Long Life Concrete Pavements (LLCP) –
Consideration of Design & Construction Features

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Presentation Outline

- LLCP Background
- LLCP Requirements
- LLCP Design & Construction Features
  - Thickness
  - Dowels
  - Base Type - lean concrete base typical in CA
  - Smoothness (best practice for constructing smooth pavements)
- Summary/Recommendations
Common PCCP Types (US)

**JPCP**
- 4.3 to 5.5 m joint spacing
- $t = 150$ to 200 mm (streets); 200 to 250 mm (secondary roads); 300 to 350 mm (primary and interstate systems)
- Dowels & stabilized base for medium/heavy volume of truck traffic

**CRCP**
- Steel: 0.65 to 0.80%
- Cracking at 0.8 to 2 m, tight cracks
- Terminal joints at structures
Widened Slab/Tied Shoulder

- **Widened Lane**
  - Slab paved 0.6 m wider than usual
  - Lane striped at normal 3.65 m width
  - Reduces edge and corner stress/deflections

- **Tied cement concrete shoulder**
  - Reduces edge stress/deflections
  - Reduces moisture infiltration
  - Emergency/future traffic lane
PCC P Evolution – A Long Journey

1900’s
Life – 1 season

1920’s
Life – 10+ years (?)

Resulting from improvements in design, construction & material technologies

2004
Life – 30 to 40+ years
LLCP Performance Requirements

- Structural performance
  - Long life - no major distresses
  - Routine M&R only

- Functional performance
  - Safety – no wet weather accidents
  - Smoothness – good ride

- Lower life cycle cost
  - Lower agency costs
  - Lower user operating costs
  - Very few delays & accidents

( Long Life Requires Optimization of Design Features, Construction Techniques & Materials)
Pavement Performance

- Time or Traffic
- Serviceability
  - Deficient
  - Standard D&C
  - Long Life Design & Construction

Threshold Level

Performance Benefit vs. Incremental Cost
Pavement Design Considerations

- Minimize failure conditions & costs

- Understand typical failure mechanisms
  - How does a concrete pavement crack?
  - How does a concrete pavement fault?
  - How does a concrete pavement get rough?
  - Are there other local failure conditions that need to be addressed?

- Understand impact of design features
  - Minimize costs by optimizing design features
How do Concrete Pavements Fail?

Transverse Cracking

Faulting

Smoothness (IRI)

And, localized distresses (spalling) and materials related distresses (ASR, etc.)
**Allowable Distress/Performance**

- At end of service life
  - 40 years for primary system
  - 20+ years for secondary system

<table>
<thead>
<tr>
<th>Distress</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracked Slabs, %</td>
<td>10 - 15</td>
</tr>
<tr>
<td>Faulting, mm</td>
<td>6 – 7</td>
</tr>
<tr>
<td>Smoothness (IRI), m/km</td>
<td>2.5 to 3.0</td>
</tr>
<tr>
<td>Spalling (length, severity)</td>
<td>Minimal?</td>
</tr>
<tr>
<td>Materials Related Distress</td>
<td>None</td>
</tr>
</tbody>
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LLCP Premise

- LLCP is not a “gimmick” or a “Cadillac” design, but a necessity for high volume highways.
- LLCP is a serious on-going effort by DOTs, engineers, contractors, and materials suppliers to design & construct the best concrete pavements for long term service keeping LCC in mind.
- LLCP includes the optimization of all components of design, materials & construction to produce cost-effective long-lasting (40+ years) concrete pavements.
**LLCP - FHWA/DOT LLCP Goals**

- Increased service life - 40 to 60 years
- Lower life cycle cost
- Decreased construction time
- Fewer maintenance closures
- Construction of better initial ride
- Use of efficient construction equipment & procedures (Get in & Get Out AQAP; sustainability)
- Use of improved QA/QC procedures
  - To monitor quality as paving progresses, not days or weeks later
LLCP - Caltrans Directions

- New -- Corridors with 20-year traffic > 150,000 vpd or > 15,000 tpd
- Rehab -- Corridors with current traffic > 150,000 vpd or > 15,000 tpd
  (Rehab policy under review)

- Added initial cost ~ 3 to 5 % ($25K to $50K/lane-mile)
Caltrans Concrete Pavement Policy  
(Highway Design Manual – Chapter 600)

- Structural design
  - Base – stabilized (LCB or ATB) if TI > 10
  - Other bases – free draining ATPB/CTPB or aggregate base
  - No bonding between PCC & LCB
  - PCC thickness = 300 mm (max shown in tables for TI > 14)
  - Tied-concrete shoulder or widened lane with AC shoulder

- Drainage design guidelines

- Cross-section design guidelines

- Pavement selection process guidelines
LLCP Directions - Other DOTs

- MinnDOT -- 60 year design - Jointed (Twin Cities)
  - Durable concrete aggregate (D-cracking concerns)
  - Higher specified air – 8.5 +/- 1.5 % (75% entrained air)
  - 35% GGBF Slag; w/cm < 0.40
  - 1.5 in. diam. stainless steel clad dowels from UK (cost > $12/bar)
  - Slab thickness – 34 mm (vs. standard of 32 mm)
  - Cost: placement - $6/sy; concrete - $75/cy; clad dowels - $12/bar

- Illinois DOT -- 30+ year CRCP (I-70 demo & Chicago area)
  - Higher steel content
  - 33 to 36 mm thickness
  - 150 mm ATB over 300 mm aggregate subbase
  - Durable concrete aggregate (D-cracking concerns)
  - Epoxy-coated steel & tie-bars
LLCP Elements – Structural Design

- **Design features**
  - Thickness
  - Widened lane and/or tied concrete shoulder
  - Joint layout (spacing)
  - Base type & drainage considerations
  - Load transfer mechanism (dowels)

- **Design details**

- **Plans & specifications**
  - Clearly defined requirements
  - Requirements must support design objectives
  - May require supplementary provisional specs

**Eliminate Early Age Distress**
LLCP Elements - Materials

Concrete
- Durable – no MRD; Low shrinkage
- Desired structural properties (f, E, α)

Joint system
- Dowel bars – corrosion resistant
- Sealant – 12 to 15 + years service life; minimize no. of re-sealing (re-facing) intervals

Base/Subbase
- Non-erodible (moisture insensitive system)
- Desired structural properties (f, E, a)

Subgrade
- Need for a “solid” foundation & construction platform
- Protection from swelling & freezing
LLCP Elements - Construction

- Concrete production & delivery
  - Uniform production & consistency
- Concrete placement & consolidation
  - Dowel bar/tie-bar placement
  - Consolidation monitoring
- Concrete finishing, texturing & curing
  - Minimal manual finishing
  - Durable/low-noise texture
- Concrete sawing & sealing
  - Single vs. double cut
  - Longer re-sealing intervals
- QA/QC features - continuous monitoring

Eliminate Early Age Distress
LLCP Structural Design Issues

- Needed improvements
  - Improved understanding of failure modes
    - Cracking, faulting, spalling
  - Optimization of key design features
  - Possible “out-of-the-box” design concepts for LLCP
    -- provide smoother, safer, longer-lasting CP at lower LCC

Implementation time period - Next 10 to 15 years
Critical Loading Positions

Fatigue

- Midslab loading away from transverse joint produces critical edge stresses

Erosion/faulting

- Corner loading produces critical pavement deflections
Load Transfer for LLCP

- Load-transfer is a slab’s ability to transfer part of its load to the adjacent slab
- Poor load transfer leads to:
  - Pumping & Faulting
- Also, need to consider dowel bearing stresses:
  - Dowel looseness over time
  - Dowel size important

\[ \Delta L = x \]
\[ \Delta U = 0 \]

Load Transfer = 0% (Poor)

\[ \Delta L = x \]
\[ \Delta U = x \]

Load Transfer = 100% (Good)

Load transfer (dowels) essential for LLCP

\[ P < \sim 2,500 \text{ lbf} \]
LLCP – Slab Thickness

- Thickness, edge treatment (widened lane/tied shoulder), base type & load transfer at joints are inter-related

- For LLCP, consider
  - Slab thickness > 300 mm (f(truck traffic))
  - Shorter joint spacing ~ 4.5 m works well
  - Widened outside lane and possible tied shoulder
  - Corrosion resistant dowel bars
    - May use 9 (5&4) or 10 (5&5) to reduce cost
  - Stabilized base
LLCP – Load Transfer (Dowels)

- Corrosion resistant dowels a must
  - Stainless steel clad (~$10 to $12)
  - FRP – but effectiveness not proven yet
  - Epoxy coated (low cost option) (~$4 to $5)
- 38 mm diameter minimum for t = or > 300 mm
- Can reduce no. of dowels – middle 2 to 3 dowels not necessary
  - May use 9 (5&4) or 10 (5&5) to reduce cost
- Length = 450 mm
Alternative Dowel Bars
(FHWA, DOTs, Canada, HITEC, etc)

- A number of dowel types are under study
  - Solid stainless steel; stainless steel clad; solid FRP; FRP tubes filled with concrete, elliptical shaped dowels, etc
- How do we extrapolate short-term test results to 40+ year service life?
LLCP - Base

- Non-erodible base if rainfall > ~400 mm/year
- Stabilized base – LCB/CTB or ATB for medium to heavy truck traffic
  - Very high strength LCB/CTB not necessary
- Drainable base – stability more important than high porosity – 150 to 300 m/day permeability fine
- PCC/LCB interface treatment (early age concerns)
  - Bonded/monolithic most effective, but not practical
  - Debonding treatment – 2 coats of curing, asphalt emulsion, 1 in. HMAC, or plastic/geotextile membrane
  - Joint spacing & timing of sawing critical
PCC/LCB Interface Treatment

Plastic Membrane – Indian National highways, 2004

Geotextile – Denver Airport, 2002
LLCP - Smoothness

- PCCP constructed smooth remains smoother
- Measures of smoothness for acceptance
  - IRI - < ~1.2 m/km (How to measure?)
  - PI – zero band
- Smoothness over service life ~ 2 to 3.0 m/km
  - “Low” rate of degradation in ride quality over time
    - IRI increase/year < ~ 0.05 m/km (av. Over 40 years)
Factors Affecting Initial Smoothness

- Base/subbase track-line support
  - Extend Track-line by 1m
  - Stable materials
  - Trim to grade
  - Keep track clean

- Horizontal & vertical alignment
  - String-line management

- Embedded reinforcement and fixtures
Factors Affecting Initial Smoothness Construction Operations

- Avoid stop & go operation
- Maintain uniform speed
  - > 1.5 m/minute
- Maintain uniform head
- Manage/monitor vibration
  - Check for vibrator trails
  - Use Smart Vibrator System
- Maintain steady concrete delivery
Finishing Operations

- Minimal finishing – do not over-finish – pavement does NOT have to be super-smooth
- Longer straight edges produce smoother ride
  - Kansas projects – 5 to 6 m straightedge
- Do not add water to facilitate finishing or texturing
- Finishers have final say on PCCP smoothness
LLCP - Future Directions

- Continue to improve
  - Understanding of pavement behavior
  - Design feature optimization
  - Concrete mixture optimization
  - Construction practices

- Need to perform accelerated structural & durability testing under simulated conditions
  - Cannot wait for 30 years to find out if some innovations will lead to LLCP

- End result – Well-designed & well-constructed PCCP can provide 40 to 50 year low maintenance service life with low life cycle cost!!!
Accelerated Testing/Instrumented Test Highways

<<Accelerated testing to validate design features

Instrumented Test Sections to calibrate/validate analysis models >>
Summary

➢ Future M-E procedures will allow more optimum designs
  o Will address high levels of truck traffic
  o Design life of 40 to 50+ years more reliable
  o Will consider many design features

➢ Also, major materials related improvements and construction innovations are expected in near future

➢ And, instead of “hoping for” long life, we will be designing for long life with 90+% reliability
Thank You!