 **Figure 44. Shell Oil Co. pavement vibrator.**

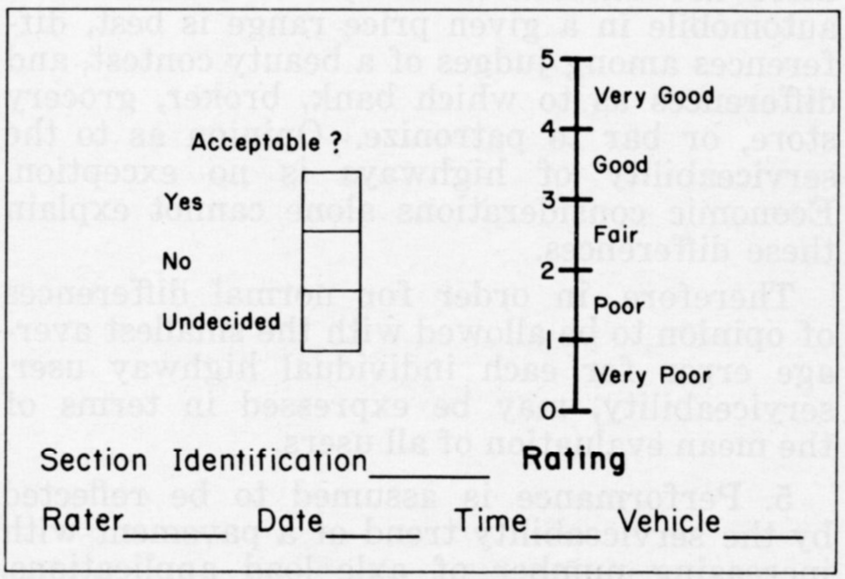
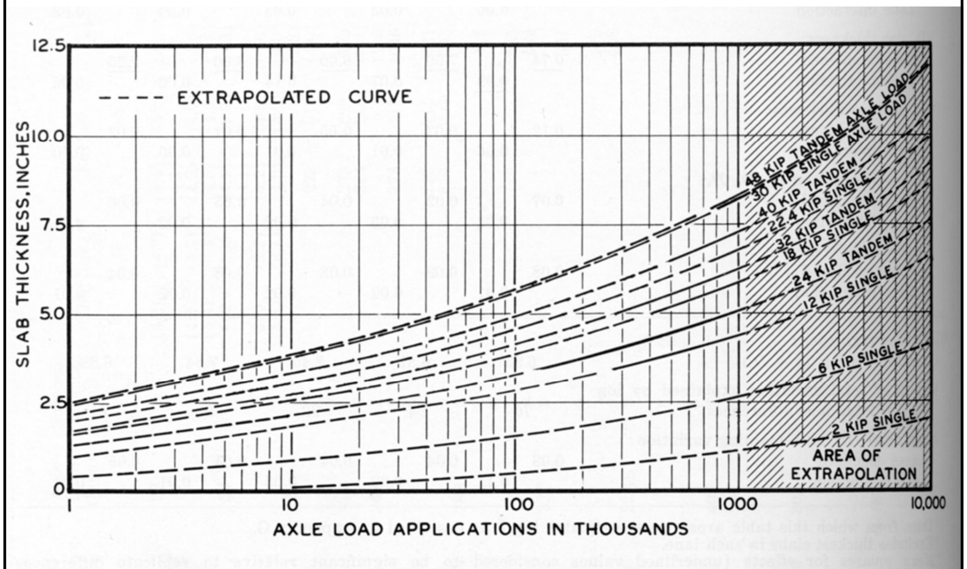


Figure 1–F. Individual present serviceability rating form.

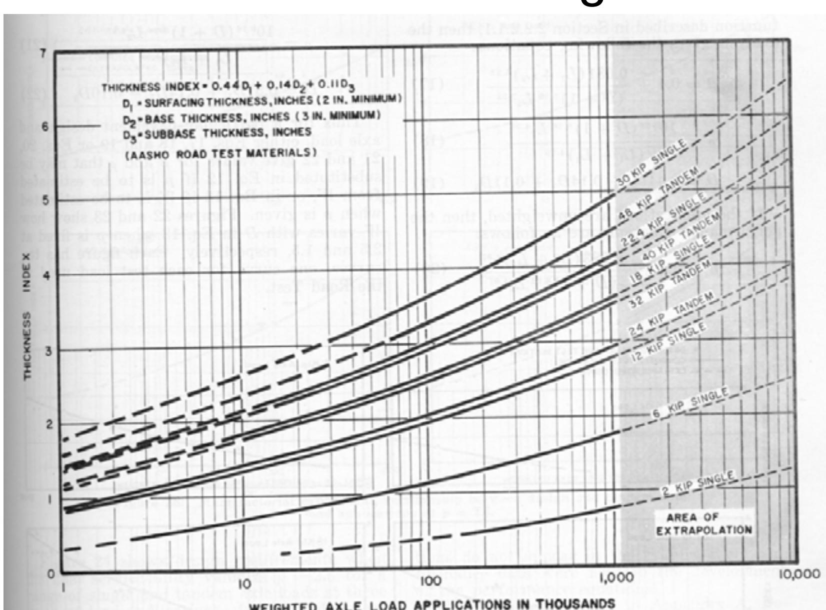
HRB, 1962

Rigid Pavement Design Curves



HRB, 1962 **Figure 116. Rigid pavement performance curves from Road Test equation, experiment design 1, for $p = 2.5$.**

Flexible Pavement Design Curves



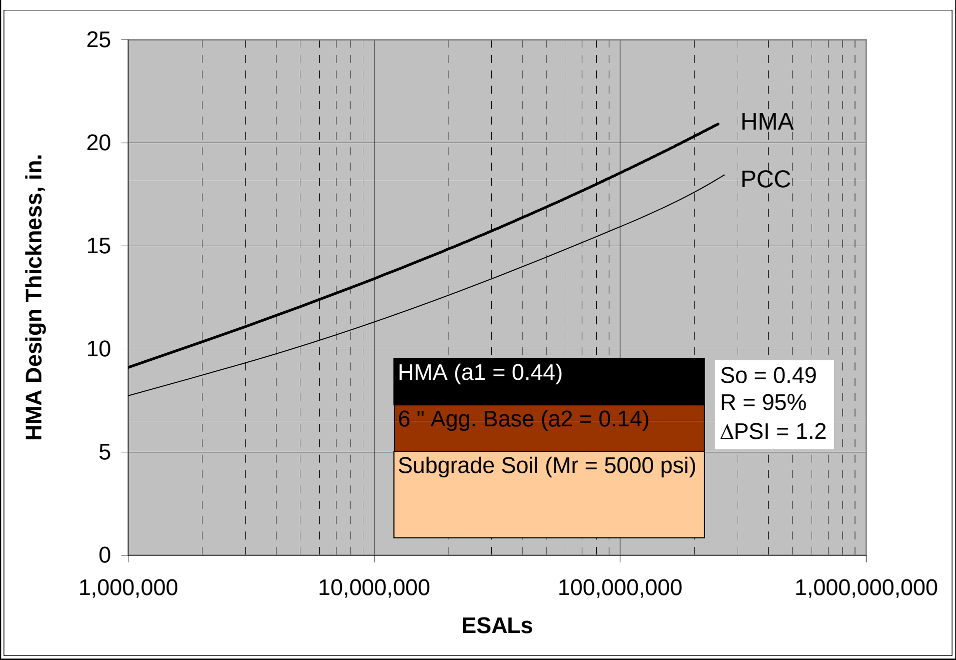
HRB, 1962 **Figure 23. Main factorial experiment, relationship between design and axle load applications at $p = 1.5$ (from Road Test equations).**

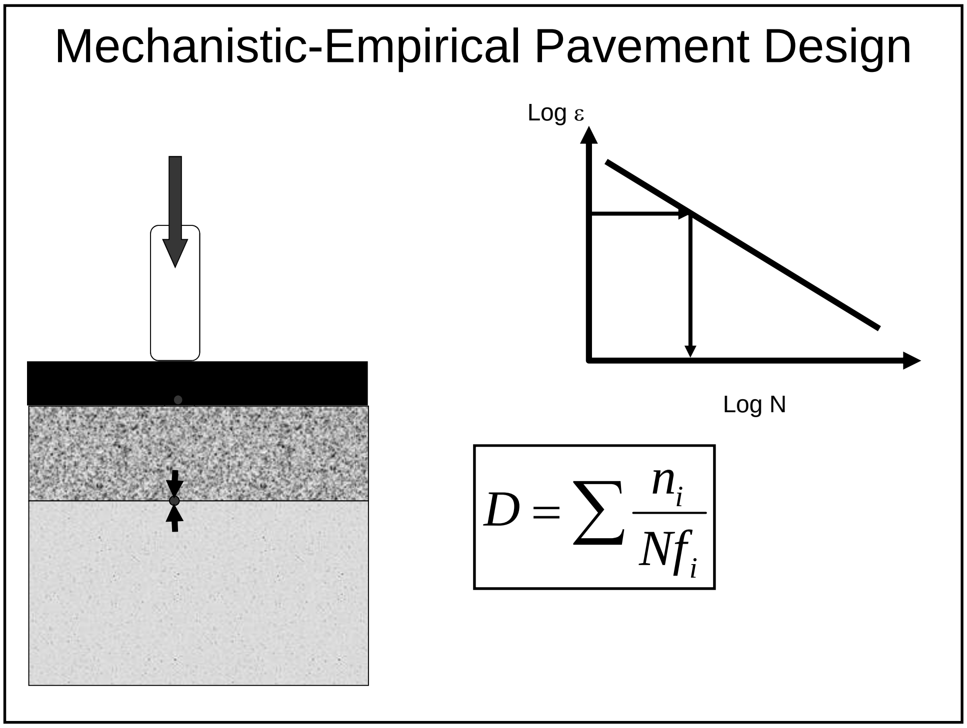
Major Disadvantages of Current System

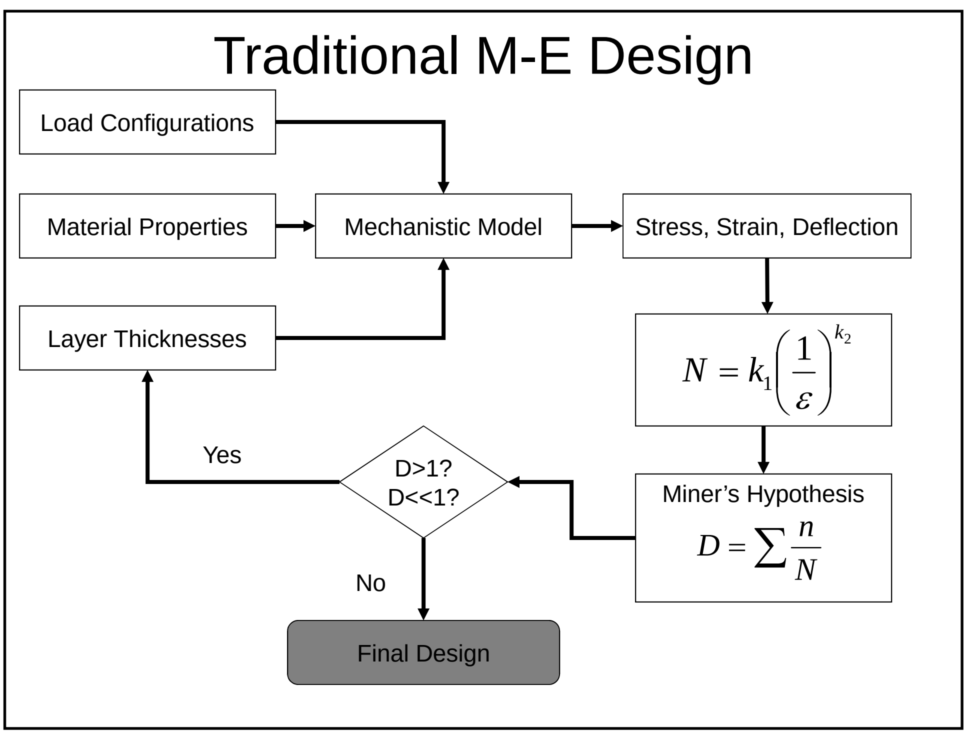
- 1 soil type
- 1 climate
- Limited pavement cross-sections
  - Max HMA thickness = 6”
- Limited traffic
  - Repetitions
  - Volume
  - Axle Types
- One set of materials
- Can only predict ΔPSI

Virtually every pavement design we conduct today is an EXTRAPOLATION!

Extrapolation can Lead to Overly Conservative Designs

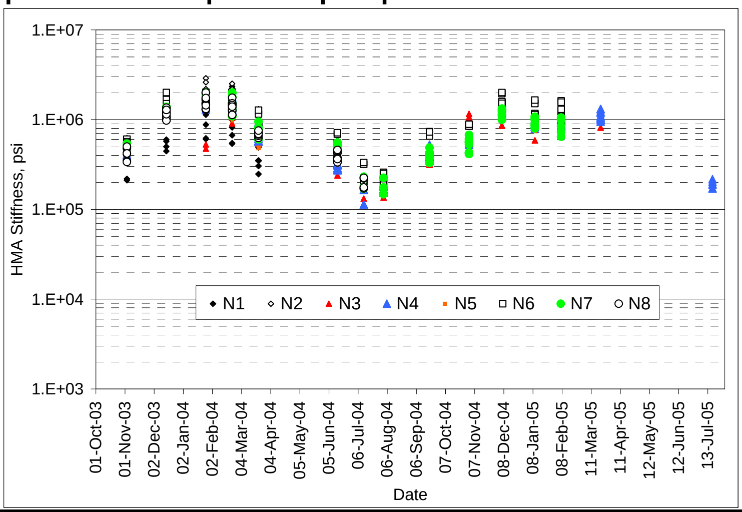



Mechanistic-Empirical Pavement Design
Log ε
Log N
$D = \sum \frac{n_i}{Nf_i}$


Traditional M-E Design
Load Configurations
Material Properties
Mechanistic Model
Stress, Strain, Deflection
Layer Thicknesses
$N = k_1 \left(\frac{1}{\varepsilon}\right)^{k_2}$
Yes
D>1?
D<<1?
Miner's Hypothesis
$D = \sum \frac{n}{N}$
No
Final Design

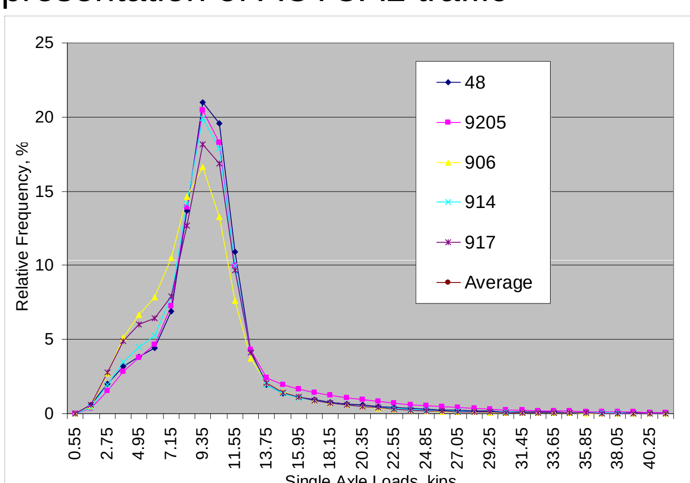
Material Characterization

- More sophisticated
- Represent in-place properties of ALL materials



Load Characterization

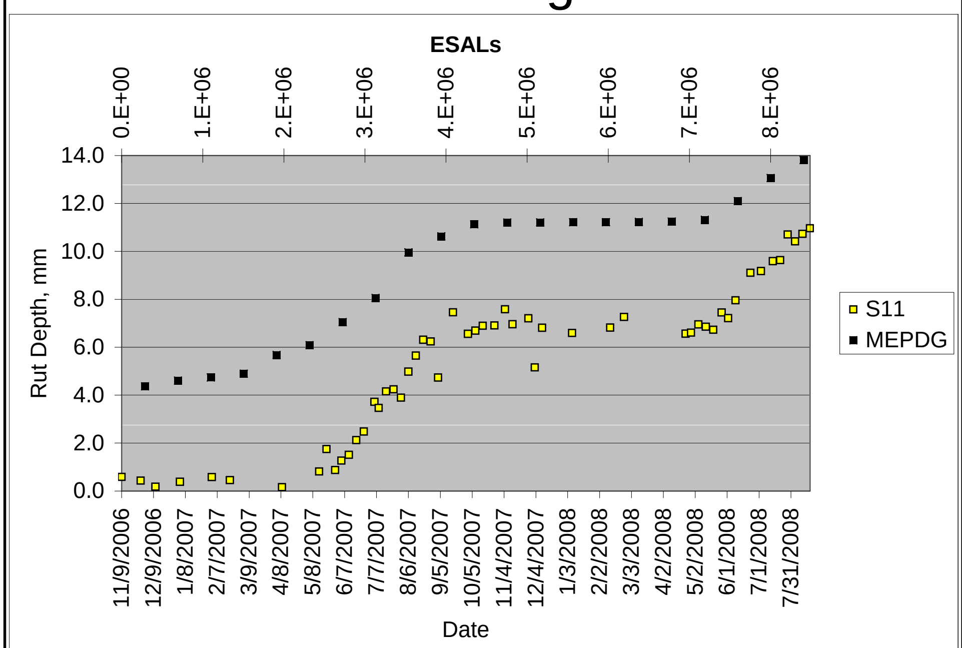
- Elimination of ESALs
- Use load spectra directly
- Better representation of ACTUAL traffic

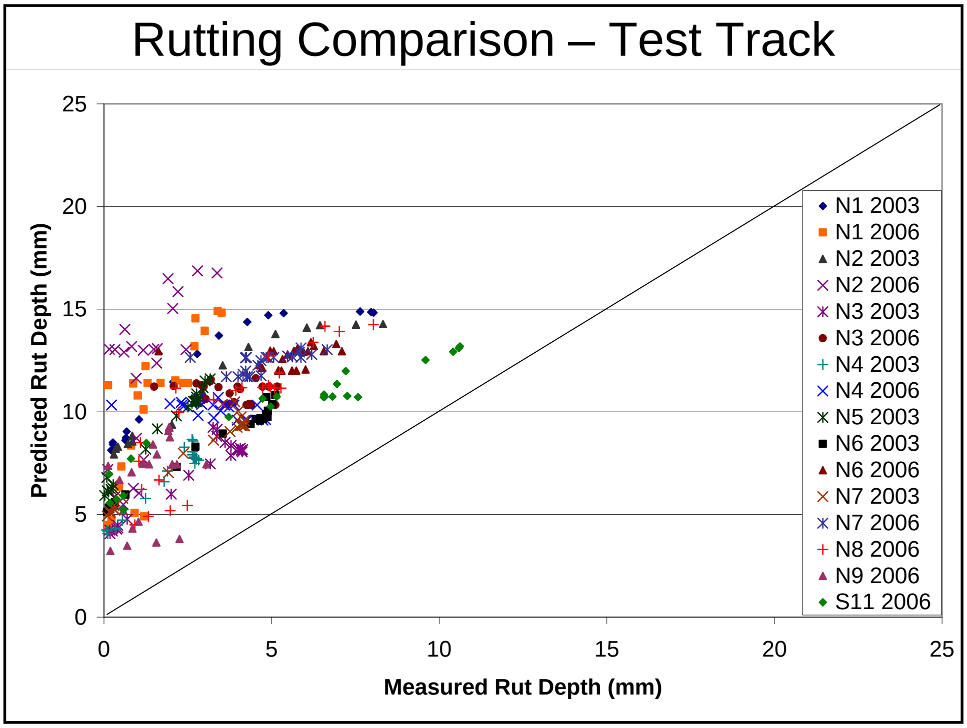


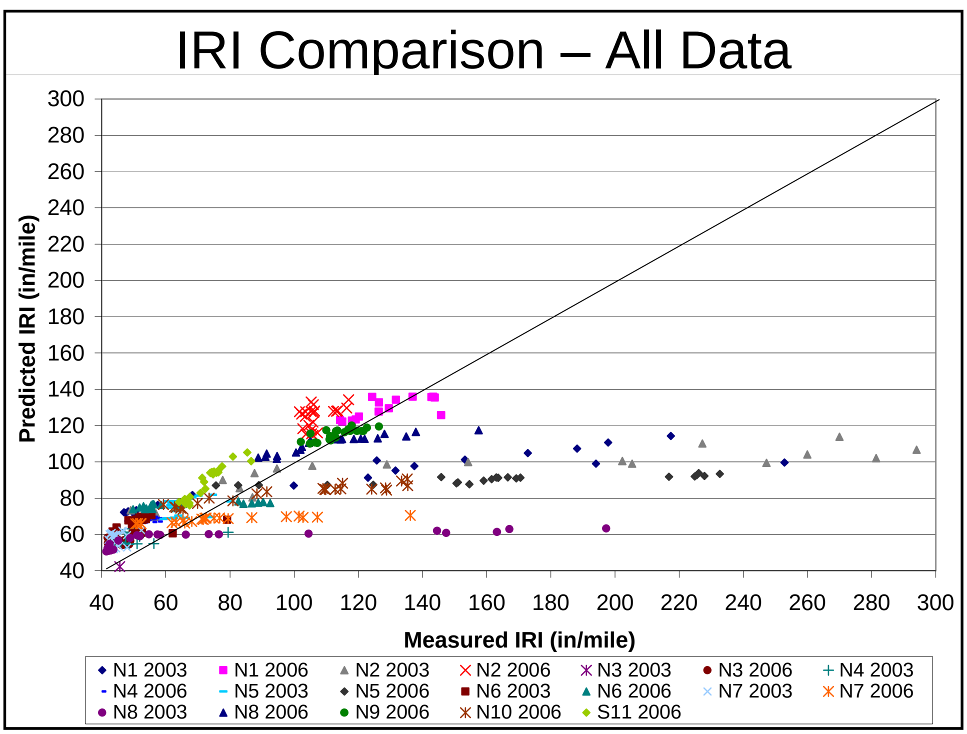
Performance Characterization

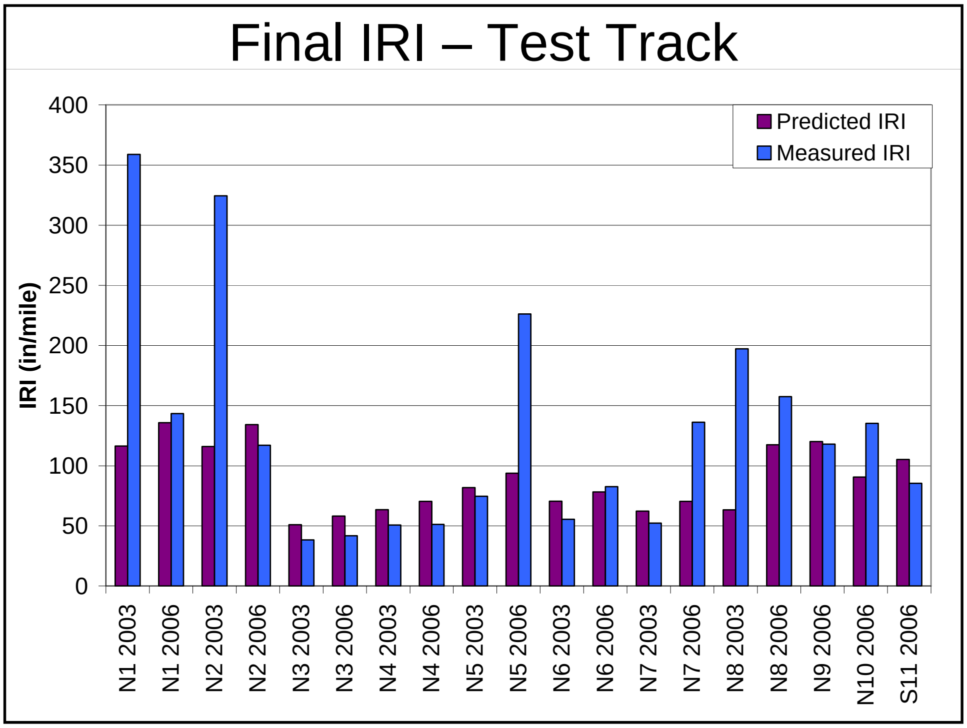
- Predict specific types of distress and time of failure

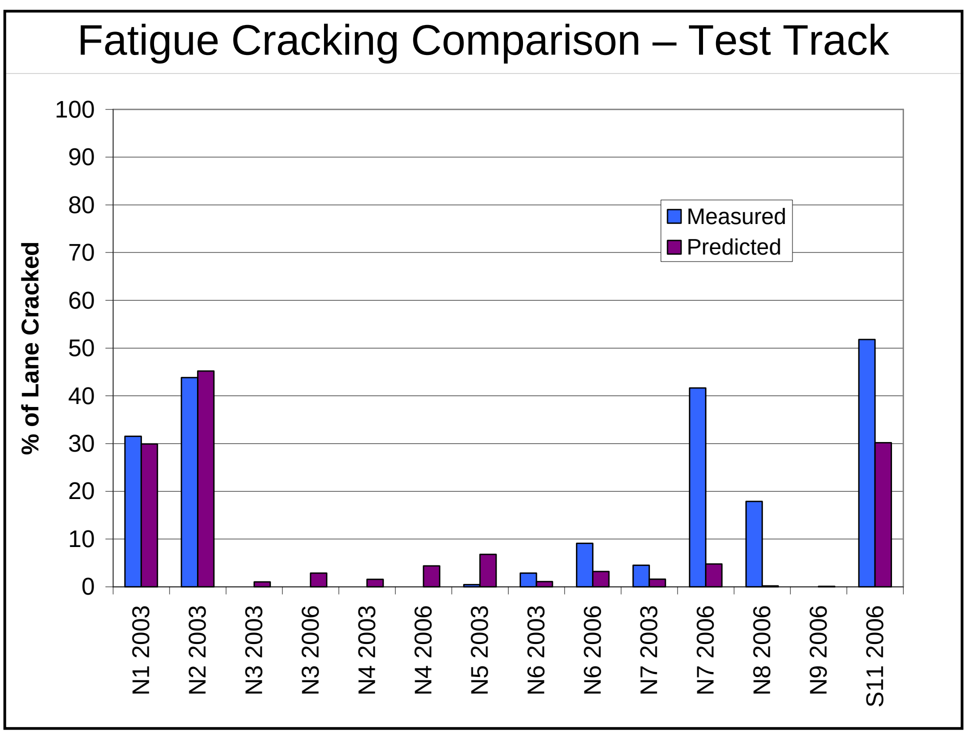
Test Track Rutting Prediction




Rutting Comparison – Test Track
Predicted Rut Depth (mm)
Measured Rut Depth (mm)
0
5
10
15
20
25
N1 2003
N1 2006
N2 2003
N2 2006
N3 2003
N3 2006
N4 2003
N4 2006
N5 2003
N6 2003
N6 2006
N7 2003
N7 2006
N8 2006
N9 2006
S11 2006


IRI Comparison – All Data
Predicted IRI (in/mile)
Measured IRI (in/mile)
40
60
80
100
120
140
160
180
200
220
240
260
280
300
N1 2003
N1 2006
N2 2003
N2 2006
N3 2003
N3 2006
N4 2003
N4 2006
N5 2003
N5 2006
N6 2003
N6 2006
N7 2003
N7 2006
N8 2003
N8 2006
N9 2006
N10 2006
S11 2006

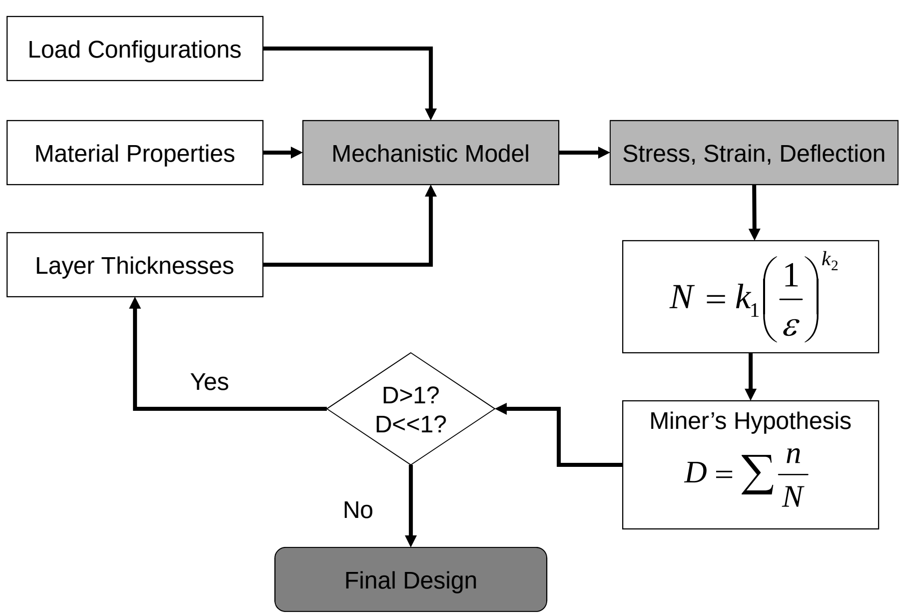

Final IRI – Test Track
IRI (in/mile)
400
350
300
250
200
150
100
50
0
Predicted IRI
Measured IRI
N1 2003
N1 2006
N2 2003
N2 2006
N3 2003
N3 2006
N4 2003
N4 2006
N5 2003
N5 2006
N6 2003
N6 2006
N7 2003
N7 2006
N8 2003
N8 2006
N9 2006
N10 2006
S11 2006

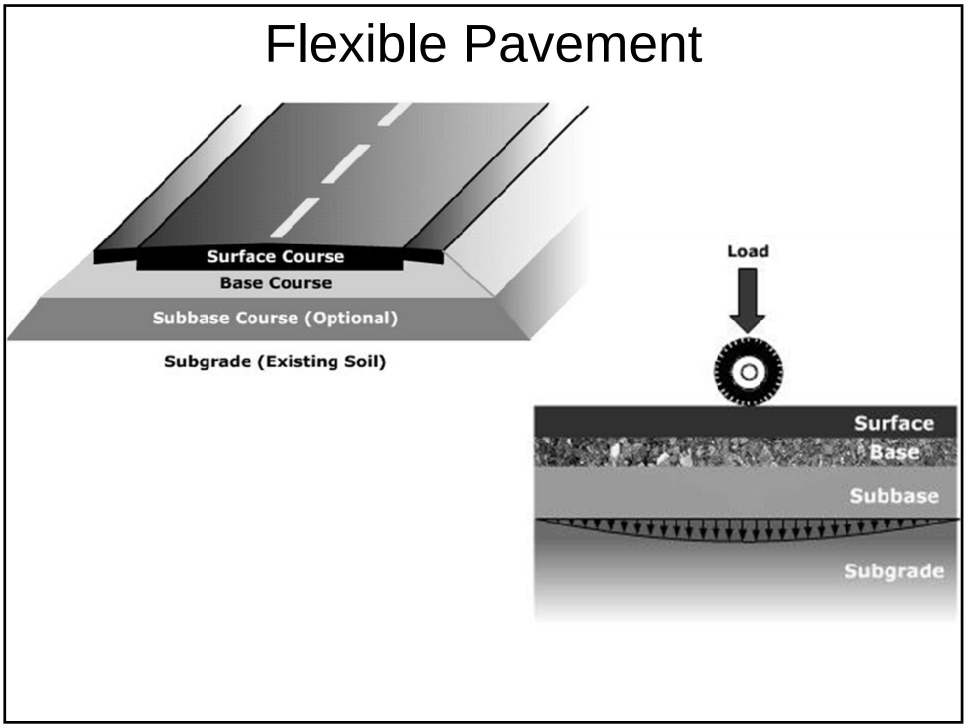

Fatigue Cracking Comparison – Test Track
% of Lane Cracked
100
90
80
70
60
50
40
30
20
10
0
Measured
Predicted
N1 2003
N2 2003
N3 2003
N3 2006
N4 2003
N4 2006
N5 2003
N6 2003
N6 2006
N7 2003
N7 2006
N8 2006
N9 2006
S11 2006

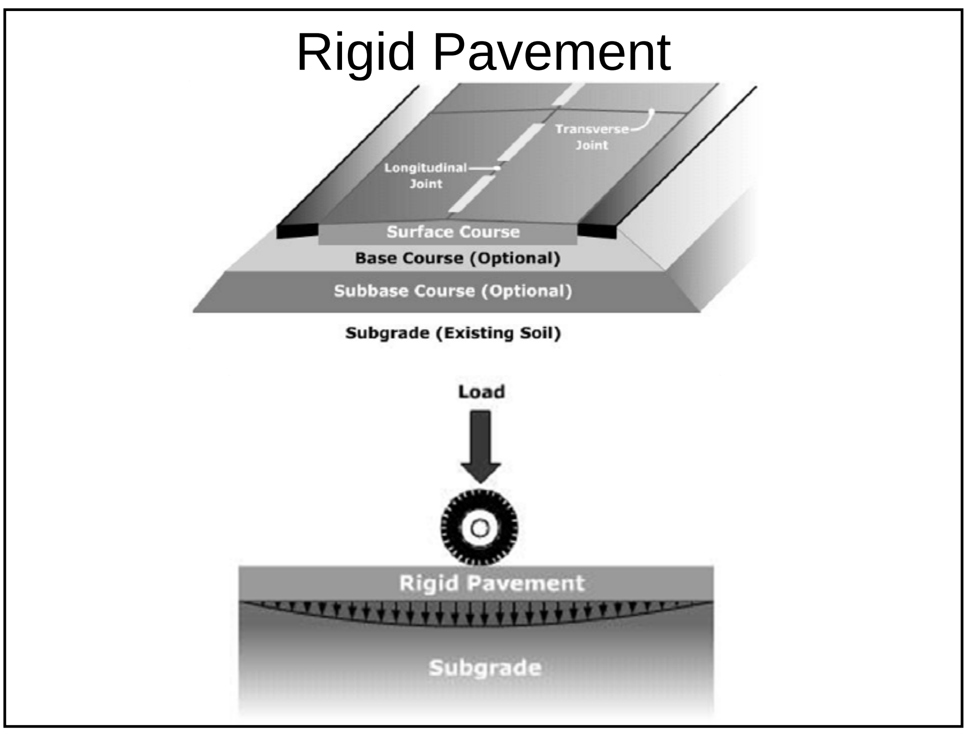
Advantages of M-E Design

- Less reliance on road tests
- Able to handle changes better
- Better characterization of materials and traffic
- Capable of predicting modes of distress
- More efficient pavement designs

Pavement Mechanics




Flexible Pavement
Surface Course
Base Course
Subbase Course (Optional)
Subgrade (Existing Soil)
Load
Surface
Base
Subbase
Subgrade

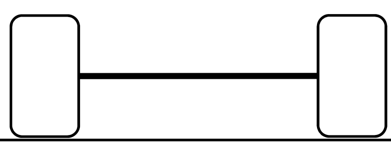

Rigid Pavement
Transverse Joint
Longitudinal Joint
Surface Course
Base Course (Optional)
Subbase Course (Optional)
Subgrade (Existing Soil)
Load
Rigid Pavement
Subgrade

Modeling Techniques

- Simple equations
  - Boussinesq
  - Westergaard
- Layered Elastic Analysis (Flexible)
  - WESLEA for Windows
- Finite Element Analysis (Rigid)
  - KENSLABs

Asphalt Pavement Example –

Determine AC thickness to withstand 10 million load repetitions



Asphalt

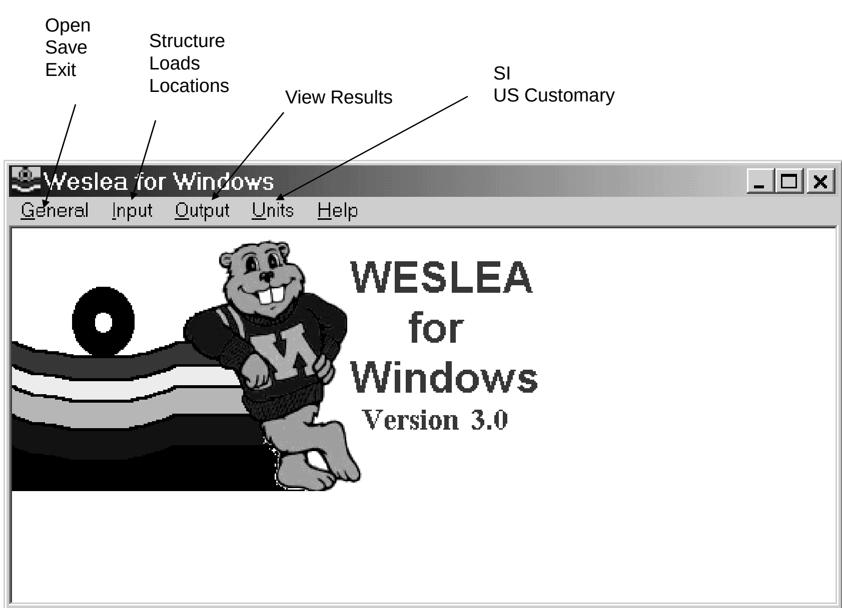
Aggregate Base

Subgrade

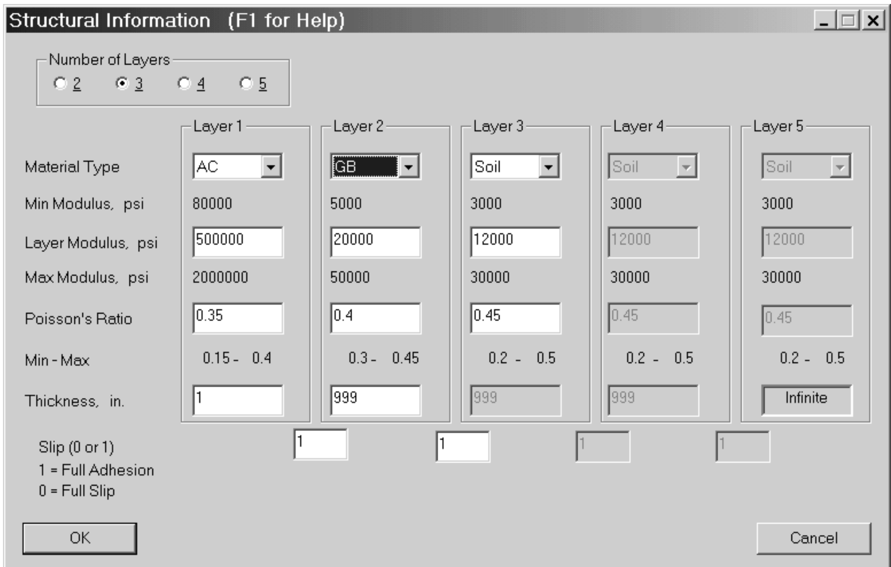
Design Results

Trial	H1, in.	$D_{fatigue}$	$D_{rutting}$

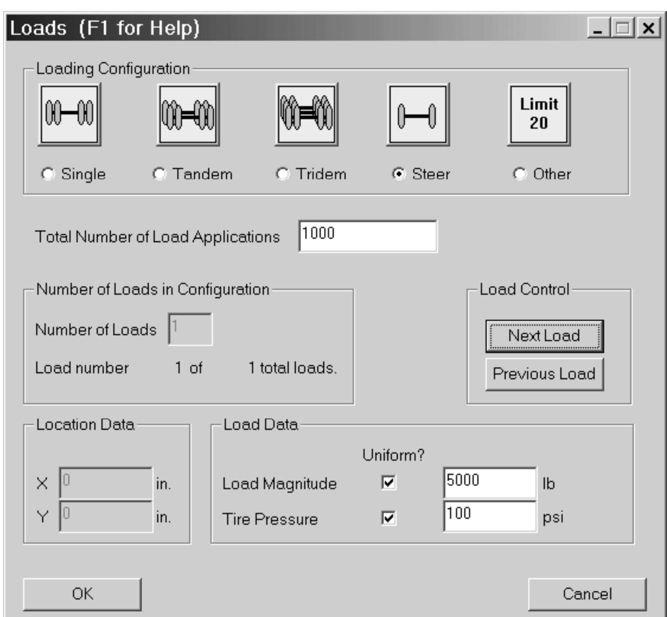
WESLEA for Windows



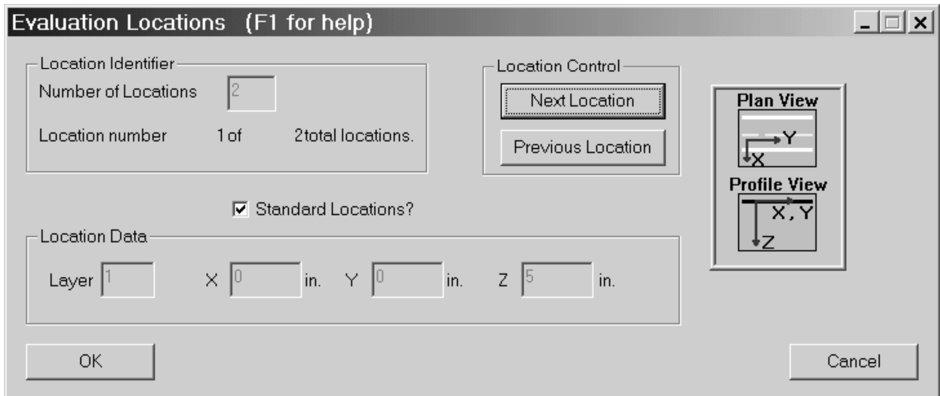
Input Structure



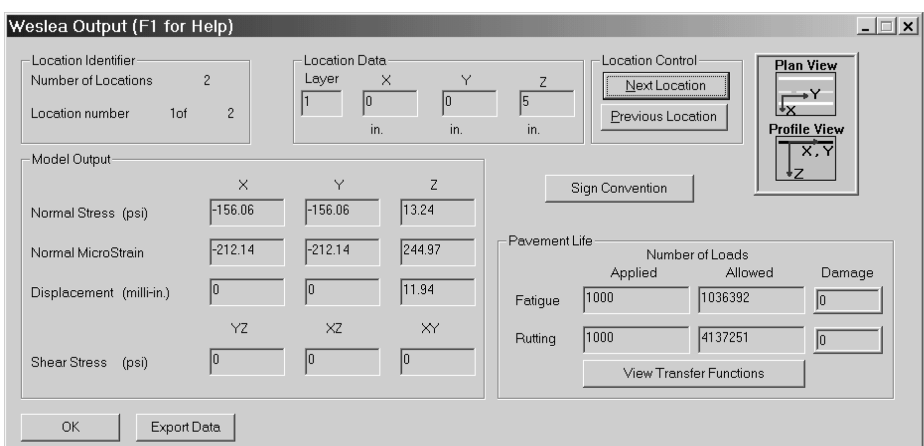
Input Loads



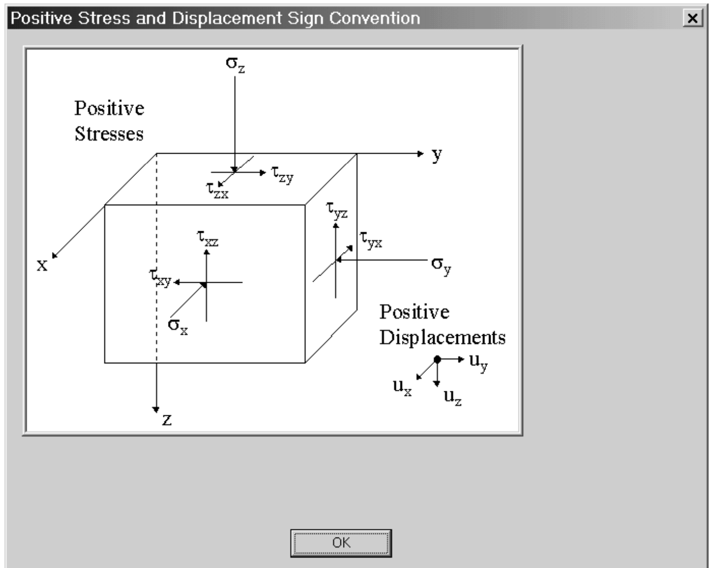
Input Evaluation Locations



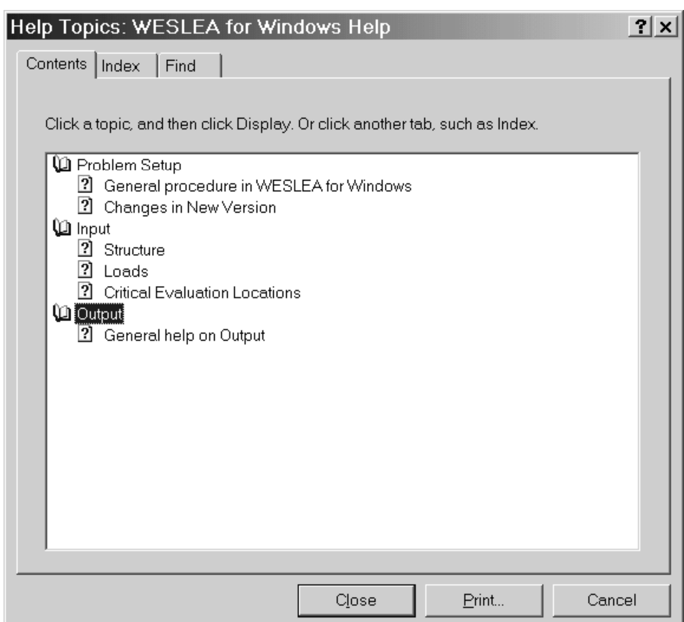
View Output



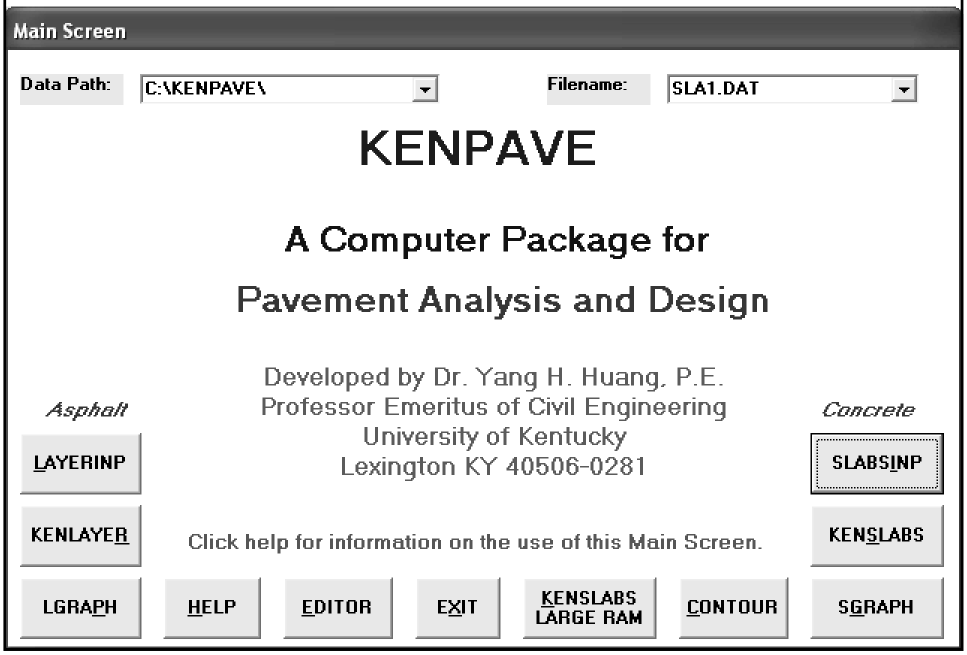
Sign Convention



Help Files

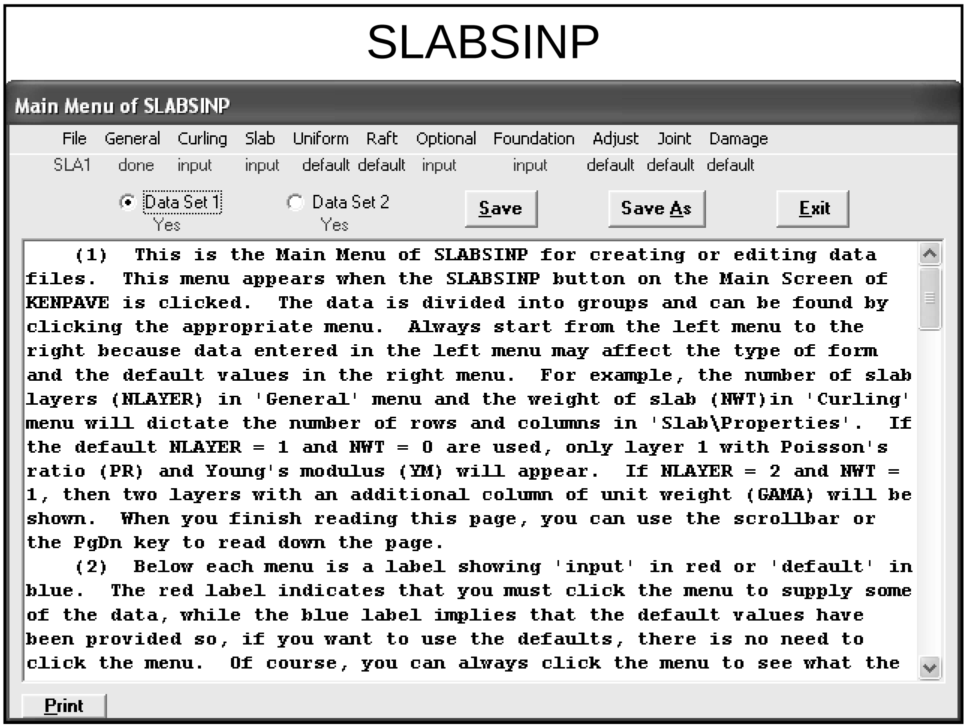


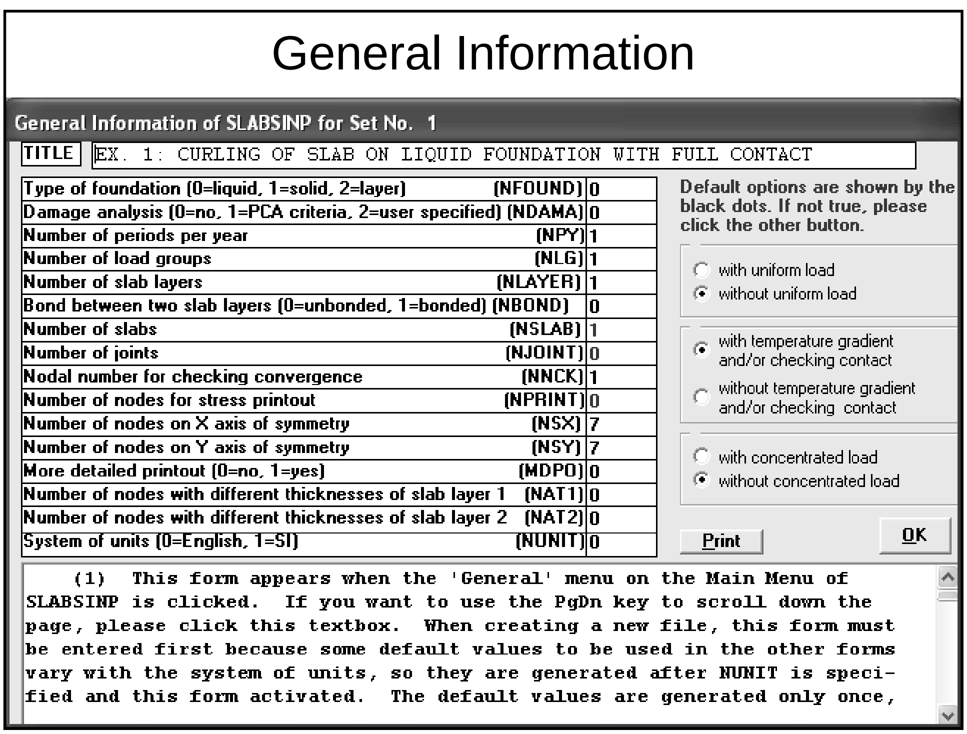
KENSLABs

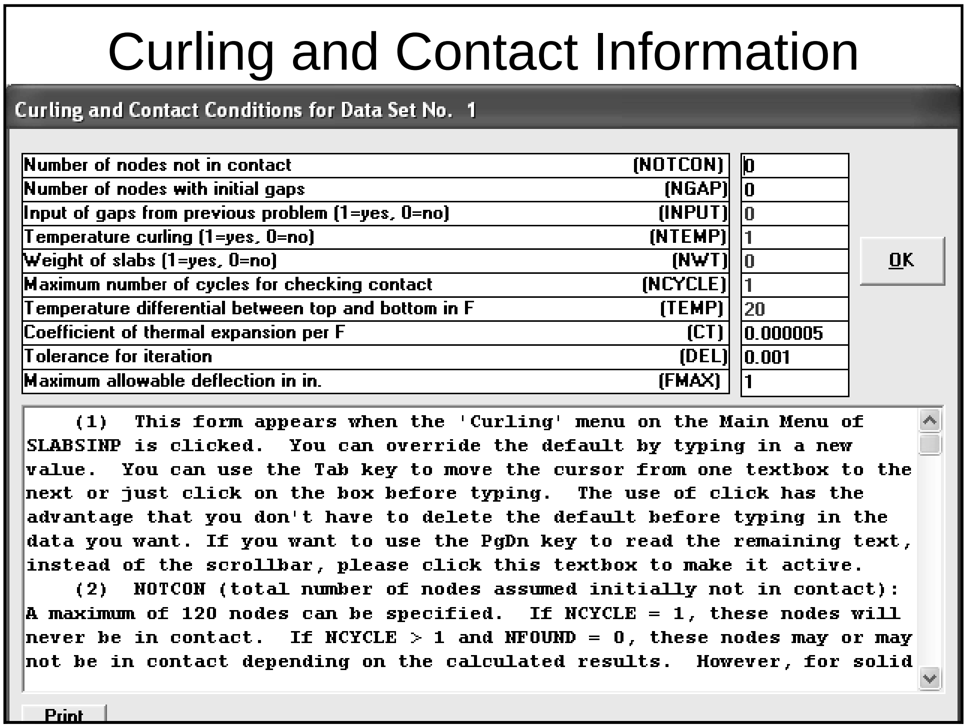


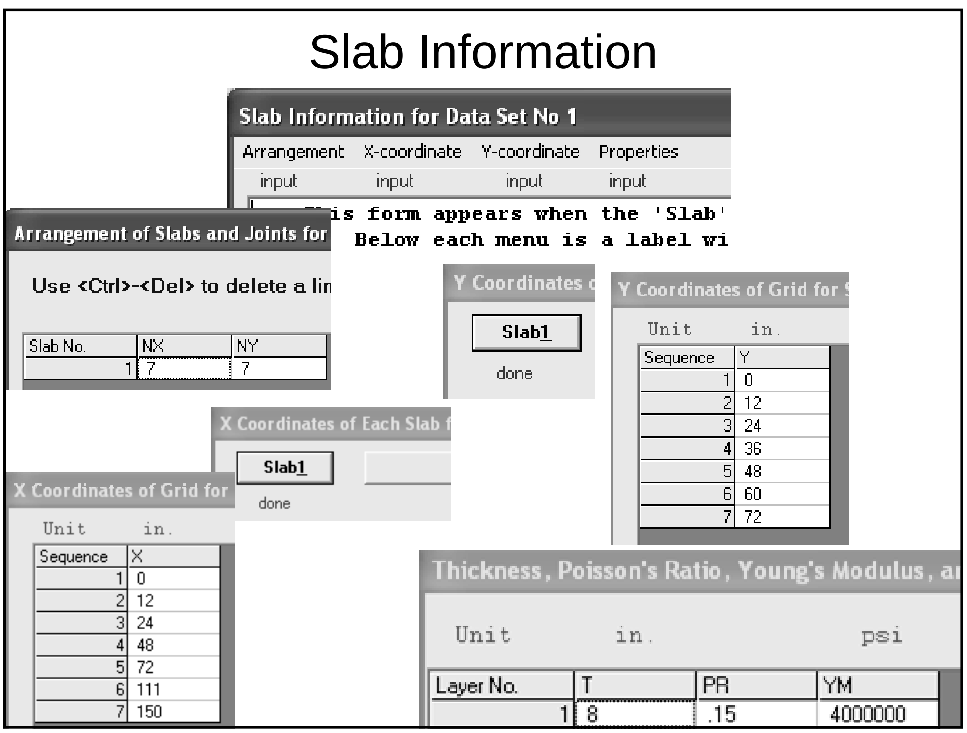
Example – Temperature Effects

SLA1.dat

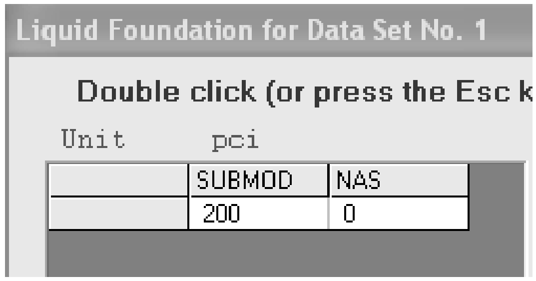

SLABSINP
Main Menu of SLABSINP
File General Curling Slab Uniform Raft Optional Foundation Adjust Joint Damage
SLA1 done input input default default input input default default default
Data Set 1 Yes
Data Set 2 Yes
Save
Save As
Exit
(1) This is the Main Menu of SLABSINP for creating or editing data files. This menu appears when the SLABSINP button on the Main Screen of KENPAVE is clicked. The data is divided into groups and can be found by clicking the appropriate menu. Always start from the left menu to the right because data entered in the left menu may affect the type of form and the default values in the right menu. For example, the number of slab layers (NLAYER) in 'General' menu and the weight of slab (NWT)in 'Curling' menu will dictate the number of rows and columns in 'Slab\Properties'. If the default NLAYER = 1 and NWT = 0 are used, only layer 1 with Poisson's ratio (PR) and Young's modulus (YM) will appear. If NLAYER = 2 and NWT = 1, then two layers with an additional column of unit weight (GAMA) will be shown. When you finish reading this page, you can use the scrollbar or the PgDn key to read down the page.
(2) Below each menu is a label showing 'input' in red or 'default' in blue. The red label indicates that you must click the menu to supply some of the data, while the blue label implies that the default values have been provided so, if you want to use the defaults, there is no need to click the menu. Of course, you can always click the menu to see what the
Print


General Information
General Information of SLABSINP for Set No. 1
TITLE EX. 1: CURLING OF SLAB ON LIQUID FOUNDATION WITH FULL CONTACT
Type of foundation (0=liquid, 1=solid, 2=layer) (NFOUND) 0
Damage analysis (0=no, 1=PCA criteria, 2=user specified) (NDAMA) 0
Number of periods per year (NPY) 1
Number of load groups (NLG) 1
Number of slab layers (NLAYER) 1
Bond between two slab layers (0=unbonded, 1=bonded) (NBOND) 0
Number of slabs (NSLAB) 1
Number of joints (NJOINT) 0
Nodal number for checking convergence (NNCK) 1
Number of nodes for stress printout (NPRINT) 0
Number of nodes on X axis of symmetry (NSX) 7
Number of nodes on Y axis of symmetry (NSY) 7
More detailed printout (0=no, 1=yes) (MDPO) 0
Number of nodes with different thicknesses of slab layer 1 (NAT1) 0
Number of nodes with different thicknesses of slab layer 2 (NAT2) 0
System of units (0=English, 1=SI) (NUNIT) 0
Default options are shown by the black dots. If not true, please click the other button.
with uniform load
without uniform load
with temperature gradient and/or checking contact
without temperature gradient and/or checking contact
with concentrated load
without concentrated load
Print
OK
(1) This form appears when the 'General' menu on the Main Menu of SLABSINP is clicked. If you want to use the PgDn key to scroll down the page, please click this textbox. When creating a new file, this form must be entered first because some default values to be used in the other forms vary with the system of units, so they are generated after NUNIT is specified and this form activated. The default values are generated only once,

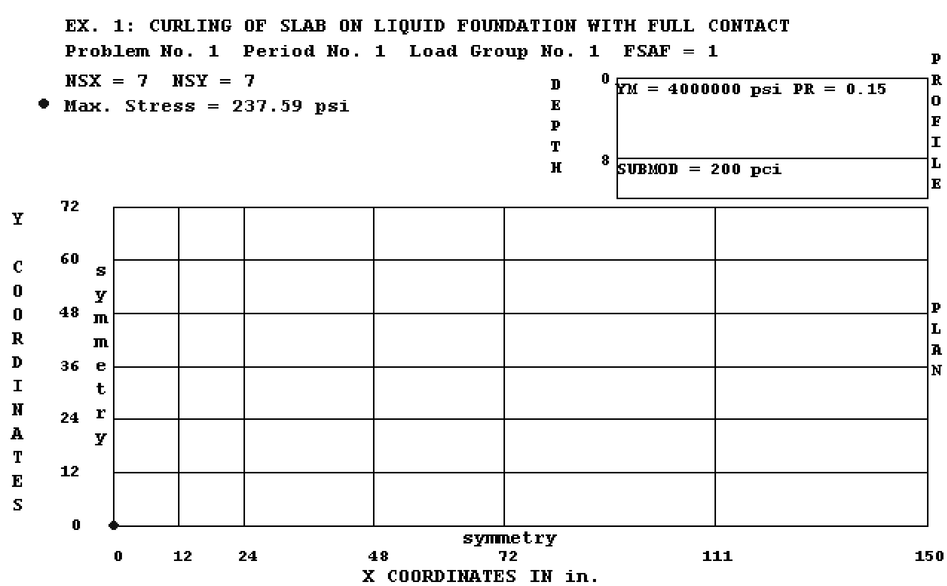

Curling and Contact Information
Curling and Contact Conditions for Data Set No. 1
Number of nodes not in contact (NOTCON) 0
Number of nodes with initial gaps (NGAP) 0
Input of gaps from previous problem (1=yes, 0=no) (INPUT) 0
Temperature curling (1=yes, 0=no) (NTEMP) 1
Weight of slabs (1=yes, 0=no) (NWT) 0
Maximum number of cycles for checking contact (NCYCLE) 1
Temperature differential between top and bottom in F (TEMP) 20
Coefficient of thermal expansion per F (CT) 0.000005
Tolerance for iteration (DEL) 0.001
Maximum allowable deflection in in. (FMAX) 1
OK
(1) This form appears when the 'Curling' menu on the Main Menu of SLABSINP is clicked. You can override the default by typing in a new value. You can use the Tab key to move the cursor from one textbox to the next or just click on the box before typing. The use of click has the advantage that you don't have to delete the default before typing in the data you want. If you want to use the PgDn key to read the remaining text, instead of the scrollbar, please click this textbox to make it active.
(2) NOTCON (total number of nodes assumed initially not in contact): A maximum of 120 nodes can be specified. If NCYCLE = 1, these nodes will never be in contact. If NCYCLE > 1 and NFOUND = 0, these nodes may or may not be in contact depending on the calculated results. However, for solid
Print

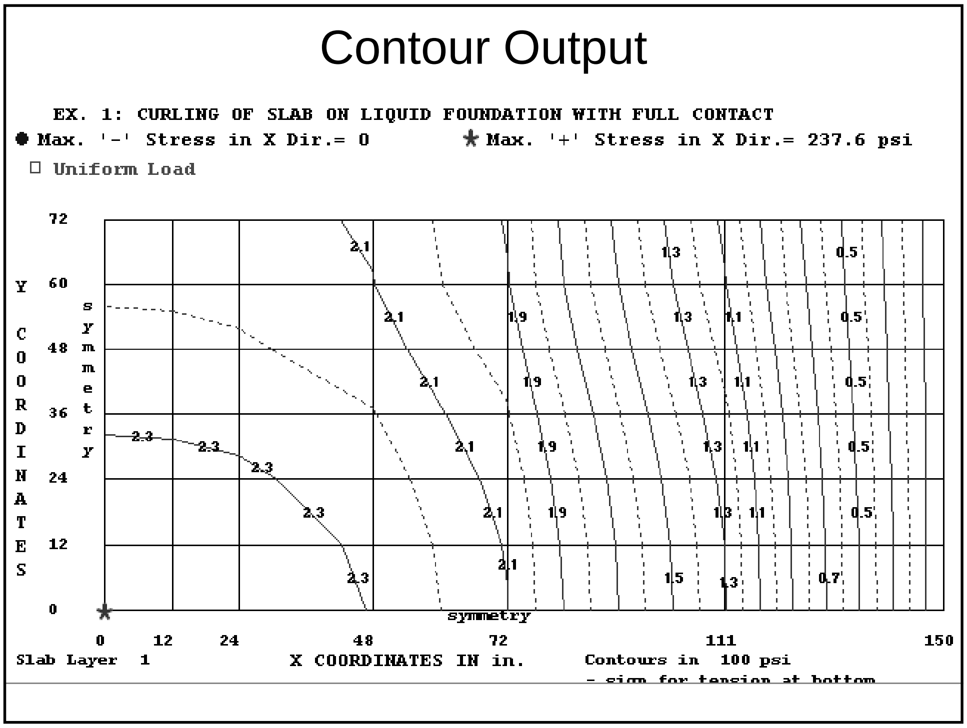

Slab Information
Slab Information for Data Set No 1
Arrangement input
X-coordinate input
Y-coordinate input
Properties input
is form appears when the 'Slab'
Below each menu is a label wi
Arrangement of Slabs and Joints for
Use <Ctrl>-<Del> to delete a lin
Slab No. NX NY
1 7 7
Y Coordinates
Slab1
done
Y Coordinates of Grid for
Unit in.
Sequence Y
1 0
2 12
3 24
4 36
5 48
6 60
7 72
X Coordinates of Each Slab
Slab1
done
X Coordinates of Grid for
Unit in.
Sequence X
1 0
2 12
3 24
4 48
5 72
6 111
7 150
Thickness, Poisson's Ratio, Young's Modulus, a
Unit in. psi
Layer No. T PR YM
1 8 .15 4000000

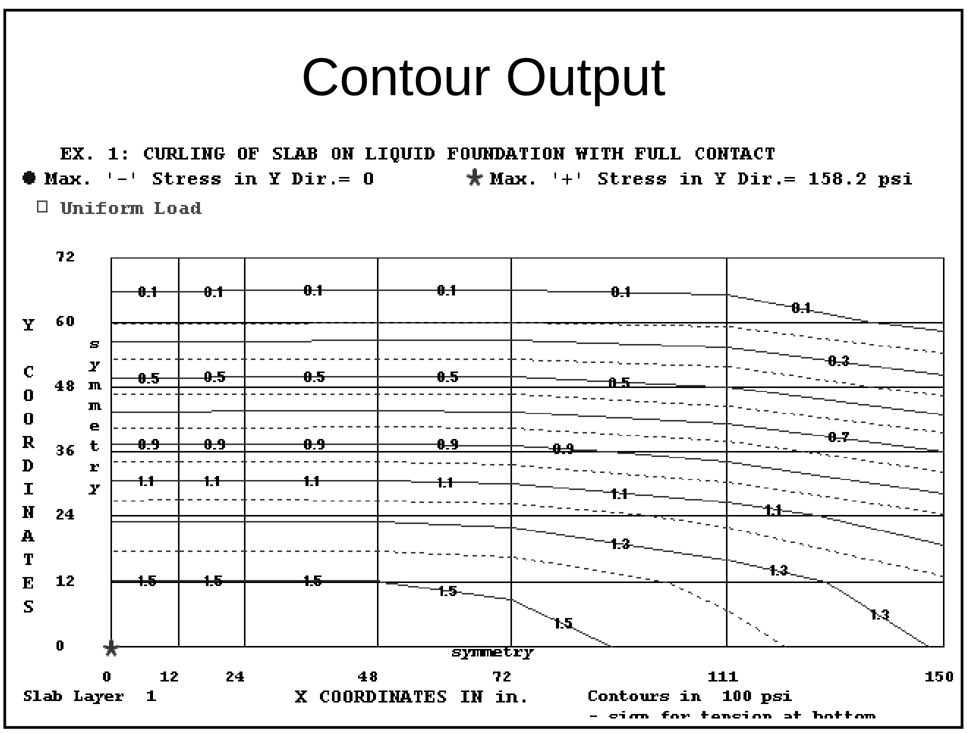
Foundation



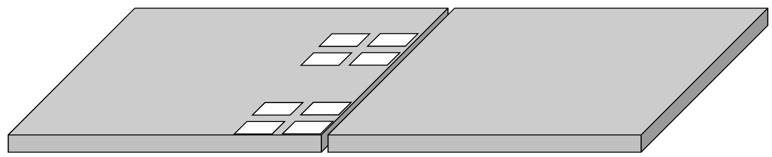
S-Graph Output




Contour Output
EX. 1: CURLING OF SLAB ON LIQUID FOUNDATION WITH FULL CONTACT
Max. '-' Stress in X Dir.= 0
Max. '+' Stress in X Dir.= 237.6 psi
Uniform Load
Y COORDINATES
symmetry
X COORDINATES IN in.
Slab Layer 1
Contours in 100 psi


Contour Output
EX. 1: CURLING OF SLAB ON LIQUID FOUNDATION WITH FULL CONTACT
Max. '-' Stress in Y Dir.= 0
Max. '+' Stress in Y Dir.= 158.2 psi
Uniform Load
Y COORDINATES
symmetry
X COORDINATES IN in.
Slab Layer 1
Contours in 100 psi

Example – Loading and Temperature



Find slab thickness to withstand 10,000,000 applications of this tandem axle.
Consider with and without temperature gradient.

SLA3.dat

First Consider Without Thermal Stresses

General Information of SLABSINP for Set No. 1

TITLE: EXAMPLE NO. 3: TWO SLABS ON SOLID FOUNDATION WITH FULL CONTACT

Type of foundation (0=liquid, 1=solid, 2=layer)	(NFOUND)	1
Damage analysis (0=no, 1=PCA criteria, 2=user specified)	(NDAMA)	0
Number of periods per year	(NPY)	1
Number of load groups	(NLG)	1
Number of slab layers	(NLAYER)	1
Bond between two slab layers (0=unbonded, 1=bonded)	(NBOND)	0
Number of slabs	(NSLAB)	2
Number of joints	(NJOINT)	1
Nodal number for checking convergence	(NNCK)	49
Number of nodes for stress printout	(NPRINT)	0
Number of nodes on X axis of symmetry	(NSX)	0
Number of nodes on Y axis of symmetry	(NSY)	0
More detailed printout (0=no, 1=yes)	(MDPO)	0
Number of nodes with different thicknesses of slab layer 1	(NAT1)	0
Number of nodes with different thicknesses of slab layer 2	(NAT2)	0
System of units (0=English, 1=SI)	(NUNIT)	0

Default options are shown by the black dots. If not true, please click the other button.

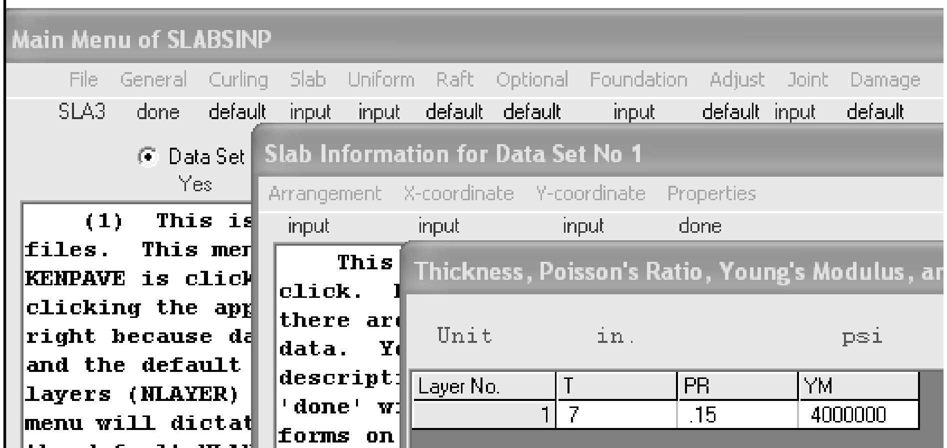
- (•) with uniform load
- ( ) without uniform load

- ( ) with temperature gradient and/or checking contact
- (•) without temperature gradient and/or checking contact

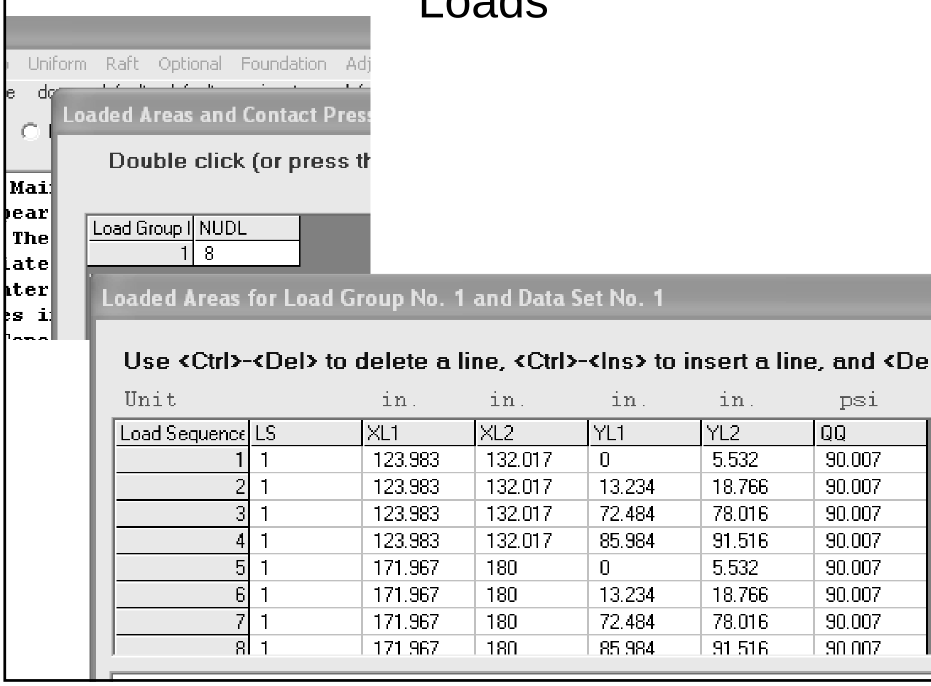
- ( ) with concentrated load
- (•) without concentrated load

Print OK

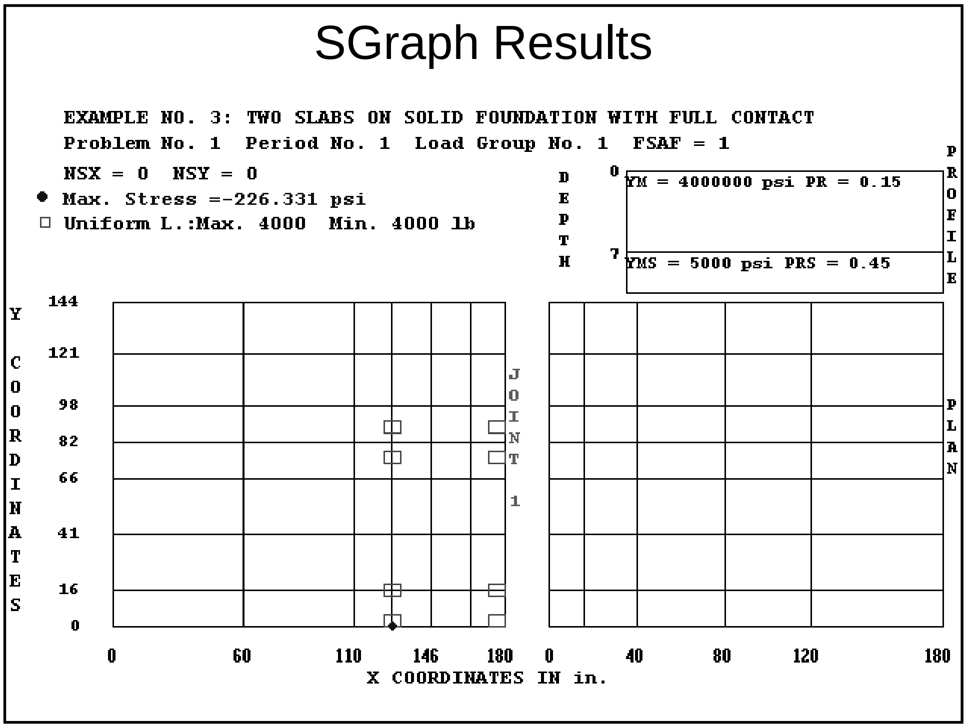
Slab Thickness

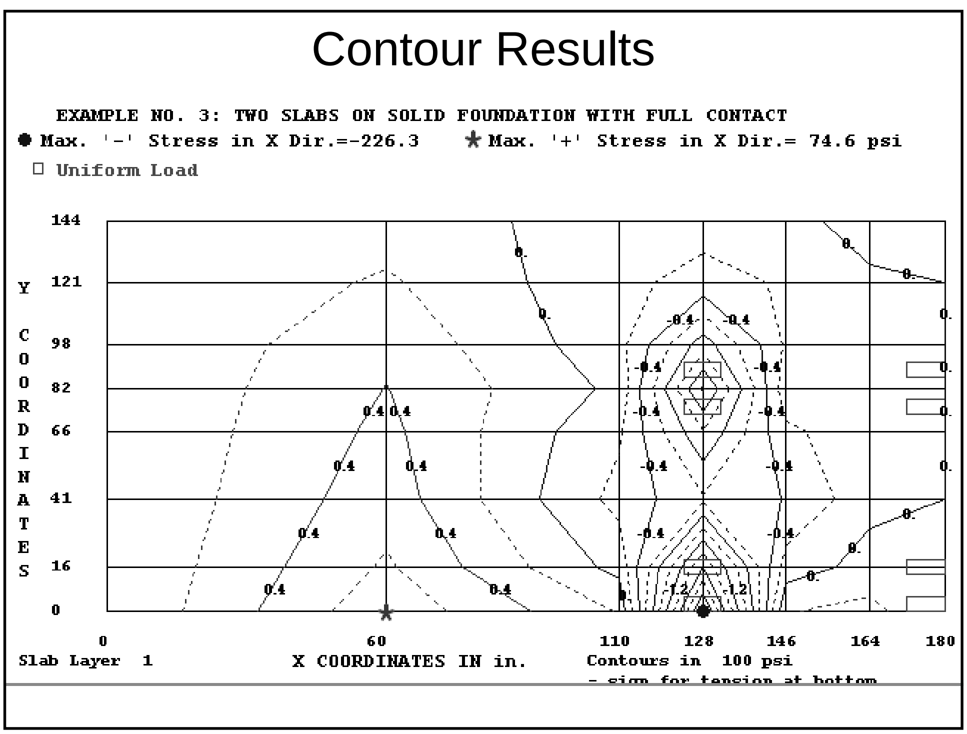


Loads



Load Sequence	LS	XL1	XL2	YL1	YL2	QQ
1	1	123.983	132.017	0	5.532	90.007
2	1	123.983	132.017	13.234	18.766	90.007
3	1	123.983	132.017	72.484	78.016	90.007
4	1	123.983	132.017	85.984	91.516	90.007
5	1	171.967	180	0	5.532	90.007
6	1	171.967	180	13.234	18.766	90.007
7	1	171.967	180	72.484	78.016	90.007
8	1	171.967	180	85.984	91.516	90.007


SGraph Results
EXAMPLE NO. 3: TWO SLABS ON SOLID FOUNDATION WITH FULL CONTACT
Problem No. 1 Period No. 1 Load Group No. 1 FSAF = 1
NSX = 0 NSY = 0
Max. Stress =-226.331 psi
Uniform L.:Max. 4000 Min. 4000 lb
DEPTH
YM = 4000000 psi PR = 0.15
YMS = 5000 psi PRS = 0.45
PROFILE
Y COORDINATES
JOINT 1
PLAN
X COORDINATES IN in.

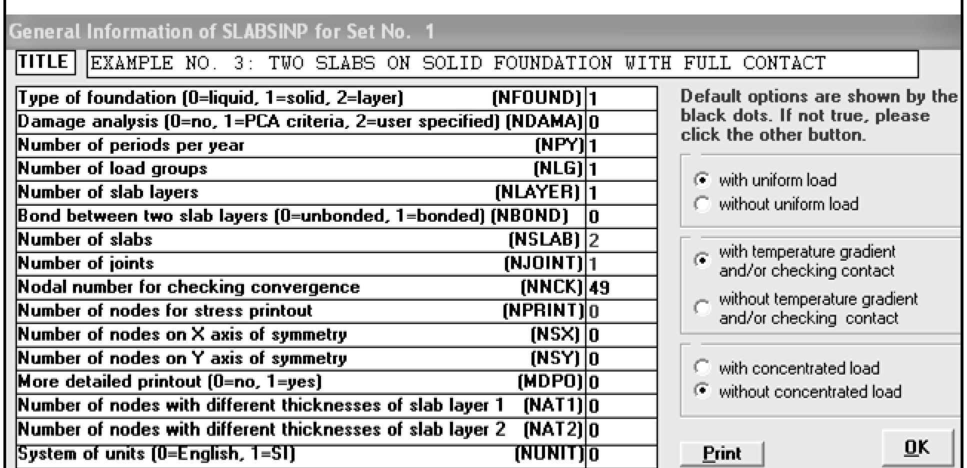

Contour Results
EXAMPLE NO. 3: TWO SLABS ON SOLID FOUNDATION WITH FULL CONTACT
Max. '-' Stress in X Dir.=-226.3
Max. '+' Stress in X Dir.= 74.6 psi
Uniform Load
Y COORDINATES
Slab Layer 1
X COORDINATES IN in.
Contours in 100 psi
- sign for tension at bottom

Design – Load Only

For 10 million load repetitions, critical stress is 360 psi

Trial	D, in.	Stress, psi

Consider Load and Thermal Effects



General Information of SLABSINP for Set No. 1

TITLE: EXAMPLE NO. 3: TWO SLABS ON SOLID FOUNDATION WITH FULL CONTACT

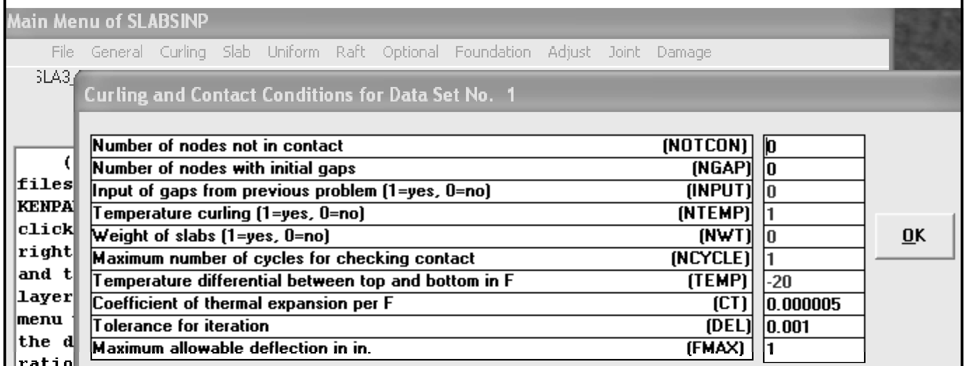
Type of foundation (0=liquid, 1=solid, 2=layer)	(NFOUND)	1
Damage analysis (0=no, 1=PCA criteria, 2=user specified)	(NDAMA)	0
Number of periods per year	(NPY)	1
Number of load groups	(NLG)	1
Number of slab layers	(NLAYER)	1
Bond between two slab layers (0=unbonded, 1=bonded)	(NBOND)	0
Number of slabs	(NSLAB)	2
Number of joints	(NJOINT)	1
Nodal number for checking convergence	(NNCK)	49
Number of nodes for stress printout	(NPRINT)	0
Number of nodes on X axis of symmetry	(NSX)	0
Number of nodes on Y axis of symmetry	(NSY)	0
More detailed printout (0=no, 1=yes)	(MDPO)	0
Number of nodes with different thicknesses of slab layer 1	(NAT1)	0
Number of nodes with different thicknesses of slab layer 2	(NAT2)	0
System of units (0=English, 1=SI)	(NUNIT)	0

Default options are shown by the black dots. If not true, please click the other button.

- (•) with uniform load
- ( ) without uniform load
- (•) with temperature gradient and/or checking contact
- ( ) without temperature gradient and/or checking contact
- ( ) with concentrated load
- (•) without concentrated load

Print OK

Enter Thermal Conditions



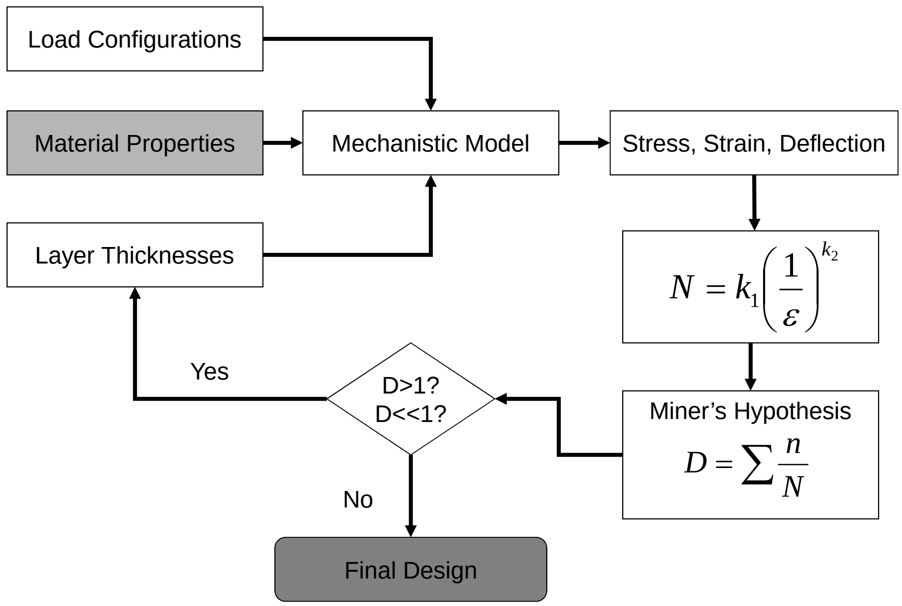
Evaluate Results…

Design – Load and Temperature Effects

For 10 million load repetitions, critical stress is 360 psi

Trial	D, in.	Stress, psi

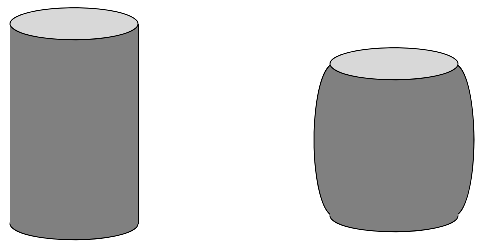
Materials Characterization



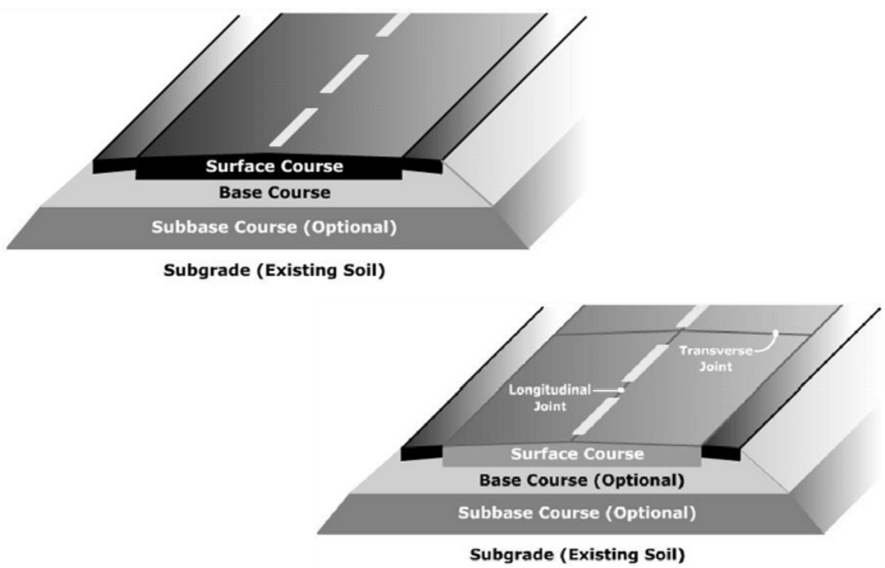
Material Properties

- Required properties defined by
  - Mechanistic models
    - Flexible
    - Rigid
  - Correlation equations
  - Transfer functions
    - Specific distresses

Modulus and Poisson Ratio



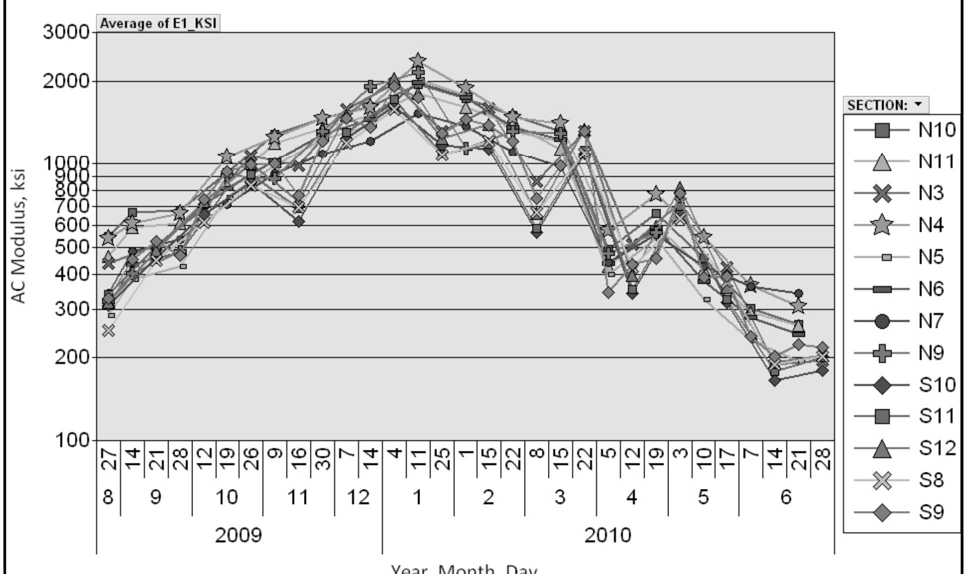
Materials to Consider

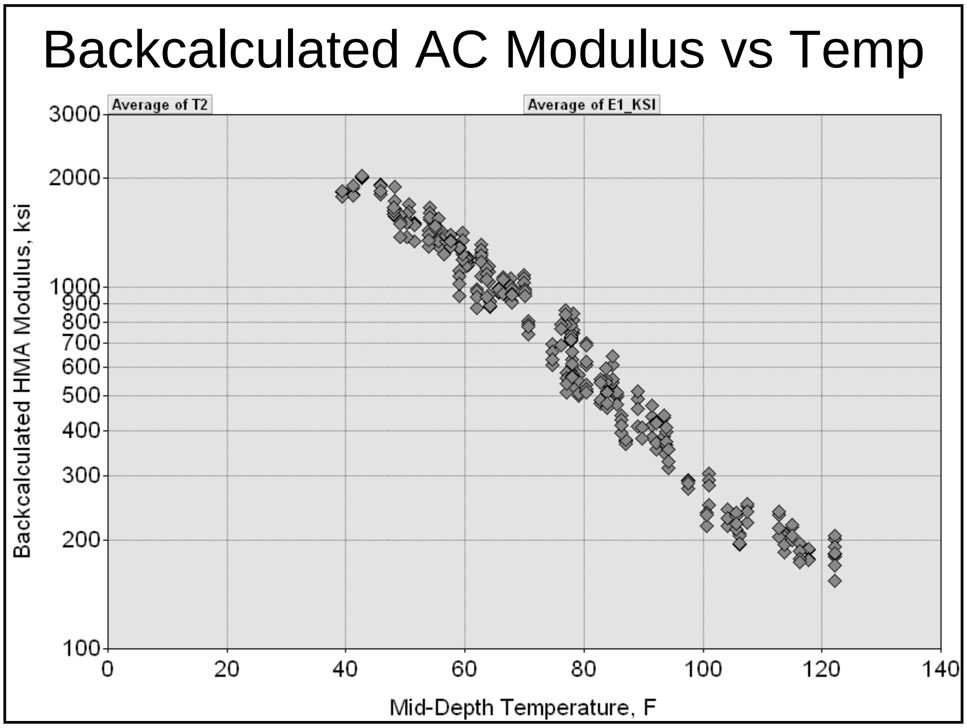


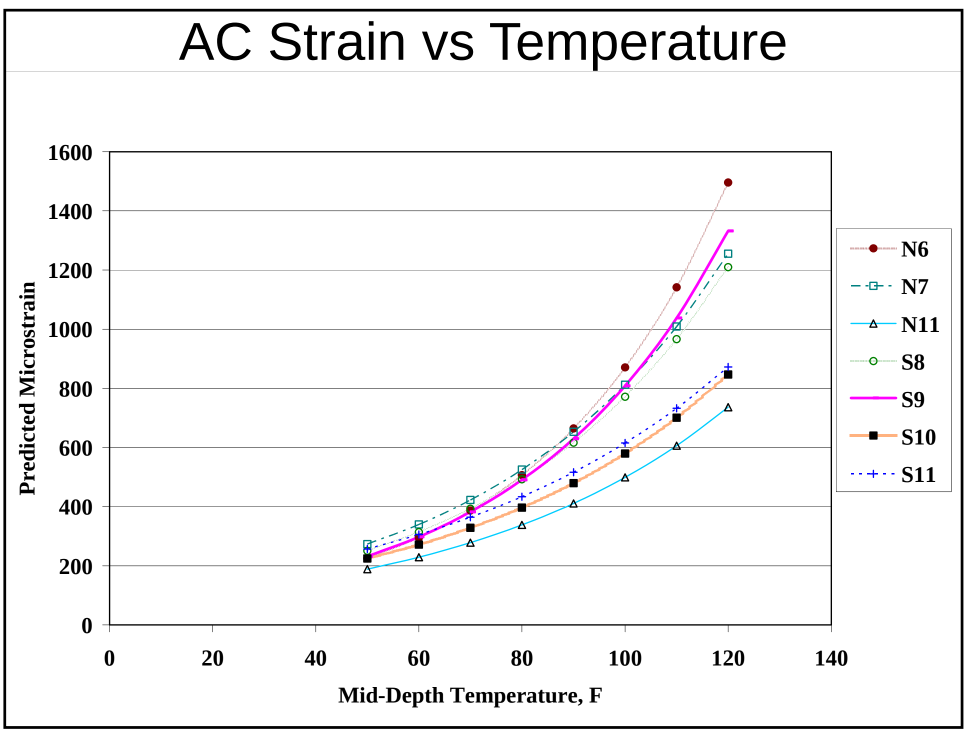
Asphalt Concrete

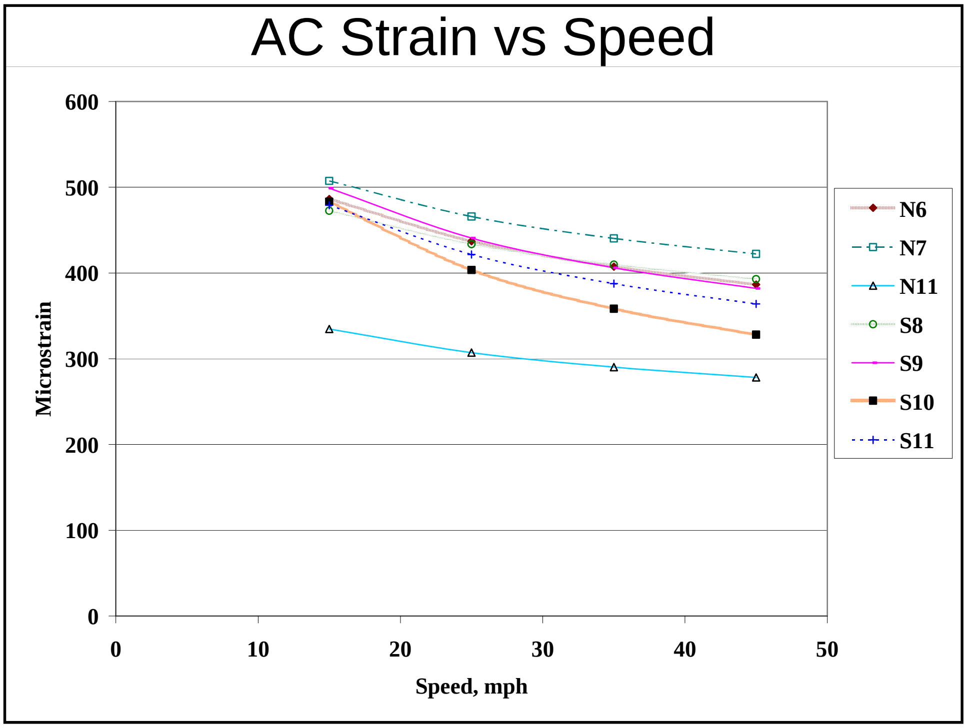
- Consider viscoelastic nature of material
  - Properties change with temperature
  - Properties change with speed of loading
  - Pavement responses change with temp and speed

Backcalculated AC Modulus vs Temp




Backcalculated AC Modulus vs Temp
Average of T2
Average of E1_KSI
Backcalculated HMA Modulus, ksi
3000
2000
1000
900
800
700
600
500
400
300
200
100
0
20
40
60
80
100
120
140
Mid-Depth Temperature, F

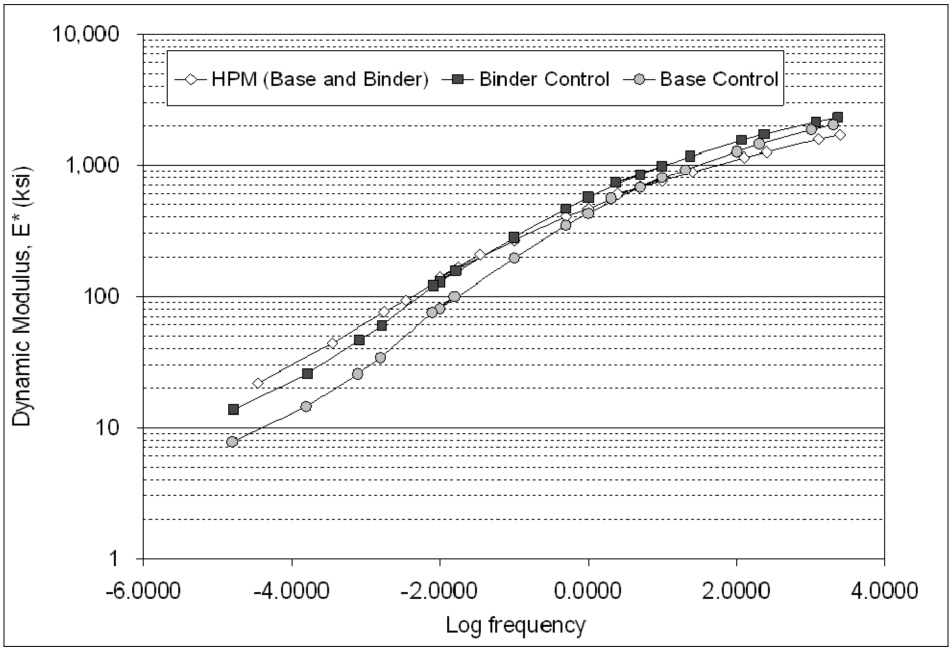

AC Strain vs Temperature
Predicted Microstrain
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
Mid-Depth Temperature, F
N6
N7
N11
S8
S9
S10
S11



Dynamic Modulus (E^*)

- AASHTO TP62-07
- Test at various temperatures and frequencies
- Establish E* master curve
  - Used in M-E design to determine modulus for stress and strain computations

Master Curve



E* Determination

- Dynamic modulus testing can be difficult
  - Low/high temperature
  - Slow/fast loading rates
- Correlations have been developed to estimate E* from other parameters
  - Witczak 1-37A
  - Witczak 1-40D
  - Hirsch

Witczak 1-37A and 1-40D Models

$$\log E^* = -1.25 + 0.029\rho_{200} - 0.0018(\rho_{200})^2 - 0.0028\rho_4 - 0.058V_a - 0.08022\frac{V_{beff}}{V_{beff} + V_a}$$

$$+\frac{3.872 - 0.0021\rho_4 + 0.004\rho_{38} - 0.000017(\rho_{38})^2 + 0.0055\rho_{34}}{1 + e^{(-0.603313 - 0.313351\log(f) - 0.393532\log(\eta))}}$$

$$\log E^* = -0.349 + 0.754\left(\left|G_b^*\right|^{-0.0052}\right)\times\left(\begin{array}{l}6.65 - 0.032\rho_{200} + 0.0027(\rho_{200})^2 + 0.011\rho_4 \\ -0.0001(\rho_4)^2 + 0.006\rho_{38} - 0.00014(\rho_{38})^2 \\ -0.08V_a - 1.06\left(\dfrac{V_{beff}}{V_a + V_{beff}}\right)\end{array}\right)$$

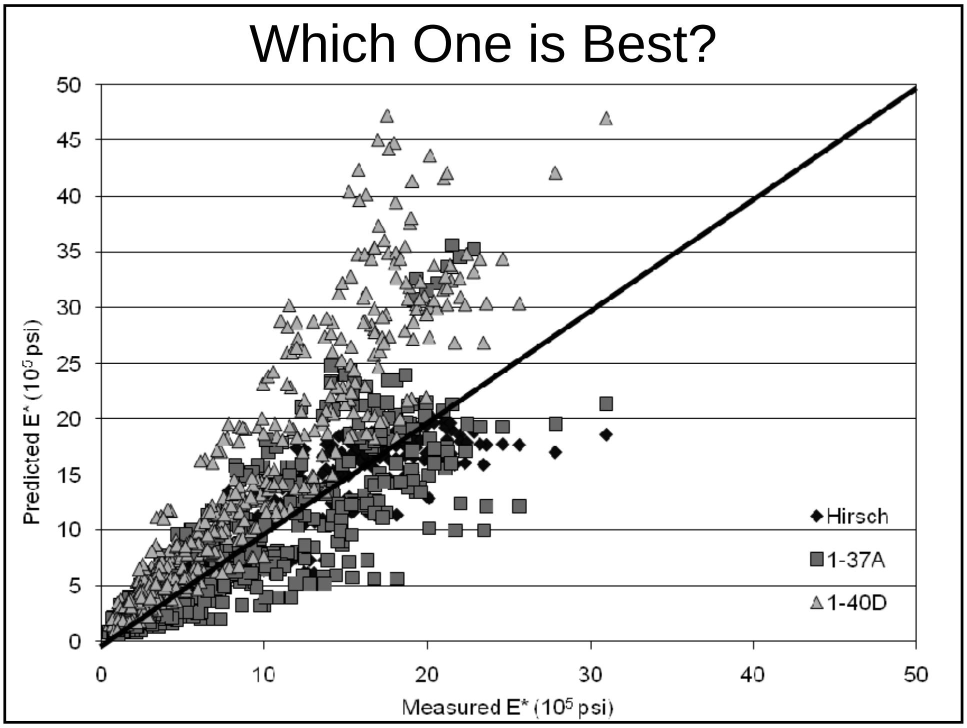
$$+\frac{2.56 + 0.03V_a + 0.71\left(\dfrac{V_{beff}}{V_a + V_{beff}}\right) + 0.012\rho_{38} - 0.0001(\rho_{38})^2 - 0.01\rho_{34}}{1 + e^{(-0.7814 - 0.5785\log\left|G_b^*\right| + 0.8834\log\delta_b)}}$$

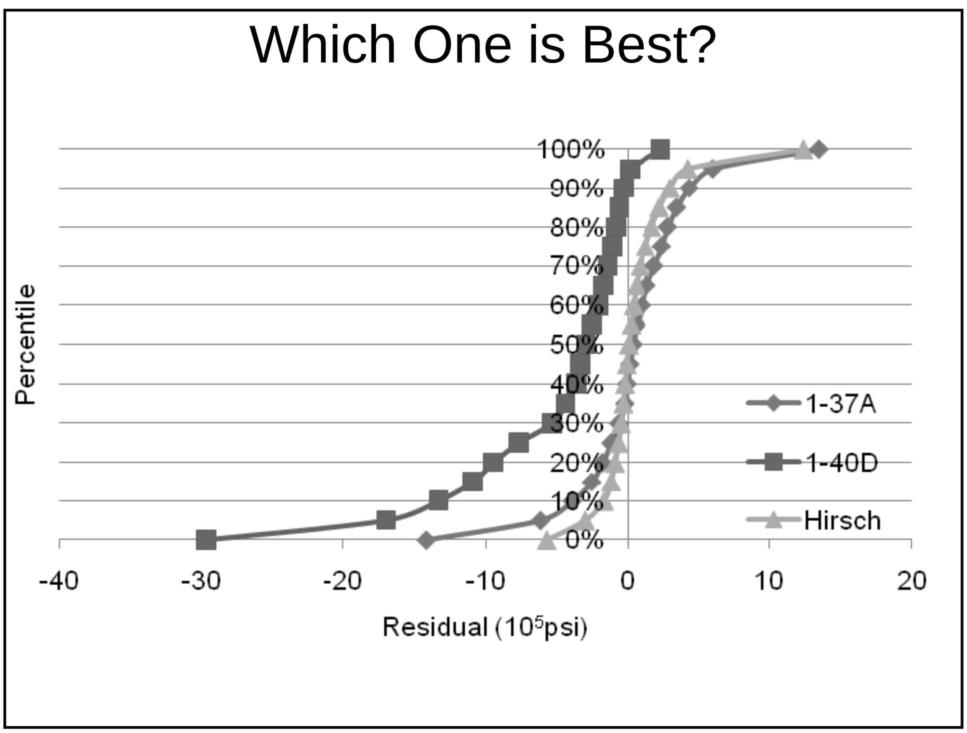
Hirsch Model

$$\left|E^*\right|_{mix} = Pc\left[4{,}200{,}000\left(1 - \frac{VMA}{100}\right) + 3\left|G^*\right|_b\left(\frac{VFA \times VMA}{10{,}000}\right)\right] +$$

$$\left(1 - PC\right)\left[\frac{1 - \left(VMA/100\right)}{4{,}200{,}000} + \frac{VMA}{3VFA\left|G^*\right|_b}\right]^{-1}$$

$$Pc = \frac{\left(20 + \dfrac{VFA \times 3\left|G^*\right|_b}{VMA}\right)^{0.58}}{650 + \left(\dfrac{VFA \times 3\left|G^*\right|_b}{VMA}\right)^{0.58}}$$


Which One is Best?
Predicted E* (10^5 psi)
Measured E* (10^5 psi)
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
Hirsch
1-37A
1-40D


Which One is Best?
Percentile
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
-40
-30
-20
-10
0
10
20
Residual (10^5psi)
1-37A
1-40D
Hirsch

Asphalt Testing

Final Report
ALDOT Project 930-685

GUIDANCE FOR M-E PAVEMENT DESIGN IMPLEMENTATION

Table 3.2 HMA and Asphalt Binder Tests

Test	Name	MEPDG Input	Current ALDOT Practice?
ASTM D 3497	Standard Test Method for Dynamic Modulus of Asphalt Mixtures	Asphalt mix - level 1: dynamic modulus information	No
AASHTO T 27	Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates	Asphalt mix - levels 2 & 3: gradation information	Yes
AASHTO T 315	Standard Method of Test for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer	Asphalt binder - levels 1 & 2: dynamic complex modulus and phase angle values	Yes

Concrete

- Consider elasticity, strength and thermal properties of concrete
  - Stresses under load
  - Curling/Warping
  - Expansion Contraction

Concrete Strength and Elasticity

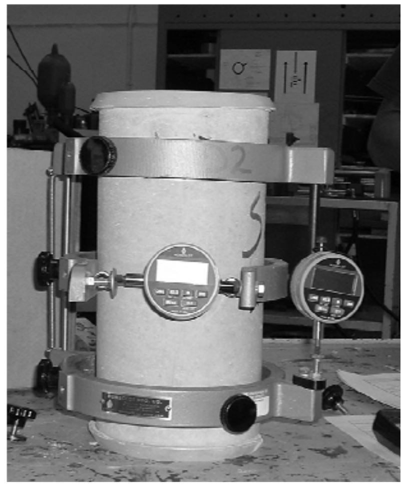
- Compressive Strength
  - ASTM C39
- Modulus of Elasticity
  - ASTM C469
- Modulus of Rupture
  - ASTM C78 (AASHTO T97)

Compressive Strength


WSDOT Pavement Guide

Modulus of Elasticity (ASTM C469)

http://civilx.unm.edu/laboratories_ss/pcc/MEasuring%20Device.JPG



http://civilx.unm.edu/laboratories_ss/pcc/comptension.JPG

Modulus of Rupture (ASTM C78)

http://civilx.unm.edu/laboratories_ss/pcc/mor_setup.JPG

http://civilx.unm.edu/laboratories_ss/pcc/mor_brokenspec.JPG

PCC - Correlations

$$S_c = k_1 \sqrt{f_c}$$ 8 ≤ k1 ≤ 10

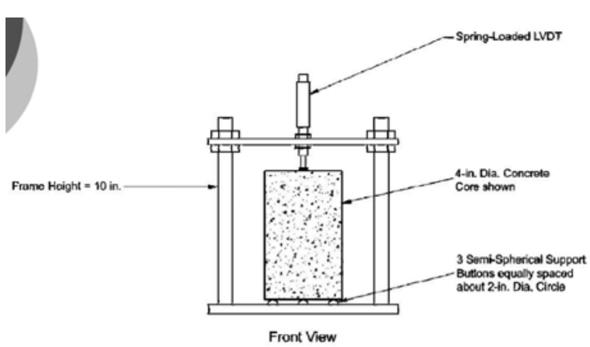
$$S_c = \frac{43.5E_c}{10^6} + 488.5$$ (Eres, 1987)

$$f_t = 6.5\sqrt{f_c}$$ (ACI)

$$E_c = 57{,}000\sqrt{f_c}$$ (ACI)

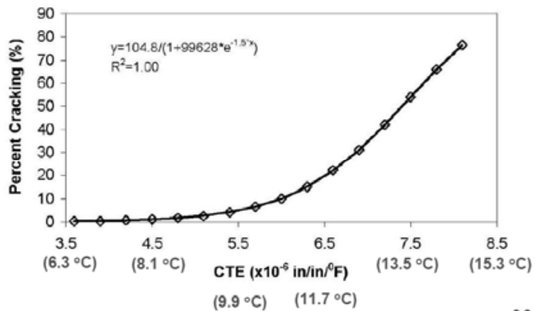
Concrete Thermal Properties

- Coefficient of thermal expansion/contraction
  - CTE
  - AASHTO TP60
    - Standard Method for CTE of Hydraulic Cement Concrete

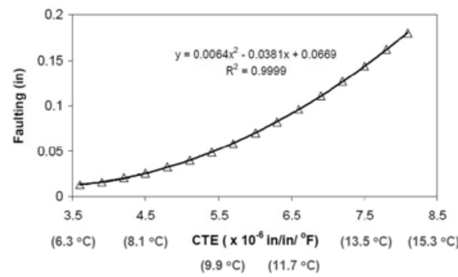


http://design.transportation.org/Documents/ConcreteCTEConcernsMay212009.pdf

Why is CTE Important?



Effect of CTE variability of Concrete Pavement Performance as predicted using the Mechanistic - Empirical Pavement Design Guide, Jussara Tanesi, M. Emin Kutay, Ala Abbas, and Richard Meininger, Transportation Research Board 2007.



Effect of CTE variability of Concrete Pavement Performance as predicted using the Mechanistic - Empirical Pavement Design Guide, Jussara Tanesi, M. Emin Kutay, Ala Abbas, and Richard Meininger, Transportation Research Board 2007.

Provisional CTE's

Coarse Aggregate Type	CTE Range ($x10^{-6}$ in./in./°F)	Average CTE ($x10^{-6}$ in./in./°F)
Siliceous River Gravel	6.82 – 7.23	6.95
Granite	5.37 – 5.91	5.60
Dolomitic Limestone	5.31 – 5.66	5.52

Sakyi-Bekoe, 2008

PCC Tests

TABLE 3.3 PCC Tests.

Test	Name	MEPDG Input	Current ALDOT Practice?
ASTM C 469	Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression	Poisson's ratio of concrete	Capable, but not routine
AASHTO TP 60	Standard Test Method for the Coefficient of Thermal Expansion of Hydraulic Cement Concrete	Coefficient of thermal expansion	No
ASTM E 1952	Standard Test Method for Thermal Conductivity and Thermal Diffusivity by Modulated Temperature Differential Scanning Calorimetry	Thermal conductivity	No
ASTM D 2766	Standard Test Method for Specific Heat of Liquids and Solids	Heat capacity	No
AASHTO T 160	Standard Method of Test for Length Change of Hardened Hydraulic Cement Mortar and Concrete	Shrinkage inputs	Yes
ASTM C 78	Standard Test Method for Flexural Strength of Concrete	Level 1 - flexural strength (modulus of rupture)	Capable, but not routine
ASTM C 39	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens	Level 2 - compressive strength	Yes
AASHTO T121	Standard Method of Test for Mass per Cubic Meter (Cubic Foot), Yield, and Air Content (Gravimetric) of Concrete	Concrete Unit Weight	Routinely done in Mix Design Phase; not routinely done in field

Unbound Materials

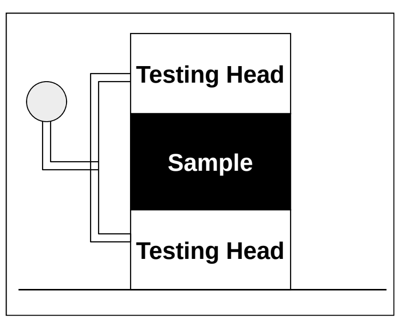
- Resilient modulus and Poisson ratio are critical
- Many approaches to measuring “strength”
- All are governed by Mohr-Coulomb behavior of material

Mohr-Coulomb Behavior

- Granular materials fail due to combination of normal and shear stresses
  - Characterize strength by shear resistance
    - $\tau = c + \sigma \tan\phi$

R-Value

- Soils, granular media tested by stabilometer
  - Closed system triaxial test
- Measures internal friction of material

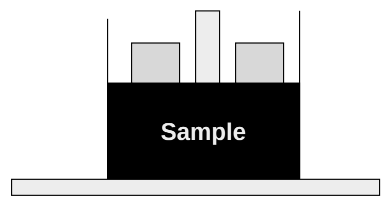


$$R = 100 - \frac{100}{\frac{2.5}{D_2}\left[\frac{P_v}{P_h} - 1\right] + 1}$$

What is the R-Value if the horizontal and vertical pressures are equal?

California Bearing Ratio - CBR

- Soil and granular media penetration test
- Test any soil and divide penetration value to that of a standard
- Lower penetration =
- Dependent upon soil texture, moisture, density



Resilient Modulus, M_R

- Primary input for pavement design
  - Unbound material characterization
  - Repetitive loading

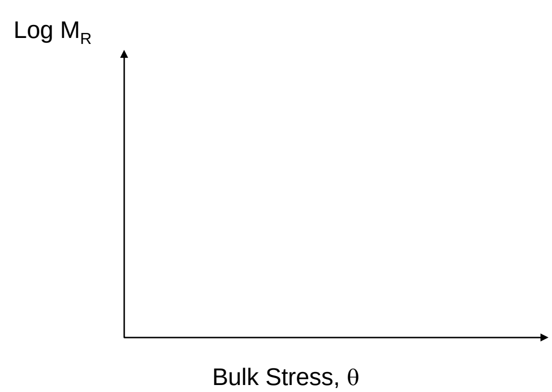
$$M_R = \frac{\sigma_d}{\varepsilon_r}$$

σ_d = deviatoric stress
ε_r = recoverable strain

M_R - Schematic

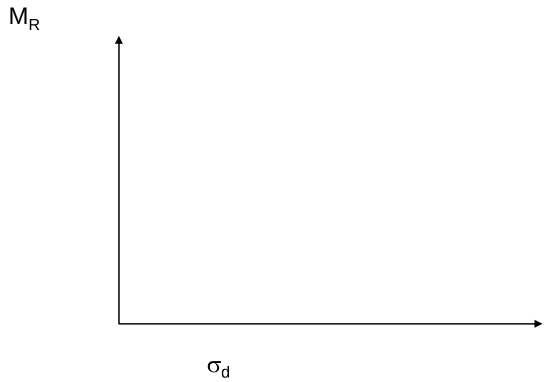
M_R – Granular Materials

- Effect of confining pressure, σ_3



M_R – Fine Grained Soils

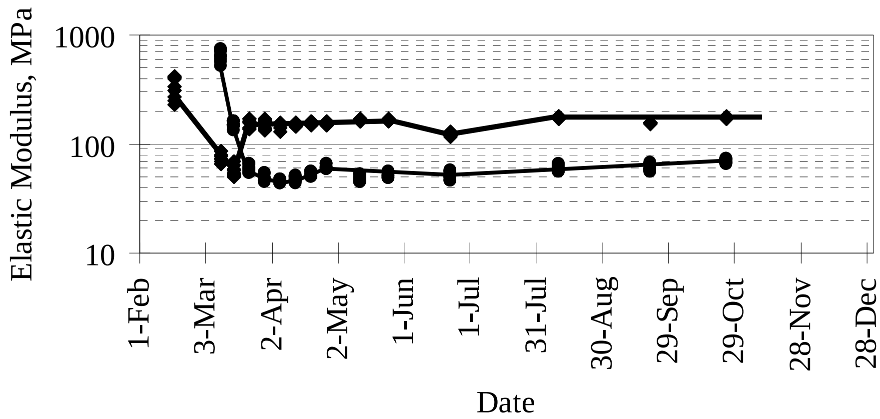
- Influenced by deviatoric stress



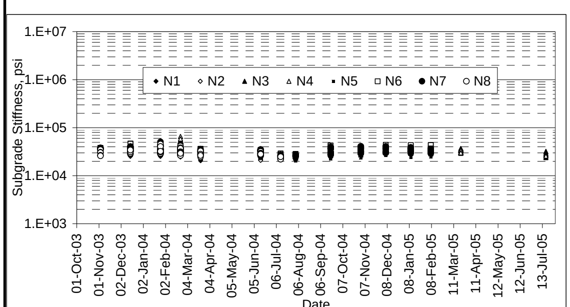
Unbound Material Correlations

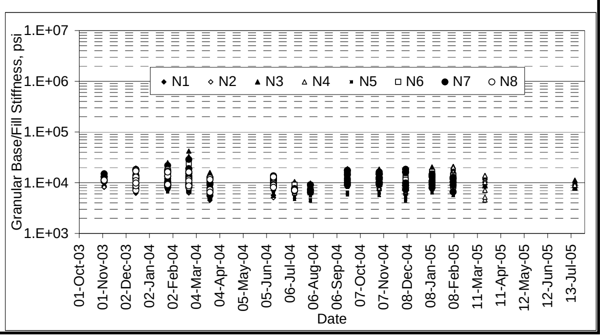
Strength/Index Property	Model	Comments	Test Standard
CBR	$M_r = 2555(CBR)^{0.64}$	CBR = California Bearing Ratio, percent	AASHTO T193—The California Bearing Ratio
R-value	$M_r = 1155 + 555R$	R = R-value	AASHTO T190—Resistance R-Value and Expansion Pressure of Compacted Soils
AASHTO layer coefficient	$M_r = 30000\left(\frac{a_i}{0.14}\right)$	a_i = AASHTO layer coefficient	AASHTO Guide for the Design of Pavement Structures (1993)
PI and gradation*	$CBR = \frac{75}{1 + 0.728(wPI)}$	wPI = P200*PI P200= percent passing No. 200 sieve size PI = plasticity index, percent	AASHTO T27—Sieve Analysis of Coarse and Fine Aggregates AASHTO T90—Determining the Plastic Limit and Plasticity Index of Soils
DCP*	$CBR = \frac{292}{DCP^{1.12}}$	CBR = California Bearing Ratio, percent DCP =DCP index, in/blow	ASTM D6951—Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications

Seasonal Variations



Seasonal Variations



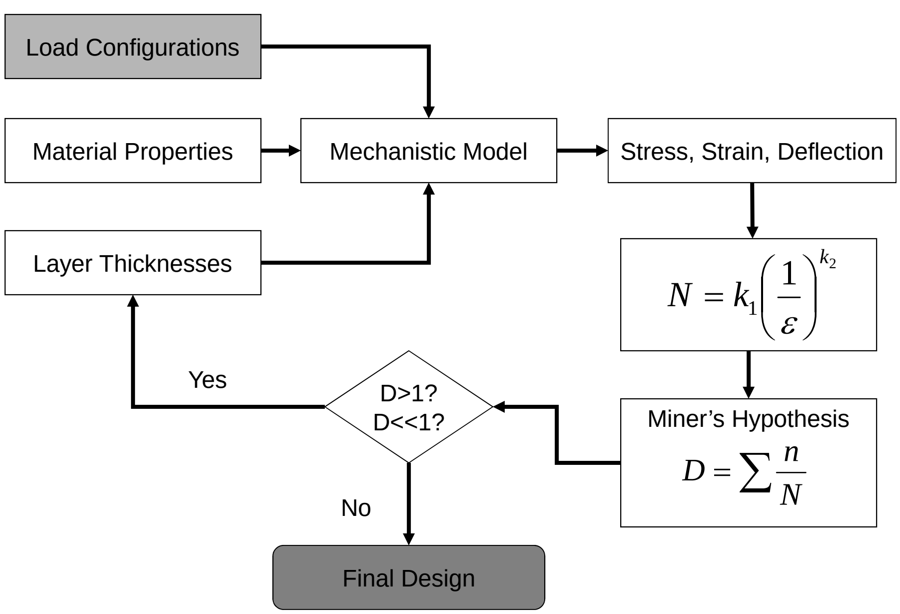


Unbound Material Testing

TABLE 3.5 Base and Subgrade Material Tests

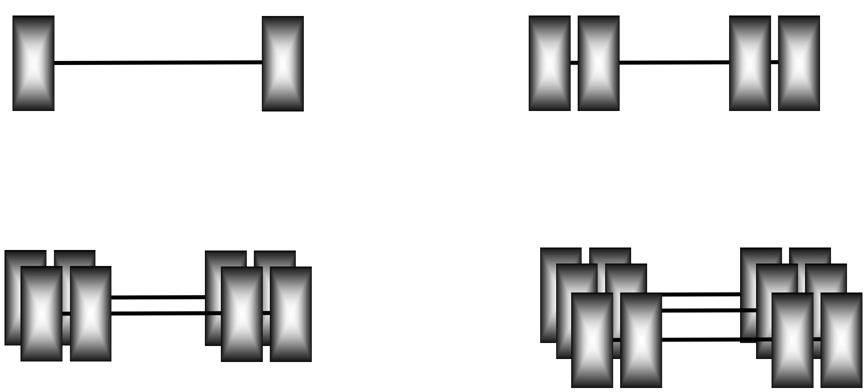
Test	Name	MEPDG Input	Current ALDOT Practice?
ASTM C 469	Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression	Chemically stabilized materials - lean concrete or cement-treated aggregate (level 1)	No-but could be tested by PCC Group
AASHTO T 307	Standard Method of Test for Determining Resilient Modulus of Soils and Aggregate Materials	Chemically stabilized materials - lime stabilized soils (level 1)	Yes
AASHTO T 22	Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens	Chemically stabilized materials - lean concrete or cement-treated aggregate correlation equation (level 2)	No - but could be tested by PCC group
ASTM D 1633	Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders	Chemically stabilized materials - soil cement correlation equation (level 2)	No - but could be tested by PCC group
ASTM C 593	Standard Specification for Fly Ash and Other Pozzolans for Use with Lime for Soil Stabilization	Chemically stabilized materials - lime-cement-flyash correlation equation (level 2)	No
ASTM D 5102	Standard Test Method for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures	Chemically stabilized materials - lime stabilized soils correlation equation (level 2)	Yes

Traffic Characterization

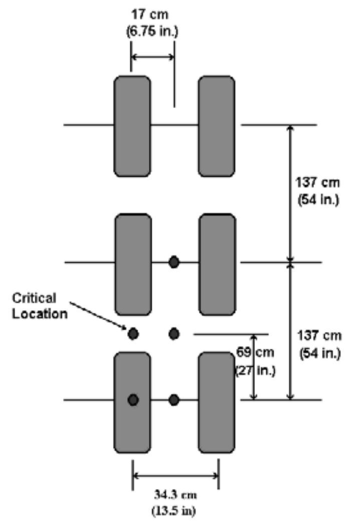


Axle Load Spectra

- Traffic characterized by
  - Axle types and frequency
  - Load magnitude distributions



Load Definition for Pavement Modeling



Traffic Inputs and Axle Load Spectra Characterization

- Key data needed
  - Current traffic volume (AADTT)
  - Projected traffic growth (% growth)
  - Or, future traffic volume (AADTT)
  - Distribution by vehicle class
  - Distribution of axle types/vehicle
    - Single, tandem, tridem, quad, steer
      - Distribution of weights (axle loads) within axle type

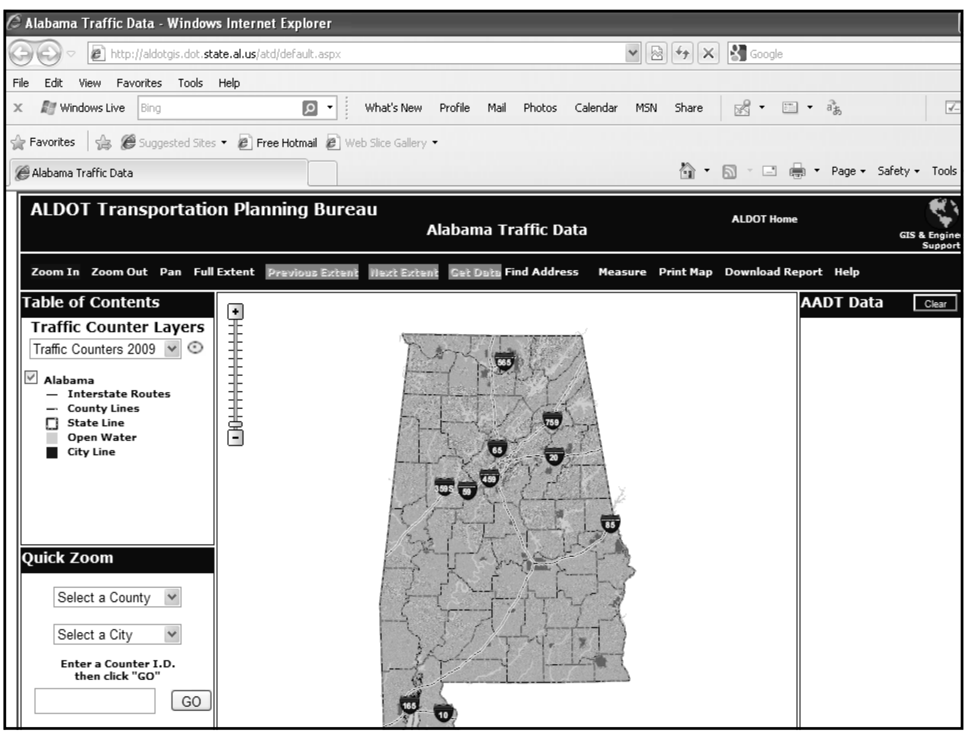
Traffic Inputs: Resources

ALDOT Traffic Data online

- Near bottom right of ALDOT's home page, click on "Traffic Data"

ALDOT Bureau of Transportation Planning

- For project-specific requests



ALDOT Traffic Data Online: Example

So, what is here that we can really use??

Counter ID	IN-41-526
Station	526
County	41
City	N/A
Route	85
Milepoint	47.47
AADT 2009	31290
AADT 2008	30980
AADT 2007	30730
AADT 2006	30610
AADT 2005	29770
AADT 2004	28890
AADT 2003	27890
AADT 2002	27040
AADT 2001	25920
K	11
D	65
TDHV	20
TADT	27
Heavy	85
Functional Class	1
Description	N/A

ALDOT Traffic Data (available through Transportation Planning Bureau)

AADTT (truck traffic) at over 5,000 locations statewide…

- About 120 permanent/continuous count stations
- About 2,100 “temporary” count stations (to meet FHWA Highway Performance Monitoring system requirements)
- About 3,000 other locations

ALDOT Traffic Data
(available through Transportation Planning Bureau)

Monthly adjustment factors:

- Currently produced for the permanent count stations only for all heavy vehicles as a group (classes 4-13)
- Can be derived by vehicle class but not currently done

ALDOT Traffic Data
(available through Transportation Planning Bureau)

Vehicle class distributions:

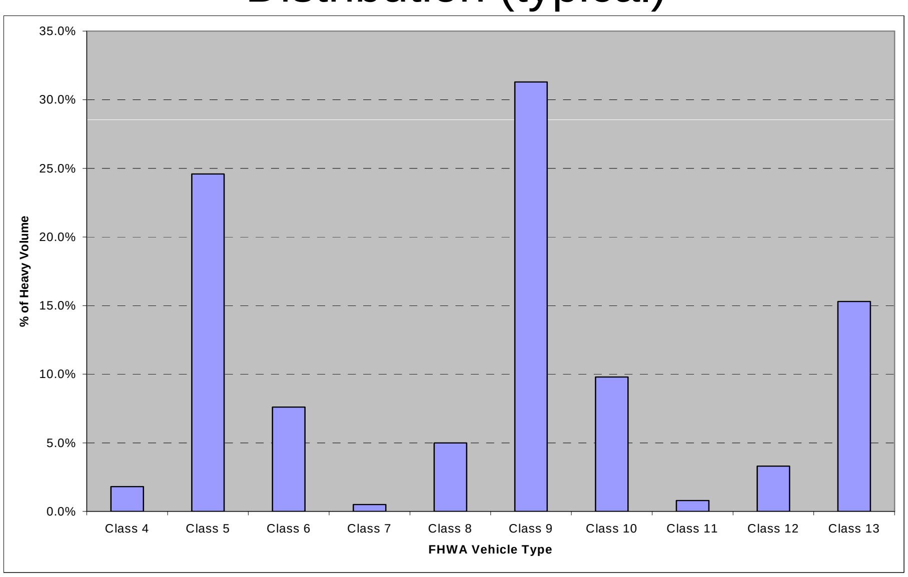
- Currently produced for all 2,100 HPMS sites (based solely on axle spacing)

Vehicle Classification: FHWA "Scheme F"

1. Motorcycles	2. Passenger Cars	3. 2-Axle, 4-Tire Single Units, Pick-up or Van	
4. Buses	5. 2-Axle, 6 Tire Single Units	6. 3-Axle, Single Units	7. 4 or More Axles, Single Unit
8. 3 to 4 Axles, Single Trailer (2S1, 2S2, 3S1)	9. 5 Axles, Single Trailer (3S2, 3S2 split)	10. 6 or More Axles, Single Trailer (3S3, 3S4)	
11. 5 or Less Axles, Multi-Trailers (2S1-2)	12. 6 Axles, Multi-Trailers (2S2-2, 3S1-2)	13. 7 or More Axles, Multi-Trailers (3S2-2)	

129

Rural Interstate – Vehicle Class Distribution (typical)



ALDOT Traffic Data
(available through Transportation Planning Bureau)

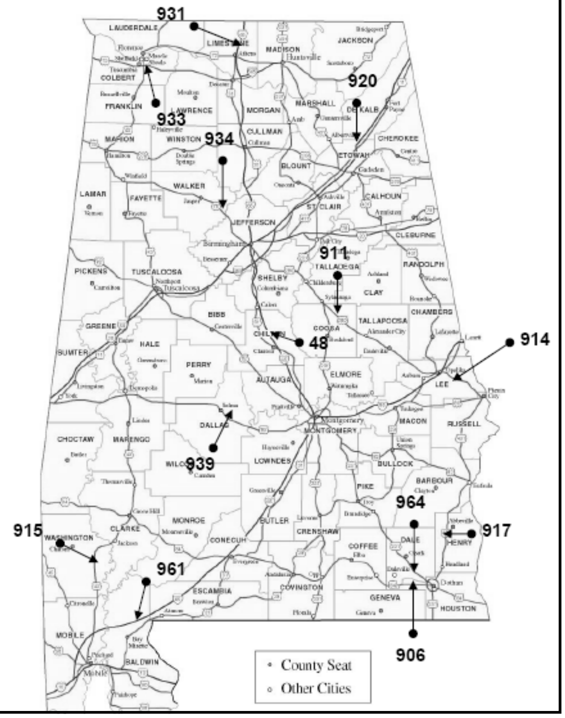
Axle load distributions (load spectra):
- Not currently generated
- A resource does exist…ALDOT WIM sites

ALDOT WIM Sites

ALDOT currently maintains 12 WIM (weigh-in-motion) sites around the state

WIM sites are a critical source of axle load spectra information!

ALDOT
WIM Sites
(2001)



Axle Load Distributions

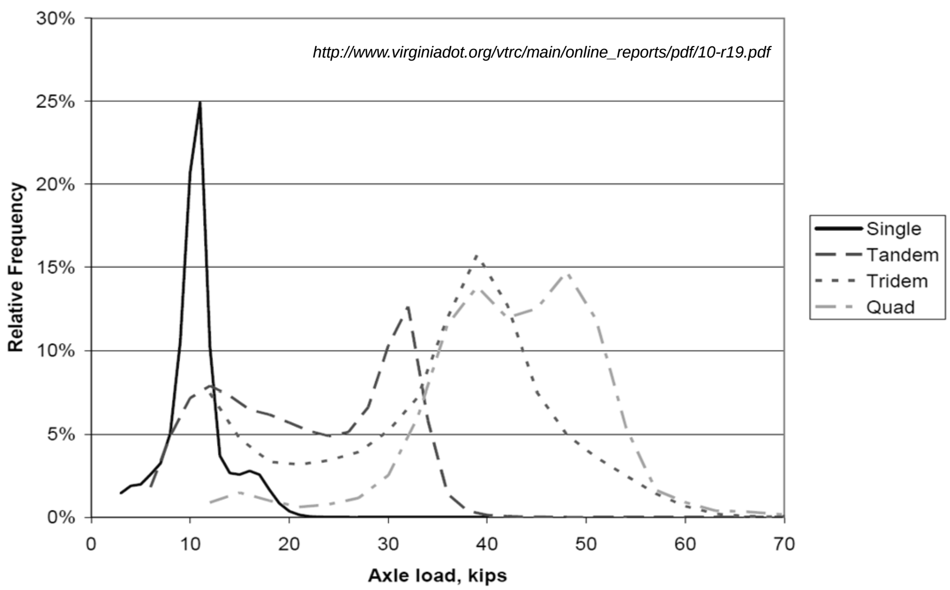
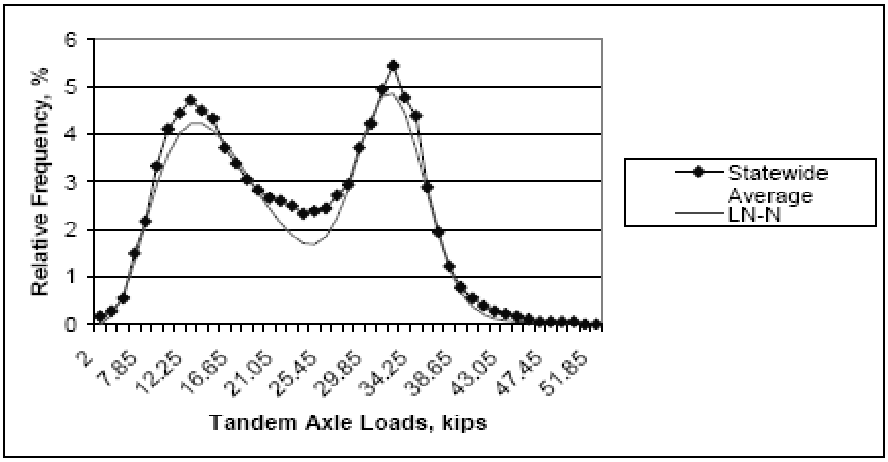


Figure 3. Statewide Axle-load spectra from All Vehicle Classifications

Axle Load Distribution:
ALDOT statewide average (2001), tandem axle groups



Axle Load Distribution:
ALDOT station 911 (2001), single axles

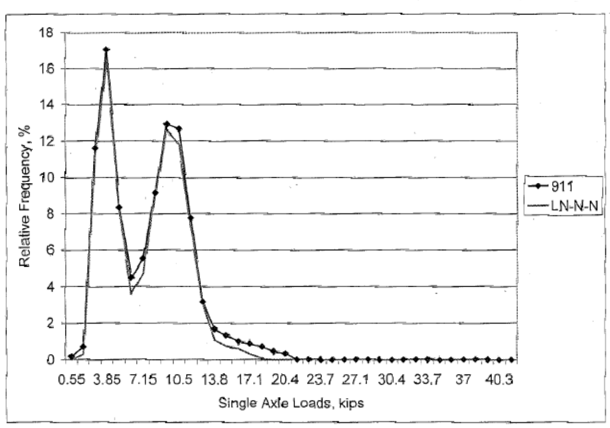


Figure B.5 Station 911, Single Axles

Axle Load Distribution:
ALDOT station 911 (2001), tandem axle groups

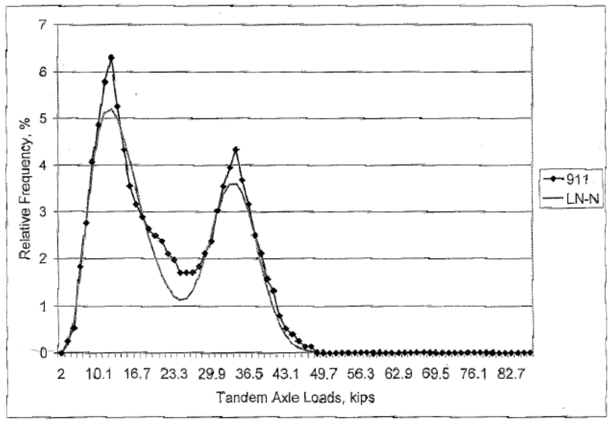
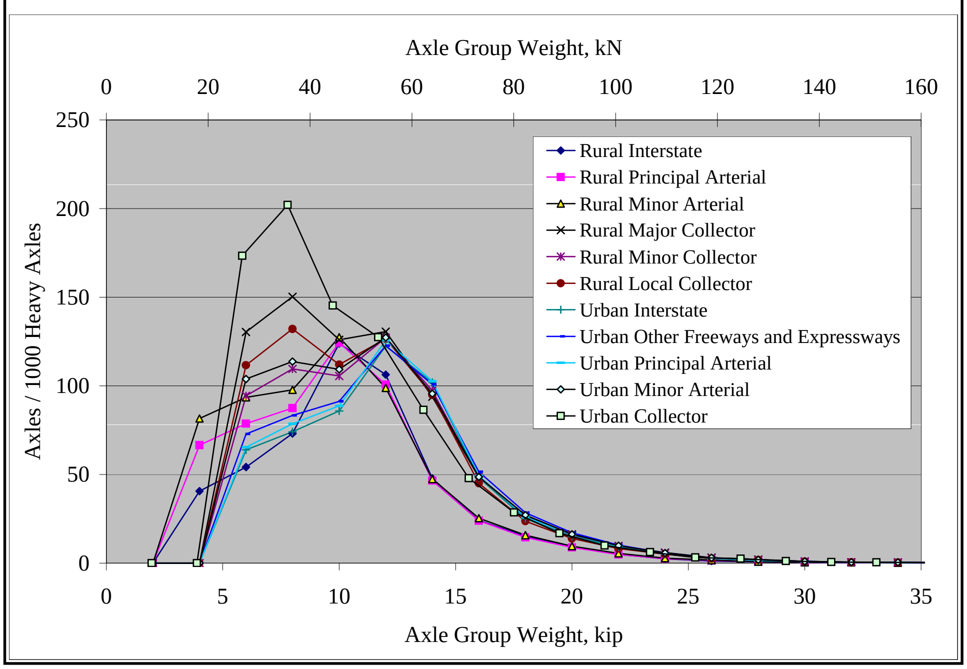
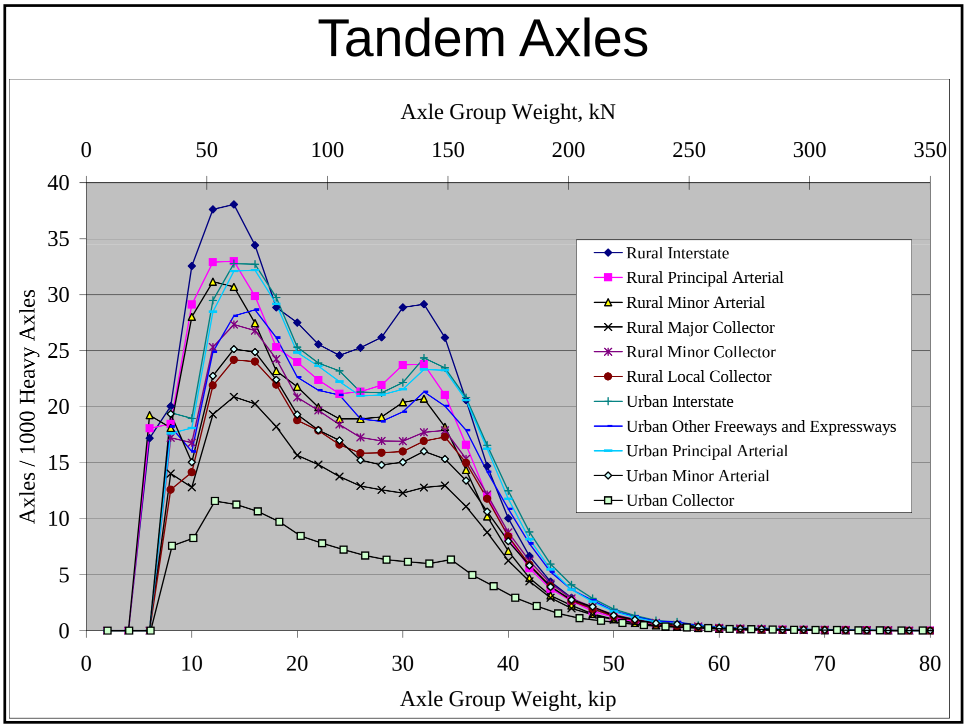
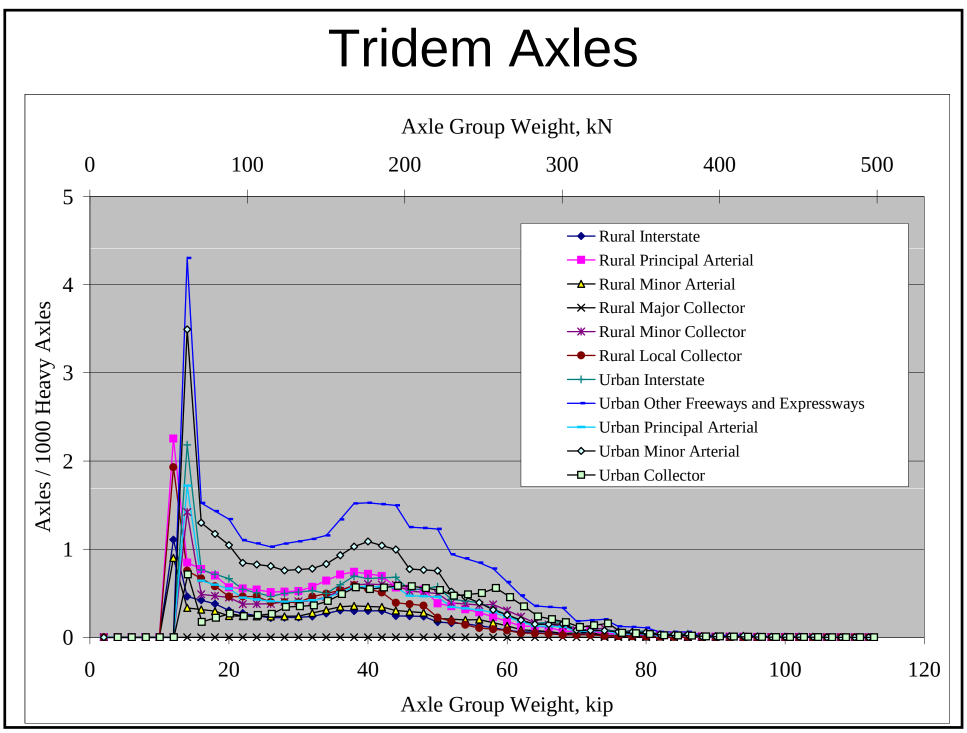


Figure B.6 Station 911, Tandem Axles

Single Axles




Tandem Axles
Axle Group Weight, kN
0
50
100
150
200
250
300
350
Axles / 1000 Heavy Axles
40
35
30
25
20
15
10
5
0
Rural Interstate
Rural Principal Arterial
Rural Minor Arterial
Rural Major Collector
Rural Minor Collector
Rural Local Collector
Urban Interstate
Urban Other Freeways and Expressways
Urban Principal Arterial
Urban Minor Arterial
Urban Collector
0
10
20
30
40
50
60
70
80
Axle Group Weight, kip


Tridem Axles
Axle Group Weight, kN
0
100
200
300
400
500
Axles / 1000 Heavy Axles
5
4
3
2
1
0
Rural Interstate
Rural Principal Arterial
Rural Minor Arterial
Rural Major Collector
Rural Minor Collector
Rural Local Collector
Urban Interstate
Urban Other Freeways and Expressways
Urban Principal Arterial
Urban Minor Arterial
Urban Collector
0
20
40
60
80
100
120
Axle Group Weight, kip

Study of traffic inputs

- ALDOT-sponsored research study getting underway at Auburn will:
  - Develop axle load distributions, vehicle class distributions, and monthly adjustment factors from WIM sites
  - Develop vehicle class distributions from WIM sites
    - Already generated by ALDOT from permanent count stations
  - Develop monthly adjustment factors from WIM sites and permanent count stations

Study of traffic inputs

- ALDOT-sponsored research study getting underway at Auburn will:
  - Determine if the default values provided in the MEPDG are appropriate, or should regional and/or site-specific factors be used
  - Examine impacts of differences between MEPDG defaults and state/regional/site factors on pavement designs

Prior study of traffic inputs

- ALDOT-sponsored research completed in 2005 at Auburn found:
  - A statewide average axle load distribution was generally appropriate (as opposed to site-specific information)
- However…
  - This was based on 2001 data
  - This was based on only 12 sites!
  - This was using the 1993 AASHTO method (ESALs)
  - This did not compare Alabama data with national average

Looking ahead:
Traffic and the MEPDG software

- What capabilities will the MEPDG software offer (with respect to traffic inputs)?

Traffic Inputs in the MEPDG Software

Traffic inputs are grouped into the following four categories in the MEPDG:

- Traffic volume parameters
- Traffic volume adjustment factors
- Axle load distribution factors
- General traffic inputs

MEPDG Traffic Inputs: Traffic Volume Parameters

- Initial two-way AADTT (annual average daily truck traffic)
  - Default values are not provided (of course!)

- Number of lanes in the design direction
- Percent of trucks in design direction
- Percent of trucks in design lane
- Operational speed

Default values are provided for these…

MEPDG Traffic Inputs:
Traffic Volume Adjustment Factors

- Monthly adjustment factors
- Hourly distribution
- Vehicle class distribution
- Growth rate

Default values are provided for all of these…

MEPDG Traffic Inputs:
Axle Load Distribution Factors

- Daily distribution of axle loads for each category of axle group (single, tandem, tridem, and quad)
  - Default values are provided

However, are they appropriate for use in Alabama?

MEPDG Traffic Inputs:
General Traffic Inputs

- It's a long list…
  - – Mean wheel location, wheel wander, tire pressure, dual tire spacing,…

Default values
are provided for
all of these…

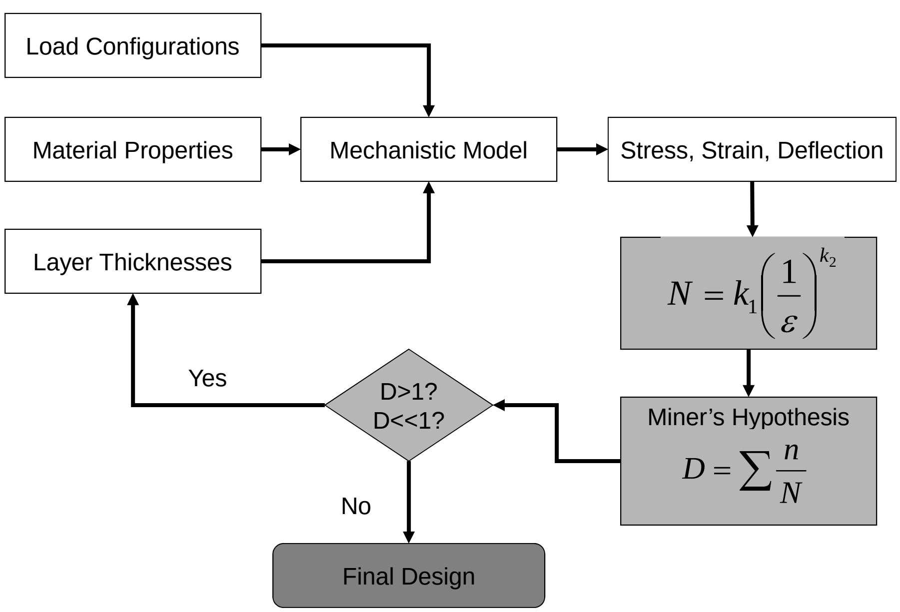
MEPDG Traffic Inputs:
Critical Decision Points

- Need: AADTT (truck traffic)
  - – Either current and growth rate, or
  - – Future / design year
- Other key items for which use of default values may not be appropriate:
  - – Vehicle class distributions
  - – Monthly adjustment factors
  - – Axle load distributions

Traffic Summary

- Traffic data can be highly regional and site specific
- When possible/warranted, need to develop site-specific information
- Prior study recommended using statewide averages in some cases

Performance Prediction



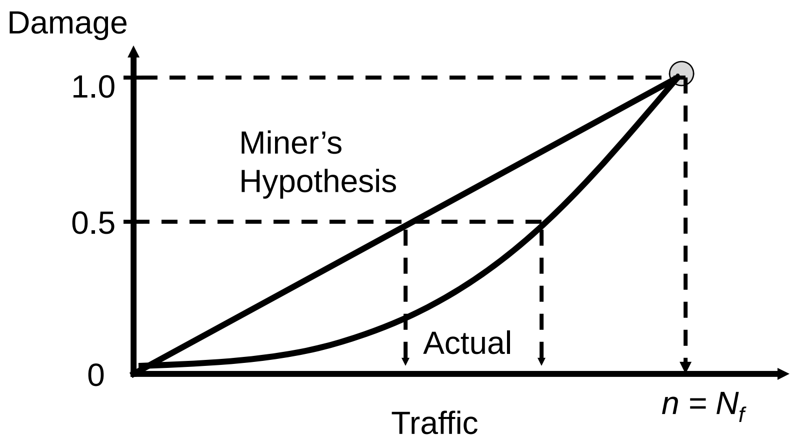
Miner's Hypothesis

- Provides the ability to sum damage for a specific distress type
- $D = \Sigma\, n_i/N_i \leq 1.0$

where n_i = actual number of loads during condition i

N_i = allowable number of loads during condition i

How Does Damage Accumulate?

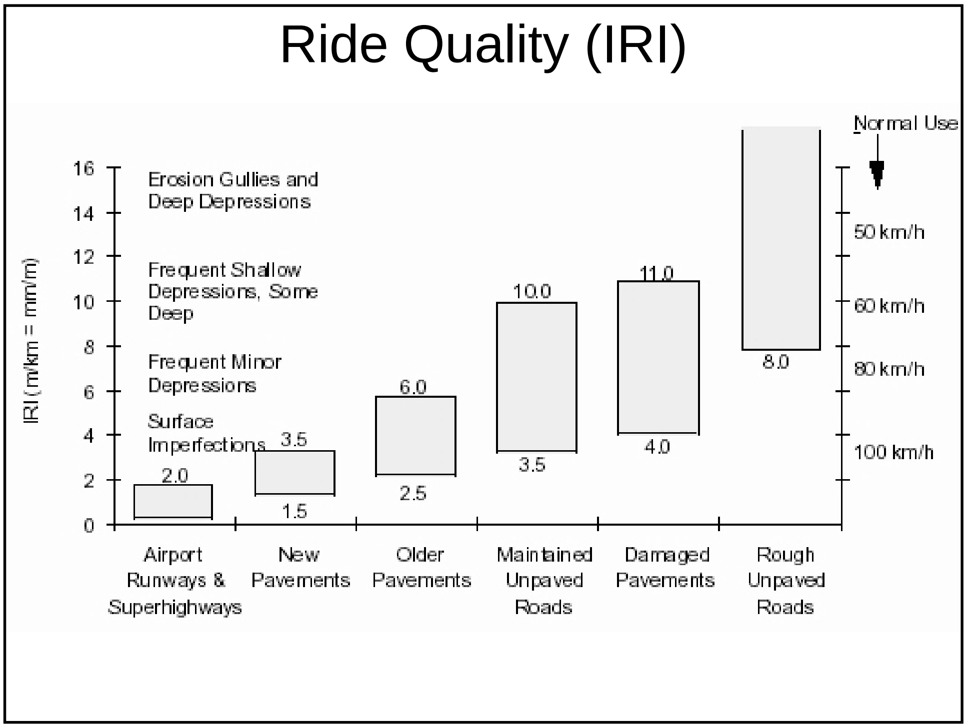


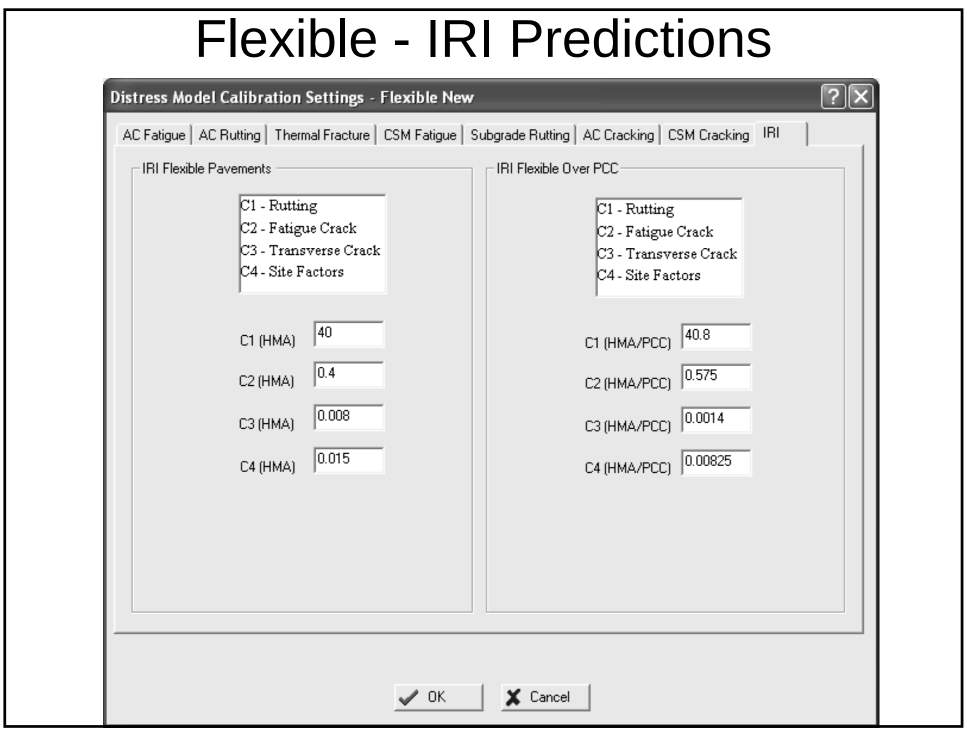
Performance Prediction

- Transfer functions for each distress
- Require local calibration
- Predict performance vs time

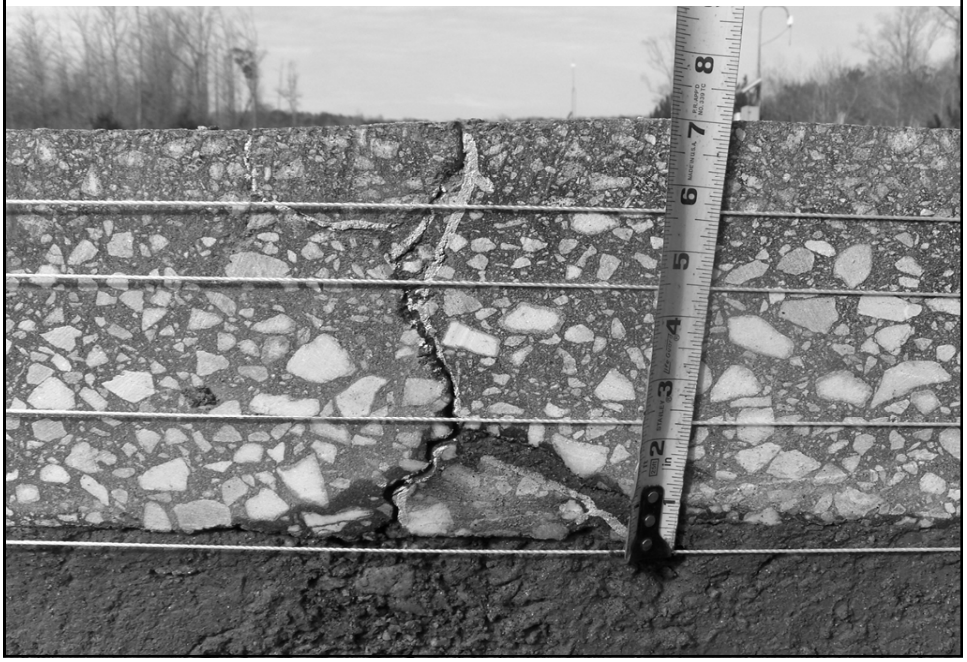
Flexible Pavement Predictions

- Ride quality
- Top-down cracking
- Bottom-up fatigue cracking
- AC thermal fracture
- Total pavement rutting
- AC rutting

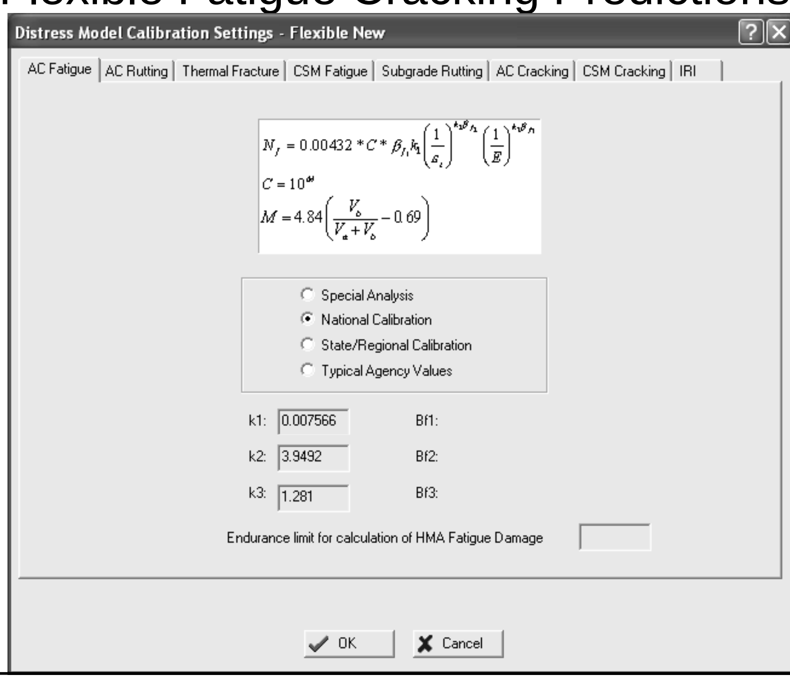

Ride Quality (IRI)
Normal Use
16
14
12
10
8
6
4
2
0
IRI (m/km = mm/m)
Erosion Gullies and Deep Depressions
Frequent Shallow Depressions, Some Deep
Frequent Minor Depressions
Surface Imperfections
2.0
3.5
1.5
6.0
2.5
10.0
3.5
11.0
4.0
8.0
50 km/h
60 km/h
80 km/h
100 km/h
Airport Runways & Superhighways
New Pavements
Older Pavements
Maintained Unpaved Roads
Damaged Pavements
Rough Unpaved Roads


Flexible - IRI Predictions
Distress Model Calibration Settings - Flexible New
AC Fatigue
AC Rutting
Thermal Fracture
CSM Fatigue
Subgrade Rutting
AC Cracking
CSM Cracking
IRI
IRI Flexible Pavements
C1 - Rutting
C2 - Fatigue Crack
C3 - Transverse Crack
C4 - Site Factors
C1 (HMA) 40
C2 (HMA) 0.4
C3 (HMA) 0.008
C4 (HMA) 0.015
IRI Flexible Over PCC
C1 - Rutting
C2 - Fatigue Crack
C3 - Transverse Crack
C4 - Site Factors
C1 (HMA/PCC) 40.8
C2 (HMA/PCC) 0.575
C3 (HMA/PCC) 0.0014
C4 (HMA/PCC) 0.00825
OK
Cancel

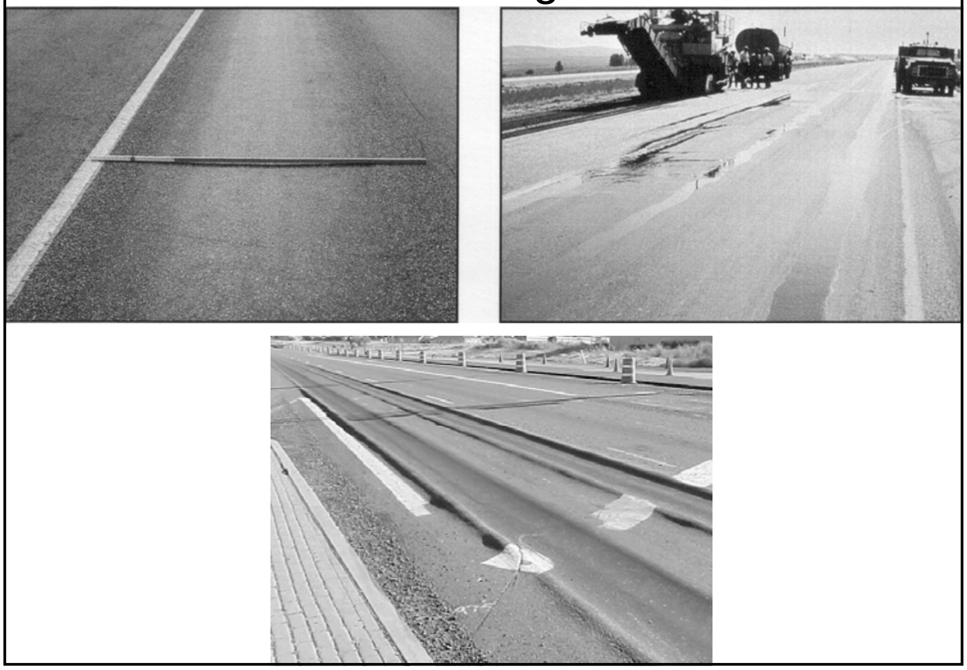

Fatigue Cracking



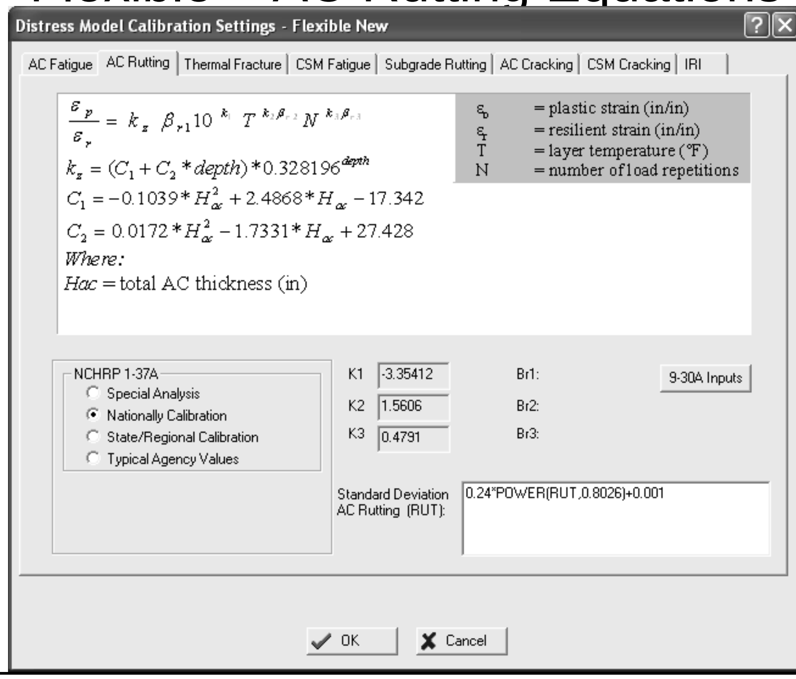
Flexible Fatigue Cracking Predictions



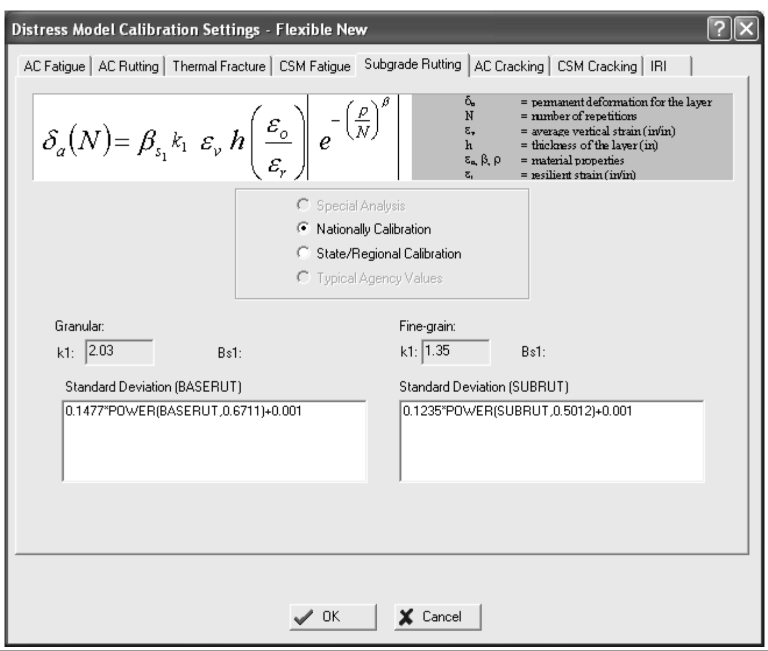
Rutting



Flexible – AC Rutting Equations



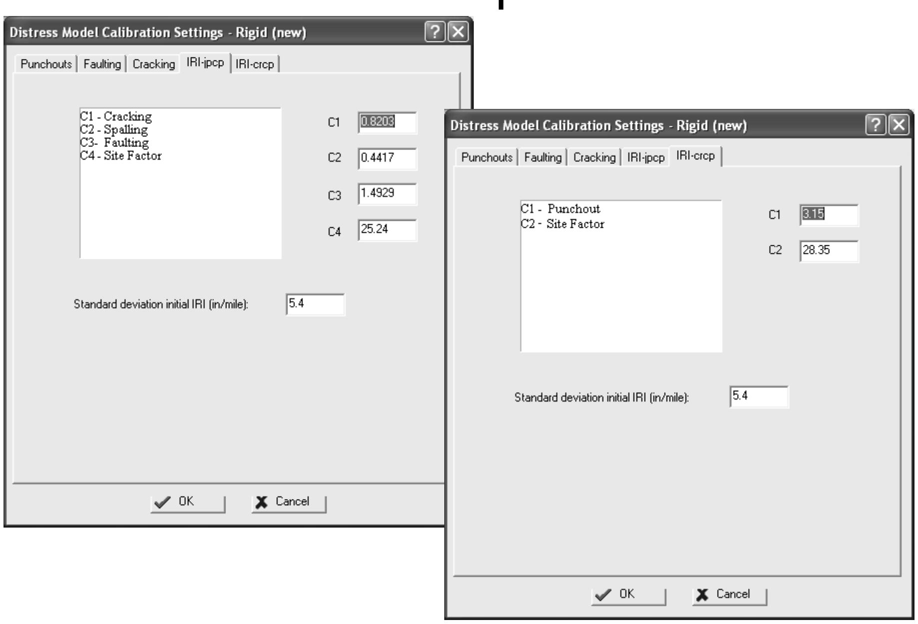
Flexible – Subgrade Rutting Equations



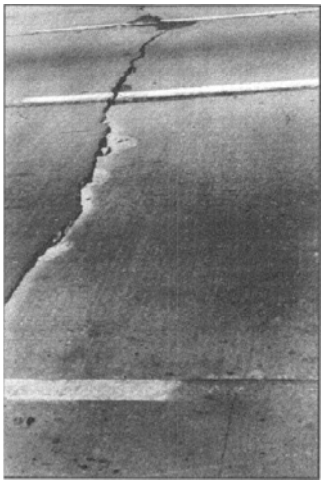
Rigid Pavement Predictions

- Ride quality
- Transverse cracking
- Joint faulting
- Pavement specific distresses
  - Punchouts
  - Crack width
  - Crack spacing

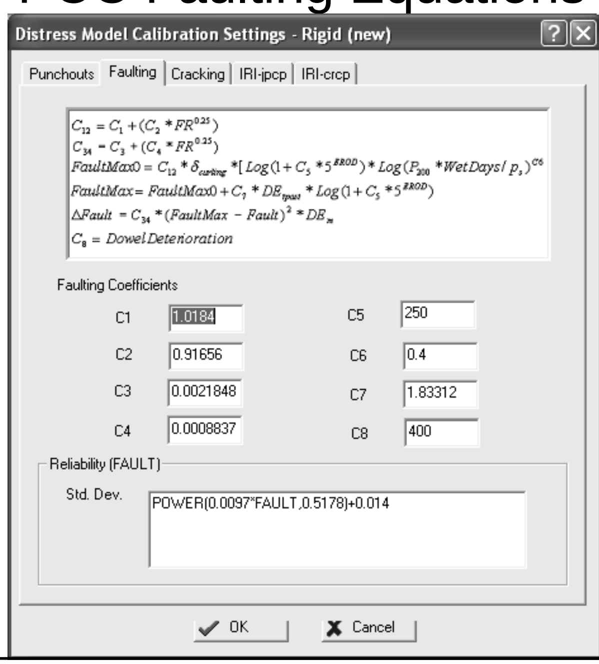
PCC IRI Equations



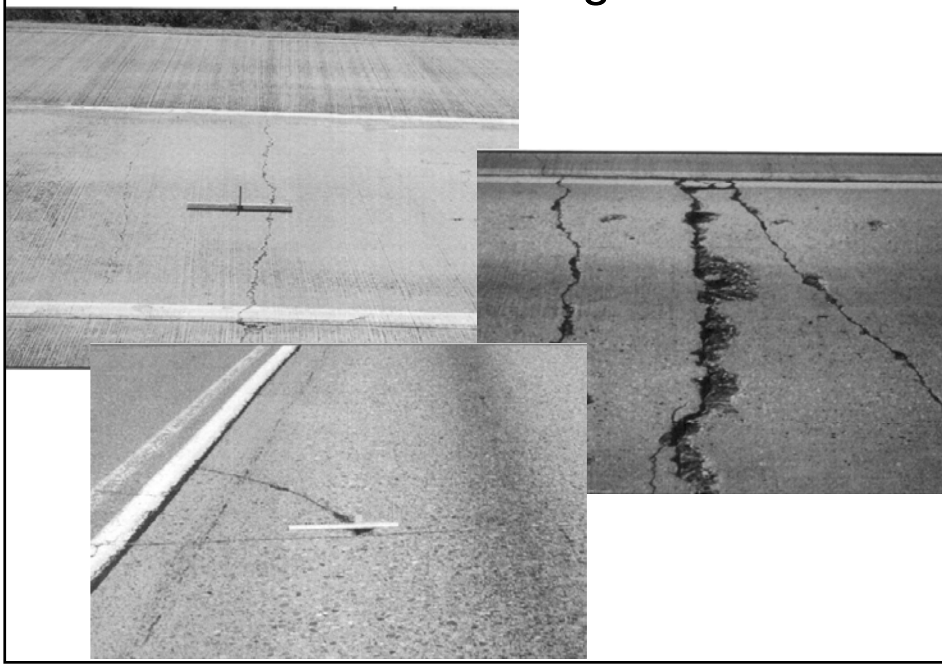
Faulting



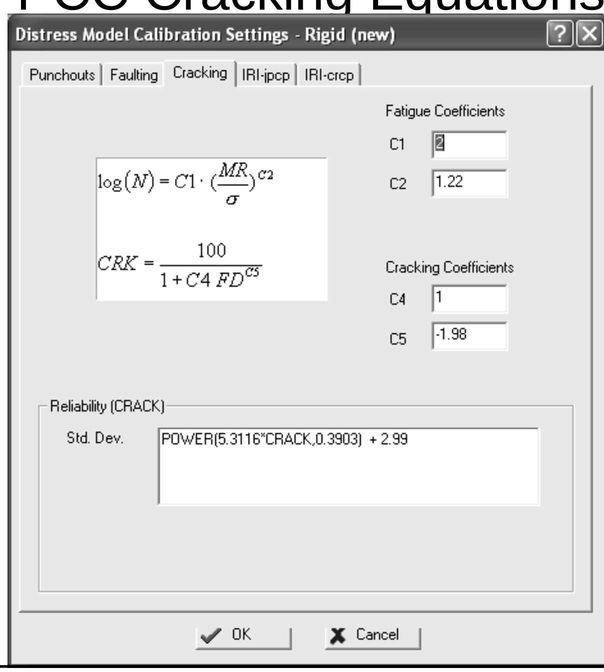
PCC Faulting Equations



Cracking

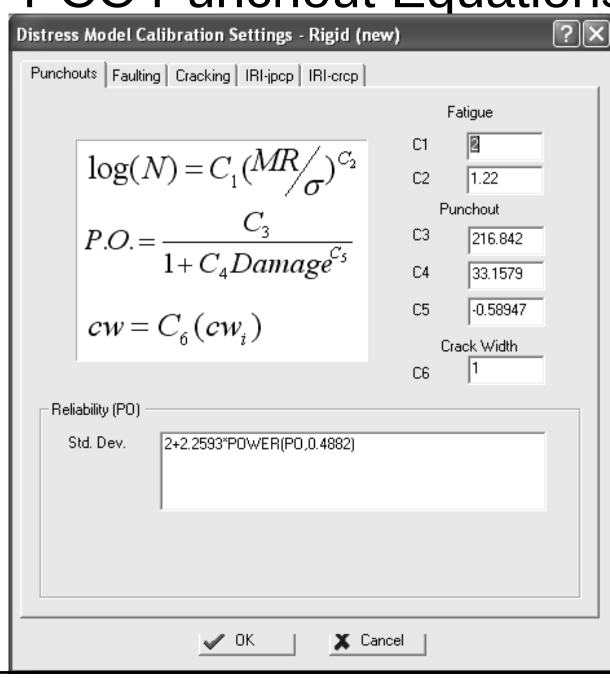


PCC Cracking Equations



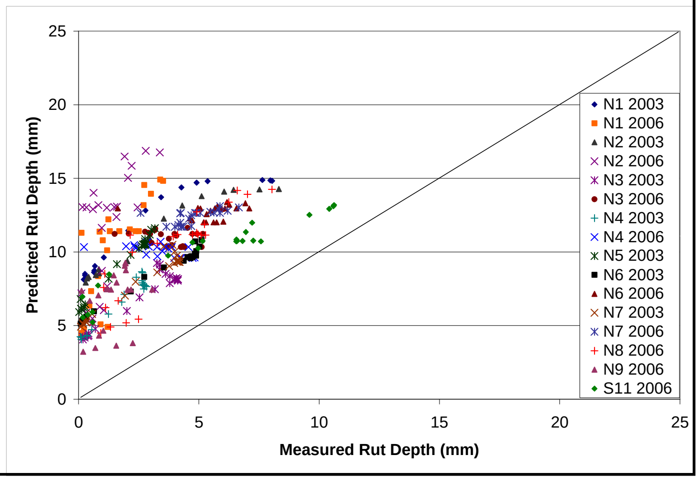
Punchouts

PCC Punchout Equations



Local Calibration

- Must match predicted and observed performance
  - Adjust calibration settings

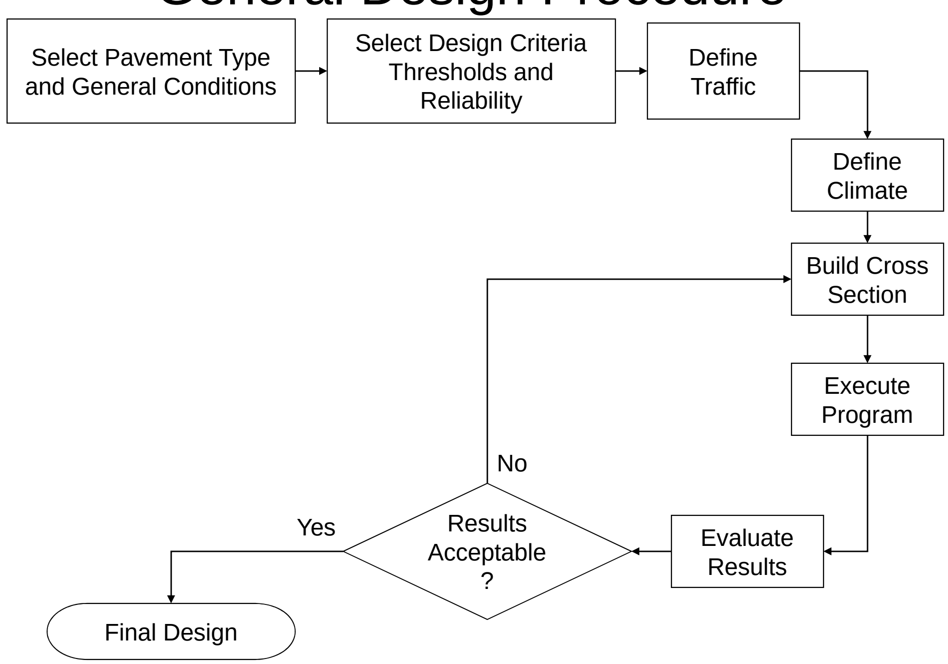


Mechanistic-Empirical Pavement Design Guide (Version 1.1)

MEPDG Online Resources

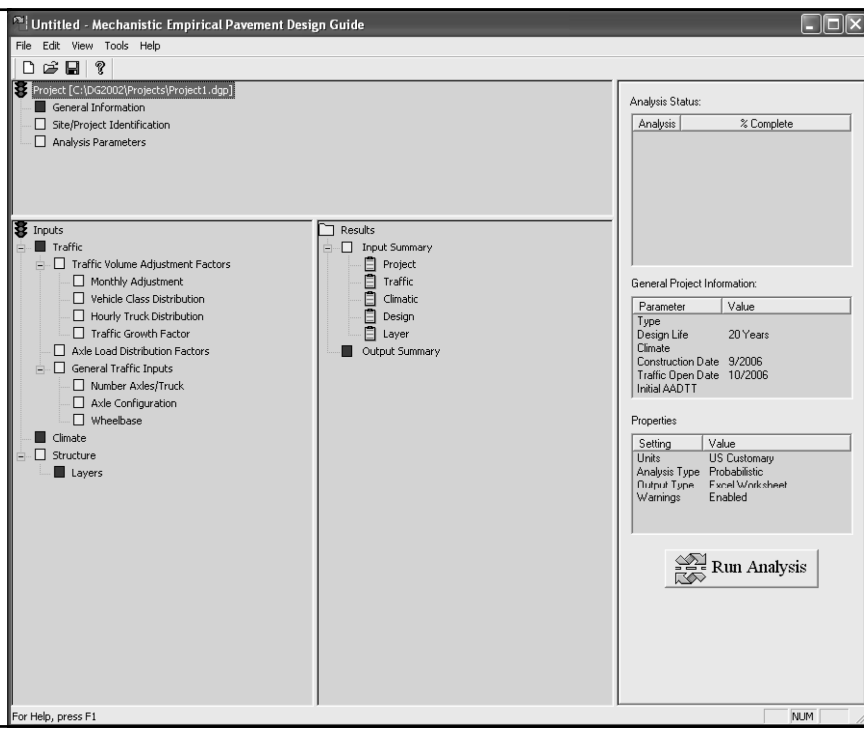
- http://www.trb.org/mepdg/
  - NCHRP 1-37A Documents
  - Software
    - MEPDG and Climate Files
- Google "Highway Community Exchange 1-37A"
  - Web-based discussion group
- http://www.fhwa.dot.gov/pavement/dgit/index.cfm
  - FHWA Design Guide Implementation Team (DGIT)
- http://www.eng.auburn.edu/users/timmdav/MEPDGWebsite/draft2/index.htm
  - MEPDG interactive help resource

General Design Procedure

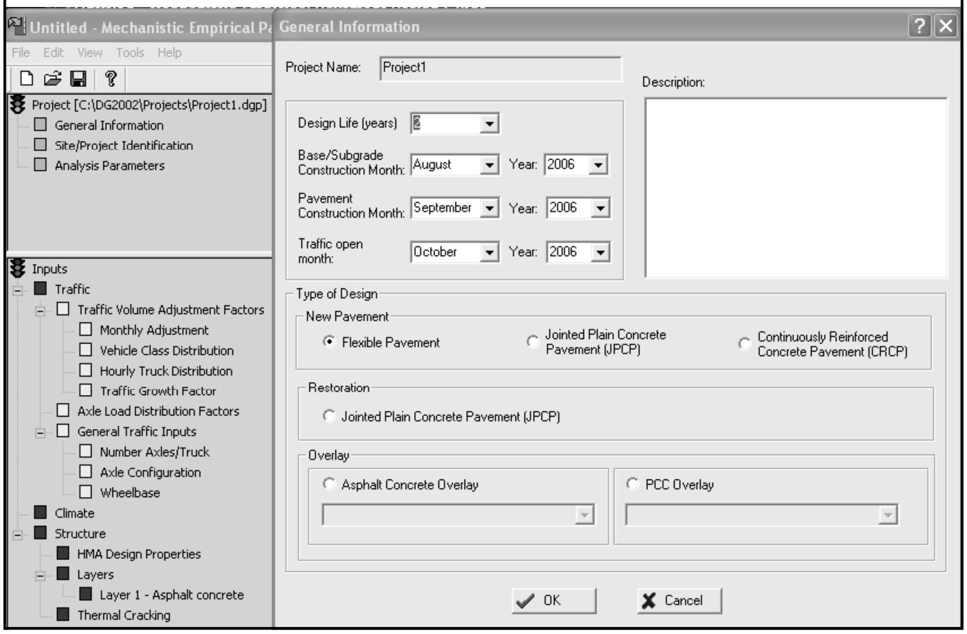


MEPDG Design Levels

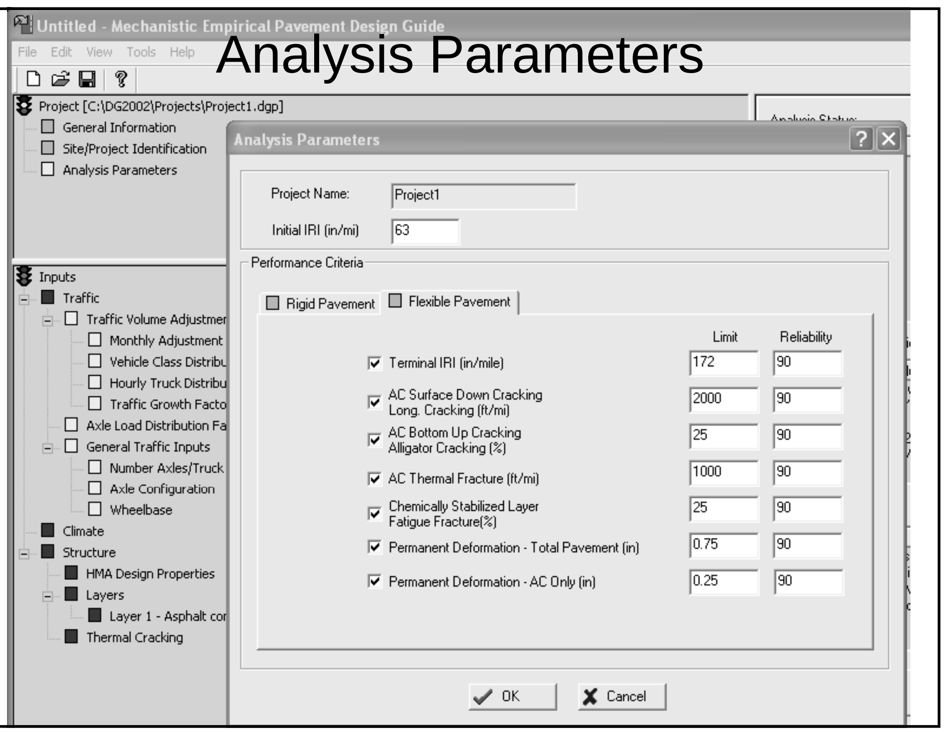
- Level 1 = I know a lot!
- Level 2 = I have a pretty good idea
- Level 3 = I'm sort of guessing here

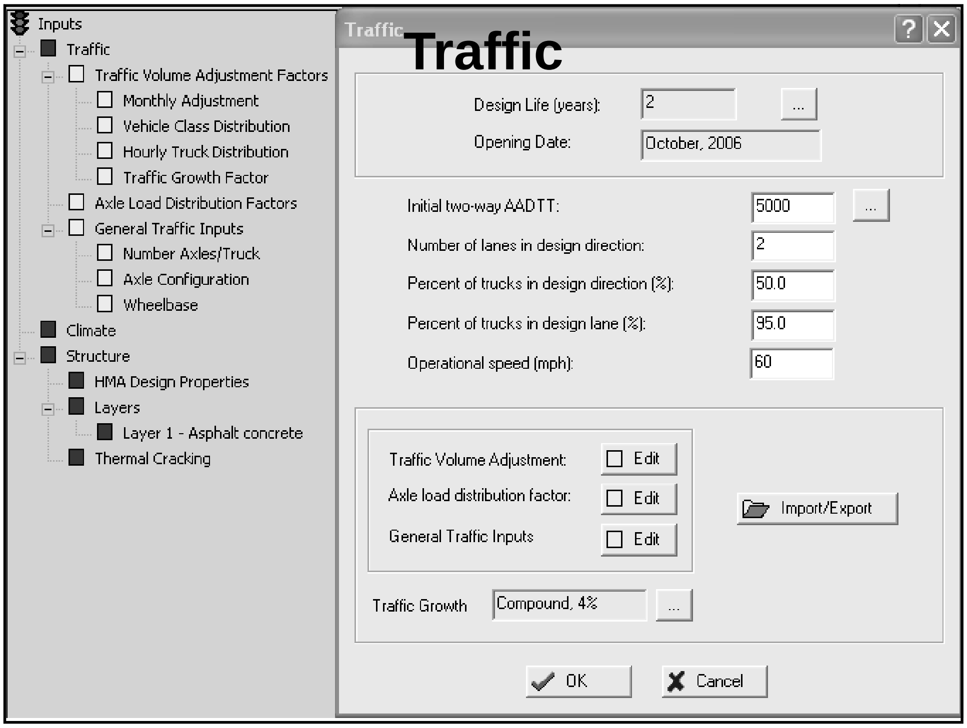


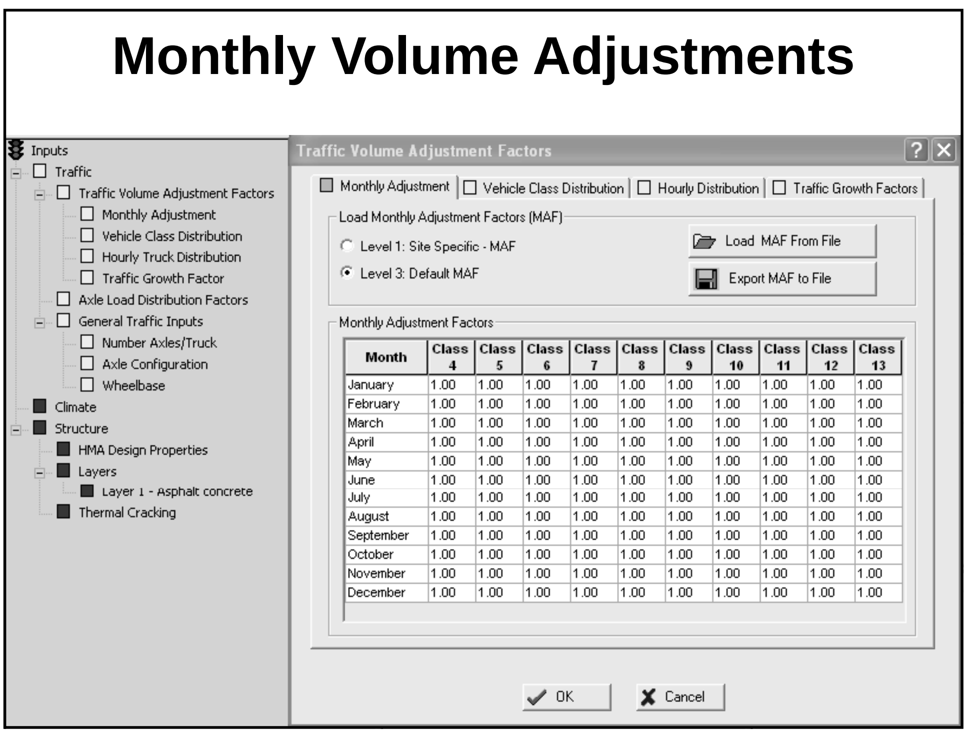
General Information



Analysis Parameters

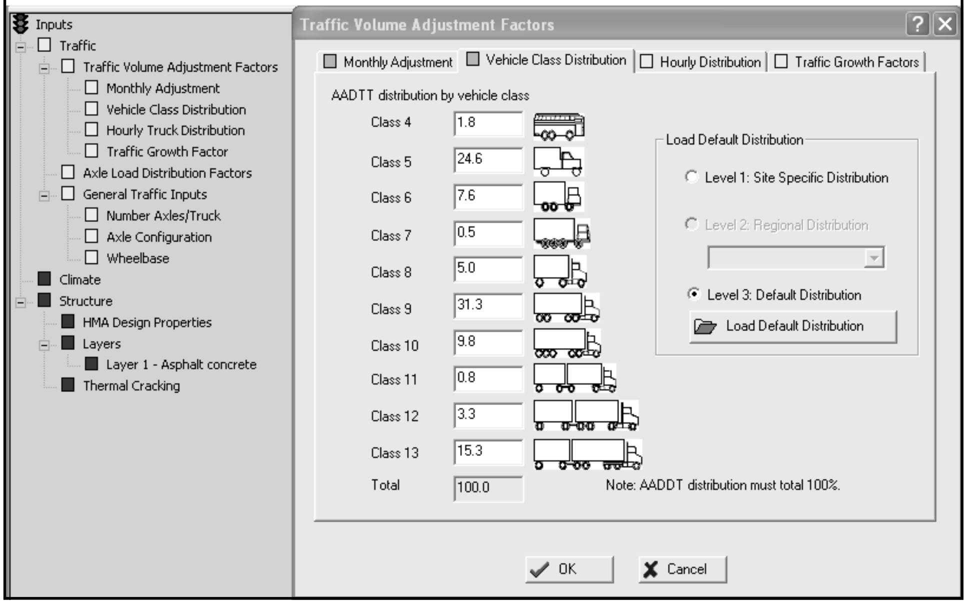




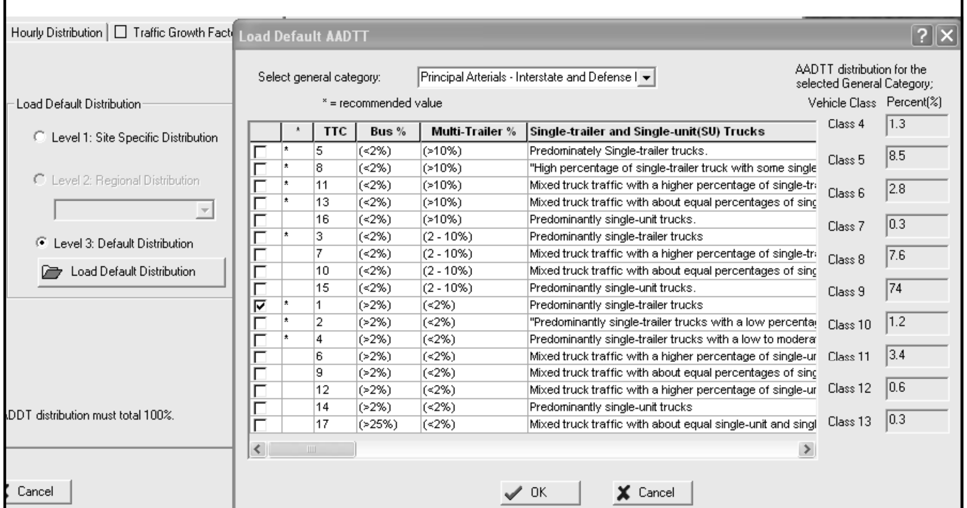


Month	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Types



Default Vehicle Type Distributions

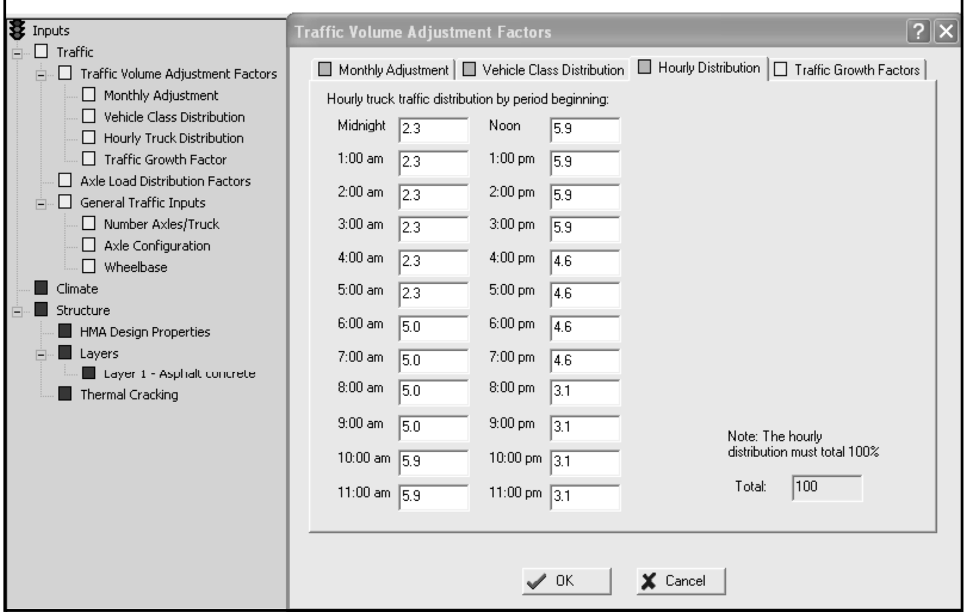


MEPDG Truck Traffic Classification

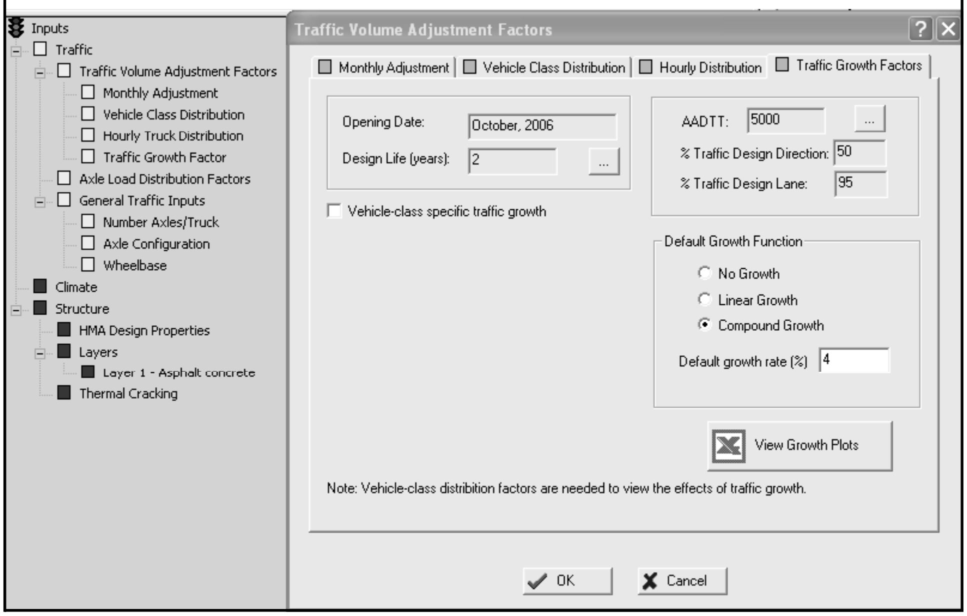
TTC Group	TTC Description	Vehicle/Truck Class Distribution (percent)									
		4	5	6	7	8	9	10	11	12	13
1	Major single-trailer truck route (type I)	1.3	8.5	2.8	0.3	7.6	74.0	1.2	3.4	0.6	0.3
2	Major single-trailer truck route (Type II)	2.4	14.1	4.5	0.7	7.9	66.3	1.4	2.2	0.3	0.2
3	Major single- and multi- trailer truck route (Type I)	0.9	11.6	3.6	0.2	6.7	62.0	4.8	2.6	1.4	6.2
4	Major single-trailer truck route (Type III)	2.4	22.7	5.7	1.4	8.1	55.5	1.7	2.2	0.2	0.4
5	Major single- and multi- trailer truck route (Type II).	0.9	14.2	3.5	0.6	6.9	54.0	5.0	2.7	1.2	11.0
6	Intermediate light and single-trailer truck route (I)	2.8	31.0	7.3	0.8	9.3	44.8	2.3	1.0	0.4	0.3
7	Major mixed truck route (Type I)	1.0	23.8	4.2	0.5	10.2	42.2	5.8	2.6	1.3	8.4
8	Major multi-trailer truck route (Type I)	1.7	19.3	4.6	0.9	6.7	44.8	6.0	2.6	1.6	11.8
9	Intermediate light and single-trailer truck route (II)	3.3	34.0	11.7	1.6	9.9	36.2	1.0	1.8	0.2	0.3
10	Major mixed truck route (Type II)	0.8	30.8	6.9	0.1	7.8	37.5	3.7	1.2	4.5	6.7
11	Major multi-trailer truck route (Type II)	1.8	24.6	7.6	0.5	5.0	31.3	9.8	0.8	3.3	15.3
12	Intermediate light and single-trailer truck route (III)	3.9	40.8	11.7	1.5	12.2	25.0	2.7	0.6	0.3	1.3
13	Major mixed truck route (Type III)	0.8	33.6	6.2	0.1	7.9	26.0	10.5	1.4	3.2	10.3
14	Major light truck route (Type I)	2.9	56.9	10.4	3.7	9.2	15.3	0.6	0.3	0.4	0.3
15	Major light truck route (Type II)	1.8	56.5	8.5	1.8	6.2	14.1	5.4	0.0	0.0	5.7
16	Major light and multi-trailer truck route	1.3	48.4	10.8	1.9	6.7	13.4	4.3	0.5	0.1	12.6
17	Major bus route	36.2	14.6	13.4	0.5	14.6	17.8	0.5	0.8	0.1	1.5

http://onlinepubs.trb.org/onlinepubs/archive/mepdg/Part2_Chapter4_Traffic.pdf

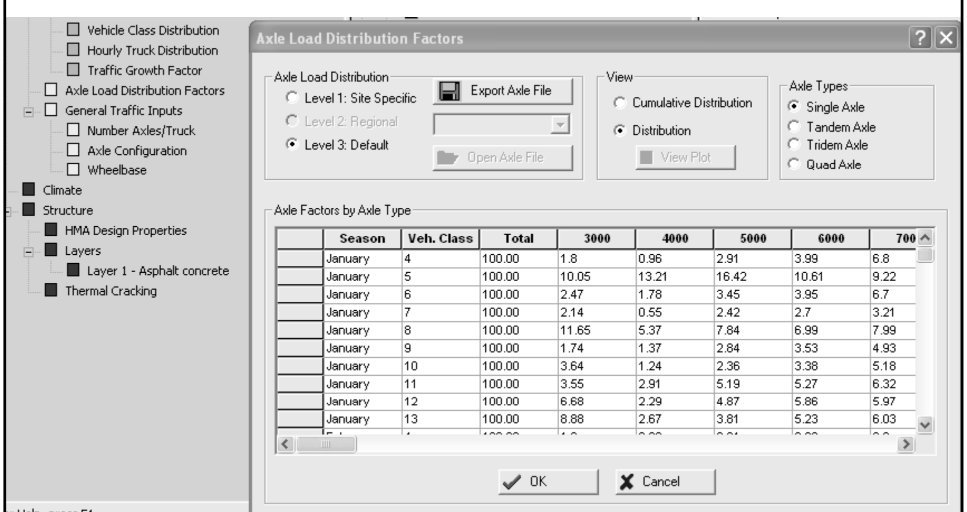
Hourly Volume

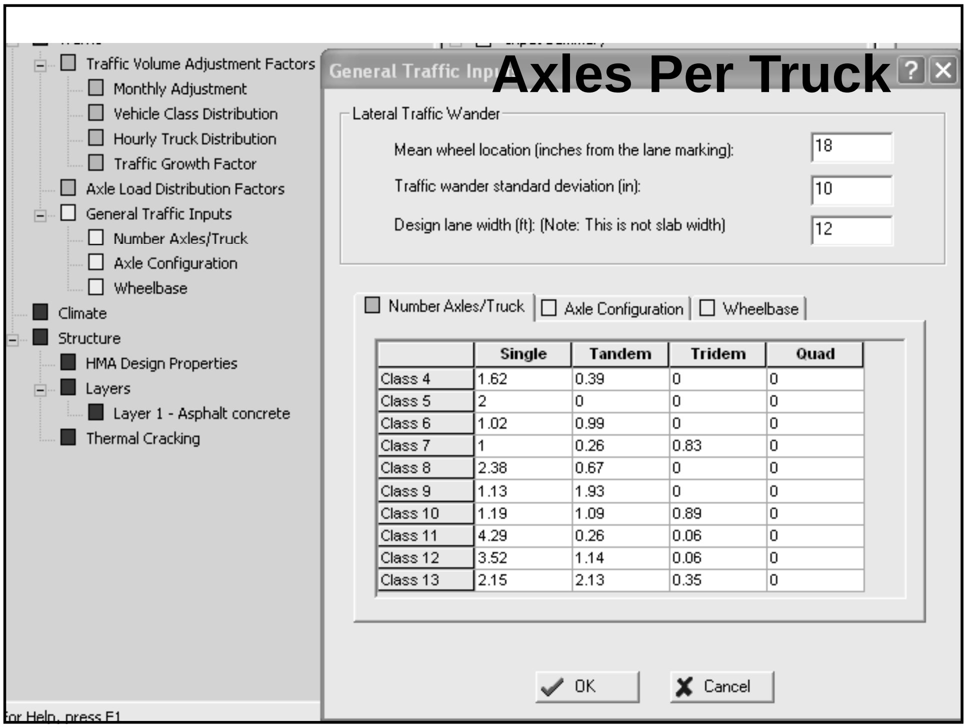


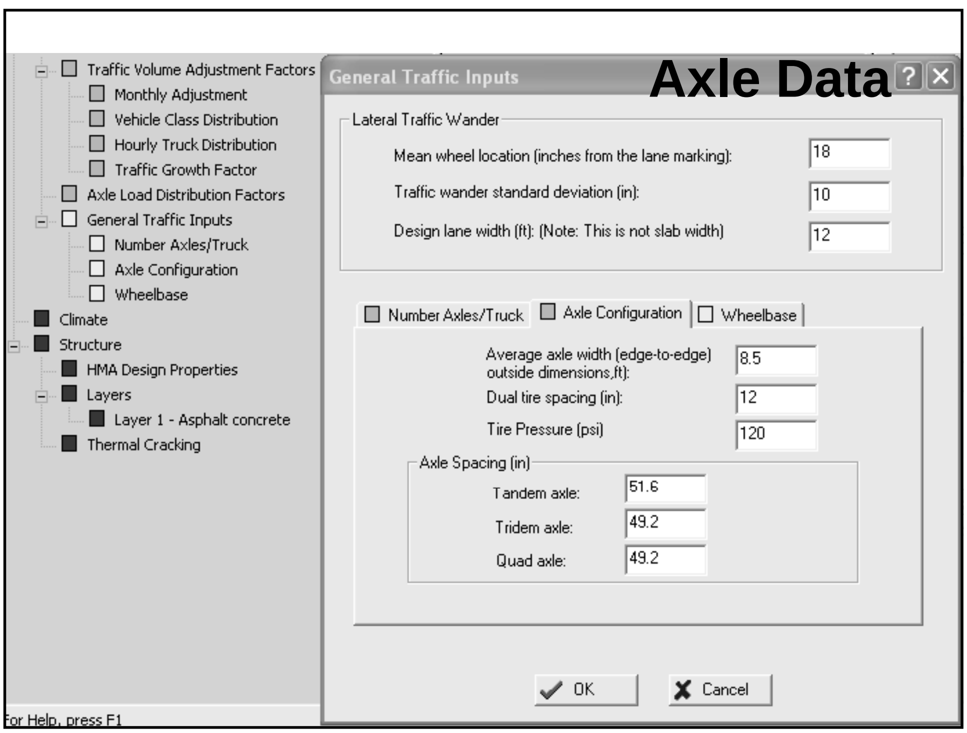
Traffic Growth

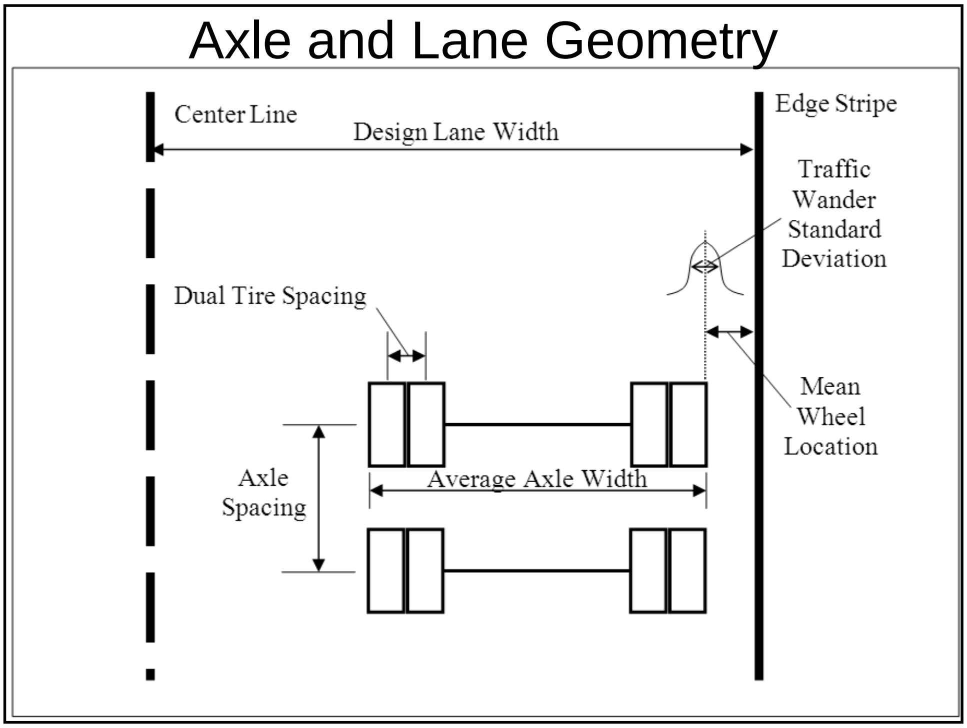


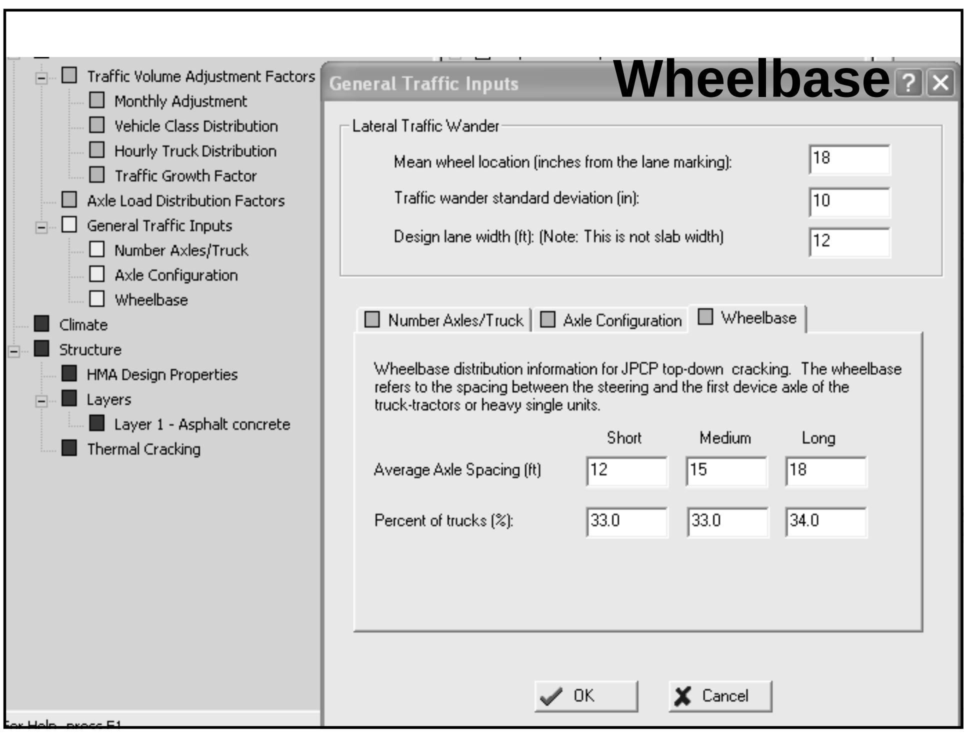
Axle Load Distributions




Axles Per Truck
General Traffic Inp
Traffic Volume Adjustment Factors
Monthly Adjustment
Vehicle Class Distribution
Hourly Truck Distribution
Traffic Growth Factor
Axle Load Distribution Factors
General Traffic Inputs
Number Axles/Truck
Axle Configuration
Wheelbase
Climate
Structure
HMA Design Properties
Layers
Layer 1 - Asphalt concrete
Thermal Cracking
Lateral Traffic Wander
Mean wheel location (inches from the lane marking): 18
Traffic wander standard deviation (in): 10
Design lane width (ft): (Note: This is not slab width) 12
Number Axles/Truck
Axle Configuration
Wheelbase
Single Tandem Tridem Quad
Class 4 1.62 0.39 0 0
Class 5 2 0 0 0
Class 6 1.02 0.99 0 0
Class 7 1 0.26 0.83 0
Class 8 2.38 0.67 0 0
Class 9 1.13 1.93 0 0
Class 10 1.19 1.09 0.89 0
Class 11 4.29 0.26 0.06 0
Class 12 3.52 1.14 0.06 0
Class 13 2.15 2.13 0.35 0
OK
Cancel
For Help, press F1

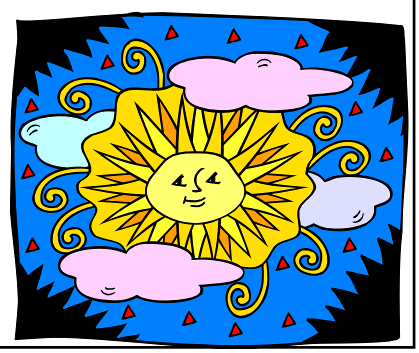

General Traffic Inputs
Axle Data
Traffic Volume Adjustment Factors
Monthly Adjustment
Vehicle Class Distribution
Hourly Truck Distribution
Traffic Growth Factor
Axle Load Distribution Factors
General Traffic Inputs
Number Axles/Truck
Axle Configuration
Wheelbase
Climate
Structure
HMA Design Properties
Layers
Layer 1 - Asphalt concrete
Thermal Cracking
Lateral Traffic Wander
Mean wheel location (inches from the lane marking): 18
Traffic wander standard deviation (in): 10
Design lane width (ft): (Note: This is not slab width) 12
Number Axles/Truck
Axle Configuration
Wheelbase
Average axle width (edge-to-edge) outside dimensions,ft): 8.5
Dual tire spacing (in): 12
Tire Pressure (psi) 120
Axle Spacing (in)
Tandem axle: 51.6
Tridem axle: 49.2
Quad axle: 49.2
OK
Cancel
For Help, press F1


Axle and Lane Geometry
Center Line
Design Lane Width
Edge Stripe
Traffic Wander Standard Deviation
Dual Tire Spacing
Mean Wheel Location
Axle Spacing
Average Axle Width

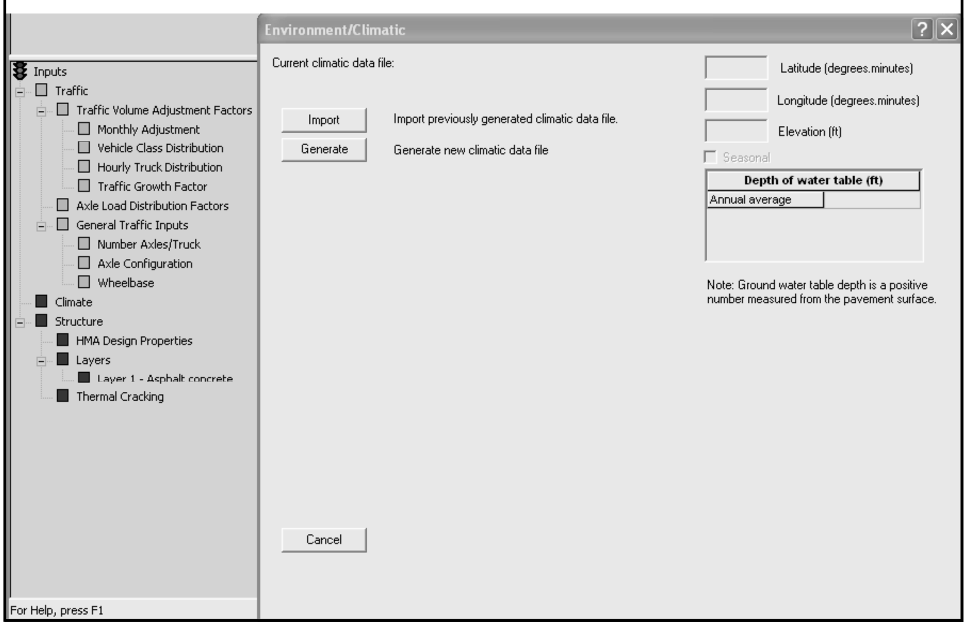

Wheelbase
Traffic Volume Adjustment Factors
Monthly Adjustment
Vehicle Class Distribution
Hourly Truck Distribution
Traffic Growth Factor
Axle Load Distribution Factors
General Traffic Inputs
Number Axles/Truck
Axle Configuration
Wheelbase
Climate
Structure
HMA Design Properties
Layers
Layer 1 - Asphalt concrete
Thermal Cracking
General Traffic Inputs
Lateral Traffic Wander
Mean wheel location (inches from the lane marking): 18
Traffic wander standard deviation (in): 10
Design lane width (ft): (Note: This is not slab width) 12
Number Axles/Truck
Axle Configuration
Wheelbase
Wheelbase distribution information for JPCP top-down cracking. The wheelbase refers to the spacing between the steering and the first device axle of the truck-tractors or heavy single units.
Short
Medium
Long
Average Axle Spacing (ft) 12 15 18
Percent of trucks (%): 33.0 33.0 34.0
OK
Cancel

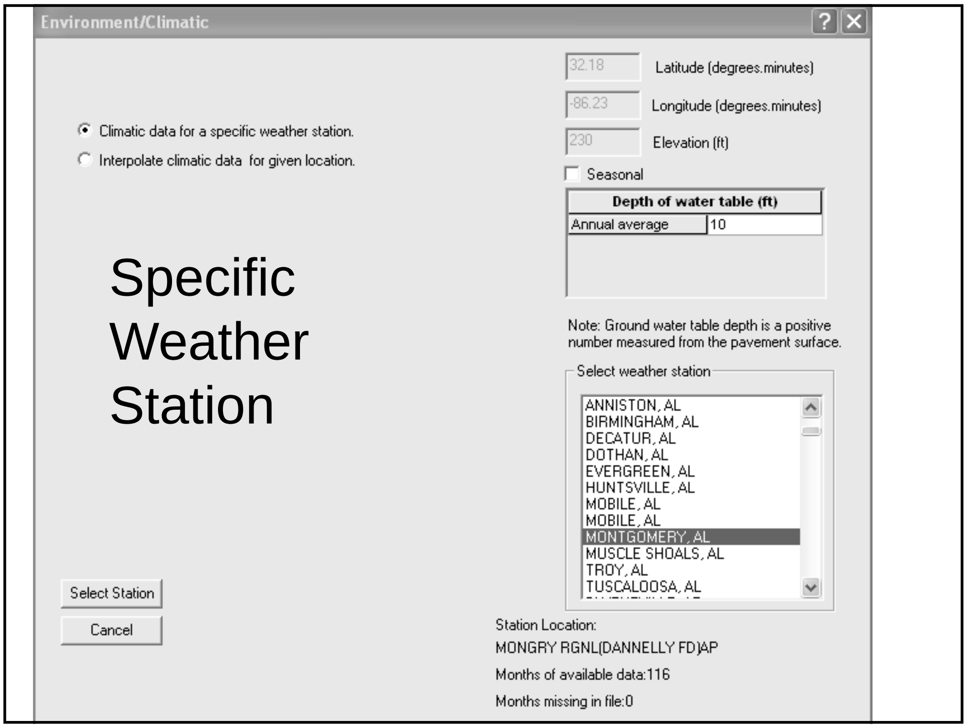
Climate

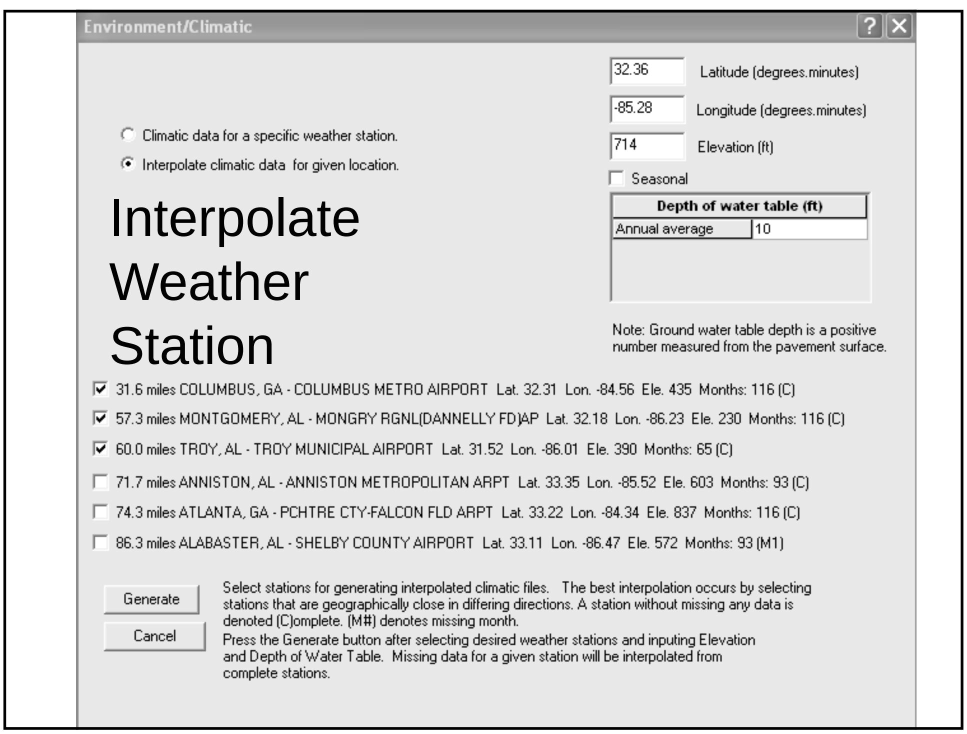
- MEPDG uses Enhanced Integrated Climate Model
  - – Historical weather data
  - – Future projects of
    - Moisture movement
    - Moisture state
    - Temperature



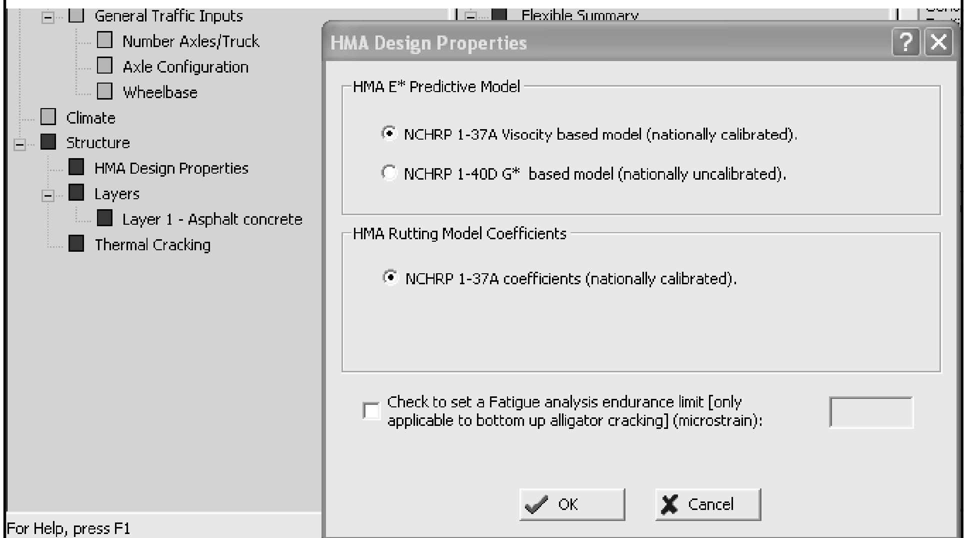
Climate



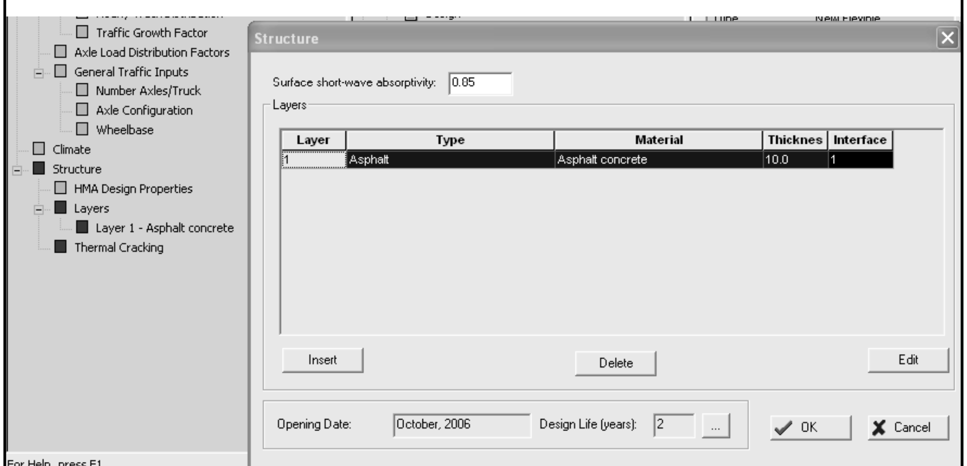

Environment/Climatic
32.18
Latitude (degrees.minutes)
-86.23
Longitude (degrees.minutes)
230
Elevation (ft)
Climatic data for a specific weather station.
Interpolate climatic data for given location.
Seasonal
Depth of water table (ft)
Annual average
10
Specific Weather Station
Note: Ground water table depth is a positive number measured from the pavement surface.
Select weather station
ANNISTON, AL
BIRMINGHAM, AL
DECATUR, AL
DOTHAN, AL
EVERGREEN, AL
HUNTSVILLE, AL
MOBILE, AL
MOBILE, AL
MONTGOMERY, AL
MUSCLE SHOALS, AL
TROY, AL
TUSCALOOSA, AL
Select Station
Cancel
Station Location:
MONGRY RGNL(DANNELLY FD)AP
Months of available data:116
Months missing in file:0


Environment/Climatic
32.36
Latitude (degrees.minutes)
-85.28
Longitude (degrees.minutes)
714
Elevation (ft)
Climatic data for a specific weather station.
Interpolate climatic data for given location.
Seasonal
Depth of water table (ft)
Annual average
10
Interpolate Weather Station
Note: Ground water table depth is a positive number measured from the pavement surface.
31.6 miles COLUMBUS, GA - COLUMBUS METRO AIRPORT Lat. 32.31 Lon. -84.56 Ele. 435 Months: 116 (C)
57.3 miles MONTGOMERY, AL - MONGRY RGNL(DANNELLY FD)AP Lat. 32.18 Lon. -86.23 Ele. 230 Months: 116 (C)
60.0 miles TROY, AL - TROY MUNICIPAL AIRPORT Lat. 31.52 Lon. -86.01 Ele. 390 Months: 65 (C)
71.7 miles ANNISTON, AL - ANNISTON METROPOLITAN ARPT Lat. 33.35 Lon. -85.52 Ele. 603 Months: 93 (C)
74.3 miles ATLANTA, GA - PCHTRE CTY-FALCON FLD ARPT Lat. 33.22 Lon. -84.34 Ele. 837 Months: 116 (C)
86.3 miles ALABASTER, AL - SHELBY COUNTY AIRPORT Lat. 33.11 Lon. -86.47 Ele. 572 Months: 93 (M1)
Generate
Cancel
Select stations for generating interpolated climatic files. The best interpolation occurs by selecting stations that are geographically close in differing directions. A station without missing any data is denoted (C)omplete. (M#) denotes missing month.
Press the Generate button after selecting desired weather stations and inputing Elevation and Depth of Water Table. Missing data for a given station will be interpolated from complete stations.

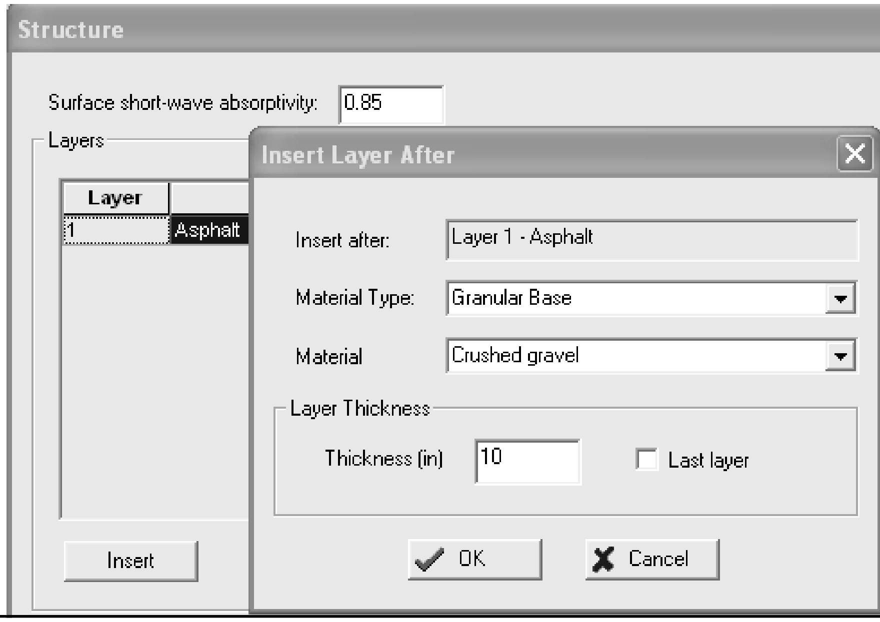
HMA Design Properties



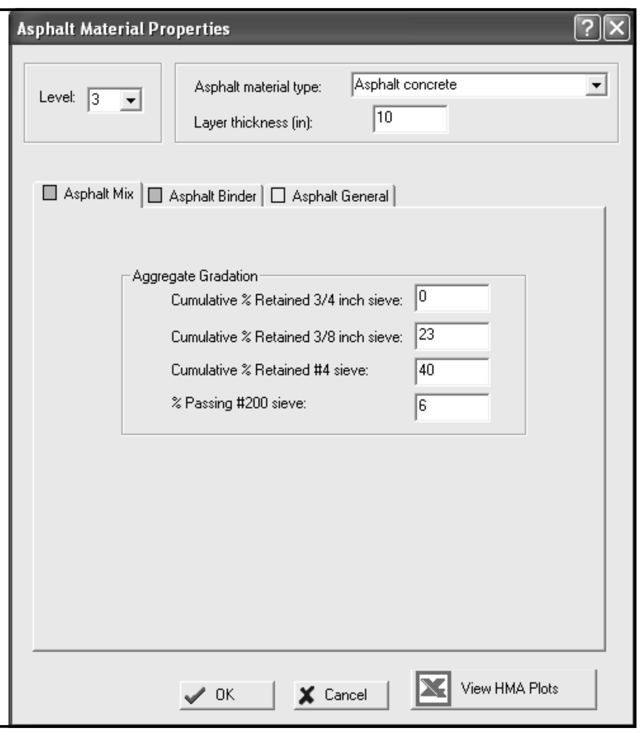
Input Structural Layers



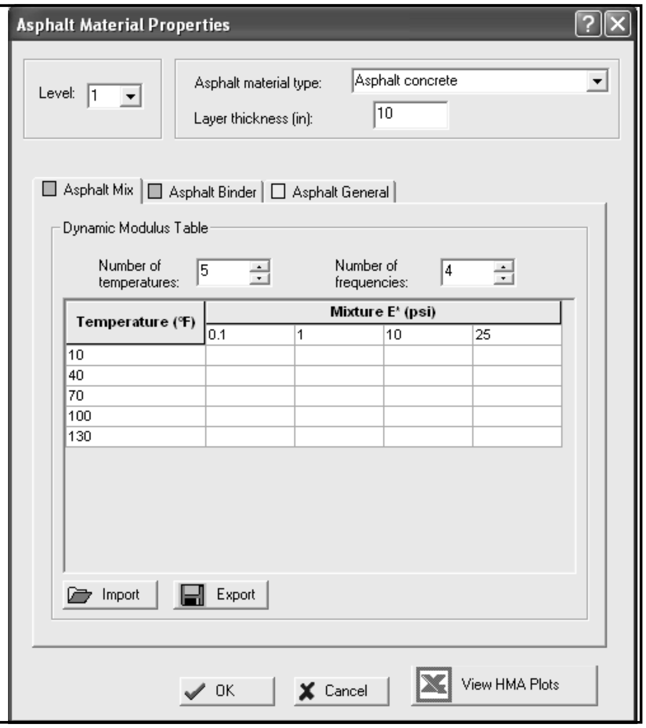
Insert Layer



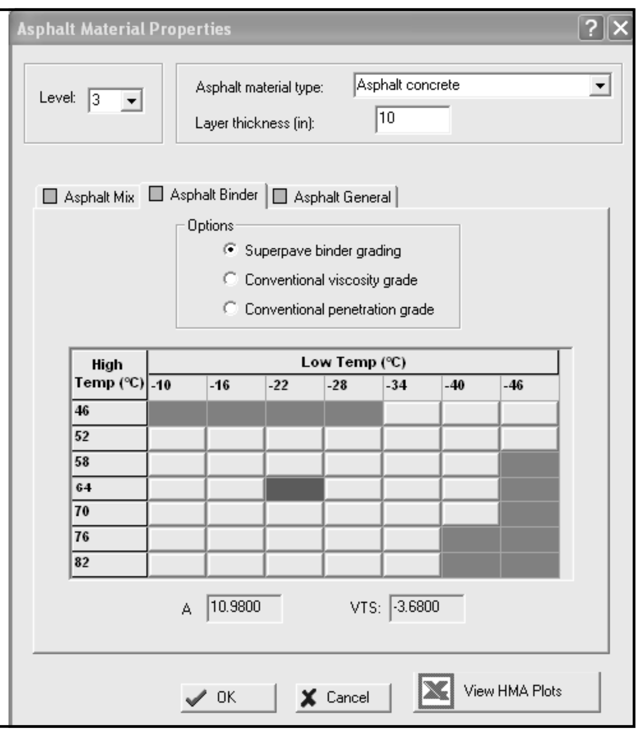
Asphalt Mix Levels 2 & 3



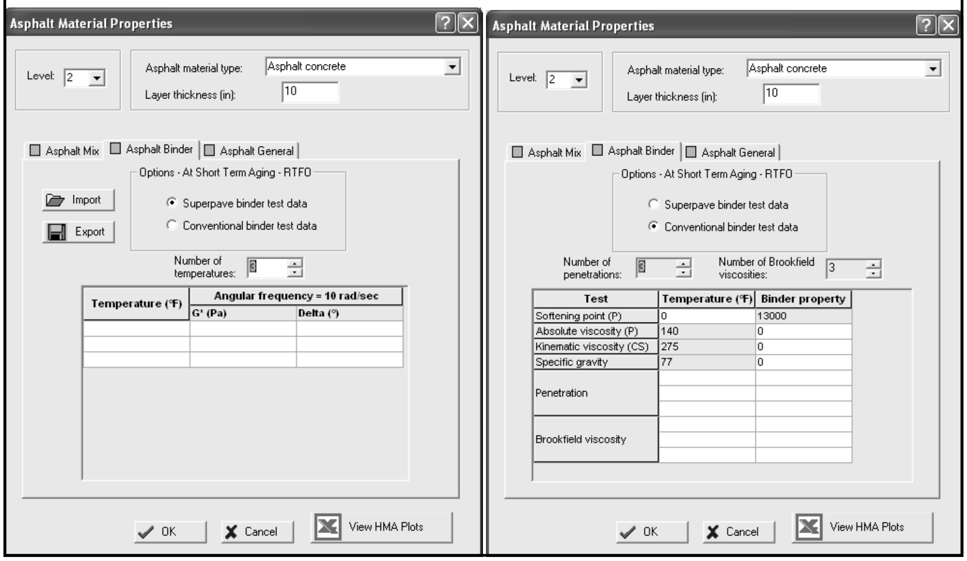
Asphalt
Mix
Level 1



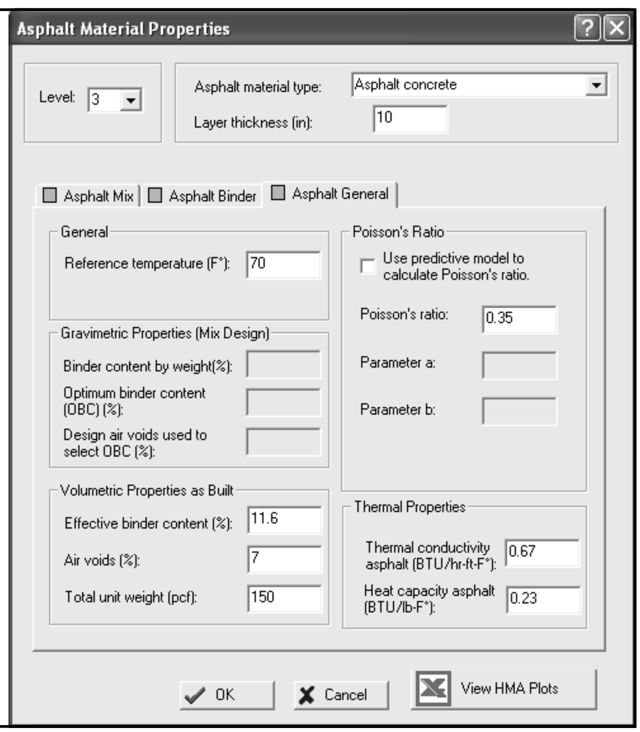
Asphalt
Binder
Level 3



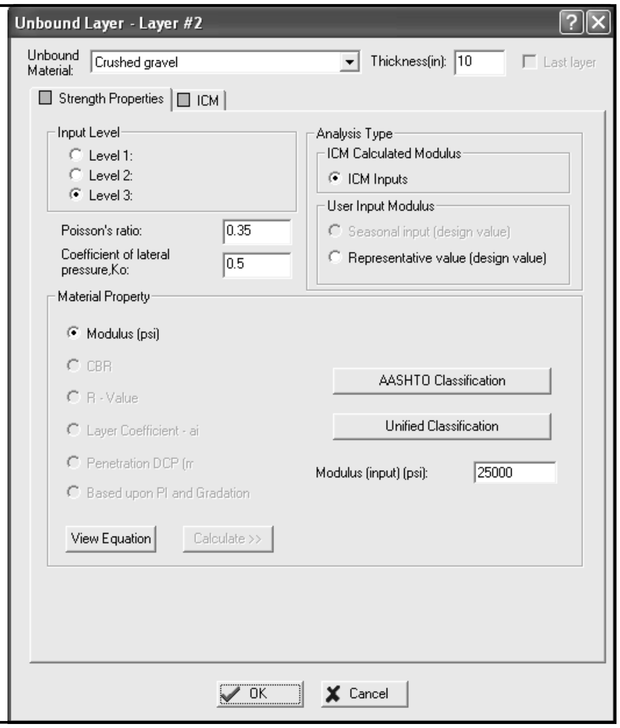
Asphalt Binder Levels 1 & 2



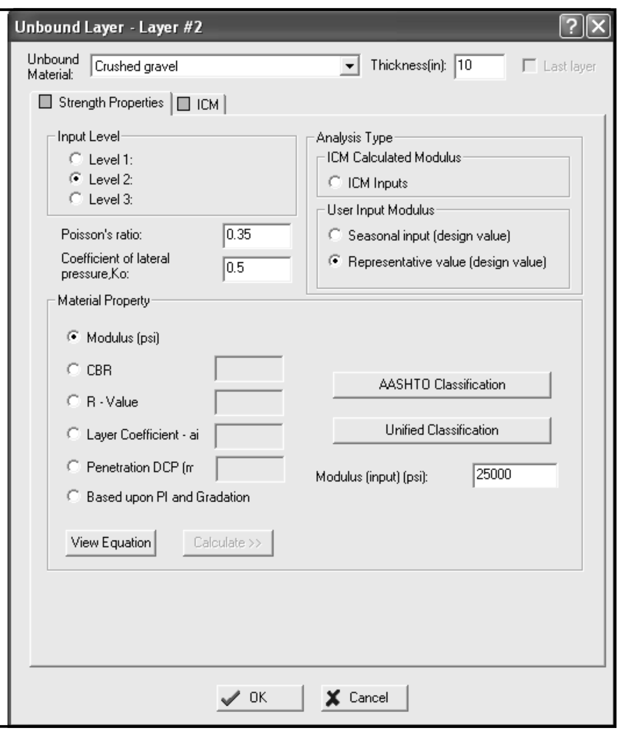
Asphalt General Levels 1 - 3



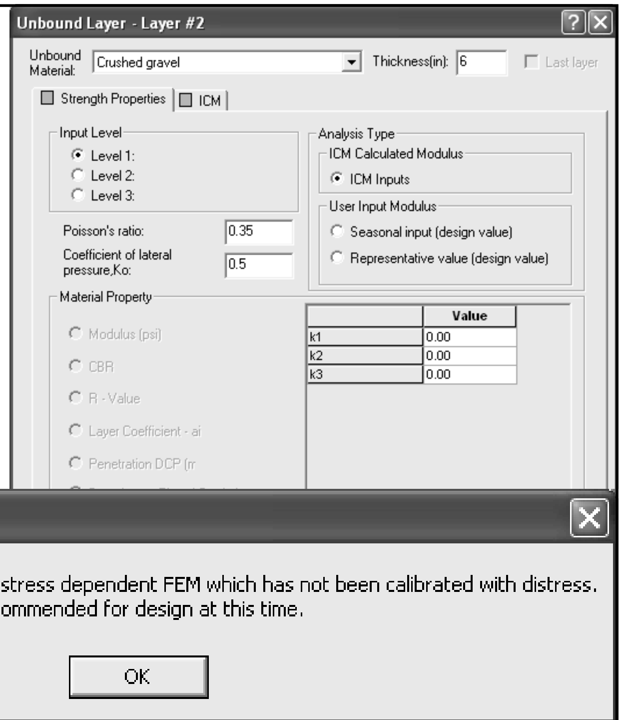
Unbound Strength Properties Level 3



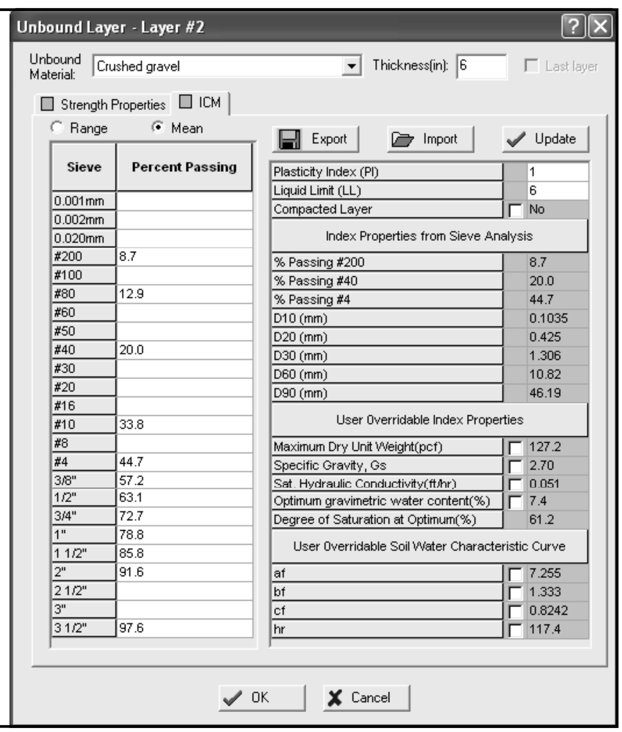
Unbound Strength Properties Level 2

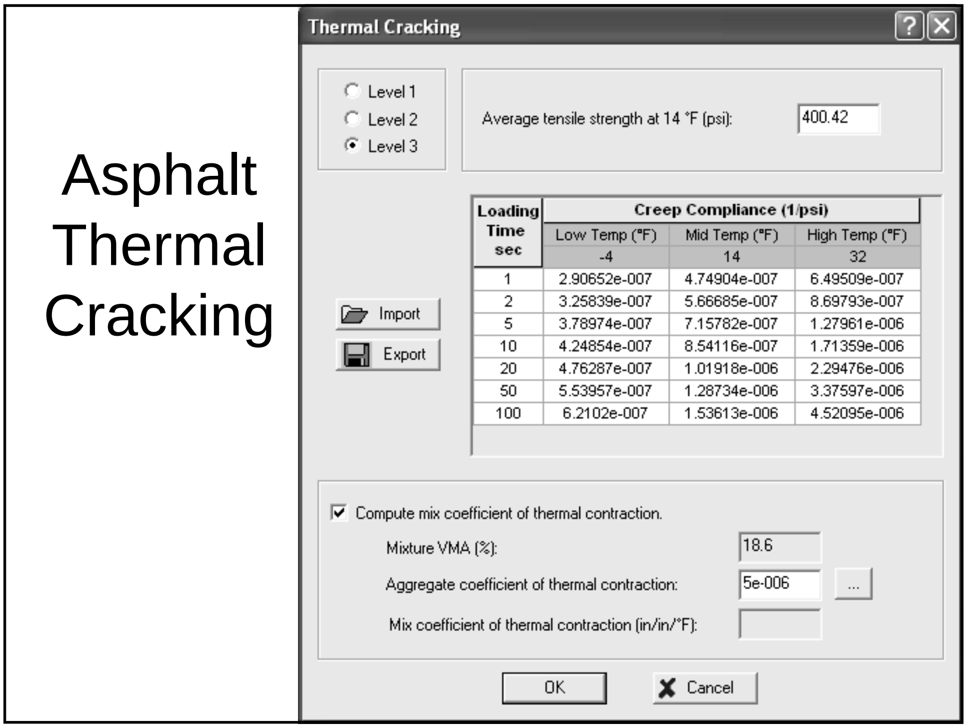


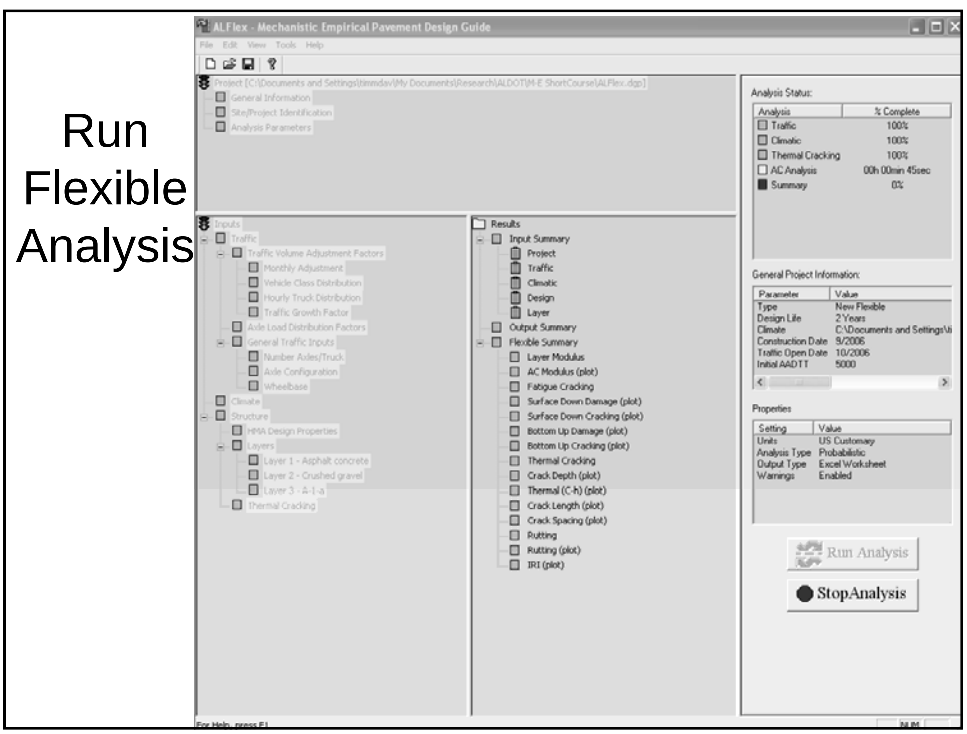
Unbound Strength Properties Level 1 <u>Not</u> Calibrated



Unbound ICM Properties




Asphalt Thermal Cracking
Thermal Cracking
Level 1
Level 2
Level 3
Average tensile strength at 14 °F (psi):
400.42
Loading Time sec
Creep Compliance (1/psi)
Low Temp (°F) -4
Mid Temp (°F) 14
High Temp (°F) 32
1 2.90652e-007 4.74904e-007 6.49509e-007
2 3.25839e-007 5.66685e-007 8.69793e-007
5 3.78974e-007 7.15782e-007 1.27961e-006
10 4.24854e-007 8.54116e-007 1.71359e-006
20 4.76287e-007 1.01918e-006 2.29476e-006
50 5.53957e-007 1.28734e-006 3.37597e-006
100 6.2102e-007 1.53613e-006 4.52095e-006
Import
Export
Compute mix coefficient of thermal contraction.
Mixture VMA (%):
18.6
Aggregate coefficient of thermal contraction:
5e-006
Mix coefficient of thermal contraction (in/in/°F):
OK
Cancel

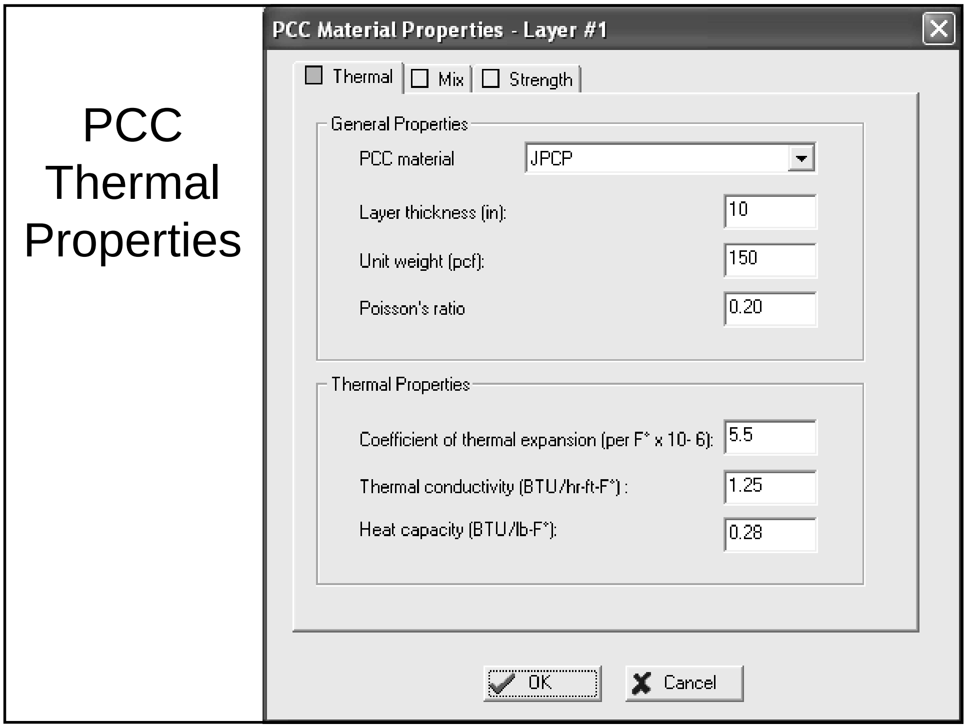

Run Flexible Analysis
Run Analysis
StopAnalysis

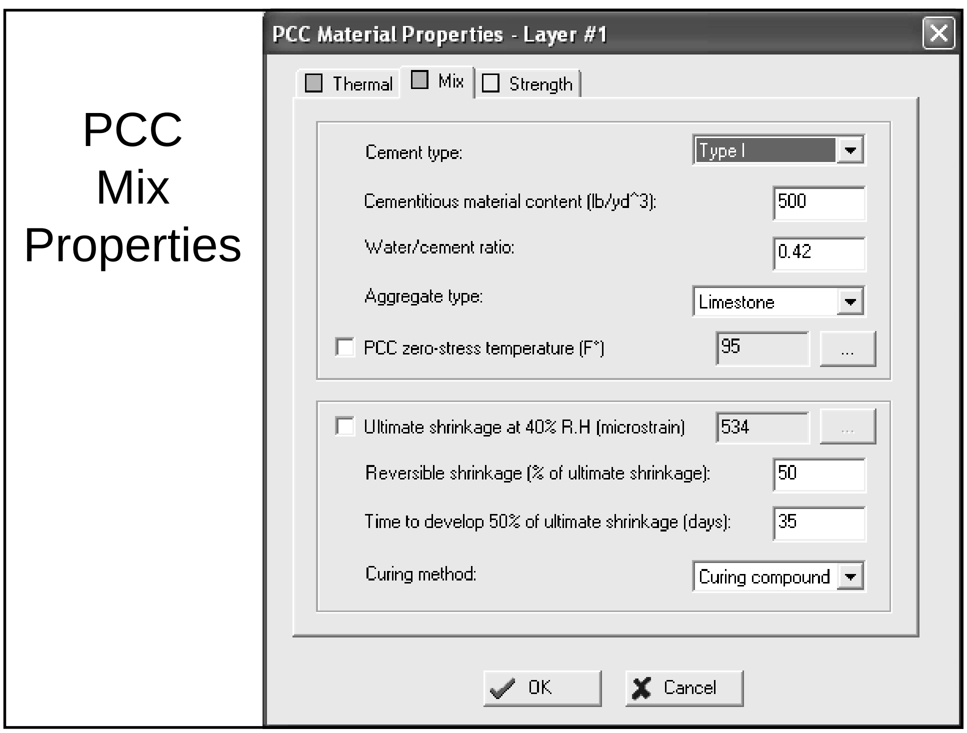
Evaluate Results

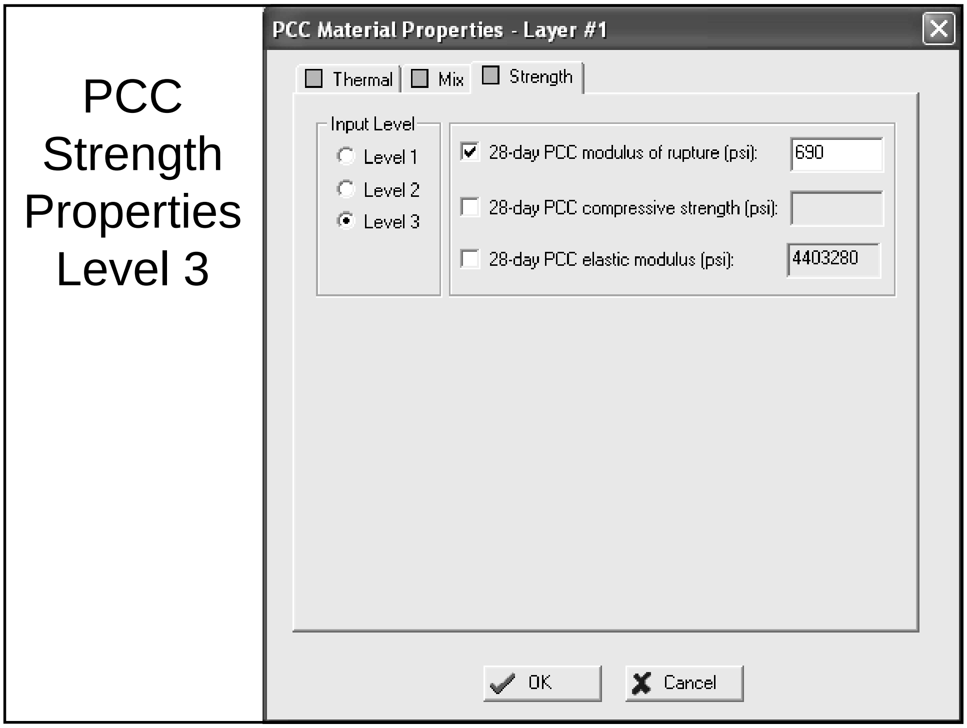
Project: ALFlex
Reliability Summary

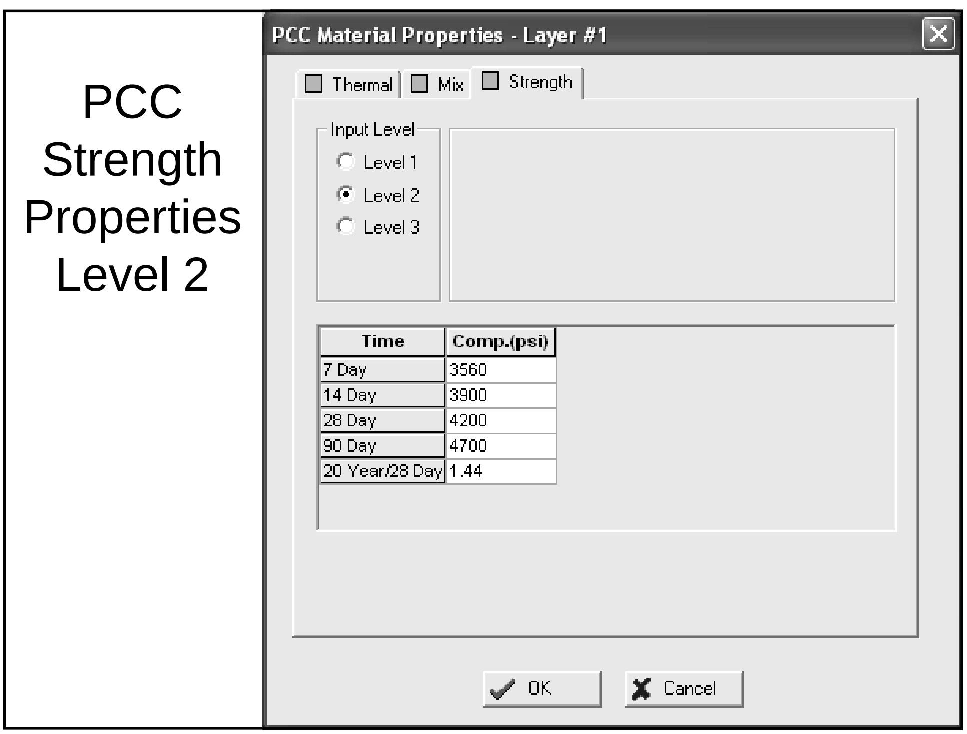
Performance Criteria	Distress Target	Reliability Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	77.8	99.999	Pass
AC Surface Down Cracking (Long. Cracking) (ft/mile):	2000	90	25.5	96.55	Pass
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0.1	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	1	99.999	Pass
Chemically Stabilized Layer (Fatigue Fracture)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.25	90	0.17	91.76	Pass
Permanent Deformation (Total Pavement) (in):	0.75	90	0.35	99.999	Pass

Rigid Design

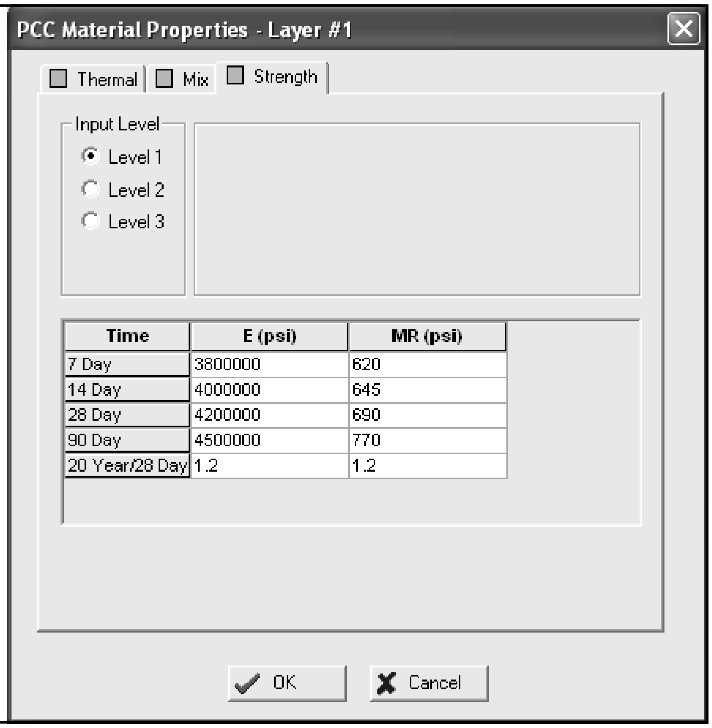

PCC Thermal Properties
PCC Material Properties - Layer #1
Thermal
Mix
Strength
General Properties
PCC material
JPCP
Layer thickness (in):
10
Unit weight (pcf):
150
Poisson's ratio
0.20
Thermal Properties
Coefficient of thermal expansion (per F° x 10- 6):
5.5
Thermal conductivity (BTU/hr-ft-F°) :
1.25
Heat capacity (BTU/lb-F°):
0.28
OK
Cancel


PCC Mix Properties
PCC Material Properties - Layer #1
Thermal
Mix
Strength
Cement type:
Type I
Cementitious material content (lb/yd^3):
500
Water/cement ratio:
0.42
Aggregate type:
Limestone
PCC zero-stress temperature (F°)
95
...
Ultimate shrinkage at 40% R.H (microstrain)
534
...
Reversible shrinkage (% of ultimate shrinkage):
50
Time to develop 50% of ultimate shrinkage (days):
35
Curing method:
Curing compound
OK
Cancel

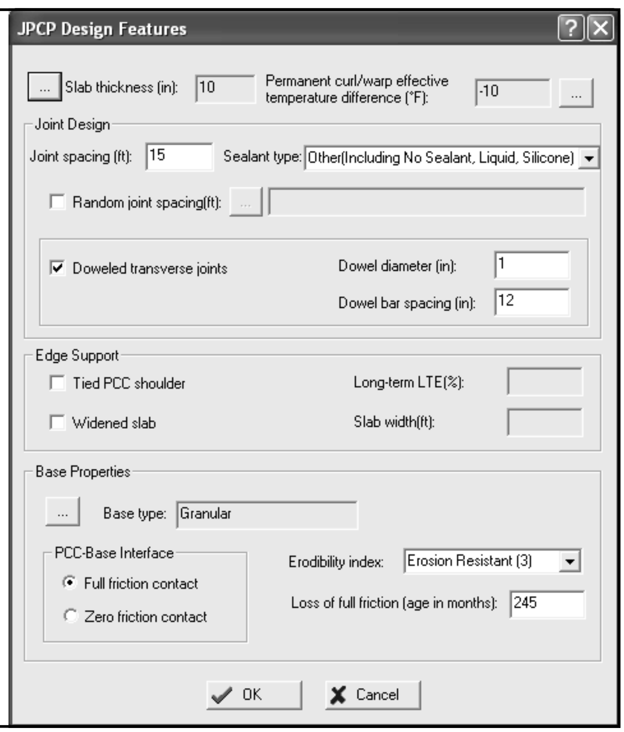

PCC Strength Properties Level 3
PCC Material Properties - Layer #1
Thermal
Mix
Strength
Input Level
Level 1
Level 2
Level 3
28-day PCC modulus of rupture (psi):
690
28-day PCC compressive strength (psi):
28-day PCC elastic modulus (psi):
4403280
OK
Cancel


PCC Strength Properties Level 2
PCC Material Properties - Layer #1
Thermal
Mix
Strength
Input Level
Level 1
Level 2
Level 3
Time
Comp.(psi)
7 Day
3560
14 Day
3900
28 Day
4200
90 Day
4700
20 Year/28 Day
1.44
OK
Cancel

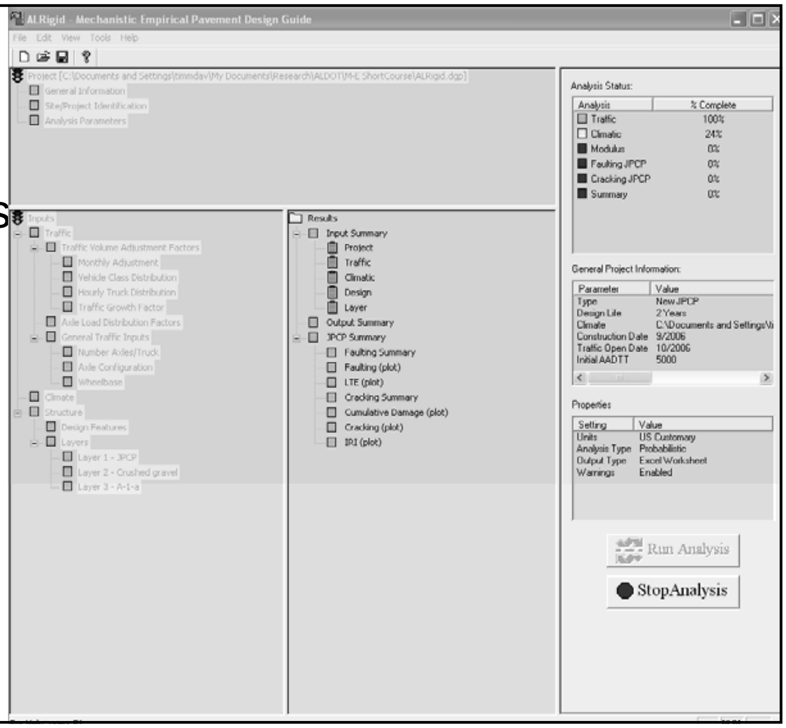
PCC Strength Properties Level 1



PCC Design Features



Run Analysis



Evaluate Results

Project: ALRigid
Reliability Summary

Performance Criteria	Distress Target	Reliability Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	68.8	99.999	Pass
Transverse Cracking (% slabs cracked)	15	90	0	99.999	Pass
Mean Joint Faulting (in)	0.12	90	0.012	99.999	Pass

APPENDIX B – COURSE REVIEW FORM

INTRODUCTION TO MECHANISTIC-EMPIRICAL
PAVEMENT DESIGN SHORTCOURSE
December 2-3, 2010
Harbert Engineering Center – Auburn University
Please complete this questionnaire at the end of the course.

1 = Strongly Disagree; 3 = Neutral; 5 = Strongly Agree					
This course met my expectations. Comments:	1	2	3	4	5
I can apply what I learned to my work. Comments:	1	2	3	4	5
I have a good understanding of mechanistic-empirical pavement design. Comments:	1	2	3	4	5
The computer-based activities contributed to my understanding. Comments:	1	2	3	4	5
The course was well-organized and delivered effectively. Comments:	1	2	3	4	5
The length of course and format were appropriate. Comments:	1	2	3	4	5
Interaction between instructors and participants was satisfactory. Comments:	1	2	3	4	5
Use of participant notebooks during course contributed to learning. Comments:	1	2	3	4	5
The instructional facilities were adequate for this course. Comments:	1	2	3	4	5
The break facilities were adequate for this course. Comments:	1	2	3	4	5
What did you like most about this course?					
What did you like least about this course?					

Please provide additional comments on back of this sheet.