Effective Pavement Program Management for Cities and Counties

John Harvey, PhD, P.E.
Erik Updyke, P.E.
Public Works Officers Institute
March 8, 2023

LEAGUE OF CALIFORNIA CITIES

COUNTY ENGINEERS ASSOCIATION OF CALIFORNIA FOUNDED 1914

City and County Pavement Improvement Center

CCPIC Mission and Vision

- **Mission**
  - CCPIC works with local governments to increase pavement technical capability through timely, relevant, and practical support, training, outreach and research
- **Vision**
  - Making local government-managed pavements last longer, cost less, and be more sustainable

City and County Pavement Improvement Center

- Sponsored by the League of California Cities, County Engineers Association of California, and the California State Association of Counties
- Chartered September 28, 2018

City and County Pavement Improvement Center

- **University of California Partners**
  - University of California Pavement Research Center (lead)
  - UC Berkeley ITS Tech Transfer
- **California State University Partners**
  - CSU-Chico, CSU-Long Beach, Cal Poly San Luis Obispo

CCPIC Organization

- **Governance**
  - Governance Board consisting of 6 city and 6 county transportation professionals
- **Current Funding**
  - Seed funding from SB1 through:
    - Institute of Transportation Studies at UC Davis, UC Berkeley, UC Los Angeles, UC Irvine
    - Mineta Transportation Institute at San Jose State University

CCPIC Scope

- **Technology Transfer:**
  - Training courses
  - Pavement engineering and management and construction inspection certificate programs for working professionals through UC Berkeley ITS Tech Transfer
  - Outreach
- **Technical Resources:**
  - Technical briefs, guidance, sample specifications, tools, and other resources
- **Resource Centers:**
  - Outreach, questions, pilot study documentation, and forensic investigations
- **Research and Development:**
  - For local government needs that are not covered by State and Federal efforts
  - Adapting work done for Caltrans

Pavement Engineering & Management (PEM) Certificate Program

- **PEM Certificate Program Overview**
  - For engineers, asset managers, upper-level managers, technicians and construction inspectors
  - 88.5 hours of training
    - 56.5 hours in core classes, 32 hours in electives
    - Majority of classes to be offered online
  - In four categories:
    - Fundamentals
    - Management
    - Materials and Construction
    - Design

Pavement Engineering & Management Certificate: Curriculum

	Fundamentals	Hrs	Management	Hrs	Materials and Construction	Hrs	Design	Hrs
CORE 56.5 required	CCA-01 Introduction to Pavement Engineering and Management	10	CCB-01 Life Cycle Cost Analysis	4	CCC-01 Asphalt Concrete Materials and Mix Design	8		
	CCA-02 Pavement Sustainability	4	CCB-02 Pavement Management Systems and Preservation Strategies	10	CCC-02 Pavement Preservation Treatments, Materials, Construction, Quality Assurance	8		
					CCC-03 Pavement Construction Specifications and Quality Assurance	12.5		
56.5	**Fundamentals, CORE**	14	**Management, CORE**	14	**Materials and Construction, CORE**	28.5	**Design, CORE**	0
ELECTIVE 32 required 84 offered			CCB-21 Financing and Cash Flow for Pavement Networks	4	CCC-21 Concrete Materials & Mix Design	8	CCD-21 Asphalt Pavement Structural Section Design	8
			CCB-22 Integrated Asset Management for Multi-Functional Pavements	8	CCC-22 In-Place Recycling	8	CCD-22 Design, Construction, and Maintenance of Interlocking Concrete Pavers	6
					CCC-23 Gravel Roads Engineering, Construction, and Management	8	CCD-23 Concrete Pavement Design	8
					CCC-24 Roadway Construction Phasing, Scheduling, and Traffic Control	4		
					MISC Classes from Pavement Construction Inspection Certificate curriculum			
					CCC-26 Pavement Construction Management	8		
					CCC-27 Asphalt Pavement Maintenance Construction	6		
					TS-10 Work Zone Safety	8		
84	**Fundamentals, ELECTIVE**	0	**Management, ELECTIVE**	12	**Materials and Construction, ELECTIVE**	50	**Design, ELECTIVE**	22
Total for Certificate 88.5 hours	**Fundamentals**	14	**Management**	26	**Materials and Construction**	78.5	**Design**	22

Pavement Construction Inspection (PCI) Certificate Program

- **PCI Certificate Program Overview**
  - For engineers, material testing technicians and construction inspectors
  - 80.5 hours of training
    - 68.5 hours in core classes, 12 hours in electives
    - Majority of classes to be offered online

Pavement Construction Inspection Certificate: Curriculum

	Core		Hrs
CORE 68.5 required	PD-01	Construction Inspection	16
	CCI-01	Asphalt Pavement Construction Inspection	4
	CCI-02	Concrete Pavement Construction Inspection	4
	CCI-03	Concrete Street Improvements Construction Inspection	4
	CCI-04	Pavement Preservation Construction Inspection	4
	CCC-02	Pavement Preservation Treatments, Materials, Construction, Quality Assurance	8
	CCC-03	Pavement Construction Specifications and Quality Assurance	12.5
	CCC-26	Pavement Construction Management	8
	TS-10	Work Zone Safety	8
68.5	**Core**		**68.5**
	Electives (choose 12 hours from list below)		**Hrs**
ELECTIVE 12 required 26 offered	CCC-22	In-Place Recycling	8
	CCC-24	Roadway Construction Phasing, Scheduling, and Traffic Control	4
	CCI-06	Construction Inspection of Asphalt-Rubber Pavement Materials	2
	PD-02	Construction Inspection of Traffic Signals	8
	TS-18	Excavation and Trenching Safety	4
12	**Electives**		**26**
80.5	**Total required for certificate**		

CCPIC Training: Upcoming Classes

Code	Title	Date/Cost
CCC-03	Pavement Construction Specifications and Quality Assurance	March 13 - 21, 2023/$240
CCB-02	Pavement Management Systems and Preservation Strategies	March 28 – April 5, 2023/$190
CCA-01	Introduction to Pavement Engineering and Management	May 1-10, 2023/$190

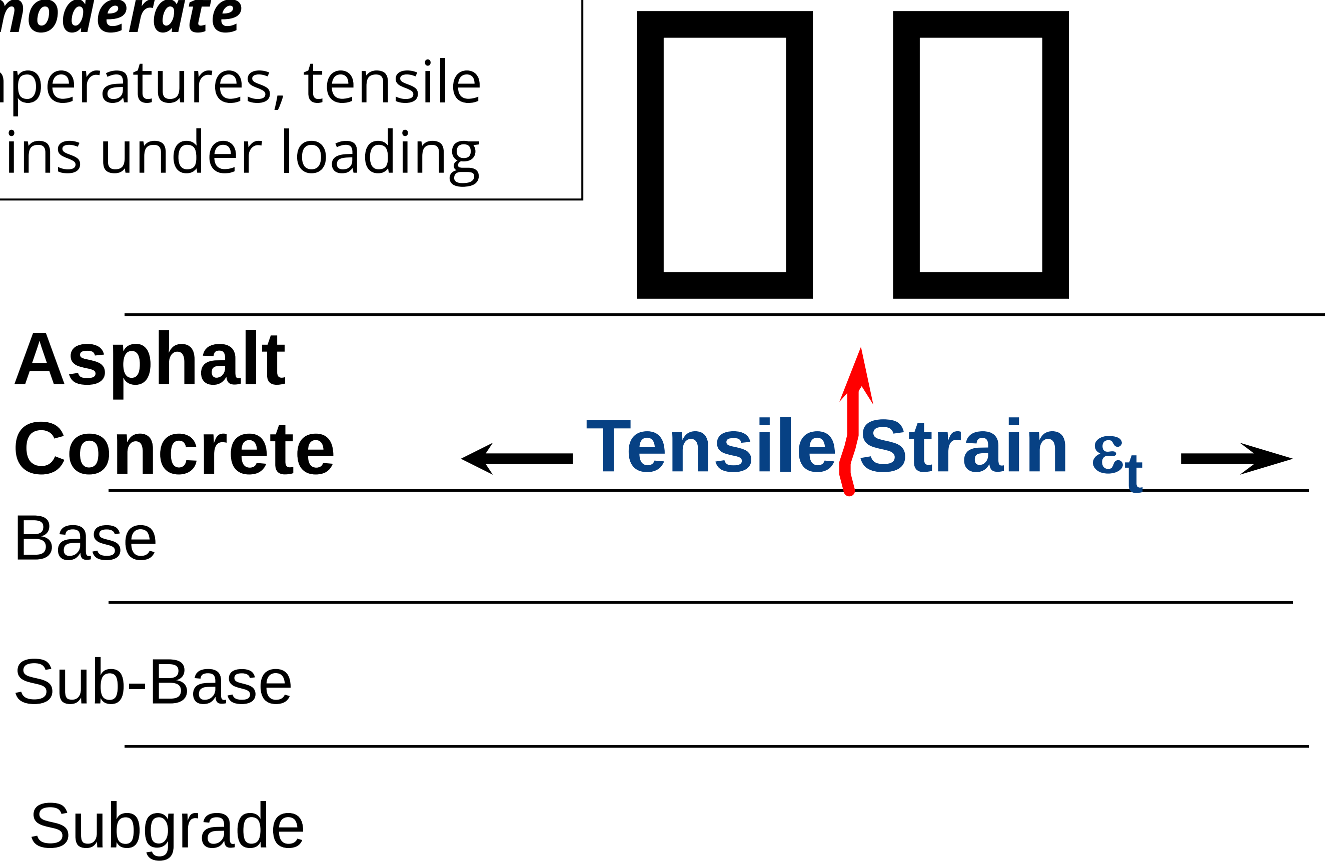
Pavement Distresses

Identifying Types to Better Manage Asphalt Pavement

City and County
Pavement Improvement Center

Bottom Up Fatigue Cracking

At ***moderate*** temperatures, tensile strains under loading



Load-Related: Bottom-Up Fatigue Cracking

- **Interaction** of asphalt concrete layer, support of underlying structure, materials selection, construction compaction
- **Traffic loading:**
  - Only the truck loads count, cars are too light
  - Slower speeds = longer durations = bigger strains
- **Environment:**
  - Temperature
  - Water sensitivity
  - Aging

Initial Wheel Path Cracking

- May be transverse or Longititudinal
- Distress descriptions can be seen in the ***FHWA Distress Identification Manual***

Cracks Connect: Alligator Cracking

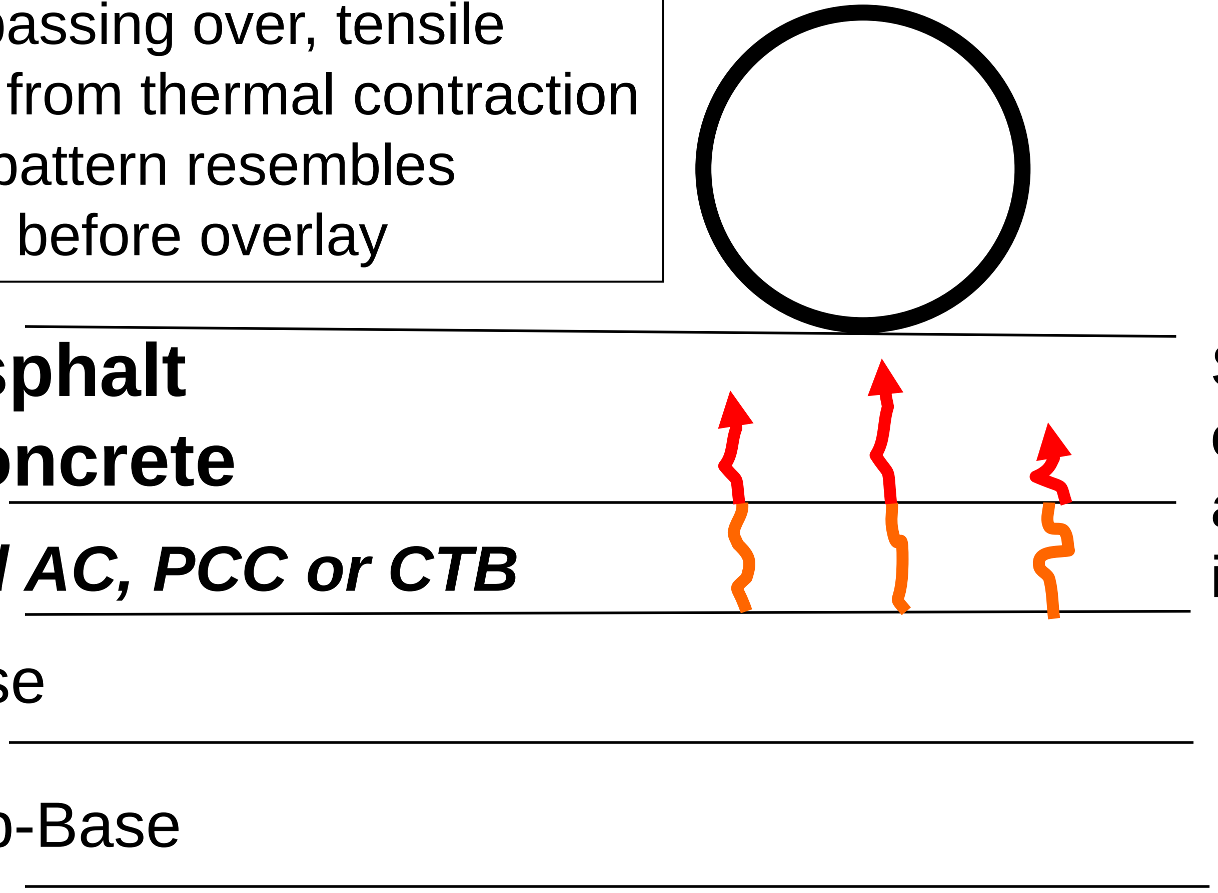
- Distress descriptions can be seen in the ***FHWA Distress Identification Manual***

Fatigue Cracking in Wheel Paths

- Distress descriptions can be seen in the ***FHWA Distress Identification Manual***

Reflective Fatigue Cracking

- Shear and tensile strains from loads passing over, tensile strains from thermal contraction
- Crack pattern resembles pattern before overlay

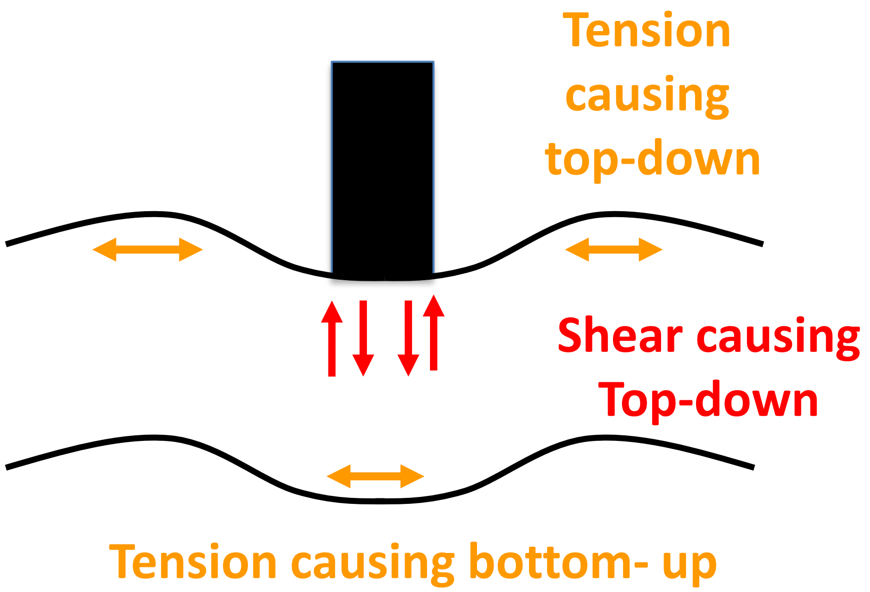


Reflective Cracking of Underlying Block Cracking and Longitudinal Joint, 7 Years Old

- **Avoid putting longitudinal joints in the wheel paths!**

Load-Related: Top-Down Fatigue Cracking

- Identified in the 1990s
- Cracking due to high tensile and shear stresses at the HMA surface near edges of truck tires



Top-Down Fatigue Cracking

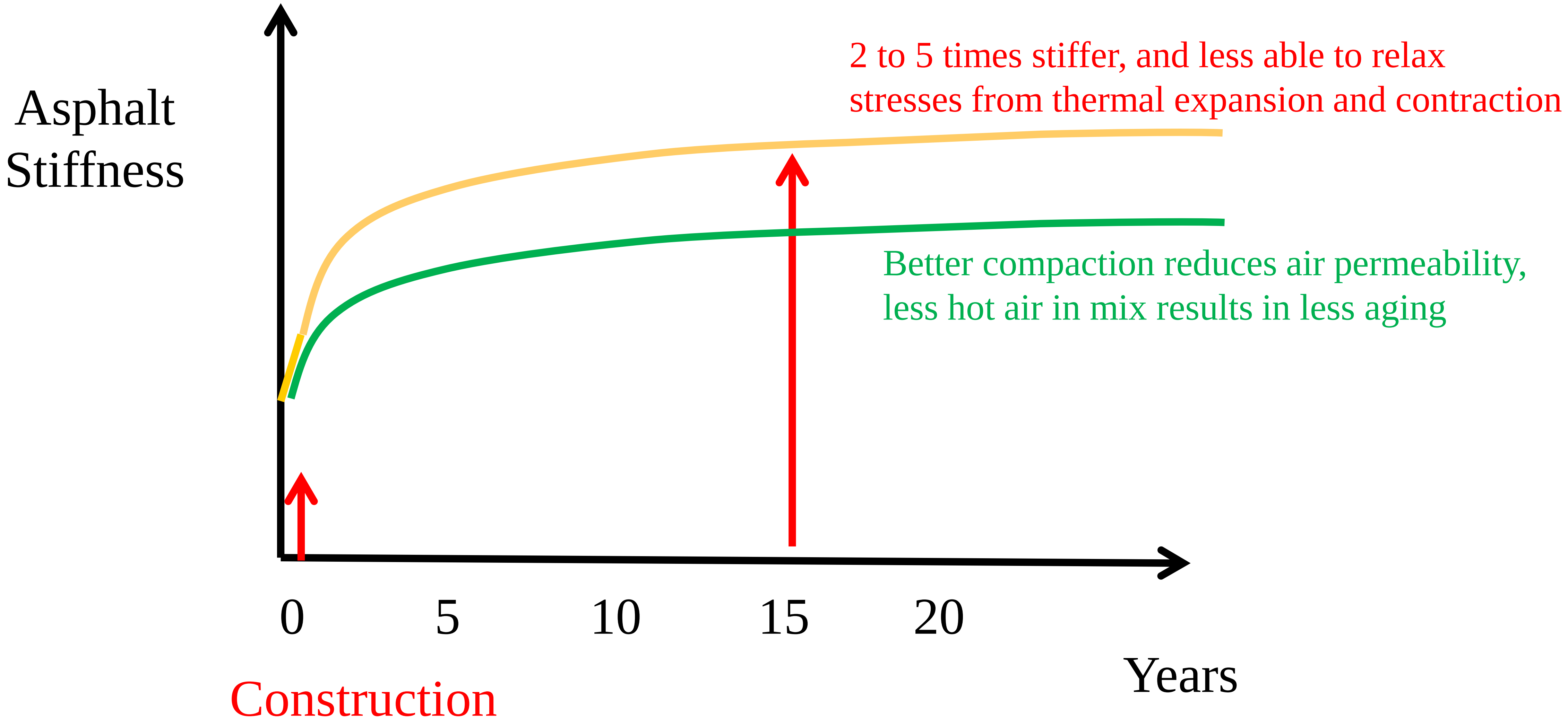
- Thin HMA (< 4”): Fatigue cracking generally starts at the top
- Thick HMA ($\geq$ 4”): Fatigue cracking generally starts at the bottom
  Note, thickness of AC in photo on the previous slide is 20”
- Traffic loading: High truck tire pressures

Load-Related Fatigue Cracking: Strategies

- Fatigue cracking becomes alligator cracking, and eventually forms potholes
- Surface treatments will slow a little, but mostly helps with age-related block cracking, not fatigue cracking
- Will need to do periodic mill and fill with digouts of localized deep cracking
- Mill and fill may not be cost-effective once alligator cracking is extensive
  - Consider partial-depth (cold in-place recycling) or full-depth reclamation (FDR) depending on the extent of cracking and rutting depth
- Do not let wheel path cracking become extensive or reconstruction will be required

Aging

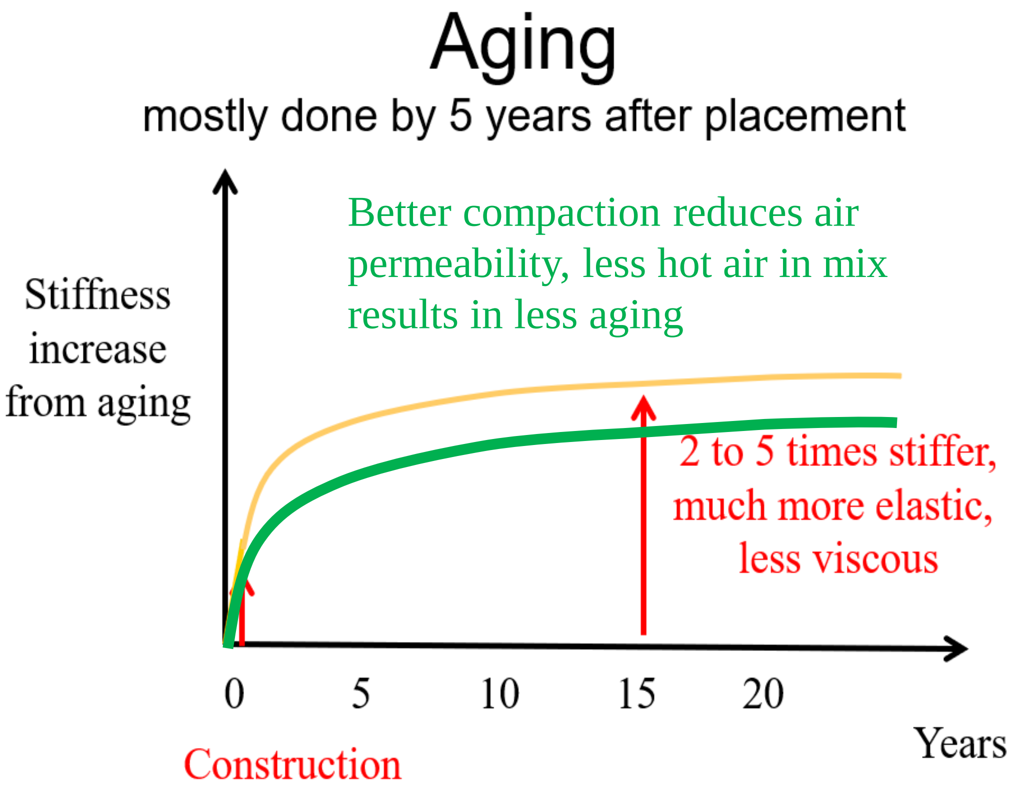
Amount of aging depends on asphalt chemistry, construction compaction, modifiers



Aging of the Asphalt Binder and its Effects

- **Aging:**
  - Caused by oxidation and volatilization
  - Faster if high permeability and Temperature (curve)
  - Permeability greatly reduced with better HMA/AC compaction (curve)

- **Effects:**
  - Stiffening of the mix over time
  - Won’t relax stresses from thermal contraction as well



Age-Related: Block Cracking

- Typically caused by long-term aging of HMA/AC and daily temperature cycling (expansion/contraction)

- May also be reflection cracking from shrinkage cracks in cement treated base or underlying HMA/AC

- Poor HMA/AC compaction allows air to enter and age the asphalt faster

Good compaction limits entry of air and slows oxidation

Age-Related: Block Cracking

- Block cracking is top-down
- Distress descriptions can be seen in the ***FHWA Distress Identification Manual***

Age-Related Cracking: Strategies

- Keep the surface protected from aging
- Can potentially use perpetual fog seals, or slurry seal or micro surfacings
  - Slurry seal typically not applied to RHMA/ARHM
- What frequency?
  - After aging has progressed
    - About 7 to 12 years
  - Before cracking starts
    - Do not let cracking get extensive
  - Doing more frequently is not cost-effective

Moisture Damage

- Moisture damage is assessed by taking both dry and wet cores and measuring the in-situ pavement permeability.

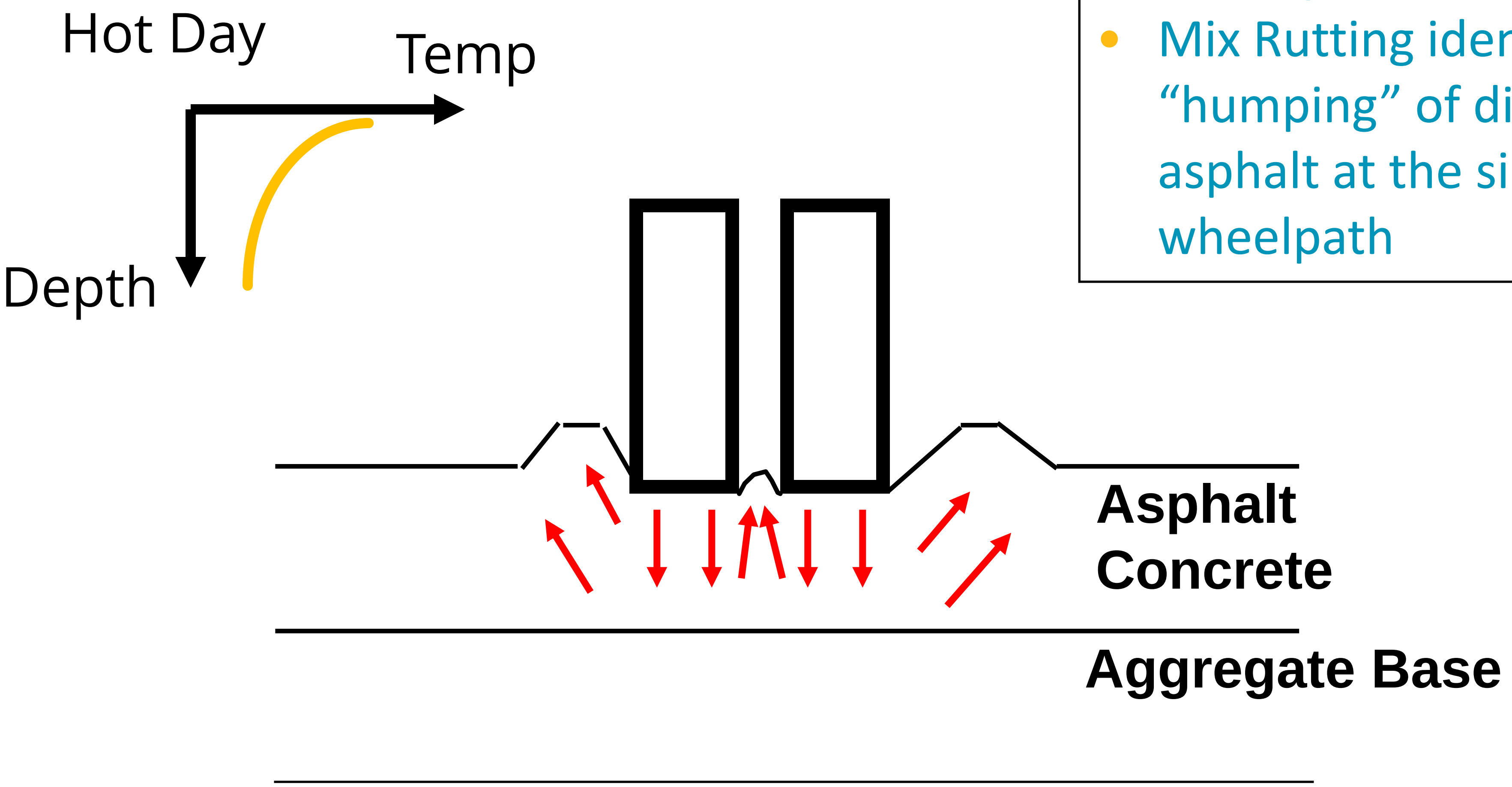
- The extent of moisture damage is evaluated for each core.

Moisture Damage

- Layer 1 AV=13%
- Layer 2 AV=6.3%
- Water entered 1, trapped between layers

AC/HMA Mix Rutting

- High shear stresses at edges of tires
- Asphalt softer under slow moving traffic
- Mix Rutting identified by "humping" of displaced asphalt at the sides of wheelpath



AC/HMA Mix Rutting

- **Poor compaction makes rutting happen faster**
- **Much more shearing**
- **Some due to more compaction from traffic**
  - But only in wheel paths
  - Doesn't help with aging and block cracking

Other Distresses: Delamination/Debonding

- Lack of bonding reduces overlay fatigue life by about 50%, even if no shoving
- Due to insufficient tack coat
- application
- Surface must be dry, clean,
- free of dust and residual millings
- Place between lifts, even if
- underlying lift is still hot
- Specify by residual amount
- Track-resistant materials available
- Spray pavers may be available

Delamination/Debonding: Tack Coat Application

- Proper tack coat application results in the pavement layers acting as a composite section
- Analogous to glue used in structural laminated beam
- Uniform application over the pavement surface, not streaked
- Ensure spray bar is pressurized and discharge cones overlap at least twice
- Encourage proper application by making a **separate Bid Item**.

Pavement Condition Index (PCI)

There's More (and Less) to the Score

City and County
Pavement Improvement Center

Choosing Cost-Effective Strategies: Use of PMS Data and LCCA

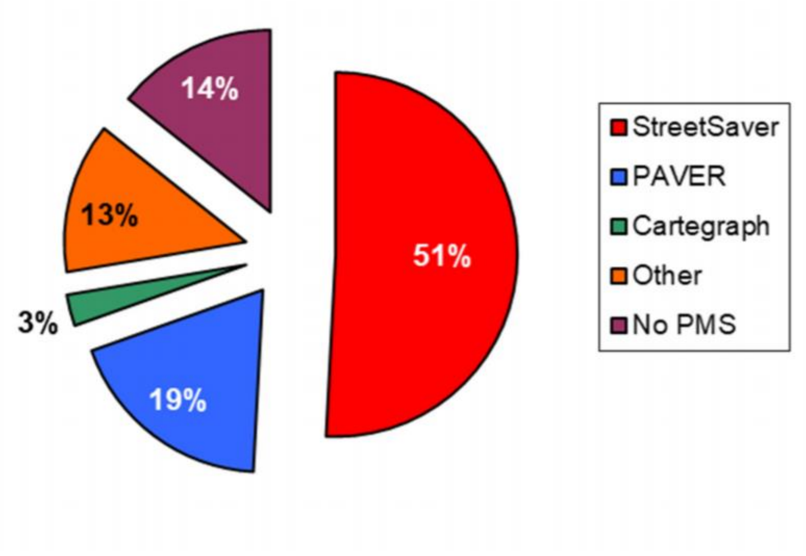


Figure B.4 PMS Software Used By Cities And Counties

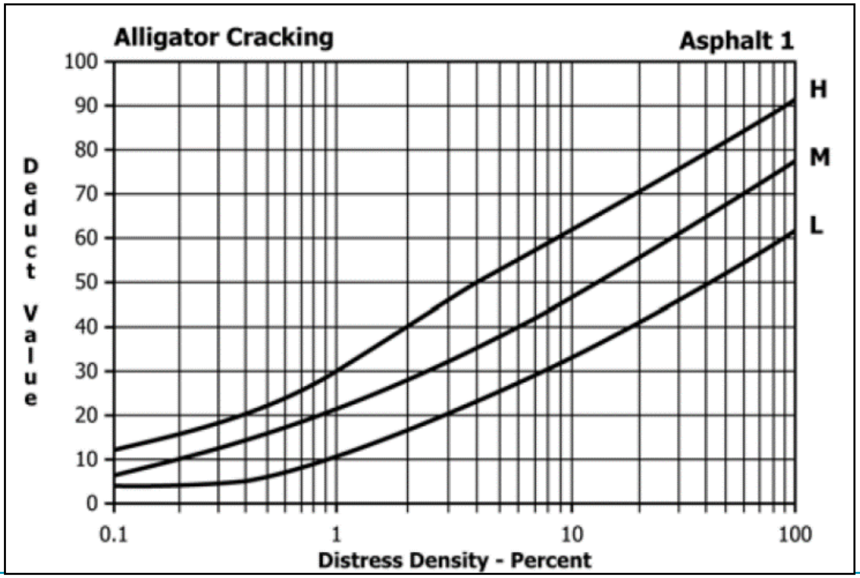
- Understanding the performance of your pavements is key to good pavement management and life cycle cost analysis (LCCA).
- ***Pavement condition*** is typically calculated and described in terms of pavement condition index (PCI).
- Agencies need to take one step back behind PCI to better understand ***pavement performance*** in order to better understand PMS data and make better strategy decisions.

Pavement Condition Index (PCI)

- **Definition/Standard:**
  - *"A numerical rating resulting from a pavement condition survey that represents the severity of surface distresses."*
    FHWA, *Practical Guide for Quality Management of Pavement Condition Data Collection*, page 87
  - ASTM D6433, *"Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys"*

Pavement Condition Index (PCI)

- **Calculation:**
  - *"An equation converts the severity and extent of each distress into a so-called "deduct value"; different deduct equations are used for the different distress types.*
  - *All the deduct values obtained across all the distress types are then added up and subtracted from 100.*
  - *The result is a PCI on a scale of 0 to 10."*



Variables in the PCI

- **Fatigue cracking and potholes caused by *heavy loads*:**
  - Alligator cracking
  - Potholes

- **Cracking caused by *aging:***
  - Block cracking
  - Reflective (joints and underlying distress)
  - Longitudinal and transverse cracking

- **Other distresses:**
  - Low ride quality
  - Bleeding
  - Bumps and sags
  - Corrugations
  - Depressions
  - Edge cracking
  - Lane/shoulder drop-off
  - Patching and utility cut patching
  - Polished aggregate
  - Rutting
  - Shoving
  - Slippage cracking
  - Swelling
  - Weathering and raveling

Pavement Condition Index (PCI)

- **Problems and Limitations:**
  - *"… it has **limitations as an engineering tool** for local governments making pavement management decisions."*
  - *"Specifically, when a PCI is developed from condition survey data, **a lot of important engineering information is lost**, particularly data regarding cracking."*
  - *"A major deficiency in PCI is that roadway segments **can have the same or similar PCI [a tie score] but very different types of distress**."*

Same or Similar PCI:
Different Distresses = Different Strategies

CASE 1: TRAFFIC LOADING RELATED, PCI = 34			
DISTRESS	SEVERITY	QUANTITY	DV
Alligator Cracks	High	1x6	18
Alligator Cracks	Medium	1x4 1x5 1x7	17
Potholes	Medium	3	48
Potholes	Low	3	30
Rutting	Low	2x5 2x8	10
CASE 2: AGE, CONSTRUCTION, UTILITIES, OTHER FACTORS, PCI = 32			
Long/Trans Crack	High	15 20 8 6 12 18 6x7	43
Long/Trans Crack	Medium	25x2 18 13 9 10	20
Patching/Utility	High	25x4 25x2	40
Patching/Utility	Medium	12x6 4x7	20
Block Cracks	High	4x6 6x5	13

Pavement Condition Index (PCI)

- **The "Tiebreaker:"**
  - *"For these cases, **examining the distress types and extents of the distresses** and their effect on the pavement structure, **along with other available project-level data**, could serve as a tiebreaker to augment PCI making network-level and project scoping decisions."*

Summary: The "More" and the "Less"

- **What's "Less"?**
  - *"PCI is a simple, effective communication tool, but when used alone it is insufficient for choosing the right strategy at the right time to maximize the cost-effectiveness of pavement funding."*
  - PCI is not a measure of structure.
  - PCI alone is less information than is needed to select the appropriate strategy based on pavement distress

- **What's "More?"**
  - *"Managing pavement networks primarily based on identification of age- and load-related cracking will result in **more** informed and cost-effective treatment timing and selection."*
  - More project-level analysis and information is needed in order to select the appropriate strategy.

Project-Level Analysis

An overview of common destructive and non-destructive testing

City and County
Pavement Improvement Center

Destructive/Non-Destructive Testing

- **Destructive Testing:**
  - Cores
  - Borings
  - Material Testing

- **Non-Destructive Testing:**
  - Falling Weight Deflectometer (FWD)
  - Dynamic Cone Penetrometer (DCP)
  - Ground Penetrating Radar

Cores

- Notes (photos to the right):
  - Core was taken around the crack
  - Various layers include soil mix pavement (bottom)

Material Testing

- **Material Testing (Subgrade Soil Characterization):**
  - Atterberg Limits: CT 204/ASTM D4318/AASHTO T 90
    - Liquid Limit (LL)
    - Plastic Limit (PL)
    - Plasticity Index (PI)
    - Expansive Soils: PI > 12
  - Sieve Analysis: CT 202

- **Material Testing (Subgrade Strength):**
  - California R-Value
  - California Bearing Ratio

Falling Weight Deflectometer (FWD)

- California Test 356 (357 for M-E design)

Dynamic Cone Penetrometer (DCP)

- ASTM D6951
- Works well with core holes
- Limited to upper one meter of soil
- Approximate (empirical) relationships with CBR and R-Value
- Relates to elastic modulus (M-E design)

Ground Penetrating Radar (GPR)

- Analogous to an X-Ray
- Provides continuous pavement thicknesses
- Compare to, and calibrate based on, cores
- Readily performed on a network or project leve
- Incorporate data into pavement management system

Strategy Selection

Considerations for Future Projects

Questions to Ask

- Are the cracks due to fatigue in the wheel paths (traffic), or aging of entire surface (environment), or both?
- Is the network-level strategy in the PMS appropriate for the types of cracking?
- Did the last project on the same route perform as expected? If not:
  - What’s changed?
  - Is the structural section adequate?
  - Was a thorough project-level investigation, associated testing, and calculations performed?
  - Was the appropriate strategy selected?
  - What binder was used? Should a modified binder (polymer, asphalt-rubber) be used in the next project (particularly useful if inlay/overlaying cracking)?

Pavement "MRI": Before Strategy Selection

- **M = Materials**:
  - What is the existing structural section composed of?
  - Subgrade, base material type and thickness, HMA/AC (gradation, binder grade, thickness)

- **R = Review:**
  - Completed projects at 3, 5, and 10-year milestones
  - As-built plans
  - Material testing records
  - Traffic counts/traffic index calculations/projections
  - Resident Engineer/Inspector records
  - Change Orders

Pavement “MRI”: Before Strategy Selection

- **I = Investigation:**
  - Was a project-level site investigation performed?
  - Borings
  - Cores
  - Dynamic Cone Penetrometer (DCP)
  - Falling Weight Deflectometer (FWD)
  - Subgrade Soil Classification Testing (SE, R-Value/CBR, PI)

Asphalt Compaction

The Importance and Effect on Life Cycle Costs

City and County
Pavement Improvement Center

Effect of Asphalt Compaction on Asphalt Surfaced Pavement Distresses

- **Distresses:**
  - Fatigue cracking
    - top down
    - bottom up
    - reflective
  - Rutting
  - Block cracking
  - Raveling
  - Low-temperature "thermal" cracking
  - Moisture damage
- ***Good compaction helps with ALL of these!***

Longitudinal Cracking due to Poor Joint Compaction

- Longitudinal cracks out of wheel path, or in wheel path but straight and often showing raveling and cracking
- Poor compaction major contributor
- Visible after rainfall
- Wedge joint construction helps with compaction
- Do not put longitudinal joints in wheel paths

Getting Good Asphalt Compaction

- **Maximum lift thickness**
  - About 3 to 4 inches
- **Maximum size aggregate in gradation**
  - Not more than 1/3 lift thickness
- **Use pneumatic tired rollers for the passes between vibratory steel and later static steel**

- **Material Transfer Vehicles (MTV) remix the material before depositing in the paving machine. Remixing prevents segregation and results in a more uniform mixture temperature, both of which facilitate compaction when placing**

Getting Good Asphalt Compaction

- Use a ***quantitative*** (not method) ***specification*** to measure compaction.
- Specify in terms of ***in-place bulk density and theoretical maximum density*** (TMD), not laboratory test maximum density (LTMD).
- Use cores or nuclear gauges ***correlated*** for the specific mix/project (California Test 375/AASHTO T209) by construction of a test strip.
- Apply and enforce ***payment reductions*** if the specified density is not achieved.
- ***General Rule***: 1% increase in constructed air voids = 10% reduction in fatigue life.

Benefits of Good Compaction

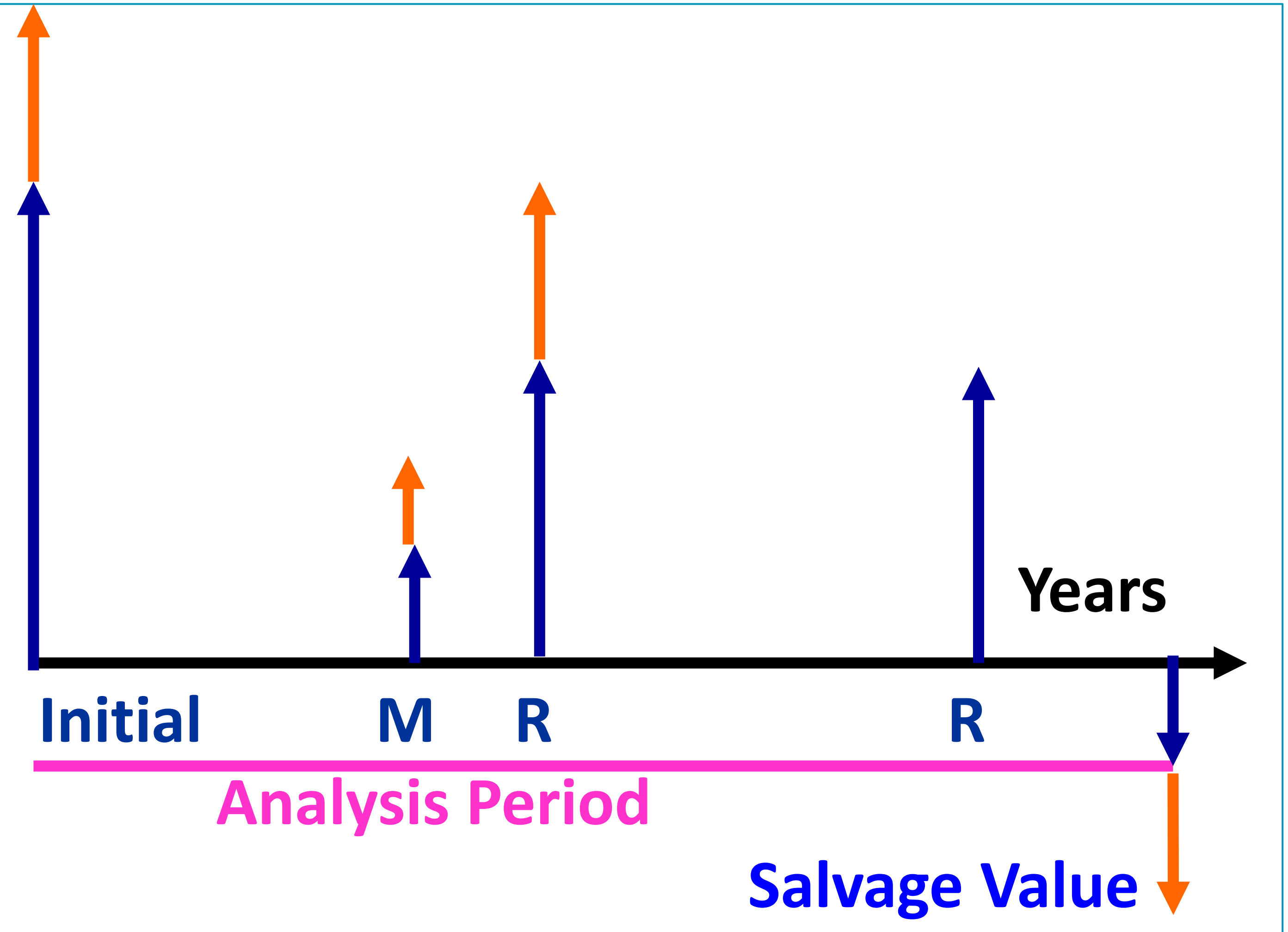
- **Reduced/Retarded Pavement Distress/Aging:**
  - Longer cracking life (fatigue and age-related)
  - Less rutting in the pavement structural section
  - Less permeability, water damage
  - Slower aging, less raveling

- **Cost-Effectiveness:**
  - Little or no increase in construction cost
  - Reduced Life Cycle cost

Life Cycle Cost Analysis

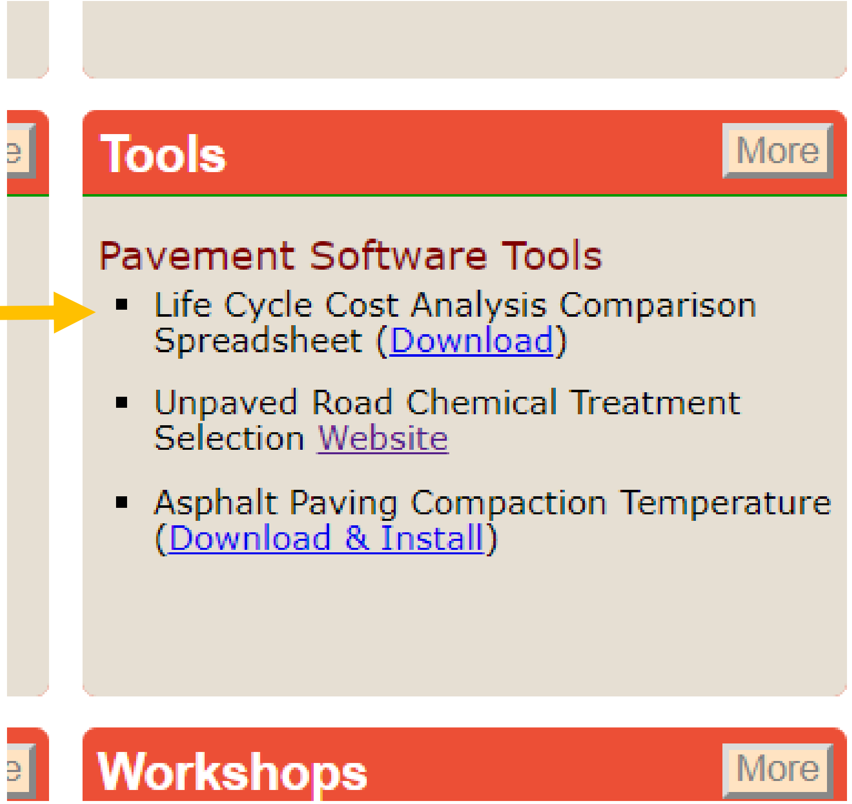
Life Cycle Cost Analysis (LCCA)

- Net Present Value = the total of costs over the analysis period, including discount rate.
- Equivalent Uniform Annual Cost = spread NPV over time, with discount.
- **$ (Agency Costs)**
- **$ (User Costs)**



CCPIC LCCA Excel Tool

- Excel tool to calculate Net Present Value, Salvage Value and Equivalent Uniform Annual Cost
- Can compare 3 scenarios side by side
- Can choose and edit the list and sequence of treatments



LCCA: Effect of Asphalt Compaction

- Use a quantitative (*not method*) specification to measure compaction.
- Reference a standard specification or write the spec in terms of ***in-place bulk density*** and ***theoretical maximum density*** (TMD), and not *laboratory theoretical maximum density* (LTMD)
- Use cores or nuclear gauges correlated for the specific mix/project as the basis for determining the in-place density on at least a daily basis
- Apply, ***<u>and enforce</u>***, payment reductions if the compaction doesn't meet your specifications.
- Caltrans Standard Specifications specify TMD
- A future change to the Greenbook, Change No. 301SM, will specify TMD.

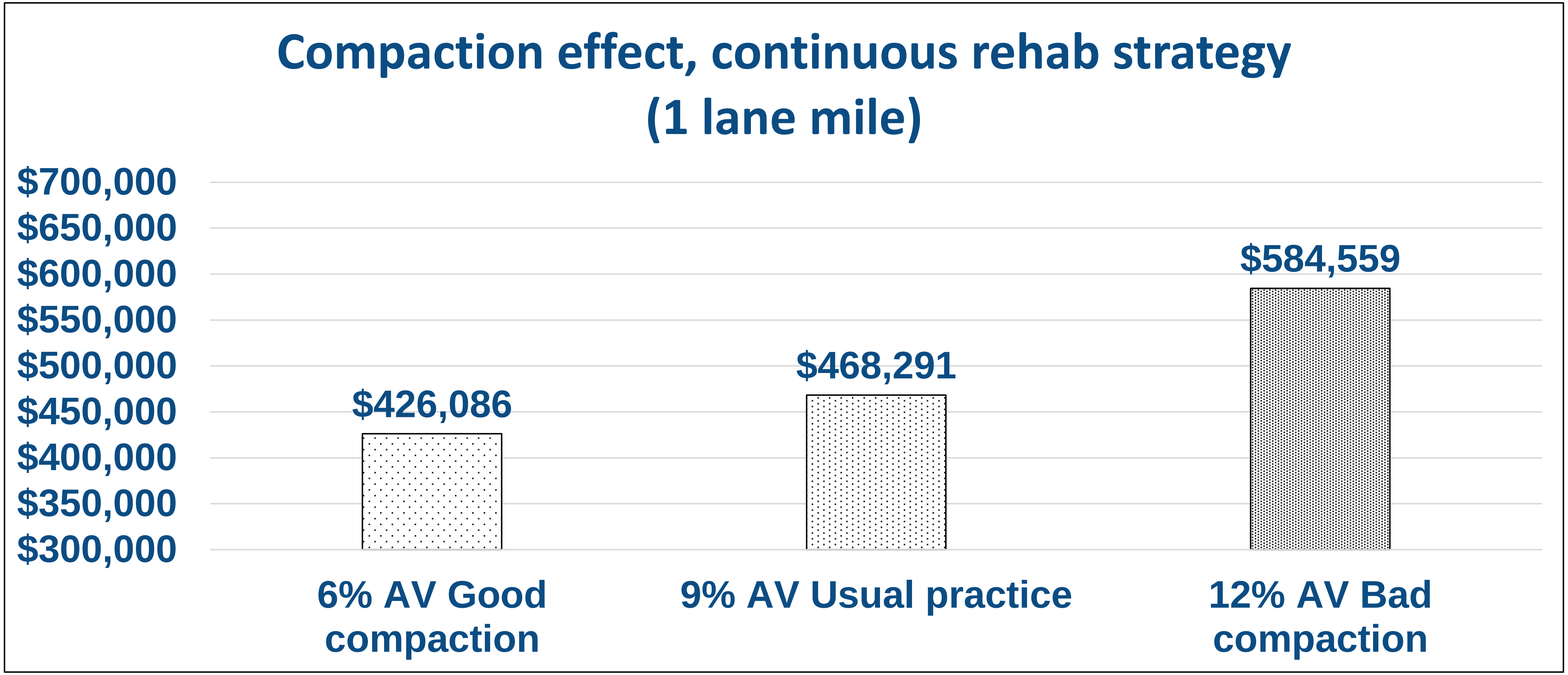
General rule: 1% increase in constructed air-voids = 10% *<u>reduction</u>* in fatigue life

LCCA: Effect of Asphalt Compaction

- Won't this increase the bid cost for my asphalt?
- Isn't the cost of managing this specification high?
- Won't coring damage my new pavement?
- What can I do to help my contractors meet and exceed the specification and further increase the life of my overlays?

- Yes, but not significantly. The additional expense will be recovered by the lower life cycle cost.
- No.
- Cores are only needed from the test strip to correlate the nuclear gauge. If the compaction meets specifications, no further coring will be necessary.
- Require QC testing. Discuss at a pre-paving meeting.

LCCA: Effect of Asphalt Compaction



Summary

Takeaways for thought and application

Takeaways

- The ability to make good engineering decisions regarding the timing and type of strategy based only on PCI is limited; analyze the cracking.

- Focus on cracking, separated by:
  - Streets with heavy trucks/buses, wheel path fatigue cracking and age related cracking: will need rehabilitation eventually
  - Streets with no heavy vehicles, age related cracking only: can use only preservation treatments if timely

- Life cycle cost analysis (LCCA) is a practical tool to determine the most cost-effective strategies:
  - Needs good performance estimates, agencies can use their own information

Takeaways

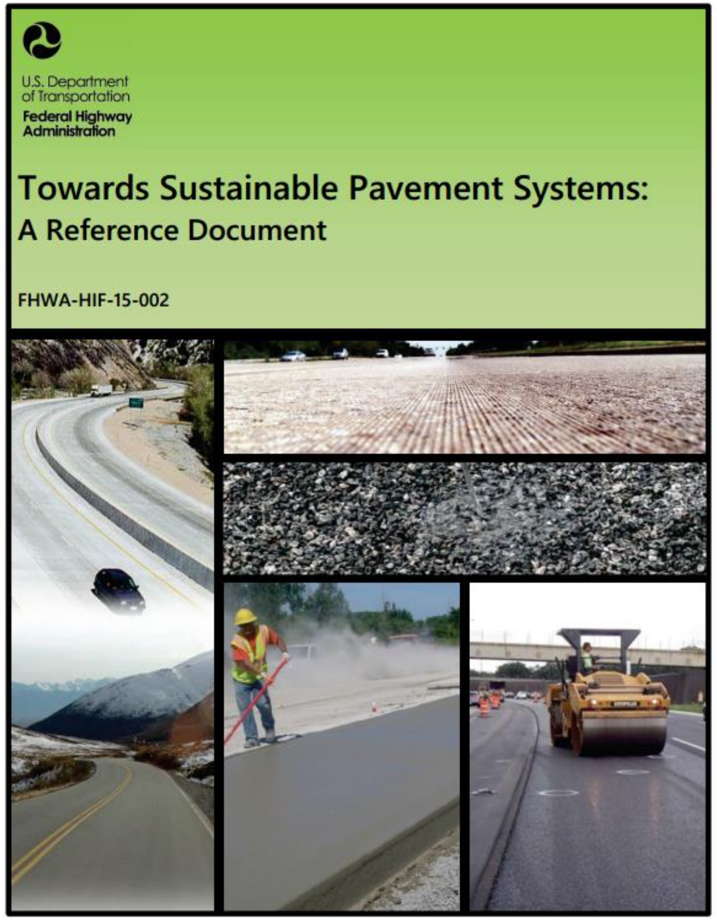
- A strong asphalt compaction specification is the most cost-effective change:
  - 92% relative to theoretical maximum density (TMD), not laboratory test maximum density (LTMD)
  - Must be consistently enforced in order to work
  - See Special Provision posted on the CCPIC website
- CCPIC currently offers a Pavement Engineering and Management Certificate Program and a Pavement Construction Inspection Certificate Program

Resources

References and Links

Sustainable Pavements

- FHWA Sustainable Pavements Task Group
  - Sustainable pavement reference document (2015)
  - Covers everything about pavement
    and sustainability
    - Cost
    - Environment
    - (they usually go together)
  - Tech briefs and webinars



- http://www.fhwa.dot.gov/pavement/sustainability/ref_doc.cfm

References/Links

- **City and County Pavement Improvement Center (CCPIC):** www.ucprc.ucdavis.edu/ccpic
- ***"Pavement Condition Index (PCI): There's More (and Less) to the Score"*** www.ucprc.ucdavis.edu/ccpic/pdf/PCI 4-Pager final v2.pdf
- **University of California Pavement Research Center (UCPRC):** www.ucprc.ucdavis.edu
- **Maintenance Technical Advisory Guides (MTAG):** https://www.csuchico.edu/cp2c/library/caltrans-documents.shtml

References/Links

- **FHWA "*Distress Identification Manual*:"** https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/13092/13092.pdf
- **Caltrans "*Tack Coat Guidelines*:"** www.ucprc.ucdavis.edu/ccpic/pdf/Caltrans%20Tack%20Coat%20Guidelines.PDF

Questions?

- **John Harvey**: jtharvey@ucdavis.edu
- **Erik Updyke:** eupdyke@ucdavis.edu