PRE-XVII CONGRESO ARGENTINO de Vialidad y Tránsito

8º EXPOVIAL ARGENTINA

expo 2014 vial Argentina

3 AL 6 DE NOVIEMBRE 2014

HOTEL PANAMERICANO - Buenos Aires, Argentina

Base Design Considerations for Jointed Concrete

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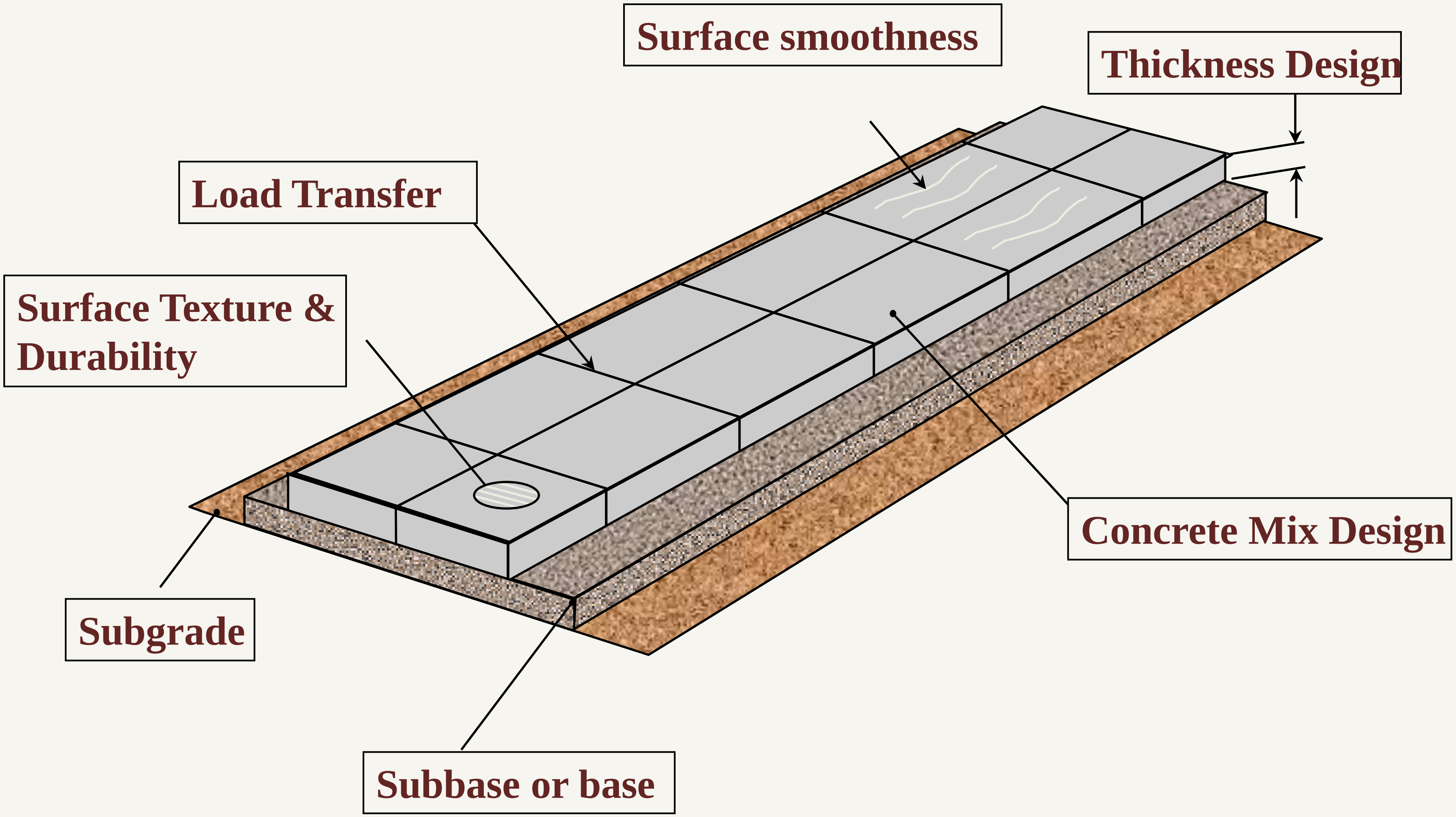
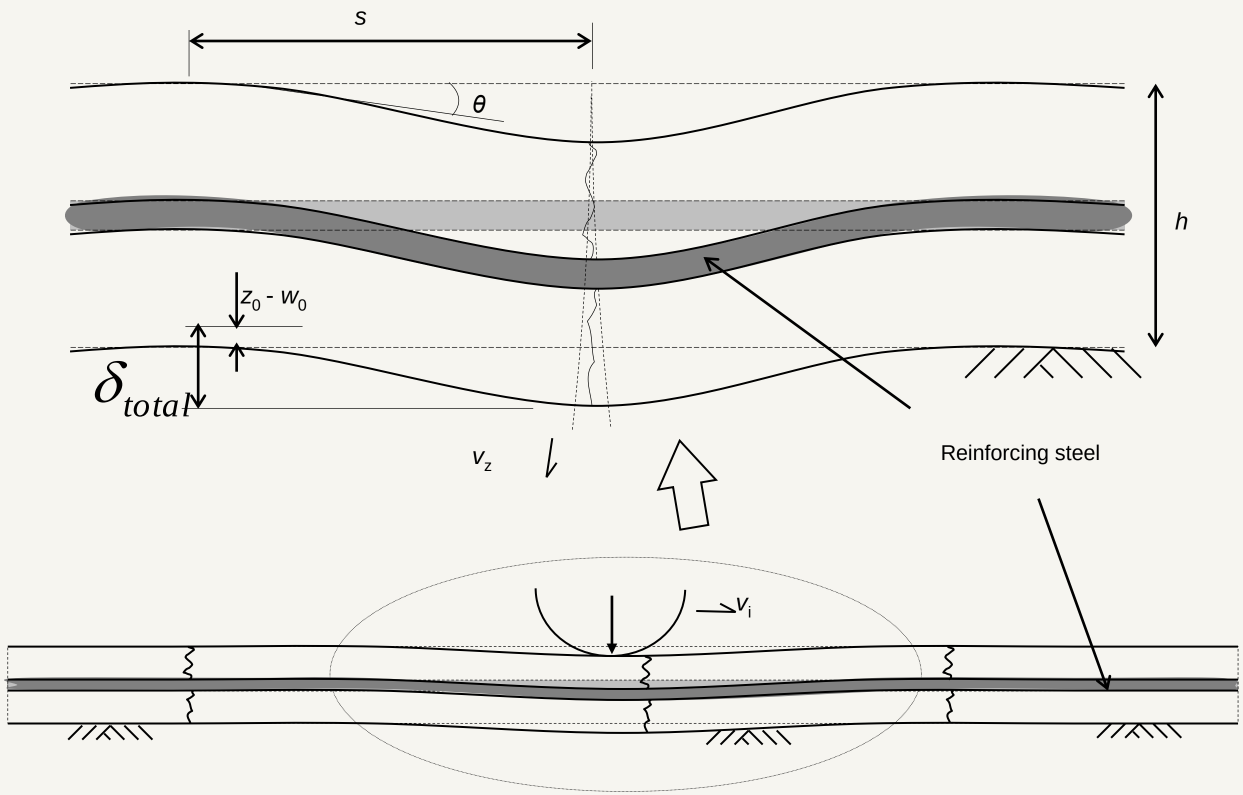
Discussion

- ✓ What is Erosion
- ✓ Effects on Performance
- ✓ Erosion Testing
- ✓ Use of Erosion In Design
- ✓ Field Assessment of Erosion

Jointed Plain Concrete Pavements (JPCP): Design Features



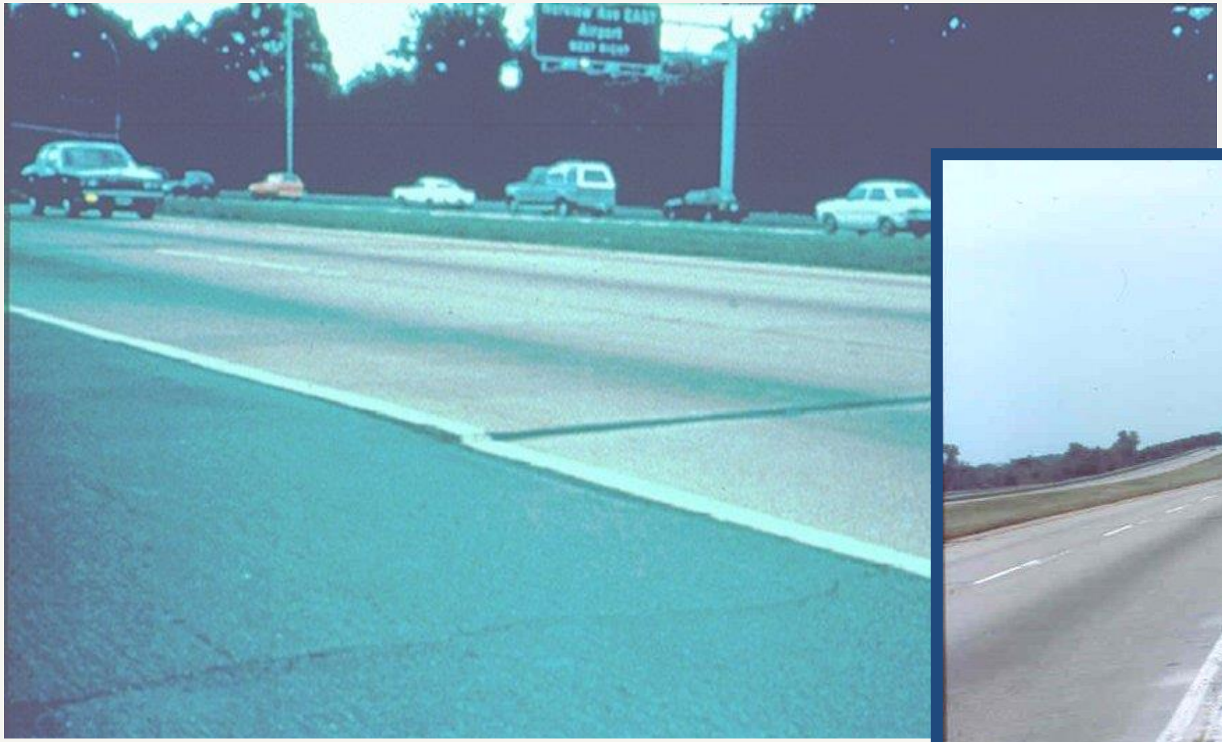
JPC Pavement - Loaded Slab Behavior



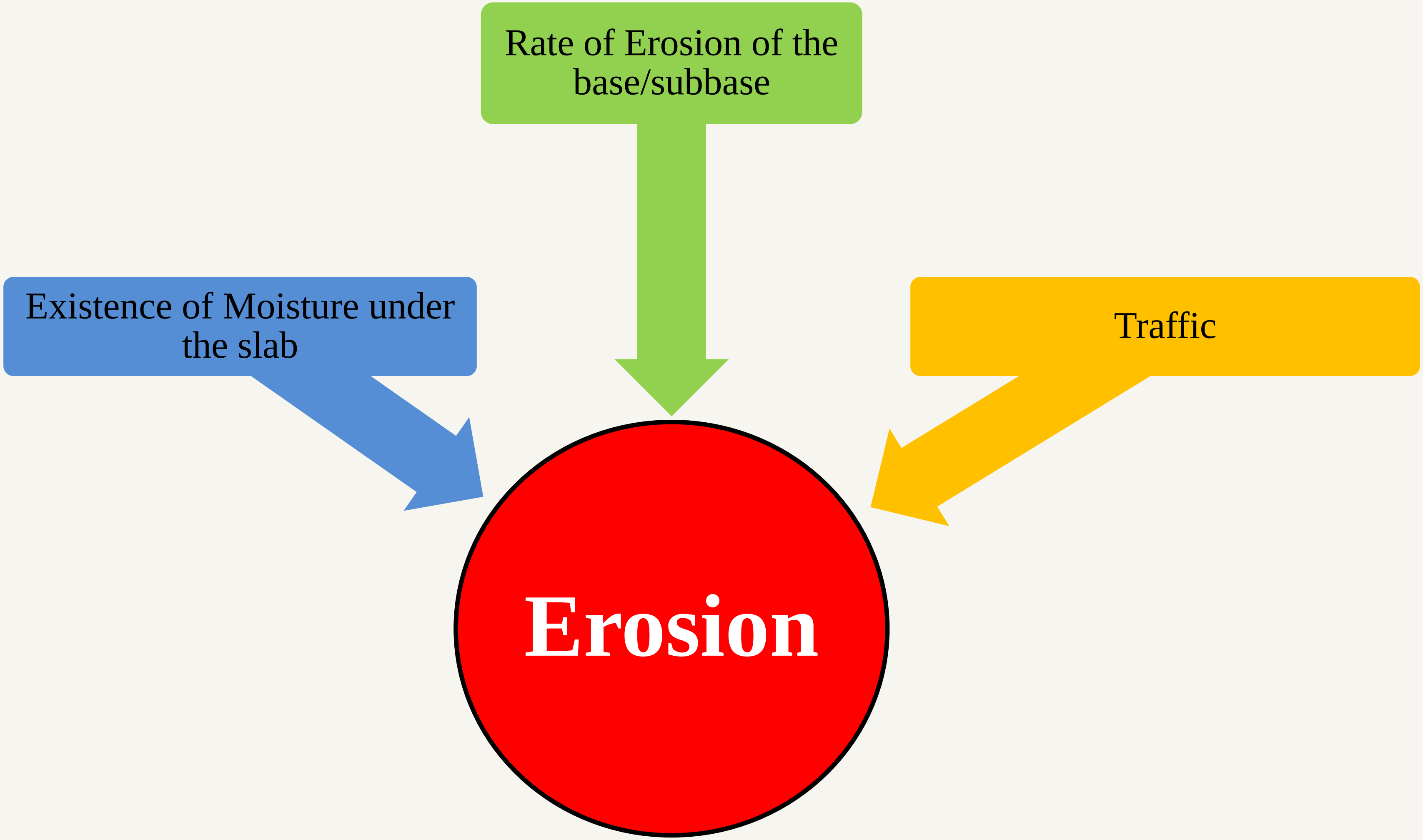
Field Testing

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

Faulting Distress

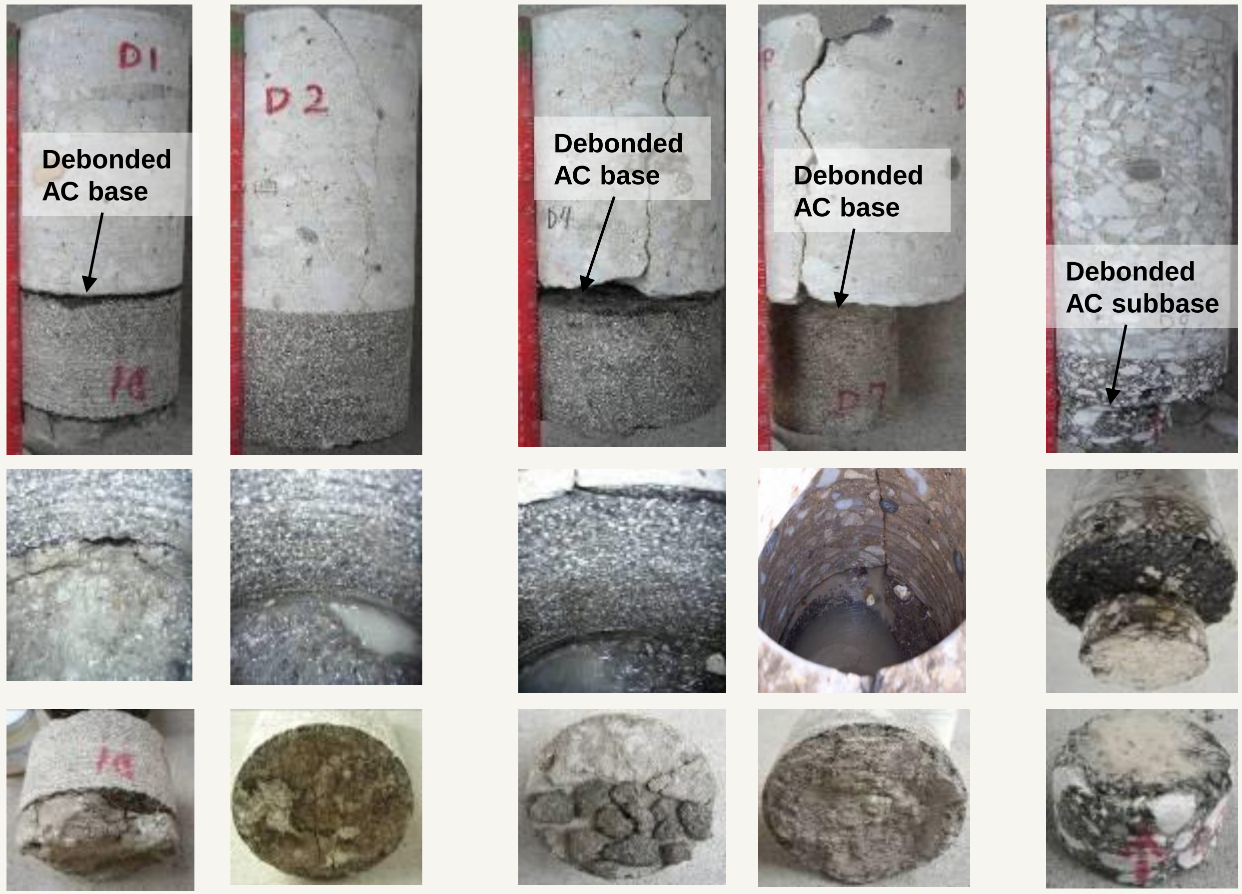


The Three Main Elements of Erosion



The Role of Moisture

US 81/287 – Cores

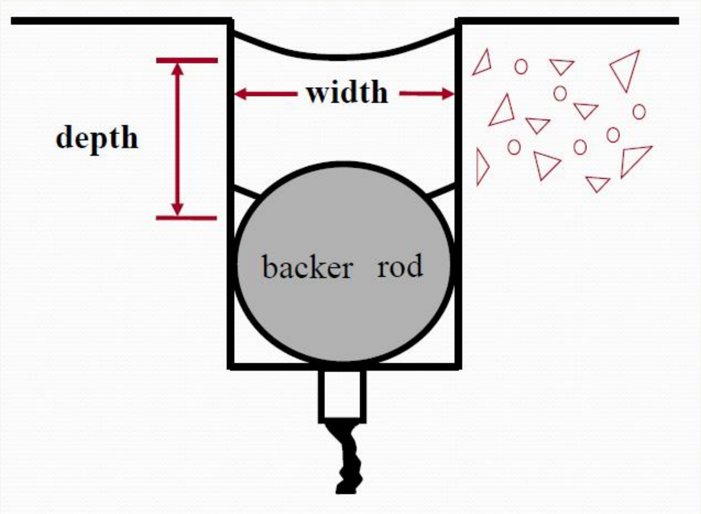


AC base bottom | AC base bottom | AC base bottom | AC base bottom | AC subbase top

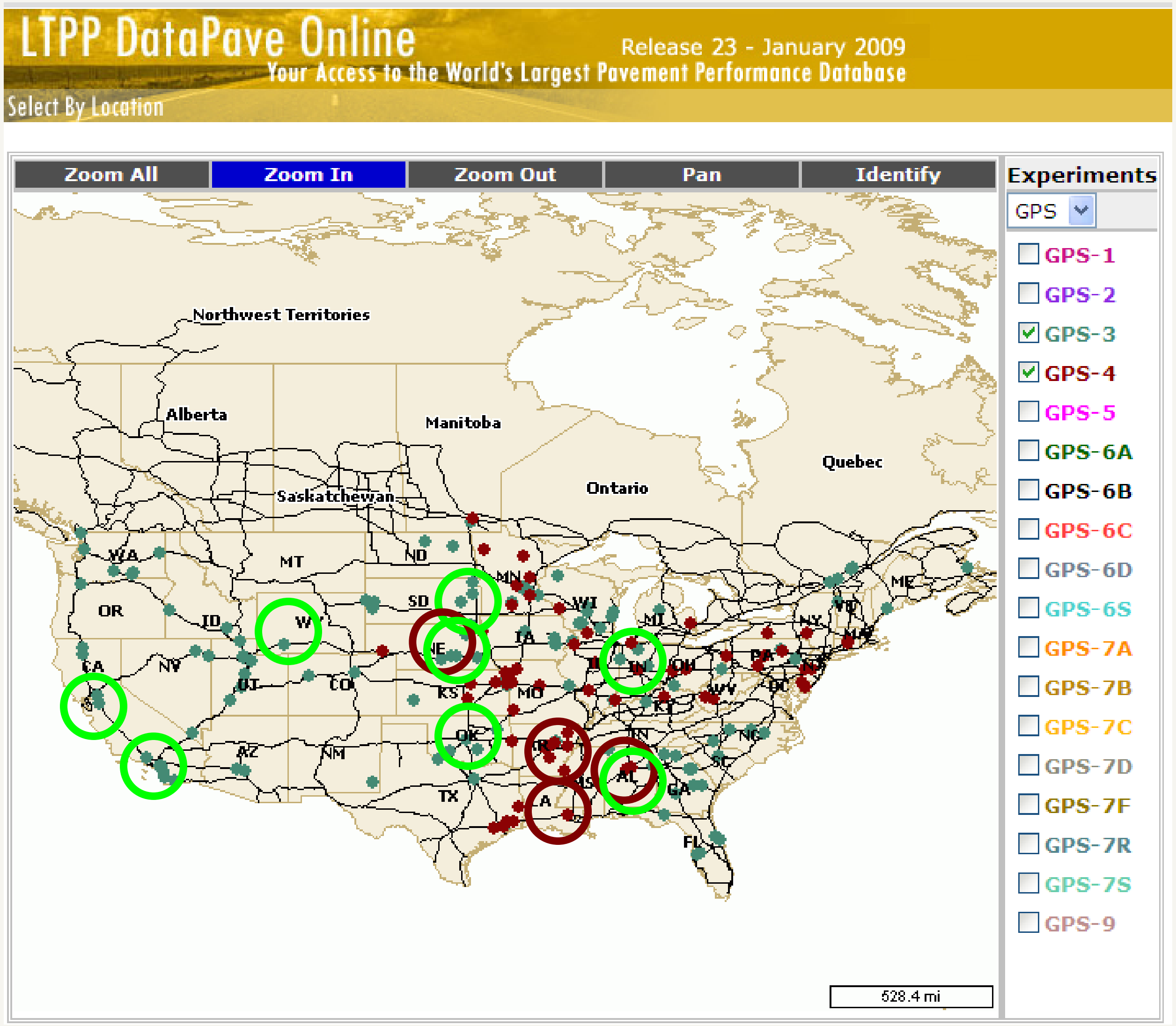
Section 1 | Section 2 | Section 3

Jointing and Sealing Practices

- Making an initial saw cut to control cracking
- Making a second saw cut to create a reservoir for joint sealant
- Cleaning and preparing the reservoir faces
- Placing a backer rod in the reservoir, to keep the sealant from adhering to the bottom of the reservoir and to create a curved bottom surface for the sealant.
- Placing sealant material in the reservoir

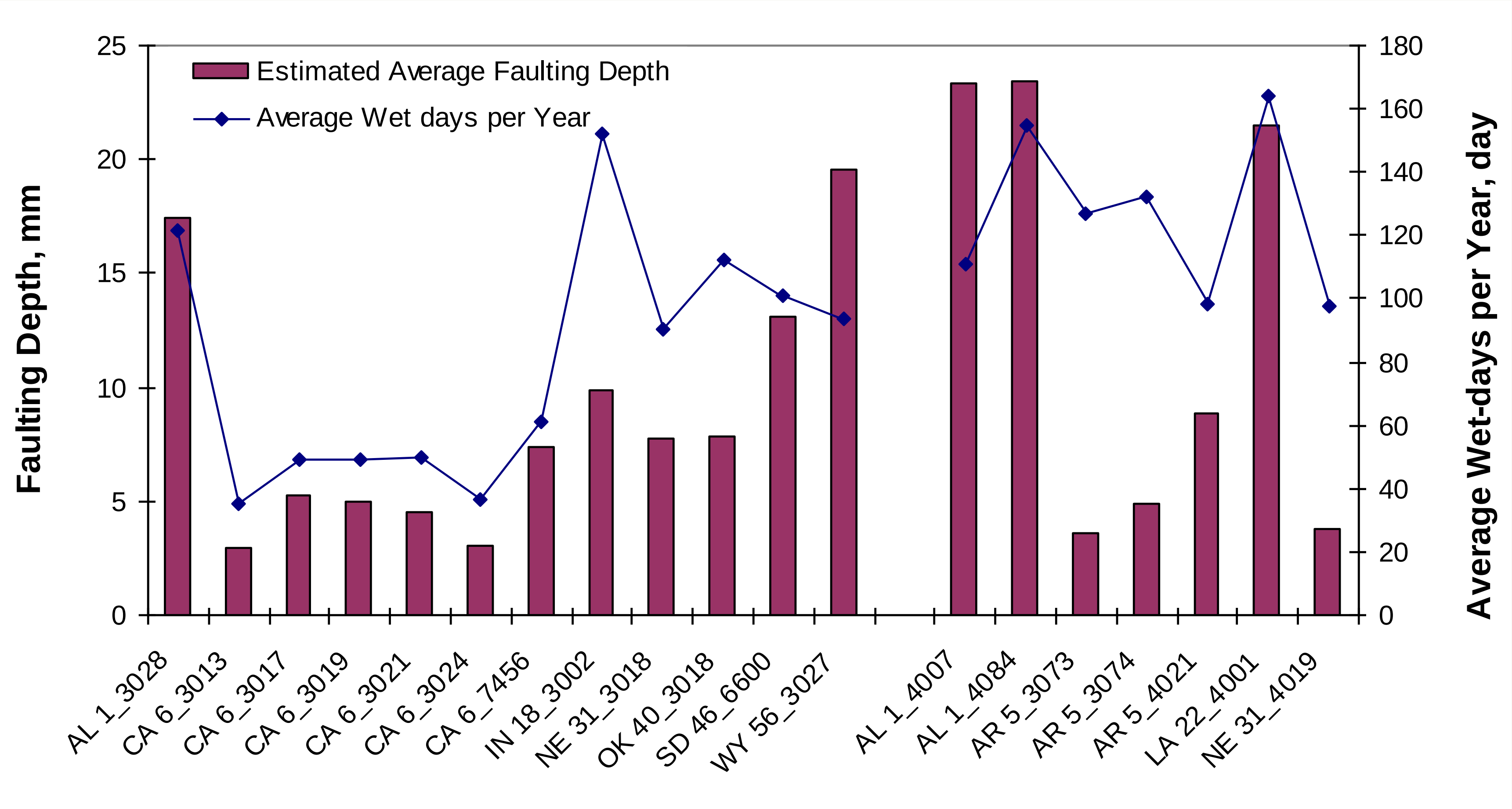


LTPP Faulting Data Sections



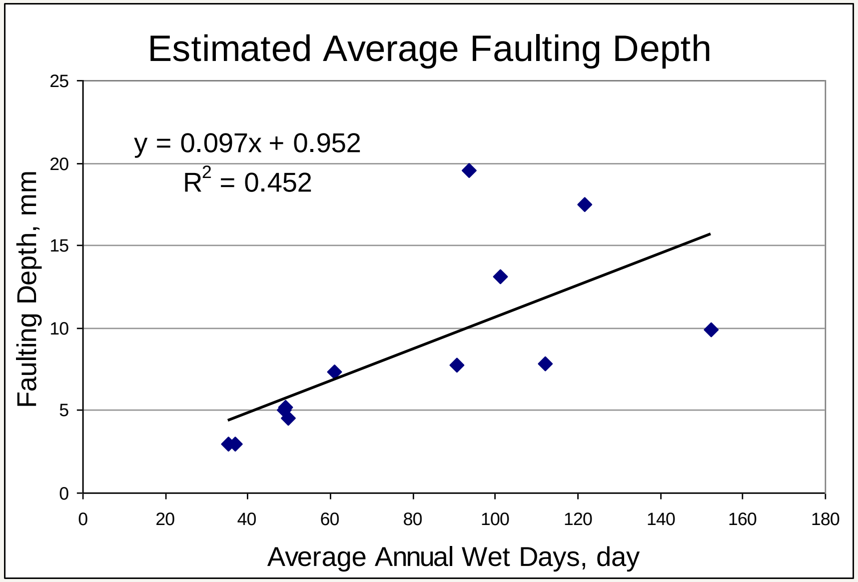
State and Section ID	Pavement Type
AL 1_3028	JPCP
CA 6_3013	JPCP
CA 6_3017	JPCP
CA 6_3019	JPCP
CA 6_3021	JPCP
CA 6_3024	JPCP
CA 6_7456	JPCP
IN 18_3002	JPCP
NE 31_3018	JPCP
OK 40_3018	JPCP
SD 46_6600	JPCP
WY 56_3027	JPCP
AL 1_4007	JRCP
AL 1_4084	JRCP
AR 5_3073	JRCP
AR 5_3074	JRCP
AR 5_4021	JRCP
LA 22_4001	JRCP
NE 31_4019	JRCP

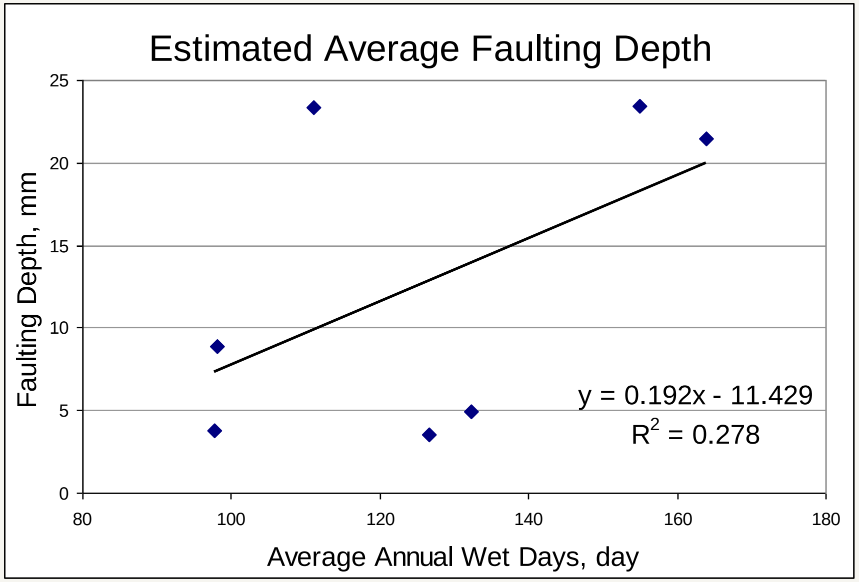
Estimated Average Faulting Depth



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

Faulting and Number of Wet days



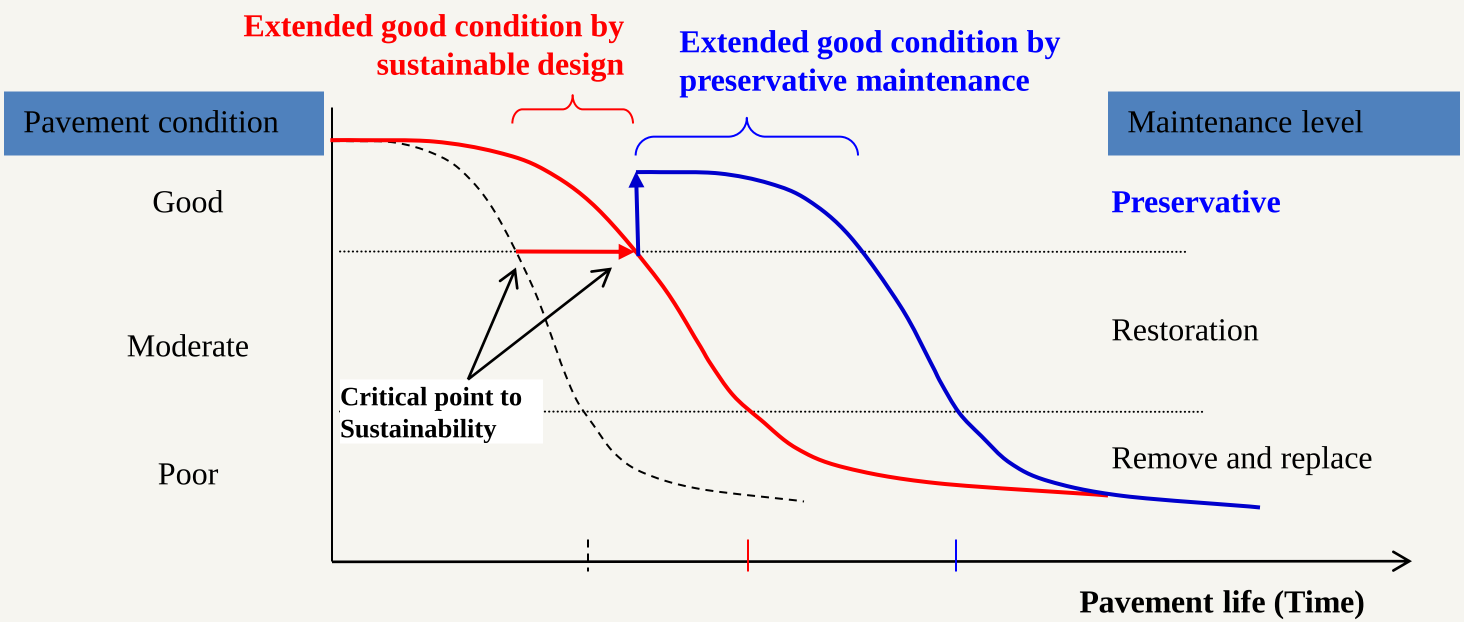


JPCP Sections

JRCP Sections

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

Sustainability of Pavement



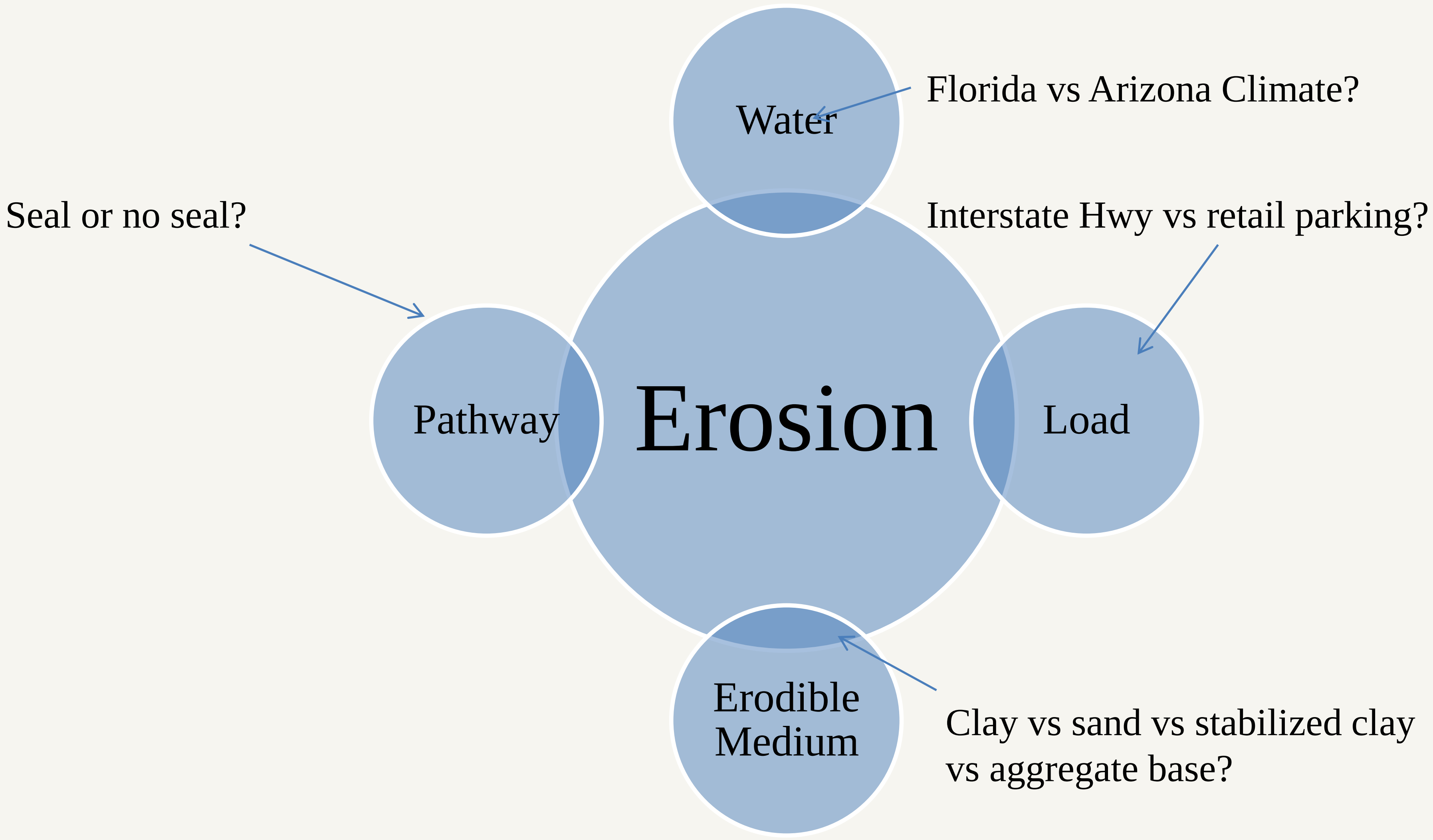
Reduce slab deflection by improving

- Slab thickness
- Joint/crack load transfer
- Subbase and subgrade support

Sustainable Pavement Design

Erosion Mechanisms: What's Needed?

Do our Current Design Procedures or Test Methods Account for These Mechanisms?



PCA 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

AASHTO MEPDG

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

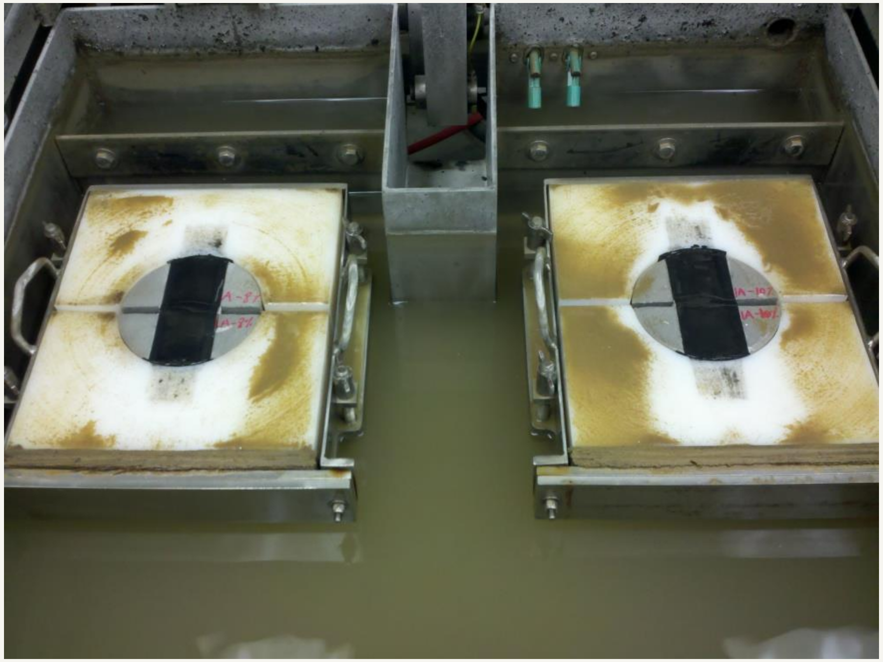
$$FAULTMAX_i = FAULTMAX_0 + C_7 * \sum_{j=1}^{m} DE_j * Log(1 + C_5 * 5.0^{EROD})^{C_6}$$

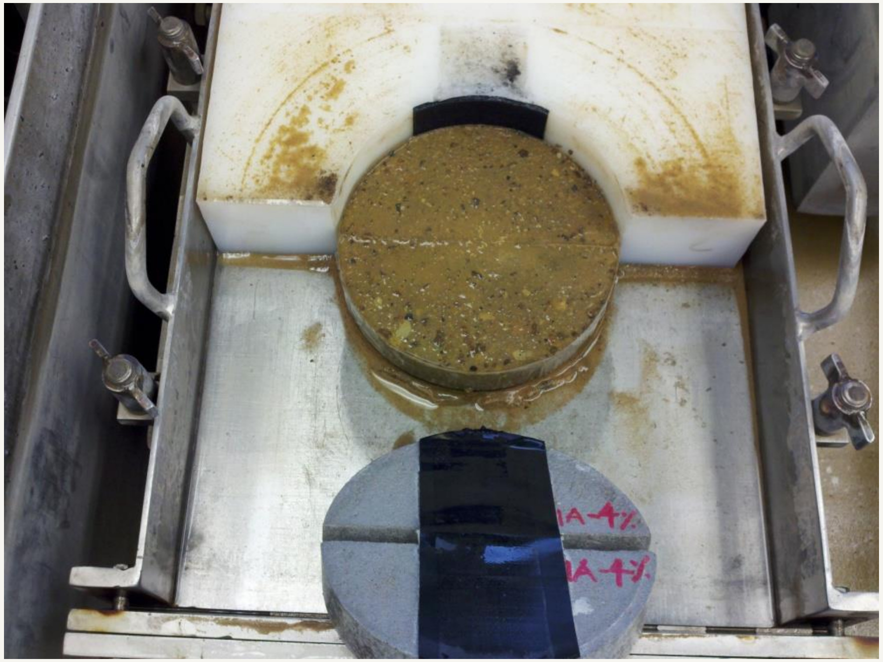
$$FAULTMAX_0 = C_{12} * \delta_{curling} * \left[Log(1 + C_5 * 5.0^{EROD}) * Log(\frac{P_{200} * WetDays}{P_s}) \right]^{C_6}$$

Where,

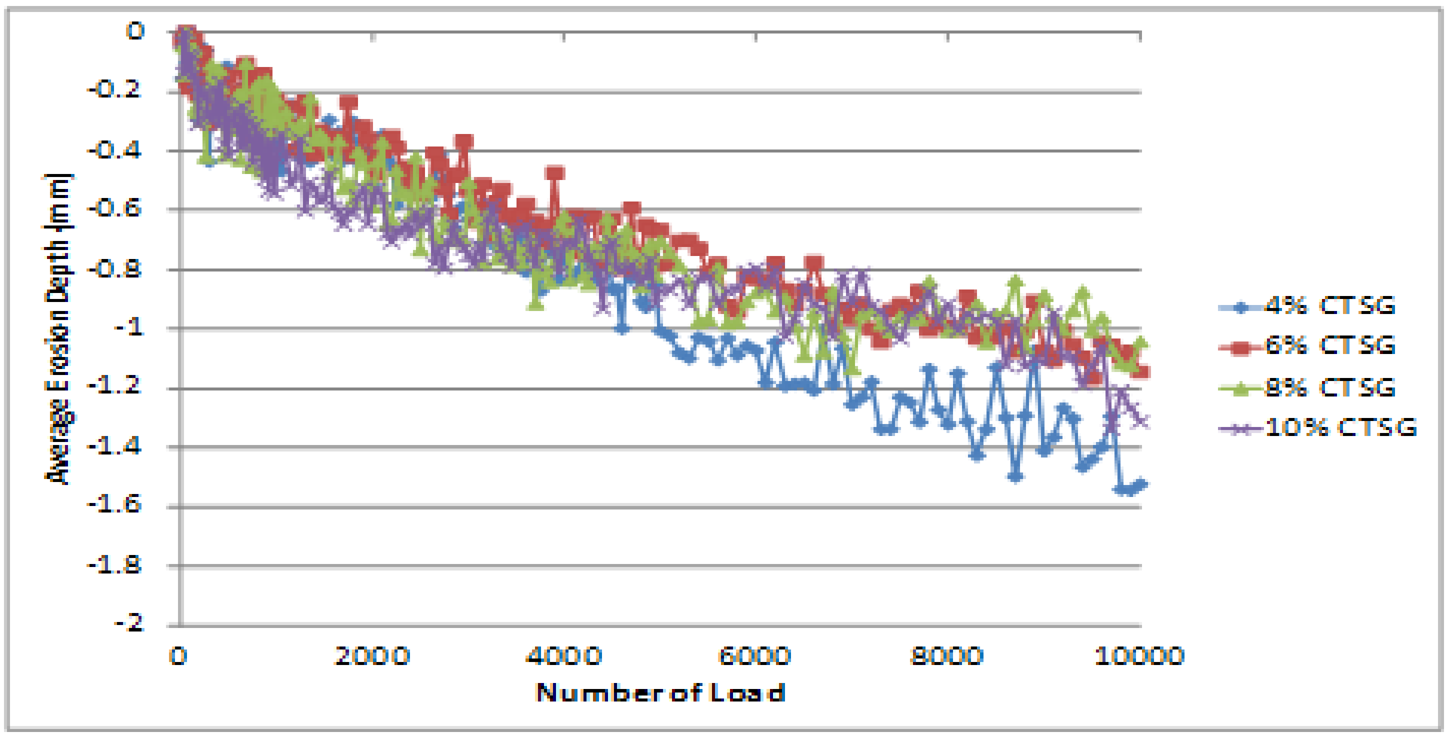
$FAULTMAX_i$	= maximum mean transverse joint faulting for month i, in
$FAULTMAX_0$	= initial maximum mean transverse joint faulting, in
$EROD$	= base/subbase erodibility factor
DE_i	= differential deformation energy accumulated during month i
C_{12}	= $C_1 + C_2 * FR^{0.25}$
C_i	= calibration constants
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)

Hamburg wheel-tracking device (HWTD)



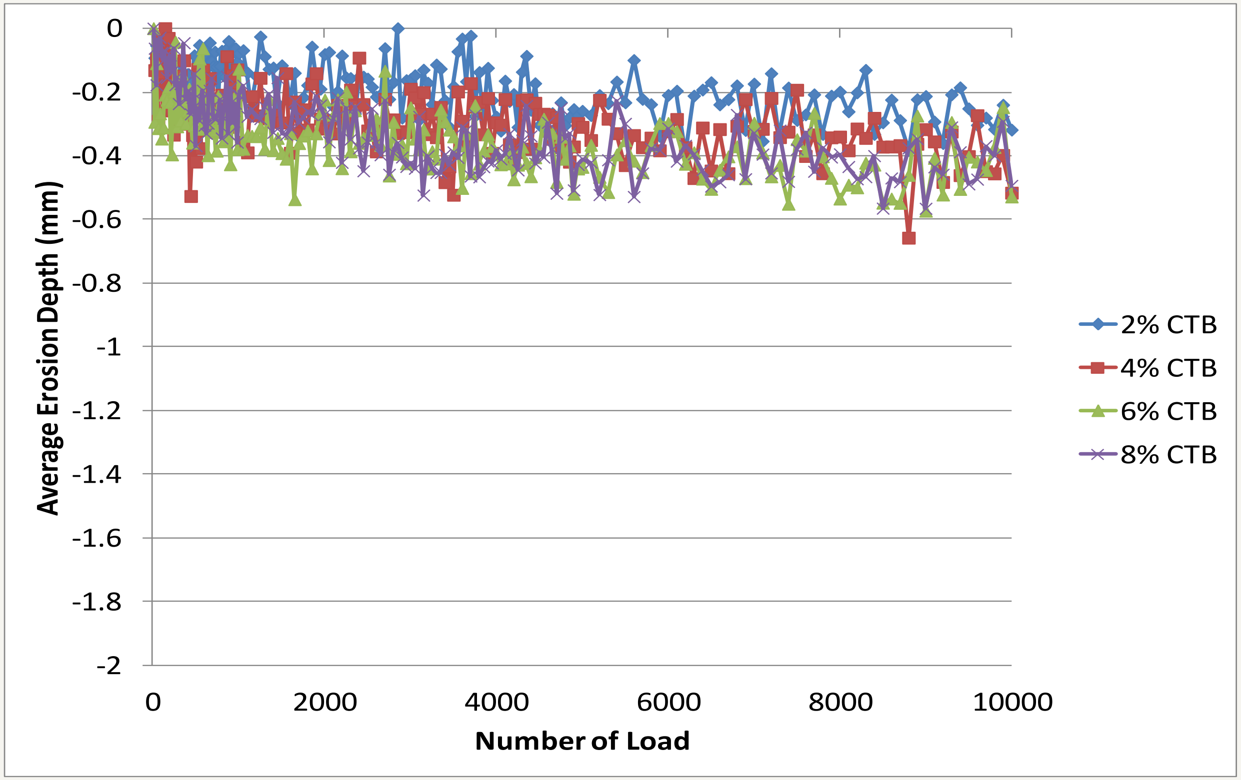


Erosion Results – CTS



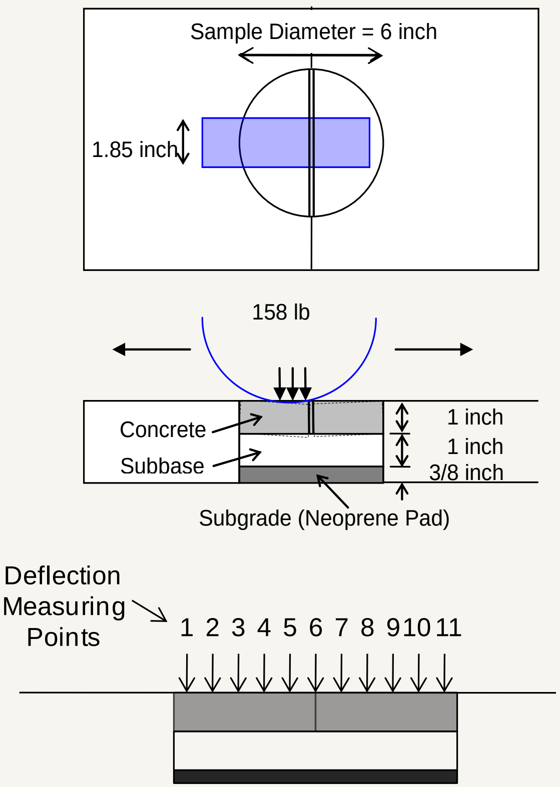
HWTD erosion Test on cement treated subgrade

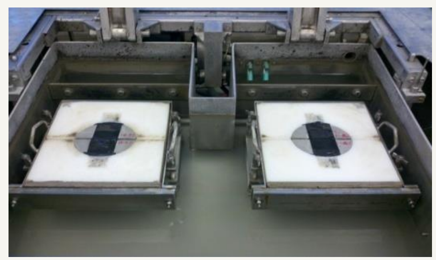
Erosion Results – CTB



HWTD erosion Test on cement treated base

Erosion Test and Shear Stress Model



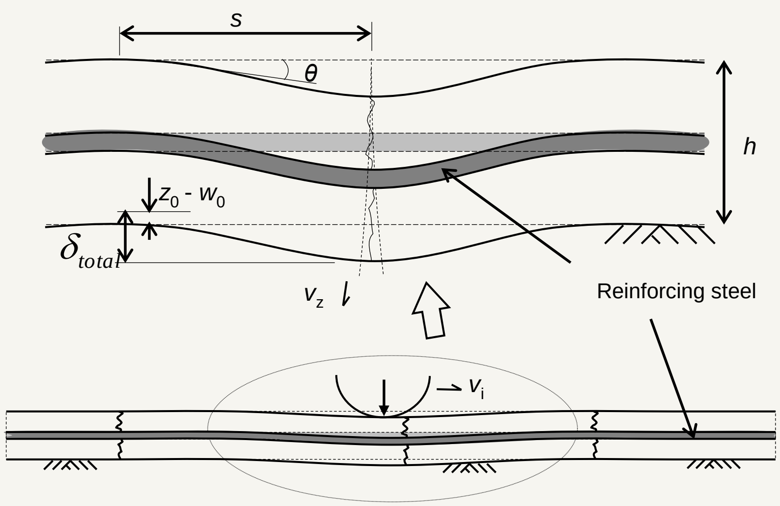


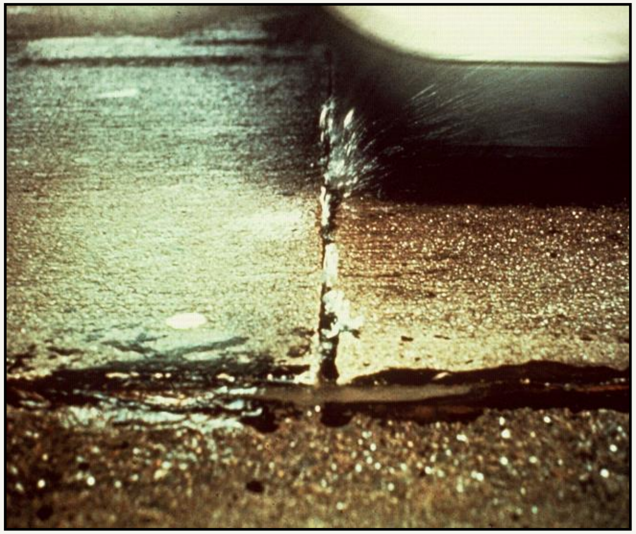
$$\tau_p = \chi\tau_b + (1-\chi)\tau_u$$

$$\tau_i = \frac{V_s\left\{1-\left[\frac{2\left(h_c - x_{na}\right)}{h_i}\right]^2\right\}}{h_i b \frac{E_{base}}{E_c}} = \left(\frac{\partial\delta_{L_i}}{\partial X}\right)_{e-p} \frac{E_{sb}}{2\left(1+\upsilon\right)}\left(\frac{1}{\chi}\right)$$

$$f_e = \left(1-\%\mathrm{E}\right)\left[\left(1-\mathrm{P}(\sigma_\mathrm{n} > 0)\right) f_c + f_\mathrm{F}\right]$$

Consideration of Erosion In Design





- Damages the Slab/Subbase Interface
- Lowers Friction
- Reduces Composite Slab Thickness
- Reduces k-Value
- Increases Stress
  - Bending Stress
  - Shear: Loss of LT

Partially Bonded System

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

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

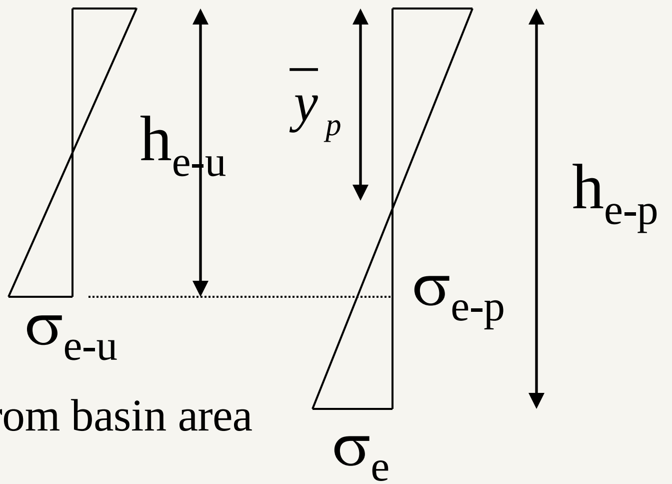
Notes on h_{e-p}:

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

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

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

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

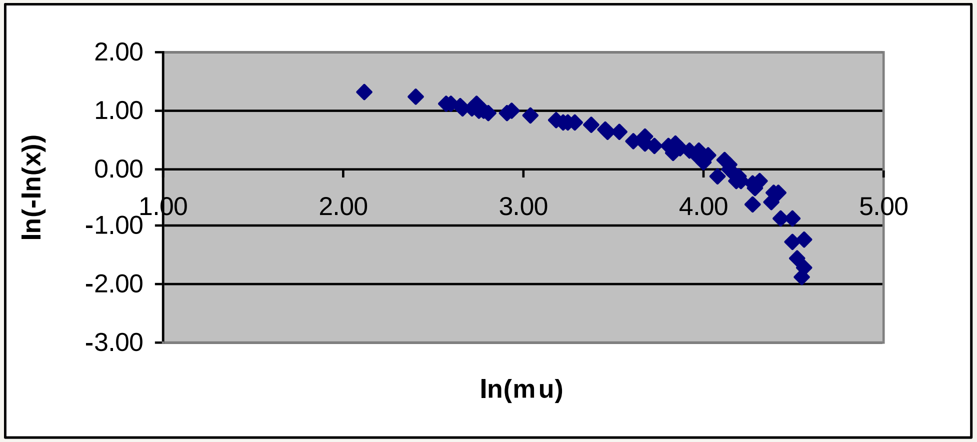


Transformed Section

Equivalent Interlayer Friction

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

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



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

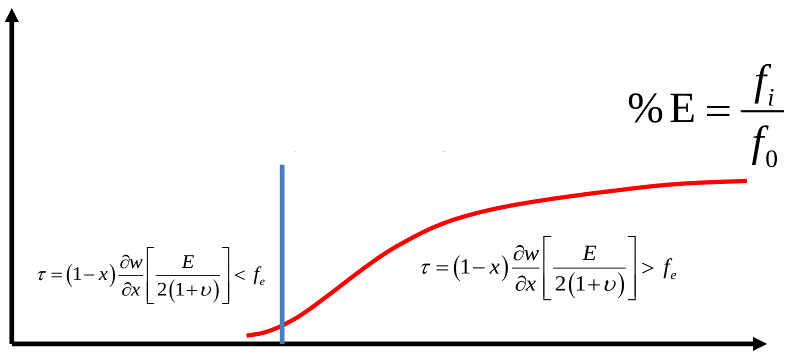
A $= e^{\frac{1.232 - 0.065\mu}{B}}$

B $= -\left(0.039 y^2\right)$

y = Ln(μ)

Erosion Testing

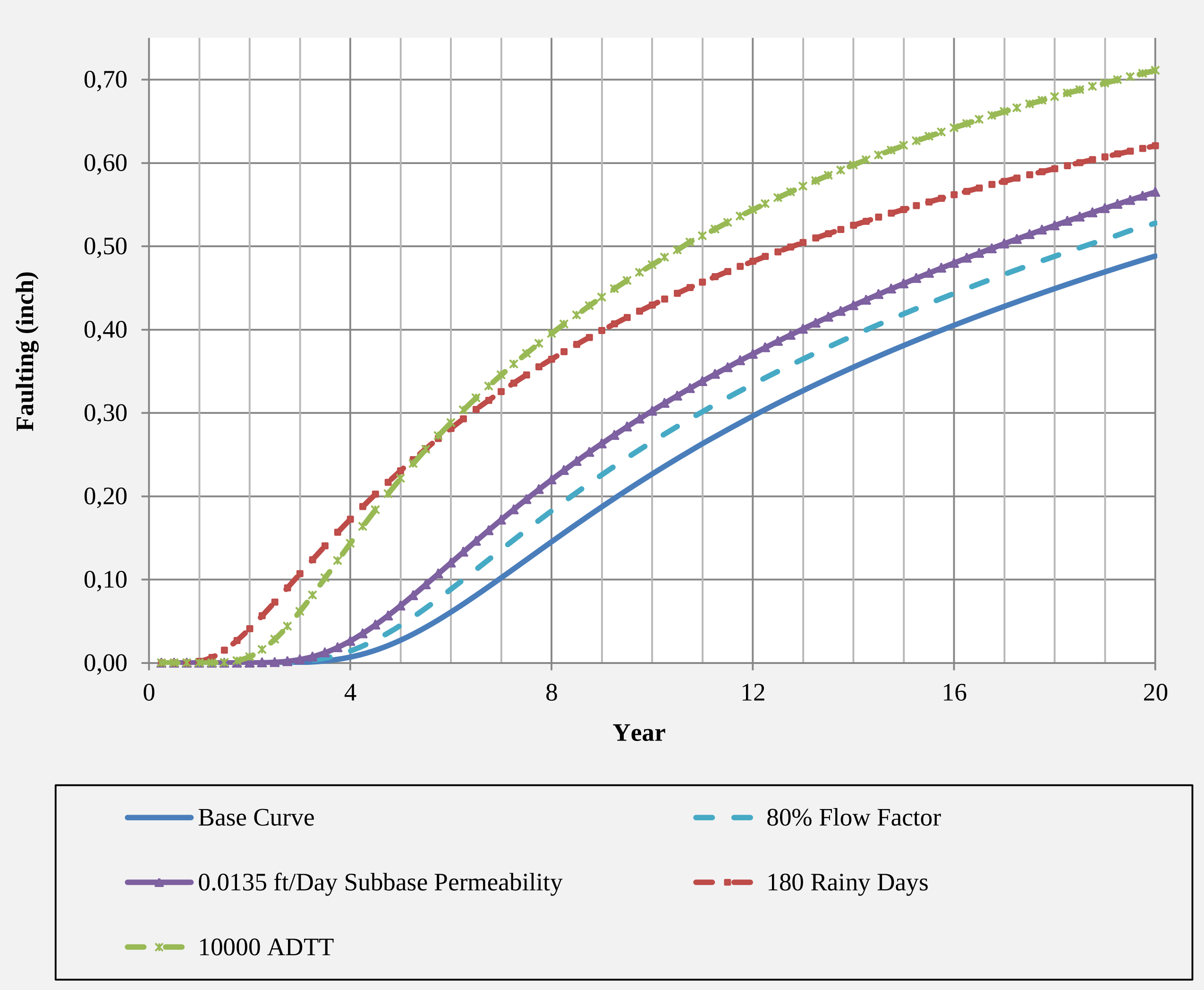
$$\%E = \frac{f_i}{f_0} = e^{-\left(\frac{\rho}{D_i}\right)^{\alpha}}$$



Where

- $\%E$ = Percent of erosion = $\frac{Fault_i}{Fault_0}$
- f_i = Level of faulting per load cycle i
- f_0 = Ultimate faulting
- D_i = Damage ratio per load cycle i ($D_i = N_i/N_f$)
- Δ = Erosion initiation shift factor
- α = Erosion rate factor
- ρ = Calibration factor
- N_i = Effective ESAL per load cycle i

Erosion-Based Design Process



- Determine Traffic
- Base Cohesive Strength
- Calc Shear Stress
- Estimate NWD
- Determine Erosion Damage
- Determine Interlayer Frictional Resistance and Reduced k-Value
- Determine Composite Thickness
- Determine Loss of LT
- Determine Bending Stress

Erosion Model

$$\%E = \frac{f_i}{f_0} = e^{-\left(\frac{\rho}{D_i}\right)^{\alpha}}; \; D = \frac{\sum N}{N_f}; \; N_f = 10^{k_1 + k_2 r}; \; r = \frac{\tau}{f_\tau}$$

Where

$\%E$	= Percent of erosion
f_i	= Level of faulting per load cycle i
f_0	= Ultimate faulting
D_i	= Damage ratio per load cycle i ***($D_i = N_i/N_f$)***
Δ	= Erosion initiation shift factor
α	= Erosion rate factor
ρ	= Calibration factor
N_i	= Effective ESAL per load cycle i

Presence of Moisture

$$Damage, D_i = \sum \frac{N_i}{N_f} \times (\%\text{Wet Days})$$

N_i = Effective ESAL

$$N_W = P\% * 365$$

$$P\% = p_1 * p_2 * (1 + p_3)$$

P% is a adjustment factor that contains three factors :

p_1: Probability of the Rain (# of wet days/ 365)

p_2 : Surface Inflow Factor

p_3 Subbase Drainage Factor

Interlayer Friction Model

$$f_e = \left(1 - \%\mathrm{E}\right)\left(\left[\left(1 - \mathrm{Prob}(\sigma_\mathrm{n} > 0)\right) f_c + f_\mathrm{F}\right]\right.$$

$$\sigma_n = \sigma_0 - f_t;\ \sigma_0 = \frac{3w}{S^2}\left(\ell_e - \ell\right) k \ell_e$$

$$f_c = \text{ cohesive or shear strength; } f_\mathrm{F} = q \tan\phi$$

$$\%\mathrm{E} = \frac{f_i}{f_0} = e^{-\left(\frac{\rho}{D_i}\right)^{\alpha}}$$

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

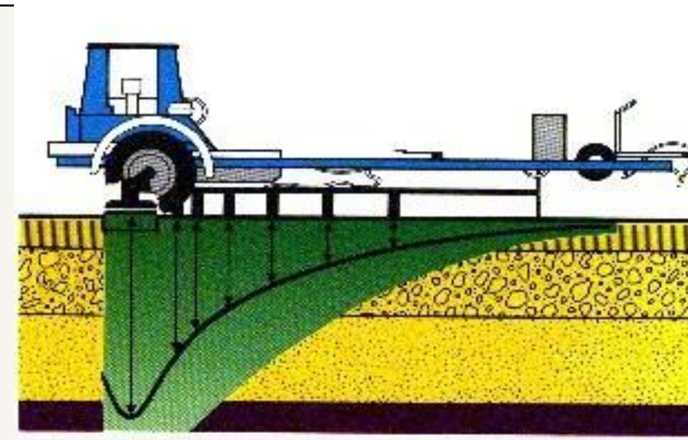
Field Evaluation of Erosion Damage

- Flow Tests (Infiltration Test)
- Ground Penetration Radar (GPR)
- Falling Weight Deflectometer (FWD)
- Core Samples

Toward South →

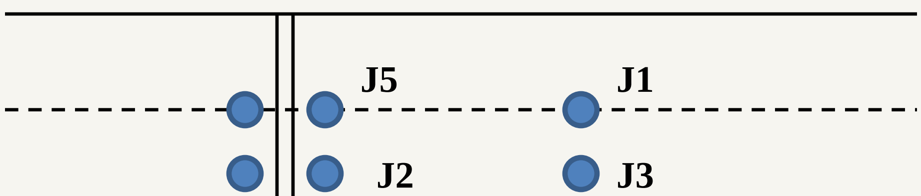
TS 3 Hot Pour Sealants	TS 2 Silicone (Poor Condition)	TS 1 Unsealed

Falling Weight Deflectometer (FWD)



Drops on :

- **Joints (Approach Slab and Leave Slab)**
- **Center of the Slab**
- **Edges and Corners**



$$f_e = \left(1 - \%E\right)\left[\left(1 - P(\sigma_n > 0)\right) f_c + f_F\right]$$

Equivalent Thickness

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

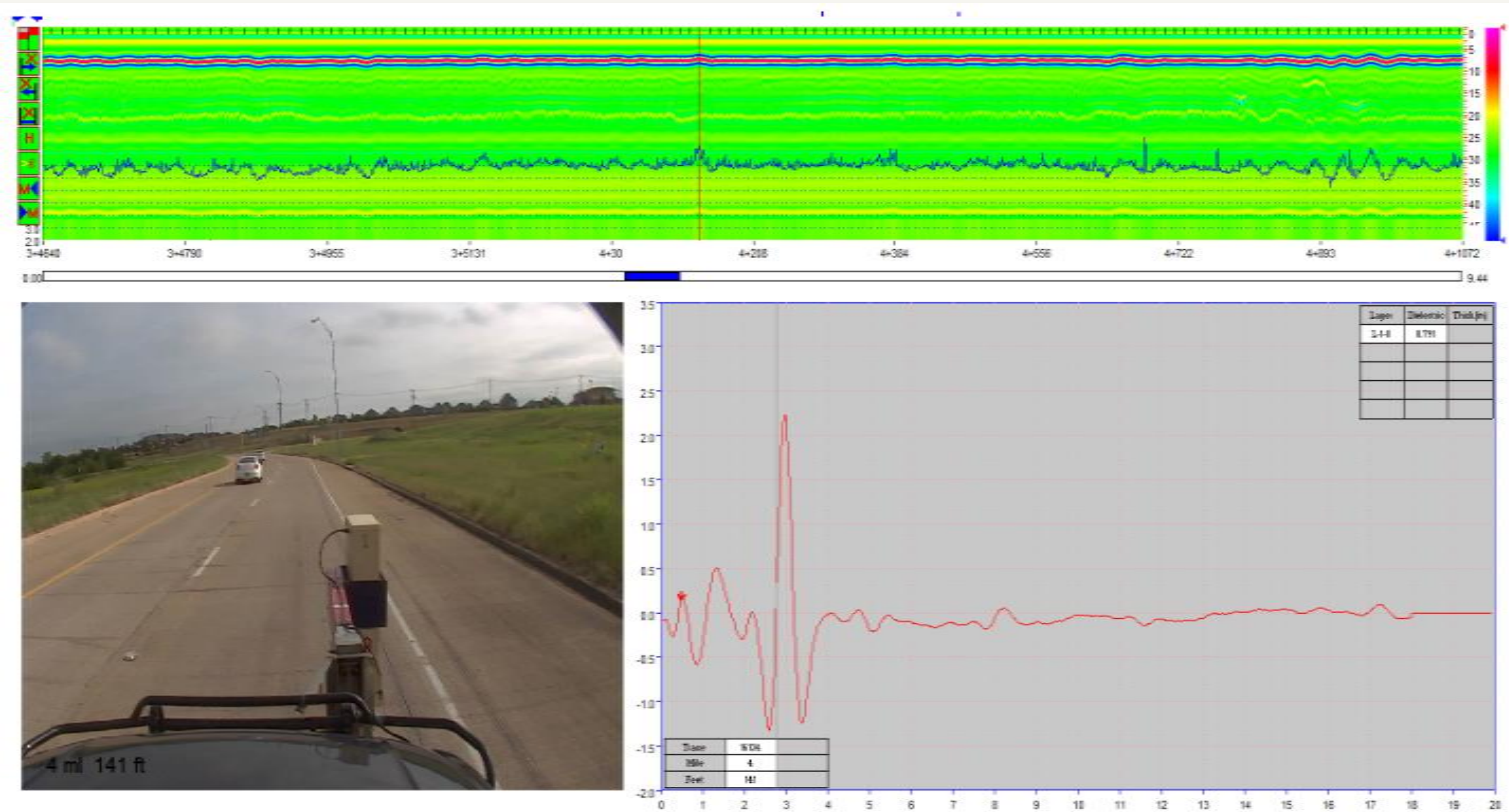
h_{e-p} ⇒ Equivalent Thickness

ℓm ⇒ Measured Value

k_b ⇒ Back-calculated

E_c ⇒ Based on Cores

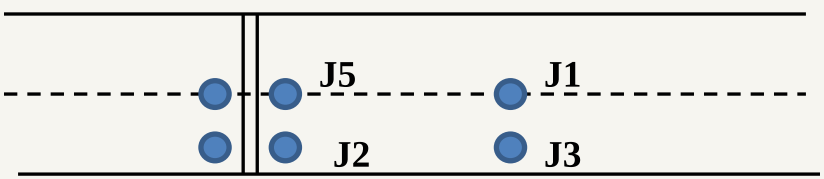
GPR Testing

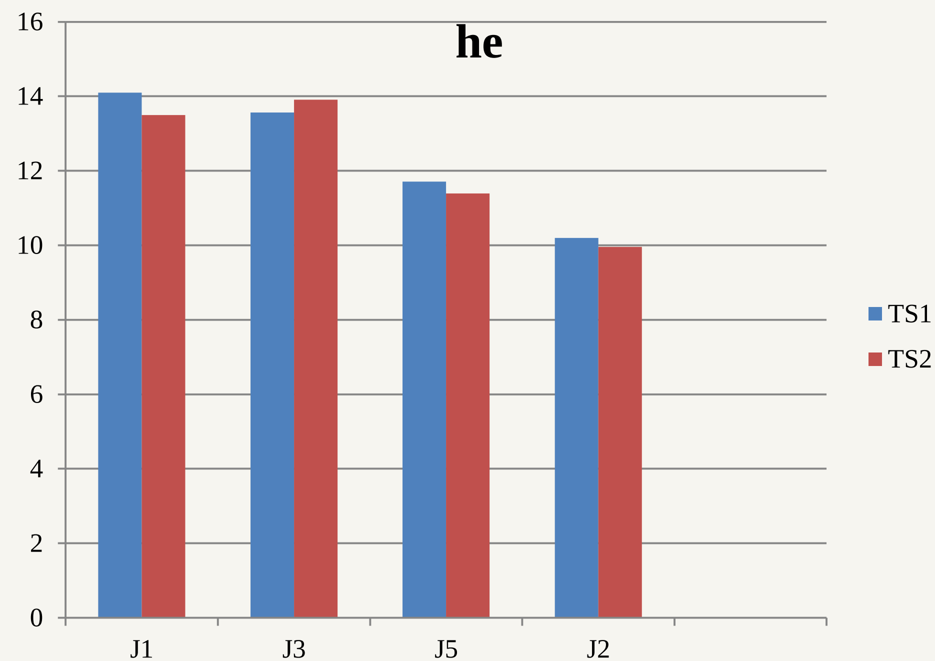


Erosion Results – h_e

TS1 Afternoon Read				
Position	J1	J3	J5	J2
he	14.10	13.57	11.71	10.20

TS 2 Afternoon Read				
Position	J1	J3	J5	J2
he	13.50	13.91	11.39	9.96





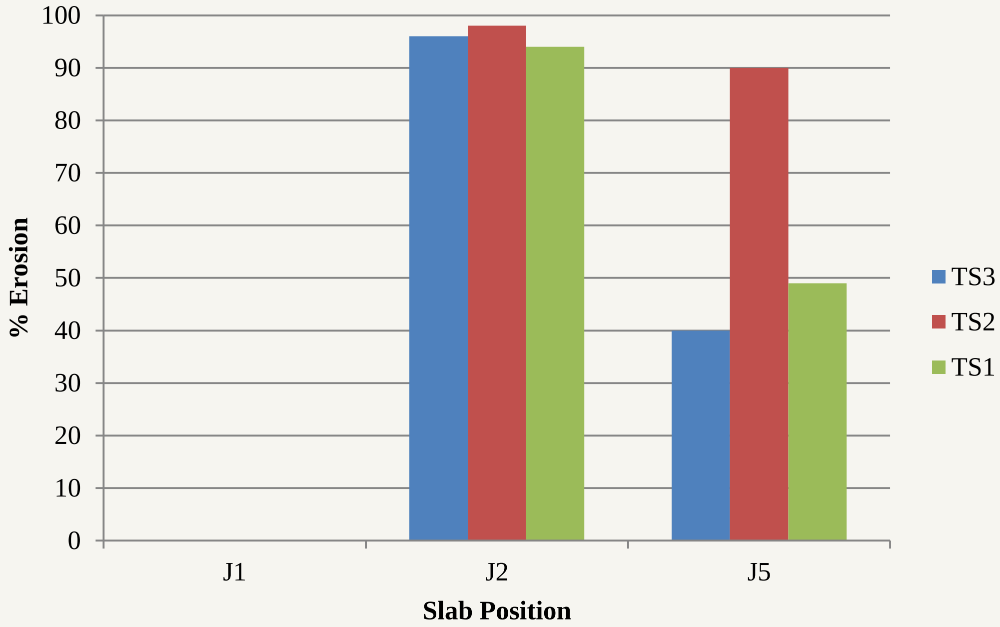
Falling Weight Deflectometer (FWD)

Erosion Results –%E

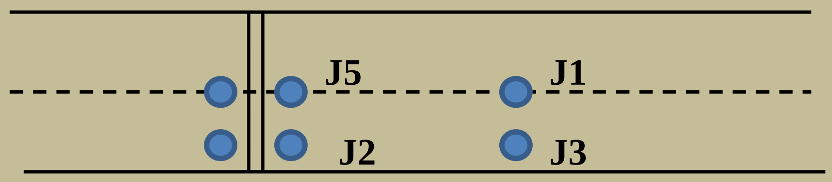
TS3			
Position	J1	J2	J5
Erosion %	0	96	40

TS2			
Position	J1	J2	J5
Erosion %	0	98	90

TS1			
Position	J1	J2	J5
Erosion %	0	94	49



Erosion %



Erosion Results – CRC

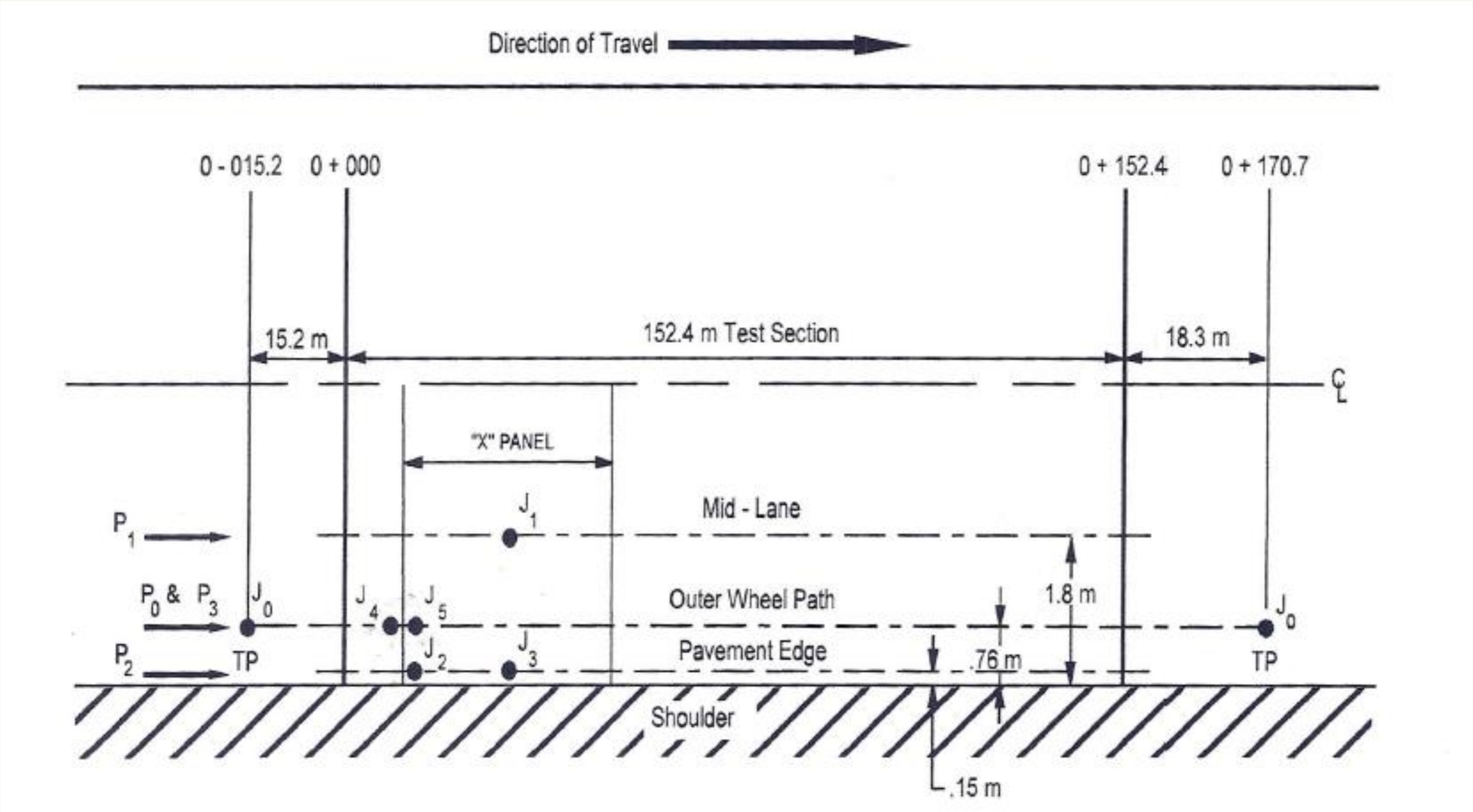
Table 2 Erosion Analysis Results.

	h_e	μ_e	$P(\sigma_n>0)$	μ_c	μ_F	%E
w/o fabric	302mm (11.9″)	32.5	15%	41.7	4.8	10%
w/fabric	226mm (8.9″)	1.54	75%			89%

Conclusions

- Erosion leads to loss of support and faulting
- Subbase shear strength is key to erosion resistance
- Field evaluation reveals that slab corners and edges are susceptible to erosion
- Considering erosion effects may also help to avoid overly conservative designs and better material/traffic combinations

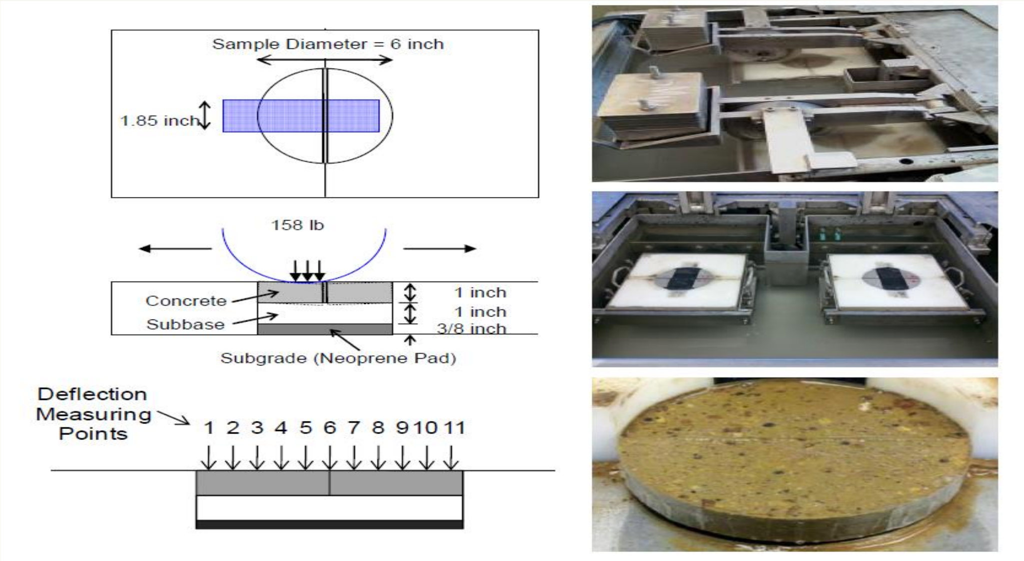
FWD Testing Pattern



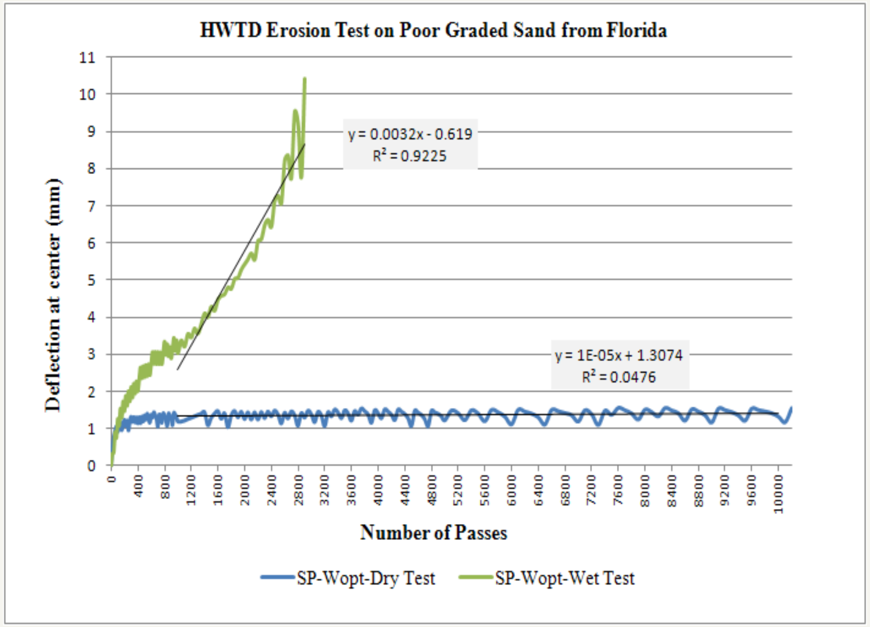
$$f_e = (1 - \%E)\left[(1 - P(\sigma_n > 0))\, f_c + f_F\right]$$

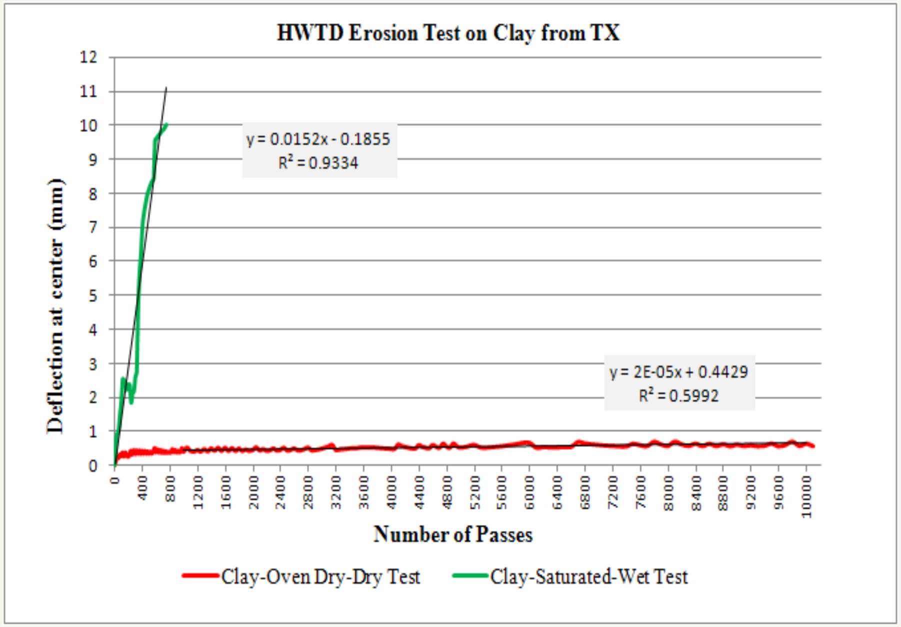
Hamburg wheel-tracking device (HWTD)

- Subbase material 25.4 mm (1 in.) thick placed on a neoprene
- Jointed concrete block 25.4 mm (1 in.) thick.
- A wheel load of 71.6 kg (158 lb) is applied at a 60-rpm load frequency
- Measurements consist of the depth of erosion Vs the number of passes



HWTD





Material	Material Location	Material Moisture When Tested	Test Condition	Erodibility (mm/million passes)
SP	FL	Optimum	Wet	3200
Clay	TX	Saturated	Wet	15200

Dynamic Foundation Modulus (K_{dyn})

$$k_b = \frac{w_0^* P}{w_0 \ell_e^2}$$

Where

P	= wheel load (F)
w_0	= center plate deflection (L)

$$w_0^* = \frac{1}{8}\left[1 + \left(\frac{1}{2\pi}\right)\left(\ln\left(\frac{a}{2\ell_e}\right) + \gamma - 1.25\right)\left(\frac{a}{\ell_e}\right)^2\right]$$

(center of slab loading)