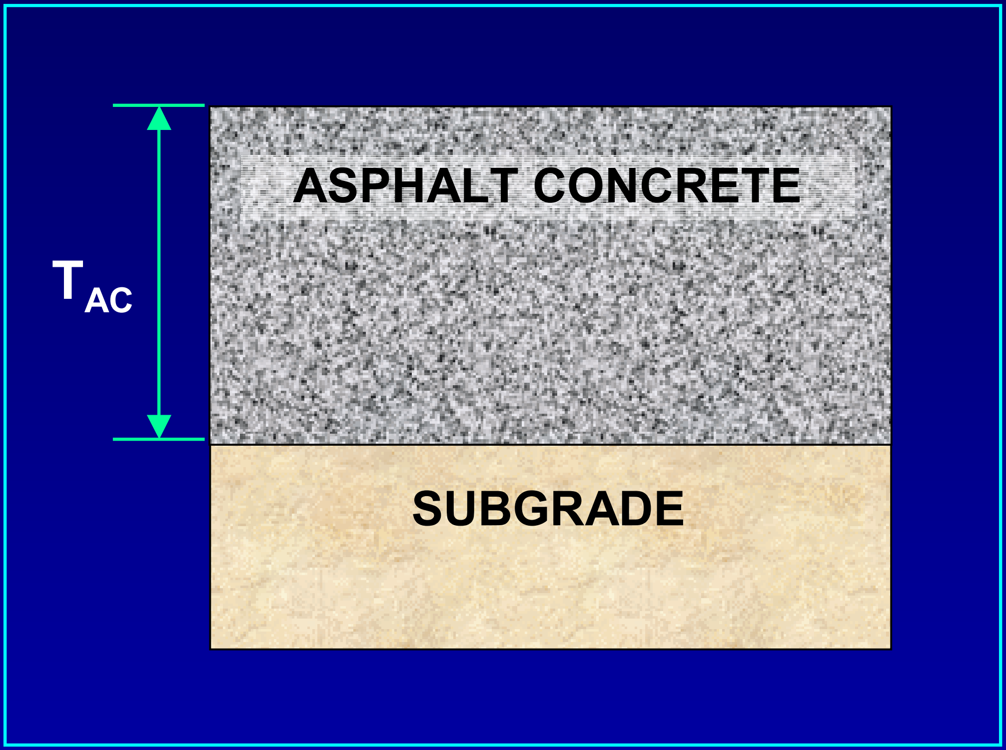
STRUCTURAL DESIGN OF LONG-LIFE ASPHALT PAVEMENTS

Marshall R. Thompson
Professor Emeritus
Department of Civil Engineering
University of Illinois @ U-C

1867



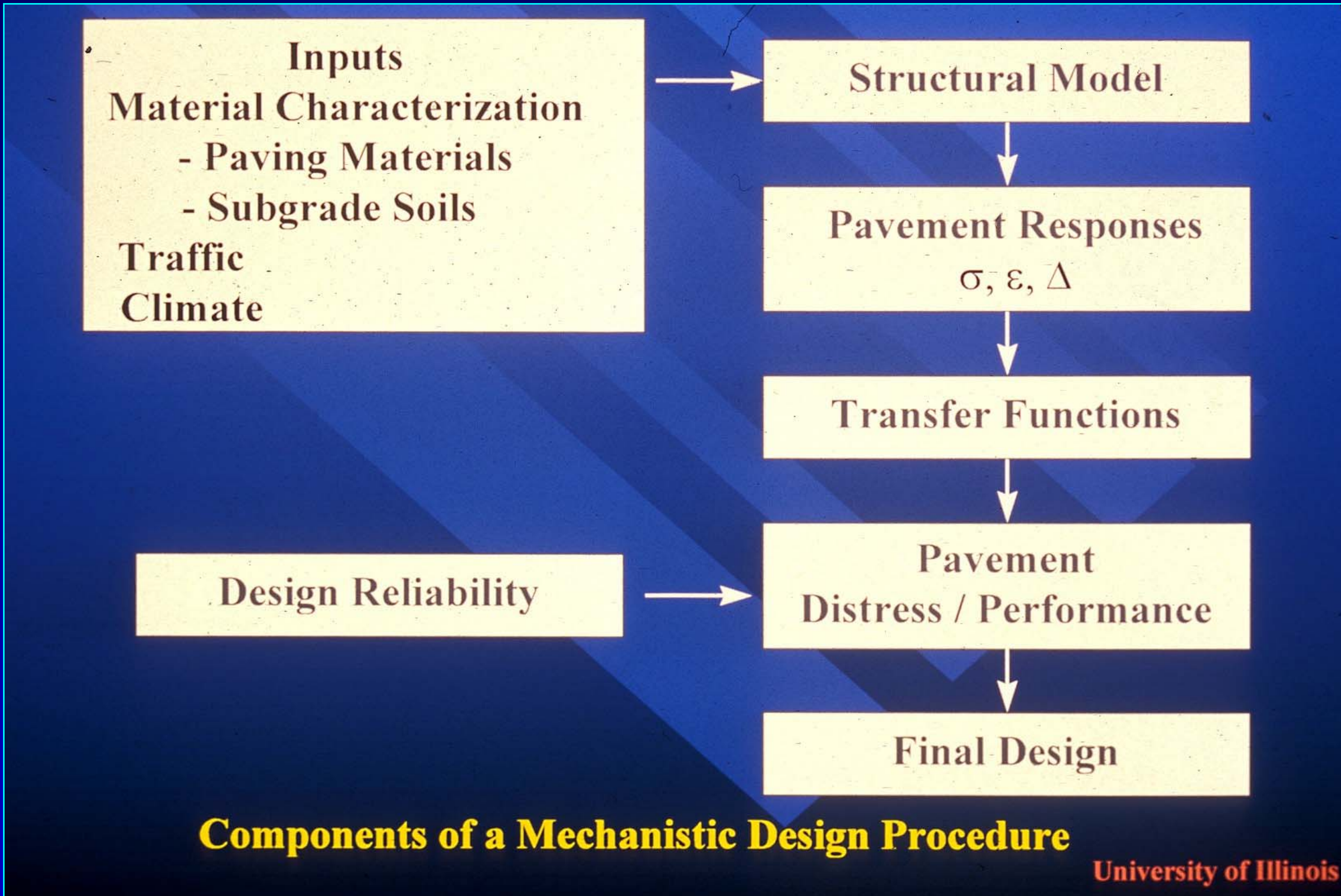
DESIGN

- AC FATIGUE
- AC RUTTING
- SUBGRADE RUTTING

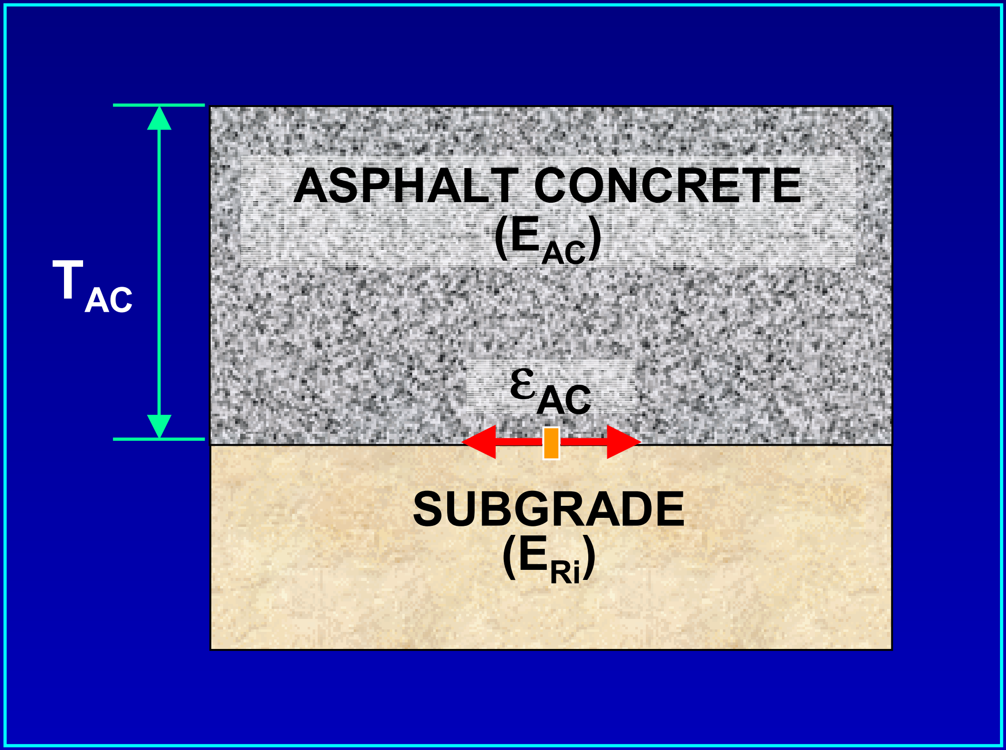
PHILOSOPHY

* "VERY LOW" PROBABILITY OF HMA FATIGUE
* MILL & FILL REHAB

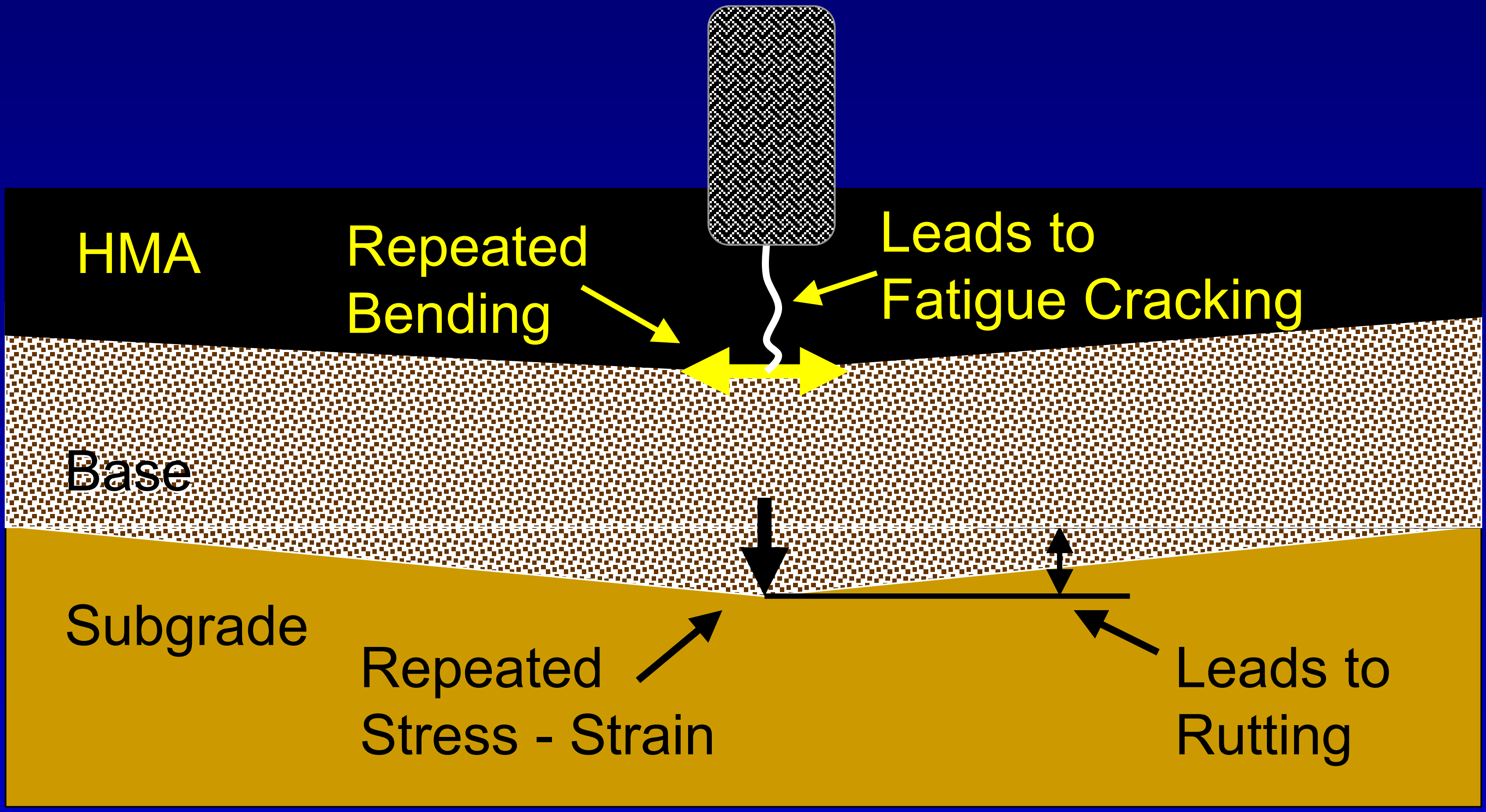
  - RUTTING
  - "SURFACE WEATHERING"
  - "TOP-DOWN" CRACKING


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

FULL-DEPTH AC PAVEMENT



EXTENDED LIFE HMA DESIGN CONCEPTS



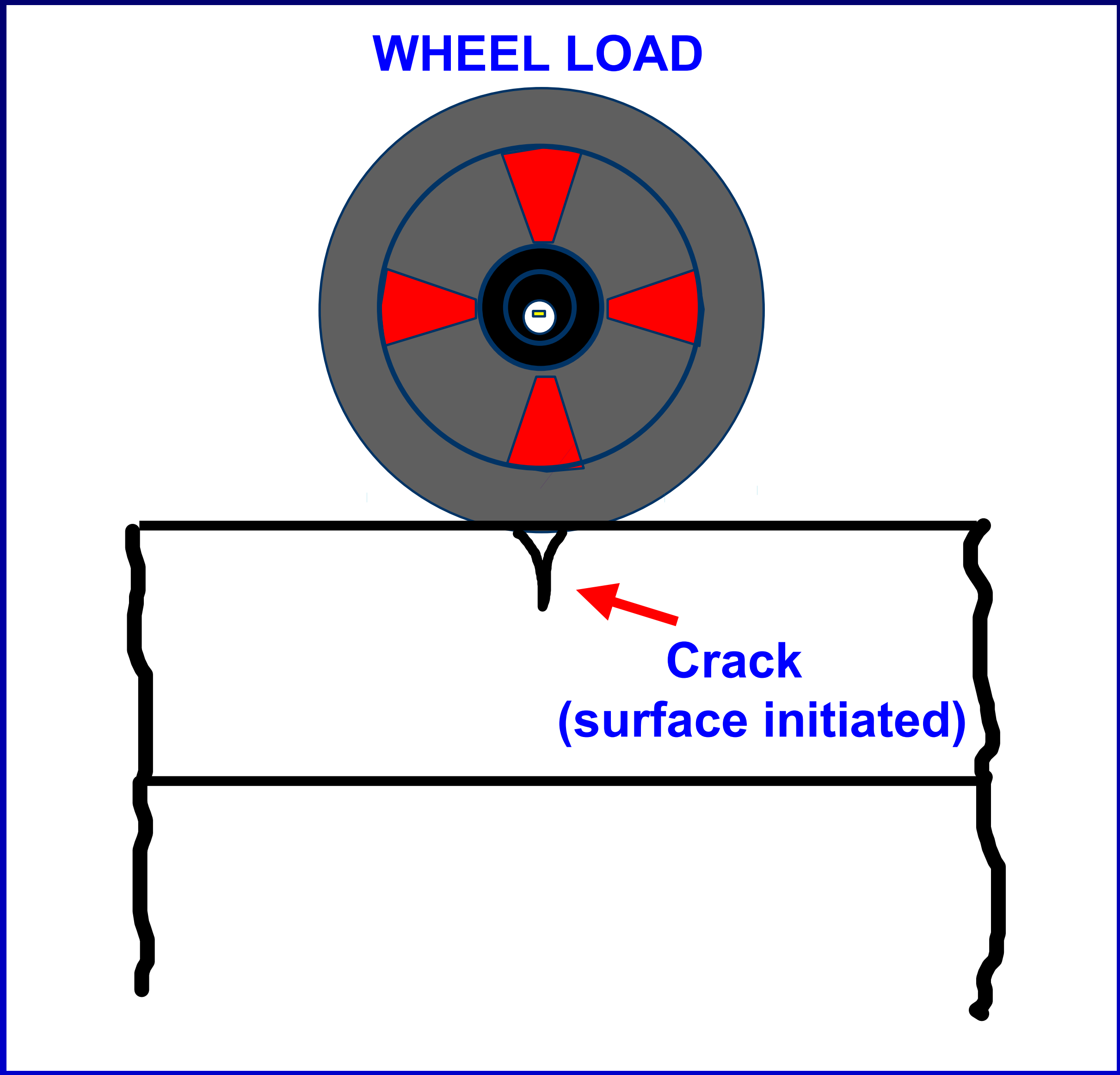
NON-STRUCTURAL RUTTING

TRL

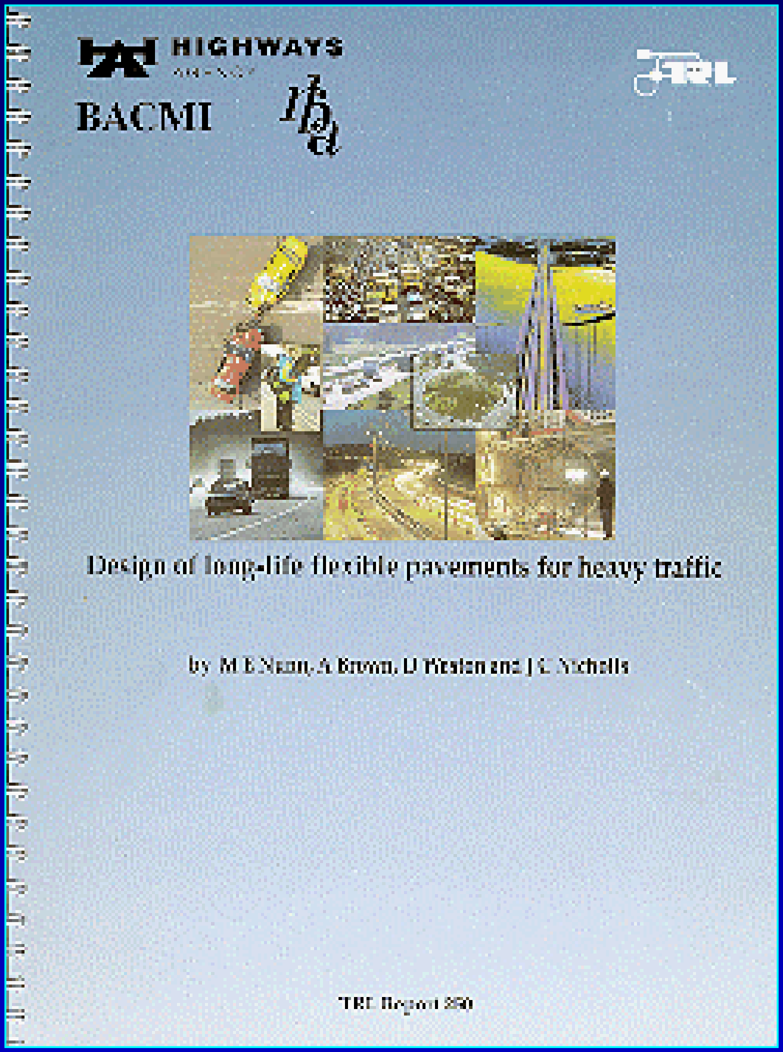

TRL
M32
CORE
M32(S) 9


TRL

TOP-DOWN CRACKING



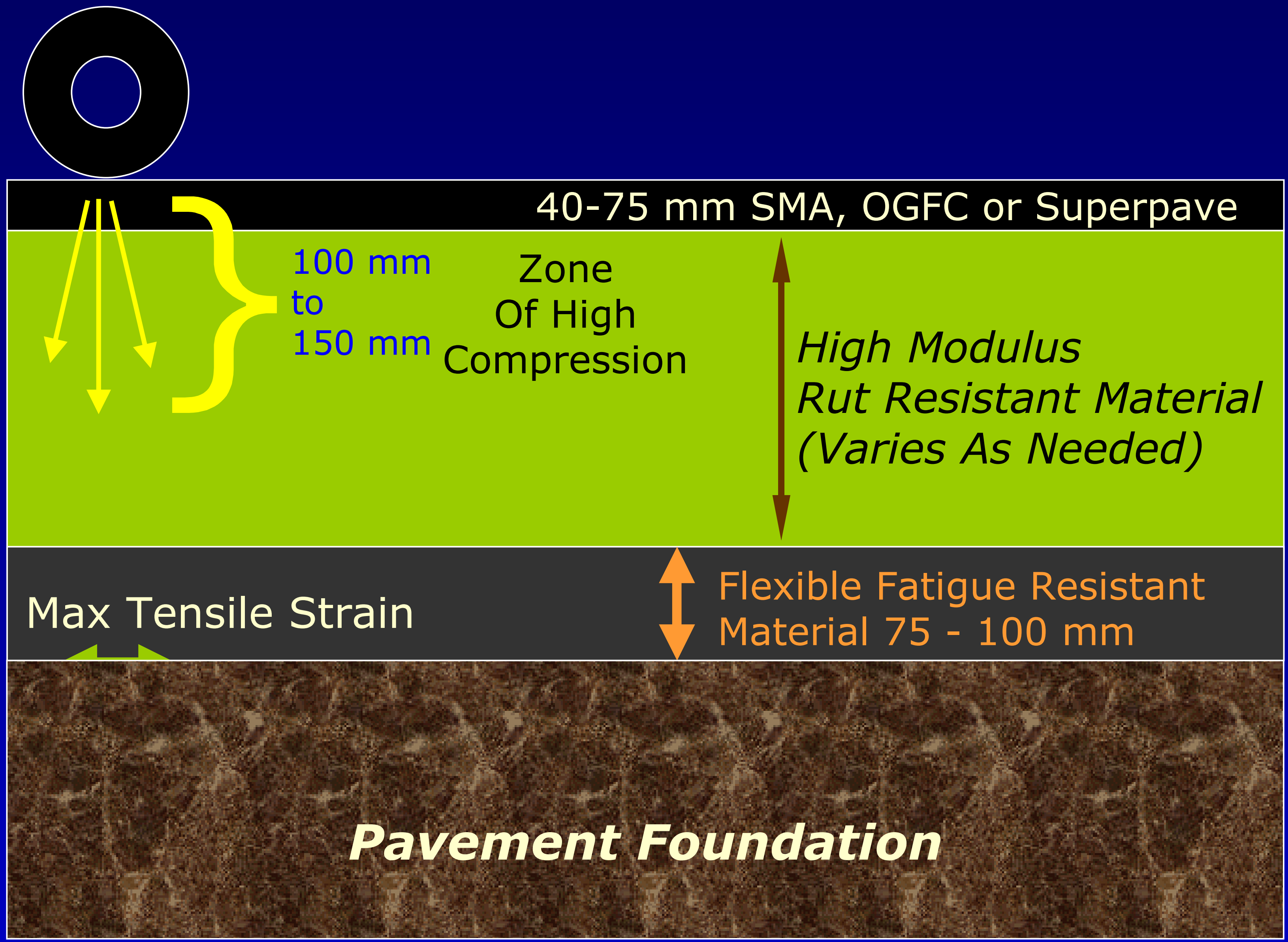
TRL



TRL Report 250
Nunn, Brown, Weston & Nicholls

Design of Long-Life Flexible Pavements for Heavy Traffic

http:\\www.trl.co.uk



40-75 mm SMA, OGFC or Superpave
100 mm to 150 mm
Zone Of High Compression
High Modulus Rut Resistant Material (Varies As Needed)
Max Tensile Strain
Flexible Fatigue Resistant Material 75 - 100 mm
Pavement Foundation

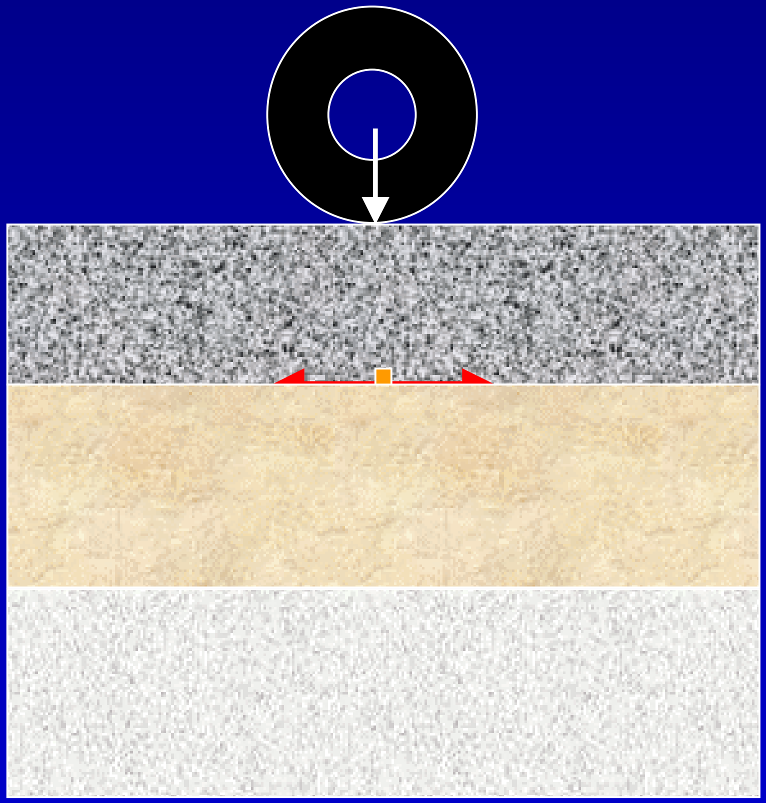
AASHTO TP 8-94

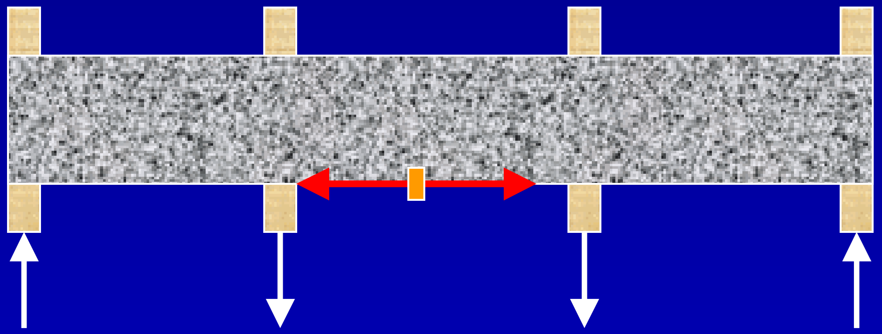
Standard Test Method for Determination of the Fatigue Life of Compacted HMA Subjected to Repeated Flexural Bending

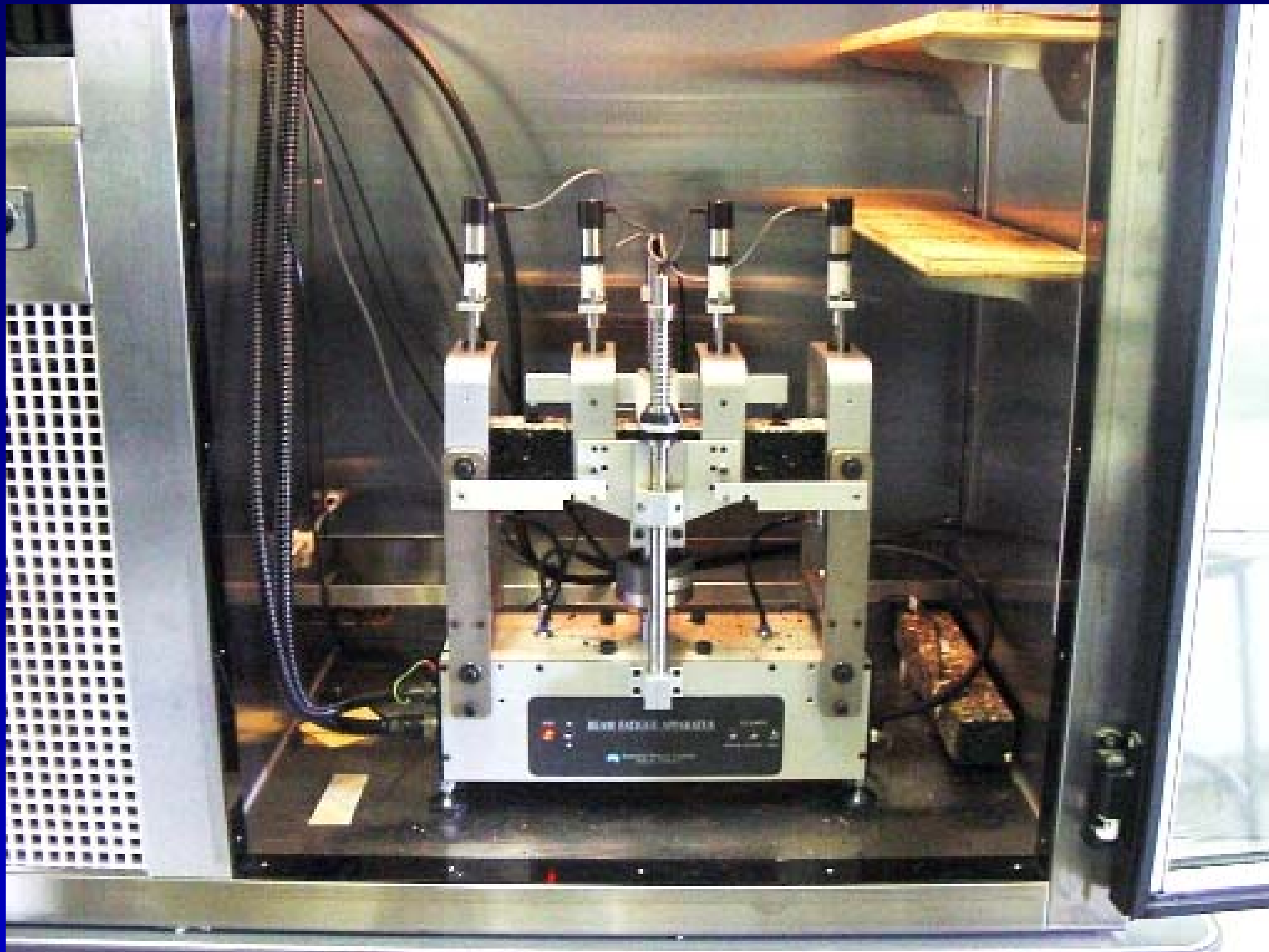
FATIGUE DESIGN

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

Other Configurations

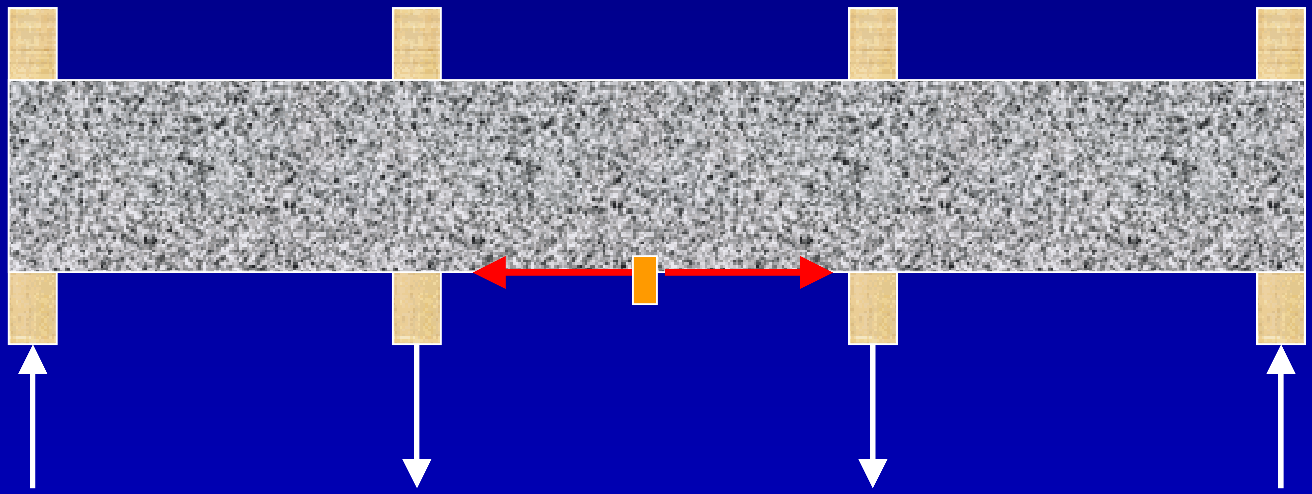






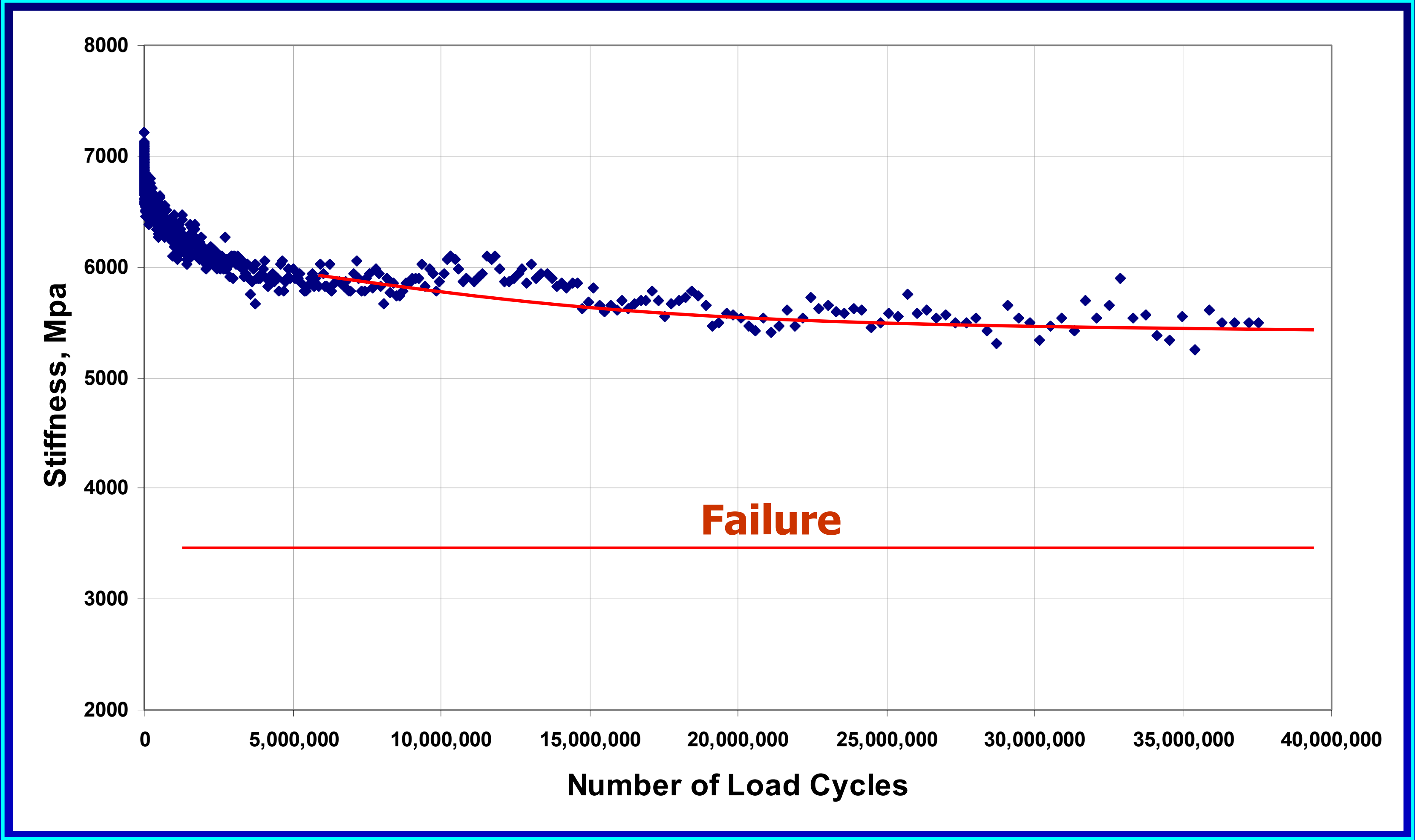
FATIGUE TESTING

- Tensile Strain in Flexural Beam Test
  - Other Configurations

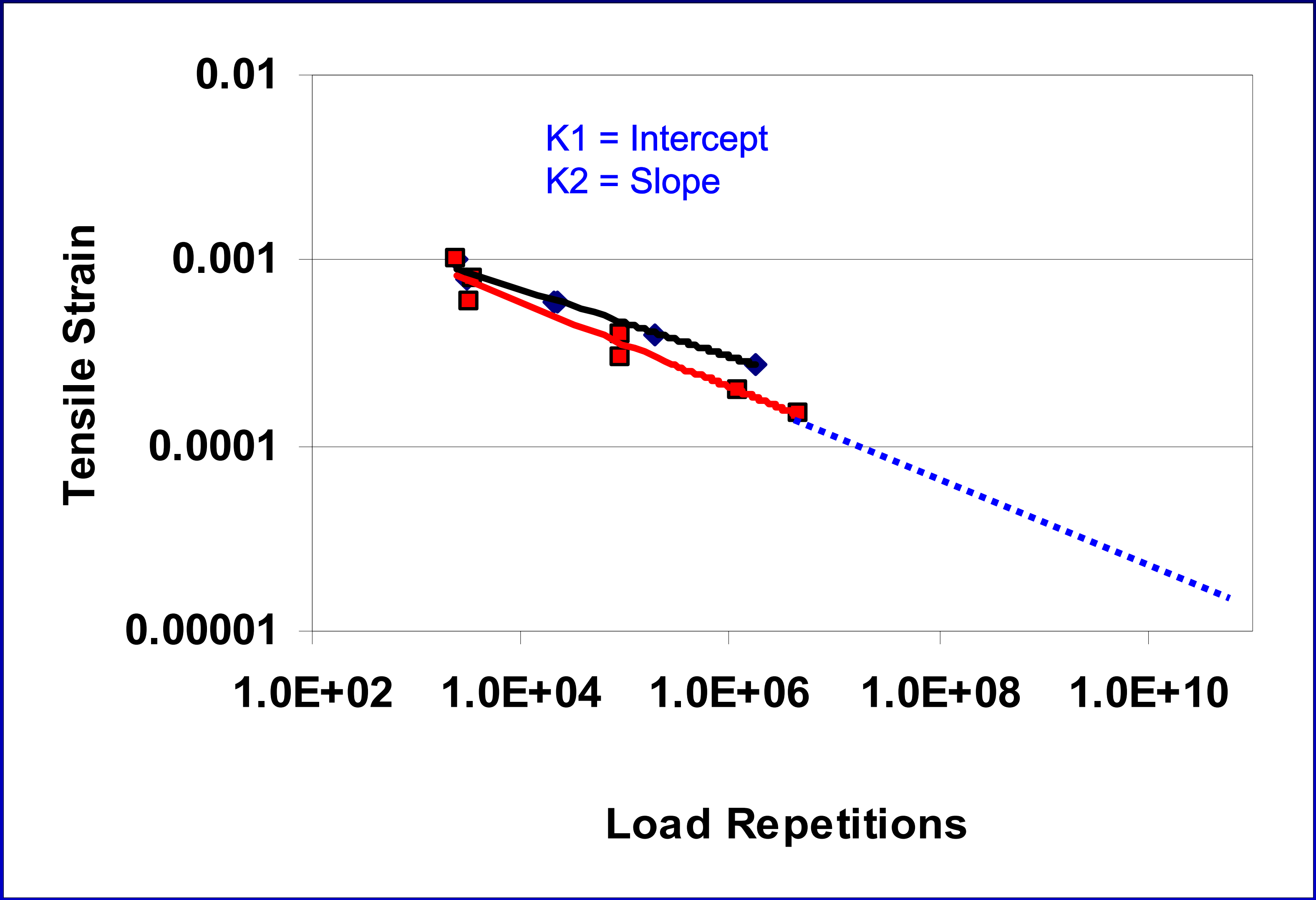


  - 10 Hz Haversine Load, 20° C, Controlled Strain

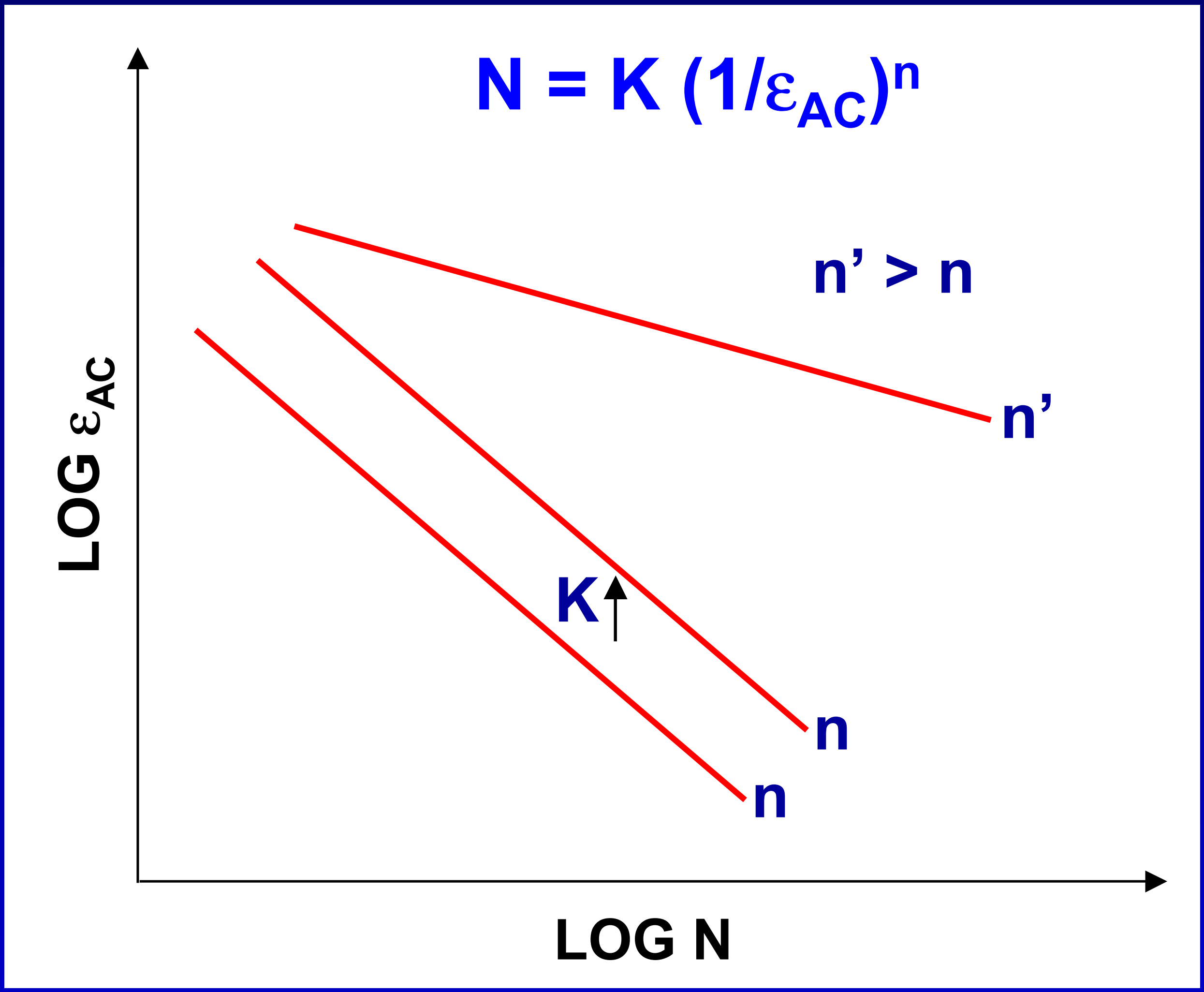
STIFFNESS CURVE



LABORATORY ALGORITHM



AC FATIGUE



FATIGUE ALGORITHM

- $N_f = K1(1/\varepsilon)^{K2}$
- $N_f = K(\varepsilon)^a \ (E^*)^b$
- 2002 Guide Will Have an Algorithm

HMA FATIGUE

$$N = K\,(1 / \varepsilon_{AC})^{n}$$

n : 3.5 - 6

2003 TRB PAPERS
Ghuzlan - Carpenter – Shen
University of IL @ U-C

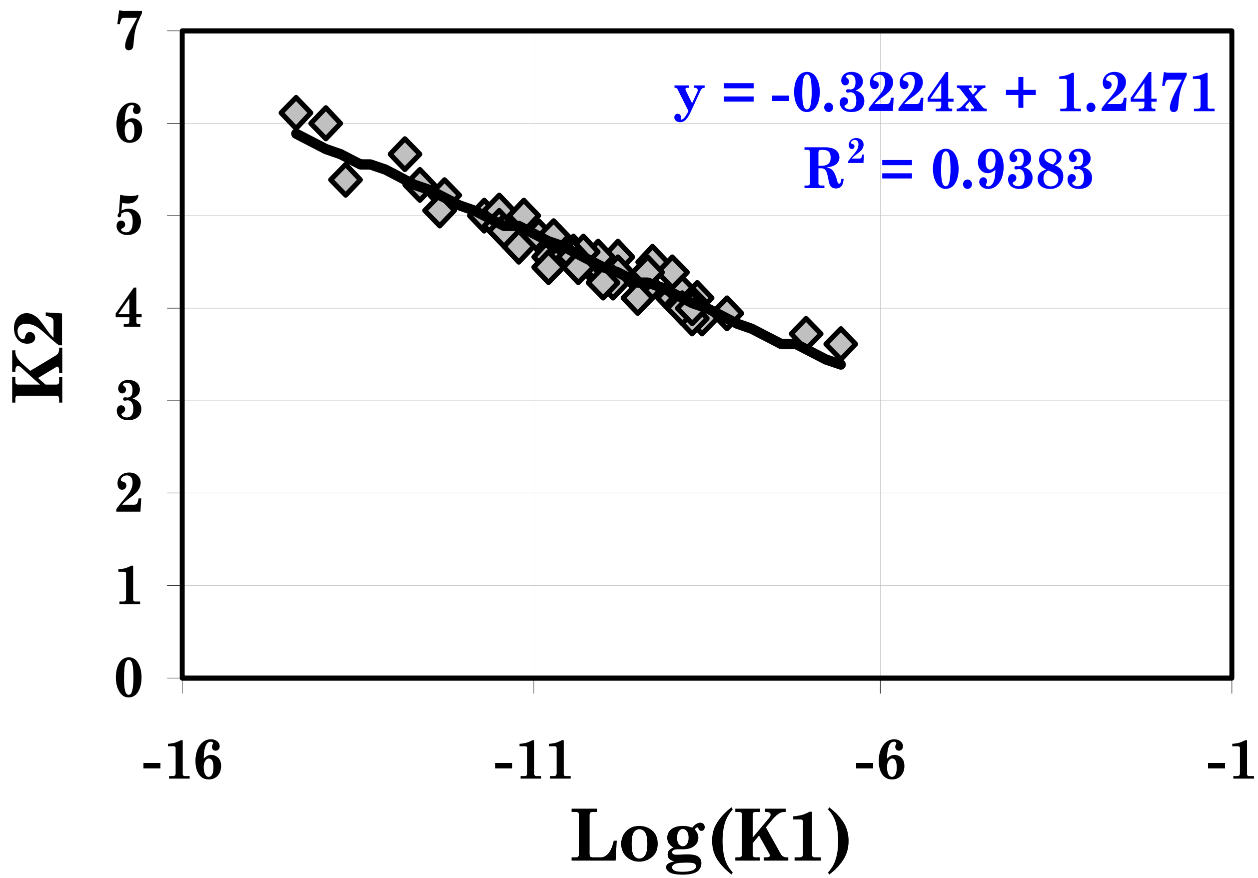
- Traditional Fatigue Analysis of Asphalt Concrete Mixtures

- A Fatigue Endurance Limit for Highway and Airport Pavements

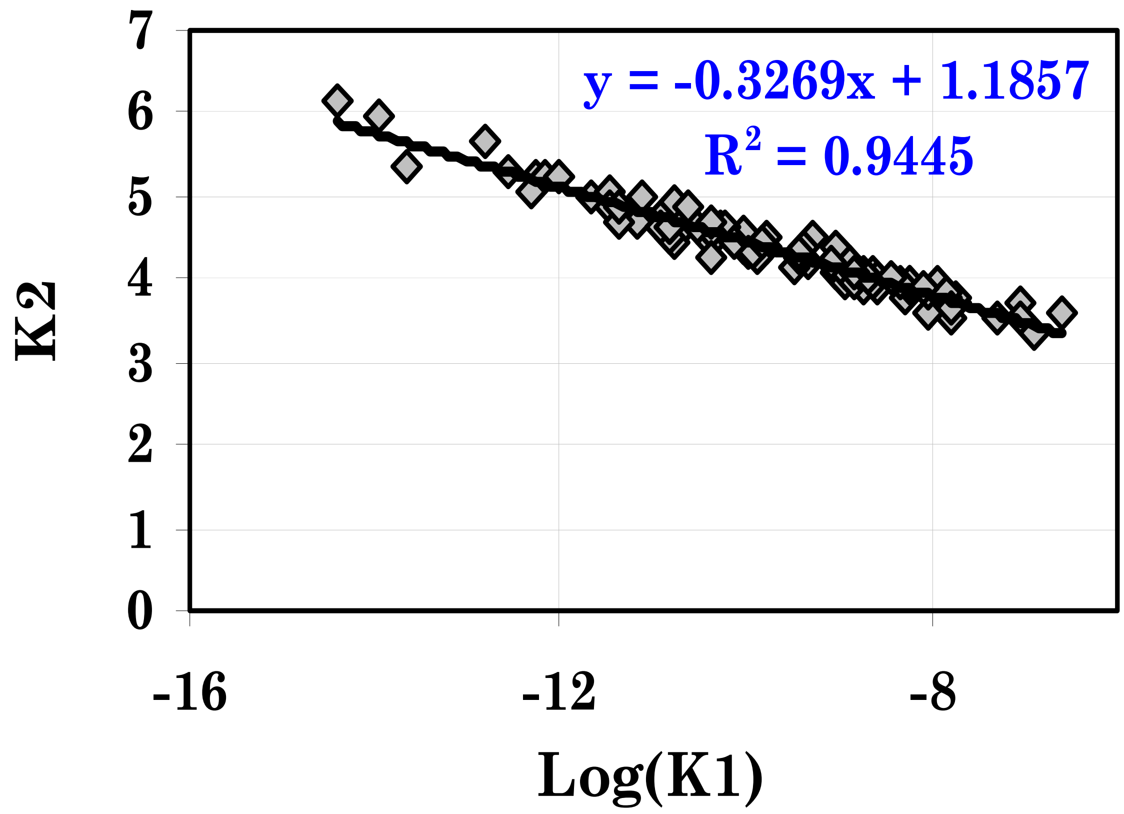
MATERIALS – 84 MIXES

- Illinois DOT
  - 25 mixes, 19, 12.5, 9.5 mm NMS
  - Production Samples
- Aggregate Interlock
  - Gradation Control, One Aggregate
- Dubai, U.A.E.
  - 4 Asphalts, 2 Aggregates, 8 gradations
- Various Others

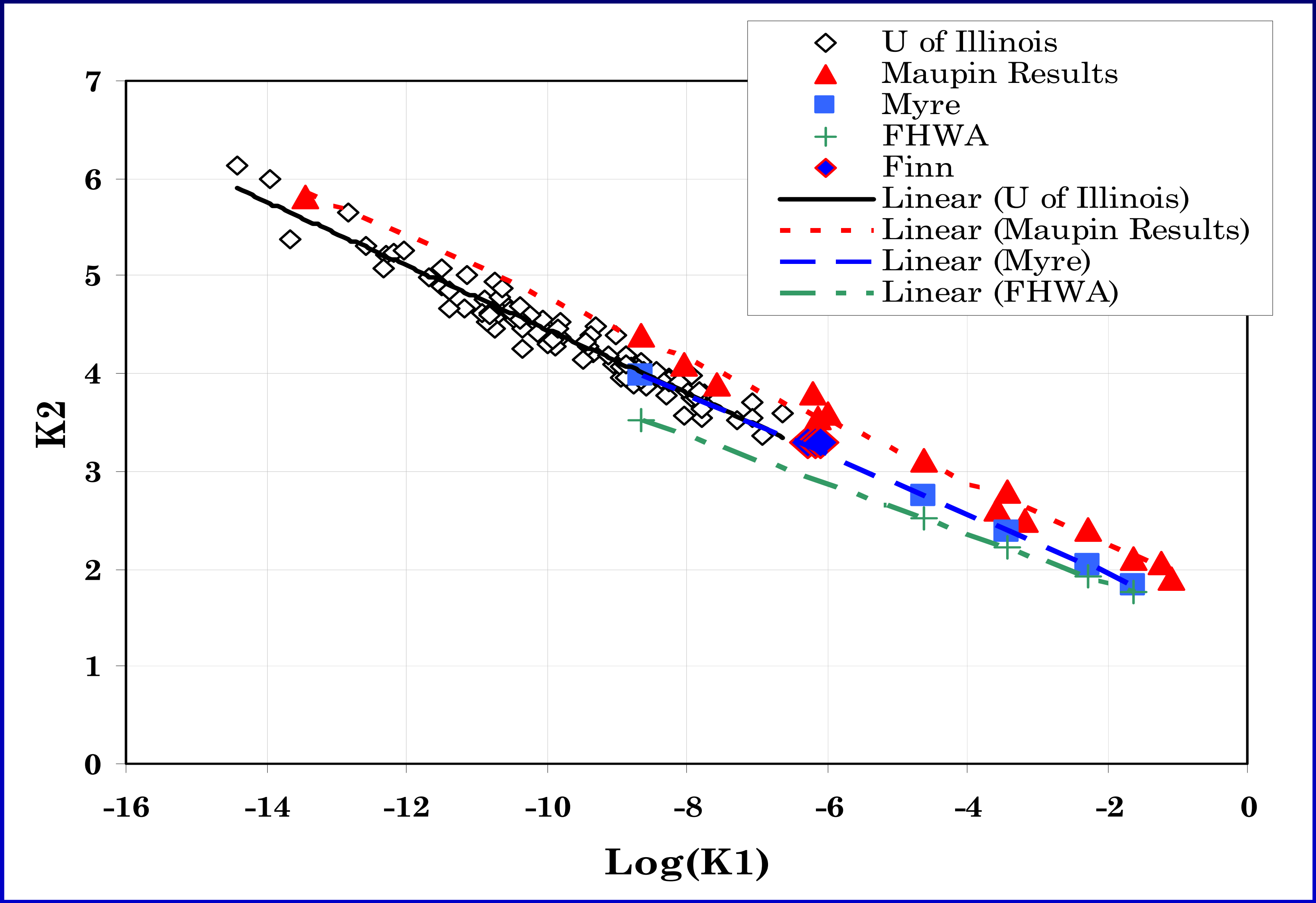
ILLINOIS DOT



ALL MIXTURES



OTHER STUDIES



K – n RELATIONS

- Myre / Norway NTH (1992)
  LOG K = (1.332 – n) / 0.306

- U of IL
  Ghuzlan & Carpenter (2001)
  LOG K = (1.186 – n) / 0.327

MAUPIN WORK

- Constant Strain Conditions
  - Different Failure Assumptions
  - One-Third Modulus Reduction

- $K2 = 0.0374\ \sigma_{IT} - 0.744$

- Calculate K1

  - σ_{IT} = Indirect Tensile Strength (psi) @ 72°F
  - Marshall Samples

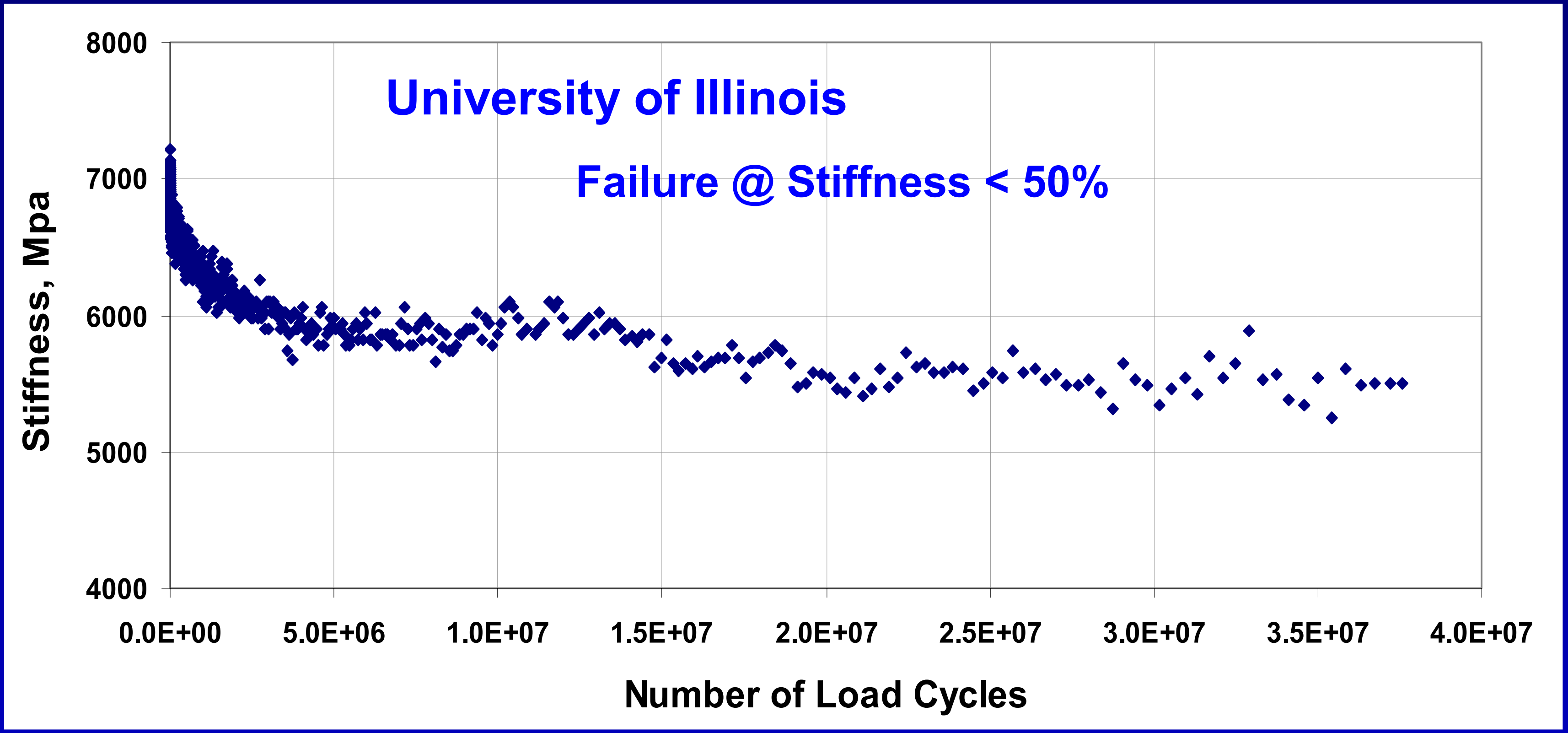
THERE IS

NO "UNIQUE"

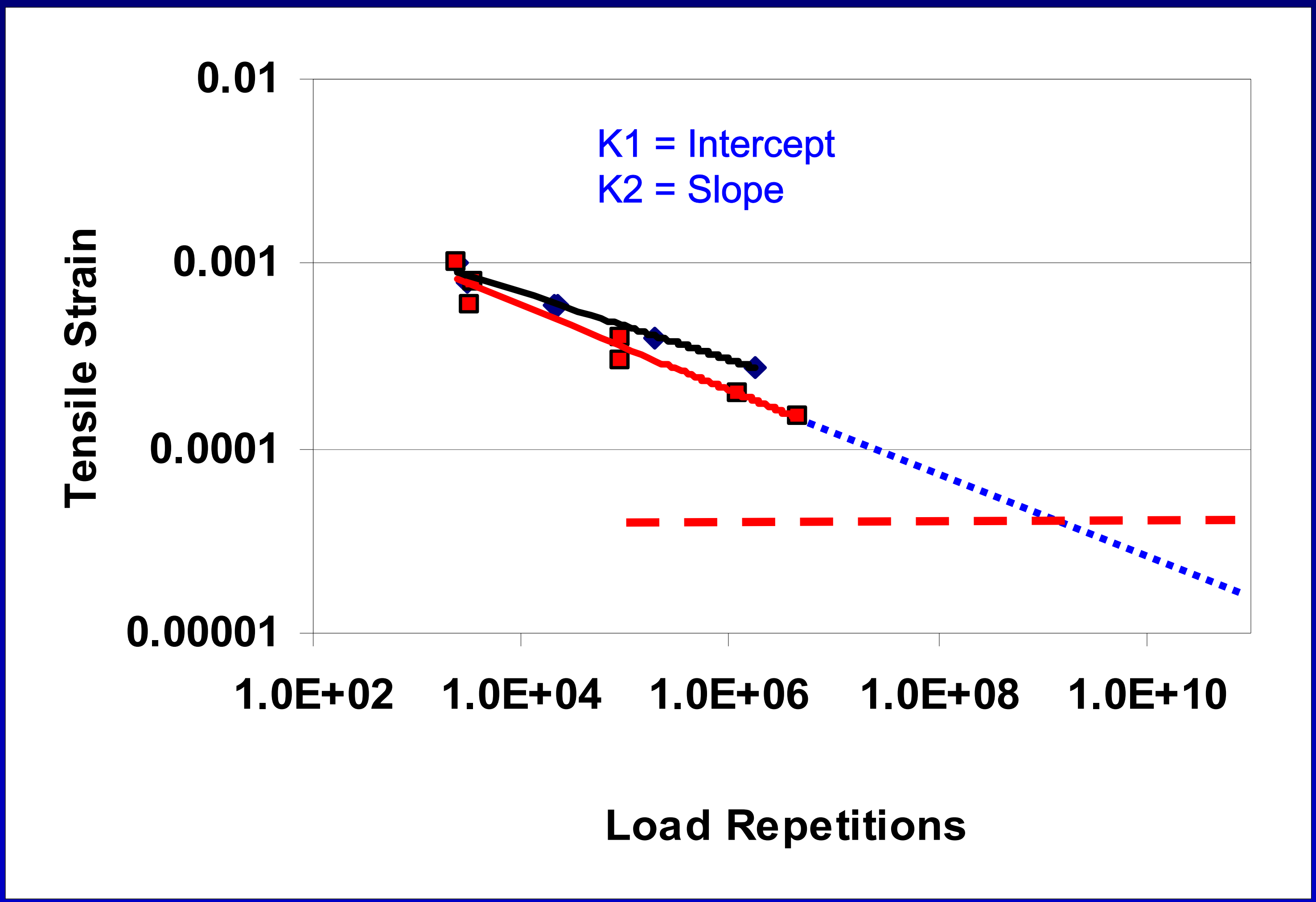
HMA FATIGUE ALGORITHM !!!!

LOW STRAIN HMA FATIGUE BEHAVIOR

70 Micro Strain Test



FATIGUE ENDURANCE LIMIT



FATIGUE ENDURANCE LIMIT

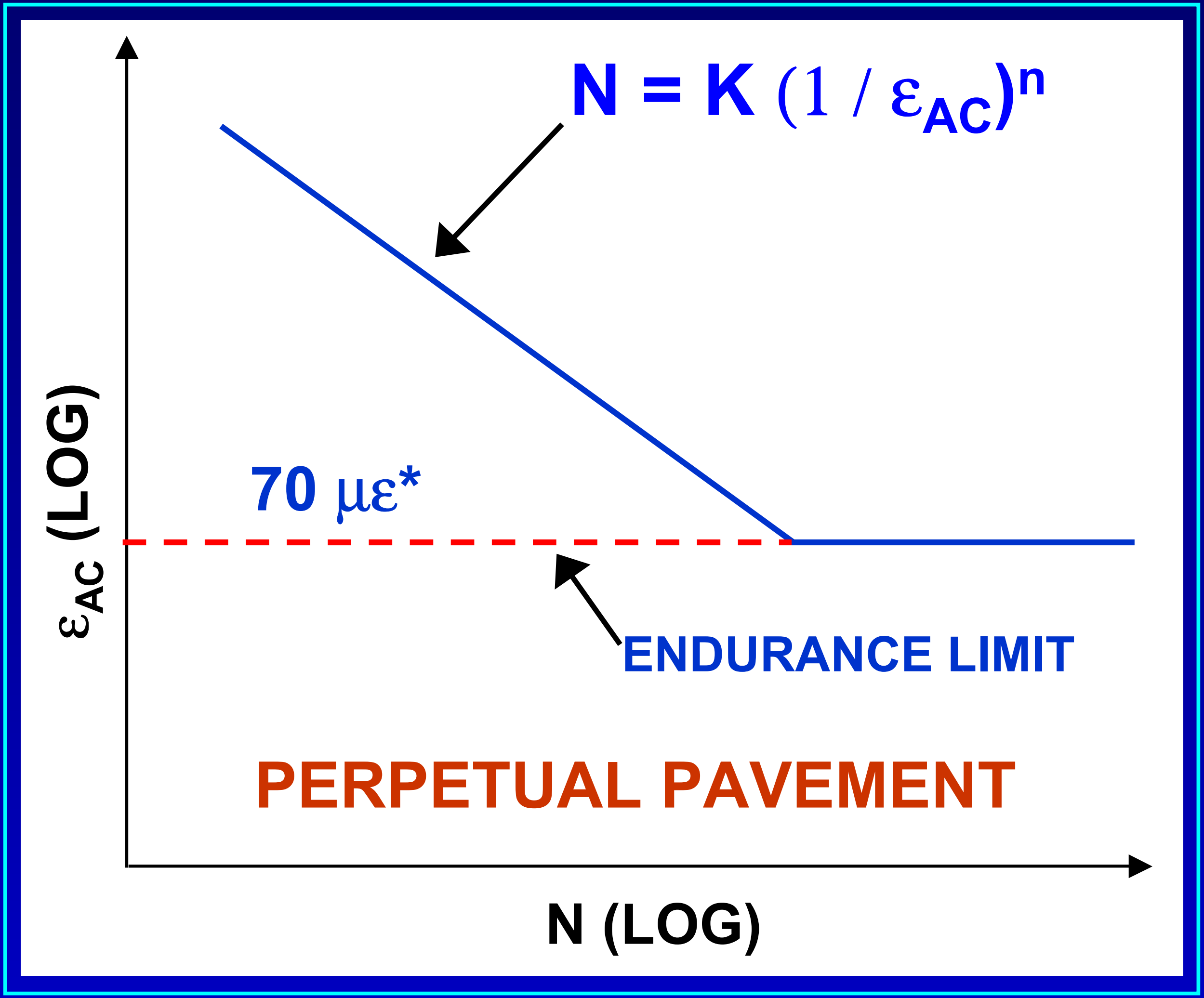
- Damage and Healing Concepts and Test Data Support a Strain Limit Below Which Damage Does Not Accumulate
- Different Limit for Different Mixes and Binders

Significance of Fatigue Endurance Limit

"….such a limit would provide a thickness limit for the pavement..Increasing the thickness beyond the limiting thickness… would provide no increased structural resistance to fatigue damage and represent an unneeded expense."

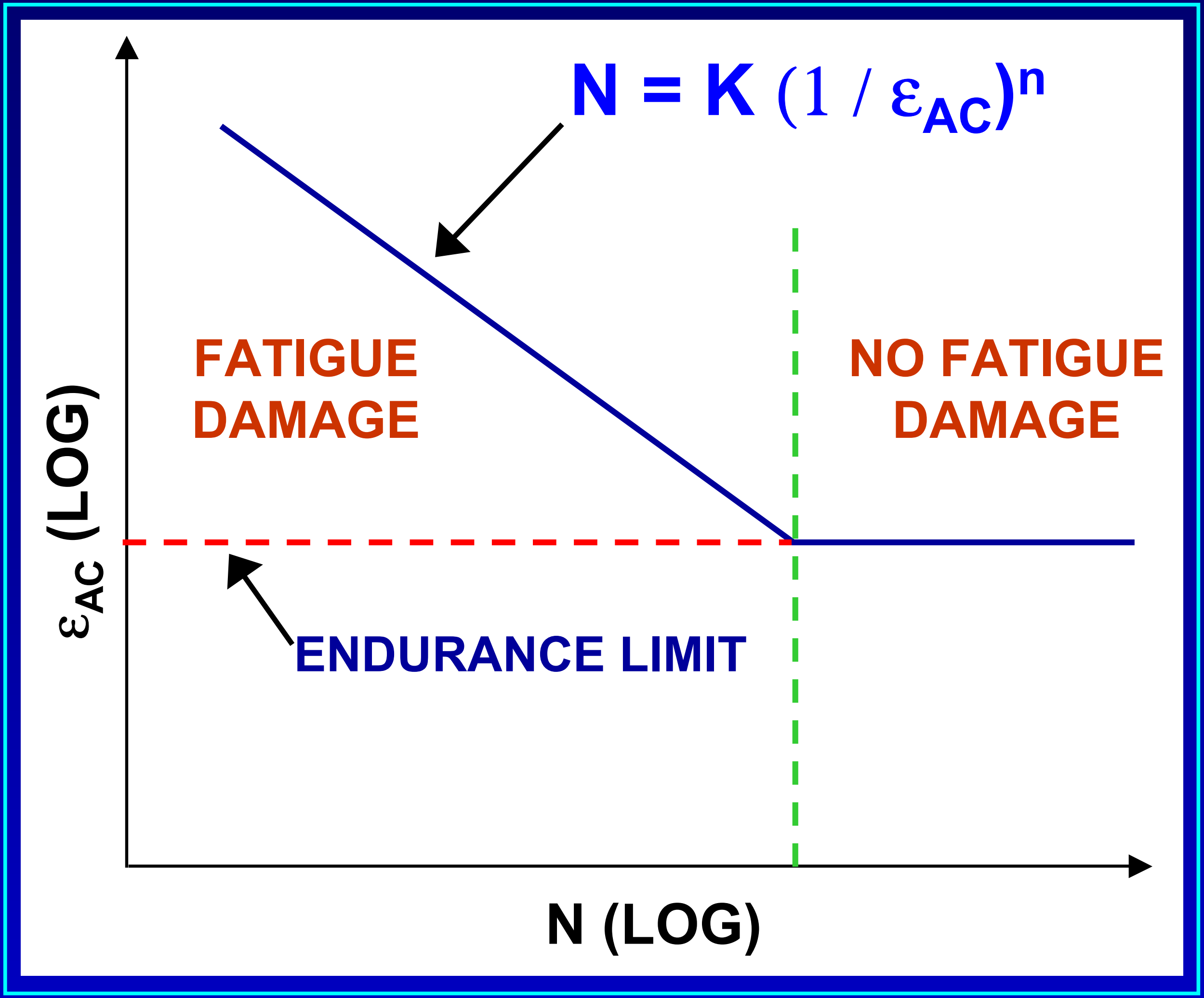
Prof. Carpenter

HMA FATIGUE



*Monismith and McLean ('72 AAPT)

HMA FATIGUE



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

$$P_i = \frac{N_i}{N_{Ti}}(100)$$

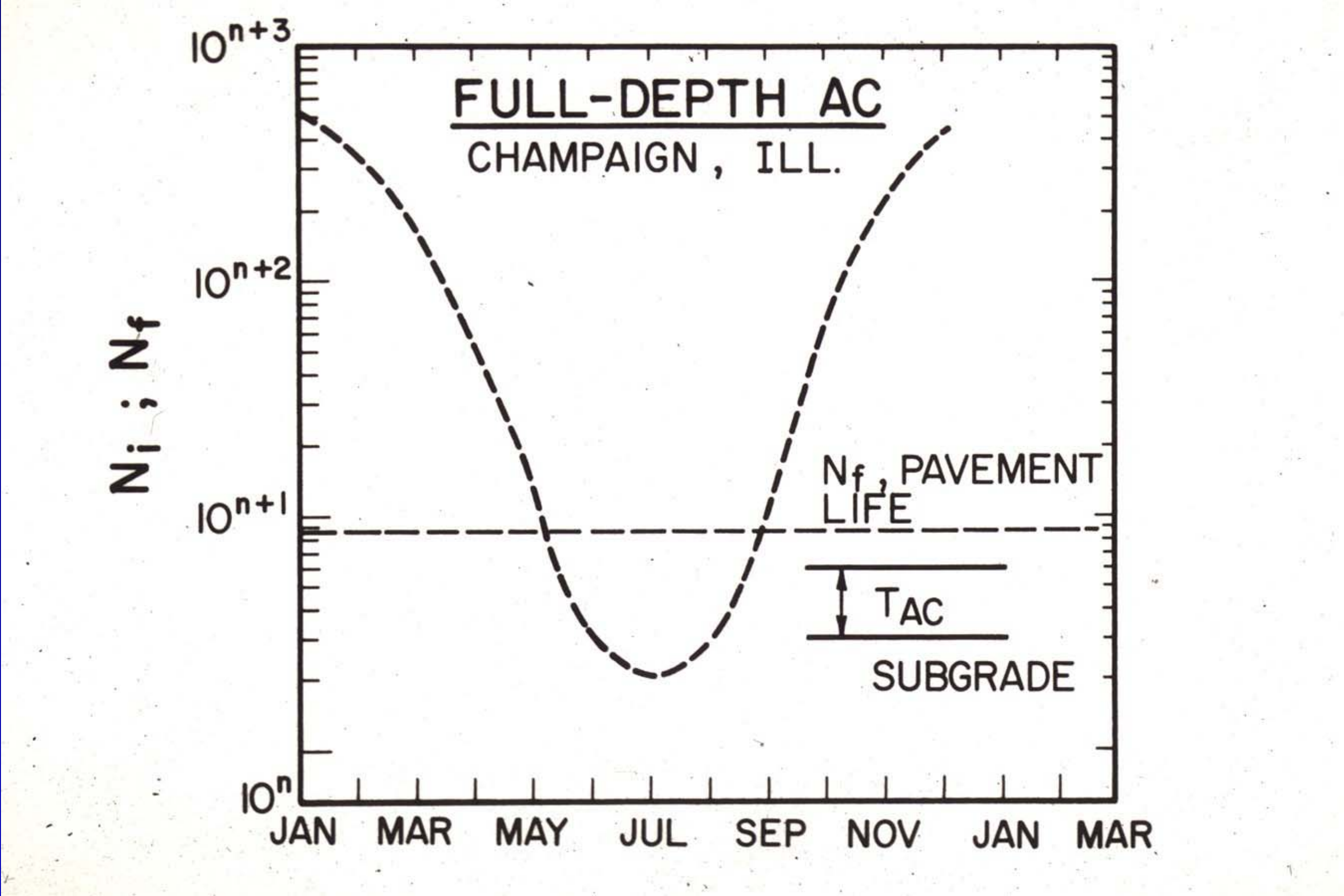
$$\text{FAILURE :} \quad \sum_{i=1}^{n} P_i = 100$$

MINER'S

$$N_f = \frac{12}{\sum_{i=1}^{12} \frac{1}{N_i}}$$

N_f = "TOTAL" PAVT. LIFE

N_i = PAVT. LIFE-MONTH "i"


FULL-DEPTH AC
CHAMPAIGN, ILL.
N_i ; N_f
10^{n+3}
10^{n+2}
10^{n+1}
10^n
N_f, PAVEMENT LIFE
T_{AC}
SUBGRADE
JAN
MAR
MAY
JUL
SEP
NOV
JAN
MAR

STRUCTURAL MODELLING

Elastic Layer (ELP)

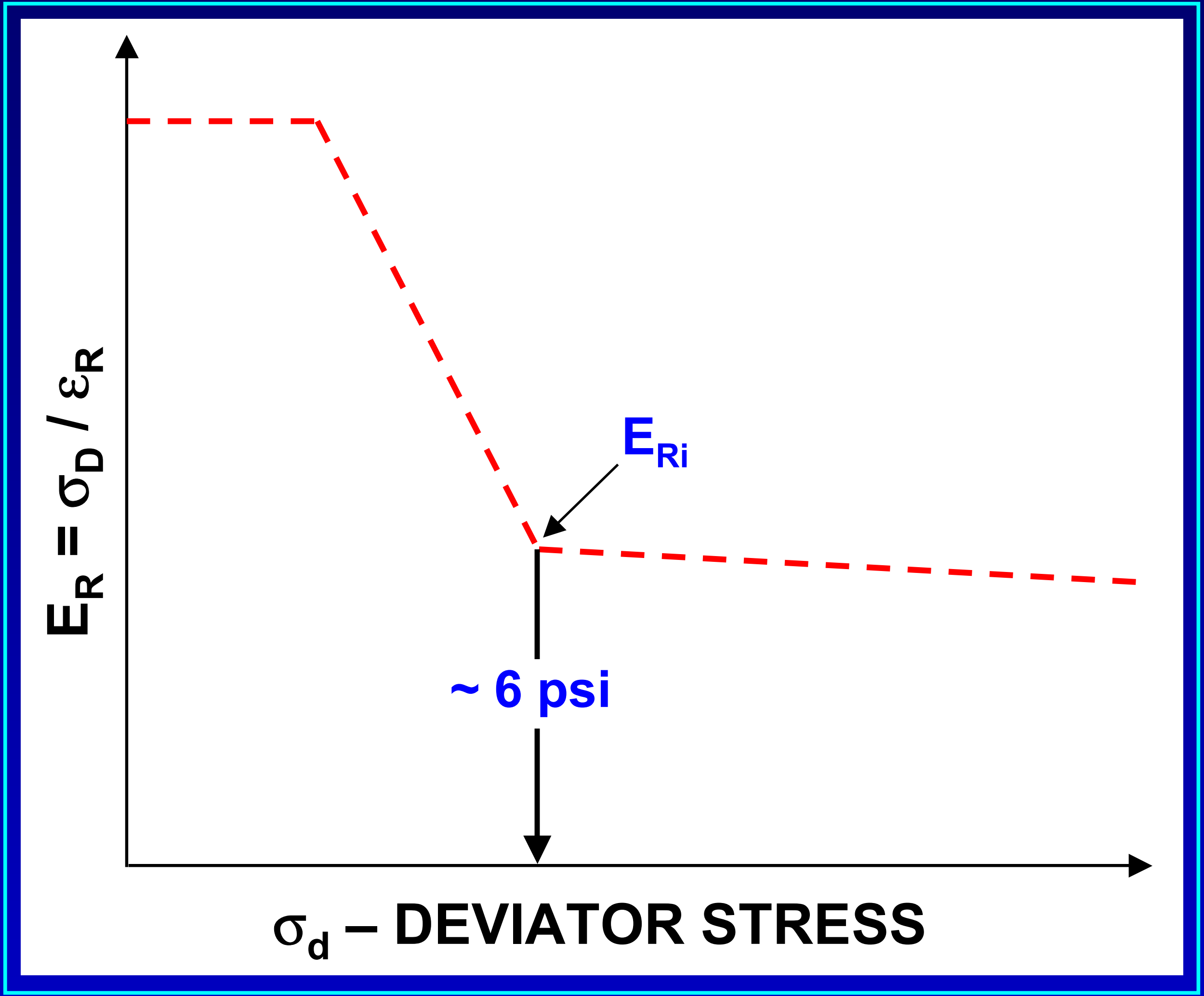
Stress Dependent

Finite Element

STRUCTURAL MODEL

ILLI-PAVE

FINE - GRAINED



E_{Ri} CORRELATIONS

$E_{Ri} = 0.37\ Q_u - 0.86$

$E_{Ri}(\text{OPT M.C.}) = 4.46 + 0.098\ (\%\text{Clay}) + 0.119\ (\text{PI})$

$Q_u = 4.5\ \text{CBR}$

E_{Ri} - ksi

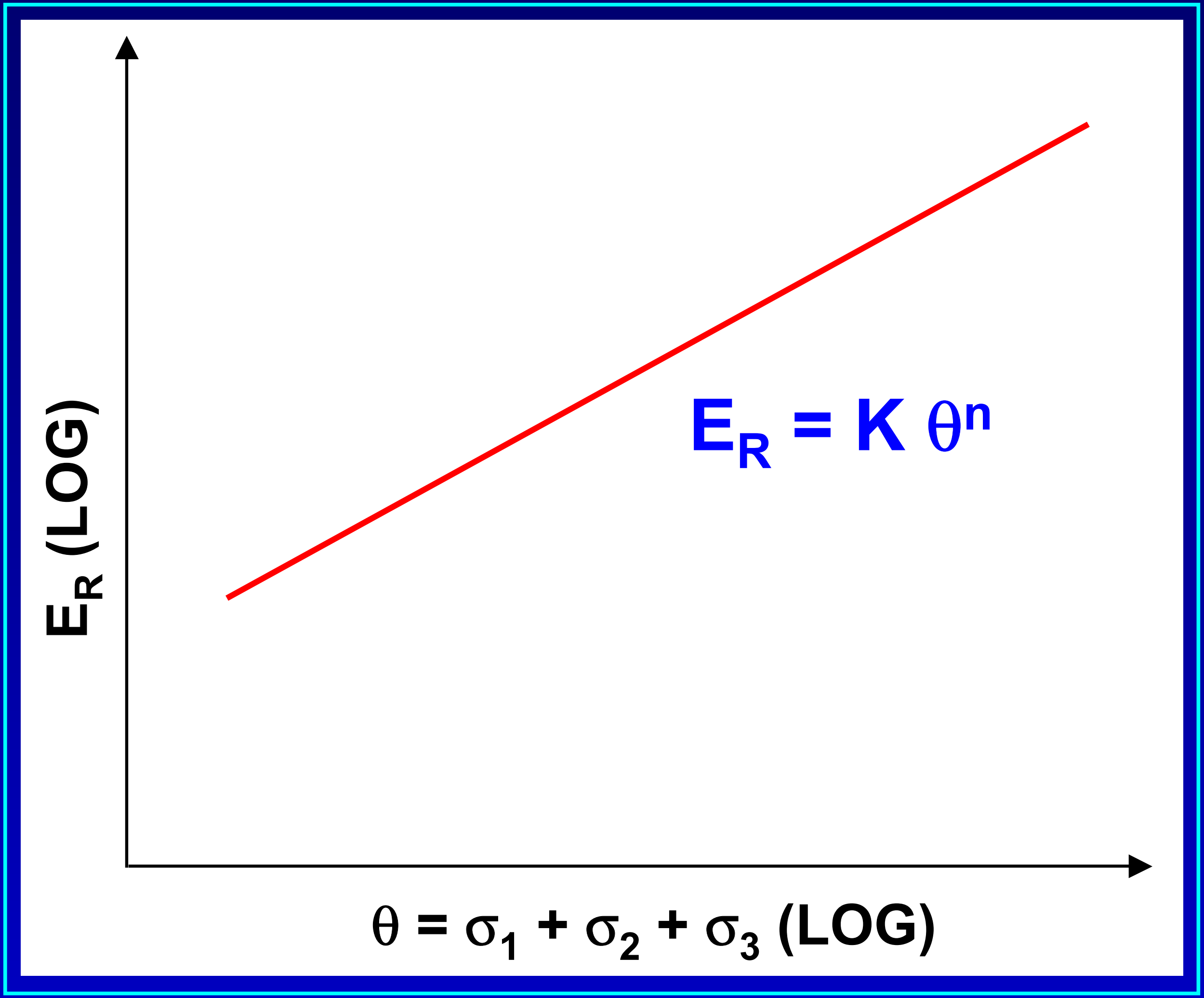
Q_u - psi

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

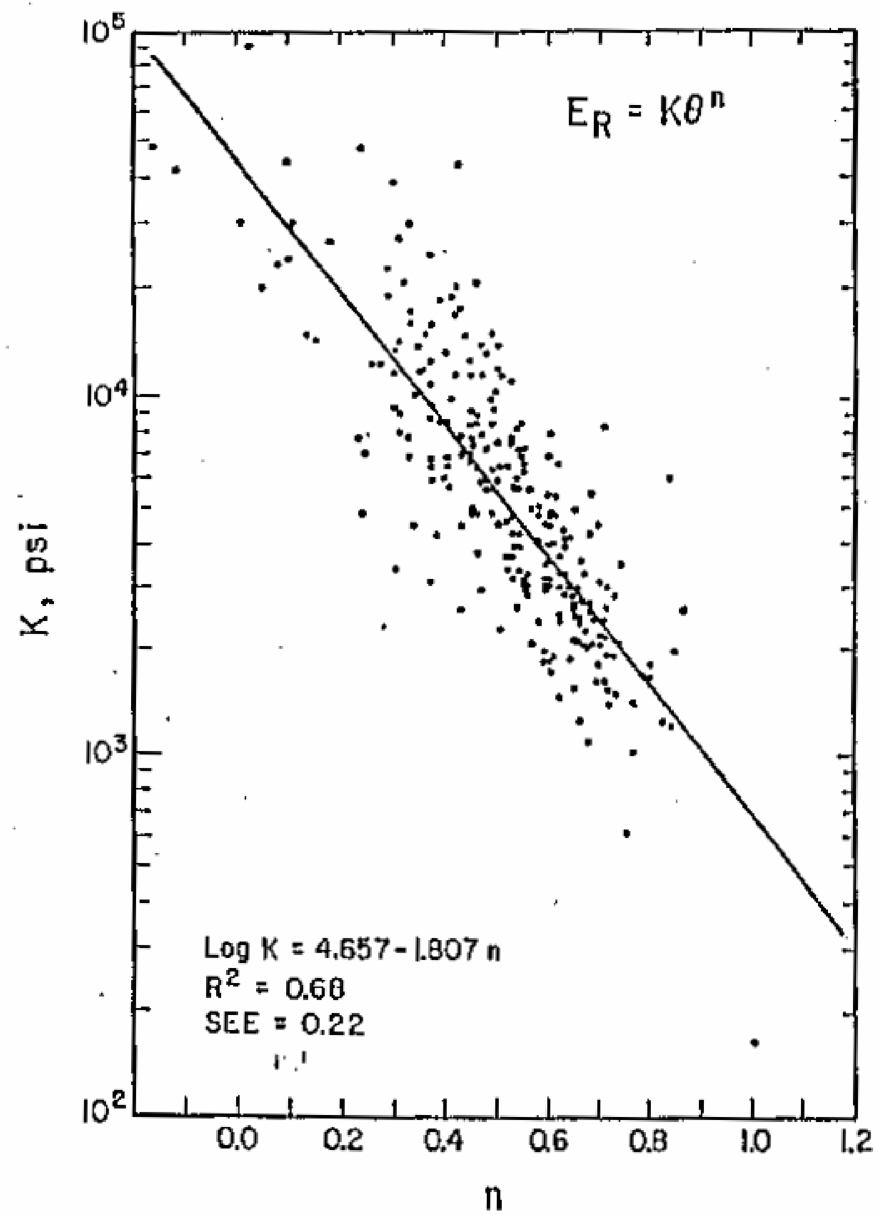
E_{Ri} (ksi) = 0.42 Qu (psi) - 2

GRANULAR MATERIAL



$$E_R = K\,\theta^n$$

AGGREGATE CLASS	K, psi	n
SILTY SANDS (8)	1620	0.62
SAND GRAVEL (37)	4480	0.53
SAND/AGG BLENDS (78)	4350	0.59
CRUSHED STONE (115)	7210	0.45



$E_R = K\theta^n$
Log K = 4.657 - 1.807 n
R^2 = 0.68
SEE = 0.22
K, psi
n
10^5
10^4
10^3
10^2
0.0
0.2
0.4
0.6
0.8
1.0
1.2

WHAT IS THE MODULUS ???

ELP – CONSTANT E!!!

HOT MIX ASPHALT

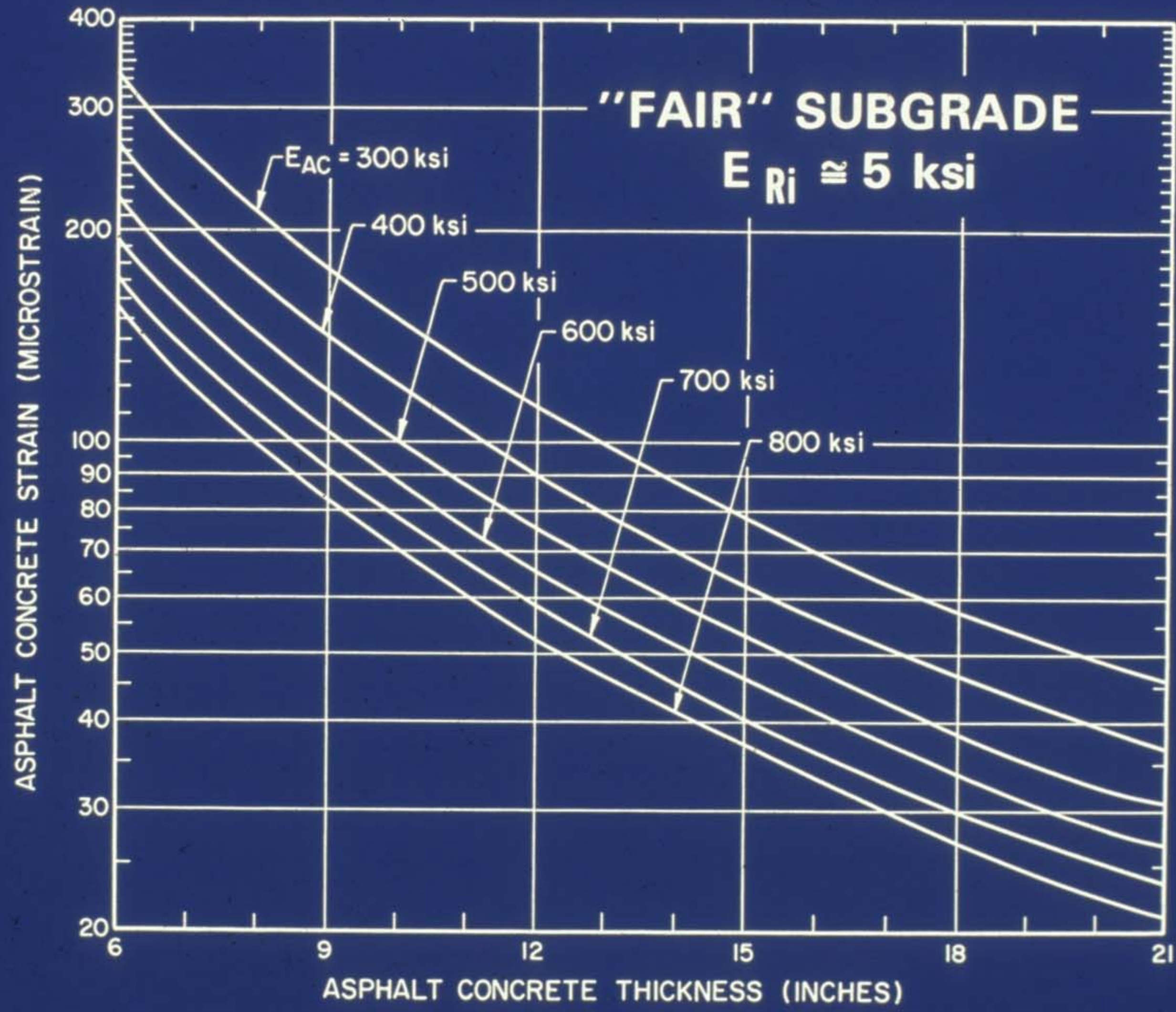
LINEAR ELASTIC (E)

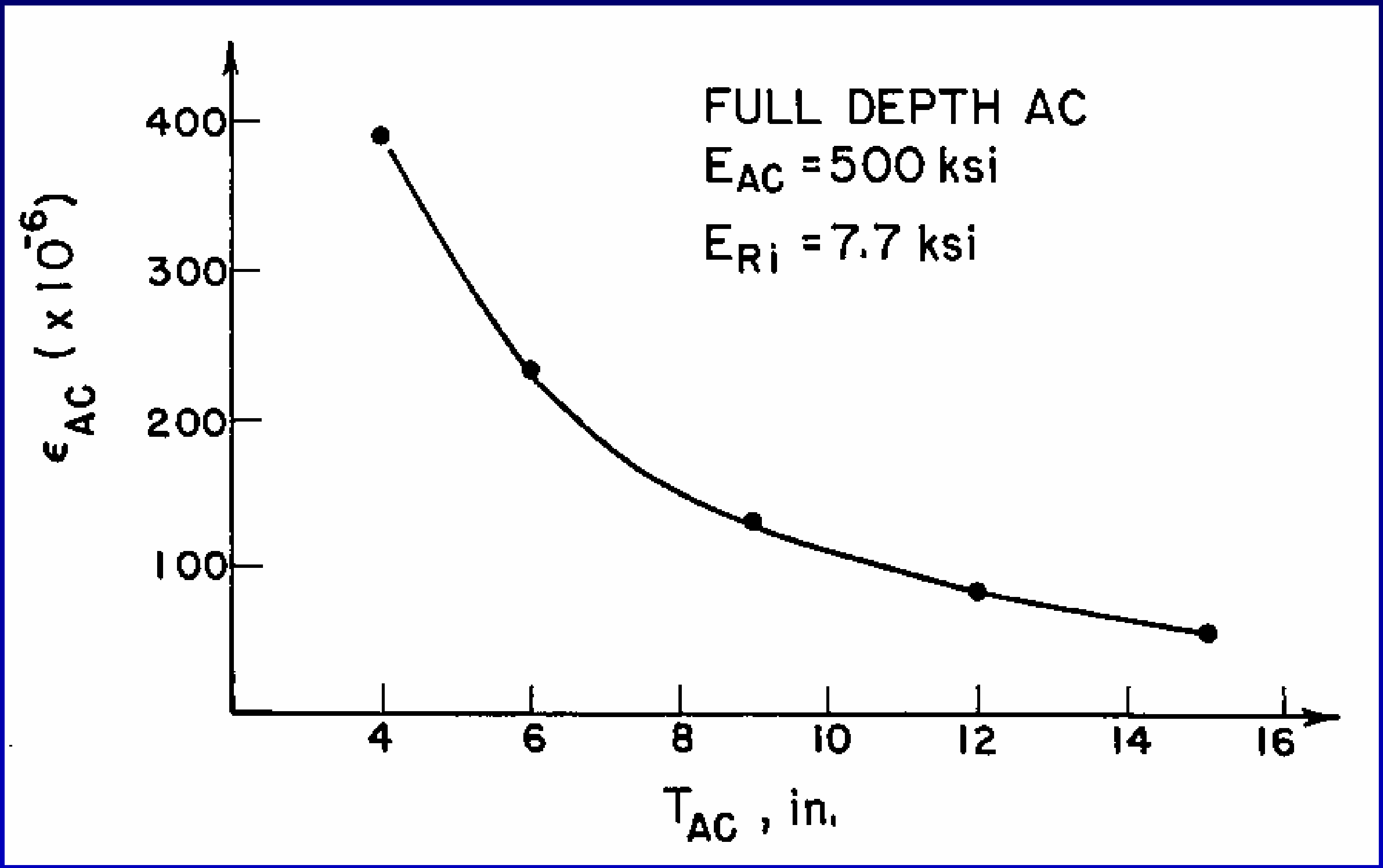
E = f (Temp & Freq)

FULL-DEPTH AC

$$\text{LOG } \varepsilon_{AC} = 5.746 - 1.589 \text{ LOG } T_{AC} - 0.774 \text{ LOG } E_{AC} - 0.097 \text{ LOG } E_{Ri}$$

ε_{AC} : $\mu\varepsilon$ T_{AC} : in. E_{AC} , E_{Ri} : ksi


"FAIR" SUBGRADE
E Ri ≅ 5 ksi
EAC = 300 ksi
400 ksi
500 ksi
600 ksi
700 ksi
800 ksi
400
300
200
100
90
80
70
60
50
40
30
20
6
9
12
15
18
21
ASPHALT CONCRETE STRAIN (MICROSTRAIN)
ASPHALT CONCRETE THICKNESS (INCHES)



FULL DEPTH AC
E_AC = 500 ksi
E_Ri = 7.7 ksi
ε_AC (x10^-6)
400
300
200
100
4
6
8
10
12
14
16
T_AC , in.

O. A. Fonesca & M. W. Witczak
AAPT Proceedings – 1996

"A Prediction Methodology for the Dynamic Modulus of In-Place Aged Asphalt Mixtures"

M. W. Witczak & O. A. Fonesca
TRB RECORD No.1540 (1996)

"Revised Predictive Model for Dynamic (Complex) Modulus of Asphalt Mixtures"

(AASHTO – 2002 Guide)

ASPHALT INSTITUTE EQUATION

E_{AC} = f (X_1 , X_2 , X_n)

P_{200} = % - # 200

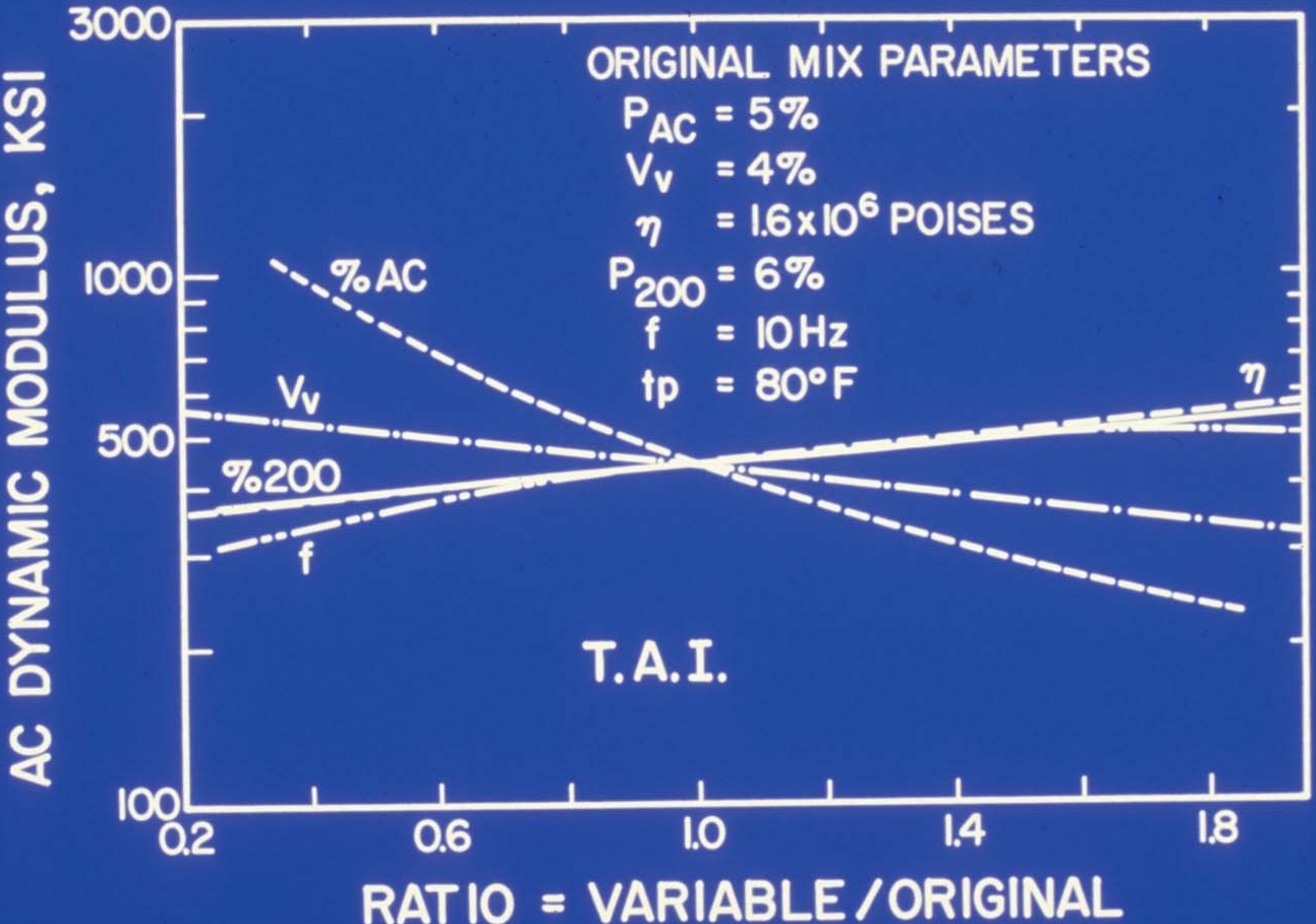
V_V = % AIR VOIDS

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

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

t_p = TEMPERATURE (F)

f = FREQUENCY (HZ)



3000
1000
500
100
AC DYNAMIC MODULUS, KSI
0.2
0.6
1.0
1.4
1.8
RATIO = VARIABLE / ORIGINAL
ORIGINAL MIX PARAMETERS
P_{AC} = 5%
V_v = 4%
η = 1.6×10^6 POISES
P_{200} = 6%
f = 10 Hz
tp = 80°F
%AC
V_v
%200
f
η
T.A.I.

SEASONAL EFFECTS

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

MUST CONSIDER IN M-E DESIGN

PG GRADE EFFECTS

	HMA MODULUS (ksi)	
TEMP (°F)	64-22	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

PG 70-22

TEMP (°F)	HMA MODULUS (ksi) AC-4.0 %*	HMA MODULUS (ksi) AC-3.5 %**
70	1195	1160
75	995	975
80	820	815
85	670	675
90	540	550

* AV: 2.5 %
- # 200: 3 %

** AV: 4.0 %
f = 10 hz

ASPHALT INSTITUTE PROCEDURE

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

Z: INCHES FROM SURFACE

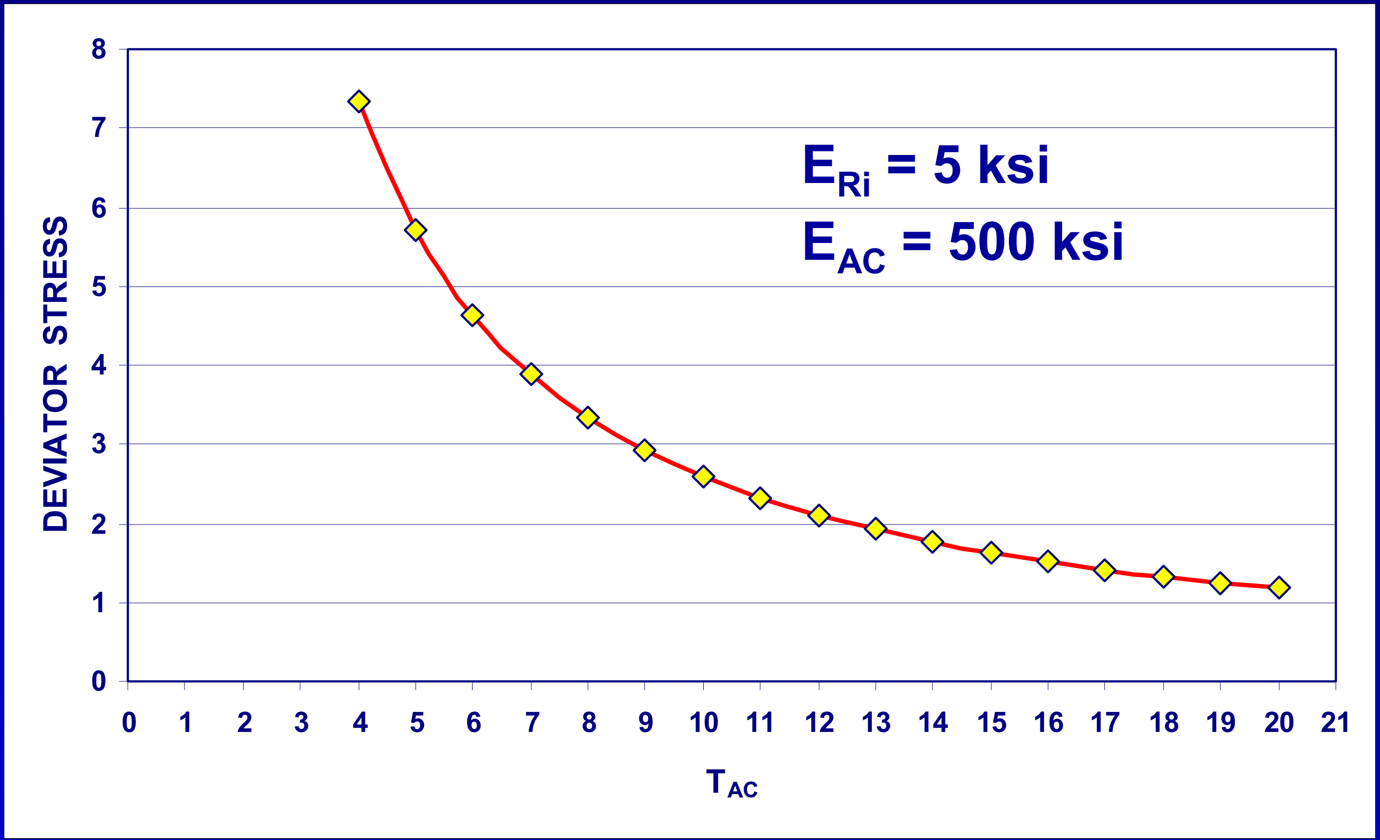
CHAMPAIGN, IL		
MONTH	MMAT (°F)	MMPT (°F)
JAN	27.1	32.5/30.4
FEB	33.0	39.1/37.9
MAR	40.6	47.8/46.6
APR	51.2	58.9/59.5
MAY	62.5	72.0/73.9
JUN	72.0	83.4/82.9
JUL	74.7	86.5/84.9
AUG	72.8	84.3/82.3
SEP	65.8	76.4/74.1
OCT	54.7	63.7/62.5
NOV	41.8	49.1/46.8
DEC	32.4	38.5/38.0

ICM/AI

FULL-DEPTH AC

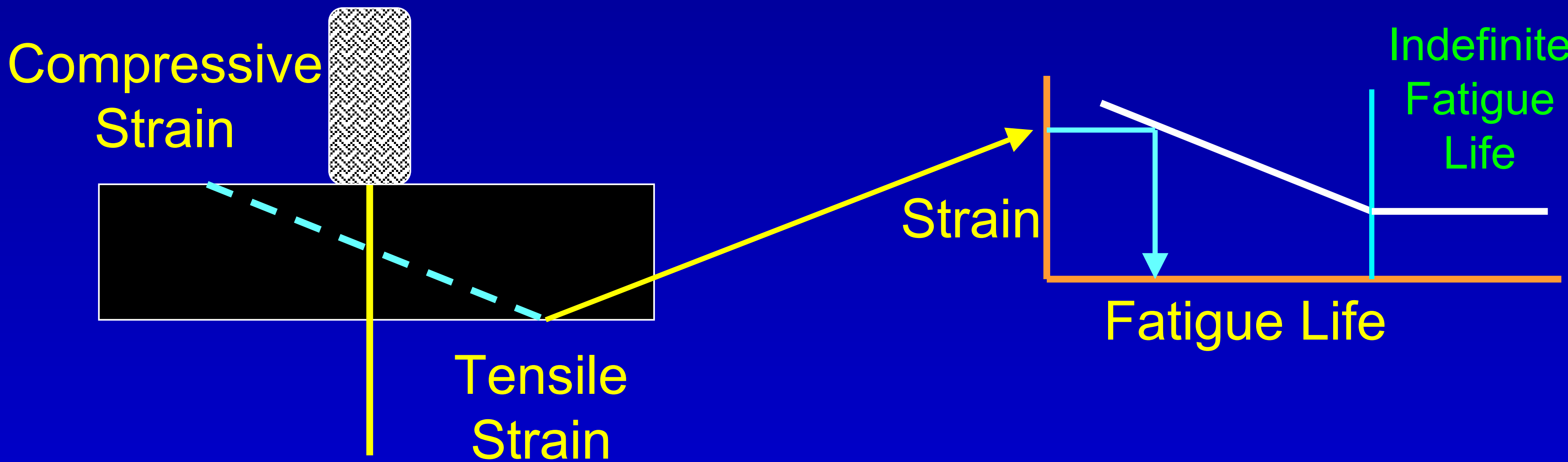
$$\text{LOG } \sigma_D = 2.74 - 1.14 \text{ LOG } T_{AC} - 0.515 \text{ LOG } E_{AC} + 0.29 \text{ LOG } E_{Ri}$$

σ_D : psi T_{AC} : in. E_{AC} , E_{Ri} : ksi



Pavement Design Concepts

- **Fatigue Resistant Asphalt Base**
  - Minimize Tensile Strain with Pavement Thickness
  - Thin Asphalt Pavement = Higher Strain
  - Higher Strain = Shorter Fatigue Life



PERPETUAL PAVEMENT

(70 MICRO-STRAIN / 9 kips)

(SUBGRADE E_{Ri} - 5 ksi)

AC MODULUS (ksi)	AC THICKNESS (inches)
800	10.00
700	10.75
600	11.50
500	12.50
400	14.00
300	16.00

PERPETUAL PAVEMENT

(70 MICRO-STRAIN / 10 kips)

(SUBGRADE E_{Ri} - 5 ksi)

AC MODULUS (ksi)	AC THICKNESS (inches)
800	10.7
700	11.4
600	12.3
500	13.4
400	15.0
300	17.2

CMI - IL

19 mm SP mix

*AC: 4.8 % PG 64-22 *- # 200: 5 %

*AV: 4.0 % *f = 10 hz

$$\text{LOG } E_{AC} \text{ (ksi)} = 4.33 - 0.0198 \, T \, (^{o}F)$$

$$N = 8.2 * 10^{-8} (1/\varepsilon_{AC})^{3.5}$$

T_{AC} = 13.5 inches E_{Ri} = 5 ksi

*N_F w/o Endurance Limit: 119 MESALS

*July AC Strain: 70 $\mu\varepsilon$

"PERPETUAL" PAVEMENT

RUBBLIZED PCCP

WITH

HMA OVERLAY

THE MHB
I-70 / IL

THE MHB

Z-GRID ROLLER

PAVING OPERATION

HOT-MIX ASPHALT OVERLAY DESIGN CONCEPTS FOR RUBBLIZED PORTLAND CEMENT CONCRETE PAVEMENTS

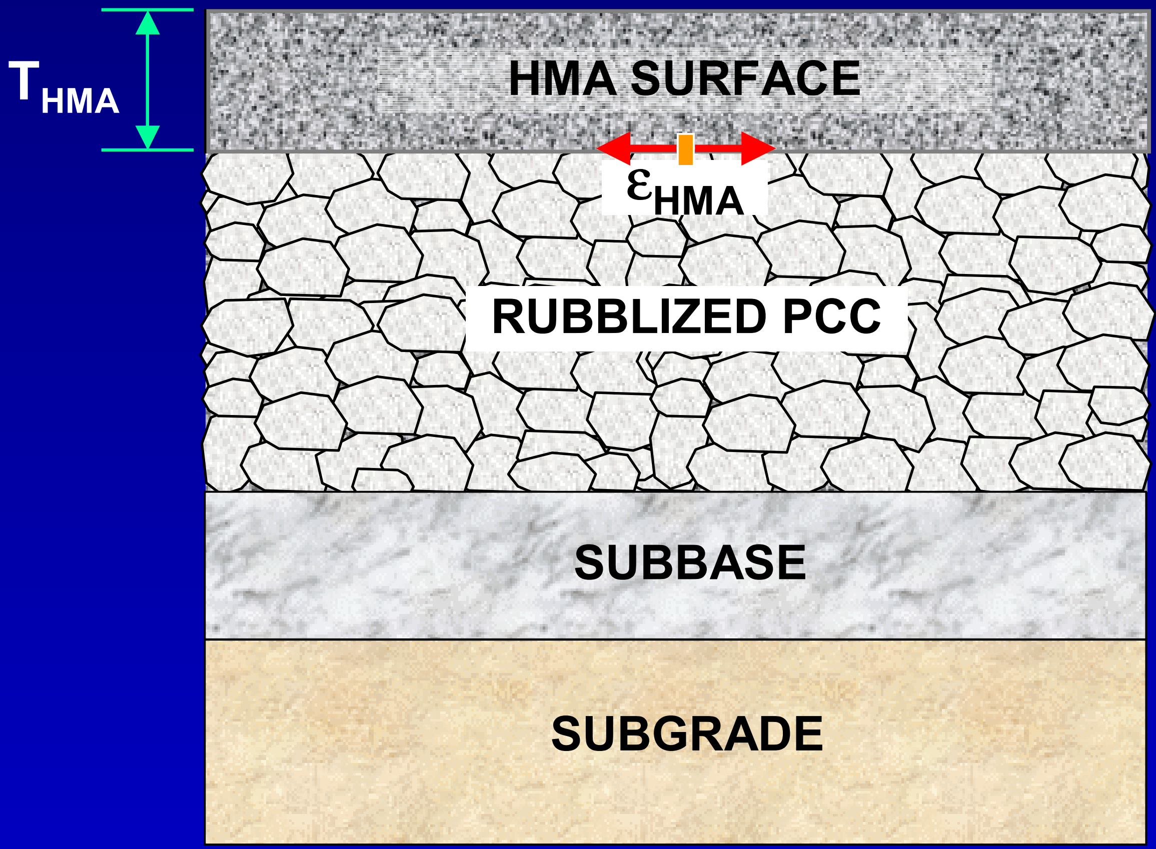
Marshall R. Thompson
TRB Record 1684 (1999)

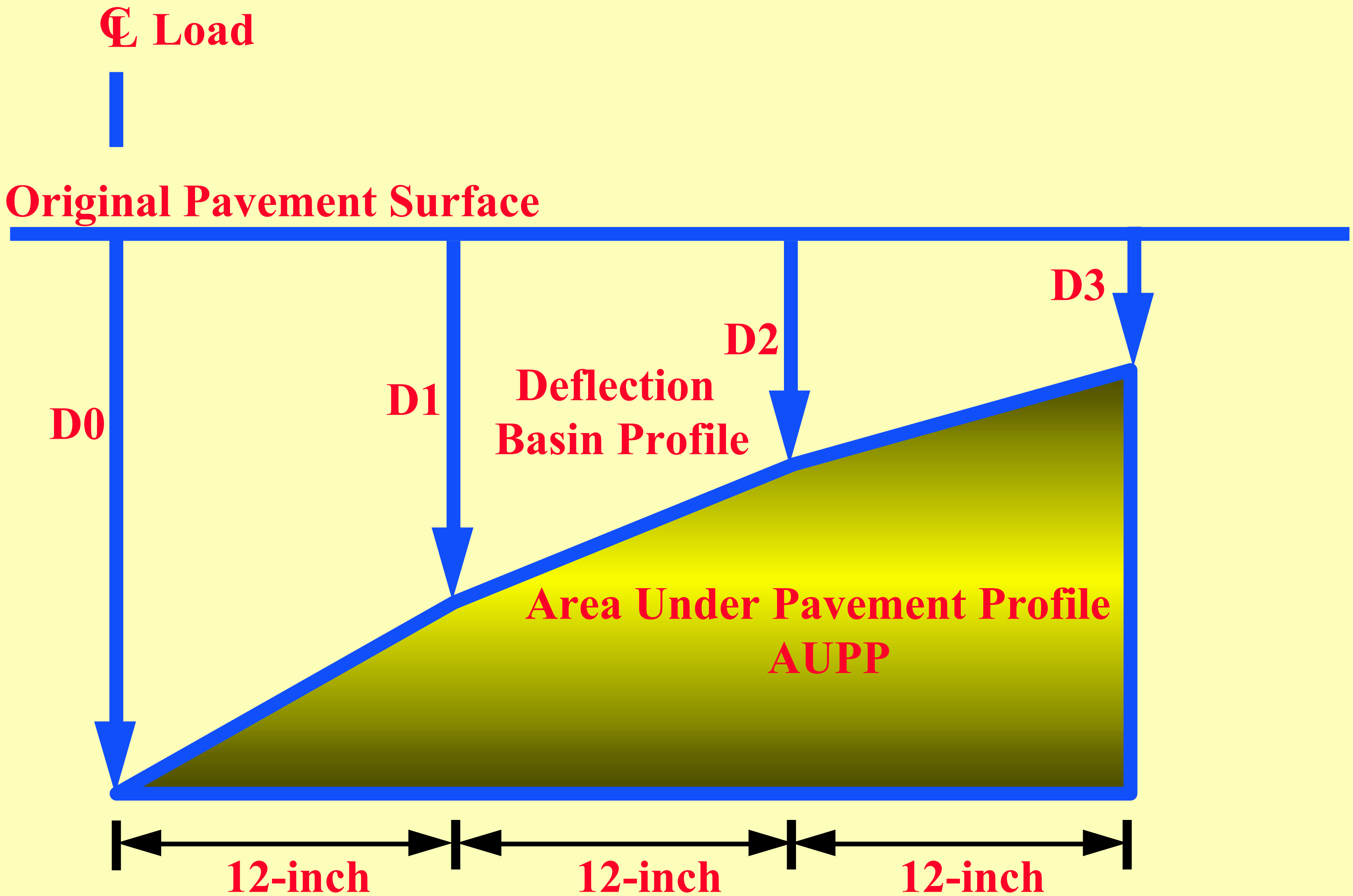
$$\text{LOG } \varepsilon_{AC} = 1.001 + 1.024 \text{ LOG(AUPP)}$$

$$\text{LOG(AUPP)} = 1.865 - 0.393 \text{ LOG}(E_{AC}T^3 / 1000)$$

ε_{AC} = Micro-strain (10^{-6})
AUPP – inches
E_{AC} – ksi
T – inches

RUBBLIZED PVT SECTION





AREA = 6*(D0 + 2*D1 + 2*D2 + D3) / D0

AUPP = (5*D0 - 2*D1 - 2*D2 - D3) / 2

PERPETUAL PAVEMENT

RUBBLIZED PCCP
(70 MICRO-STRAIN)

AC MODULUS (ksi)	AC THICKNESS (inches)
800	8.2
700	8.6
600	9.0
500	9.6
400	10.4
300	11.4

CHAMPAIGN, IL
HMA OL / RUBBLIZED PCCP

JULY MMPT = 86.5 ^{o}F

E_{AC} = 370 ksi

T_{AC} = 11 inches

HMA ε = 67 Micro - ε

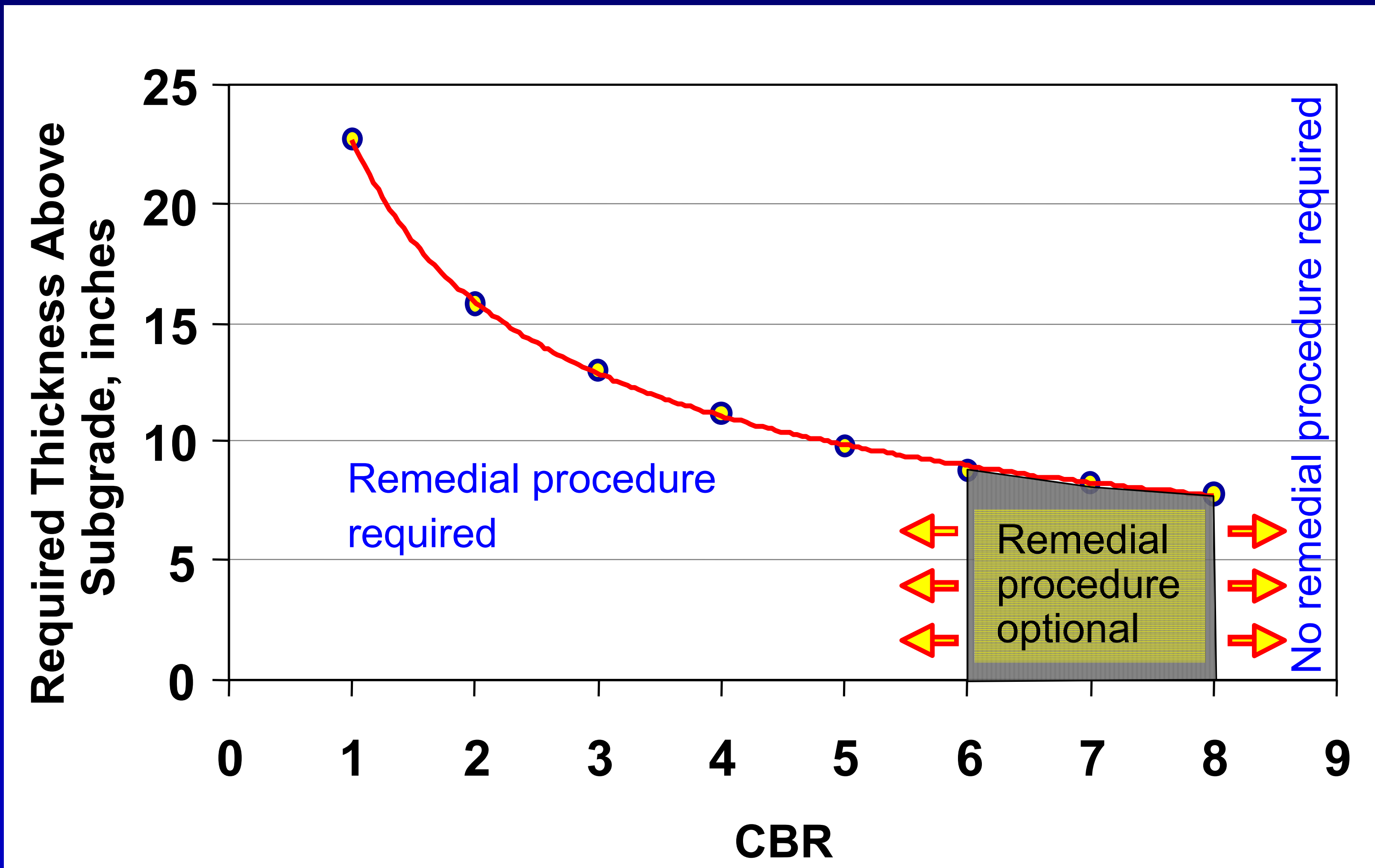
Why are Perpetual Pavements Important?

- Lower Life Cycle Cost
  - Better Use of Resources
  - Low Incremental Costs for Surface Renewal
- Lower User Delay Cost
  - Shorter Work Zone Periods
  - Off-Peak Period Construction

FULL-DEPTH AC

FULL QUALITY AC

Foundation - Illinois



THANK YOU !!

???????