AAPA's 14th International Flexible Pavements Conference

Sydney

25–28 September 2011

BLACK WITH WHITE - AN ASSESSMENT OF POTENTIAL REHABILITATION TREATMENTS FOR CONCRETE PAVEMENT

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AUSTRALIAN ASPHALT PAVEMENT ASSOCIATION

Rigid Pavement Distresses

THE PROBLEM!!!!

PCCP DISTRESSES

* SLAB CRACKING

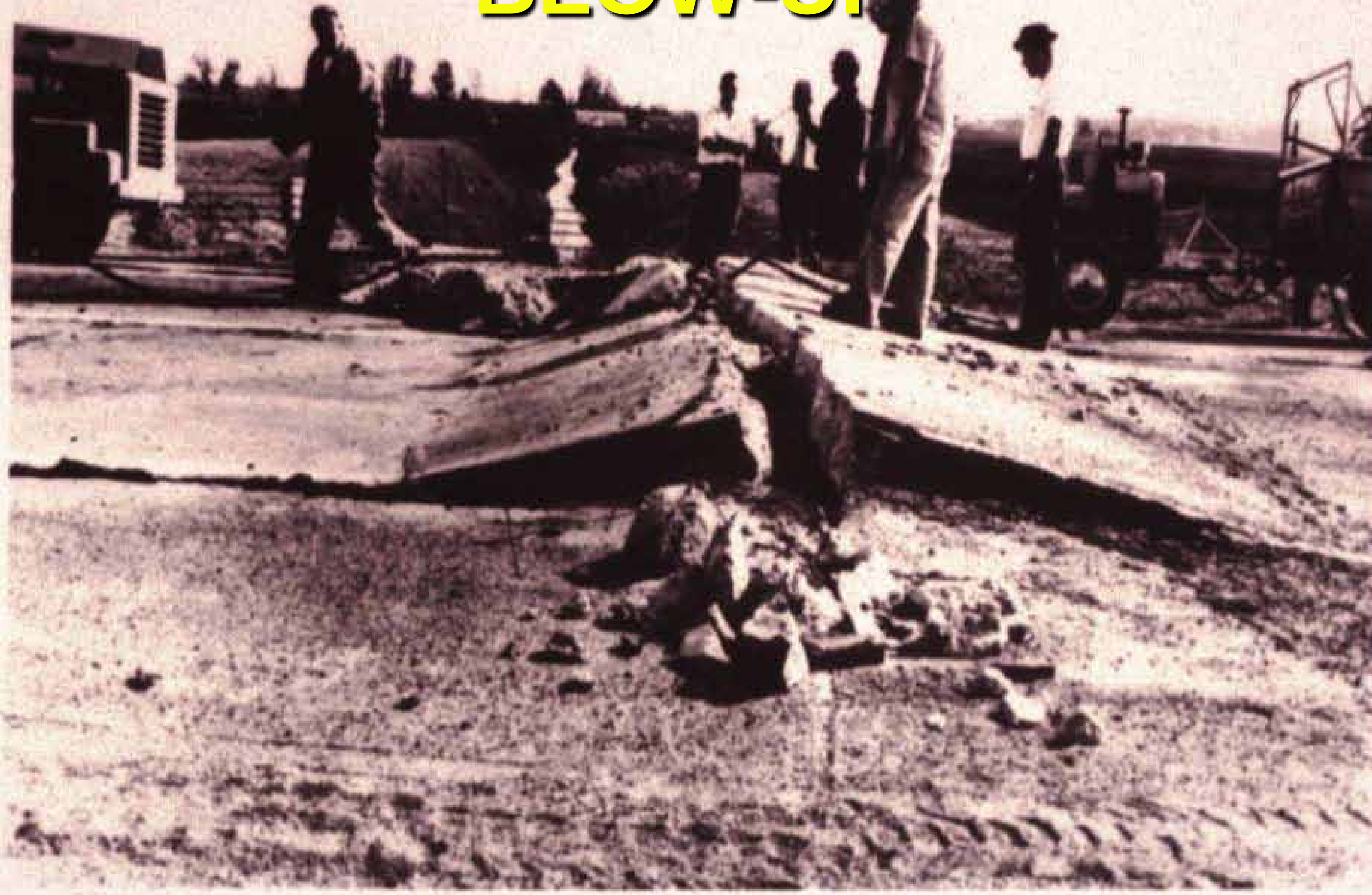
* CRACK & JOINT SPALLING/DETERIORATION

* JOINT FAULTING

* CRCP "PUNCHOUTS"

* PCC DISINTEGRATION (D-CRACKING / ASR)

BLOW-UP



BUCKLING - BLOW-UP

BLOW-UP

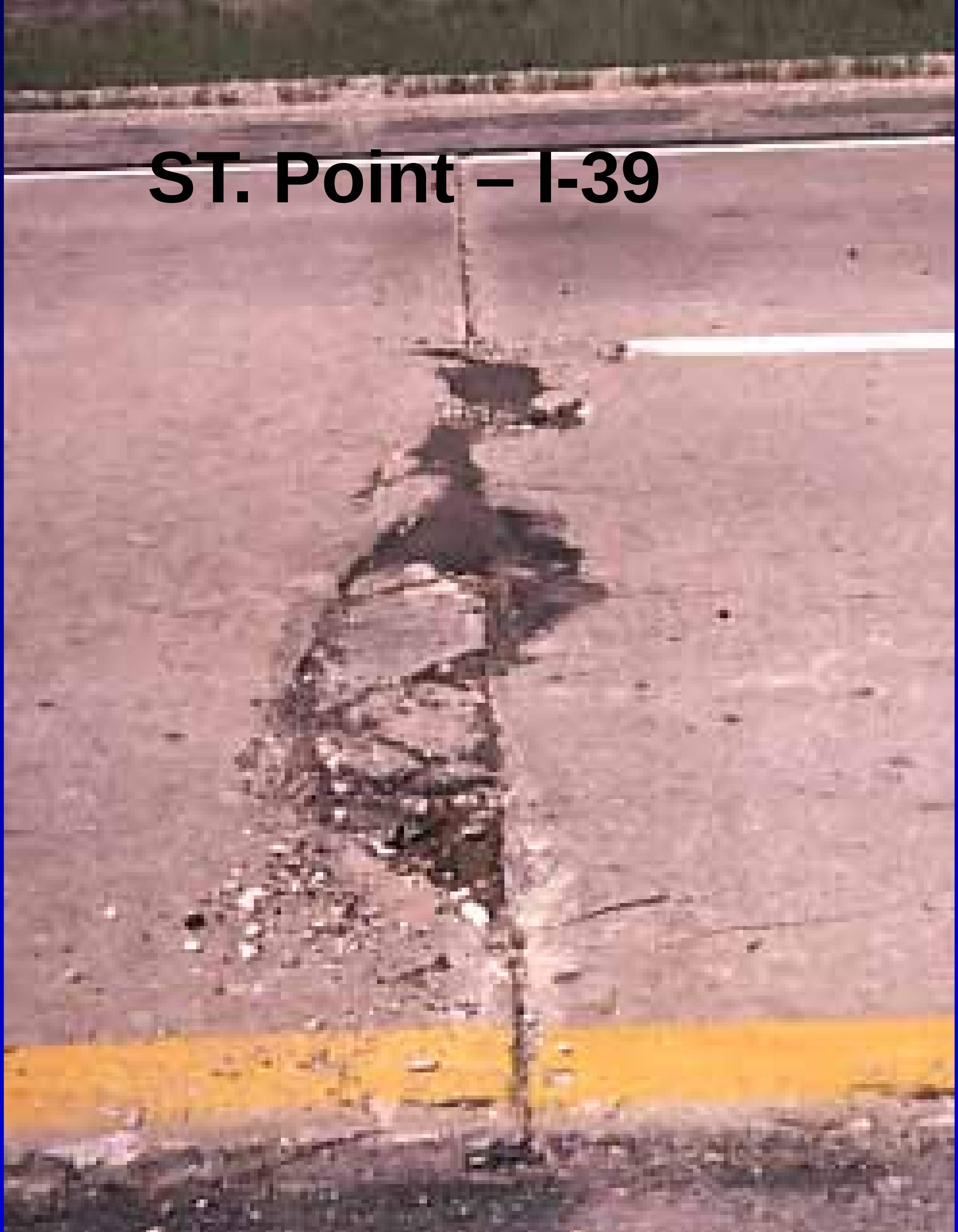

ST. PT. / I-39

Cracking — Transverse

Crack Deterioration (Spalling)


Joint
Deterioration
(Spalling)

ST. Point – I-39



Distortion — Faulting

Cracking — Longitudinal

AU - LONGITUDINAL CRACKING




Cracking — Corner Break

B-F ROAD
7-INCH PCCP

B-F ROAD
7-INCH PCCP


CRCP CRACKING PATTERN

CRCP Cracks

CRCP Punchout Distress

CRCP PUNCHOUT
SEVERE

CRCP FAILURE I-72


I-72 CRCP
FAILURE


EXPOSED REBAR

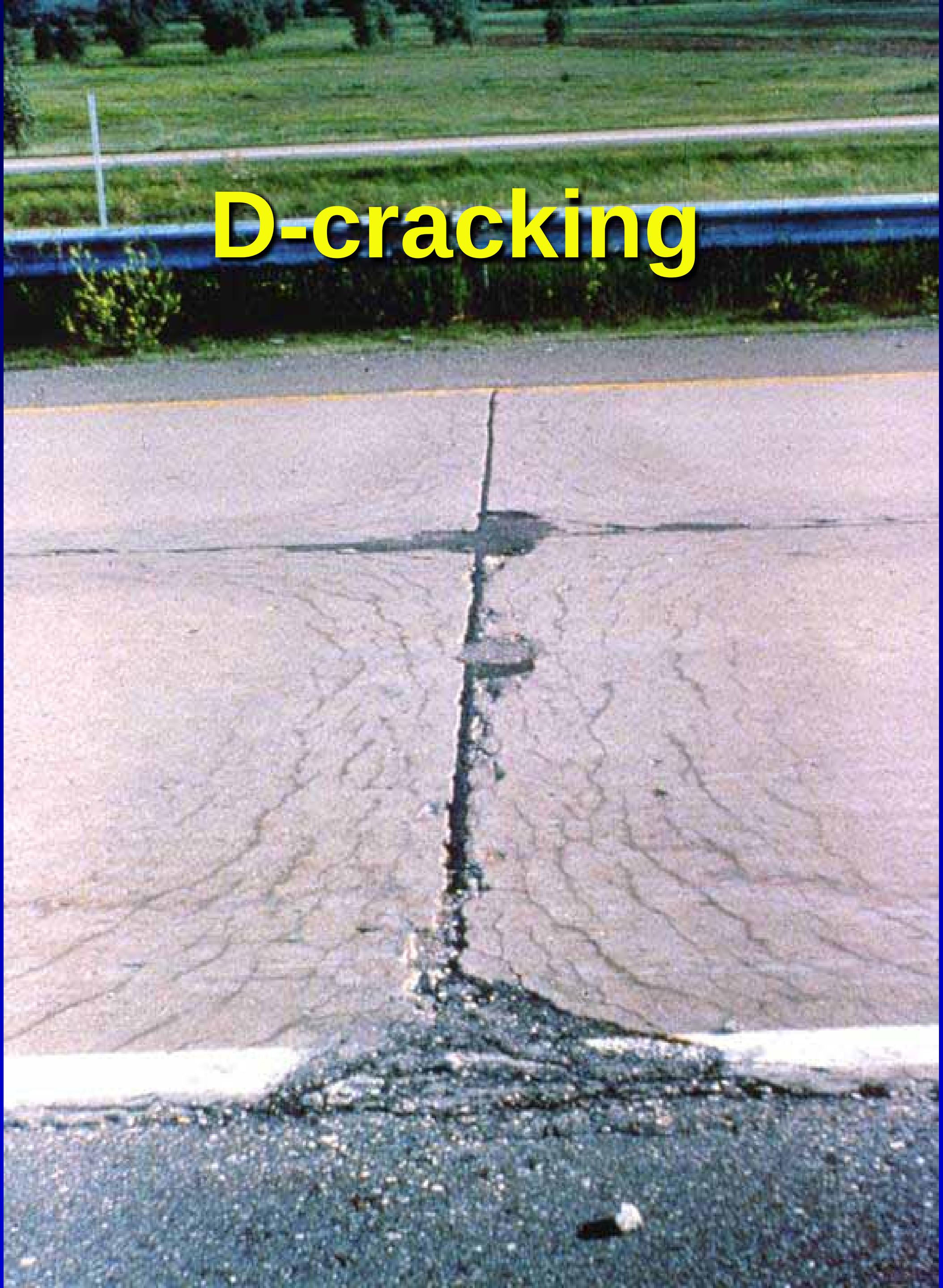
PCC Load Failure

Fatigue Failure

JPCP Pumping

Distortion/Cracking — Pumping

D-cracking



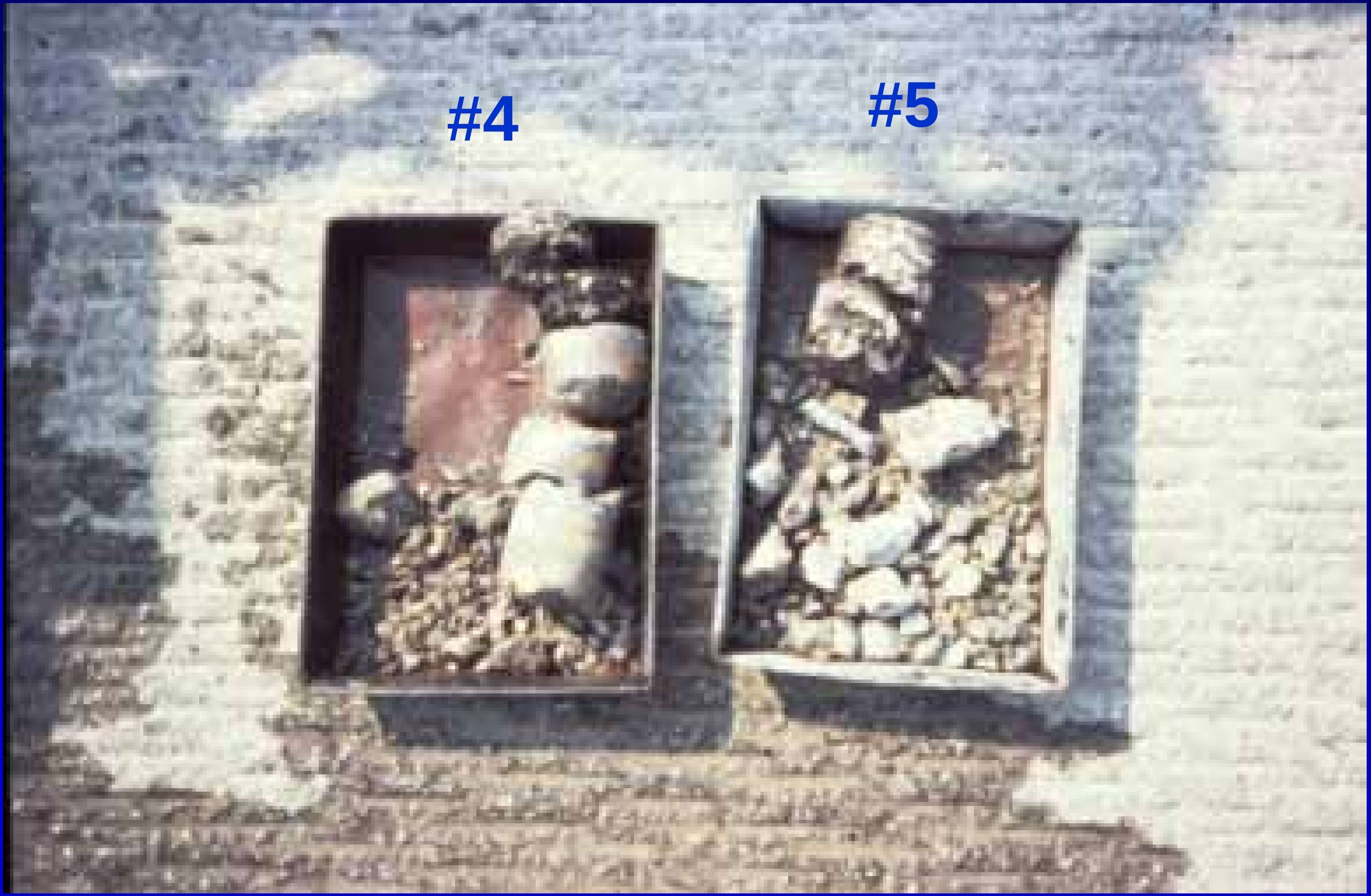
D-CRACKING (Willard Airport)





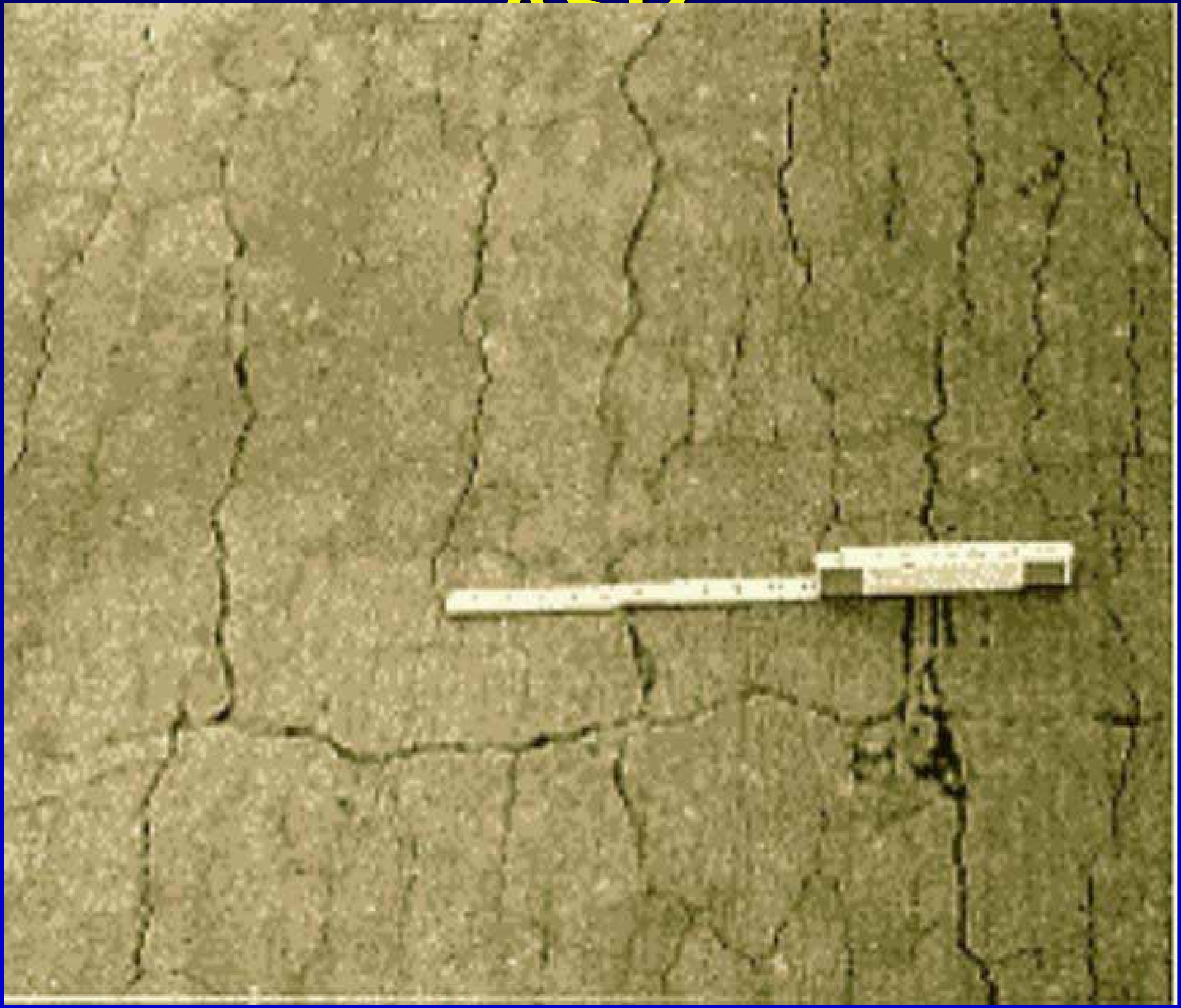
4
5

D-CRACKED PCC



Cracking/Disintegration — Alkali-Silica Reaction (ASR)

ASR



ASR / I-76 /CO

CONCRETE PAVEMENT REHAB PROCEDURES

- PATCHING / SLAB REPLACEMENT
- PATCHING + HMA OL
- JOINT REPAIR
  (REPLACE – DOWEL BAR RETROFIT)
- MILLING (FAULTING - FRICTION)
- HMA OL
- SLAB FRACTURING
  + CRACK & SEAT + HMA OL
  + RUBBLIZATION + HMA OL

BACKGROUND

- THOMPSON – NCHRP SYTNTHESIS #144 (1989)
- BREAK/CRACK/SEAT – PREVALENT
- RUBBLIZATION – LESS COMMON

NAPA – PCS (1991)

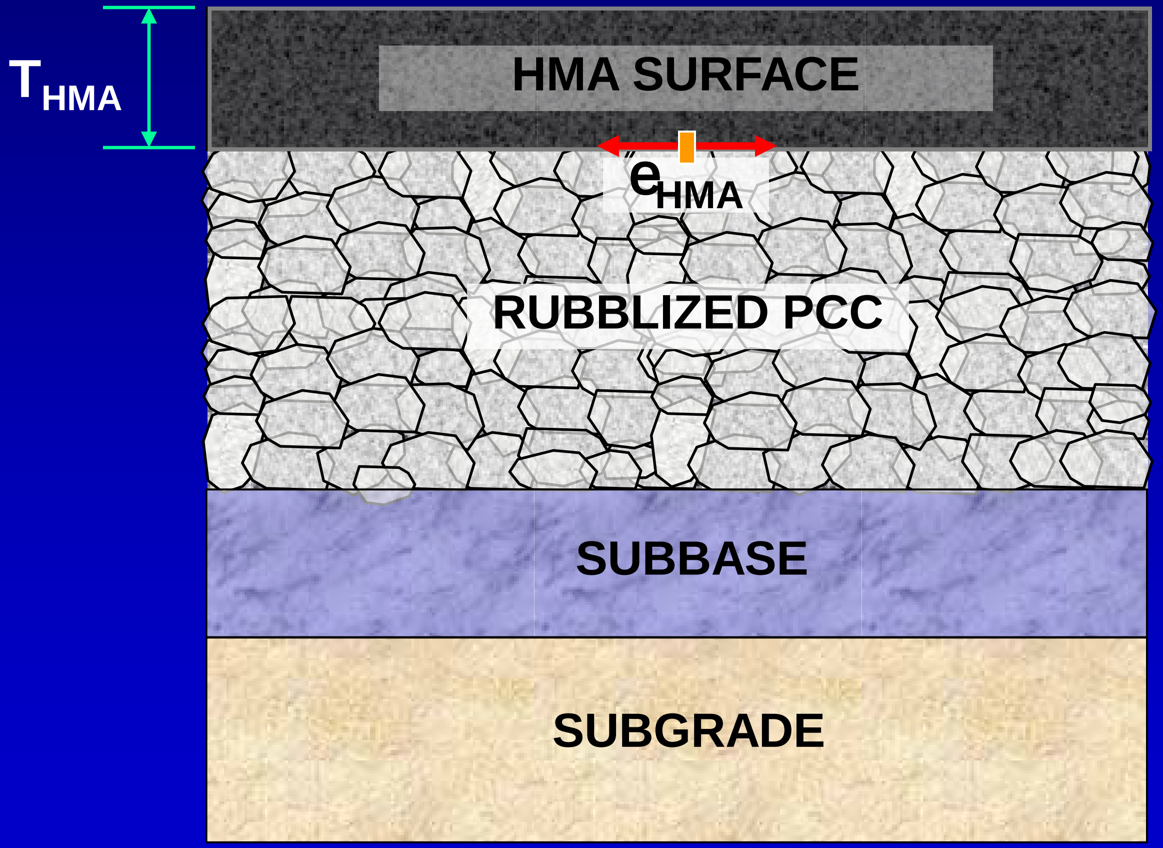
RUBBLIZATION IS MOST EFFECTIVE PROCEDURE

FOR ADDRESSING REFLECTIVE CRACKING

THE SOLUTION !!!!!

RUBBLIZATION + AC OL

RUBBLIZED PVT SECTION



WHEN TO RUBBLIZE ??

* PCCP PATCHING
- QUANTITY
- BID PRICE

* CONSTRUCTION ISSUES
- TIME
- LANE CLOSURES
- "CLEARANCES"
- SHOULDERS
- "OTHER"

* RUBBLIZED PVT "STRENGTH"
- PCCP THICKNESS
- PC SEGMENT SIZE
- SUBBASE TYPE/THICKNESS
- SUBGRADE CBR

WHY RUBBLIZE ???

* EASE OF CONSTRUCTION

* LITTLE PATCHING

* THICKER HMA OL

* HMA QUALITY > > >
  "PCC PATCH"

* REDUCED CONSTRUCTION $

* MORE "UNIFORM"

* FAILURE MODE:

  AC FATIGUE; **NOT**

  - REFLECTIVE CRACKING
  - CRACK DETERIORATION
  - PUNCHOUTS

* REDUCED MAINTENANCE $

SUMMARY

- RUBBLIZATION IS EFFECTIVE!!!
- RUBBLIZATION MOST POPULAR
- RUBBLIZATION IS ECONOMICAL
- RPB & MHB EFFECTIVE
- RUBBLIZATION + HMA OL PROJECTS HAVE PROVIDED OUTSTANDING PERFORMANCE

RUBBLIZATION EQUIPMENT

RUBBLIZATION EQUIPMENT

- MID-80S: RESONANT BREAKER
- 1995: MULTI-HEAD BREAKER (MHB1)

THE PB4

MHB / 2003 / I-70


ANTIGO

MHB

* LANE WIDTH !!!!

* ONE PASS !!!!

MHB CHARACTERISTICS

- TWO HAMMER ROWS
- 6 IN EACH ROW
- HAMMER WIDTH: 8 INCHES (1.5-INCH “STRIKE BAR”)
- STD WIDTH: 8 FEET

MHB

*“GROUND-UP DESIGN”
* HAMMER WEIGHTS VARY
    + 1.2 KIPS
    + 1.5 KIPS
    + COMBINATIONS
* MAX DROP HEIGHT: 60 INCHES
* MATCH MHB & WING SET-UP
  TO PROJECT (3 -13 FEET)
* OPERATE “SELECTED HAMMERS”

MHB LOADING

- MHB WEIGHTS
  * STD MHB: 47 KIPS
  * MHB+2 WINGS: 58 KIPS

- LOADING (58 KIP-MHB)
  * STEERING: 2@ 2.5= 5 kips
  * DRIVE: 2@ 21.5= 43 kips
  * TRAILING: 2@ 5= 10 kips

NOTE: TRAILING AXLE CAN BE LIFTED
(ALL LOADS ON "UNBROKEN" PVT!!!)

WHEEL LOAD FACTORS

- THIN PCCP
- THIN BASE/SUBBASE
- UNSTABLE BASE/SUBBASE
- LOW STRENGTH SUBGRADE

MHB OPERATION

- BREAKING ENERGY (BE):

  BE = f (HAMMER WEIGHT & DROP HEIGHT)

- VARY TRAVEL SPEED
  (TYPICAL: 4-6 INCH SPACING)

- ADJUST HEIGHT & SPEED AS NEEDED
  ("ON-THE-RUN")

MHB DISTINCTIVE FEATURES

- LANE WIDTH / ONE PASS
- OPERATE "CLOSE TO" PAVT C-L, CURB LINE, BARRIERS
- PRODUCE "RANGE" OF FRACTURE PATTERNS (B/C/S – RUBBLIZATION) (WEIGHT/HEIGHT/# HAMMERS/SPEED)
- "PRODUCTION TRAIN"
- MHB RELIABILITY

SPECIALTIES CO. – INDIANAPOLIS, IN

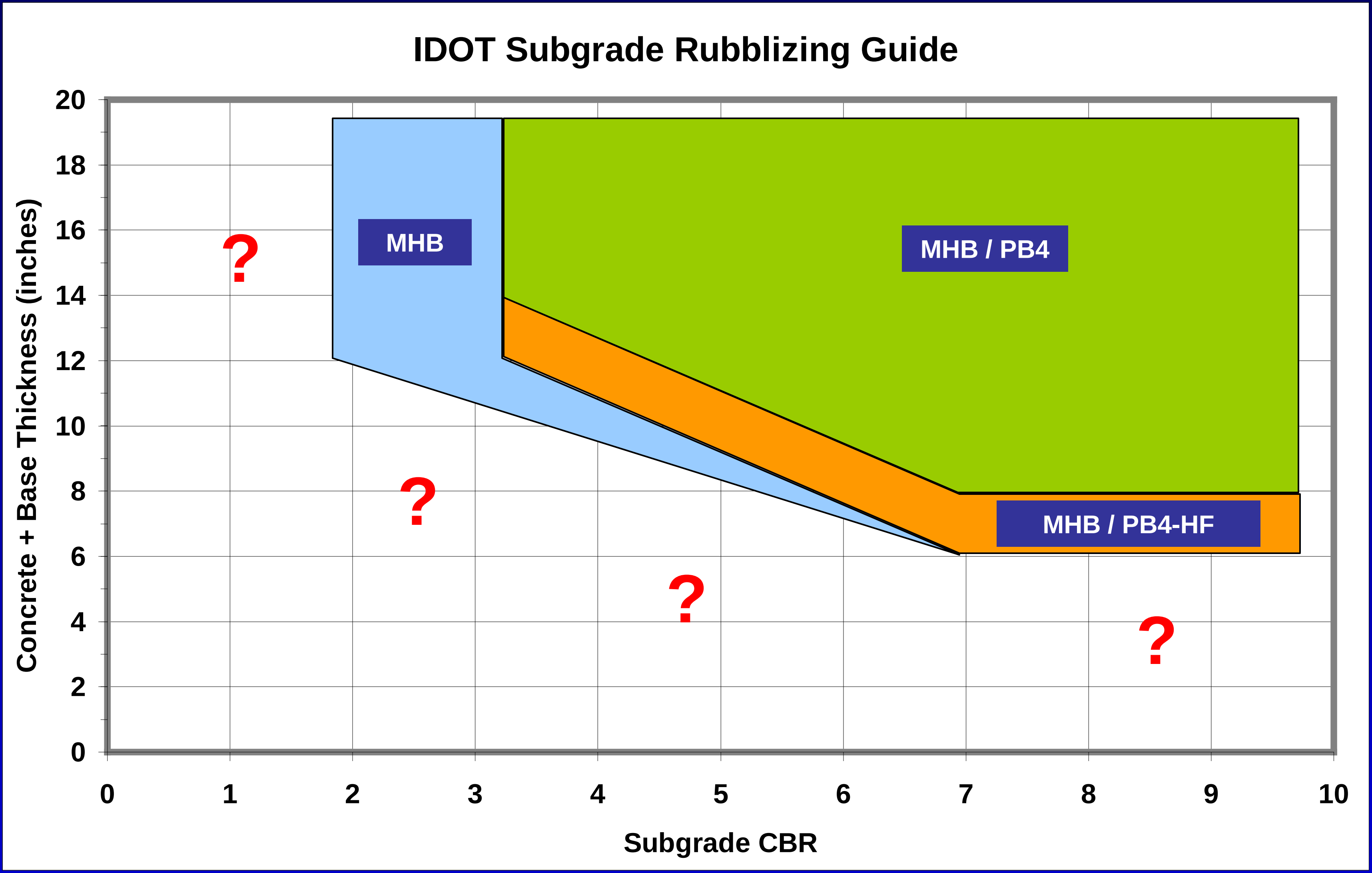
ONE ROW OF HAMMERS

SPECIALTIES CO. – INDIANAPOLIS, IN

RUBBLIZATION CONSTRUCTION

ROADTEC
an Astec Industries Company

RX-700 Cold Planer


IDOT Subgrade Rubblizing Guide
Concrete + Base Thickness (inches)
Subgrade CBR
0
2
4
6
8
10
12
14
16
18
20
0
1
2
3
4
5
6
7
8
9
10
MHB
MHB / PB4
MHB / PB4-HF
?
?
?
?

THE PB4

“UNSTABLE RUBBLIZED PCCP

“UNSTABLE “ RUBBLIZED PCCP !!

PB4 – MAX WHEEL LOAD

“UNSTABLE RUBBLIZED PCCP”

150-180 m/hr - 500-600 ft/hr

I-70 TEST PIT / CRCP

I-70 TEST PIT

MHB – PASS
NOTE "FLAKY" SURFACE

“Z-GRID” ROLLER

RUBBLIZED PCCP COMPACTION

* Z-GRID – VIBRATORY

* VIBRATORY STEEL

* RUBBER-TIRED

* VIBRATORY STEEL – PRIOR TO PAVING

Z-GRID ROLLER

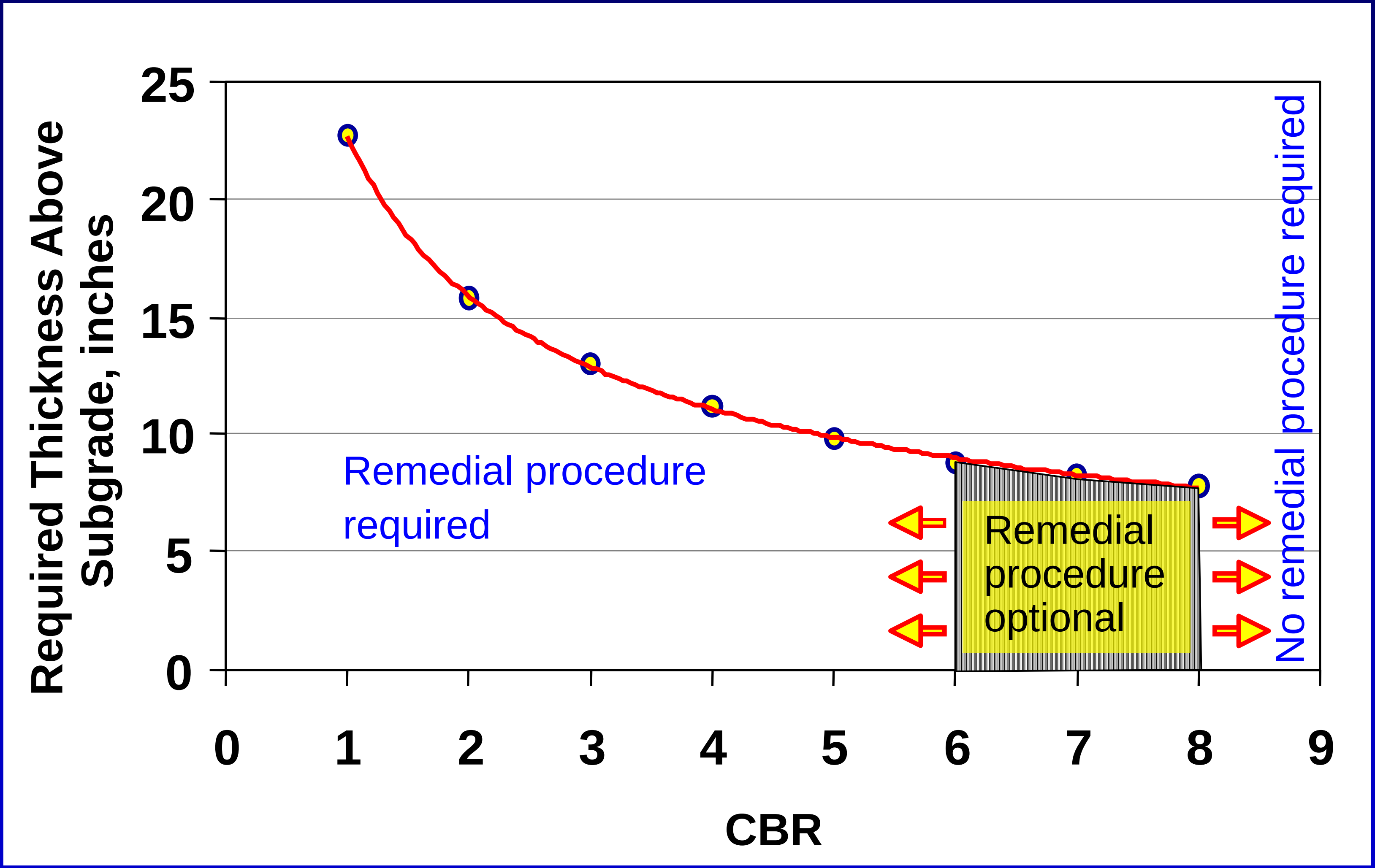

5567
INGERSOLL-RAND

RUBBER-TIRED ROLLER

FINAL COMPACTION

“FINISHED – RUBBLIZED” PCCP

Foundation - Illinois



TRACKED B-K PAVER

CONVENTIONAL PAVING

I-70 / SB2500

RUBBLIZATION SPECS
PC SEGMENT SIZE

* *MAXIMUM SIZE*
REFLECTIVE CRACKING
PC SEGMENT ROCKING
"SEATING" - HEAVY ROLLER

* *MINIMUM SIZE*
"CONSTRUCTABILITY"
PVT "STRENGTH"

PCC SEGMENTS

* C/B&S : 12 - 30 INS.
* RUBBLIZE: = 12-IN. MAX

FRACTURED SLAB CONCEPT

* MAX SIZE CONTROL

< 12 INS.

< 15 INS.

< 18/?? INS. (+)

(+ C/B & SEAT SIZES)

RUBBLIZATION SPECS

IDOT -I-57@EDGEWOOD
IDOT -I57@GREENUP

\>50%< 3 INS (ABOVE STEEL)
\>50%< 9 INS (BELOW STEEL)
"BREAK" PCC-STEEL BOND

IDOT - I-57/UNION CO.

"FINE"
\>50%< 3 INS (ABOVE STEEL)
\>50%< 9 INS (BELOW STEEL)
"BREAK" PCC-STEEL BOND

"COARSE"
\>75%< 9 INS
100%< 12 INS

SEGMENT SIZE EFFECTS

IDOT - D9
I-57

T_{AC} = 7 INS
AC TEMP - 70° F

Δ (mils)	AUPP (INS)	E_{Ri} (ksi)
COARSE:		
10.1	12.1	10.9
FINE:		
13.5	16.1	9.8

SEGMENT SIZE EFFECTS

OR I-5

NORTH GRANTS PASS - EVANS CREEK

T_{AC} = 8 INS
8-INS RUBBLIZED JRCP
6-INS AGG SUBBASE

Δ (mils)	AUPP (INS)	E_{Ri} (ksi)
COARSE:		
3.2	2.6	16.7
FINE:		
4.5	3.7	14.5

NOTE: 2-inch AC surface to be placed

IL RUBBLIZED PCCP SPECS

SURFACE / UPPER SLAB:

75% < 3 INCHES

LOWER SLAB:

75% < 9 INCHES

MAX SIZE: 12 INCHES

FRACTURED PCCP SPECS

* WI RUBBLIZED PCCP

MAX SIZE: 12 INCHES

75% < THAN 9 INCHES (BOTTOM 1/2)

75% < THAN 3 INCHES (TOP 1/2)

75% < THAN 2 INCHES (SURFACE)

* WI C&S PC SEGMENT SIZES

APPROXIMATELY 4.5 SQ FT (25”X25”)

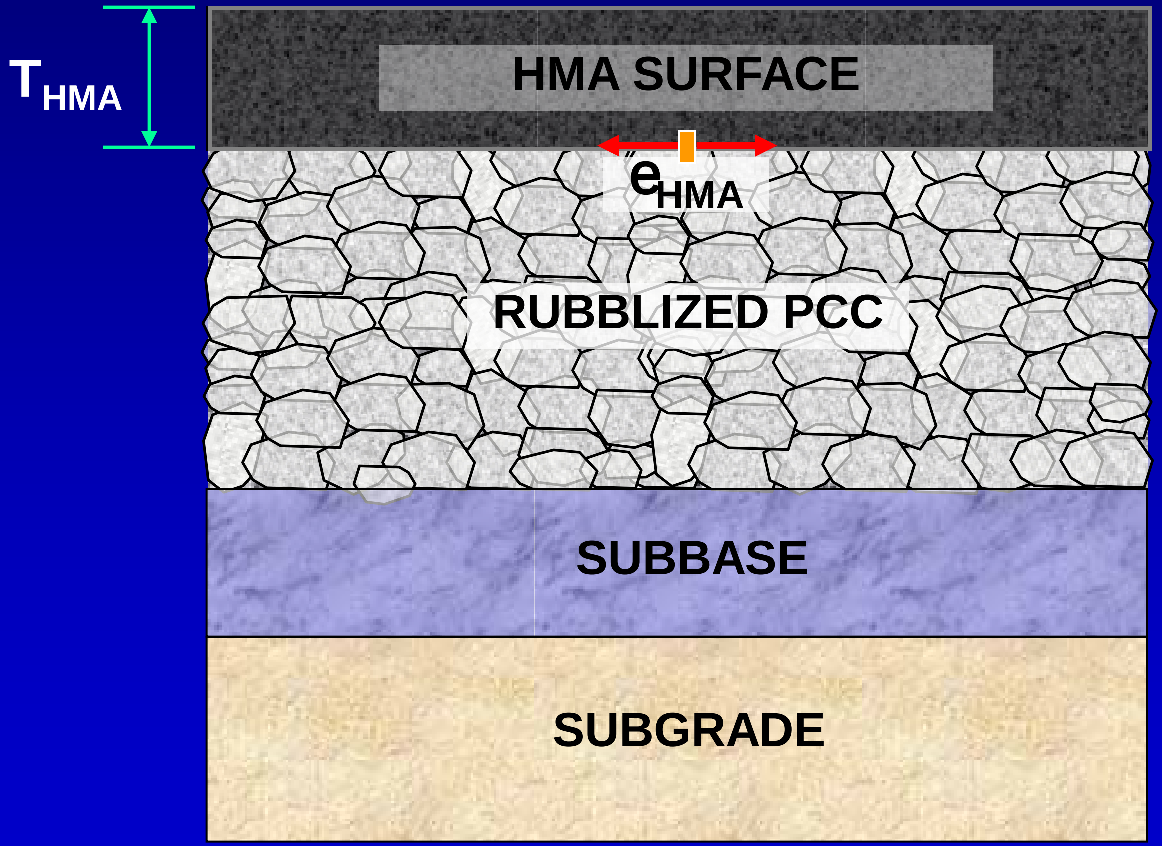
APPROXIMATELY 6.5 SQ FT (30”x30”)

* KY C&SEAT PC SEGMENT SIZES

< 20% > 24 INCHES

0% > 30 INCHES

RUBBLIZED PVT SECTION



CRITICAL DESIGN CRITERION

“HMA FATIGUE”

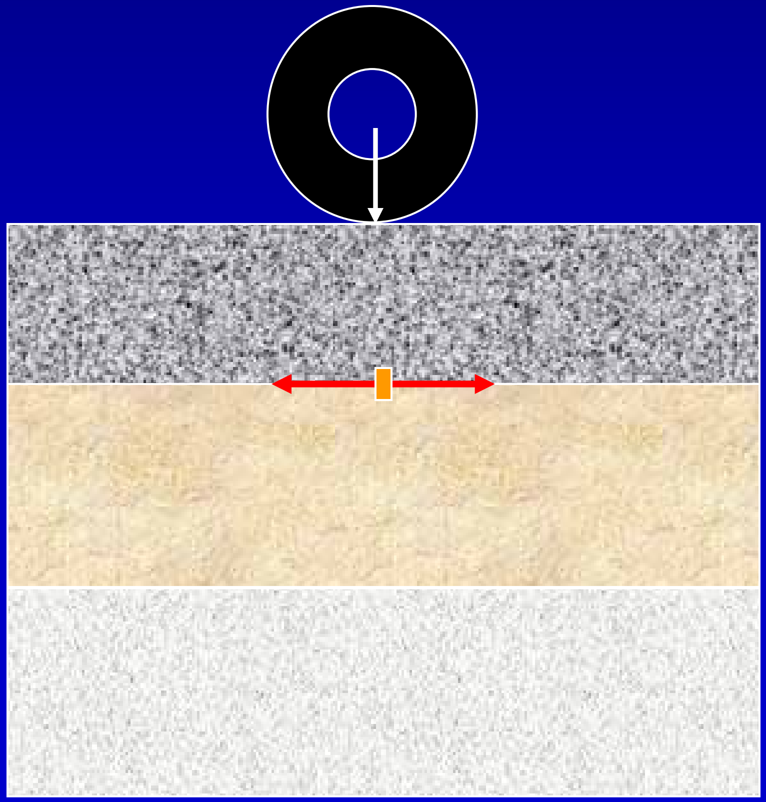
AASHTO TP 8-94

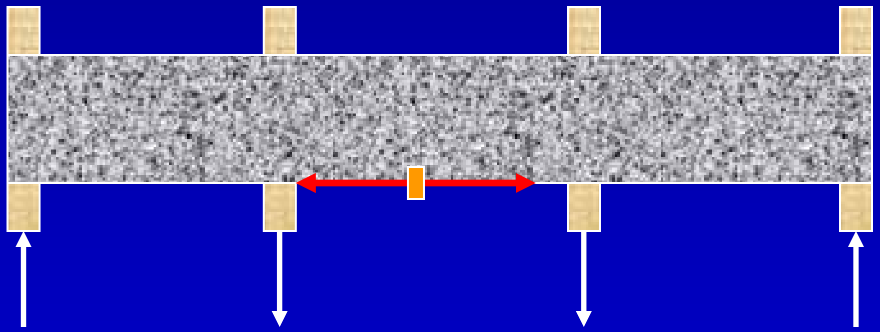
Standard Test Method for Determination of the Fatigue Life of Compacted HMA Subjected to Repeated Flexural Bending

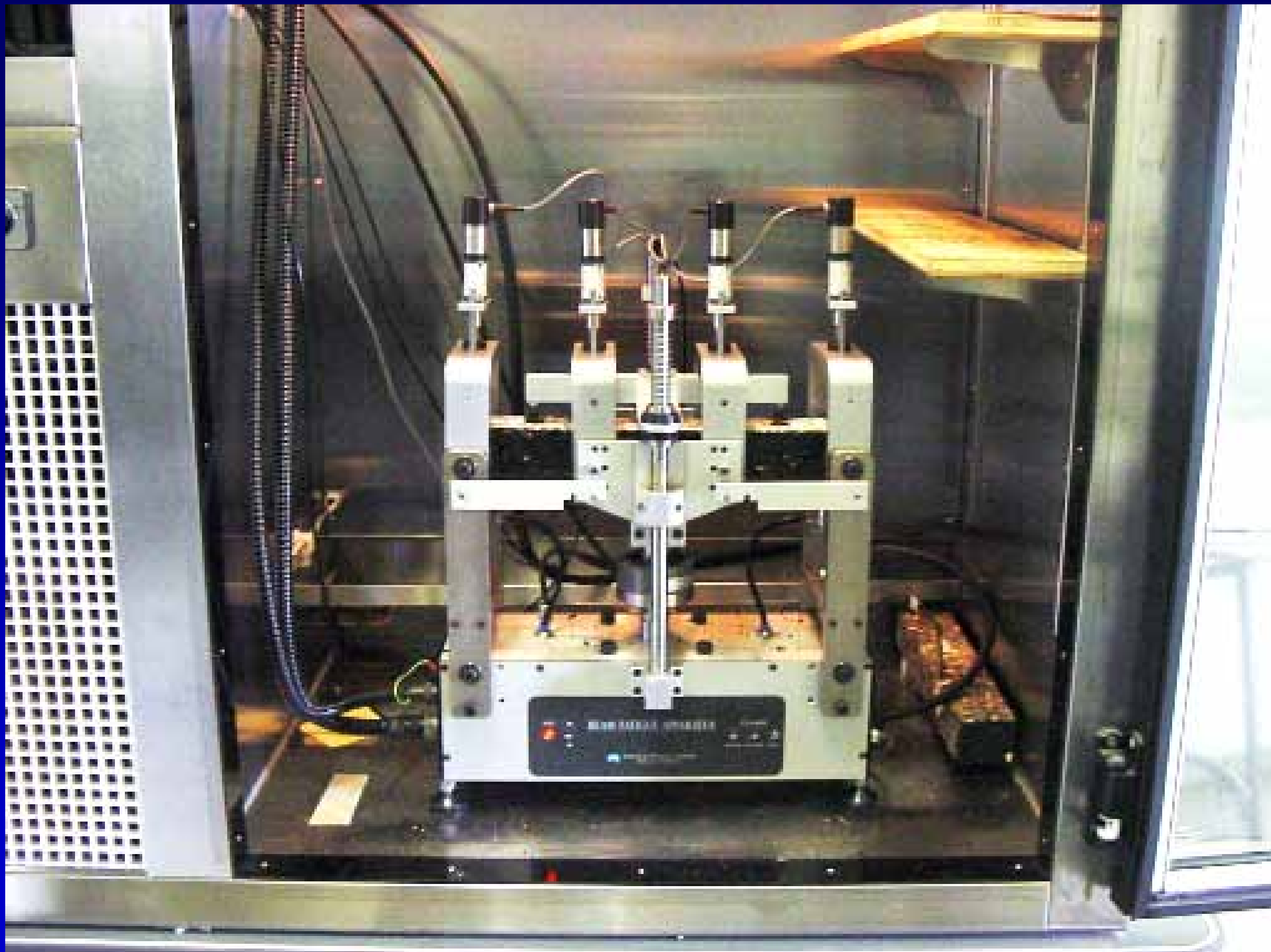
FATIGUE DESIGN

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

Other Configurations

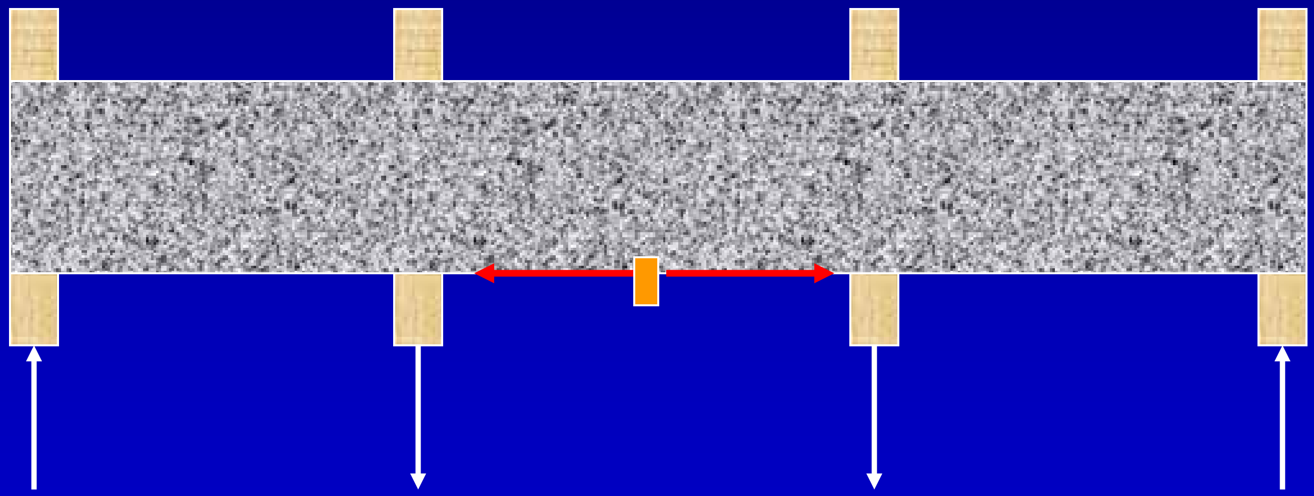






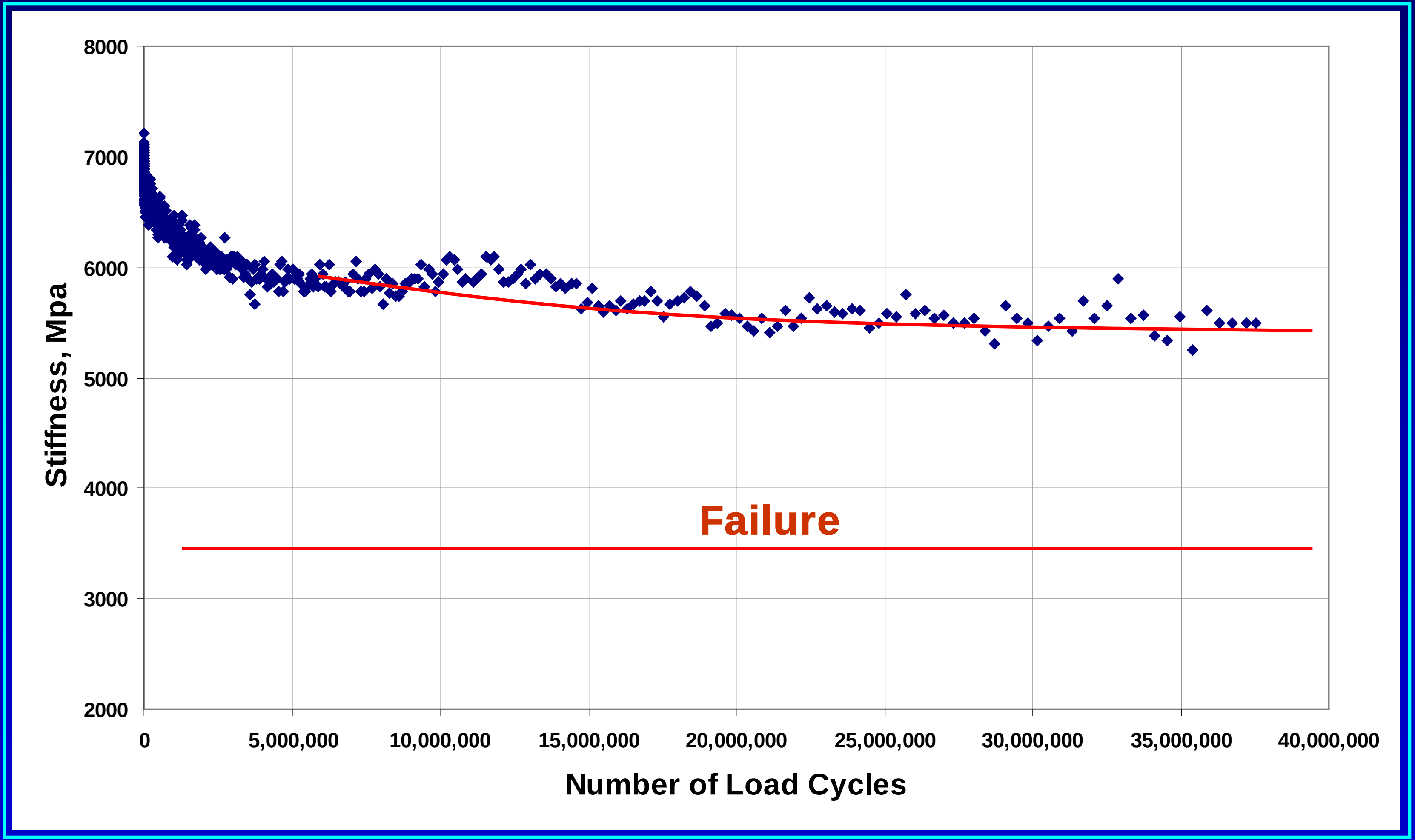
FATIGUE TESTING

- **Tensile Strain in Flexural Beam Test**
  - **Other Configurations**

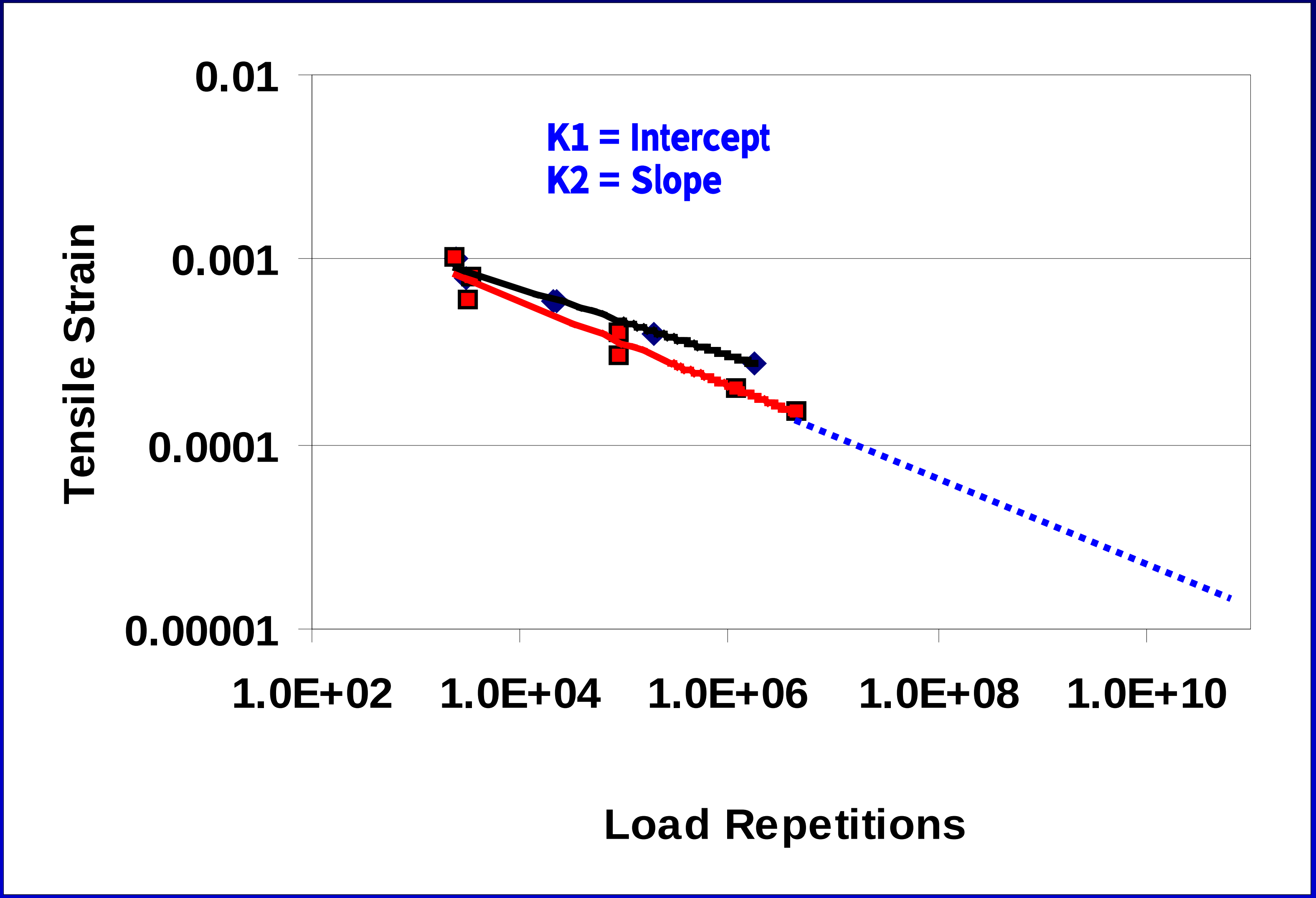


  - **10 Hz Haversine Load, 20º C, Controlled Strain**

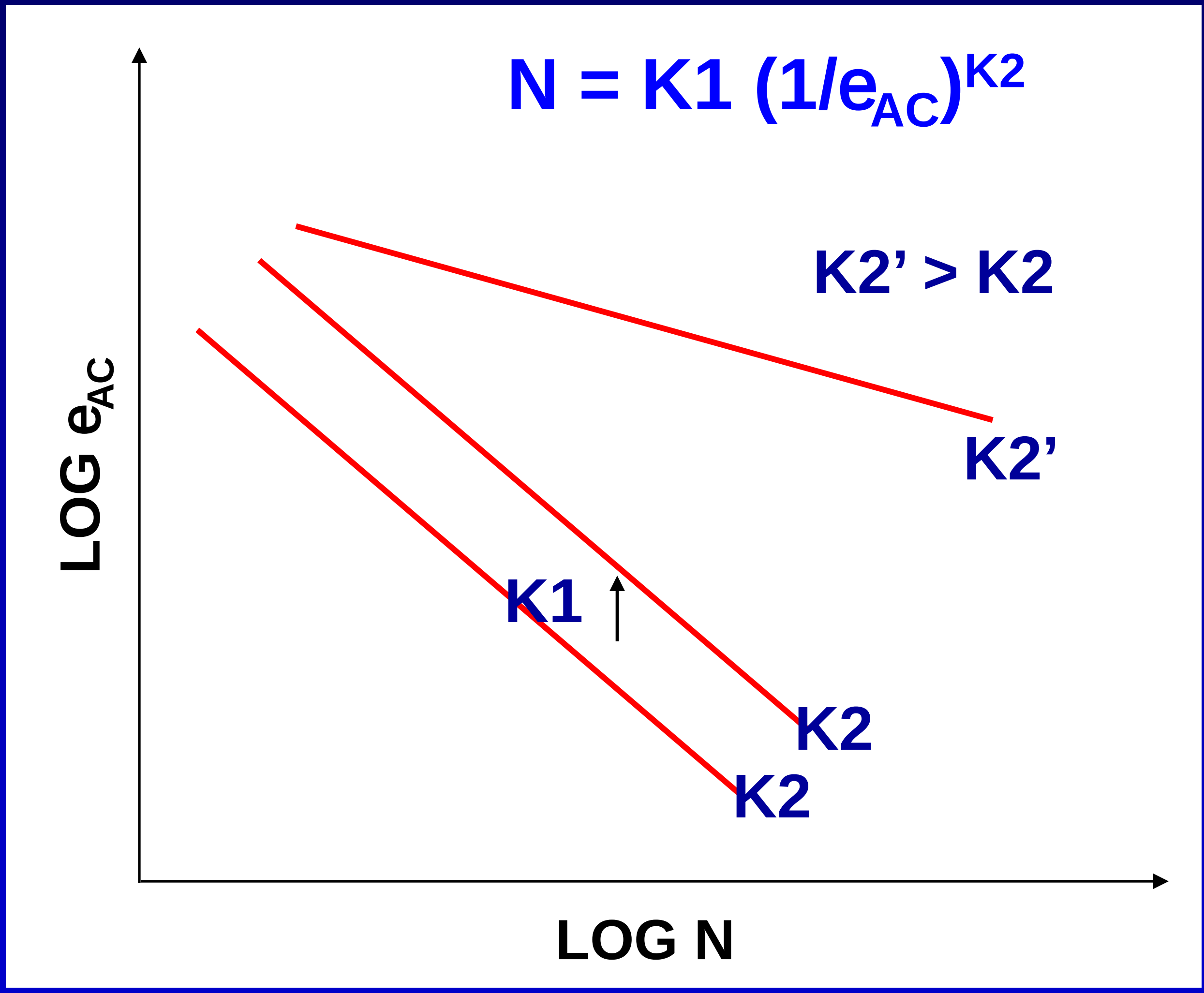
STIFFNESS CURVE



LABORATORY ALGORITHM



AC FATIGUE



FATIGUE ALGORITHMS

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

IL / PerRoad

$$N_f = K\ (1/e)^a\ (1/E^*)^b$$

AASHTO MEPDG

$$N_f = R_f * [\ (V_{b)})\ /\ (S_{mix} * \ e)]^5$$

Austroads

IDOT HMA FATIGUE DATA SUMMARY 84 MIXES

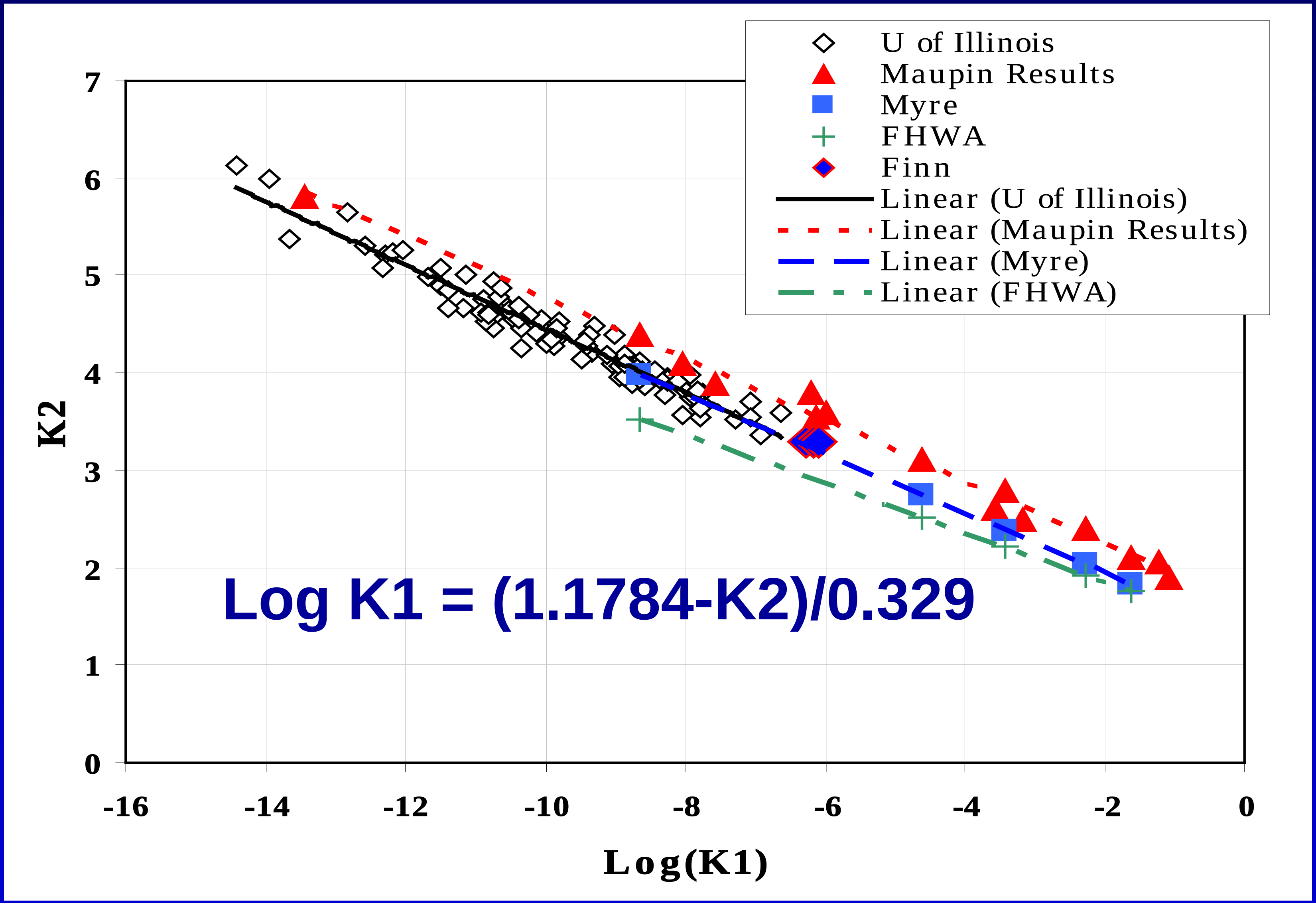
$$N = K1\,(1/\varepsilon)^{K2}$$

Minimum K2: 3.5

90% K2: 4.0

Average K2: 4.5

OTHER STUDIES



$$N = RF\left[\frac{6918(0.856\,V_B + 1.08)}{S_{mix}^{0.36}\,\mu\varepsilon}\right]^5$$

where

S_{mix} = asphalt modulus (MPa)

V_B = volume of binder in asphalt mix = 11%

RF = 1, desired project reliability 95%

AUSTROADS – PAVEMENT DESIGN -SHELL

RF: 2.5/80%-2.0/85%-1.5/90%-1.0/95%-0.67/97.5%

THERE IS

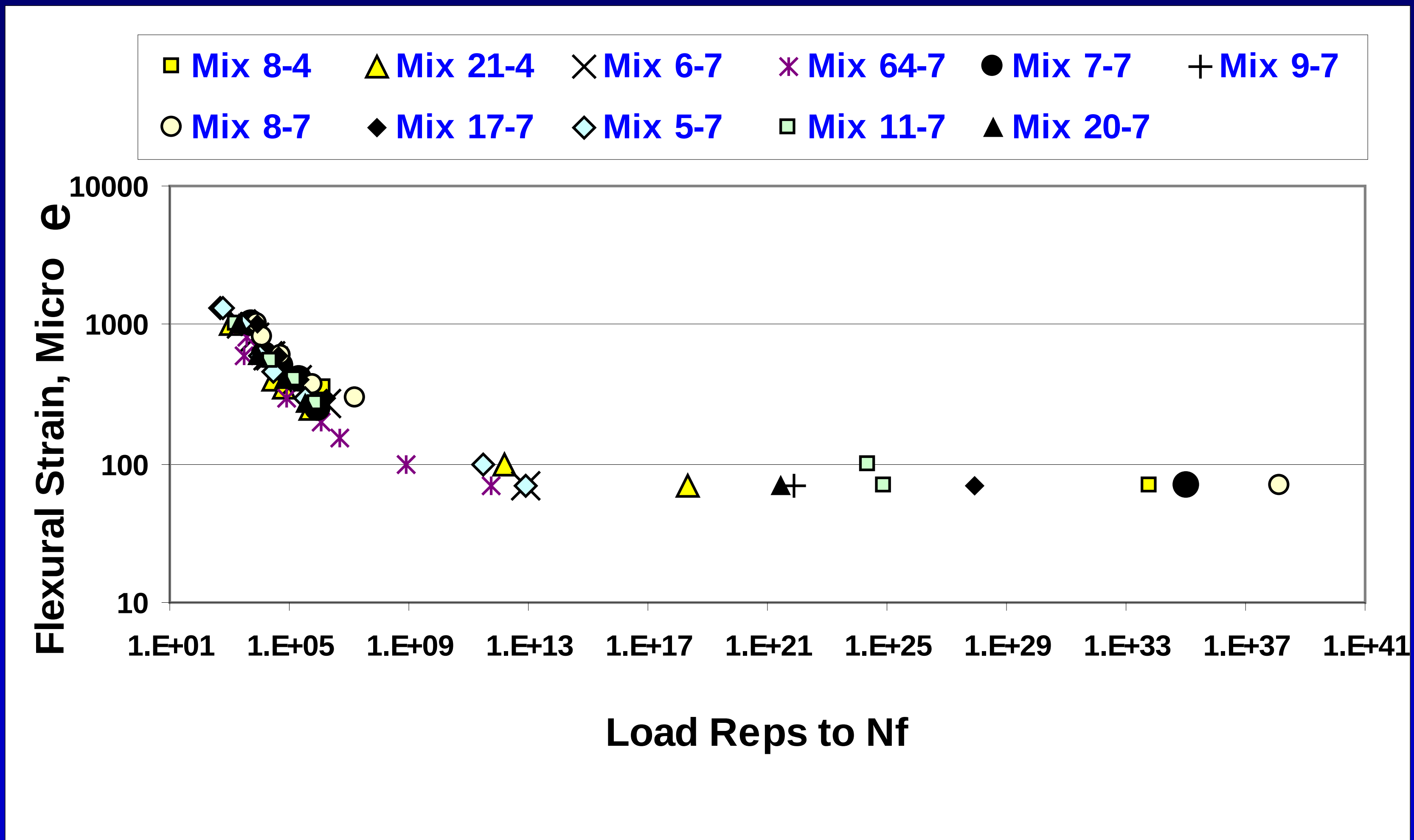
NO “UNIQUE”

HMA FATIGUE ALGORITHM !!!!

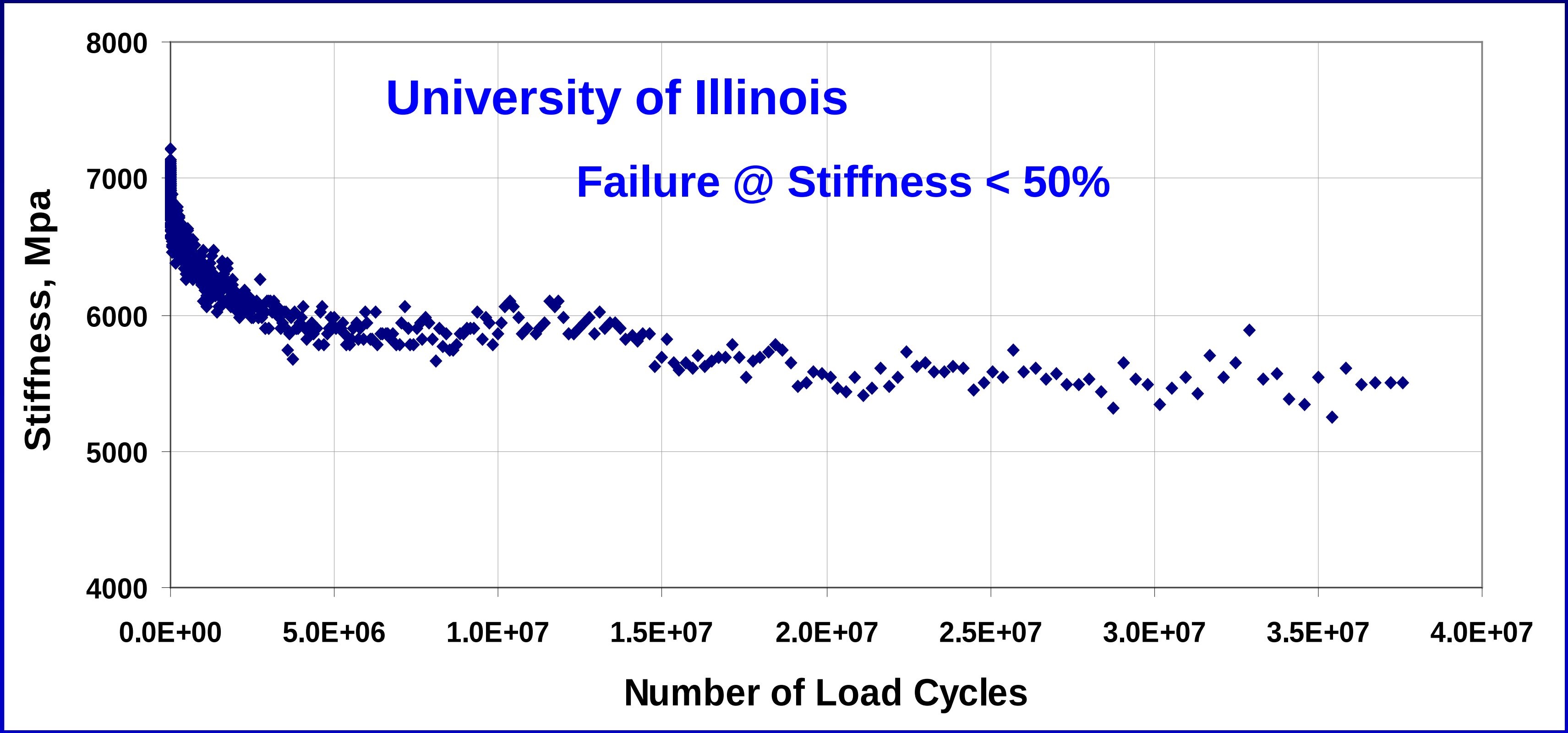
FATIGUE ENDURANCE LIMIT

FEL

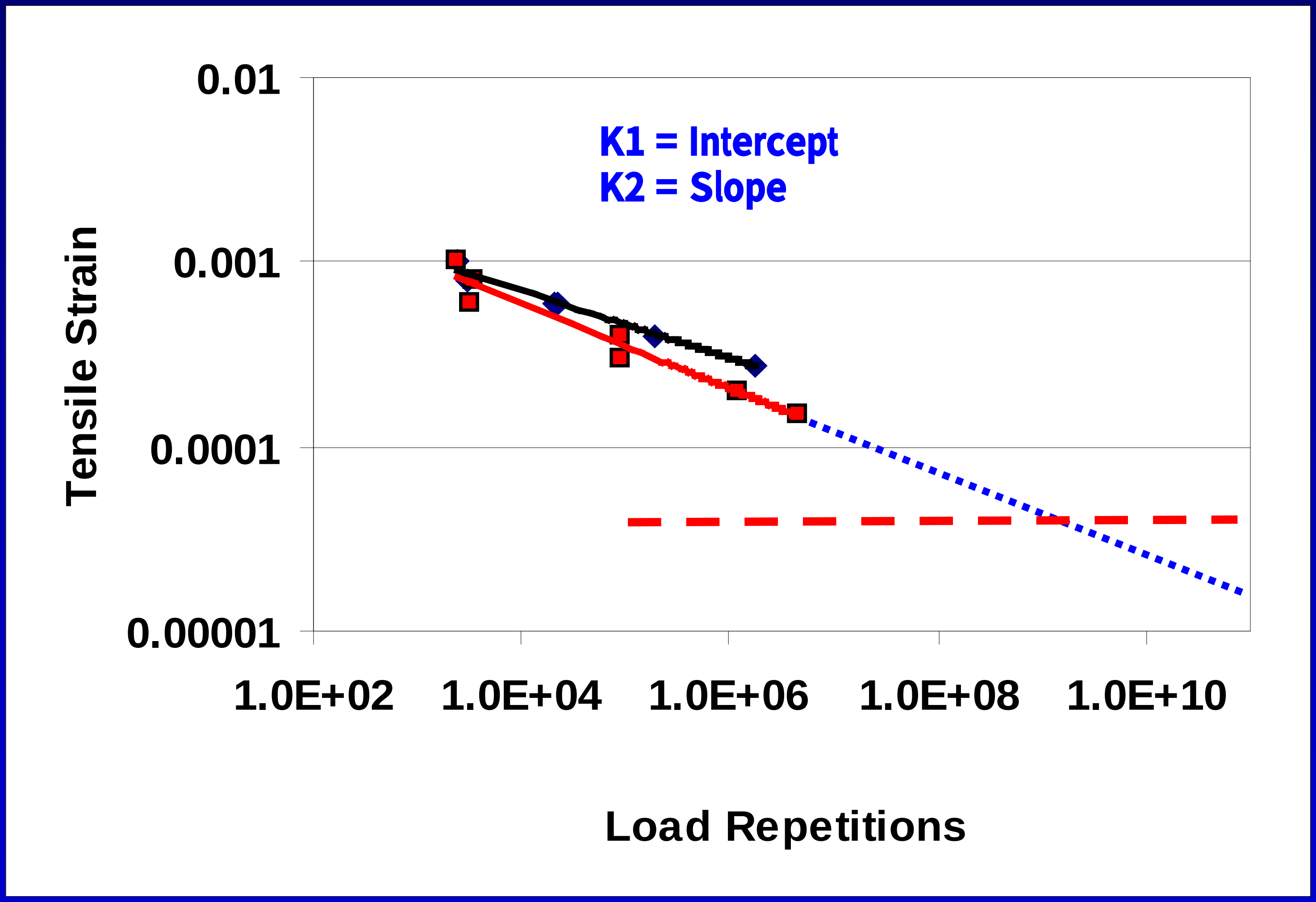
LOW STRAIN TESTING



70 Micro Strain Test



FATIGUE ENDURANCE LIMIT



FATIGUE ENDURANCE LIMIT

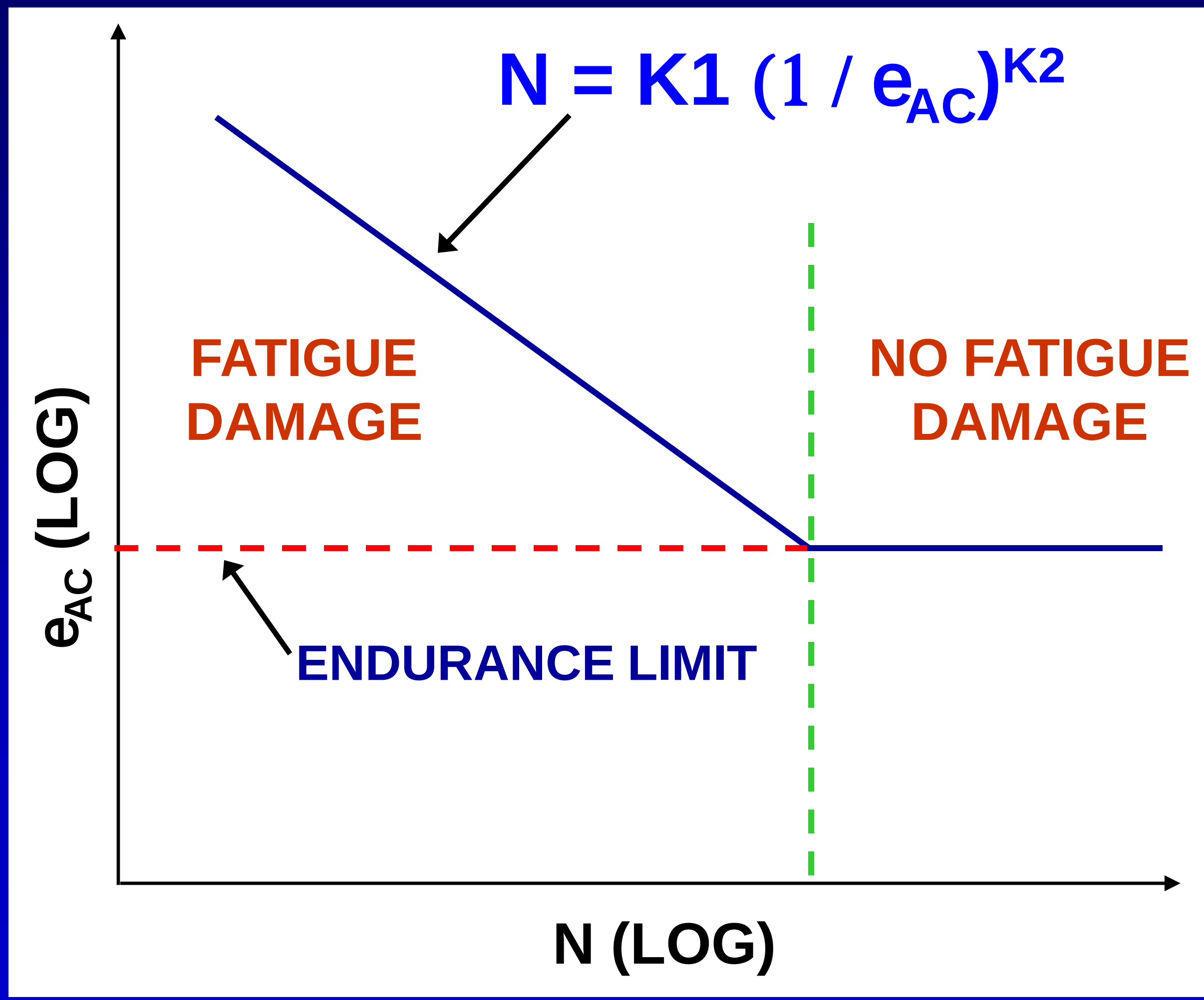
* Damage and Healing Concepts and Test Data Support a Strain Limit (the FEL) Below Which Fatigue Damage Does Not Accumulate

- FEL Is Not The Same for All HMAs.

- Carpenter – UofI

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

HMA FATIGUE

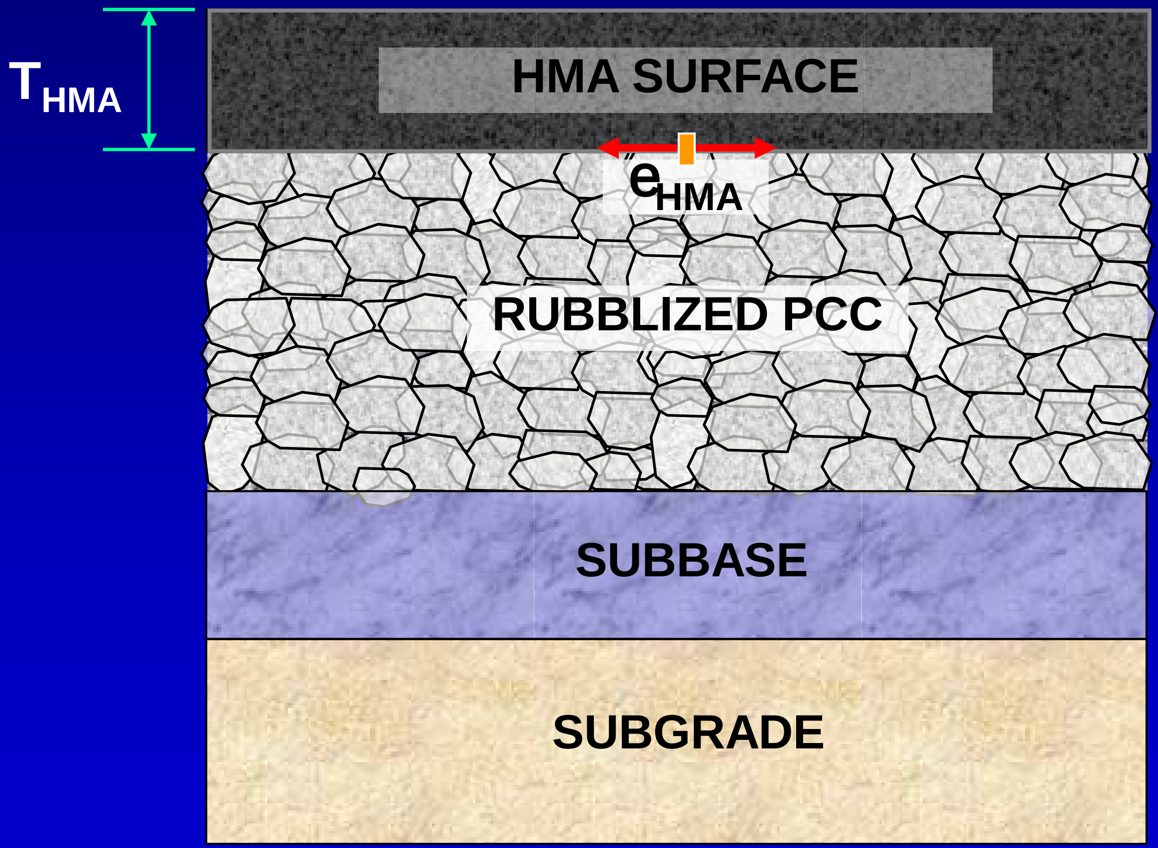

$N = K1\,(1 / e_{AC})^{K2}$
FATIGUE DAMAGE
NO FATIGUE DAMAGE
ENDURANCE LIMIT
e_{AC} (LOG)
N (LOG)

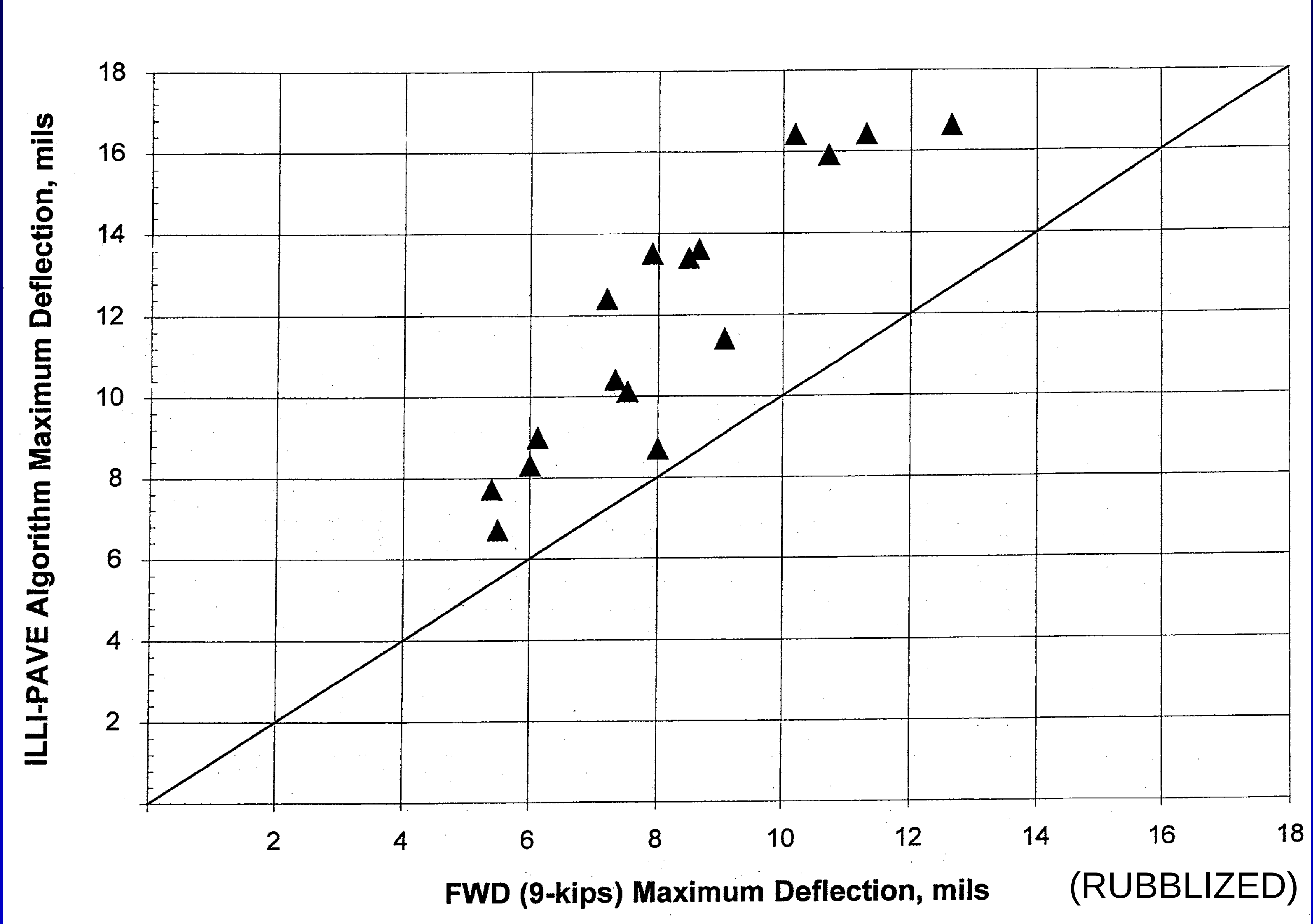
FEL = ??????

K1 & K2 = ??????

HMA OL THICKNESS

RUBBLIZED PVT SECTION





GRANULAR VS RUBBLIZED PCCP

HMA OVERLAY THICKNESS

* "STRUCTURAL NUMBER" - COEFFICIENT
  - NAPA: "a_2"
    (75%-0.34; 99%-0.29)
  - ASPHALT INSTITUTE
    ("a_2" = 0.2)
  - AASHTO / 1993
    ("a_2" = 0.14 - 0.30)
* ASPHALT INSTITUTE
  - CONVENTIONAL FLEXIBLE PVT
    (RUBBLIZED PCCP = GRANULAR)
* MECHANISTIC-EMPIRICAL
  - AC FATIGUE
  - SUBGRADE STRESS RATIO
    (SELDOM CONTROLS)

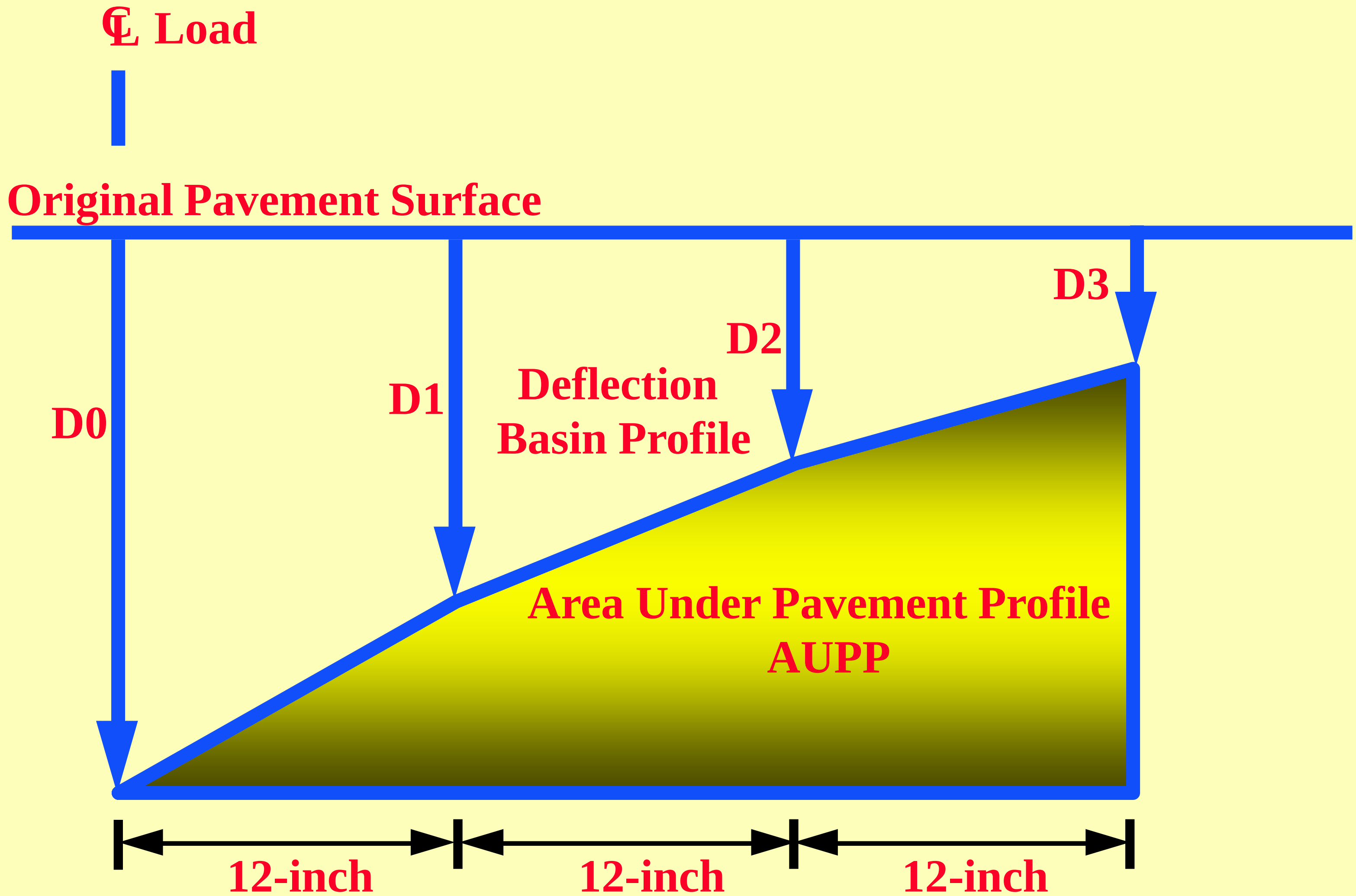
HOT-MIX ASPHALT OVERLAY DESIGN CONCEPTS FOR RUBBLIZED PORTLAND CEMENT CONCRETE PAVEMENTS

Marshall R. Thompson
TRB Record 1684 (1999)

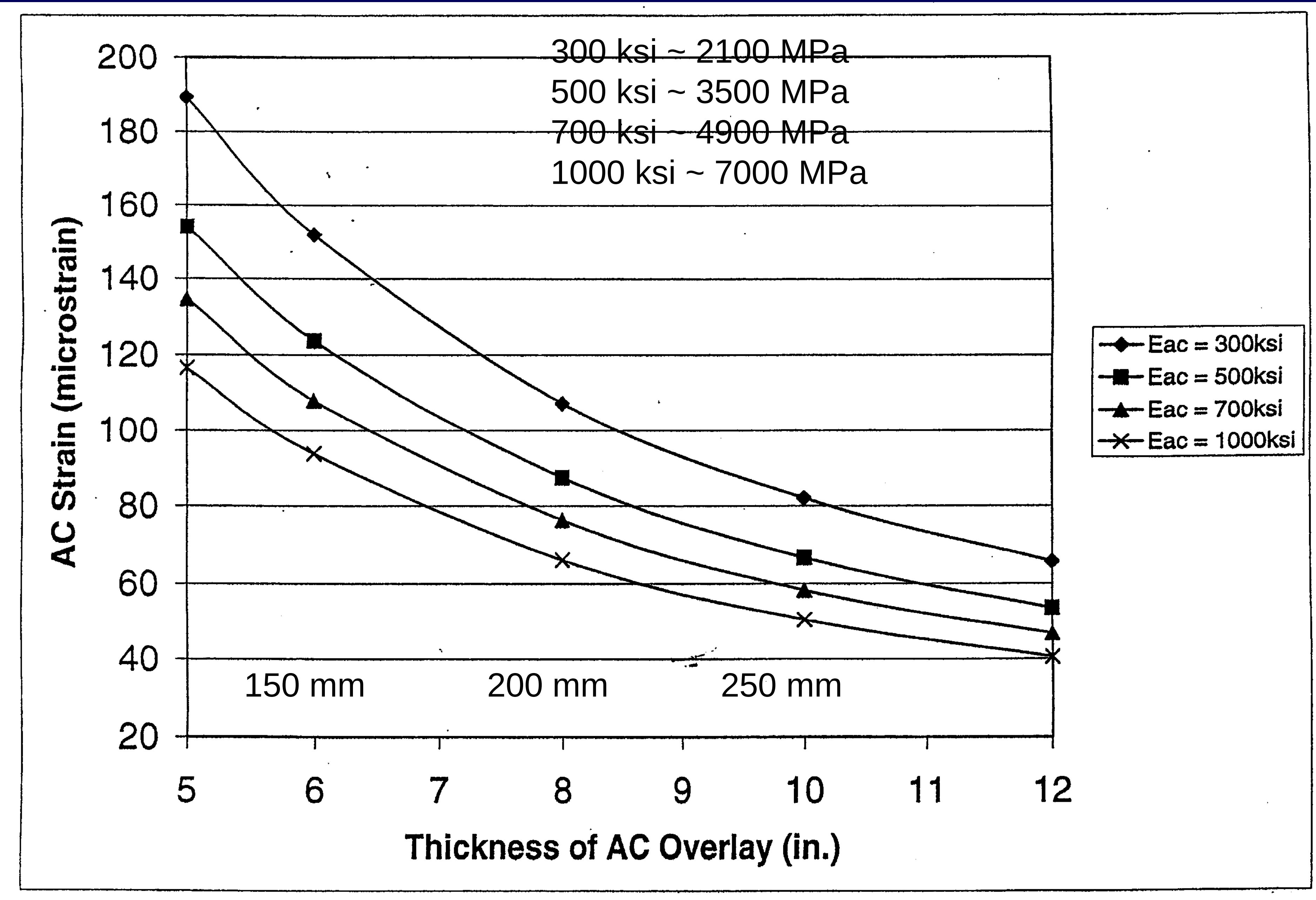
$$\text{LOG } e_{AC} = 1.001 + 1.024 \text{ LOG(AUPP)}$$

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

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



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



300 ksi ~ 2100 MPa
500 ksi ~ 3500 MPa
700 ksi ~ 4900 MPa
1000 ksi ~ 7000 MPa
AC Strain (microstrain)
200
180
160
140
120
100
80
60
40
20
150 mm
200 mm
250 mm
5
6
7
8
9
10
11
12
Thickness of AC Overlay (in.)
Eac = 300ksi
Eac = 500ksi
Eac = 700ksi
Eac = 1000ksi

SEASONAL EFFECTS

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

MUST CONSIDER IN M-E DESIGN

NAPA - IS 132
THREE LEVELS OF DESIGN

I – STRUCTURAL #
(PICK SUBGRADE)

II - STRUCTURAL #
(SUBGRADE MODULUS TESTING)

III - PerRoad
*** HMA FATIGUE**
*** SUBGRADE RUTTING**
(Perpetual Pavt. Option)

AU EXAMPLES

* THICKNESS – MESALS

* PERPETUAL PAVT THICKNESS

TYPICAL AU PCCP
(High ESALs)

230 mm – JPCP
(30-40 MPa)

130 mm – “Lean Concrete” (High FA)
(5 MPa / 20-30 MPa)

CBR: 5-10

$$N = RF\left[\frac{6918(0.856\,V_B + 1.08)}{S_{mix}^{0.36}\,\mu\varepsilon}\right]^5$$

where

S_{mix} = asphalt modulus (MPa)

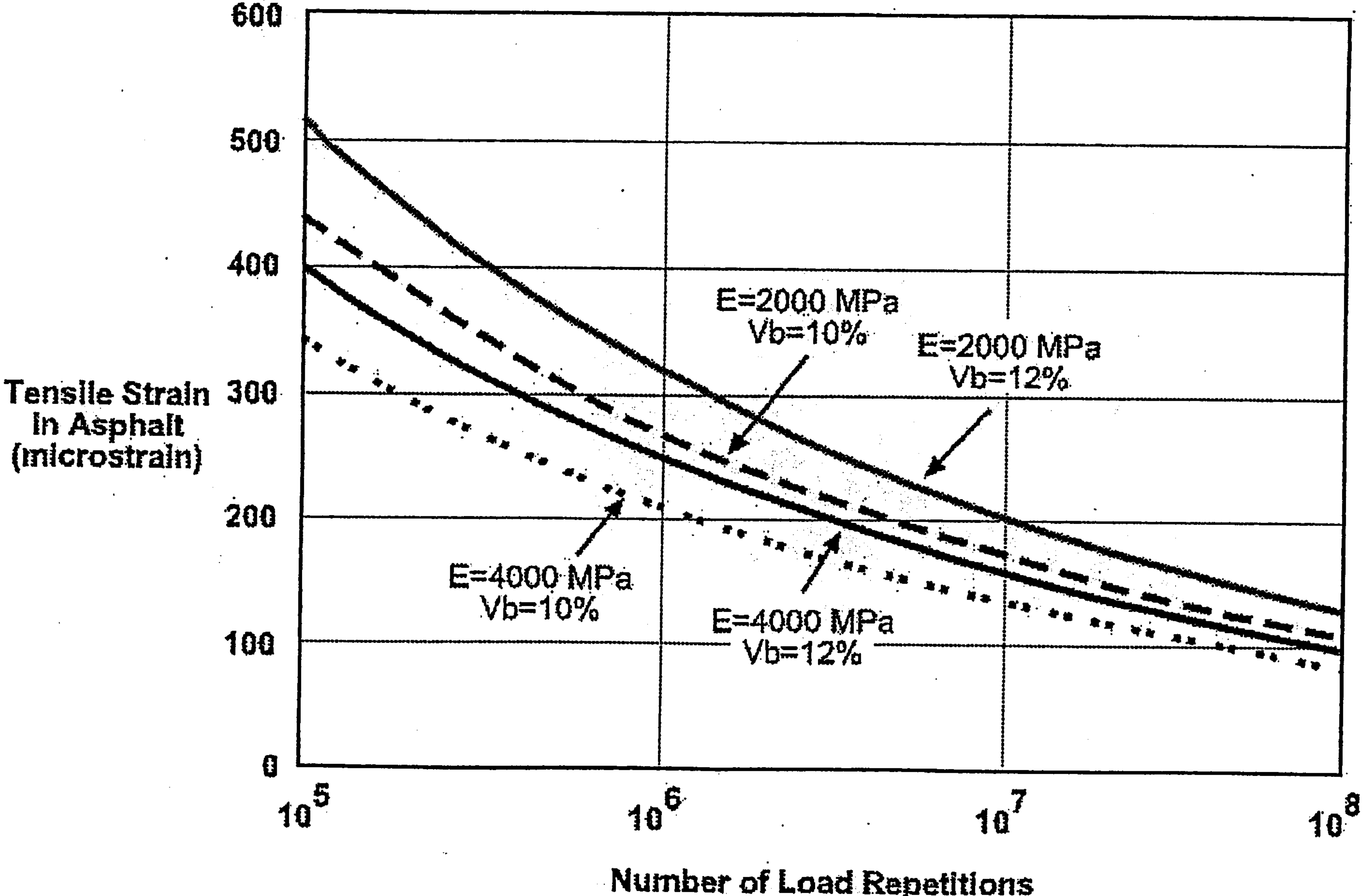
V_B = volume of binder in asphalt mix = 11%

RF = 1, desired project reliability 95%

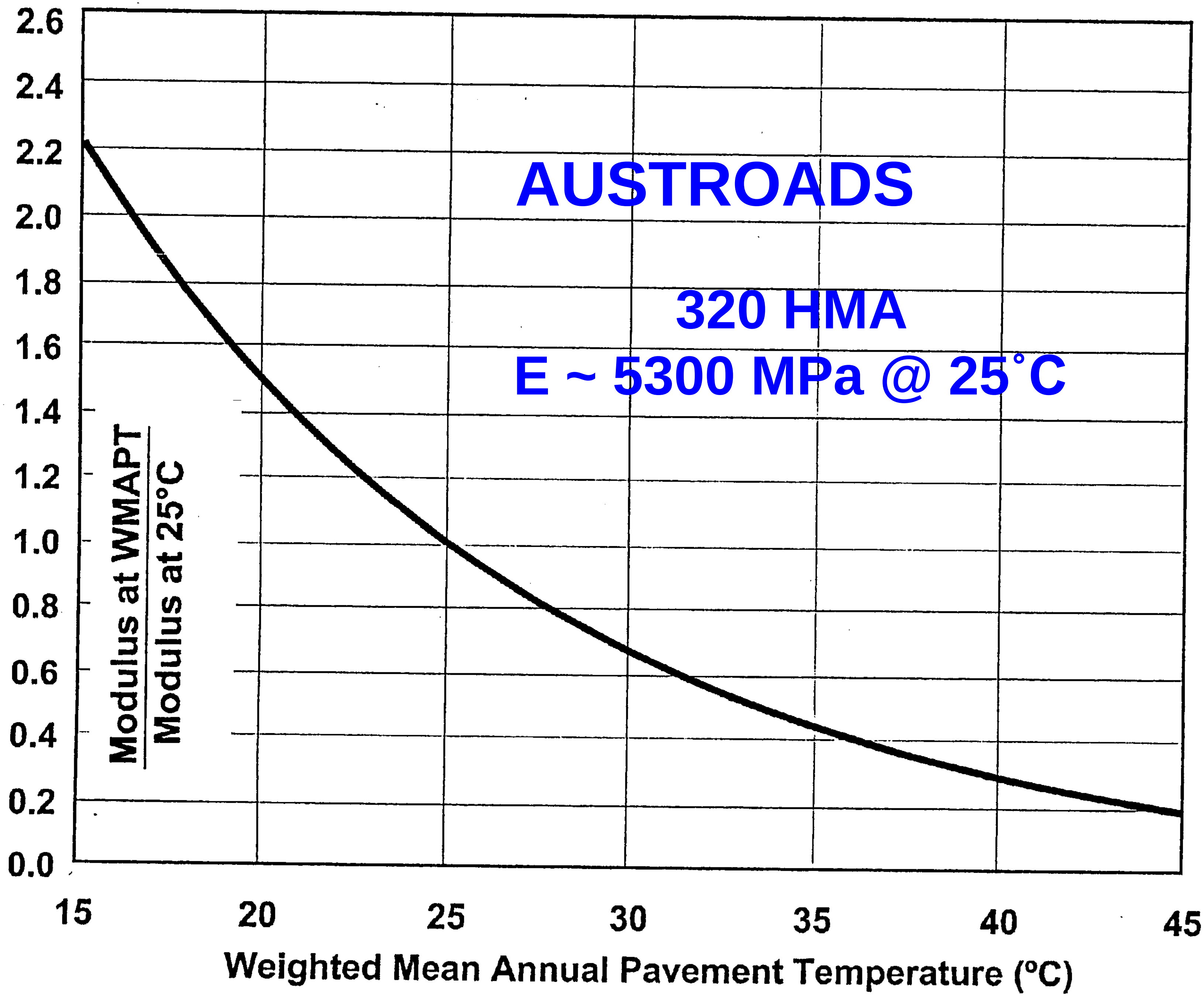
AUSTROADS – PAVEMENT DESIGN -SHELL

RF: 2.5/80%-2.0/85%-1.5/90%-1.0/95%-0.67/97.5%

RF = 95%



600
500
400
300
200
100
0
Tensile Strain
in Asphalt
(microstrain)
E=2000 MPa
Vb=10%
E=2000 MPa
Vb=12%
E=4000 MPa
Vb=10%
E=4000 MPa
Vb=12%
10^5
10^6
10^7
10^8
Number of Load Repetitions


AUSTROADS
320 HMA
E ~ 5300 MPa @ 25˚C
Modulus at WMAPT / Modulus at 25°C
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
15
20
25
30
35
40
45
Weighted Mean Annual Pavement Temperature (°C)

HMA (mm)	MELBOURNE (24˚C)*	SYDNEY (28˚C)*	BRISBANE (32˚C)*
150	102**/33***	113/32	127/29
200	72/189	80/182	90/164
250	55/729	61/706	68/668
300	44/2218	49/2112	55/1931

* WMAPT ** HMA STRAIN - (MICRO-STRAIN) *** MESALS

RUBBLIZED PCCP – MESAL ESTIMATES

SITE	70**	80**	90**	100**
MELBOURNE (29.6˚C - 3710*)	240 ***	215	195	180
SYDNEY (32˚C - 3180*)	250	225	205	185
BRISBANE (35˚C - 2280*)	280	250	230	210

* HMA MODULUS (MPa) / JAN. PAVT. TEMP.
** FEL (MICRO-STRAIN) *** HMA THICKNESS (mm)

PERPETUAL PAVT THICKNESS – VARIABLE FEL

RUBBLIZATION TECHNOLOGY ASSESSMENT

RUBBLIZATION "WARRANTS" **

CONSTRUCTION EQPMNT/PROCEDURES ******

SPECIFICATIONS ***

RUBBLIZATION ENGINEERING ***

HMA OL THICKNESS DESIGN ***

PERTINENT REFERENCES

"BREAKING/CRACKING AND SEATING CONCRETE PAVEMENTS,"
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THANK YOU !!

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