The Concrete Pavement Preservation Series IV Concrete Pavement Management and Preservation Resources

Michael Darter, PE PhD

June 23, 2020

IOWA STATE UNIVERSITY
Institute for Transportation

National Concrete Pavement Technology Center

Who is supporting this webinar?

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ICPA Iowa Concrete Paving Association

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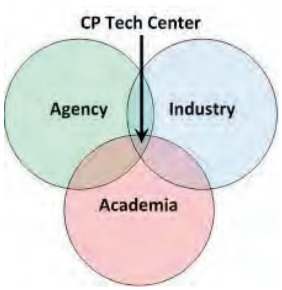
The CP Tech Center

The National Concrete Pavement Technology Center (CP Tech Center) at Iowa State University is a national resource for concrete pavement research and **TECHNOLOGY TRANSFER.**



Another Resource: Will be updated 4th quarter 2020

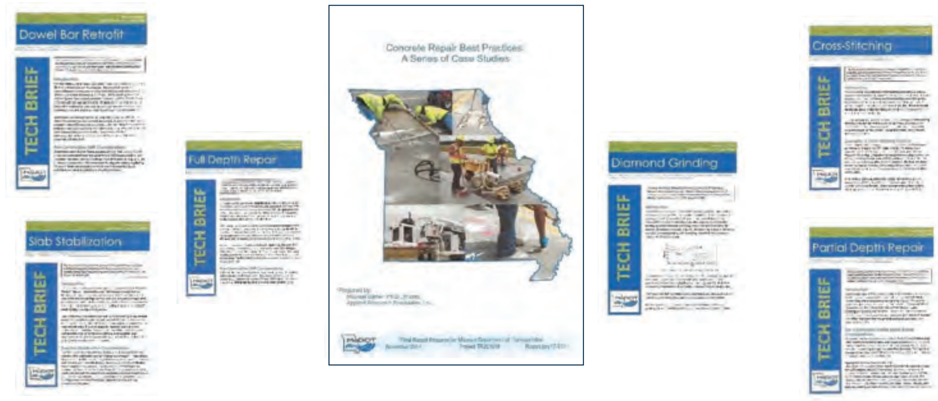
- Introduction
- Preventive Maintenance and Pavement Preservation Concepts
- Concrete Pavement Evaluation p. 17-57
- Slab Stabilization and Slab Jacking
- Partial-Depth Repairs
- Full-Depth Repairs
- Retrofitted Edge Drains
- Dowel Bar Retrofit, Cross Stitching, and Slot Stitching
- Diamond Grinding and Grooving
- Joint Resealing and Crack Sealing
- Concrete Overlays
- Strategy Selection

WBT on-line
Free NHI Contractor Training Courses

- FHWA-NHI-134207A *How to Construct Durable Full-Depth Repairs in Concrete Pavements*
- FHWA-NHI-134207B *How to Construct Durable Partial-Depth Repairs in Concrete Pavements*
- FHWA-NHI-134207C *Proper Diamond Grinding Techniques for Pavement Preservation*
- FHWA-NHI-134207D *Proper Construction Techniques for Dowel Bar Retrofit and Cross-Stitching*
- FHWA-NHI-134207E *Proper Joint Sealing Techniques for Pavement Preservation*

Missouri DOT Website

https://spexternal.modot.mo.gov/sites/cm/CORDT/



Upcoming Webinar Schedule – Technology Tuesday

July 21 **Achieving Smoothness in Concrete Pavement Construction**

August 18 **Concrete Pavement Joint Design, Layout and Construction**

September 22 **Resiliency/Resilient Pavement Systems**

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About the Presenter

Michael Darter, PE PhD, is an international authority in repair/preservation, rehabilitation, evaluation, construction, and design of concrete pavements. Through his consulting, research, and teaching work over the past 50 years, he has contributed significant new knowledge and many best-practice guidelines, specifications, training courses, and engineering tools for concrete repair and preservation.

Mike received his BS and MS degrees from the University of Utah and went on to obtain his PhD at the University of Texas at Austin

During his famed career in pavement engineering, Dr. Darter was a Pavement Engineer for the Utah DOT, a highly revered Professor at the University of Illinois at Urbana-Champaign and the Principal Engineer with Applied Research Associates, Inc.

Learning Objectives

Repair/Preservation of Concrete Pavements

- Become acquainted with MoDOT/FHWA National State & Contractor survey & interview results for six repair/preservation techniques.
- Identify appropriate Pre-Construction considerations (usage & design).
- Awareness of successful Specifications & Construction guidelines.
- List successful Inspection/ Acceptance procedures.
- Increased knowledge of Performance & Survival experience of each treatment.

Questions?

- Questions are encouraged. Please enter your questions in the question box and we will share the Q & A electronically following the webinar.
- PDH certificates are available and will be sent to all participants electronically.
- Presentations and recordings will be posted on the CP Tech Website.

www.cptechcenter.org

The Concrete Pavement Preservation Series IV Concrete Pavement Management and Preservation Resources

Dr. Michael Darter

Iowa State University
Institute for Transportation

National Concrete Pavement Technology Center

Overview

- A National Survey was conducted to gauge the experiences of State DOTs & Contractors with several concrete pavement **repair/preservation techniques**, with emphasis on <u>design</u>, <u>specifications</u>, <u>construction practices</u>, <u>inspection/acceptance</u>, & <u>performance</u>.
- State DOTs that are <u>leaders</u> in best practices for six <u>repair/preservation techniques</u> were selected.
- <u>Questionnaires & Interviews</u> of 15 expert State & Contractor personnel in 7 States were completed.

State & Contractor Survey

State Personnel

- **UT: Jason Simmons**, UDOT
- **MO: John Donahue**, MoDOT
- **WA: Jeff Uhlmeyer**, WSDOT
- **MN: Gordon Bruhn**, MnDOT
- **CA: Linus Motumah**, CalTrans
- **GA: Wouter Gulden**, Ret. GDOT
- **KS: Rick Barezinsky**, KDOT

Contractor Personnel

- **UT: Ken Passey**, A-Core Conc. Cutting, Inc.
- **MO: Terry Kraemer**, Diamond Service, Inc.
- **WA: Robert Seghetti**, ACME Concrete Paving, Inc.
- **MN: Matt Zeller**, Minnesota Concrete Pavement Association
- **MN: Terry Kraemer**, Diamond Services, Inc.
- **CA: Casey Holloway**, Penhall Company
- **GA: John Depman**, Penhall Company
- **KS: Robert Kennedy**, Koss Construction Company

Repair/Preservation Techniques

1. Full-depth Repair (FDR) & Slab Replacement
2. Partial-depth Repair (PDR)
3. Dowel Bar Retrofit (DBR)
4. Diamond Grinding (DG)
5. Cross Stitching (CS)
6. Slab Stabilization (SS)

Missouri DOT Website

https://spexternal.modot.mo.gov/sites/cm/CORDT/

1. **Report:** **"Concrete Repair Best Practices: A Series of Case Studies" 2017**
2. **"6 Tech Briefs"**
3. **"6 Training Presentations"**

Sponsored by: MoDOT & FHWA

Conducted by: Applied Research Associates, Inc.

Missouri DOT Website

https://spexternal.modot.mo.gov/sites/cm/CORDT/

Full-Depth Repair Key Factors

California (JPCP), Missouri (JRCP), and the other States have developed and refined FDR techniques and specifications that have produced 15+ year service lives:

- Appropriate FDR conditions
- **State FDR load transfer design**
- Length/width of FDR
- Repair of base area
- **Anchoring dowel bars**
- Opening to traffic
- Inspection/Acceptance
- **Performance**

State FDR Load Transfer Design

State	Slab Thick (in)	Dowel Location	Dowels At Joint	Dowel Dia-meter (in)
CA	=<9	WP	4+4 @ 12 in	1.25
GA	=<10	Uniform	11 @ 16 in	1.25
MO	All	WP	5+5@ 12 in	1.00
MN	All	Uniform	*11 @ 12 in	1.25
CA	>9	WP	4+4 @ 12 in	1.5
UT	All	WP	4+4@ 12 in	1.5
WA	All	Uniform	11@ 12 in	1.5
GA	>10	Uniform	11 @ 16 in	1.5

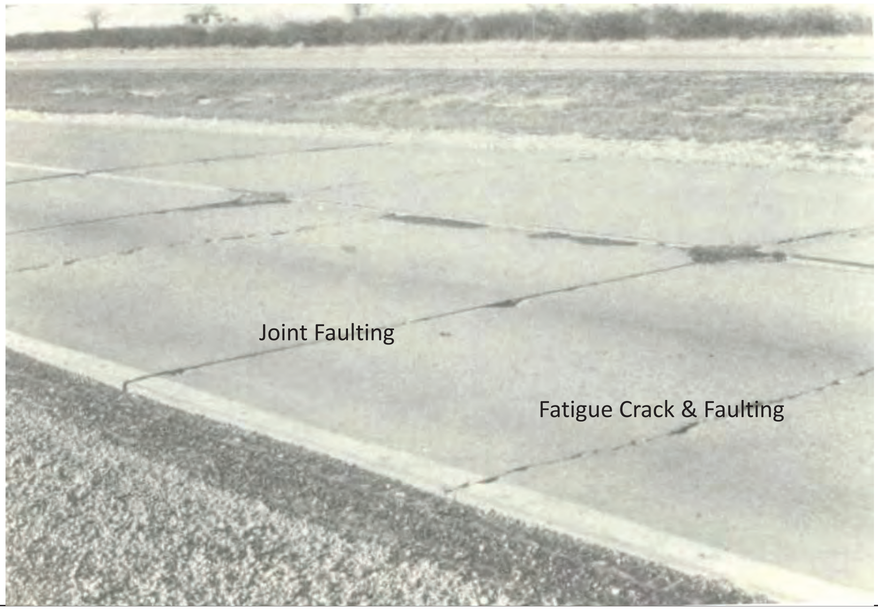
*Needed due to variability in anchoring dowels

Dowel Diameter

- The **dowel bar diameter** is the most critical design factor, since a slight change in diameter (e.g., ¼ inch) dramatically affects the steel/concrete bearing stress under a wheel load.
- Loosening of the dowel bar reduces joint LTE and increases base erosion, faulting, and roughness.
- Field tests have clearly shown that **larger diameter bars** show less transverse joint faulting.

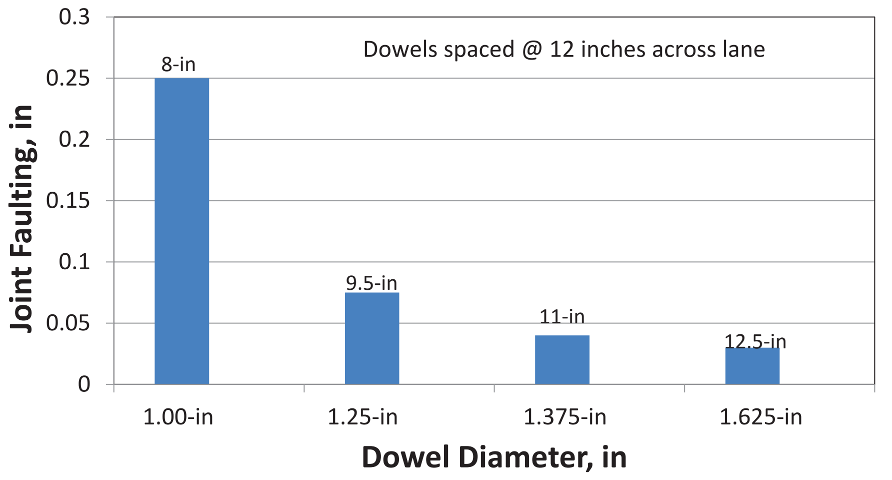
I-80 Extended AASHTO Road Test

Joint Faulting & Cracking, 1958-1975

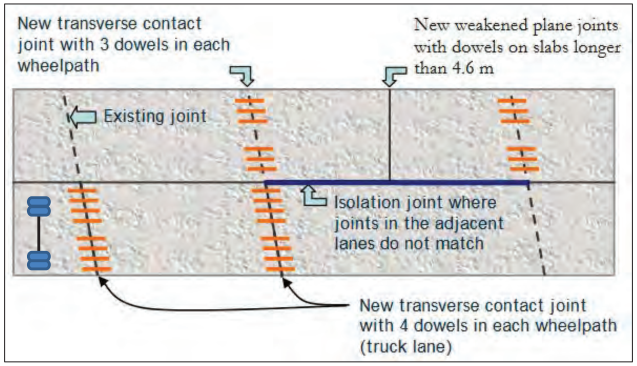


I-80 Extended AASHTO Road Test

JPCP/Gran. (1958-1975)



Layout of Dowels Across Joints



Most truck wheels nearer edge of slab makes it desirable to focus dowels near edge and in wheel paths. (Source: Caltrans)

FDR Anchoring Dowels [Key Issue]

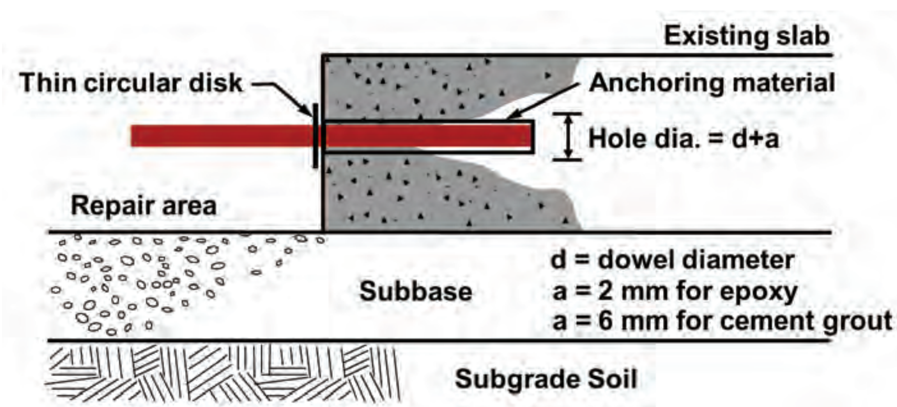
- **Anchoring of the dowel bars permanently** into the existing slab is the most critical FDR placement step.
- If not done properly, the dowels will eventually become loose, the FDR joint will lose joint LTE, and pumping and faulting will develop.

FDR Anchoring Dowels [Key Issue]

- **Most State specifications require:**
  - Drilling holes for dowel + annular gap
  - Clean with air
  - Inject epoxy resin or grout into the hole
  - Rotate the bar during insertion
  - Use grout retention rings
  - Place end caps on protruding dowels
  - Coat bars with lubricant

Anchoring Dowel Bar Into Slab

(FHWA/NHI 1998)



Sawcut Through Existing Joint Showing Lack of Anchoring Material Around Dowelbar: No Grout Retention Ring

(photo courtesy Dr. Mark B. Snyder)

Sawcut Through Existing Joint Showing Good Surrounding Anchoring Material Around Dowelbars: Grout Retention Ring

(photo courtesy Dr. Mark B. Snyder)

Full-Depth Repair Performance

- Performance of FDR in California, Missouri, Georgia, Minnesota, Utah, and Washington has been overall good (with some exceptions).
  - Service life ranging from 10 to 20+ years for JPCP and JRCP.
- California: Surveys of **Rapid Strength Concrete** (RSC) slab replacement projects at 3 & at 13-years showed promising results.

California Highway I-10 EB (PM 15-30)

Near San Bernardino showing two 14-year old RSC slabs outer Lane #4.

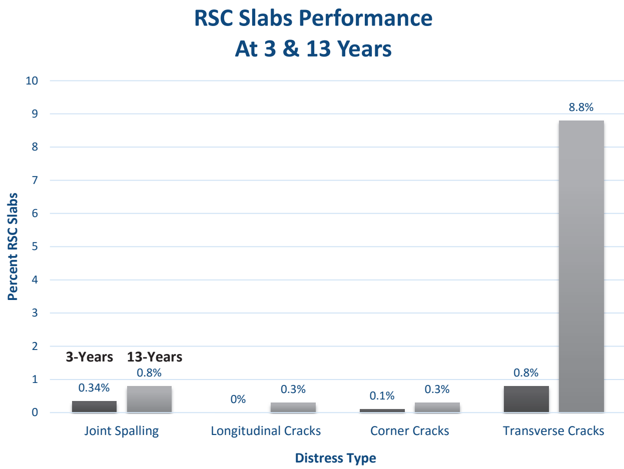
Rapid Strength Concrete (RSC) is made with hydraulic cement that develops minimum opening age and 7-day modulus of rupture:

- Night placement: 11-pm closing & 5-am opening.
- Mod. Rupture Str. > 400-psi before opening traffic & >600-psi 7-days.
- Materials: 4x4 MB; CTS

Surveys of RSC projects at 3 & 13-years showed:

- Very low amounts of joint spalling, shrinkage cracking, longitudinal cracks, and corner cracks.
- Transverse fatigue top down cracking in heavy truck lanes was the only significant development in 13-years.

Performance Rapid Strength Concrete (RSC) --- 8-9 inch Independent Slab Replacement (CA)



Caltrans Random Vs Continuous RSC

Pavement Design	Caltrans 41-9: Individual RSC Slab Replacement	Caltrans 40-5: Continuous RSC Slab Replacement
Slab Thickness	Same as Existing (8-9 in)	Thicker 10-12 in
Base Course	LCB or CTB	New LCB
Joint Spacing	Existing JPCP 12, 13, 18, 19-ft	14-ft/Dowels

Dowel Bar Retrofit Key Factors

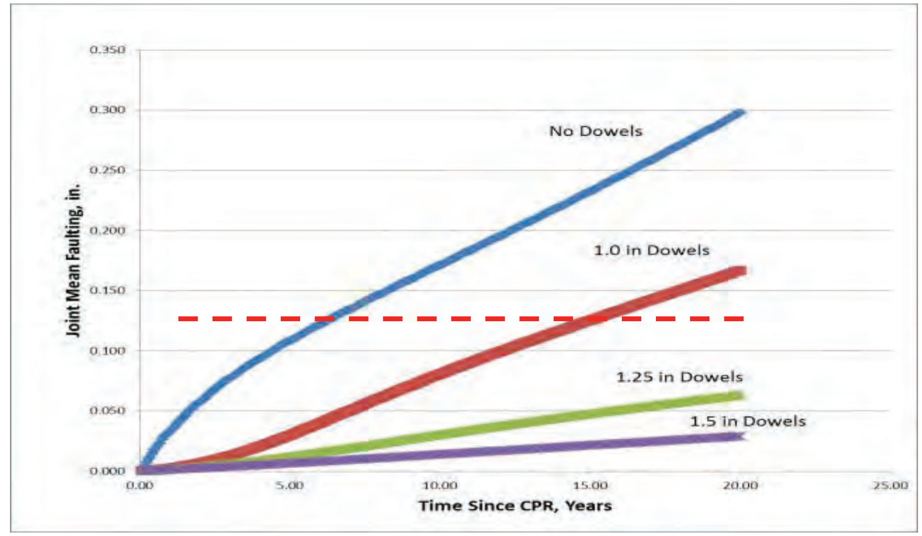
Washington and the other States have developed and refined DBR techniques and specifications that have produced long service lives for JPCP and JRCP projects.

- Appropriate conditions for DBR.
- Effectiveness of the DBR design/layout.
- DBR slot material.
- Inspection/acceptance of DBR.
- Performance of DBR

Appropriate DBR Conditions

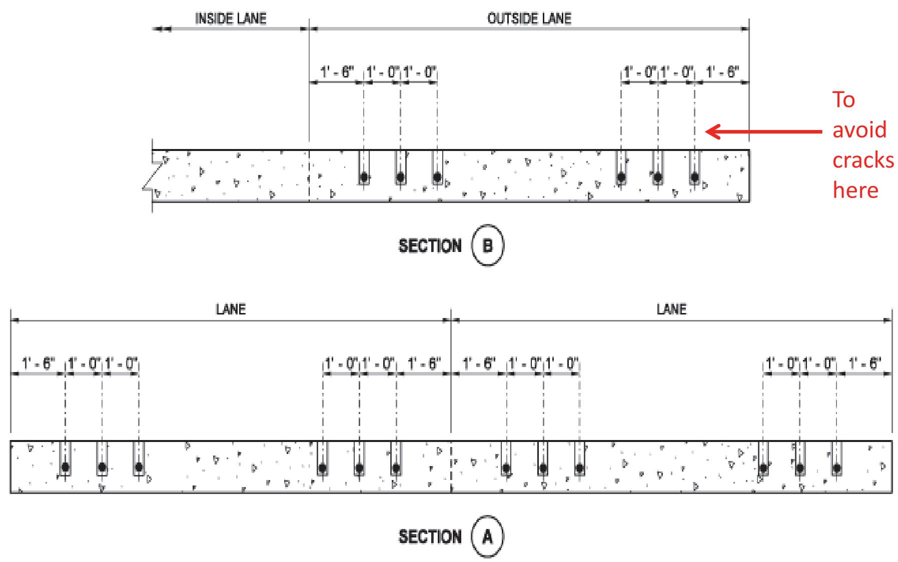
- If existing mean joint faulting is > 0.125 inches (causing high IRI) it is highly likely that faulting will develop similarly after diamond grinding if no DBR.
- The **AASHTOWare Pavement ME Design** software can be used to estimate future faulting & cracking w/ and w/o DBR.

AASHTOWare Pavement ME Design Faulting Prediction for a JPCP Grinding Project



Missouri DBR of Transverse Crack JRCP (10 yrs)

Washington DBR Layout/Design



State DBR Designs

State	No. Bars / Wheelpath	Bar Diameter, inch
Washington	3	1.50
Utah	3	1.50
California (>9 in)	3	1.50
California (<9 in)	3	1.25
Missouri	3	1.25
Minnesota	3	1.25

Projects in California and Minnesota have shown an increase in transverse joint LTE from 30 or less to over 80 percent after DBE, which indicates why very little faulting has developed.

Retrofit Dowel Bar Specifications

Placing Assembled DBR Into Slot

Retrofit Dowel Bar Slot Material

- Washington uses prepackaged mortar extended with aggregate (example product: CTS non-shrink rapid set grout).
- These materials have provided good performance in Washington. The slot material is placed, consolidated, and cured until ready to open to traffic.
- California uses polyester concrete consisting of polyester resin binder and dry aggregate. The existing slot surface is treated with high molecular weight methacrylate bond agent.

Inspection/Acceptance of DBR

- **Washington has a detailed inspection plan in their construction manual** that includes meeting with the contractor, visual confirmation of slots, sandblasting faces clean, aligning dowels properly, ensuring foam core inserts are vertical to form the joint, consolidating fill material, and working equipment to accomplish these tasks.
- **Contractors in Washington believe that inspection of the slot is extremely important.** Sandblasting is believed to be the only way to get it clean (water blasting does not appear to work as well as sand blasting which aids bonding).

Performance of DBR

Washington

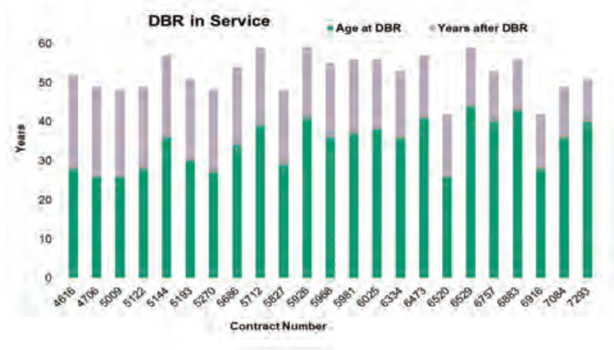
- Overall, DBR performance has been good with very few performance issues. If constructed as part of CPR and done earlier in the JPCP life, the future pavement life can be extended 20 to 30 years.

California

- DBR projects have performed well in California, with typical service life between 10 and 15 years. DBR joints have been tested using the FWD for LTE > 80%, which is an effective criterion for good performance.

WSDOT DBR/Grinding Survival Data

(Add 3 years to these lives)

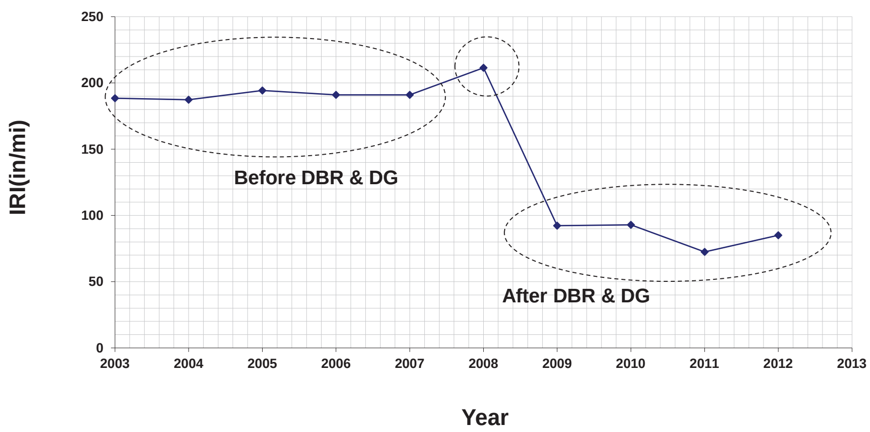


Diamond Grinding

All of these States have outstanding diamond grinding specifications and performance:

1. Significant roughness reduction.
2. Good frictional & textured surfaces.
3. Significant noise reduction.
4. Multiple grinding applications with pavement life extensions until next CPR, OL, or reconstruction.

Impact of Diamond Grinding On Smoothness (20-50-80% IRI Reduction)



Texas DOT

Diamond Grinding: Project Selection

- Proper design & construction of all CPR repairs must be accomplished without causing problems to grinding, e.g., slab jacking, & lots of **elastomeric "soft" or "melt-able" patches that cannot be ground and damages grinding equipment**.

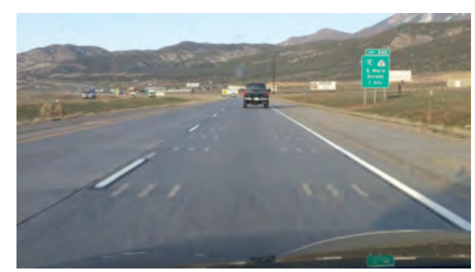
Diamond Grinding: Incentives

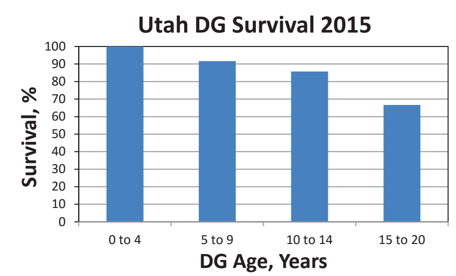
- **Incentives/disincentives** are used by a number of States for grinding smoothness. <u>The incentive has to be enough to make it worthwhile to the contractor to increase their effort to achieve a smoother surface.</u>
- **Smoother pavement = longer life!**
- Knowing they can acquire a bonus allows experienced contractors to lower their diamond grinding unit bid price by an amount equivalent to the bonus.

Utah Diamond Grinding Survival

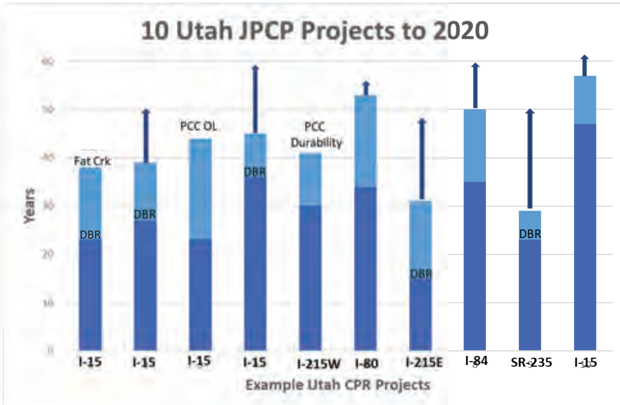
(58 Projects 1988-2015)

- 91% of Diamond Grinding projects still in service (up to 17-years in service to 2015).
- 100% Diamond Grinding projects that included DBR are still in service with good performance.
- Preservation/Repair significantly helped extend the life before a Structural Overlay or Reconstruction was required.





Utah Diamond Grind/DBR Life Extension



Utah I-15 NB

(1984 Construction, 2007 DG/DBR)

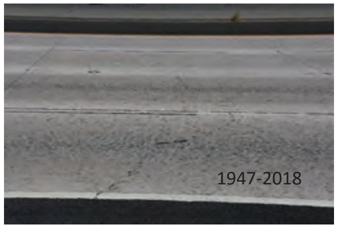
Diamond Grinding: Project Selection

- **Multiple diamond grindings (2 to 4 times)** on projects over the years (reduction in slab thickness) has not shown much evidence of an increase in structural fatigue cracking.
  – Use AASHTO ME “Restoration” to check future fatigue cracking in particular for reduced thickness, as well as faulting, and IRI.

San Bernardino Freeway, CA

8-in/3-in AC, Non-Doweled, JPCP (I-10 Outer 2-Lanes)

Constructed/Diamond Ground	In-Service Years
Construction 1947 (Route 66)	New
DG 1967 (1st DG in USA)	20
DG 1983-85	17
DG 1998-2000	15
DG 2012-2015 (parts of I-10)	15



Cross-Stitching Key Factors

Kansas and the other States have developed and refined cross-stitching techniques and specifications that have contributed to long service lives for JPCP and JRCP projects.

- Appropriate conditions for Cross-Stitching.
- Effectiveness of the Cross-Stitching bar design/layout.
- Drilling holes & anchoring tie-bar material.
- Inspection/acceptance of Cross-stitching.
- Performance of Cross-Stitching

Appropriate Conditions Cross-Stitching

- Cross-stitching is a technique applied to an existing concrete pavement, can be new or older, to longitudinal cracks and joints to keep tight.
- Cross-stitching has been performed on slabs typically 7 inches or thicker successfully. One contractor reported that cross-stitching performed on a 5-inch concrete slab also worked out well.

Cross-Stitching: Key Points

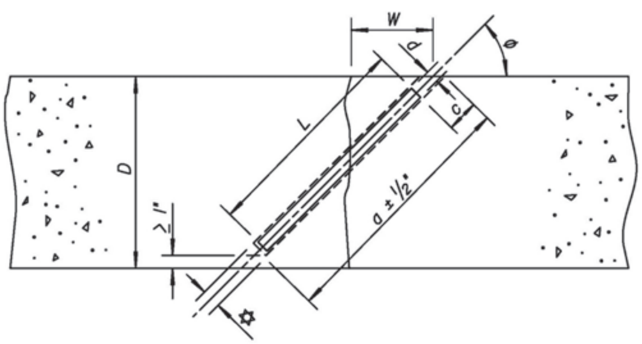
- High percentage of longitudinal cracks and joints will open up over time if not "reinforced" creating serious problems.

Photo of Longitudinal Crack w/Cross-Stitched Tiebar, 10 years (MO)

Design Aspects Cross-Stitching

- Criteria of existing joint or crack:
  - Contractors have successfully cross-stitched cracks/joints up to 1 inch wide, and they have performed well. The technique has not worked well on cracks/joints wider than 1 inch, and it should not be done.
- Kansas hole layout, alternating sides
  - Longitudinal Joints: 30-inch spacing, 0.75 in rebar (0.15 percent area steel, 10-inch slab)
  - Longitudinal Cracks: 24-inch spacing, 0.75 in rebar (0.18 percent area steel, 10-inch slab)

Kansas: Drilled Hole Detail



SECTION A-A
TIE BAR INSERTION DETAILS

✿ *Drill diameter will be not less than 1/4" larger than the tie bar diameter and no more than 3/8" larger than the tie bar diameter.*

Performance: Cross-Stitching

- **Kansas:** Cross-stitching of longitudinal cracks and joints has maintained crack width over time, and no spalling has occurred. The 2002 East Topeka Interchange project with over 30 miles of cross-stitching of the longitudinal joint is still performing well, and the longitudinal joint is tight (15y).
- **Missouri:** The oldest cross-stitching projects are 10 years old. These projects exhibit only a few locations of spalling of the longitudinal cracks. These projects on I-70 and elsewhere were under very heavy truck traffic, and some cracks were in the wheel paths.
- **Minnesota:** Longitudinal cracks have maintained crack width over time. One project in Minnesota was a 5- to 6-inch thin portland cement concrete overlay with longitudinal cracks. The project is now nearly 10 years old, and longitudinal cracks are still in good condition. Overall, a 20+ year service life is estimated.

Partial Depth Repair(PDR): Key Points

Keys To Long Life PDR (Highest Risk Treatment)

1. **The first key is to limit usage to the appropriate joint and crack locations and conditions.** Minnesota, Washington, California, Missouri, Georgia, and Utah use PDR for spall repair of transverse and longitudinal joints where there is sound concrete in the bottom half of the slab.
2. **The second key is the detail and effectiveness of the specifications, special provisions, and standard drawings (design) for PDR.** Minnesota (lead State) and the other States provide significant design and specification detail for PDR including field boundaries, removal of concrete, forming of joints, inspection/acceptance, and curing.

Partial Depth Repair(PDR): Key Points

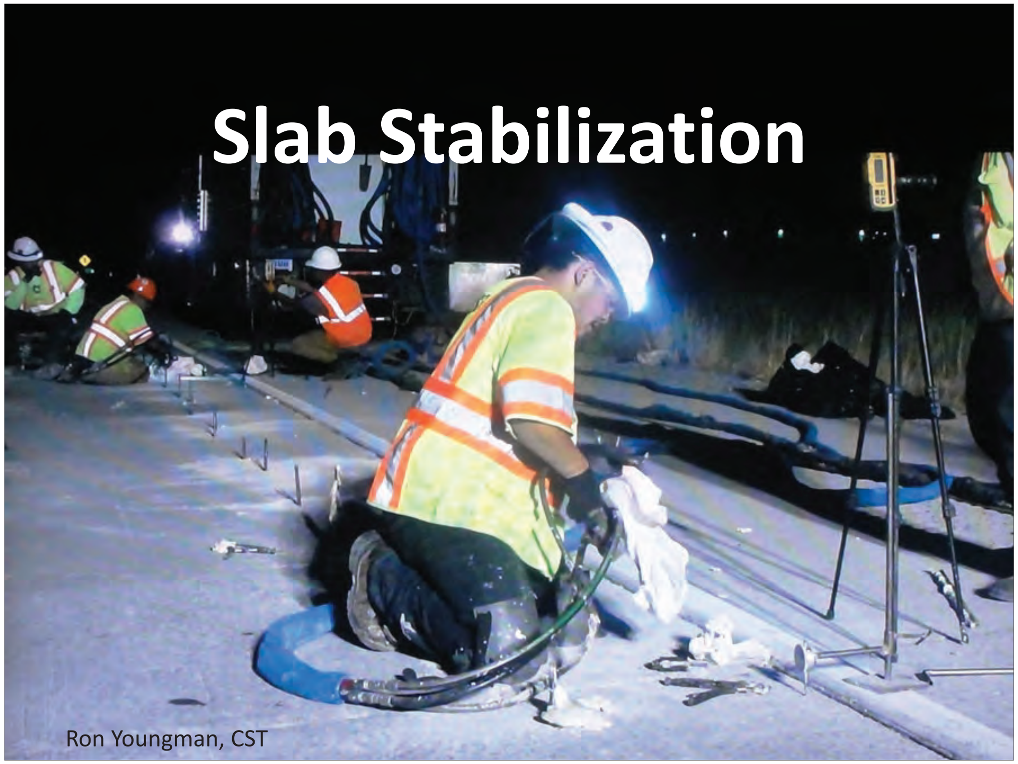
Keys To Long Life PDR

3. **The third key is the repair material**, where conventional and proprietary rapid setting cementitious mixtures are extensively used.
4. **The fourth key is the inspection/acceptance procedures** and their effectiveness. Warranties (e.g., 30 days) appear to be an effective approach.

Performance of PDR

- Overall the performance of PDR shows that this technique has been highly variable, both within and between States.
- If properly installed using the procedures established in Minnesota and the other States surveyed, and placed by knowledgeable contractors with effective inspection, and a 30-day warrantee:
  - PDR typically lasts 10 to 15 years or more.
  - However, if things are not done properly, the PDR ends up with a short life of < 5 years.
- For example, if a PDR is placed in a situation where there is surrounding concrete deterioration, slab has underlying deterioration > ½ thickness, then it will not last long. A full-depth repair would have been a much more effective repair for these situations.

Slab Stabilization



Ron Youngman, CST

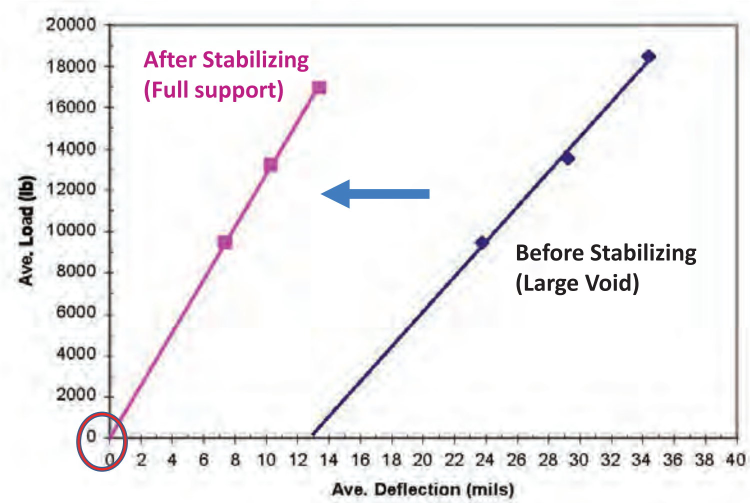
Slab Stabilization Key Factors

- **Slab stabilization** is defined in Missouri & Georgia as the restoration of full support at slab joints/cracks, locations where deflection testing indicates loss of support.
- **Key factors** include locating slab corners with loss of support, appropriate drilling of holes, injecting non-erodible material into the holes that do not lift slab significantly but fill in voids below, and finally testing to assure full support to the slab.

FWD Load/Deflection Testing At Slab Corners Verifies Loss of Support

Missouri Uses FWD Load Vs Deflection: Loss of Support at Corners

1993 AASHTO Guide, Part III, Chapter 3, Section 3.5.



Slab Stabilization Material

- **Material that is injected** beneath slabs/stabilized base is critical to erosion & pumping.
- Lots of **cement grout and asphalt** used in past. These have been largely successful.
- Today, **polyurethane material** is most used successfully to restore support and this material may also have some ability to reduce future erosion and pumping and improve joint LTE if properly placed.

Performance Slab Stabilization

- **Missouri.** The typical service life of slab stabilized jointed reinforced concrete pavement (mostly at working transverse cracks) in Missouri was estimated by experienced staff of the State at 5-10 years.
- **A contractor** who has conducted many concrete pavement restoration projects estimates life of slab stabilization using polyurethane injection material as 10-15 years.

Summary

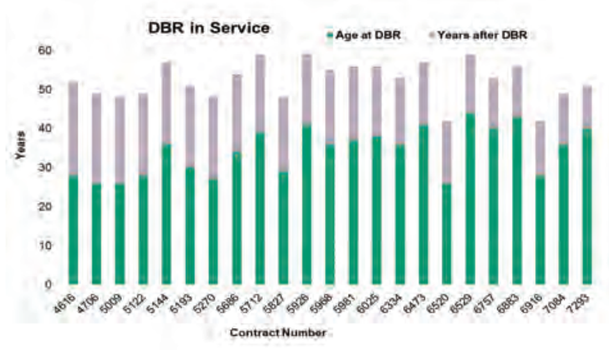
Repair/Preservation Performance

Final point: What is the overall impact of the combined repair/preservation treatments on the performance & survival of JPCP?

- Everyone that I interviewed believed that collectively these treatments have a very significant impact on the survival and service life of JPCP before major rehabilitation was required (e.g. overlay, reconstruction)
- Lets look at the Data: Washington & Utah

WSDOT DBR Survival Data

(Add 3 years to these lives)



Utah Survival Results: OL & RECON

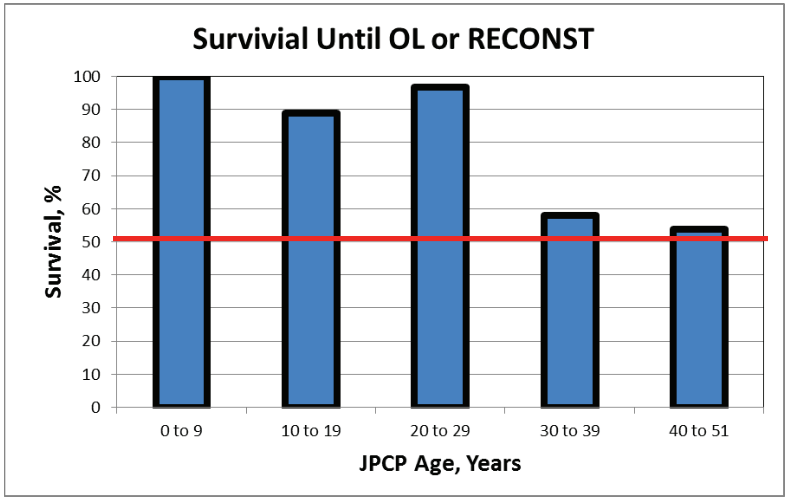
(1964-2015: 108 JPCP)

Survival Data Summary JPCP			
JPCP Age Years	Total Sections	OL & RECON Sections*	SURVIVAL % Sections
0 to 9	27	0	100
10 to 19	18	2	89
20 to 29	31	1	97
30 to 39	19	8	58
40 to 51	13	6	54
Totals	108	17	--

* 51% had received repair/preservation treatments (CPR)

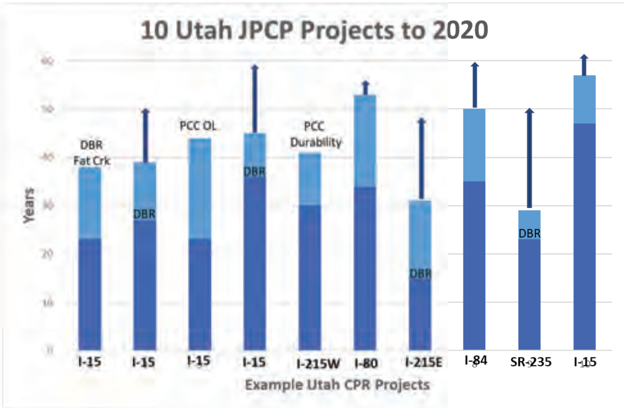
Utah Survival Results

(1964-2015: 108 JPCP)



Utah Survival Results

- Mean life (until major rehab of overlays or reconstruction) of 108 JPCP projects since 1964 was 40 to 51-years. (Design life = 20-yrs)
- Major distress types:
  - Transverse joint faulting (no dowels in older projects)
  - Some longitudinal cracking & transverse (fatigue) cracking
  - Some joint spalling from low air content, etc.
- How was this long life achieved? 51% of these JPCP received repair/preservation treatments: slab replacement, partial-depth repair, dowel bar retrofit, & diamond grinding.



Mean Life Extension = Total Life / Original JPCP Life = 1.8

Utah I-215E SLC

(1988 Construction, 2005 DG/DBR)

Missouri DOT Website

https://spexternal.modot.mo.gov/sites/cm/CORDT/

- Tech Report, Tech Briefs, & Training Presentations available on Missouri DOT website. [Thanks to MoDOT & FHWA funding]
- Repair & Preservation techniques applied before reaching "poor" conditions can increase the life of JPCP by about double the non-preserved life!