ICPA Seminar on Concrete Pavements Best Practices & New Technical DNV Specifications
Buenos Aires, November 23, 2017

Evolution of Concrete Pavements in the United States



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Some Words of Engineering Wisdom

- *The Romans knew how to build long-lasting roads (example of the Appian Way always cited)*

- ***Yes and No!*** *They designed for 5,000 wagon loads/year, each wagon weighing about 1,000 libras (3 libra = 1 kg)*

Some Words of Engineering Wisdom

We are designing for millions of heavy 16-wheeler truck loadings/year for our roads and for airport pavements carrying aircrafts weighing 100's of thousands of kilograms

Challenges for Pavement Engineers - 1

- In the US, managing a heavily used pavement infrastructure system – primarily upgrading and rehabilitating pavements under traffic

Challenges for Pavement Engineers - 2

- Ensuring what we do as engineers and technologists leads to sustainable choices – *meeting the needs of the present without compromising the ability of future generations to meet their own needs*

Optimize use of construction technology thru sound design and construction practices to preserve resources and minimize damage to the environment while making acceptable economical decisions

What Are Our Pavement Expectations?

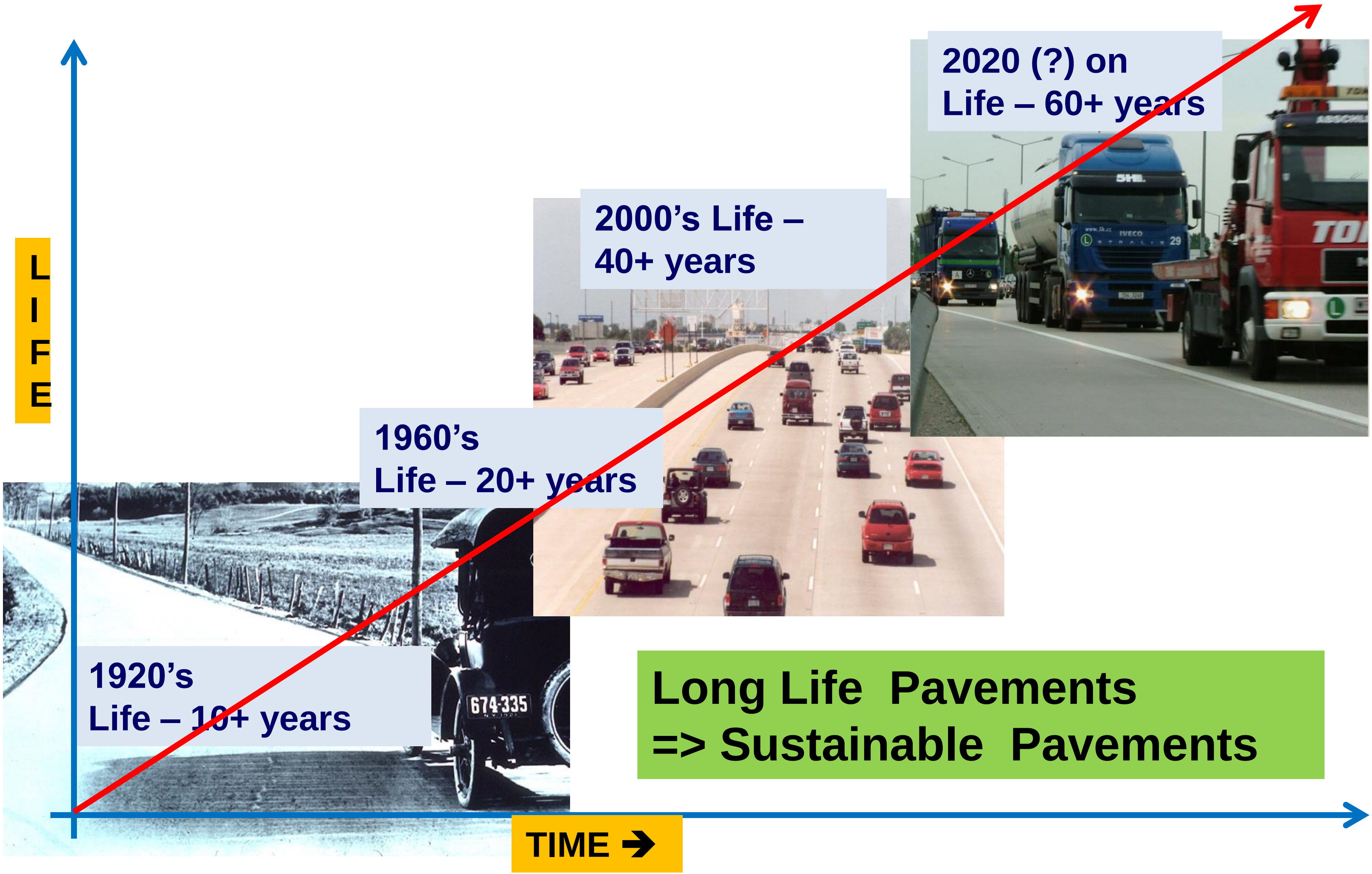
- Long life with low maintenance
  - US: 40+ years
  - Argentina: 20 years?
- Cost competitive – initial & long term
- **Sustainable**
  - Use of more recycled and local materials
- ***User friendly***
  - Safe (zero wet weather accidents!)
  - Comfortable (smooth) ride
  - Low pavement-tire noise

Presentation Outline

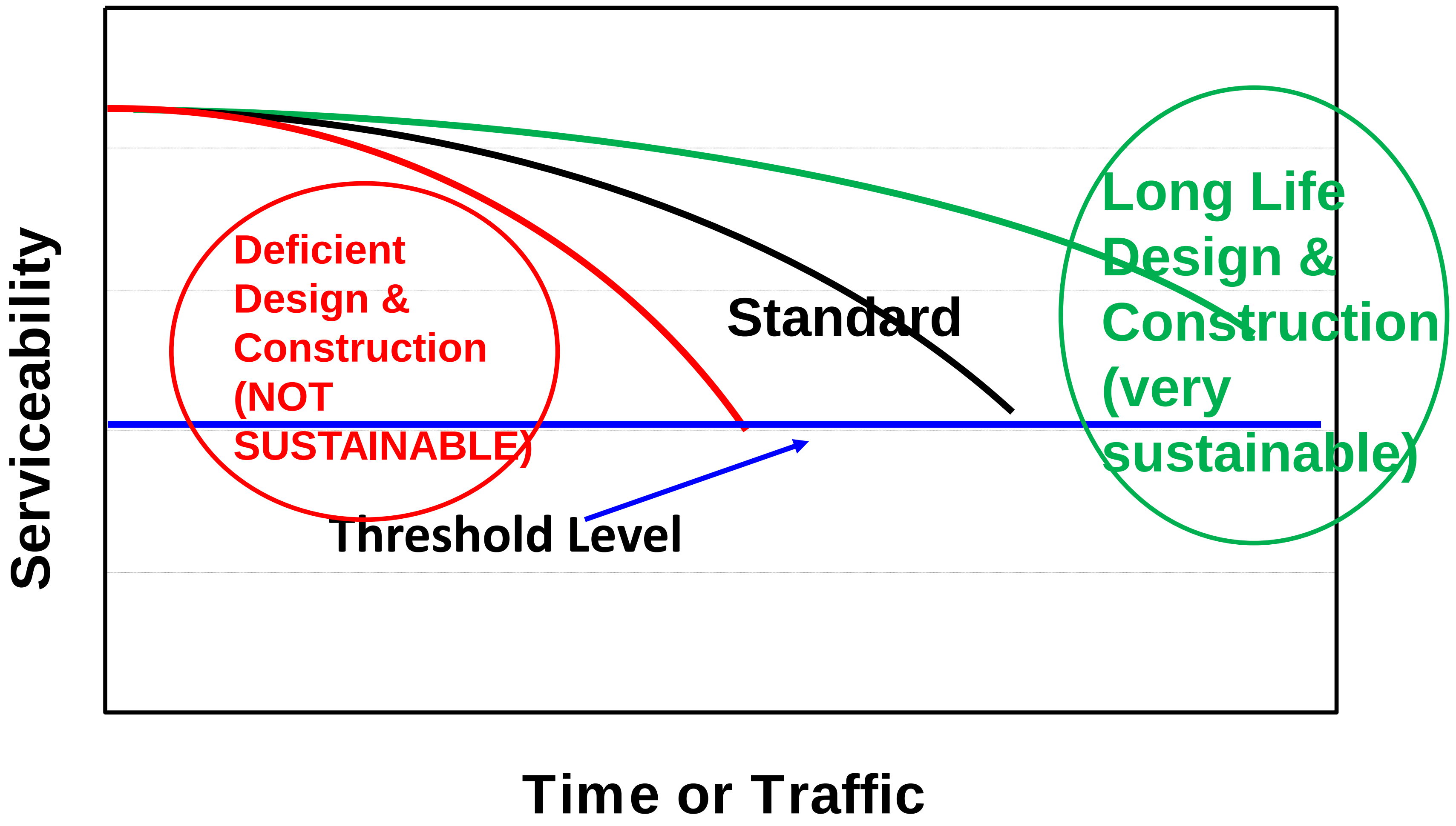
- Introduction
- Historical developments
  - Early developments
  - State of technology – 1975/1980
  - Developments since 1990
  - Florida Test Road (2018 construction)
- Current Practices
  - Design Considerations
  - Construction Considerations
  - MR&R Considerations
  - Sustainability Considerations
  - User Considerations
  - Cost Considerations

Concrete Pavement Evolution - USA

A Mature technology in the Year 2017



Pavement Performance Expectation



Concrete Pavement Evolution - USA – A Long Journey

Conventional cast-in-place concrete pavements – Over 125 years old & we are still trying to make them better

Concrete Pavement Evolution – Another Long Journey?

During June 2017, a replicate strip was constructed at the location of the 1891 test strip in Bellefontaine. <u>Will it last over a 100 years?</u>

Achieving Long Life

- Long-life concrete pavements have been attainable for a long time in the US
  - Many pavements are still in place after 40+ years of service under heavy traffic

August 2017
Caltrans (California) marks <u>70-year</u> anniversary of I-10 concrete pavement section near Los Angeles
(270,000 vpd)

Achieving Long Life

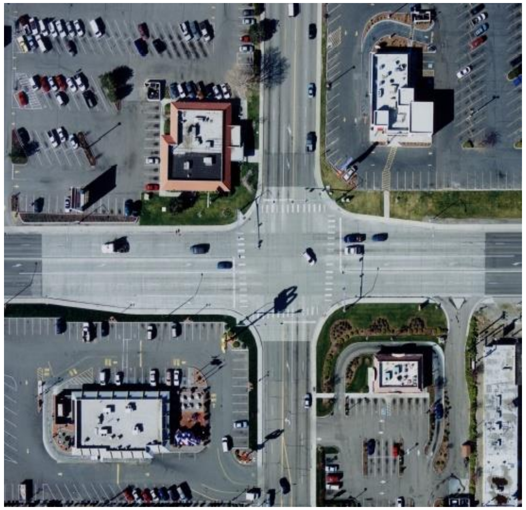
- As indicated, long-life concrete pavements have been attainable
- However, there is a need to obtain long-life **consistently** by ensuring:
  - Good pavement designs
    - Structural - to carry truck traffic
    - Drainage - to remove excess moisture
  - Use of durable materials (concrete, base)
  - Quality construction
  - And, timely corrective treatments

US Technology Evolution from about 1975/1980 to Today

How Did We Arrive at This Point in Concrete Pavement Technology?
(From ~20 year designs to 40+ years designs)

US Concrete Pavement Applications

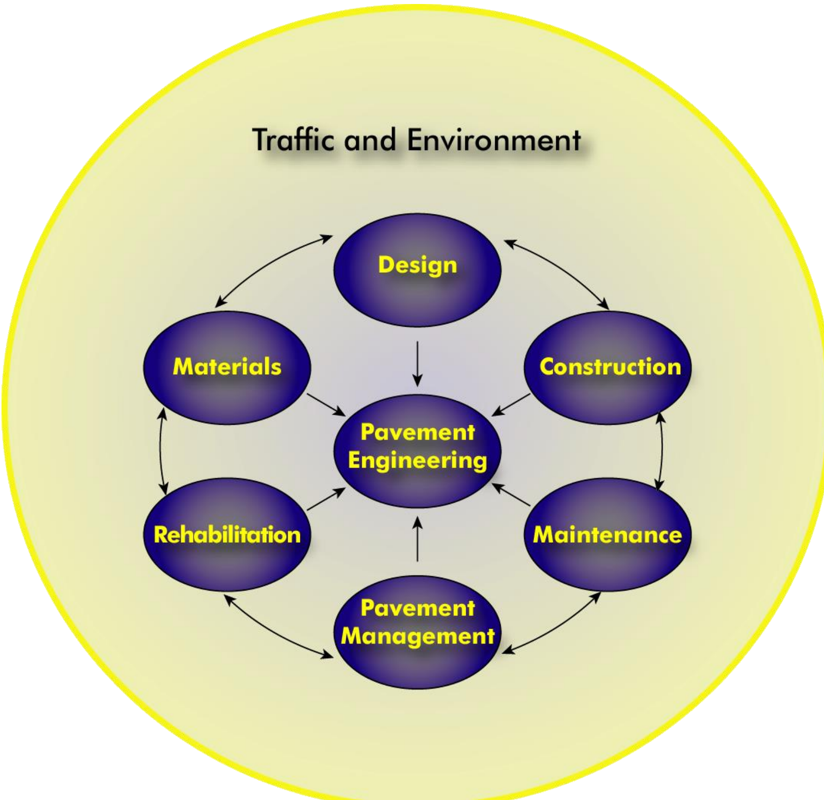
A wide range of applications



US Concrete Pavement Use

- Pavement of choice for high volume truck traffic and urban areas where <u>long-life pavements</u> are necessary
- Widely used for airport runways/taxiways/aprons
- Widely used for city streets and parking lots
- RCC pavements becoming popular for off-highway applications, streets, and retrofit shoulders
- Also, permeable (pervious) pavement use increasing in urban areas
- When pavement selection is done on basis of life-cycle cost analysis, concrete pavements are typically cheaper

Concrete Pavement Technology Evolution
– A Century of Progress – Quest for Long Life



- Mechanistic Analysis – improving understanding of pavement behavior
- Field investigations/Test Roads (MnRoad, etc.), LTPP
- Improving Concrete
- Improving Base Materials
- Improving Construction Processes
- Improving Testing Processes
    - NDT/Accelerated Testing
- Incorporating Sustainability Considerations

US State of Technology – 1910's to 1960's - Jointed Concrete Pavements

- Advances in
  - Pavement analysis – understanding the behavior of concrete pavements
  - Early road tests
  - AASHO Road Test (1958-1960)
  - Concrete materials improvements
  - Began to use design features – joints, load transfer, base/subbase

Early Road Test (1921)

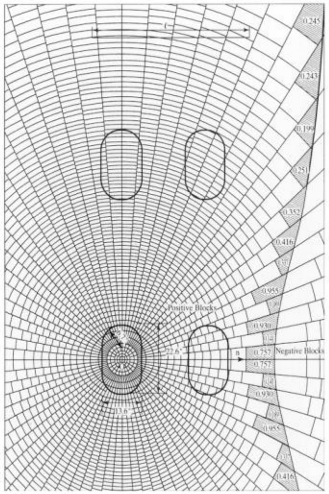


FIGURE 4.12
Application of influence chart for determining moment (1 in. = 25.4 mm)
(After Pickett and Ray (1951).)

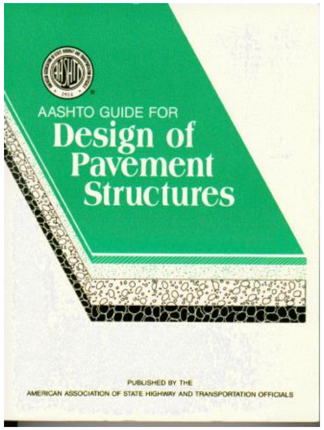
AASHO Road Test (1958-1960

US State of Technology – 1975/1980
- Jointed Concrete Pavements

- US just completing the 65,000 km Interstate Highway System – early 1960's to mid-1970's
- Designs based on the findings from the AASHO Road Test & new AASHO Pavement Design Procedure
- PCA design procedure under development (1984)

US State of Technology – 1975/1980
- Jointed Concrete Pavements

- Structural designs (for freeways with truck traffic)
  - Design period – 20 years
  - Thickness – 200 to 250 mm
  - Jointing
    - Joint spacing – 4.65 t0 6 m
    - Dowel bars at 300 mm spacing
    - Width – 3.65 m



- Shoulder – AC or granular
- Base/subbase – Granular, CTB and ATB
- Drainage provisions – not actively considered
- Surface texture – Transverse tining
- Smoothness requirement – yes, but no penalty

US State of Technology – 1975/1980
- Jointed Concrete Pavements

- Concrete
  - Type I and II cements only; little use of supplementary cementitious materials
  - Coarse & fine aggregates only (~65%/35% ratio)
  - Basic admixtures (AEA, WRA)
  - 28-day flexural strength ~ 4 Mpa
  - Aggregate durability testing – not much

- Construction
  - Slipform paving
  - Dowels placed using baskets

US State of Technology – 1975/1980 - Limitations

- First the traffic
  - We had seriously **underestimated the truck traffic** during the interstate highway construction (1960’s)
  - The 20 year truck traffic was achieved within 6 to 10 years on many projects
- Under-designs (less thickness, poor drainage) led to poor performance, requiring pavement repairs & rehabilitation within 15 to 20 years
  - **Pumping was a major distress due to erodible and poor draining bases**
- Also, need for better surface texture and smoother surface was recognized for high speed traffic

US State of Technology
- Performance & Directions after 1990

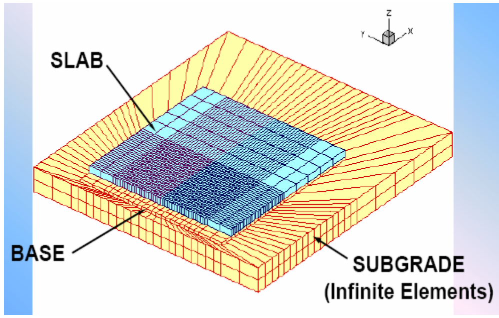
- We started addressing the poor erodible base/drainage/pumping/joint faulting issues
  - In the past, we **wrongly compensated for poor base/drainage by increasing slab thickness**
  - During early 1990's, we started using **open-graded base** layers (typically, asphalt-treated) with high porosity but low stability and **we did not have good experience**
- Now, we are using stabilized bases (AC or cement-treated) and free-draining bases (low fines) and dowel bars at joints for medium to heavy truck traffic

1990's to Present

(Focus on Rehabilitation & Reconstruction)

- Accounting for heavier vehicle loadings over longer period (40 years)
  - Highway truck loadings
  - Heavier aircraft loadings

- Advances in analysis in design
  - 3-D finite element analysis
  - Mechanistic-Empirical pavement designs
  - Advances in concrete materials
  - Advances in construction equipment
  - Advances in repair & rehab technologies

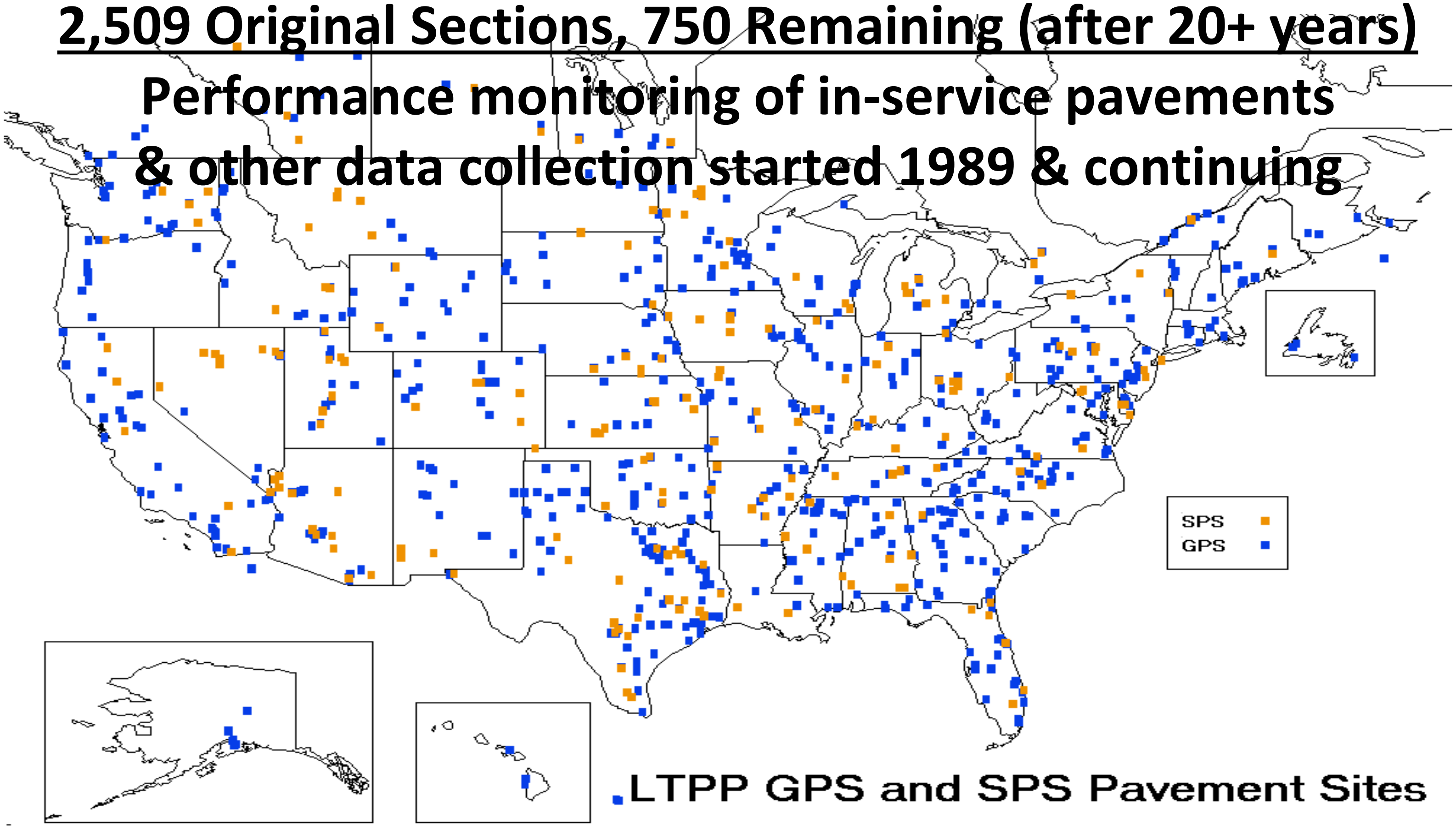


- The US Long Life Pavement Performance Program

US Long Term Pavement Performance Program to Support Improved Pavement Design & Construction Practices (1988 to present)

2,509 Original Sections, 750 Remaining (after 20+ years)

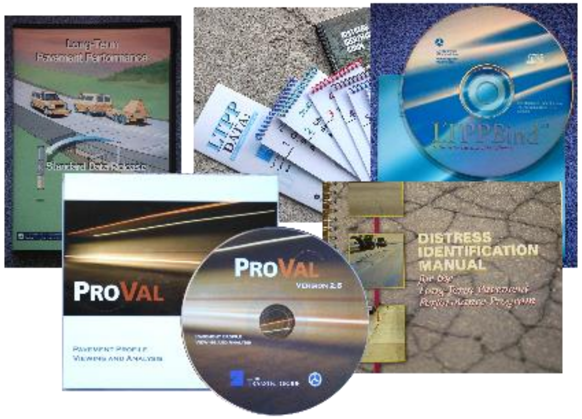
Performance monitoring of in-service pavements & other data collection started 1989 & continuing



Data from the test sections used to develop the US ME pavement design guide for concrete & asphalt pavements (1999 to 2005)

LTPP Products In Use

- Comprehensive construction & performance database on over 2,500 test sections throughout US & Canada
  - Database available online (DATAPAVE) & used for MEPDG development
- Standardized Pavement Distress Identification Manual
- Standardized pavement testing (Deflection Testing (FWD), smoothness measurement) procedures
- & many topic specific studies related to understanding pavement behavior & improving pavement performance



Minnesota Test Road (MnRoad) Opened in 1994 & continuing

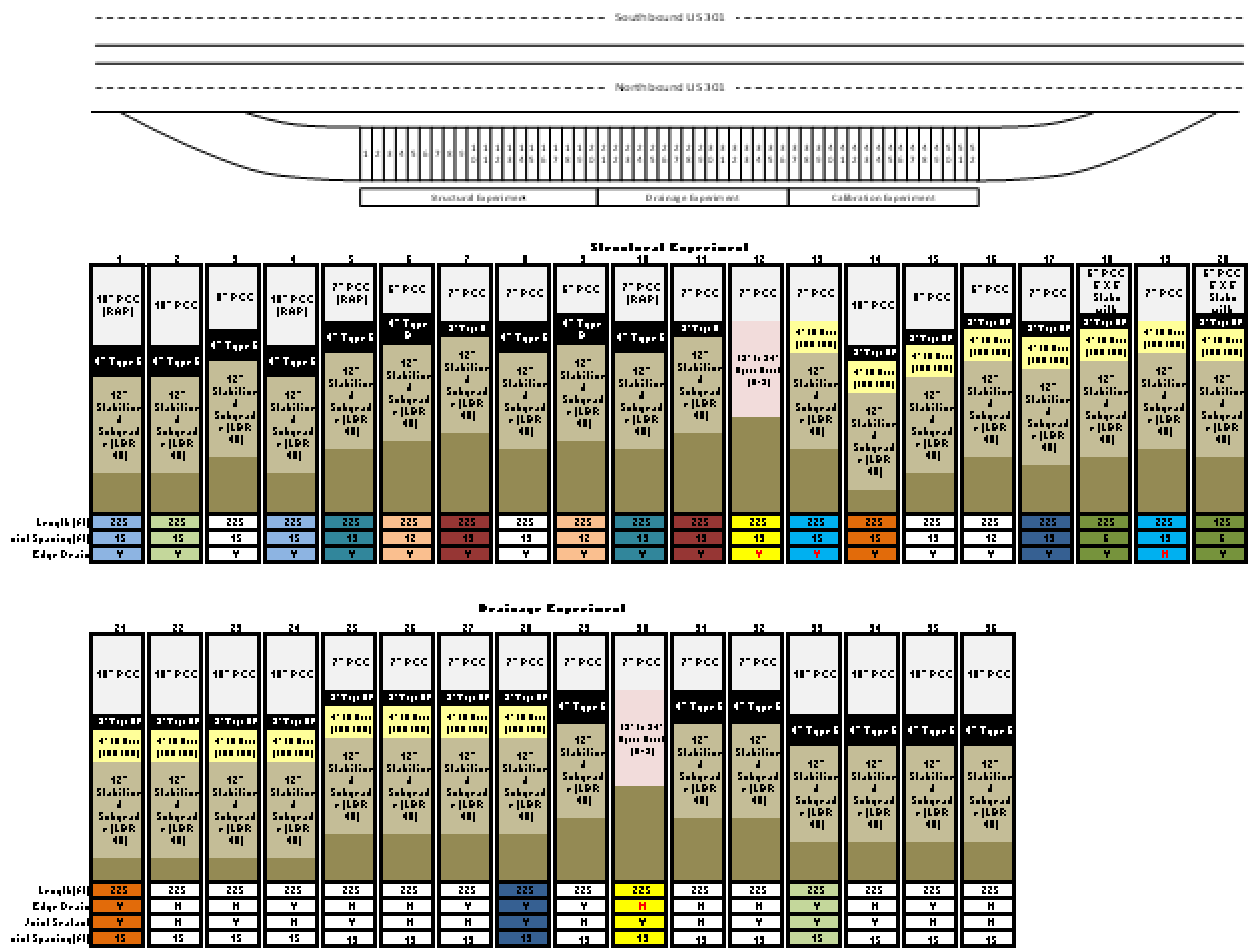
- ➢ In-service test sections to evaluate performance of concrete and asphalt pavements
- ➢ Findings used to improve concrete pavement design details and construction practices
  - ➢ Now, thin concrete overlay test sections

CL3, CL4, or CL5 = Class 3, 4, or 5 base material

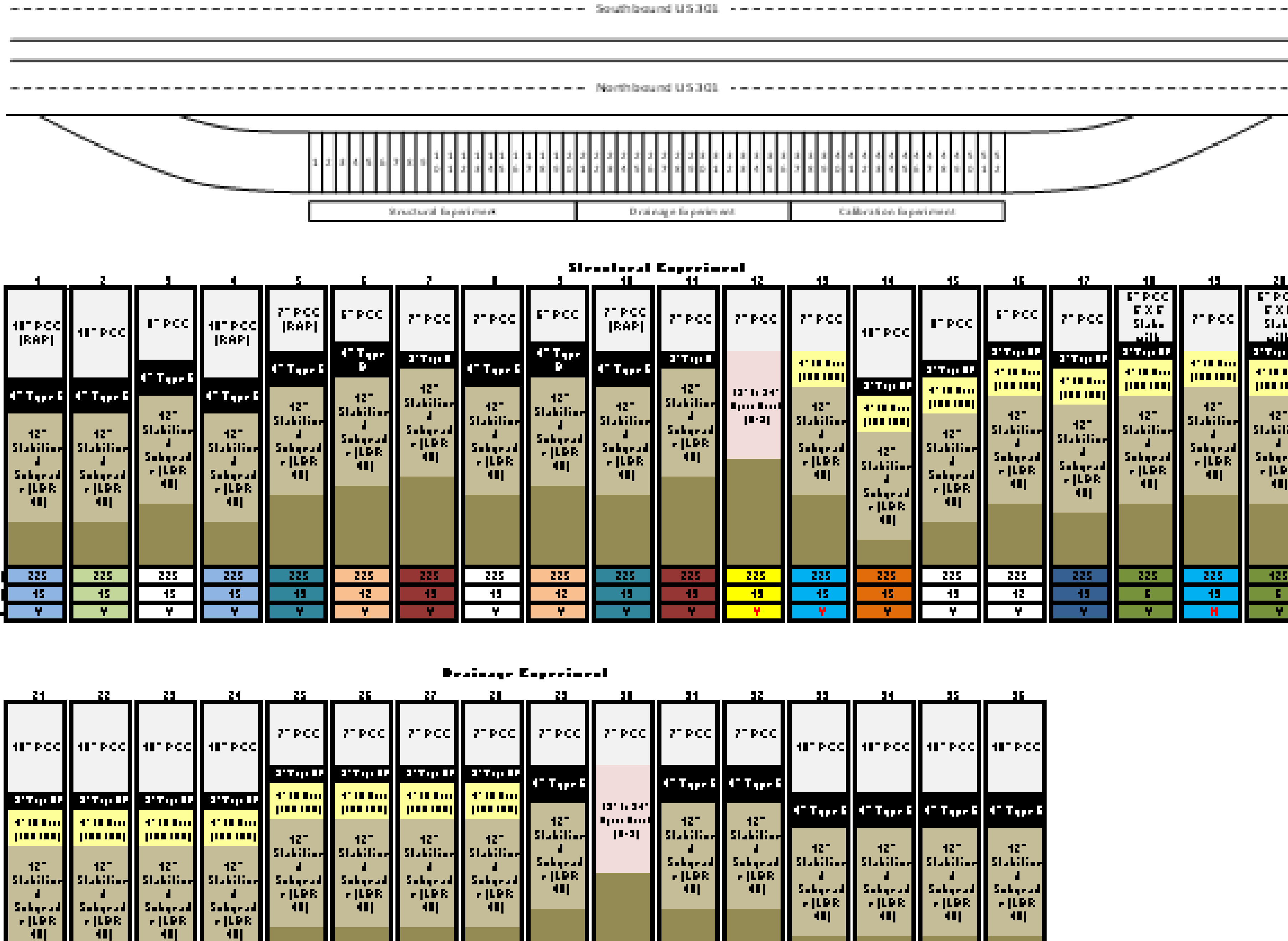
Florida Concrete Test Road (US 301)
Construction Planned for 2018

In-service test sections to evaluate performance of concrete pavements (4 km, two lanes)

Evaluate different design features & calibrate MEPDG design procedure for use in Florida



Florida Concrete Test Road (US 301)



Current US Definition of Long-Life Concrete Pavements

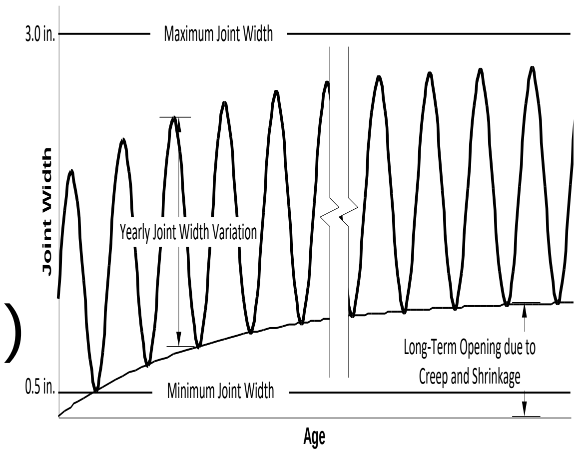
- Original PCC surface service life – 40+ years
  - **The next frontier – 60+ years service life**
- Pavement will not exhibit premature failures and materials related distress
  - **Pavement failure should be a result of traffic loading**
- Pavement will have reduced potential for cracking, faulting & spalling, and
- Pavement will maintain desirable ride and surface texture characteristics with minimal intervention activities to correct for ride & texture, for joint resealing, and minor repairs

Long-Life Concrete Pavements are Sustainable Pavements

Concrete Pavement Design Targets

The Challenge!

- Pavements need to accommodate
  - 40 to 60+ annual seasonal changes
  - 15,000 to 20,000 daily temperature variations in the concrete slab (curling)
    - And, joint openings/closings
  - 100 to 200 million truck loadings
  - 200 to 200 million axle loadings at joints
  - And, little or no maintenance & restoration activities
- And, hopefully do all this sustainably!



How Do We Get Longer Life?
(From ~20 years to 40+ years)

- Designing longer life concrete pavements (40+ years)
  - By optimizing pavement design
    - Reduce slab cracking by reducing stresses
    - Reduce joint faulting by reducing deflections
      - By maintaining higher level of load transfer at joints
      - By using better support under the slab
- Eliminating risk of early age failures
  - Improve construction process control
  - Use durable concrete
- Provide durable concrete surface characteristics
  - Longer lasting surface texture (for user safety)
  - A smoother riding surface that remains smooth (for user comfort)

US State of Technology – 1975/1980 versus Today - Jointed Concrete Pavements

- Structural designs (for freeways with truck traffic)
  - Design period – ~~20~~ **40** years (using ASSHTO MEPDG)
  - Thickness – ~~200 to 250~~ **250 to 300** mm
  - Jointing
    - Joint spacing – 4.65 t0 6 m **(4.65 m)**
    - Dowel bars at 300 mm spacing **(But at wheel paths only)**
    - Width – 3.65 m
- Shoulder – AC or granular **(widened lane & PCC)**
- Base/subbase – Granular, CTB and ATB
- Drainage provisions – **actively** considered
- Surface texture – ~~Transverse~~ **longitudinal tining**
- Smoothness requirement – yes, **but WITH penalty**

US State of Technology – 1975/1980 versus Today - Jointed Concrete Pavements

- Concrete
  - Type I and II cements only; **always use of supplementary cementitious materials (flyash, slag)**
  - **Coarse & intermediate & fine aggregates** well-graded aggregates)
  - Basic admixtures (AEA, WRA, **and other**)
  - 28-day flexural strength ~ **4.5 to 5** Mpa
  - Aggregate durability testing – **always (ASR, etc)**
- Construction
  - Slipform paving
  - Dowels placed using baskets & inserters

US State of Technology – 1975/1980 versus Today

- Traffic considerations
  - Active use of truck weighing stations along all major highways
  - Serious penalty for over-loading
  - Use Weigh-in-Motion (WIM)
  - Development of better traffic forecasting models

Current Efforts to Continue to Improve Concrete Pavement Practices

- Design
  - MEPDG implementation by most US DOTs
  - Optimizing design features
  - Composite pavement ($PCC^{(+)}/PCC^{(-)}$)
  - Precast pavement (rapid rehab/reconstruction)
- Concrete (major focus: durability & sustainability)
  - Dense (well) graded aggregates (3+ sizes)
  - Less cement use, more SCM (flyash & slag)
  - Two-lift paving ($PCC^{(+)}/PCC^{(-)}$)
  - Internally cured concrete

Current Efforts to Continue to Improve Concrete Pavement Practices

- Construction
  - Jointing
  - Two-lift paving
  - Stringless paving
  - End product specification (PRS)
  - Pro-active contractor process control
    - Concrete testing; profile testing
- Repair/Rehabilitation
  - Rapid/Accelerated
    - Full closures vs. night/weekend closures
  - Thin concrete overlay use
  - Precast pavement use (ramps, bus lanes, intersections)

Current Efforts to Continue to Improve Concrete Pavement Practices

- Surface characteristics/user benefits
  - Reduce wet weather accidents
  - Improve ride (longer lasting smoother surface)
  - Reduce pavement/tire noise
- Construction management
  - Minimize extended lane closures
  - Reduce congestion
  - Reduce work zone accidents

What Are Our Expectations of Our Concrete Pavements?
(At end of initial service life (40+ years))

Distress	New	In-Service
Cracked slab panels	0%	10 – 15 % (20 to 30/km)
Joint step faulting, mm	0	**6 to 8**
Joint & crack spalling	0	Minimal
Smoothness (IRI), m/km	**1.0 to 1.5**	2.5 to 3.0
Surface friction (texture), FN	>50 (?)	> 35 (?)
Concrete materials related distress (e.g., ASR)	**None**	None

Top Design Considerations for High Performance Concrete Pavements

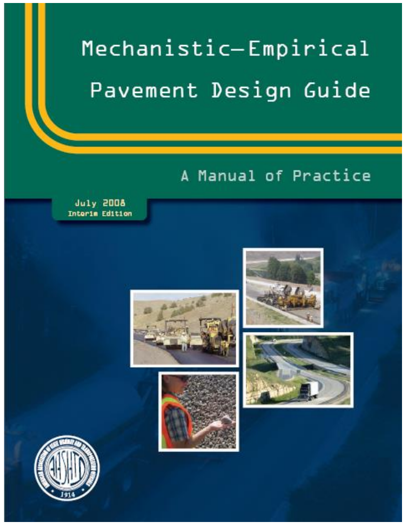
- *Focus on design features, not slab thickness*
- *Effective load transfer at joints*
- *PCCP support condition/drainage*

Comprehensive Long-Life Concrete Pavement Design

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

Comprehensive Long-Life Concrete Pavement Design

- New Mechanistic-Empirical Pavement Design Guide (MEPDG) allows **optimization** of many key design features to develop LLCP designs – a holistic (systems) approach
  - Joint spacing
  - Base type (& drainage?)
  - Edge support
  - Load transfer at joints
  - Concrete thickness/strength



- **End result**
  - **More cost-effective & reliable designs**
  - **More sustainable designs**

Sustainability Considerations in Concrete Pavement Design

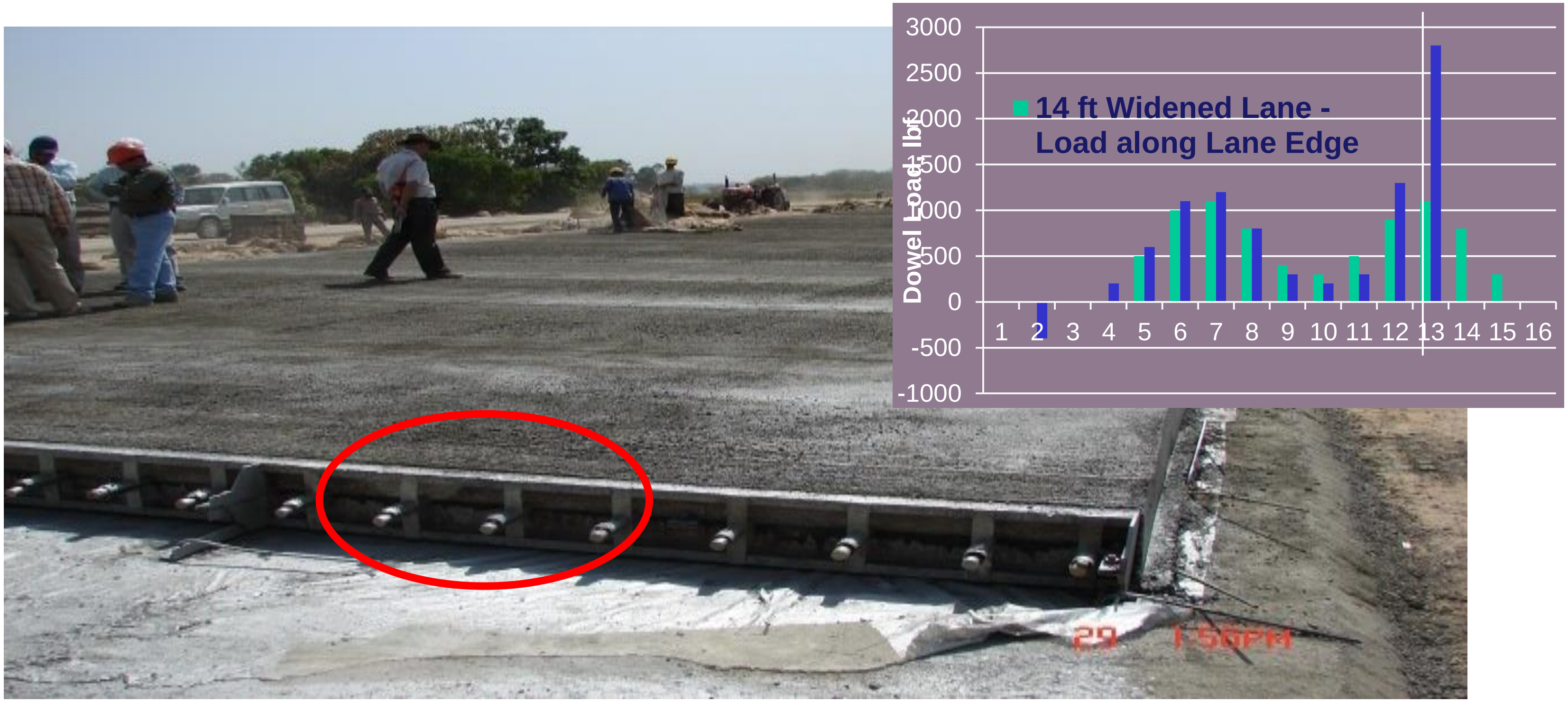
- Some simple changes in approach to reduce concrete volume & amount of other materials <u>without compromising performance</u>
  - Reduce slab thickness
    - Improve foundation/base (European approach)
    - Use widened lane & shorter joint spacing
  - Reduce materials
    - Reduce no. of dowel bars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

Joint Load Transfer for LLCP

- Joint spacing
  - 4.6 m max for most highway applications
    - Less if siliceous aggregates used in concrete (high CTE)
    - Less for thinner slabs
  - Uniform spacing & perpendicular joints
- Dowels for truck-loaded highways
  - Slab t $\geq$ 200 mm or ESALs $\geq$ 5 million
  - Minimum 32 mm diameter
  - **No need for middle 2 to 3 bars in the middle**

Joint Load Transfer for LLCP

- No need for middle 2 to 3 bars in the middle
- Only wheel path dowel bars necessary
- For corner loading, outer 3 to 4 dowels critical



Support Condition for LLCP

- Past US Approach – Do the best we can?
- European approach – Start with a good (standard) foundation
- We are now constructing better support – <u>cannot undo poor support in future R&R</u>
- Non-erodible base - prevention of pumping
- Stiffer support - reduction in slab stresses & deflections
- Provide stable and uniform construction platform – helps achieve better concrete surface finish

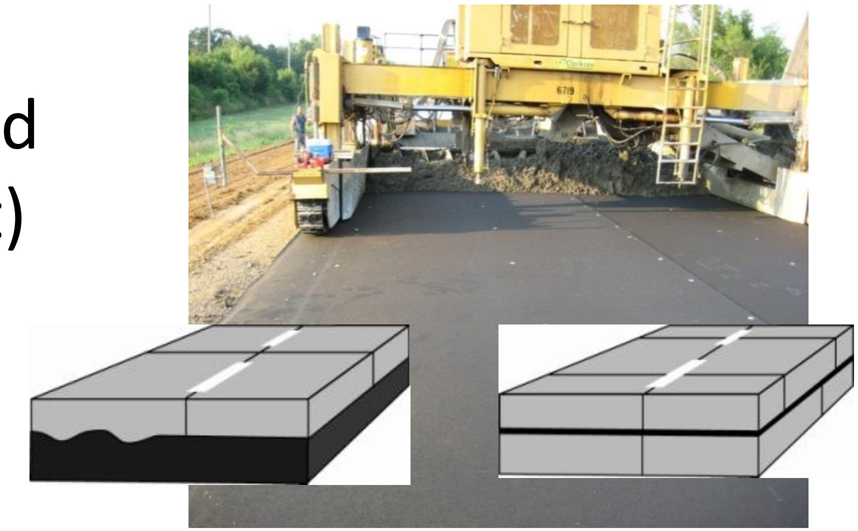
Support Condition for LLCP

Base Type Selection

- Provide for needed subsurface drainage
- Untreated granular (aggregate) bases should be reserved for low traffic
- **Stabilized (treated) bases for LLCP (40+ years)**
  - Asphalt-treated/Cement-treated
  - Lean concrete bases (US Caltrans use) with softer interlayer
  - Free-draining bases – treated or untreated, but with lower permeability (100 to 150 m/day) and better stability
  - Daylighted free-draining bases

High Performance Thin Concrete Overlays of Asphalt & Concrete Pavements

- Thin unbonded overlay (placed over AC or concrete pavement)
  - Conventional: $t \geq 200$ mm
  - Thin (recent):
    - Thickness – 150 to 200 mm
    - Jointing – 1.8 by 1.8 m
- Thin bonded overlays of AC pavements
    - Thickness – 150 to 175 mm.
    - Jointing – 1.8 by 1.8 m



Unbonded Overlay over Existing Concrete Pavement with Fabric Interlayer (Missouri)

Top 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*

Construction Quality for LLCP

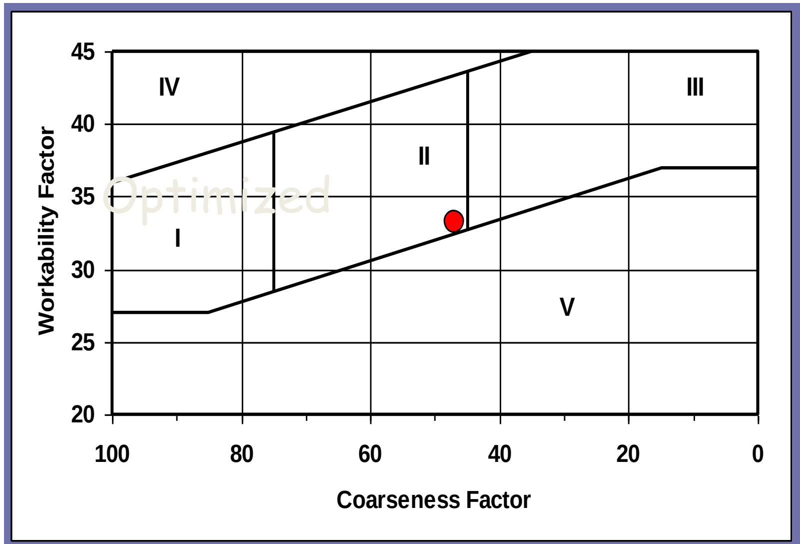
- For construction projects, achieving quality equates to conformance to requirements
  - Requirements need to be <u>well defined</u>, can be <u>measured</u>, and are <u>not arbitrary</u>
- **Quality must be built into a project. It is not a hit or miss proposition**

•Owner <u>should not expect</u> more than what is specified

•Contractor <u>may not deliver</u> more than what is specified

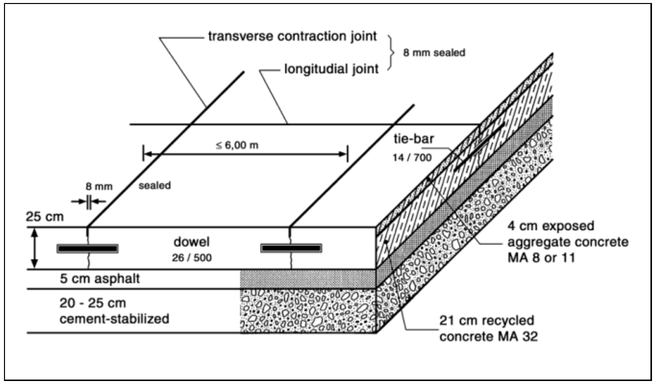
Concrete Management for LLCPTypical US Paving Concrete Mixture

- Minimum 28-day flexural strength ~ 4 to 4.5 Mpa
  - Minimum fc ~ 38 to 30 Mpa
- Maximum w/cm ratio < 0.50 (0.45 freeze areas)
- Well-graded aggregates (3+ bins) (Shilstone)
- **Greener cementitious materials**
- Advanced admixtures (future of concrete)



Concrete Management for LLCP
Ideal Paving Concrete Mixture

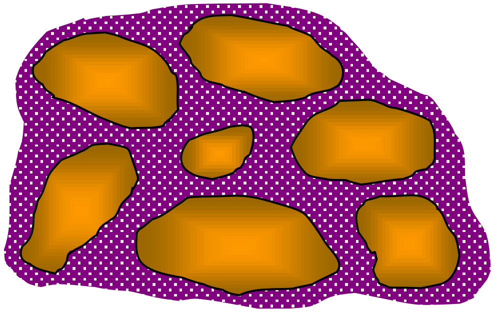
- US vs. European approach (Freeways)
  - US: ~4.5 Mpa MR & slab t = 300 to 325 mm
  - European: 5.0+ Mpa & slab t = 250 mm
- **Design for low paste - most concrete durability concerns are due to paste issues**
  - Results in better slipform paving & better finishing
- 2-lift paving – Top: $PCC^{(+)}$; Bottom: $PCC^{(-)}$, based on European practice, allows use of marginal aggregates in lower lift of concrete



Concrete Management for LLCP

Cement Reduction for Paving Concrete

- Some simple changes to reduce cement use
  - 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
  - Increase use of SCMs (flyash & slag)
    - Results in more durable concrete
    - Efficient use of waste products/by-products



  - Use Greener cements
    - Blended cements (ASTM C595)
    - Performance-based cements (ASTM C1157), including portland limestone cement
    - Non-portland cements – under development

Concrete Management for LLCP
From Placement to Curing

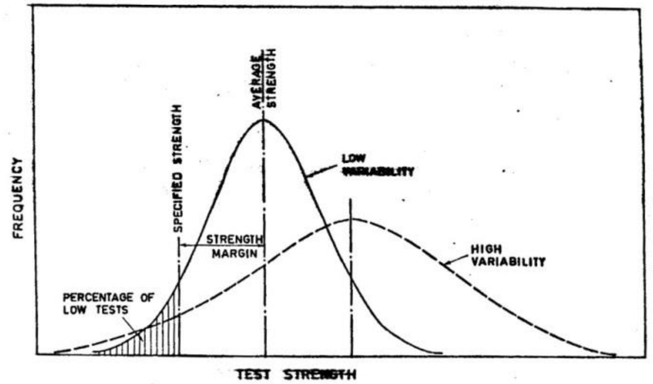
- Proper consolidation
  - Use of smart vibrator system
  - **Check cores for proper consolidation**
- Minimize tendency to over-finish surface
  - Brings more paste to the surface
  - **Surface does not have to be super-smooth**
- Timely curing
  - A concern on many projects during hot weather
- Timely & proper joint sawing
  - Not an issue for transverse sawing, **but delay in longitudinal sawing can result in premature cracking**

Well-Developed Specs for LLCP

Construction Specification Objective

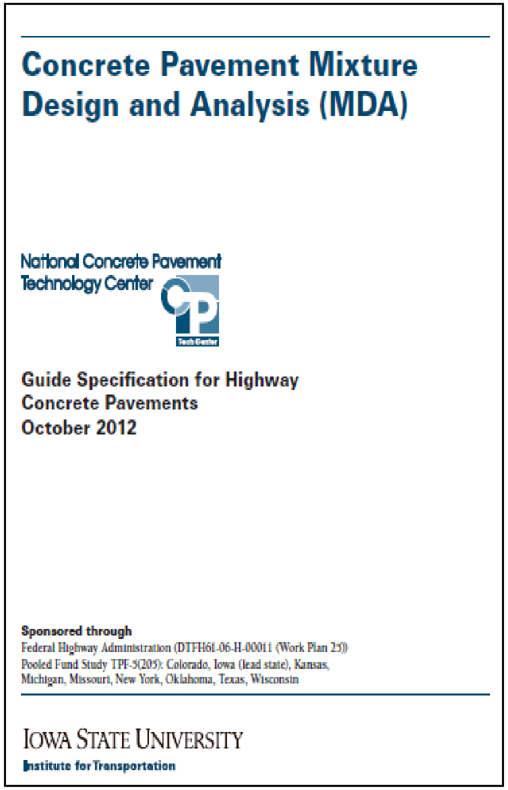
- To identify and accommodate or minimize variability in the concrete pavement construction process
  - To deliver an end product that is durable
  - To minimize **risk** of premature failures
  - To minimize owner's **risk** of accepting a marginal product
  - To minimize contractor's **risk** of rejection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

Good Specs lead to Good Construction!



Well Developed Specs
(End Product Emphasis)

- The future is end product specs
  - Need to move away from prescriptive specs
- End product specs enable clear definition of critical paving processes. Processes must be:
  - Objectively definable
  - Can be measured
  - Are not arbitrary



Concrete Pavement Mixture Design and Analysis (MDA)

National Concrete Pavement Technology Center

Guide Specification for Highway Concrete Pavements
October 2012

Sponsored through
Federal Highway Administration (DTFH61-06-H-00011 (Work Plan 25))
Pooled Fund Study TPF-5(205): Colorado, Iowa (lead state), Kansas, Michigan, Missouri, New York, Oklahoma, Texas, Wisconsin

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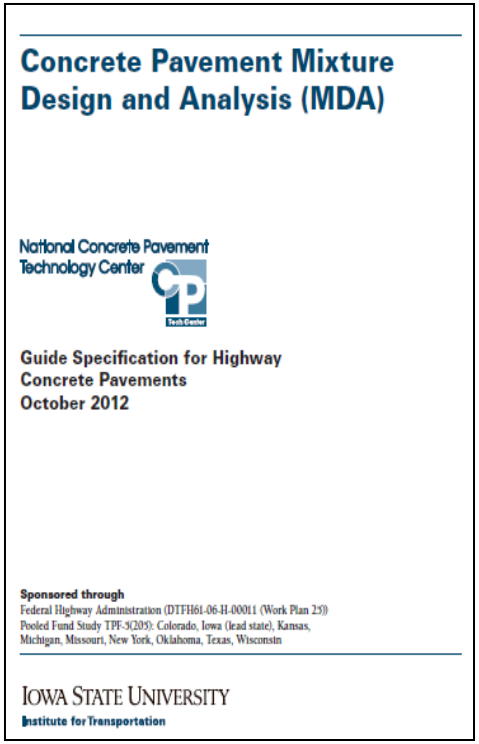
Well Developed Specs
(Non-prescriptive Requirement)

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..



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Contractor Process Control for LLCP

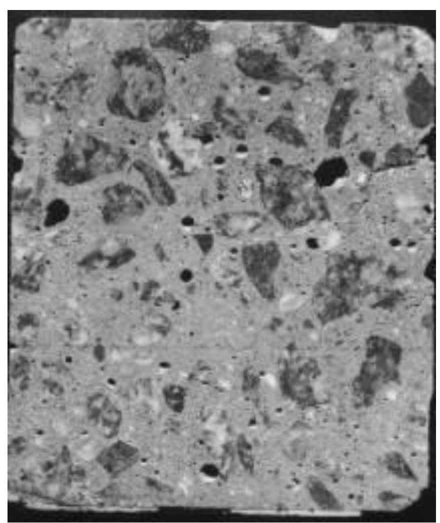
- Ideal contractor process control (QC) limits or eliminates placement of marginal concrete & use of marginal construction processes
  - **Do not produce concrete if aggregate grad. not met**
  - **Reject concrete loads if requirements not met**
  - **Stop paving process if placement (edge slump) or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

- Process control tests
  - Aggregate gradation & concrete mixture
  - Slab thickness
  - Concrete "slump" & air & density/consolidation
  - Profile (behind paver) & texture
  - Dowel bar alignment

Contractor Process Control

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

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

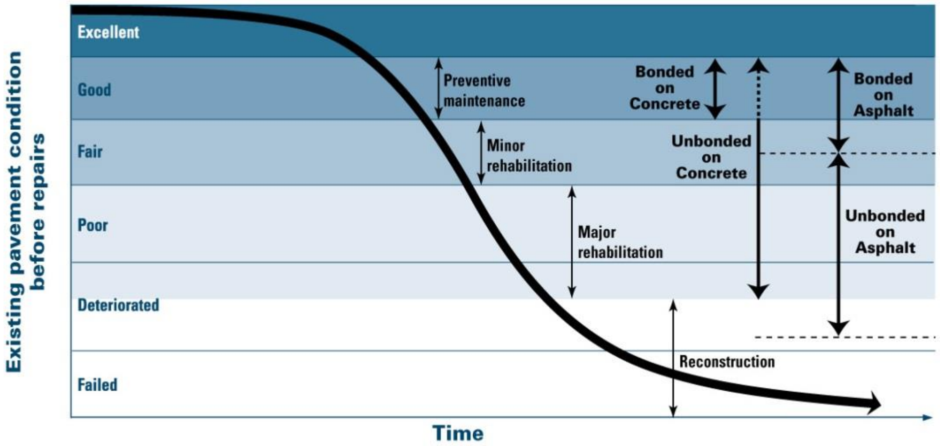
Agency Acceptance Testing
Determine the Degree of Compliance

- Perform sufficient testing to verify marginal materials & construction techniques are not being used
  - Statistically based sample testing best
  - Preferably rapid nondestructive testing
- Test for end product metrics (PWL)
  - Slab thickness
  - Concrete strength
  - Concrete durability – denseness
  - Smoothness & texture
  - Dowel bar alignment
  - Early age distress

Ideal Testing ➔ Behind paver

Top M&R Considerations
(To extend the service life of LLCP)

- Timely Maintenance & Concrete Pavement Restoration (CPR)
- Accelerated M&R
  - Minimize Lane Closures & Traffic Congestion
  - Improve Work Zone Safety



Maintenance & Rehabilitation Overview

- **We expect new high performance concrete pavements will provide low maintenance service life**
- 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 over 30 to 40 years.
- **With timely M&R strategies, we can continue to extend the service life of many of these older pavements without resorting to "fracturing" & reconstruction**
  - **Economical & sustainability benefits**

Timely M&R for LLCP
Extend service Life of Existing Pavements

- With minimal effort and lower costs, we can extend service life of most concrete pavements <u>without fracturing, resurfacing & reconstruction</u>
- Joint resealing – important if it can be done correctly
- Well-performing repair techniques are available – to maintain ride/texture/structural capacity
  - FDR, PDR, DBR, grinding, concrete/RCC shoulder retrofit
- But, maintenance & rehabilitation must be done in a timely manner & done well **(<u>No more fixing the fix</u>)**

Accelerated M&R Technologies

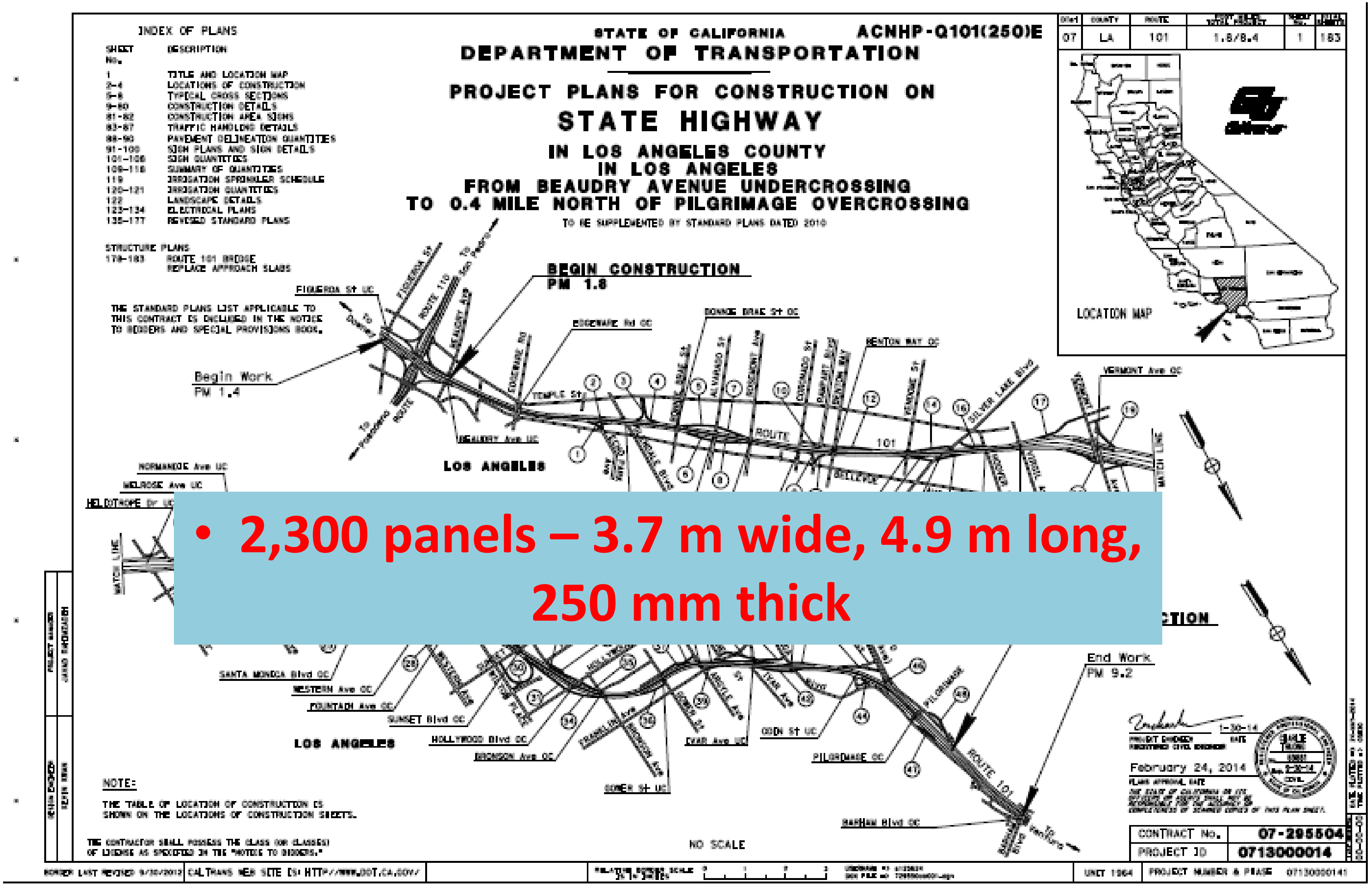
Minimize Lane Closures & Traffic Congestion & Improve Work Zone Safety

- Take advantage of advances in repair materials
  - Rapid set concretes (cementitious binder)
  - Polymer-based materials
  - Other
- Consider precast pavement for full-depth repairs & longer length rehabilitation
  - Production use by NYSDOT, NJDOT, Illinois Tollway, Caltrans, and other agencies in the US
  - Cost effective & longer-lasting

High Performance Repair Applications

Precast Panels - New Jersey I-295

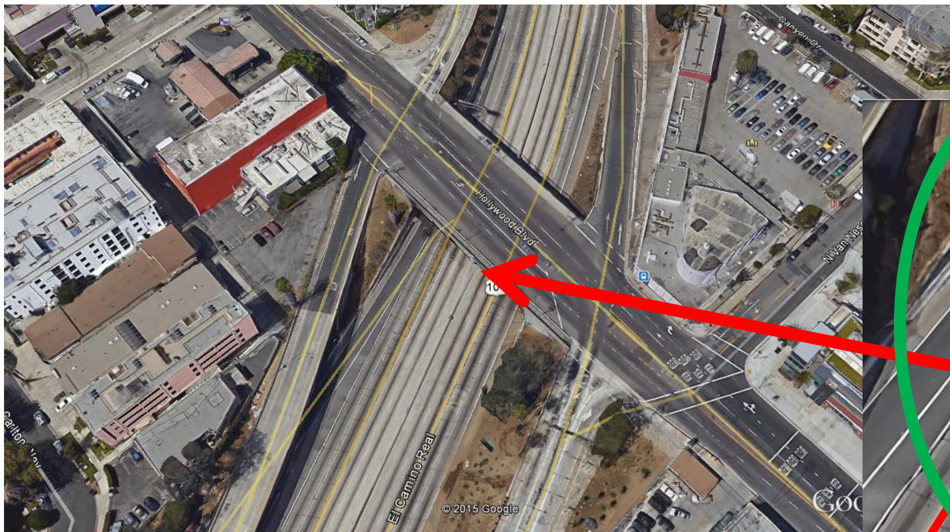
A Real Continuous Installation
The SH101 Project (Los Angeles Downtown)



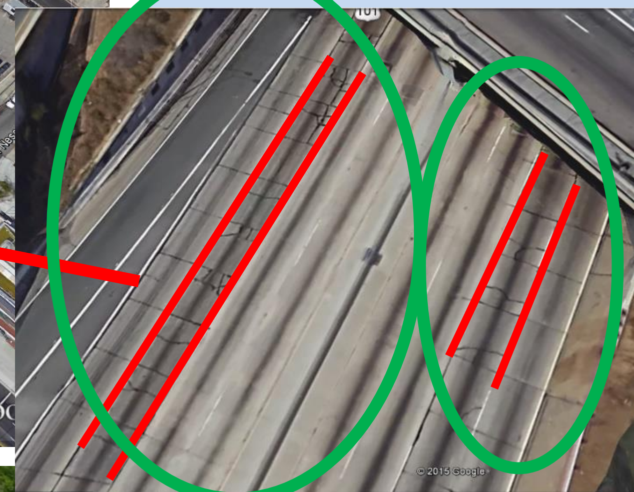
- **2,300 panels – 3.7 m wide, 4.9 m long, 250 mm thick**

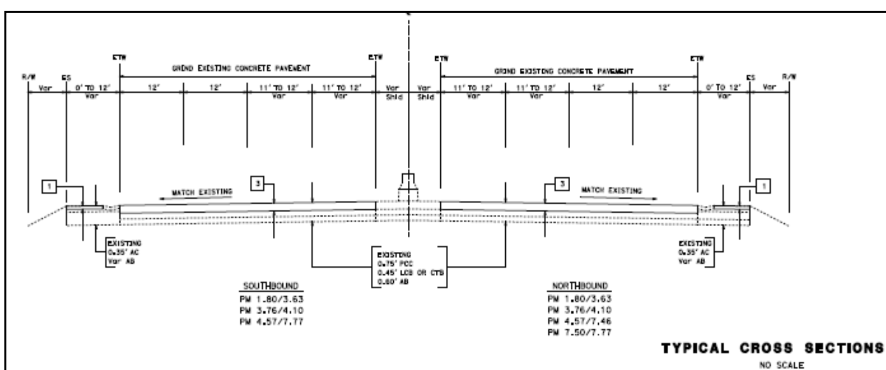
Overall Site Views

(typically 4 lanes in each direction; work in outside two lanes; heavy traffic; challenging work areas)



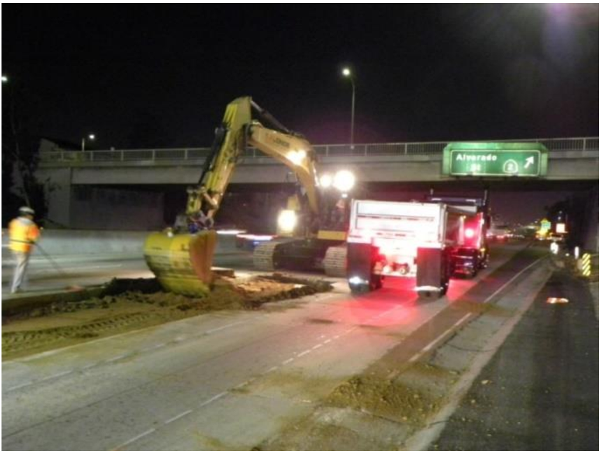
<< At Hollywood Blvd

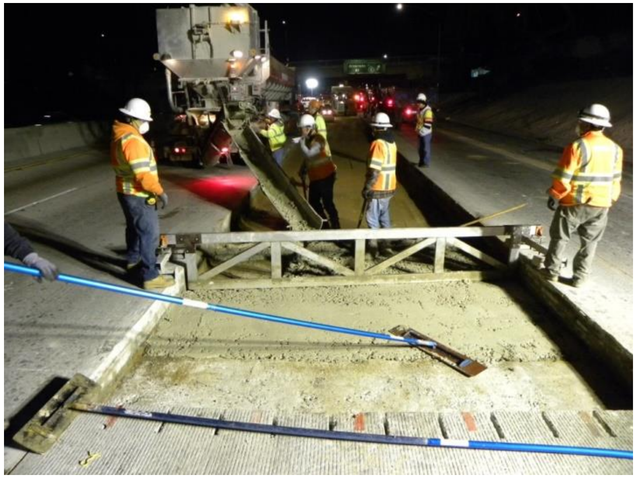




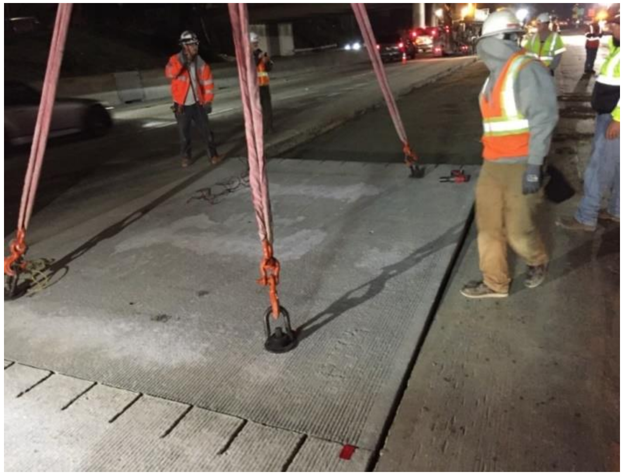
Near Benton Way >>

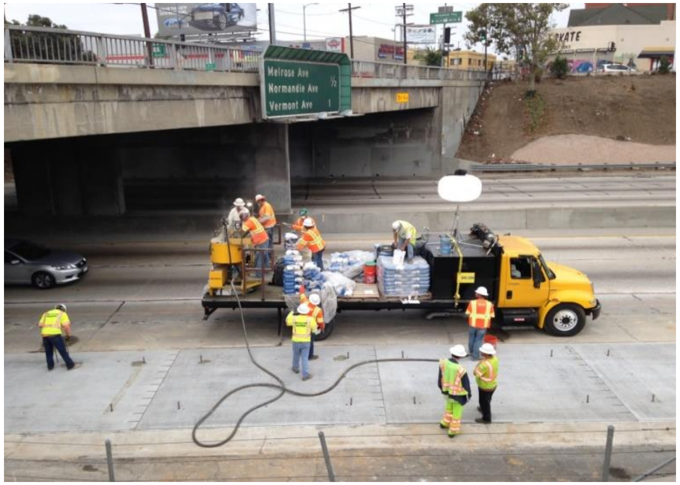
California SH 101 Panel Installation

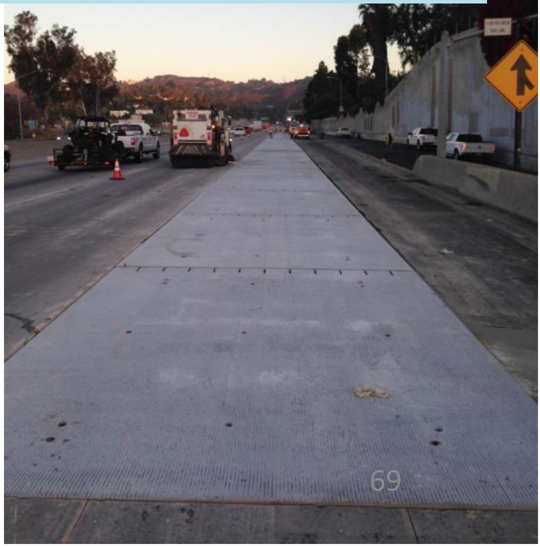




- **Weekend nights only; up to 50 panels/night (~250 meters/night)**
- **New rapid setting Lean Concrete Base; leveling lifts**







Final Thoughts

Smart Engineering & Many Small Steps **=>** *Big Gains*

- We have the engineering know-how to design & construct ***HIGH PERFORMING LONG LIFE*** concrete pavements that are long-lasting and low maintenance, ***but we need to apply this knowledge <u>consistently</u>***
- We are also considering the sustainability impacts in our design and construction practices while striving to produce longer lasting high performance concrete pavements
  - **<u>Pavements that are not long-lasting ARE OF COURSE NOT sustainable</u>**

Final Thoughts

- Design concrete pavements that have low risk of early failures
  - **Design for at least 30 year initial life (US => 40+ years)**
- Minimize long distance transportation of construction materials
  - **Use local and recycled materials**
- Use materials that are durable and can be recycled
- Ensure that the construction process is well controlled to minimize built-in failure conditions
  - **Well designed & well constructed concrete pavement should not need repairs for the first 15 to 20 years**
- Ensure timely maintenance is performed when needed

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