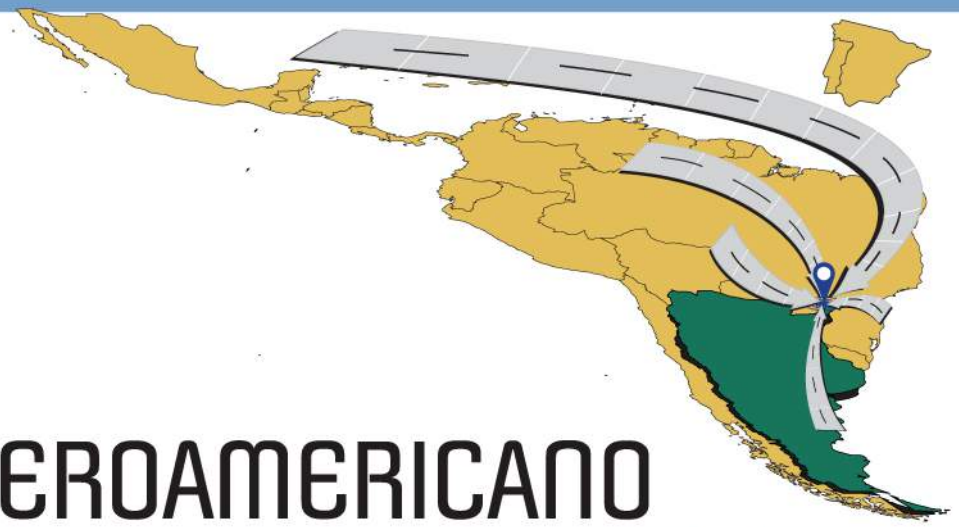

6º CONGRESO IBEROAMERICANO de Pavimentos de Hormigón

Puerto Iguazú, Argentina

23 y 24 de abril de 2015

Organizan:

Federación Iberoamericana del Hormigón Premezclado

ASOCIACION ARGENTINA del HORMIGON ELABORADO

Co-sponsor:

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Impact of Construction Quality on Durability of Concrete Pavements

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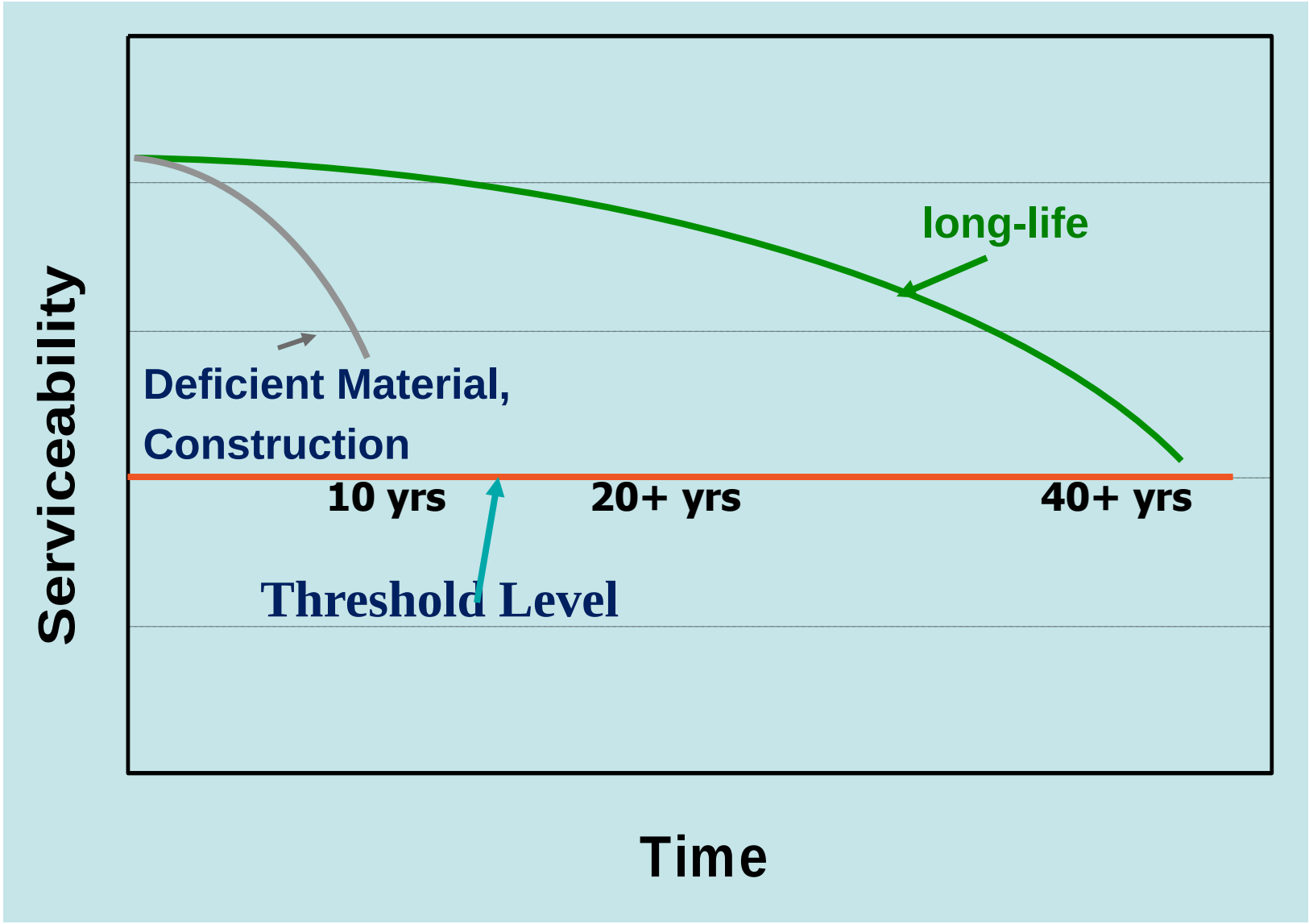
Do We Have Construction Quality Issues?

- Is our end product well defined & constructible?
- Do our constructed concrete pavements result in as-expected end product – as constructed & wrt in-service performance?
- What are some of the common issues that put a concrete pavement project in jeopardy?
  - Poorly developed spec; end product not defined well; plans and specifications misunderstood by contractor

Concrete Pavement Performance: Some Questions?

- Do we have concrete pavement durability or long-term performance issues?
  - If yes, are these issues related to design deficiencies or construction quality?
- Do we have construction quality issues?
  - **Are specs constructible? Can end product requirements be achieved?**
- What good are specs if they are not enforced and/or not followed?

Quality vs. Pavement Performance



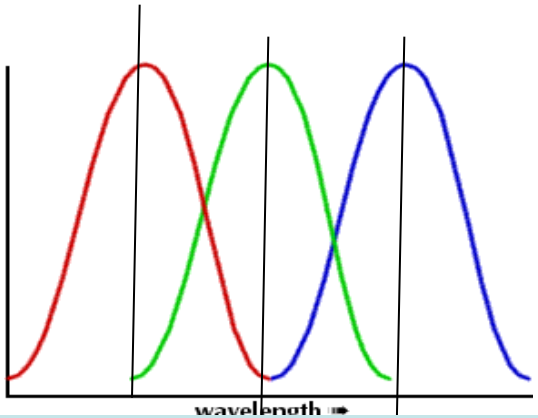
Impact of Poor Construction Quality

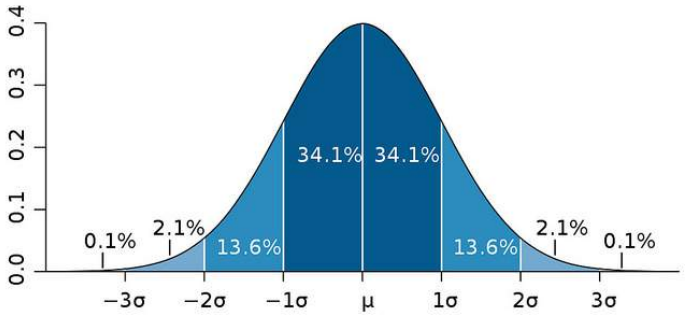
- For the owner/agency: Frequent maintenance & repairs ➔ Higher costs
- For the contractor: Cost of removal and replacement & cost of litigation ➔ Higher cost
- For the users: Congestion, more accidents; higher vehicle operating costs ➔ Safety & rough roads
- For the economy: Congestion, higher costs for goods & services ➔ Economic slow down

EVERY SEGMENT OF ECONOMY LOSES WHEN WE CONSTRUCT POOR QUALITY OF ROADS THAT DO NOT LAST LONG WITHOUT SIGNIFICANT MAINTENANCE & REPAIR

Presentation Outline

- Concept of Quality
- Concept of Durability
- Concrete Pavement Durability Indicators
- Quality Considerations for Durable Concrete Pavements
- Ensuring Quality (thru good specs/PRS)





Achieving target **and** **Minimizing variability**

Concept of Quality

- What is “quality”?
  - In its broadest sense, quality is a degree of excellence: the extent to which something is fit for its purpose.
  - In the narrow sense, product or service quality is defined as conformance with requirement, freedom from defects, or simply a degree of customer satisfaction.
  - Quality can also be defined as the totality of characteristics of a product or service that relates to its ability to satisfy objectively defined stated needs

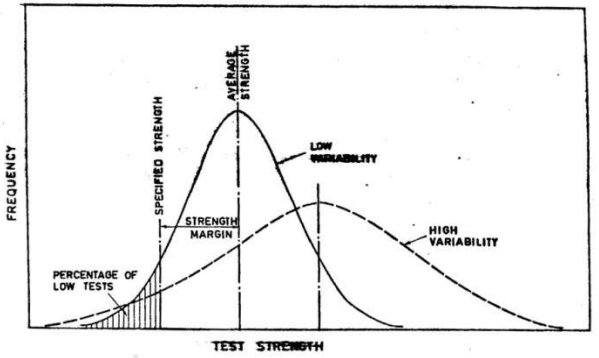
What is Construction Quality?

- For construction projects, achieving quality work equates to conformance to requirements
  - **Requirements need to be well defined, can be measured, and are not arbitrary**
- Owner should not expect more than what is specified
- Contractor most likely will not deliver more than what is specified
- **Quality cannot be defined qualitatively**

Construction Specification Objective

- Quality is defined thru construction plans and specification
- Plans & specifications define the end product and try to minimize variability in the concrete pavement construction process
  - To deliver an end product that is **“durable” and meet design expectations**
  - To minimize **risk** of premature failures
  - To minimize owner’s **risk** of accepting a marginal product
  - To minimize contractor’s **risk** acceptable product

Good Plans & Specs lead to Good Construction!



Fundamental Assumption

- A fundamental assumption made during the preparation of plans and specifications for an pavement project is that **a quality pavement performs well.**
  - Quality, objectively defined, is an inherent property of a well-constructed pavement.
  - Good materials and construction practices are necessary for producing high quality and long lasting concrete pavements.
  - Even if a pavement is designed to the highest standards, it will not perform well if it is not constructed well.

Quality vs. Construction Variability

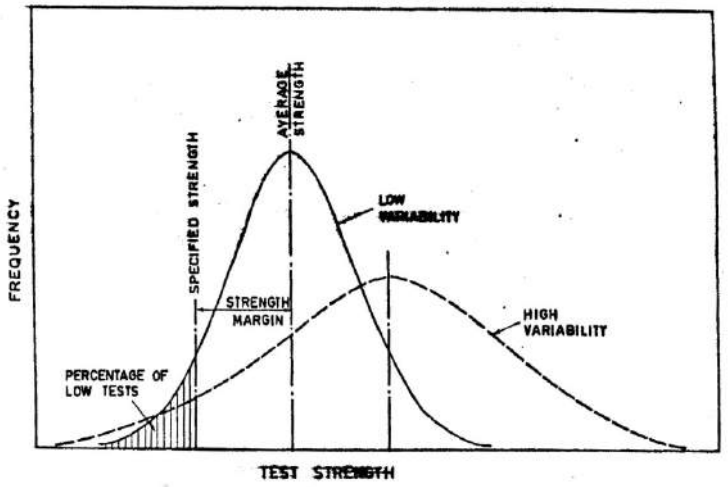
- Variability is an inherent part of construction.
  - Material, Process, and Testing (precision and bias)
- All sources of variability have a negative impact on the property being measured.
- Need to understand the magnitude of the different sources of variability
- Quality construction requires control over all sources of variability.

Reasonable Levels of Quality (In terms of acceptable standard deviation (variability))

- Subgrade Density: 20 to 50 kg/m3 (1 to 3 pcf)
- Concrete Thickness: 6 to 15 mm
- Concrete Flex Strength: 0.30 to 0.40 MPa
- Concrete fc: 3 to 4.5 MPa

Higher levels of variability ➔ construction process is not under control (and/or testing procedures are marginal)

End result: poorly performing pavement



Plans & Specification Role - Avoiding Early Failures & Ensuring Long Life

Pavement failure should be a result of structural distress (repeated truck loadings) and not due to concrete material, support or construction related defects

Quality in Concrete Pavement Construction Process

- The general rigid pavement construction procedure involves (sequentially):
  - Construction materials selection and procurement
  - Subgrade, subbase, and base preparation
  - Concrete production
  - Concrete placement, consolidation, and finishing
  - Concrete texturing and curing and
  - Joint sawing and sealing.

- **Quality construction, as defined by plans and specifications, is important at all stages of the construction process**
- **All processes affect pavement durability and serviceability, some less, some more**

Key Construction Quality Items

- Concrete strength (for early opening)
- Slab thickness (non-destructive/rapid)
- Profile/ride (correct paving process)
- Air content (behind paver)
- Dowel bar alignment (behind paver/rapid)
- Premature cracking (eliminate)

Ideal Testing ➔ Behind paver, not in front of paver

Contractor Process Control

- Ideal contractor process control (QC) limits or eliminates placement of marginal concrete & use of marginal construction processes
  - Do not produce concrete if aggregate gradation not met
  - Reject concrete loads if requirements not met
  - Stop paving if placement 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

Contractor must have his process under control!

Acceptance Testing

- Intent of testing is not to discriminate absolutely between good and bad end product
  - Otherwise, we would be testing every cy of concrete and every sy of the pavement
- Intent is to discriminate sufficiently to minimize
  - Contractor's risk of good end product being rejected
  - Owner's risk of a bad end product being accepted
- Balance is maintained by type & extent of testing and rules used to accept test results

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
  - Preferably rapid nondestructive testing
- Test for end product metrics
  - Slab thickness
  - Concrete strength
  - Concrete durability – air content/ denseness
  - Smoothness & texture
  - Dowel bar alignment (?)
  - Early age distress

Ideal Testing ➔ In finished pavement

Concept of Durability

- Durability is the ability to last a long time (design period) without significant deterioration. For concrete pavements, we consider two aspects of durability
  - o Concrete durability
  - o Concrete pavement durability, typically referred to in terms of long-life

Concrete Durability

- It is the ability of the concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties.
  - Different concretes require different degrees of durability depending on the exposure environment and the properties desired.
  - Concrete ingredients, their proportioning, interactions between them, placing and curing practices, and the service environment determine the ultimate durability and life of the concrete.

Concrete Durability Indicators

- Strength
- Aggregate quality (by specification)
- Air content (for freeze/thaw damage mitigation)
- Concrete consolidation
- Concrete permeability (concrete denseness)

A Definition of Durable (Long-Life) Concrete Pavements

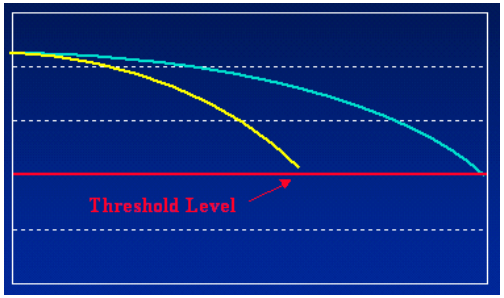
- Original PCC surface service life – 40+ years
  - **The next frontier – 60+ years service life**
- Pavement will not exhibit premature failures and materials related distress
  - **Pavement failure should be a result of traffic loading**
- Pavement will have reduced potential for cracking, faulting & 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

Concrete Pavement Durability (Long-Life)

- Concrete pavement durability or long-life is the ability of the pavement to provide the desired service (objectively defined) over the design period without significant development of distress and need for lane closures for repairs.
- Indicators of concrete pavement durability are
  - Concrete durability
  - Joint durability (pumping & faulting ➔ f(deflections))
  - Slab durability (slab cracking ➔ f(stresses vs. strength))
  - Surface texture durability (friction ➔ f(texture))
  - Smoothness durability (ride quality ➔ f(initial smoothness & distress development))

Concrete Pavement Performance

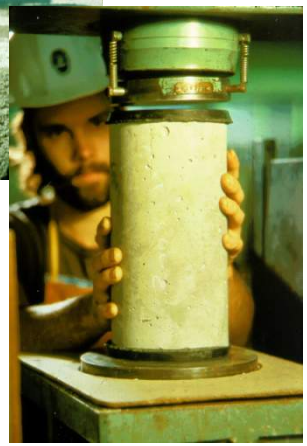
- At end of service life
  - 40+ years for primary system



Distress	Value
Cracked Slabs, %	10 - 15
Faulting, in.	0.15 to 0.25
Smoothness (IRI), in./mile	150 to 180
Spalling	Minimal?
Materials Related Distress	None

Concrete Pavement Durability Indicators

- Concrete strength
- Slab thickness
- Initial smoothness
- Dowel bar alignment at joints



Bad End Product Quality Definitions

- Not good examples quality definitions (subjective?)
  - o Durable concrete
  - o Good quality pavement
  - o Well-consolidated concrete
  - o Homogeneous concrete mixture
  - o No aggregate segregation
  - o Good surface texture
  - o Smooth surface
  - o Dowel bars properly aligned

Agency, contractor, and inspectors may have different expectations of what above means!

Good End Product Quality Definitions

- Good objective examples **& associated pay adjustments**
  - o Measured thickness
  - o Measured concrete strength
  - o Measured air system in concrete
  - o Measured smoothness (IRI)
  - o Measured texture (Average texture depth)
  - o Dowel bar alignment metrics
  - o Concrete durability surrogate tests (ASR, F/T, RCP, etc.)

Contractor knows what the agency wants!
He may not like it, but his bid includes cost associated with risk of not meeting requirements.

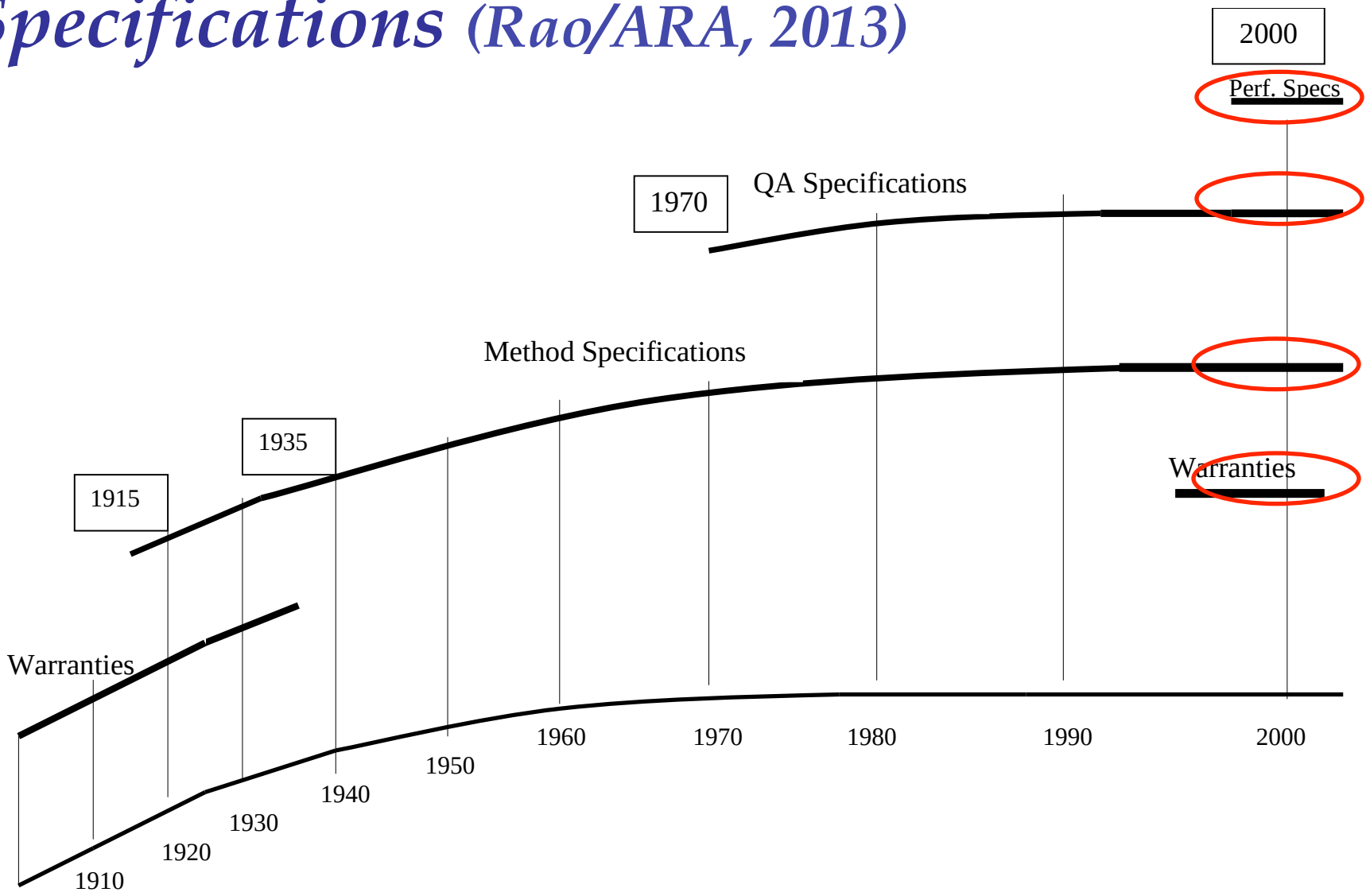
How Do We Ensure Quality in Construction

- By developing good plans and specifications
  - Move away from prescriptive/method specifications
  - Start with End Result Specifications (ERS)
  - Transition to Performance Related Specifications (PRS)
- By requiring use of durable materials
- By ensuring proper contractor process control (QC)
- By conducting necessary quality assurance (QA) testing to verify compliance with specification requirements

Concrete Pavement Construction Specs

- Traditional – prescriptive (method) spec
  - Construction process, individual paving raw materials requirements, and processed materials requirements are prescribed. Typically, penalties for not meeting requirements are set arbitrarily.
- Desired – end result or performance related spec
  - Defines required end product, the criteria to judge end product, and verification methods to evaluate the end product without requirements for how the end product is to be obtained. Typically, penalties for not meeting requirements are set by estimating impact on performance

Evolution Of Highway Construction Specifications (Rao/ARA, 2013)



PCC PRS History (Rao, ARA, 2013)

- FHWA sponsored PRS R&D since 1990's
- 1990 – 1993: PaveSpec 1.0
  - FHWA/U Illinois Prototype LCC-based PRS
- 1994 – 1997: PaveSpec 2.0
  - Initial PRS Developed; 4 Shadow Field Trials
- 1997 – 2006: PaveSpec 3.0
  - Improved Performance Prediction Models
  - Local Procedures and Guidelines
  - Several PRS projects constructed
- 2013-2015: PaveSpec 4.0 Under Development

Performance Specs

- ERS – Contractor responsible for producing the end result
  - Agency accepts or rejects end product and may apply a pay adjustment for non-compliance
  - Contractor has greater flexibility in performing work
  - Some prescriptive requirements to account for characteristics that cannot yet be defined objectively
- PRS – Construction quality characteristics are related to predicted performance and life cycle costs thru models

Performance Spec Needs

- Quality levels or engineering properties that can be related to pavement distress/performance
- Test to measure the quality levels/engineering properties
- Criteria for accepting/rejecting quality levels/ engineering properties
- Testing plans (statistical) to measure compliance
- Price adjustments for failure to comply
  - **BASIS FOR PRICE ADJUSTMENT?**

ERS/PRS

- The key components of a well-developed ERS/ PRS include the following:
  - Requirements for the product end result
  - Contractor's quality control (process control) plan
  - Acceptance (verification) testing
  - A reasonably rational basis for pay adjustments for most requirements
- In ERS/PRS, quality of the product is ensured (quality assurance) by quality control tests performed by the contractor and acceptance tests conducted by the agency.

End Product Requirements
(Example: NCPTC Guide Spec (2012))

- Preemptive steps
  - Reject marginal concrete materials (at plant)
  - Reject marginal concrete (at site)
  - Stop using marginal paving processes (at site)
- Pay metrics (hardened concrete)
  - Slab thickness (pay adjustment)
  - Concrete strength (pay adjustment)
  - Smoothness (corrective work/pay adjustment)
  - Air content (pay adjustment)
- Corrective work
  - Premature joint spalling/premature cracking
  - Surface texture - grinding

Other End Product Requirements

- Concrete
  - Air system parameters – hardened concrete (MTO) – pay adjustment
- Pavement
  - Dowel alignment – pay adjustment/PWL (MTO/Illinois Tollway)
  - Surface texture – corrective work (grinding)

The contractor is entirely responsible for materials and processes that produce the end product!

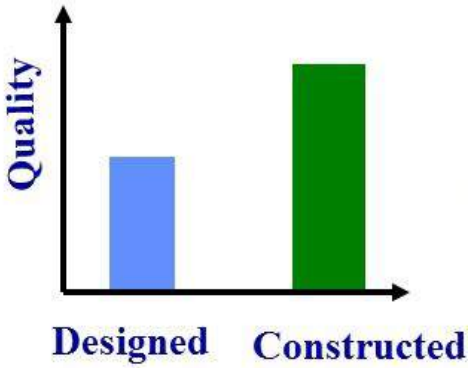
Processes, including concrete mixture, are proprietary to contractors!

PRS Lot by Lot Basis

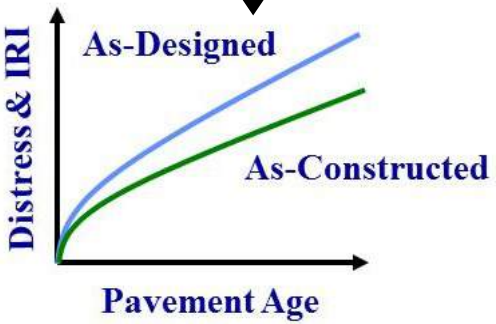
PAVESPEC

Establish Performance Criteria

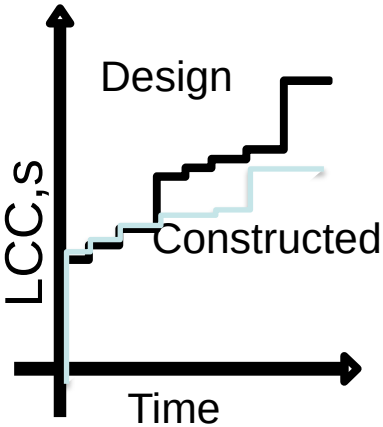
Identify AQCs and Target Values



Design AQC vs. As-Constructed AQC



Model ME Performance



Compare As-Built and As-Designed

M&R Plan

Pay Factor f(ΔLCC)

Ensuring Quality to Improve Concrete Pavement Durability

- Subgrade/subbase/base
  - Required compaction and strength properties, as needed
- Concrete
  - Aggregate selection
  - Cementitious materials selection
  - Concrete mixture design
  - Managing water/cementitious materials (w/cm) ratio
  - Concrete consistency from batch to batch
  - Concrete strength (and air content)
  - Concrete shrinkage
  - Concrete coefficient of thermal expansion

Ensuring Quality to Improve Concrete Pavement Durability

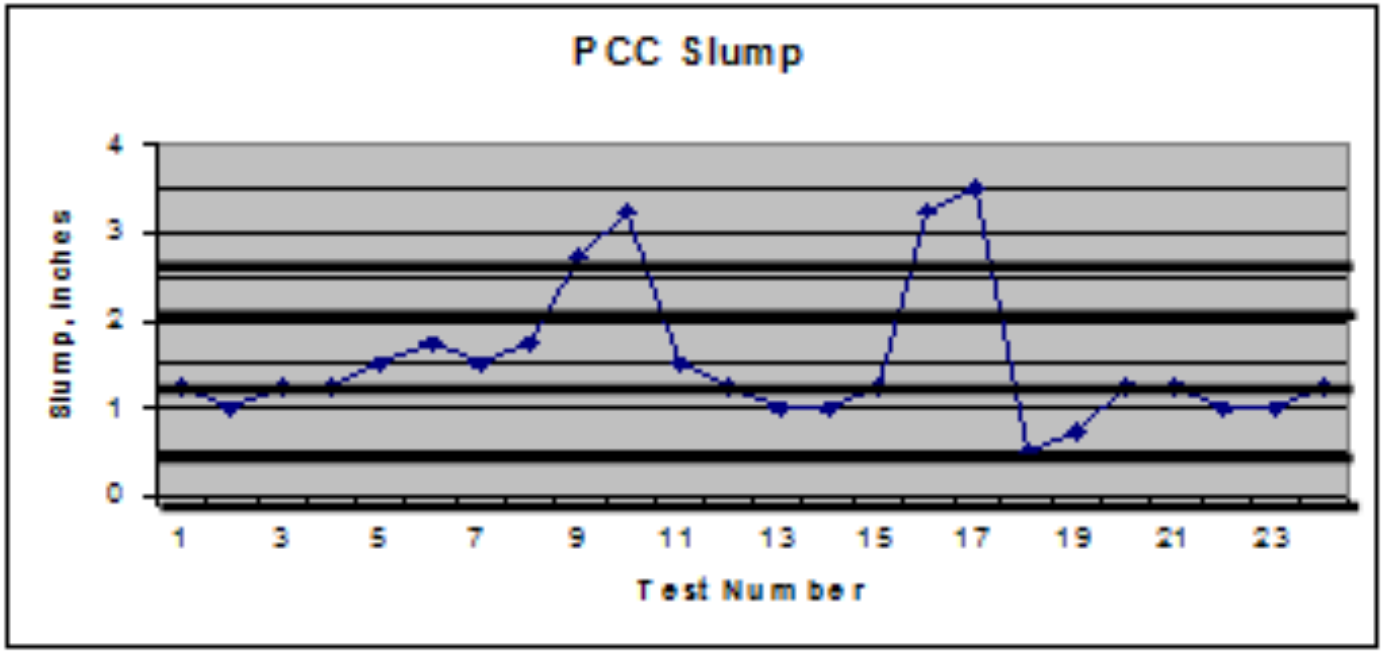
- Concrete placement, consolidation & finishing
  - Homogeneous mixture behind paver (no segregation)
  - Required consolidation (density/unit weight)
  - Just enough surface finishing to ensure smoothness
  - Ensure required thickness
  - Ensure required cross-sectional geometry (no edge slump)
  - Ensure dowel bar alignment

Ensuring Quality to Improve Concrete Pavement Durability

- Concrete texturing
  - Proper/timely tining (depth & spacing)
- Concrete curing
  - Proper/timely curing
  - Avoid extreme conditions (hot/windy)
- Joint sawing
  - Proper/timely joint sawing
- Eliminate early age failures
  - Plastic shrinkage cracking
  - Full-depth cracking
  - Joint spalling (during joint sawing)

Ensuring Quality to Improve Concrete Pavement Durability

- Other factors
  - Development of a project specific Quality



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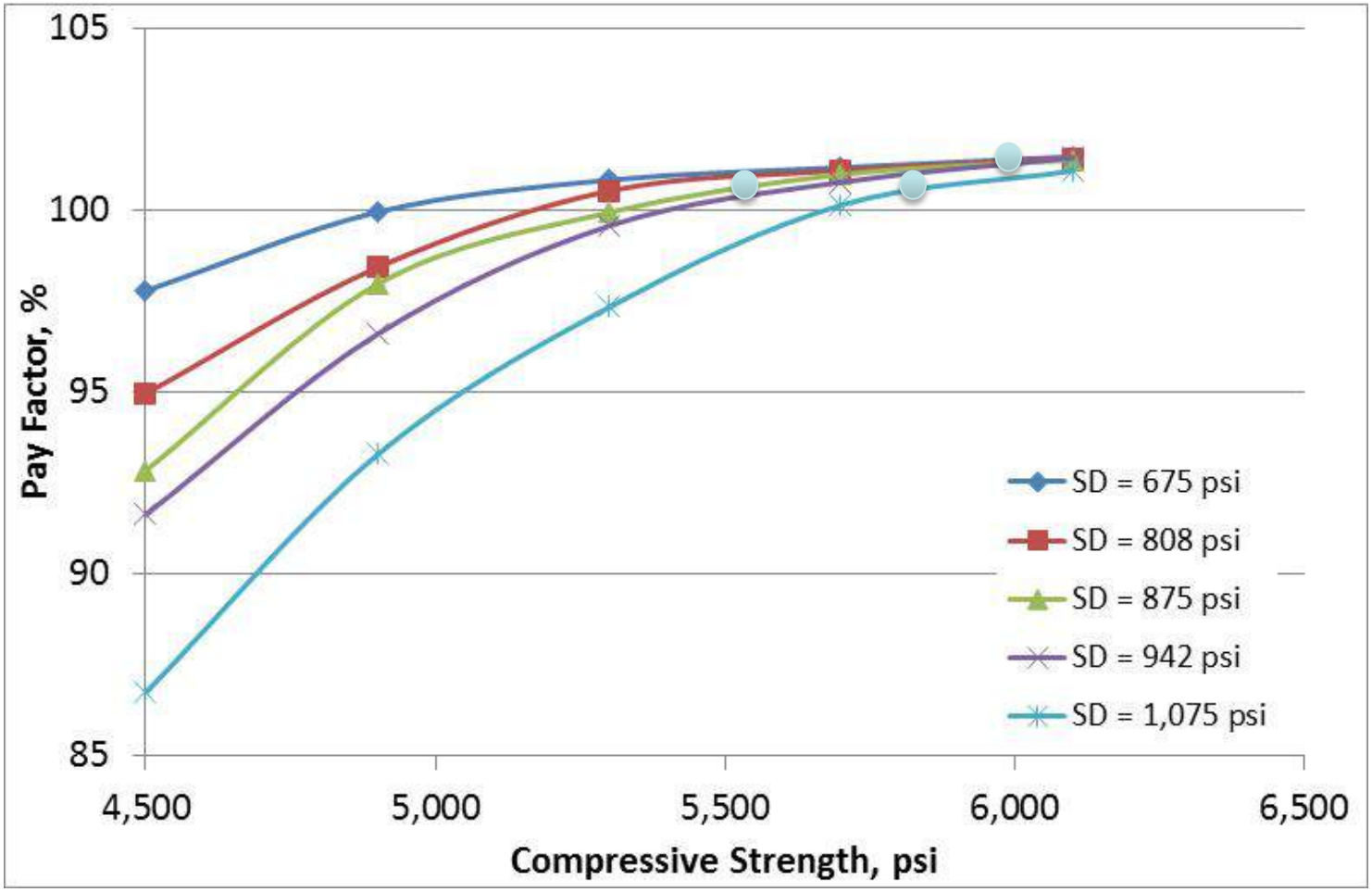
e key

    - **Understanding of penalties for poor quality of work**
  - Good record-keeping of construction related data
  - Use of process control charts to ensure processes are under control

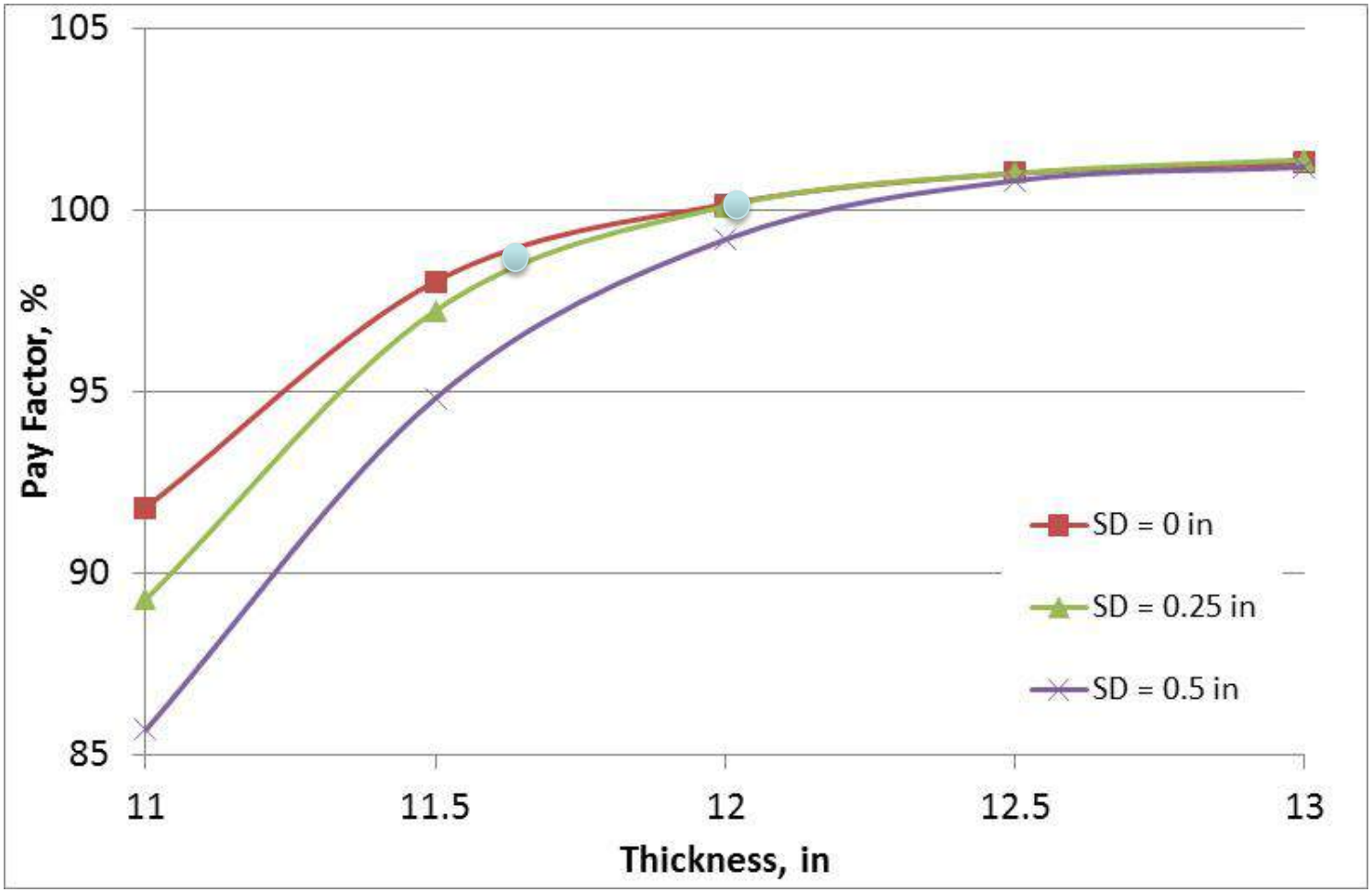
Determining Impact of Quality Concrete Pavement Durability

- Impact of concrete strength and slab thickness can be determined reasonably well using analysis/design procedures (AASHTO Darwin, ACPA StreetPave, AASHTO ME Design (MEPDG, etc.)
  - Low thickness ➔ reduced life
  - Low concrete strength ➔ reduced life
- Soon, PRS software can be used to more objectively determine impact on service life in terms of slab cracking and faulting and smoothness ➔ Penalties for poor quality can be rationally be assessed

Illinois Tollway Shadow Implementation - Strength Variability

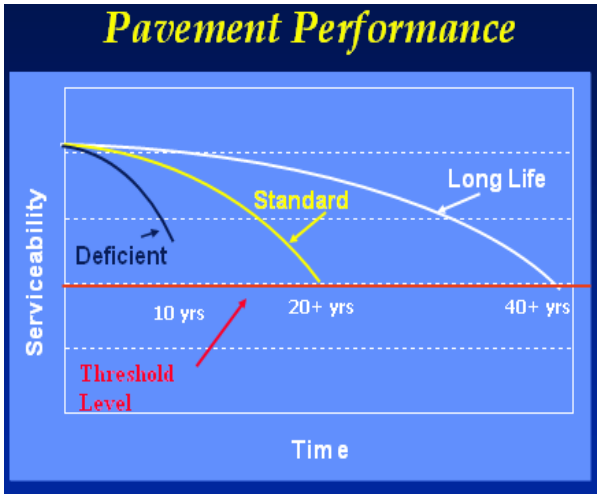


Illinois Tollway Shadow Implementation - Thickness Variability



Summary - Cost of Poor Quality

- For highway agencies
  - Traffic congestion & accidents
  - Reduced service life
  - Higher life cycle costs
- For contractor
  - Corrective measures
  - Partial payments
  - Cost of claims (litigation)
- For the users
  - Unsafe roads & congestion
  - Costs



Really, it does not require much effort to ensure good construction

Thank You!

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