The Asphalt Pavement Alliance Presents:

A Five-Part Webinar Series On Mechanistic Empirical Pavement Design Guide (MEPDG) Implementation Specific to Asphalt Pavements

Part 1: Pavement Design, Where We've Come From and What We're Trying to Accomplish

Part 2: Local Calibration

Part 3: Individual Distress Models

Part 4: Major Inputs – Where Do They Come From & How Do We Get Them?

Part 5: Moving Beyond Data Input (Advanced)

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The Asphalt Pavement Alliance Presents:

A Five-Part Webinar Series On Mechanistic Empirical Pavement Design Guide (MEPDG) Implementation Specific to Asphalt Pavements

- **Today's Webinar: Part-3**
  The Individual Distress Models
- **Speaker:**
  Kevin Hall, PhD., P.E.
  Professor and Head of the Department of Civil Engineering at the University of Arkansas
- **Moderator:**
  Mike Kvach, APA

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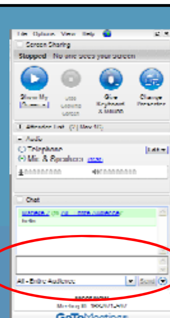
Webinar Protocol:

- **Audio Quality**
  - All attendees have been muted upon joining.
- **Questions & Answers**
  - Questions Box – Make sure to change the drop-down menu to "Organizer & Panelists Only"
- **Recorded Webinars**
  - www.asphaltfacts.com/webinars/
  - Click on: "View Webinars"



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Part 3:
Individual Distress Models

- **Speaker:**
  Kevin Hall, PhD., P.E.
  Professor and Head of the Department of Civil Engineering at the University of Arkansas
- **Panelist:**
  David Newcomb, Ph.D., P.E.
  Senior Research Scientist with the Texas Transportation Institute

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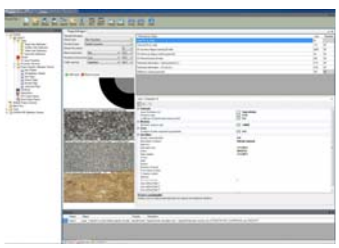
Flexible Pavement Performance Models in Pavement-ME^{TM}

Kevin D. Hall, Ph.D., P.E.
Professor and Head, Dept. of Civil Engineering
21st Century Leadership Chair in Civil Engineering

Dave Newcomb, Ph.D., P.E.
Senior Research Engineer
TTI / Texas A&M University



Pavement-ME^{TM} Webinar Series
Presentation #3
Asphalt Pavement Alliance
September 9, 2013

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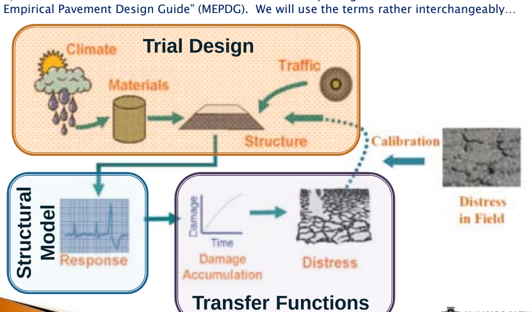
Pavement–ME^{TM} = MEPDG?

Quick note about terms: "Pavement–ME" is the software package which contains the "Mechanistic–Empirical Pavement Design Guide" (MEPDG). We will use the terms rather interchangeably…



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Setting the Stage

- What we WILL discuss
  - Pavement response models and transfer functions
  - Applicability of the models
  - Sensitivity of performance predictions to model inputs
  - Implications
  - Reliability (time permitting)
- What we WILL NOT discuss
  - "Why" the model forms are what they are

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Transfer Functions

Example: 'Traditional' Asphalt Institute:

Asphalt Fatigue

$N_f = 0.0796*(\varepsilon_r)^{-3.291}\ E^{-0.854}$

ε_r = tensile strain in AC

Rutting (subgrade)

$N_f = 1.365*10^{-9}\ (\varepsilon_z)^{-4.477}$

ε_z = vertical strain in subgrade

N_f = load applications to "failure"

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Accumulated Damage Concept

- Extension of Miner's Hypothesis
  - Pavement 'damage' caused by each load is *proportional* to the predicted N_f (loads to failure)
  - Incremental damage(s) are *additive*

For Design: total accumulated damage < 1.0

$$\sum \frac{n}{N_f} < 1.0$$

For each "n" applications of a load/axle configuration which causes a stress/strain related to N_f cycles to failure...

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Sensitivity

- Key Question: what factors influence the performance prediction?

i.e.

HMA thickness ↓ = Alligator Cracking ↑

Binder Content ↑ = Rutting ↑

One-at-a-Time (OAT) "Local" Analysis

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Sensitivity: interdependencies

i.e.

HMA thickness ↓

Binder Content ↑

Gradation Change ↑

Alligator Cracking

Rutting

IRI

GLOBAL Sensitivity Analysis (GSA)

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Sensitivity: A Few Efforts…

- Lee and Hall, 2004
- Kim, Ceylan and Heitzman, 2005
- Graves and Mahboub, 2006
- Tran and Hall, 2007
- Buch et al. 2008
- Li, Pierce, Hallenbeck and Uhlmeyer, 2009
- Sayyady et al. 2010
- Orobio, 2010
- Mallela, 2011
- Zapata and Salim, 2012
- **NCHRP 1-47: Schwartz, et al**

GLOBAL Sensitivity Analysis (GSA)

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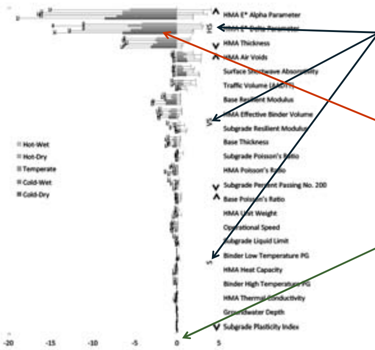
Sensitivity: 1-47 Interpretation



HS: Hyper-Sensitive
VS: Very Sensitive
S: Sensitive

Negative values inversely proportional, e.g. property ↓ = distress ↑

Statistical Property is Normalized Sensitivity Index (NSI)
-- scaled with the distress;
(relative values can be compared across distress types)

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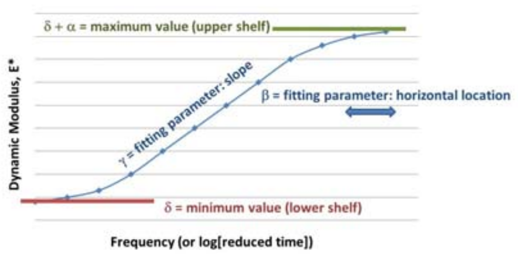
Asphalt Master Curve (E*) Parameters

$$\log(E^*) = \delta + \frac{\alpha}{1+e^{\beta+\gamma \log t_r}}$$

t_r = loading time (frequency, speed)

β = *function of* binder viscosity
(typically set by binder grade, temp)
(from climate file)



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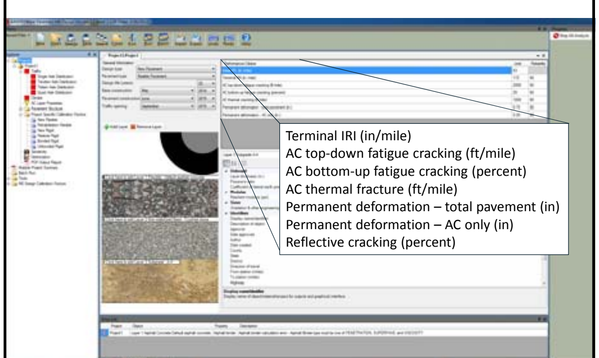

Terminal IRI (in/mile)
AC top-down fatigue cracking (ft/mile)
AC bottom-up fatigue cracking (percent)
AC thermal fracture (ft/mile)
Permanent deformation – total pavement (in)
Permanent deformation – AC only (in)
Reflective cracking (percent)

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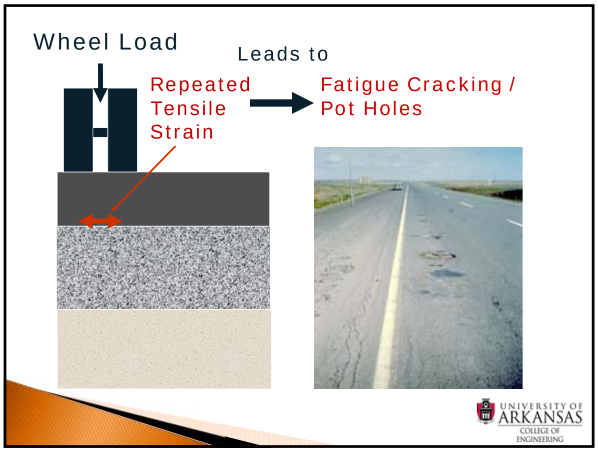

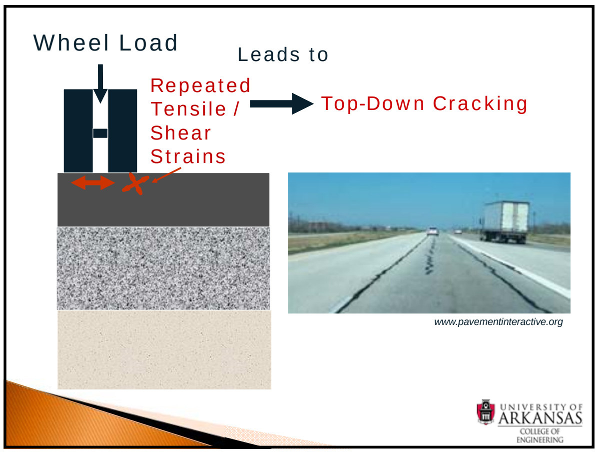

MEPDG: Fatigue Cracking (general form)

$$N_f = 0.00432 C \beta_{f1} \left(\frac{1}{\varepsilon_t}\right)^{3.9492\beta_{f2}} \left(\frac{1}{E}\right)^{1.281\beta_{f3}}$$

$$C = 10^M$$

$$M = 4.84\left(\frac{V_b}{V_a + V_b} - 0.69\right)$$

ε_t = tensile strain at the critical location
E = stiffness of the material
C = laboratory to field adjustment factor
V_b = effective binder content (%)
V_a = air voids (%)
β_{fi} = Calibration coefficients

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MEPDG: Fatigue Damage and Transfer Functions

$$D = \sum_{i=1}^{T} \frac{n_i}{N_i}$$

$$F.C.bottom\_up = \left(\frac{6000}{1 + e^{(C_1 * C_1^{'} + C_2 * C_2^{'} * \log 10(D * 100))}} \right) * \left(\frac{1}{60} \right)$$

$C_1 = 1.0$
$C_2 = 1.0$
$C_2' = -2.40874 - 39.748 * (1 + h_{ac})^{-2.856}$
$C_1' = -2 * C_2'$
h_{ac} = AC thickness

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MEPDG: Fatigue Damage and Transfer Functions

$$D = \sum_{i=1}^{T} \frac{n_i}{N_i}$$

$$F.C.top\_down = \left(\frac{1000}{1 + e^{(C_1 - C_2 * \log D)}} \right) * (10.56)$$

D = top-down damage,
$C_1 = 7$,
$C_2 = 3.5$.

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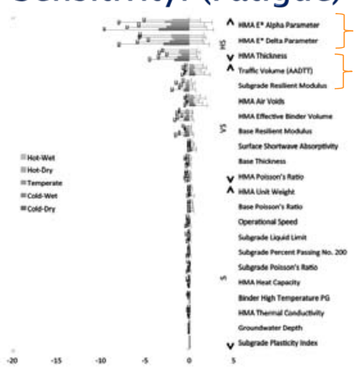
Sensitivity: (Fatigue) Cracking



Master Curve Parameters

Expected…

????

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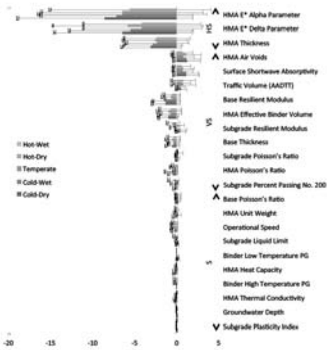
Sensitivity: Long. Cracking



Master Curve Parameters

Expected…

????

Expected…

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MEPDG: Thermal Cracking

$$C_f = 400N\left(\frac{\log(C/h_{ac})}{\sigma}\right)$$

C_f = amount of thermal cracking (ft/500 ft)
N = standard normal distribution at ( )
C = crack depth (in)
h_{ac} = thickness of asphalt layer (in)

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MEPDG: Thermal Cracking

$$\Delta C = (k\beta_t)^{n+1} A \Delta K^n \qquad A = 10^{(4.389 - 2.52\log(E\sigma_m n))}$$

ΔC = change in crack depth due to a cooling cycle
k = regression coefficient determined through field calibration
B_t = calibration coefficent
A, n = fracture parameters for asphalt mixture
ΔK = change in stress intensity factor due to a cooling cycle
E = mixture stiffness
σ_m = undamaged mixture tensile strength

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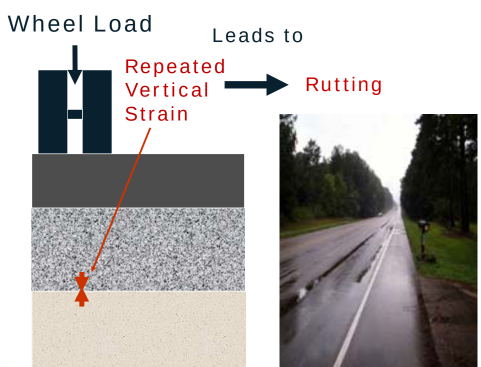
Sensitivity: Thermal Cracking

There is no prediction of thermal cracking when the appropriate binder grade is selected…



MEPDG: Rutting

$$RD = \sum_{i=1}^{nsublayers} \varepsilon_p^i h^i$$

RD = *pavement total permanent deformation*

i = *number of sublayers*

ε_p^i = total plastic strain in sublayer i

h^i = thickness of sublayer i

MEPDG: Rutting (AC)

$$\frac{\varepsilon_p}{\varepsilon_r} = k_z \beta_{r1} * 10^{-3.35412} T^{1.5606 \beta_{r2}} N^{0.4791 \beta_{r3}}$$

ε_p = *accumulated plastic strain*

ε_r = *resilient strain of HMA (function of loading time, mixture, temp)*

k_1 = depth parameter (to account for confining pressure at various depths)

T = *Temperature (F)*

N = *Number of load applications*

β_{ri} = *Calibration Coefficients*

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MEPDG: Rutting (AC)

$$\frac{\varepsilon_p}{\varepsilon_r} = k_z \beta_{r1} * 10^{-3.35412} T^{1.5606 \beta_{r2}} N^{0.4791 \beta_{r3}}$$

k_z = depth parameter (to account for confining pressure at various depths)

$$k_1 = (C_1 + C_2 * depth) * 0.328196^{depth}$$

$$C_1 = -0.1039 * h_{ac}^2 + 2.4868 * h_{ac} - 17.342$$

$$C_2 = 0.0172 * h_{ac}^2 - 1.7331 * h_{ac} + 27.428$$

h_{ac} = AC thickness

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MEPDG: Rutting (Unbound)

$$\delta_a(N) = \beta_{s1} k_1 \varepsilon_v h \left(\frac{\varepsilon_0}{\varepsilon_r} \right) e^{-\left(\frac{\rho}{N} \right)^{\beta}}$$

δ_a = permanent deformation for the layer/sublayer (in)

N = number of traffic repetitions

ε_0 ρ β = material properties

β_{s1} = calibration factor

ε_r = resilient strain from laboratory tests (in/in)

ε_v = average vertical resilient strain in the layer/sublayer as obtained from the primary response model (in/in)

h = thickness of the layer/sublayer (in)

k_1 = material coefficient (granular: 2.03 fine: 1.35)

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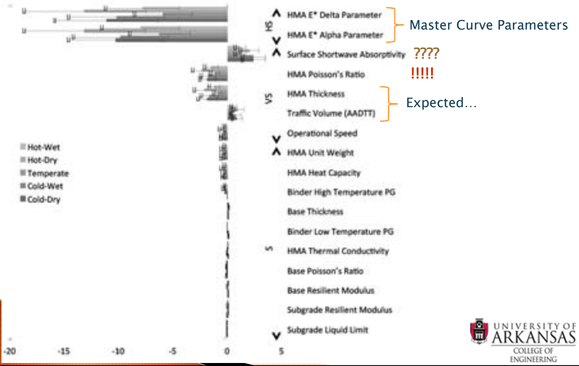
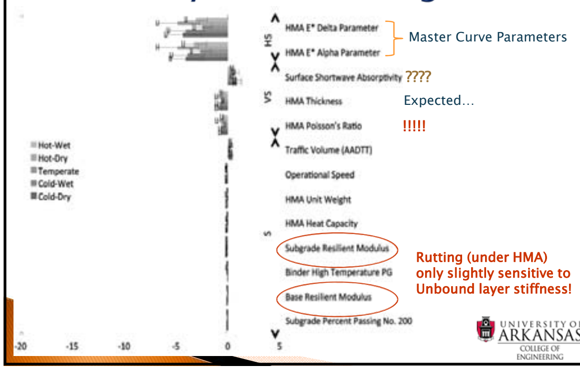
Sensitivity: HMA Rutting



Sensitivity: Total Rutting



MEPDG: Ride Quality (IRI)

$$IRI = IRI_0 + 0.0463\left[SF\left(e^{\frac{age}{20}} - 1\right)\right] + 0.00119\,(TC_L)_T + 0.1834\,(COV_{RD}) + 0.00384\,(FC)_T + 0.00736\,(BC)_T + 0.00115\,(LC_{SNWP})_{MH}$$

IRI = IRI at any given time, m/km
IRI_0 = initial IRI, m/km
SF = site factor
COV_{RD} = coefficient of variation of the rut depths
$(TC_L)_T$ = total length of transverse cracking, m/km
$(FC)_T$ = fatigue cracking in wheel path, percent
$(BC)_T$ = area of block cracking as a percent of total lane area
$(LC_{SNWP})_{MH}$ = length of moderate and high severity sealed longitudinal cracks outside wheelpath, m/km

MEPDG: Ride Quality (IRI) (Asphalt-Treated Base)

$$IRI = IRI_0 + 0.0099947\,(Age) + 0.0005183\,(FI) + 0.00235\,(FC)_T + 18.36\left[\frac{1}{(TC_S)_H}\right] + 0.9694\,(P)_H$$

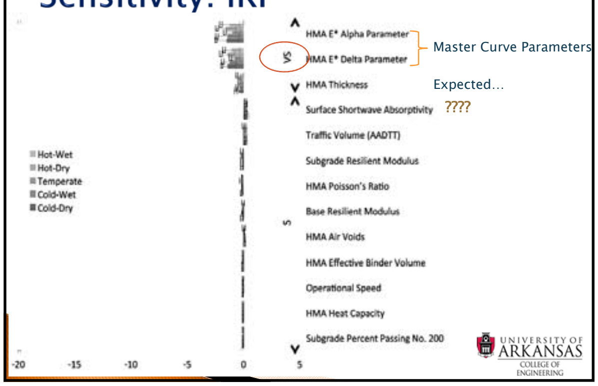
$(TC_S)_H$ = average spacing of high severity transverse cracking, m
$(P)_H$ = average of high severity patches, percent of total lane area, %

MEPDG: Ride Quality (IRI) (Chemically-Treated Base)

$$IRI = IRI_0 + 0.00732\,(FC)_T + 0.07647\,(SD_{RD}) + 0.0001449\,(TC_L)_T + 0.00842\,(BC)_T + 0.002115\,(LC_{NWP})_{MH}$$

$(LC_{NWP})_{MH}$ = medium and high severity sealed longitudinal cracking outside the wheel path, m/km.
SD_{RD} = standard deviation of the rut depth, mm

Sensitivity: IRI



TO SUMMARIZE…

- Performance Prediction Models
  - Bottom-up fatigue cracking, thermal cracking, rutting, IRI appear functional at this time
  - Top-down cracking, reflection cracking appear to be less functional at this time
- Hyper-sensitive or Very Sensitive for "most" (4 out of 5) distress predictions:
  - E* alpha & E* delta *(in other words…Dynamic Modulus)*
  - HMA thickness
  - Surface shortwave absorptivity
  - Poisson's ratio
- Very Sensitive for multiple distress predictions:
  - Air Voids
  - Effective Binder Volume
  - Traffic Volume

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A Word About Design Reliability…

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"Reliability" : Standard Deviations

AC Rutting:	0.24*Pow(RUT,0.8026)+0.001
Thermal Cracking:	0.3972*THERMAL+20.422 (Level 3)
Unbound Rutting (Granular):	0.1477*Pow(BASERUT,0.6711)+0.001
Unbound Rutting (Fine):	0.1235*Pow(SUBRUT,0.5012)+0.001
AC Top-Down Cracking:	200+2300/(1+exp(1.072-2.1654log(TOP+0.0001)))
AC Bottom-Up Cracking:	1.13+13/(1+exp(7.57-15.5log(BOT+0.0001)))

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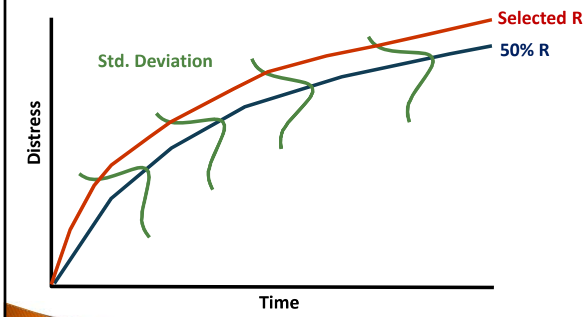
"Reliability"



QUESTIONS?

Thank You!

Next Webinar: Wednesday, September 11th

Part 4: Major Inputs – Where Do They Come From & How Do We Get Them?

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