Design and Rehabilitation Strategies for Sustainable Concrete Pavements

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SUSTAINABILITY

Sustainable Solutions

Economic

Environmental

Social
To a highway agency, sustainability, first and foremost, is the ability to provide pavements in its charge in an acceptable condition.

Indication of unsustainable practice:

- Mounting backlog of pavement rehab needs
- Annual shortfall of roadway budget for meeting critical needs is estimated at $116 billion
Washington State’s roadway preservation budget trend (Mahoney et. al 2010)

22-year Roadway Preservation Funding (Constant 2007 Dollars)

- Average funding over 4 Bienniums is $208 million per year
- Total reduced funding over 7 Bienniums is $936 million

Fiscal Year:
- 1992 to 2013

"Stimulus"
Smoothness trend of NHS (HPMS)
Key points

- Economic sustainability is the biggest challenge facing DOTs today
- The long-life pavement approach greatly enhances the highway agencies’ ability to meet the pavement needs
  - Building long-life, low-maintenance pavements
  - Taking proactive measures to preserve the pavement
- The sustainability is improved automatically
Via Apia, 312 B.C.
Current practice

- Pavements are designed to fail
  - Finite design period
  - Pavements are designed for relatively high levels of distress at the end of the design period
- Repairs are not made until distresses progress to high severity
- Structural overlays are used primarily as a corrective measure
  - Typically used on pavements in poor condition
  - A thicker overlay is generally required
What is needed

- Design pavements to last as long as the materials
  - Pavements should remain distress-free within the design period
  - Utilize design features that ensure good long-term performance
- Apply preventive treatments to preserve the pavement structure
  - For sustainability, preservation is better than reconstruction
  - Prevention is the best preservation strategy
ME design

Trial Design ➔ Climatic Data ➔ Material Properties ➔ Traffic ➔ Predicted Performance ➔ Mechanistic Analysis ➔ Design Guide Software
Effects of slab thickness on cracking (MEPDG)

Traffic: 30 million ESALs
Wet-freeze climate
15-ft joint spacing

Percent slab cracking vs. Slab thickness, in

- 95% reliability cracking
- Average cracking
Effects of slab thickness on traffic capacity (MEPDG)

Average percent slab cracking vs Traffic, million ESALs for different slab thicknesses:
- 10.5 in
- 11.0 in
- 11.5 in
- 12.0 in
## Benefits of conservative design (MEPDG)

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Relative Damage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>80k-5Axle</td>
<td>1.0</td>
<td>Reference</td>
</tr>
<tr>
<td>88-kip 38/38</td>
<td>+0.5 in</td>
<td>+0.5 in</td>
</tr>
<tr>
<td>94k-5Axle (41/41)</td>
<td>+1.0 in</td>
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</tr>
<tr>
<td>100k-5Axle (44/44)</td>
<td>+1.0 in</td>
<td></td>
</tr>
<tr>
<td>100k-6Axle (41/47)</td>
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<td></td>
</tr>
<tr>
<td>110k-6Axle (44/54)</td>
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</tbody>
</table>

Reference:
- +0.5 in
- +1.0 in
Sustainable rehabilitation strategy

- Repair cracks while they can be effectively treated by dowel or tie bar retrofit
  - Less intrusive, and is at least as effective as full-depth repair (similar service life)
  - Significantly lower cost

- Apply structural enhancements when structural cracks begin to develop
  - A relatively thin HMA overlay can be highly effective in greatly extending service life
Pavement condition vs. age
Pavement condition vs. age – current practice
Pavement condition vs. age – preservation approach
Pavement condition vs. age – long-life pavement
Cost Considerations
Current practice
Cost considerations

- Minimizing LCC of a single project does not provide the best results for the network.
- Highway investment decision is a resource allocation problem.
- At any given funding level, the optimum solution is one that buys the most service life for the network: total lane-mile-years.
Remaining life over time

Remaining Life, yrs

Year

Project
Remaining life of project in the network, year 0

Remaining life, yrs

Project
Remaining life of project in the network, year x
Effects of service-life on project load

- Total number of projects rehabilitated or reconstructed
- Year
- 15-yr life
- 25-yr life
- 50-yr life
Two Dimensions of Paving

Coverage: lane-miles

Service Life: years

Unit of Paving = lane-mile-years

A network of x lane-miles of pavement requires an addition of x lane-mile-years of service life each year to maintain status quo

A Quick Check of Your Highway Network Health: FHWA-IF-07-006
Measure of Paving Costs

<table>
<thead>
<tr>
<th>Option 1</th>
<th>1 mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life</td>
<td>Cost</td>
</tr>
<tr>
<td>15 yrs</td>
<td>$200</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Option 2</th>
<th>30 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life</td>
<td>Cost</td>
</tr>
<tr>
<td>30 yrs</td>
<td>$220</td>
</tr>
</tbody>
</table>
## Measure of Paving Costs

<table>
<thead>
<tr>
<th>Option 1</th>
<th>15 yrs</th>
<th>$200</th>
<th>$13.33 / lane-mi-yr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13 yrs</td>
<td>$45</td>
<td>$3.46 / lane-mi-yr</td>
</tr>
<tr>
<td></td>
<td>12 yrs</td>
<td>$45</td>
<td>$3.75 / lane-mi-yr</td>
</tr>
<tr>
<td></td>
<td>40 yrs</td>
<td>$290</td>
<td>$7.25 / lane-mi-yr</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Option 2</th>
<th>30 yrs</th>
<th>$220</th>
<th>$7.33 / lane-mi-yr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 yrs</td>
<td>$30</td>
<td>$3.00 / lane-mi-yr</td>
</tr>
<tr>
<td></td>
<td>10 yrs</td>
<td>$30</td>
<td>$3.00 / lane-mi-yr</td>
</tr>
<tr>
<td></td>
<td>50 yrs</td>
<td>$280</td>
<td>$5.60 / lane-mi-yr</td>
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</tbody>
</table>
Effects of service life on relative cost/value
## LCC vs $/lane-mi-yr for Roman Road

<table>
<thead>
<tr>
<th>Life</th>
<th>Agency Cost</th>
<th>PV</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 yrs</td>
<td>$150 /mi</td>
<td>$2.5 /mi</td>
<td>$65,220 / lane-mi-yr</td>
</tr>
<tr>
<td></td>
<td>Reconstruct</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>99 times</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,300 yrs</td>
<td>$3.0 /mi</td>
<td>$3.0 /mi</td>
<td>$1,300 / lane-mi-yr</td>
</tr>
</tbody>
</table>
Summary

- Current practices are not conducive to realizing the full performance potential of pavements
- Preferable practices
  - Design pavements to last as long as the material
  - Make repairs as early as possible to prevent further deterioration
  - Use overlays as a preventive treatment to preserve the pavement structure
- Evaluate cost as a resource allocation problem
  - Key parameter: \$/lane-mi-year
  - Over time, optimizing $/lane-mi-year will minimize the number of projects that needs to be reconstructed