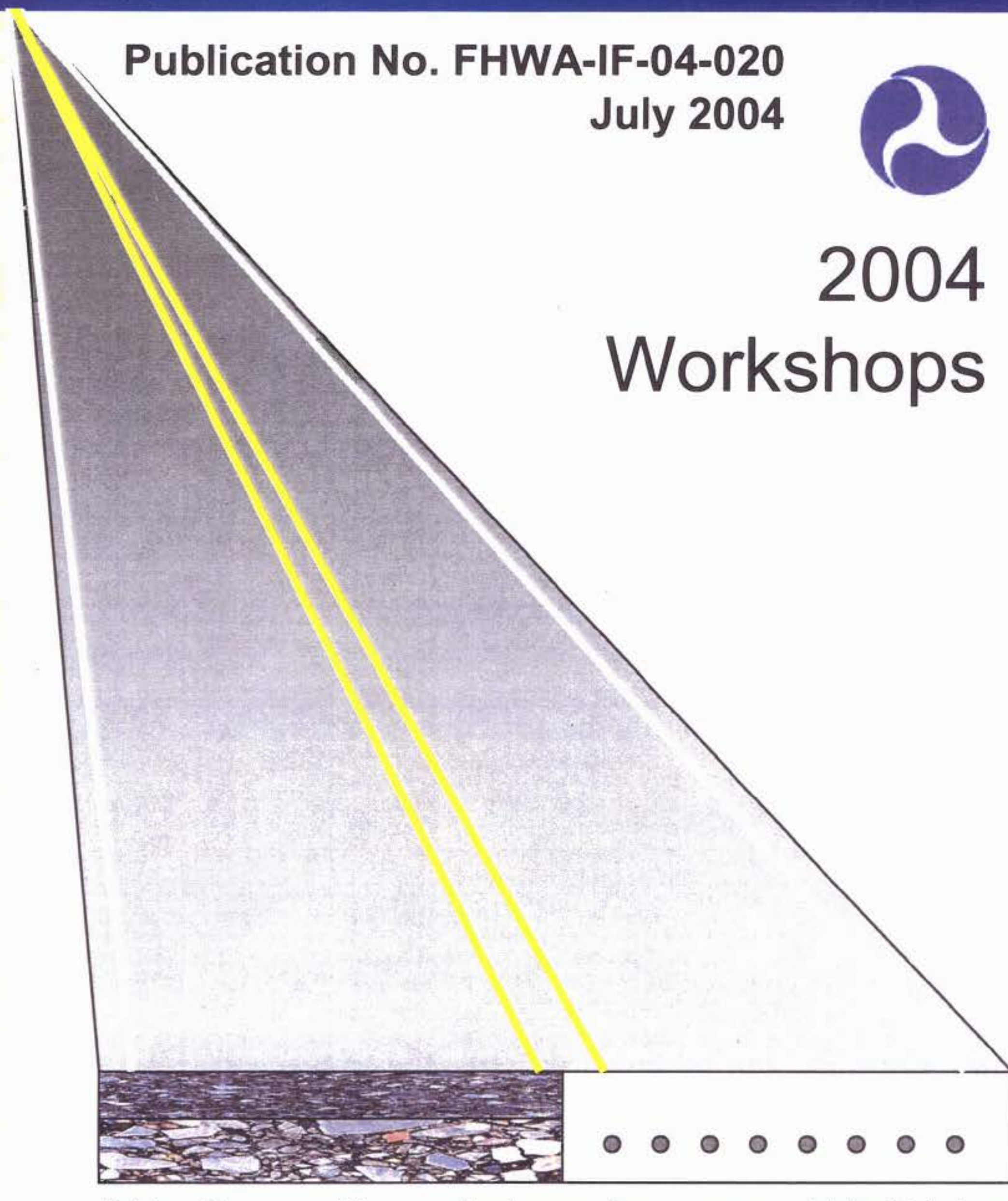
Mechanistic - Empirical Design Guide

Publication No. FHWA-IF-04-020
July 2004

Design
Guide
Implementation
Team



2004 Workshops

Federal Highway Administration

http://www.fhwa.dot.gov/pavement/dgit.htm

Workshop to Introduce the Mechanistic-Empirical (M-E) Pavement Design Guide

Federal Highway Administration and State Highway Agencies

Agenda

The full-day schedule will be adjusted to accommodate the work schedules of the host agencies.

8:00-8:15 am	Workshop welcome	Local agency
8:15-9:15 am	Design Guide Introduction	DGIT *
9:15-10:15 am	What's Different in M-E Guide	DGIT *
10:15-10:30 am	BREAK	
10:30-11:30 am	HMA Aspects of the M-E Guide	DGIT *
11:30-1:00 pm	LUNCH	
1:00-2:00 pm	PCC Aspects of the M-E Guide	DGIT *
2:00-2:45 pm	Implementation of the M-E Guide	DGIT *
2:45-3:00 pm	BREAK	
3:00-3:45 pm	State Implementation Activities	Local agency
3:45-4:30 pm	Open Discussion	All
4:30-5:00pm	Wrap-up and Adjourn	DGIT *

* FHWA's design guide implementation team (DGIT) will make these presentations. Typically, three members of the DGIT will participate as instructors in each workshop. The names of all DGIT instructors are listed on the following page.

DGIT Instructors for FHWA's 2004 M-E Design Guide Workshops

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Mechanistic-Empirical Design Guide

New and Rehabilitated Pavement Structures

Introduction

U.S. Department of Transportation
Federal Highway Administration

Objectives of the Workshop

- Introduce the M-E Design Guide
- Discuss status
- Describe key elements
- Highlight capabilities
- Provide an opportunity to discuss evaluation and implementation

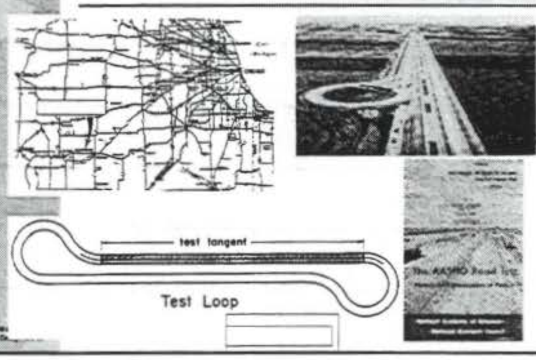
Introduction Outline

- Current pavement design procedures
- Need for change
- Capabilities of M-E design systems
- NCHRP 1-37A project –Background & Highlights
- FHWA's role in the implementation process

Design Methodologies

- Experience
- Empirical
  - Statistical models from road tests
- Mechanistic-empirical
  - Calculation of pavement responses, i.e., stresses, strains, deformations
  - Empirical pavement performance models
- Mechanistic

AASHO Road Test



AASHO Road Test Achievements

- Serviceability concept - PSI
- Traffic damage factors – ESALs
- Structural number concept – Sn
- Empirical Process
- Simplified Pavement Design

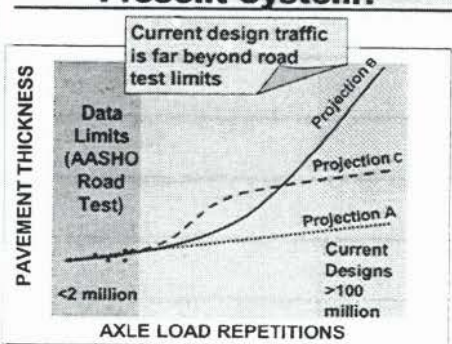
What's Being Used in 2003

Design Procedures	DOTs
1972 AASHTO Guide	3
1986 AASHTO Guide	2
1993 AASHTO Guide	26
Agency's own pavement design guide or combination of AASHTO/Agency design procedures	17

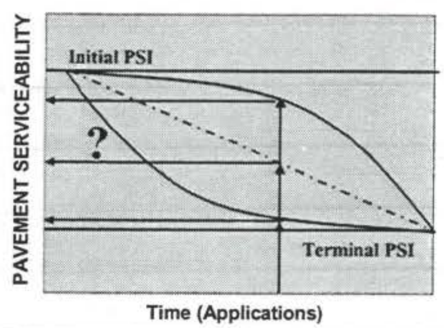
Limitations of the AASHO Road Test Based Procedures

- One climate – Ottawa, Illinois
- Limited Span – two years
- Limited Traffic – generally < 2 million
- 1950s vehicles
- 1950s materials and construction
- Only new construction

Limitations of the Present System?



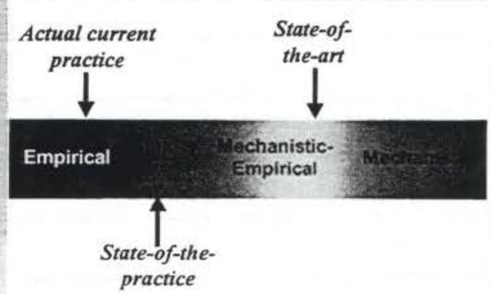
AASHO Serviceability



Structural Number

- Flexible Pavements
  - Not fundamental properties
  - Cannot be measured in laboratory
  - Cannot be established for new materials
- Rigid Pavements
  - "K" value
  - Bumping to account for stabilized layers
- No fundamental load carrying capacity

Development Continuum



NCHRP 1-37A Project

A coordinated and cooperative effort to improve the state of the practice for pavement design by developing a system that incorporates advances in pavement design.

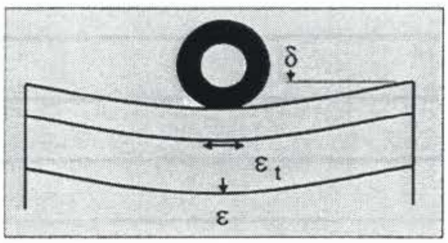
Empirical Procedures

to

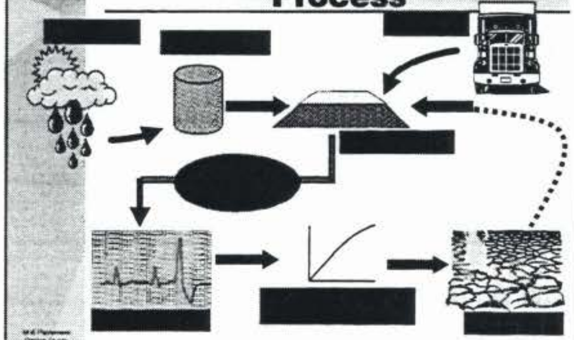
Mechanistic-Empirical Procedures

Mechanistic - Empirical Principles

M-E Principles = Engineering Fundamentals



M-E Pavement Design Process



Terminology

- M-E Design Guide
- NCHRP 1-37A Guide
- 2002 Design Guide
- New Design Guide
- Guide for M-E Design

ALL THE SAME THING!

Not AASHTO Design Guide.

How will I benefit from the M-E Design Guide?

It Ties Together:
- Structural Design
- Materials Selection
- Construction

Making sure that the design criteria have been met or exceeded.

Agency/Owner

and

Contractor/Supplier

M-E Guide Capabilities

- **Integrated effects -**
  - **Each current and future loading**
  - **Site specific climate (ICM)**
  - **Material changes over time**

M-E Guide Capabilities

- Predicts specific distresses based upon analysis on fundamental materials properties and M-E principles
- Tool for forensic analysis

M-E Guide Capabilities

- Allows design of -
  - New pavements
  - Composite pavements
  - Rehabilitation / overlays
- Evaluate effects of specification changes

M-E Design Guide Basics

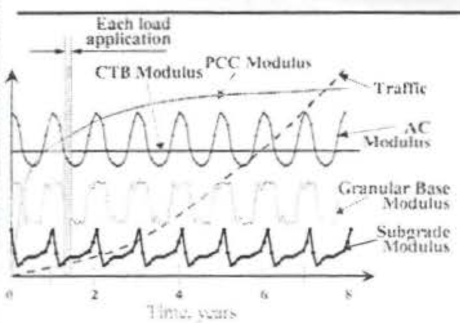
M-E Design Guide - Basics

• Proven theories
• M-E based
• Modular design
• One software / common interfaces
• Hierarchical inputs
• HMA – elastic layer basis
• PCC – finite element basis
• National (LTPP) & local calibration
• All documentation accessible

Why are so Many Details Needed?

- Materials properties change with time and environment
- Calculates incremental damage for each load
- Damaged dependent upon stress strain and material properties at time of loading

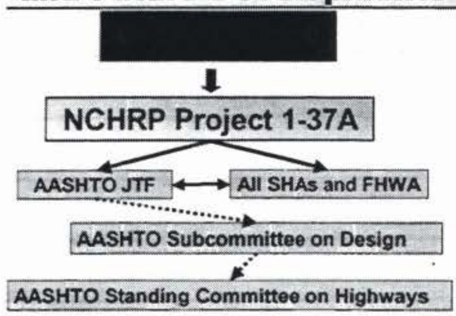
Pavement Design Variables



Why is Incremental Damage Important?

- Allows for incremental performance predictions during performance period
- Adjustments of scheduled rehab(s) based on as-constructed and actual performance data
- Basis for performance measures for long term warranties 5, 10, 15 years

AASHTO Guide – Current and Future Developments



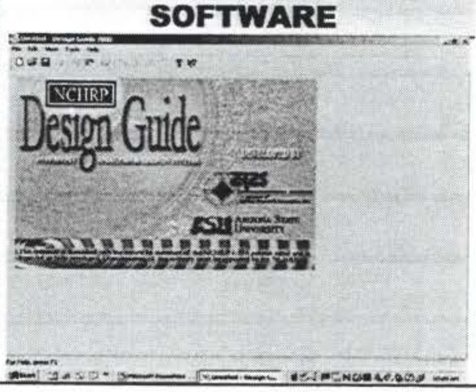
M-E Design Guide Timeline

- NCHRP project deliverables
  - Hard copy
  - CD version
  - Web-based version
- Concerns to be addressed
- Enhancements to be made

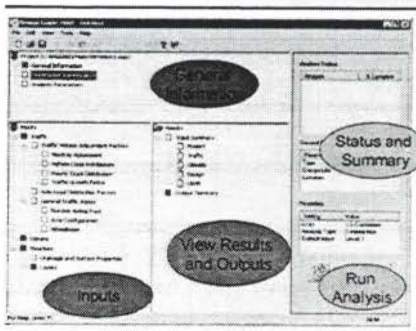
Enhancements Underway

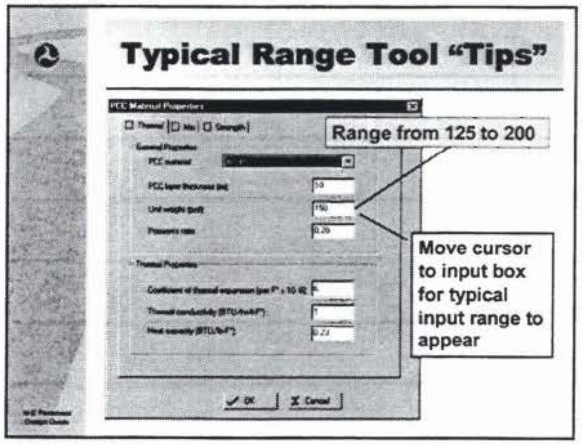
- Design Models -
  - Top Down cracking-NCHRP 1-42
  - Reflective cracking-NCHRP 1-41
- Traffic Interface-NCHRP 1-39
- Implementation-NCHRP 1-40
- Data collection for calibration of HMA models – NCHRP 9-30A

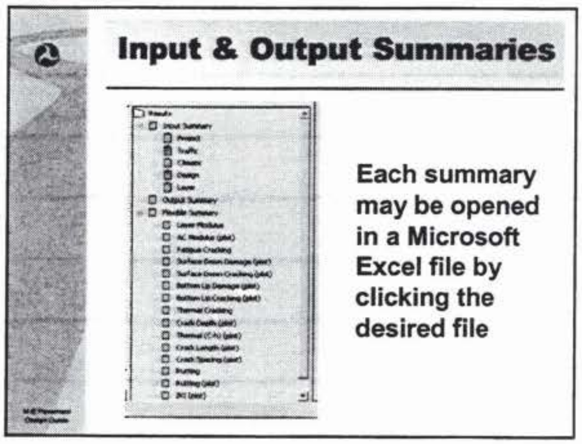
M-E DESIGN GUIDE SOFTWARE

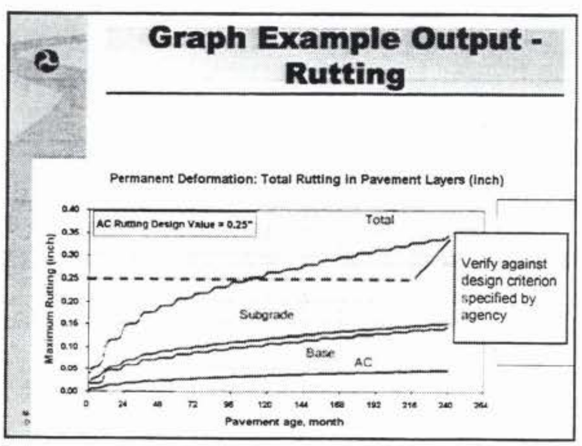


Convenient Input Layout




Typical Range Tool "Tips"
Range from 125 to 200
Move cursor to input box for typical input range to appear


Input & Output Summaries
Each summary may be opened in a Microsoft Excel file by clicking the desired file


Graph Example Output - Rutting
Permanent Deformation: Total Rutting in Pavement Layers (inch)
AC Rutting Design Value = 0.25"
Total
Subgrade
Base
AC
Maximum Rutting (inch)
Pavement age, month
Verify against design criterion specified by agency

FHWA's Role in Design Guide Implementation

How does this program fit into the FHWA's national program?

M-E Pavement Design Guide

FHWA Pavement Program Vision

"Pavements that meet our customers' needs and are safe, cost-effective, long-lasting and can be effectively maintained"

M-E Pavement Design Guide

FHWA Pavement Program

- Encompasses all pavement elements
- Integrated throughout FHWA
- Multi-faceted activities
- Supports AASHTO initiatives
- Created a Design Guide Implementation Team (DGIT)

M-E Pavement Design Guide

DGIT PURPOSE

To assist State highway agencies and industry in development and implementation of the M-E Pavement Design Guide

Elements of the DGIT Plan

- Workshops
- Training
- Technical Assistance
- Refinements

http://www.fhwa.dot.gov/pavement/dgit.htm

Questions?

www.fhwa.dot.gov/pavement/

The New and the Different

Guide for
Mechanistic - Empirical (M-E)
Design of New and Rehabilitated
Pavement Structures

U.S. Department of Transportation
Federal Highway Administration

The New and the Different

- Session outline
  - Capabilities
  - Compare AASHTO & M-E Guides
  - Inputs
    - Climate Traffic
    - ACP PCCP
    - Unbound materials
  - Reliability
  - Calibration and Testing

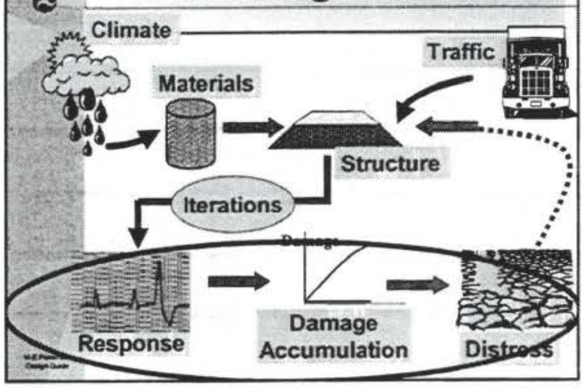
Capabilities

- Wide range of pavement structures
  - New
  - Rehabilitated
- Explicit treatment of major factors
  - Traffic – Over-weight trucks
  - Climate – Site specific and over time
  - Materials – New and different
  - Support – Foundation and existing pavement

Capabilities

- Models to predict change in distress over time
- User establishes acceptance criteria
  - Distresses and smoothness

M-E Design Process

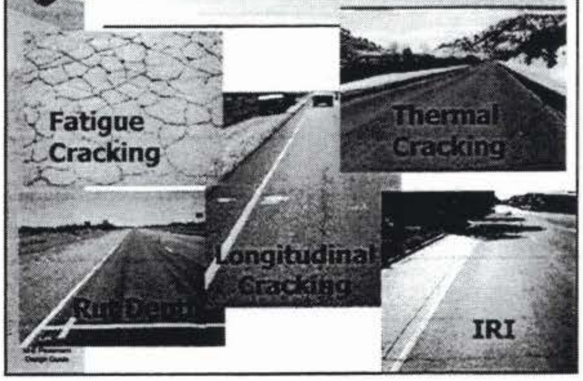


The New and Different

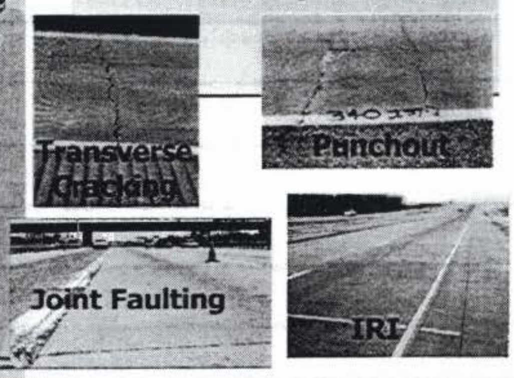
Outputs

1993 Guide	M-E Guide
Structural Number and / or Rigid Pavement Thickness	Time Series Distress and Smoothness Prediction

M-E Guide Outputs: Flexible



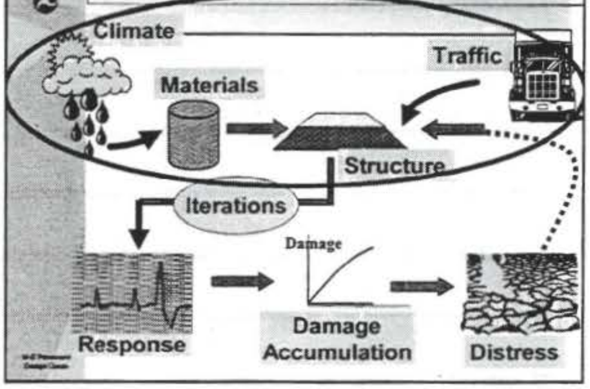
M-E Guide Outputs: Rigid



M-E Guide Software

The M-E Pavement Design Guide is an Analysis Program

M-E Design Process



The New and Different

	1993 Guide	M-E Guide
Input Levels	Single Value	Hierarchical Levels Level Three Level Two Level One

Hierarchical Levels

Level Three .. Defaults

Level Two .... Correlations
(Routine significant projects)

Level One ..... Project specific data
(Research, forensics and high level important projects)

Hierarchical Levels

Level	Source	Usage
Three	Defaults in M-E software	Routine projects
Two	Local correlations	More significant projects
One	Project-specific data	Research, forensics and high-level projects

Design Inputs - Hierarchical Levels

Input levels can be mixed and matched

Damage calculations are exactly the same regardless of design input level

Climatic Data

The New and Different

Climate

1993 Guide	M-E Guide
Seasonal Adjustments	Inputs for EICM
Drainage Coefficients	Thermal Properties Wind Speed Air Temperature Water Table Depth Sun Radiation Precipitation

Climatic Inputs

Input	1	2	3
Level	√	√	√

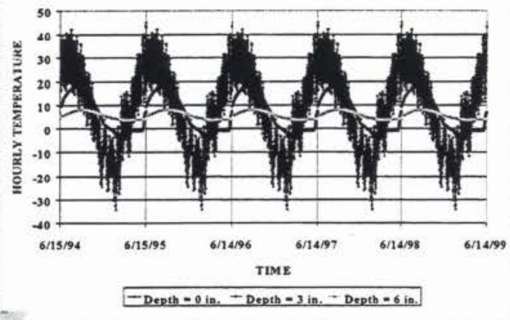
- Identify weather station
  - Pick from 800 sites
  - Create virtual by averaging surrounding sites
- Create EICM file
- Depth to water table

Processing EICM Inputs - Flexible Design

Adjustments -

- Unbound materials
  - Resilient modulus
  - Moisture content
- HMA Hourly temperature profile
  - Thermal cracking
  - Rutting

Hourly Temperature Profile - HMA

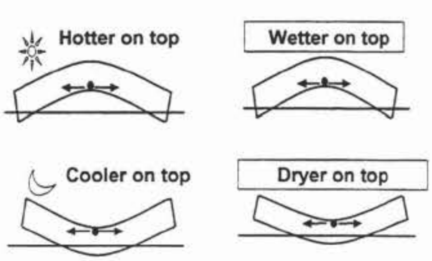


Processing Climatic Inputs - Rigid Design

- EICM used to predict
  - Hourly temperature profile
  - Monthly moisture gradient

Concrete Slab Temperature and Moisture Gradients

Curling | Warping



TRAFFIC INPUTS

M-E Pavement Design Guide

The New and Different

	1993 Guide	M-E Guide
T r a f f i c	ESALs	Axle Load Spectra
	Truck Equivalency Factors	Truck Speed Gear/Axle Configuration Axle/Tire Spacing Tire Pressure Traffic Wander Monthly, Daily Distribution Factors

M-E Pavement Design Guide

Traffic Hierarchical Input Levels

M-E Pavement Design Guide

Traffic Module Inputs - Overview

Input Parameters	Input Level		
	1	2	3
AADTT for Base Year	√	√	
AADT and Percent Trucks for Base Year			√
Directional Distribution Factor	√	√	√
Lane Distribution Factor	√	√	√
Truck Distribution Factors - Base Year	√	√	
Axle Load Distribution Factors	√	√	
Monthly Distribution Factors	√	√	√

Traffic Module Inputs - Overview

Input Parameters	Input Level		
	1	2	3
Hourly Distribution Factors	√	√	√
Truck Traffic Growth Function/Factor	√	√	√
Axle Load Distribution Factors	√	√	
Truck Traffic Classification (TTC) Factor			√
No. of Axle Types per Truck Class	√	√	
Axle Spacing	√	√	
Axle Load Groups	√	√	√
Tire Spacing/Axle Configuration	√	√	√
Tire Pressure	√	√	√

Traffic Module Output Files (Load Spectra)

Year	Month	Hour	Axle Type	Load Group				
				0-2	2-4	4-6	..	x-y
i	j	k	Single					
			Tandem					
			Tridem					
			Quad					

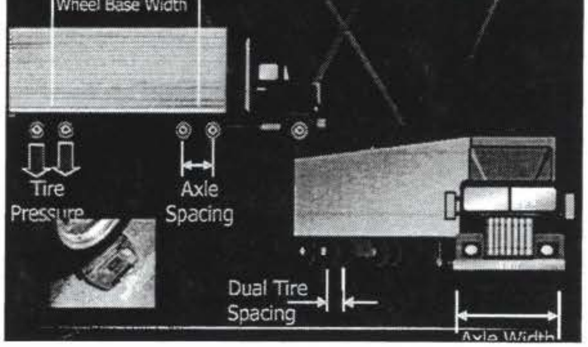
Truck and Axle Load Distribution Factors

Input Level	1	2	3
			√

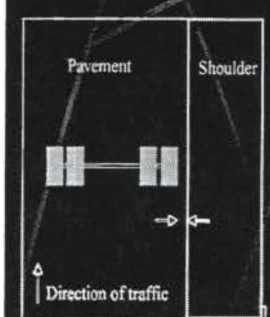
- Use Truck Traffic Classification (TTC):
  - Defaults derived from LTPP Data
  - Select one of the 17 Groups
    - TTC Selection is based on functional classification and overall distribution of the major truck classes (buses, single unit trucks, single-trailer trucks, and multi-trailer trucks)

M-E Pavement Design Guide

Axle Configuration Parameters



Traffic Wander



Used to calculate pavement responses & the number of axle load applications over a point for predicting distress & performance.

- Mean wheel location = 18 in.
- Standard deviation = 10 in.
- Design lane width.

NCHRP 1-39

Traffic Data Collection, Analysis & Forecasting for M-E Design

- Developed Software - TrafLoad
- Beta version under review
  - Reads C-card and W-card data
  - Manipulates data into M-E Guide format
  - Intended to supply traffic needs of M-E Guide

The New and Different

Foundation

1993 Guide	M-E Guide
Resilient Modulus "k" values	Universal non-linear Resilient modulus Model

Unbound Materials - Aggregates & Subgrade

- Resilient Modulus
  - Level 3 Defaults
  - Level 2 Correlations
  - Level 1 Materials specific testing
- Variability
  - None
  - Seasonal Values
  - EICM

Unbound Material - General Properties

Input Level	1	2	3
	√	√	√

- Select unbound material type from -
  - AASHTO Classification (AASHTO M 145)
  - Unified Soil Classification System (ASTM D 2487)
  - Other (crushed stone, cold recycled AC)
- Layer Thickness - inches

Rigid Design

Subgrade resilient modulus is converted to a k-value that produces equivalent surface deflections for each month in year

Flexible Design

ASPHALT MATERIAL PROPERTY AND DESIGN INPUTS

The New and Different - Flexible Design

HMA Materials

1993 Guide	M-E Guide
Layer coefficient	Dynamic modulus
IDT resilient modulus (68°F)	Poisson's ratio

Mix Dynamic Modulus

- Level
  - 3 – Predictive equation & binder class
  - 2 – Predictive equation & binder tests
  - 1 – Laboratory mix tests
- Predictive equation
  - Gradation
  - Air Voids
  - Asphalt content
  - Binder information

Rigid Design

CONCRETE MATERIAL PROPERTY & DESIGN INPUTS

The New and Different - Rigid Design

PCC Materials

1993 Guide	M-E Guide
Modulus Flexural strength Tensile strength (28-day)	Modulus of elasticity (7, 14, 28 & 90-day) Flexural strength Tensile strength Poisson's ratio Thermal properties - Drying shrinkage Coefficient of thermal expansion

M-E Pavement Design Guide

JPCP Design Features

Input Level	1	2	3
	√	√	√

- Joint Details
  - Joint spacing
  - Sealant type
  - Dowel diameter and spacing
- Edge Support
  - Shoulder type and LTE
  - Widened slab
- Base properties
  - Base type
  - Interface type, i.e. bonded or unbonded
  - Erodibility

M-E Pavement Design Guide

CRCP Design Features

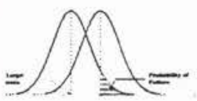
Input Level	1	2	3
	√	√	√

- Reinforcement
  - Bar diameter
  - Spacing
  - Percent steel
- Base properties
  - Base type
  - Erodibility
  - Base/slab friction coefficient
- Crack spacing - optional

M-E Pavement Design Guide

Performance Evaluation

- Procedure evaluates the trial design to determine if it meets the desired performance criteria at individually set reliability levels

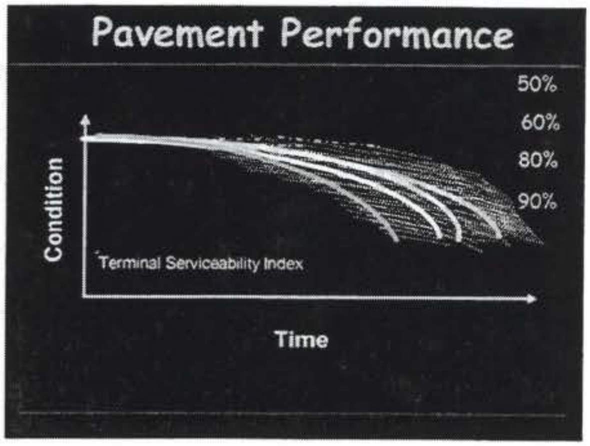


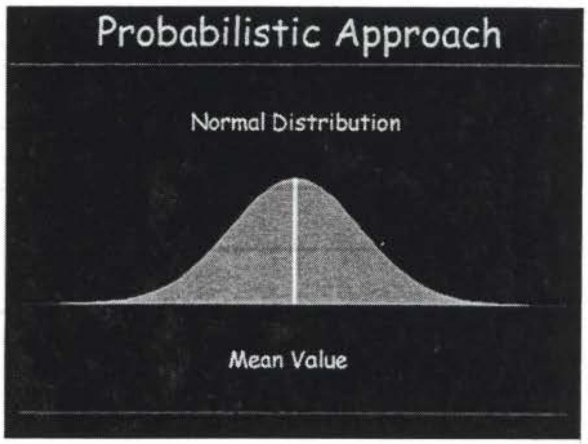
New Approach to Design Reliability

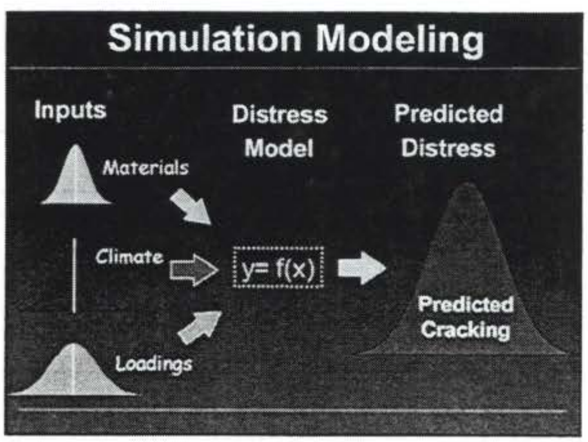
- Different than AASHTO 1986/93
- Based on predicted distresses and IRI
- User selects reliability levels and performance criteria for distresses and IRI

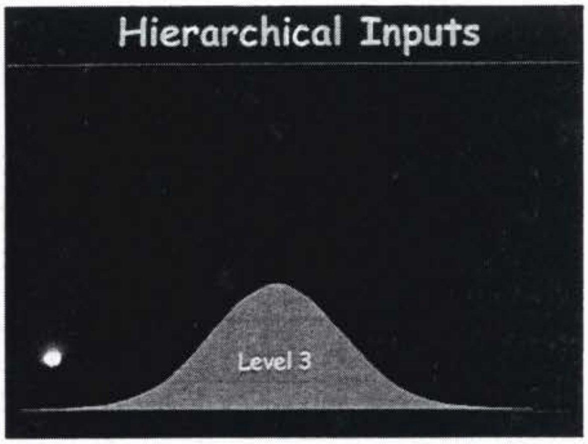
Reliability

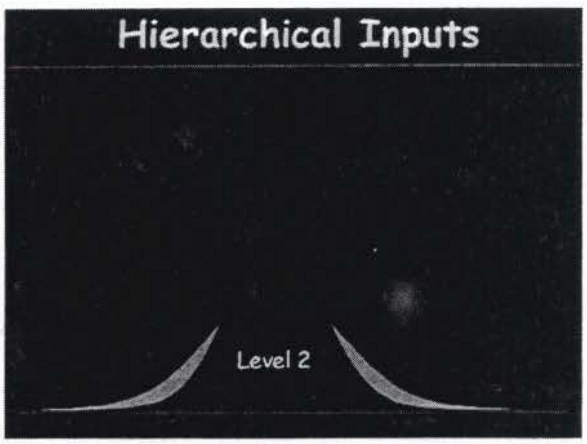
- As proposed
  - Probabilistic approach
  - Monte Carlo simulation
- As Delivered
  - Variability of predicted vs observed
  - Calibrated to national LTPP data (Level 3)

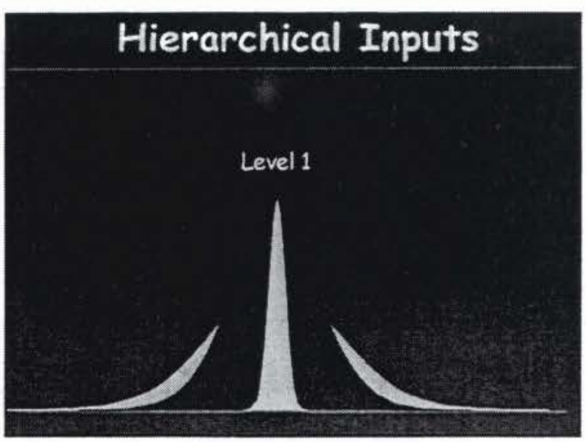

Pavement Performance
50%
60%
80%
90%
Condition
Terminal Serviceability Index
Time

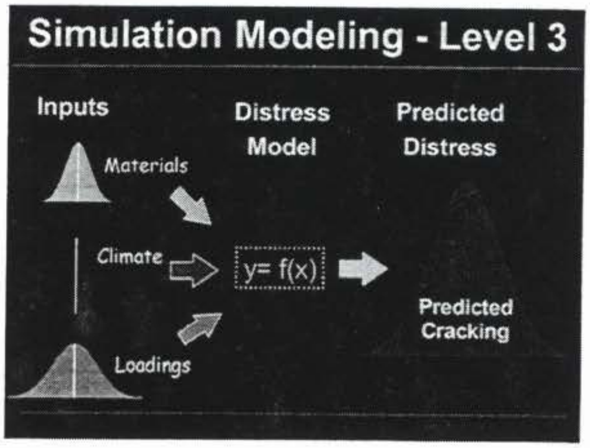

Probabilistic Approach
Normal Distribution
Mean Value

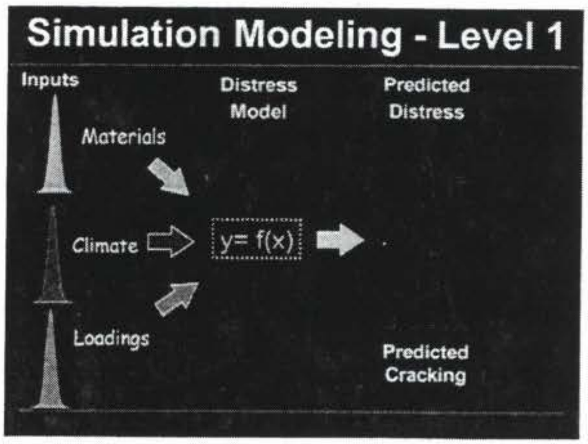

Simulation Modeling
Inputs
Distress Model
Predicted Distress
Materials
Climate
y= f(x)
Predicted Cracking
Loadings

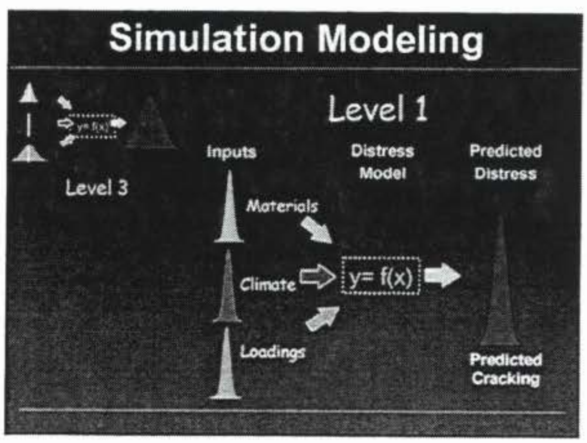

Hierarchical Inputs
Level 3


Hierarchical Inputs
Level 2


Hierarchical Inputs
Level 1


Simulation Modeling - Level 3
Inputs
Distress Model
Predicted Distress
Materials
Climate
y= f(x)
Loadings
Predicted Cracking

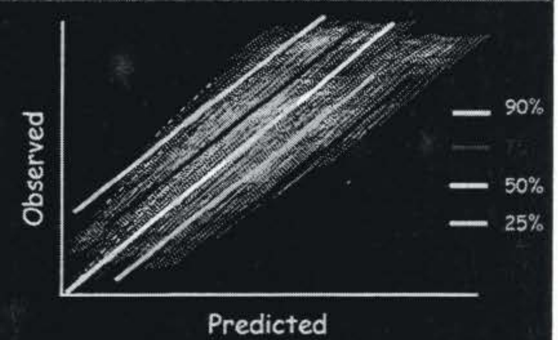

Simulation Modeling - Level 1
Inputs
Distress Model
Predicted Distress
Materials
Climate
y= f(x)
Loadings
Predicted Cracking


Simulation Modeling
Level 3
Level 1
Inputs
Distress Model
Predicted Distress
Materials
Climate
y= f(x)
Loadings
Predicted Cracking

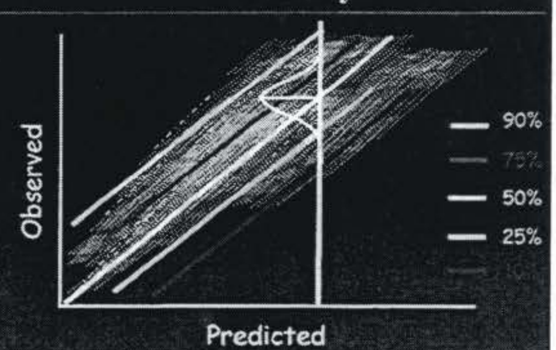
Reliability

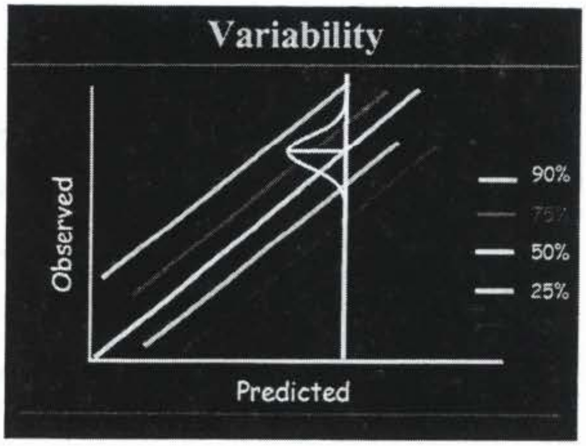
- As proposed
  - Probabilistic approach
  - Monte Carlo simulation
- As Delivered
  - Variability of predicted vs observed
  - Calibrated to national LTPP data inputs (Level 3)
  - Based on national calibration/LTPP

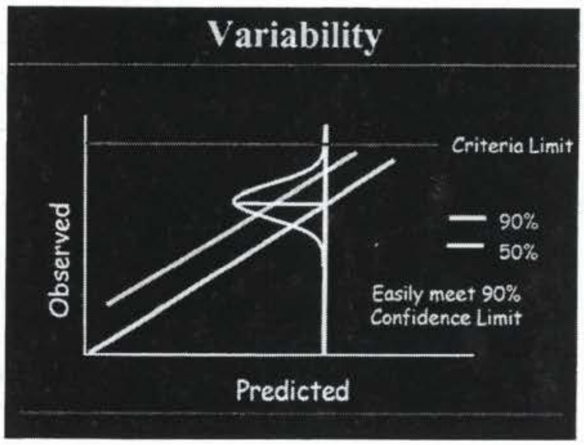
Variability

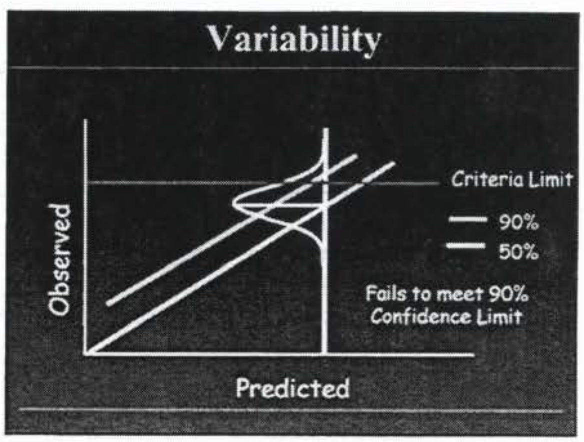


Variability

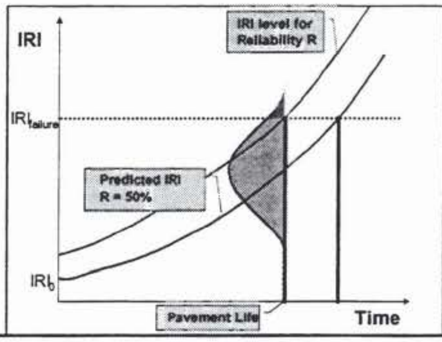



Variability
Observed
Predicted
90%
75%
50%
25%

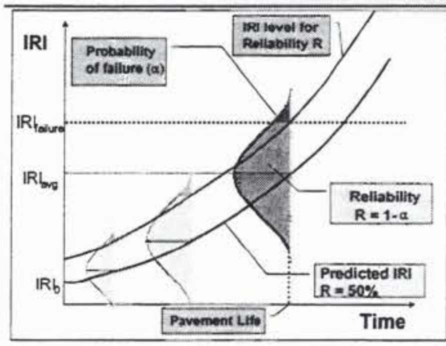

Variability
Criteria Limit
Observed
90%
50%
Easily meet 90%
Confidence Limit
Predicted


Variability
Criteria Limit
Observed
90%
50%
Fails to meet 90%
Confidence Limit
Predicted

Assessment of Reliability



Assessment of Reliability



M-E Guide Calibration

- Done with national LTPP data
- Default values also from LTPP
- Confirm/change national defaults
- NCHRP 1-40 guidelines for local calibration (future FHWA workshops)

Implementation – Calibration

- Requires extensive experimental studies, including:
  - Field testing programs
  - Laboratory testing
  - Data analysis

Field Testing Programs

- Select agency test sites (LTPP and others) that includes entire range of -
  - Climate types and areas in the agency
  - Traffic characteristics
  - Pavement types -
    - HMA (all types) and PCC (all types)
    - Types of overlays and rehabilitation alternatives
    - Base and subgrade types
    - Joint types in PCC

Field Testing Programs
continued

- Obtain pavement performance data
  - Distress surveys
  - FWD and core testing
  - Pavement profile
  - Material related distresses
- Determine in-place material properties

Laboratory Testing

- Extract cores
- Determine properties of in-situ material
- Calibration test are the same as those performed for new designs

NCHRP 9-30

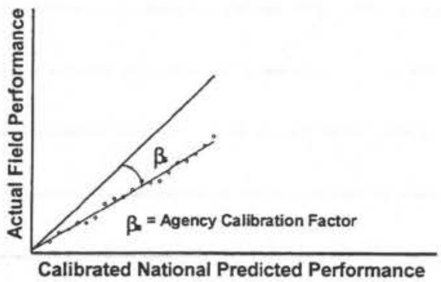
"Experimental Plan for Calibration and Validation of HMA Performance Models for Mix & Structural Design"

- Set up a national database for HMA calibration
- Initially populated with NCHRP 9-19 and LTPP data
- NCHRP 9-30A to populate database for missing material types

Data Analysis

Local calibration will involve recalibrating distress models using data collected from the selected local sections

Regional/Local Calibration Process



Summary

- Covered M-E guide capabilities, inputs, reliability, and calibration
- Compared AASHTO & M-E guides
- Described local calibration process
- Detailed the inputs needed for flexible and rigid designs

Flexible Pavement Design

The Mechanistic-Empirical Way

U.S. Department of Transportation
Federal Highway Administration

Presentation Outline

- What's new in flexible pavement design using the M-E guide?
- Example of M-E design
  - Differences
  - Capabilities
- Tests and equipment

What's New in Flexible Pavement Design?

- Analysis model – layered elastic
- Distress is based on material performance
  - Fatigue - top down and bottom up
  - Rutting
  - Thermal cracking

Capabilities

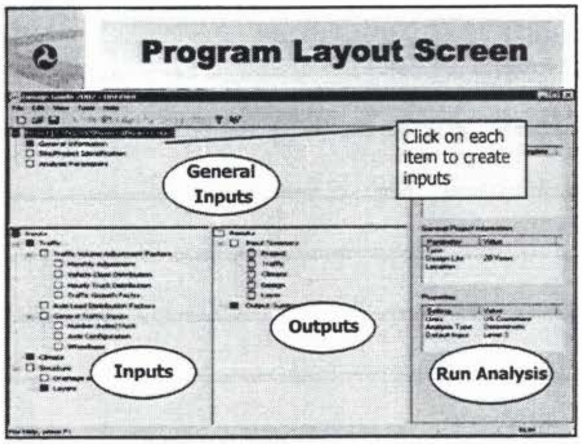
- Provides link between
  - Asphalt mixture design
  - Performance prediction
  - Structural design
- HMA overlays over -
  - flexible pavements
  - fractured rigid pavements
  - rigid pavements

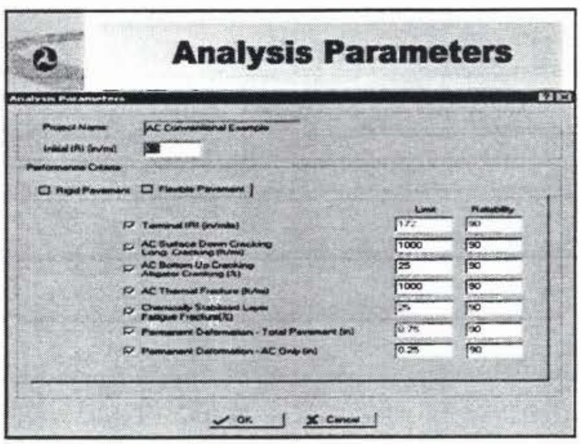
Capabilities

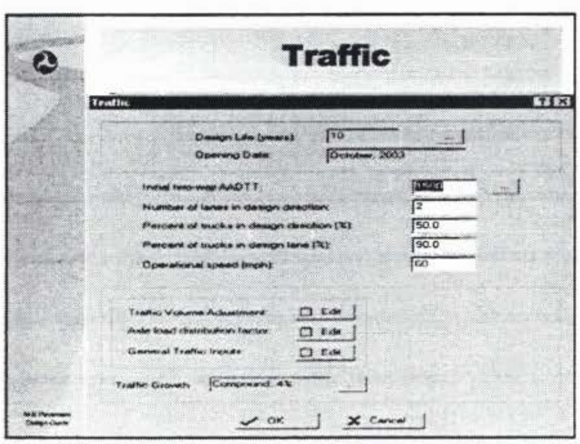
- Integrated with Superpave system
- Models calibrated using LTPP data
- "Plug and Play" prediction models
- Includes method for local calibration

Example Simulation

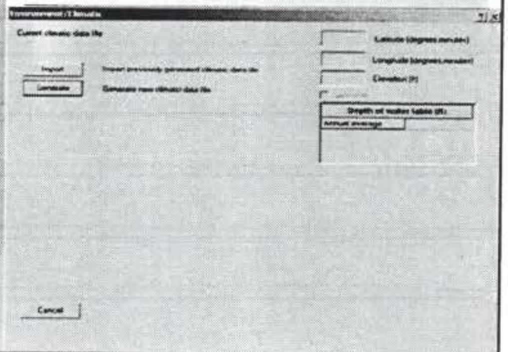
- New flexible pavement
- Conventional design (HMA over aggregate base)


Program Layout Screen
Click on each item to create inputs
General Inputs
Outputs
Inputs
Run Analysis


Analysis Parameters
AC Conventional Example
OK
Cancel


Traffic
Design Life (years)
10
Opening Date
October, 2003
Number of lanes in design direction
2
Percent of trucks in design direction (%)
50.0
Percent of trucks in design lane (%)
90.0
Operational speed (mph)
60
Traffic Growth
Compound, 4%
OK
Cancel

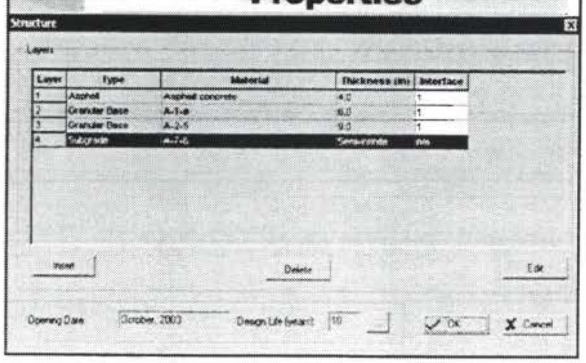
Climate



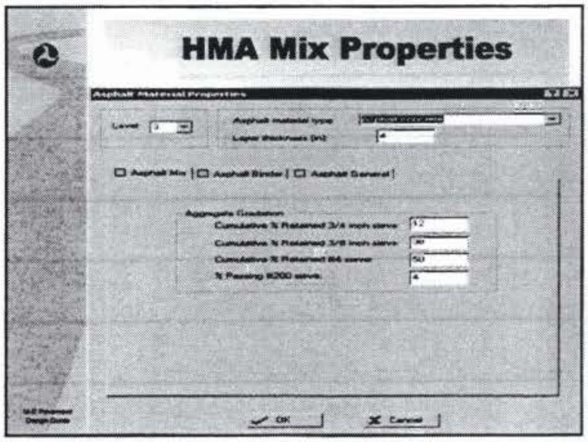
Structure Inputs

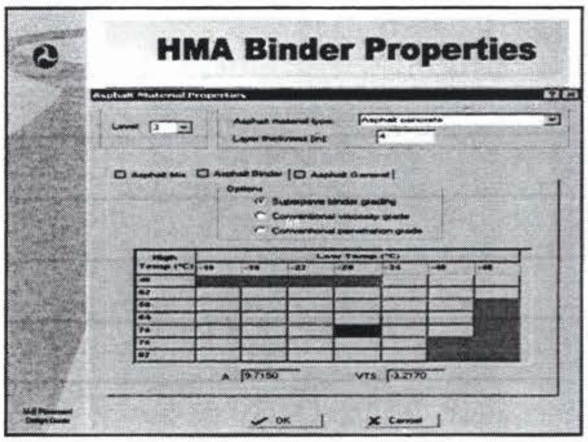
- User needs to choose layers and the trial design
- Example - Conventional HMA -
  - 4.0-inch HMA layer
  - 6.0-inch Granular Base layer (A-1-a)
  - 9.0-inch Granular Base layer (A-2-5)
  - Natural subgrade (A-7-6)

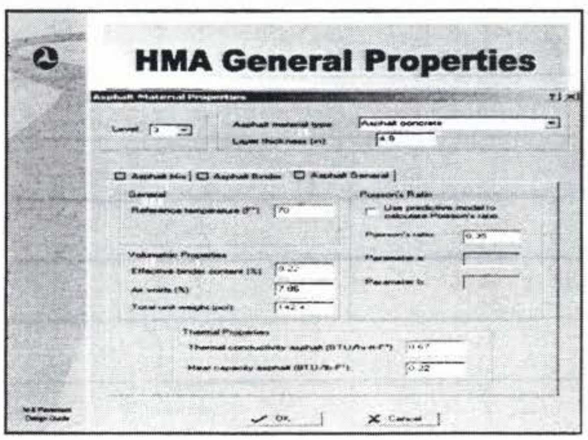
Add Layers and Edit Layer Properties

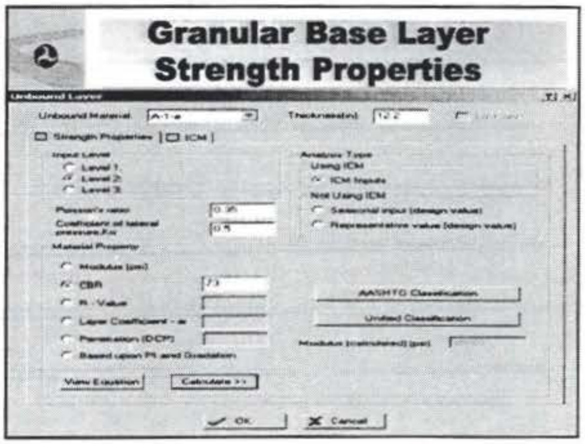


Layer	Type	Material	Thickness (in)	Interface
1	Asphalt	Asphalt concrete	4.0	1
2	Granular Base	A-1-a	6.0	1
3	Granular Base	A-2-5	9.0	1
4	Subgrade	A-7-6	Semi-infinite	n/a


HMA Mix Properties
Asphalt Material Properties
Level
Asphalt material type
Layer thickness (in)
Asphalt Mix
Asphalt Binder
Asphalt General
Aggregate Gradation
Cumulative % Retained 3/4 inch sieve
12
Cumulative % Retained 3/8 inch sieve
Cumulative % Retained #4 sieve
50
% Passing #200 sieve
OK
Cancel

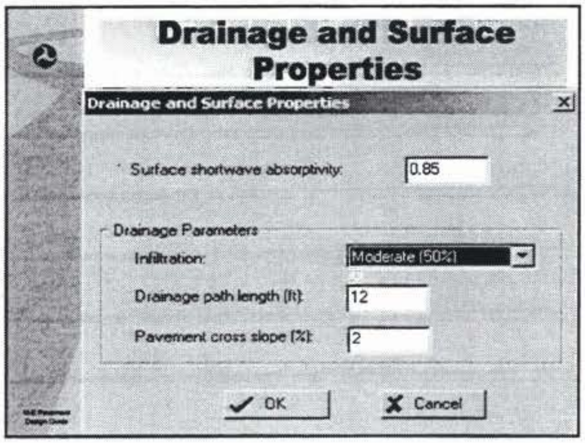

HMA Binder Properties
Asphalt Material Properties
Level
Asphalt material type
Asphalt concrete
Layer thickness (in)
4
Asphalt Mix
Asphalt Binder
Asphalt General
Options
Superpave binder grading
Conventional viscosity grade
Conventional penetration grade
High Temp (°C)
Low Temp (°C)
A
9.7150
VTS
-3.2170
OK
Cancel

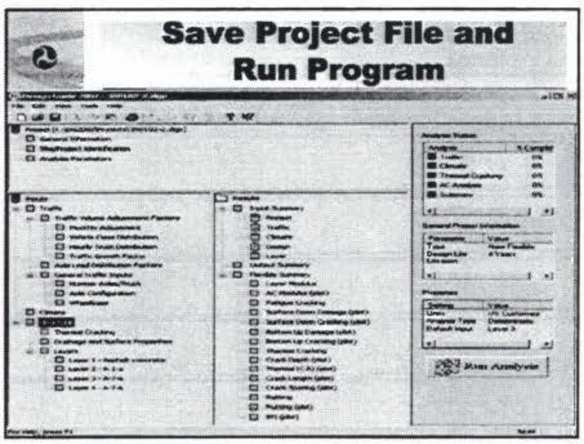

HMA General Properties
Asphalt Material Properties
Level
Asphalt material type
Asphalt concrete
Layer thickness (in)
Asphalt Mix
Asphalt Binder
Asphalt General
General
Reference temperature (F°)
70
Poisson's Ratio
Use predictive model to calculate Poisson's ratio
Poisson's ratio
0.35
Parameter a
Parameter b
Volumetric Properties
Effective binder content (%)
Air voids (%)
7.06
Total unit weight (pcf)
Thermal Properties
Thermal conductivity asphalt (BTU/hr-ft-F°)
Heat capacity asphalt (BTU/lb-F°)
0.22
OK
Cancel

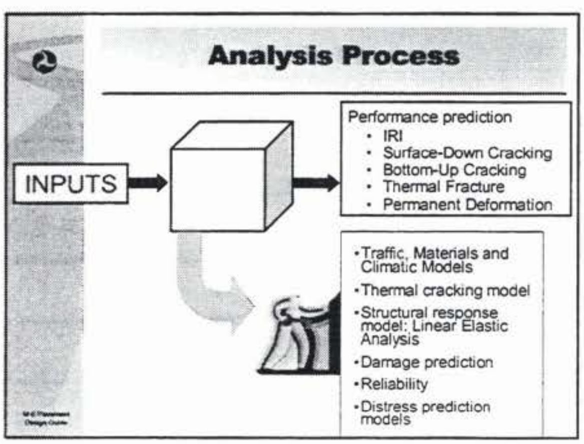

Granular Base Layer
Strength Properties

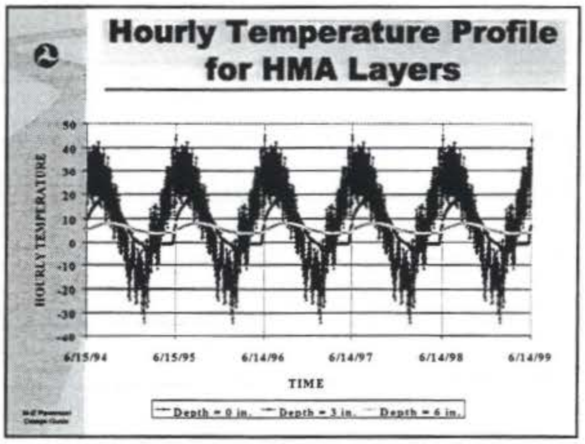

Compacted Subgrade
Strength Properties

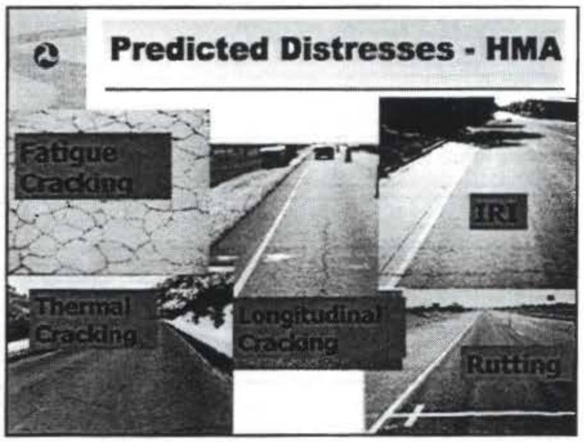

Natural Subgrade Layer
Strength Properties

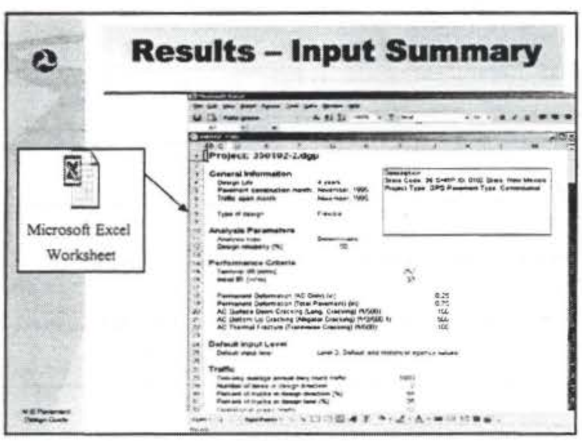

Drainage and Surface Properties
Drainage and Surface Properties
Surface shortwave absorptivity: 0.85
Drainage Parameters
Infiltration: Moderate (50%)
Drainage path length (ft): 12
Pavement cross slope (%): 2
OK
Cancel

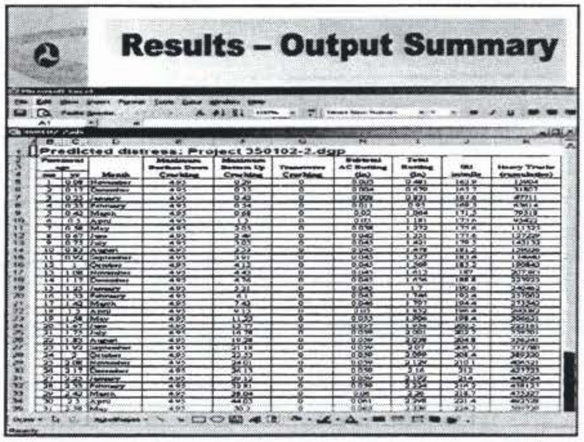

Save Project File and Run Program
Run Analysis

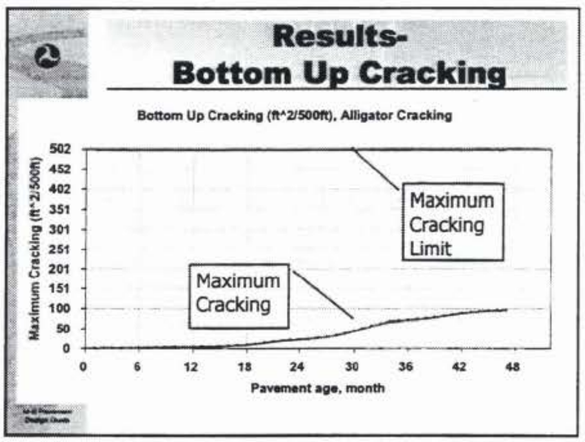

Analysis Process
INPUTS
Performance prediction
• IRI
• Surface-Down Cracking
• Bottom-Up Cracking
• Thermal Fracture
• Permanent Deformation
•Traffic, Materials and Climatic Models
•Thermal cracking model
•Structural response model: Linear Elastic Analysis
•Damage prediction
•Reliability
•Distress prediction models

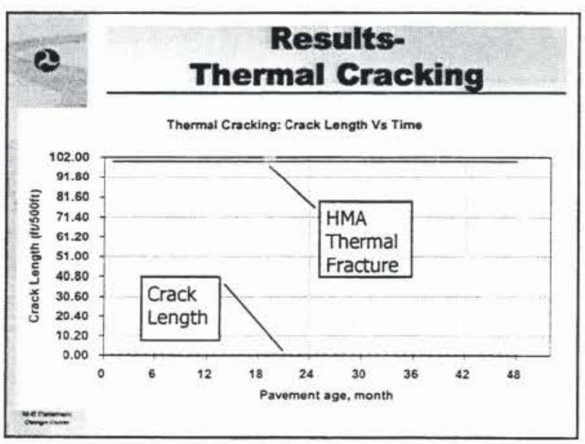

Hourly Temperature Profile for HMA Layers
HOURLY TEMPERATURE
50
40
30
20
10
0
-10
-20
-30
-40
6/15/94
6/15/95
6/14/96
6/14/97
6/14/98
6/14/99
TIME
Depth = 0 in.
Depth = 3 in.
Depth = 6 in.


Predicted Distresses - HMA
Fatigue Cracking
IRI
Thermal Cracking
Longitudinal Cracking
Rutting

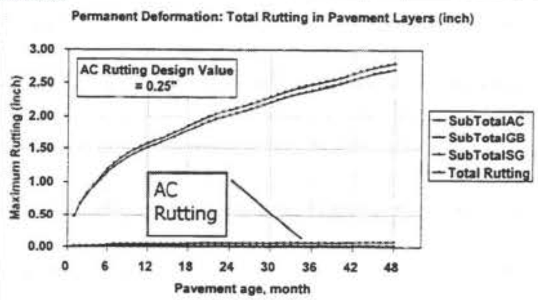

Results – Input Summary
Microsoft Excel Worksheet


Results – Output Summary
Predicted distress: Project 350102-2.dgp

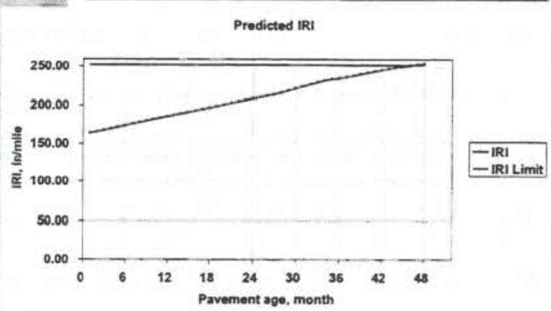

Results-
Bottom Up Cracking
Bottom Up Cracking (ft^2/500ft), Alligator Cracking
Maximum Cracking (ft^2/500ft)
502
452
402
351
301
251
201
151
100
50
0
0
6
12
18
24
30
36
42
48
Pavement age, month
Maximum Cracking Limit
Maximum Cracking


Results-
Thermal Cracking
Thermal Cracking: Crack Length Vs Time
Crack Length (ft/500ft)
102.00
91.80
81.60
71.40
61.20
51.00
40.80
30.60
20.40
10.20
0.00
0
6
12
18
24
30
36
42
48
Pavement age, month
HMA Thermal Fracture
Crack Length

Results - Permanent Deformation

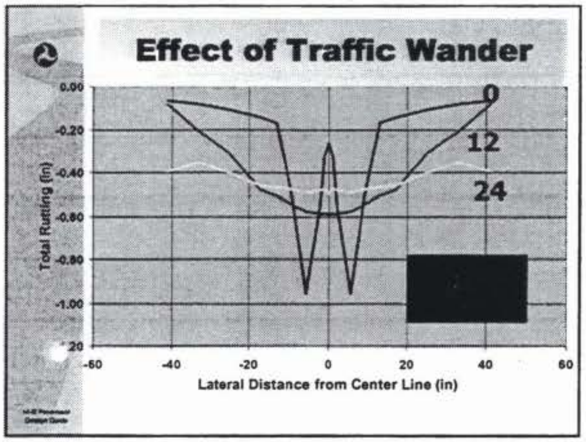


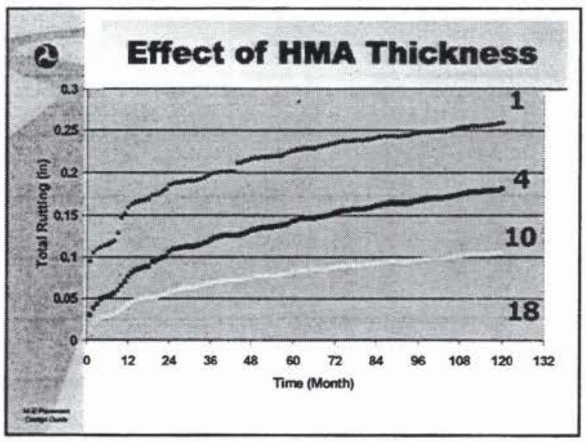
Results- IRI

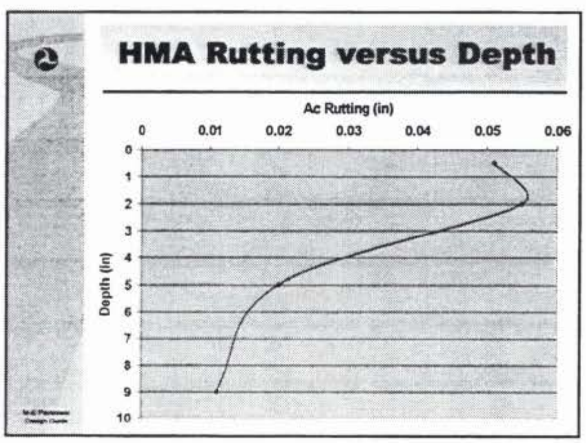


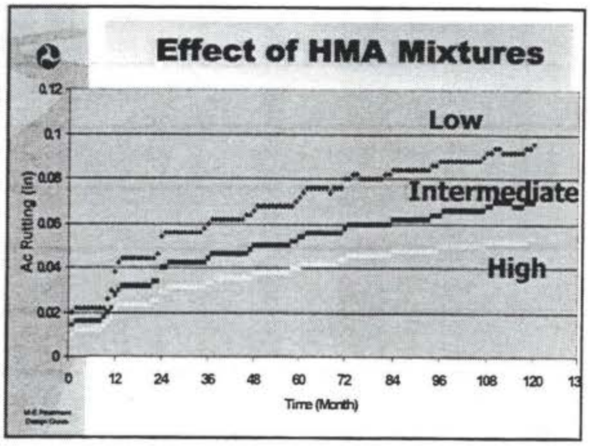
Sensitivity Examples

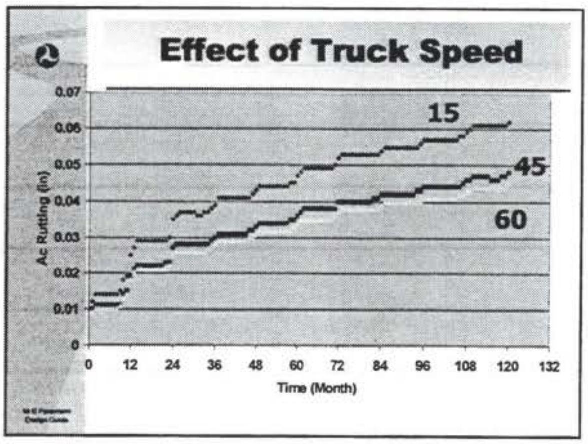
"For illustration purposes only"

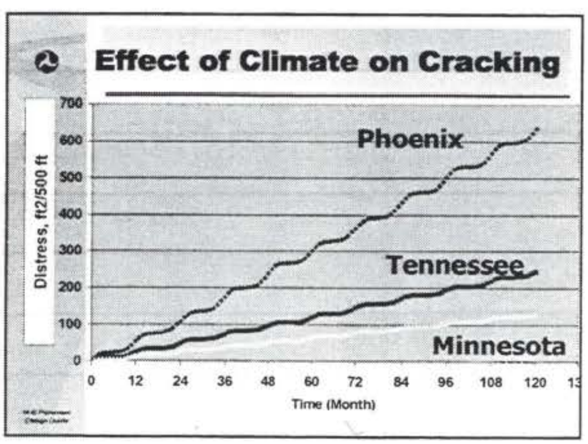

Effect of Traffic Wander
0
12
24
[redacted]
Total Rutting (in)
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-60
-40
-20
0
20
40
60
Lateral Distance from Center Line (in)

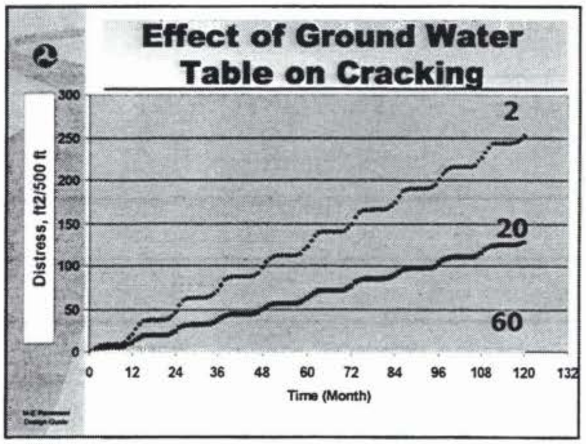

Effect of HMA Thickness
1
4
10
18
Total Rutting (in)
0
0.05
0.1
0.15
0.2
0.25
0.3
0
12
24
36
48
60
72
84
96
108
120
132
Time (Month)


HMA Rutting versus Depth
Ac Rutting (in)
0
0.01
0.02
0.03
0.04
0.05
0.06
Depth (in)
0
1
2
3
4
5
6
7
8
9
10

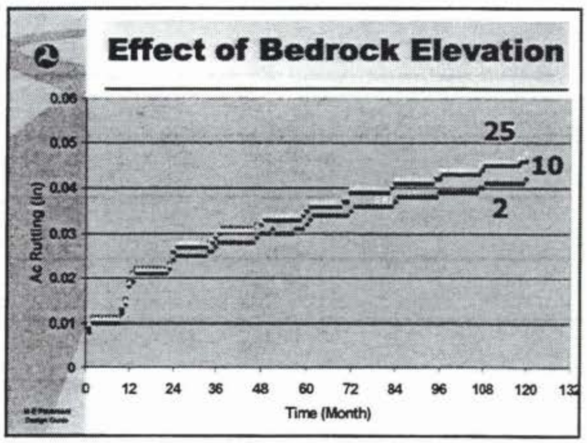

Effect of HMA Mixtures
Ac Rutting (in)
0.12
0.1
0.08
0.06
0.04
0.02
0
Low
Intermediate
High
0 12 24 36 48 60 72 84 96 108 120
Time (Month)


Effect of Truck Speed
Ac Rutting (in)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
15
45
60
0 12 24 36 48 60 72 84 96 108 120 132
Time (Month)

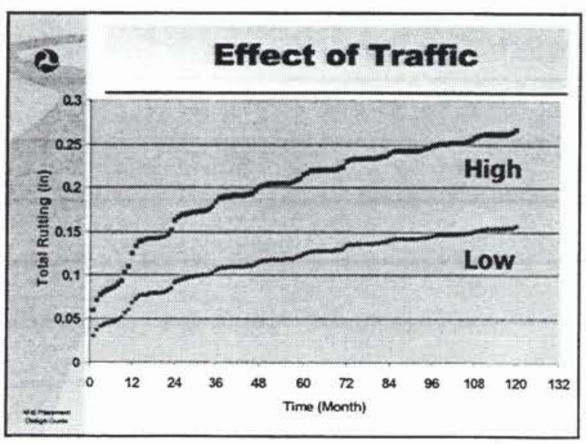

Effect of Climate on Cracking
Distress, ft2/500 ft
700
600
500
400
300
200
100
0
Phoenix
Tennessee
Minnesota
0 12 24 36 48 60 72 84 96 108 120
Time (Month)



Effect of Ground Water Table on Cracking
Distress, ft2/500 ft
300
250
200
150
100
50
0
2
20
60
0 12 24 36 48 60 72 84 96 108 120 132
Time (Month)



Effect of Bedrock Elevation
Ac Rutting (in)
0.06
0.05
0.04
0.03
0.02
0.01
0
25
10
2
0 12 24 36 48 60 72 84 96 108 120 132
Time (Month)



Effect of Traffic
Total Rutting (in)
0.3
0.25
0.2
0.15
0.1
0.05
0
High
Low
0 12 24 36 48 60 72 84 96 108 120 132
Time (Month)

Overview of Tests & Equipment

HMA LAB TESTS

HMA Materials Data

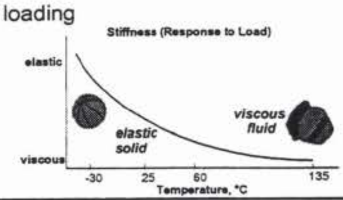
Material	Parameter	Level 1	Level 2	Level 3
Mix	Master Curve	Mix Specific	Not Required	Not Required
	IDT-Creep/Strength	Mix Specific	Reduced Testing	Reduced Testing
	Air Voids	Not Required	Mix Design	Specification
Asphalt	G*/Phase Angle	AASHTO MP1 Binder Test	AASHTO MP1 Binder Test	Not Required
	Pen./Vis./PG	Not Required	Mix Design	Not Required
	Type (PG, Vis.)	Not Required	Not Required	Specification
Agg.	Effective SG.	Not Required	Mix Design	Quarry Specific
	Gradation	Not Required	Mix Design	Specification

HMA Binder Characterization

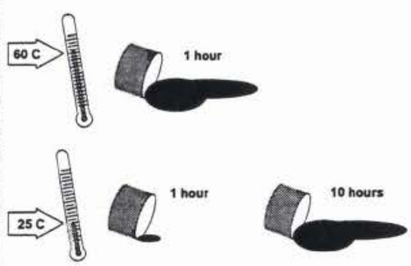
- Penetration
  - ASTM D5 and AASHTO T49
- Viscosity at 60°C
  - ASTM D2171 and AASHTO T202
- Viscosity at 135°C
  - ASTM D2170 and AASHTO T201
- Brookfield Viscosity
  - AASHTO TP 48
- Softening Point
- Shear Modulus
  - AASHTO TP 5

Consistency Behavior

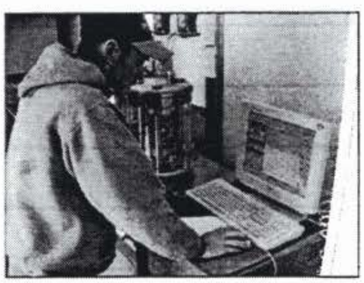
- Indicator of Viscous and Elastic Characteristics of the Material
- Factors Affecting HMA Behavior
  - Temperature
  - Rate of loading
  - Aging

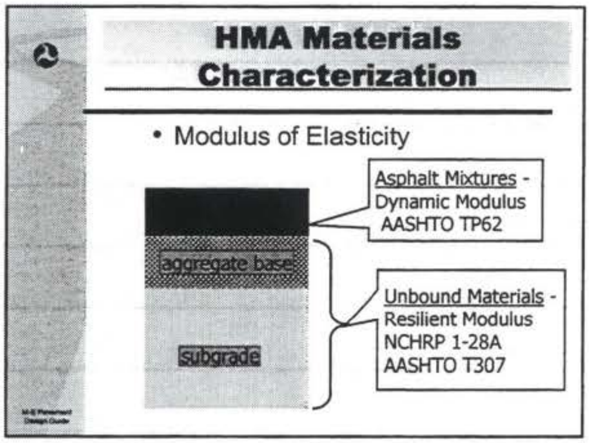


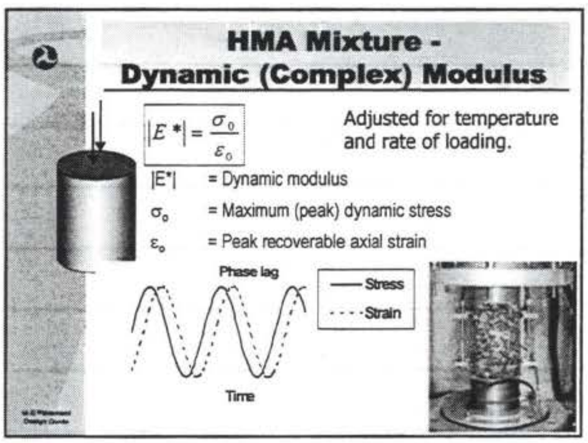
Temperature-Rate of Loading Relationship

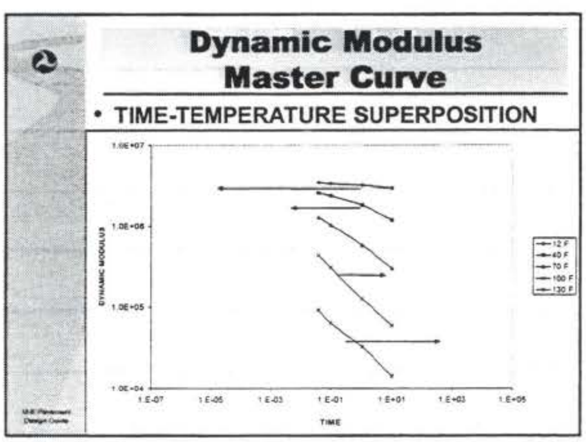


Mixture Characterization

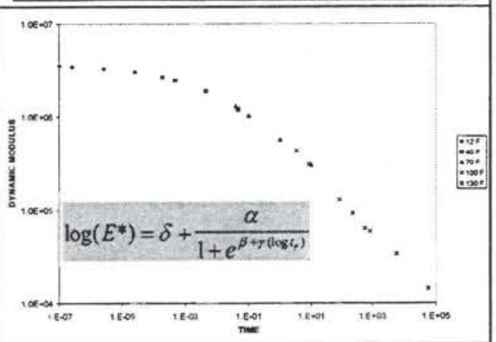



HMA Materials Characterization
• Modulus of Elasticity
Asphalt Mixtures - Dynamic Modulus AASHTO TP62
aggregate base
subgrade
Unbound Materials - Resilient Modulus NCHRP 1-28A AASHTO T307


HMA Mixture - Dynamic (Complex) Modulus
$|E^*| = \frac{\sigma_0}{\varepsilon_0}$
Adjusted for temperature and rate of loading.
|E*| = Dynamic modulus
σ_o = Maximum (peak) dynamic stress
ε_o = Peak recoverable axial strain
Phase lag
Stress
Strain
Time


Dynamic Modulus Master Curve
• TIME-TEMPERATURE SUPERPOSITION
DYNAMIC MODULUS
TIME
12 F
40 F
70 F
100 F
130 F

Dynamic Modulus Master Curve



Unbound Materials and Subgrades

Parameter	Input Level 1	Input Level 2	Input Level 3
Resilient Modulus	Site/Material Specific	Not Required	Not Required
Gradation	Not Required	Material Specific	Not Required
Hydrometer Analysis	Not Required	Material Specific	Not Required
Atterberg Limits	Not Required	Material Specific	Not Required
M-D Relations	Not Required	Material Specific	Not Required
DCP – Base CBR, R-Value - Soil	Not Required	Material Specific	Not Required
Classification	Not Required	Not Required	Default, Material Specific

Summary

- What's new in flexible pavement design using the M-E guide?
- Example of M-E design
  - Differences
  - Capabilities
- Tests and equipment

Rigid Pavement Design

The Mechanistic-Empirical Way

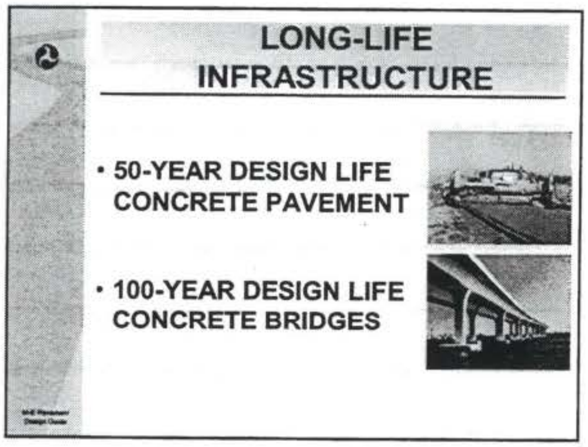
U.S. Department of Transportation
Federal Highway Administration

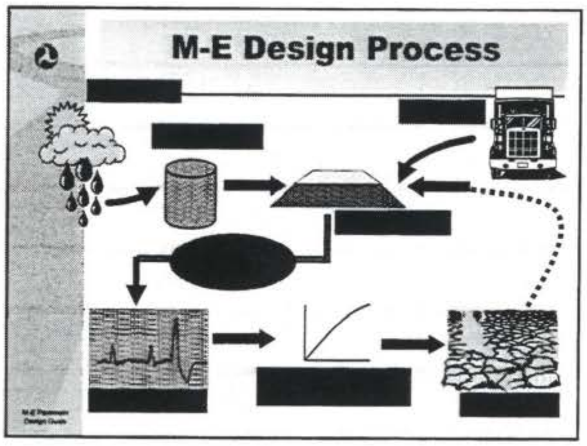
Objectives

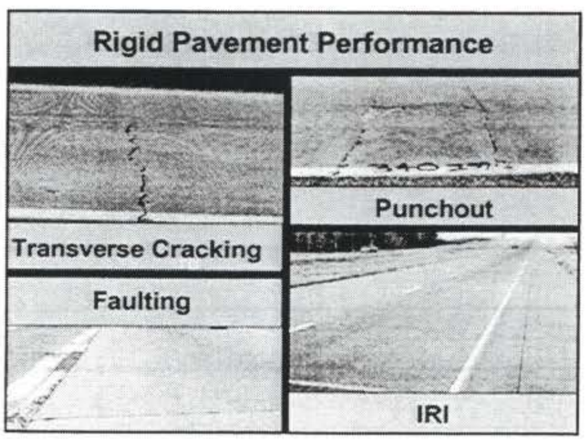
- Demonstrate capabilities of the M-E Design Guide procedure for PCC pavements
- Show impact of individual design features on development of distresses

Session Outline

- Overview of rigid pavements
- Sensitivity analysis using the M-E Design Guide


LONG-LIFE INFRASTRUCTURE
• 50-YEAR DESIGN LIFE CONCRETE PAVEMENT
• 100-YEAR DESIGN LIFE CONCRETE BRIDGES


M-E Design Process


Rigid Pavement Performance
Transverse Cracking
Punchout
Faulting
IRI

Materials Characterization PCC Pavement Layers

- Strength & Elastic Modulus (over time)
- Coefficient of Thermal Expansion
- Drying Shrinkage (over time)
- Base Erosion Index

Required Concrete Parameters

- Modulus of Elasticity
- Poisson's ratio
- Modulus of rupture
- Shrinkage
- Compressive strength
- Split tensile strength
- Coefficient of thermal expansion

Incremental Damage Concept – Accumulation for PCC Pavements

- Design life divided into monthly increments
- Specific material properties, traffic and climatic data used for each increment

Damage Increments over Time

Sensitivity Analysis Using the M-E Design Guide

1. Reference design – Analysis of reference JPCP and revised features
2. Rehabilitation design – Analysis of unbonded JPCP overlay and revised features
3. CRCP design – Analysis of new design and revised features

The approach we're using

- Define the reference design
- Select design features to revise
- Compare performance based on resulting distresses

Reference JPCP Design

- Existing JPCP Pavement
  - I-78 Pennsylvania
  - Use the real data from LTPP Section 42-3044 (Input levels 2 & 3)
- Sensitivity analysis
  - Evaluate design feature impacts by changing the following selected design features one at a time –

Joint Spacing	Edge Support
Slab Thickness	Base Type
PCC Properties	Geographic Location

Reference JPCP Design & Revised Features

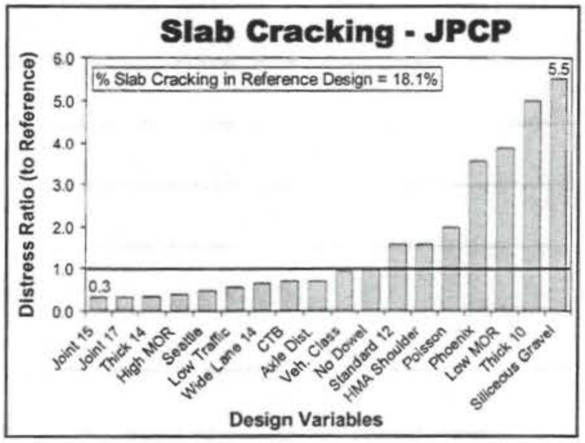
Design Features		Reference Design	Revised Features
Location	Weather data	Harrisburg, PA	• Seattle, WA • Phoenix, AZ
Traffic	2-way AADTT	5,750 (heavy)	3,000 (medium)
	Vehicle class dist.	Default (TTC=1) Multi-trailer < 2%	Default (TTC=5) Multi-trailer > 10%
	Axle load dist.	Site specific data from LTPP DataPave	Default
Joint	Joint Spacing	20 feet	17 and 15 feet
	Dowel Bar	Yes 1-in. dia., 12 in. on center	No
Edge Support	Shoulder Type	Tied PCC	• HMA Shoulder • Standard (W=12ft.) • Wide lane (W=14ft.)

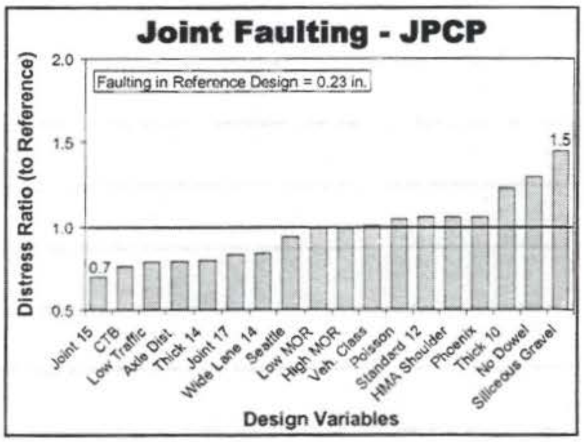
Reference JPCP Design & Revised Features

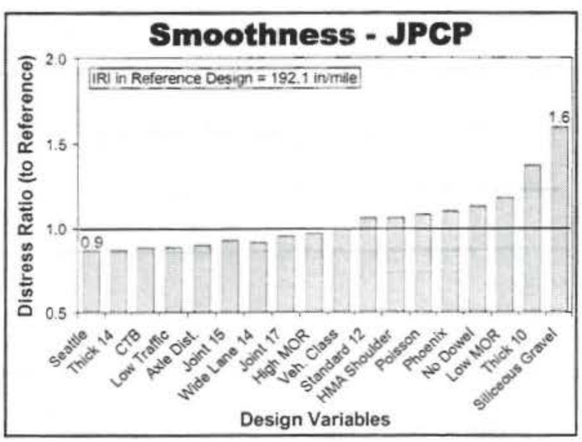
Design Features		Reference Design	Revised Features
PCC Properties	28-day Modulus of Rupture	600 psi	500 and 700 psi
	Coarse Aggregate (CTE of PCC)	Limestone (5.0×10^{-6} in./in./F)	Siliceous Gravel (7.0×10^{-6} in./in./F)
	Poisson's Ratio	0.15	0.20
Layer	PCC Slab	12 inches	10 and 14 inches
	Base	10-in. Granular (A1a) (Ebase = 50,000 psi)	10-in. CTB (Ebase = 1,000,000 psi)
	Subgrade	Fine grained soil (Esub = 5,000 psi)	No change

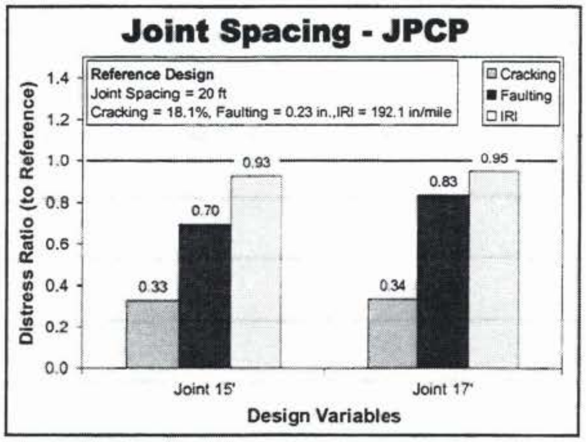
JPCP Analysis

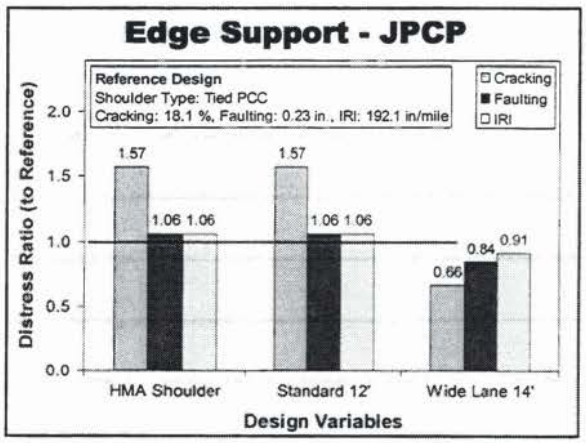
- Sensitivity of pavement performance to revised features
- Express sensitivity as distress ratio
- Distress ratio – M-E analysis results for the revised design divided by results for the reference design:
  - »Slab Cracking
  - »Joint Faulting
  - »Smoothness

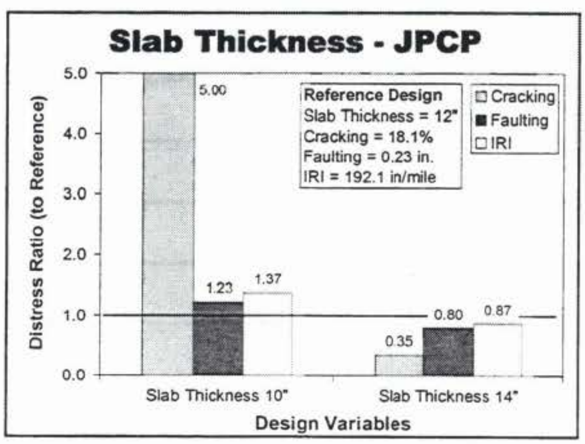

Slab Cracking - JPCP
% Slab Cracking in Reference Design = 18.1%
Distress Ratio (to Reference)
Design Variables
Joint 15
Joint 17
Thick 14
High MOR
Seattle
Low Traffic
Wide Lane 14
CTB
Axle Dist.
Veh. Class
No Dowel
Standard 12
HMA Shoulder
Poisson
Phoenix
Low MOR
Thick 10
Siliceous Gravel
0.3
5.5

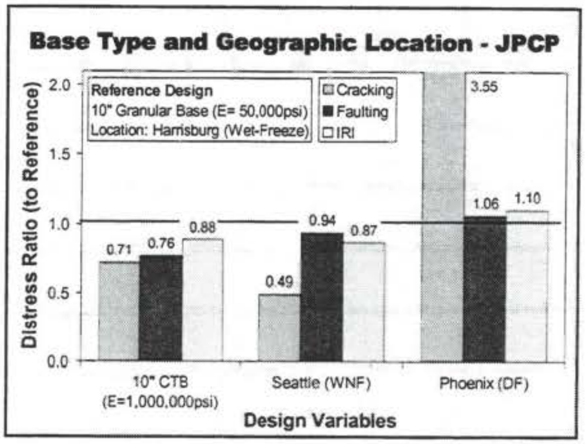

Joint Faulting - JPCP
Faulting in Reference Design = 0.23 in.
Distress Ratio (to Reference)
Design Variables
Joint 15
CTB
Low Traffic
Axle Dist.
Thick 14
Joint 17
Wide Lane 14
Seattle
Low MOR
High MOR
Veh. Class
Poisson
Standard 12
HMA Shoulder
Phoenix
Thick 10
No Dowel
Siliceous Gravel
0.7
1.5

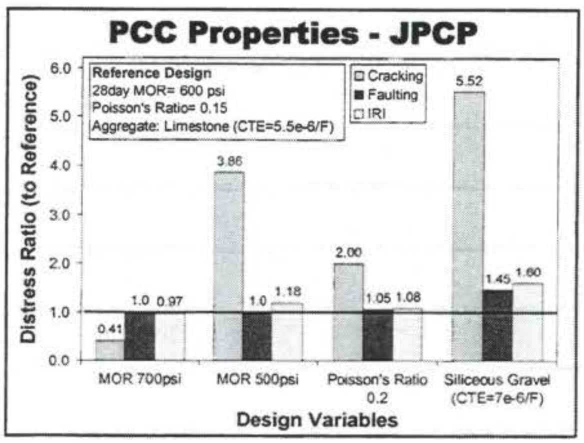

Smoothness - JPCP
IRI in Reference Design = 192.1 in/mile
Distress Ratio (to Reference)
Design Variables
Seattle
Thick 14
CTB
Low Traffic
Axle Dist.
Joint 15
Wide Lane 14
Joint 17
High MOR
Veh. Class
Standard 12
HMA Shoulder
Poisson
Phoenix
No Dowel
Low MOR
Thick 10
Siliceous Gravel
0.9
1.6

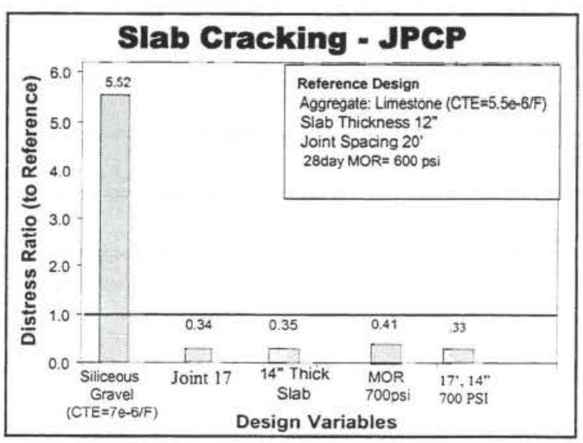

Joint Spacing - JPCP
Reference Design
Joint Spacing = 20 ft
Cracking = 18.1%, Faulting = 0.23 in.,IRI = 192.1 in/mile
Cracking
Faulting
IRI
Distress Ratio (to Reference)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.33
0.70
0.93
0.34
0.83
0.95
Joint 15'
Joint 17'
Design Variables


Edge Support - JPCP
Reference Design
Shoulder Type: Tied PCC
Cracking: 18.1 %, Faulting: 0.23 in., IRI: 192.1 in/mile
Cracking
Faulting
IRI
Distress Ratio (to Reference)
2.0
1.5
1.0
0.5
0.0
1.57
1.06 1.06
1.57
1.06 1.06
0.66
0.84
0.91
HMA Shoulder
Standard 12'
Wide Lane 14'
Design Variables


Slab Thickness - JPCP
Reference Design
Slab Thickness = 12"
Cracking = 18.1%
Faulting = 0.23 in.
IRI = 192.1 in/mile
Cracking
Faulting
IRI
Distress Ratio (to Reference)
5.0
4.0
3.0
2.0
1.0
0.0
5.00
1.23
1.37
0.35
0.80
0.87
Slab Thickness 10"
Slab Thickness 14"
Design Variables


Base Type and Geographic Location - JPCP
Reference Design
10" Granular Base (E= 50,000psi)
Location: Harrisburg (Wet-Freeze)
Cracking
Faulting
IRI
Distress Ratio (to Reference)
2.0
1.5
1.0
0.5
0.0
0.71
0.76
0.88
0.49
0.94
0.87
3.55
1.06
1.10
10" CTB
(E=1,000,000psi)
Seattle (WNF)
Phoenix (DF)
Design Variables


PCC Properties - JPCP
Reference Design
28day MOR= 600 psi
Poisson's Ratio= 0.15
Aggregate: Limestone (CTE=5.5e-6/F)
Cracking
Faulting
IRI
Distress Ratio (to Reference)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.41
1.0
0.97
3.86
1.0
1.18
2.00
1.05
1.08
5.52
1.45
1.60
MOR 700psi
MOR 500psi
Poisson's Ratio
0.2
Siliceous Gravel
(CTE=7e-6/F)
Design Variables


Slab Cracking - JPCP
Reference Design
Aggregate: Limestone (CTE=5.5e-6/F)
Slab Thickness 12"
Joint Spacing 20'
28day MOR= 600 psi
Distress Ratio (to Reference)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5.52
0.34
0.35
0.41
.33
Siliceous
Gravel
(CTE=7e-6/F)
Joint 17
14" Thick
Slab
MOR
700psi
17', 14"
700 PSI
Design Variables

JPCP OVERLAY EXAMPLE

Unbonded JPCP Overlay for Rehabilitation of the JPCP Reference Design

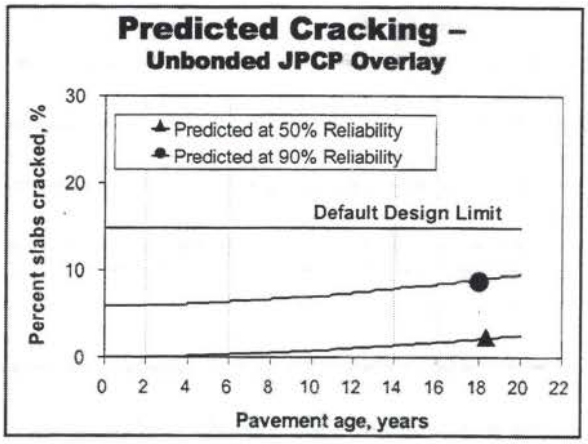
Design Inputs – JPCP Overlay on JPCP

- Existing Pavement (Reference Design) –
  - I-78 Pennsylvania – JPCP Pavement
  - LTPP Sect. 42-3044 (Input levels 2 & 3)
- Rehabilitated Pavement Structure –

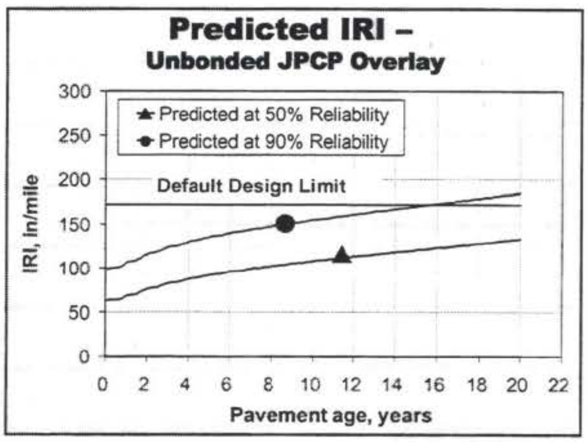
JPCP Overlay	10 inches
HMA Separator Layer	2 inches
Existing JPCP	12 inches
Granular Base	10 inches
Subgrade	–

Unbonded JPCP Overlay - Design Inputs

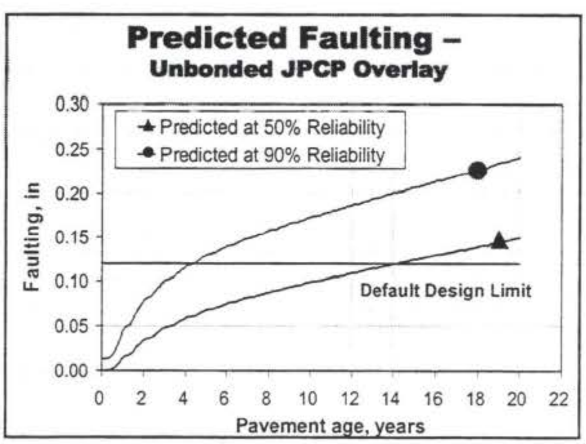
- Concrete materials & mixture properties –
  - Flexural Strength, 600 psi at 28 days
  - Coeff. of thermal expansion, 5.0×10^{-6} in./in./F
- Other design features –
  - Dowels, 1-inch diameter, 12-inch spacing
  - Joint spacing, 20 feet
  - Tied PCC shoulder
  - E_{base}, 50,000 psi
  - $E_{subbase}$, 5,000 psi
  - No repair of underlying reference JPCP



Predicted Cracking –
Unbonded JPCP Overlay
Predicted at 50% Reliability
Predicted at 90% Reliability
Default Design Limit
Percent slabs cracked, %
0
10
20
30
0 2 4 6 8 10 12 14 16 18 20 22
Pavement age, years



Predicted IRI –
Unbonded JPCP Overlay
Predicted at 50% Reliability
Predicted at 90% Reliability
Default Design Limit
IRI, in/mile
0
50
100
150
200
250
300
0 2 4 6 8 10 12 14 16 18 20 22
Pavement age, years



Predicted Faulting –
Unbonded JPCP Overlay
Predicted at 50% Reliability
Predicted at 90% Reliability
Default Design Limit
Faulting, in
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0 2 4 6 8 10 12 14 16 18 20 22
Pavement age, years

Unbonded JPCP Overlay

Design Parameter	Distress Type					
	% Slabs Cracked		Faulting, inches		IRI, in./mi.	
	Reliability		Reliability		Reliability	
	50%	90%	50%	90%	50%	90%
Failure Criteria	15	15	.125	.125	172	172
Reference Design	2.5	9.6	0.15	0.24	137	187
Joint Spacing 20 →17	0.1	6.1	0.12	0.20	129	181
Joint Spacing 20→10	0.0	6.0	0.05	0.11	117	172
Thickness 10→12	1.0	7.4	0.12	0.20	122	172
Dowel bar diameter increased 1.0 →1.5 in.	2.5	9.6	0.03	0.08	90	130

M-E Pavement Design Guide

CRCP Design Examples

CRCP - Design Approach

- Define reference design
- Evaluate the impacts of modified –
  - Steel reinforcement bar diameter
  - Steel placement depth
  - Concrete slab thickness
- Select a modified design
- Compare performance of modified design in three geographic locations

CRCP - Design Inputs

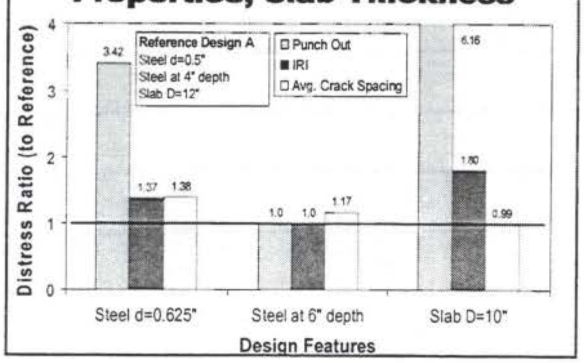
Use the same design inputs as used in the preceding JPCP reference design for –

- Material Properties
- Traffic Characteristics
- Subsurface Layers
- Tied PCC Shoulder

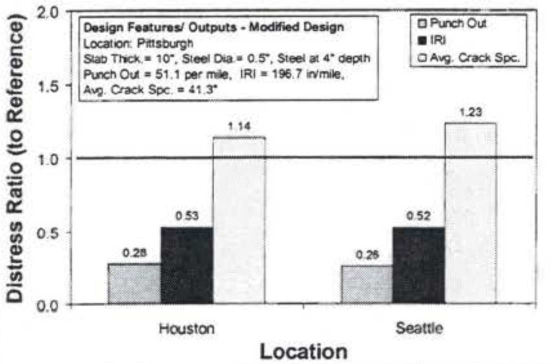
Summary - CRCP Design Examples

Location	Slab Depth, inches	Steel Ratio, %	Rebar Diameter, inches	Rebar Depth, inches	Analysis results at the end of 30-year design life			Years to reach the performance limits	
					Avg. Crack Spacing (in)	Punch out (per mile)	IRI (in/mile)	Punch out (Limit=10)	IRI (Limit=172)
Pittsburgh	12	0.7	0.5	4	41.6	8.3	109.4	*	*
Pittsburgh	12	0.7	0.625	4	57.6	28.4	149.8	26.5	*
Pittsburgh	12	0.7	0.625	6	66.3	46.2	186.6	24.6	29.3
Pittsburgh	12	0.7	0.5	6	48.5	8.3	109.4	*	*
Pittsburgh	10	0.7	0.5	4	41.3	51.1	196.7	14.3	29.4
Houston	10	0.7	0.5	4	47	14.2	103.8	12.8	*
Seattle	10	0.7	0.5	4	50.8	13.3	102.6	14.5	*

CRCP – Effects of Steel Properties, Slab Thickness



CRCP – Climatic Effect



Summary

- Demonstrated some capabilities of the M-E design guide
- Showed impact of design features on distresses developed in –
  - JPCP – Reference and revised-feature designs
  - Unbonded JPCP overlay – New and revised-feature designs for rehabilitation of reference JPCP
  - CRCP – New and revised-feature designs with input similar to JPCP

Implementation

Mechanistic-Empirical Pavement Design Guide

U.S. Department of Transportation
Federal Highway Administration

What are the key benefits of the M-E Design Guide?

- Improved confidence in design
- Increased pavement life
- More cost-effective designs
- Special analysis capabilities
  - Extrapolation for unusual designs
  - Complicated rehab designs
  - Identify problems with existing designs
  - Forensic analyses
  - Special loadings

How will I benefit from the Design Guide?

It Ties Together:
- Structural Design
- Materials Selection
- Construction

Making sure that the design criteria have been met or exceeded.

Agency/Owner

and

Contractor/Supplier

M-E Design Guide - Significant Challenges

- The process represents a radical change in the way pavements are analyzed and designed
- Implementation will require a significant commitment of resources to be successful
- Time required 3-5 years (minimum)
- The design guide is not a cookbook

Implementation Challenges

- Requires leadership & coordination
- Individual champions needed
- Lead States are needed
- Specialization in the pavement engineering discipline
- Technical assistance mechanism needed (DGIT is a start)

M-E Guide Implementation Requirements

- Compare new and existing design systems
- Evaluate sensitivity to local factors and conditions
- Move from national to local calibration
- Develop short & long-term action plans

Implementation - A five-step process

System Knowledge
↓
Action Plan
↓
Verification
↓
Calibration
↓
Validation

Step 1 - System Knowledge

- Release of final product
- Understanding concepts and procedures
- Experience using product

Is the M-E Guide Ready to Implement?

- Panel concerns
- JTF concerns
- Expectation - AASHTO standard
- Time required to change
- Future enhancement activities
- Best available national system!

Step 2 - Action Plan

- Questions for action plan
  - What needs to change?
  - Can local data information be used/converted?
  - What is most critical?
  - How much it will cost?

Experimental Concepts Definitions

Step 3 - Verification: Assuring general reasonableness of results

Step 4 - Calibration: Minimizing the difference between predicted and observed distresses

Step 5 - Validation: Confirming the accuracy of results after calibration

Step 3 - Verification

- Questions needing answers
  - Does it make sense?
  - Predict logical results?
  - Does it fit local conditions?
  - Represent improvement?
  - Potential for adjustment?

Step 4 - Calibration

- Questions needing answers
  - Is there a significant difference between local data and national defaults?
  - What data is needed?
  - How long performance period?
  - How many sites needed?

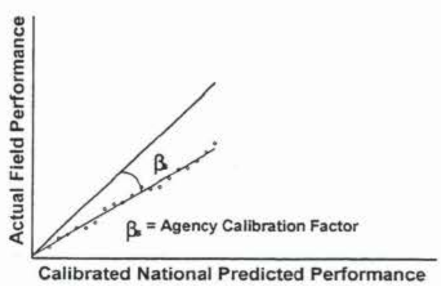
M-E Guide Calibration

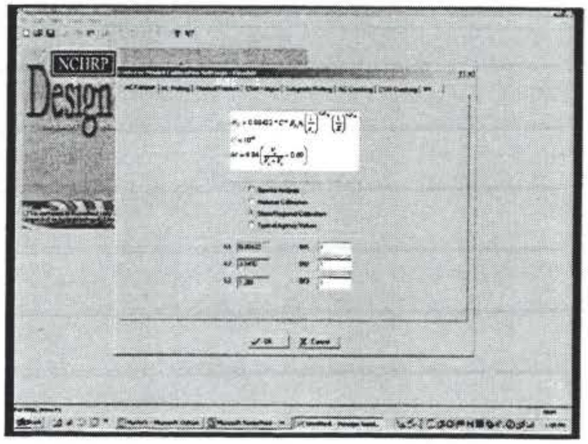
✓Done with national LTPP data

✓Default values also from LTPP

✓Confirm or change national defaults

Regional / Local Calibration Process





Calibration

- Requires extensive experimental studies, including:
  - Field testing programs
  - Laboratory testing
  - Data analysis

Pool resources to maximize effort and efficiency!

Required Data Bases

- Materials database
- Traffic database
- Performance database
- Rehabilitation database

Are the States Ready to Implement the M-E Guide?

Questionnaire Responses

What's Being Used in 2003

Pavement Design Procedures	DOTs
1972 AASHTO Guide	3
1986 AASHTO Guide	2
1993 AASHTO Guide	26
Agency's own design guide or combination of AASHTO and Agency procedures	17

Flexible Pavement Distresses Needing Calibration

- **Rutting -** Unbound base/subbase/ subgrade layers, HMA layers and total rut depth
- **Fatigue Cracking -** Surface down, longitudinal and bottom-up alligator cracking
- **Transverse (Thermal) Cracking**
- **IRI -** Accuracy depends upon predictive accuracy of all other distresses

Rigid Pavement Distresses Needing Calibration

- **Faulting in JPCP**
- **Transverse Cracking in JPCP -** Top-down and bottom-up cracking
- **Edge Punchout in CRCP**
- **IRI -** Accuracy depends upon predictive accuracy of all other distress

Step 5 - Validation

- **Questions needing answers**
  - **Do the calibration factors produce consistent results throughout the State?**
  - **How many sites needed?**
  - **How often to re-calibrate?**

Current Knowledge of the M-E Guide

Knowledge level	DOTs
Heard the term, but know little	8
Attended an introduction workshop or presentation	21
Participated in the JTF panel for the NCHRP project	14
Attended workshop and/or presentation and participated in JTF panel	5

Receptiveness to M-E Guide

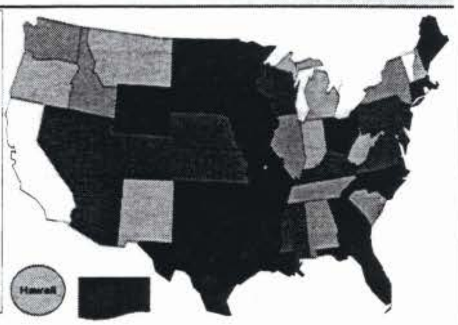
Yes, all for it

Yes, but need convince

Neutral

No, not until proven

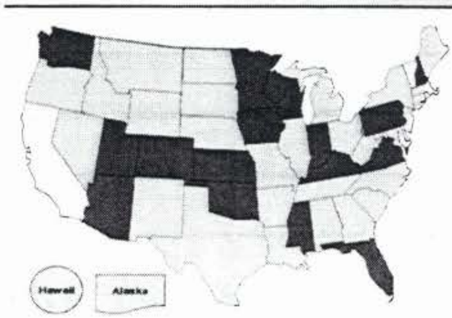
No, not at all



Implementation Plan

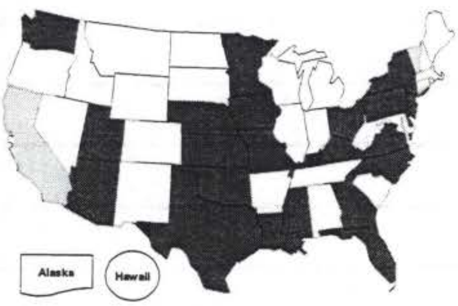
YES

NO

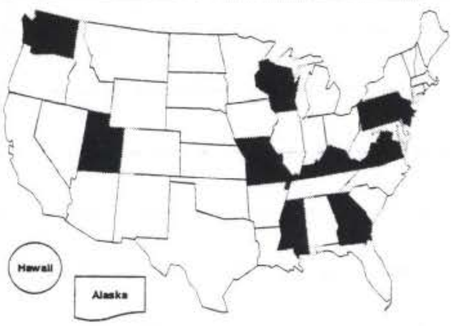


Data Collection to Support Calibration

YES
NO
Reply



Possible Lead States



Workshop Summary

- Capabilities of M-E Design Guide
- Understanding M-E basics
- Limitations of current practice
- Need for change
- M-E software
- Implementation steps
- FHWA support