

# Minnesota DOT Experience with High Performance Dowel Bars

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# What Drives Concrete Pavement Performance in Minnesota?

- In 1995, MnDOT moved away from strength to low w/c ratio specification for acceptance
- Principal factors that guide the current spec:
  - Mix durability
    - ASR mitigation requirements
    - Optimized Gradations
    - Controlling the w/c ratio
  - Emphasis on Quality (QC/QA)
  - Pavement Smoothness
  - Improved Curing Materials and Practices
  - Use of Incentives/disincentives

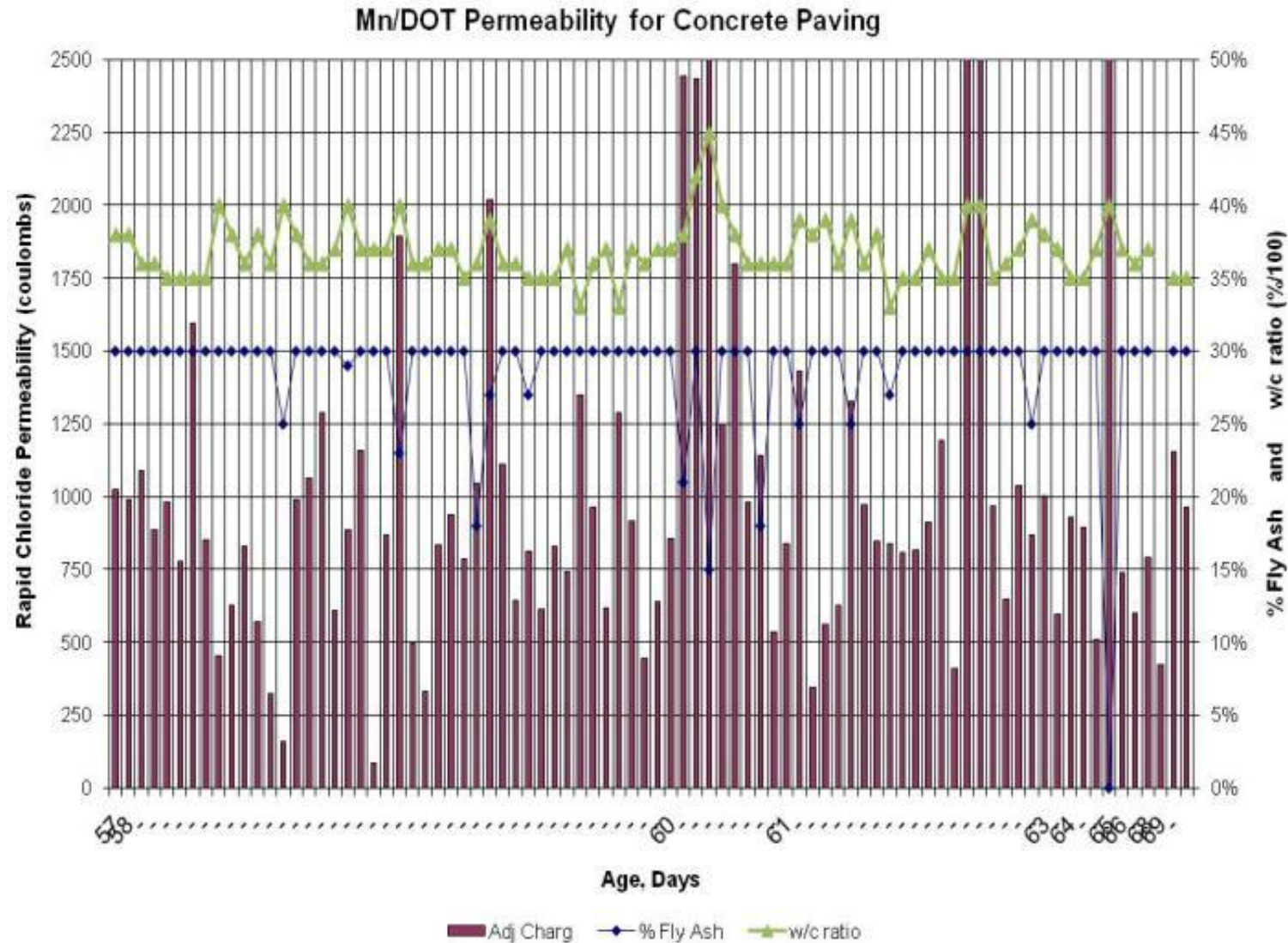


# In 2000, Construction of Long-Life Concrete Pavement

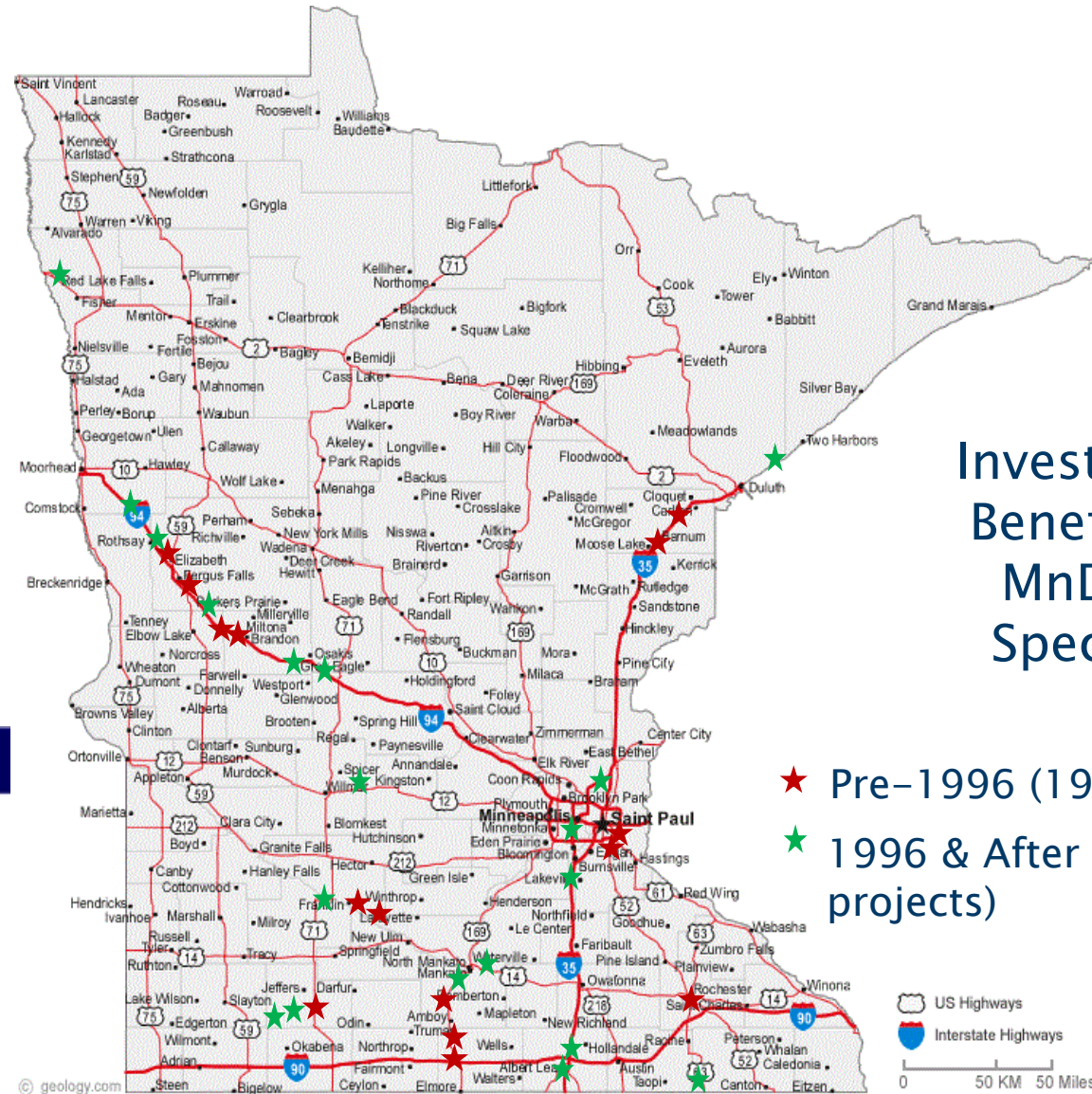
- Transition from 35-year design life to 60-year design life by adding 1" concrete
- Haystack 8-18 gradation required, low w/c ratio, high quality aggregate, permeability spec (max 2500 coulombs @ 28 days), preformed elastomeric joint sealants
- Corrosion resistant (High Performance) dowel bars



# Permeability Requirements for HPC



Max of 2500 coulombs  
at 28 days for HPC



## Investigation of Benefits of the MnDOT w/c Specification

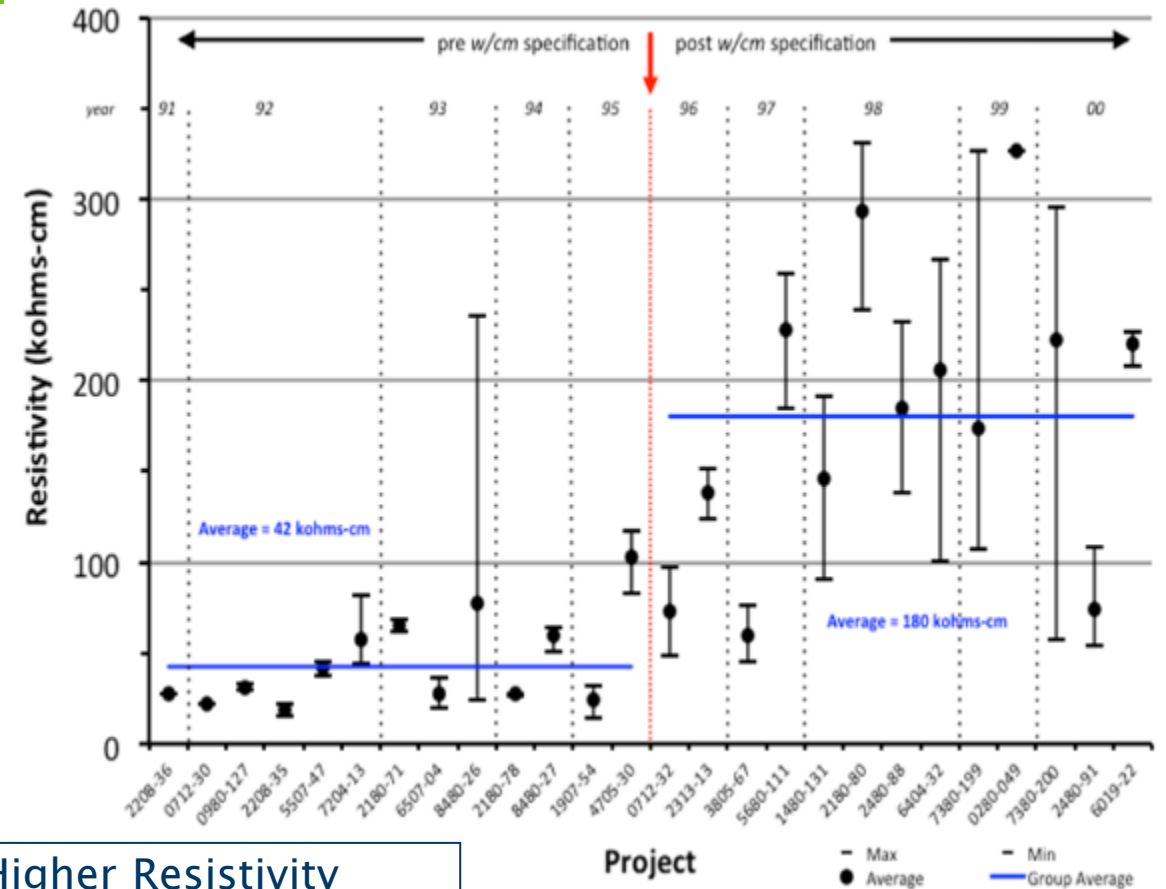
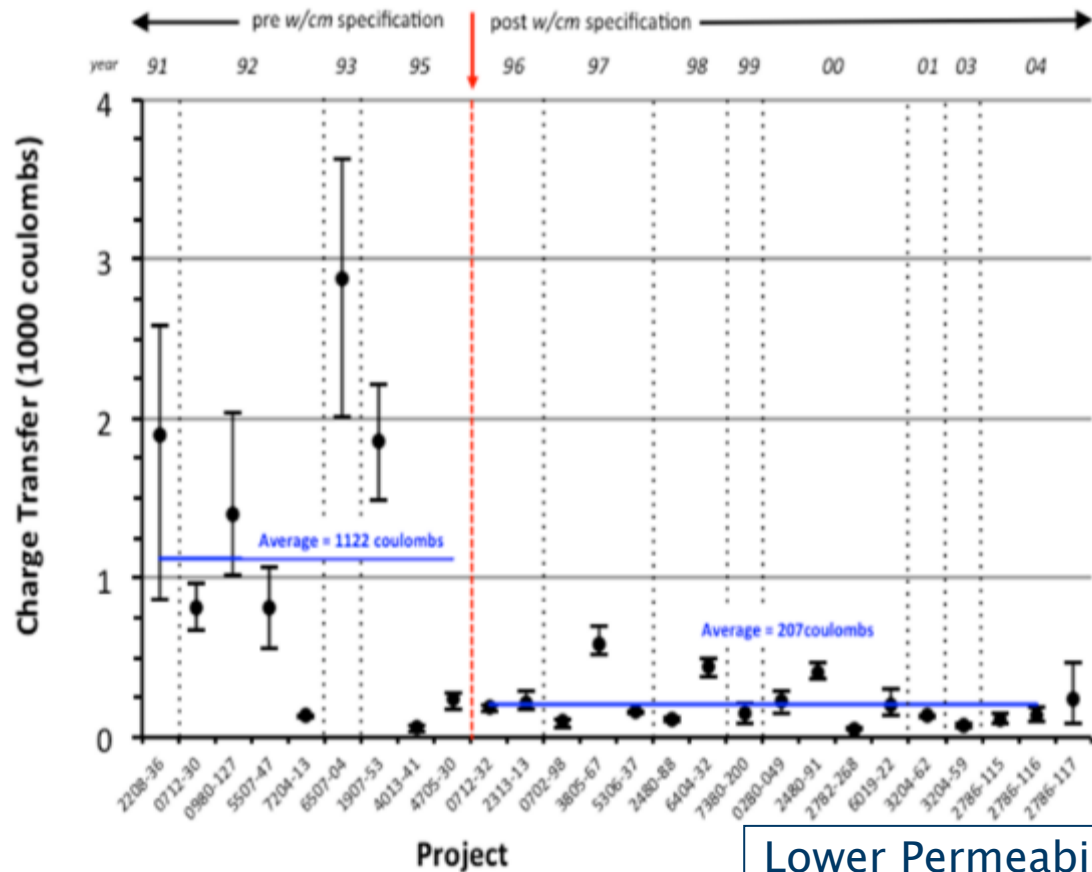
- ★ Pre-1996 (19 projects)
- ★ 1996 & After (15 projects)



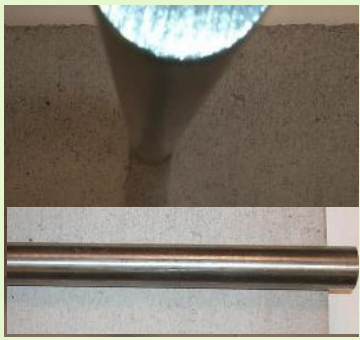
### Impact of Water/ Cementitious-Based Concrete Mix Design Specification Changes on Concrete Pavement Quality

Gerard Moulton, Principal Investigator  
American Engineering Testing, Inc.  
July 2018  
Research Project  
Final Report 2018-25

# W/C Spec Impact on Permeability (C1202)/Resistivity (T358)



- Lower Permeability/Higher Resistivity
- Concrete holds less water
  - Fights the ingress of deicers
  - Lower critical saturation level
  - Can't transport as much water



**316L Solid Stainless Steel  
Approved 2000\***



**Stainless Steel Clad  
with Steel Core  
Approved 2000**



**Stainless Steel Tube with  
Steel Core  
Approved 2006\***



**Stainless Steel Tube  
with Grout  
Approved 2006**



**Stainless Steel Pipe  
Approved 2006\***

# MnDOT High-Performance Dowel Bars Approval Timeline

\*On current MnDOT Approved List



**Zinc "Clad" Rolled Alloy  
Sleeve  
Approved 2006**



**Glass Fiber Reinforced  
Dowel over Carbon Steel Bar  
Approved 2013**



**Zinc Galvanized Steel  
Tube  
Approved 2016**




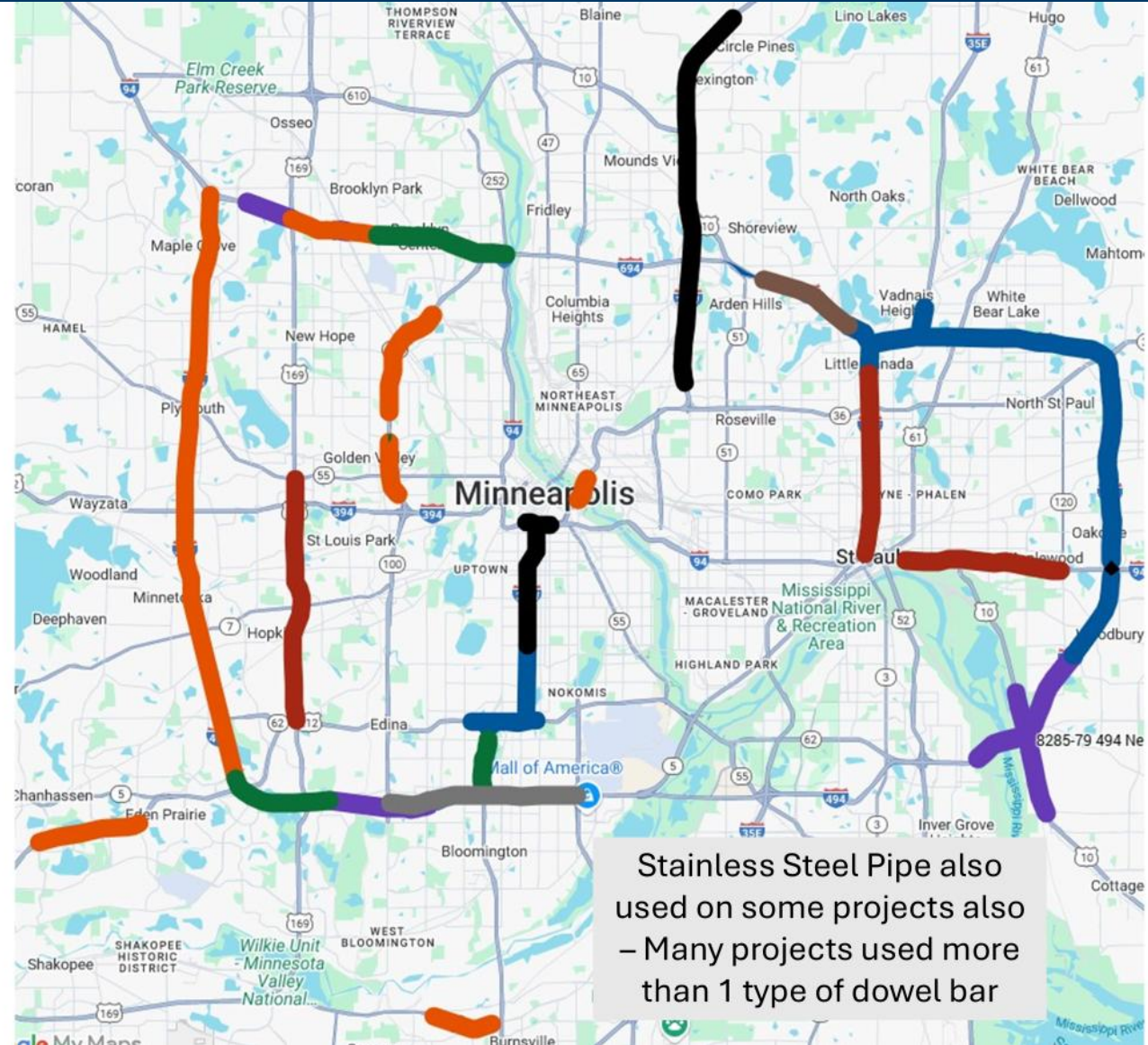
**Zinc Galvanized Tube with  
A934 Epoxy  
Approved 2016\***



**Carbon Steel with A934  
Epoxy and Abrasion  
Resistant Overcoat  
Approved 2017\***

# Use of High-Performance Dowel Bars in MN 41 projects between 2000 and 2025

-  Solid Stainless Steel Bar
-  Stainless Steel Clad with Steel Core
-  Stainless Steel Tube with Steel Core
-  Zinc Rolled Alloy Sleeve Bonded to Solid Steel Bar
-  GFRP Coated Steel Bars
-  Galvanized Steel Tube
-  Galvanized Steel Tube with ASTM A934 Epoxy
-  Solid Steel Bar with ASTM A934 Epoxy and Abrasion Resistant Overcoat

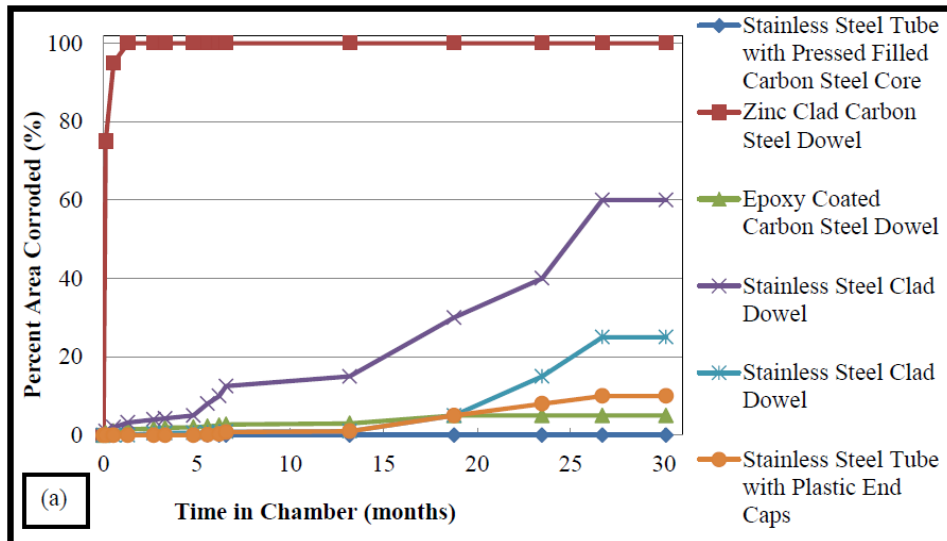
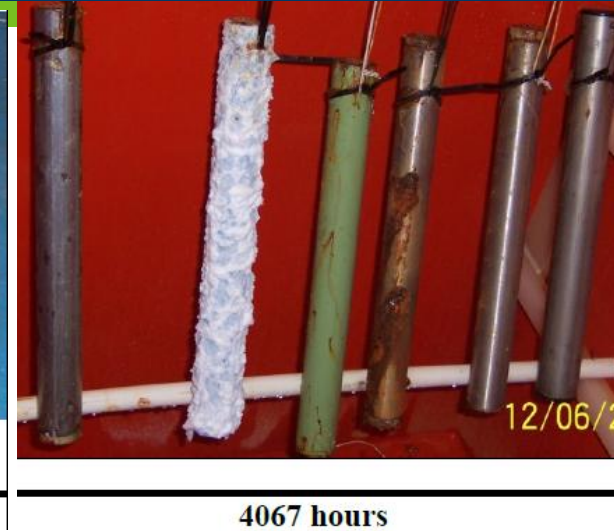
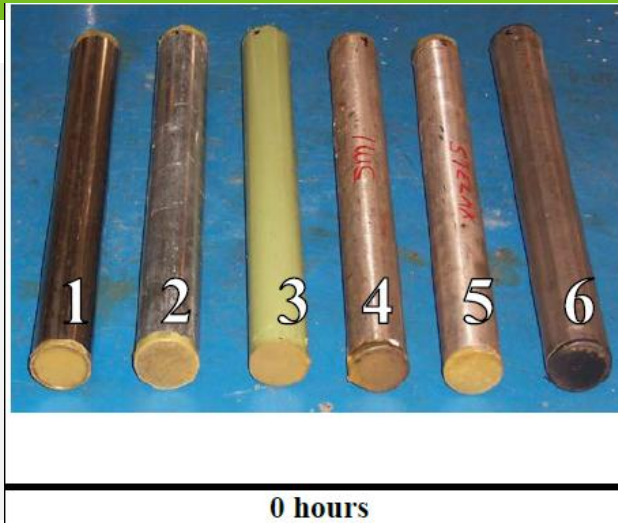


# Challenges to implementing High-Performance Dowel Bars

- Increased cost vs. Epoxy Coated Dowel Bars
- New High-performance dowel bar types continued to emerge
  - Usually lower cost
  - More readily available
- What about coatings that weren't traditional epoxy coating
  - MnDOT performed salt scaling research in 2008 and 2024
- What about products that weren't steel?
  - How do approve these new products?
  - How to anchor dowel bars to baskets?

# MnDOT Salt Fog Corrosion Chamber (ASTM B117-09) – Testing performed in 2008 for 44 months

- 1 – Stainless steel tube with steel core
- 2 – Zinc clad steel bar
- 3 – Epoxy coated steel bar
- 4 – Stainless steel clad bar
- 5 – Stainless steel clad bar
- 6 – Stainless steel tube with caps



(Izevbekhai, Akkari, 2011)

# MnDOT Salt Fog Corrosion Chamber (ASTM B117-09) – Testing performed in 2024 for 13 weeks

Week Zero



Week Three



Week Six



Week Nine



Week Thirteen (No pictures for Week Twelve)



Appearing (Left to Right): Zinc galvanized tube without epoxy with caps on both ends; Zinc galvanized tube with A934 epoxy with caps on both ends; Epoxy coated dowel bar; Zinc galvanized tube with A934 epoxy with cap on one end; Zinc galvanized tube with A934 epoxy with plastic caps on both ends; Zinc galvanized tube without epoxy and no caps

(Aydin, Izevbekhai, 2025, Draft Report)

# Conclusions – Salt Fog Corrosion Chamber Testing

- Showed minimal to no signs of corrosion
  - Stainless Steel Tube with Steel Core
  - Epoxy Coated Steel Dowel Bar
  - Stainless Steel Tube with Caps
  - Stainless Steel Clad (1 manufacturer)
  - Zinc Galvanized A934 Epoxy steel tube capped and with plastic cap
- Showed signs of significant corrosion (hydrozincite, aka “white rust”)
  - Stainless Steel Clad (1 manufacturer)
  - Zinc “Clad” Rolled Alloy with steel core
  - Zinc Galvanized steel tube (non-epoxy coated)

*Maria's thoughts: It is understood that this is an aggressive test that may not be appropriate for all materials and the behavior of these dowel bars in concrete may or may not yield different results.*

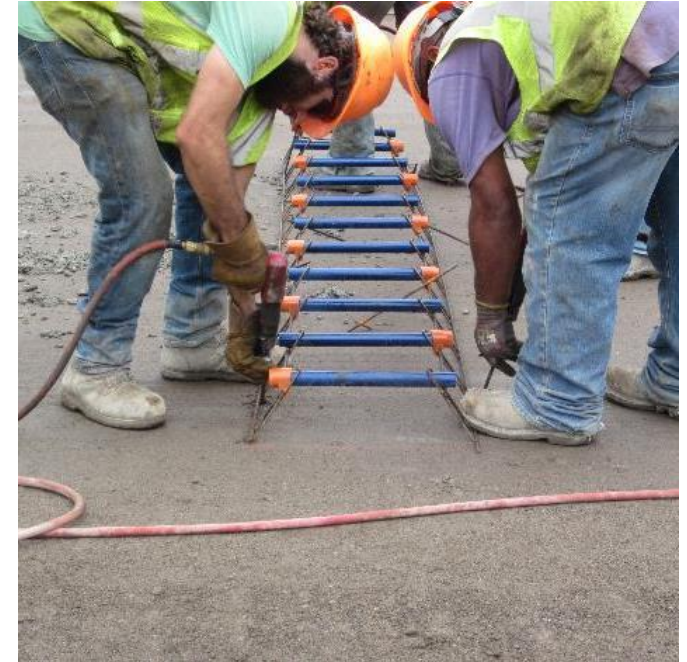


## MnDOT Experience – Stainless Steel Clad with Steel Core

- Experienced no issues in 2002-2003
- In 2004, rejected all unused stainless steel clad dowels on all projects due to rusting and staining of the bars



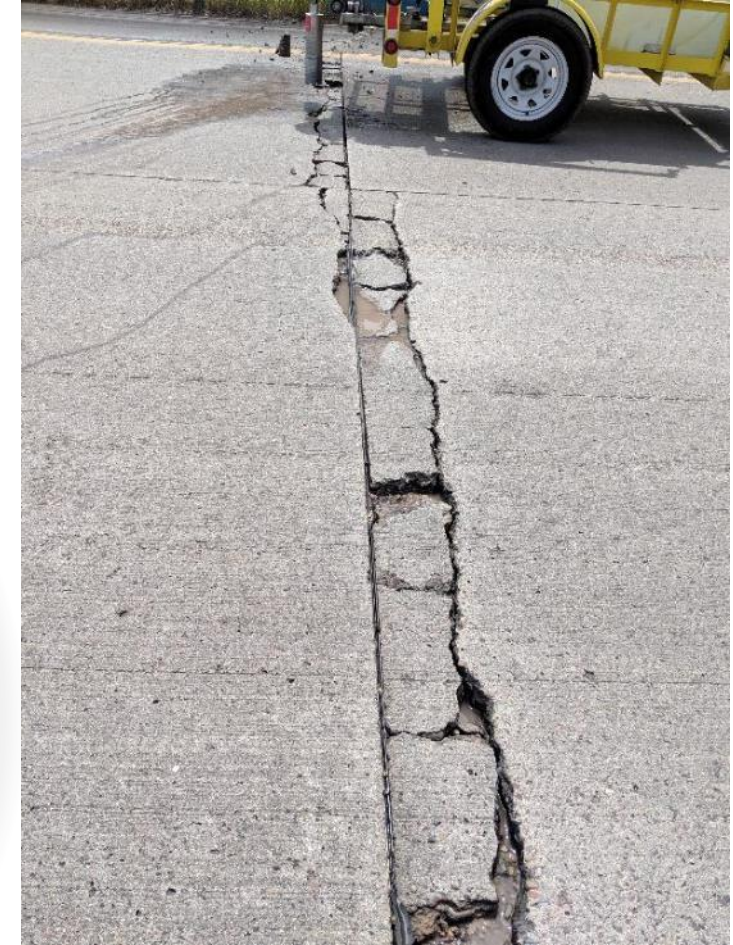
## MnDOT Experience – GFRP Coated Steel Bars



- Used on 5 projects between 2014 and 2018
- Needed alternative solution for attaching bars to baskets
- Issues when installing dowel bars in header sections
- Concerns with recycling in the future



MnDOT  
Experience –  
Zinc Rolled  
Alloy Sleeve  
Bonded to  
Solid Steel Bar



- Used on 8 projects between 2007-2016
- In 2016, Started observing non-typical pavement distresses
- Removed from APL in 2020



## MnDOT Experience – Zinc Galvanized Steel Tubes (non-epoxy coated)



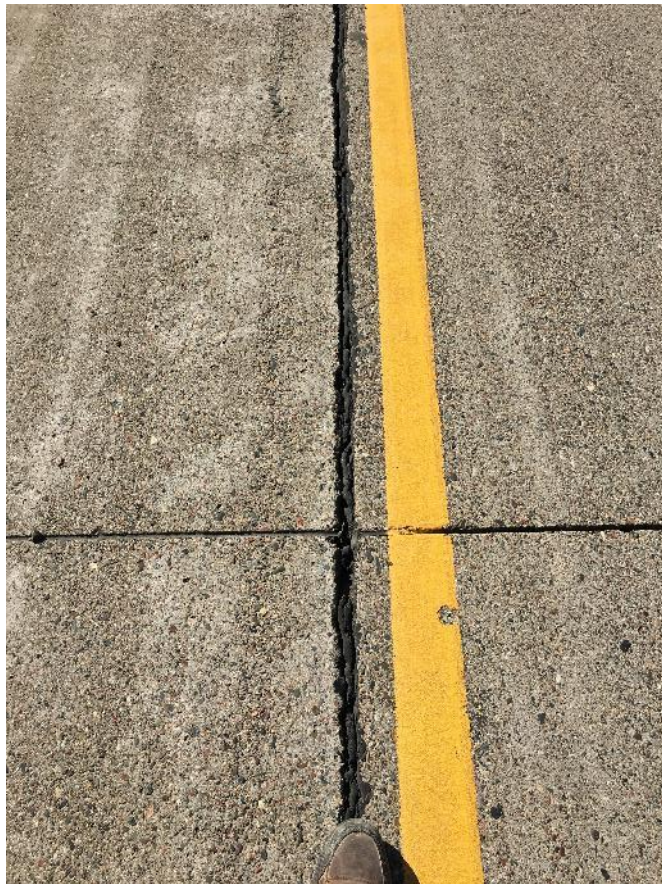
- **Used on 1 projects between 2016 – 2017**
- **Due to issues with zinc clad bars, decided to core these bars also**
- **MnDOT was only State to allow non-epoxy coated**
- **Removed from APL in 2020 as a precautionary measure**

# MnDOT High Performance Dowel Bars – Work Plan

- In 2020, after continued progression of pavement distresses in multiple pavements with zinc clad dowel bars a research plan was developed
  - Researcher – Bernard Izevbekhai with support from MnDOT Concrete Engineering Unit, MnDOT Chemical Lab, and American Engineering and Testing
  - Coring – the various dowel bar sections where access was available
  - Petrographic Analysis, Chemical Evaluation, XRD and SEM testing
  - FWD and Mira Testing
  - IRI Data analysis
  - Visual observations through reviewing MnDOT Pavement Management VideoLog

# MnDOT High Performance Dowel Bars – 35W Solid Stainless Steel Dowel Bar

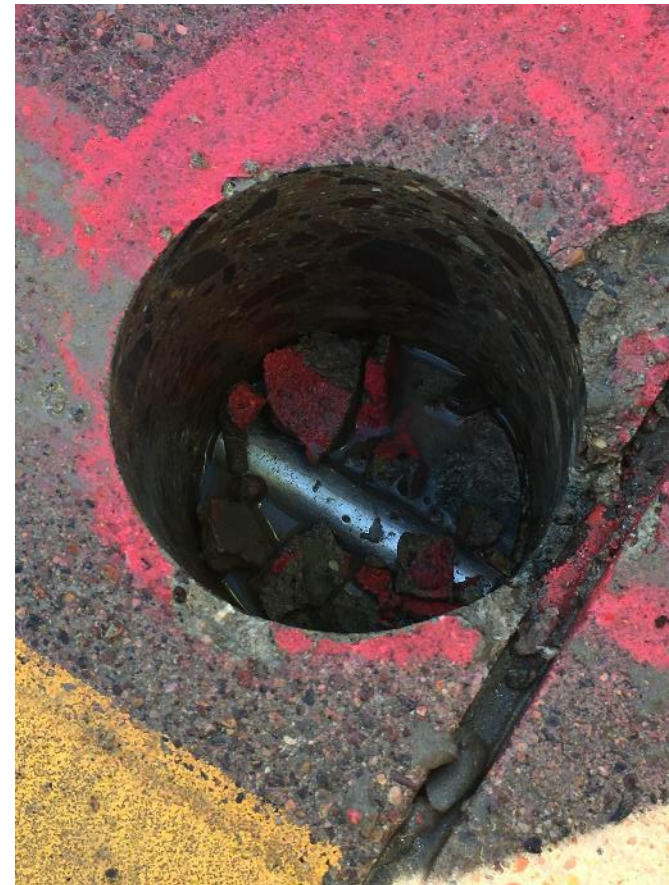
- No visual distresses at surface – could not get core drill bit through dowel bar



Placed 2000

Cored 2020

20 years old



# MnDOT High Performance Dowel Bars – 494 Bailey Rd Stainless Steel Clad with Steel Core



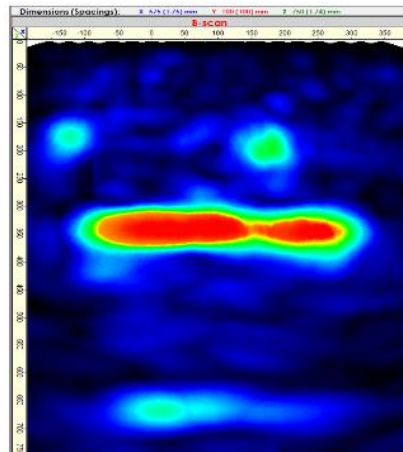
MIRA Testing  
(Red  
represents  
dowel bar)



Placed 2003-  
2005

Cored 2020

15 years old



# MnDOT High Performance Dowel Bars – 35E/694 Zinc “clad” rolled alloy sleeve with steel core



Placed 2007-  
2009

Cored 2020

~12 years old

# MnDOT High Performance Dowel Bars – 35E/694 Zinc “clad” rolled alloy sleeve with steel core



Placed 2007-2009

Cored 2020

~12 years old

# MnDOT High Performance Dowel Bars – 694/TH 36 Zinc “clad” rolled alloy sleeve with steel core



Placed 2010  
Cored 2020  
10 years old

# MnDOT High Performance Dowel Bars – 35W/TH 62 Zinc “clad” rolled alloy sleeve with steel core



Placed 2008-  
2010

Cored 2020

~11 years old



# MnDOT High Performance Dowel Bars – 35W/TH 62 Zinc “clad” rolled alloy sleeve with steel core



# MnDOT High Performance Dowel Bars – TH 694/Rice Street Zinc Galvanized Steel Tube (without epoxy)



Placed 2016  
Cored 2020  
4 years old



# MnDOT High Performance Dowel Bars – TH 694/Rice Street Zinc Galvanized Steel Tube (without epoxy)

Placed 2016  
Cored 2020  
4 years old



# MnDOT High Performance Dowel Bars – TH 694/Rice Street Zinc Galvanized Steel Tube (without epoxy)

Placed 2016

Cored 2025

9 years old



# MnDOT High Performance Dowel Bars – 35W/TH 62

## Petrography - Zinc “clad” rolled alloy sleeve with steel core



Photo: 13

Sample ID: 62A  
Mag: 5x

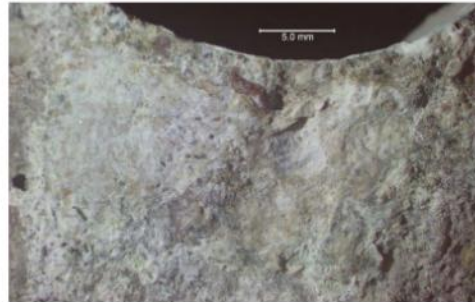


Photo: 9

Sample ID: 62A  
Mag: 5x



Photo: 15

Sample ID: 62A  
Mag: 5x



Photo: 10

Sample ID: 62A  
Mag: 10x

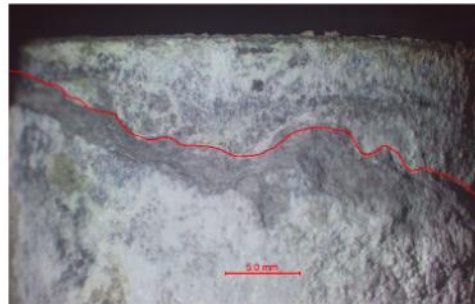


Photo: 16

Sample ID: 62A  
Mag: 5x

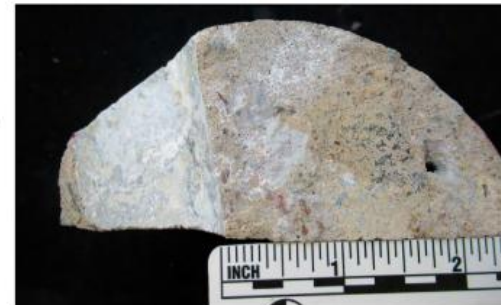


Photo: 23

Sample ID: 62A  
Mag: 5x

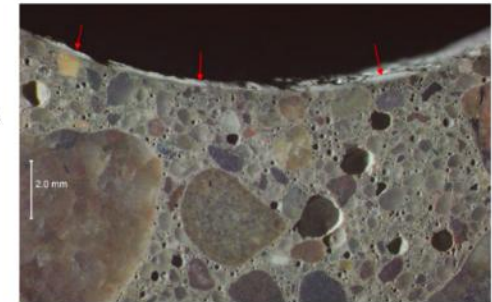


Photo: 20

Sample ID: 62A  
Mag: 10x

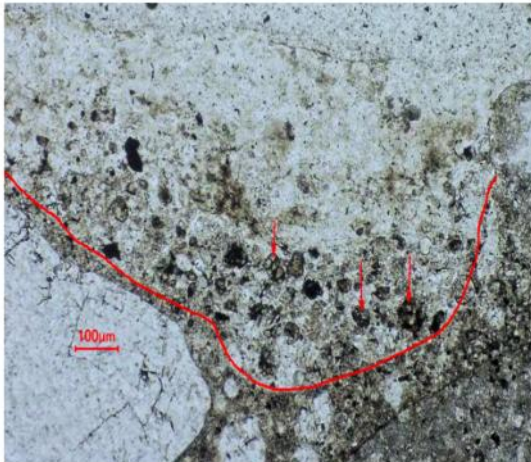


Photo: 20

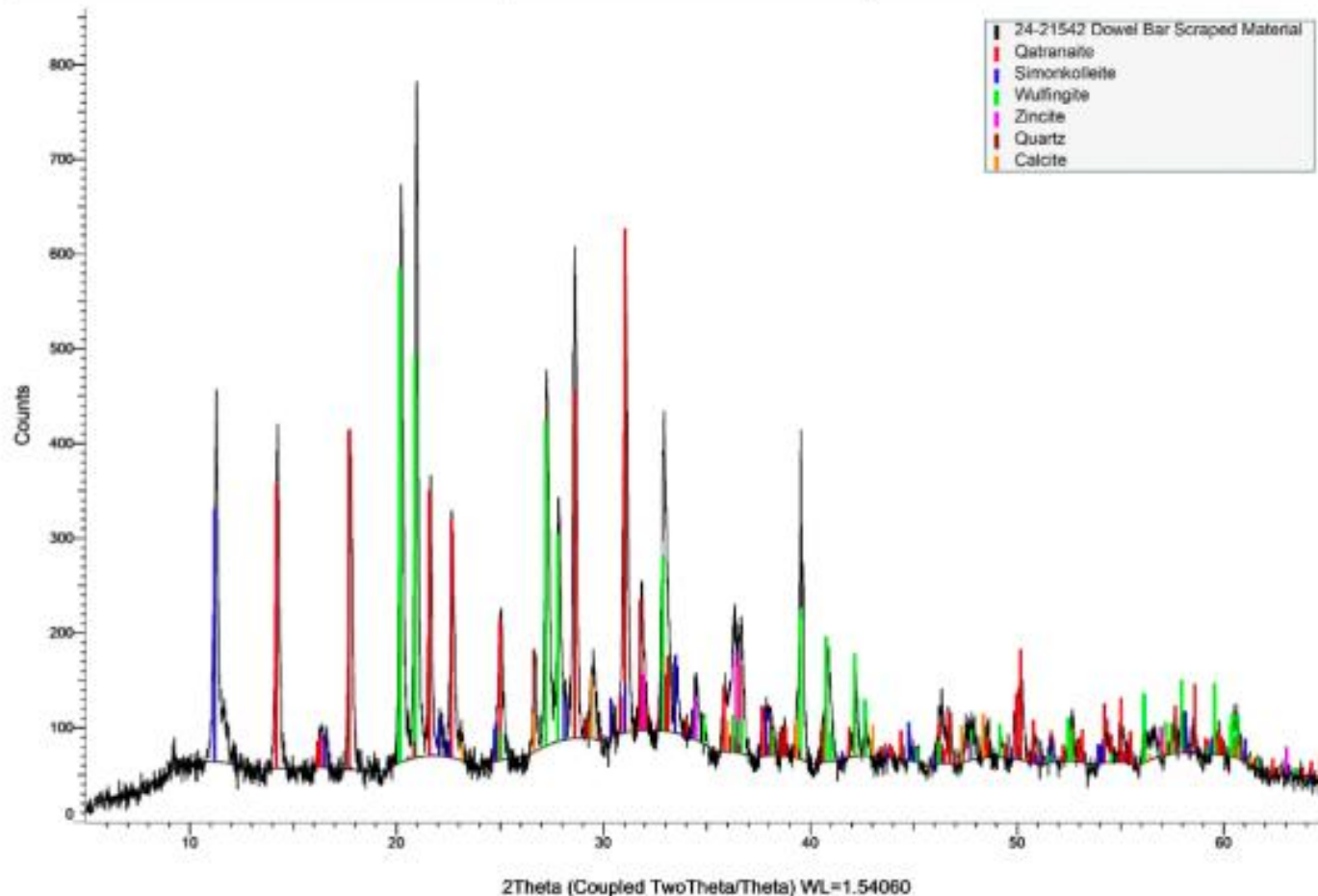
Sample ID: 62A  
Mag: 200x

Description: Zone of altered paste (above red line) within approximately 0.5 mm of the dowel bar, viewed in thin section under transmitted plane polarized light. Note the corrosion product envelopes residual portland cement particles (red arrows).

- Images show corrosion product coating the fracture plane and coating the zinc clad dowel bar
- Similar conditions observed in other zinc clad dowel bars from other projects

# MnDOT High Performance Dowel Bars – 35E/694 Powder X-Ray Diffraction Testing

24-21542 MNDOT Dowel Bar Scraped Material Powder X-Ray Diffraction Rescan



- Elements found from Zinc Clad Dowel Bar Scraped Material
  - Qatranite (calcium hexahydroxodixincate dihydrate)
  - Simonkollite (zinc hydroxchloride)
  - Wulfingite (zinc hydroxide)
  - Zincite (zinc oxide)
  - Quartz
  - Calcite
- Similar conditions observed in zinc clad dowel bars from other projects (4 analysis from 3 projects)

**Project:** Interstate 694

**Description:** X-ray diffraction pattern of scraped corrosion product from dowel bar.

# MnDOT High Performance Dowel Bars – Conclusions Petrography and Chemical Analysis

- The original petrographic analysis on TH 694 in Oakdale showed traces of other corrosion products which were not initially considered when the original search was for Hydrozincite. In practice, other corrosion products are more likely to occur than would hydrozincite.
- Subsequent corrosion products observed included Wulfingite and Zincite and a final revisiting of the samples resulted in a detection of a very strange and relatively rare product called Qatranite.
- Initial petrographic analysis showed a preponderance of Simonkollite which is a product that would occur in the presence of air water and deicing compounds.
- Zincite, Wulfingite and Qatranite are products that would form in the presence of air and water and would not need deicers to form. The Chemical formula of Hydrozincite suggests that it can be overwhelmed by deicing compounds to result in Simonkollite.

(Izevbekhai, et.al 2022 – draft report)

# MnDOT High Performance Dowel Bars – Network Evaluation

- 40 sections were evaluated comparing zinc (zinc clad and zinc galvanized) and non-zinc sections
  - FWD and Mira Testing
  - IRI Data analysis
  - Remaining Service Life
  - Visual observations through reviewing MnDOT Pavement Management VideoLog
- Conclusions
  - From a network perspective, no real difference between zinc and non-zinc sections

# MnDOT High Performance Dowel Bars Study - Conclusions

- Field performance of the pavement sections containing zinc clad dowel bars has exhibited non-typical cracking at the surface
- As a precautionary measure, field coring of zinc galvanized dowel bar (non-epoxy coated) were also cored
- Coring identified some type of volume changes related to the zinc in both types of dowel bars, resulting in a white substance appearing on the outside of the dowel bar and in some cases, expanding into the adjacent concrete surface.
- It seems the joints locked either due to up due to the zinc corrosion product or the zinc cladding sleeve breaking away from the dowel bar causing a non-uniform section for the joint to expand and contract.
- Other High Performance Dowel Bars (solid stainless and stainless steel clad) sections have not exhibited this abnormal cracking nor displayed any sort of “corrosion” when cored



# NCC/ACPA Dowel Bar Work with Mark Snyder

- Guide to Dowel Load Transfer Systems – September 2011
- 2012 – NCC Webinar with dowel bar and dowel basket assembly standardization recommendations
- TTCC Pooled Fund – Supported testing and development of 4 dowel bar vs. 1 dowel bar load testing and analysis
- ACPA support for initial drafting of new dowel bar requirements
- NCC Dowel Bar Task Force to update AASHTO T253 and AASHTO M254 to be better representative of dowel bars
- MnDOT has used 15” long dowel bars for over 30 years – no reduction in service observed
  - <http://www.mrr.dot.state.mn.us/research/pdf/199929.pdf>



SEPTEMBER 2011



# Dowel Bar Bond Breaker Material

- Some concerns with application of form release agent in the field and if that contributed to the zinc clad and zinc galvanized dowel bars locking up the joints or a chemical reaction between the form release and the zinc product
- Require dowel bars and dowel baskets to be dipped in a waxy bond breaker material.  
(Effective June 2020 lettings)



# MnDOT Transition to A934 Purple Epoxy Coated Dowel Bars (ASTM A1078, Type 2)

- In 2026 most new projects will require ASTM A1078, Type 2 purple epoxy coated dowel bars to replace Type 1 green epoxy coated dowel bars.
- See project Special Provisions 3302
- The purple dowel can be substituted for the green dowel.



# What are next steps for High Performance Dowel Bars in MN?

- *3302 Special Provision - Alternate Dowel Bars -*  
The Engineer will allow use of alternate dowel bar types listed on the [High Performance Dowel Bars APL](#) in accordance with 1605, “Substitute Materials”. Do not intermix different dowel types or sizes unless allowed by the Concrete Engineer.
- Metro policy to date is use on and inside the 494-694 loop in combination with unsealed joints
- Currently evaluating whether to transition all dowels to purple epoxy or keep utilizing HP dowel bars in the Mpls-St. Paul Metro Area

## High Performance Dowel Bars

Updated March 1, 2024

Product	Manufacturer	1.25 inch	1.5 inch
<a href="#">CMI Dowel</a>	<a href="#">Construction Materials, Inc.</a>	Yes	Yes
<a href="#">O-Dowel HP-Type 2</a>	<a href="#">O-Dowel, Inc.</a>	Yes	Yes
<a href="#">Armour Coat</a>	<a href="#">American Highway</a>	Yes	Yes
<a href="#">316L Solid Stainless Steel Bar</a>	Not Specified	Yes	Yes
<a href="#">316L Stainless Steel Schedule 40 Pipe</a>	Not Specified	No	Yes

Thank You,  
Questions?

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