Pavement Design

TTP Orientation Seminar
2013
What are Pavements?

• Engineered structures in contact with the earth's surface built to facilitate movement of people and goods
  – Pedestrians
  – Personal vehicles
  – Freight and freight handling
  – Trains and trams
  – Aircraft and spacecraft
Pavement Types

• Asphalt Concrete Surface
  – Granular bases
  – Subgrade

• Concrete Surface
  – Various bases
  – Subgrade

• Surface Treatment
  – Thin sprayed asphalt on granular bases

• Permeable Pavement
  – Open graded asphalt or concrete layers, open granular layers, on uncompacted subgrade
What are Pavements?
What are pavements?
What are pavements?
Why Build Pavements?

• Provide all-weather mobility for road users
Why Build Pavements?
Why Build Pavements?
Who are the Stakeholders?

- User
- Owner
- Builder
- Society
  - Internal
  - External
Pavement Life Cycle

• Infrastructure Life Cycle
  – Deployment
  – Maintenance
  – Rehabilitation
  – Reconstruction (Abandonment? Reuse?)

• Goal at all stages is greater efficiency
  – how is efficiency defined?
## Where Are We Now?

<table>
<thead>
<tr>
<th>Years</th>
<th>Infrastructure</th>
<th>Pavement Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970-2050</td>
<td>Management</td>
<td>M &amp; R Scheduling, Condition Assessment</td>
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</table>
Years | Infrastructure | Pavilion Research
---|---|---
1995-2025 | Reconstruction | Reconstruction, Materials Optimization, Traffic Considerations, ReDesign
2010-2050 | Sustainability | Materials ReUse, Vehicle/Pavement Interaction, New Materials, Information Technology Integration
Is There a Pattern?

Continued expansion of the system boundaries in which pavement problems are defined
What Causes Pavement Distress?

• Traffic
• Environment
• Interaction of traffic/environment, construction quality, materials, design
Traffic Variables

Highways - it’s the trucks

• Loads
• Tire pressures
• Speeds
• Dynamics (interaction with roughness)
• Which are most important?
• One fully loaded truck pass causes same damage as about 5,000 passes of an SUV
Super Single Tires
Australian for “truck”

“Road Train”
Local Government Pavement Design

- Some agencies
  - Standard cross sections and materials
  - Little or no construction inspection (particularly compaction)
  - No money for testing and analysis

- Other agencies
  - Design for particular traffic, environment, soils
  - Good construction inspection
  - Testing and analysis (is there a net cost savings?)

- Standard specifications and design methods
  - Greenbook (mostly in S. California)
  - Use of state specifications (much of N. California, joint powers financing, federally funded projects)
  - Use of consultants
What are Pavements Made Of? and will this change?

- Most pavements are made of engineered soils and processed rock
- Asphalt concrete is 85% aggregate by volume; 10% asphalt; some plastic, rubber modifiers
- Portland cement concrete is 70% aggregate by volume; 11% portland cement; up to 25% of cement replaced by fly ash; some steel

- Nearly all of these materials can be perpetually recyclable into the same infrastructure
Fifty-Year Aggregate Demand Compared to Permitted Aggregate Resources*

The pie diagrams show the projected 50-year demand for aggregate as of January 2005 compared to currently permitted aggregate resources (in short tons). The 50-year demand for a particular study area is graphically represented by one of four pie diagram sizes. Study area boundaries are shown on the index map of aggregate studies (lower left).

* Permitted aggregate resources (also called aggregate reserves) are those portions of the resources for which local land agencies (county and cities) have issued mining permits. Non-permitted aggregate resources information is given in each aggregate study report. See accompanying text for references to these reports.

Legend

- 50-year demand that will not be a permitted resource
- Permitted aggregate resources
- 50-year demand is 25 to 200 million
- 50-year demand is > 200 to 500 million
- 50-year demand is < 500 to 1000 million
- 50-year demand is > 500 to 1000 million
- 50-year demand is more than 1000 million

Examples

- 50-year demand for aggregate is permitted resources total 25 million
- 50-year demand
- 25/100 Million Tons (permitted resources/ 50 y)
- 50-year demand for aggregate is permitted resources are greater than 500/510 Million Tons (permitted resources/ 50 y)

Scale: 1:1,100,000
Projection: Transverse Mercator, NAD 83
Pavements: will the demand for them increase or decrease?

Pavements sorted by transportation mode

- Streets, roads, highways, freeways, parking
- Railroads, switching yards, intermodal yards
- Runways, taxiways, aprons
- Land-side port facilities, container yards
- Bike paths, sidewalks, other hardscape
What is the impact on pavements of efforts to improve sustainability?

• Vehicle fuel economy and fuel type will change

• Fuel type change impact on available materials?

• Fuel economy change impact on functional and structural requirements?
  – Smoothness requirements
    • Impacts on product life cycle and waste
  – Pneumatic tire loads and inflation pressures
  – Operating speeds and suspension systems
  – Repetitions
How can the environmental impact of pavements be reduced?

- Understand the pavement life cycle
- Identify environmental costs
- Consider environmental costs in decision-making
- Identify how to reduce environmental costs considering interactions with other systems
- Determine how to make new methods standard practice
Figure 3.1: UCPRC Pavement LCA Framework.
Some basic good practices

• Minimize the annual use of new materials
  – Perpetual reuse
  – Make materials/pavements last longer
  – Thinner pavements

• Reduce the environmental costs of new materials and recycling
  – Local materials, reduce hauling distance
  – Reduce energy needs
  – Low-impact materials

• Reduce the delay associated with construction

• Keep high traffic roads smooth
I-710 Reduction of Pavement Thickness Using Mechanistic Design

<table>
<thead>
<tr>
<th>Conventional design</th>
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</thead>
<tbody>
<tr>
<td>535 mm thick asphalt concrete</td>
</tr>
<tr>
<td>8 % air-voids, same mix design throughout</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mechanistic design</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 mm PBA-6a</td>
</tr>
<tr>
<td>125 mm, 5 % air-voids, AR-8000</td>
</tr>
<tr>
<td>75 mm, Rich Bottom</td>
</tr>
</tbody>
</table>
Assembly Bill 32 (2006) requires
2020 GHG emissions at 1990 levels
2050 GHG emissions at 20% of 1990 levels
Pavement Rolling Resistance

• Roughness (models available)
  – Measured with International Roughness Index (IRI)
  – Dissipates energy through suspension

• Macrotecture (models available)
  – Dissipates energy through tire distortion

• Deflection (models under development)
  – Theory: dissipates energy through deflection of viscoelastic pavement materials (HMA)
  – Theory: larger deflection and viscoelasticity results in vehicle always running uphill
Case Study 1 (KER-5): Asphalt overlay on rural/flat freeway

10 mile (16 km) segment
- Rural freeway
- 2 lanes, southbound
- AADT: 34,000; ~35% trucks

Compare:
- Routine maintenance
- 5 year overlay:
  - HMA or RHMA

<table>
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<tr>
<th>Lane</th>
<th>Cars</th>
<th>Trucks</th>
<th>IRI</th>
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</thead>
<tbody>
<tr>
<td>Inner Lane</td>
<td>77%</td>
<td>9%</td>
<td>158</td>
</tr>
<tr>
<td>Outer Lane</td>
<td>23%</td>
<td>91%</td>
<td>222</td>
</tr>
</tbody>
</table>
Kern-5 (high traffic): Cumulative life cycle energy savings of HMA overlay compared to "Routine Maintenance"

<table>
<thead>
<tr>
<th>Year</th>
<th>3% Traffic growth: Smooth Rehab</th>
<th>3% Traffic growth: Less Smooth Rehab</th>
<th>0% Traffic growth: Smooth Rehab</th>
<th>0% Traffic growth: Less Smooth Rehab</th>
</tr>
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<tbody>
<tr>
<td>2012</td>
<td>0.39</td>
<td>0.79</td>
<td>1.19</td>
<td>-0.19</td>
</tr>
<tr>
<td>2013</td>
<td>0.39</td>
<td>0.79</td>
<td>1.19</td>
<td>-0.19</td>
</tr>
<tr>
<td>2014</td>
<td>0.39</td>
<td>0.79</td>
<td>1.19</td>
<td>-0.19</td>
</tr>
<tr>
<td>2015</td>
<td>0.39</td>
<td>0.79</td>
<td>1.19</td>
<td>-0.19</td>
</tr>
<tr>
<td>2016</td>
<td>0.39</td>
<td>0.79</td>
<td>1.19</td>
<td>-0.19</td>
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<tr>
<td>2017</td>
<td>0.39</td>
<td>0.79</td>
<td>1.19</td>
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HMA overlay, 5 year life, payback analysis

Cumulative Energy Saving Compared to Do Nothing (10^6 MJ)

Equivalent Gasoline (10^6 Gal)

- Smoother
  - Initial IRI = 63 in/mile

- Less Smooth
  - Initial IRI = 106 in/mile

Construction
Case Study 4 (IMP-86):
Concrete CPR B on rural/flat highway

5 mile (16 km) segment in need of rehab
- Rural highway
- 2 lanes, southbound
- AADT: ~11,200; ~29% trucks

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<tr>
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<tr>
<td>Outer Lane</td>
<td>24%</td>
<td>92%</td>
<td>183</td>
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Compare:
- Do Nothing
- 10 year CPR B
  - Grind
  - 3% slab replacement
Cumulative Energy Saving Compared to Do Nothing (10^6 MJ)

- 3% Traffic growth: Smooth Rehab
- 3% Traffic growth: Medium Smooth Rehab
- 3% Traffic growth: Less Smooth Rehab
- 0% Traffic growth: Smooth Rehab
- 0% Traffic growth: Medium Smooth Rehab
- 0% Traffic growth: Less Smooth Rehab

**Slab replacement + grind, 10 year life, payback analysis**

**Smother**
Initial IRI = 57, 72 in/mile

**Average Smoothness**
Initial IRI = 104, 108 in/mile

**Less Smooth**
Initial IRI = 140, 144 in/mile
Conclusions from project-level case studies

• Smoothing rough pavement has great potential to reduce energy consumption and GHG emission.

• Emissions from construction and materials for high traffic volume roads can be paid back very quickly (in less than 1 year at extreme).

• For low traffic volume roads, material production and construction emissions will never be paid back with use phase savings.
## 10 year Results of Optimal vs Previous IRI Trigger

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<tbody>
<tr>
<td>&lt; 2,517</td>
<td>----</td>
<td>12,068</td>
<td>0.24</td>
<td>-5,127</td>
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<tr>
<td>2,517 to 11,704</td>
<td>152</td>
<td>12,068</td>
<td>0.28</td>
<td>3,818</td>
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<tr>
<td>11,704 to 19,108</td>
<td>127</td>
<td>4,827</td>
<td>0.29</td>
<td>2,420</td>
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<tr>
<td>19,108 to 33,908</td>
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<td>4,827</td>
<td>0.52</td>
<td>1,283</td>
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<tr>
<td>33,908 to 64,656</td>
<td>101</td>
<td>4,827</td>
<td>1.68</td>
<td>1,030</td>
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<tr>
<td>64,656 to 95,184</td>
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<td>4,827</td>
<td>2.03</td>
<td>638</td>
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<tr>
<td>&gt; 95,184</td>
<td>101</td>
<td>4,827</td>
<td>3.11</td>
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<tr>
<td>Total</td>
<td></td>
<td></td>
<td>8.15</td>
<td>688</td>
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CO₂ Payback Period
Using Life Cycle Analysis for Design Life Comparison

• Savings are not immediately realized
  – Payback ~30-45 years in the future
• Future is highly uncertain
  – Technological advancements
  – Uncertain demand
• What’s the right analysis period?

Global Warming Potential

Cumulative GWP (MT CO₂-eq)

Time (years)

Break-even point