Integrating Design, Construction, and Traffic for Rapid Highway Rehabilitation Projects

Long Life Asphalt and Concrete Pavement and Fast-Track Construction

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Outline of presentation

- California context for pavement rehabilitation design and construction
- Problem definition and approach: Long-life pavement rehabilitation strategies (LLPRS)
- Long-life pavement design approaches
  - Concrete
  - Asphalt
- Construction analysis and optimization
- Some examples
California Context

- State highway network, approximate statistics:
  - 80,000 lane-km
  - 24,000 centerline-km
  - 70% asphalt surface
    - Flexible
    - Semi-rigid
    - Composite
  - 30% concrete surface
    - Nearly all plain jointed without dowels

- Major urban and inter-urban routes mostly deployed 1955-1975 with 20 year design lives
Percentage of Total VMT with Rough Ride (IRI > 170) by Highway Type

- NHS-Interstate
- NHS-non Interstate
- Non NHS
- All State Highways

Highway Category

- 2002
- 2003
- 2004
- 2005
- 2007
Average Annual Precipitation (Inches), California
Period: 1961-1990

Desert
100 mm

North Coast
2500 mm

Oregon Climate Service, 1995
Caltrans
CLIMATE REGIONS
Evaluation Data and Mapping
February 16, 2005

STATE OF CALIFORNIA
Business, Transportation and Housing Agency
Department of Transportation
Average Daily Long-Haul Freight Truck Traffic on the National Highway System: 2007

Note: Long-haul freight trucks typically serve locations at least 50 miles apart, excluding trucks that are used in movements by multiple modes and mail.

Typical Urban Freeway Failures (I-10)

A.D.T = 240,000 (Truck 7%)
Long-Life Pavement Rehabilitation Strategies (LLPRS)

• Long-Life requires poor condition and >150,000 ADT or >15,000 ADTT
  – 2,000 lane-km meet these criteria

• Funding limitations

• Design and Construction criteria:
  – 30+ year design lives, minimum maintenance
  – 55-hour weekends or 72-hour weekday construction closures
  – Minimize lane closures
Problem: How to Optimize Long Life Rehabilitation Strategies on Multiple Criteria

• **Want Long Life and Fast Construction and Minimum Traffic Delay**
  – pavement design strategies:
    • *longer life pavements take longer to construct*
  – construction windows/traffic delays:
    • *shorter windows less efficient for construction*
    • *some strategies can’t be built in 7 to 10 hour windows*
    • *which windows minimize total traffic delay: 55 hour weekend, 72 hour weekday, continuous?*

• **Requires Integration**
  – Pavement Engineering + Construction Engineering + Traffic Engineering
Current Long-Life Rehab Strategies

**Typical now**

- 200-225 mm PCC or HMA
- 100-150 mm CTB or AB
- CSOL Crack and Seat PCC, Place Thick AC Overlay

**FDAC**

- Remove existing, Replace with full-depth HMA structure

- Remove PCC or overlay HMA, with 200-300 mm PCC
- Retain or replace existing base
General Pavement Approach

• Drive distresses to the surface
• Keep the materials simple to produce and the design simple to construct
• Integrate
  – mix design
  – structural design
  – constructability
Concrete Pavement Design

- **Prior to 2005:**
  - Empirical thickness design catalog
  - All jointed plain concrete

- **After 2005:**
  - Developed new JPC design catalog using MEPDG, with state calibration
  - Experimenting with pre-cast for rapid rehabilitation
  - New CRC design catalog and specifications since 2009
Status of MEPDG implementation in CA

• MEPDG nationally calibrated
  – 13 of the 183 calibration sites are from CA

• Process to validate the models before implementing them
  – Sensitivity Analysis
  – Validate using Accelerated Pavement Testing (some, mostly effects of dowels, widened lanes)
  – Calibration using field data

• Catalog developed with locally calibrated 0.8 version of the software
  – Slab/base bonding most significant variable for cracking
Sensitivity Analysis

• Generally results are reasonable

• Some issues with the models
  – Subgrade effect counter-intuitive
  – Subbase thickness and type has no effect
  – CTE & surface absorptivity very sensitive

• Results:
  – Dowels
  – Use previous empirical subbase designs
  – Designs for traffic and climate regions
Effect of surface absorptivity on transverse cracking
Longitudinal & Corner Cracking Significant in CA, not in MEPDG

Low humidity: shrinkage gradients + truck traffic
Pre-cast used in some nighttime closures
HVS testing of Ft. Miller system showed generally good results in 2003.
Pre-cast Results

- Some issues with sand bed erodibility and gasket
- Required grinding
- One recent project had problems, waiting forensic results

After HVS Test
Recent alternative pre-cast post-tension

- Pilot projects with pre-cast, post-tensioned slabs in LA, Bay Area in 2011
- Anchor system in middle, up to 6 m long slabs tied together in each direction
- Nighttime closures
  - Remove pre-cut existing concrete
  - Place and tension slabs
Asphalt Pavement Design

• Prior to 2002
  – R-value method (empirical)

• 2002
  – ME design long-life asphalt I-710

• 2002-current
  – Development of CalME mechanistic design models and software (alternative to MEPDG)

• 2011
  – ME designs on three projects designed with CalME, specifications based on ME input
I-710 Crack, Seat and Overlay (CSOL) between bridges

**Sacrificial layer – safety, noise** 25-50 mm

**Top layer – rutting, cracking** 75-100 mm

**Middle layer – cracking, rutting** Varying thickness

**Bottom layer - cracking** fabric 30 mm

Cracked and Seated PCC

**Base layers**

subgrade
Full-Depth Asphalt Concrete (FDAC) under bridges

- Sacrificial layer – safety, noise
  - Existing grade: 25-50 mm

- Top layer – rutting, cracking
  - Existing grade: 75-100 mm

- Middle layer – cracking, rutting
  - Varying thickness

- Rich Bottom layer - cracking
  - Existing grade: 50-75 mm

- Granular base (recycled PCC)
  - Existing grade: 0 or 150 mm

- Subgrade
### I-710 Reduction of Full-Depth Pavement Thickness Under Bridges

<table>
<thead>
<tr>
<th>Asphalt Institute 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>
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</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>
Reduction of Air-Voids 8% to 5 %

- Fatigue Life (ESAL)
  - AR4000c (8% av, 5% ac), AR4000c (8% av, 5% ac)
  - AR4000c (5% av, 5% ac), AR4000c (5% av, 5% ac)
  - Traffic Index 15
  - Traffic Index 17

Graph showing the relationship between Total AC thickness (mm) and Fatigue Life (ESAL) with different air-void percentages and traffic indices.
Reduction of Air-Voids 8% to 5%

Initial cost only considered
Rich-Bottom Design

• **Definition**
  – Same mix as middle layer
  – 0 to 3 % air-voids
  – Bitumen content increased 0.5% to facilitate compaction

• **Benefit is from increased compaction, not increased asphalt content**

• **Must be out of zone of rutting risk**
  – More than about 150 mm below surface depending on climate, traffic
Effect of Rich Bottom

- AR4000c (8% av, 5% ac), AR4000c (8% av, 5% ac)
- AR4000c (5% av, 5% ac), AR4000c (5% av, 5% ac)
- AR4000c (5% av, 5% ac), AR4000c (2% av, 5% ac)
- AR4000c (5% av, 5% ac), AR4000c (2% av, 5.5% ac)
Full-depth: Paving 75mm AR-8000 Rich-bottom
HMA Delivery Truck Sinks (get stuck) 3 hrs Suspension
Concrete Crushing Plant (Source of SG Aggregate)
Surface Mix Rutting

- Stiffest mix may not be most rut resistant
  – Especially conventional vs polymer modified

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Asphalt Content</th>
<th>Air-Void Content</th>
<th>G* at 100 repetitions (MPa)</th>
<th>RSST-CH repetitions to 5 % permanent shear strain</th>
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</thead>
<tbody>
<tr>
<td>RAC-G</td>
<td>7.6</td>
<td>13.7</td>
<td>30</td>
<td>120</td>
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<tr>
<td>AR4000</td>
<td>5.1</td>
<td>7.2</td>
<td>79</td>
<td>5,992</td>
</tr>
<tr>
<td>PBA-6a</td>
<td>4.7</td>
<td>3.8</td>
<td>32</td>
<td>1,230,000</td>
</tr>
</tbody>
</table>

Tested at 50 C
HVS Rut Test Results

Temperature = 50 C at 50 mm depth

Rut Depth, mm

HVS Load Applications

38-mm RAC-G
62-mm RAC-G
75-mm AR-4000
76-mm PBA-6A
Unbound Layers Rutting

- Subgrade strain models often control design thickness for very high traffic pavements
  - Extrapolated beyond calibration data
- Probably overly conservative, because
  - Thick AC layers reduce stresses on unbound layers
  - Neglect previous compaction by traffic
- Use stress/strength type relationships
HVS testing, mostly 100 kN wheel loads at 7 km/hr

HVS Load Applications
Total Rut at Top of Aggregate Base mm

- 500/514
- 502/515

150 mm AC initial traffic
225 mm AC traffic on overlay

10
20
30
40
50
60
70
80
90
100
110
120

0
2
4
6
8
10
12

- 2,000,000 4,000,000 6,000,000

HVS Load Applications

- 150 mm AC
- 225 mm AC

Initial traffic
Traffic on overlay
Performance Testing

• Specimen Fabrication
  - Caltrans LLP – AC1 “Sample Preparation Design and Testing for Long Life Hot Mix Asphalt Pavements”
  - AASHTO PP3-94 Rolling Wheel Compaction:
Modified Mix Design - Shear & Fatigue Testing
Modified Mix Design - Hamburg Wheel Tracking for Moisture Sensitivity
2011 Perf Specifications (Red Bluff I-5)
(all with confidence interval in favor of contractor)

• PG64-28PM surface
  – 6 % air-voids
  – RSST-CH (AASHTO T 320) min repetitions

• PG64-16 middle layer with 25% RAP
  – 6 % air-voids
  – RSST-CH (AASHTO T 320) min repetitions
  – Flexural fatigue (AASHTO T 321) min repetitions
  – Flexural stiffness

• PG64-16 rich bottom layer
  – 3 % air-voids, + 0.5 % binder
  – Flexural fatigue (AASHTO T 321) min repetitions
  – Flexural stiffness