Long-Life Concrete Pavement

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Topics Addressed in Presentation

• Long-life Pavement Perspective
• History
• High-Performance Concrete Pavement
• Improvements
  • Joint Design
  • Thickness?
  • Materials
What do you consider to be long life pavement?

- 0-10 yrs.
- 11-20 yrs.
- 21-30 yrs.
- 31-40 yrs.
- 41-50 yrs.
- 51-60 yrs.
- 61+ yrs.
How do you measure pavement life?

- Time to 1st Rehab.
- Time to Reconstruction
- Time to Threshold IRI
- Time to Threshold PSI
- No. of Trucks
- No. Loads to 50% cracking
How much extra should we pay to get long pavement life?

- 0%
- 5%
- 10%
- 15%
- 20%
- 25%
- 30%
- 35% +
What is important to getting long pavement life?

- Roadbed or Grade
- Thickness Design
- Joint Design
- Concrete Materials
- Specifications
- Construction Quality
Long-Life Pavement Perspective...

What has to be done differently to meet your desires for longer pavement life, according to your requirements?
Where do you start?

- Design
- Materials
- Construction

- Performance
- Current Needs
- Future Expectations

NO SACRED COWS
Everything goes on the table…
Basic Elements of a Modern Concrete Pavement

- Longitudinal joint
- Transverse joint
- Subgrade
- Surface texture (smoothness or rideability)
- Thickness design
- Concrete materials
- Dowel bars
- Tiebars
- Subbase or base
- Drainage
Where to make biggest improvements?

- Concrete Durability
  - Paste
  - Aggregates

- Joints
  - Dimensions
  - Dowels

- Subgrade/Subbase

- Specifications
  - Process Control not Strength-Based

WHY NOT THICKNESS???????
Long-Life Concrete Pavement

Aren’t we really talking about High-Performance Concrete Pavement?
Early Highway Pavements

Front Street, Chicago
   Built in 1905, Lasted 60 years

Woodward Ave, Detroit
   Built in 1909,
   First mile of PCC
Pine Bluff, Ark
- Built in 1913
- 24 miles long, 5” thick
- Referred to as the “Dollarway”
- Motorists would travel great distances to be able to drive up to 45 mph
- It’s preserved in a rest area along U.S. 6
The “First” Highway Bill

- In 1916 the Federal Highway Act was enacted
  - Lobbied by bicyclists organization “Wheelman of America”
- In 1916, there were 10,000 autos in the U.S.
- Some concrete roads built under the act are still in service
Average versus Outstanding

Median

99th Percentile
1956 Interstate Highway Act

- A 41,000 mile interconnected network of limited access highways. The majority of interstate highways were constructed in the 1960’s and 70’s.
- Many concrete roads built under the act are still in service
Comparative Performance Studies
Overview

Selected highway corridors (interstate era):

- I-40 in Western Tennessee
- I-15 in Utah, South of Salt Lake City
- I-40 in Eastern Oklahoma
Survival Analysis Results - I-40 in TN

Percent in Service

- 25%
- 50%
- 75%
- Mean Life

Age

Percent in Service

JPCP
ACP
Survival Analysis Results - I-15 in UT

Note: Over 50% of Concrete Sections Have Not Failed (>32 Years)
Survival Analysis Results - I-40 in OK

Note: Over 50% of Concrete Sections Have Not Failed (>30 Years)
Long-Life Concrete Pavements

- Do not necessarily require elements of high-performance concrete pavement (HPCP)
- Would benefit from HPCP techniques
  - Narrow the variability of performance
  - Address key elements
- May include improvements HPCP cases have not considered
High-Performance Concrete Pavement

- **Goal of HPCP Program per FHWA**
  - Explore applicability of design and construction innovations to provide long-lasting, economical PCC pavements

- HPCP program is not “high strength” concrete

- HPCP is the combination of: materials, mix design, structural design, and construction activities...
  - to ensure long-term pavement performance in a specific application
HPCP Projects

- Twenty three (23) projects in 13 States
- Range of design features and construction innovations
  - Alternate Dowel Bars
  - Durable Concrete Mixes
  - Improved Materials (including fiber-reinforced PCC)
  - Optimized Surface Textures
  - Joint Sealing Variations
Long-Life Pavements

Joint Design Improvements
Alternate Dowel Bars

- Iowa
- Illinois
- Wisconsin
- Ohio
- Kansas
Dowel Bar Corrosion
Alternate Dowel Bars

- **Materials**
  - Fiber-Reinforced Composite (FRC)
  - Grout-filled FRC
  - Stainless Steel
  - Stainless Steel Clad
  - Grout-filled Stainless Steel tubes
  - MMFX Steel

- **Elliptical Shapes**
Alternate Dowel Bars
Alternate Dowel Bars
Long-Life Pavements

Thickness Design?
Empirical Design

- Early pavement design methods were empirical and based on the results of various road tests
  - Bates Road Test
  - Maryland Road Test
  - AASHO Road Test
  - Others
First Design Equations

- In 1926, Prof. Westergaard, University of Illinois published equations for stresses and deflections of concrete pavement.
- To test Westergaard’s equation, the Bureau of Public Roads (forerunner of FHWA) conducted four years of testing and published a very complete report on the “Structural Design of Concrete Pavements”.

\[
d = \sqrt{\frac{cp}{s}}
\]

- \(d\) = thickness
- \(c\) = stress coefficient
- \(p\) = wheel load
- \(s\) = allowable tensile stress
AASHO Road Test - Extended Design Equation

- Developed mechanistic-empirical relationship between Log W and stress ratio.

\[
\text{Log}(W) = A + B \text{ Log } \frac{S'c}{\sigma}
\]

- \(W\) = Number of axle loads to terminal serviceability
  (from main loop equation)
- \(A\) = Regression constant
- \(B\) = Slope of Log W vs. Log \(\frac{S'c}{\sigma}\) curve
- \(S'c\) = 28-day flexural strength, 3rd point loading
- \(\sigma\) = Spangler’s corner stress
Log(ESALs) = \( Z_R \cdot s_o + 7.35 \cdot \log(D+1) - 0.06 \) + 
\[ \Delta \text{PSI} \]
\[ \frac{4.5 - 1.5}{1 + \frac{1.624 \cdot 10^7}{(D + 1)^{8.46}}} \]
+ (4.22 - 0.32p_t) \log \left( \frac{S'_c \cdot C_d \cdot \left[D^{0.75} - 1.132\right]}{215.63 \cdot J \cdot \left[D^{0.75} - \frac{18.42}{(E_c / k)^{0.25}}\right]} \right)
Current AASHTO vs. 2002 Design

AASHTO Design Guide

AASHO Road Test

- Wide range of structural/rehab designs
- 50+ million loads

- Limited structural sections
- 1.1 million load reps

- 1 climate/2 years
- 1 set of materials

- All climates over 20-40 years
- New & diverse materials

- design
- traffic
- climate
- materials
Thickness Design Impact?

- Mechanistic-empirical design
  - Offers a more scientific and potentially “reasonable” approach
- To implement AASHTO 2002 successfully
  - Must calibrate
  - Must develop realistic inputs
  - Must have working knowledge of mechanistic-empirical design fundamentals
- But... do not expect large changes in required thicknesses
  - Could even go down for long-life timeframes
Long-Life Pavements

Concrete Materials
Paste Durability – Minnesota Case

- Required Maximum 28 day Rapid Chloride Permeability to be 2500 coulombs
- Increased Target Plastic Air Content from 6.5% to 8.5% (+ 1.5%)
- Require max W/C = 0.40 (same as current)
- Use Poly-alpha-methylstylene curing compound
Rapid Chloride Permeability Results of HPC Mixes
(w/c = 0.365, sample @ 28 days)

All fly ash 25% replacement, GGBFS 35%
Aggregate Durability – Minnesota Case

- Maximum of 20% limestone in gravel, with incentives to reduce to 10%
- Incentives to use Class A aggregate (quarried igneous, metamorphic)
- Well graded aggregate required
  - reduce paste, improve workability
  - 8 to 18 specification.
Aggregate Selection

- Watch for Water Demand
  - Fine aggregate gradation
  - Combined aggregate gradation
  - Cement content (+400 lb)
  - Supplementary Materials

ASTM C33 requirements are not always favorable
ASTM C33?

Grading distribution of sand allowed by some states, but does not meet ASTM C-33 limits --- Results in a mixture prone to early problems.
ASTM C33?

Grading distribution of sand with high bulking volume that meets ASTM C-33 ---
Results in a mixture prone to early problems
Grading distribution of well-graded sand that meets ASTM C-33 --- Results in mixture with little potential to contribute problems
1. Coarseness Factor = \( \frac{\% \text{ RETAINED ABOVE } 3/8 \text{ in. (9.5 mm) SIEVE}}{\% \text{ RETAINED ABOVE } \#8 (2.36 \text{ mm) SIEVE}} \times 100 \)

2. Workability Factor = \( \frac{\% \text{ PASSING } \#8 (2.36 \text{ mm) SIEVE}}{\% \text{ RETAINED ABOVE } \#8 (2.36 \text{ mm) SIEVE}} \times 100 \)
Long-Life Pavements

Kansas Demo Project
HPCP – Kansas Demo Project

- Alternative Dowel Materials and spacing,
  - Fiber reinforced and stainless steel dowel bars, Cross Flex

- New mix designs
  - Ground Granulated Blast Furnace Slag (GGBSF)
  - Recycled asphalt

- Joint sawing and sealing options

- Longitudinal Tining

- Curing

- Two lift construction
Kansas HPCP Demonstration

Fiber Reinforced Polymer Dowels
Kansas HPCP Demonstration

Cross-Flex

Not a Good Idea
Kansas HPCP Demonstration

- Soft-cut
- Magnum
- Other sections were Seal / No Seal
- Target
Kansas HPCP Demonstration

Fiber Reinforced Concrete
3M Polyolefin Fibers
Kansas HPCP Demonstration

Two lift construction
With RAP
Kansas HPCP Demonstration

Two lift construction
With High Absorption
Limestone
How long will Kansas HPCP last?

- Looking for 30-50 years.
- Pavement life is measured in terms of vehicle loading as well as time.
  - If subjected to a higher (or heavier) traffic than designed for, the service life will probably be shorter than expected.
Summary

• Long-life has different meanings
• Getting there requires improving design, materials and construction
• Lessons from HPCP work are of value
• Concrete is the long-life pavement
Industry Perspective

Make the Goal of Long-Life Pavement:

- Structurally superior pavement
- Environmentally sound pavement
- Safer and quieter pavement
- Smoother pavement
- Cost-optimized pavement
Additional Information

- Contact ACPA
- Phone: 847-966-2272
- www.pavement.com

THANK YOU!