NCHRP 1-37

"Development Of The 2002 Guide For The Design Of New And Rehabilitated Pavements"

Project Overview

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Chair. AASHTO Joint Task Force On Pavements

Background

- AASHTO Guide For Design Of New And Rehabilitated Pavement Structures
  - 1998, 1993, 1986, 1972 Editions
  - 1959 AASHO Road Test
  - Supplemented, Refined, And Updated By Research And New Experience

Background

- AASHTO Joint Task Force On Pavements
  - Recommended Need For An NCHRP Study To Develop A New Pavement Design Guide
- AASHTO Standing Committee On Research Approved Funding - - NCHRP Project 1-37

Development Of 2002 Guide For Design Of New And Rehabilitated Pavement

- NCHRP 1-37 -- Detailed Work Plan
  (Conceptual Plan)
- NCHRP 1-37A -- Guide Development
  (State of Practice -- No New Research)

NCHRP Project 1-37A

- Responsible Staff Officer

  Dr. Amir N. Hanna

  Senior Program Officer

- Web Site

  www.2002designguide.com

Objective

Develop and deliver the guide for design of new and rehabilitated pavement structures

- *Based on mechanistic-empirical principals*
- *Accompanied by the necessary computational software*
- *For eventual adoption and distribution by AASHTO*

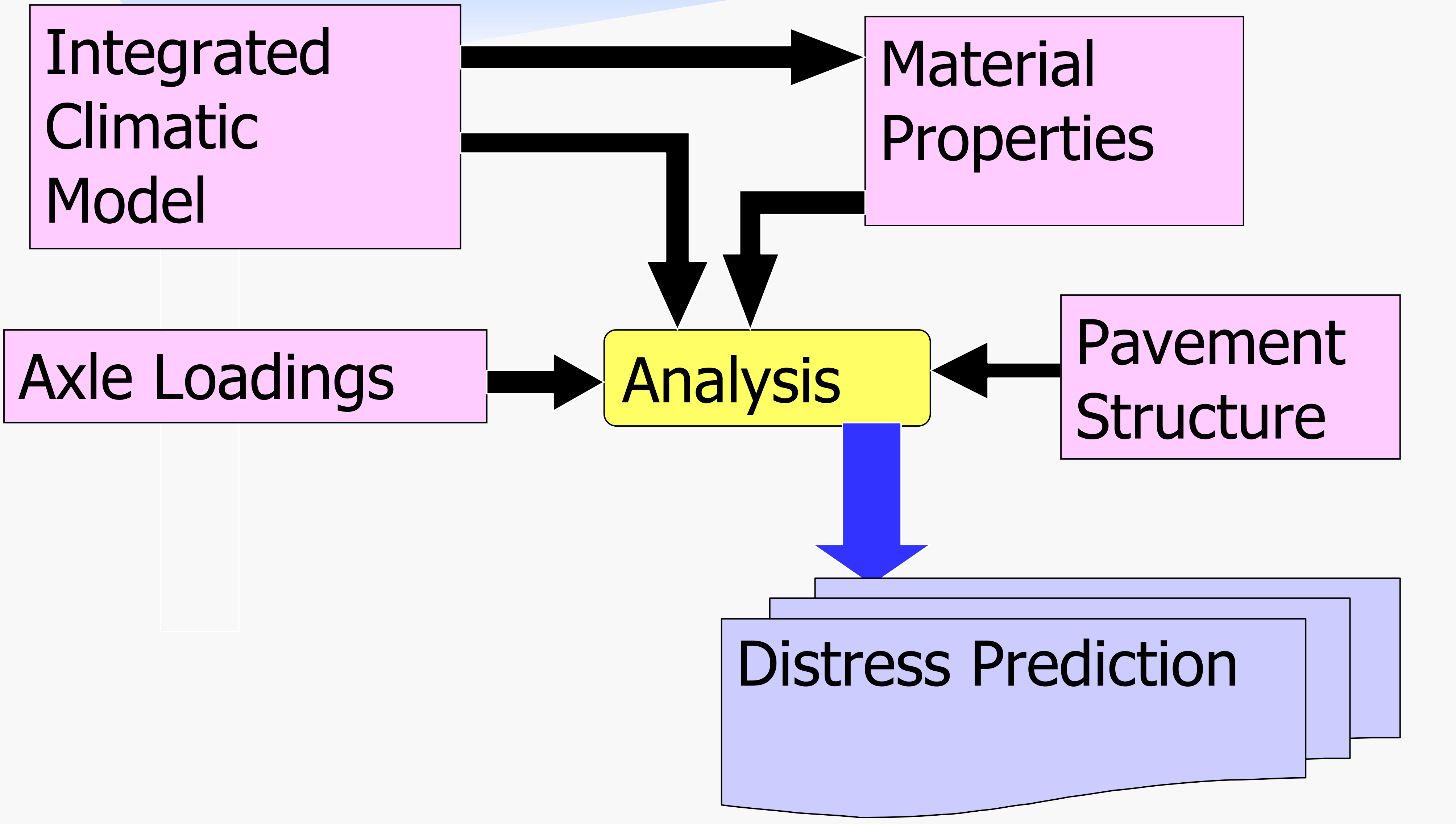
Scope of Guide

- Procedures for pavement design/analysis
- Procedures for evaluating existing pavements
- Recommendations on rehabilitation treatments, subdrainage, and foundation improvements

Scope of Guide

- Procedures for LCCA, reliability, and traffic analysis
- Procedures for calibrating for local conditions
- Guidance for developing agency-specific procedures/catalogs

Guide Processes



Design Inputs

- Inputs will generally include both a mean value and an estimate of variability

Hierarchical Input Levels

- Level 1

  Project specific
- Level 2

  Region factors
- Level 3

  Default values

Climatic Factors

- Integrated Climatic Model
  - Prediction of pavement temperature
  - Changes in subsurface moisture
  - Frozen layers

Material Properties

- Subgrade
  - Stiffness is adjusted based on the ICM's prediction of moisture content
  - Frozen versus thawed condition
- Asphalt aging
- Changes in PCC strength

Material Properties

- Asphalt Mixtures
  - Dynamic Modulus

    Adjusted for:

      Temperature

      Time of loading

      Aging

Structural design is related to mixture design

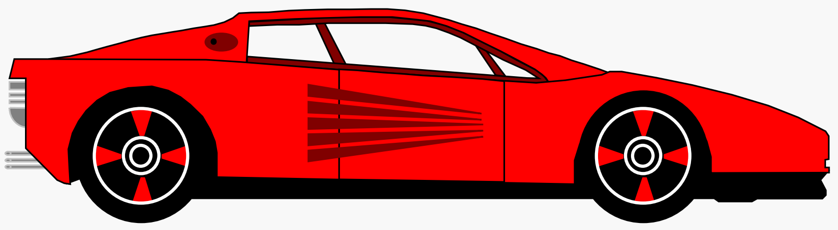
Materials Characterization

- **Unbound materials**: Level 1 resilient modulus test (same as for flexible pavements)
- **FWD testing and E backcalculation:** slab,base,subg.
- **Portland cement concrete:** lab testing
  - Elastic Modulus Level 1 (ASTM C469)
  - Elastic Modulus Levels 2 & 3 [$E_c=33\rho^{3/2}(f'c)^{1/2}$]
  - Modulus of Rupture [3rd point], time series
  - Coefficient of Thermal Exp. [New ASTM]
  - Coefficient of Drying Shrinkage (ASTM C490)
- **Base treated material:** brush erosion test

Traffic Data for Pavement Design

- No more ESAL’s!!!
- Traffic input will be numbers of axles by type and weight
- Same type and quality of raw traffic data currently used to compute ESAL’s

Axle Load Spectra



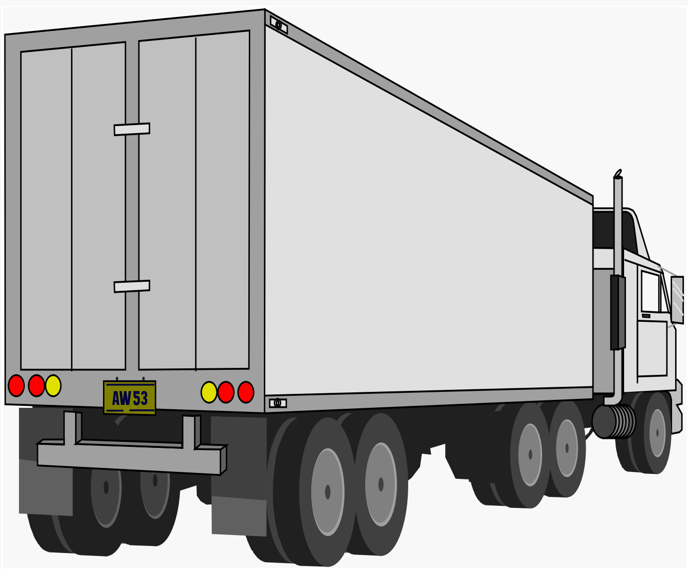
- Will replace old ESAL approach
- An ESAL conversion will be included
- Traffic data collection equipment used in LTPP SPS program will be adaptable to Guide

Axle Load Spectra

Axle Load (1000 lbs)	Number of Axles			
	Single	Tandem	Tridem	Quad
11-14	5,000	400	100	5
15-18	3000	2000	500	10
19-22	200	5000	800	30
23-26	50	4000	1000	80
27-30	6	2000	1500	100
etc				

Guide - Design Inputs

Heirarchical Traffic Levels



- **<u>Level 1</u>- Site specific vehicle classification and axle weight data**
- **<u>Level 2</u> - Site specific vehicle classification data/regional (state) axle weight data**
- **<u>Level 3</u> - Site specific vehicle volume data/default axle load data**

Flexible Pavements

Hierarchical Input Levels

Flexible Pavements

- ***Analysis procedure will be independent of input level***
  - *Lower levels of inputs will have higher variability which will be considered in the reliability analysis*
- ***Level 2 inputs reflect current practice and currently available data***

Distress Transfer Functions

Flexible Pavements

- **Permanent Deformation or Rutting (Pd)**
  - **AC**
  - **Unbound Materials**

- **Fatigue Cracking**
  - **AC (Surface Down & Bottom Up)**
  - **CTB**
- **Thermal Fracture**

Software Analysis Plan

Options

- Multi-Layer Elastic Solution
  (Main Engine :JULEA)

2. 2D Desai Finite Element Analysis
   (For Special Loading Conditions, Non-Linear Unbound Material Characterization)

Design Inputs

Incremental Damage

- **Changes over time are addressed**
  - **Material strength and stiffness**
  - **seasonal moisture and temperature**
  - **variations in traffic seasonally and over time**

Enhanced Integrated Climatic Model (EICM)

Output of the EICM

- ***Environmental Effects Adjustment Factors for the M_R***

FEA / LEA Module

- ***Temperature Frequency Distribution at mid-depth of bound sublayers***

Fatigue / Permanent Deformations Modules

- ***Hourly Temperature Profiles at every inch within AC and/or PCC layer(s)***

Thermal Cracking Module

- ***Average Moisture Content for Bound and Unbound Materials***

Permanent Deformation Module for Unbound Materials

AC Complex Modulus

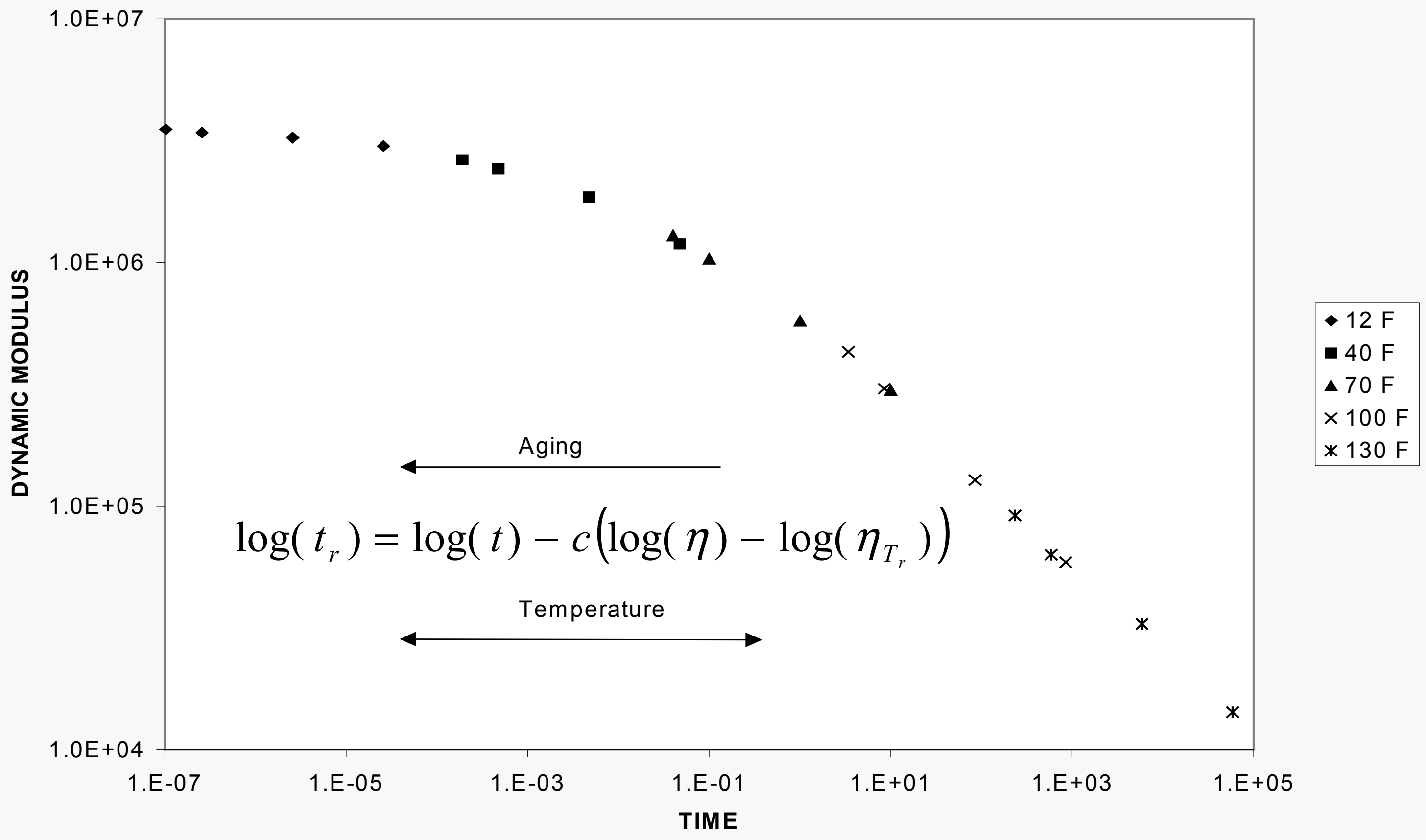
Modulus of Asphaltic Mixtures

General Approach will be:

- ***Based Upon the Dynamic Complex Modulus Test (E*)***
- ***Hierarchical In Nature***

DYNAMIC MODULUS MASTERCURVE

- TIME-TEMPERATURE AGE SUPERPOSITION



SUMMARY -- Hierarchical Input Levels Flexible Pavements

- ***LEVEL 1***
  - ***MIXTURE SPECIFIC TEST DATA***
    - ***MIXTURE E****
    - ***BINDER G****
- ***LEVEL 2***
  - ***BINDER TEST DATA AND WITCZAK DYNAMIC MODULUS EQUATION***
    - ***BINDER G****
    - ***REPRESENTATIVE MIX VOLUMETRICS***
- ***LEVEL 3***
  - ***BINDER GRADE AND WITCZAK DYNAMIC MODULUS EQUATION***
    - ***BINDER GRADE***
    - ***REPRESENTATIVE MIX VOLUMETRICS***

Fatigue

Basic Fatigue Equation

$$N_f = K_1 \left(\frac{1}{\varepsilon_t} \right)^{k_2} \left(\frac{1}{E} \right)^{k_3}$$

$$= K_1 (\varepsilon_t)^{-k_2} (E)^{-k_3}$$

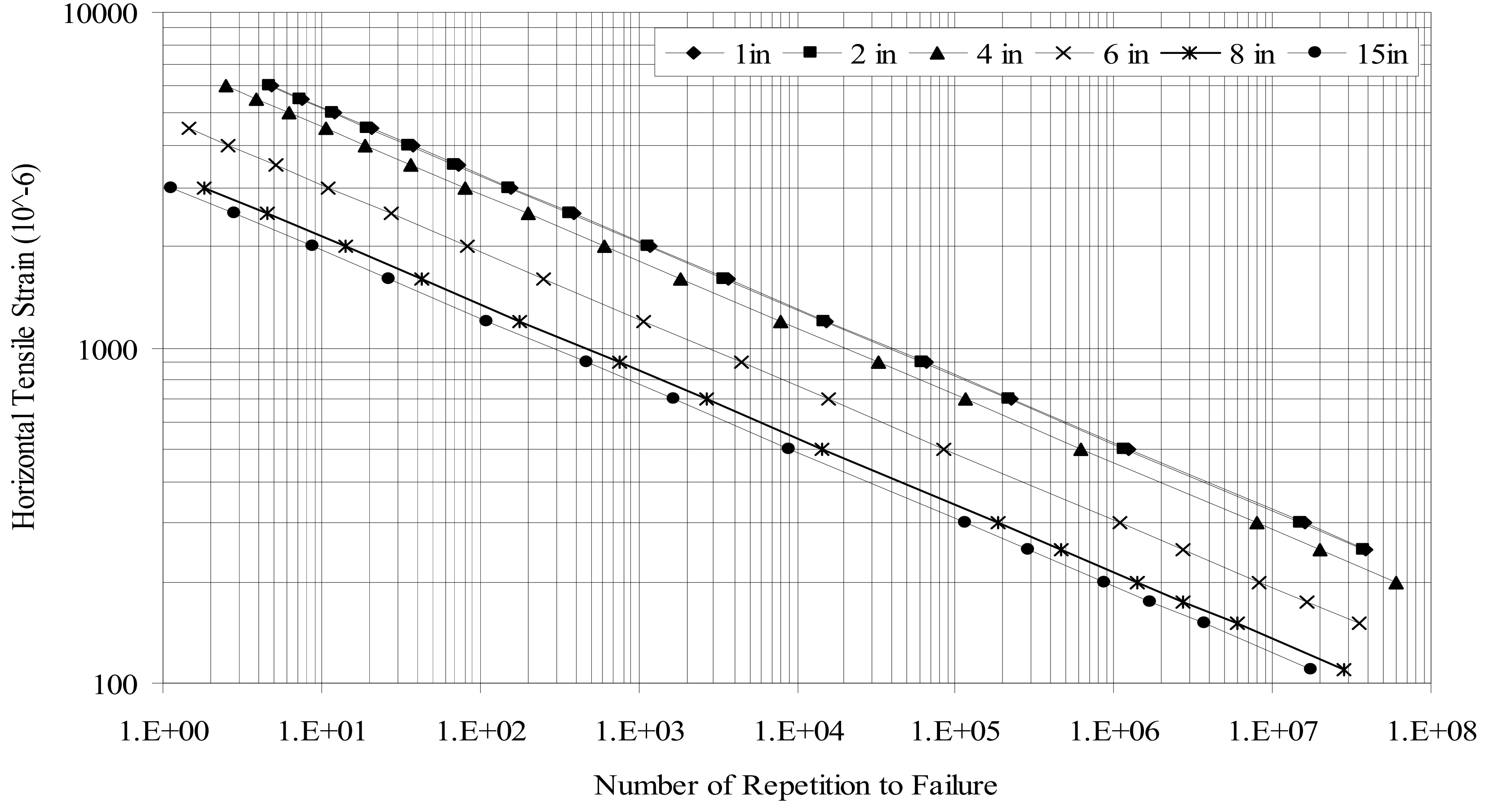
N_f = number of repetitions to fatigue cracking

e_t = tensile strain at the critical location

E = stiffness of the material

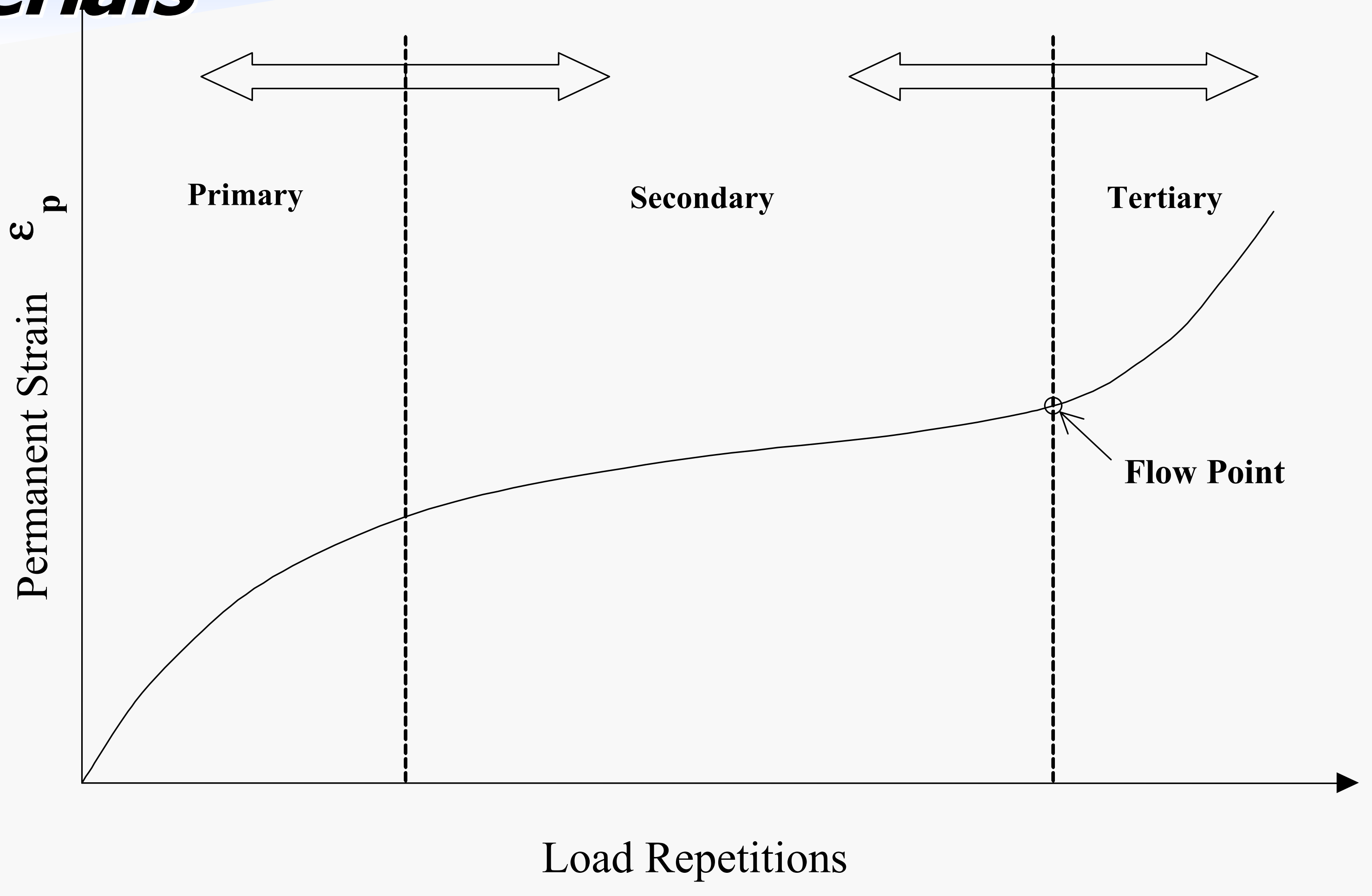
K_1, k_2, k_3 = laboratory calibration parameters

Typical Fatigue Curve Relationship



AC Permanent Deformation

Typical Repeated Load Permanent Deformation Behavior of Pavement Materials



Permanent Deformation Models

$$\log\left(\frac{\varepsilon_p}{\varepsilon_r}\right) = -3.74938 + 0.4262\ \log(N) + 2.02755\log(T)$$

$R^2 = 0.73$

$S_e = 0.309$

$S_e/S_y = 0.522$

$N_{tests} = 3476$

IRI Distress Models

Conceptual Model

$$IRI = IRI_o + \Delta\, IRI$$

$$\Delta\, IRI = f(D_j, S_f)$$

IRI_o = Pavement Smoothness when it is Newly Constructed

D_j = Effect of Surface Distresses

S_f = Effect of Non-Distress Variables or Site Factor

IRI Models for Original HMA Pavements

- ***Unbound Aggregate Bases and Subbases***

$$IRI = IRI_o + 0.03670(SF)[e^{age/20} - 1] + 0.00325(FC) + 0.4092(COV_{RD}/100) + 0.00106(TC) + 0.00704(BC) + 0.00156(SLCNWP_{MH})$$

SF = Site factor

$e^{age/20}-1$ = Age factor

FC = Fatigue cracking

RD = Rut Depth

SD_{RD} = Standard deviation of rut depth

TC = Length of transverse cracking

BC = Area of block cracking

$SLCNWP_{MH}$ = Length of sealed longitudinal cracks outside wheel path

$$COV_{RD} = \frac{SD_{RD}}{RD} = \frac{0.665 + 0.2126(RD)}{RD}$$

IRI Models for HMA Overlays

- ***HMA Overlays Placed on Flexible Pavements***

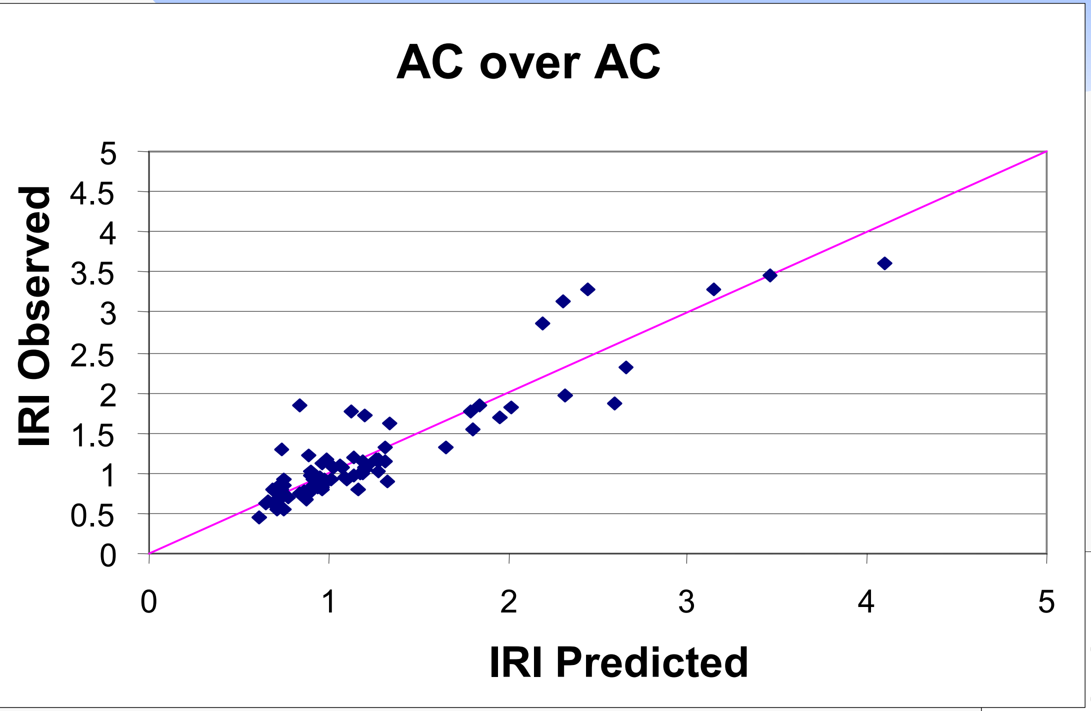
$$IRI = IRI_O + 0.04283[Ln(Age+1)] + 0.00880(FC) + 0.00129(TC_{MH}) + 2.9065(BC_H) + 8.7702(P_H) + 0.00100(SLCNWP)$$

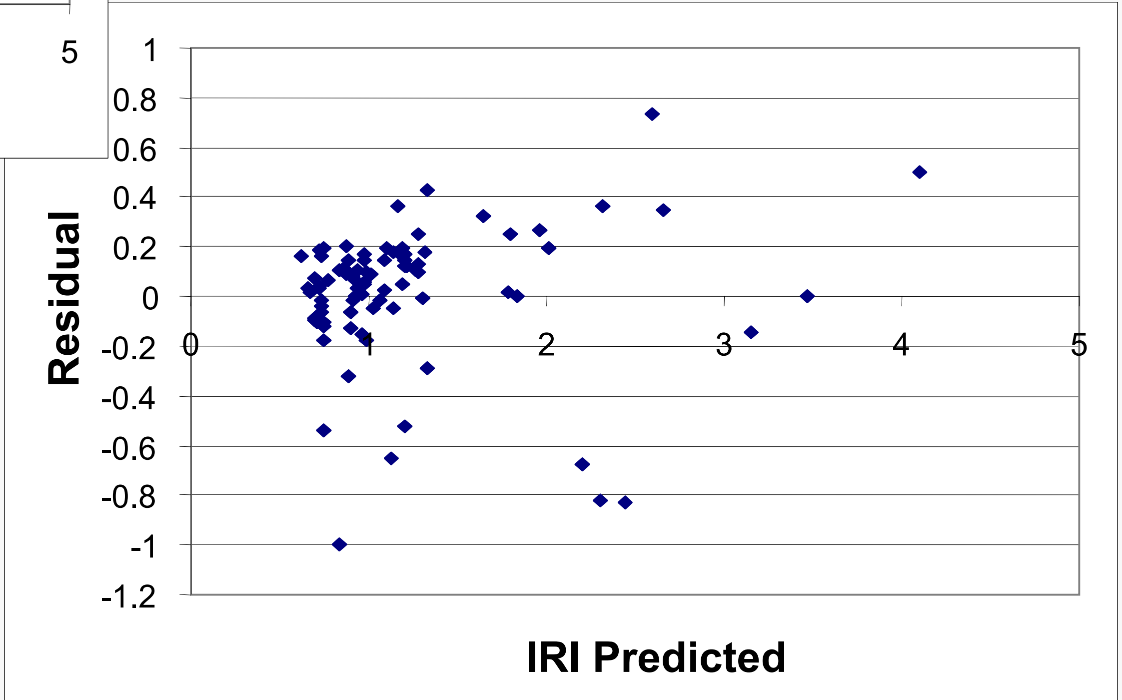
$Ln(Age+1) = Age\ factor$

- ***HMA Overlays Placed on Rigid Pavements***

$$IRI = IRI_O + 0.02069(RD) + 8.396\ [1/(TCS_{MH}+1)] + 13.122(P_{MH})$$

Measured vs. Predicted IRI





Calibration by Distress Type

- ***M-E models require a process of "calibration" to ensure that they will be reliable models.***
- ***This will require three ongoing steps:***
- ***(1) Verification***
- ***(2) Calibration***
- ***(3) Validation***

Calibration and Validation Data

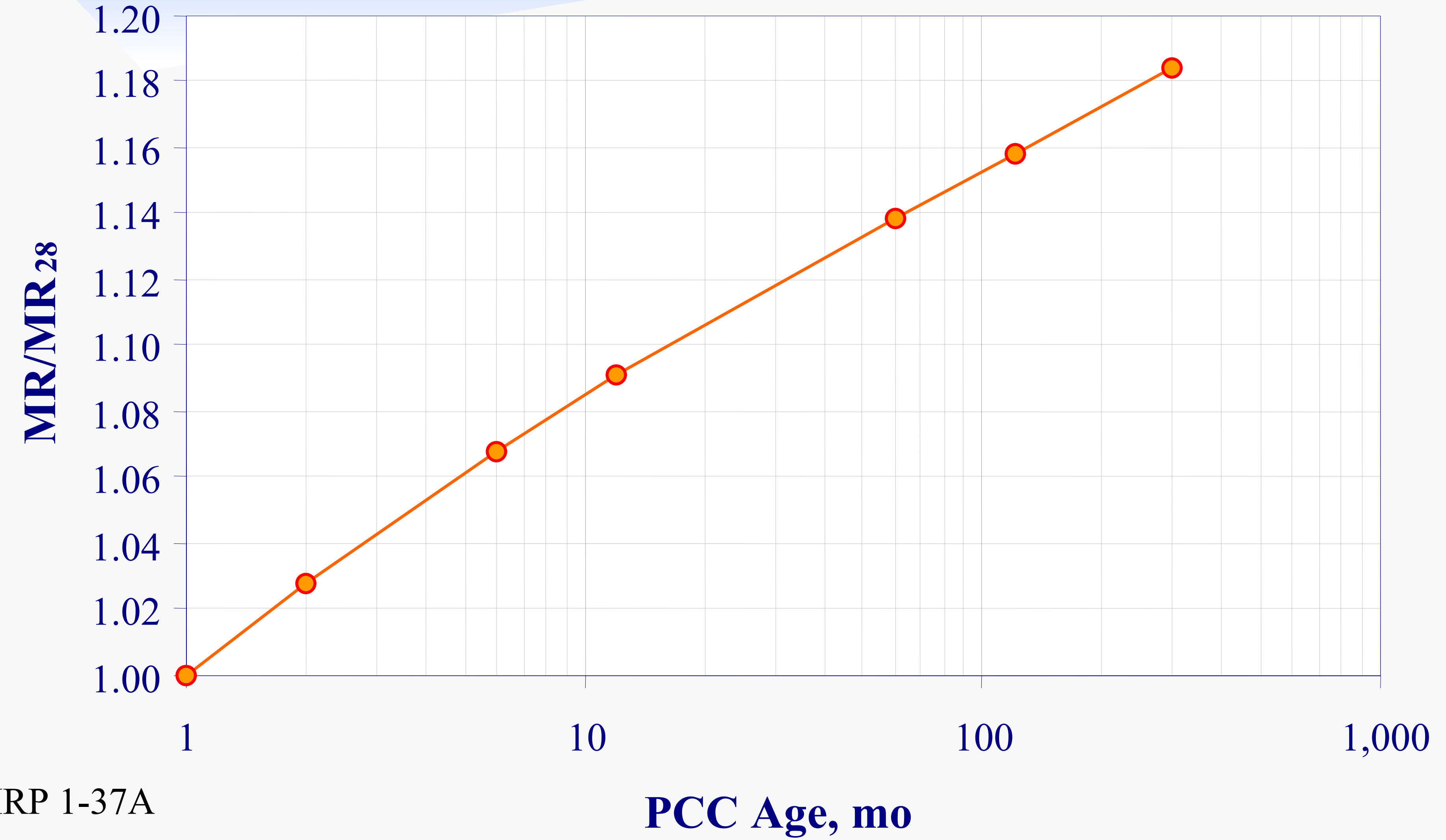
- ***Field measured distress data from in-service highway sections will be primarily used.***
- ***LTPP will be the primary data set utilized due to its quality, quantity, geographic distribution, types of pavements/rehab, and variables included in database.***
- ***Extremely Critical Work Task Leading to Acceptance or Rejection of Design Guide Approach***

Rigid Pavements

Mechanistic Based Rigid Pavement Design and Rehabilitation

- Hierarchical design inputs/trial design
- Materials characterization
- Structural modeling of pavement/subgrade
- Key distress types and smoothness
  - Critical stresses and deflections
  - Distress/smoothness models
  - Incremental “damage” computation
  - Calibrate “damage” to physical distress
- Reliability of design
- Design iteration
- Special rehabilitation items

PCC Strength Gain With Age



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Foundation

- Subgrade inputs identical to flexible pavement design
  - Laboratory resilient modulus test or backcalculation
  - EICM used to predict subgrade moisture and generate seasonal modulus values
- Elastic layer program used to predict seasonal PCC surface deflections
  - PCC surface deflections used to backcalculate seasonal subgrade k-values

Structural Modeling of Pavement/Subgrade

- **FE Response Model**
  - ISLAB2000—enhanced 2.5D FEM
  - ERES/U.Michigan/MSU/MichTech/UnivMn/UnivIllinois
- **Capabilities**
  - Multiple pavement/overlay layers and foundation, slab curling, cracks and joints, multi-wheel loads, relative rapid solutions

Structural Modeling of Pavement/Subgrade

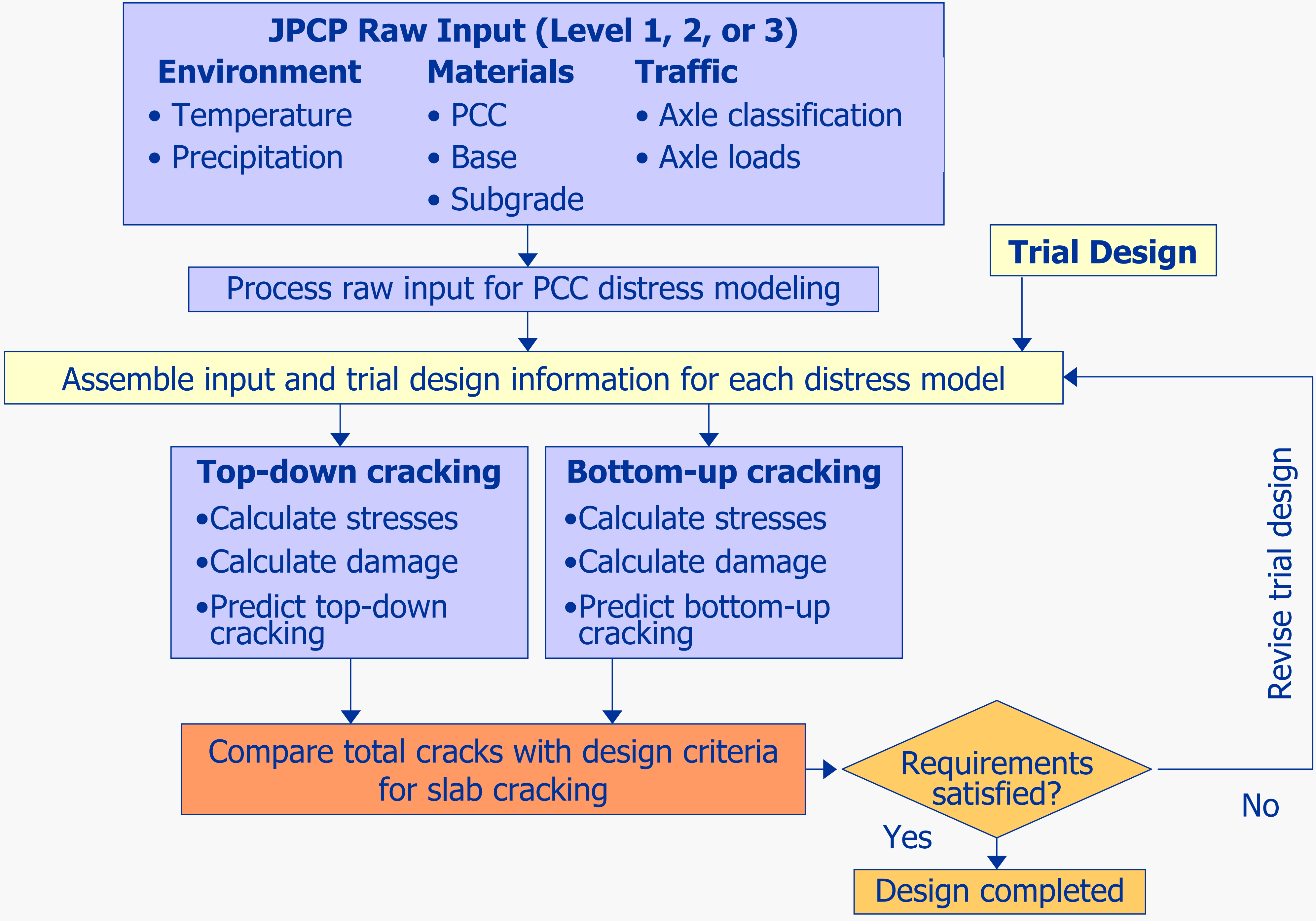
- **Rapid solutions (Neural networks)**
  - Develop large databases of ISLAB2000 runs for each design situation (bottom-up cracking, top-down cracking, joint faulting, punchouts), axle type, and axle location
  - Id key structural parameters
  - Train neural networks to predict parameters
- NN accurately represents ISLAB2000 responses
- Provides near instantaneous solutions

Mechanistic Based Rigid Pavement Design and Rehabilitation

- Hierarchical design inputs/trial design
- Materials characterization
- Structural modeling of pavement/subgrade
- ***Predict key distress types and smoothness***
  - Critical stresses and deflections
  - Mechanistic based model
  - Incremental "damage" computation
  - Calibrate "damage" to physical distress

Predict Key Distress Types & Smoothness (New and Rehabilitated Pavements)

- **JPCP distress**
  - Transverse cracking—bottom-up
  - Transverse cracking—top-down
  - Joint Faulting
- **CRCP punchouts**—crack LTE loss, top-down
- **Smoothness** (IRI)


JPCP Raw Input (Level 1, 2, or 3)
Environment
• Temperature
• Precipitation
Materials
• PCC
• Base
• Subgrade
Traffic
• Axle classification
• Axle loads
Trial Design
Process raw input for PCC distress modeling
Assemble input and trial design information for each distress model
Top-down cracking
•Calculate stresses
•Calculate damage
•Predict top-down cracking
Bottom-up cracking
•Calculate stresses
•Calculate damage
•Predict bottom-up cracking
Revise trial design
Compare total cracks with design criteria for slab cracking
Requirements satisfied?
No
Yes
Design completed

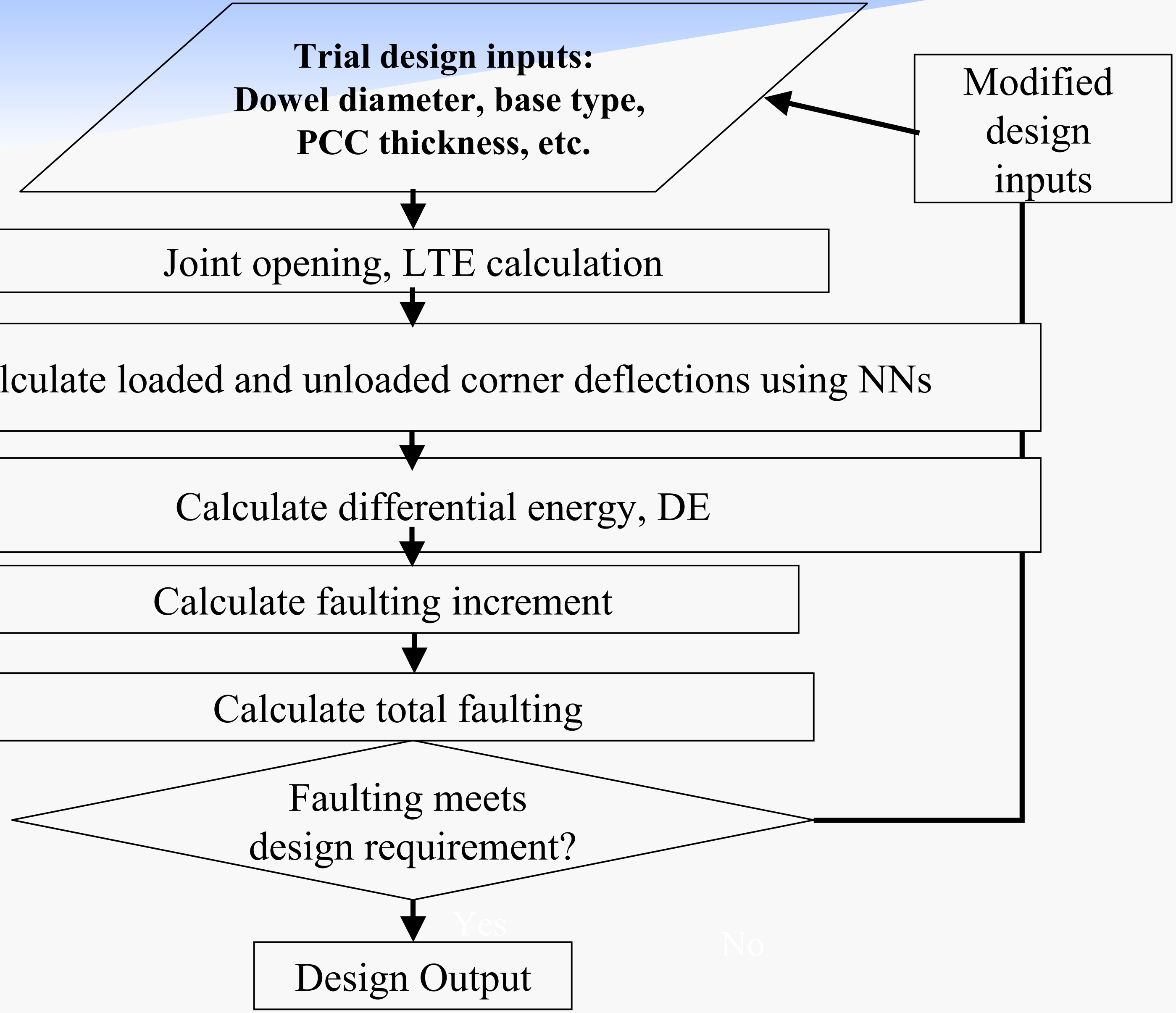
Joint Faulting Parameters

- Axle type, loading, lateral position, number
- Temperature gradient curling (positive daytime)
- Combined built-in temperature gradient & top drying shrinkage (negative)
- Slab thickness, modulus, strength, coef. exp.
- Base thickness, modulus
- Subgrade modulus
- Joint spacing, slab width
- Transverse joint LTE, longitudinal joint LTE

Faulting Modeling Procedure

- Utilized concepts of faulting models from NAPCOM, NCHRP 1-34, PRS 3
  - Use subgrade differential energy (DE) as the main structural response parameter
- Improvements: Temperature curling and incremental faulting accumulation with the rate of faulting depending on the faulting level
- Calibration and validation using LTPP and FHWA/RPPR databases

Overall Faulting Model Flowchart



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JPCP Smoothness Model

$$IRI = IRI_I + 0.0137CRK + 0.007SPALL + 0.005PATCH + 0.0015TFAULT + 0.04SF$$

where:

- IRI_I = Initial IRI, m/km
- CRK = percent slabs with cracking (transverse and corner breaks [all severities])
- SPALL = percentage of joints with spalling (medium and high severities)
- PATCH = area with flexible or rigid patching (all severities), m^2
- TFAULT = total joint faulting, mm/km

JPCP Smoothness Model, cont'd

SF = site factor = AGE*(1 + FI$^{1.5}$)(1 + P$_{0.075}$)/10^{6}

where:

AGE = pavement age, yr

FI = Freezing index, ^{o}C days

$P_{0.075}$ = percent subgrade material passing 0.075-mm sieve

CRCP Smoothness Model

$$\mathbf{IRI = IRI_I + 0.003TCRK + 0.2NPATCH + 0.08PUNCH + 0.45SF}$$

where:

IRI_I = initial IRI

TC = mid to high transverse cracking/km

PUNCH = number of mid- to high-severity punchouts/km

PATCH = Number of mid- to high-severity flexible or rigid patching

CRCP Smoothness Model, cont'd

SF = site factor = AGE*(1 + FI)(1 + $P_{0.075}$)/10^6

where

AGE = pavement age, yr

FI = Freezing index, °C days

$P_{0.075}$ = percent subgrade material passing 0.075-mm sieve

Design Reliability

- Uncertainty or variability of all inputs and models (standard deviation, COV, distribution type)
- What gets built in field is different than design
- Estimated traffic is different than actual
- Variation exists along project
- Limitations in all distress and smoothness models

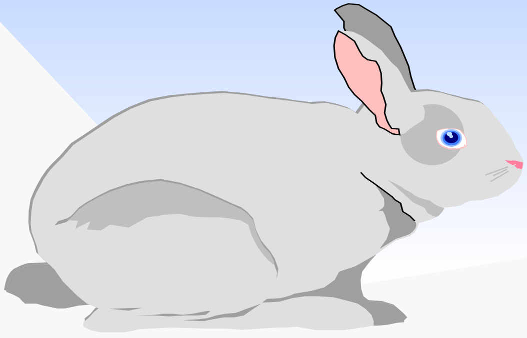
Hierarchical Design Input Levels & Reliability/Uncertainty

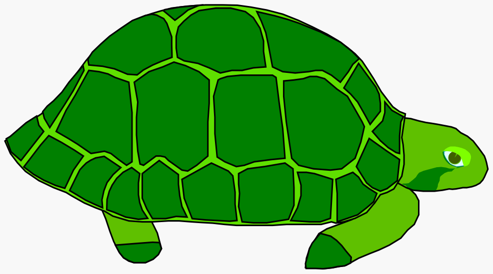
- **Level 1—Highest input certainty**
  - Inputs obtained from significant lab or in situ field testing—lowest estimation error
- **Level 2—Medium input certainly**
  - Inputs obtained from correlations, limited testing, previous testing
- **Level 3—Lowest input certainty**
  - Inputs based on estimating or default values or typical values—highest estimation error

Benefits of Mechanistic Design for Rigid Pavements

- Ability to ***structurally model*** rigid pavements with different site conditions, design features and materials
- Ability to accumulate damage ***incrementally*** (month by month over life)
- Ability to predict (and prevent) key ***distresses and smoothness***
- Ability to ***calibrate*** to local or regional conditions

Progress Schedule





Are we there yet?

- **June 30, 2003**
  - All draft deliverable, including Design Guide appendices and example problems;
  - Software; and
  - Marketing and training materials
- **October 30, 2003**
  - All final (revised) deliverables
- **November 30, 2003**
  - Draft SI version of the Guide
- **December 30, 2003**
  - Final (revised) SI version of the Guide

Future

- NCHRP 1-40

  National/Regional Workshops
- Review/Concurrence by JTFP
- Review/Concurrence by Subcommittee On Design
- Review/Concurrence by Standing Committee On Highways

Questions