Top 10 Considerations for Designing, Constructing & Maintaining Long-Life Concrete Pavements

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Presentation Outline

Ø Introductory

Ø Top 3 Design Considerations
  o Focus on Design Features
  o Joint Load Transfer
  o PCCP Support Condition/Drainage

Ø Top 5 Construction Considerations
  o Construction Quality
    § Poor Design/Quality Construction vs. Good Design/Poor Construction
  o Concrete Management – from Plant to Curing
  o Well-developed Specs/End Product Emphasis
  o Contractor Process Control
  o Agency Acceptance Testing
Top 2 M&R Considerations
  - Timely M&R
  - Accelerated M&R (to Minimize Traffic Congestion & Improve Work Zone Safety)
Concrete Pavements
– A Mature Technology in the Year 2013

1900’s
Life - 1 season

1920’s
Life – 10+ years (?)

1960’s
Life – 20+ years

2000 on
Life – 40+ years

Resulting from improvements in design, construction & material technologies
Sustainable & Longer Life Concrete Pavements - Are We There Yet?

Ø Are our concrete pavement practices the best they can be? Are these practices sustainable?
Ø Is there room for improvements?
  o In design, materials, construction practices, M&R
Ø Will it cost more & are the improvements worth the additional effort?
Ø Should we be happy with the status quo?
HOW CAN WE GET THERE?

Simply by Achieving Consistently What We Know is Attainable &

Continue Making Concrete Pavements Cheaper & Sustainable (in terms of overall LCA) by Taking Advantage of New Developments
US Expanded Definition of Long-Life Concrete Pavements

Ø Original PCC surface service life – 40+ years
Ø Pavement will not exhibit premature failures and materials related distress
  o Pavement failure => Result of traffic loading
Ø Pavement will have reduced potential for cracking, faulting & spalling, and
Ø Pavement will maintain desirable ride and surface texture characteristics with minimal intervention activities to correct for ride & texture, for joint resealing, and minor repairs
Current PCCP Hot Topics

Ø Design
  o MEPDG implementation
  o Optimizing design features
  o Composite pavement (PCC$^{(+)}/$PCC$^{(-)}$ for new)
  o Precast pavement (rapid rehab/reconstruction)
  o In with the old – CRCP getting more attention

Ø Materials (major focus: durability & sustainability)
  o Dense (well) graded aggregates (3+ sizes)
  o Less cement use, more SCM (flyash & slag)
  o Two-lift paving (PCC$^{(+)}$/PCC$^{(-)}$)
  o Joint concrete durability (joint rot issue)
Current PCCP Hot Topics

Ø Construction
  o Jointing
    § Single vs. double cut; sealing vs. no-sealing
    § Dowel bar alignment testing & specification
  o Two-lift paving
  o Stringless paving
  o End product specification/PRS
  o Pro-active contractor process control
    § Concrete testing; profile testing

Ø Repair/Rehabilitation
  o Rapid/Accelerated
    § Full closures vs. night/weekend closures
  o Thin concrete overlay use
  o Precast pavement use
Current PCCP Hot Topics

Ø Surface characteristics/user benefits
- Reduce wet weather accidents
- Improve ride
- Reduce pavement/tire noise

Ø Construction management
- Minimize extended lane closures
- Reduce congestion
- Reduce work zone accidents

Ø US FHWA national focus areas
- Recycling
What Are Our Expectations of Our Concrete Pavements?

Ø At end of service life
  o 40+ years for primary system
  o 20+ years for secondary system (??)

<table>
<thead>
<tr>
<th>Distress</th>
<th>Value</th>
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<tr>
<td>Cracked Slabs, %</td>
<td>10 - 15</td>
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<tr>
<td>Faulting, in.</td>
<td>0.25 or less (?)</td>
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<td>(Consider grinding before threshold is reached)</td>
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<tr>
<td>Smoothness (IRI), in./mile</td>
<td>150 to 180</td>
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<tr>
<td>Spalling</td>
<td>Minimal?</td>
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<td>Materials Related Distress</td>
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Top 3 Design Considerations

- Focus on Design Features
- Load Transfer at joints
- PCCP Support Condition/Drainage
1 - Comprehensive Long-Life Concrete Pavement Design

Ø More than just slab thickness
Ø Incorporation of appropriate design features to enhance performance (e.g., improved base, dowel bars, etc.)
Ø Must design pavement as a system
  o Consider interactive effects of all design elements
  o Consider overall cost effectiveness
  o Consider use of locally available & recycled materials
1 - Comprehensive Long-Life Concrete Pavement Design

New Mechanistic-Empirical Pavement Design Guide (MEPDG) allows optimization of many key design features to develop LLCP designs:

- Joint spacing
- Base type (& drainage?)
- Edge support
- Load transfer at joints
- Concrete thickness/strength

End result:

- More cost-effective & reliable designs
- More sustainable designs

No more excuses to make design errors!
1 - Comprehensive Long-Life Concrete Pavement Design

Ø Some simple changes in approach to reduce concrete volume & amount of other materials without compromising performance
  - Reduce slab thickness
    § Improve foundation/base (European approach)
    § Use widened lane & shorter joint spacing
  - Reduce materials
    § Reduce no. of dowel bars (9 or 10 vs. 12 per lane)
    § Reduce joint sealant material (single cut sawing)

Ø Other changes
  - Consider two-lift design & construction to allow use of local/marginal & recycled materials in the lower lift.
2 - Joint Load Transfer —

Ø Joint spacing – Typical practice
  o 15 ft (4.6 m) max for most highway applications
  o Uniform spacing & perpendicular joints

Ø Load transfer (40+ year design)
  o Corrosion protection a must
    § Epoxy-coated (?)
    § Clad bars (steel/zinc)
    § Microcomposite steel (MMFX)
    § Fiber-reinforced polymer (FRP)
2 - Joint Load Transfer

Ø Dowels for truck-loaded highways, typically for:
- Slab t > 8 in or ESALs ≥ 5 million
- Minimum 1.25 in (32 mm) diameter

Ø Round dowels meet needs & are economical

Ø Need to maintain LTE at joints - > 70%

Ø NO NEED FOR MIDDLE 2 to 3 BARS IN EACH LANE
2 - Joint Load Transfer

Ø For corner loading, outer 3 to 4 dowels critical
Ø Dowel size can be adjusted for widened lanes
3 – Support Condition/Drainage

Ø US Approach – Do the best we can?
Ø European approach – Start with a good foundation
Ø We must construct better support – cannot undo poor support in future R&R
Ø Non-erodible base - prevention of pumping
Ø Stiffer support - reduction in slab stresses & deflections; less rolling resistance (MIT study)
Ø Provide stable and uniform construction platform – achieve better concrete surface finish

*Mentality switch – Refer to a base as a base & not as a subbase*
3 – Support Condition/ Drainage Base Type Selection

Ø Provide for needed base-slab friction
Ø Provide for needed frost heave protection
Ø Provide for needed subsurface drainage
Ø Untreated granular (aggregate) bases should be reserved for low traffic
Ø **Stabilized (treated) bases for LLCP (40+ years)**
  o Asphalt-treated/Cement-treated
  o Lean concrete bases (Caltrans use)
  o Permeable bases – treated
3 – Support Condition/Drainage

Pavement Subsurface Drainage

Ø Need to pay more attention
Ø Rapidly remove water from beneath pavement structure
  o Stability vs. porosity: use lower permeability material
    <300 - 500 ft/day (90 - 150 m/day)
Ø Drainable Pavement System
  o Daylighted permeable base
  o Permeable base with edge drainage system
Top 5 Construction Considerations

• Construction Quality
  • Poor Design/Quality Construction vs. Good Design/Poor Construction
• Concrete Management – from plant to joint sawing
• Well-developed Specs/End Product Emphasis
• Contractor Process Control
• Agency Acceptance Testing
4 - Construction Quality?

Ø For construction projects, achieving quality equates to conformance to requirements

  o Requirements need to be well defined, can be measured, and are not arbitrary

Ø Quality must be built into a project. It is not a hit or miss proposition.

- Owner should not expect more than what is specified
- Contractor may not deliver more than what is specified
4 - Construction Quality?

Poor Design/Quality Construction vs. Good Design/Poor Construction

A poorly designed pavement but well constructed will outlast a well designed pavement but poorly constructed

Ray Rollings
Retired, Corps of Engineers
5 – Concrete Management

Typical US Paving Concrete Mixture

Ø Minimum 28-day flexural strength ~ 650 psi
  o Minimum fc ~ 4,000 psi
Ø Maximum w/cm ratio < 0.50 (0.45 freeze areas)
Ø Well-graded aggregates (3+ bins) (Shilstone)
Ø Greener cementitious materials
Ø Advanced admixtures (future of concrete)
5 – Concrete Management

Ideal Paving Concrete Mixture

Ø US vs. European approach (Freeways)
  o US: ~650 psi MR & slab t = 12 to 14 in.
  o European: 750+ psi & slab t = 10 in.

Ø Design for low paste - most concrete durability concerns are due to paste issues
  o Results in better slipform paving & better finishing

Ø 2-lift paving – Top: PCC\(^{(+)}\); Bottom: PCC\(^{(-)}\)
5 – Concrete Management
Cement Reduction for Paving Concrete

Ø Some simple changes to reduce cement use
  o Reduce paste content (most problematic component)
    § Use of optimized gradation & use larger maximum aggregate size
    § Reconsider minimum cementitious materials requirement (current: typically, 540 pcy); consider end product spec
  o Increase use of SCMs (flyash & slag)
    § Results in more durable concrete
    § Efficient use of waste products/by-products
  o Use Greener cements
    § Blended cements (ASTM C595)
    § Performance-based cements (ASTM C1157), including portland limestone cement
    § Non-portland cements – under development
5 – Concrete Management

The Joint Rot Issue

Ø Some joints are deteriorating faster than we would like (Peter Taylor)
Ø Some key findings
  o Paste saturation is a main culprit (f(freeze/thaw))
  o Need better quality concrete – $w/cm < 0.40$ & good in-situ air system & dense concrete & well-draining pavement, especially at the joint
5 – Concrete Management  
From Placement to Curing

Ø Proper consolidation
  o Use of smart vibrator system
  o Check cores for proper consolidation

Ø Minimize tendency to over-finish surface
  o Brings more paste to the surface
  o Surface does not have to be super-smooth

Ø Timely curing
  o A concern on many projects during hot weather

Ø Timely & proper joint sawing
  o Not an issue for transverse sawing, but delay in longitudinal sawing can result in premature cracking
6 – Well-Developed Specs

Construction Specification Objective

Ø To identify and accommodate or minimize variability in the concrete pavement construction process
  o To deliver an end product that is durable
  o To minimize risk of premature failures
  o To minimize owner’s risk of accepting a marginal product
  o To minimize contractor’s risk of rejection of an acceptable product

Good Specs lead to Good Construction!
6 – Well Developed Specs
(End Product Emphasis)

Ø The future is end product specs
  o Need to move away from prescriptive specs

Ø End product specs enable clear definition of critical paving processes. Processes must be:
  o Objectively definable
  o Can be measured
  o Are not arbitrary
5.4 Paving Equipment
The paving equipment shall be capable of placing and consolidating the concrete uniformly across the width of placement. The equipment shall shape the concrete to the specified cross section. Paving equipment shall be fitted with internal vibrators and be equipped with a vibrator monitoring device that indicates the frequency of each installed vibrator. The vibrator mounting shall allow adjustments to the vibrator depth and attitude.
7 – Contractor Process Control

Ø Ideal contractor process control (QC) limits or eliminates placement of marginal concrete & use of marginal construction processes
  o Do not produce concrete if aggregate grad. not met
  o Reject concrete loads if requirements not met
  o Stop paving process if placement (edge slump) or consolidation issues

Ø Process control tests
  o Aggregate gradation & concrete mixture
  o Slab thickness
  o Concrete “slump” & air & density/consolidation
  o Profile (behind paver) & texture
  o Dowel bar alignment
7 – Contractor Process Control

Ø Ideal contractor process control
   o Material is rejected or process is stopped when the testing indicates that end product requirements are not being met
   o Minimizes placement of marginal or non-acceptable concrete

We accept that problems develop during construction, but it cannot be all day long, every day

Contractor must have his process under control!
8 – Agency Acceptance Testing
Determine the Degree of Compliance

Ø Perform sufficient testing to verify marginal materials & construction techniques are not being used
  o Statistically based sample testing best
  o Preferably rapid nondestructive testing

Ø Test for end product metrics (PWL)
  o Slab thickness
  o Concrete strength
  o Concrete durability – air/denseness
  o Smoothness & texture
  o Dowel bar alignment (?)
  o Early age distress

Ideal Testing [✓] Behind paver, not in front of paver
Top 2 M&R Considerations

- **Timely Maintenance & CPR**
- **Accelerated M&R**
  - Minimize Lane Closures & Traffic Congestion
  - Improve Work Zone Safety
M&R Overview

Ø We expect that current & future new concrete pavements will provide a low maintenance service life.

Ø However, we still have to manage concrete pavements constructed more than 20 years ago & designed for ~20+ years. Many of these pavements have been in place for 40+ years.

Ø With timely M&R strategies, we can continue to extend the service life of many of these older concrete pavements without resorting to “fracturing” & reconstruction.

  o Economical & sustainability benefits
9 – Timely M&CPR
Extend service Life of Existing Pavements

Ø With minimal effort and lower costs, we can extend service life of most concrete pavements without fracturing, resurfacing & reconstruction

Ø Well-performing CPR techniques are available – to maintain ride/texture/structural capacity
  o FDR, DBR, grinding, concrete shoulder retrofit
  o Joint resealing? – topic of debate

Ø But, M&CPR must be done in a timely manner & done well (NO MORE FIXING THE FIX)
10 – Accelerated M&R Technologies
Minimize Lane Closures & Traffic Congestion & Improve Work Zone Safety

Ø Take advantage of advances in repair materials
  o Rapid set concretes (cementitious binder)
  o Polymer-based materials
  o Other

Ø Consider precast pavement for full-depth repairs & rehabilitation
  o Production use by NYSDOT, NJDOT, Illinois Tollway, Caltrans
  o Cost effective & longer-lasting
Repair Applications
NJ I-295 (Fort Miller System)
Repair Applications

Illinois Tollway – Chicago Area
(Generic Narrow-Mouth Slot system)
CA I-680 Precast Prestressed System
Up to 36 ft long panels over new RSLCB, 2011
Achieving LLCP (40+ years)

Many Small Steps => Big Gains (LLCPs)
One Small Misstep => Premature Failure (PPCPs)

Ø Optimizing long-life pavement designs
   o Thickness reduction; fewer dowel bars
   o Single cut joints; better bases/foundation

Ø Managing the construction processes & materials

Ø Effectively extending service life of existing pavements by timely M&CPR