Concrete Pavement Repair Best Practices

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Study Conducted for Missouri Department of Transportation

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Objectives

- Conduct a National Survey to gauge the experiences of State DOTs with six concrete pavement repair techniques, with emphasis on design, specifications, construction practices, and project acceptance.
- Select State DOTs that lead in best practices for construction and acceptance of concrete repair techniques.

Objectives

- Prepare a **“Case Study Document”** and **“Tech Brief”** for each CPR technique.
- Report is completed, reviewed, revised, and soon to be published this fall.

Expert Task Group, ETG

- **John Donahue**, Missouri DOT (Project Manager)
- **Jason Simmons**, Utah DOT.
- **Jeff Ulhmeyer**, Washington State DOT.
- **Terry Kraemer**, Contractor, Diamond Surface.
- **Todd M. LaTorella**, MO/KS Concrete Pavement Assn.
- **Larry Scofield**, Int. Grinding and Grooving Association
- **Matt Zeller**, Concrete Pavement Association of MN
- **Joe Moore**, Missouri DOT

*ARA team expresses great appreciation to the ETG members for their advice and review of the repair techniques!

State & Contractor Survey: Climates

Climate	FDR	PDR	DG	DBR	Cross-Stitch	Slab Stab-ilization
Dry-Non-Freeze	CA	CA	CA	CA	---	---
Dry-Freeze	UT WA	UT WA	UT WA	UT WA	UT KS	--- ---
Wet-Freeze	MO MN	MO MN	MO MN	MO MN	MO MN	MO ---
Wet-Non-Freeze	CA WA GA	CA WA GA	CA WA GA	CA WA ---	--- --- ---	--- --- GA

Dowel Bar Retrofit

Dowel Bar Retrofit Key Factors

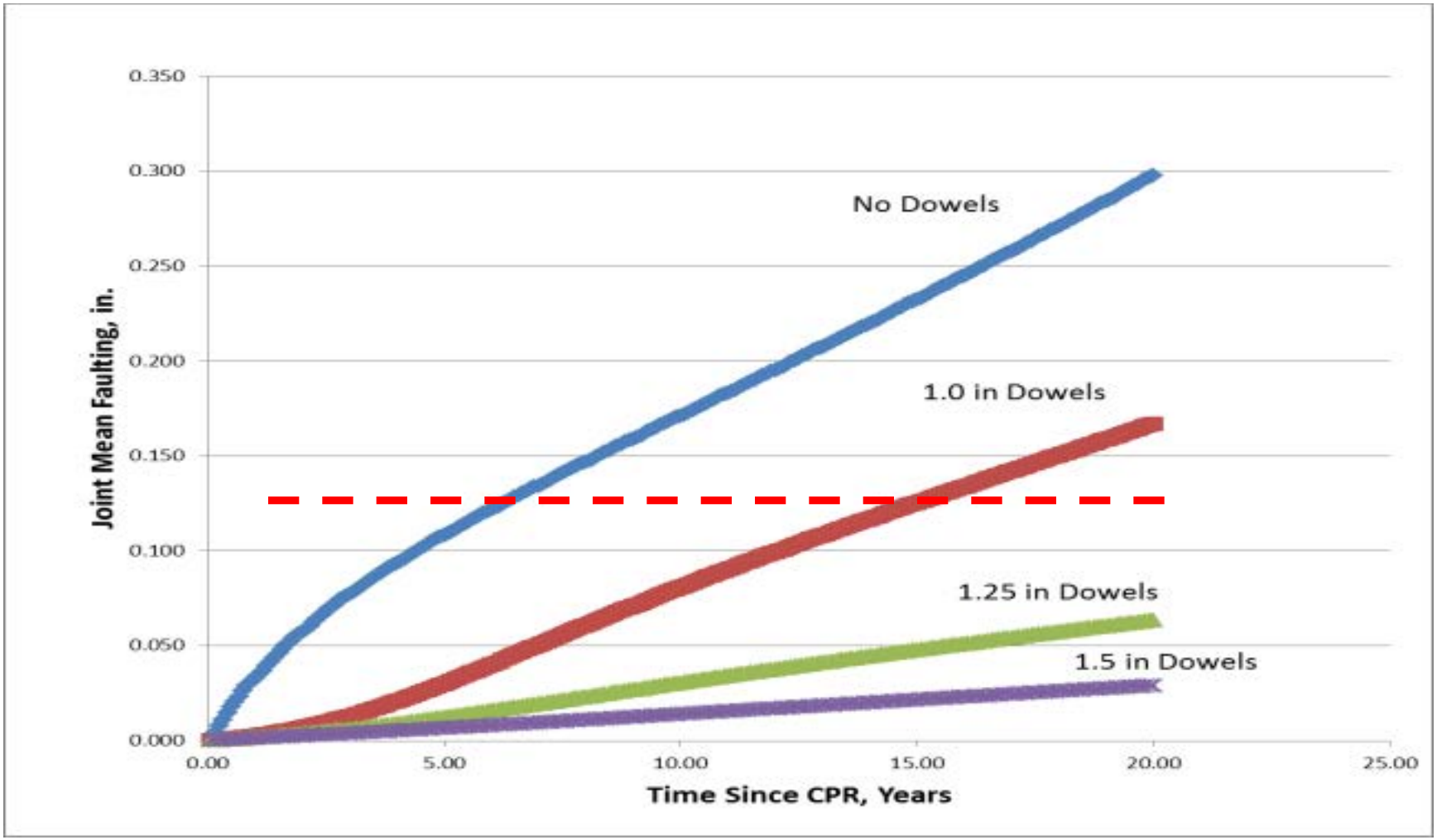
Washington and the other States have developed and refined DBR techniques and specifications that have produced long service lives for JPCP and JRCP projects.

- 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

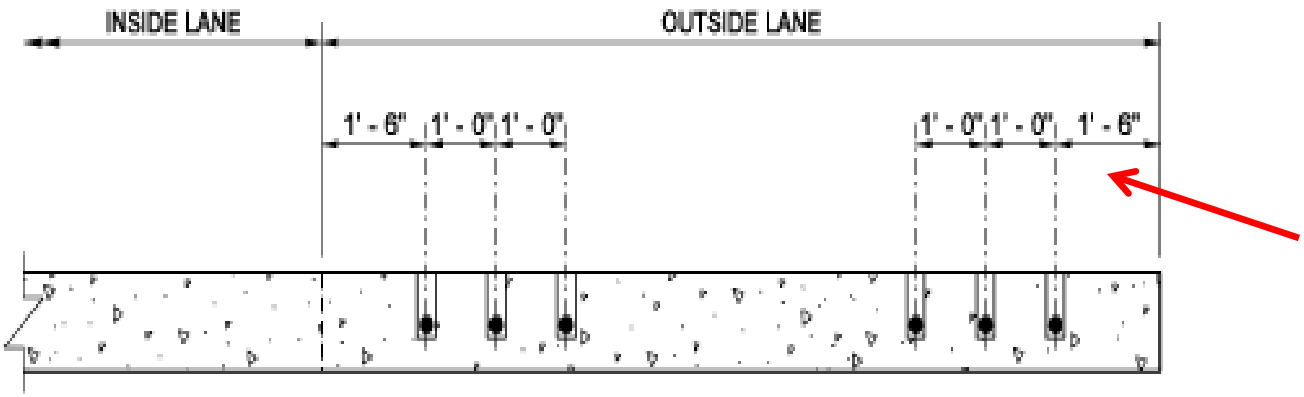


Missouri DBR of Transverse Crack JRCP (10 yrs)

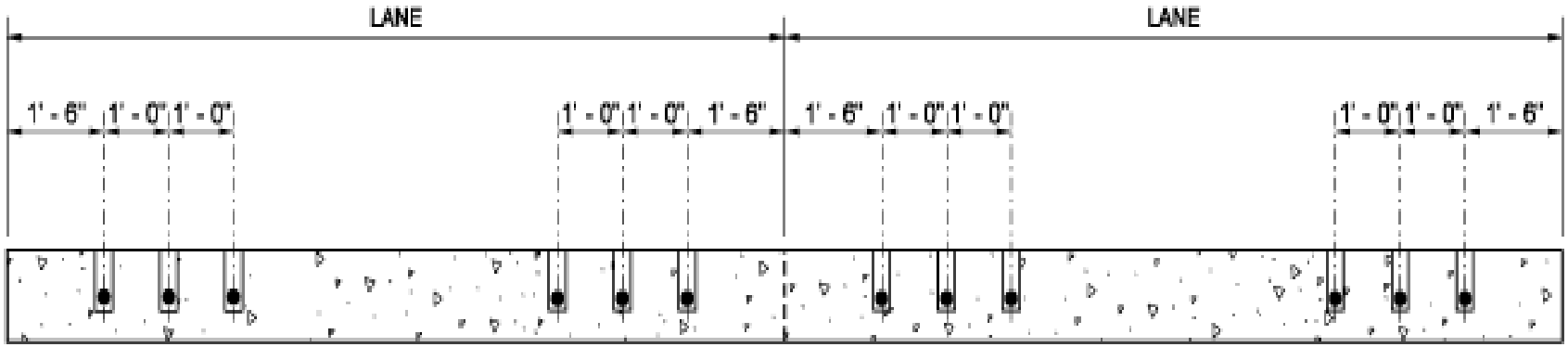
Dowel Bar Retrofit Design

- Washington requires three 1.5 inch dowels per wheel path that are spaced at 12 inches apart.
- 18-inch spacing from the outer edge of the slab to the first dowel bar to prevent cracking near the slab corner.

Washington DBR Layout/Design



SECTION B



SECTION A

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) and 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 the ultimate DBR performance criterion.


Full-Depth Repair (FDR)
FHWA, 1998

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

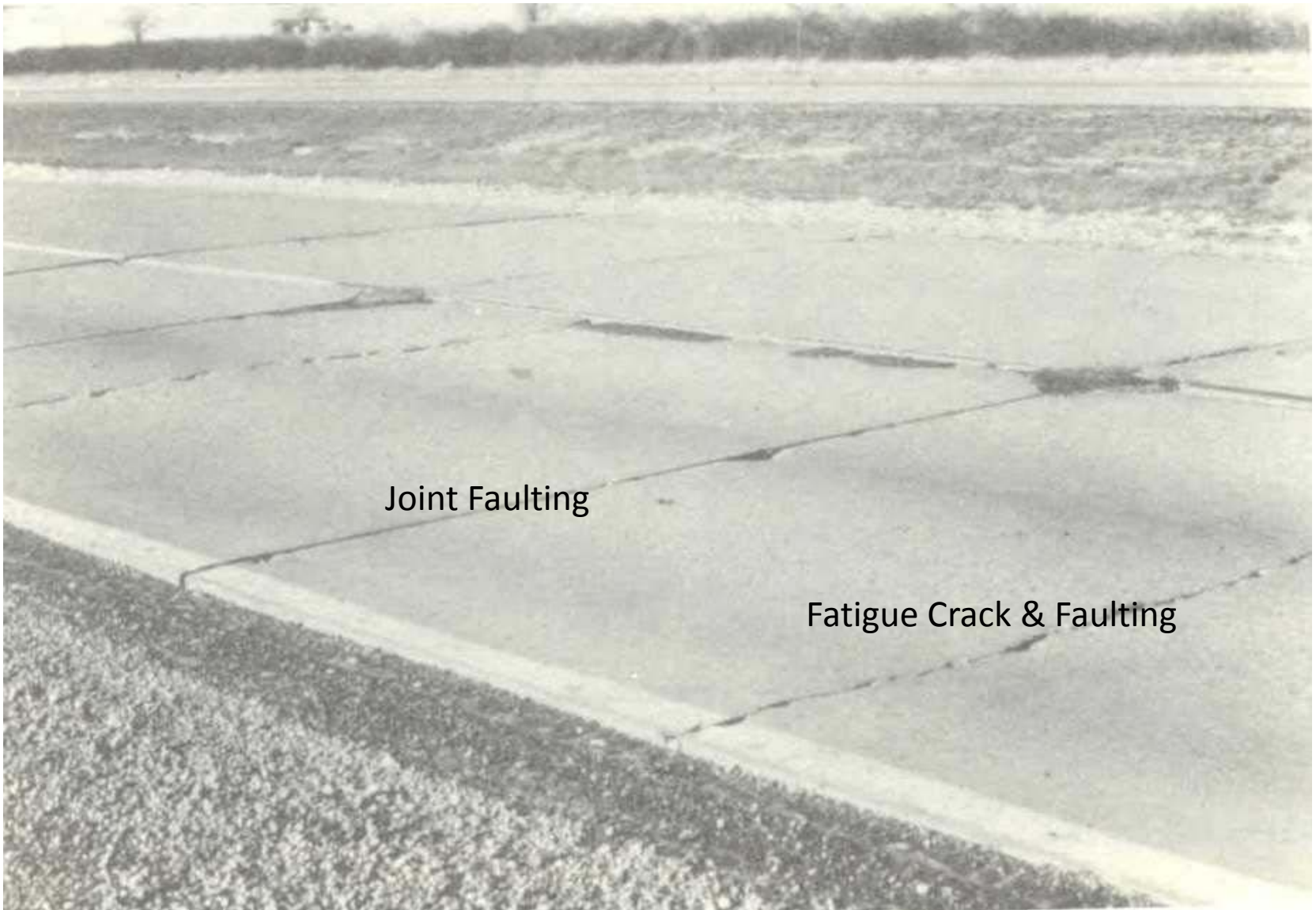
*Needed due to variability in anchoring dowels

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.

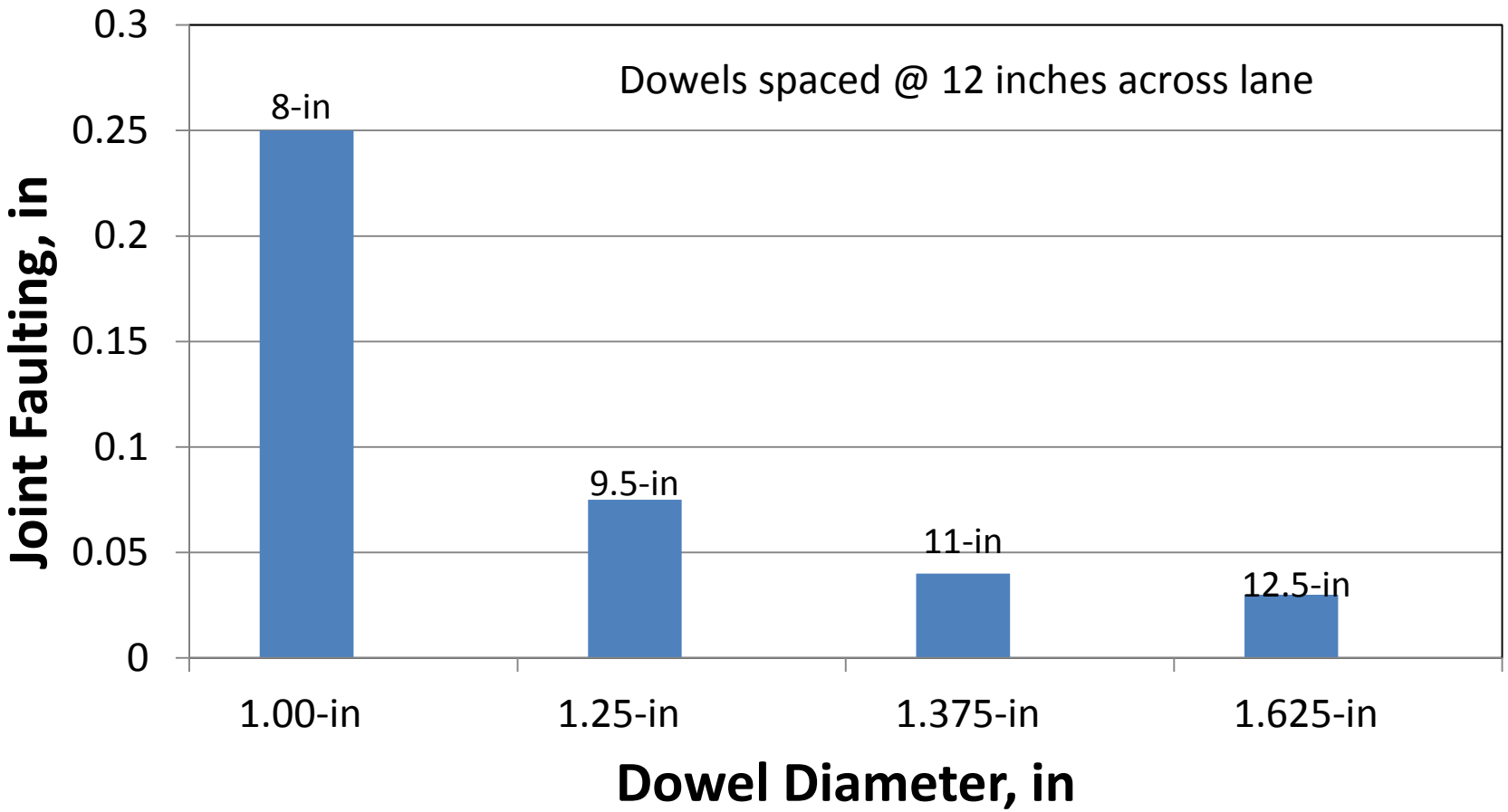
I-80 Extended AASHTO Road Test

Joint Faulting & Cracking, 1958-1975

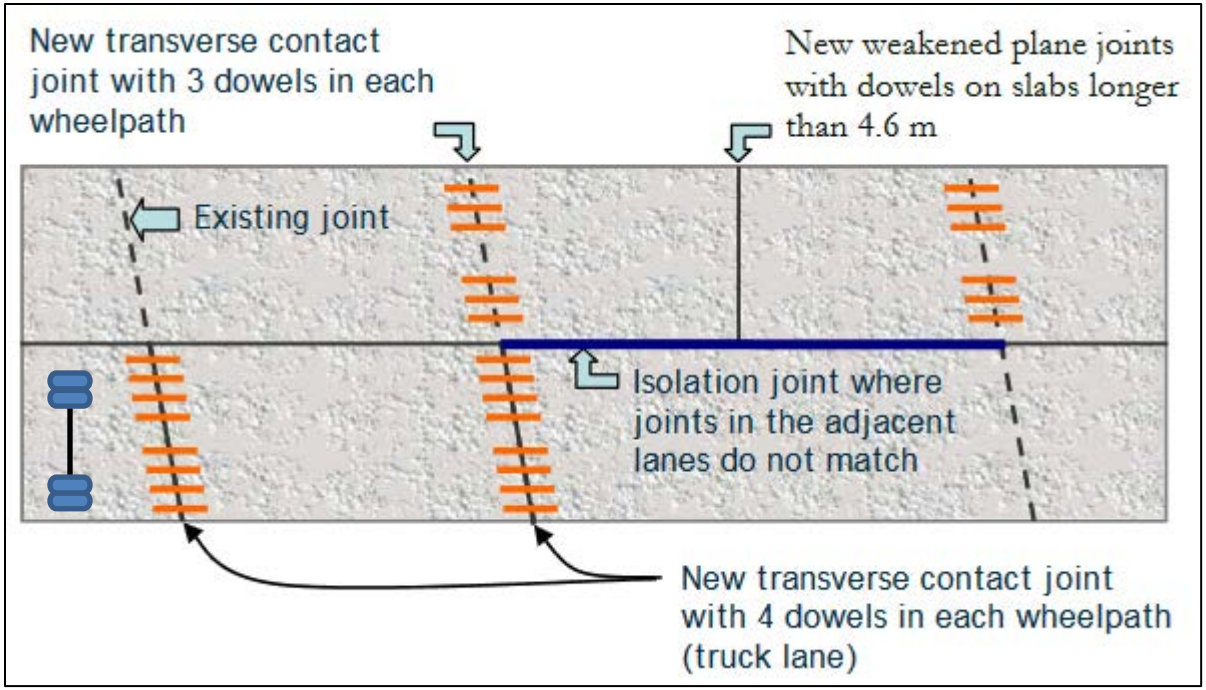


I-80 Extended AASHTO Road Test

JPCP/Gran. (1958-1975)



Layout of Dowels Across Joints



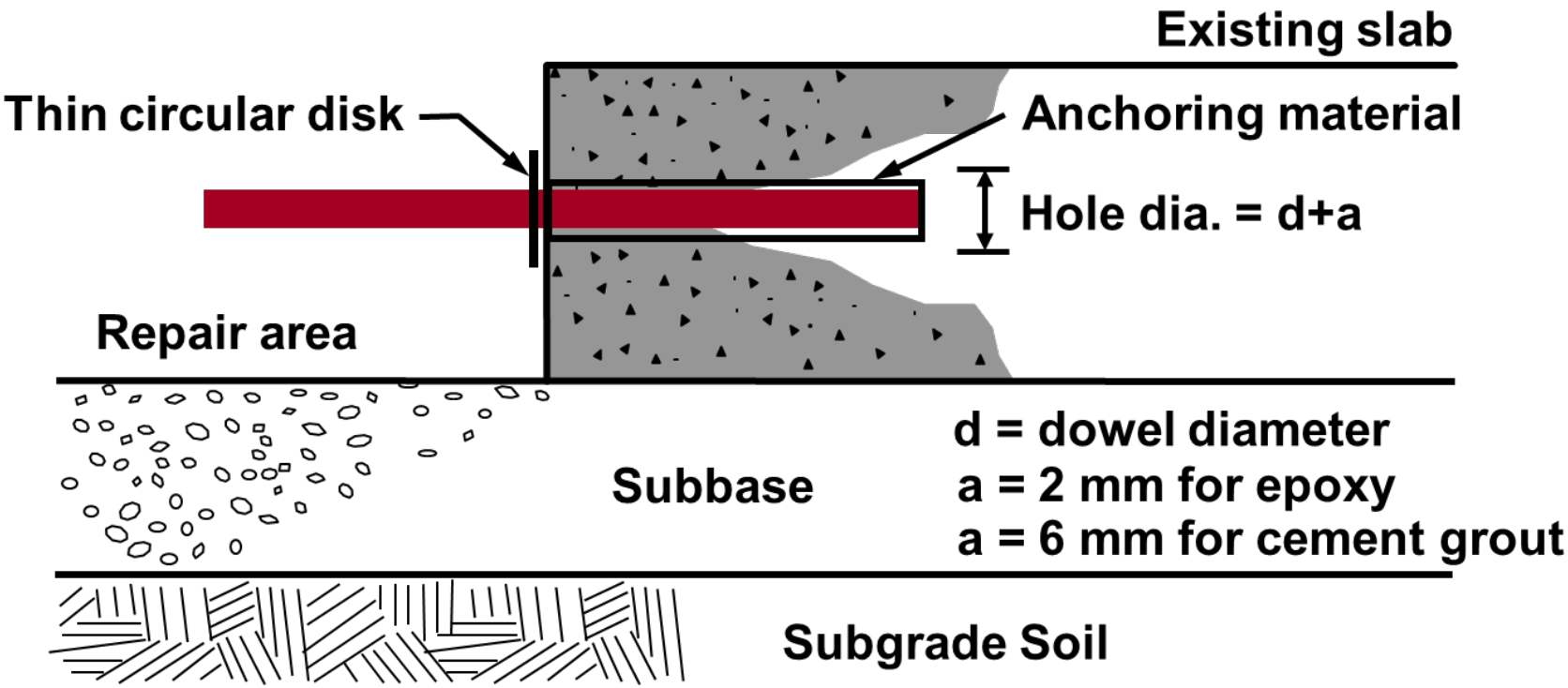
Most truck wheels nearer edge of slab makes it desirable to focus dowels near edge and in wheel paths. Inner dowels do little to reduce deflections at edge of slab.

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.
- **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, and coat bars with lubricant.

Anchoring Dowel Bar Into Slab

(FHWA/NHI 1998)



Sawcut Through Existing Joint Showing Lack of Anchoring Material Around Dowelbar

(photo courtesy Mark B. Snyder)

Sawcut Through Existing Joint Showing Good Surrounding Anchoring Material Around Dowelbars

(photo courtesy 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), providing a service life ranging from 10 to 20+ years for JPCP and JRCP.
- A recent performance survey in California indicated that a very high percentage of rapid strength concrete FDR (98.6 percent) are performing very well after 3 to 8 years on a dozen projects.

Slab Stabilization

Ron Youngman, CST

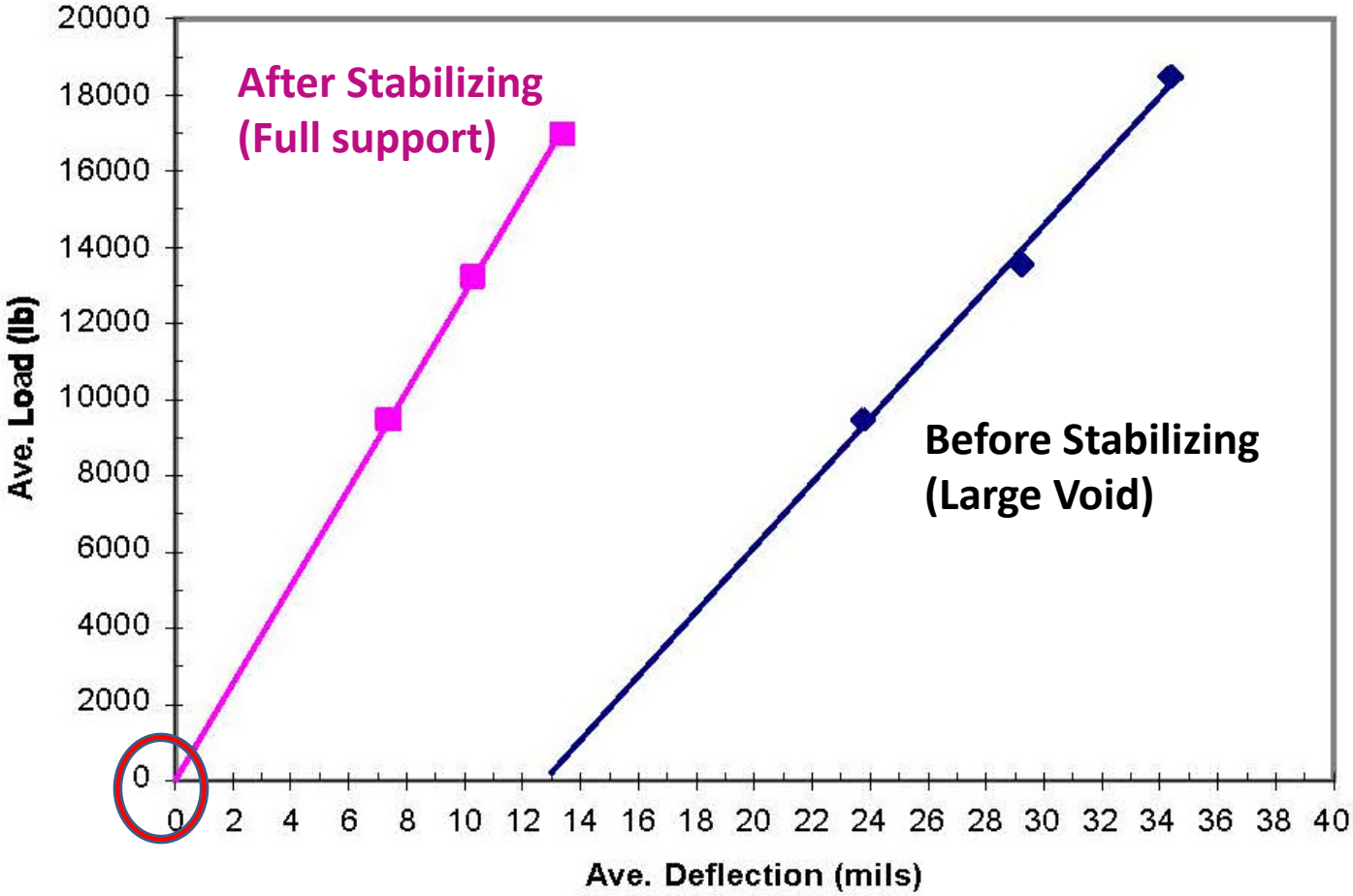
Slab Stabilization Key Factors

- **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.**
  - Note: Slab lifting or jacking for settlements is very important but not part of this study.
- **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.
- The **polyurethane material** is currently being used very 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.

Inspection/Acceptance

- The **best acceptance criterion is to conduct deflection testing of joints** that were stabilization along the project to verify that full support has been achieved (to reduce work load, you can test only a fraction of the joints).
- This is a straightforward procedure using deflection testing at a corner with a range of loads and corresponding measured deflections.

Performance

- **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.

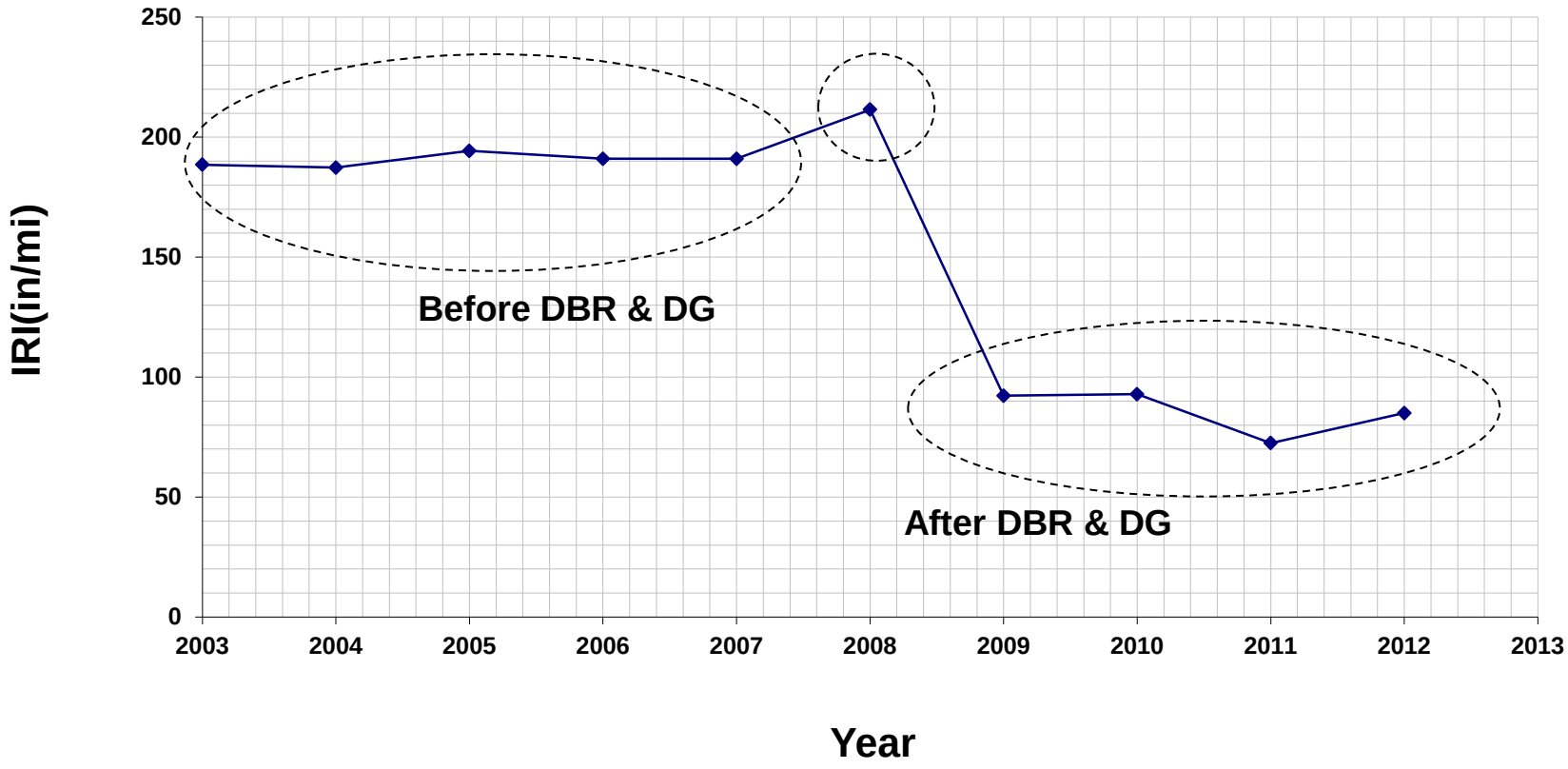

Diamond Grinding

Diamond Grinding

This **Case Study Report** focuses on diamond grinding in Utah but includes information from Georgia, Minnesota, Missouri, California, and Washington. Significant identified benefits:

1. Significant roughness reduction.
2. Good frictional & textured surfaces.
3. Significant noise reduction.
4. Multiple 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

- No serious durability problems (especially lower portion of slab).
- For non-doweled projects, dowel bar retrofit can be specified to eliminate re-faulting.
- If the existing concrete slab has a softer type aggregate (e.g., limestone), then wider diamond grinding blade spacing must be considered to minimize texture wear (NGCS can also be used as its texture includes grooves).

Diamond Grinding: Project Selection

- Proper design & construction of all CPR repairs must be accomplished (without causing problems to grinding, e.g., slab jacking, elastomeric “soft” patches that cannot be ground and damages equipment).
- Conventional diamond grinding reduces pavement/tire noise significantly. The NGCS texture has resulted in a lower tire/pavement noise than conventional diamond grinding.

Diamond Grinding: Project Selection

- Multiple diamond grindings 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, as well as faulting, and IRI.
- The specifications for diamond grinding from all of these States are considered to be very effective.

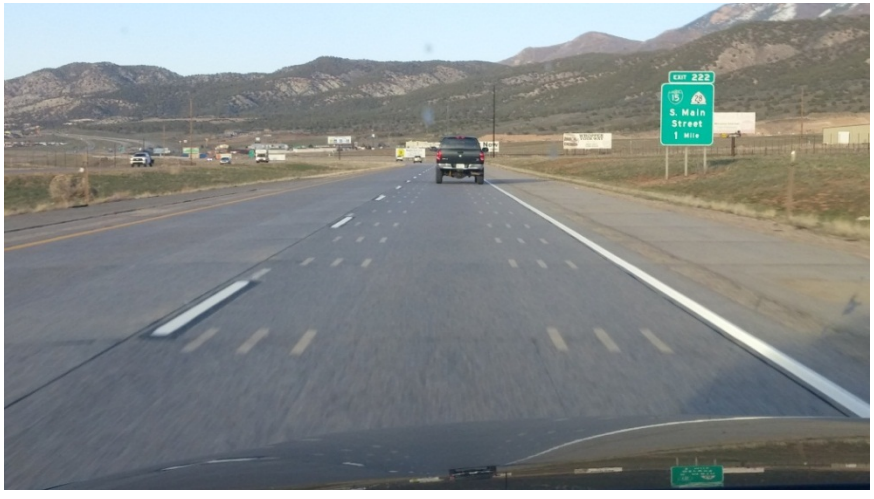
Diamond Grinding: Incentives

- **Incentives/disincentives** are used by a number of States for grinding smoothness. The **incentive has to be enough to make it worth it to the contractor** to increase their effort to achieve a smoother surface.
- 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 JPCP Survival

(108 Projects 1964-2015)

- 50 percent of non-doweled JPCP required CPR at **10 to 19 years (joint faulting).**
- CPR preservation helped extend the life to an average of **41 to 51 years** before structural Overlay or Reconstruction was required.
- **CPR including Diamond Grinding techniques** played a major role in more than doubling JPCP 20-year service life!



San Bernardino Freeway, CA

8-inch Non-Doweled, JPCP (Route 66/I-10)

Constructed/Diamond Ground	Service Years
Construction 1946	New
DG 1965	19
DG 1984	19
DG 1997	13
DG 2005	8
DG 2017	12

Diamond Grinding Performance

- These States have demonstrated:
  - Non-doweled: 10 to 15 years service.
  - DBR: 15 to 30 years service (depends on PCC durability).
  - Some projects in these States have had CPR with diamond grinding up to 3 to 4 times with acceptable service lives.

Cross-Stitching

Cross-Stitching Key Factors

Kansas and the other States have developed and refined cross-stitching techniques and specifications that have produced 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

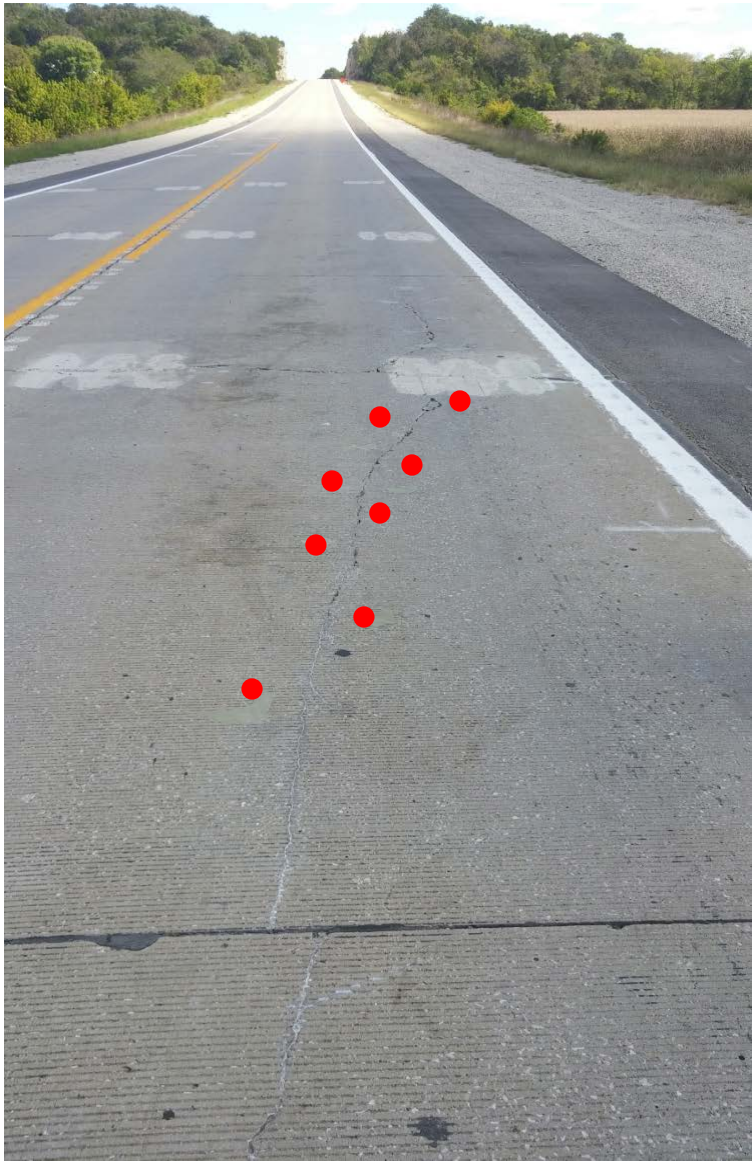
Appropriate Conditions Cross-Stitching

- 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.
- This case study report focuses on cross-stitching in Kansas but also includes information from Missouri, Minnesota, and Utah.

Cross-Stitching: Key Points

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

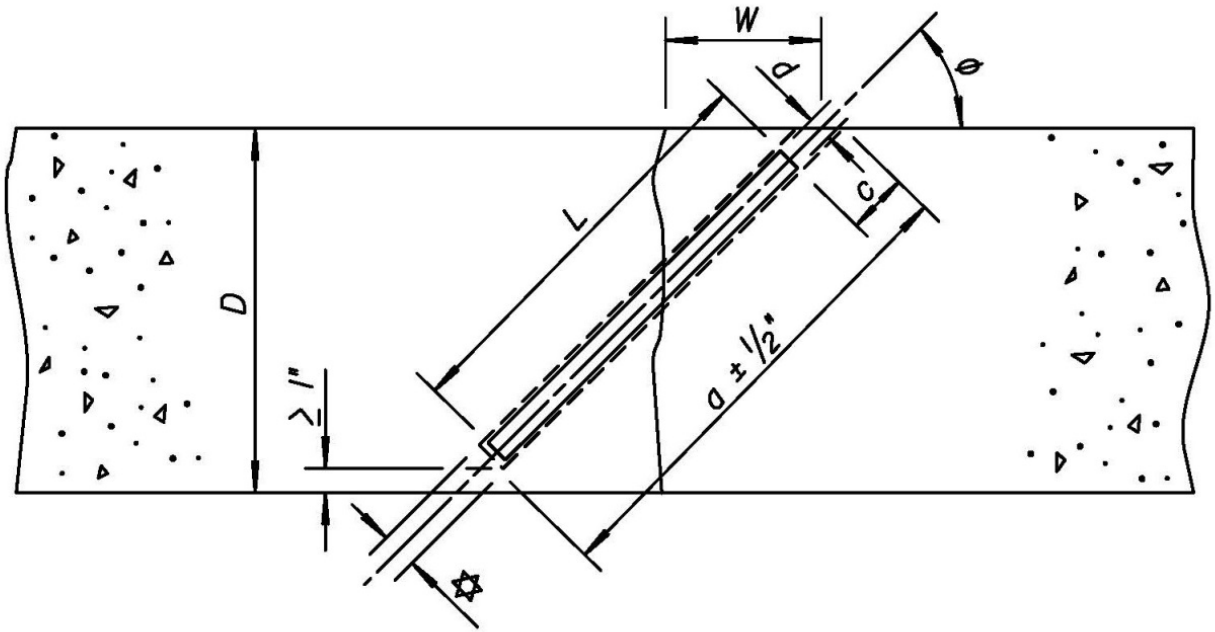
Photo of Longitudinal Crack w/Cross-Stitched Tiebar, 10 years (MO)



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 (0.6 percent area steel, 10-inch slab)
  - Longitudinal Cracks: 24-inch spacing, 0.75 in rebar (0.75 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.*

Kansas Cross-Stitching Design

Slab Thickness (in)	Angle with Horizon	Offset to Drill Hole (in)	Rebar Diameter (in)	Rebar Length (in)	Hole Length (in)	Minimum Depth Bar (in)
8.0	35°	5.75	0.75	9.00	12.50	3.00
8.5	35°	6.00	0.75	9.50	13.00	3.00
9.0	35°	6.50	0.75	10.50	14.00	3.00
9.5	35°	6.75	0.75	11.50	15.00	3.00
10.0	40°	6.00	0.75	11.00	14.00	2.50
10.5	40°	6.25	0.75	12.00	15.00	2.50
11.0	40°	6.50	0.75	12.50	15.50	2.50
11.5	40°	6.75	0.75	13.50	16.50	2.50
12.0	45°	6.00	0.75	13.00	15.75	2.25
12.5	45°	6.25	0.75	13.50	16.25	2.25
13.0	45°	6.50	1.00	14.00	17.00	2.50
13.5	45°	6.75	1.00	14.50	17.50	2.50
14.0	45°	7.00	1.00	15.50	18.50	2.50
14.5	45°	7.25	1.00	16.00	19.00	2.50
15.0	45°	7.50	1.00	1.00	20.00	2.50

Inspection/Acceptance: Cross-Stitching

- Maintaining the angle of the drill.
- Making sure the drill cannot drill through slab bottom.
- Checking the hole location (distance from the joint or crack) and spacing.
- Verifying the size of the tiebar.
- Checking the anchoring process, including cleaning of the hole and insertion of epoxy and bar in the specified rotational way.
- Observing that the drilling and anchoring procedures should not spall the surface of the concrete.

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 joint is very tight.
- **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.

Final Report

- This presentation covers only the highlights & Partial Depth Repairs were not included due to limited time. Please see the final project report for many other important details. The final report is under publication and should be out in the fall of 2017.
  - "Concrete Pavement Repair Best Practices," Technical Report prepared by Applied Research Associates, Inc. for the Missouri Department of Transportation, 2017.