Minnesota DOT Experience with High Performance Dowel Bars

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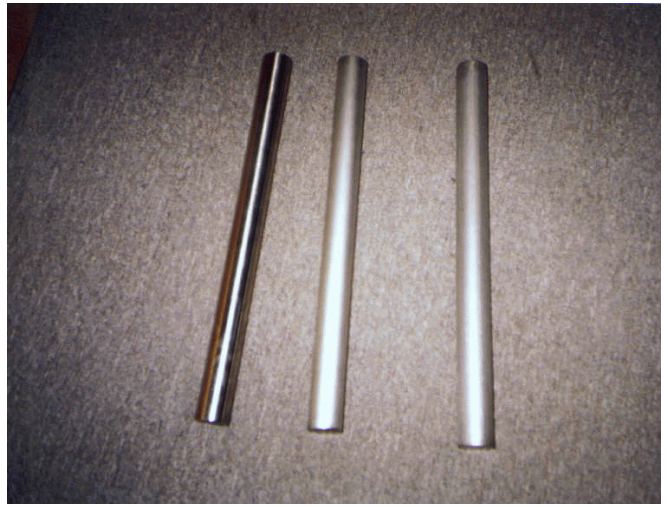
DEPARTMENT OF TRANSPORTATION

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 to 60-year design life (doubling traffic) 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



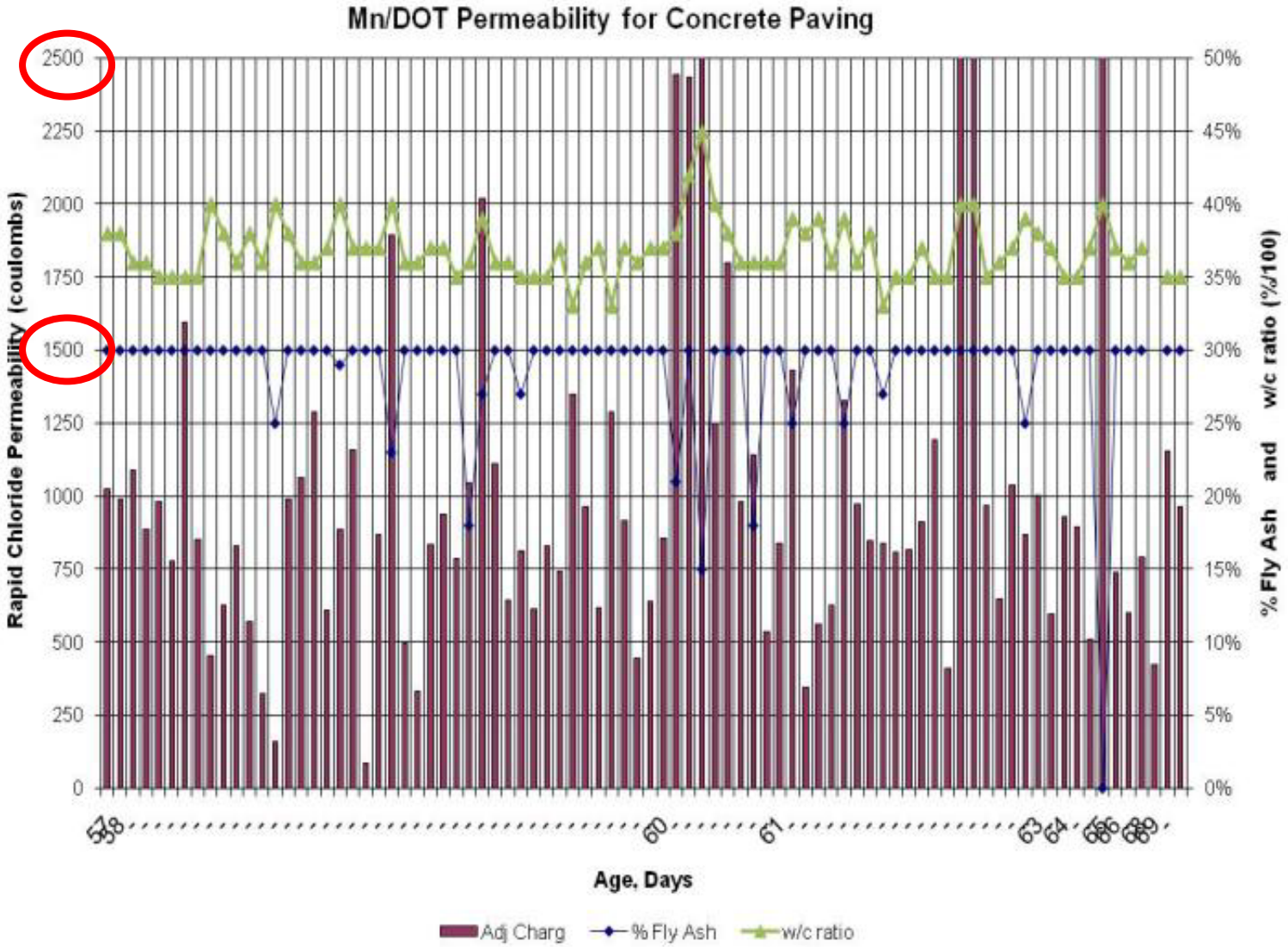
Permeability Requirements for HPC

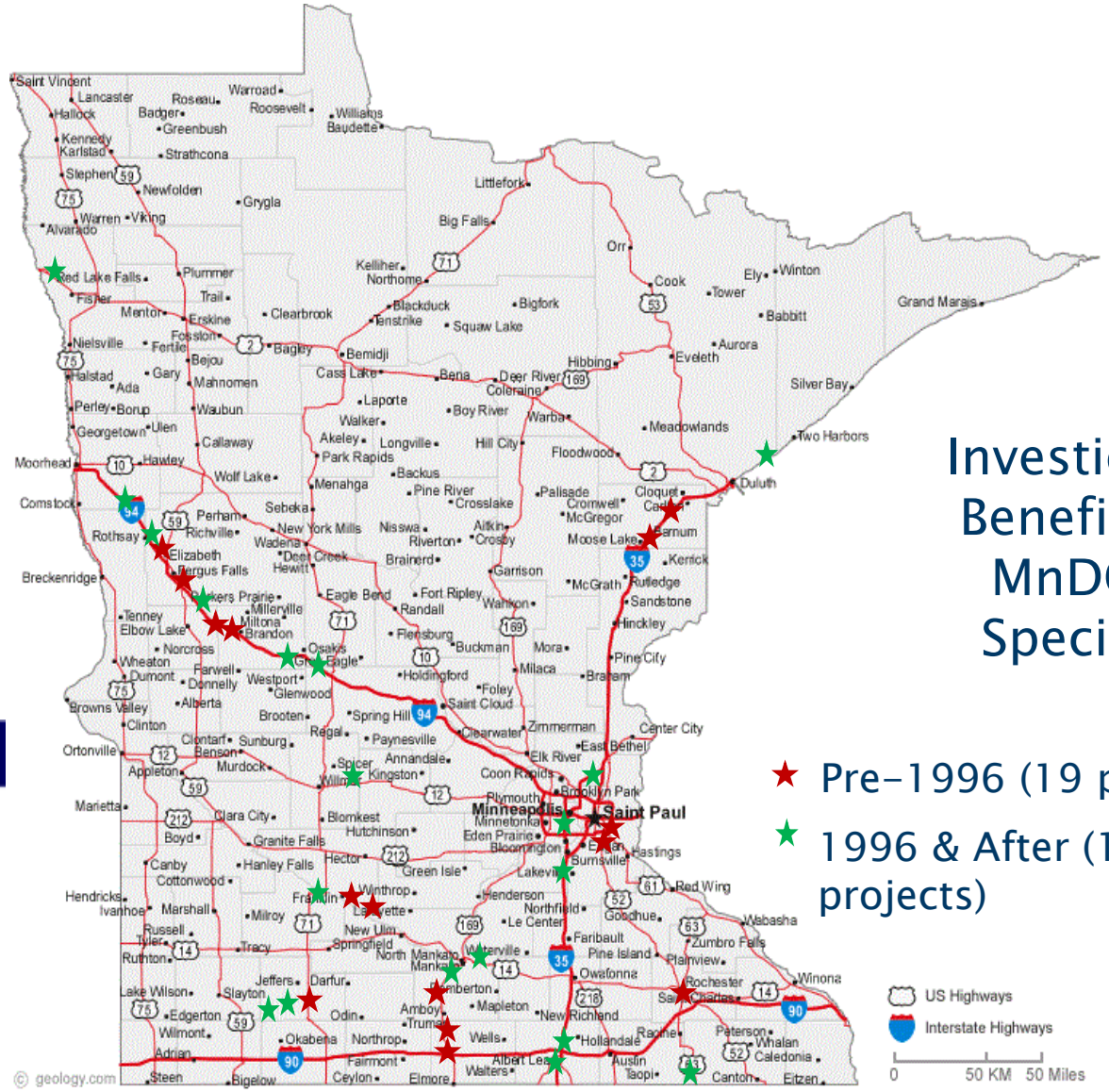
HPC Specification:
Max of 2500 coulombs at 28 days

Evaluation of concrete mixtures (using concrete thickness cores):
0 – 30% fly ash
0.33 – 0.45 w/c ratio

Results:
When ≥ 25% fly ash and maximum w/c ratio < 0.40
– most concrete paving mixtures <2500 coulombs at 57-69 days

Removed permeability requirement in 2010 but still required HPC dowel bars





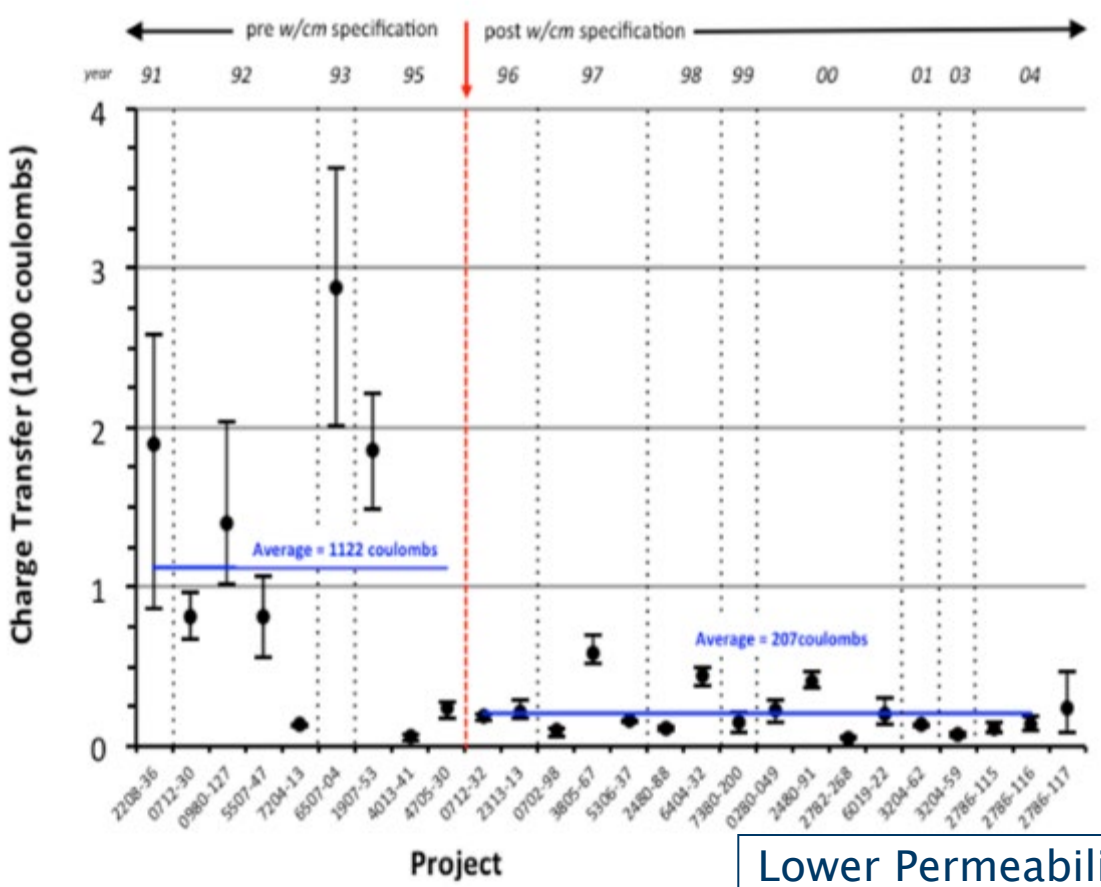
Investigation of Benefits of the MnDOT w/c Specification

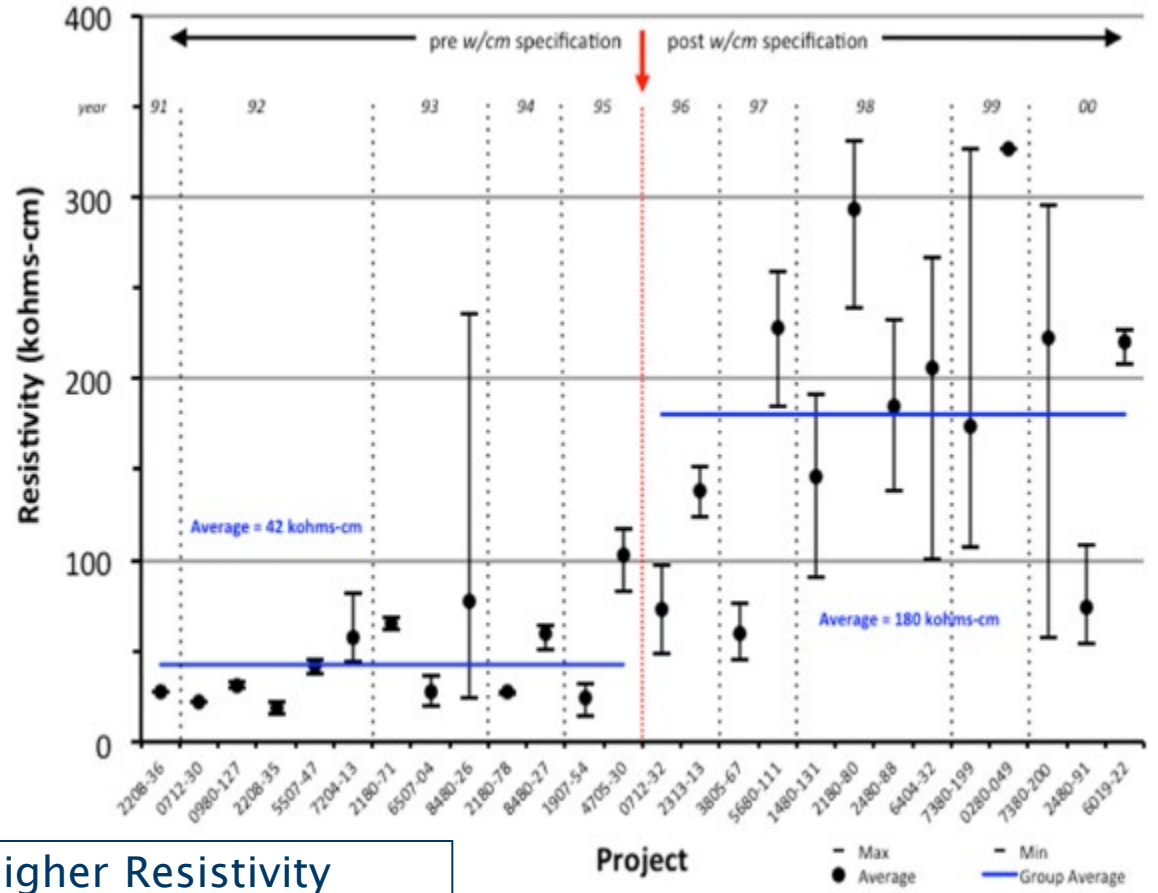
★ Pre-1996 (19 projects)

★ 1996 & After (15 projects)

FINAL REPORT: http://www.dot.state.mn.us/research/reports/2018/201825.pdf

W/C Spec Limits, Optimized Gradations, and High SCMs (fly ash) Impact on Permeability (C1202)/Resistivity (T358)

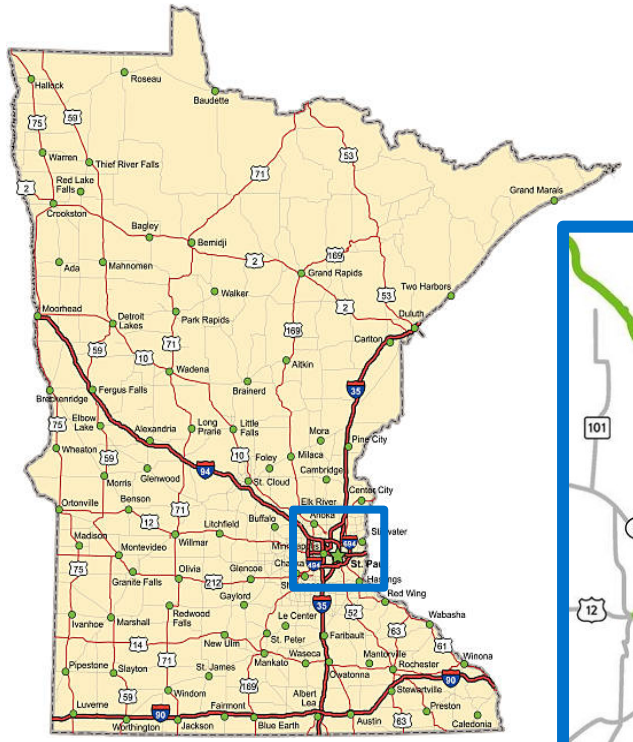


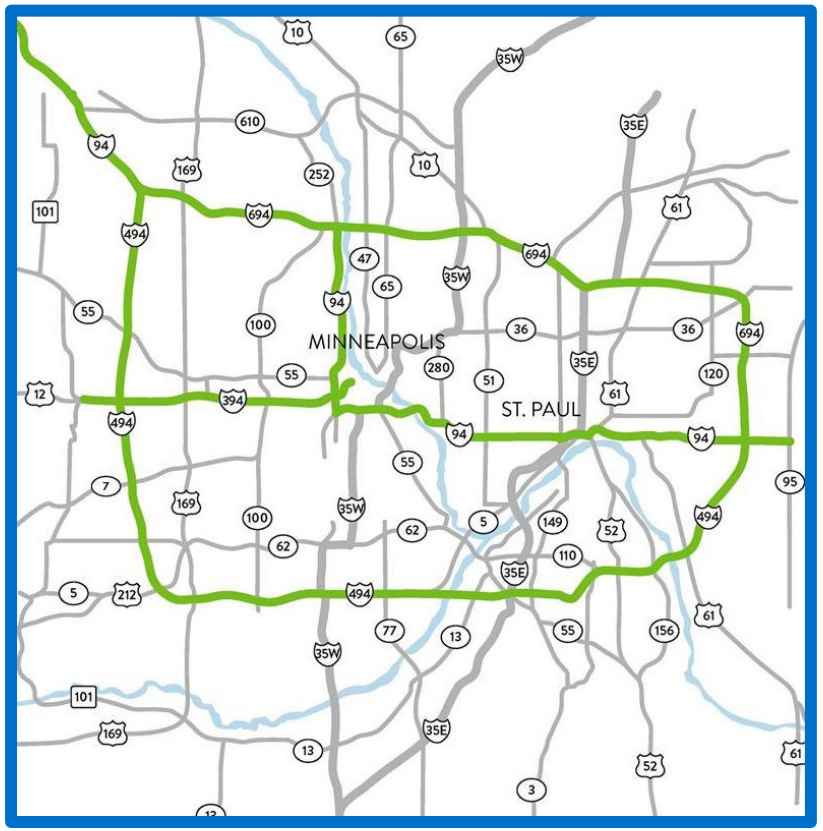


Lower Permeability/Higher Resistivity
-Concrete holds less water
-Fights the ingress of deicers
-Lower critical saturation level
-Can't transport as much water

Implementing High-Performance Dowel Bars

- MnDOT Metro District Policy since 2002
  - All concrete pavements on or around the 694/494 loop would use HP dowel bars
  - Until 2016, we sealed transverse joints with preformed elastomeric joint sealant
  - 2016 and beyond – 1/8” saw cuts and stopped sealing since using HP dowel bars (save money)





Stainless Steel Clad with Steel Core Approved 2000

316L Solid Stainless Steel 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 Products List

Zinc "Clad" Rolled Alloy Sleeve Approved 2006

Glass Fiber Reinforced Dowel over Carbon Steel Bar Approved 2013

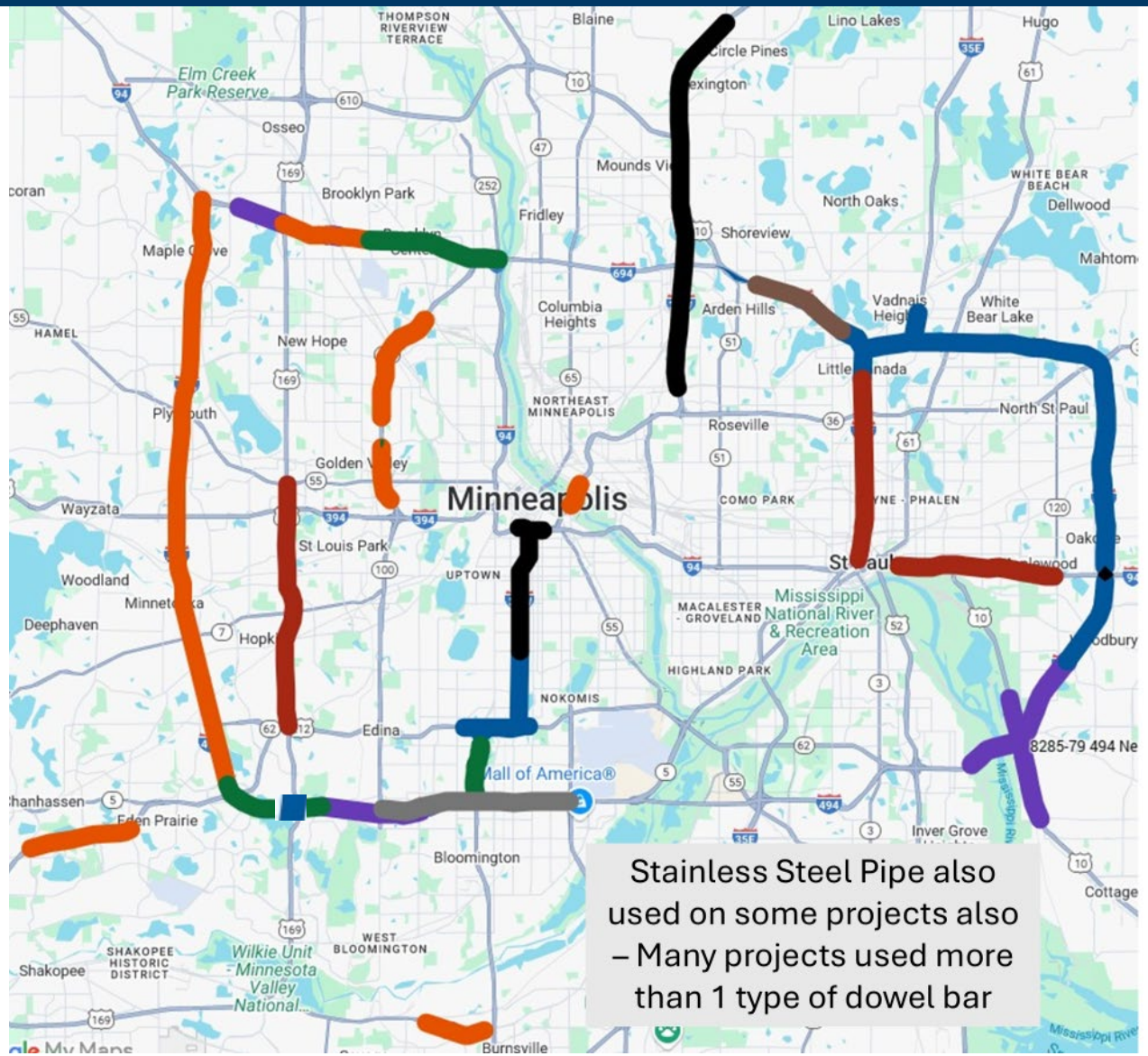
Zinc Galvanized Steel Tube Approved 2016

Zinc Galvanized Steel 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

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



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?

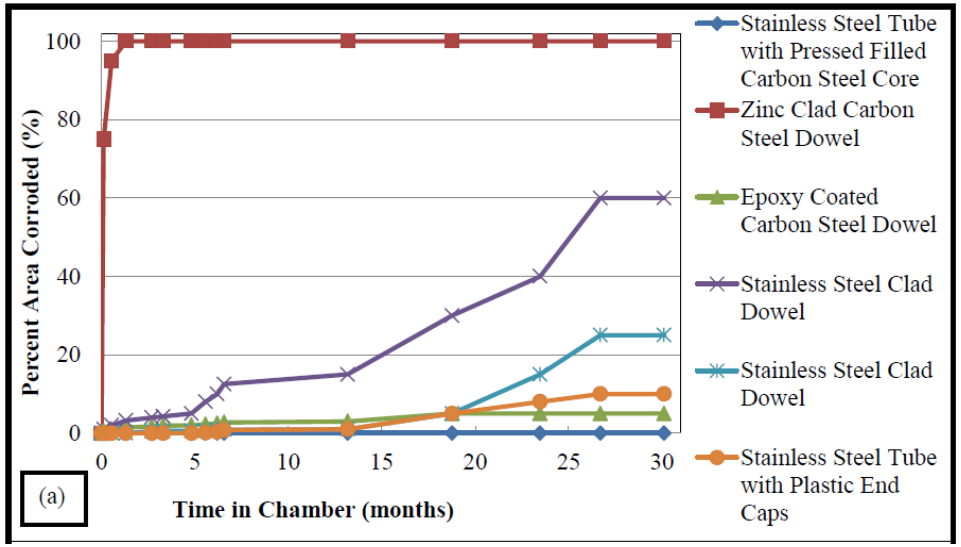
MnDOT Salt Fog Corrosion Chamber (ASTM B117-09) – Testing performed in 2008 for 44 months

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

0 hours

4067 hours


13032 hours



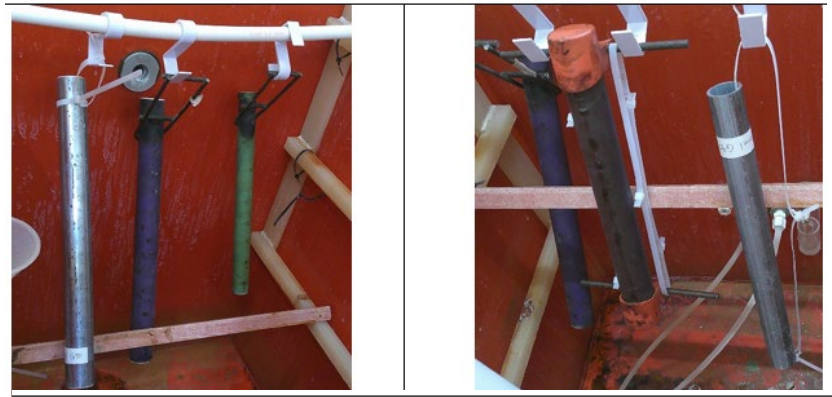

21408 hours


32106hours

(Izevbekhai, Akkari, 2011)

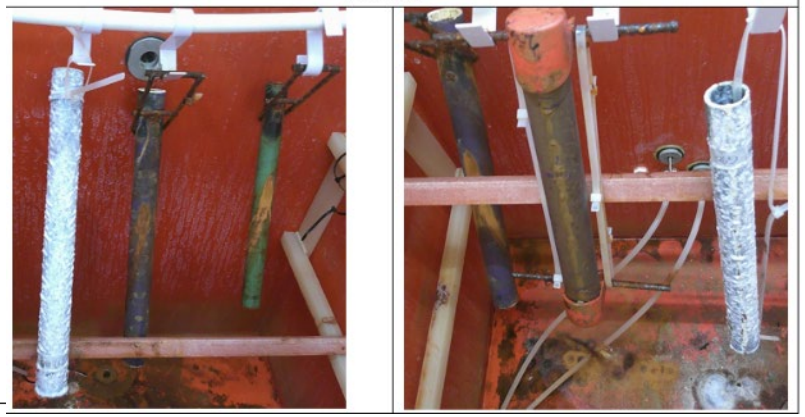
MnDOT Salt Fog Corrosion Chamber (ASTM B117-09) – Testing performed in 2024 for 13 weeks

Week Zero



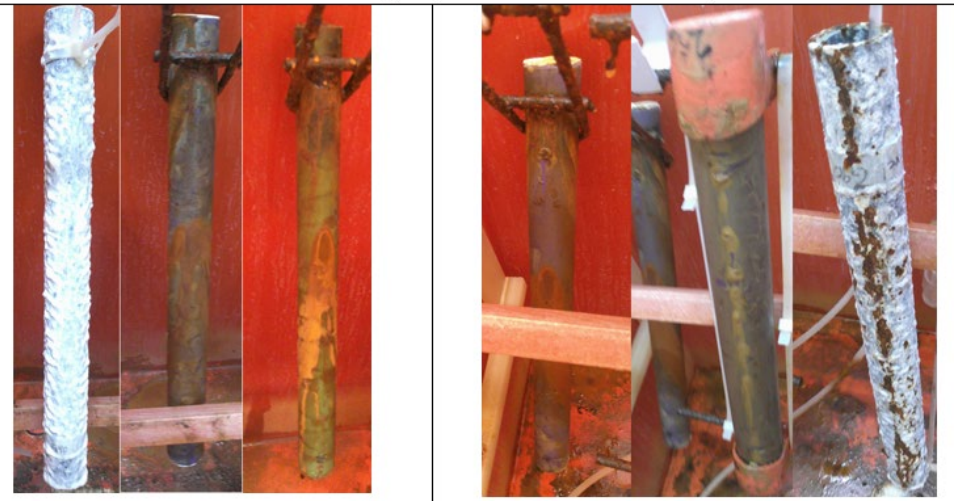
Week Three

Week Six

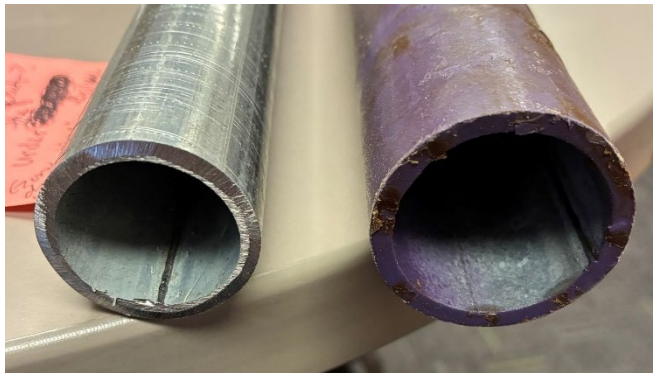


Week Nine

Week Thirteen (No pictures for Week Twelve)



Zinc Galvanized Tubes
w/out epoxy with A934 epoxy



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)

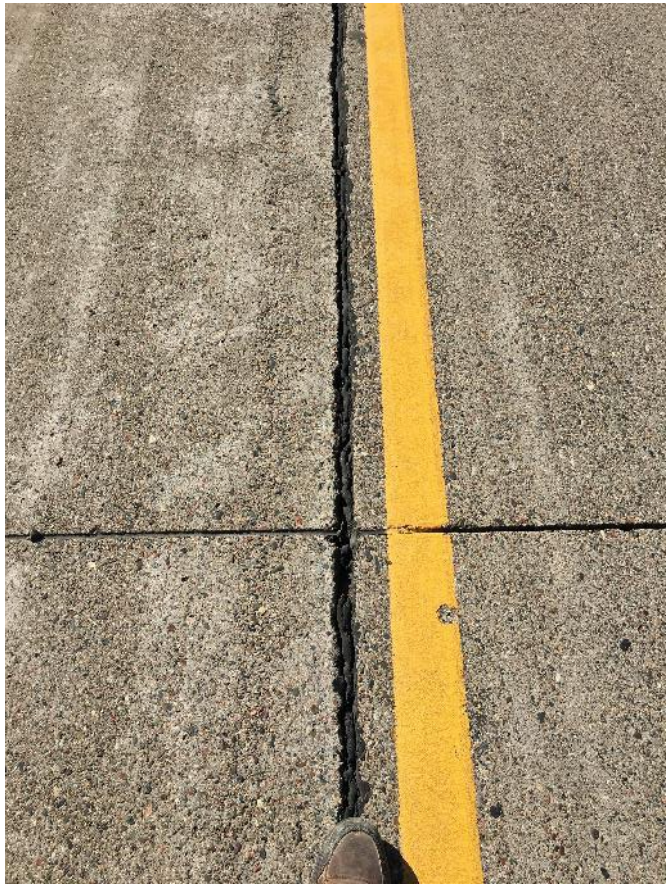
- **Used on 1 projects between 2016 – 2017**
- **Due to issues with zinc clad bars, decided to core these bars also**
- **MnDOT was only State to allow non-epoxy coated**
- **Removed from APL in 2020 as a precautionary measure**

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

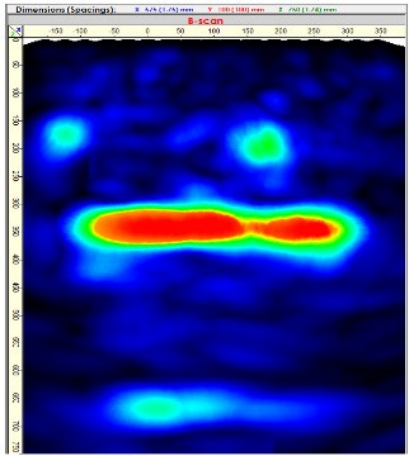
MIRA Testing

(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

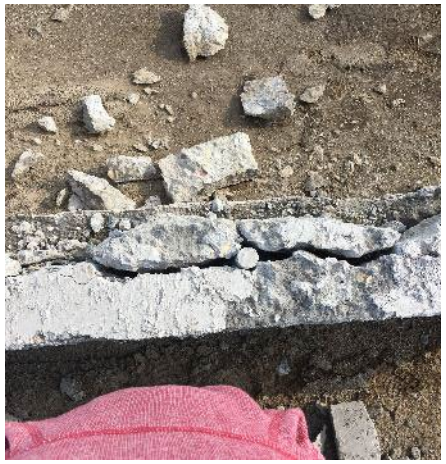




Placed 2008-2010

Cored 2020

~11 years old




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









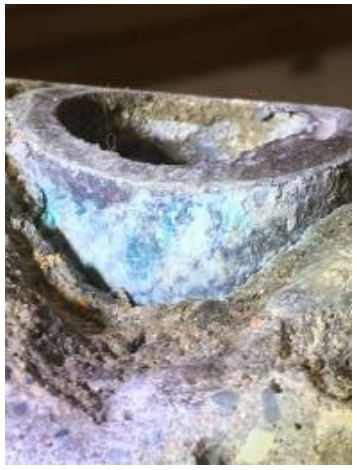

MnDOT High Performance Dowel Bars – TH 694/Rice Street
Zinc Galvanized Steel Tube (without epoxy)




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

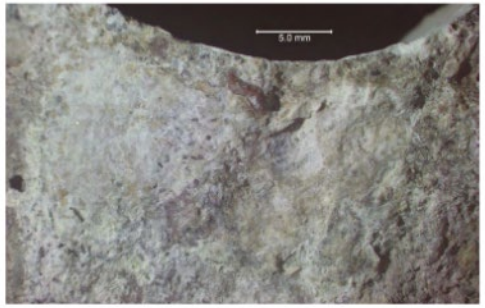


Photo: 13

Sample ID: 62A
Mag: 5x

Description: Corrosion product coating a fragment of concrete originally located within the s vertical fracture plane of the sample, as viewed at low magnification.

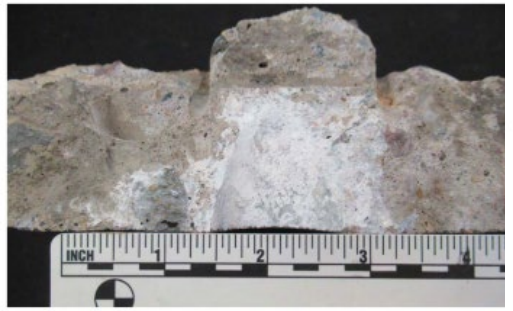


Photo: 9

Sample ID: 62A

Description: Corrosion product coating the impression of the dowel bar and extending latera into the concrete paste, viewed on the sub-horizontal fracture plane of the sample.

Photo: 15

Sample ID: 62A
Mag: 5x

Description: Zinc cladding (red arrows) with corrosion product on its top surface and covering the underlying steel.

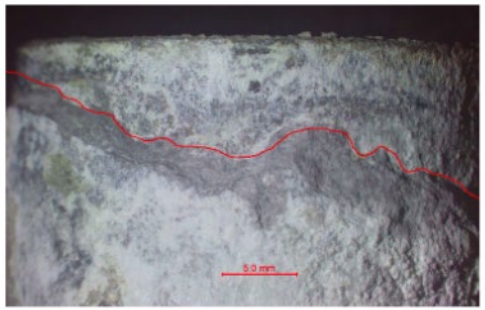


Photo: 14

Sample ID: 62A
Mag: 5x

Description: Corrosion product coating the zinc-clad dowel bar, as viewed as low magnificat Note the zinc-cladding is completely gone above the red line.

Photo: 10

Sample ID: 62A

Description: Corrosion product coating the impression of the dowel bar and extending latera into the concrete paste, viewed on the bottom surface of the core sample.

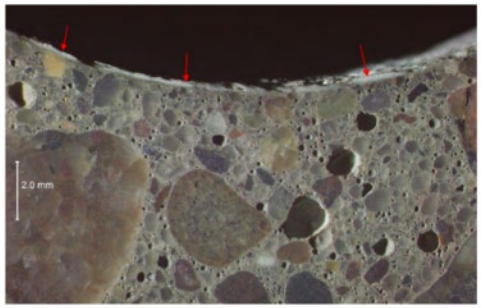


Photo: 16

Sample ID: 62A
Mag: 10x

Description: White corrosion product lining the dowel bar impression, as viewed on saw cut and lapped cross section at low magnification.

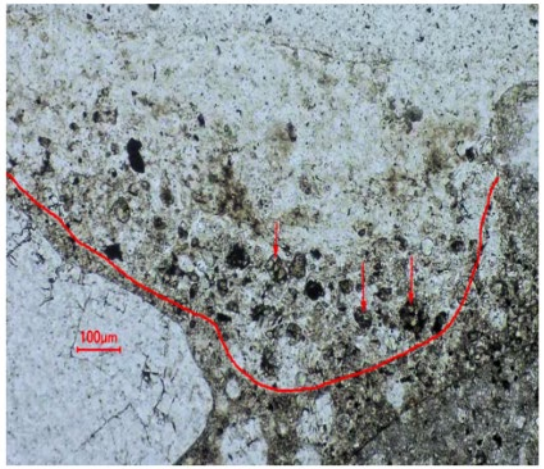


Photo: 23

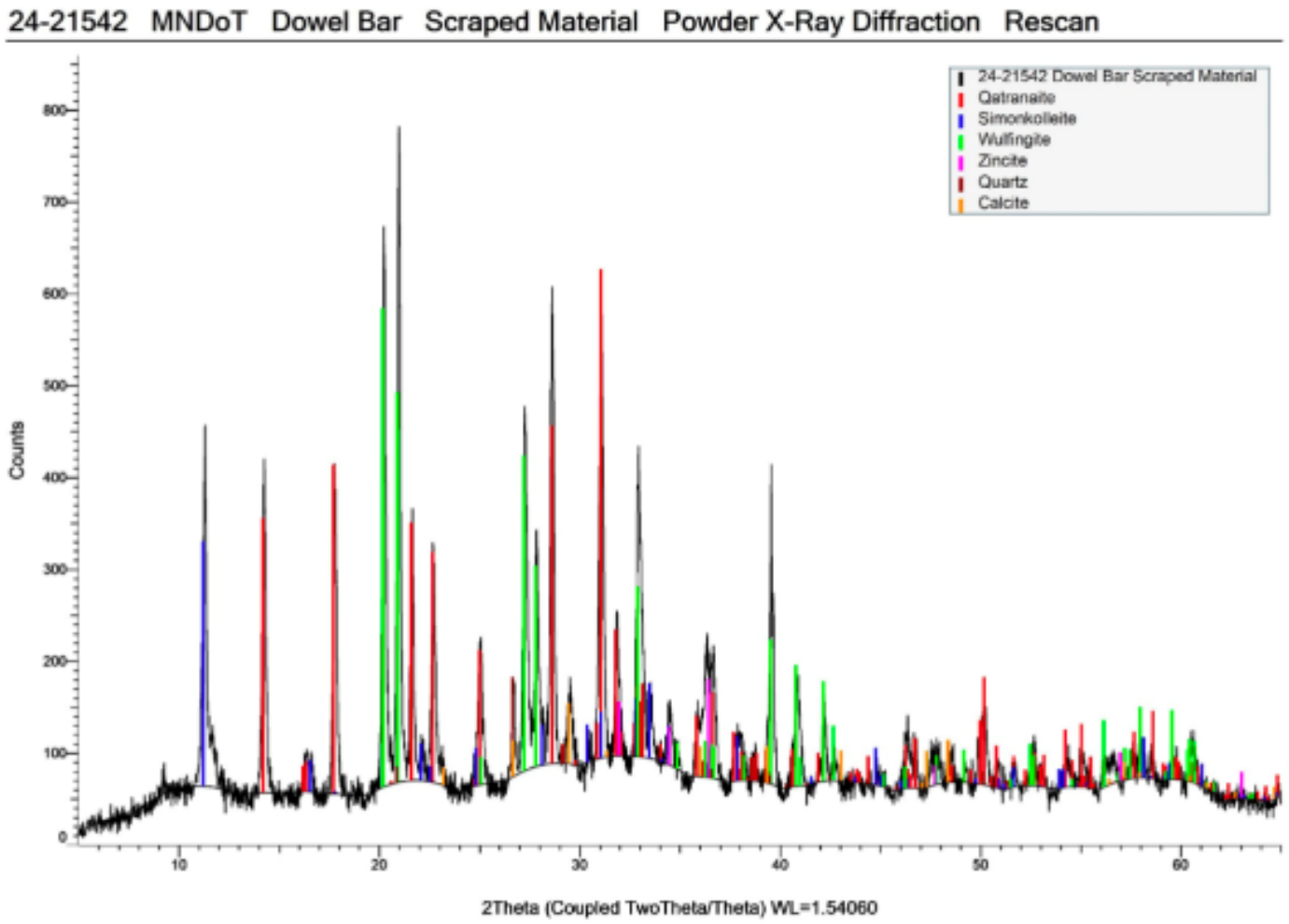
Sample ID: 62A
Mag: 200x

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

(Izevbekhai, et.al 2022 – draft report)

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



Project: Interstate 694 **Description**: X-ray diffraction pattern of scraped corrosion product from dowel bar.

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

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 Qatranaite 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

(Izevbekhai, et.al 2022 – draft report)

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 up either 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

Dowel Bar Bond Breaker Material

- Some concerns with application/lack of proper 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

- MnDOT now requires dowel bars and dowel baskets to be dipped in a waxy bond breaker material. (Effective June 2020)

What does MnDOT require now?

- In 2026, most new projects will require ASTM A1078, Type 2 purple epoxy coated dowel bars to replace Type 1 green epoxy dowel bars.
- Purple dowel can be substituted for the green dowel.
- Discussed regional specifications for epoxy coating
  - ND, SD, IA, WI – Michigan already allows

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
CMI Dowel	Construction Materials, Inc.	Yes	Yes
O-Dowel HP-Type 2	O-Dowel, Inc.	Yes	Yes
Armour Coat	American Highway	Yes	Yes
316L Solid Stainless Steel Bar	Not Specified	Yes	Yes
316L Stainless Steel Schedule 40 Pipe	Not Specified	No	Yes

Thank You,
Questions?

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