Modelling Erosion in Design

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Key Model Components

The three main elements of erosion

Properties - Lab
Model - Tested Properties
Performance - Field

Erosion

Sustainability of Pavement

Reduce slab deflection by improving:
- Slab thickness
- Joint/crack load transfer
- Rigid or semi-rigid support

Sustainable Pavement Design

AASHTO MEPDG

Erosion Mechanisms: What’s Needed?
Do our Current Design Procedures or Test Methods Account for These Mechanisms?

Erosion

Pathway

Water
Load

Erodible Medium

Clay vs Sand vs Stabilized Clay vs Aggregate Base?

Seal or No Seal?

Florida vs Arizona Climate?

Interstate Hwy vs Retail Parking?
Interlayer Abraded Material and Moisture

US 81/287 – Cores

Section 1  Section 2  Section 3

Debonded AC base  Debonded AC base  Debonded AC base  Debonded AC subbase

Interlayer Friction Model

\[ f_c = (1 - \%E) \left[ (1 - \text{Prob}(\sigma > 0)) f_f + f_f \right] \]

\[ \sigma_c = \sigma_0 - f_f; \quad \sigma_0 = \frac{3w}{S^2} (f_f - f_f) k \ell \nu \]

\[ f_f = \text{cohesive or shear strength}; \]

\[ f_f = q \tan \phi \]

\[ \%E = \frac{f_f}{f_f} = e^{-\frac{\sigma}{\sigma_f}} \]

Interlayer Erosion Model

\[ \%E = \frac{f_f}{f_f} = e^{-\frac{\sigma}{\sigma_f}} \]

\[ D = N \sum_{i=1}^{N} \times (\%\text{Wet Days}); \quad N_f = 10^{A+D} \]

Where

\( \%E \) = Percent of erosion
\( f_f = \) Level of faulting per load cycle i
\( f_f = \) Ultimate faulting
\( D_i = \) Damage ratio per load cycle i
\( A = \) Erosion initiation shift factor
\( u = \) Erosion rate factor
\( p = \) Calibration factor
\( N_f = \) Effective ESAL per load cycle i

We Need a Bridge?

- The effects of No-Seal system ties to Erosion issue in the base
- Erosion can directly lead to Faulting and Spalling
- Damaged base repair is too expensive (Full Depth Repair)

Erosion Testing

We Need a Bridge?

- The effects of No-Seal system ties to Erosion issue in the base
- Erosion can directly lead to Faulting and Spalling
- Damaged base repair is too expensive (Full Depth Repair)

Erosion Model

\[ \%E = \frac{f_f}{f_f} = e^{-\frac{\sigma}{\sigma_f}} \times D \]

\[ D = N \sum_{i=1}^{N} \times (\%\text{Wet Days}); \quad N_f = 10^{A+D} \]

Where

\( \%E \) = Percent of erosion
\( f_f = \) Level of faulting per load cycle i
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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
Shear Strength

The resistance of the slab/subbase interface:
1. Interfacial bond (as may be represented by the cohesive strength of the subbase material), \( f_c \)
2. Interfacial sliding resistance, \( \phi \) angle

For cohesive soils, these shear characteristics change with amount of moisture that exists in the soil that is due to the effect of suction.

\[
\tau = \frac{\sigma_i - C}{\tan \phi}
\]

Where:
- \( \sigma_i \) = Normal Stresses,
- \( C \) = Cohesion,
- \( \phi \) = Angle of internal friction,
- \( \theta \) = Volumetric water content,
- \( h_m \) = Matric suction,
- \( f \) = Unsaturated shear factor

\[
f_c = (1 - \%E) \left[ (1 - P(\sigma_c > 0)) f_c + f_f \right]
\]

Erosion Test and Shear Stress Model

\[
\tau_e = \tau_c + (1 - \chi) \tau_s
\]

\[
f_e = \left(1 - \%E \right) \left[ (1 - P(\sigma_c > 0)) f_e + f_f \right]
\]

Falling Weight Deflectometer (FWD)

Drops on:
- Joints (Approach Slab and Leave Slab)
- Center of the Slab
- Edges and Corners

\[
f_e = (1 - \%E) \left[ (1 - P(\sigma_c > 0)) f_e + f_f \right]
\]

Faulting Modeling

- Determine Traffic
- Base Cohesive Strength
- Calculate 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-Based Design Process
Model Validation

<table>
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<tr>
<th>SHRP ID</th>
<th>Slab Thickness (in)</th>
<th>Base Thickness (in)</th>
<th>Subbase Thickness (in)</th>
<th>AADT Traffic (Ki)</th>
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T-Test

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<td>P-Value</td>
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The null hypothesis of zero mean difference cannot be rejected at a 95% confidence level (P-value is much larger than 0.05).

Conclusions

- Erosion is a result of traffic, base, and drainage/seal design
- Subbase CoF is key to erosion resistance
- Field evaluation reveals that slab corners and edges are critical erosion areas
- Consideration of the erosion factors will fundamentally change the focus of concrete pavement design