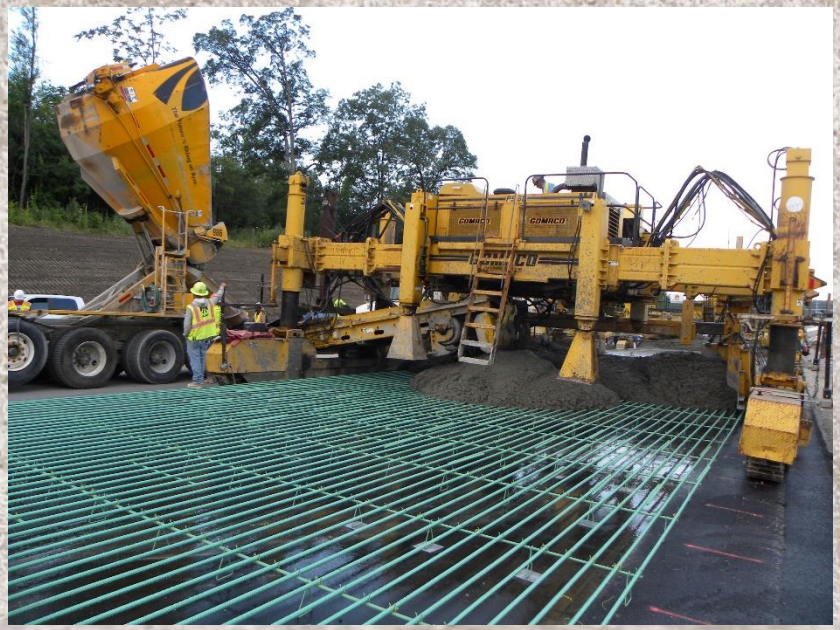
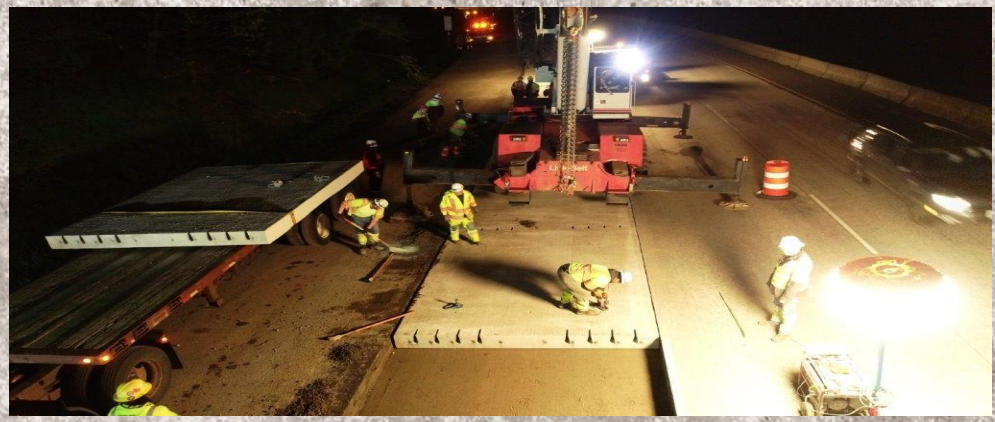
LONG-LIFE CONCRETE PAVEMENTS – 40 YEARS OF INNOVATION





Shiraz Tayabji
Advanced Concrete Pavement Consultancy LLC
Fulton, Maryland, USA
April 1, 2021

Thank You

- *My sincere appreciation to ACI Committee 325 Chair Kurt Smith and members and ACI for supporting these two sessions today.*

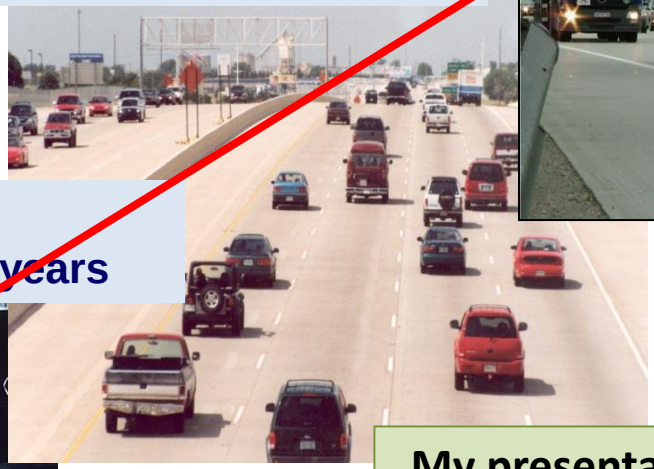
- *It is a great honor to have your career acknowledged by your peers and colleagues.*

Advancing Concrete Pavement Technology

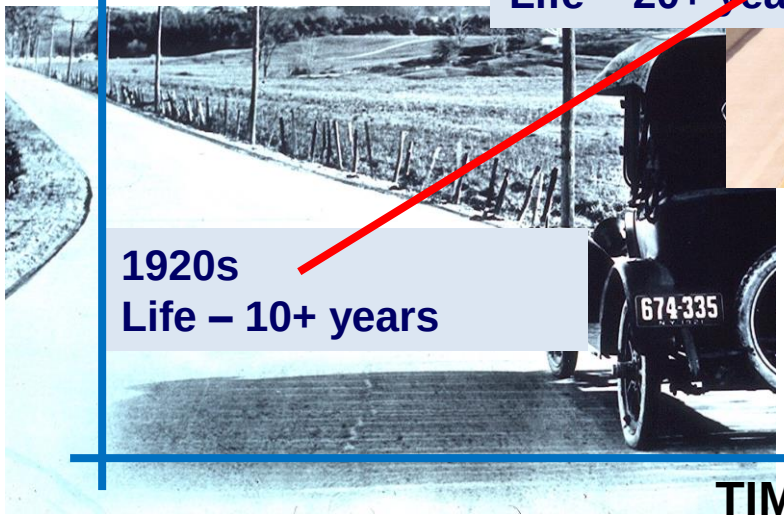
Implementing Innovations to Improve the Best Practices

~~2020~~ 2025(?): Life – minimal-maintenance/modular/Resilient

2000s Life – 40+ years & sustainable



1960s
Life – 20+ years



1920s
Life – 10+ years

LIFE

TIME ➔

My presentation focuses on the period between about 1978 & to-date)

Concrete Pavement Technology
– Circa 1978

- Interstate highway construction ending
- Most concrete pavements being designed for 20-year initial life
  - Using the AASHO design equations derived from the AASHO Test Road (PSI based)
  - Or, using the 1967 PCA stress-based design procedure – by Fordyce/Packard (Westergaard equation – Picket & Ray stress charts)
- Slipform paving widely used
- "Father's" concrete mixtures in use
- Paving concrete durability understanding just beginning

- Computing – IBM mainframe using punch-cards; TI/HP programmable calculators, no PCs/laptops/cellphones
- Chicago Cubs still without a championship
- Micro-soft founded in 1975 (1976 revenues: $16,000)
- Apple founded in 1976
- Superman movie out

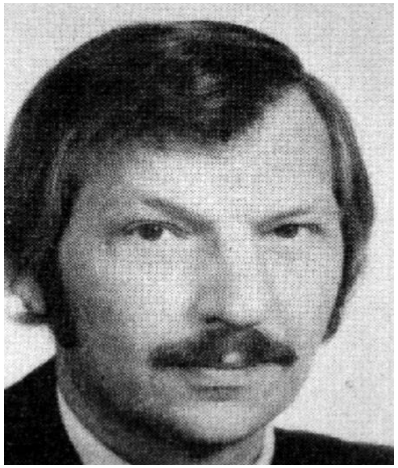
Microsoft staff in Albuquerque, December 7, 1978

Concrete Pavement Technology
– Circa 1978

- Moratorium on automatic dowel bar inserters (J-hooks)
- Concrete overlay (over concrete) market developing
- Use of skewed joints (still)
- Curling and warping effects understood but not incorporated in design procedures
- Roller compacted concrete use just beginning
- Prestressed concrete pavements being advanced (My first FHWA project - 1978; worked with Peter Nussbaum/Bengt Friberg) – an innovation NOT further developed and NOT implemented into practice
- No FWD testing – load testing using in-situ instrumentation
- Concrete pavement smoothness becoming a concern

Concrete Pavement Technology
– Circa 1978

- Pavement engineering being taught at many US universities
  - incorporating MS and Ph. D. programs
- Textbooks on pavement engineering
  - Yoder & Witczak; Huang



2020 Text books

- Delatte – Concrete Pavement Design, Construction and Performance
- Tech Center – IMCP for Concrete Pavements
- And lots and lots and lots of topic-specific guides, tech-briefs, tech summaries, tech notes, etc.

First Purdue Conference

West Lafayette, Indiana – Feb 1977

Eldon J. Yoder, Chair

- Key papers
  - Zero-maintenance pavement design – Darter/Barenberg
  - Design & construction of concrete pavements – Nussbaum/Lokken
  - Concrete pavements in Europe (several papers)
  - Design considerations for control of joint faulting of undoweled pavements – Packard
  - Design procedure for CRCP – McCullough
  - Performance of CRCP in Indiana – Faiz/Yoder
  - Prestressed pavements – Theory into practice – Friberg
  - Navy experience in eliminating keys from construction joints of Navy airfield pavements – Brown/Jones
  - Econocrete in pavement design – Yrjanson
  - Concept for rigid pavement overlay design – Smith/Treybig/McCullough
  - Steel fibrous concrete pavements for airport pavements – Parker/Rice

12th ISCP Conference

Minneapolis, Minnesota (Virtual) – August 2021

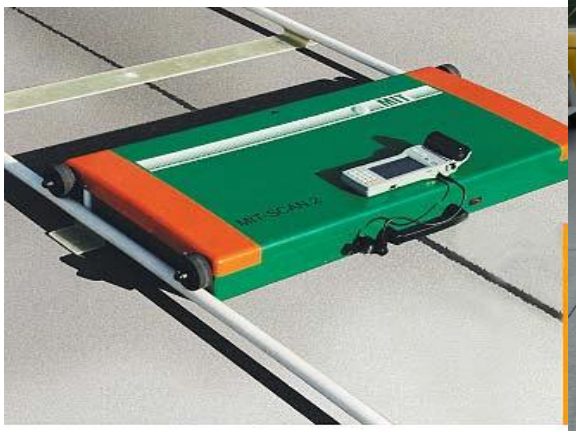
- Key papers
  - Successful ASR Prevention in Germany – Influencing Factors and Adequate Measures – Robin Przondziono
  - Sensitivity Analysis of FAARFIELD Rigid Airport Pavement Thickness Determination – G. White
  - Use of Alternative Aggregates in Pavement Concrete: Research and Practice in Belgium – Elia Boonen
  - Long-Term Performance of Random Jointed Plain Concrete Pavement (JPCP) with Rapid Strength Concrete (RSC) On California Highways – Mike Darter
  - Application of Internal Curing in Slab Replacement using RSC– Mehdi Parvini
  - Field Performance of BCOAC - Linda Pierce
  - Performance of Non-Cementitious Repair Materials for Partial-Depth Repairs – Prashant Ram
  - Two-Lift Concrete Pavements Constructed Under SHRP2 Project R21 - Kurt Smith
  - A Users Guide to Performance Engineered Mixtures - Jim Grove
  - Iowa Experience on Local Calibration of AASHTOWare Pavement ME Design (PMED) for Jointed Plain Concrete Pavements – Orhan Kaya
  - Implementation of Precast Panels for Improved Maintenance of Traffic and Long-Life Performance - Shiraz Tayabji
  - Comparison Between Visual and Ultrasonic Tomography for Joint Deployment Detection Methods - Mike Wallace

Concrete Pavement Technology
– Innovations Since about 1978

- JRCP no longer being used
- Concrete shoulder use & 14 ft widened lane use
- Concrete durability focus – F-T, ASR
- Maturity testing for early opening to traffic
- Precast concrete pavement implementation began (2001 – Peter Smith/FMC Super Slab patented)
- Dowel bar alignment testing
  - Mid-1980 – Paul Okamoto and I evaluated dowel alignment (for FHWA/John Hallin) at the first modern DBI project using GPR (Gomaco slipform paver) – I-86 Pocatello, Idaho
  - Mid-1990s on – MIT Scan implementation
- Use of MIT Scan allowed agencies to approve use of the newly developed (mid-1980s) DBI

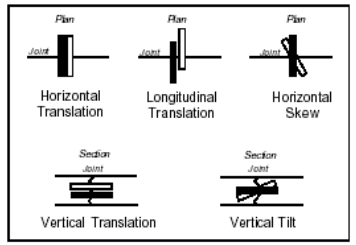
Focus on Dowel Bar Misalignment & Defects in Concrete

Dowel Bar Alignment Testing using MIT SCAN Device Allows Agencies to Approve use of Pavers with DBI



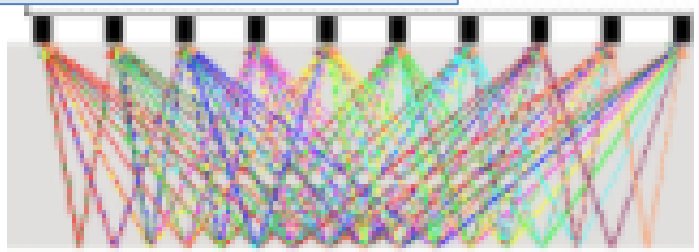
Type of Misalignment	Effect on Spalling	Cracking	Load Transfer
Horizontal Translation	—	—	yes
Longitudinal Translation	—	—	yes
Vertical Translation	yes	—	yes
Horizontal Skew	yes	yes	yes
Vertical Tilt	yes	yes	yes

Categories of dowel misalignment are illustrated below.



Misalignment categories.

Also, MIRA Tomographer – 3-D Representation of defects in concrete



45 pair per measurement (MIRA)

Concrete Pavement Technology
– Innovations Since about 1978

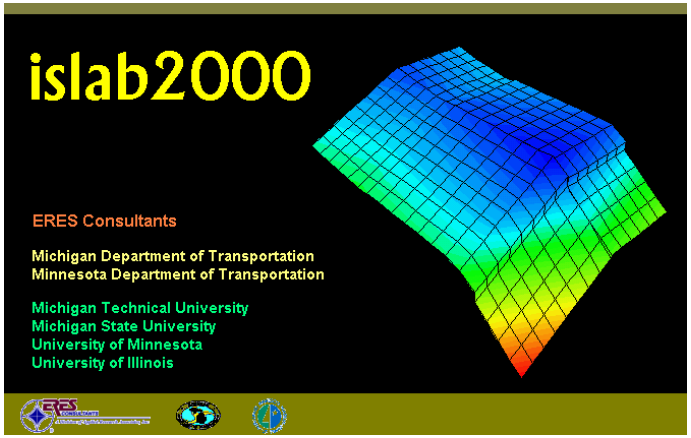
- IPRF funding supported preparation of best practices guides
- SHRP funding (~1990) led to:
  - LTPP – GPS & SPS concrete pavement experiments
  - Concrete durability research – ASR, etc.
- New test roads – MnRoad, Florida Rt 301 (2021)
- MEPDG advanced using LTPP & MnRoad data
- SHRP2 funding (2008) led to:
  - Precast concrete pavement guidelines
  - Improved concrete pavement preservation practices
- FHWA CPTP (2003) & ACPT (2008) programs: Focus – Safer, Quieter, Smoother, and sustainable long-life concrete pavements (Sam Tyson, COTR)
- FAA Tech Center supporting innovations in concrete airport pavement design
- Focus on construction quality
- Focus on concrete durability (ASR)
- Focus on rapid rehabilitation
  - Rapid-set concrete & precast pavement

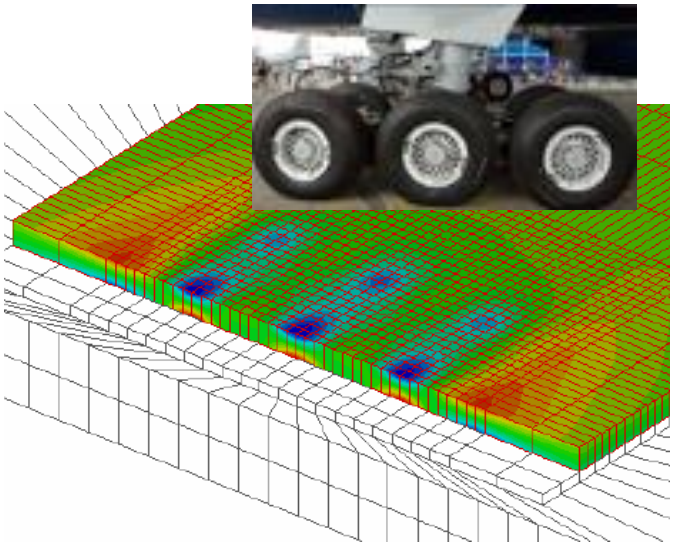
Also:
ISCP - 1998
FAA NAPTF - 1999
IPRF - 2000
CP Tech Center - 2000
FHWA MCL - 2001
NCC - 2008
MIT HUB - 2009

Concrete Pavement Technology

– Innovations Since about 1978

- FWD testing now widely implemented (Phoenix/Dynatest) – for joint testing
- Smoothness testing – IRI testing introduced
- Pavement (and now asset) management systems implemented
- FEA to analyze concrete pavement response to loading/curling (2d & 3D)
  - ILLI-SLAB/ISLAB 2000, JSLAB, KEN-SLAB, EVERFE
  - FAARFIELD 1.42 (Current)
- Modern concrete mixtures – finer cements, cementitious materials, range of admixtures, optimized aggregate gradation
  - Super Air Meter; Electrical resistivity, etc.
- HIPERPAVE being used as a QC process

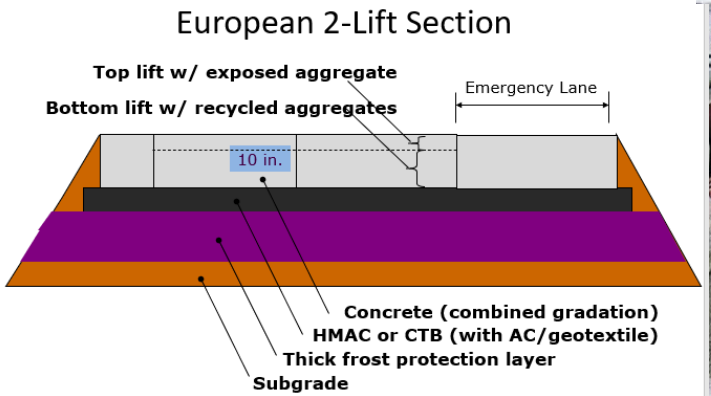




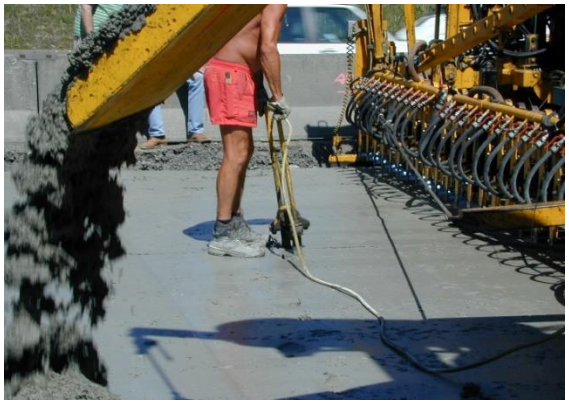
Concrete Pavement Technology

– Innovations Since about 1978

European 2-lift concrete pavement



Tie-bar placed by hand (right behind first paver)

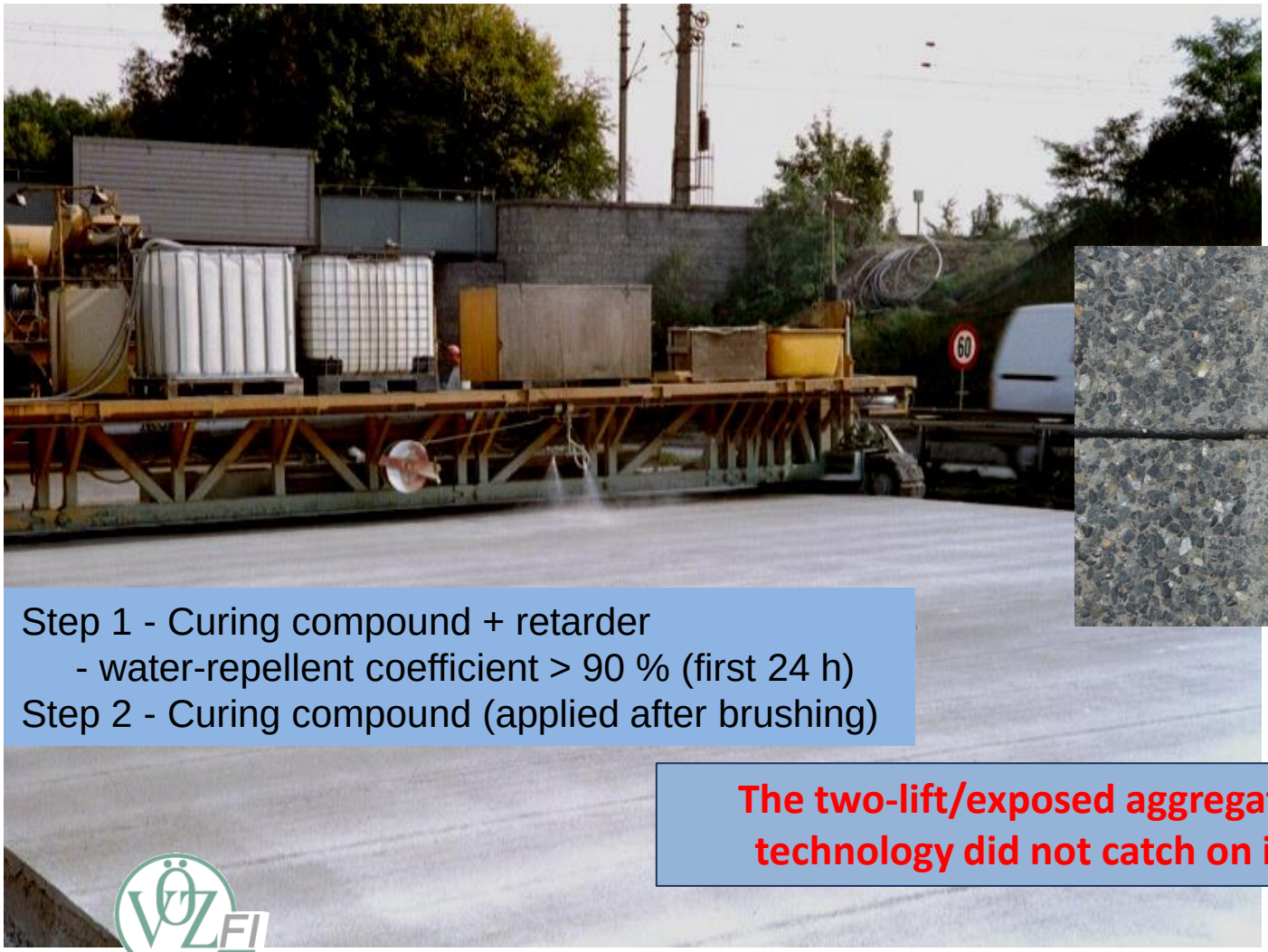


Densely compacted bottom lift – No boot sinkage

Concrete Pavement Technology

– Innovations Since about 1978

European Exposed Aggregate Surface – Low Noise



Step 1 - Curing compound + retarder
- water-repellent coefficient > 90 % (first 24 h)

Step 2 - Curing compound (applied after brushing)

The two-lift/exposed aggregate surface technology did not catch on in the US

German Pavement Section (2006)

(adopted in the US for thin, short slab overlays on concrete)

2. Standard concrete designs currently employed in Germany

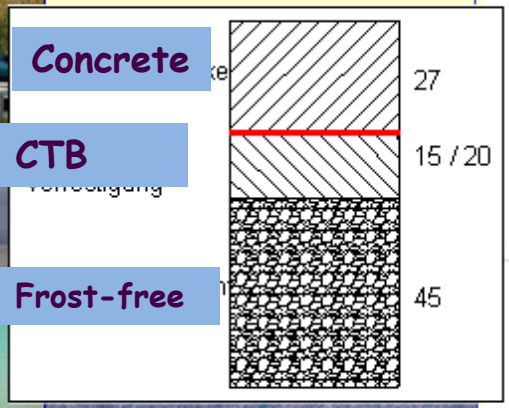
Concrete pavement on a base course with hydraulic bonding and an intermediate layer comprising non-woven fabrics

Installation

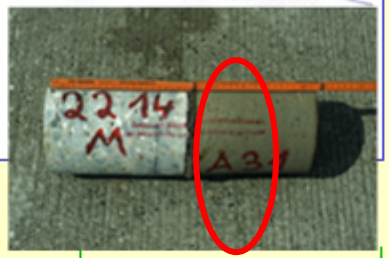
Concrete

CTB

Frost-free



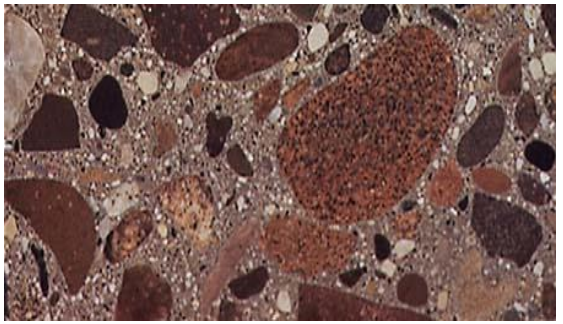
Fixing



5 mm Geotextile over CTB

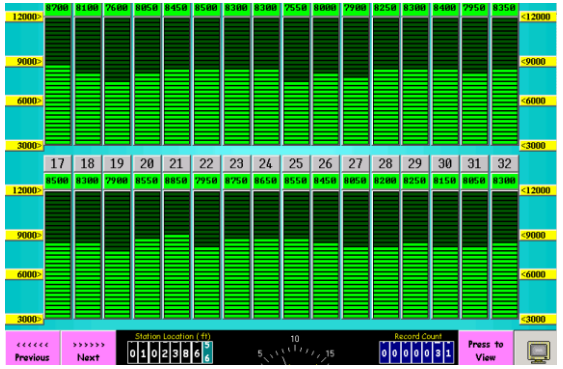
bast

Focus on Concrete Consolidation & Air-Void System



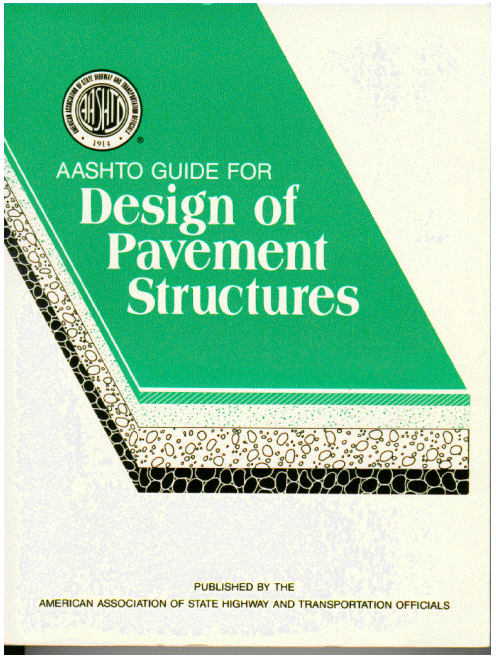
- Adequate concrete consolidation becoming a concern
  - Impermeable concrete matrix
  - Adequate air void system

- Use of smart vibrator system implemented – continuous monitoring of vibrator frequency



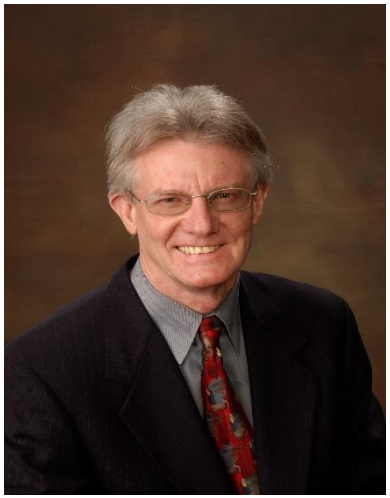
Evolution of AASHTO Design Procedures

1961-62	AASHO Interim Guide for the Design of Rigid and Flexible Pavements
1972	AASHTO Interim Guide for the Design of Pavement Structures - 1972
1981	Revised Chapter III on Portland Cement Concrete Pavement Design
1986	Guide for the Design of Pavement Structures
1993	Revised Overlay Design Procedures



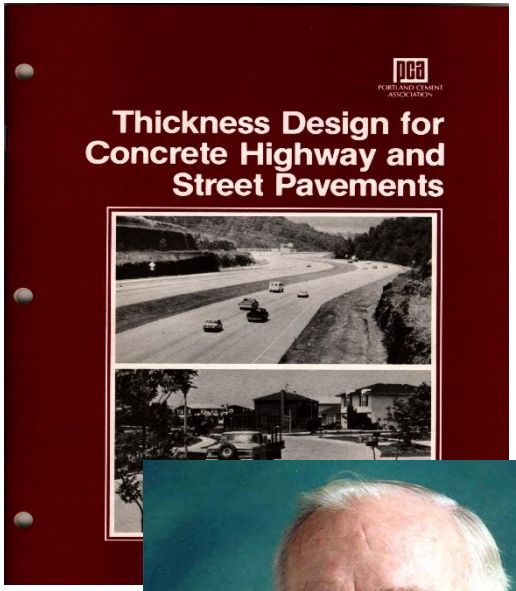
M-E Design – Zero-Maintenance Design

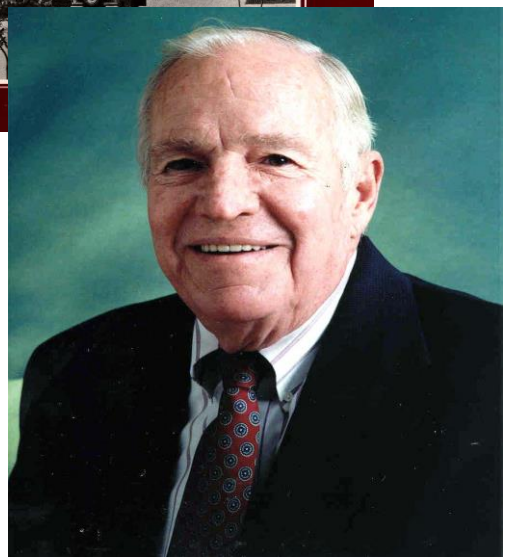
- U of Illinois study by Mike Darter and Ernie Barenberg (1977) – for FHWA
  - Westergaard based analysis for plain, jointed pavements, single and tandem axle loads
  - Fatigue cracking
  - Consideration of curling stresses
  - Cumulative damage
  - Consideration of dowels
  - Referred to as “Zero- Maintenance Design”



M-E Design - PCA Thickness Design Procedure

- PCA's design was revised in 1984 (Packard) based on finite element based mechanistic stress & deflection analysis using JSLAB
- Windows-based computer program (StreetPave) available since 2004

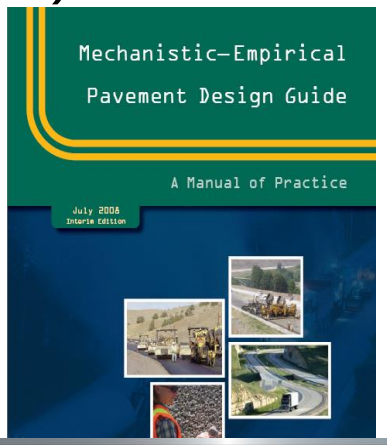




Bob Packard

AASHTO's Pavement ME Software (2006 on)
(Future of Pavement Design)

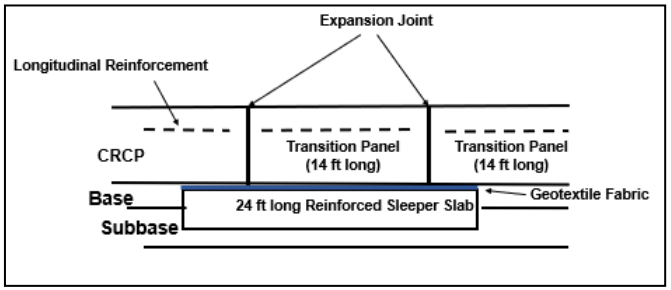
- The Mechanistic-Empirical Pavement Design Guide (MEPDG) allows optimization of many key design features to develop LLCP (Minimal-Maintenance?) designs
  - Joint spacing
  - Support (& drainage) – not adequately addressed yet
  - Edge support
  - Load transfer at joints
  - Concrete thickness/strength
- End result
  - More cost-effective & reliable designs
  - More sustainable designs
- Most US agencies have adopted the new procedure



Concrete Pavement Technology

– Innovations Since about 1978

- Single cut joint sawing
- No more skewed joints
- 15 ft joint spacing – a default value
- Advances in CRCP technology
  - Simplified terminal joint designs
  - Rapid punchout repairs using precast panels

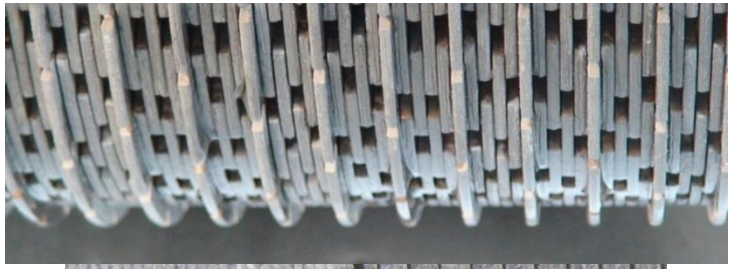


Concrete Pavement Technology

– Innovations Since about 1978

Texturing for enhanced safety & low noise surface

- Surface texture improvements to reduce pavement-tire noise
  - Longitudinal texture widely adopted
  - Next generation surface texture being implemented
- Grinding for corrective work
- For new construction (low noise surfaces)
  - Longitudinal tining
  - Conventional grinding
  - Next generation grinding
  - Exposed aggregate (not in US)



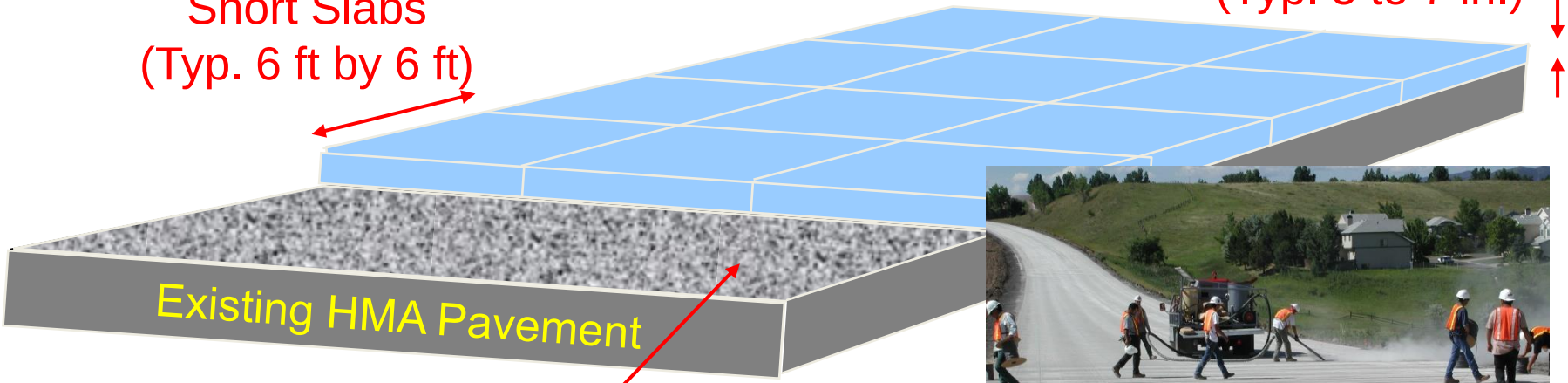
Thin Whitetopping (1992)

Short Slab Concrete Overlays of AC Pavements – Bonded & Directly Placed

Implemented in the US during the late 1990s

Thin Slabs (Typ. 5 to 7 in.)

Short Slabs (Typ. 6 ft by 6 ft)



Milled Surface (bonded) or AC leveling layer (directly placed)

Concrete Pavement Technology

– Innovations Since about 1978

- Smoothness testing
  - From straight-edge testing to California Profilograph testing
  - Current - lightweight Profiler testing (construction) to high-speed inertial Profiler (in-service) - (Monitor smoothness change from cradle to grave)

California Profilograph

Lightweight Profiler – IRI

High Speed Inertial Profiler - IRI

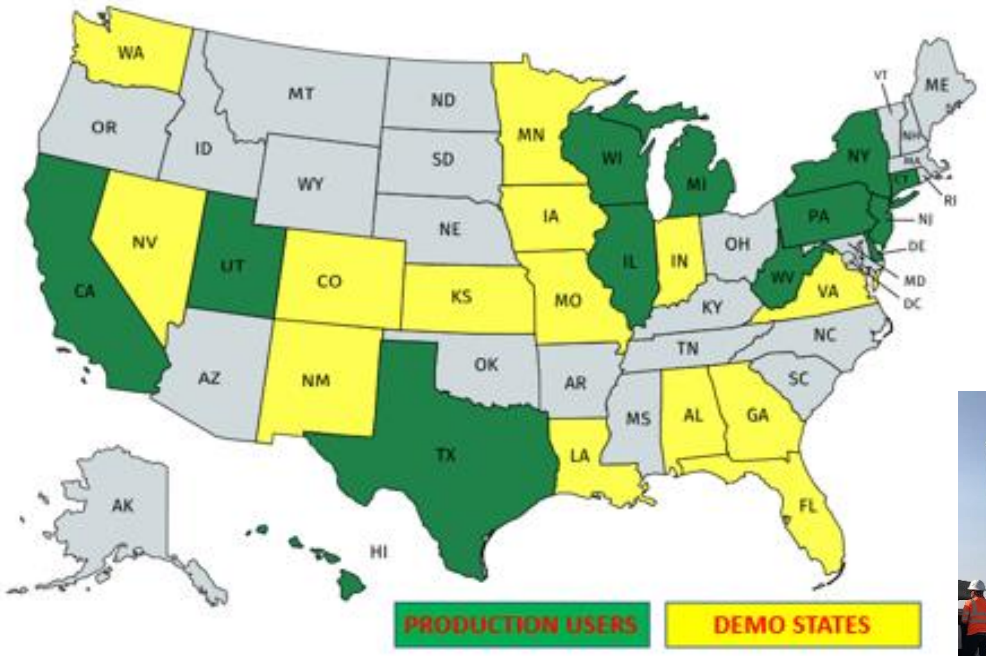
Concrete Pavement Technology
– Innovations Since about 1978

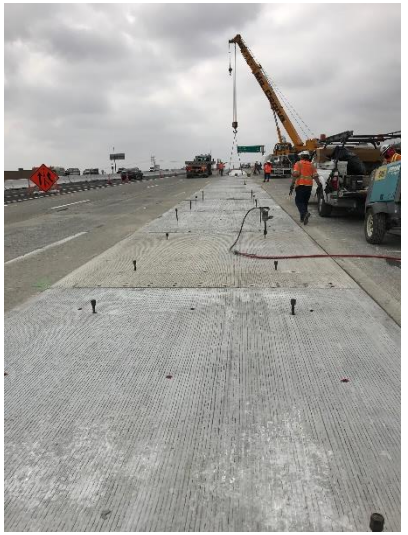
- Improved Highway RCC technology
  - Implemented during the 1980s
  - And, in 2021 still trying to get it right!
  - Density testing, bonding of lifts and construction joint durability issues continue to be a concern
  - Are these construction quality issues or technology issues?

Concrete Pavement Technology

– Innovations Since about 1978

- Precast Concrete Pavement technology
- Implemented in 2001, now routinely used in several States





Concrete Pavement Technology

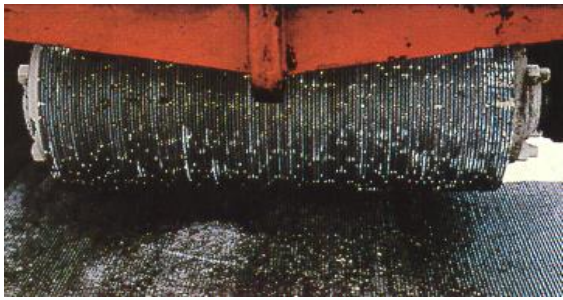
– Innovations Since about 1978

- Stringless paving
  - Laser/GPS Elevation Control
  - Stringline setup not necessary
- Profile testing behind the paver
  - Gomaco Smoothness Indicator (GSI)
  - For process control – immediate feedback to paver operator

Concrete Pavement Technology
– Innovations Since about 1978

CPR/CPP

- Dowel bar retrofit technique developed
- Grinding for smoothness & surface texture restoration
- Accelerated construction innovations
  - Fast-setting Patching/repair materials
  - High performance concrete (HPC) (not much paving applications yet!)
  - Ultra-high-performance concrete (UHPC) (not much paving applications yet!)
- Advanced rapid setting patching materials
- Reclaiming AC overlaid concrete pavement using CPR/CPP



Looking Forward to Another 40 Years

- Refined "M-E" procedures will allow "minimal-maintenance" concrete pavement designs - perpetual life, modular concrete pavements, all based on green technologies
  - Faulting no longer a design consideration for new/reconstructed pavements (We will have eliminated faulting)
  - Modular approach to pavement design & construction to allow rapid rehabilitation with minimal need for reconstruction
- NO RADICAL CHANGES IN PAVEMENT TYPES EXPECTED (Plain jointed & more CRCP, RCCP, precast & concrete overlays of AC and PCC pavements)
- Paving equipment essentially same, but more efficient
- Concrete mixtures – very low carbon footprint/extremely durable

Question – What distresses will we be addressing?

Thank You!

The last 40+ years have been very fulfilling working with you to improve concrete pavement technology.

Collectively, we have been very innovative and progressive!

And thanks to FHWA/TRB-NCHRP/AASHTO & PCA/ACPA for support of the concrete pavement technology program over the years!