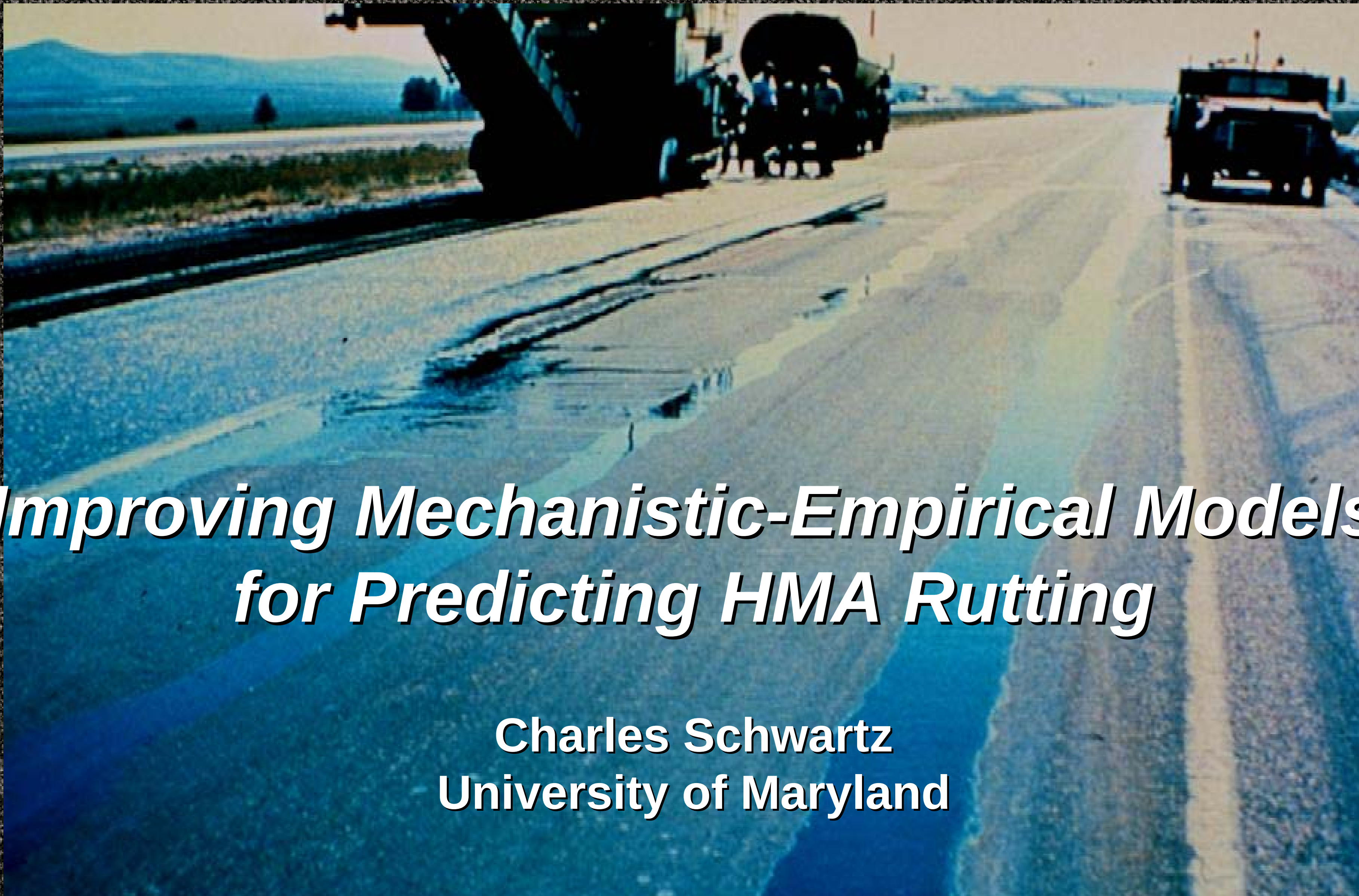


Improving Mechanistic-Empirical Models for Predicting HMA Rutting

Charles Schwartz
University of Maryland

Pavement Performance Prediction Symposium 2006, Laramie WY

NCHRP 9-30A

"Calibration of Rutting Models for HMA Structural and Mix Design "

- PI: Harold Von Quintus/Applied Research Associates
- Co-PIs:
  - Charles Schwartz/University of Maryland
  - Ramon Bonaquist/Advanced Asphalt Technologies
- Other subcontractors:
  - Burns Denton Cooley, Inc.
  - North Carolina State University

Primary Project Objectives

"Recommend revisions to the HMA rut depth prediction model in the M-E PDG developed in NCHRP Project 1-37A"

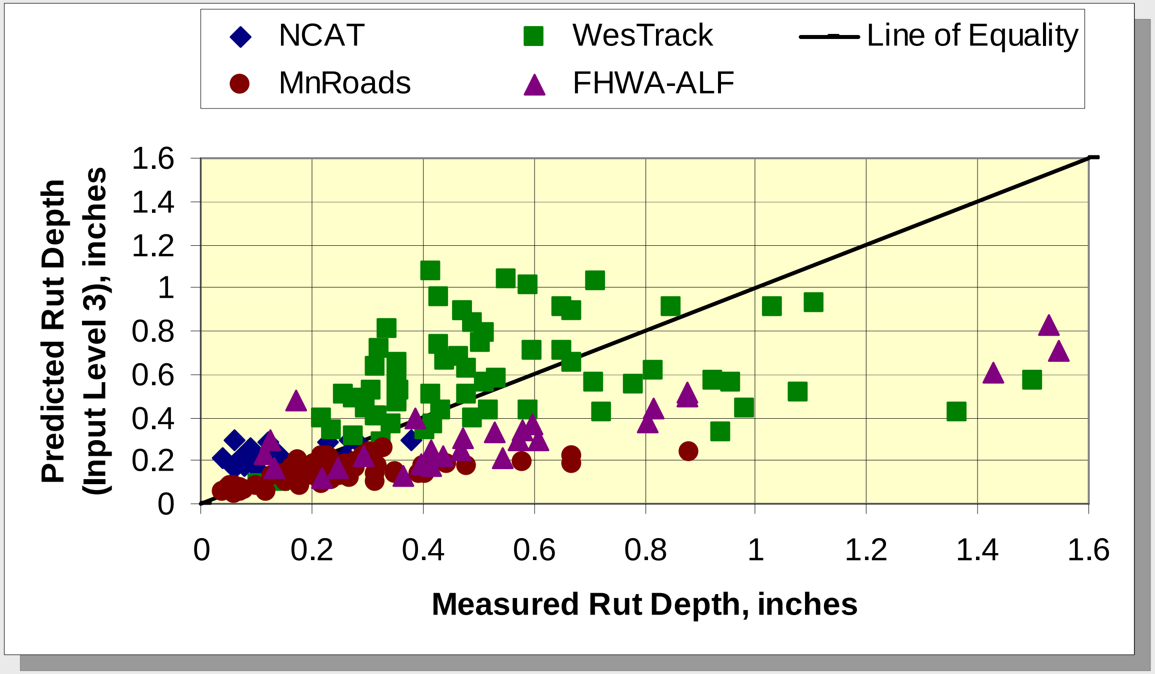
- Enhancements to existing HMA rutting model
- Investigation of alternative models
- Evaluation via calibration and validation against field sections using *measured* material properties

Secondary Project Objectives

- Compile laboratory-measured material property values for select full-scale pavement sections
- Develop a database tailored to calibration and validation of M-E distress prediction models
- Support the continuing advance toward more fully mechanistic performance prediction models

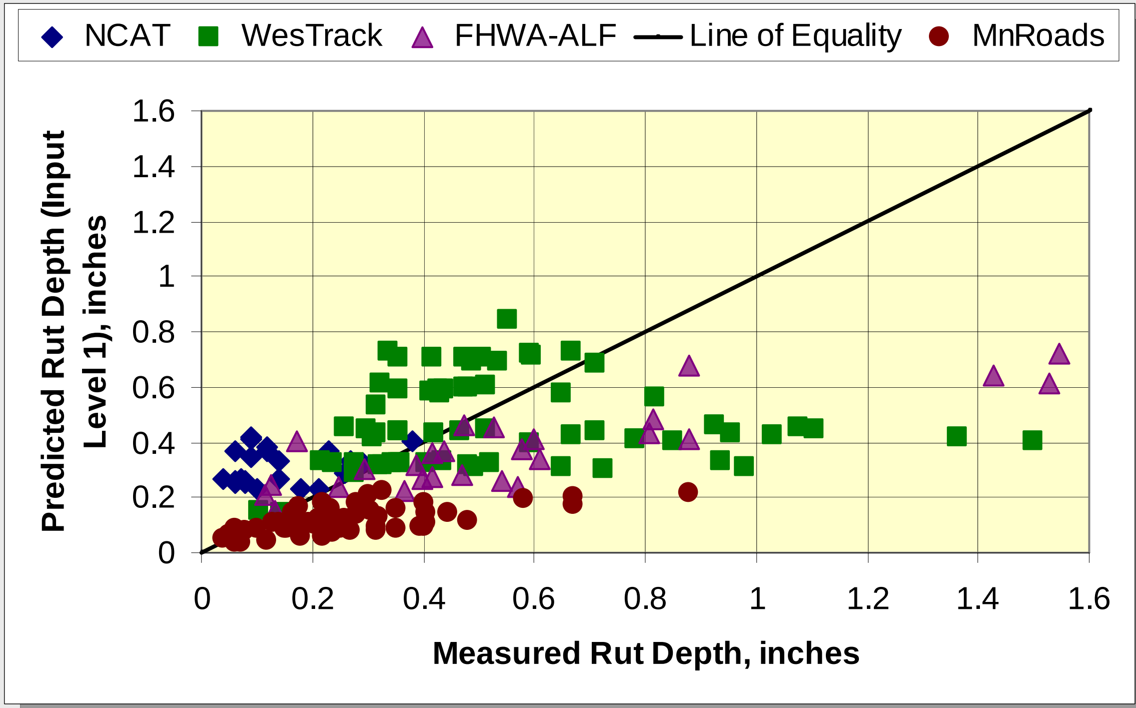
Motivation for Project

- Perceived deficiencies in current M-E model for HMA rutting:
  - Inadequate measured ("level 1") material properties for LTPP calibration sections
  - No layer properties related to permanent deformation resistance of mixture
  - Counterintuitive variations of permanent deformations with depth
  - No robust basis for apportioning measured surface rutting to various layers



Level 3 E* Inputs

Level 1 E* Inputs



Phase I: Workshop—Objectives

- Identify alternate rut models for evaluation
- Develop guidance on two key issues:
  - Maximum allowable prediction error
  - Design criterion/limit for HMA rutting
- Identify problem statements for future work
  - Short term (HMA structural, mix design; performance based specifications)
  - Long term (more mechanistic approaches)

23 participants over 2 days

Phase II: Database Design Review

Major Data Areas

- General project information
- Pavement structure
- Traffic
- Climate
- Material properties
- Performance (load-related cracking, transverse cracking, rutting, roughness)

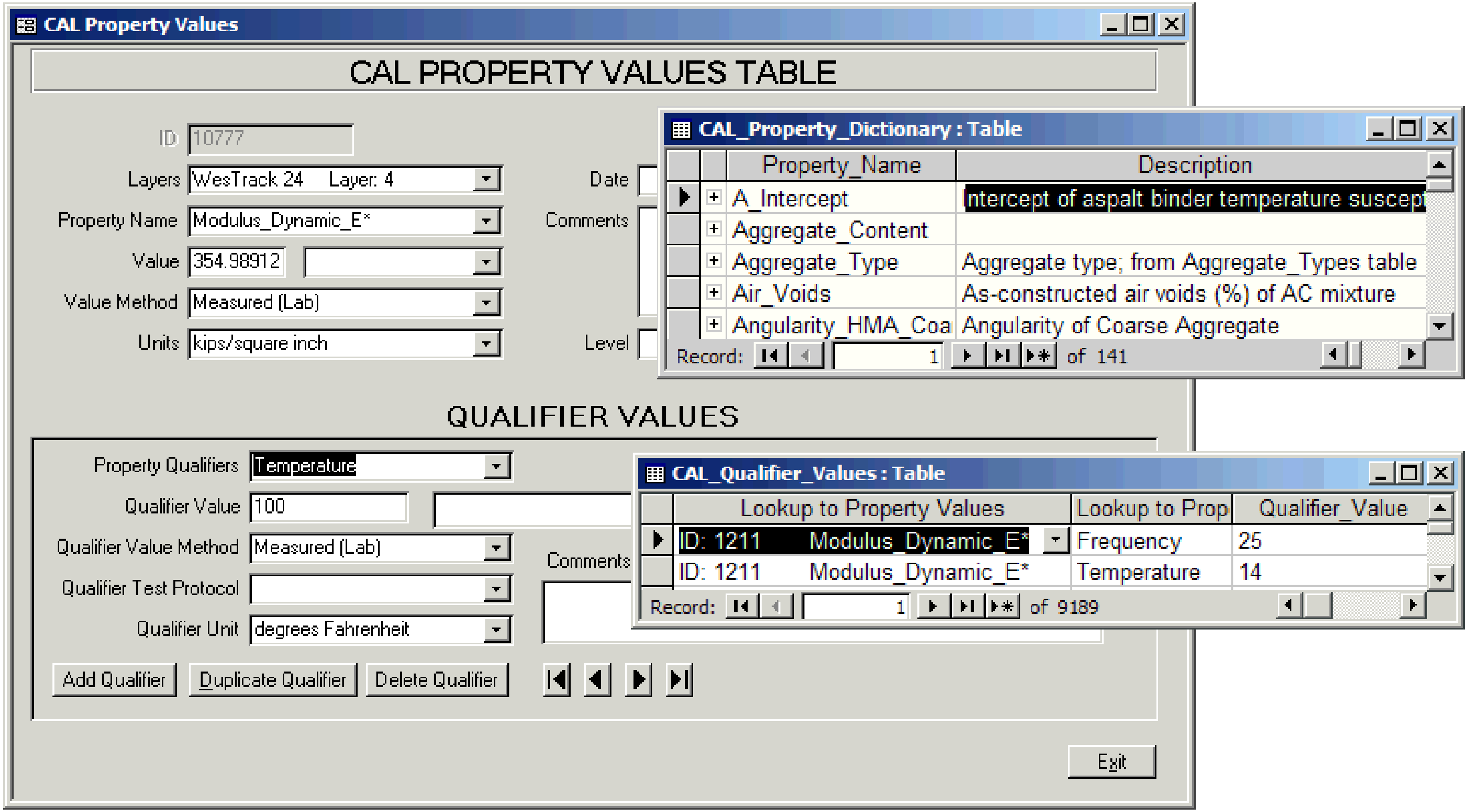
M-E_DPM Database

UNIVERSITY OF MARYLAND

M-E_DPM vs. LTPP

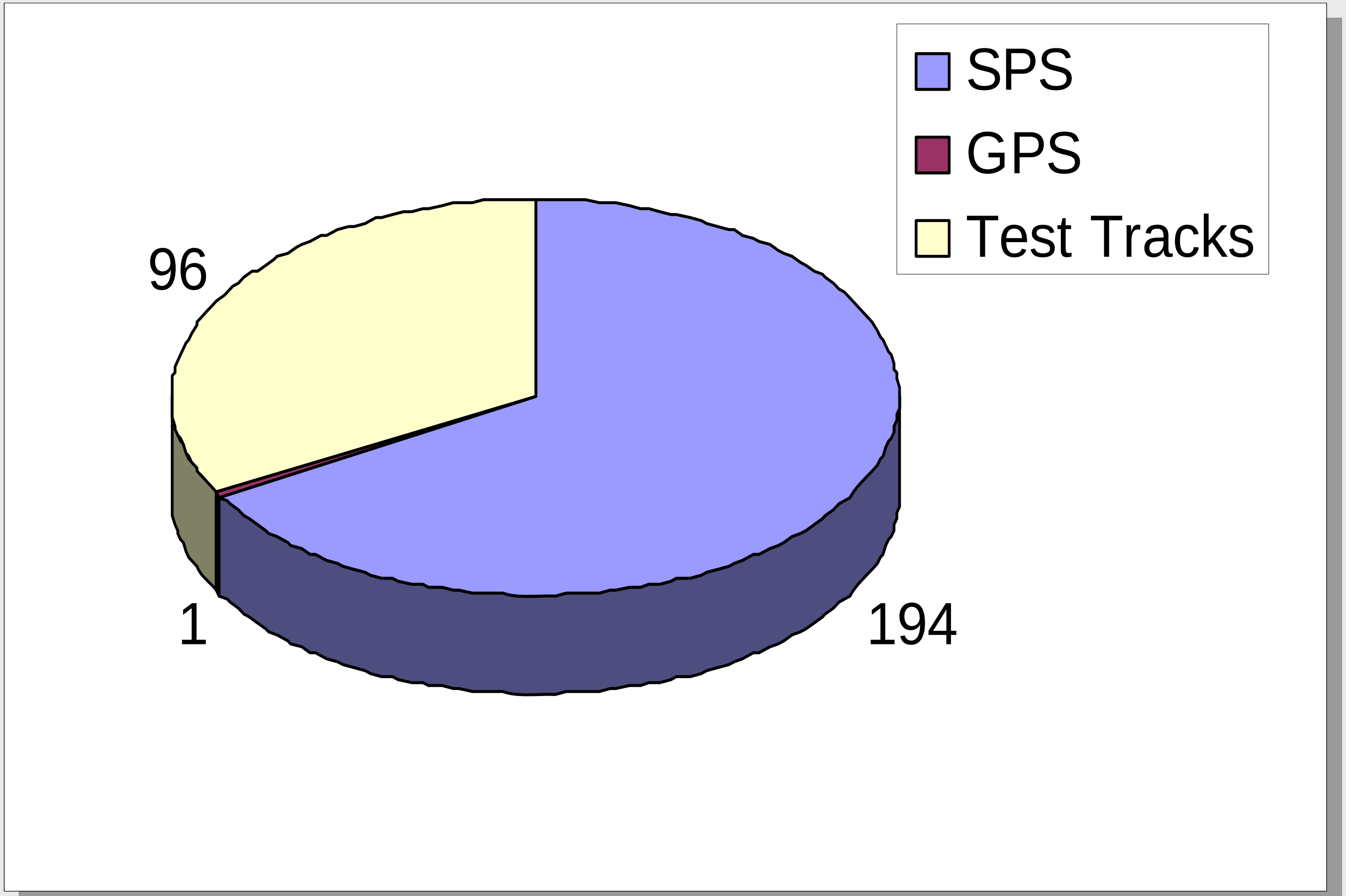
- Simpler table structures
  - No need to track complex pavement histories, e.g.
- More emphasis on material properties
  - Highly flexible, extensible definition of material property data fields
- LTPP data imported as appropriate for GPS/SPS sections
  - Traffic
  - Performance
- Focus: model calibration/validation

UNIVERSITY OF MARYLAND



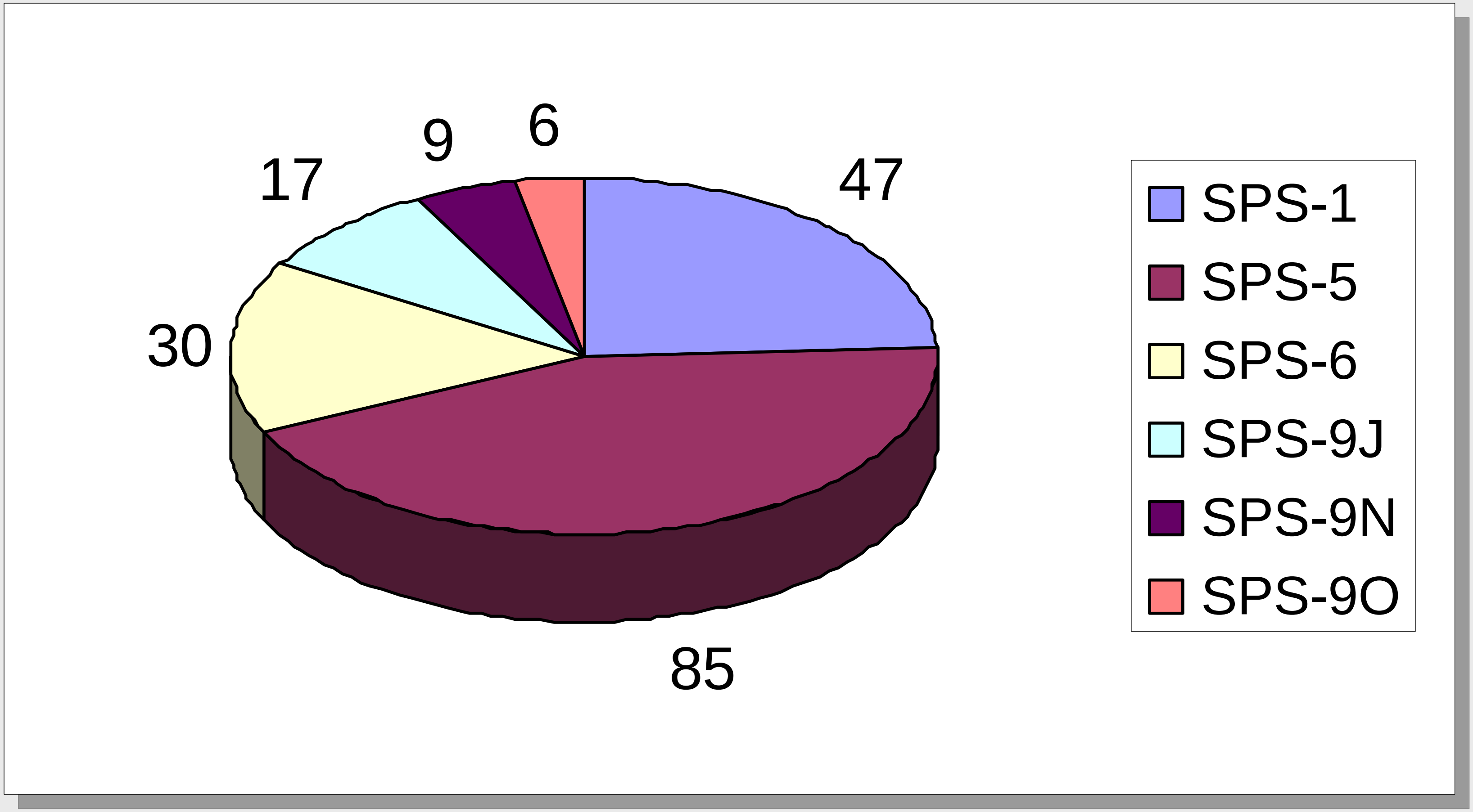
+ links to test data files

Current Database Population



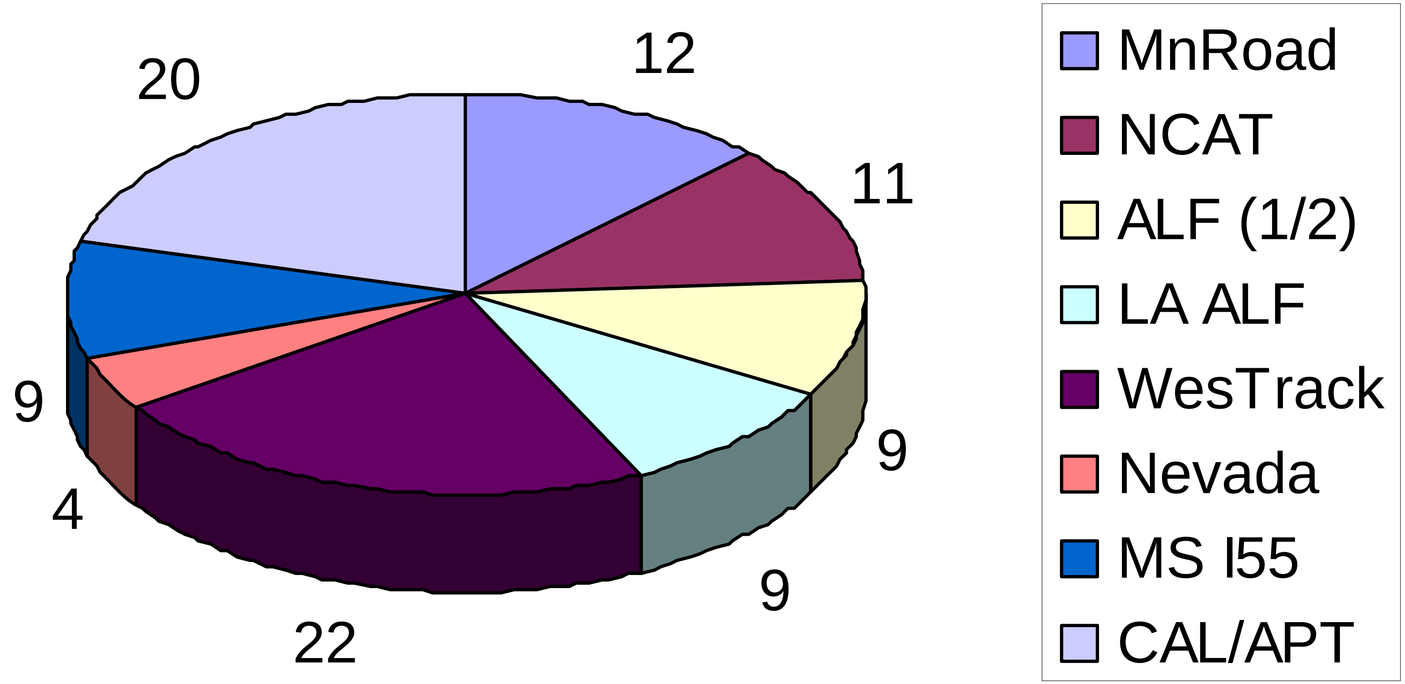
291 sections total

SPS Sections



UNIVERSITY OF MARYLAND

ALF/Test Tracks



Phase III: Execute Experimental Plan

- Final experiment matrix
- Field investigations/sample collection
- Laboratory testing
  - Part A (intensive testing of few sections)
  - Part B (routine testing of all sections)
- Database population
- Model calibration/validation/evaluation
  - Model refinement/enhancement

Experimental Plan Matrix

HMA Thick	Mix Type	Grading	VFA	New Construction		Rehabilitation				Total No. of Sections
						HMA		PCC		
				Conv.	Deep Strength	Milled	Un-Milled	Intact PCC; Crack/Break & Seat PCC	Rubb. PCC	
Thin	Neat	Fine	Low	2		1	1			4
		Fine	High	2						2
		Coarse	Low	2						2
		Coarse	High	2		1	1			4
	PMA	Fine	Low							0
		Fine	High							0
		Coarse	Low							0
		Coarse	High							0
Thick	Neat	Fine	Low		1		1	1		3
		Fine	High		1		1			2
		Coarse	Low		2	1		1	1	5
		Coarse	High		2	1			1	4
	PMA	Fine	Low		1	1				2
		Fine	High		1	1		1		3
		Coarse	Low		2		1		1	4
		Coarse	High		2		1	1	1	5
Total Sections				**8**	**12**	**6**	**6**	**4**	**4**	**40**

Identified Sections

Climate Independent or Climate Controlled				Climate Dependent, plus long-term aging of asphalt	
Little to no Aging (Test completed within months)		Some Aging (Test completed in 3 years or less)			
FHWA-ALF	Round 1	WesTrack	PRS Study	MnRoad	Round 1
FWHA-ALF	Round 2	NCAT	Round 1	MnRoad	Round 2
LSU-ALF	CTB Testing	NCAT	Round 2	LTPP	SPS-1
CalTrans	HVS 1	NCAT	Round 3	LTPP	SPS-5
CalTrans	HVS 2			LTPP	SPS-6
Florida	Round 1			LTPP	SPS-9
Florida	Round 2			Nevada	I-80
				Mississippi	I-55
				Pennsylvania	Special Study
				WRI	Binder Study

Models Considered

- "Mostly" empirical
  - World Bank
  - Baladi
- Other Mechanistic-Empirical
  - Permanent axial strain models
    - Leahy
    - Asphalt Institute
    - VESYS
    - Verstraeten
    - Uzan
  - Permanent shear strain models
    - Westrack
- Enhanced NCHRP 1-37A
  - NCHRP 1-40A+
  - NCHRP 1-40B

Models to be Evaluated

- Current model (NCHRP 1-37A)
  - New calibrations from NCHRP 1-40D
- Westrack
- NCHRP 1-40B
  - Modified RLPD characteristics based on volumetrics, gradation
- Enhanced NCHRP 1-37A

Westrack M-E based on γ_p

$$\gamma_p = a e^{b\tau} \gamma_e N^c$$

γ_p	= permanent shear strain at a depth of 2 inches below the surface
τ	= mechanistically-determined elastic shear stress at z = 2 in
γ_e	= mechanistically-determined elastic shear strain at z = 2 in
a, b, c	= material constants, obtained from SST-CH

Time-hardening principle:

$$\gamma_{p,1} = a_1 \left[\Delta N_1\right]^c$$

$$a_t = a e^{b\tau} \gamma_{e,t}$$

$$\gamma_{p,t} = a_t \left[\left(\frac{\gamma_{p,t-1}}{a_t} \right)^{\frac{1}{c}} + \Delta N_t \right]^c$$

$\gamma_{e,t}$ = elastic shear strain for the t^th^ period of loading

$\gamma_{p,t}$ = permanent shear strain for the t^th^ period

ΔN_t = number of load applications during the t^th^ period

RD = K$\gamma_{p,t}$

NCHRP 1-40B Enhancements

Material Properties

$$\frac{\varepsilon_p}{\varepsilon_r} = k_1 \left(10^{k_{r1}} T^{k_{r2}} N^{k_{r3}} \right)$$

Depth function

Adjustment of permanent deformation constants based on HMA volumetric properties

Constant k_{r1}:

$$k_{r1} = \log\left[1.5093 \times 10^{-3} \times K_{r1} \times V_a^{\,0.5213} \times V_{beff}^{\,1.0057}\right] - 3.4488$$

K_{r1} = intercept coefficient (see Figure A.1)

NCHRP 1-40B (cont'd)

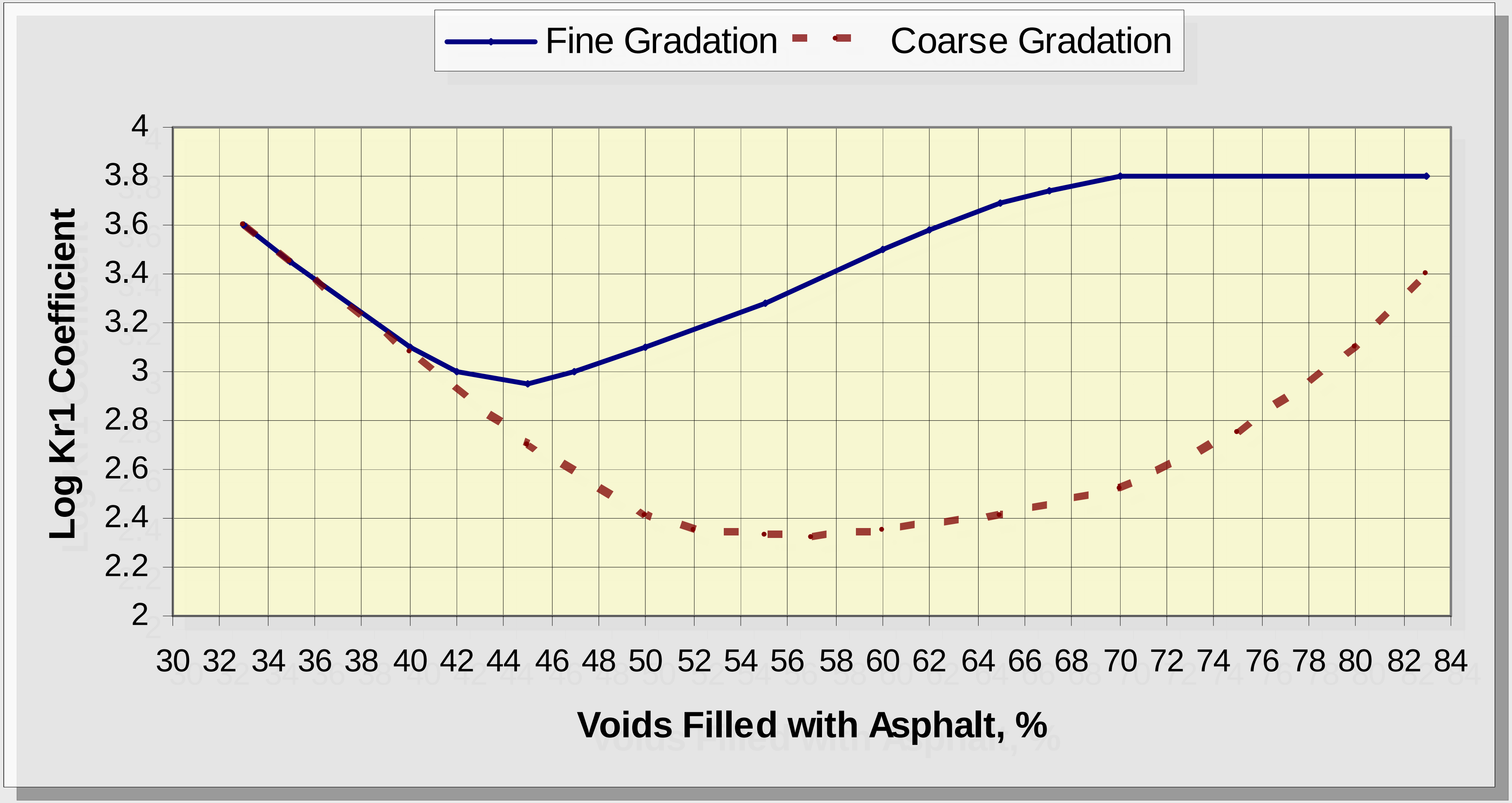


Figure A.1

NCHRP 1-40B (cont'd)

Constant k_{r2}:

$$k_{r2} = 1.5606\left(\frac{V_a}{V_{a(design)}}\right)^{0.25}\left(\frac{P_b}{P_{b(opt)}}\right)^{1.25} F_{index} C_{index}$$

$V_{a(design)}$	= design air voids
P_b	= asphalt content by weight
$P_{b(opt)}$	= design asphalt content by weight
F_{index}	= fine aggregate angularity index (Table A.2)
C_{index}	= coarse aggregate angularity index (Table A.3)

NCHRP 1-40B (cont'd)

Table A.2. Fine aggregate angularity index used to adjust permanent deformation parameters, F_{Index}.

Gradation – External to restricted zone.	Fine Aggregate Angularity	
	< 45	> 45
Dense Grading – External to Restricted Zone	1.00	0.90
Dense Grading – Through Restricted Zone	1.05	1.0

Table A.3. Coarse aggregate angularity index used to adjust permanent deformation parameters, C_{Index}.

Type of Gradation	Percent Crushed Material with Two Faces				
	0	25	50	75	100
Well Graded	1.1	1.05	1.0	1.0	0.9
Gap Graded	1.2	1.1	1.05	1.0	0.9

NCHRP 1-40B (cont'd)

Constant k_{r3}:

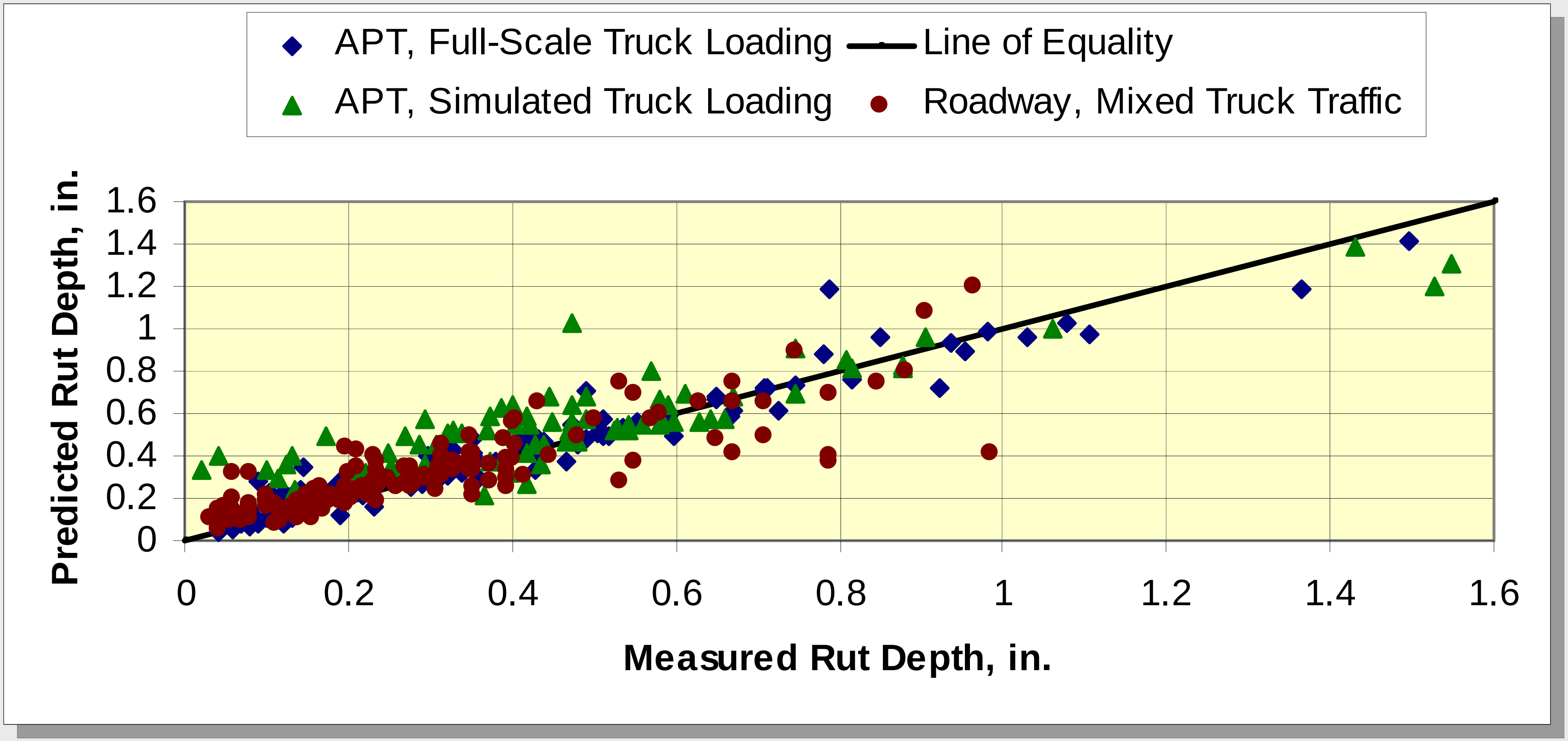
$$k_{r3} = 0.4791 \times K_{r3} \times \frac{P_b}{P_{b(opt)}}$$

K_{r3} = slope coefficient:

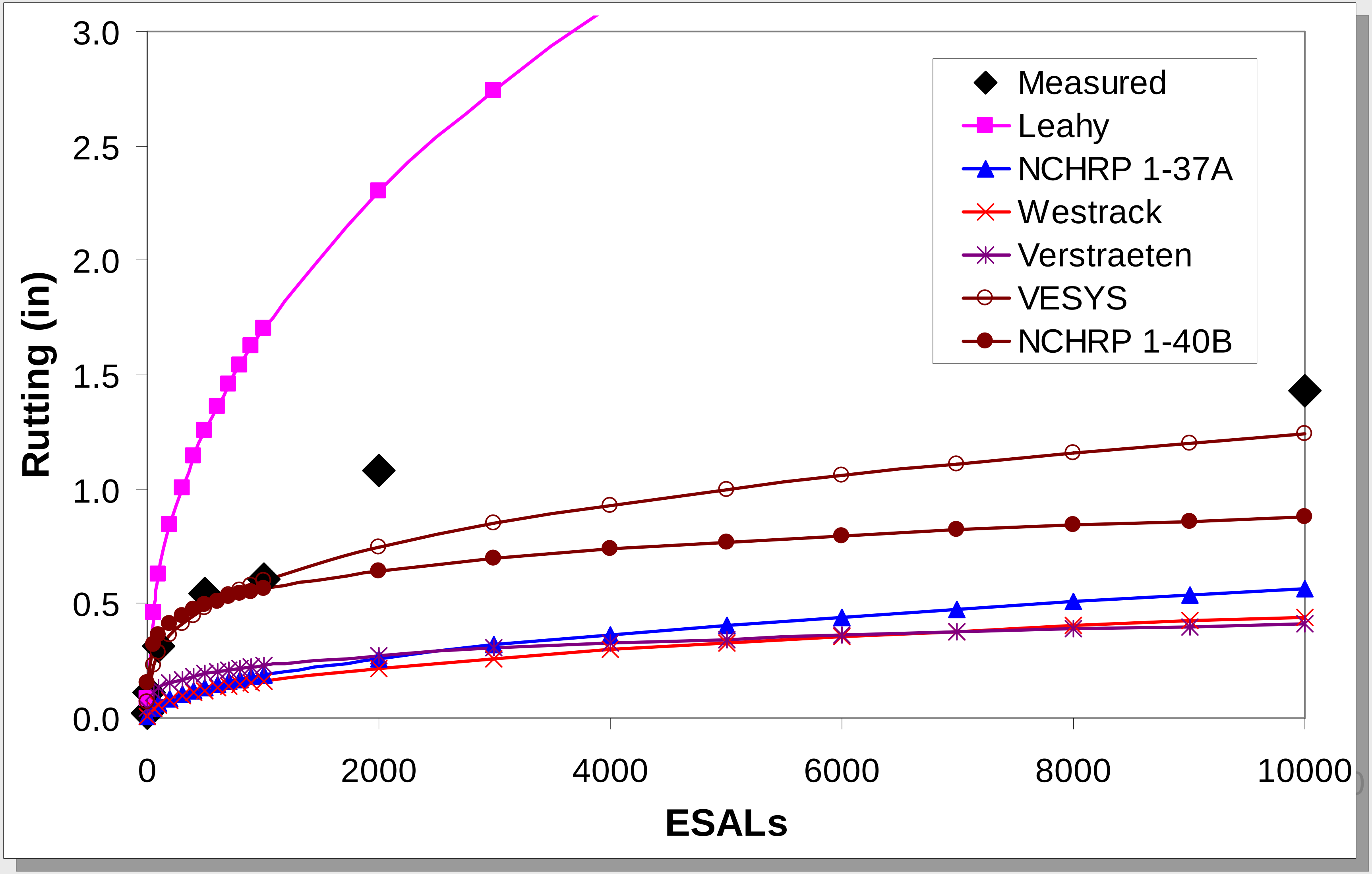
fine-graded mixtures	with GI<20	→	$K_{r3}=0.40$
coarse-graded mixtures	with 20<GI<40	→	$K_{r3}=0.70$
	with GI>40	→	$K_{r3}=0.80$

GI = gradation index = $\sum_{i=3/8}^{\#50} \left| P_i - P_{i(0.45)} \right|$

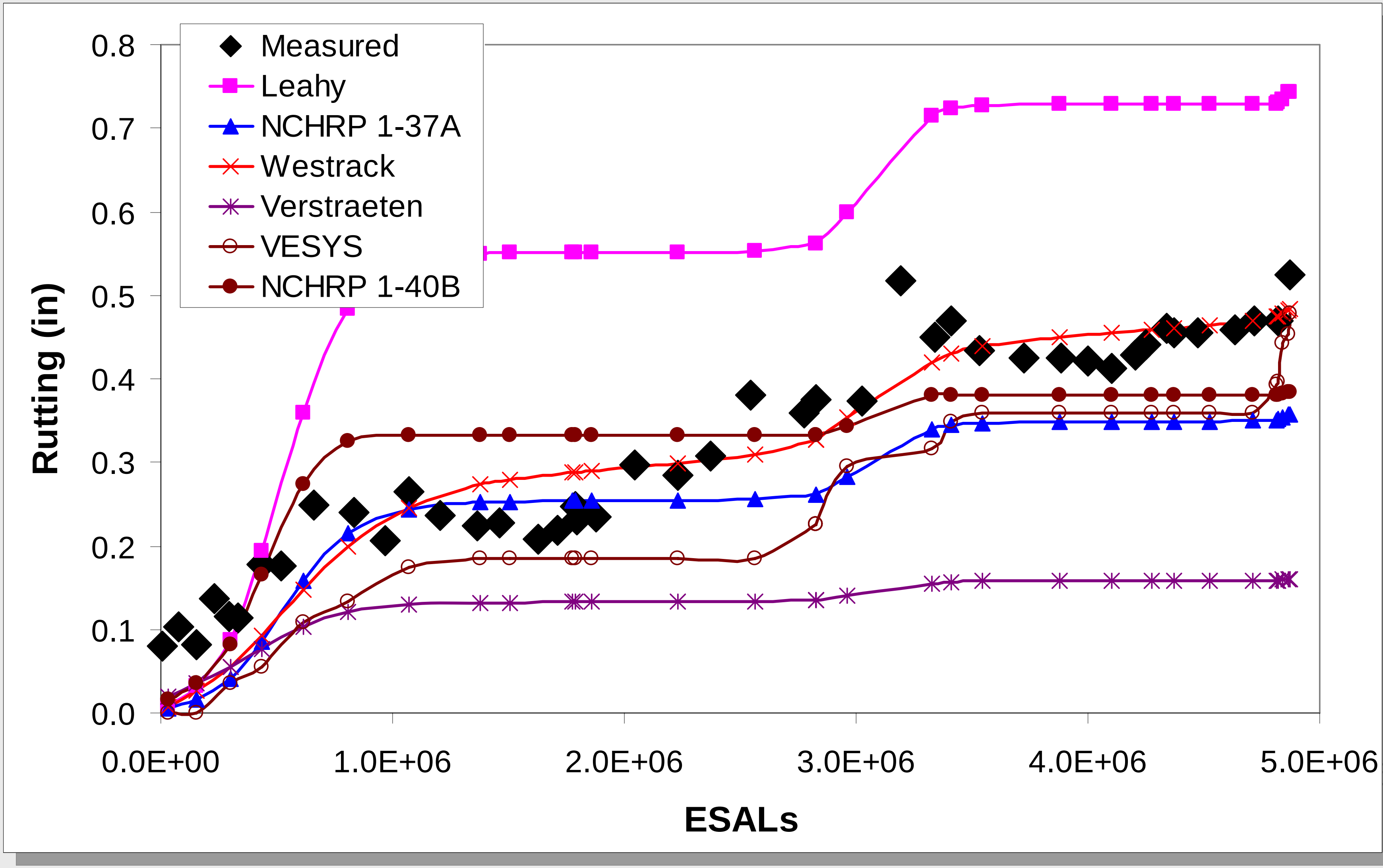
NCHRP 1-40B (cont'd)



ALF Comparisons: Lane 10



Westrack Comparisons: Section 4



UNIVERSITY OF MARYLAND

ALF Comparisons

Ranking (only sections with complete sets of data)

	Lane 5	Lane 9	Lane 10	Lane 11	Lane 12	Average
Leahy	5	5	6	5	6	5.4
1-37A	3	3	3	3	3	3.0
Westrack	6	6	4	6	5	5.4
Verstraeten	4	4	5	4	4	4.2
VESYS	1	2	1	1	2	1.4
1-40B	2	1	2	2	1	1.6

Data sources:

- Westrack: SST RSCH tests from NCHRP 9-19 + AAPT calibration procedure
- Leahy, Option A: Mixture summaries from NCHRP 9-19 reports
- VESYS: Confined RLPD tests from NCHRP 9-19 reports

UNIVERSITY OF MARYLAND

Westrack Comparisons

Ranking (only sections with complete sets of data)

	Section 4	Section 15	Section 23	Section 24	Average
Leahy	5	5	2	1	3.3
1-37A	4	3	5	5	4.3
Westrack	1	2	4	2	2.3
Verstraeten	6	4	6	6	5.5
VESYS	2	6	3	4	3.8
1-40B	3	1	1	3	2.0

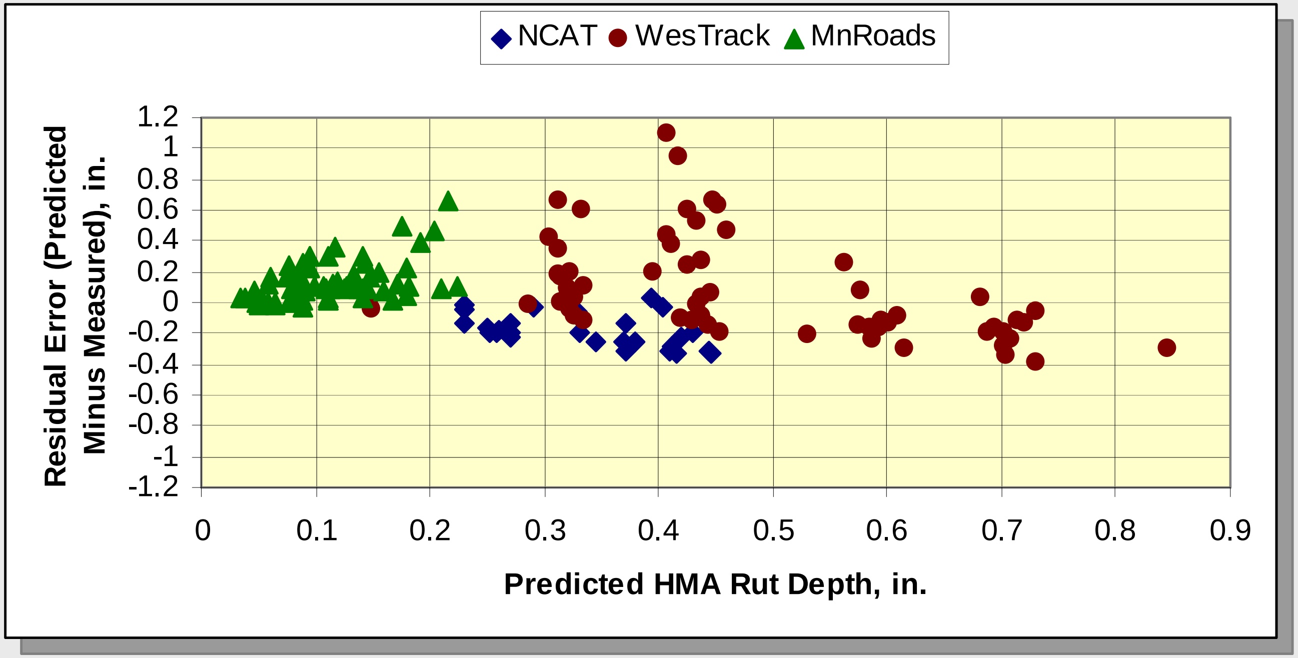
Data sources:

- Leahy, Option A: Mixture summaries from NCHRP 9-19 reports
- Westrack: Calibration parameters from Westrack report
- VESYS: Confined RLPD tests from NCHRP 9-19 reports

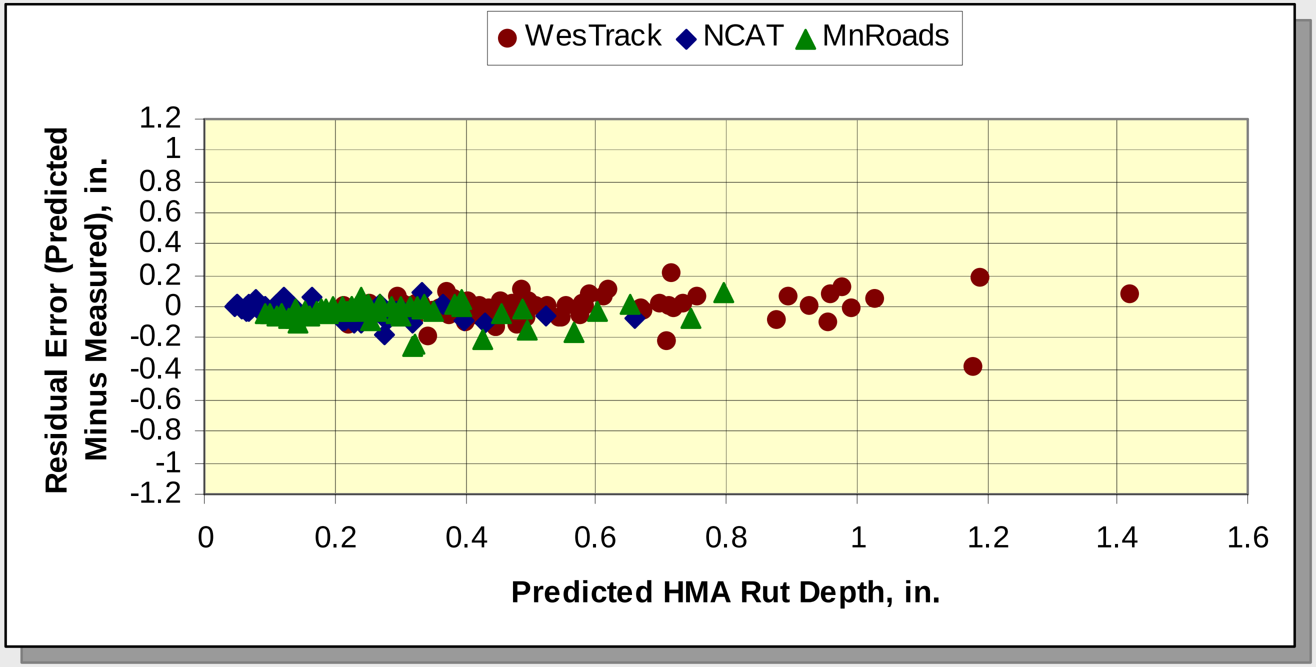
Enhanced NCHRP 1-37A

- Material-dependent RLPD properties
  - Treat as layer property rather than global parameters
- Additional stress terms/influences
  - Confining stress
  - Deviatoric stress
- More rational depth factor
  - Look to mechanistic models for guidance?

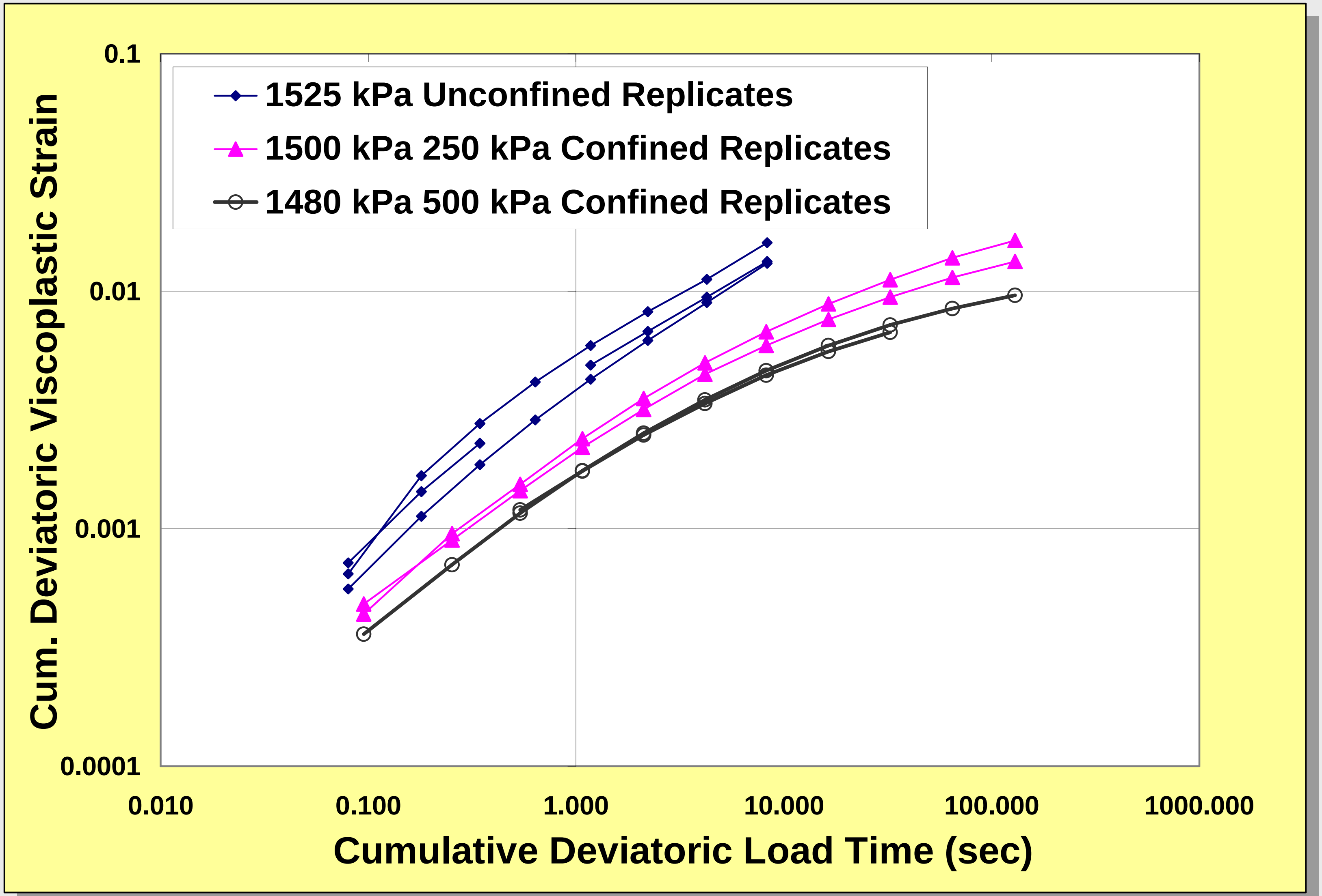
“Level 3” RLPD Properties



“Level 2” RLPD Properties (NCHRP 1-40B)

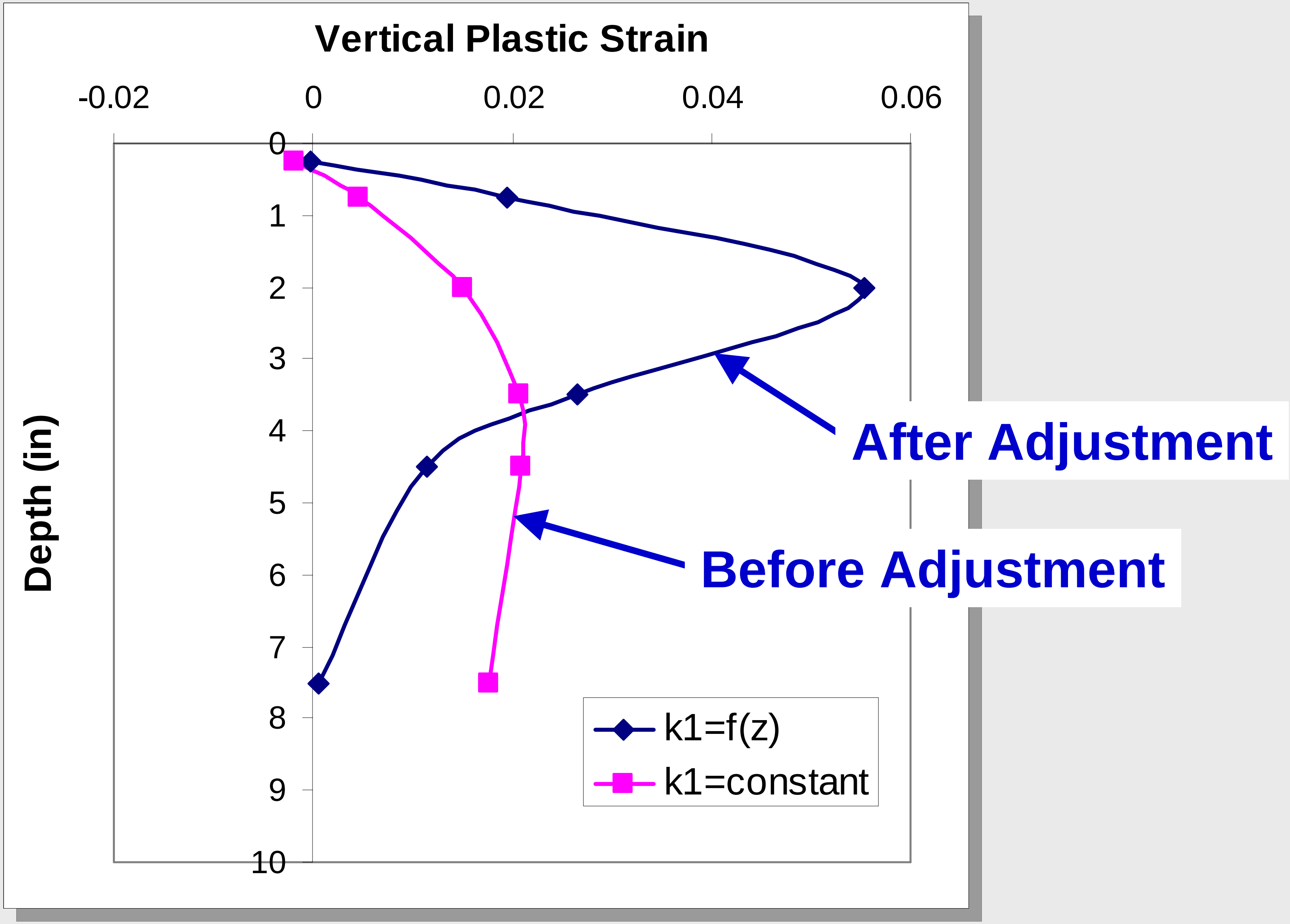


Stress Effects on Material Response



UNIVERSITY OF MARYLAND

Depth Factor



10” AC layer

Field Evaluation Activities

- Compile existing data:
  - Traffic
  - Climate
  - Visual distress
  - Performance (rutting)
  - FWD
- Collect new data:
  - Trenches
  - Cores
  - Material samples

Trenches are Essential

- Measured rutting is total rutting at surface
- M-E models predict rutting in individual layers
  - HMA
  - Unbound base/subbase
  - Subgrade
- Trench data provide rational basis for apportioning total surface rutting to layers

Material Property Tests

- For all sections:
  - Uniaxial dynamic modulus
  - Triaxial repeated load permanent deformation
  - Shear dynamic modulus
  - Repeated load constant height shear
- For selected sections:
  - Triaxial RLPD at additional stress states
  - Advanced material characterization (e.g., NCHRP 9-19 test suite):
    - Triaxial constant strain rate to failure (compression, tension)
    - Triaxial creep and recovery (compression)
    - Others?

University of Maryland

Project Timeline

- Project Panel meeting on July 27
- Phase III commences August/September
- Two year duration for Phase III

$m\text{-}E \rightarrow M\text{-}E \rightarrow M\text{-}e$