PERPETUAL PAVEMENTS
DESIGN- CONSTRUCTION-PERFORMANCE

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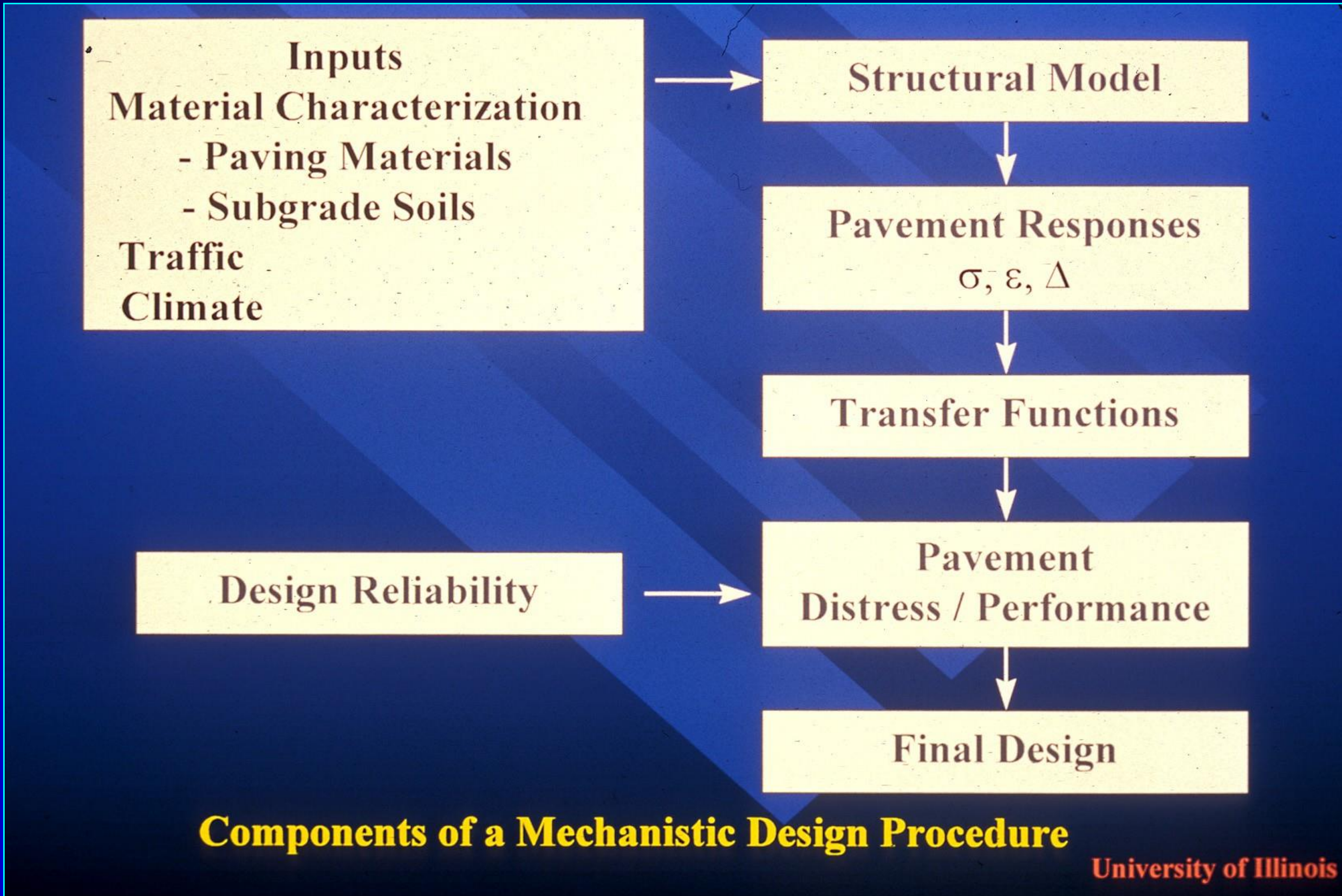
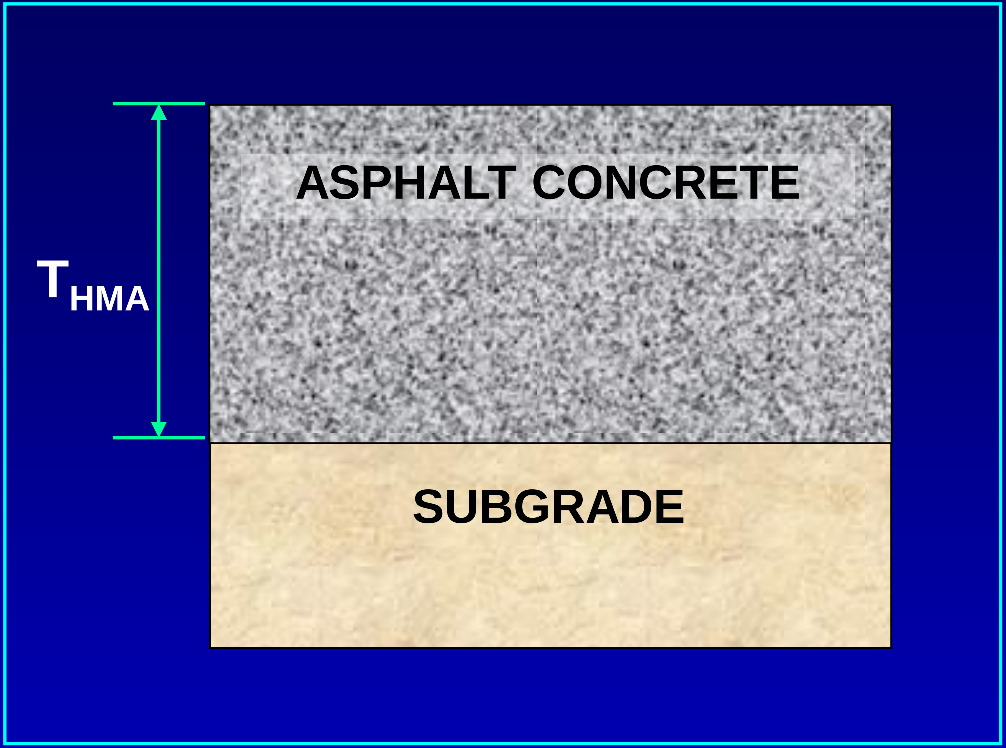
FULL-DEPTH HMA

FULL QUALITY HMA

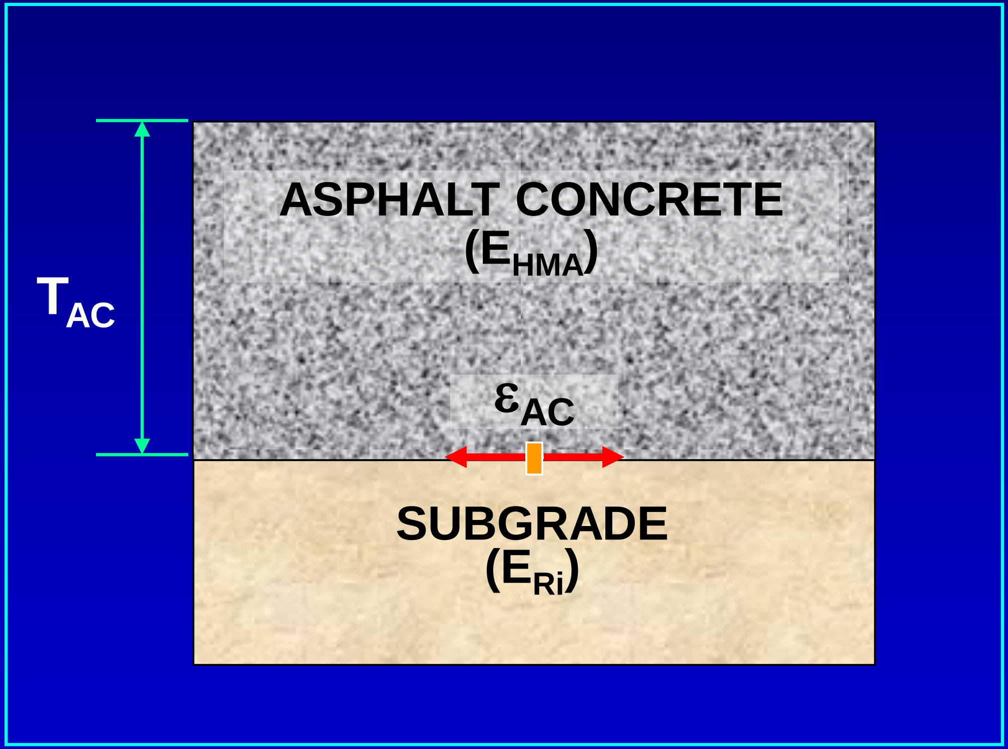

Inputs
Material Characterization
- Paving Materials
- Subgrade Soils
Traffic
Climate
Structural Model
Pavement Responses
σ, ε, Δ
Transfer Functions
Design Reliability
Pavement
Distress / Performance
Final Design
Components of a Mechanistic Design Procedure
University of Illinois



HMA DESIGN

- HMA FATIGUE
- HMA RUTTING
- SUBGRADE RUTTING

FULL-DEPTH HMA PAVEMENT



PP: HMA FATIGUE !!

IDOT
PERPETUAL PAVEMENT (PP)
EVOLUTION

ILDOT: M-E DESIGN

1989: FULL-DEPTH HMA

HMA + MODIFIED SUBGRADE (LIME-CEMENT-AGGREGATE)

Monismith & McLean

"Technology of Thick Lift Construction: Structural Design Considerations"

1972 AAPT Proceedings

70 Micro-Strain Endurance Limit!!

Michael Nunn

"Long-Life Flexible Pavements"

8th ISAP Conference

Seattle, WA – 1997

MRT: TO JAY MILLER!!

IDOT

LONG LIFE PAVEMENT ACTIVITIES (LATE 90'S/EARLY 2000'S)

ASPHALT PAVEMENT ALLIANCE (2000)

"PERPETUAL PAVEMENTS"

Huddleston – Buncher – Newcomb

ASPHALT PAVEMENT ALLIANCE

"an asphalt pavement designed and built to last longer than 50 years without requiring major structural rehabilitation or, reconstruction, and needing only periodic surface renewal in response to distresses confined to the top of the pavement."

PERPETUAL PAVEMENT DESIGN

CRITERIA :

* HMA CUMULATIVE FATIGUE DAMAGE WILL NOT OCCUR (LIMITED EXTENT)

* LONG LIFE: 40-50 YEARS

* PERIODIC MILL-FILL

ILDOT: PP DESIGN

FULL-DEPTH HMA – 2011

RUBBLIZED PCCP - 2013

HMA FATIGUE

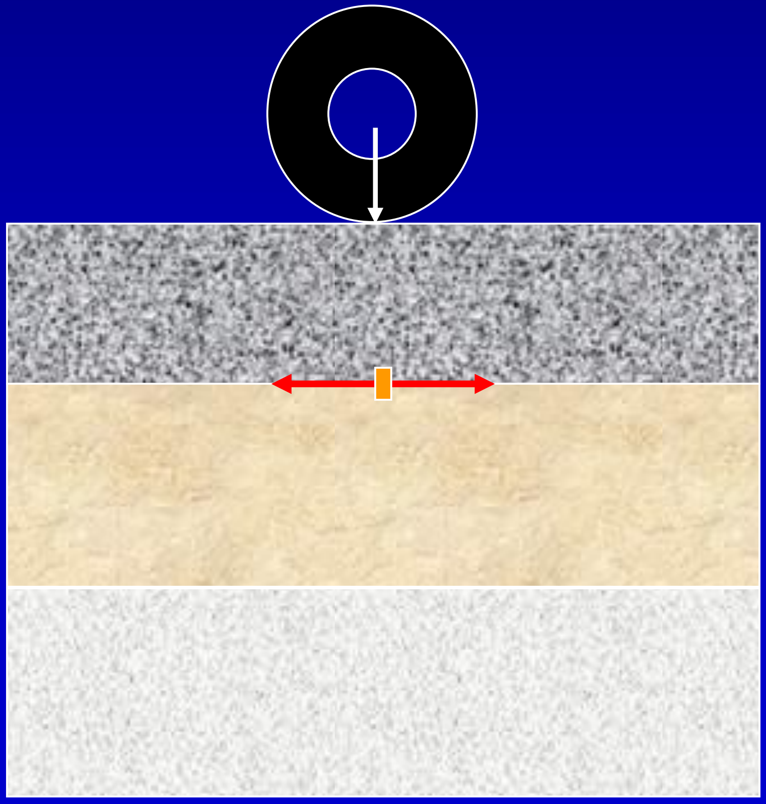
AASHTO TP 8-94

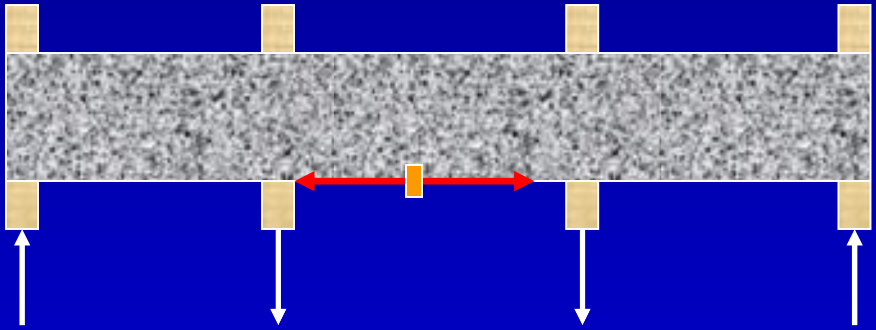
Standard Test Method for Determination of the Fatigue Life of Compacted HMA Subjected to Repeated Flexural Bending

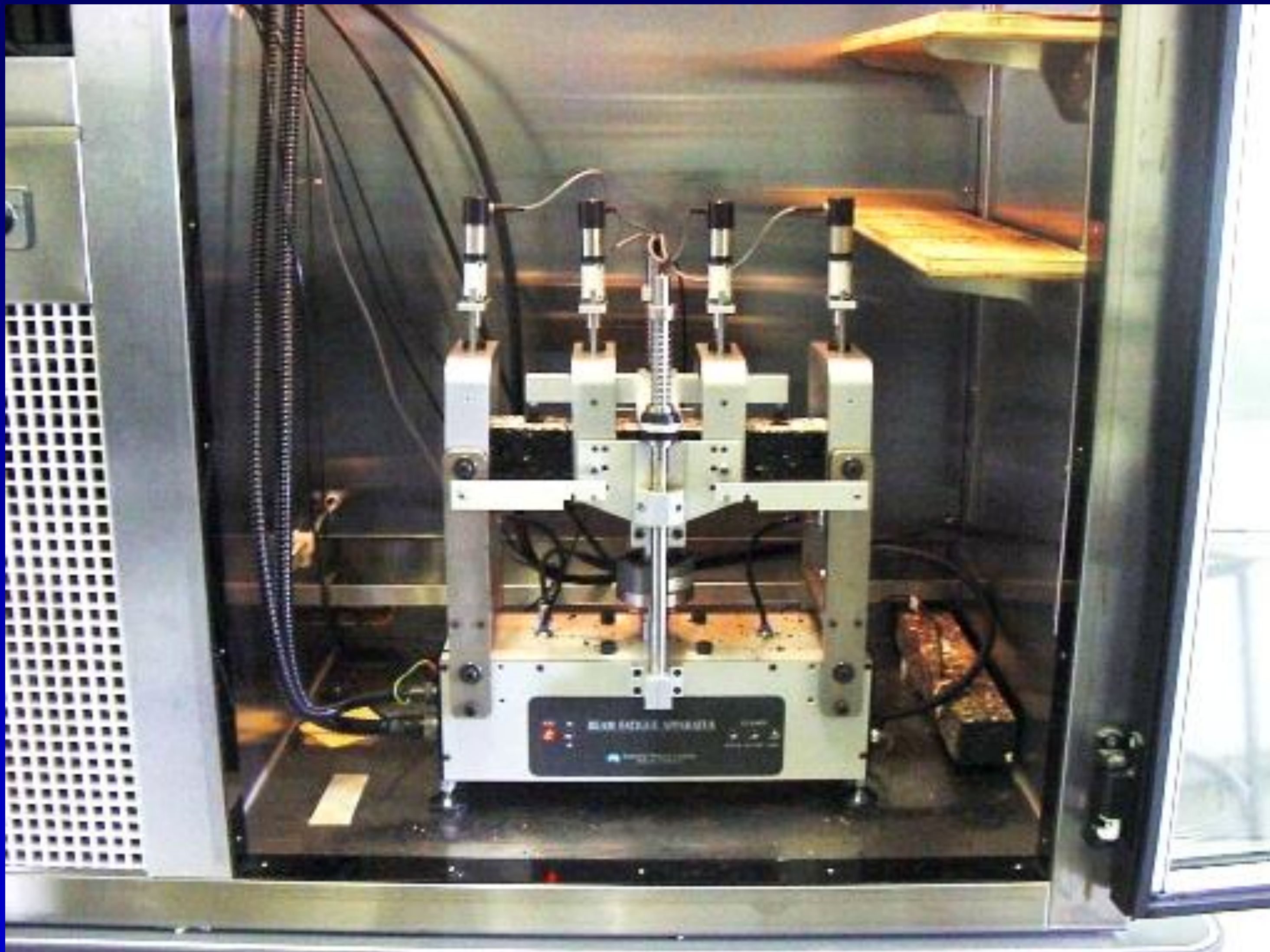
FATIGUE DESIGN

- **Tensile Strain at Bottom of Asphalt**
- **Tensile Strain in Flexural Beam Test**

Other Configurations

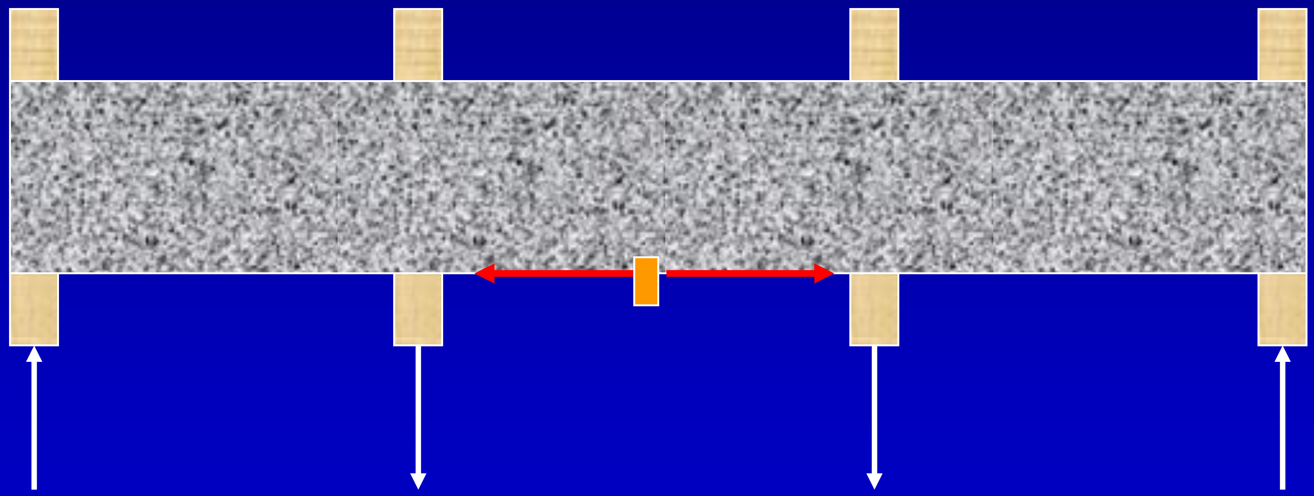






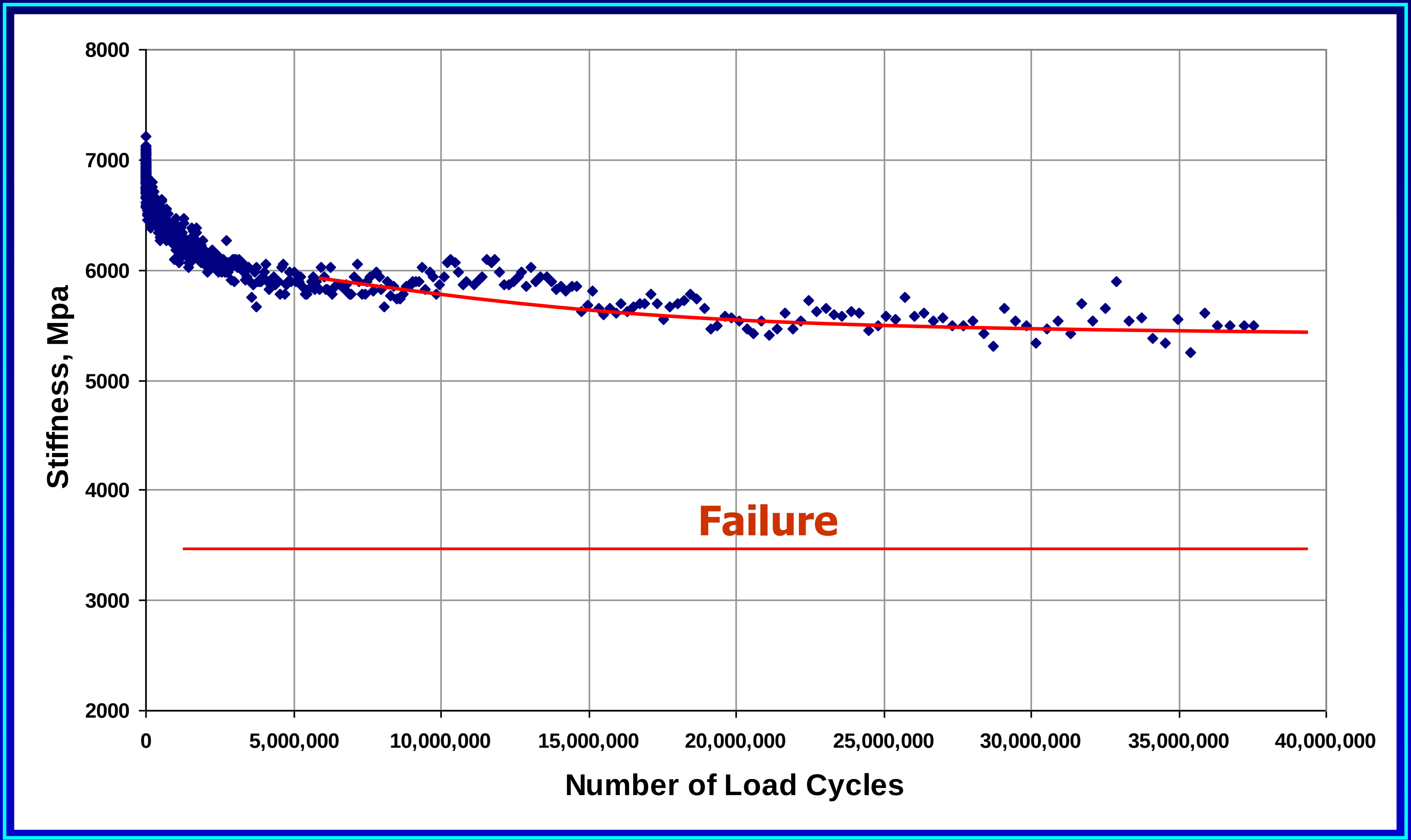
FATIGUE TESTING

- Tensile Strain in Flexural Beam Test
  - Other Configurations



  - 10 Hz Haversine Load, 20º C, Controlled Strain

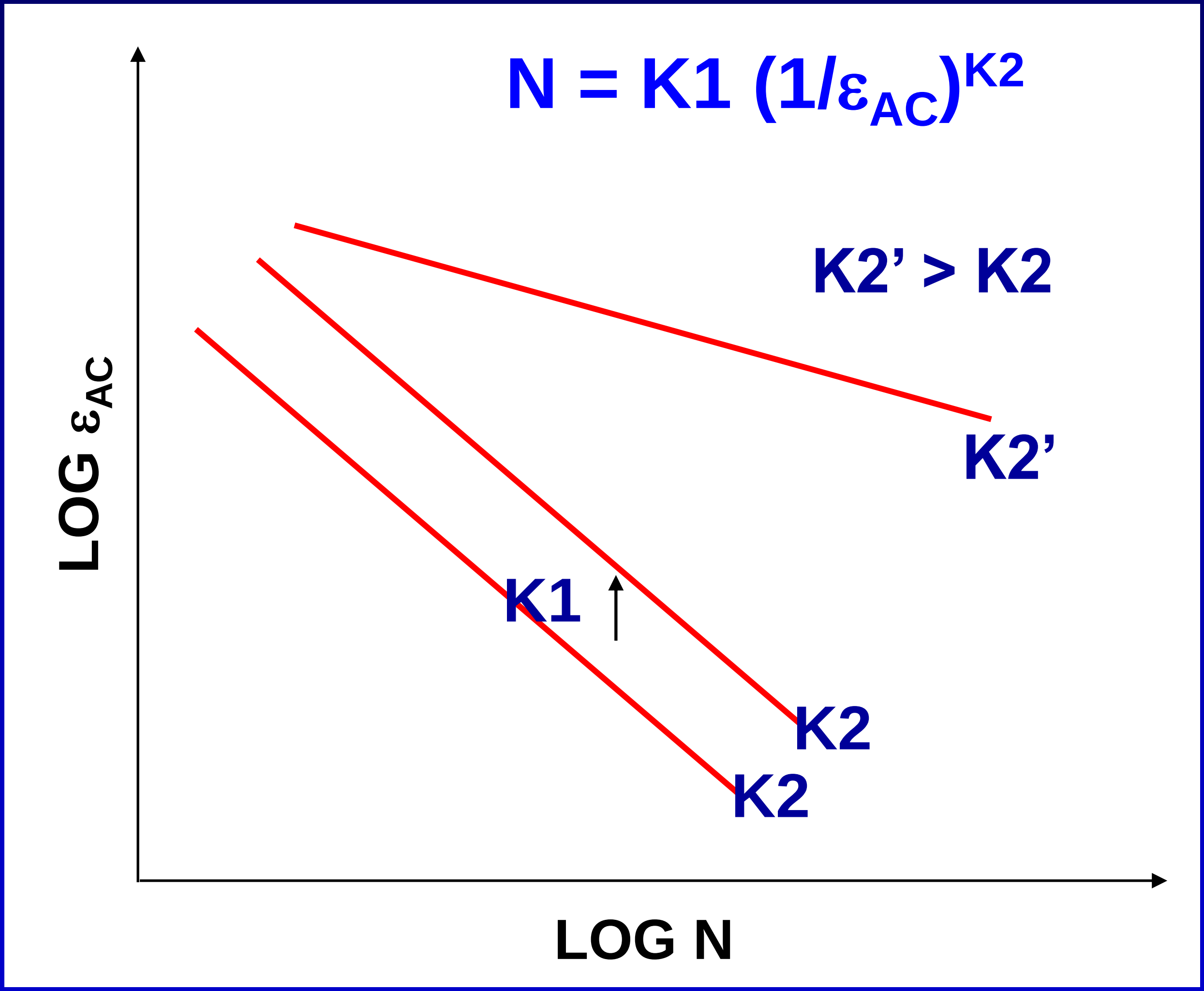
STIFFNESS CURVE



FATIGUE ALGORITHMS

$$N_f = K1(1/\varepsilon)^{K2}$$

AC FATIGUE



IDOT HMA FATIGUE (CARPENTER) DATA SUMMARY 84 MIXES

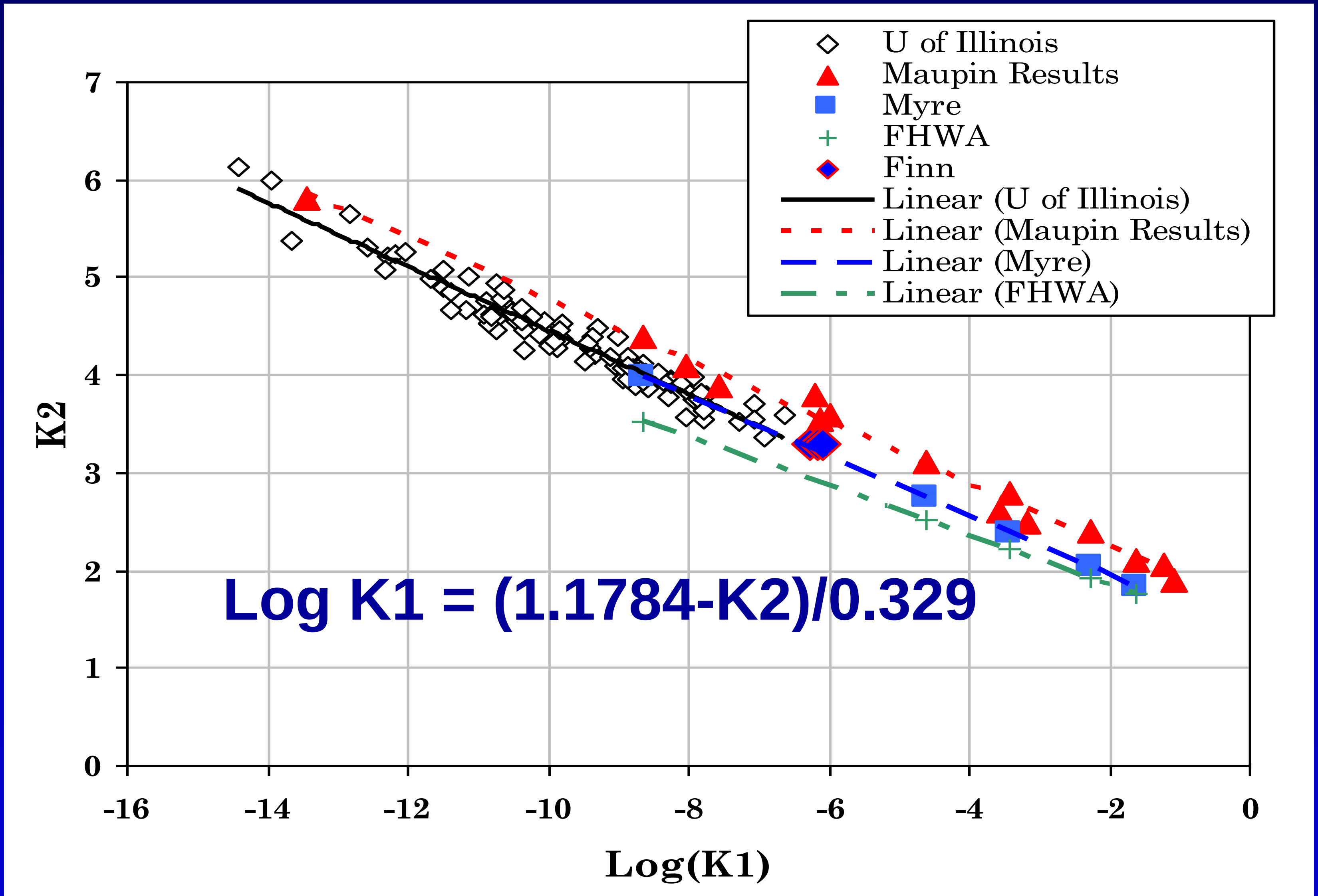
$$N = K1\,(1/\varepsilon)^{K2}$$

Minimum K2: 3.5

90% K2: 4.0

Average K2: 4.5

OTHER STUDIES



THERE IS

NO “UNIQUE”

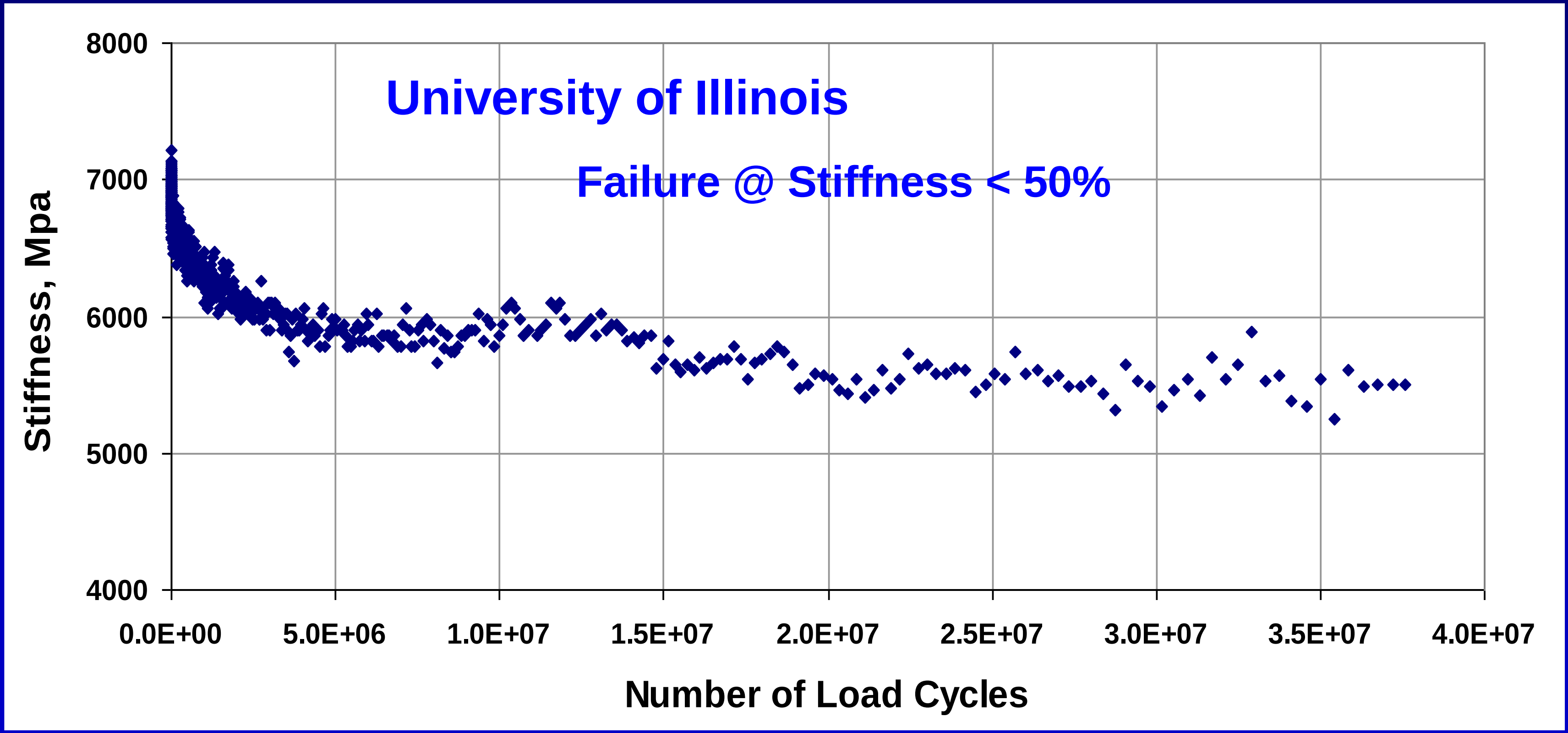
HMA FATIGUE ALGORITHM !!!!

FATIGUE ENDURANCE LIMIT

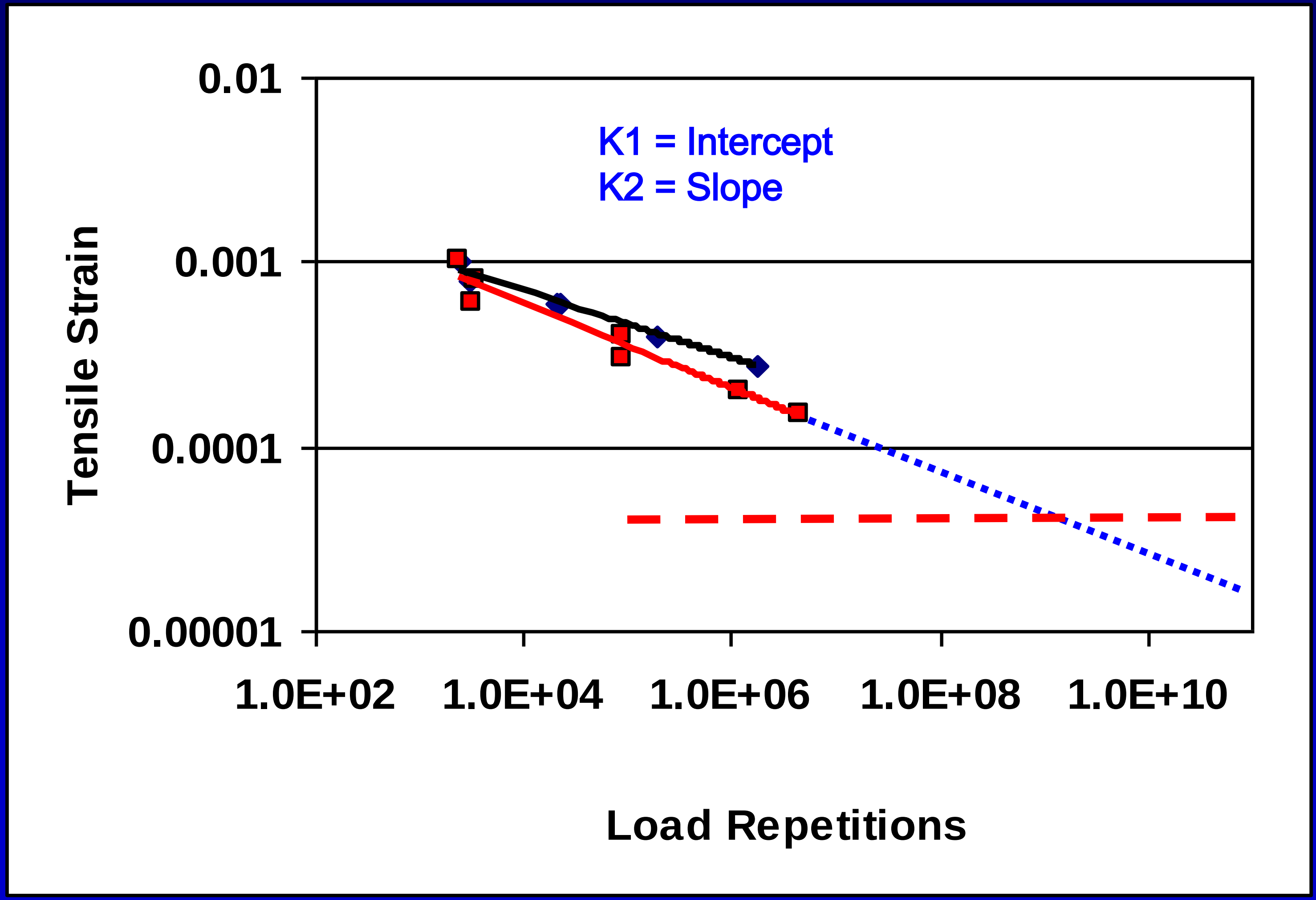
FEL

U of I
HMA FATIGUE R&D
Carpenter-Ghuzlan-Shen
University of IL @ U-C

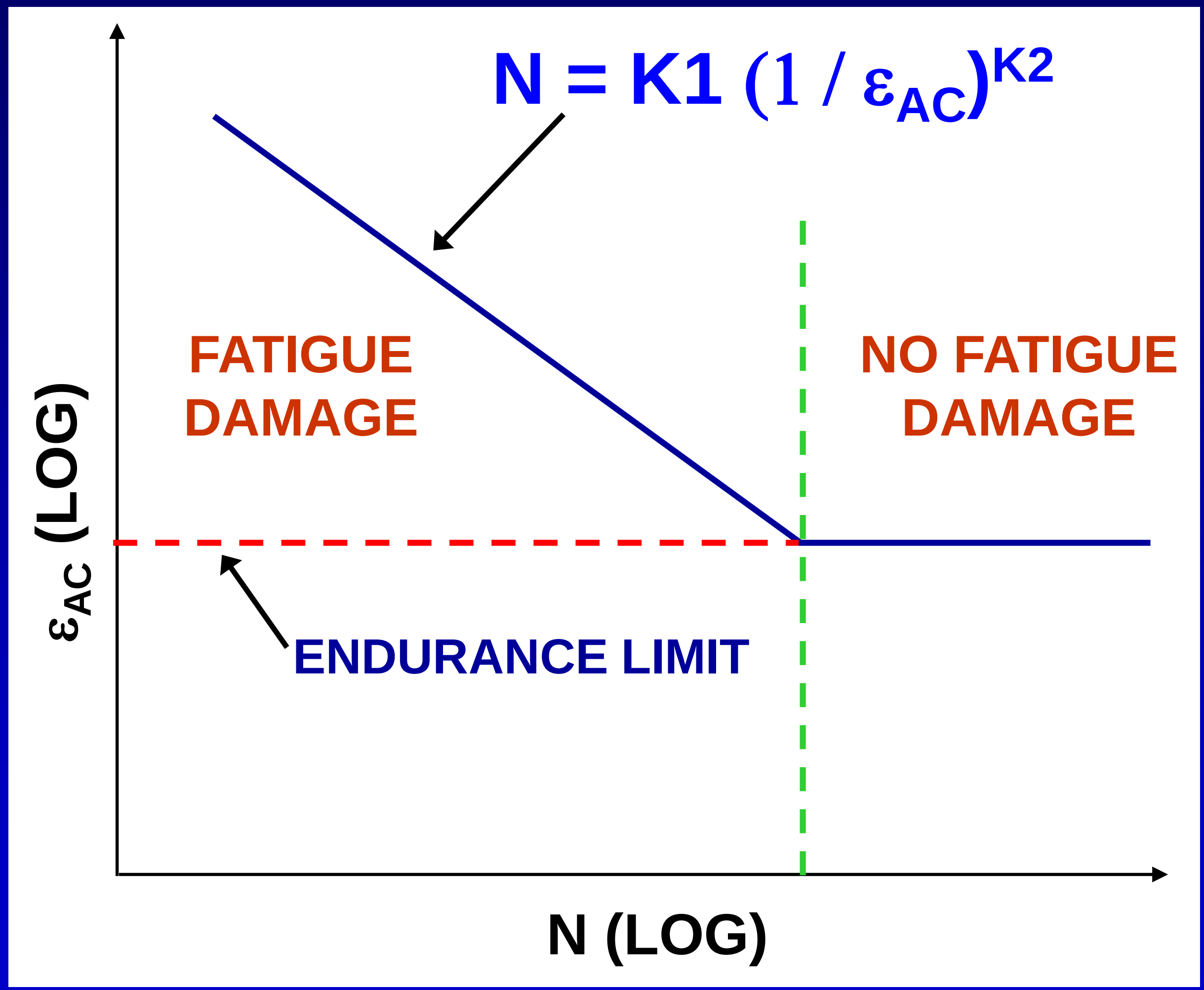
70 Micro Strain Test



FATIGUE ENDURANCE LIMIT



HMA FATIGUE



$N = K1\,(1/\varepsilon_{AC})^{K2}$
FATIGUE DAMAGE
NO FATIGUE DAMAGE
ENDURANCE LIMIT
ε_{AC} (LOG)
N (LOG)

FATIGUE ENDURANCE LIMIT

* Damage and Healing Concepts and Test Data Support a Strain Limit (the FEL) Below Which Fatigue Damage Does Not Accumulate

- FEL Is Not The Same for All HMAs.

- Carpenter – UofI

  21 HMAs / Range: 90 – 300 / AVG: 125

IDOT - PP DESIGN PROCEDURE

- THOMPSON: ILLI-PAVE
- CARPENTER: HMA FATIGUE

“Design Principles for Long Lasting HMA Pavements”

Thompson & Carpenter

ISAP Symposium
Design & Construction of
Long Lasting Asphalt Pavements

Auburn, AL
June -2004

DESIGN CONDITIONS

+ HIGHEST MMPT

+ HMA STRAIN < FEL

* VERY LIMITED “HEAVY” WHEEL LOADS INCURRED DURING LAST HALF OF JULY (CRITICAL PERIOD)!!!

* HMA CAN SUSTAIN STRAINS > FEL; INSIGNIFICANT FATIGUE DAMAGE

FEL BEHAVIOR IS RETAINED!!!!

HMA STRAIN PREDICTION

STRUCTURAL MODEL

ILLI-PAVE

ILLI-PAVE INPUTS

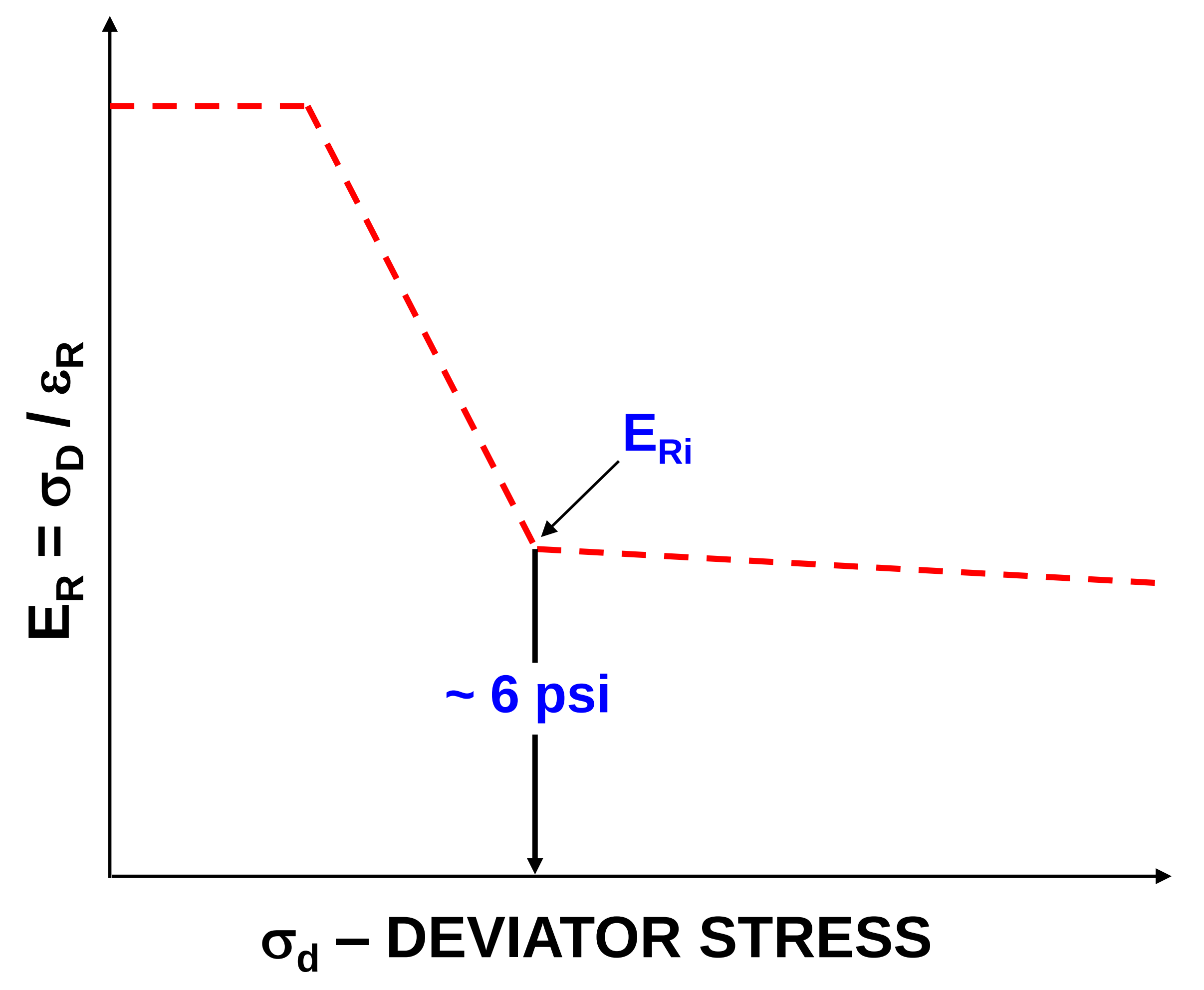
+ SUBGRADE MODULUS (E_{Ri})

+ HMA MODULUS

+ HMA THICKNESS

+ WHEEL LOAD(S)

FINE - GRAINED



MODULUS CLASSES
FINE-GRAINED SOILS

SOIL	E_{Ri} (ksi)	Qu (psi)	CBR
STIFF	12.3	33	8
MEDIUM	7.7	23	5
SOFT	3.0	13	2
VERY SOFT	1.0	6	1

E_{Ri} (ksi) = 0.42 Qu (psi) - 2

HMA MODULUS

HOT MIX ASPHALT

LINEAR ELASTIC (E)

$E = f$ (Temp & Freq)

ASPHALT INSTITUTE EQUATION

$E_{HMA} = f(X_1, X_2, X_n)$

P_{200} = % - # 200

V_V = % AIR VOIDS

$\eta_{70\ F}$ = ABSOLUTE VISCOSITY (poises x 10^6)

P_{AC} = % ASPHALT (wt. of mix)

t_p = TEMPERATURE (°F)

f = FREQUENCY (Hz)

TYPICAL HMA MODULUS-TEMPERATURE

HMA E - TEMPERATURE RELATIONS

LOG E = A – B*TEMPERATURE

HMA MODULI (TAI)
19-MM SP HMA
5%-#200 / 4% AV
4.8% Asphalt / f = 10 Hz

E_{HMA} – ksi   T – HMA Temp (F)

PG 64-22

$$\text{Log } E_{HMA} = 4.265 - 0.019\,T$$

PG 70-22

$$\text{Log } E_{HMA} = 4.307 - 0.018\,T$$

SEASONAL EFFECTS

- **HMA MODULUS VARIES !!**
- **HMA ε VARIES !!**
- **HMA FATIGUE LIFE VARIES !!**

MUST CONSIDER IN M-E DESIGN

ENHANCED INTEGRATED CLIMATIC MODEL

(Dempsey – Uof IL)
(AASHTO MEPDG)

TEMPERATURE PREDICTION ASPHALT INSTITUTE PROCEDURE

$$MMPT\ (^{o}F) = MMAT\ [1 + (1 / \{Z + 4\})] - [34 / \{Z + 4\}] + 6$$

Z: INCHES FROM SURFACE

CHAMPAIGN, IL		
MONTH	**MMAT (°F)**	**MMPT (°F)**
JAN	27.1	32.5/30.4
FEB	33.0	39.1/37.9
MAR	40.6	47.8/46.6
APR	51.2	58.9/59.5
MAY	62.5	72.0/73.9
JUN	72.0	83.4/82.9
JUL	74.7	86.5/84.9
AUG	72.8	84.3/82.3
SEP	65.8	76.4/74.1
OCT	54.7	63.7/62.5
NOV	41.8	49.1/46.8
DEC	32.4	38.5/38.0

ICM/AI

JULY MMPT (˚F) / HMA MODULUS (ksi)

ILLINOIS DATA

NORTH - 83.3 / 480

CENTRAL - 86.6 / 415

SOUTH - 89 / 375

PG 64-22 / 19 mm SP

PG GRADE EFFECTS

TEMP (°F)	HMA MODULUS (ksi) 64-22	HMA MODULUS (ksi) 70-22
70	910	1160
75	765	975
80	640	815
85	530	675
90	435	550

Asphalt: 3.5 %   AV: 4 %
- # 200: 3 %   f = 10 hz

AXLE LOADING

20-Kip Single

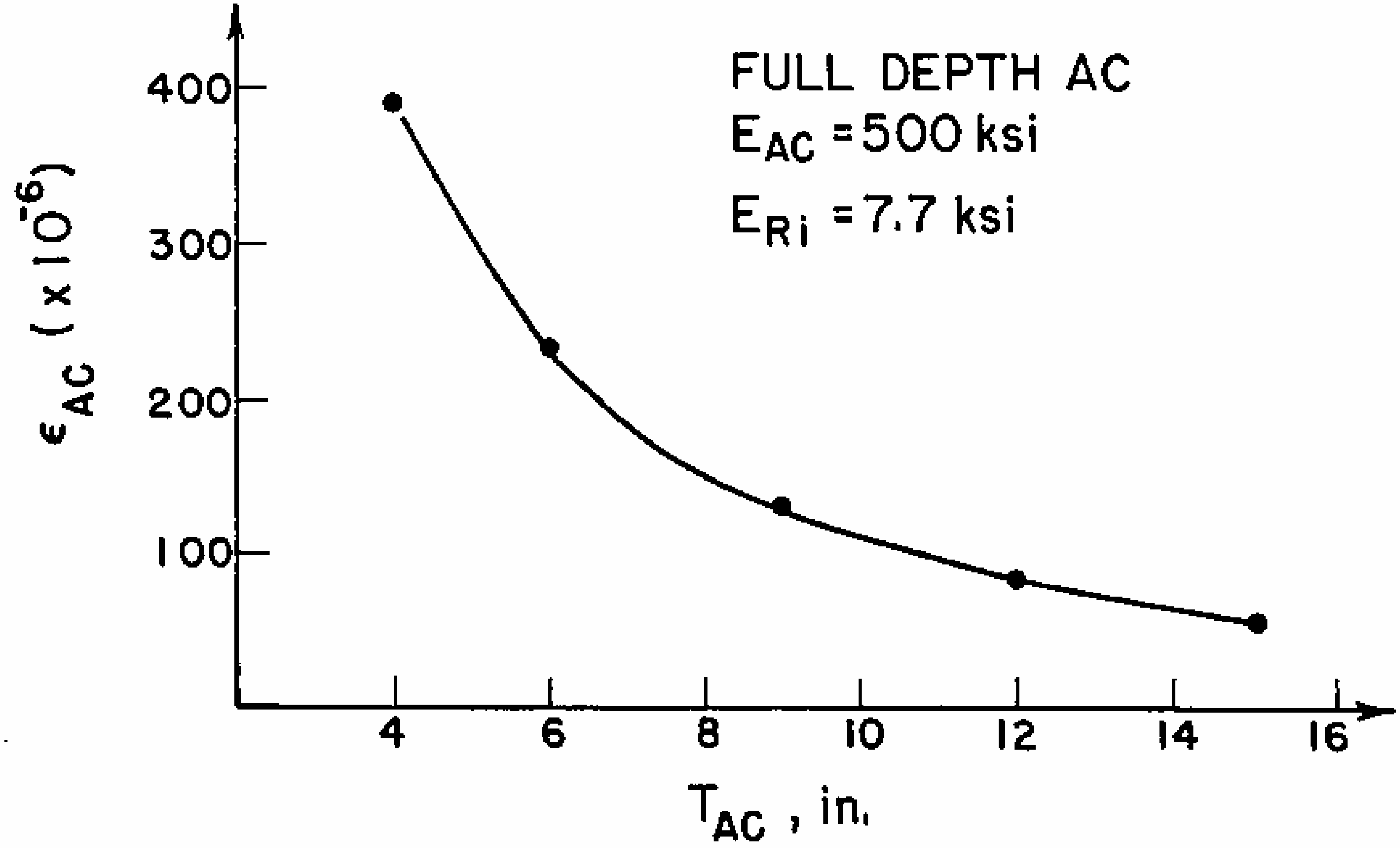
34-kip Dual/Tandem

FULL-DEPTH HMA

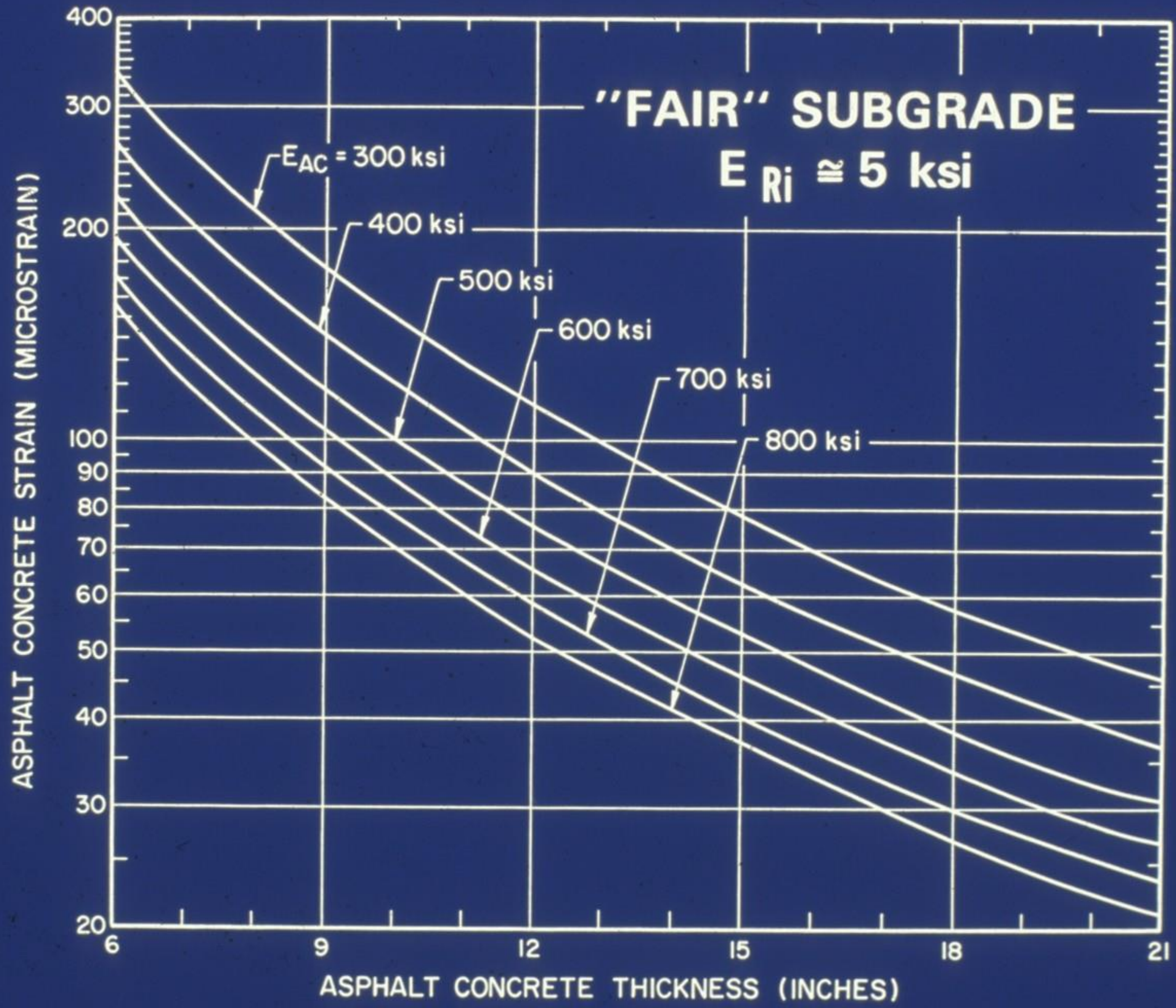
$$\text{LOG } \varepsilon_{HMA} = 5.746 - 1.589 \text{ LOG } T_{HMA}$$

$$- 0.774 \text{ LOG } E_{HMA} - 0.097 \text{ LOG } E_{Ri}$$

ε_{HMAC} : $\mu\varepsilon$ T_{HMA} : in. E_{HMA}:ksi E_{Ri} : ksi



FULL DEPTH AC
E_AC = 500 ksi
E_Ri = 7.7 ksi
ε_AC (x 10^-6)
400
300
200
100
4
6
8
10
12
14
16
T_AC , in.


"FAIR" SUBGRADE
$E_{Ri} \cong 5$ ksi
E_{AC} = 300 ksi
400 ksi
500 ksi
600 ksi
700 ksi
800 ksi
ASPHALT CONCRETE STRAIN (MICROSTRAIN)
400
300
200
100
90
80
70
60
50
40
30
20
6
9
12
15
18
21
ASPHALT CONCRETE THICKNESS (INCHES)

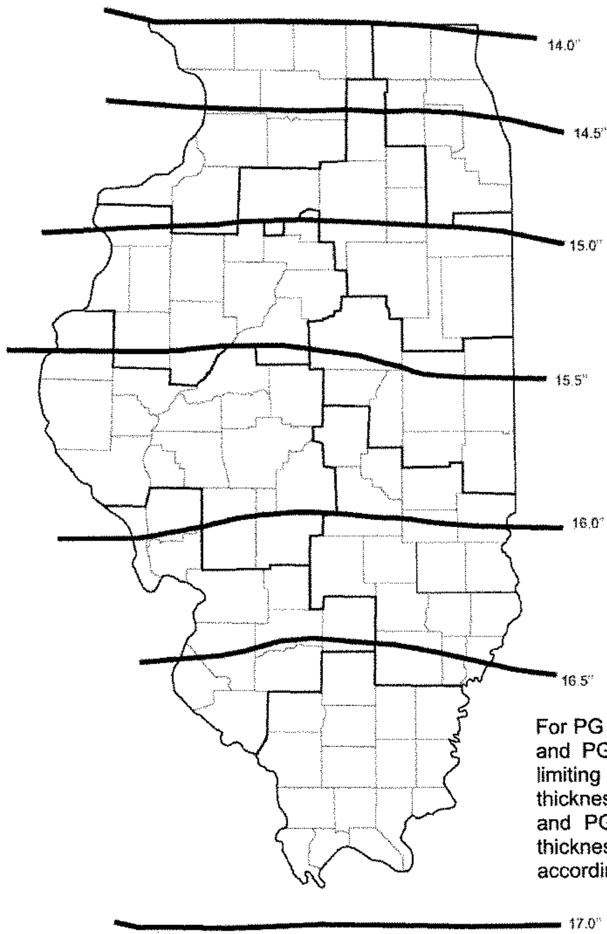
CURRENT IDOT
PP DESIGN
BD&E - Chapter 54
PAVEMENT DESIGN

TYPICAL IL PP

HMA PP

Modified Subgrade
(Cement/Lime)
Aggregate

Subgrade

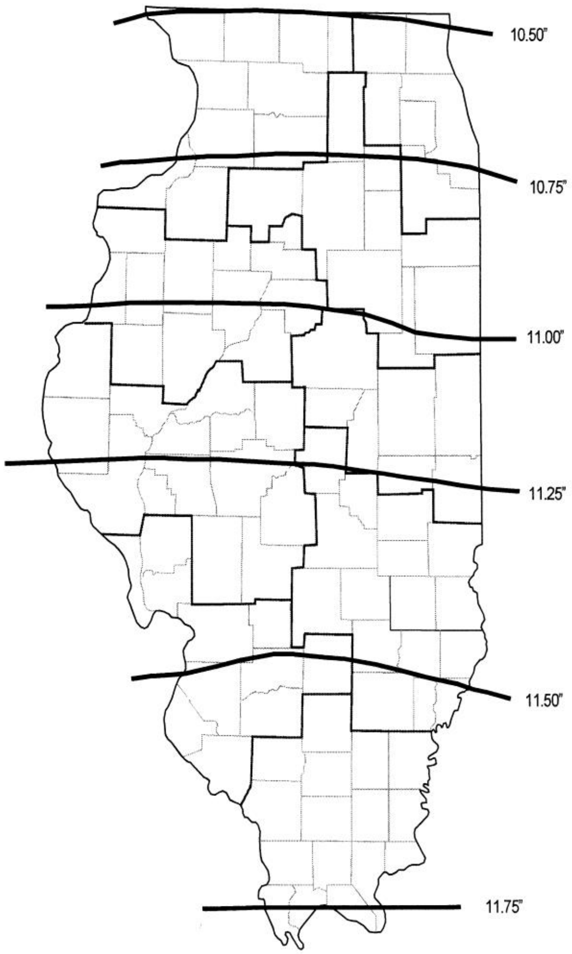


For PG 64-22, PG 70-22, PG 76-22, and PG 76-28 binder grades, read limiting strain criterion design thickness off of map. For PG 64-28 and PG 70-28 binder grades, the thickness should be corrected according to Section 54-5.01(i)8a.

Note. Thickness values based upon Mean Monthly Pavement Temperature at 4 in. depth correlated to July Mean Monthly Air Temperature, axle load of 20,000 lb, strain of 70 με, and E_{Ri} of 2 ksi.

MAXIMUM PAVEMENT THICKNESS
(Limiting Strain Criterion Design: Flexible Pavement)

Figure 54-5.I



For PG 64-22, PG 70-22, PG 76-22, and PG 76-28 binder grades, read limiting strain criterion design thickness off of map. For PG 64-28 and PG 70-28 binder grades, the thickness should be corrected according to Section 54-5.03(c)4a.

Note. Thickness values based upon Mean Monthly Pavement Temperature at 4 in. depth correlated to July Mean Monthly Air Temperature, axle load of 20,000 lb, strain of 70 με.

MAXIMUM PAVEMENT THICKNESS
(Limiting Strain Criterion Design: HMA Overlay of Rubblized PCC Pavement)

Figure 54-5.V

FEL IMPACTS

HMA MODULUS (ksi)	E_{Ri} (2 ksi)	E_{Ri} (5 ksi)	E_{Ri} (7.5 ksi)	E_{Ri} (10 ksi)
300	17.1* 15.1**	16.1 14.3	15.7 13.9	15.5 13.7
400	14.8 13.1	14.0 12.4	13.7 12.1	13.4 11.9
500	13.3 11.8	12.6 11.1	12.3 10.9`	12.0 10.7
600	12.2 10.8	11.5 10.2	11.2 9.9	11.1 9.8
700	11.3 10.0	10.7 9.5	10.4 9.2	10.2 9.1

* 70 M-STRAIN ** 85 M-STRAIN 18 K SAL

$$$$$$

1-inch HMA = 400 tons / Lane-Mile

$ / Ton HMA	$ / Lane-Mile
50	20,000
60	24,000
70	28,000
80	32,000
90	36,000

SUMMARY

- **Lab fatigue data and field performance data support the HMA FEL concept.**

- **The HMA FEL is =/> 70 Micro-Strain**
(FEL probably in 70-100 micro-strain range for typical neat asphalts and HMAs)

- **HMA PP thickness is very sensitive to FEL**
(10 micro-strain ~ 1 INCH HMA!!)

FEL = ??????

CURRENT NCHRP RESEARCH

NCHRP 9-38
Endurance Limit of HMA for Preventing Fatigue Cracking in Flexible Pavements (2010 – NCAT/AUBURN - RAY BROWN) (Carpenter - UI participated)

NCHRP 9-44
Developing a Plan for Validating an Endurance Limit for HMA Pavements (AAT- BONAQUIST - Completed)

NCHRP 9-44A

Validating an Endurance Limit for HMA Pavements: Laboratory Experiment and Algorithm Development
(ASU – WITCZAK- Completed)

NCHRP 9-59

Relating Asphalt Binder Fatigue properties tp Asphalt Mixture Fatigue Performance
***(AAT - CHRISTENSEN - 2-28-19)**

STANDARD PAVING OPERATIONS

HMA PERFORMANCE

IDOT PRR No. 165 (Oct. 2016)

"2012 – 2015 Performance Monitoring of Mechanistically-Designed Pavements"

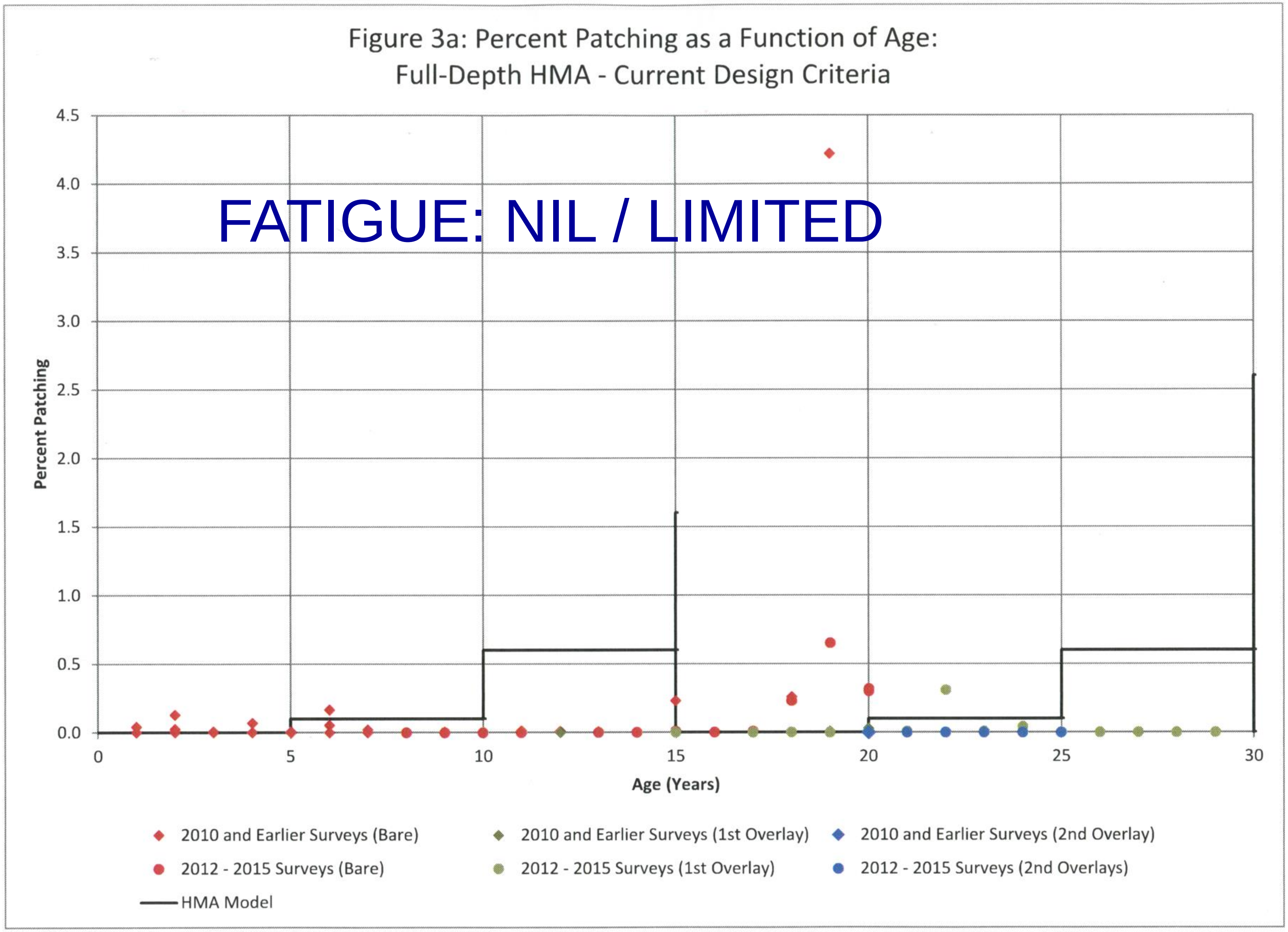


Figure 3a: Percent Patching as a Function of Age:
Full-Depth HMA - Current Design Criteria
FATIGUE: NIL / LIMITED
Percent Patching
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
Age (Years)
2010 and Earlier Surveys (Bare)
2010 and Earlier Surveys (1st Overlay)
2010 and Earlier Surveys (2nd Overlay)
2012 - 2015 Surveys (Bare)
2012 - 2015 Surveys (1st Overlay)
2012 - 2015 Surveys (2nd Overlays)
HMA Model

SURFACE DISTRESSES

RUTTING: < 0.1 - 0.2 INS

C/L CRACKING / RAVELING & WEATHERING

LITTLE “CENTER LANE CRACKING”

SOME LIMITED “BLOCK CRACKING”

PP WORKS !!!

THANKS !!!

????