The Role of Subbase Support in Concrete Pavement Sustainability

TxDOT Project 6037 - Alternatives to Asphalt Concrete Pavement Subbases for Concrete Pavement

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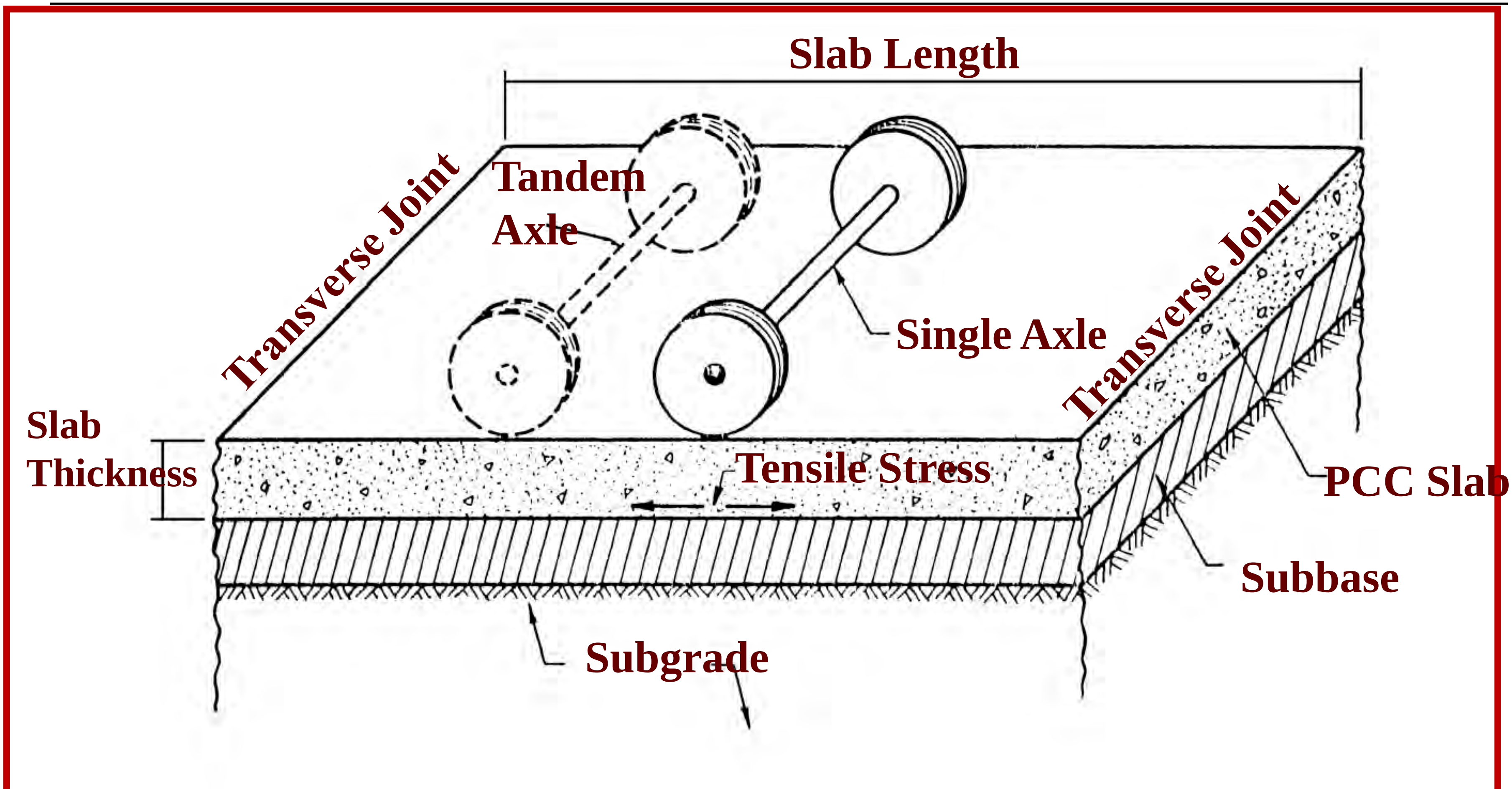
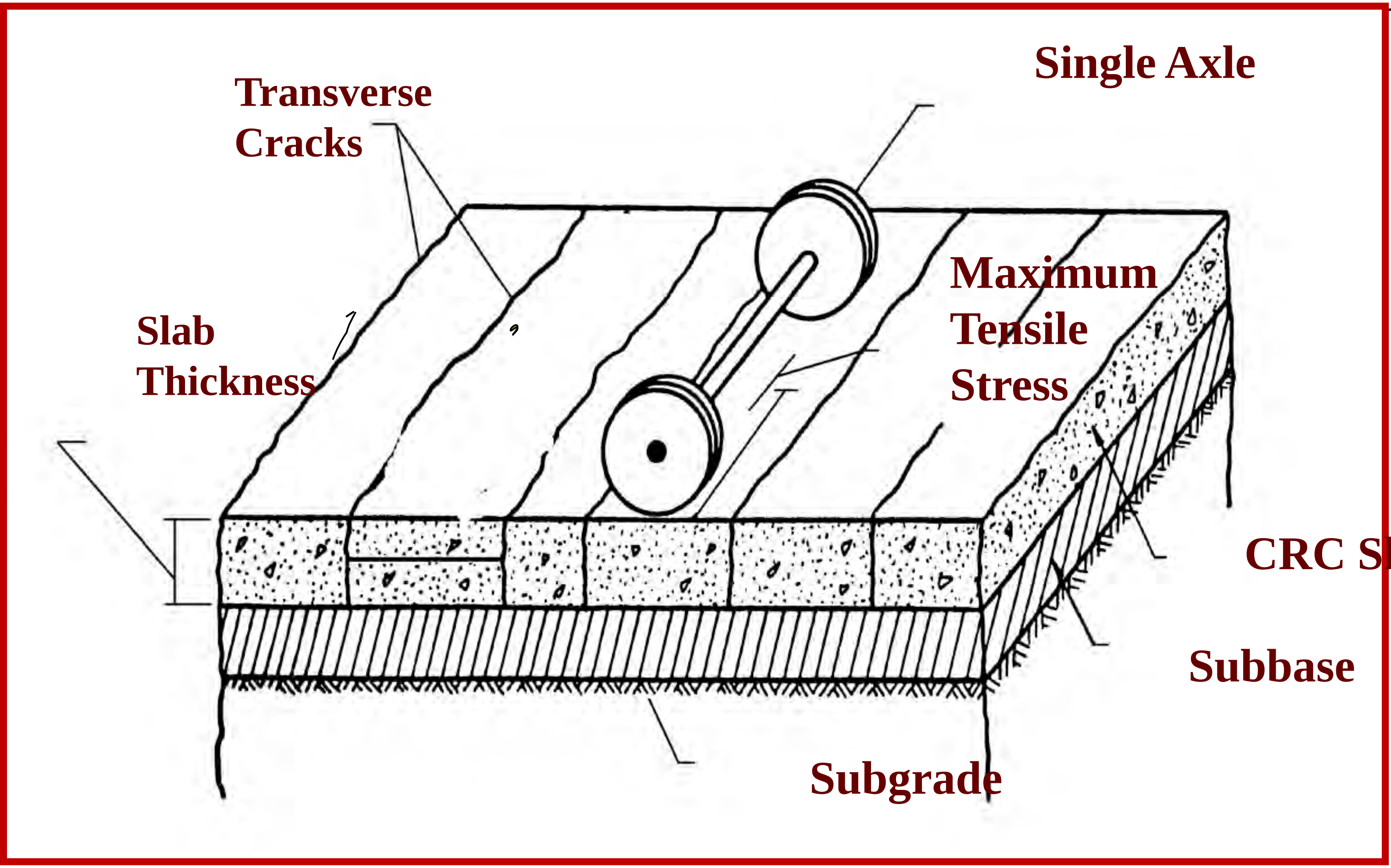
Wednesday, Jan. 12, 2011

Jointed Pavement



CRC Pavement



Corner Failure

Adjacent Patch Deterioration

Keyway Failure

Drainage Swale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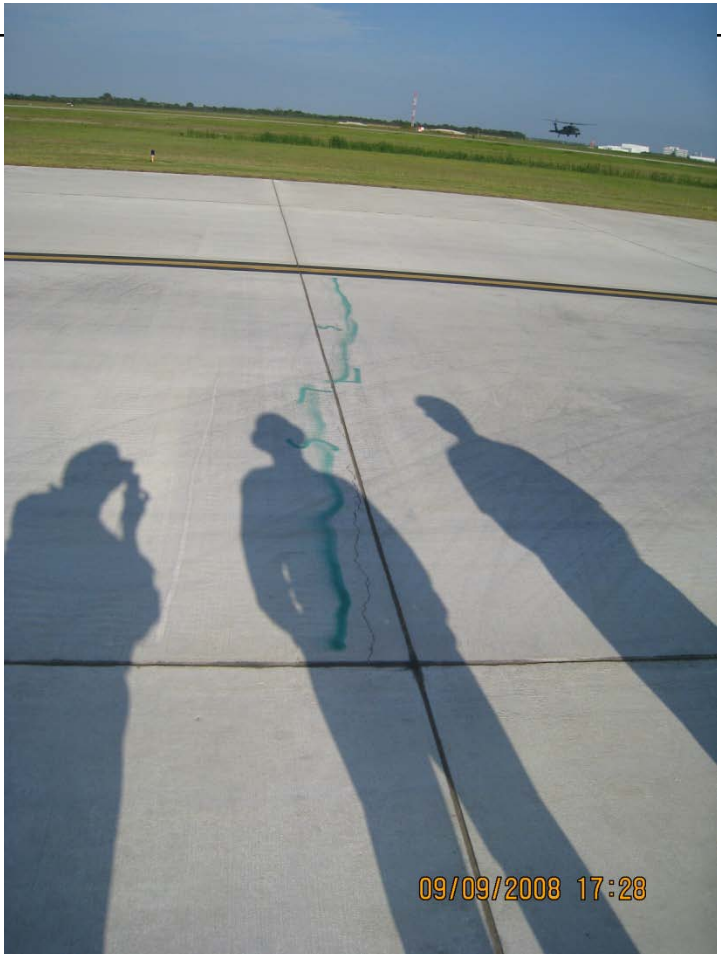
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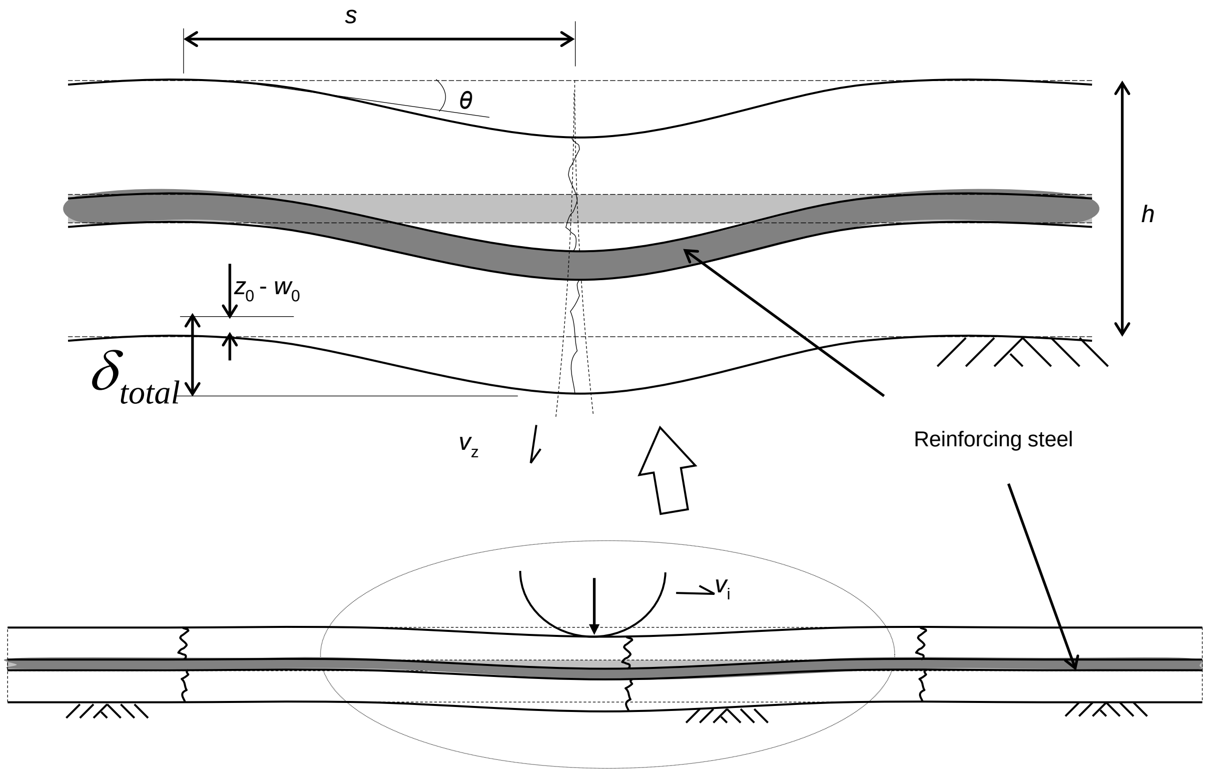
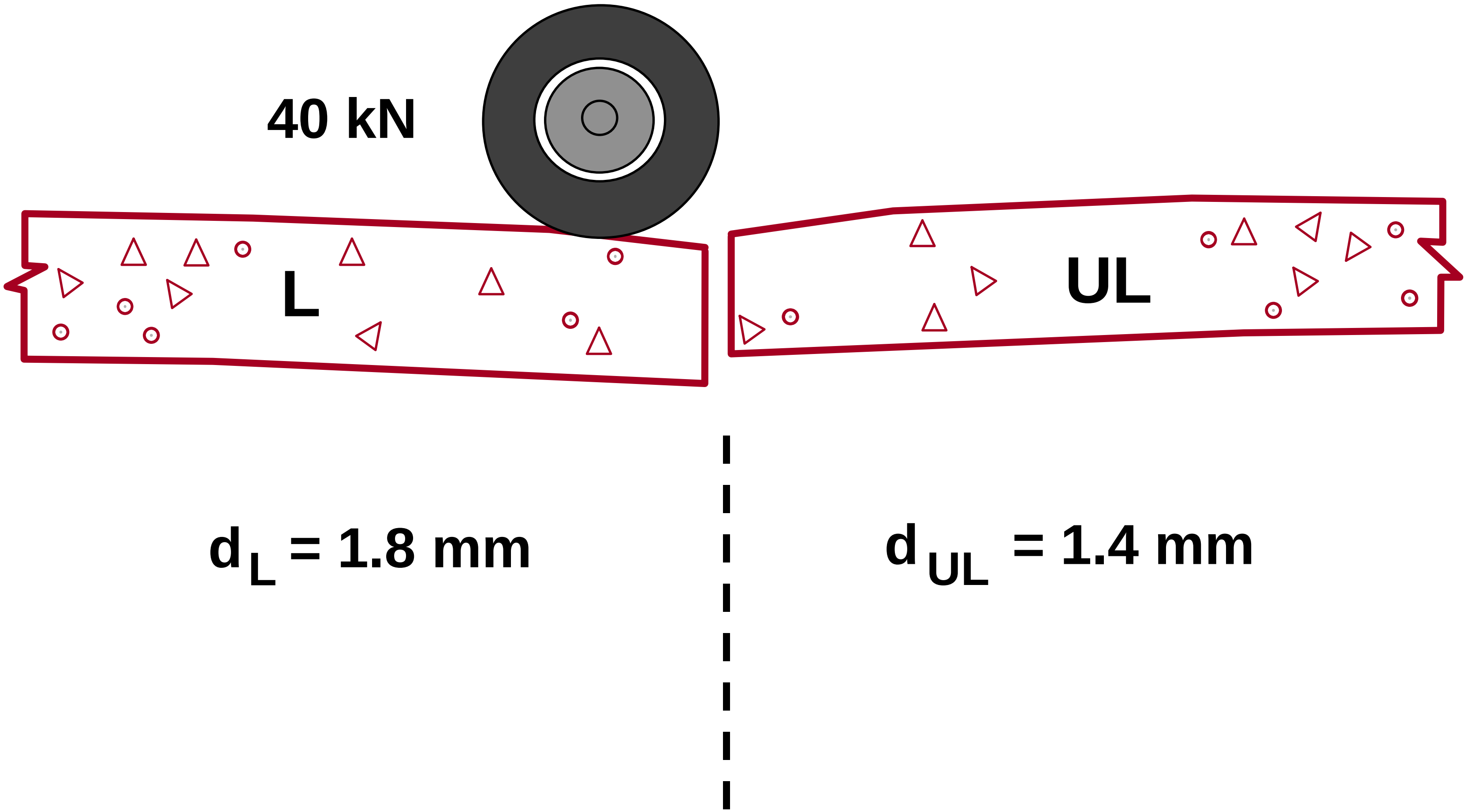
Cracking on the dowel

Erosion: Mechanically and Hydraulically Induced



Load Transfer Efficiency

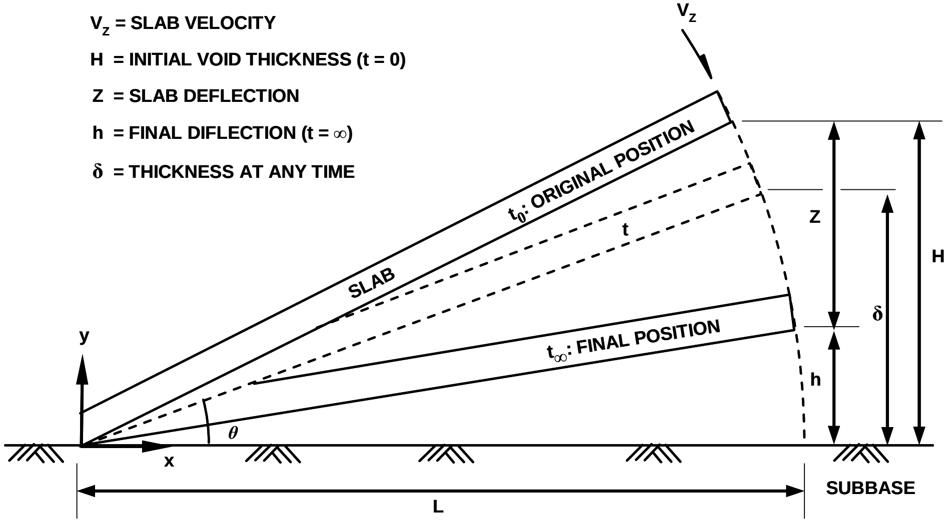


d_L = 1.8 mm

d_{UL} = 1.4 mm

Matrix Erosion Model

$$f_i = f_0 e^{-\left(\frac{\rho}{N_i - \nu}\right)^a}$$



Where, f_i = Erosion depth (L)

f_0 = Ultimate erosion depth (L)

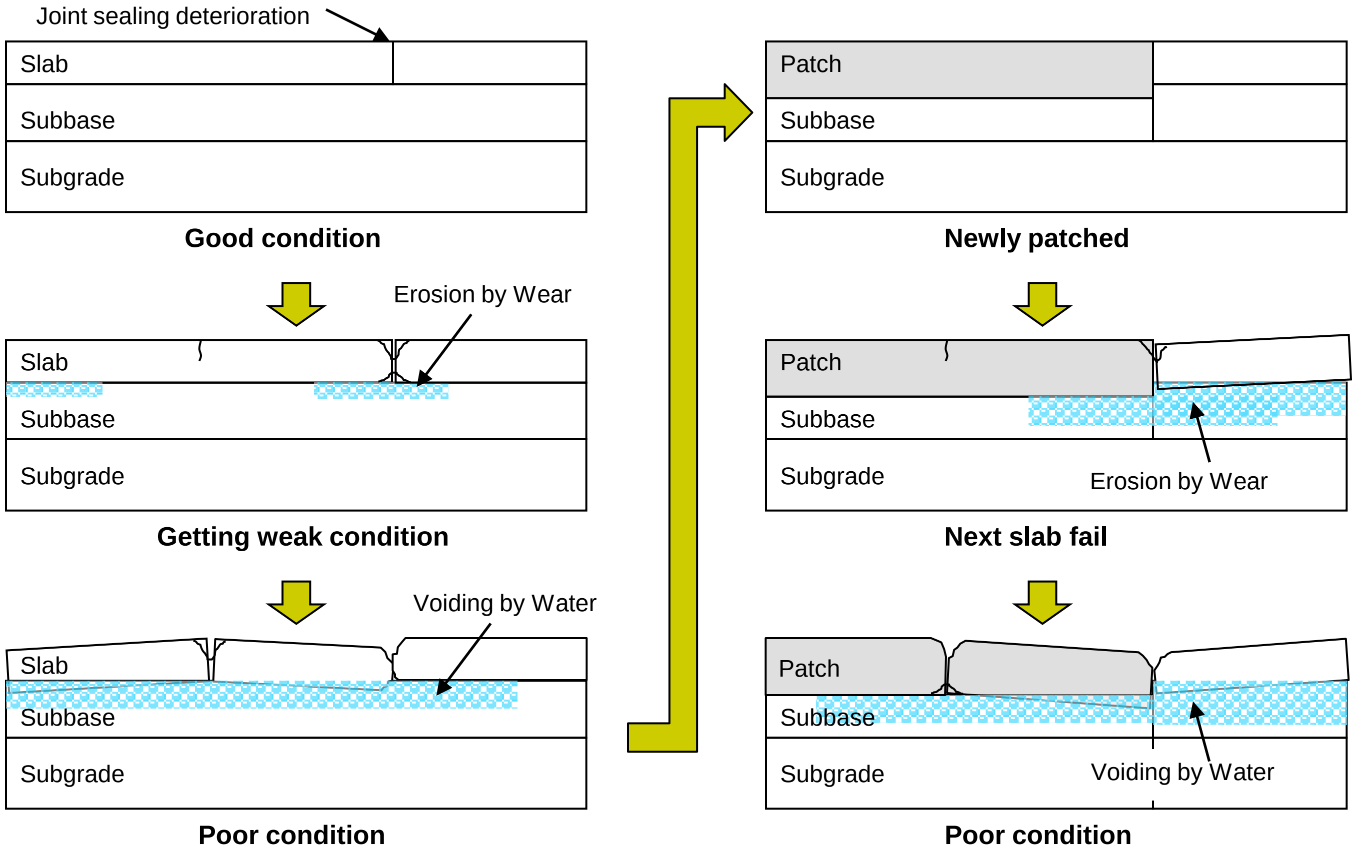
N_i = Number of axle loads per load group contributing to erosion

ρ = Calibration coefficient based on local performance

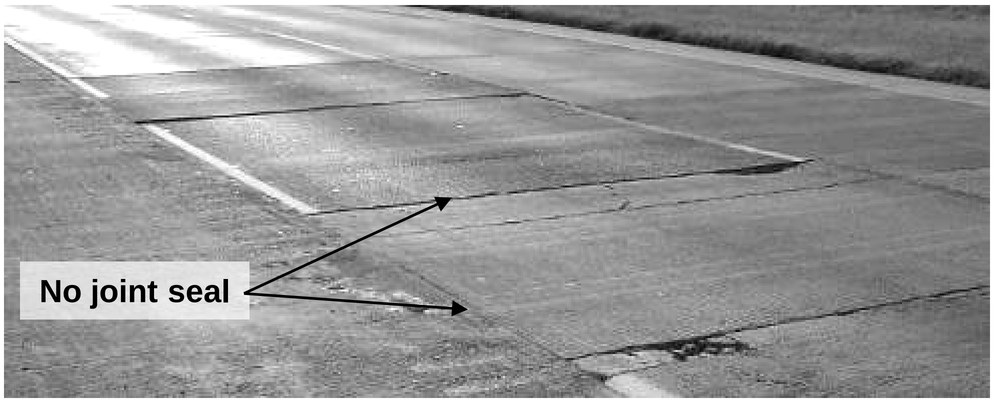
ν = Calibration coefficient represents the number of wheel loads (or time) for layer debonding to occur and erosion to initiate, 0 for lab test

a = Inverse of the rate of void development

Subbase Erosion and Pavement Deterioration Process



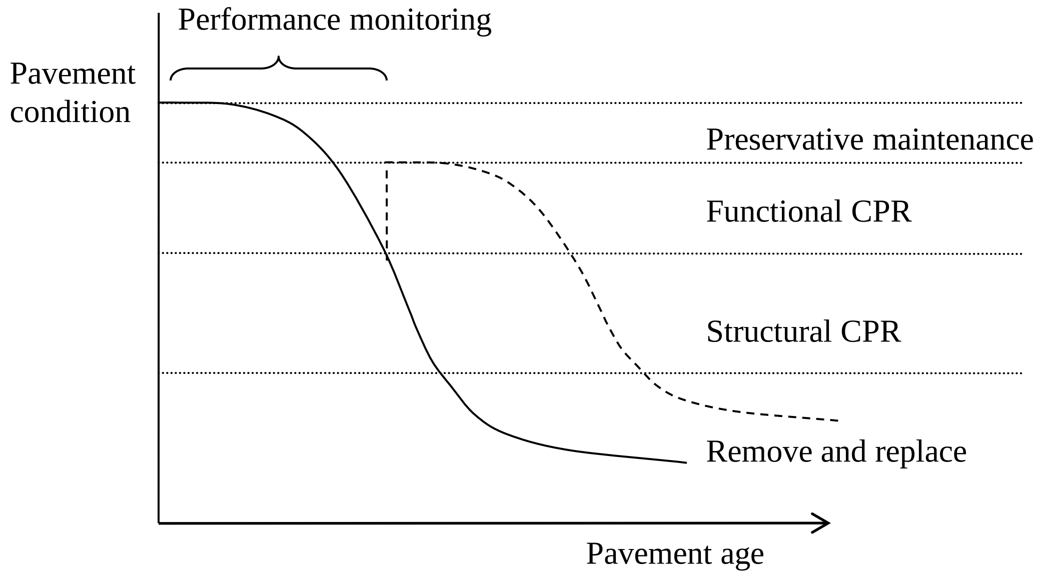
Patched Area Deterioration



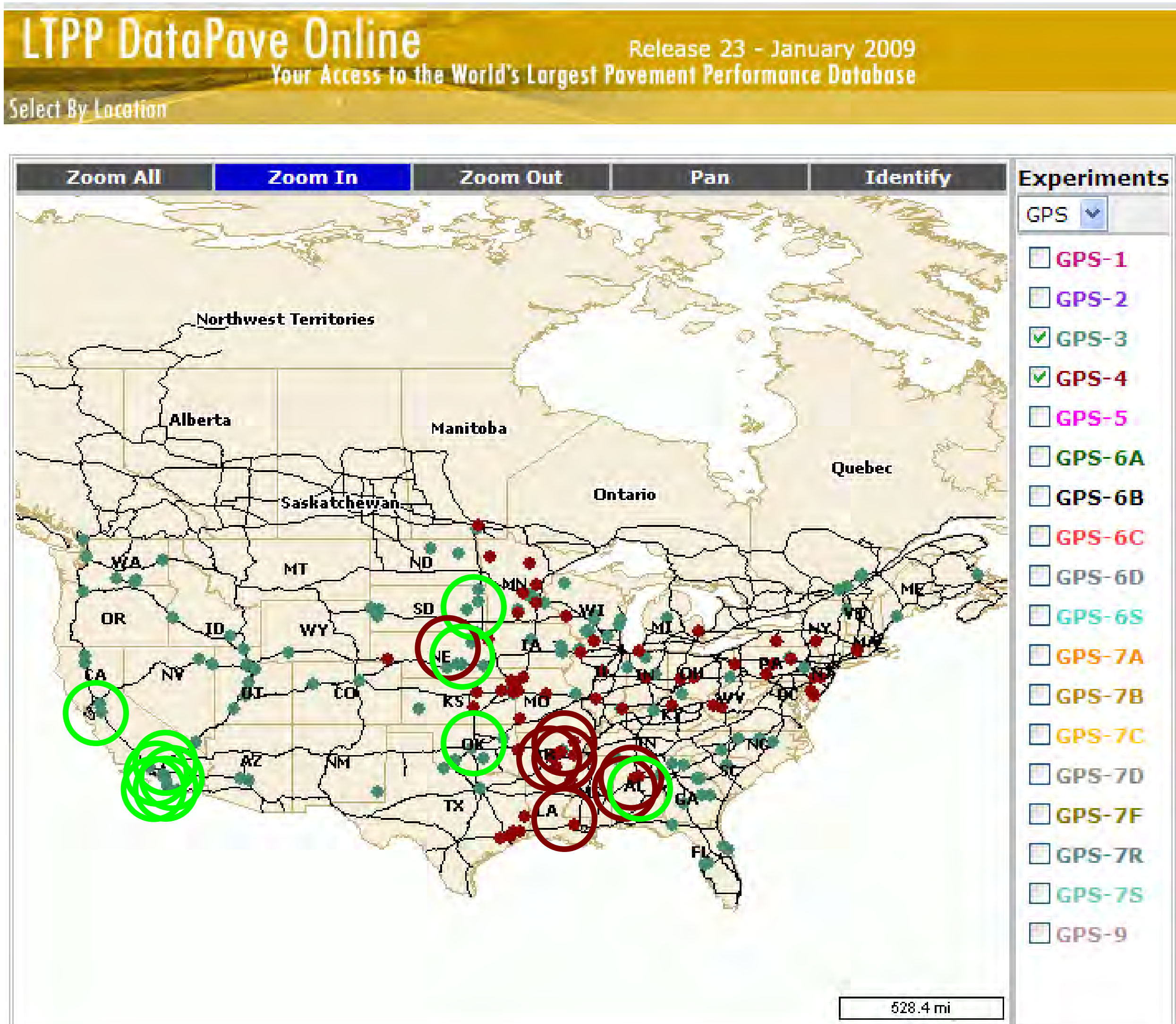
After 1 month

Maintenance Strategy

- As pavement condition degrades,
  - Repair costs and time of repair go up
  - Future renewal options become limited
- Preservative maintenance extend pavement life cost effectively

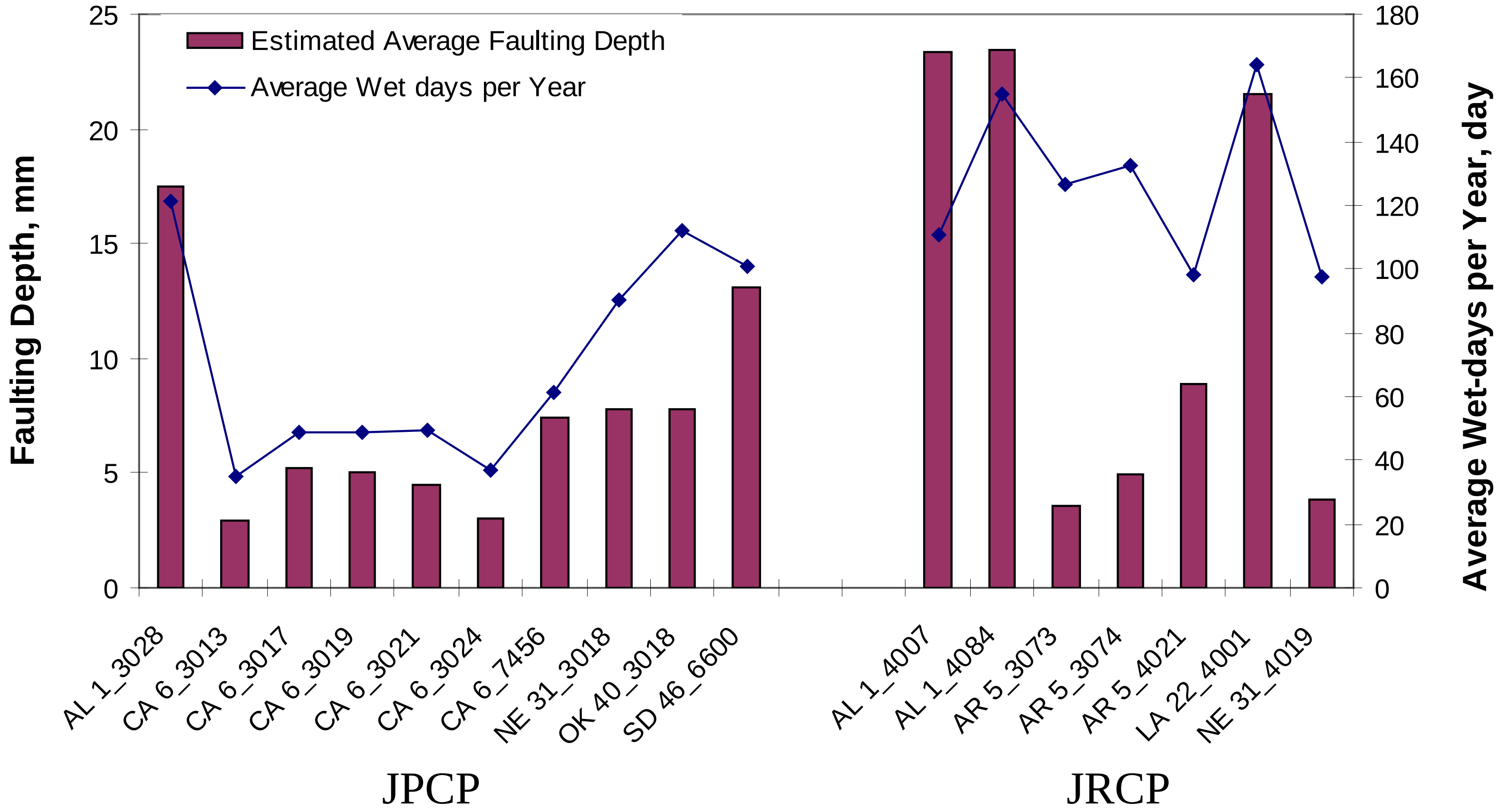


LTPP Faulting Data Sections



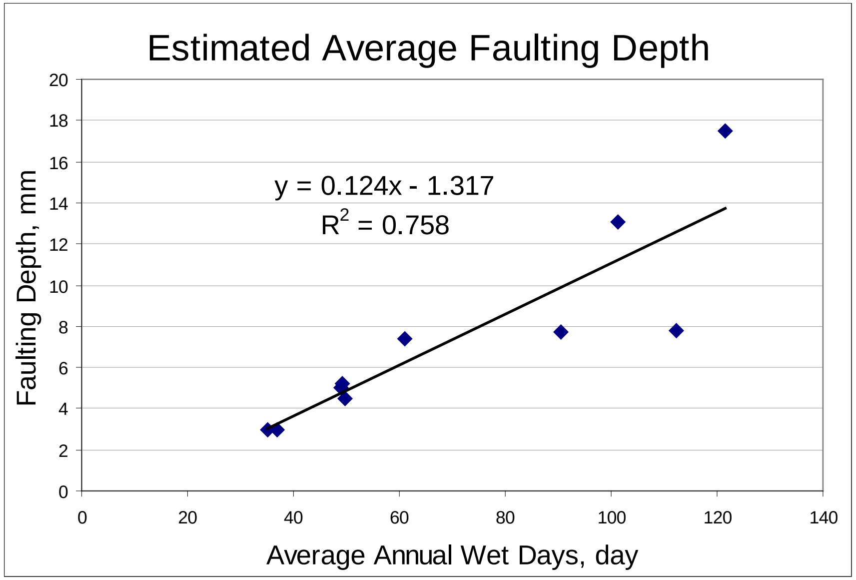
State and Section ID	Pavement Type
AL 1_3028	JPCP
CA 6_3013	JPCP
CA 6_3017	JPCP
CA 6_3019	JPCP
CA 6_3021	JPCP
CA 6_3024	JPCP
CA 6_7456	JPCP
NE 31_3018	JPCP
OK 40_3018	JPCP
SD 46_6600	JPCP
AL 1_4007	JRCP
AL 1_4084	JRCP
AR 5_3073	JRCP
AR 5_3074	JRCP
AR 5_4021	JRCP
LA 22_4001	JRCP
NE 31_4019	JRCP

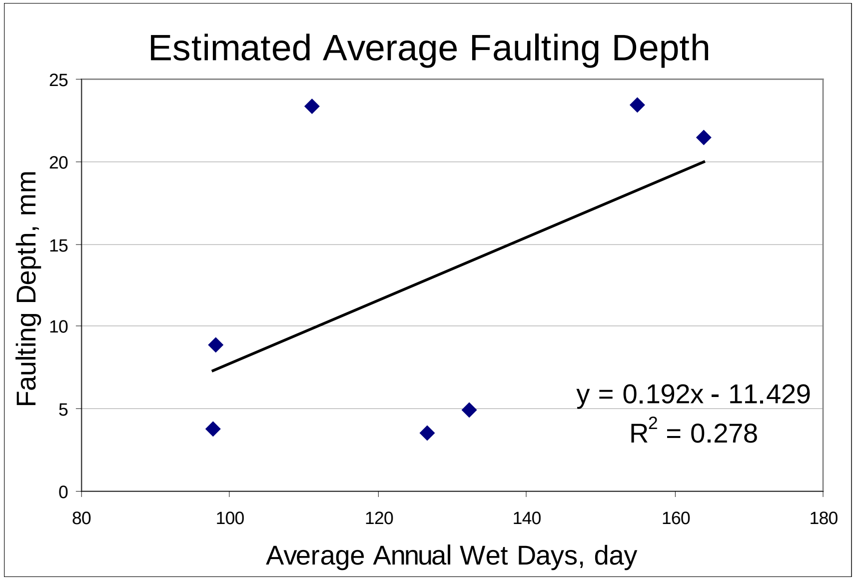
Estimated Average Faulting Depth



Wet days in LTPP database is defined as the number of days for which precipitation was greater than 0.25 mm for year

Relationship between Faulting and Number of Wet days

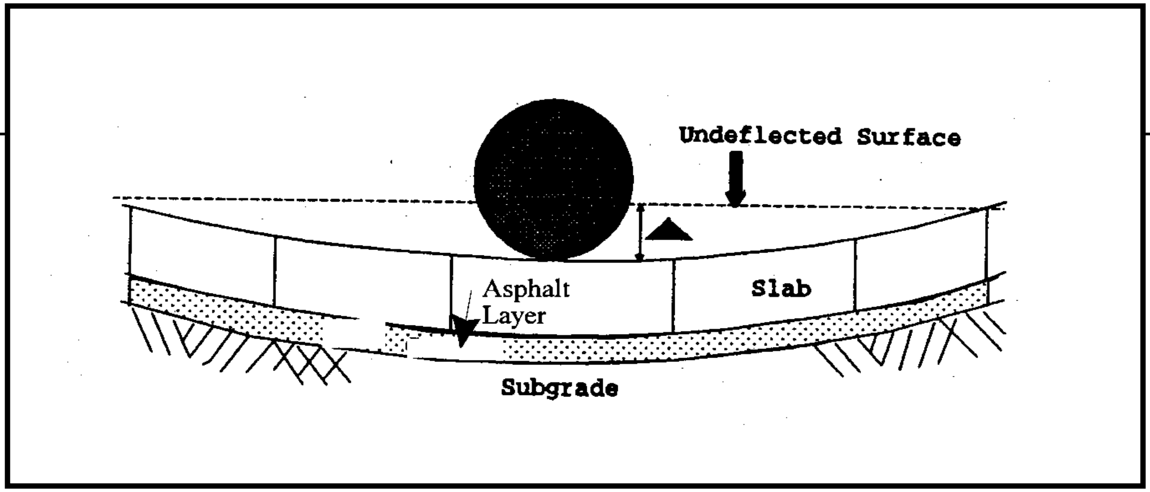


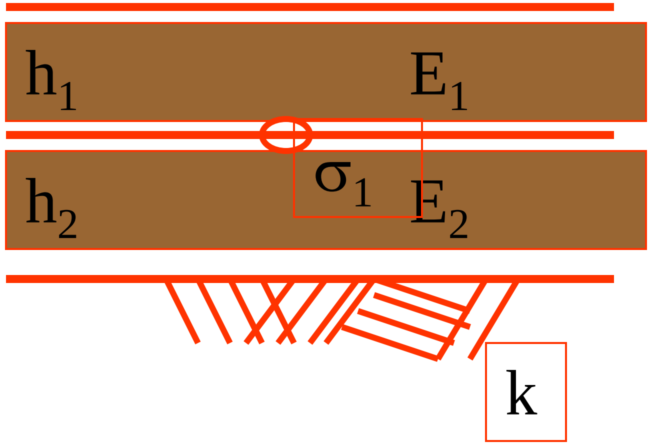


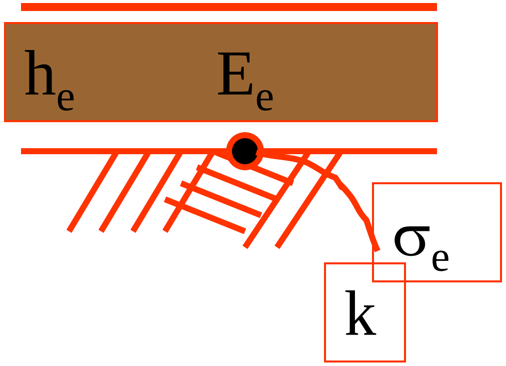
JPCP Sections

JRCP Sections

Average faulting depth is estimated at the 100 million ESAL repetitions based on LTPP faulting data


Undeflected Surface
Asphalt
Layer
Slab
Subgrade


h_1
E_1
σ_1
h_2
E_2
k

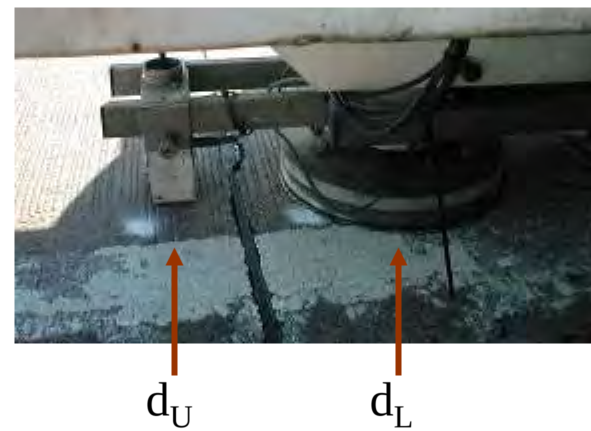

h_e
E_e
σ_e
k

$$Ba\sin\ Area = \frac{SS}{2*\delta_0}\left[\delta_0 + 2\left(\delta_1 + \delta_2 + \ldots + \delta_{j-1}\right) + \delta_j\right]$$

Falling Weight Deflectometer (cont.)

- LTE Testing
  - Measure of independent action

$$LTE = \frac{d_U}{d_L} \times 100$$



Where, LTE = Load transfer effectiveness, percent

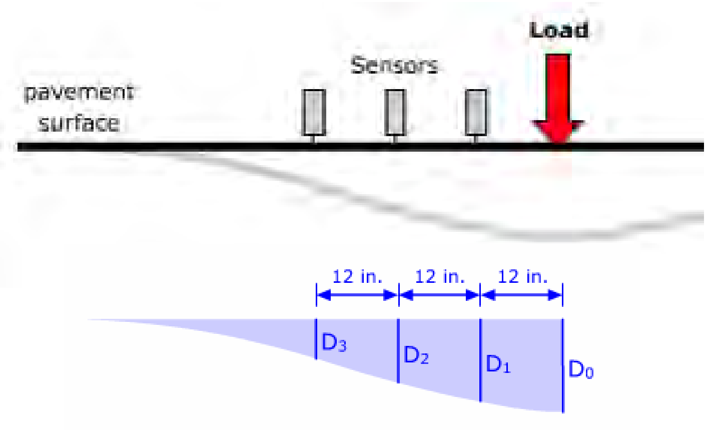
d_U = Deflection on the unloaded side of the joint or crack, mils

d_L = Deflection at the loaded side of the joint or crack, mils

LTE < 70% ⇨ Retrofit load transfer

Falling Weight Deflectometer (cont.)

- Deflection Testing



$$AREA = \frac{6(D_0 + 2D_1 + 2D_2 + D_3)}{D_0}$$

Where, *AREA* = FWD deflection parameter, in.

D_0 = Deflection at the loading position, mils

D_1 = Deflection at 12 in. from the loading position, mils

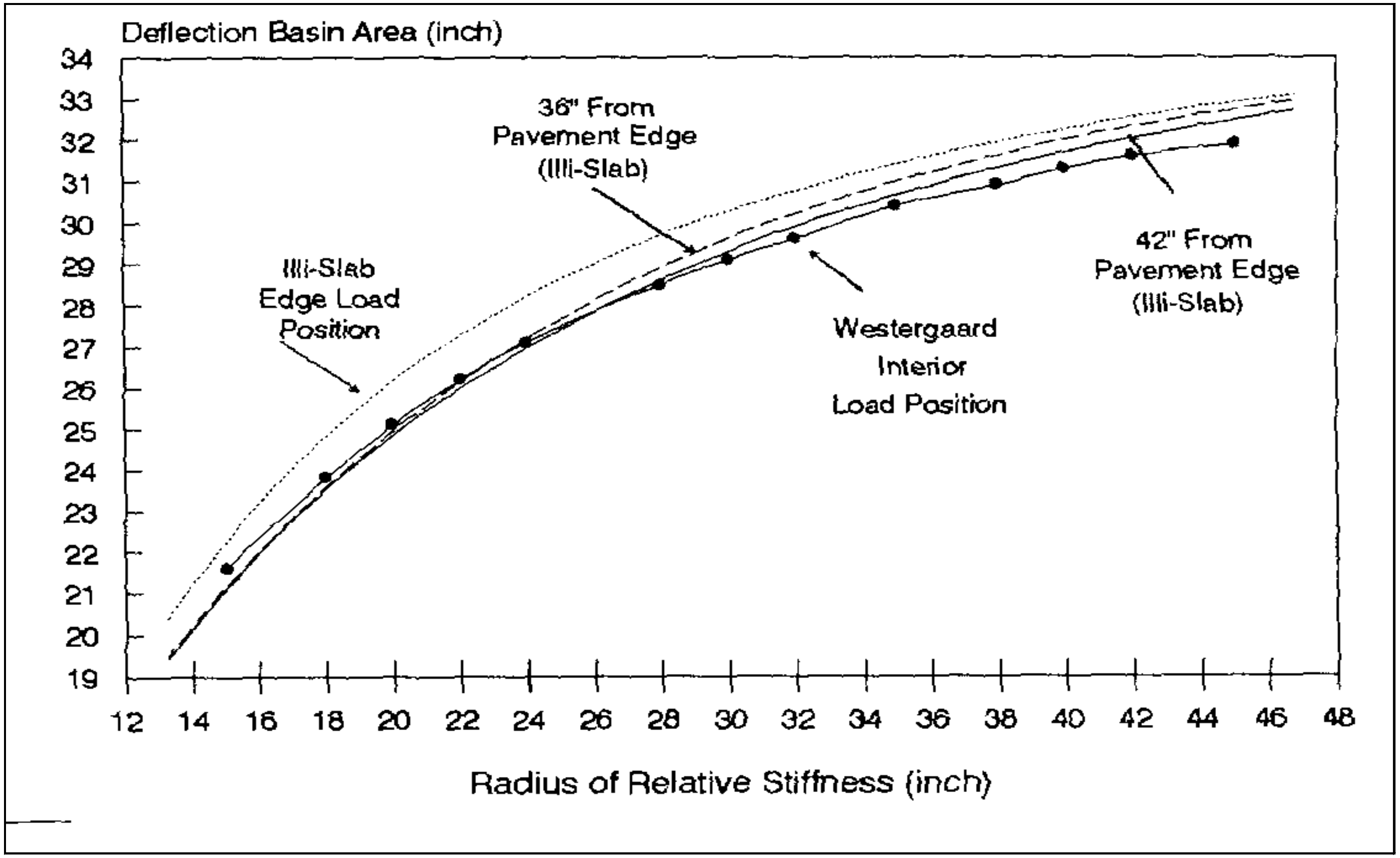
D_2 = Deflection at 24 in. from the loading position, mils

D_3 = Deflection at 36 in. from the loading position, mils

Basin area < 25 ⇨ Check base/subgrade support

Reference: Ioannides, A. M. "Dimensional Analysis in NDT Rigid Pavement Evaluation," Journal of Transportation Engineering, Vol. 116, No. 1, July 1990, pp. 23–36.

Slab Action: ℓ - Value



Equivalent Thickness

$$h_{e-p}^3 = 12\ell_m^4\left(1-\nu^2\right)\left(\frac{k_b}{E_c}\right)$$

h_{e-p} ⇒ Equivalent Thickness

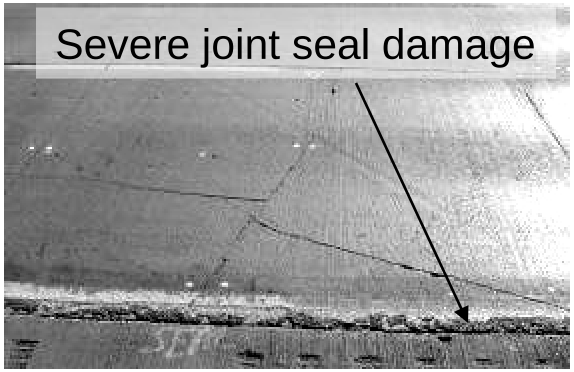
ℓm ⇒ Measured Value

k_b ⇒ Back-calculated

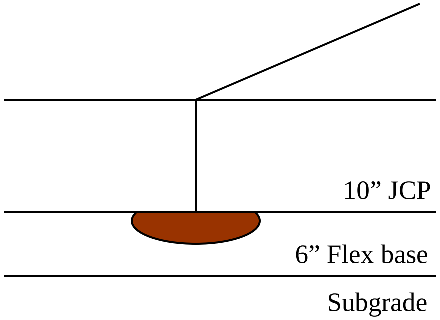
E_c ⇒ Based on Cores

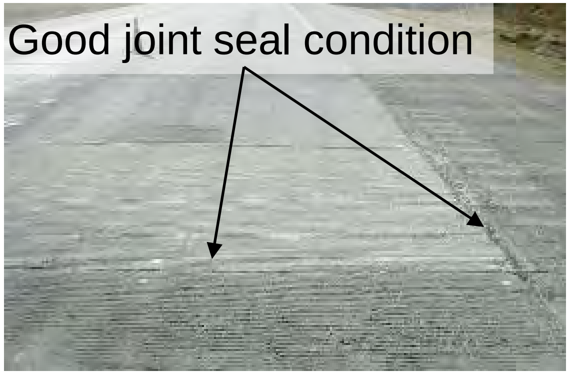
US 75 (Sherman District)

Good Performing Section



Poorly Performing Section



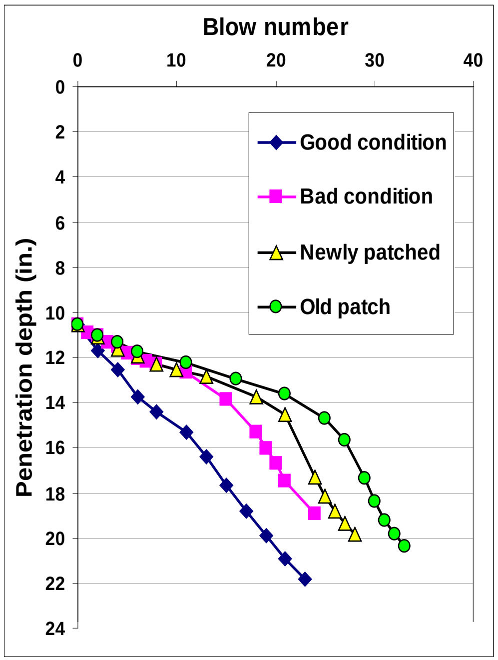


Newly Patched Section

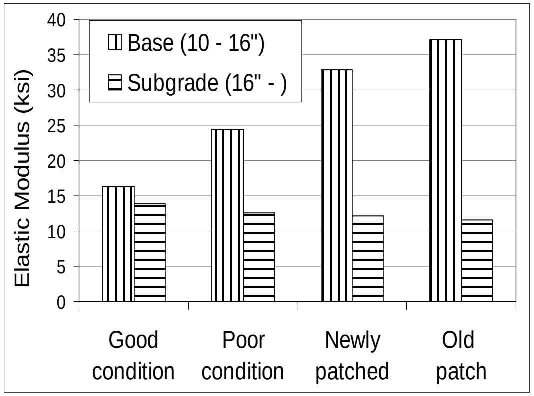
Old Patched Section

- Built in 1983
- ADT: 42,760
- Sever shoulder joint seal damage
- Flex base weakening

US 75 – DCP, Core



Penetration ratio



Depth	Good condition	Poor condition	Newly patched	Old patch
Base (10 - 16")	16.3 ksi	24.4 ksi	32.8 ksi	37.1 ksi
Subgrade (16" -)	13.9 ksi	12.6 ksi	12.1 ksi	11.6 ksi

Elastic Modulus

Base Voiding

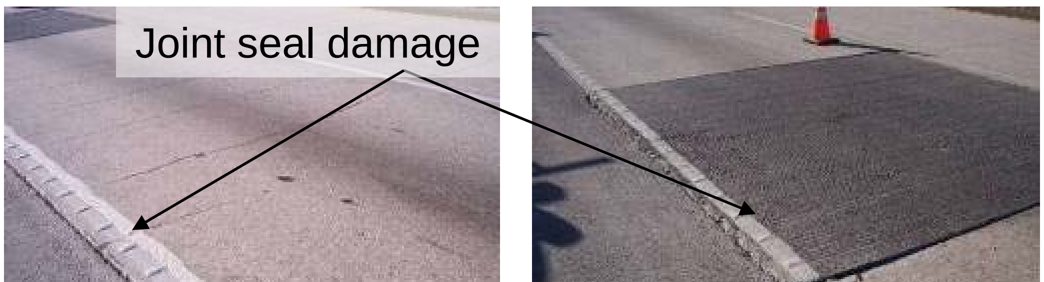

Good

Poor

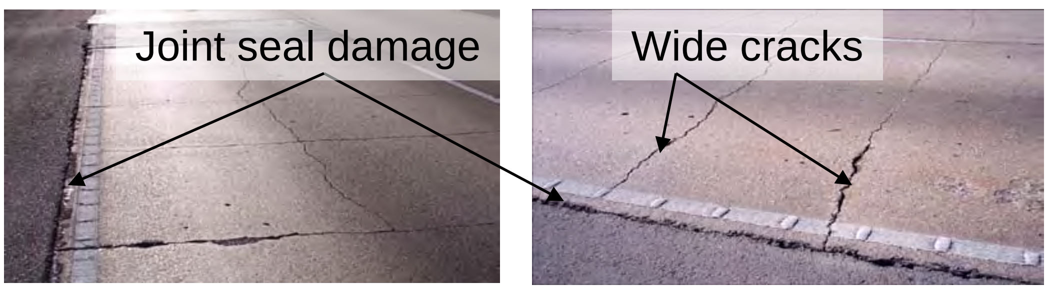
New Patch

Old Patch

US 81/287 (Wise County)

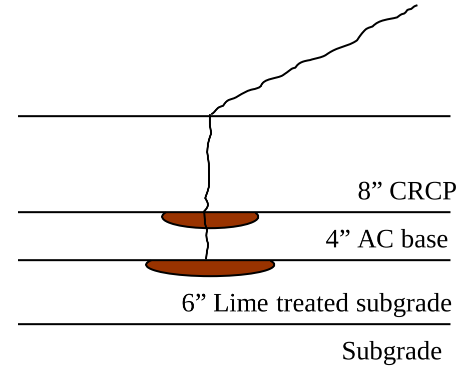


Section 1

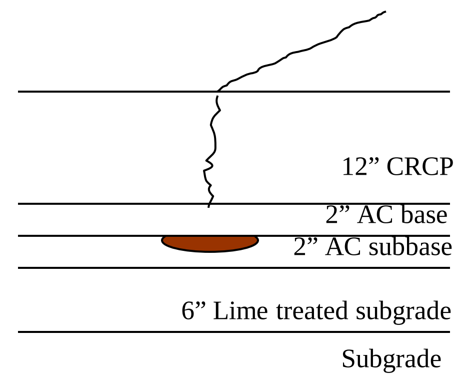


Section 2

Section 3

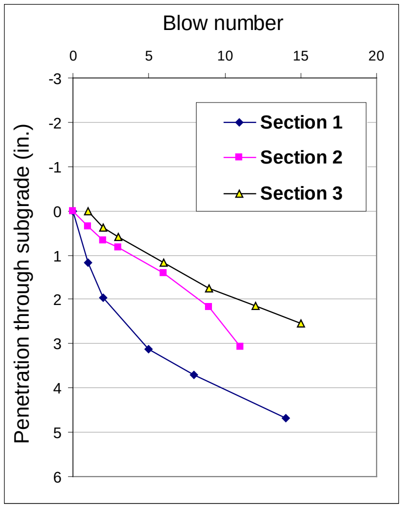


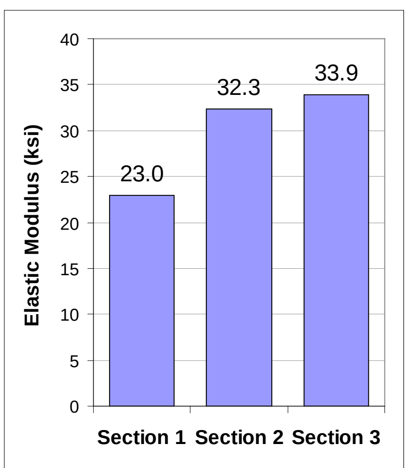
- Section 1&2, Built in 1971
- ADT: 23,000 (23% truck)
- AC base and lime treated subgrade erosion



- Section 3, Built in 1985
- ADT: 23,000 (23% truck)
- Debonded AC subbase erosion

US 81/287 – DCP, Core





AC base bottom

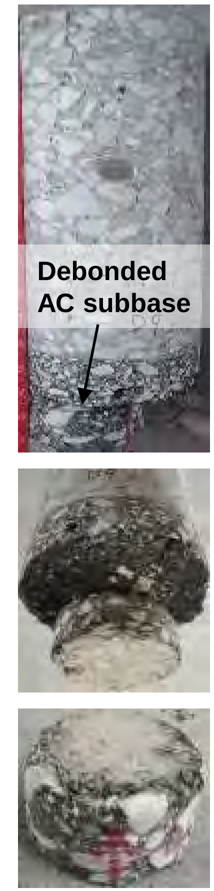

AC base bottom

Section 1

AC base bottom

AC base bottom

Section 2



AC subbase top

Section 3

US 287 (Vernon District)

Good performing area

Poor performing area

Joint & crack sealant deterioration

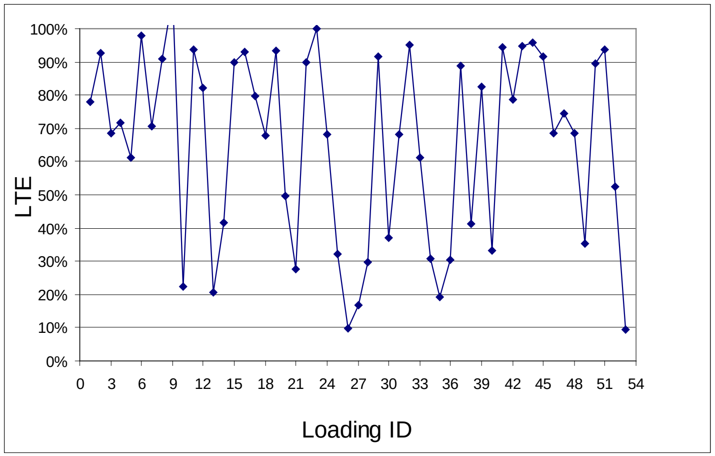
Good performing area

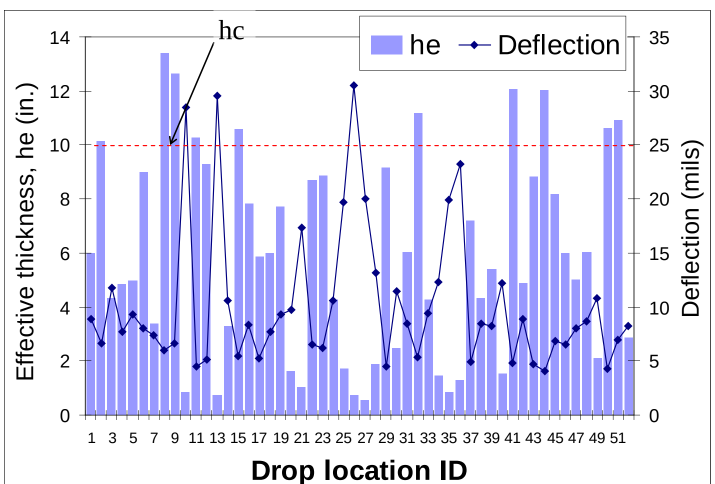
- No crack
- Good joint sealing condition

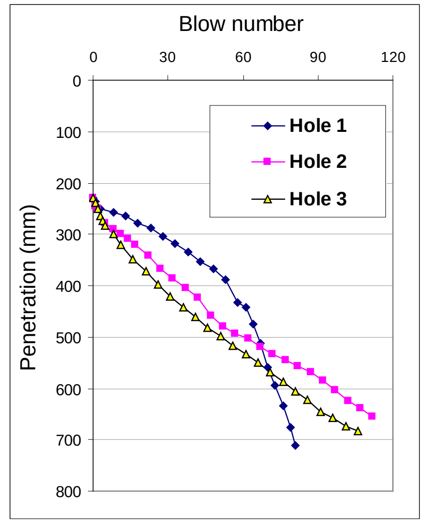
Poor performing area

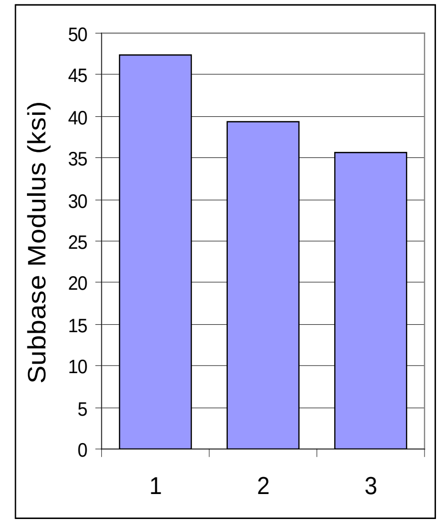
- Sever joint and crack sealant deterioration
- Wide shoulder joint opening (> ½ in.)
- Base erosion under crack

US 287 – FWD, DCP, Core



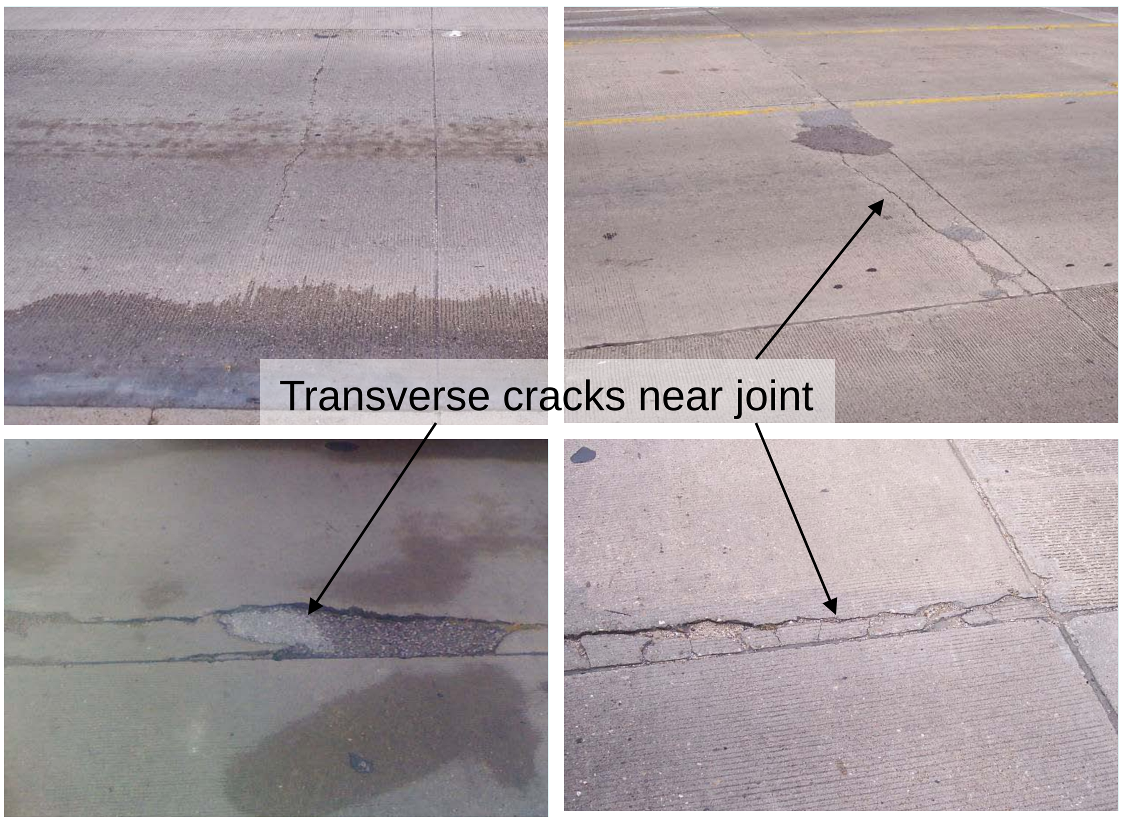


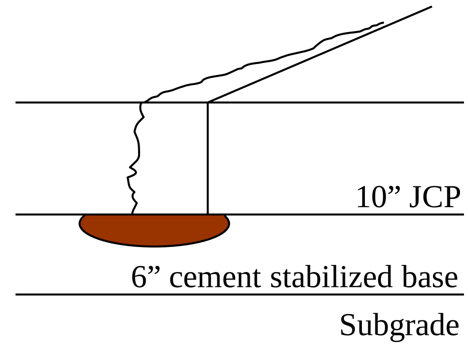




DCP penetration and Subbase Modulus

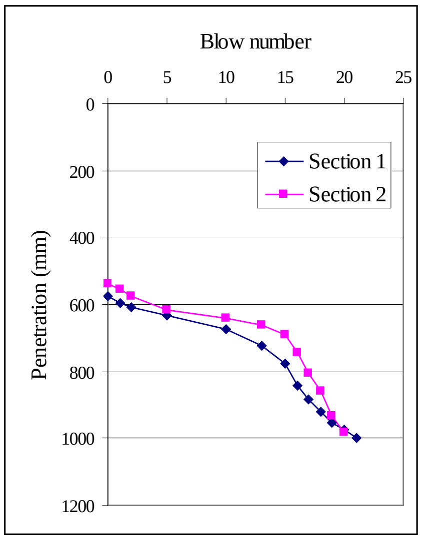
FM 364 (Beaumont District)

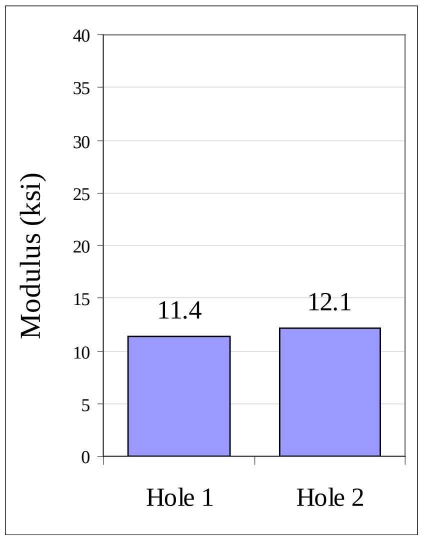




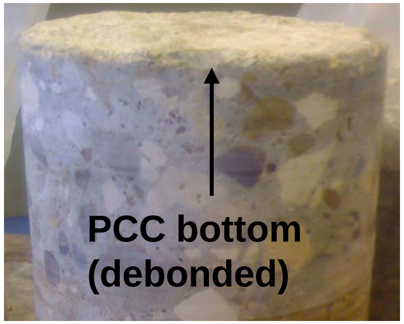
- Built in 1985
- ADT: 21,000 (2.5% truck)
- Transverse cracks near joint (no crack sealing)
- Cement treated base erosion under crack

FM 364 – DCP, Core

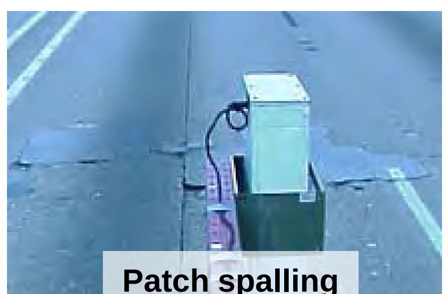


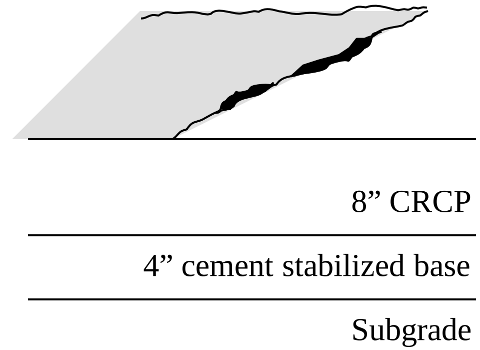


DCP result of subgrade



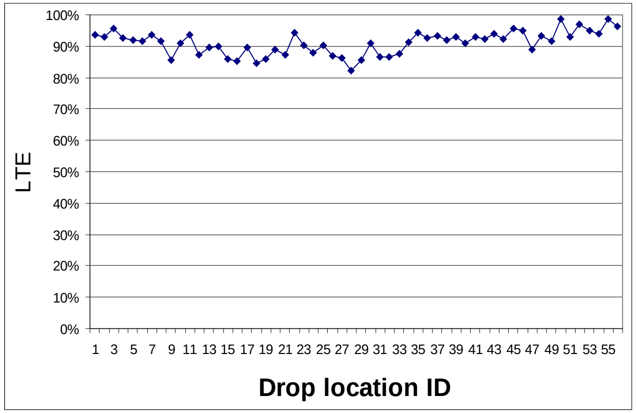
IH 635 (Dallas District)

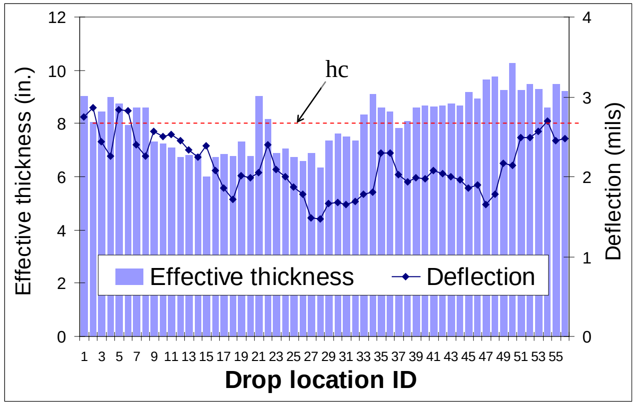




- Built in 1967
- ADT: 200,000 (12% truck)
- Spalling on cracks and patches
- Widened longitudinal joint
- No sever erosion

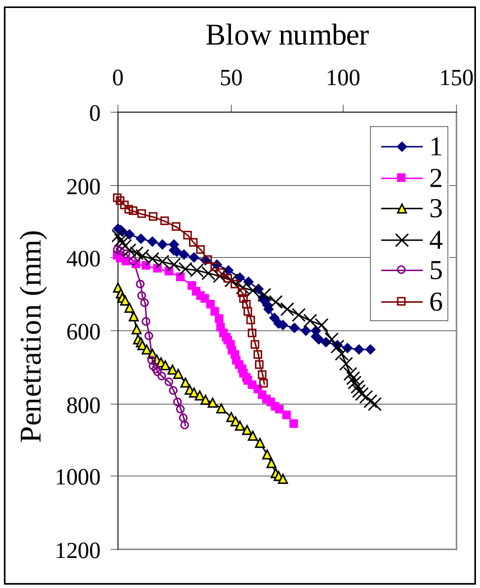
IH 635 – FWD, GPR

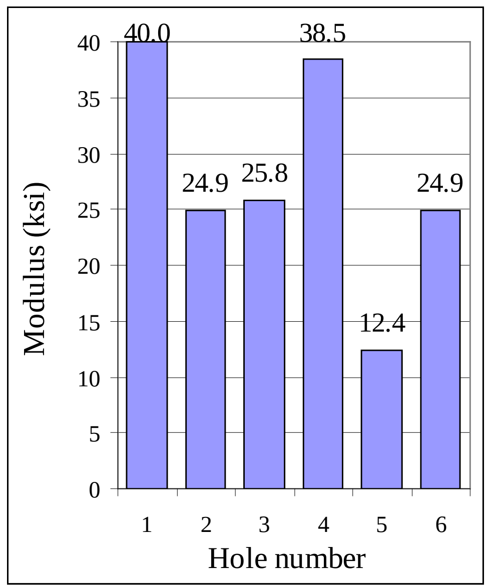




GPR along Edge Side Wheel Path

IH 635 – DCP, Core





1

2

3

4

5

6

Erosion Factors:

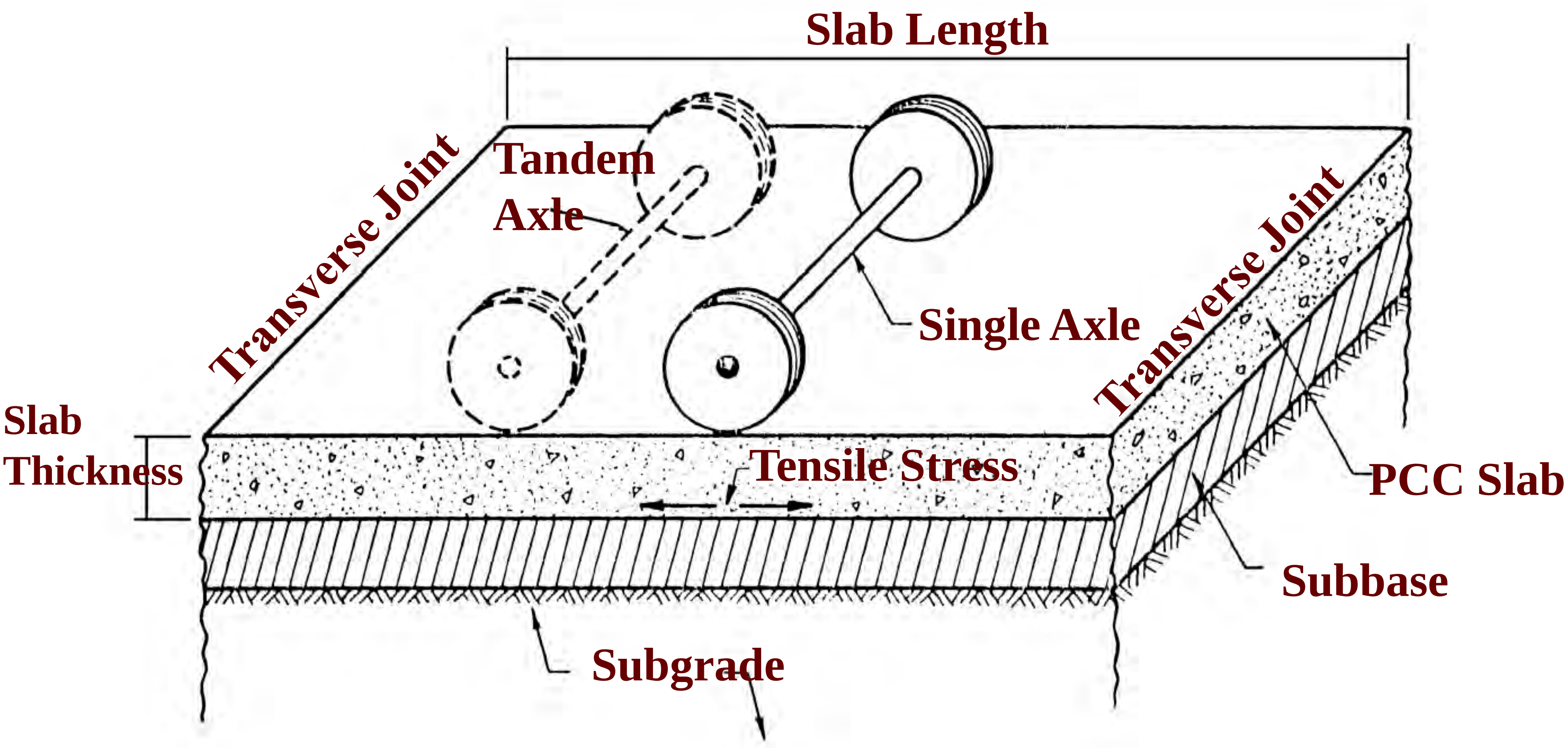
- Moisture
- Traffic
- Erodible Subbase Layer

Functions of Subbase?

1) Provide a stable construction platform
2) Prevent erosion of the pavement support
3) Reduce early bonding stress
4) Provide uniform slab support
5) Facilitate drainage
6) Provide increased slab support

Is this surface type a good idea?

What distress types do present design methods address??



MEPDG

- Fatigue Cracking
- Faulting (Jointed)
- Punchouts (CRC)
- Roughness
  - Spalling

Figure 1 Spalling in concrete pavements [Soares and Zollinger 1998].

Erosion in Design Procedures – MEPDG design method

- Included to faulting model by 5 classes of erodibility based on percent of stabilizer and compressive strength

$$FAULTMAX_i = FAULTMAX_0 + C_7 * \sum_{j=1}^{m} DE_j * Log(1 + C_5 * 5.0^{EROD})^{C_6}$$

$$FAULTMAX_0 = C_{12} * \delta_{curling} * \left[Log(1 + C_5 * 5.0^{EROD}) * Log(\frac{P_{200} * WetDays}{P_s}) \right]^{C_6}$$

Where,

$FAULTMAX_i$	= maximum mean transverse joint faulting for month i, in
$FAULTMAX_0$	= initial maximum mean transverse joint faulting, in
$EROD$	= base/subbase erodibility factor
DE_i	= differential deformation energy accumulated during month i
C_{12}	= $C_1 + C_2 * FR^{0.25}$
C_i	= calibration constants
FR	= base freezing index defined as percentage of time the top base temperature is below freezing (32 °F) temperature
$\delta_{curling}$	= maximum mean monthly slab corner upward deflection PCC due to temperature curling and moisture warping
P_s	= overburden on subgrade, lb
P_{200}	= percent subgrade material passing #200 sieve
$WetDays$	= average annual number of wet days (greater than 0.1 in rainfall)

Erosion in Design Procedures – PCA Design Method

- Empirical erosion model based on outdated highly erodible subbase type in the AASHO Road Test

$$\log N = 14.524 - 6.777(C_1 P - 9.0)^{0.103}$$

$$\text{Percent erosion damage} = 100\sum_{i=1}^{m}\frac{C_2 n_i}{N_i}$$

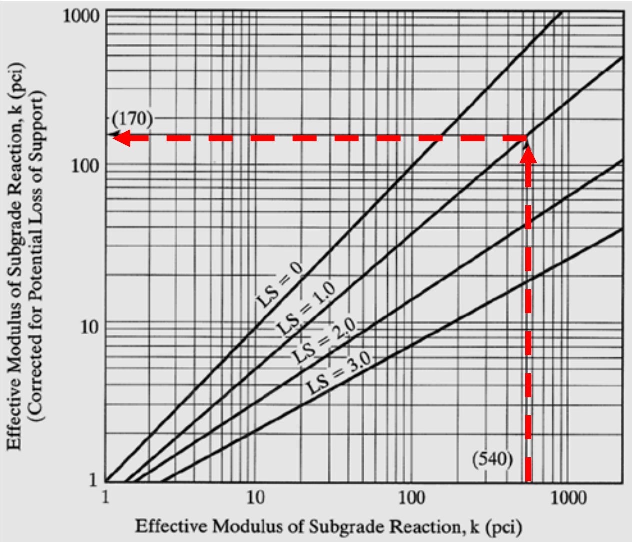
Where, N = allowable number of load repetitions based on a PSI of 3.0
C_1 = adjustment factor (1 for untreated subbase, 0.9 for stabilized subbase)
P = rate of work or power = $268.7\dfrac{p^2}{hk^{0.73}}$
p = pressure on the foundation under the slab corner in psi, $p = kw$
k = modulus of subgrade reaction in psi/in
w = corner deflection in in
h = thickness of slab in in
m = total number of load groups
C_2 = 0.06 for pavement without concrete shoulder, 0.94 for pavements with tied concrete shoulder
n_i = predicted number of repetitions for ith load group
N_i = allowable number of repetitions for ith load group

Erosion in Design Procedures – AASHTO design method

- loss of support factors affecting to the modulus of subgrade reaction – subjective range of modulus

Typical Ranges of LS Factors for Various Types of Materials

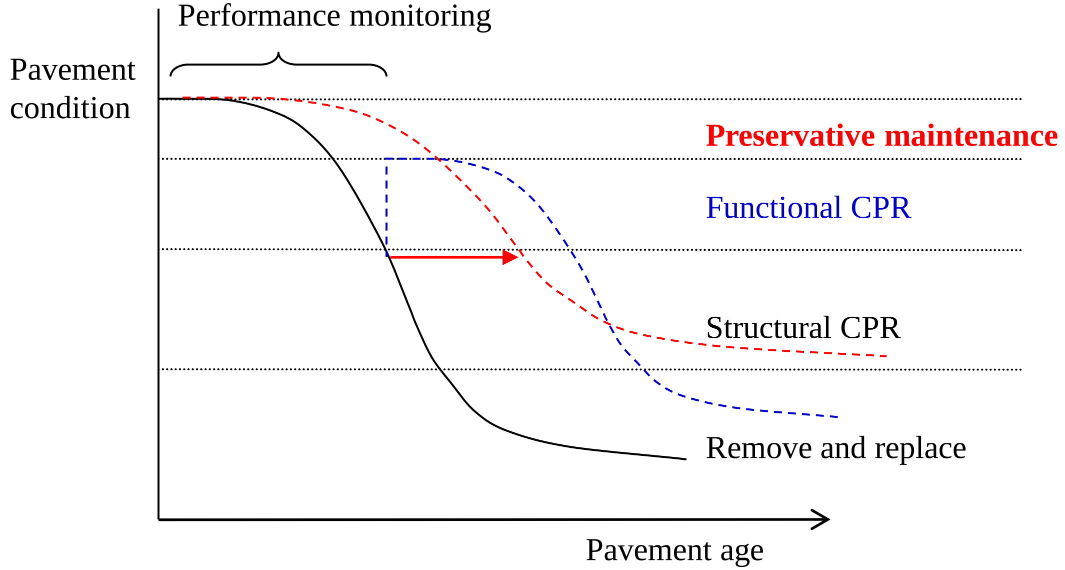
Type of Material	Loss of Support
Cement-treated granular base (E = $1x10^6$ to $2x10^6$ psi)	0.0 to 1.0
Cement aggregate mixtures (E = 500,000 to $1x10^6$ psi)	0.0 to 1.0
Asphalt-treated bases (E = 350,000 to $1x10^6$ psi)	0.0 to 1.0
Bituminous-stabilized mixture (E = 40,000 to 300,000 psi)	0.0 to 1.0
Lime-stabilized materials (E = 20,000 to 70,000 psi)	1.0 to 3.0
Unbound granular materials (E = 15,000 to 45,000 psi)	1.0 to 3.0
Fine-grained or natural subgrade materials (E = 3,000 to 40,000 psi)	2.0 to 3.0



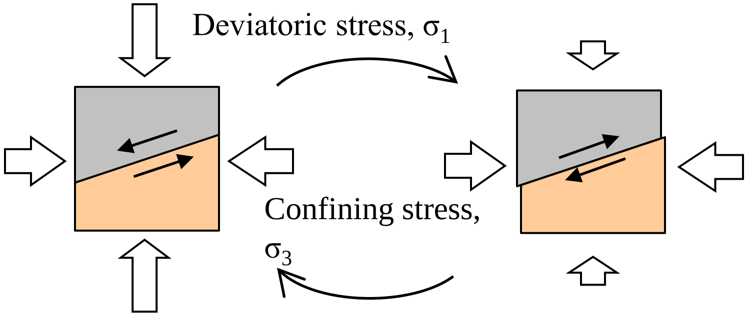
Correction of Effective Modulus of Subgrade Reaction due to Loss of Support

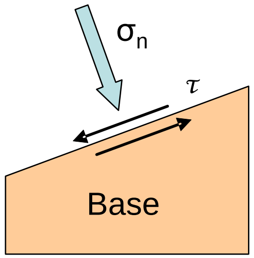
Maintenance Strategy

- As pavement condition degrades,
  - Repair costs and time of repair go up
  - Future renewal options become limited
- Preservative maintenance extend pavement life cost effectively



Erosion Test of Cement Treated Samples





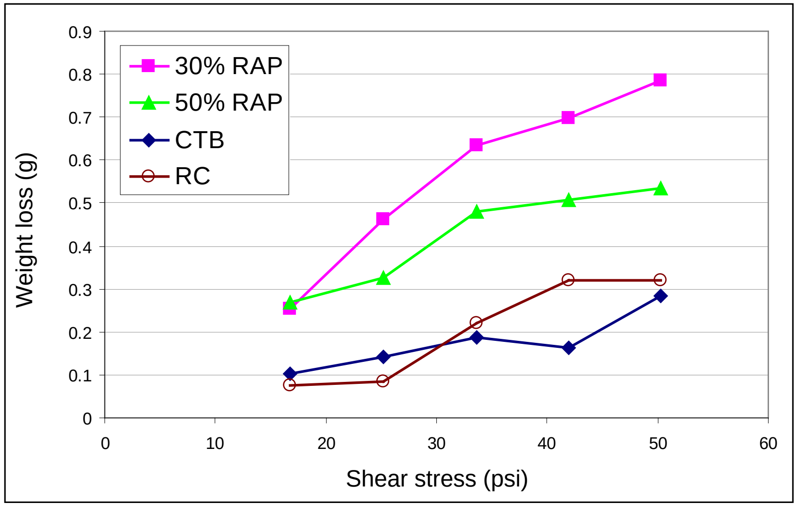
Cement treated flexbase

30% recycled asphalt

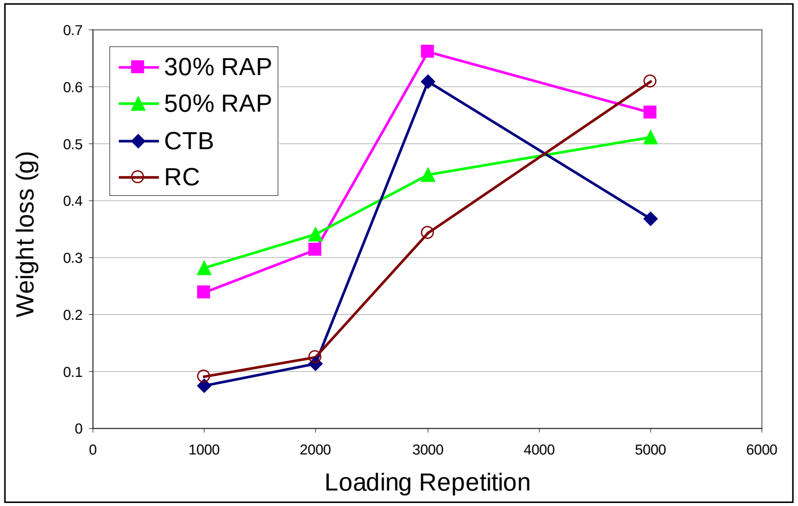
50% recycled asphalt

Crushed recycled concrete

Erosion Test Results

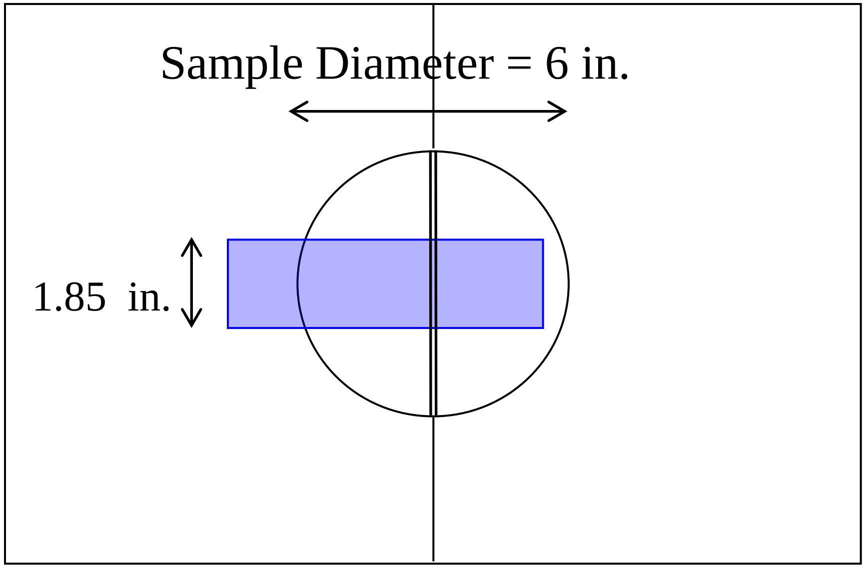


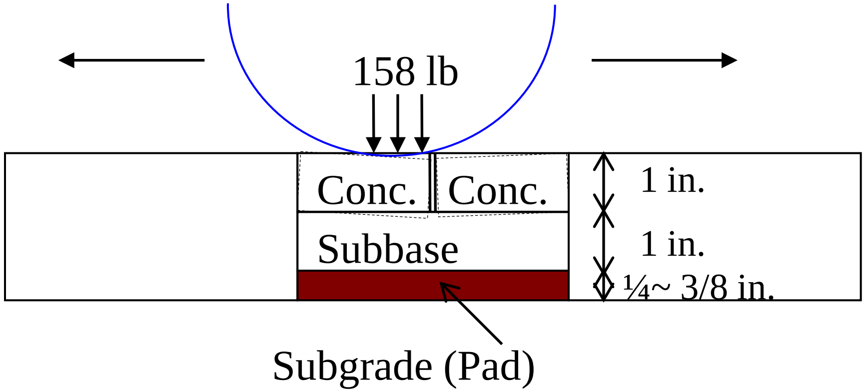
Weight Loss vs. Shear Stress Levels



Weight Loss vs. Load Repetitions

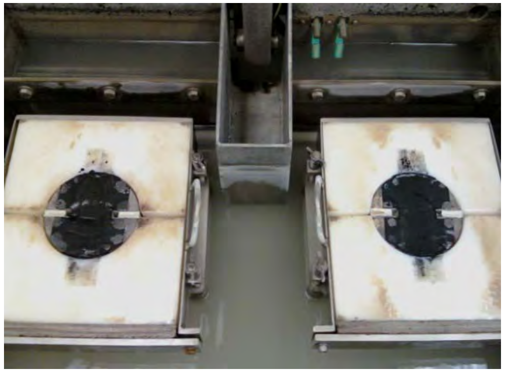
Hamburg Wheel-tracking Test



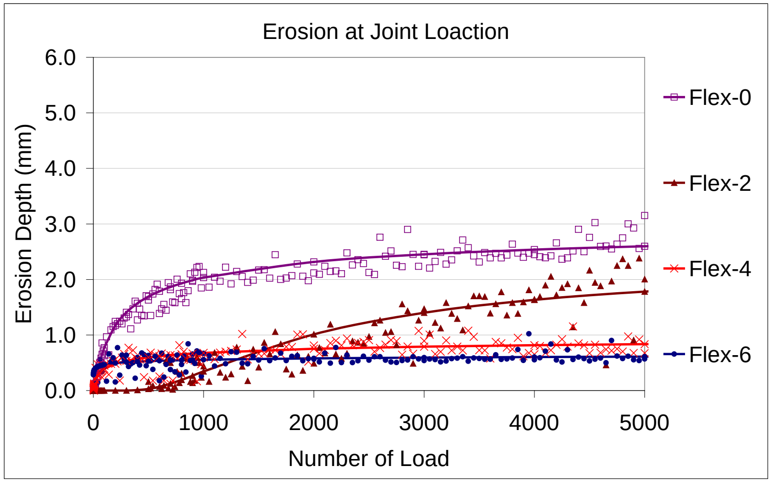


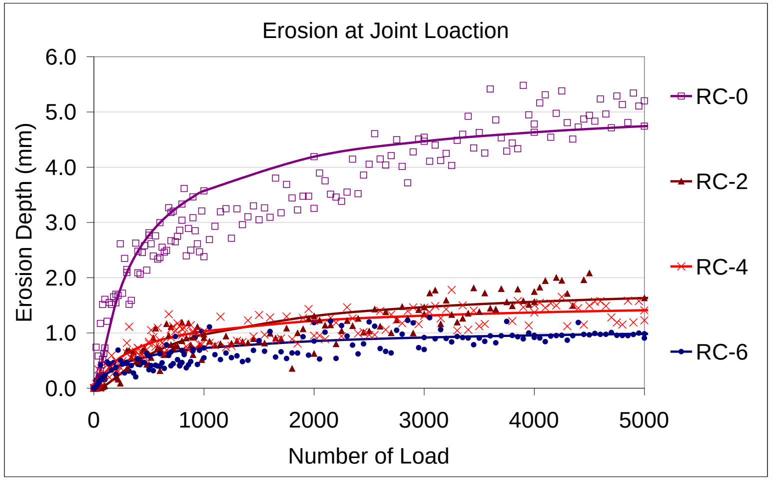
- Layer Profile
  - 1 in. Jointed Concrete
  - 1 in. Subbase Layer
  - 3/8 in. Artificial Subgrade (Rubber Pad)
- 60 ppm Load Frequency
- 25 °C Water temperature
- 5,000 or 10,000 Load Repetition
- Deflection Measurement by 11 Spots along Wheel Load

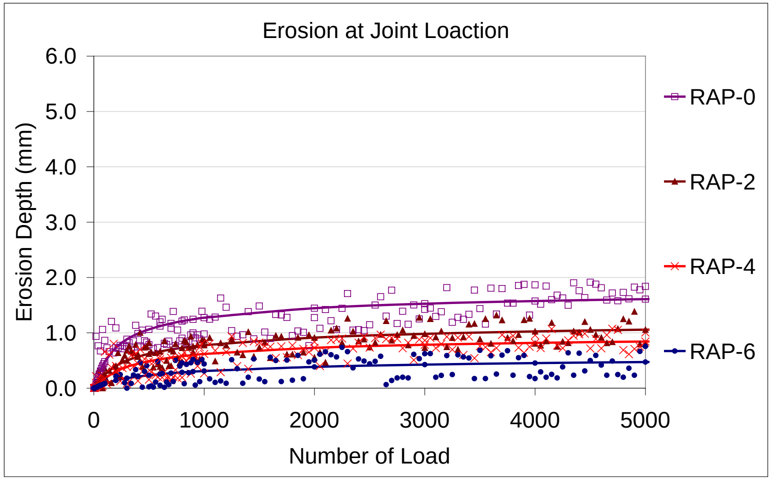
Hamburg Wheel-tracking Test

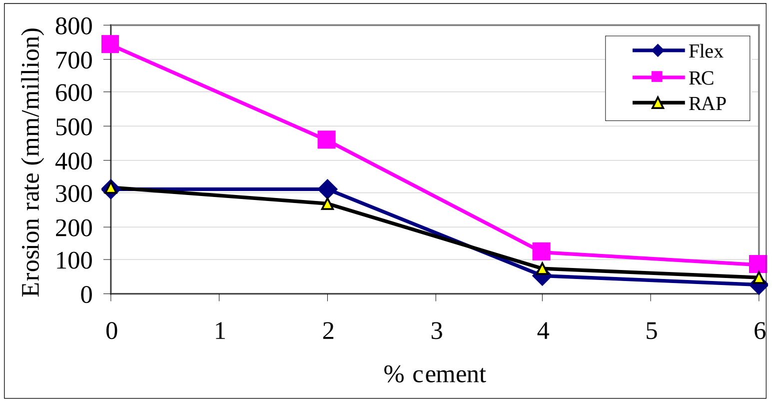



Matrix Erosion Model Fitting to HWTD Test Results



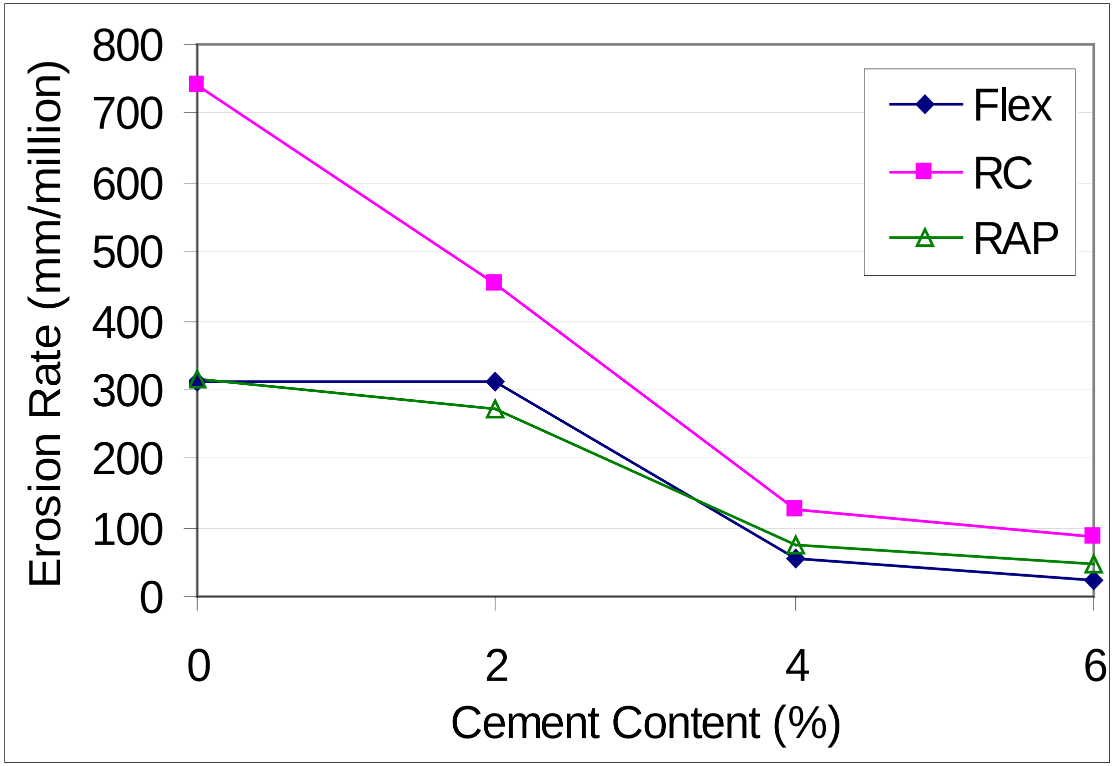




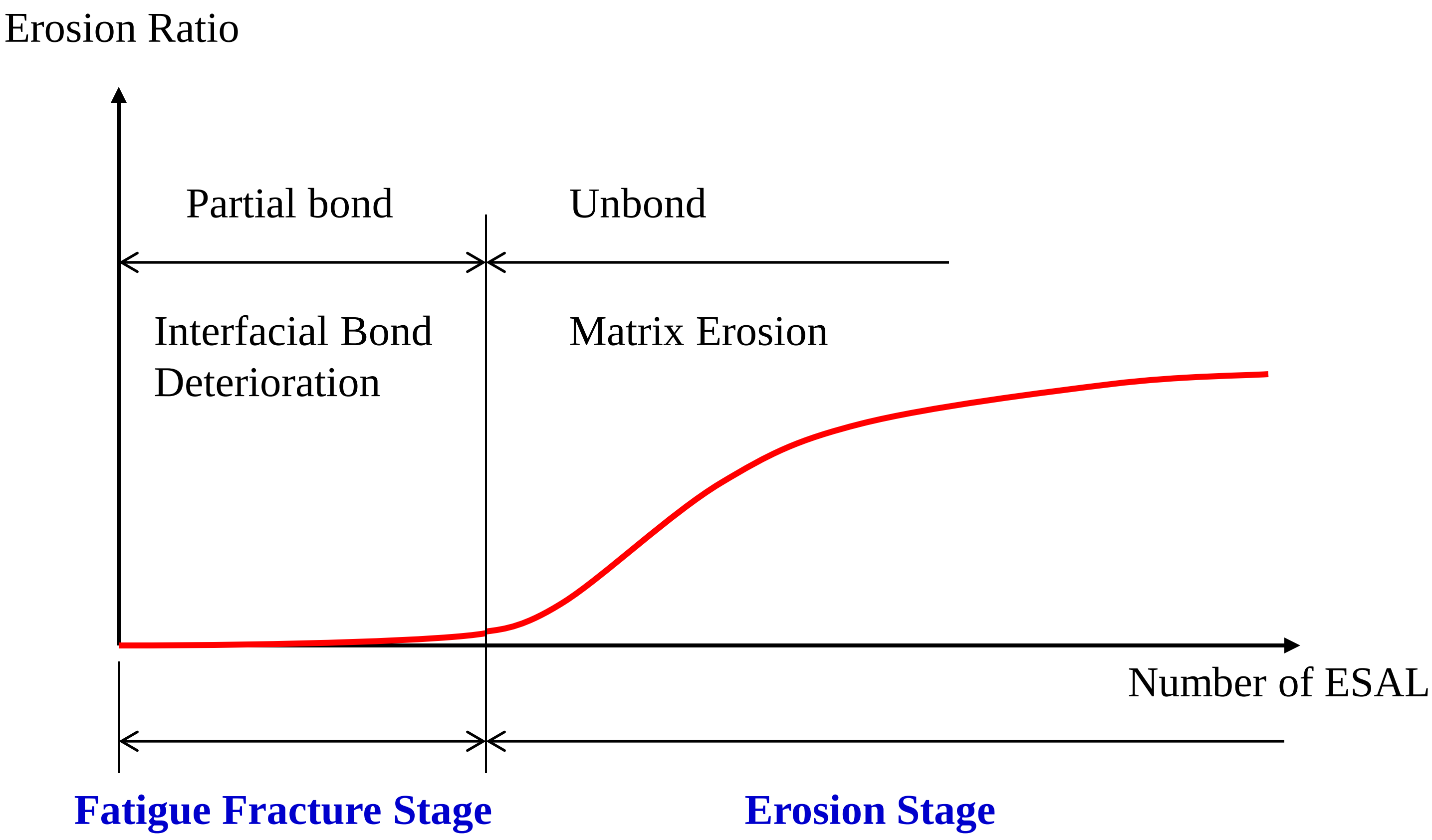


Erosion Rate at Joint Location

Hamburg Wheel-tracking Test Result

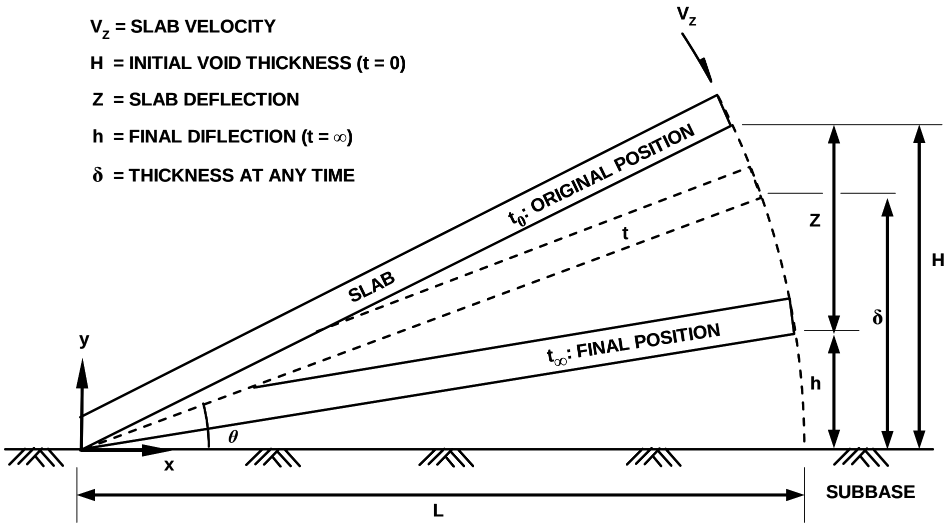


Subbase Erosion Prediction Model



Matrix Erosion Model

$$f_i = f_0 e^{-\left(\frac{\rho}{N_i - \nu}\right)^a}$$



Where, f_i = Erosion depth (L)

f_0 = Ultimate erosion depth (L)

N_i = Number of axle loads per load group contributing to erosion

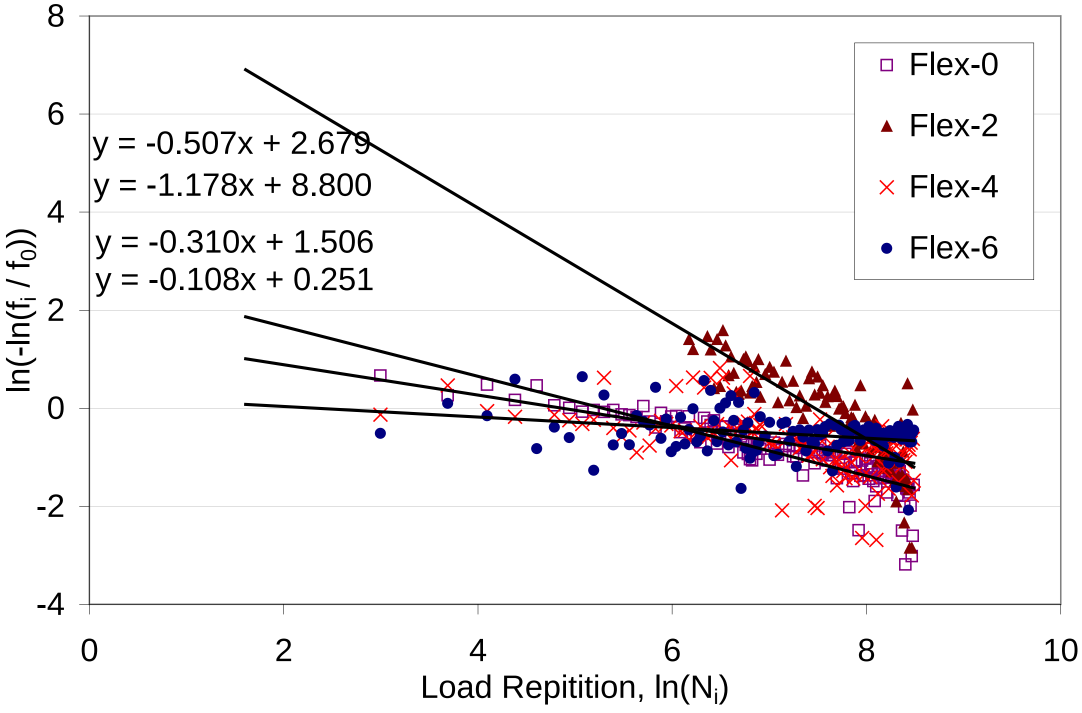
ρ = Calibration coefficient based on local performance

ν = Calibration coefficient represents the number of wheel loads (or time) for layer debonding to occur and erosion to initiate, 0 for lab test

a = Inverse of the rate of void development

Aquiring a and ρ from HWTD Test

$$\frac{f_i}{f_0} = e^{-\left(\frac{\rho}{N_i}\right)^a} \Rightarrow \ln\left(\frac{f_i}{f_0}\right) = -\left(\frac{\rho}{N_i}\right)^a \Rightarrow \ln\left(-\ln\left(\frac{f_i}{f_0}\right)\right) = \underbrace{a\ln\rho}_{b} - \underbrace{a}_{m}\ln N_i$$



In figure,

-a is the slope, m

$a\ln\rho$ is the intercept, b

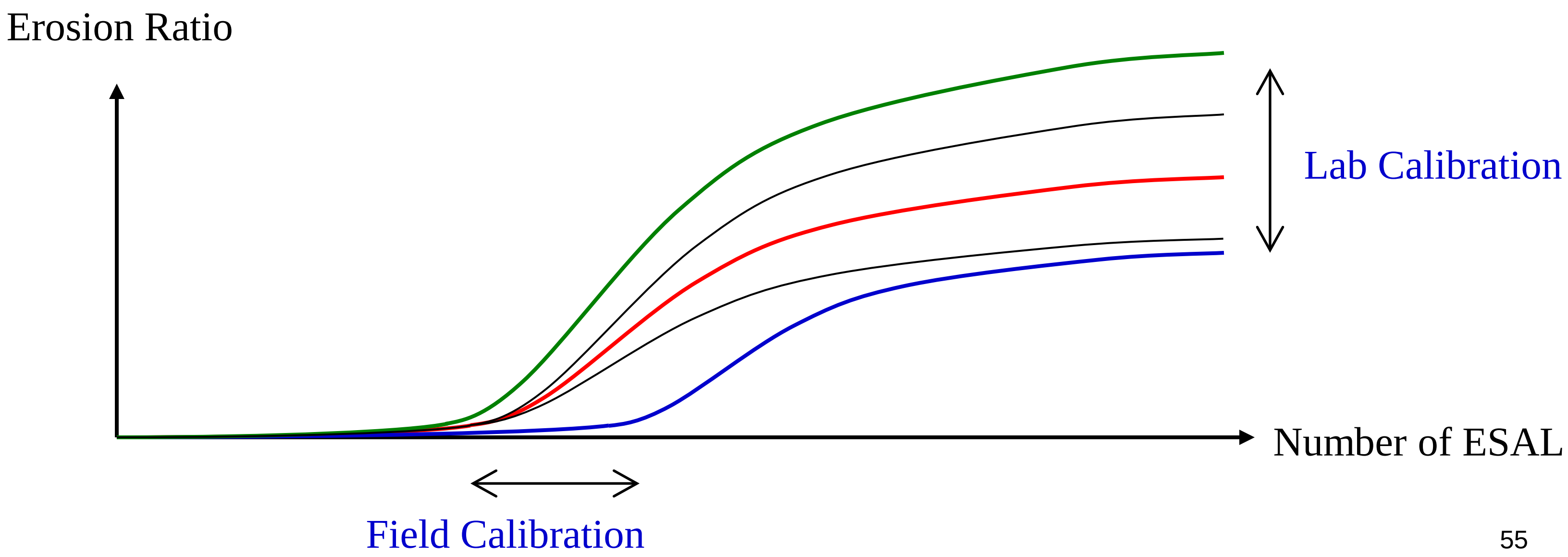
Therefore,

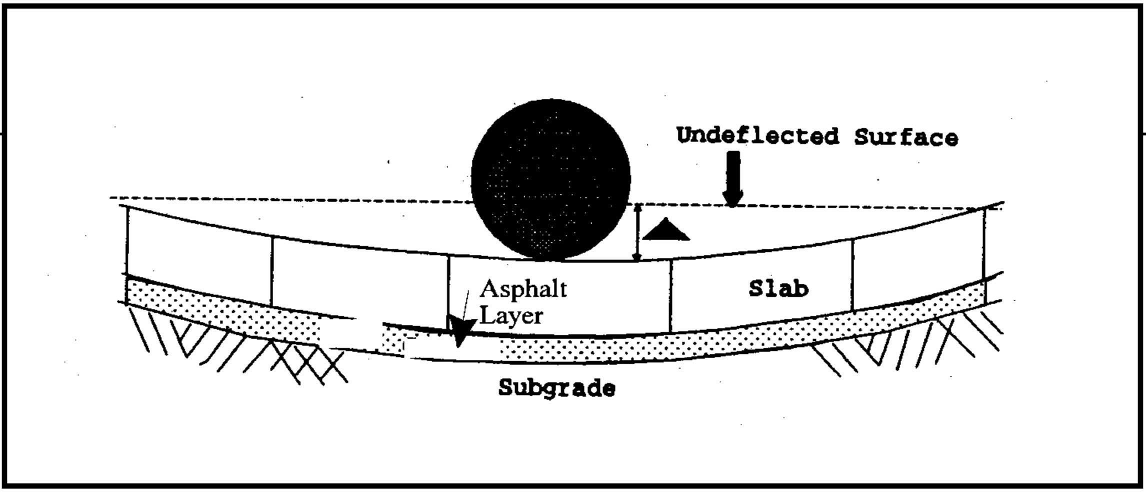
$$a = -m$$

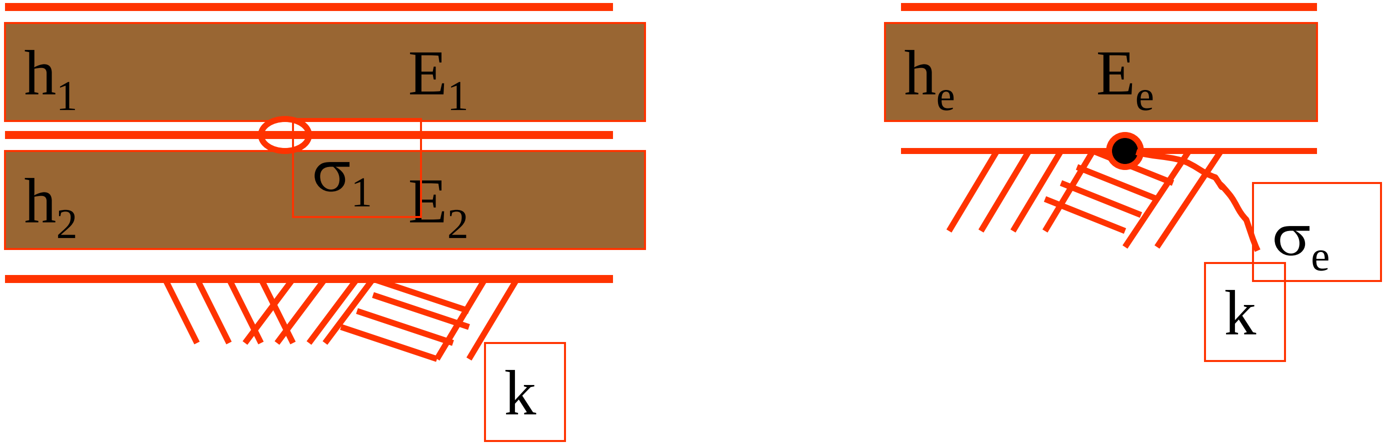
$$\rho = e^{\frac{b}{a}}$$

Erosion Prediction Model Calibration

- Interfacial bond deterioration stage need to be calibrated using field performance data
- Matrix erosion stage need to be calibrated using lab test data




Undeflected Surface
Asphalt
Layer
Slab
Subgrade


h_1
E_1
σ_1
h_2
E_2
k
h_e
E_e
σ_e
k

Unbonded Layers

$$h_e = \sqrt[3]{h_1^3 + n\,h_2^3}$$

- No separation during bending

$$w_1(x,y) = w_2(x,y) = w_e(x,y)$$

$$m_e(x,y) = m_1(x,y) + m_2(x,y)$$

$$D_e = D_1 + D_2 \quad \Rightarrow \quad E_e h_e^3 = E_1 h_1^3 + E_2 h_2^3$$

$$m_e = \left(1 + \frac{D_2}{D_1}\right) m_1$$

$$\sigma_e = \frac{b}{h_e^2}\left(1 + \frac{D_2}{D_1}\right) m_1$$

$$= \frac{h_1^2}{h_e^2}\left(\frac{E_1 h_1^3 + E_2 h_2^3}{E_1 h_1^3}\right)\sigma_1$$

$$= \frac{h_e}{h_1}\frac{E_e}{E_1}\sigma_1 \Rightarrow \sigma_1 = \frac{h_1}{h_e}\sigma_e \Rightarrow \sigma_2 = \sigma_1\, n\, {h_2}/{h_1}$$

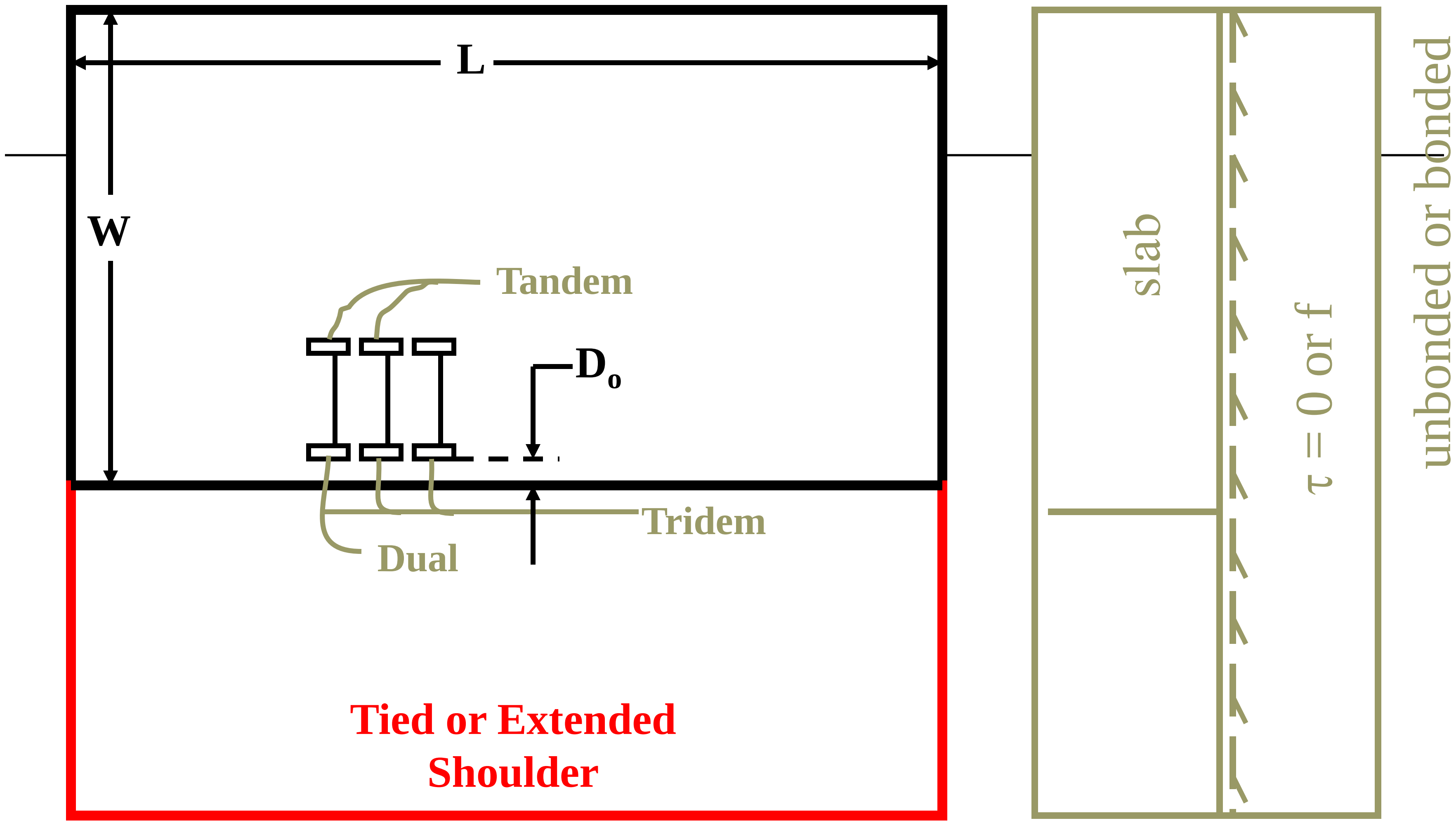
Bonded Layers

$$h_e = \left[h_1^3 + \frac{E_2}{E_1} h_2^3 + 12 \left[\left[x - \frac{h_1}{2} \right]^2 h_1 + \frac{E_2}{E_1} \left[h_1 - x + \frac{h_2}{2} \right]^2 h_2 \right] \right]^{1/3}$$

$$E_e = E_1$$

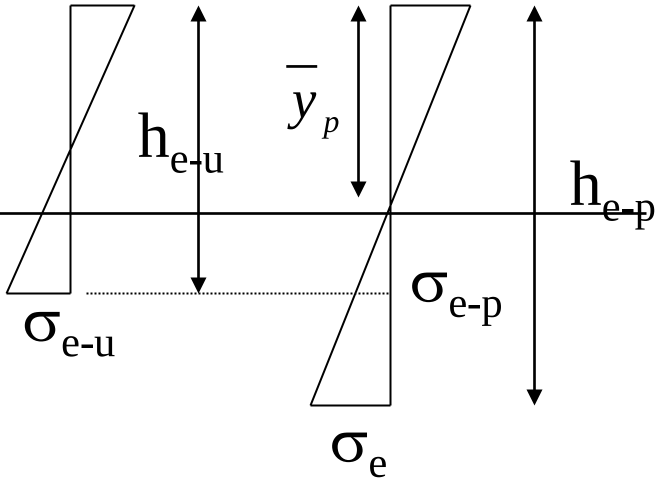
$$x = \frac{\frac{E_1 h_1^2}{2} + E_2 h_2 \left(h_1 + \frac{h_2}{2} \right)}{E_1 h_1 + E_2 h_2}$$

$$\sigma_1 = \sigma_e \frac{2 \left(h_1 - x \right)}{h_e}$$



L
W
Tandem
D_o
Tridem
Dual
Tied or Extended
Shoulder
slab
τ = 0 or f
unbonded or bonded

Partially Bonded System



Transformed Section

$$h_{e-p} = \frac{h_{e-u}}{2}(1-x) + (x)h_{e-b}$$

$x = e^{-\left(\frac{A}{\mu}\right)^m}$ (x = degree of bond; μ = coeff. of friction)

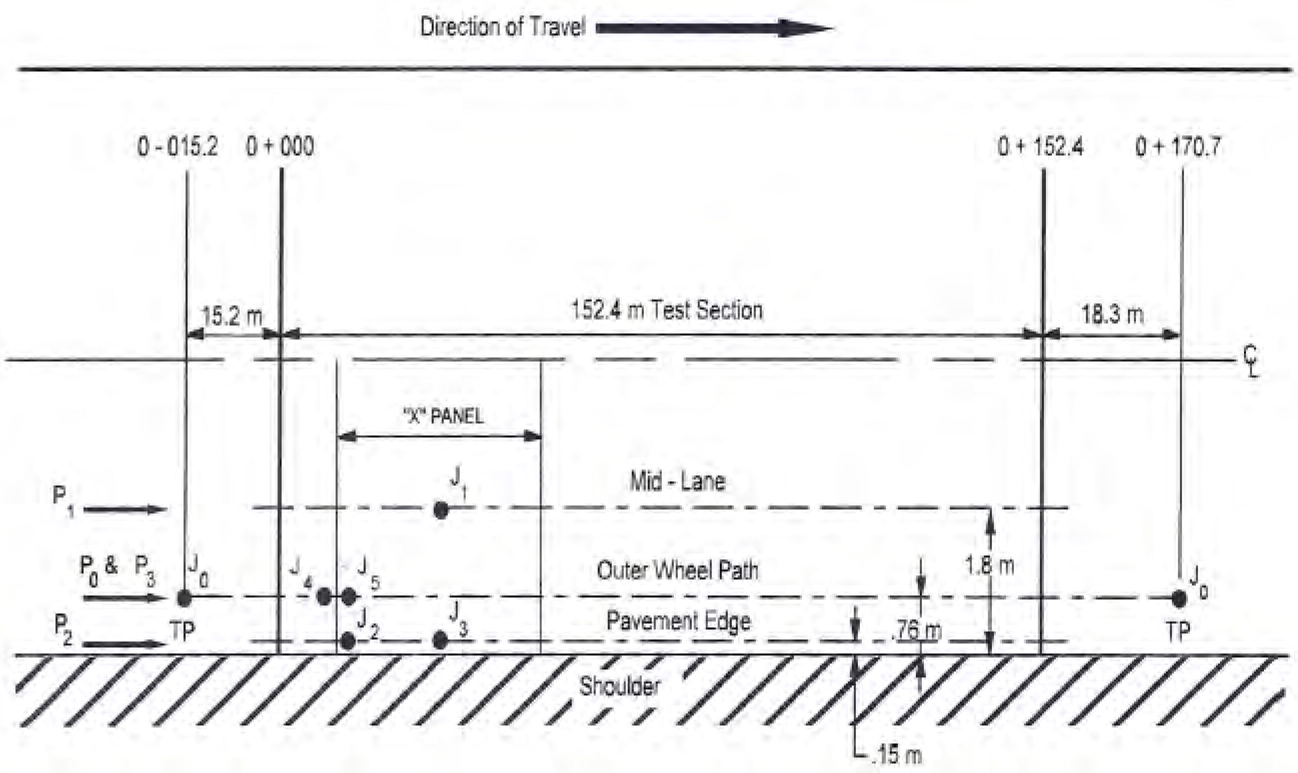
Notes on $h_{e\text{-}p}$:

1) $\ell^4_e = \dfrac{E_c h_{e-p}^{\ 3}}{12(1-\nu^2)k}$; $h^3_{e\text{-}p} = \ell^4_e \dfrac{12(1-\nu^2)k}{E_c} = h^3_e$; ℓ^4_e derived from basin area

2) $s_e = a + b\ell_e + c\ell_e^{\ 2}$; $\sigma_e = \dfrac{s_e P}{h_e^2}$

3) $\sigma_{e\text{-}p} = \sigma_{e-u} - \tau_f$; $\sigma_{e-u} = \dfrac{s_{e-u}P}{h_{e-u}^{\ 2}}$; $\tau_f = \mu\left(\dfrac{h_c}{12} + \sigma_v\right)$; $\sigma_v =$ load induced pressure

4) and $\sigma_{e-p} = \sigma_e \left[\dfrac{2\left(h_{e-u} - \bar{y}_p\right)}{h_{e-p}}\right] = \sigma_e\left[\dfrac{2\left(h_{e-u}\right)}{h_{e-p}} - 1\right]$



Direction of Travel
0 - 015.2
0 + 000
0 + 152.4
0 + 170.7
15.2 m
152.4 m Test Section
18.3 m
"X" PANEL
Mid - Lane
Outer Wheel Path
Pavement Edge
Shoulder
1.8 m
.76 m
.15 m
TP
TP

Section 12 3804

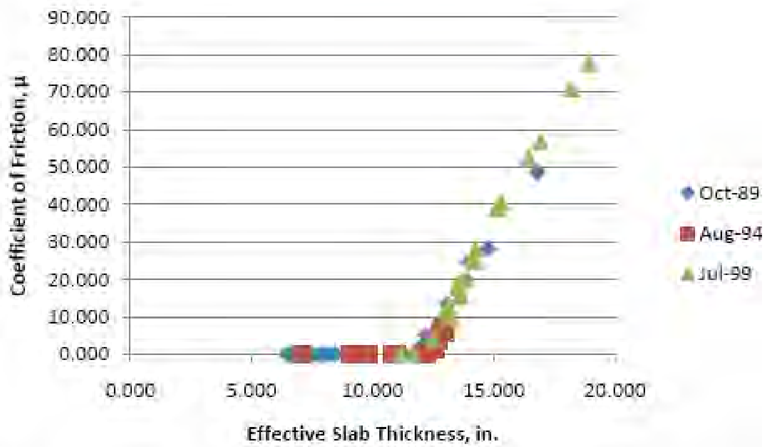


Figure B.1 Friction vs. Effective Slab Thickness for Position J1 – 12 3804.

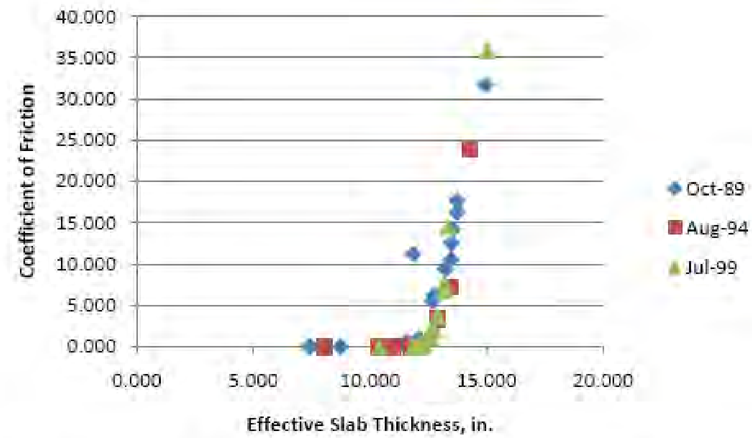


Figure B.3 Friction vs. Effective Slab Thickness for Position J3 – 12 3804.

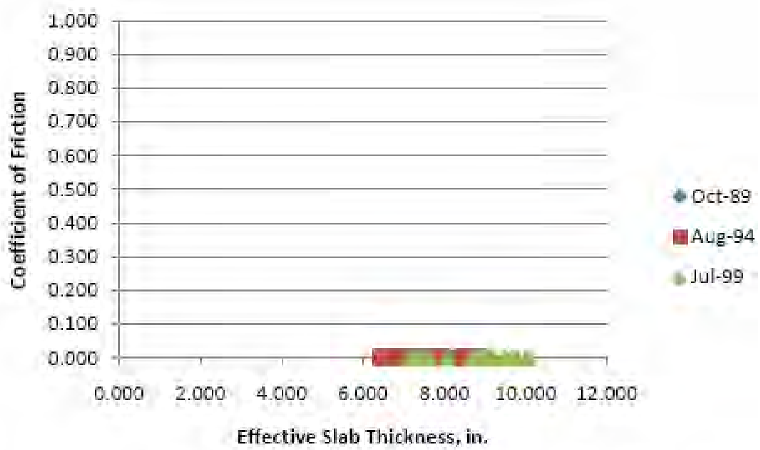


Figure B.2 Friction vs. Effective Slab Thickness for Position J2 – 12 3804.

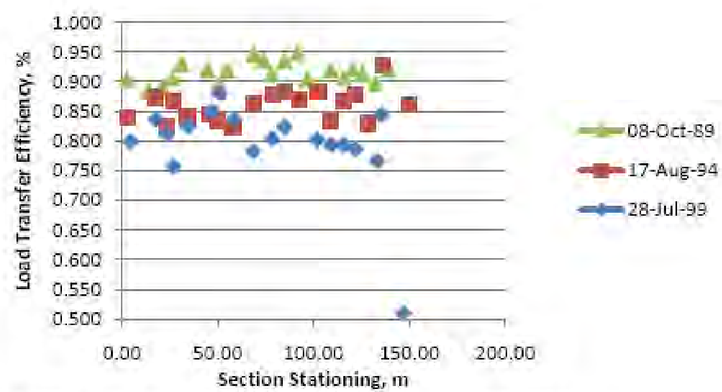
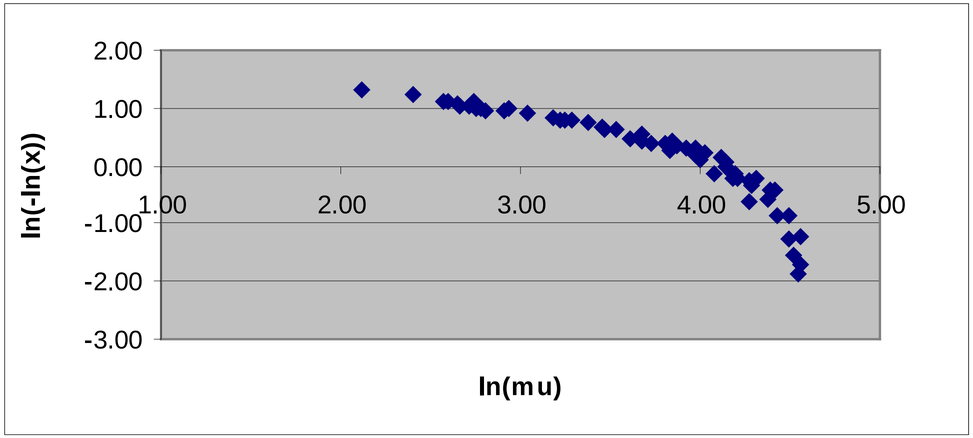


Figure B.4 LTE vs. Section Stationing for Position J4 – 12 3804.

Friction Model

$$x = \frac{h_{e-p} - h_{e-u}}{h_{e-b} - h_{e-u}} = e^{-\left(\frac{A}{\mu}\right)^B}$$

$$\mu = \frac{\sigma_{e-u} - \sigma_e \left[\frac{2h_{e-u}}{h_{e-p}} - 1 \right]}{\frac{h_c}{12} + \sigma_v}$$



Where

σ_e	$= \frac{s_e P}{h_e^2}$; $s_e = a + b\ell_e + c\ell_e^2$ (for FWD plate loading)
P	= Applied FWD load (F)
a, b, c	= 0.0006, 0.0403, and -0.0002 (for FWD plate loading)
h_c	= Concrete slab thickness (L)
σ_v	= Load induced vertical pressure (FL^{-2}) (≈ 0.7 psi)

Where

A	$= e^{\frac{3 - X\mu}{B}}$
B	$= -\left(0.039 y^2\right)$
y	$= \mathrm{Ln}(\mu)$

$\frac{\bar{\mu}}{\mu_b}$

Friction Model Parameters

Base Type	**Base Modulus (ksi)**	**Bonded μ (μ_b)**	$\frac{\bar{\mu}}{\mu_b}$	**Base Type Friction Factor (X)**
Thick HMAC (>3.5 in) over flexible base	Temperature Dependant	100	0.43 – 1.31	0.13 – 0.15
Cement Stabilized (CS)	Stabilization Content Dependant	90	1.36	0.13
Cement Aggregate Mixture (CAM)	Stabilization Content Dependant	80	0.63 -1.43	0.15
Permeable AC	Density and Temperature Dependant	70	0.66	0.15
Soil Cement (SC)	Stabilization Content Dependant	45 - 70	0.36 -1.65	0.16 – 0.22
Thin HMAC (<1.5 in) over stabilized-base	Temperature Dependant	28-55	1.83 – 2.40	0.25
Lime Rock (LR)	300 – 600	18-32	1.23 -2.19	0.22 – 0.45
Granular Base (GB)	30 - 50	8 - 37	2.40 – 4.55	0.22 – 0.63

Summary

1. Estimate erodibility using lab test data
2. Relate faulting data to # wet days
    a. Related to presence of interfacial water
3. Estimate condition of the seal
    a. Visually assess debonding
    b. Moisture content vs. time
    c. Related to infiltration rate
4. Need to know the condition of the joint
    a. Inter-layer friction
    b. Rate of infiltration

Thank you

Questions ?