FULL-DEPTH HMA PAVEMENT DESIGN

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University of Illinois @ U-C

FULL-DEPTH HMA

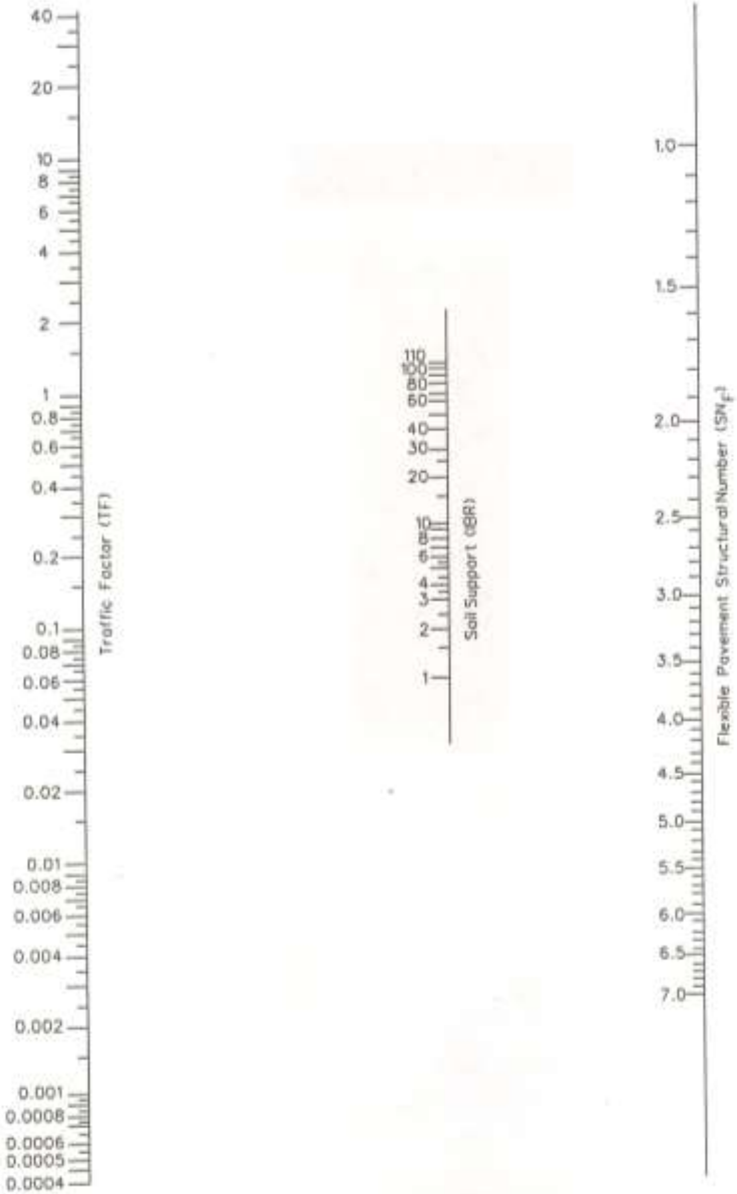
FULL QUALITY HMA

IDOT
&
FULL-DEPTH HMA PAVEMENT
(FD-HMA)

BEFORE 1989

*AASHTO SN DESIGN

* FEW FD-HMAS !!!



FLEXIBLE PAVEMENT DESIGN NOMOGRAPH
(Modified AASHTO Design: Class I Facilities)

$$SN = a_1 * T_1 + a_2 * T_2$$

Class I SURFACE

a_1 - 0.4

Class I BINDER

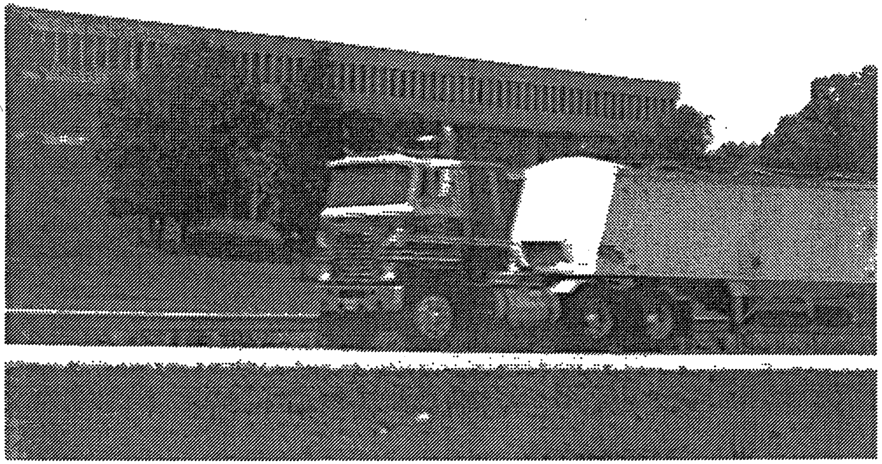
a_2 - 0.33

IN 1989:

*M-E DESIGN ADOPTED BY IDOT FOR FD-HMA

*IHR-510
MECHANISTIC EVALUATION OF ILLINOIS FLEXIBLE PAVEMENT DESIGN PROCEDURES

August 1989

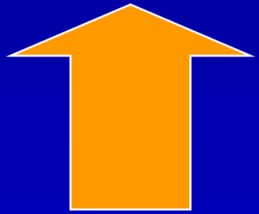


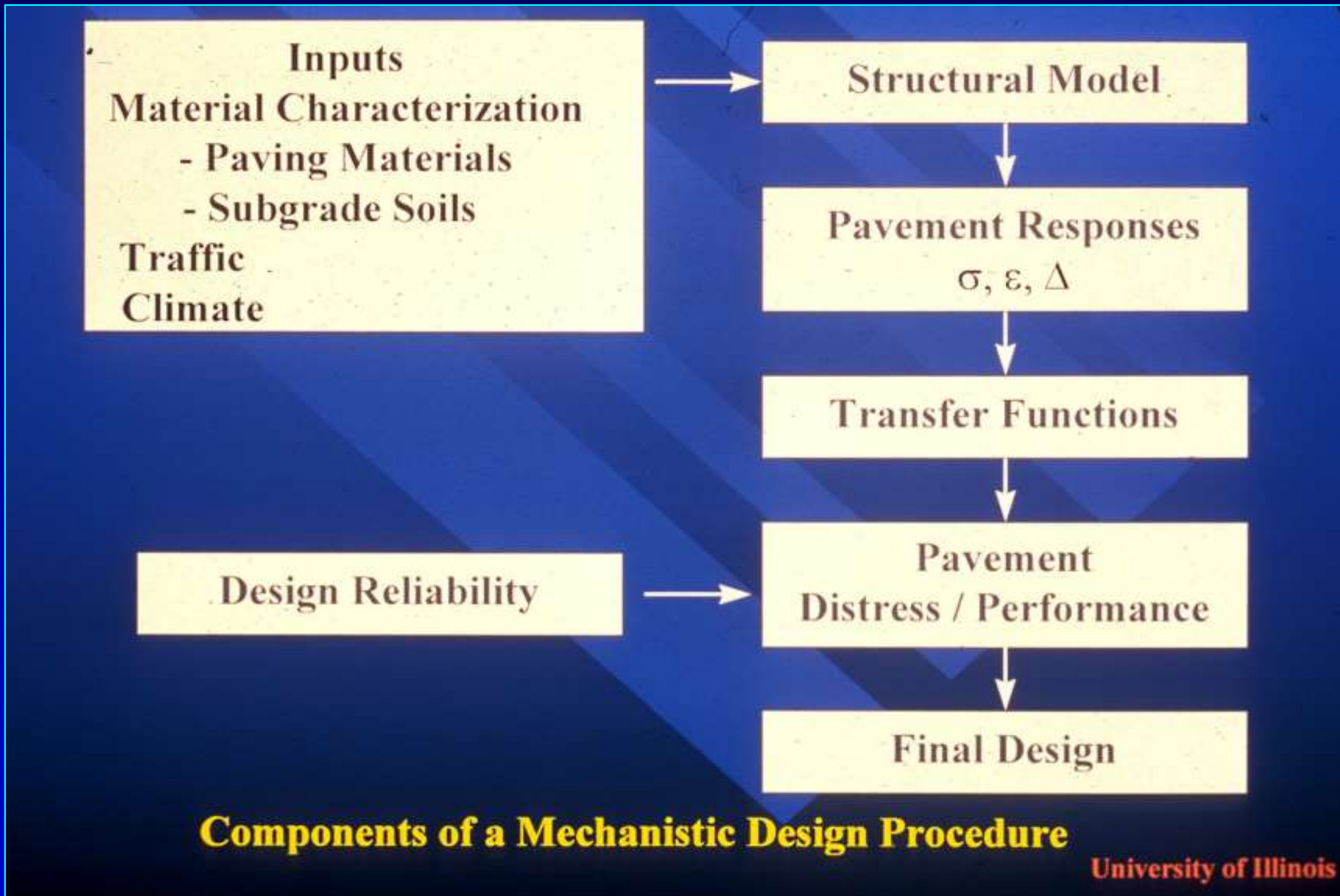
Mechanistic Pavement Design

Supplement to Section 7 of the Illinois Department of Transportation Design Manual

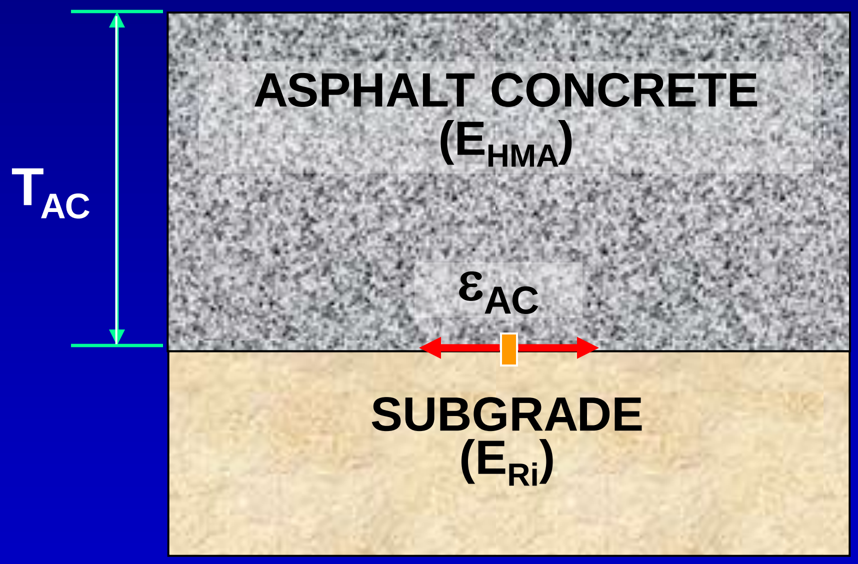
Illinois Department of Transportation

SINCE 1989:

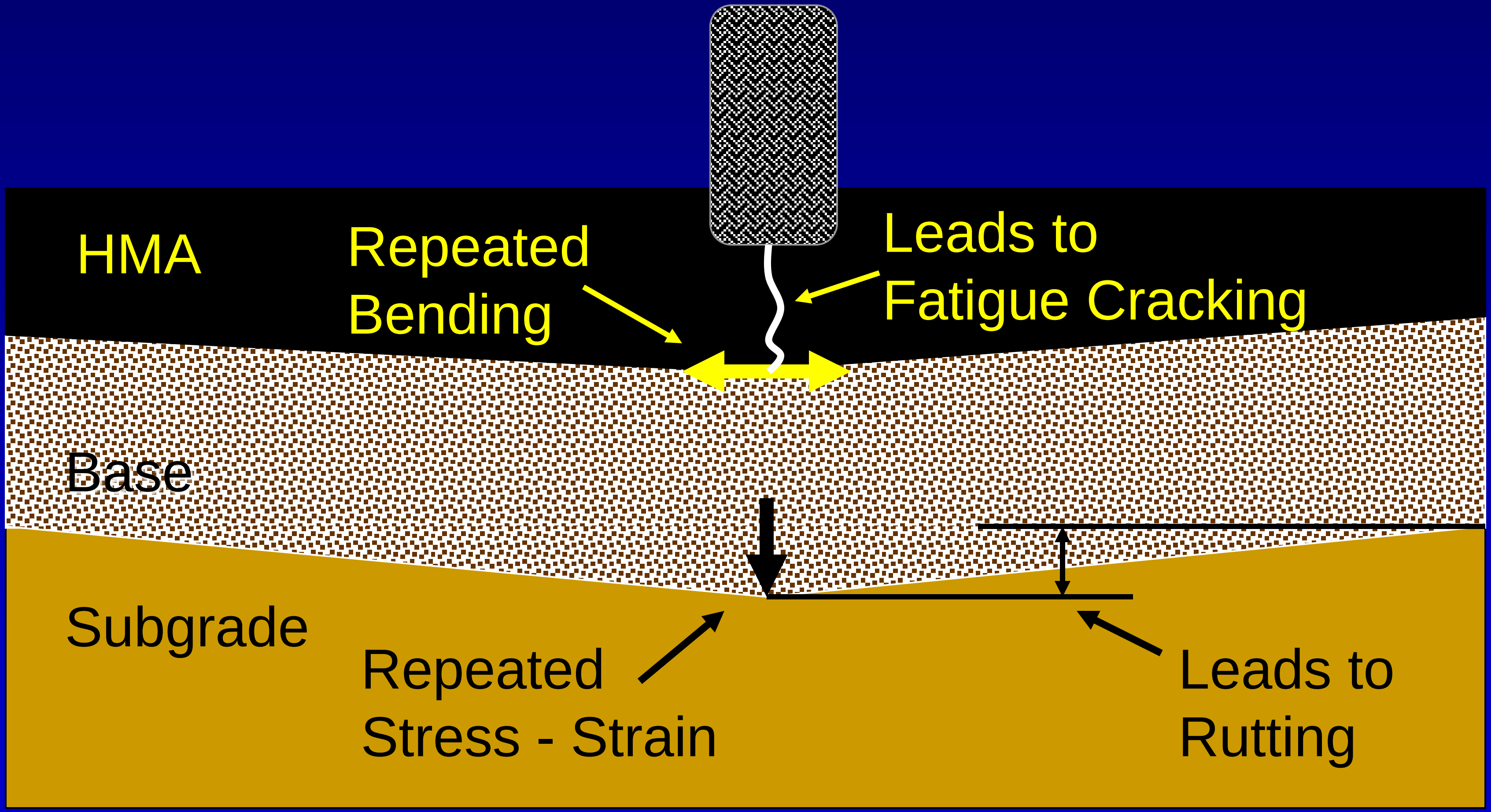
FD-HMA 

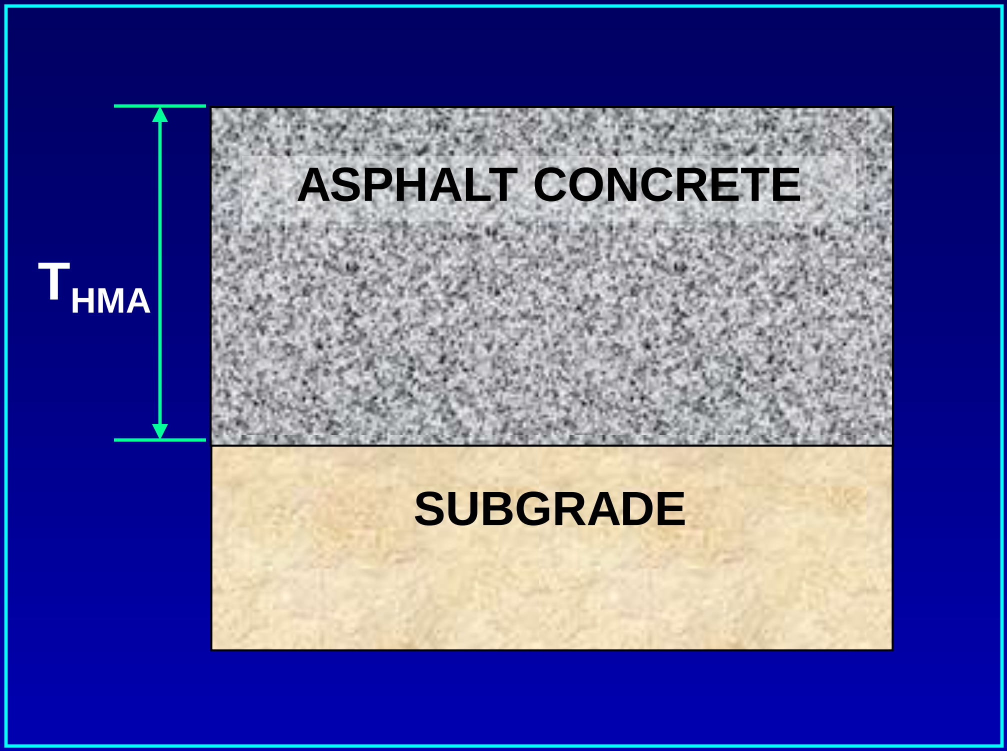

Inputs
Material Characterization
- Paving Materials
- Subgrade Soils
Traffic
Climate
Structural Model
Pavement Responses
σ, ε, Δ
Transfer Functions
Design Reliability
Pavement
Distress / Performance
Final Design
Components of a Mechanistic Design Procedure
University of Illinois

FULL-DEPTH HMA PAVEMENT



HMA
M-E DESIGN CONCEPTS





DESIGN

- HMA FATIGUE
- HMA RUTTING
- SUBGRADE RUTTING

HIGH ESAL PAVEMENTS

- SUBGRADE RUTTING –
  NORMALLY NOT A PROBLEM

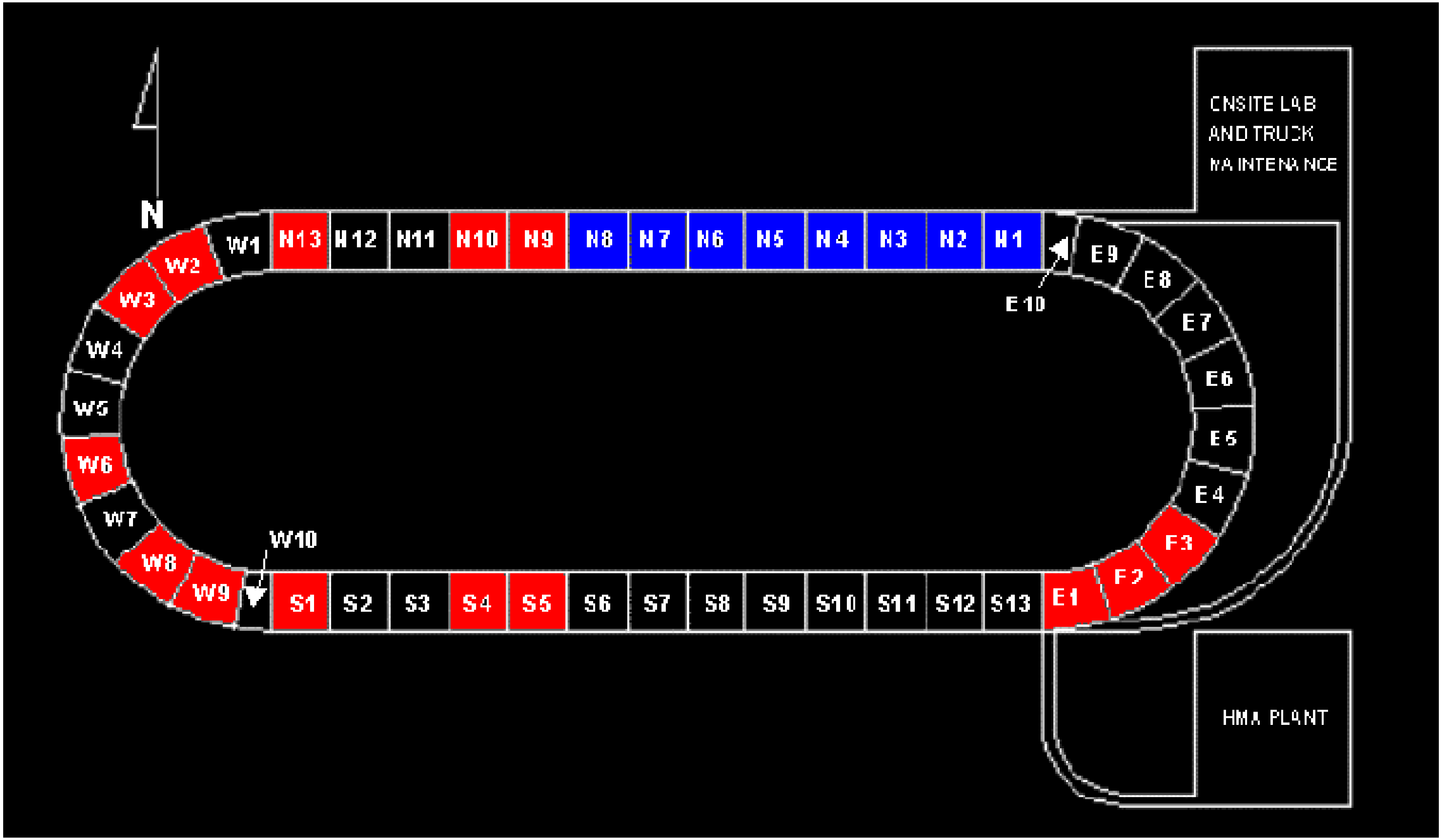
- “WORKING PLATFORM” –
  ESSENTIAL FOR PAVING!!!!!

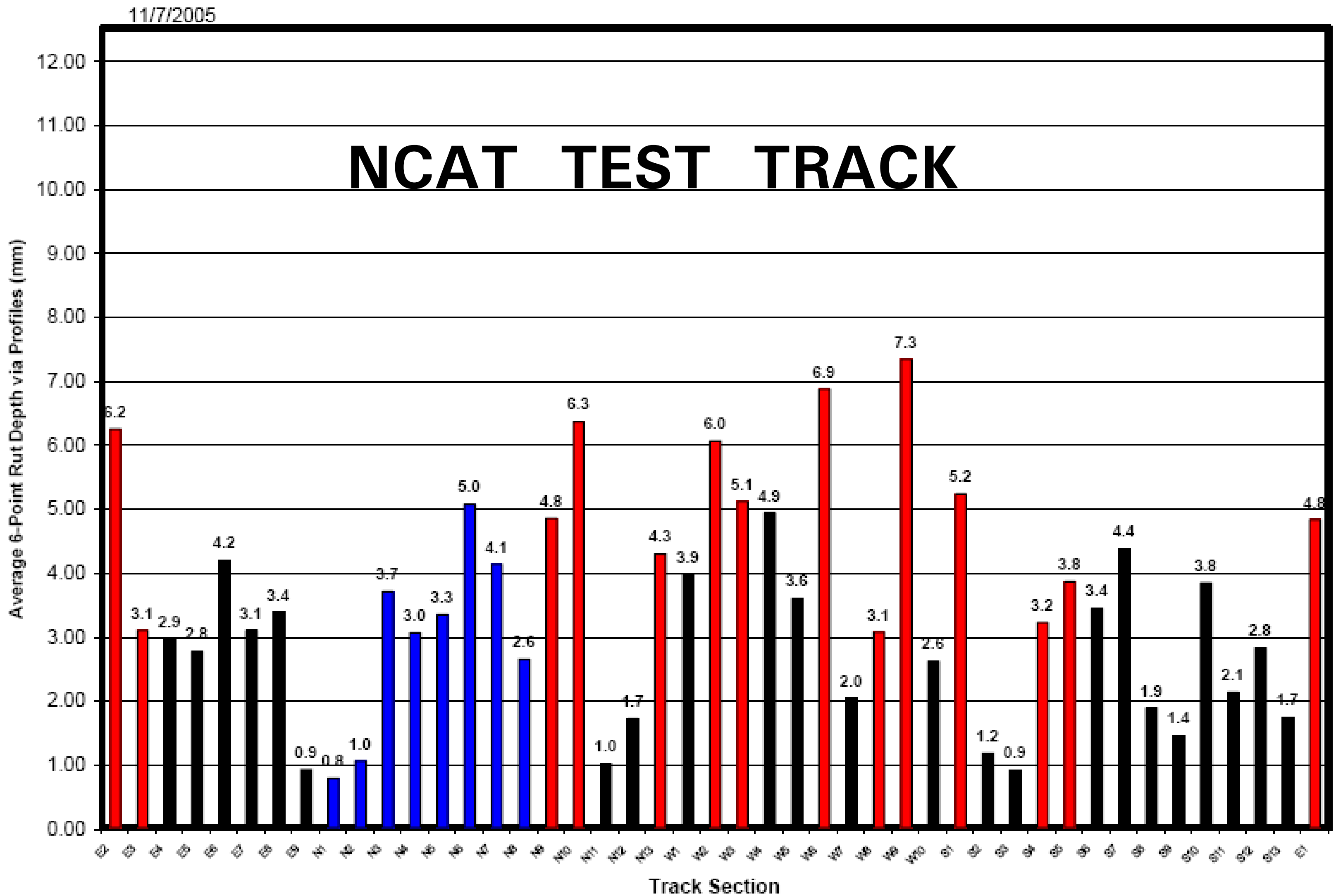
HMA RUTTING

NCAT TEST TRACK

- ORIGINAL CONSTRUCTION
- RECONSTRUCTION

ORIGINAL MILL/INLAY STRUCTURAL




11/7/2005
NCAT TEST TRACK
Average 6-Point Rut Depth via Profiles (mm)
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
6.2
3.1
2.9
2.8
4.2
3.1
3.4
0.9
0.8
1.0
3.7
3.0
3.3
5.0
4.1
2.6
4.8
6.3
1.0
1.7
4.3
3.9
6.0
5.1
4.9
3.6
6.9
2.0
3.1
7.3
2.6
5.2
1.2
0.9
3.2
3.8
3.4
4.4
1.9
1.4
3.8
2.1
2.8
1.7
4.8
Track Section

HMA RUTTING

*MATERIALS SELECTION (AGGREGATES – ASPHALT)

*MIXTURE DESIGN (SUPERPAVE)

*CONSTRUCTION QC/QA

RUT RESISTANT !!!

HMA FATIGUE

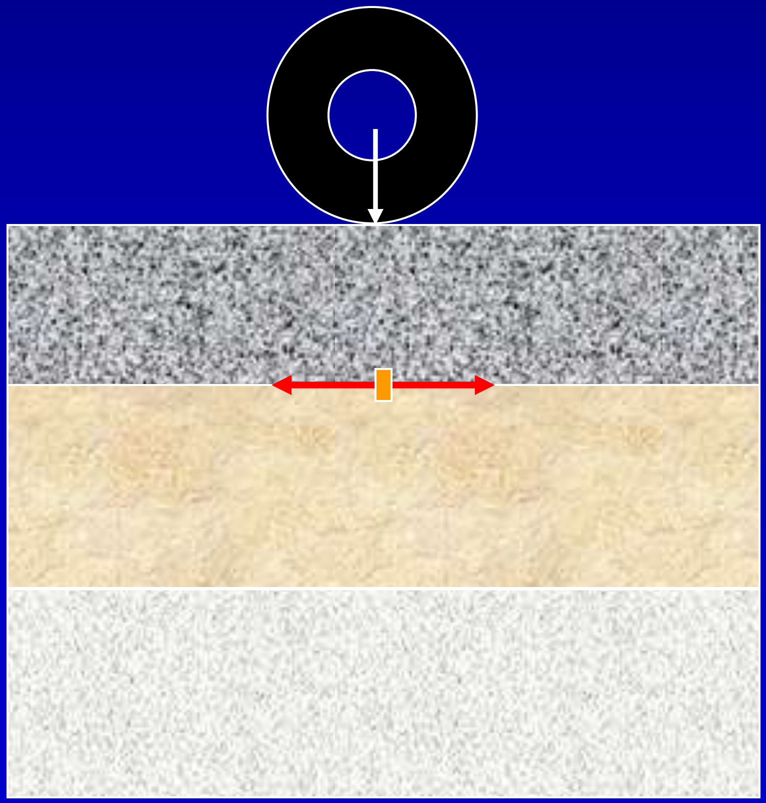
AASHTO TP 8-94

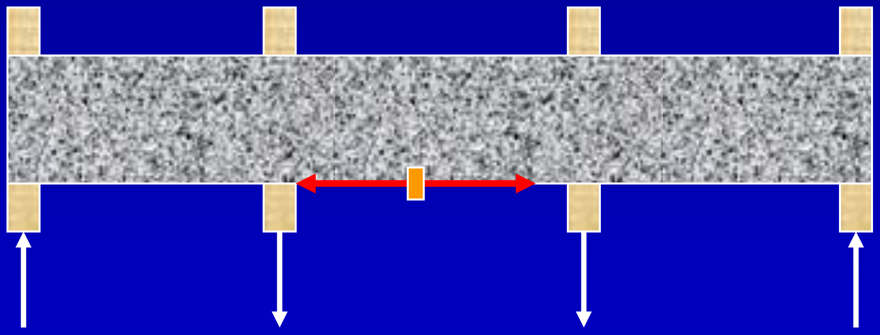
Standard Test Method for Determination of the Fatigue Life of Compacted HMA Subjected to Repeated Flexural Bending

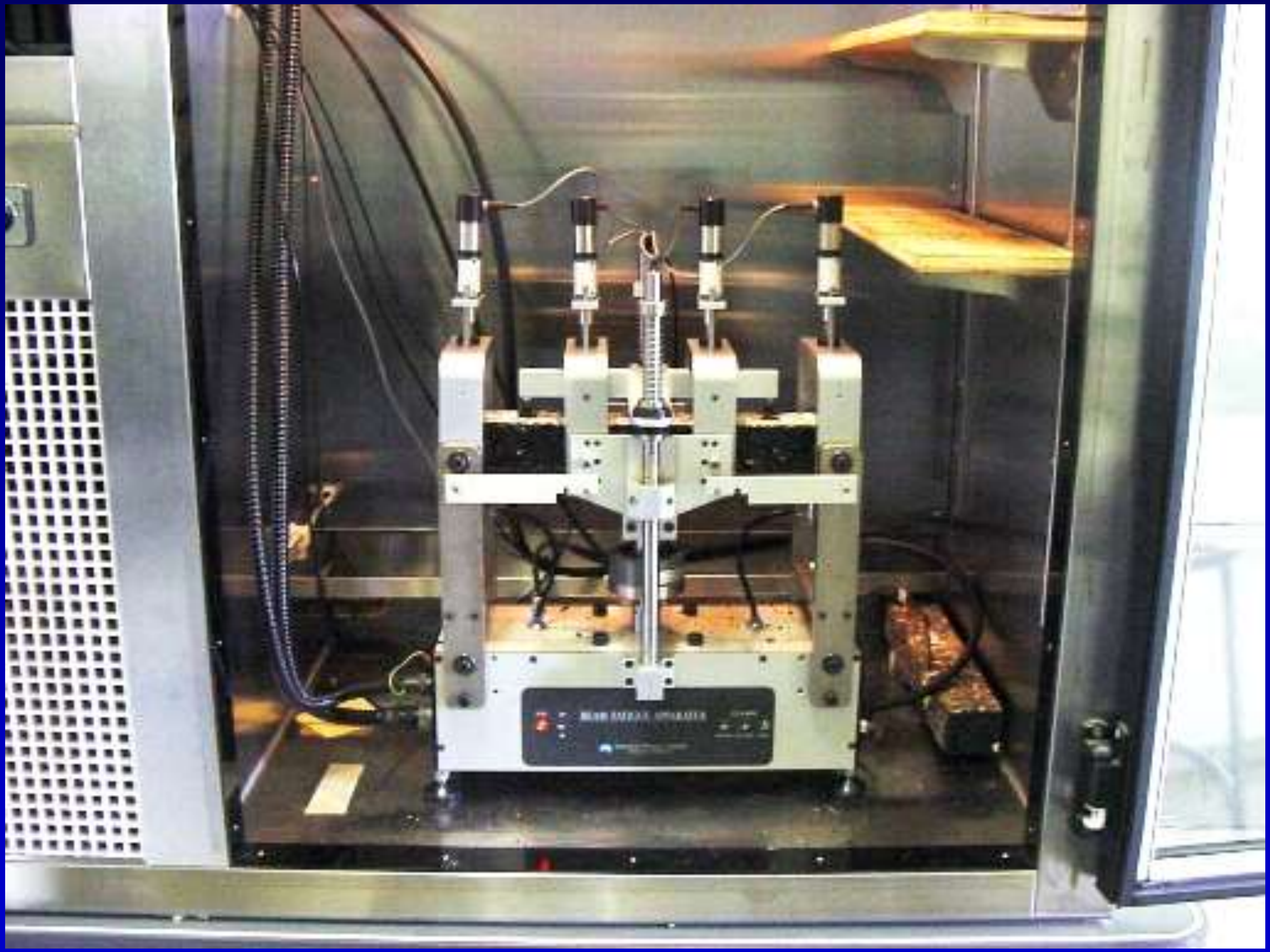
FATIGUE DESIGN

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

Other Configurations

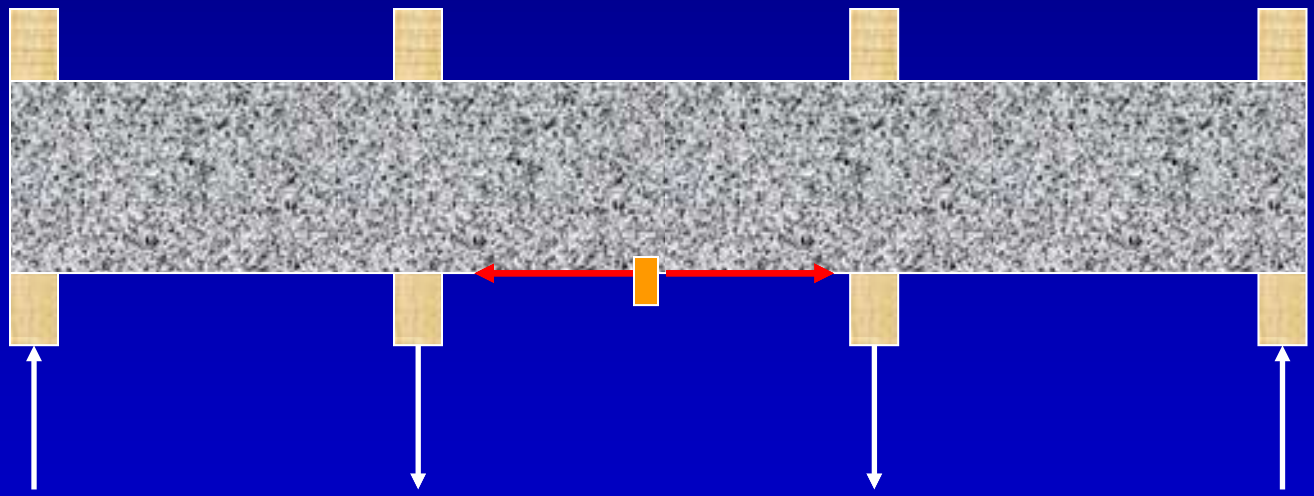






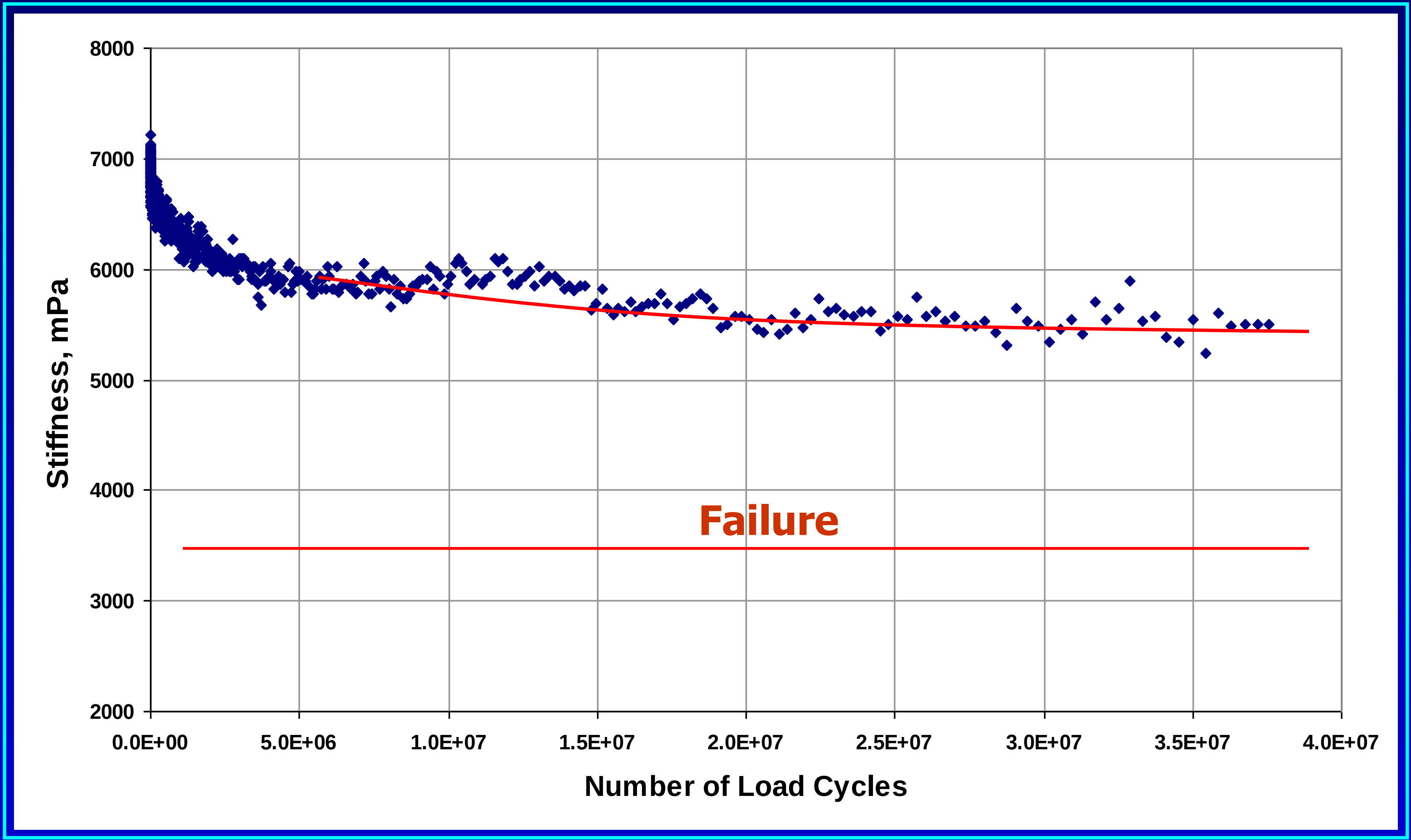
FATIGUE TESTING

- Tensile Strain in Flexural Beam Test
  - Other Configurations

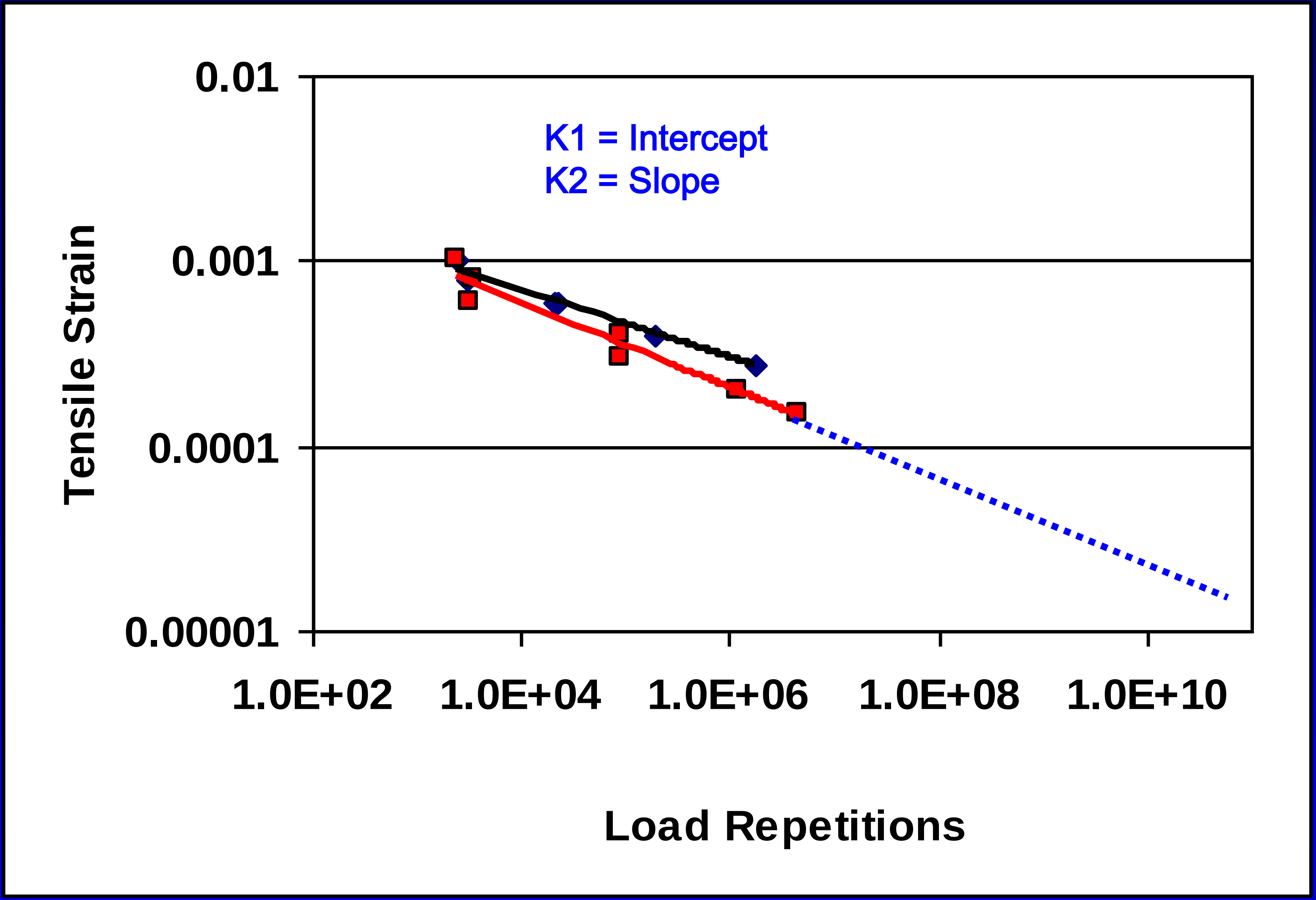


  - 10 Hz Haversine Load, 20º C, Controlled Strain

STIFFNESS CURVE



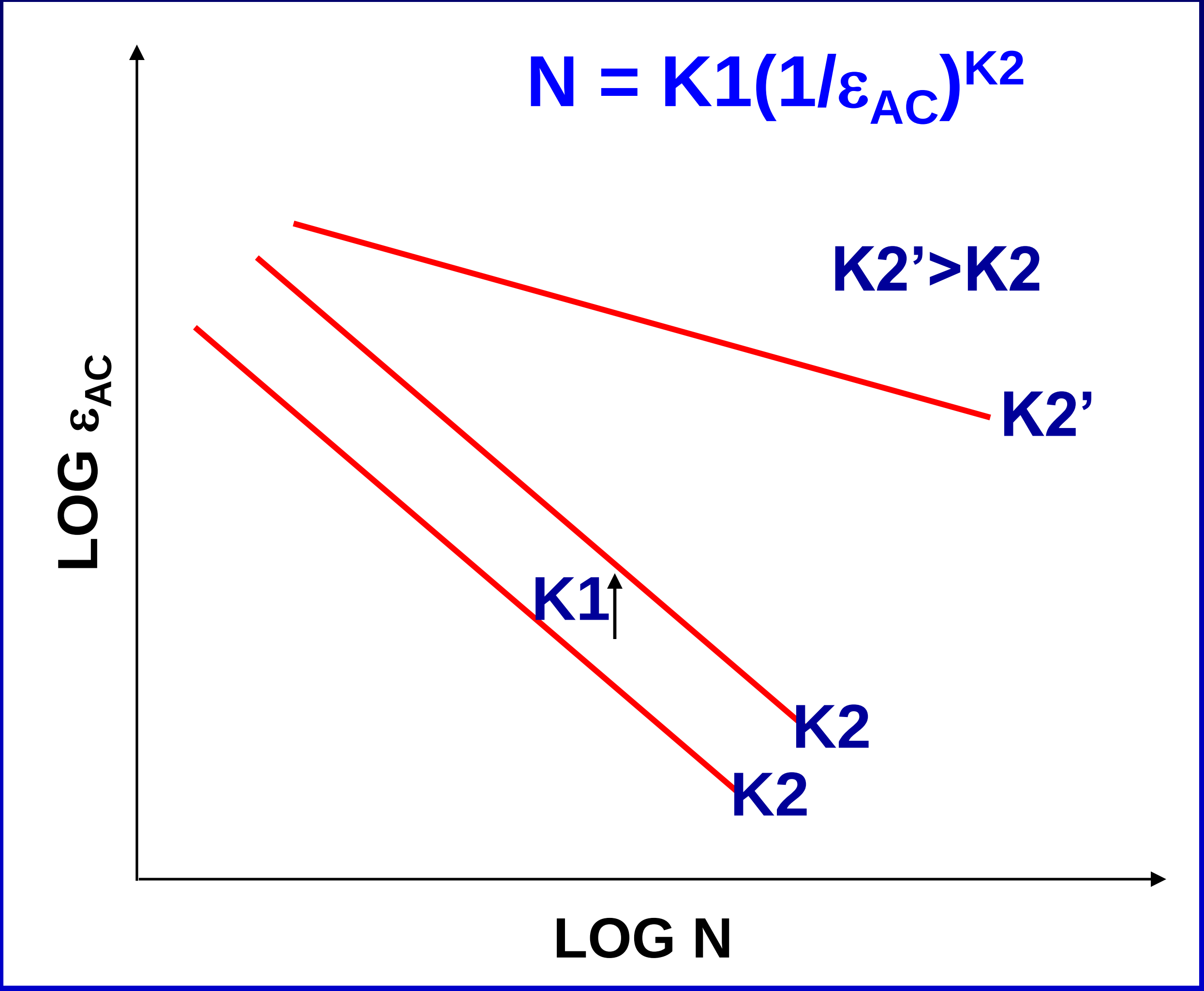
LABORATORY ALGORITHM



HMA FATIGUE ALGORITHM

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

AC FATIGUE



HMA FATIGUE

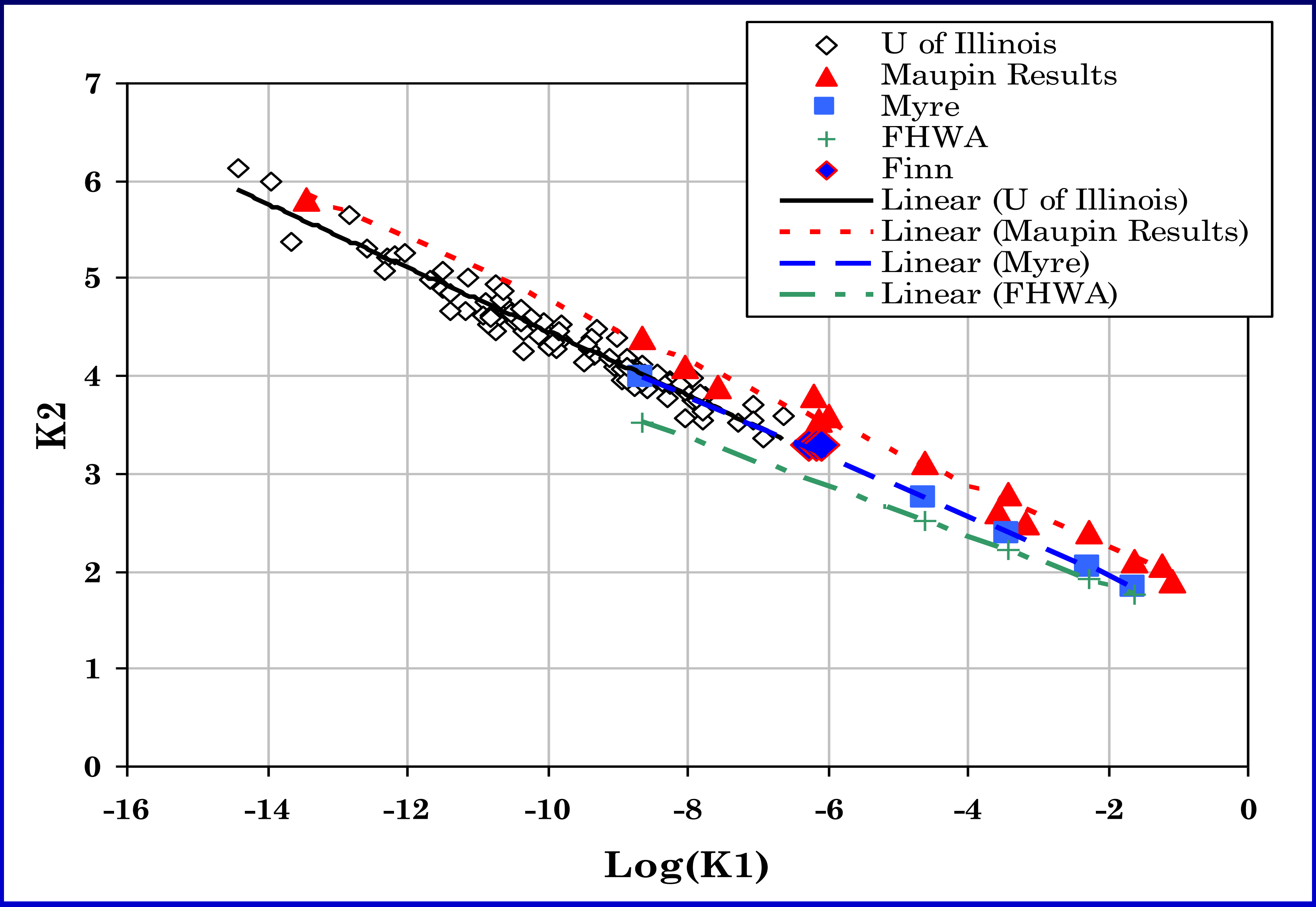
$$N = K1\ (1 / \varepsilon_{AC})^{K2}$$

K2: 3.5 - 6

CURRENT IDOT
HMA FATIGUE ALGORITHM

$$N = 5E\text{-}6 * (1 / \text{HMA STRAIN})^{3.0}$$

OTHER STUDIES



K1 – K2 RELATIONS

U of IL (IHR-39)

IDOT HMAS

$$\text{LOG K1} = (1.1784 - \text{K2}) / 0.329$$

UofI/IDOT HMA FATIGUE DATA SUMMARY

Minimum K2: 3.5

90% K2: > 4.0

Average K2: 4.5

$N = K1(1/HMA\ STRAIN)^{K2}$

HMA STRAIN (цЄ)	IDOT (1989)	K2 3.5	k2 4.0	K2 4.5
75	11.9	22.4	60.0	160.6
150	1.5	2.0	3.8	7.1
250	0.32	0.33	0.49	0.71

MESALS

THERE IS

NO “UNIQUE”

HMA FATIGUE ALGORITHM !!!!

TRADITIONAL M-E DESIGN

MINER'S

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

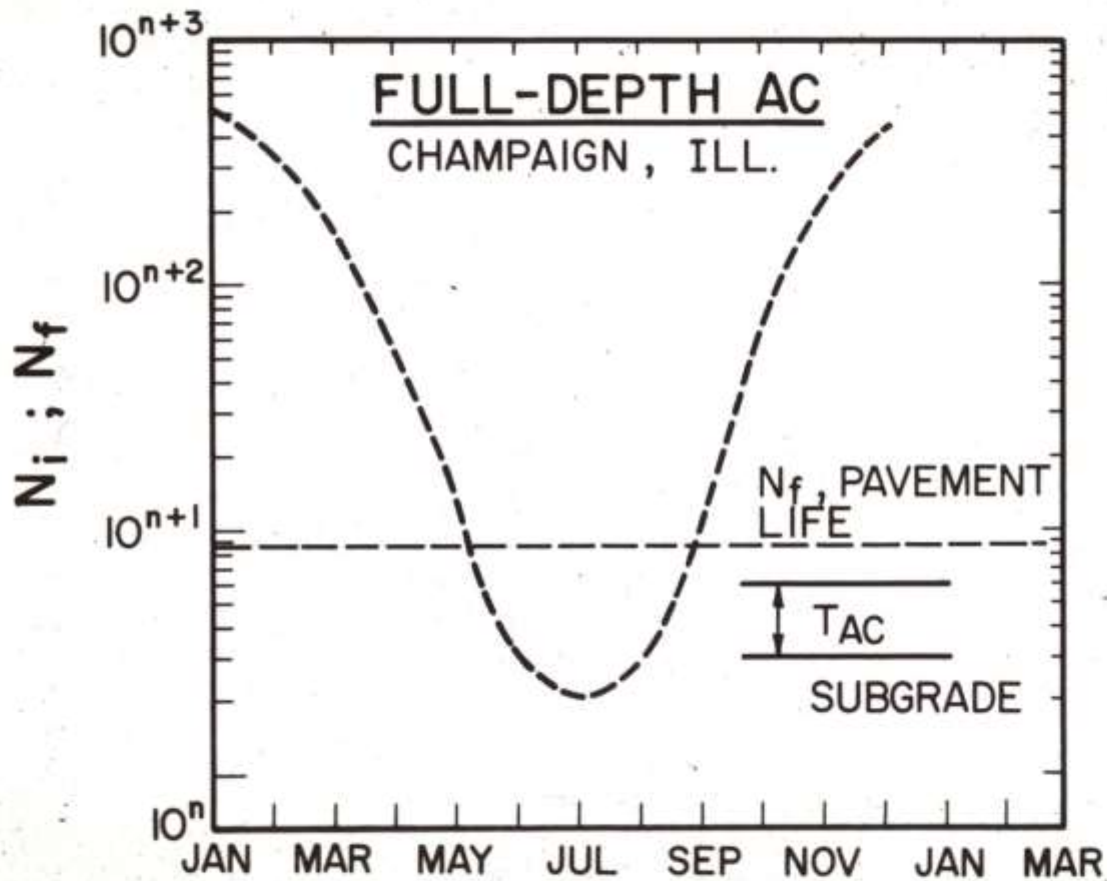
$$\text{FAILURE} : \sum_{i=1}^{n} P_i = 100$$

MINER'S

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

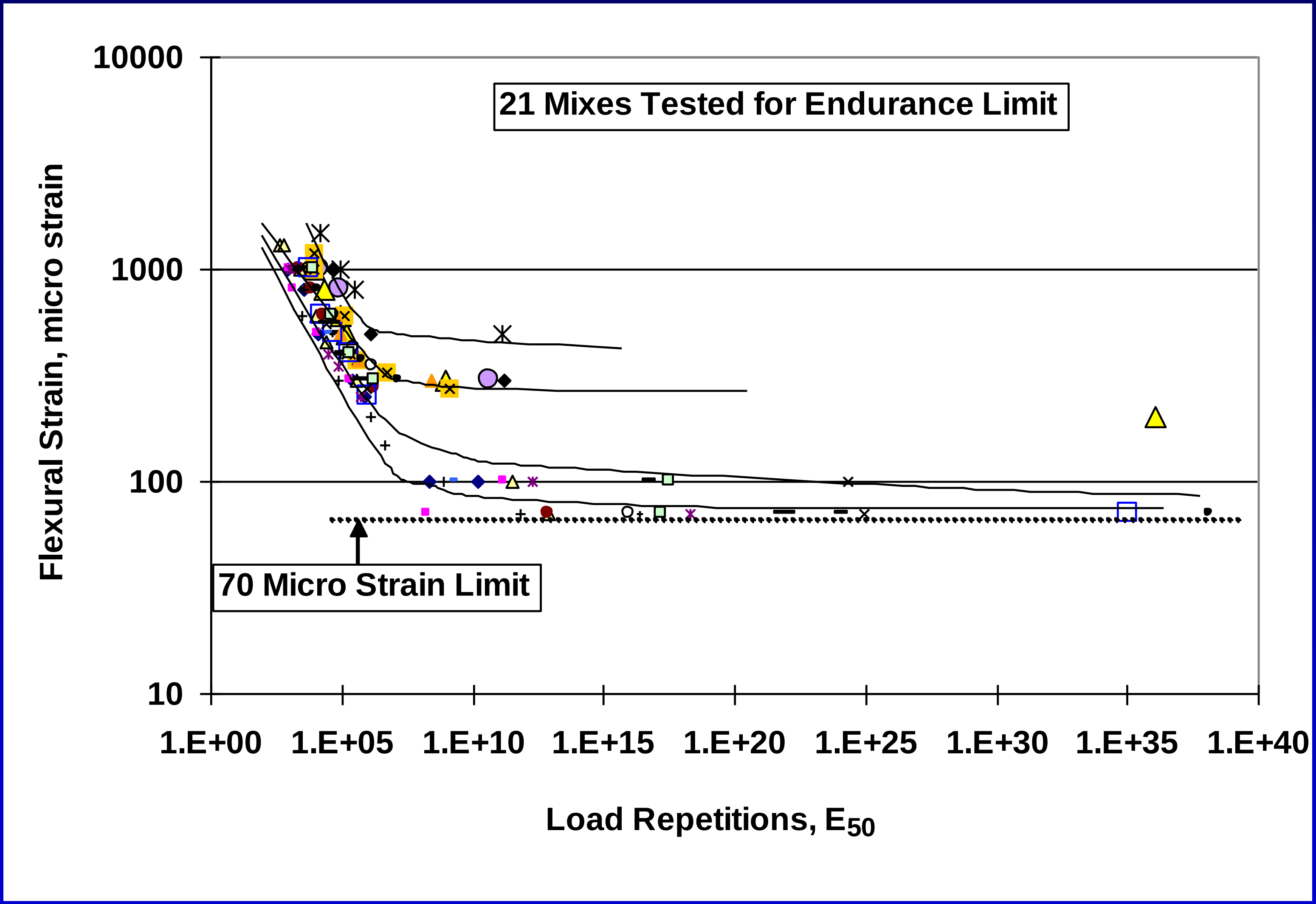
N_f = "TOTAL" PAVT. LIFE

N_i = PAVT. LIFE-MONTH "i"

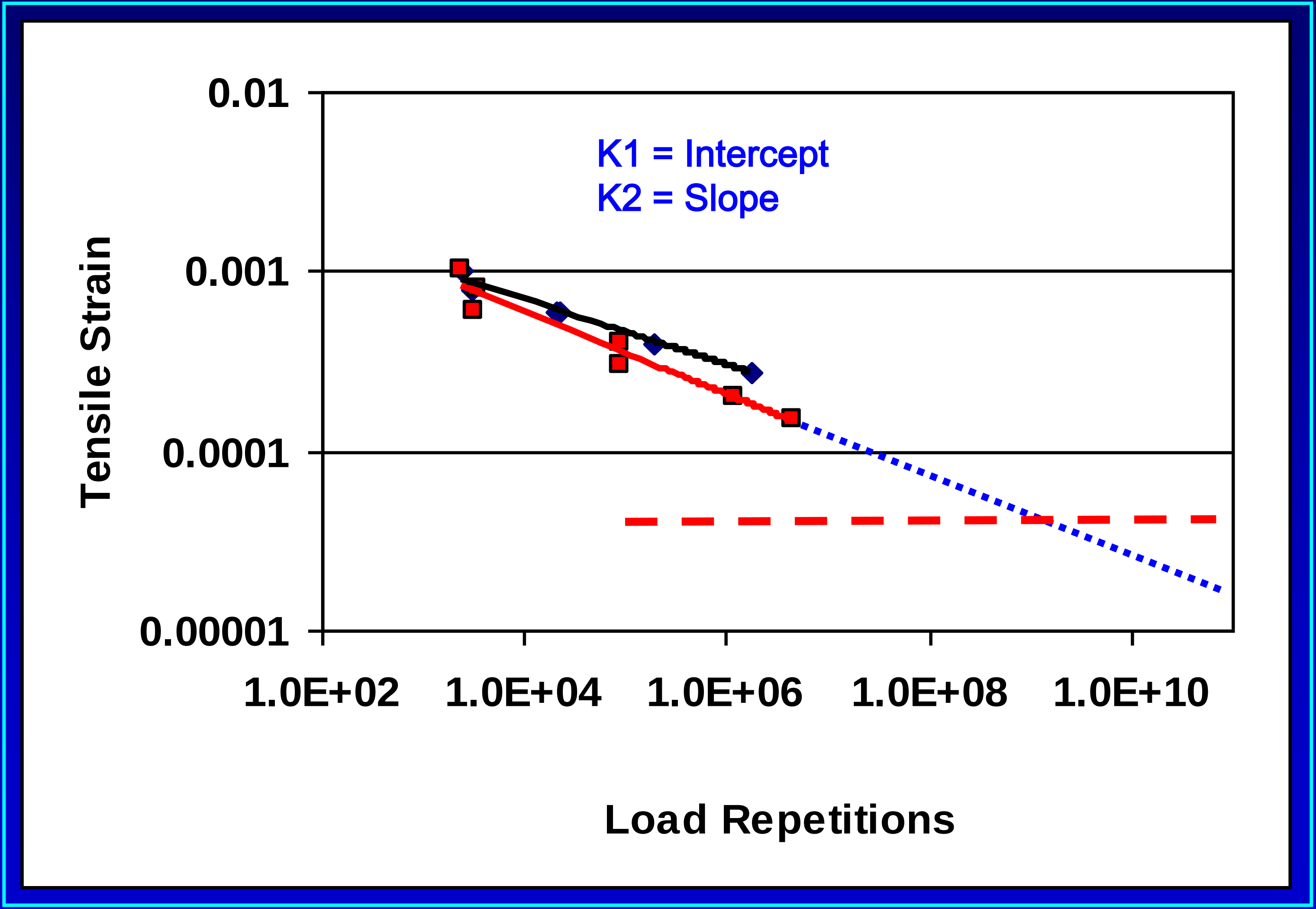


FULL-DEPTH AC
CHAMPAIGN, ILL.
10^{n+3}
10^{n+2}
10^{n+1}
10^{n}
N_i ; N_f
N_f, PAVEMENT LIFE
T_{AC}
SUBGRADE
JAN
MAR
MAY
JUL
SEP
NOV
JAN
MAR

LOW STRAIN TESTING



FATIGUE ENDURANCE LIMIT



FATIGUE ENDURANCE LIMIT

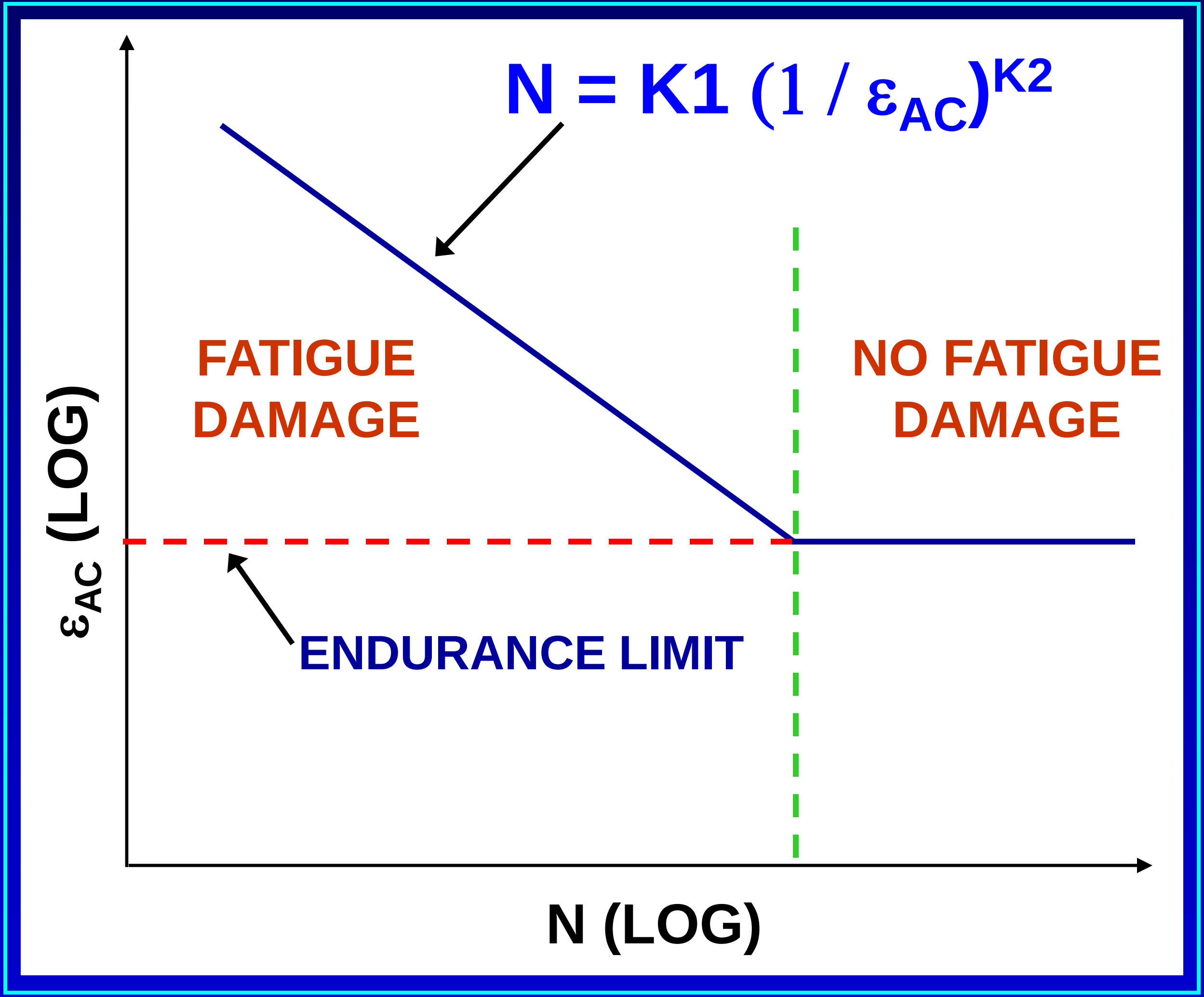
- **Damage and Healing Concepts and Test Data Support a Strain Limit Below Which Fatigue Damage Does Not Accumulate**
- **Strain Limit Is Not The Same for All HMAs.**

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



N = K1 (1 / εAC)K2
FATIGUE DAMAGE
NO FATIGUE DAMAGE
εAC (LOG)
ENDURANCE LIMIT
N (LOG)

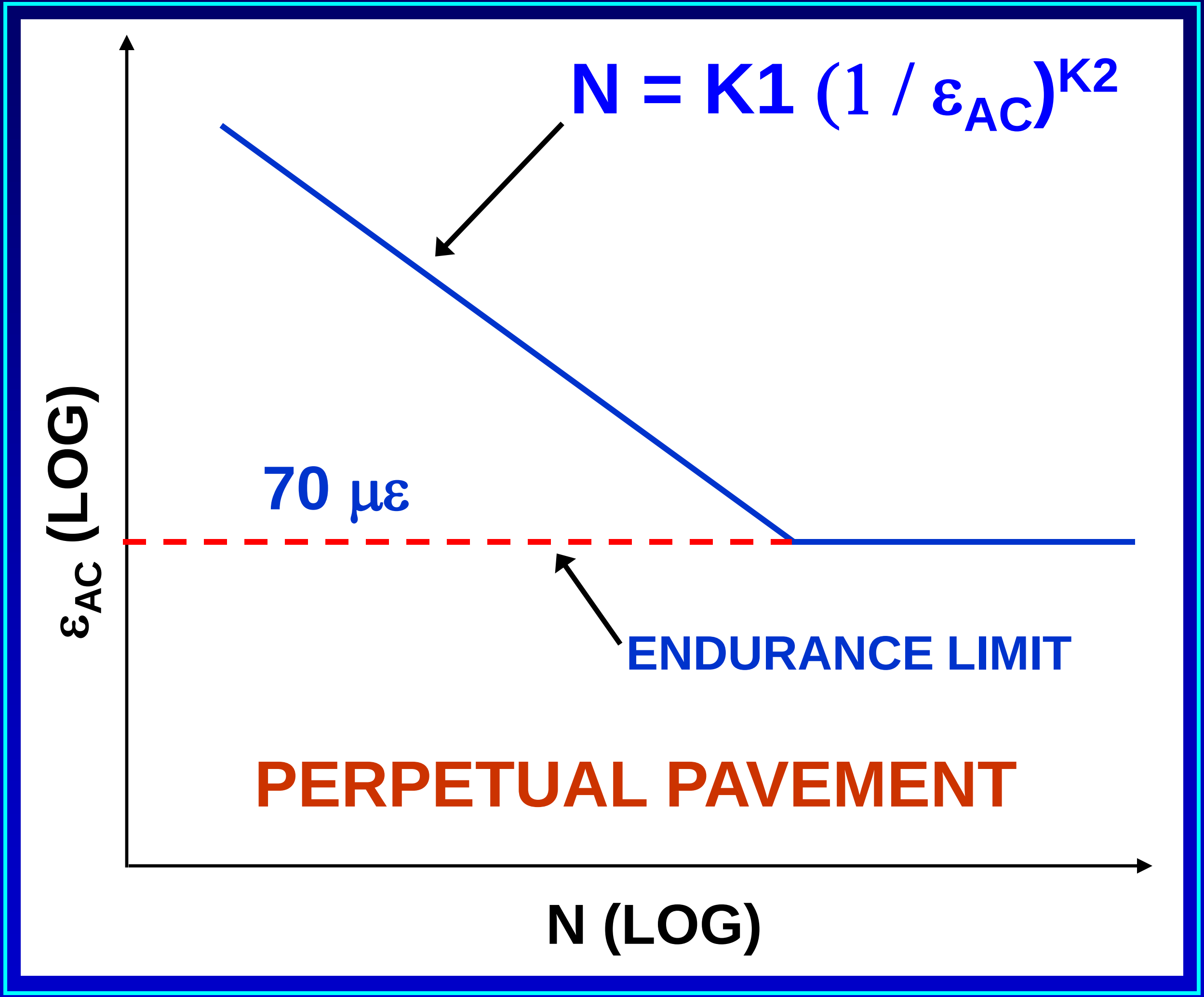
FATIGUE ENDURANCE LIMIT IDOT DATA

NEVER < 70 micro-strain!!!

GENERALLY: 70 –100 micro-strain

MAY BE > 100 micro-strain

HMA FATIGUE



*Monismith and McLean
('72 AAPT)

EFFECT OF REST PERIODS

SMALL REST PERIODS BETWEEN STRAIN REPETITIONS SIGNIFICANTLY INCREASES HMA FATIGUE LIFE

IDOT HMA
5 SECONDS: 10 X

OVERLOADING

- HMA CAN SUSTAIN "SPORADIC OVERLOADS" AND RETURN TO "ENDURANCE LIMIT" PERFORMANCE

- SUBSEQUENT HMA STRAIN REPETITIONS < ENDURANCE LIMIT:

"DO NOT COUNT"

M-E DESIGN
OF
LONG LASTING
HMA PAVEMENTS

STRUCTURAL MODEL

Stress-Dependent Finite Element

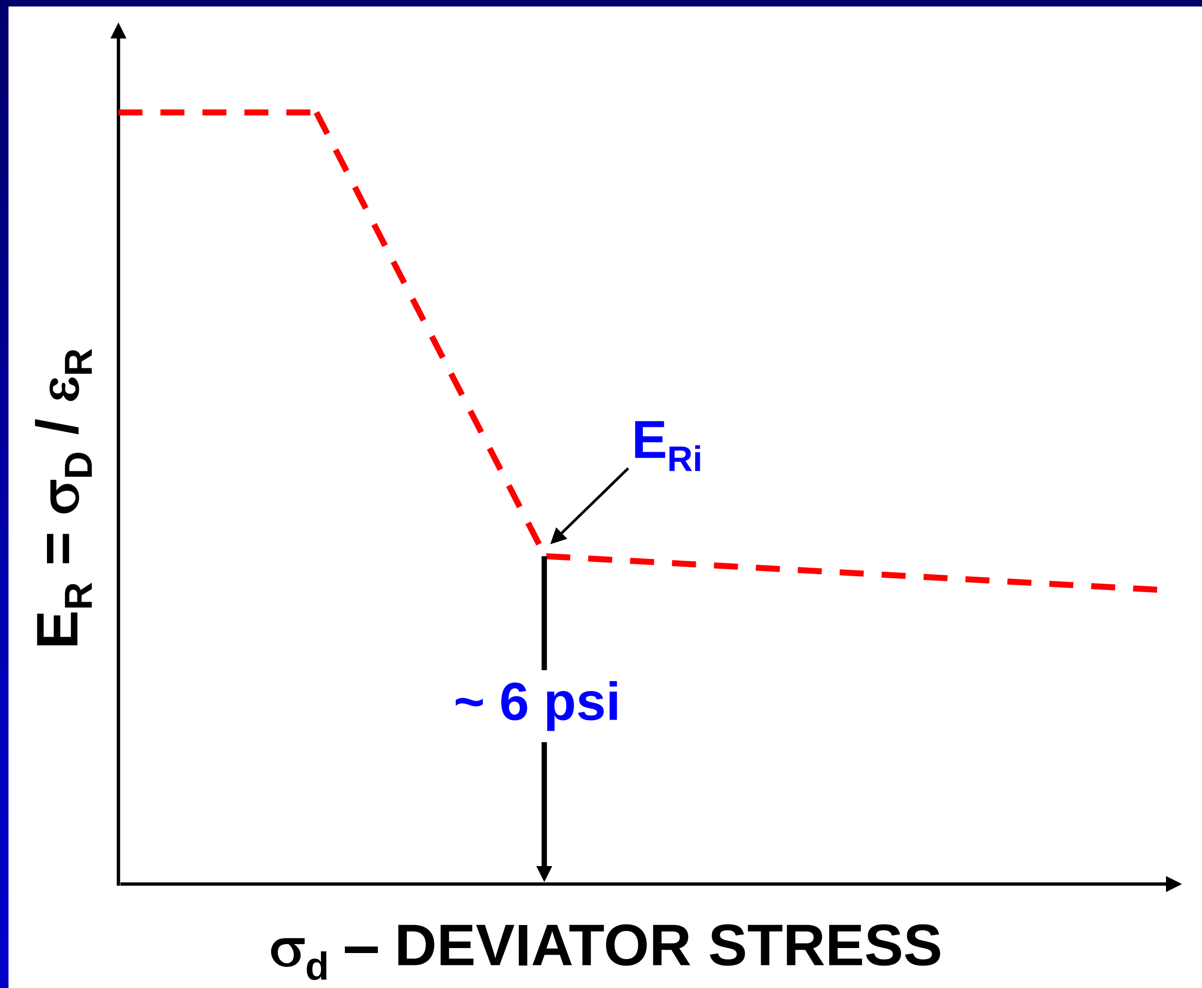
ILLI-PAVE

ILLI-PAVE INPUTS

* SUBGRADE MODULUS (E_{Ri})

* HMA MODULUS

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

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

HOT MIX ASPHALT

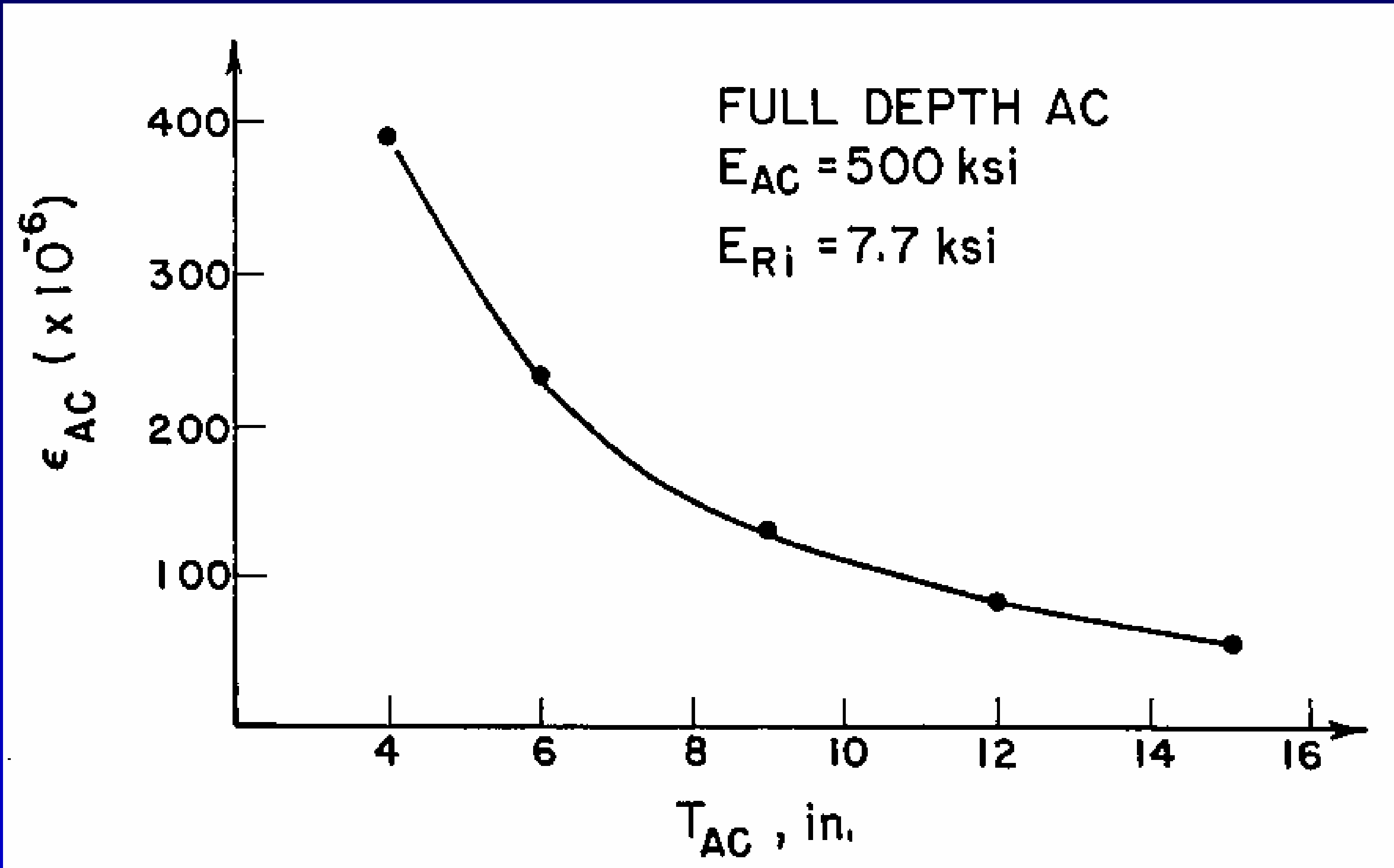
LINEAR ELASTIC (E)

E = f (Temp & Freq)

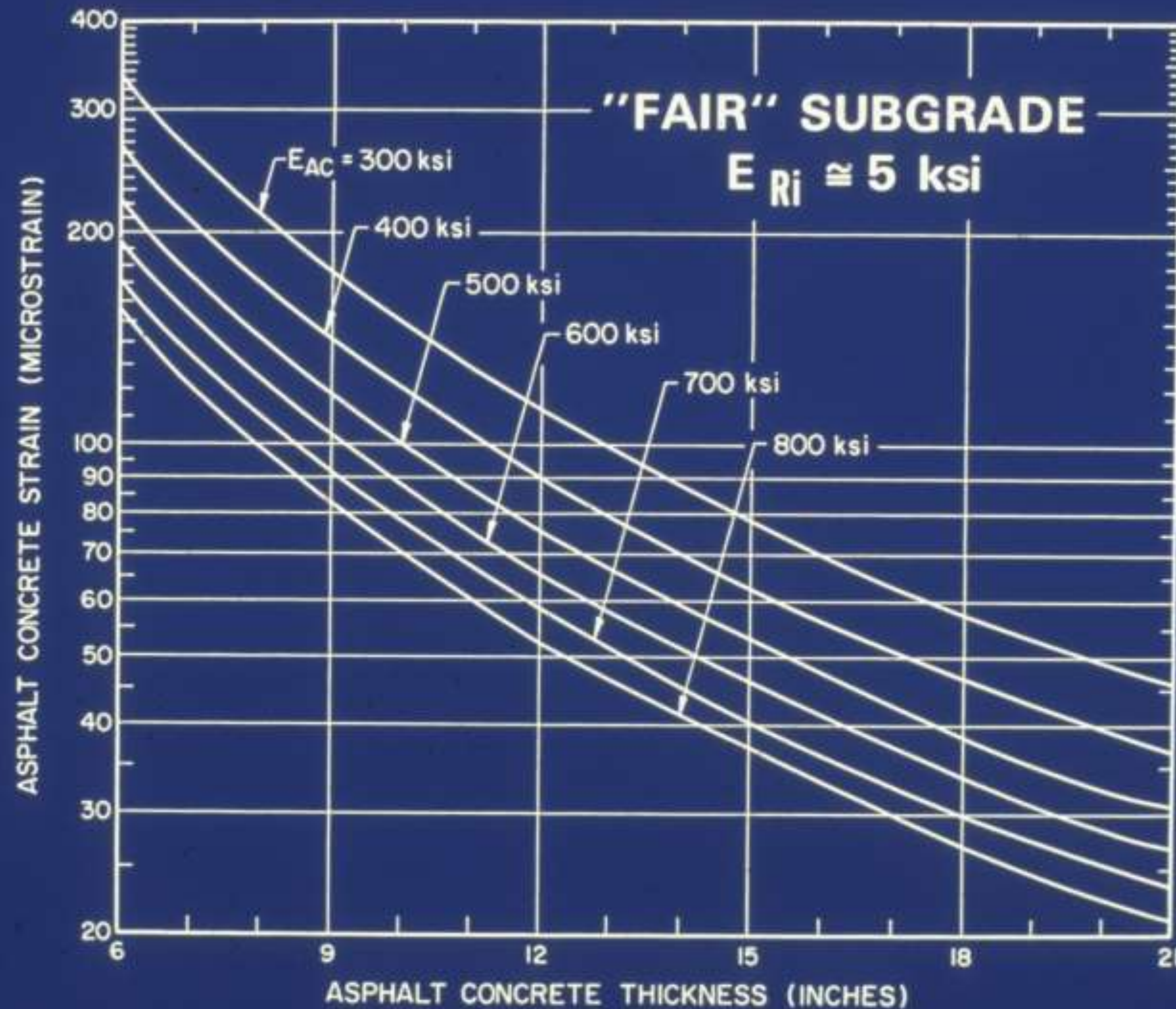
FULL-DEPTH HMA

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

ε_{HMA}: $\mu\varepsilon$ 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 ≅ 5 ksi
EAC = 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)

FULL-DEPTH HMA

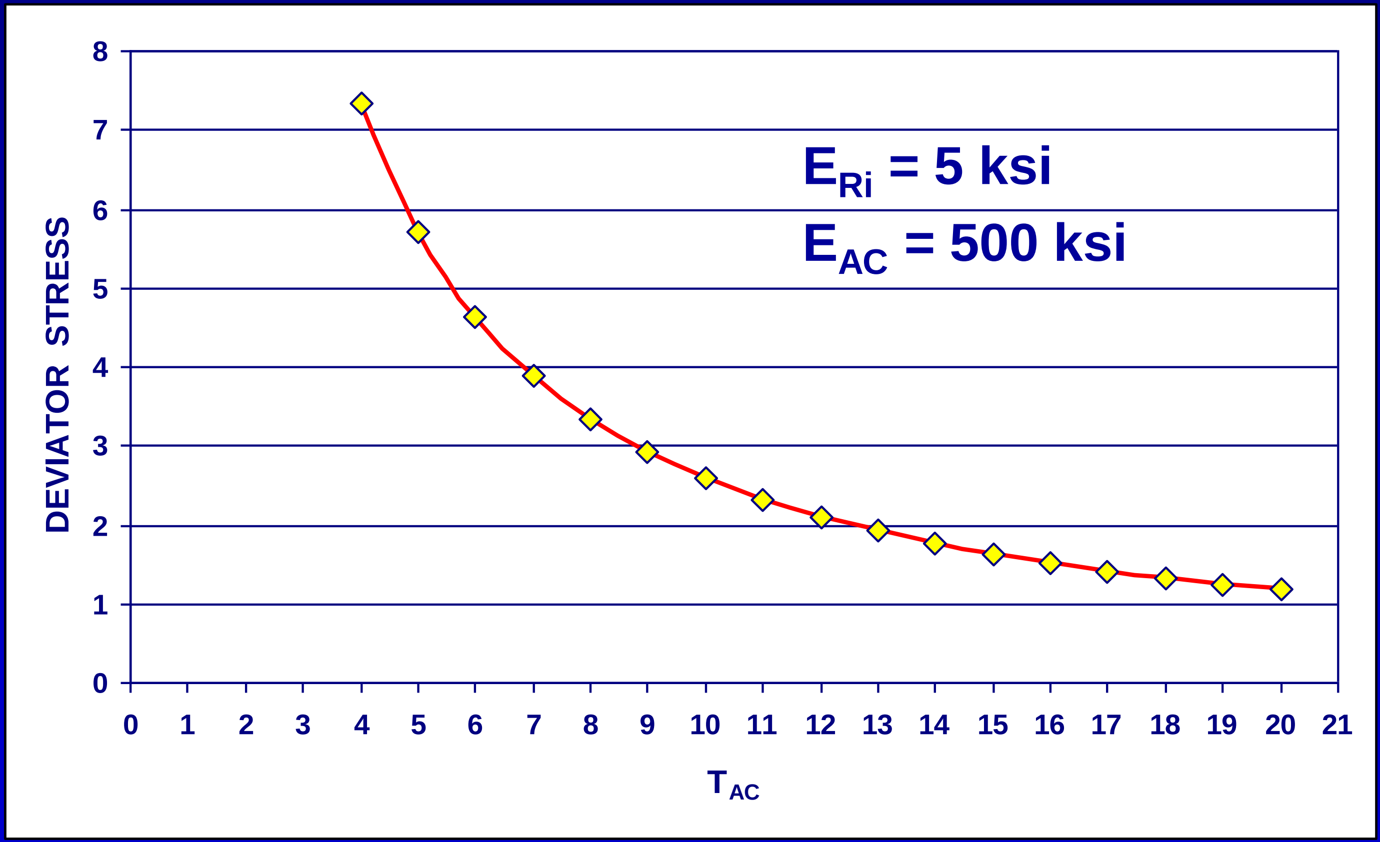
$$\text{LOG } \sigma_D = 2.74 - 1.14 \text{ LOG } T_{HMA} - 0.515 \text{ LOG } E_{HMA} + 0.29 \text{ LOG } E_{Ri}$$

σ_D: psi T_{HMA}: in. E_{HMA}:ksi E_{Ri}: ksi

FULL-DEPTH HMA

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

σ_D : psi T_{HMA} : in. E_{HMA}: ksi E_{Ri} : ksi



SEASONAL EFFECTS

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

MUST CONSIDER IN M-E DESIGN

ASPHALT INSTITUTE EQUATION
TAI RR-82-2 (1982)

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

P_{200} = % - # 200

V_V = % AIR VOIDS

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

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

t_p = TEMPERATURE (°F)

f = FREQUENCY (Hz)

PG GRADE EFFECTS

TEMP (°F)	HMA MODULUS (ksi) 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 (^oF)	HMA MODULUS (ksi) HMA-4.0 %*	HMA-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

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

$$- [34 / \{Z + 4\}] + 6$$

Z: INCHES FROM SURFACE

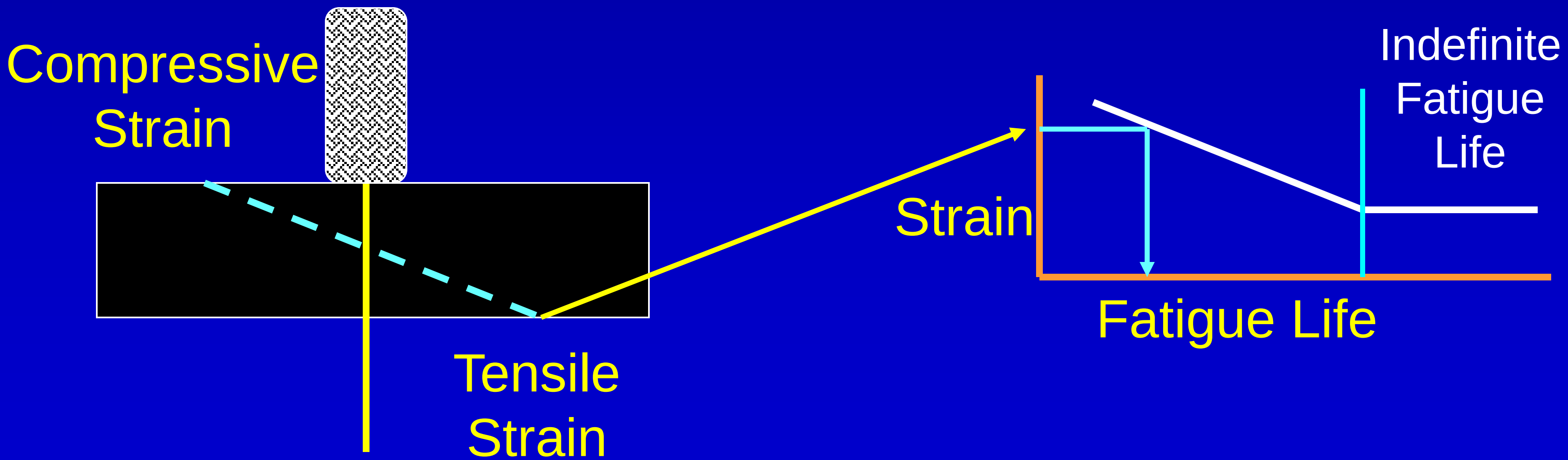
CHAMPAIGN, IL		
MONTH	**MMAT (°F)**	**MMPT (°F)**
JAN	27.1	32.5/30.4
FEB	33.0	39.1/37.9
MAR	40.6	47.8/46.6
APR	51.2	58.9/59.5
MAY	62.5	72.0/73.9
JUN	72.0	83.4/82.9
JUL	74.7	86.5/84.9
AUG	72.8	84.3/82.3
SEP	65.8	76.4/74.1
OCT	54.7	63.7/62.5
NOV	41.8	49.1/46.8
DEC	32.4	38.5/38.0

TEMPS @ 4 inches

ICM/AI

Pavement Design Concepts

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



AXLE LOADING

20-Kip Single

34-kip Dual/Tandem

TYPICAL INTERSTATE
(AASHTO 2002 Guide)

* 80% -90% / 18-Wheelers

* 2.5% Singles > 18 kips

* 1% > 20 kips

PERPETUAL PAVEMENT
(70 MICRO-STRAIN / 9 kips)
(SUBGRADE E_{Ri} - 5 ksi)

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

PERPETUAL PAVEMENT
RUBBLIZED PCCP

"HMA OVERLAY DESIGN CONCEPTS FOR RUBBLIZED PCCP"

M. R. Thompson
TRB RECORD # 1694 – 1999
(Basis for IDOT Design)

PERPETUAL PAVEMENT

RUBBLIZED PCCP
(70 MICRO-STRAIN)

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

DESIGN PRINCIPLES FOR LONG LASTING HMA PAVEMENTS

(M. Thompson & S. Carpenter)

International Society
for
Asphalt Pavements
Symposium on Design &
Construction of Long Lasting
Pavements
Auburn, AL (6-04)

IL TEMPERATURE REGIONS

REGION	JULY MMAT (°F)
NORTHERN	73
CENTRAL	75.8
SOUTHERN	78.2

JULY MMPT HMA MODULI

REGION	HMA MODULUS* (ksi)
North	370 - 485 - 685
Central	325 - 425 - 600
South	290 - 370 - 520

* 58-22 / 64-22 / 70-22

HMA THICKNESS FOR 70 Micro-Strain

REGION	9-Kip T_{HMA} (inches)*	10-Kip T_{HMA} (inches)*
North	14.5 - 12.75 - 10.75	15.5 - 13.5 - 11.5
Central	15.5 - 13.5 - 11.5	16.5 - 14.5 - 12.25
South	16.5 - 14.5 -12.25	17.25 - 15.5 - 13.0

* 58-22 / 64-22 / 70-22

SUMMARY & CONCLUSIONS

HMA FATIGUE

+ NO UNIQUE FATIGUE ALGORITHM (90% IDOT K1s > 0.4)
+ HMA DISPLAYS A "FATIGUE ENDURANCE LIMIT" (FEL)
+ FEL > 70 MICRO-STRAIN
+ REST PERIODS ARE HELPFUL
+ LIMITED OVERLOADS NOT CRITICAL

SUMMARY & CONCLUSIONS
(Continued)

PAVEMENT DESIGN

+ HMA MODULUS & THICKNESS ARE DOMINANT FACTORS
+ AI PROCEDURE O.K. FOR MMPT
+ DESIGN ELP FOR “HOTTEST MONTH”
+ AVAILABLE DATA/INFO CONFIRM VERACTIY OF PROCEDURE
+ MAX HMA THICKNESS → FEL

IDOT/UI TEAM CURRENTLY:

* REVIEWING
* UPDATING
* REVISING

IDOT'S BUREAU D/E
HMA PROCEDURE

???????????