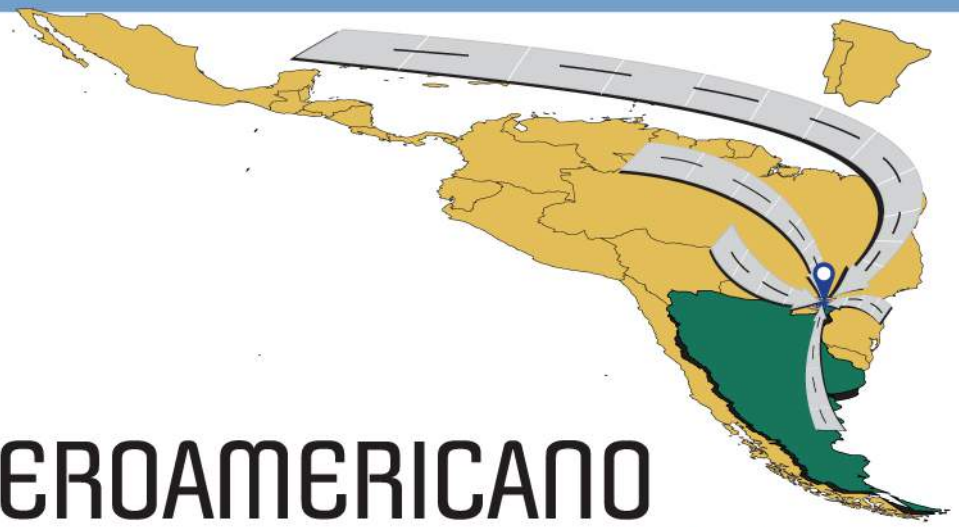

6º CONGRESO IBEROAMERICANO de Pavimentos de Hormigón

Puerto Iguazú, Argentina

23 y 24 de abril de 2015

Organizan:

Federación Iberoamericana del Hormigón Premezclado

ASOCIACION ARGENTINA del HORMIGON ELABORADO

Co-sponsor:

FICEM
FEDERACIÓN INTERAMERICANA DEL CEMENTO

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New Technologies in Products, Materials, Design and Construction of Concrete Pavements

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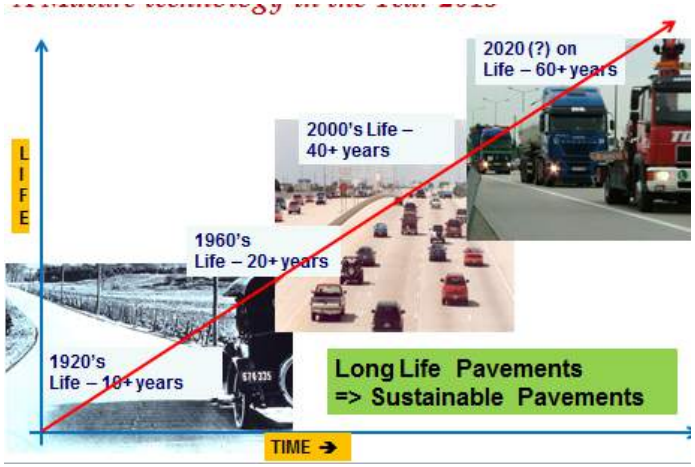
Modern Concrete Pavements

A wide range of applications

Concrete Pavements Technology – A Mature Technology in 2015

Resulting from improvements in design, construction & material technologies (over 100+ years)



But <u>still evolving</u> to improve reliability of design, durability of materials, efficiency of construction, and cost competiveness; and better meeting road user needs

Presentation Outline

- Overview of Current Best Practices for Concrete Pavements
- New Technologies
  - ***Concrete related***
  - ***Design: MEPDG process***
  - ***SHRP2 Concrete pavement products***
  - ***Construction related***
  - ***Surface texture related***
  - ***Sustainability related***

Roman Definition of Durable Pavements

- **Original pavement surface service life – Forever?**

But, would the Roman pavements maintain desirable ride & texture under the 21st century truck loadings and vehicles operating at 100 km/h?

US Targets for Long-Life (Durable) Concrete Pavements

- Original PCC surface service life – 40+ years
  - The next frontier – 60+ years service life
- d
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- ce

At some point in future, Latin American countries will need to strive for such expectations for its concrete pavements – to make concrete pavements in Latin America risk-free, durable, more cost-effective and more sustainable!

texture characteristics with minimal intervention activities to correct for ride & texture, for joint resealing, and minor repairs

Long-Life Concrete Pavements

- Long-life concrete pavements have been attainable for a long time
  - Many pavements are still in place after 40+ years of service under heavy traffic
- The main concern is achieving long-life <u>consistently</u> thru:
  - Reliable structural designs
  - Durable materials
  - Quality construction, and
  - Timely maintenance & repair

US Developments/Innovations Are Aimed At

- Reducing risk of early pavement failures by
  - Optimizing pavement structural designs
  - Identifying and not using **poor** construction materials
  - **Improving construction quality**
  - Timely pavement preservation
- Reducing overall cost of construction per km-lane (Initial cost & life cycle cost)
- Improving user safety and ride quality
- Considering sustainability by
  - Increasing use of **recycled and marginal** local materials

US Expectations of Concrete Pavements

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

Distress	Failure Value
Cracked Slabs, % (plain jointed)	**10 - 15**
Faulting, mm **(Consider grinding before threshold is reached)**	**6 or less**
Smoothness (IRI), m/km	**2.5 to 3.0**
Joint Spalling	**Minimal**
Materials Related Distress	**None (thru good specs & construction practices**

Concrete Pavement Types

- Jointed concrete pavement (most popular)
  - 100+ years of experience/innovations
- Continuously reinforced concrete pavement
  - No joints; but a bit more expensive first cost
  - 50+ years of experience
- Roller compacted concrete pavement (30 years)
  - For lower speed roads, shoulders and parking lots
  - And, heavy duty port & truck freight areas
- Thin concrete overlays (20 years)
  - Typically, for resurfacing of distressed asphalt pavement

Concrete Pavement Types

- Pervious concrete (10 years)
  - In urban areas – low speed streets & parking lots
  - Helps with storm water management
- Precast concrete pavement (15 years)
  - Conventionally jointed and posttensioned (joints at 70 to 100 m)
  - Used in urban areas for rapid overnight repair and rehabilitation
- Cast in place prestressed concrete pavements (experimental only – 1980's)
  - Thinner and joints at 70 to 100 m

Current US Practice

- Jointed concrete pavements
  - 4.6 m joint spacing (default)
  - t = 15 to 20 cm (streets); 20 25 cm (secondary roads); 25 to 35 mm (primary roads)
  - Dowels & stabilized base for medium/heavy volume of trucks
- Continuously reinforced concrete pavement (CRCP)
  - Steel: 0.70 to 0.80%
  - Cracking at 1 to 2 m, tight cracks
  - No joints; terminal joints only at structures

CRCP

- Steel: 0.65 to
- Cracking at 0
  very tight cra
- Terminal join
  structures on
- Almost a zero
  maintenance pavement

o CRCP
uction -

Roller-Compacted Concrete (RCC) Pavements

- RCC is a **cheaper** no-slump concrete that is placed using an asphalt paver and compacted by vibratory rollers.
- Consistency of damp gravel
- No forms and no reinforcing steel/dowel bars
- No finishing
- Compacted using vibratory rollers and finished with rubber-tired rollers

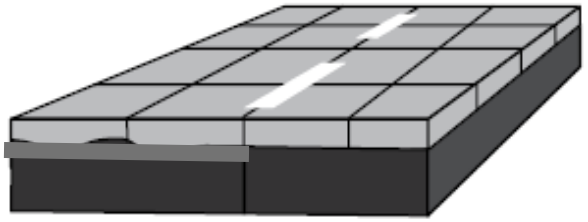
Thin Bonded Concrete Overlays of AC (Whitetopping)

- PCC overlay of existing distressed AC pavement
  - Thickness – 125 to 175 mm.
  - Jointing – 1.8 by 1.8 m
- Use increasing in the US & Latin America

Thin Unbonded Concrete Overlays

(of asphalt & concrete pavements)

- Thin unbonded overlay (placed over AC or concrete pavement)
  - Thickness – 125 to 175 mm
  - Jointing – 1.8 by 1.8 m



- Use of geo-fabric interface of unbonded overlays over existing concrete pavements, based on German practice for new construction

Unbonded Overlay over Existing Concrete Pavement with Geo-Fabric Interlayer

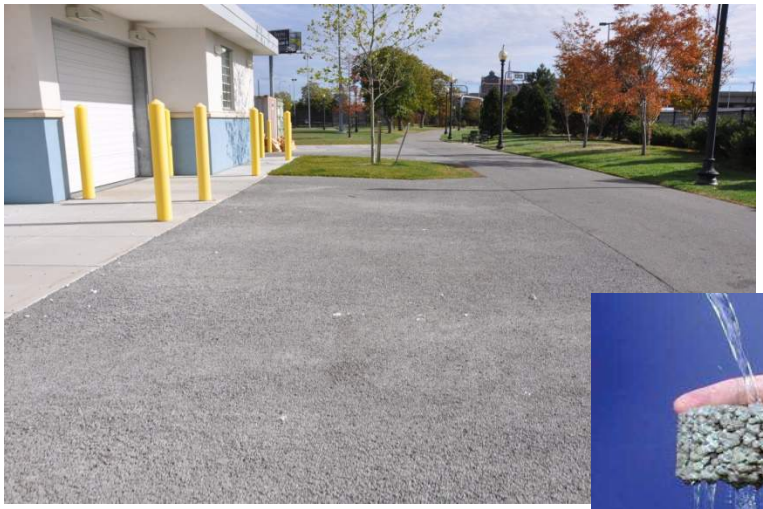
Guatemala Variation

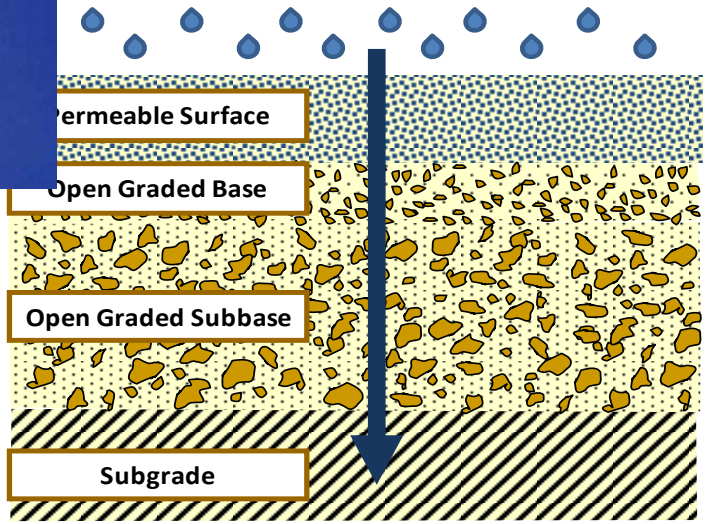
(Short joint spacing for new pavements based on good experience with bonded overlays of AC pavements)

- New Toll highway – Guatemala City
- Thickness – 225 mm or as needed (NOT THIN!)
- Jointing – 1.8 by 1.8 m
- Cement treated base; 5 mm thick fabric interlayer
- No dowel bars; only tie-bars

Pervious Concrete Pavements

(A no fines concrete surface to reduce surface runoff)

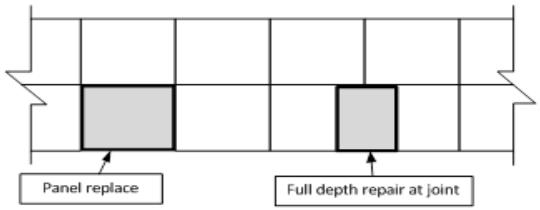


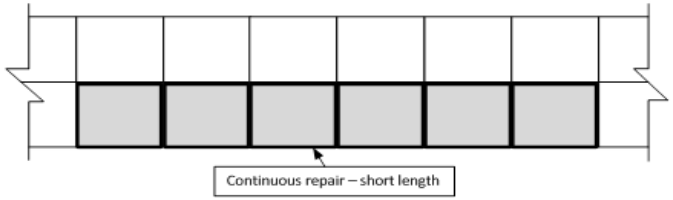


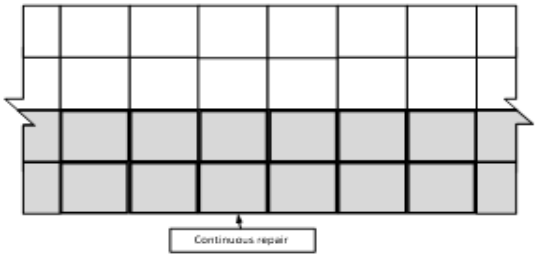
Precast Concrete Pavement Technologies

Minimize Lane Closures & Traffic Congestion & Improve Work Zone Safety (urban areas)

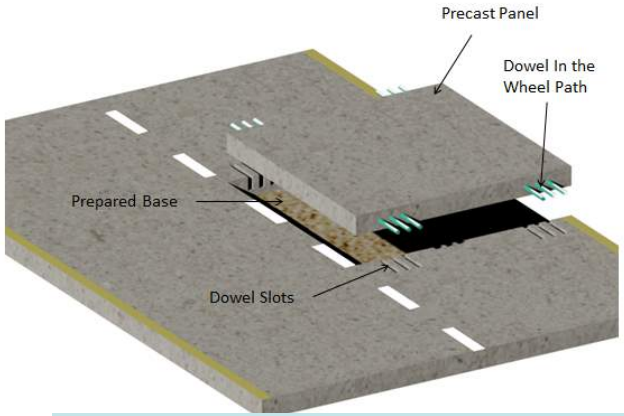
- Introduced in 2001, use of precast concrete pavement for full-depth repairs & rehabilitation is on the increase in the US
  - Production use by many US agencies
  - Cost effective & longer-lasting repairs & rehabilitation
  - Minimize lane closures (~8 pm to 5 am)

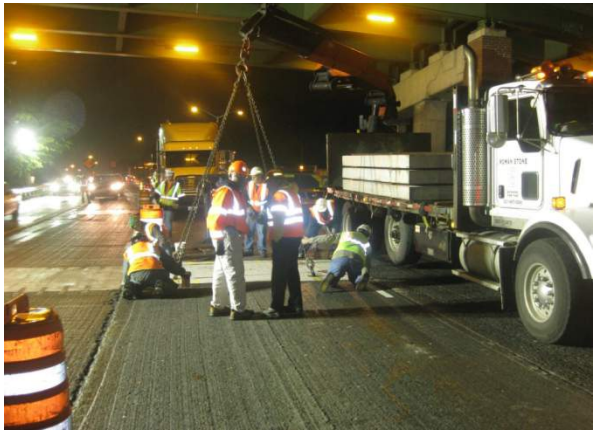




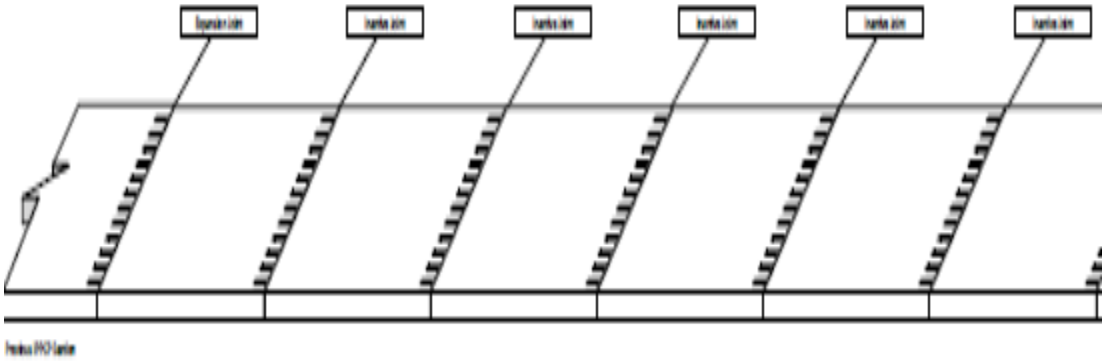


Jointed Precast Concrete Pavements





Repair Panels



Conventional Jointed PCP System

Current Efforts to Continue to Improve Concrete Pavement Practices

- Design
  - Continue to refine Mechanistic-Empirical design (MEPDG) process & promote wider implementation
  - Optimizing design features & improving design reliability
  - Composite pavement (Top lift $PCC^{(+)}$/Bottom lift $PCC^{(-)}$)
  - New pavement types
    - Thin concrete overlays of existing asphalt pavements
    - Precast pavement (for rapid rehab/reconstruction)

Current Efforts to Continue to Improve Concrete Pavement Practices

- Materials (major focus: durability & sustainability)
  - Dense (well) graded aggregates (3+ sizes)
  - Less cement use, more SCM (flyash & slag)
    - **GREENER CONCRETE**
  - **Improved additives/admixtures to improve fresh concrete properties and hardened concrete properties**
  - Two-lift paving concrete mixtures ($PCC^{(+)}/PCC^{(-)}$)
  - **Internally cured concrete using lightweight aggregate**
  - **Improved test protocols to minimize using concrete susceptible to alkali-silica reactivity (ASR)**

Current Efforts to Continue to Improve Concrete Pavement Practices

- Construction
  - Two-lift paving (Two plants & two sets of paving equipment)
    - Use of recycled and marginal aggregates in lower lift
  - Stringless paving (controlled using GPS)
  - Managing smoothness during construction
  - **End product and performance-related specification (PRS)**
  - Pro-active contractor process control
    - Reject poor materials before placement
    - Stop paving operation if process not under control
  - Green construction

Current Efforts to Continue to Improve Concrete Pavement Practices

- Repair/Rehabilitation
  - NDT procedures to rapidly and reliably identify poorly performing concrete and poorly performing concrete pavement
  - Rapid/accelerated (typically at night) for high volume highways
  - Thin concrete overlays to extend life of exist. pavements
  - Precast pavement use (mainline, ramps, bus lanes, intersections) in high volume corridors

Current Efforts to Continue to Improve Concrete Pavement Practices

- Surface characteristics
  - Improve surface texture (longer lasting surface texture)
    - **Reduce wet weather accidents**
    - Reduce pavement/tire noise
    - US: Next Generation Surface Texture
    - Australia: Low noise diamond ground surface
- Construction management (Every Day Counts)
  - Minimize extended lane closures in urban areas
  - Reduce roadwork related congestion
  - **Reduce work zone accidents**

Some Examples of Recent Developments Improve Concrete Pavement Practices

- *Concrete related*
- *Design: MEPDG process*
- *SHRP2 Concrete pavement products*
- *Construction related*
- *Surface texture related*

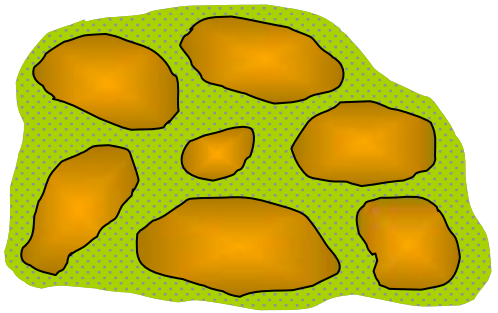
Some Examples of Recent Developments Improve Concrete Pavement Practices

Concrete related

1. ***Reduce cement use***
2. ***Use recycled and marginal aggregates***
3. ***Internal concrete curing***

US Efforts to Reduce Cement Use 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; consider end product specification
  - Increase use of 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



Use of Sustainable Concrete

Reducing Portland Cement Use
By Using Pozzolan and Slag & Greener Cements

- Class F fly ash: 15% - 25%
- Class C fly ash: 15% - 35% (limited use)
- Slag: 25% - 50%
- Silica fume: Not used in US for paving
- Natural pozzolan: Not yet used in US for paving

Blended cement use is allowed & common

Green cements under development

The Illinois Tollway's Use of Composite Concrete Pavements with Greener Concrete for Improved Sustainability

MOVE ILLINOIS

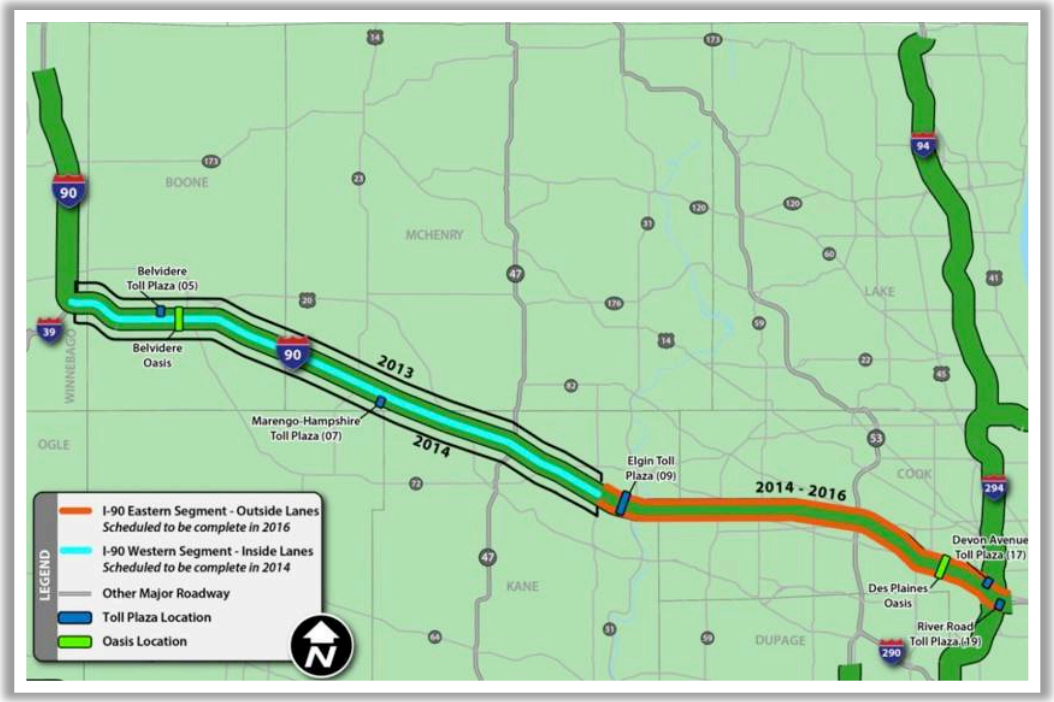
The Illinois Tollway
DRIVING THE FUTURE

- **286-mile system comprised of four tollways**
- **Opened in 1958 as a bypass around Chicago to connect Indiana and Wisconsin**
- **Carries more than 1.4 million vehicles per day**
- **Largest open road tolling system in the nation**
- **User-fee system – no state or federal gas tax dollars**

Jane Addams Memorial Tollway (I-90)

Rebuilding and widening I-90 as a 21st century, state-of-the-art corridor linking Rockford to O'Hare International Airport

- **62 miles of roadway improvements**
- **$2.2 billion budget includes $240 million to integrate transit in the corridor today, as well as future transit expansion plans**



Innovative Pavement Designs

To provide long-lasting, smooth surface to customers…

- **2-Lift concrete pavement with asphalt shoulders**
- **Incorporates various green initiatives**

Illinois Tollway Requires 100% Recycling of Concrete and Asphalt Pavements with Reconstruction

MOVE ILLINOIS

In Base Aggregates

In New Asphalt Mixes

Milled Recycled Asphalt Pavement is Fractionated on Most All Projects

What is FRAP?

- Old asphalt pavement that has been milled and fractionated (graded)
- Coarse FRAP contains 2 to 3% asphalt binder
  - HMA has 5-6%
- Contains about 14% agglomerated particles (clumps of sand/asphalt)
- Sizes range from ½" to No. 4 size sieve.

Why use FRAP in Concrete?

- Sustainability
  - Disposal/hauling energy
  - Natural resource depletion
  - Carbon footprint
    - Economy!!!

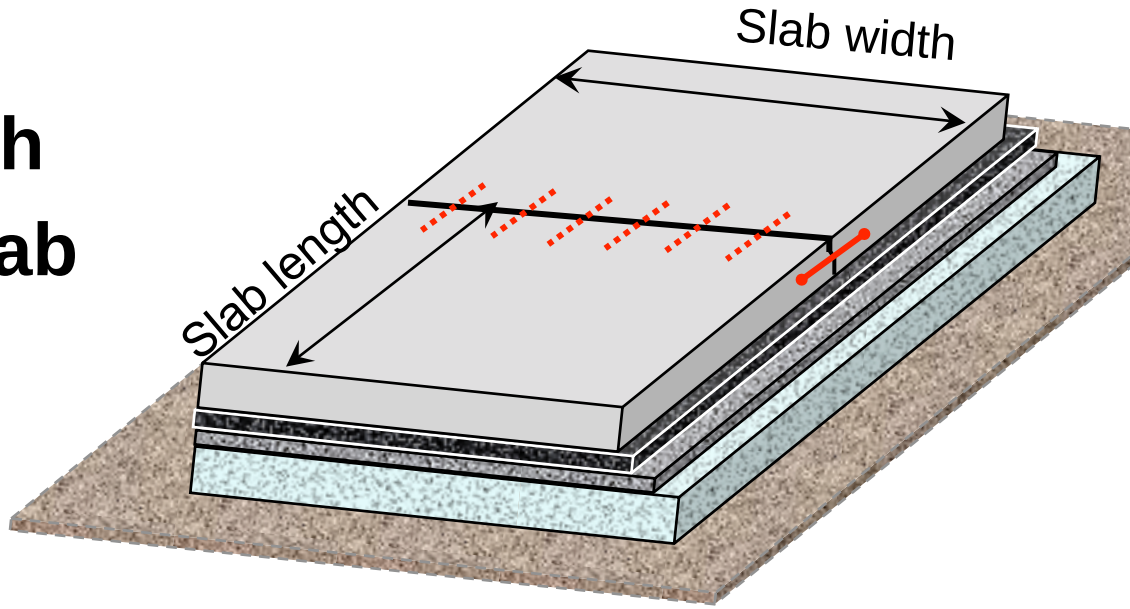
Lot of Coarse FRAP Left Over for Concrete

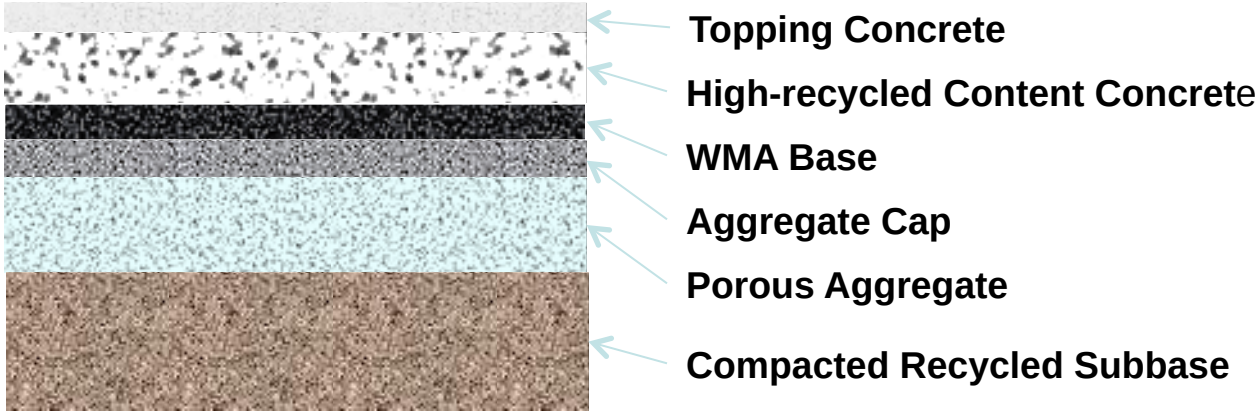
- **Fine FRAP (<#4 sieve) used by the Tollway as a liquid binder replacement in new asphalt mixes with reclaimed asphalt shingles (RAS)**

- **Large stockpiles of coarse FRAP remain unused and take up space – now used for lower lift concrete**

I-90 Concrete Pavement Design Details

- 4.65 m slab length
- 0.3 m widened slab
- Doweled Joints
- 45 cm of base





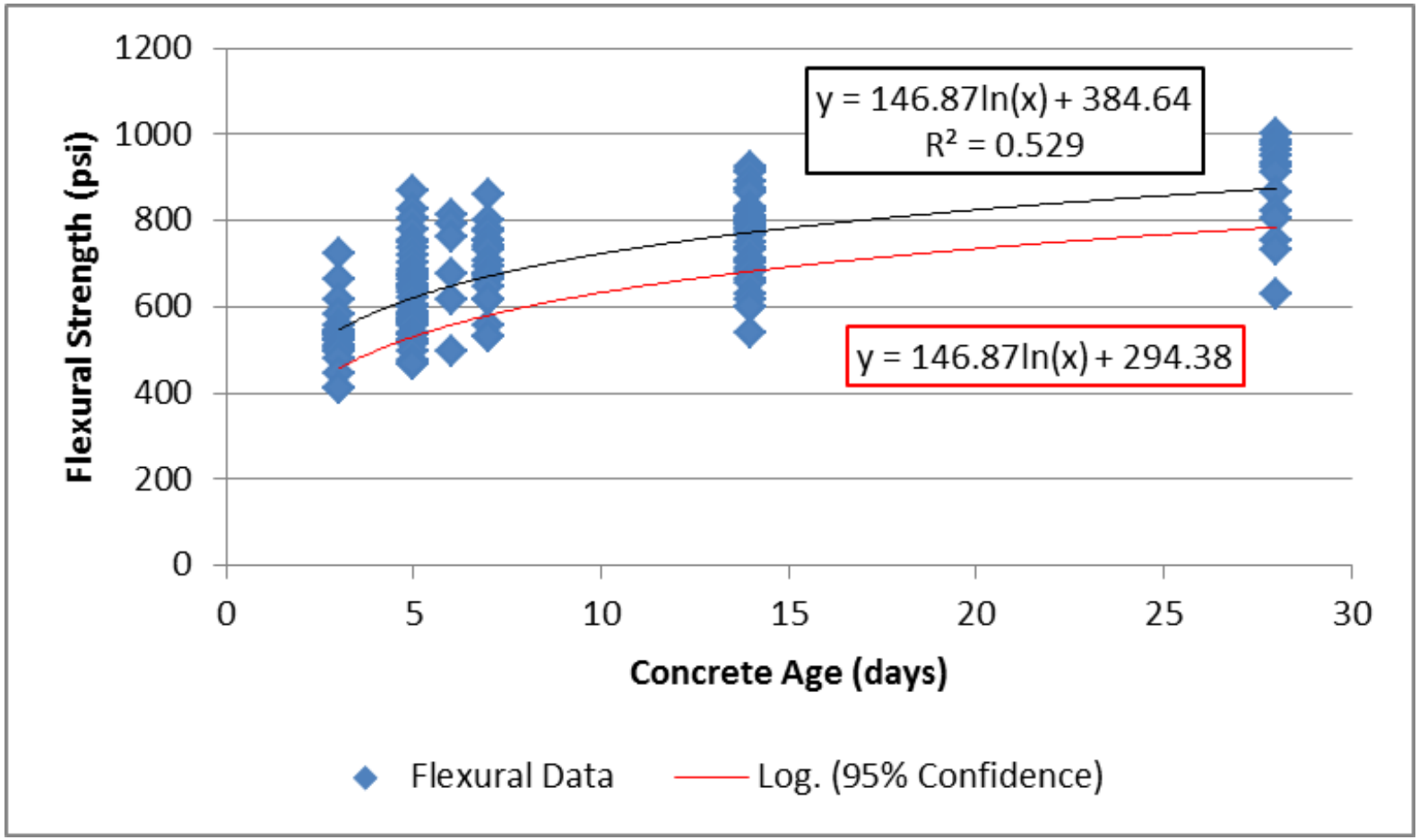
Typical Black Rock Mix Design Used in 2013

- ***Typical Proportions:***

	Lbs/Cu Yd
Cement	375
Class C Fly Ash	145
Slag Cement	60
Coarse Aggregate*	1575
Black Rock	273
Natural Sand	1196

*** - IDOT CM-11 Crushed Stone (~ AASHTO #6 Stone)**

Summary of Flexural Strength Data on 2013 Ternary Black Rock Mixes



Summary of I-90 Reconstruction – 2013 & 2014

Two slip form pavers / two belt placers for double lane placements only

Internal Concrete Curing (ICC)
(Using lightweight aggregate)

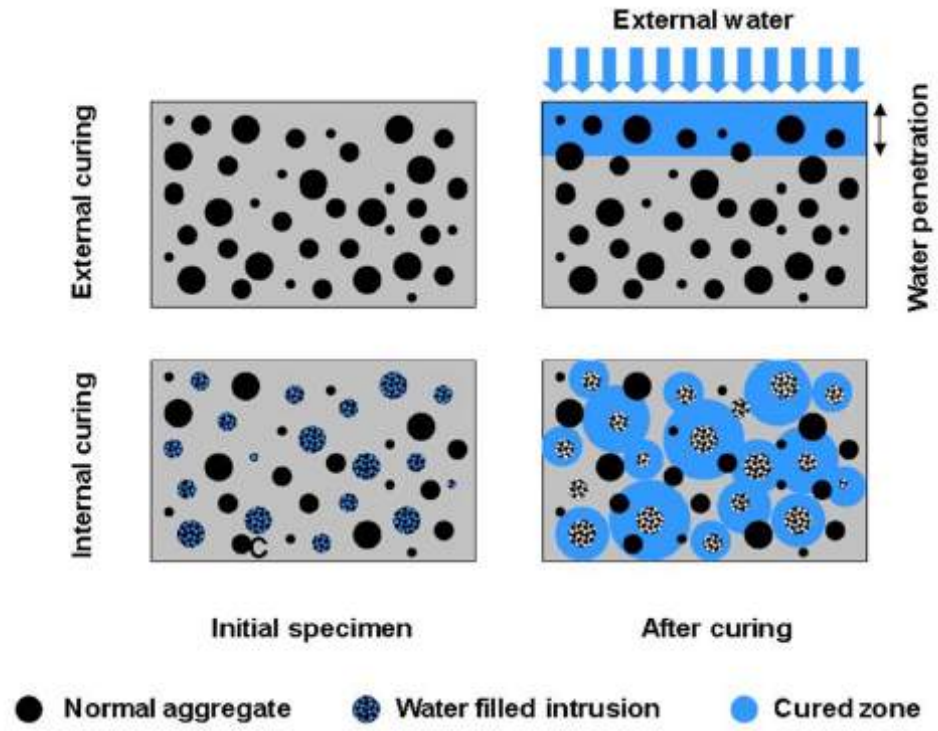
- More interest developing in use of internally cured concrete for concrete pavements
  - Current use for bridge deck applications
- ICC is based on partial (~30% by volume) replacement of fine & intermediate size aggregates with saturated light weight aggregates (expanded shale, clay or slate)
- ICC allows prolonged hydration of concrete beyond the initial curing period
  - Eliminates plastic shrinkage cracking
  - Reduces long-term drying shrinkage & slab warping
  - Improves strength properties

Internal Concrete Curing
(Using lightweight aggregate)

- ICC mechanism ➔

- In US, ASTM (C1761) and ACI (ACI 308/213 – R13)documents provide guidance and test methods

- Paving process same as for conventional concrete



Some Examples of Recent Developments Improve Concrete Pavement Practices

Design: MEPDG process

AASHTOWare Pavement ME Design ***Version 2.1

AASHTOWare Pavement ME Design is the next generation of AAS
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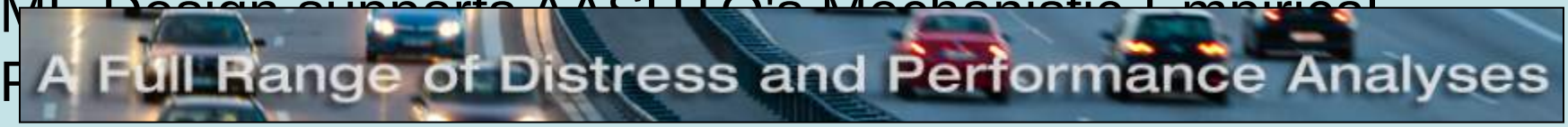
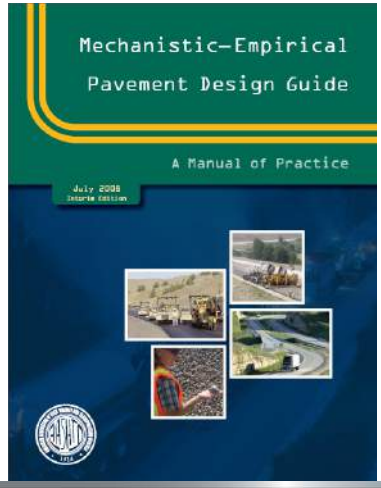


Practice. .

Comprehensive Long-Life Concrete Pavement Design

- The 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

PvD AASHTOWare Pavement ME Design AASHTO

- Most US agencies have adopted the new procedure
  - Agencies are at various stages of implementation

ME Design Process

Foundation Analysis

Climate

Materials Properties

Traffic Analysis

Performance criteria & reliability

Inputs

Revise Trial Design

Trial Design

Pavement Response Model

Damage Accumulation Over time

Analysis

Calibrated Damage-Distress/IRI Models

No

Meet Performance Criteria?

Yes

Joint Faulting

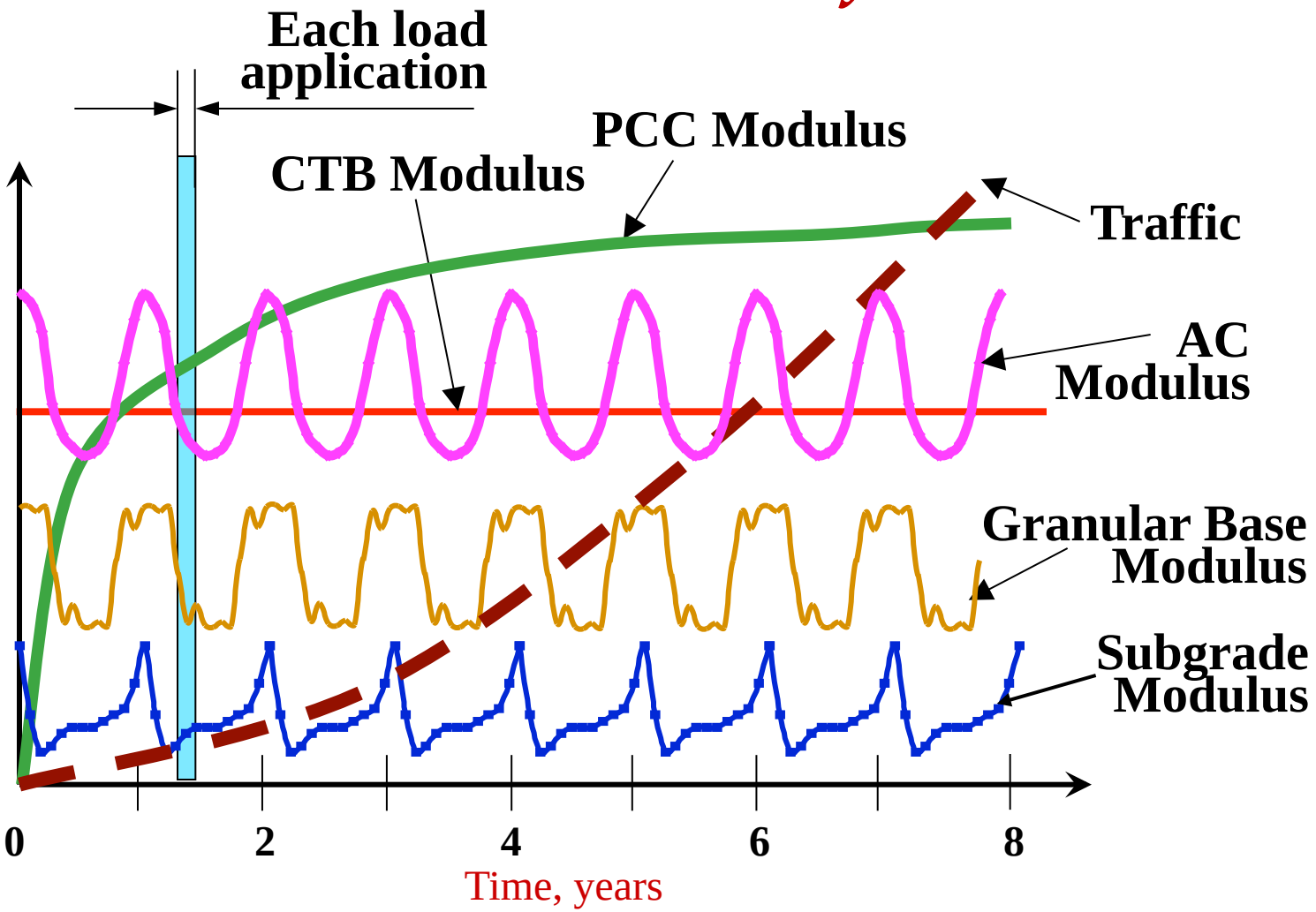
Cracking

Smoothness

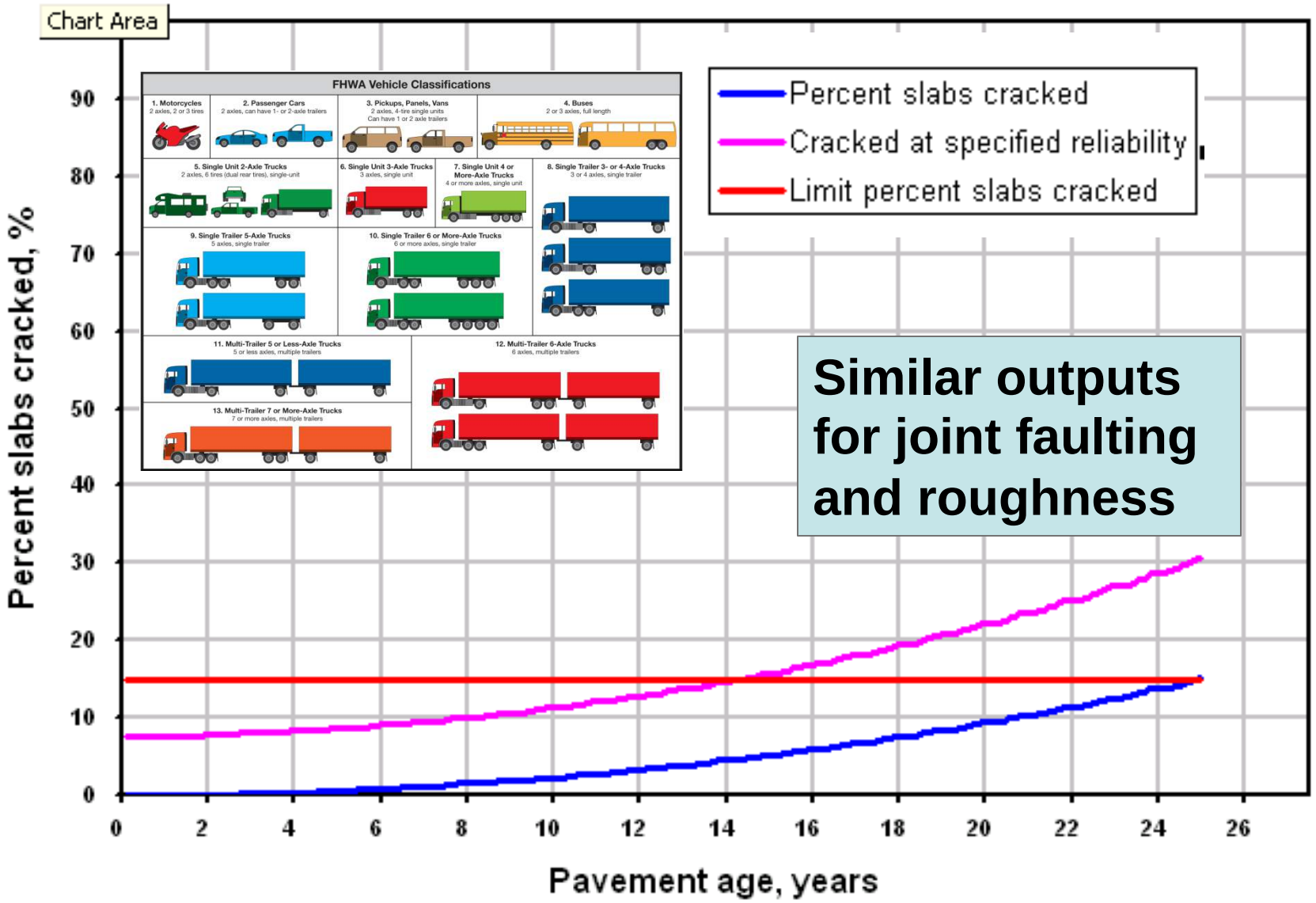
Outputs

Final Design (Check for optimum design)

Seasonal Analysis of Pavement Damage over Service Life



Example Results



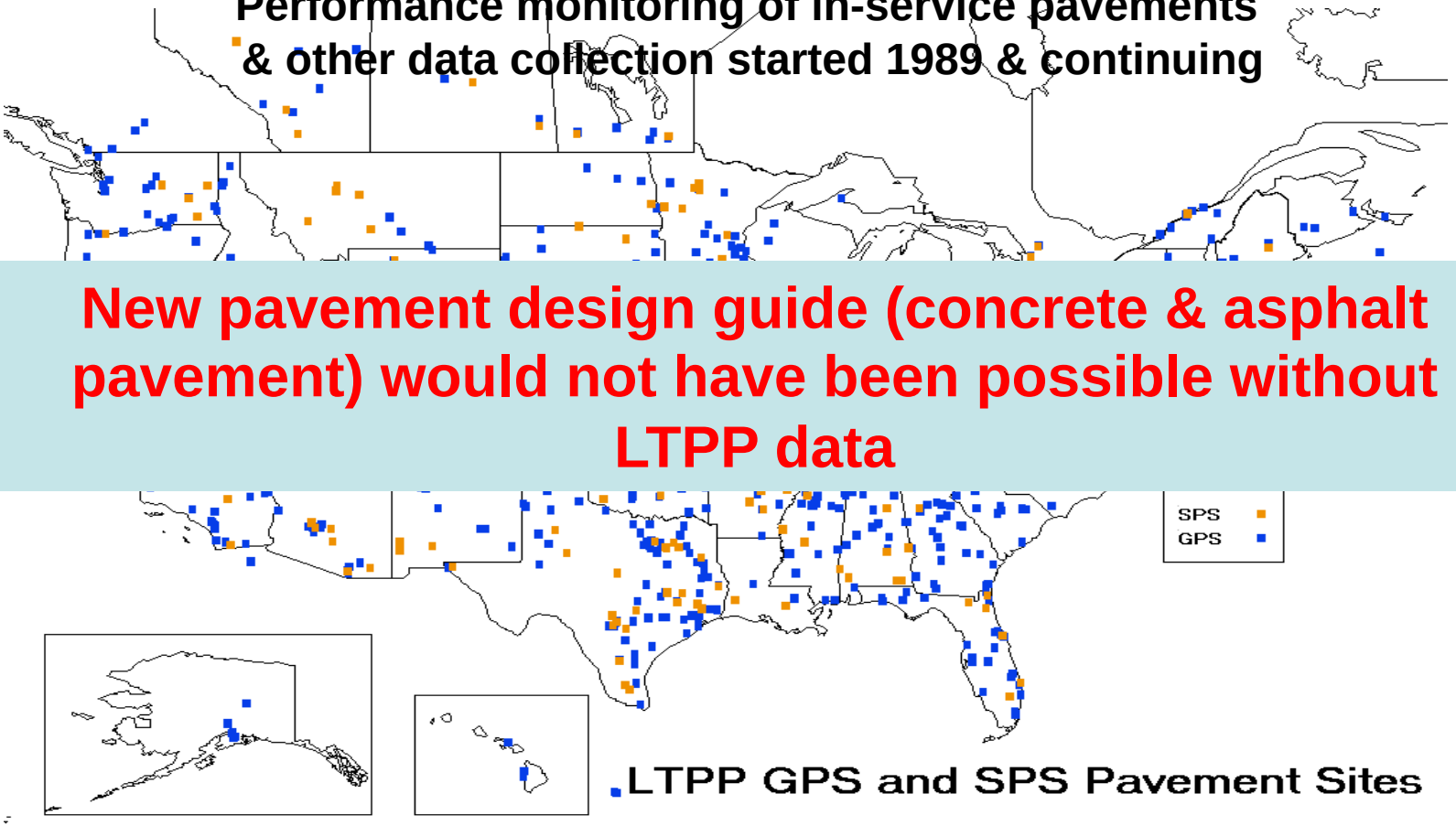
Current Status of MEPDG

- ME Design software version 2.1 released
- Most US highway agencies adopting MEPDG and ME Design software for design of jointed concrete pavements
  - Most agencies are performing local calibration to fit their regional conditions and needs
  - Most agencies are developing databases on construction materials and traffic

US Long Term Pavement Performance (LTPP) Program

2,509 Original Sections, 750 Remaining

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



New pavement design guide (concrete & asphalt pavement) would not have been possible without LTPP data

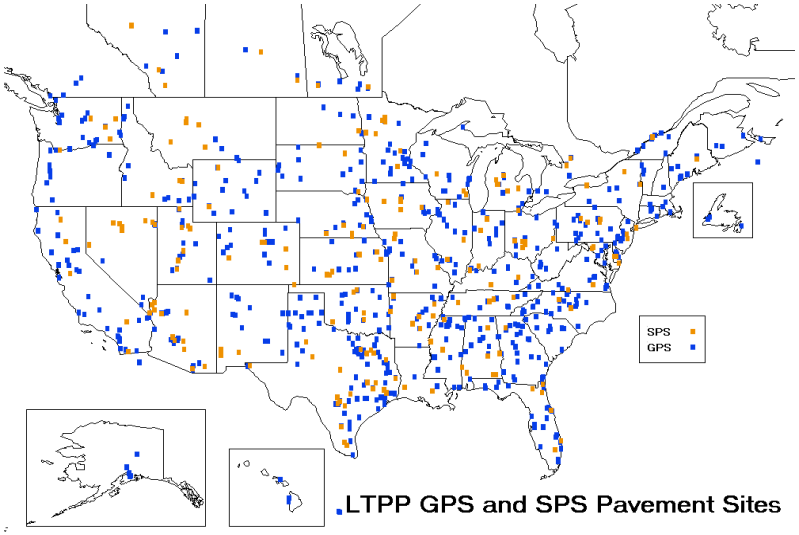
LTPP Products In Use

- Some Completed Products
  - Standardized Pavement Distress Identification Manual
  - Deflection Testing (FWD) Calibration Procedures
  - Profiler Procedures
  - ProVAL software for smoothness
  - DataPave (database) Online
  - & many topic specific studies related to pavement performance

Latin America Long Term Concrete Pavement Performance (LTCPP) Program

Latin American countries should initiate their own mini-LTPP studies for CONCRETE PAVEMENTS

to improve understanding of how to optimize concrete pavement performance in each country



LTPP GPS and SPS Pavement Sites

Some Examples of Recent Developments Improve Concrete Pavement Practices

US Strategic Highway Research Program 2 (SHRP2) Concrete pavement products (2007-2015)

1. *Composite concrete pavements*
2. *Precast concrete pavements*
3. *Construction-time smoothness management*
4. *Extending life of existing pavements*
5. *Pavement preservation*

SHRP2 (2007 – 2015)

- SHRP 2 was created to find strategic solutions to three national transportation challenges: improving highway safety, reducing congestion, and improving methods for renewing roads and bridges.
- SHRP has undertaken more than 100 research projects focused in four areas--**safety, renewal, reliability, and capacity.**
- The research results are now being made available in a series of effective solutions that will improve the way transportation professionals plan, operate, maintain, and ensure safety on US roadways.

SHRP2 SOLUTIONS
TOOLS FOR THE ROAD AHEAD

Save lives, Save money,

SHRP2 Concrete Pavement Products

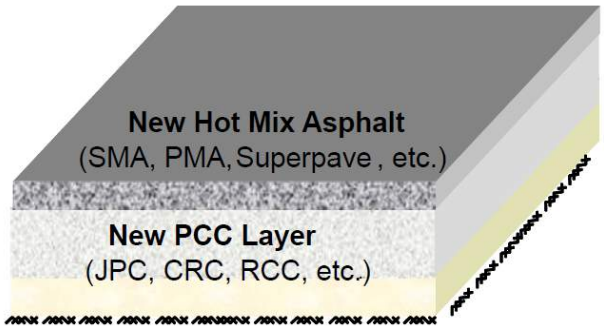
Composite concrete pavements

The objective of this project was to investigate the design and construction of new composite pavement systems, one of the system being a PCC surface over a PCC layer (based on European practice)

- Result: Reduced life-cycle costs (thicker lower-cost bottom layer with recycled aggregate, thinner high-quality surface layer) & Improved sustainability.
- Final products: Improved design and construction guidelines available

Composite Pavement Systems

- HMA over PCC



R21

- PCC over PCC

BENEFITS:

- Provides long-life with excellent surface characteristics, but also allows for repaid renewal when needed.
- Economical, sustainable pavement structures that use can use recycled materials or locally available materials.

PRODUCTS: Up-to-date guidelines, techniques and specs to greatly advance the state of practice. Includes detailed recommendations for inputs to DARWIN-ME design guide.

SHRP2 Project R05 (2008 – 2012)

Improving Precast Concrete Pavement Technology

- Overall findings.
- Findings based on field testing.
- Guidelines for PCP design.
- Guidelines for PCP fabrication.
- Guidelines for PCP installation.
- Guidelines for PCP project selection.
- Guidelines for PCP system acceptance.
- Model specifications.

SHRP2 Concrete Pavement Products

Construction-time smoothness management

The purpose of this project was to enable real-time control of concrete pavement smoothness during construction by measuring smoothness in real time

- ***Result:*** Improved long-term pavement performance and reduced pavement life-cycle maintenance and repair costs; improved QC of new pavements by paving contractors; reduced vehicle operating costs & safer and smoother roads for traveling public.
- Final products: Validation of the use of GOMACO GSI and Ames RTP systems

SHRP2: Real-Time Smoothness Measurements on PCC Pavements

Benefits:

- Provides real-time information for process control of smoothness
- Allows for immediate adjustments to equipment and operations
- Minimizes pavement grinding and remediation
- Better quality control
- Potentially better long-term performance

R06 E

Non-Destructive Testing Tools

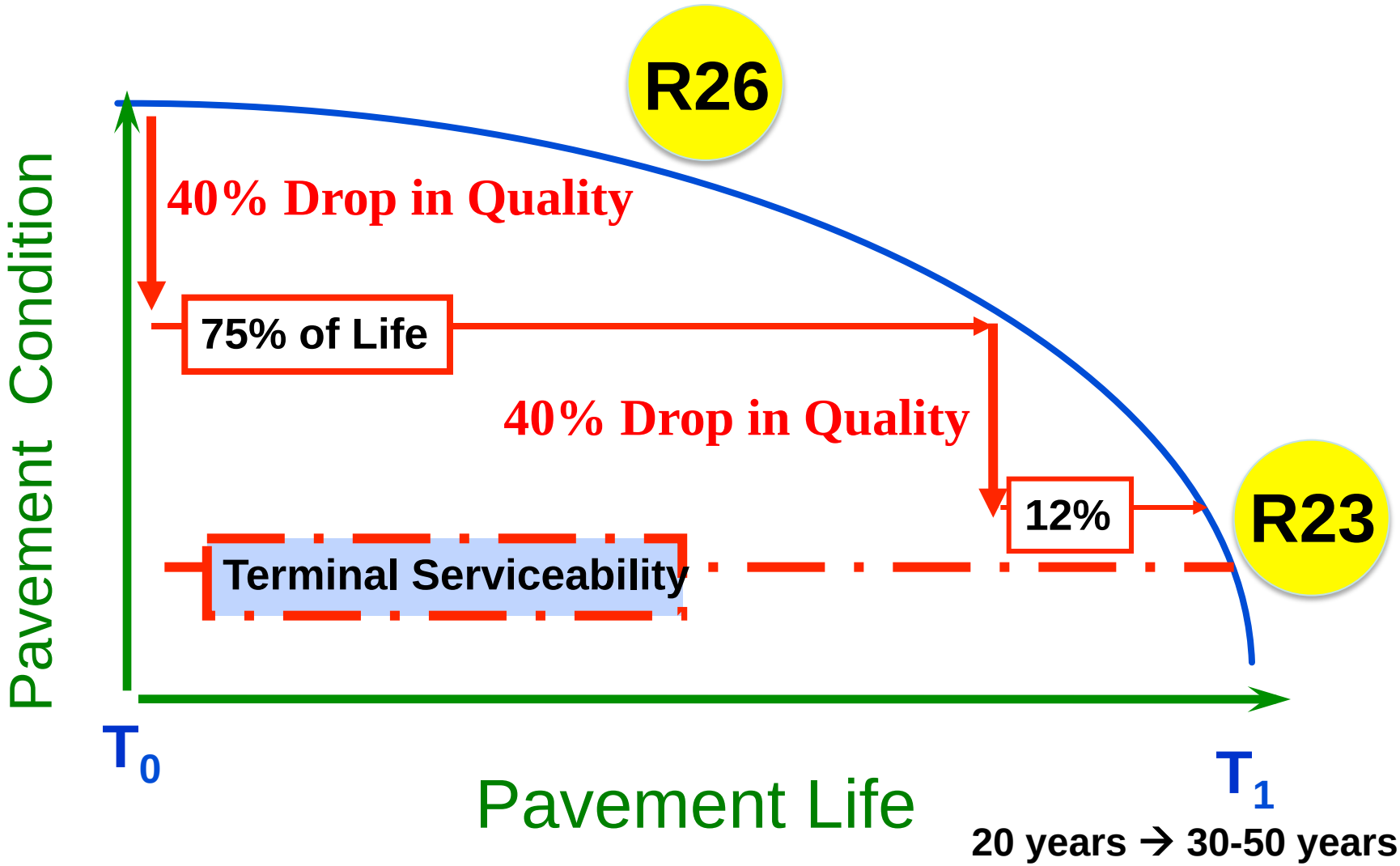
SHRP2 Concrete Pavement Products

Extending life of existing pavements

The goal of this project was to develop reliable procedures that identify when existing pavements can be used in place and the methods necessary to incorporate the original pavement into the new pavement structure while achieving long life.

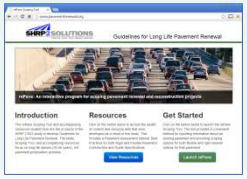
- Result: Reduced costs and shorter construction period by reuse of existing pavement, increased construction productivity & reduced traffic impacts and increased safety.
- Final products: Web-based improved design and construction guidelines available

Pavement Deterioration Curve



SHRP2 R23 Pavement Renewal Solutions

www.pavementrenewal.org

Product	Benefits
 ***rePave* Scoping Tool**	✓ Will encourage longer lasting designs. ✓ Realistic scoping assessments and easy to use. ✓ Guides user through data gathering process.
 **Project Assessment Manual (including Life Cycle Assessment, Traffic)**	✓ Combines traditional rehabilitation data needs with up-to-date tools such as CA4PRS (construction productivity and work zones).
  **Best Practices: Flexible and Rigid**	✓ Document practices that are critical for designing and constructing long lasting pavements. ✓ Combine key practices with specifications.
 **Guide Specifications**	✓ Specification elements can be incorporated in preexisting agency standard specifications.
  **LCCA, Emerging Technologies**	✓ Encourage use of LCCA. ✓ Create awareness of emerging pavement technologies.

SHRP2 Concrete Pavement Products

Pavement preservation

- The objective of this project was to provide guidance for more effectively matching the pavement condition and other considerations with suitable treatments for preserving high-traffic-volume roadways.
- Result: Improved long-term pavement performance and reduced pavement life-cycle costs by optimized system preservation through improved strategies
- Final products: Best practices guidelines for evaluating existing pavements and for preservation treatments

Some Examples of Recent Developments Improve Concrete Pavement Practices

Construction related

1. Performance related specifications

US Efforts to Develop Better Construction Processes

- The future is end product specifications/PRS
  - US moving away from prescriptive specs
- End product specs & PRS enable clear definition of critical paving processes/outcomes & incorporate more rational pay factors
  - Processes are objectively defined, are constructible, are not arbitrary & can be measured
  - Contractor responsible & accountable for end product
  - Contractor process control prevents placement of marginal concrete and use of marginal construction processes
  - Penalties are set by estimating impact on performance

Performance-Related Specifications

"PRS are QA specifications that describe the desired levels of key materials and construction quality characteristics that have been found to correlate with fundamental engineering properties that predict performance"

"PRS employ the quantified relationships containing the characteristics to predict as-constructed pavement performance. ***They thus provide the basis for rational acceptance/pay adjustment decisions****."*

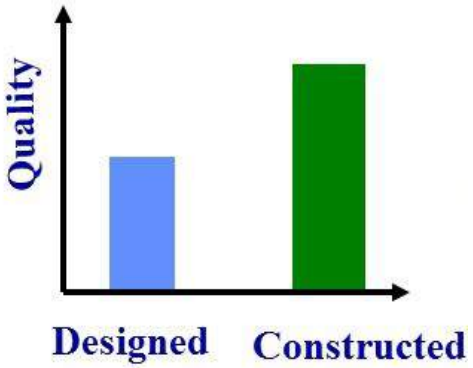
Transportation Research Circular Number E-C137
Glossary of Highway Quality Assurance Terms

PRS Lot by Lot Basis

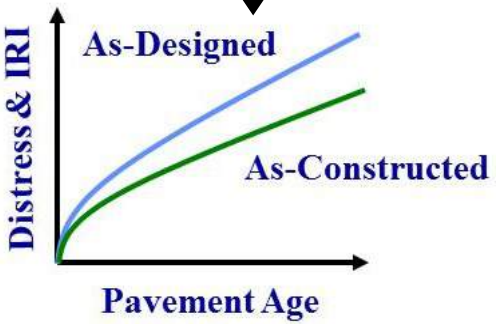
PAVESPEC

Establish Performance Criteria

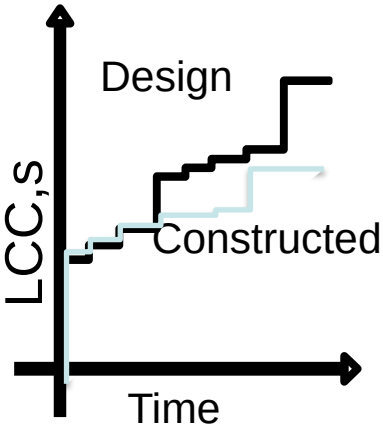
Identify AQCs and Target Values



Design AQC vs. As-Constructed AQC



Model ME Performance



Compare As-Built and As-Designed

M&R Plan

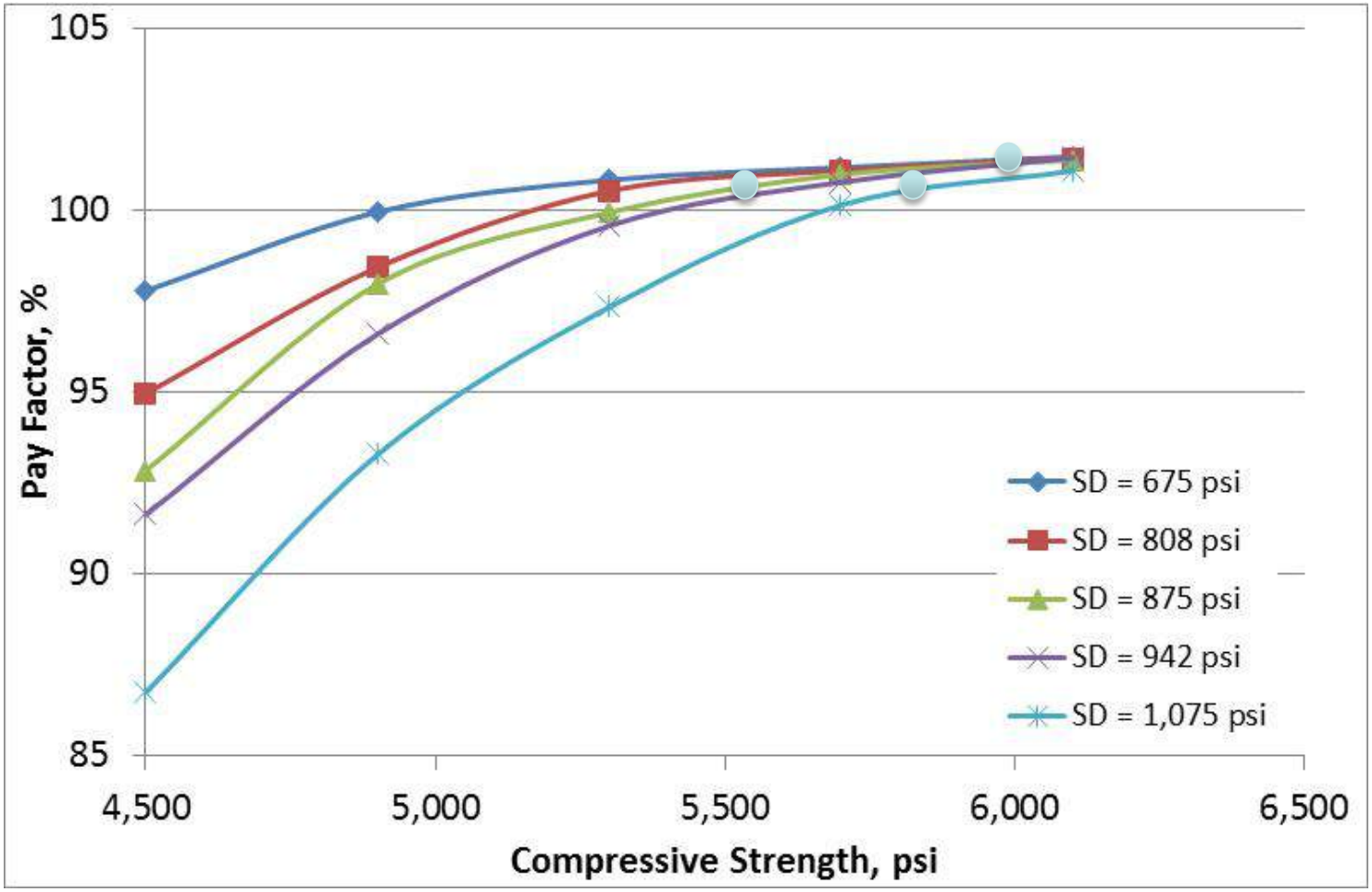
Pay Factor f(ΔLCC)

PaveSpec 4.0 Software
(with MEPDG Models and AQCs)

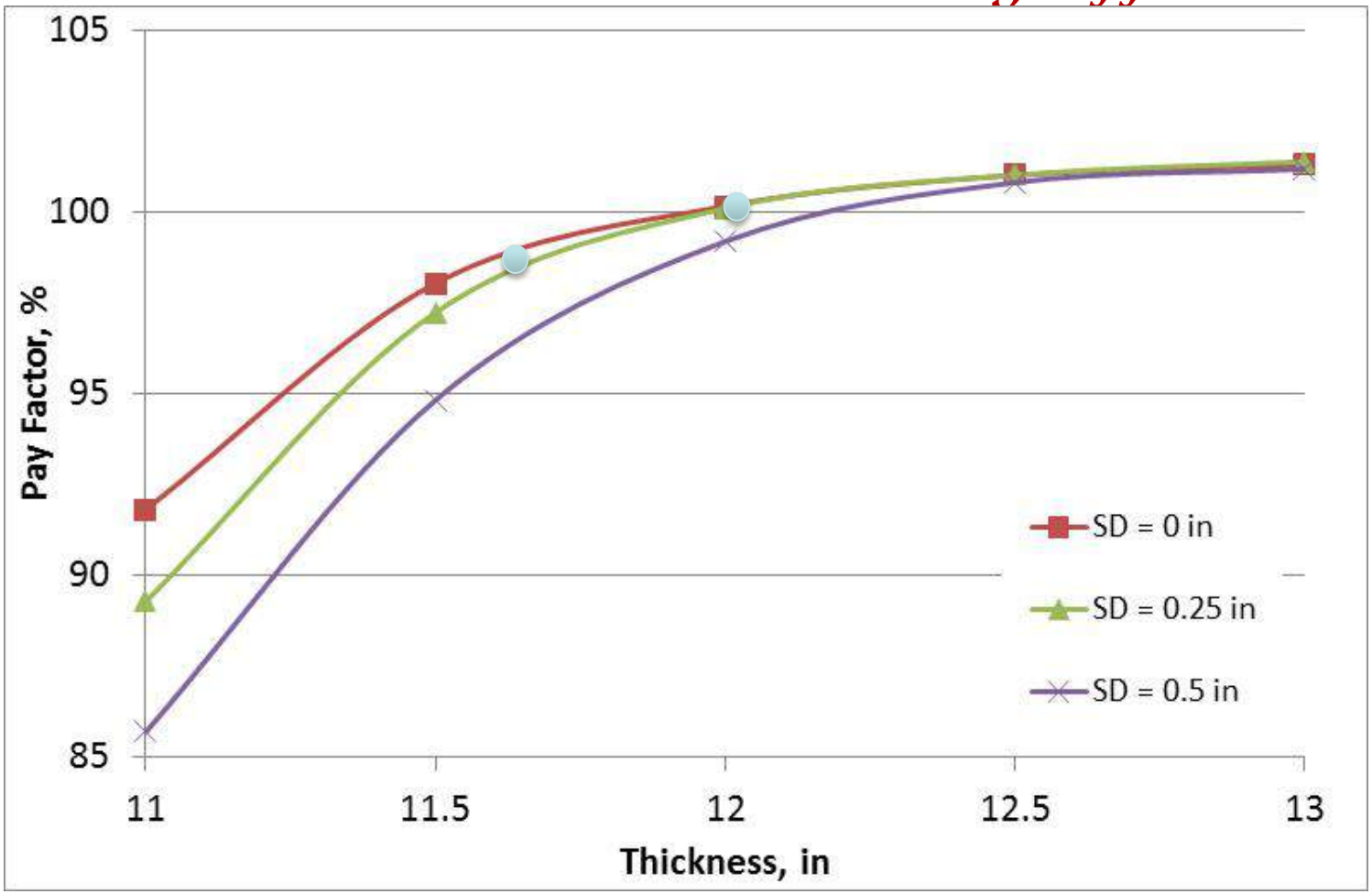
Input	Significantly Impact Distress			
	Transverse "Slab" Cracking	Transverse Joint Faulting	Transverse Joint Spalling	Smoothness
Initial Smoothness	X	X	X	X
PCC Strength	X			X
PCC Thickness	X	X	X	X
PCC CTE	X	X		X
Effective Dowel Diameter*		X		X
PCC air content			X	X
PCC mix w/c ratio	X	X	X	X

CTE: coefficient of thermal expansion

Illinois Tollway Shadow Implementation - Strength Variability Effect



Illinois Tollway Shadow Implementation - Thickness Variability effect



Some Examples of Recent Developments Improve Concrete Pavement Practices

<u>Surface texture related</u>

- ***US: NGST***
- ***Australia: LNDGT***

Surface Texture Development

(for safety & now for low noise)

1920s-1970s
Brooming/Burlap Drag

1970s
Transverse & Longitudinal Tining
Turf Drag
Grooving/Grinding (existing)

1990s
Random
Tining

1990s
Exposed Aggr.
Grind *(new)*

1920 1960 1970 1980 1990 2000

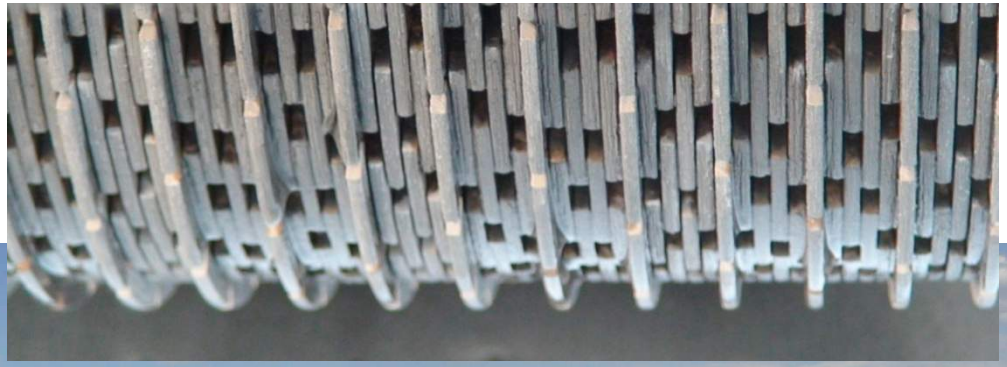
Concrete Texturing – New for US

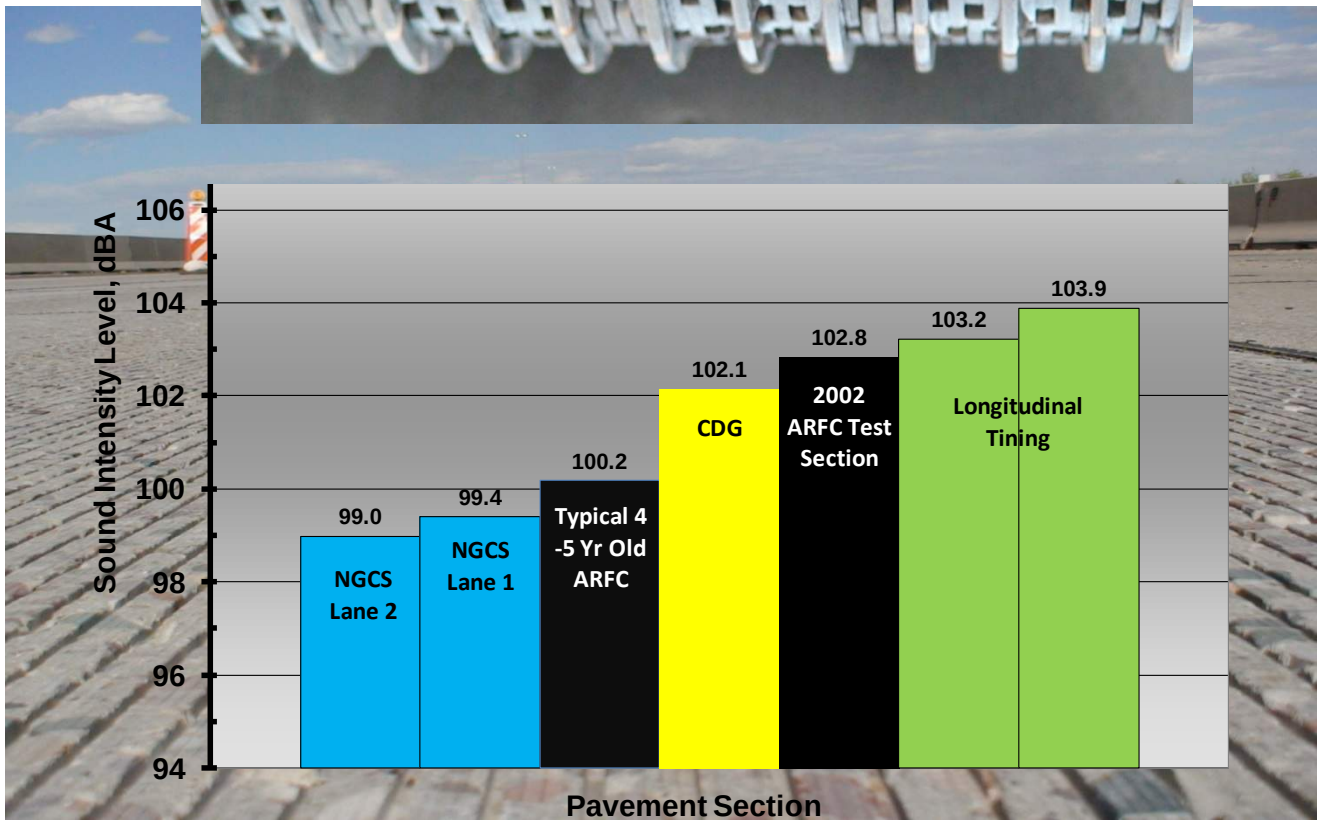
(enhanced safety & low noise surface)

- Addresses noise concerns in urban areas
- Conventional grinding for new
- Under development
  - Next generation surface texture (grinding)
  - 2 Step process – flush grind & grooving
  - Grooving: 3.2 mm by 3.5 mm by ~15 mm

Next Generation Concrete Surface

(Shallow grinding & grooving)

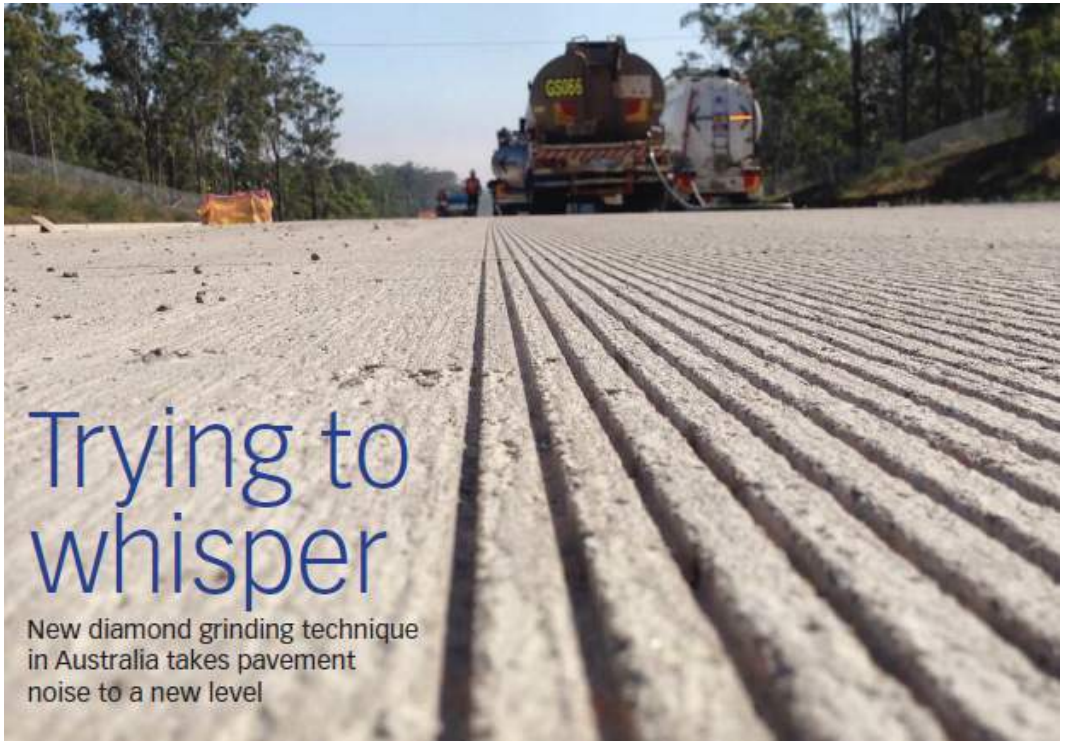




Australian Low Noise Diamond Ground (LNDG) Surface

(Burlap drag & grooving)

- Average texture depth: 1.1 to 1.6 mm



Summary

- We have the engineering know-how to design & construct concrete pavements that are durable/ long-lasting & sustainable, ***but we need to apply this knowledge consistently***
  - Pavements that are not durable/long-lasting ARE NOT sustainable
- So, we need to continue to refine our processes and materials to ensure high probability of long-term good performance, as designed for.

Thank You!

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