October 12, 2021
ICRI 2021 Fall Convention

Concrete Rehabilitation Design for the Historic 3rd Avenue Bridge

WJE

HNTB

Arne Johnson
Principal
Wiss, Janney, Elstner Associates, Inc.

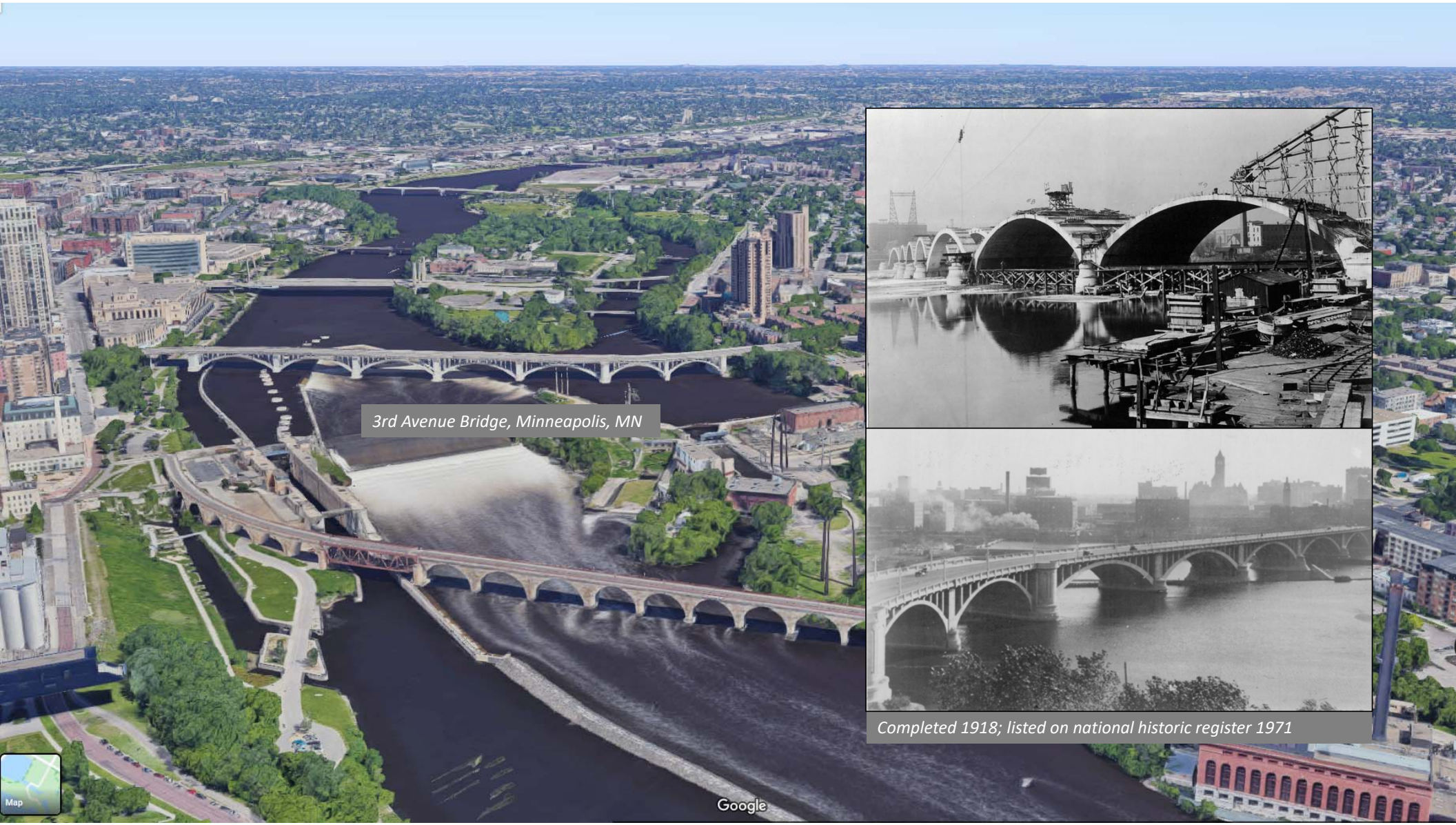
Dan Enser
Associate Vice President
HNTB Corporation

DEPARTMENT OF TRANSPORTATION

Ames Construction, Inc.®

ICRI CONCRETE REPAIR
Restore | Repurpose | Renew

Project Background


3rd Avenue Bridge, Minneapolis, MN
Completed 1918; listed on national historic register 1971
Map
Google

Drone Overview

Project Background - Bridge Description

1st Rehabilitation

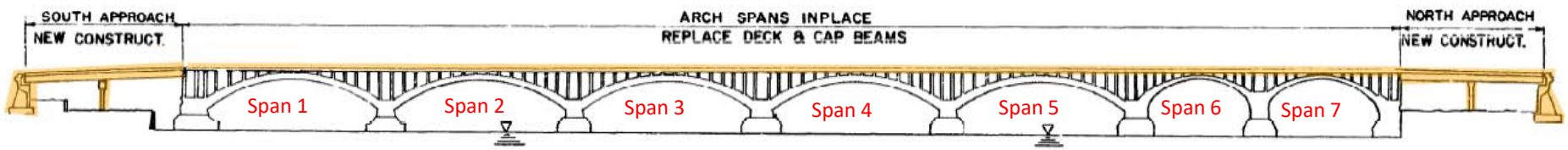
Expansion Joint Replacement, shotcrete repairs

1918 | 1939 | 1979-1980 | 2003 | 2014

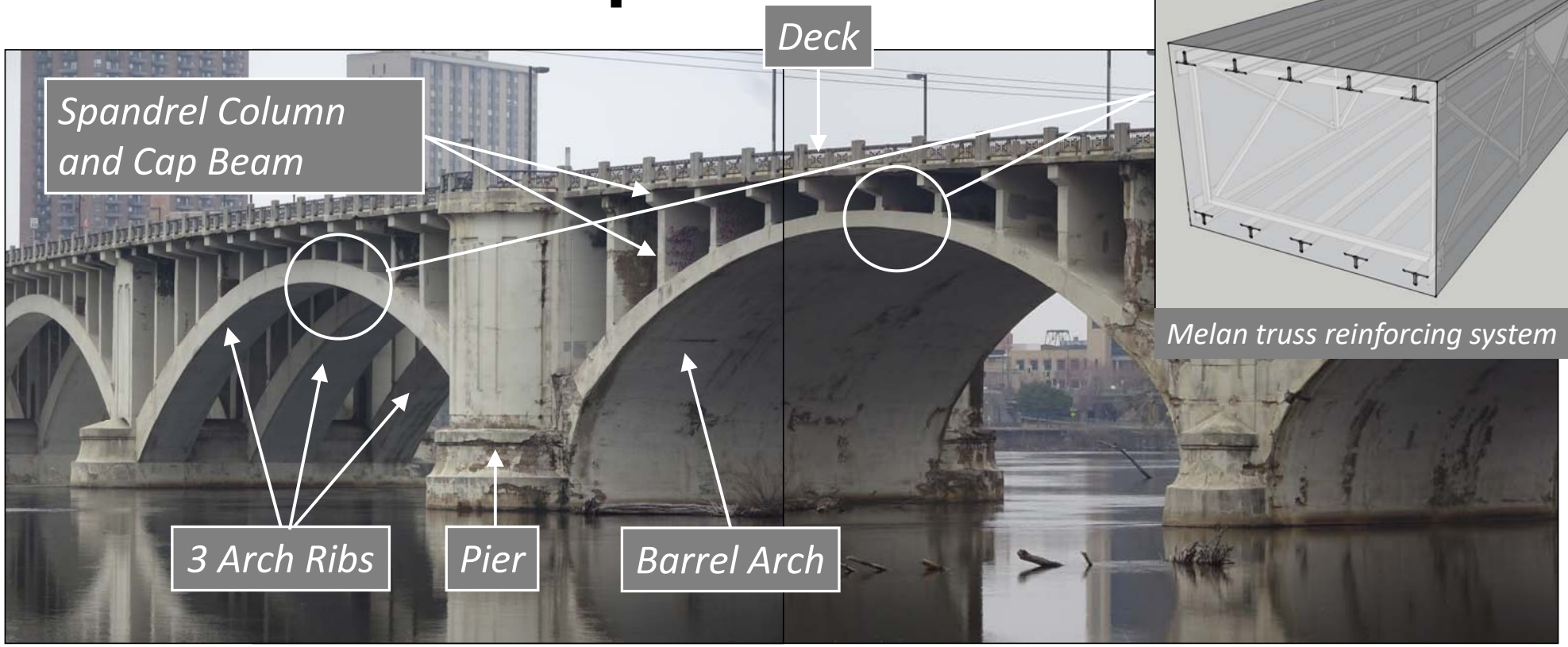
Bridge number 2440, opened to traffic on June 14th

2nd Rehabilitation (See graphic below)

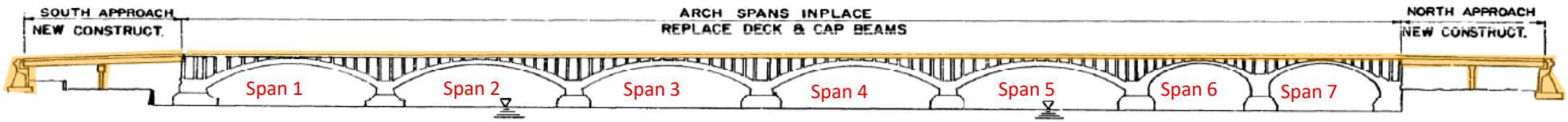
Foundation Repair Project



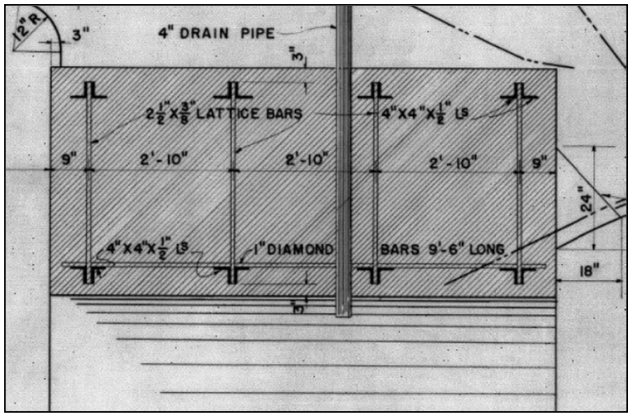
Structure Description

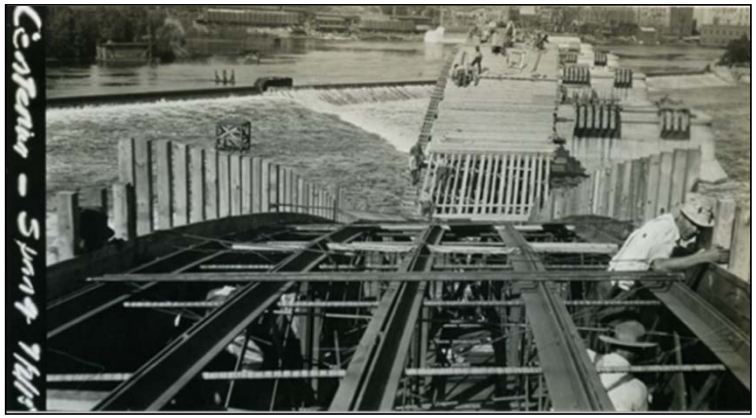


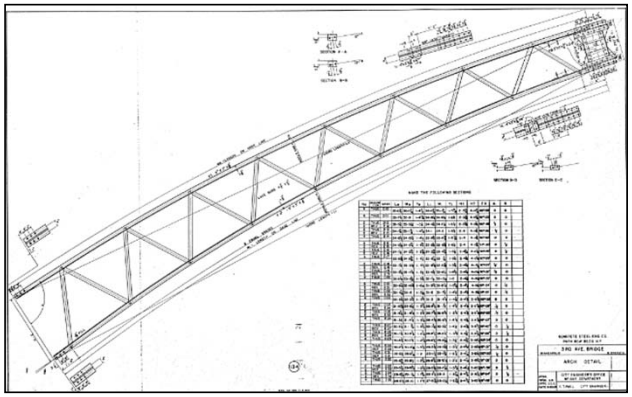
Melan truss reinforcing system

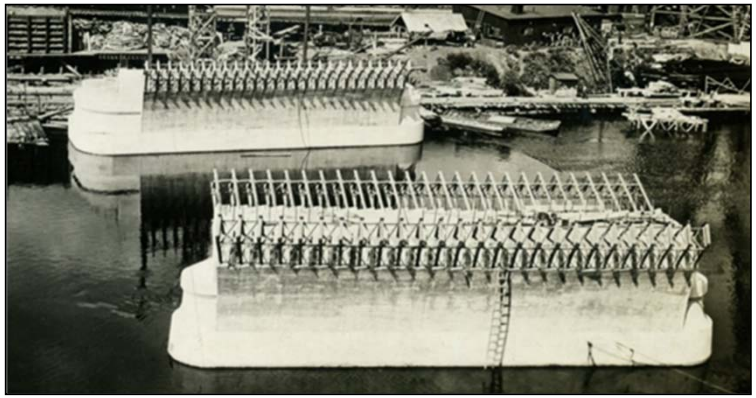


Melan System







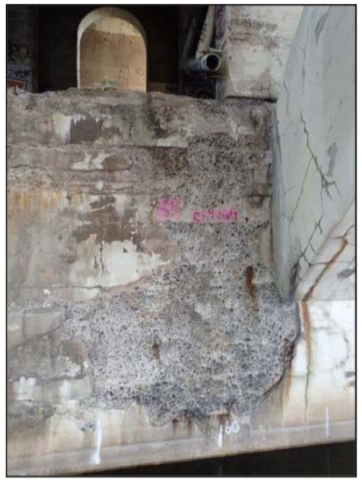


Primary Need

- Significant structural deficiencies and condition issues that need addressed
- Purpose of the rehabilitation is to address the condition issues and to achieve a target service life of 50

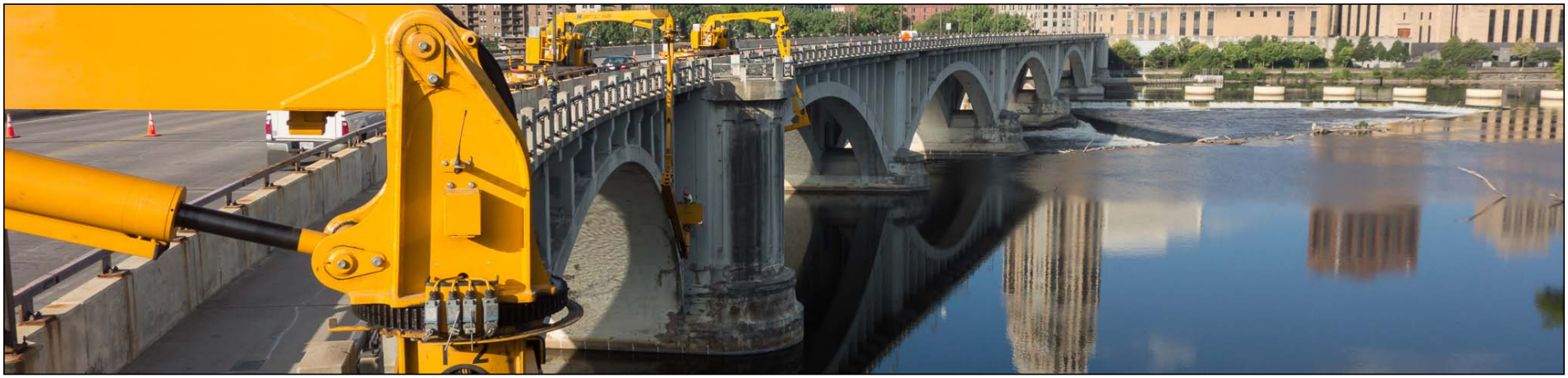

Deterioration of the deck and cap beams

Arch ribs

Pier bases near waterline and below drains

Structural distress



Evaluation and Forensics - Bridge Inspection and Condition Assessment

Phase 1 – Bridge Inspection and Comprehensive Condition Assessment

Phase 2 – Field Testing, Material Sampling, Laboratory Testing

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Importance of Comprehensive Condition Assessment

Why so important for historic concrete?

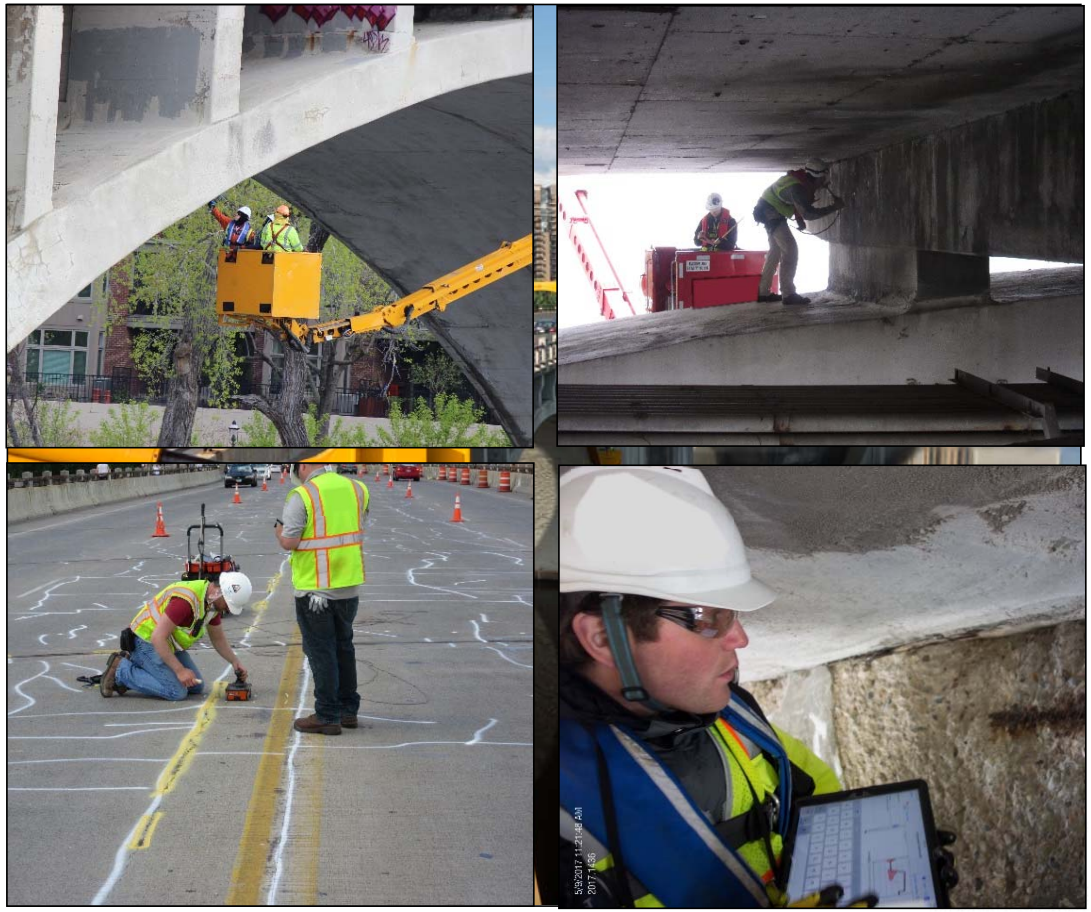
- Historic concrete has unique deterioration mechanisms considerably different than for modern concrete
- Conditions can vary widely across bridge:
  - Concrete often highly variable
  - Often multiple past repair projects
- Usually extensive damage in concrete that needs to be carefully documented and strategically repaired
- Historically significant features need thorough documentation for preservation

Objectives of Condition Assessment

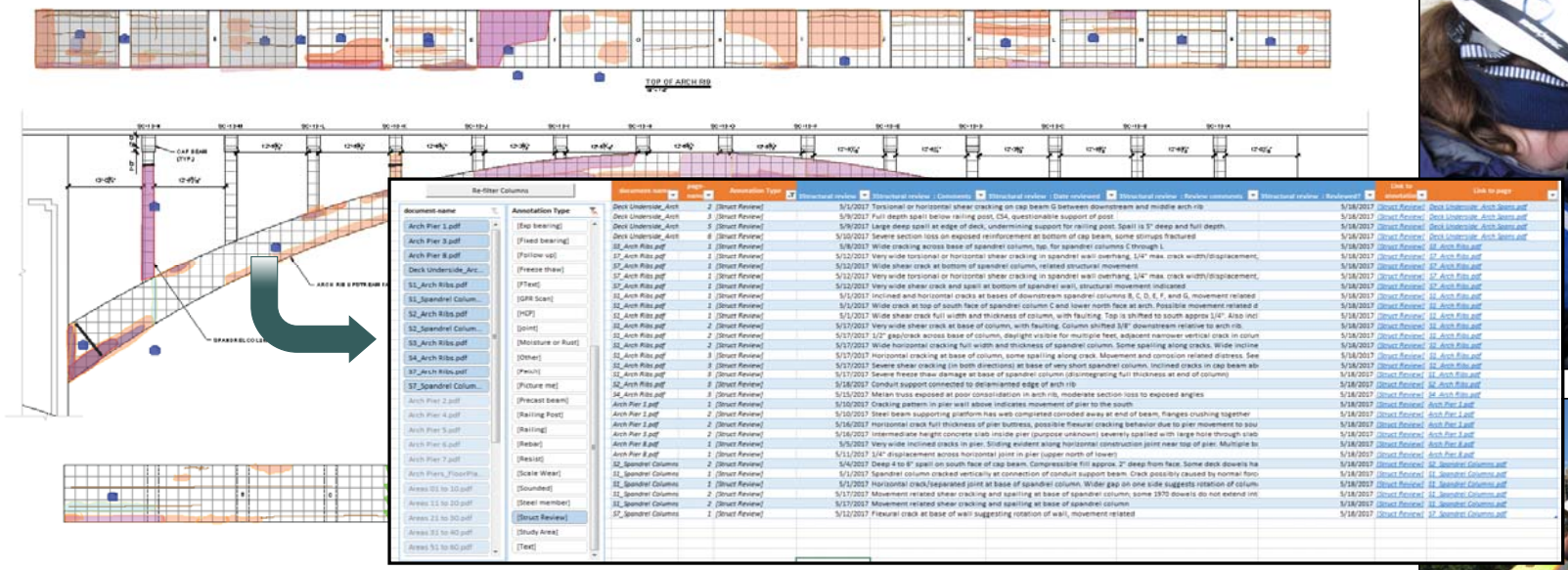
1. Characterize the construction of the bridge
2. Determine current conditions
3. Document historic features
4. Identify deterioration mechanisms, which often include:
   - Chloride-induced corrosion damage
   - Carbonation-induced corrosion damage
   - Freeze-thaw damage
   - Other materials-based mechanisms (ASR, etc.)
   - Structurally-induced distress

Phase 1 – Bridge Inspection

- Close-up visual inspection and sounding of 100% of exposed surfaces
- Mapped all distress conditions on scaled drawings
- Documented condition states according to MnDOT standards (CS1 through CS4)
- Notes taken digitally on iPads



Phase 1 – Bridge Inspection

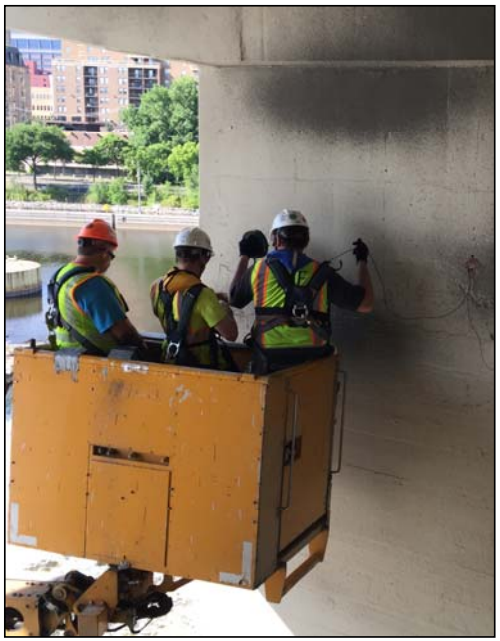


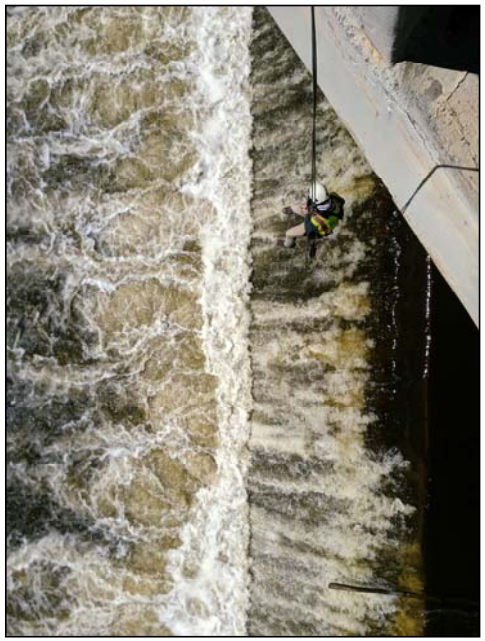
	Coating	Crack	Delamination, spall, or exposed rebar	Efflorescence	Freeze-thaw distress	Moisture/rust staining	Patch	Scale, wear, or abrasion
CS1								
CS2								
CS3								
CS4								

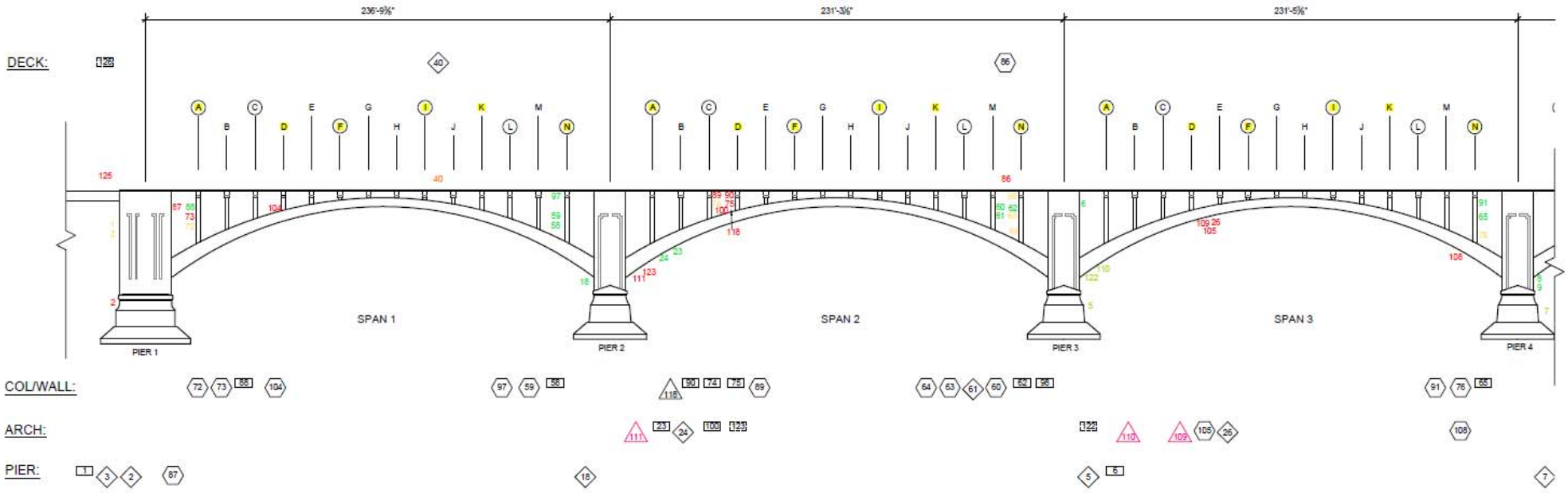
- Full digital record, accessible now and future
- Powerful post-processing abilities

Phase 2 – Field Testing, Material Sampling and Lab Testing

- Select study areas representative of full range of conditions observed in overall inspection
- At each study area:
  - In-depth non-destructive field testing
  - Sample removals for laboratory testing
- Goals:
  - Identify mechanisms of deterioration occurring in concrete across bridge, by element
  - Determine mechanical properties for load rating
  - Gather data as basis for projecting service life





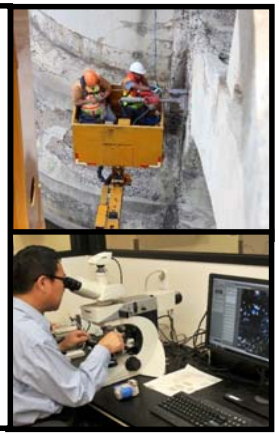


Study Area Locations

- Spatial distribution across bridge
- Range of exposure conditions (upstream, downstream, at/away from joints, etc.)
- Some at each material type, vintage, condition severity

By the Numbers:

- Total test locations: 137
- NDE areas: 73
- Concrete samples: 81
- Steel samples: 10



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Field Testing

- Delamination surveys
- Reinforcing steel location (GPR)
- Corrosion potential surveys (half cells)
- Corrosion rate measurements
- Resistivity testing
- Carbonation testing
- Ultrasonic thickness testing
- Sample removal

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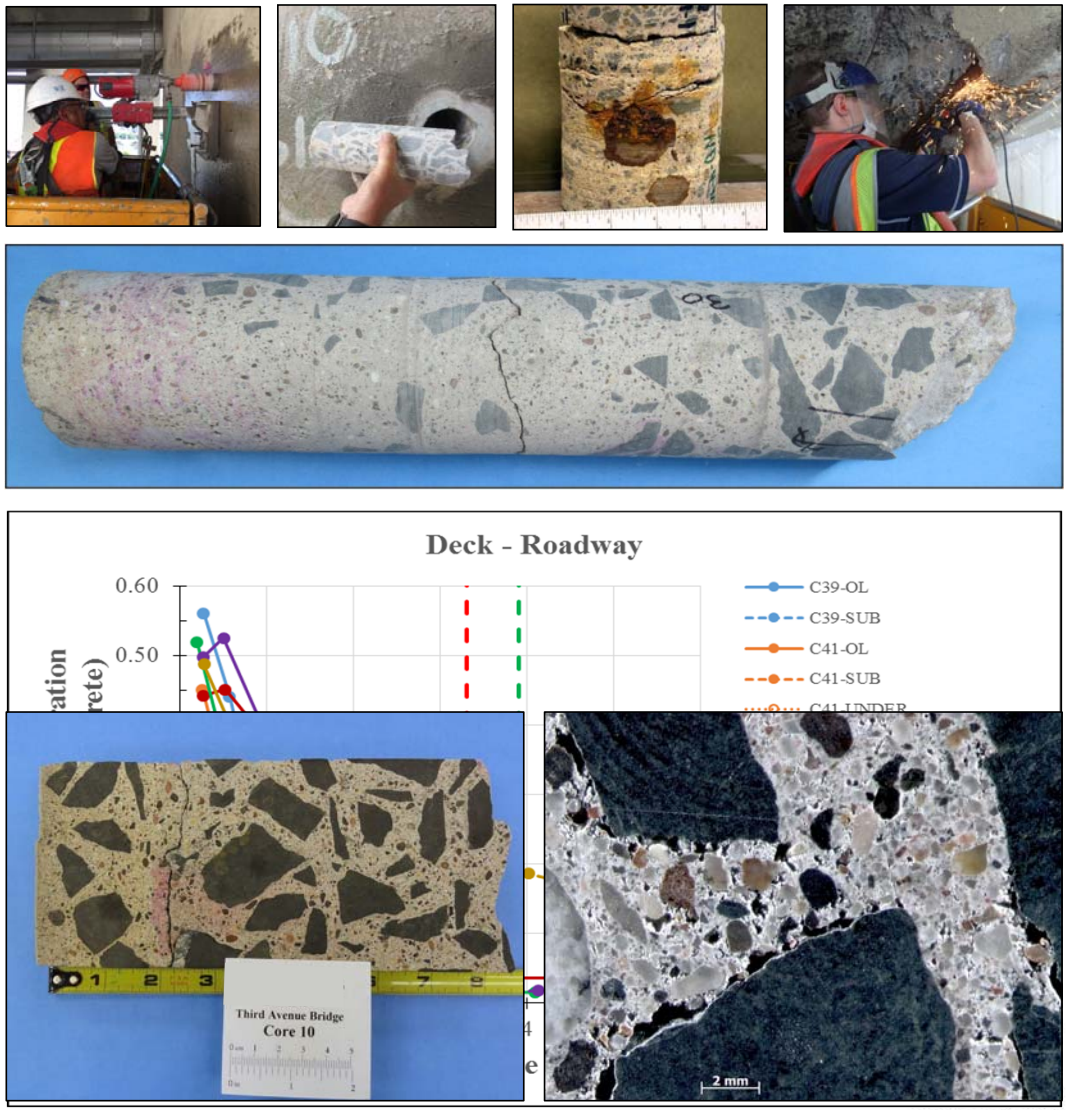
Lab Testing

Samples:

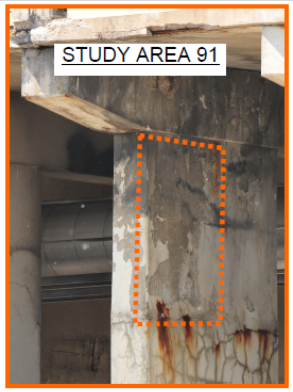
- 81 concrete samples (mainly cores)
- 10 reinforcing steel samples

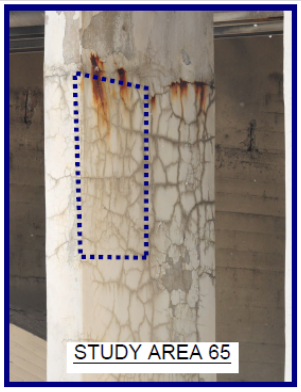
Lab Testing:

- Concrete compressive strength
- Reinforcing steel mechanical testing
- Chloride content profiles with depth
- Petrographic analyses:
  - Freeze-thaw cracking
  - Air content
  - Carbonation depth
  - Paste-aggregate characteristics
  - Other deleterious reactions

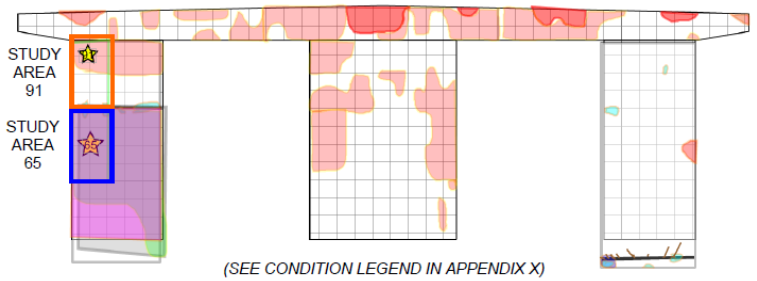


Synthesis Sheets
By Element

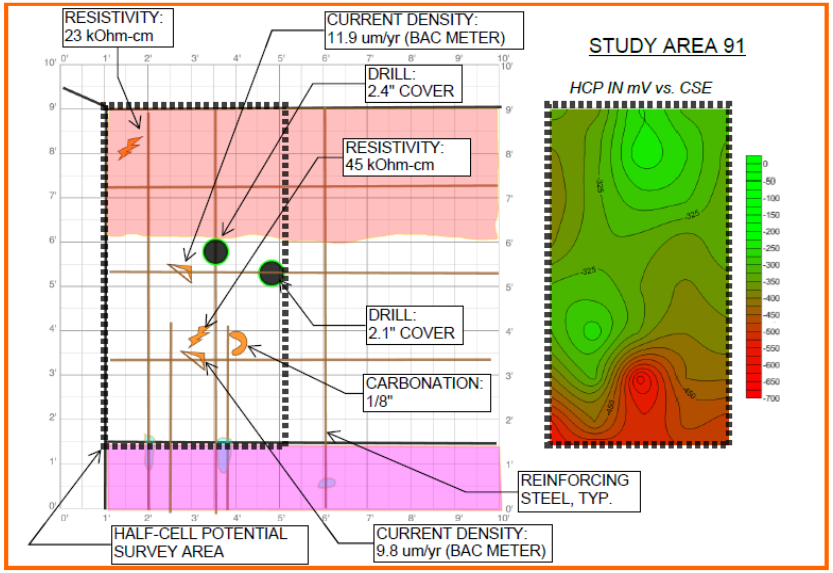


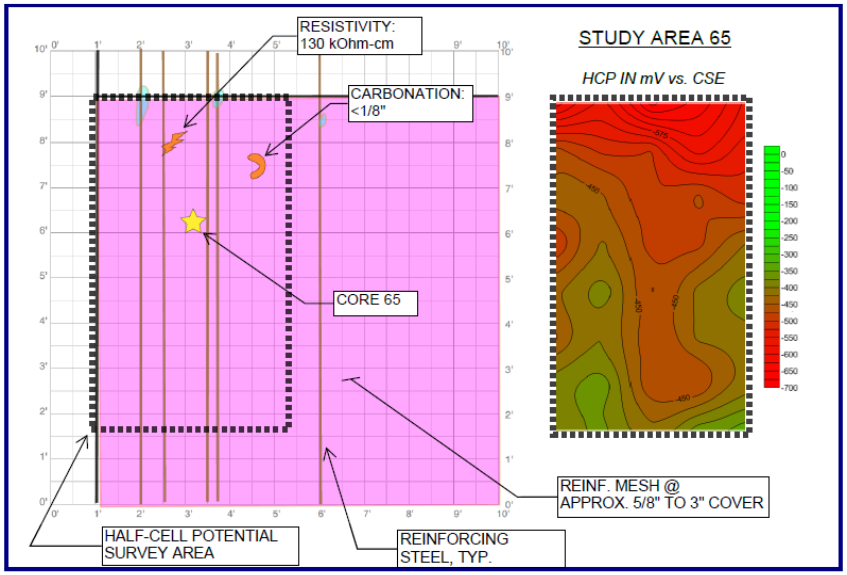


ARCH SPAN 3 - SPANDREL COLUMN N - NORTH FACE
Expansion Joint Since 1918



(SEE CONDITION LEGEND IN APPENDIX X)





Study Area	Inspection Date	Type	Physical Condition	Core Sample(s)	HCP - Avg. (mV vs. CSE)	HCP - Min. (mV vs. CSE)	Resistivity - Avg. (kOhm-cm)	Current Density - Avg. (um/yr)	Cover Vertical Bars - Avg. (in.)	Cover Horizontal Bars - Avg. (in.)	Representative Minimum Cover (in.)	Carbonation (in.)	Mechanisms of Distress	Notes/Interpretation
91	7/15/2017	NDE Only	Poor	N/A	-368	-595	34	10.85	3.7	2.6	2.1	1/8	Chloride Exposure	--
65	7/15/2017	NDE and Core	Poor	65	-466	-683	130	N/A	N/A	N/A	0.6 (Mesh)	<1/8	Other - Moisture Ingress and Cracking	Mesh Reinforcement Present in Patched Area

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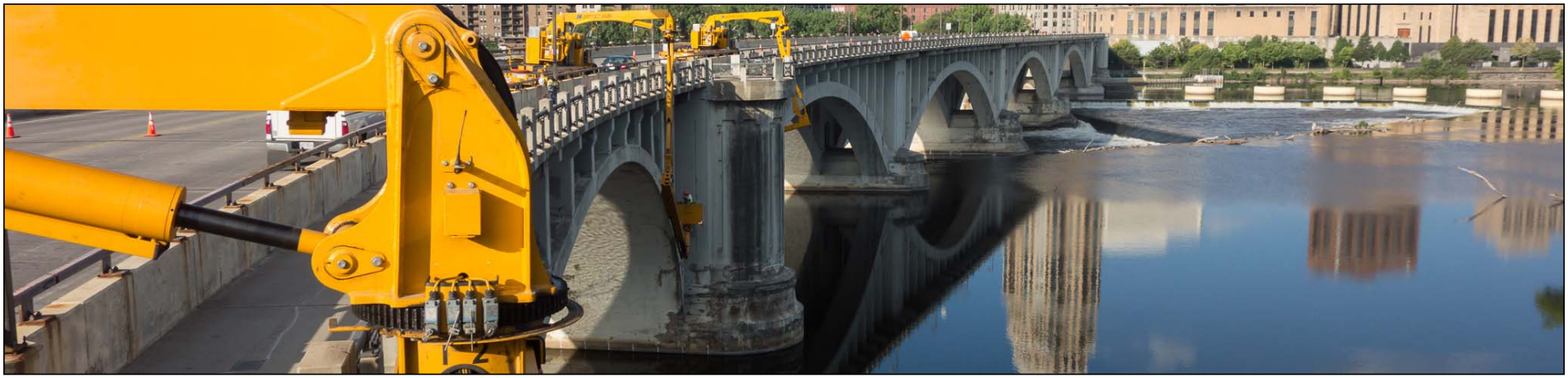


Concrete Rehabilitation Design and Construction

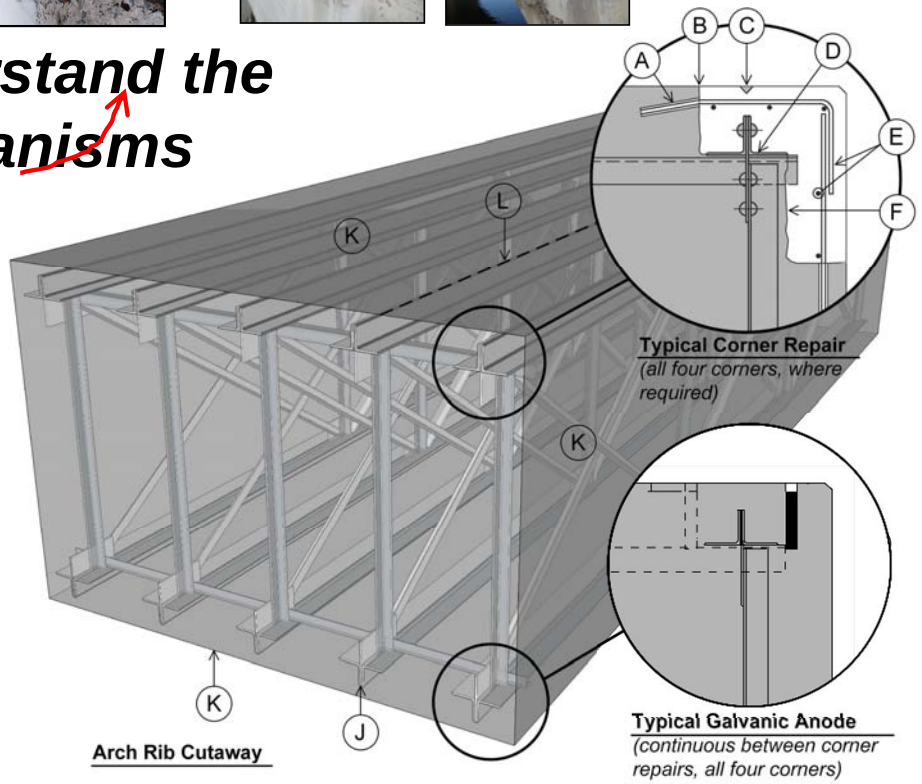
1. High quality surface repairs for historic concrete
2. Accurately estimating concrete repair quantities
3. Deep concrete repairs for freeze-thaw damage
4. Mitigation of freeze-thaw damage and reinforcing steel corrosion (to extend service life)
   - Coating and enhanced water barrier in critical zones, targeted cathodic protection
5. Matching concrete repairs to original concrete texture and color

ICRI CONCRETE REPAIR

1. Quality Repairs for Historic Concrete

Understand the mechanisms

and defeat



Design and detail the repairs for durability

- **Keep water from penetrating** (mechanisms are water-driven)
- Proper substrate preparation
- Reinforcement for crack control and anchorage
- High-quality materials, placement, and quality control

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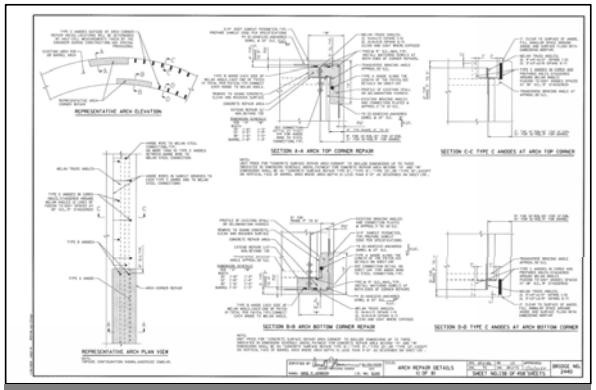
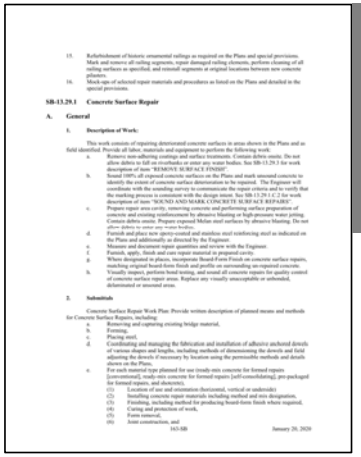
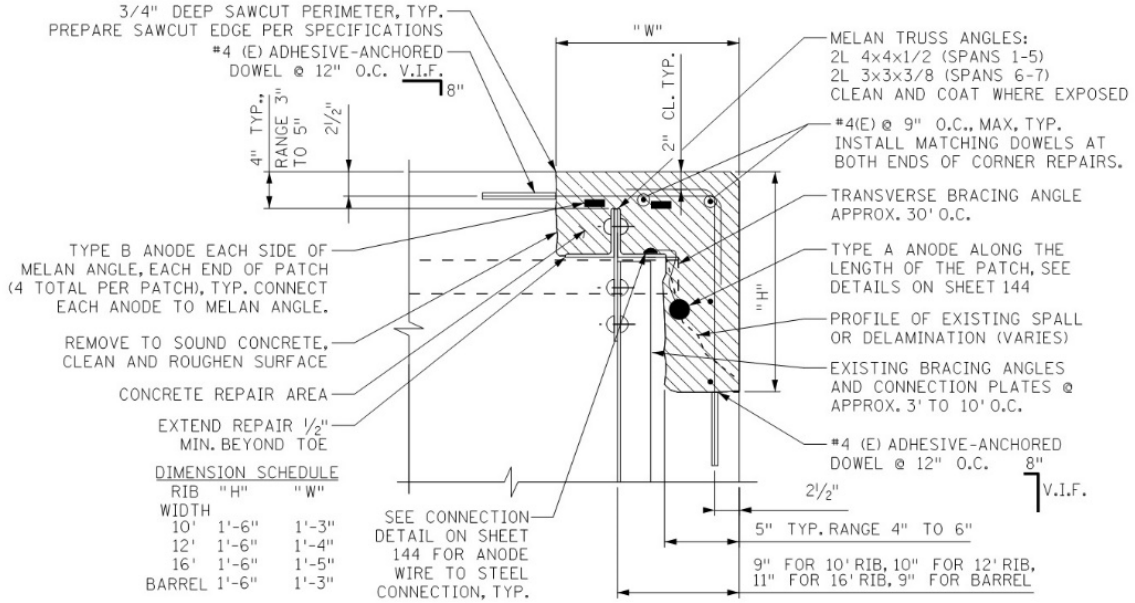
Example – Arch Corner Repair Detail



35 sheets concrete repair details
107 sheets concrete repair



101 pages customized specifications for concrete



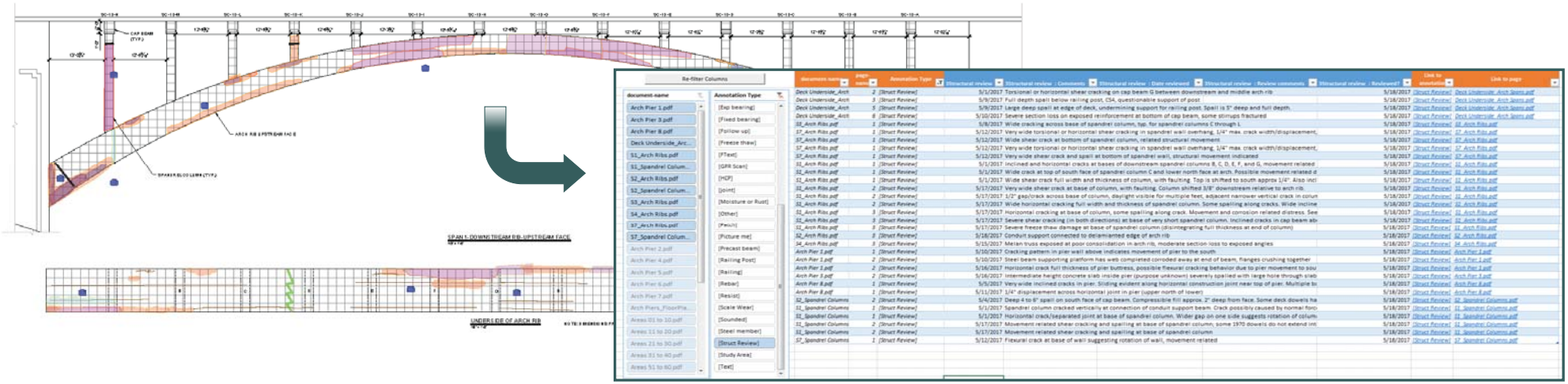
SECTION A-A ARCH TOP CORNER REPAIR

Key points:

- Excavate to steel angles
- Clean and coat steel
- Dowels to keep bond lines tight
- Reinforcing to control cracking within patch
- Anodes at ends to defeat halo effect
- Continuous anode to protect unexposed angle surface
- Shotcrete or CIP repair with QC
- Proper (wet) curing

2. Accurately Estimating and Controlling Concrete Repair Quantities

- **Distress Quantities (DQ)** – As mapped areas that warrant a repair
  - Can calculate DQ directly from inspection software (total area of all “blobs”)
- **Three factors** to convert DQ’s to repair quantity estimates on Plans
  - [Quantity Estimate] = [DQ] * [Squaring Off Factor] * [Time Delay Factor] * [Other Factor]



Total Repair Factor ("Growth Factor")

- Across all elements, total of all factors (sometimes called "growth factor") was approximately **1.8 to 2.2** x DQ (as mapped)

	Squaring Off Factor (average)	Time Delay Factor	Other Factor	Total Repair Factor
Arch Ribs	1.28	1.23	1.15	1.81
Barrel Arches	1.43	1.23	1.15	2.02
Pier Walls (Exterior and Interior Faces)	1.56	1.23	1.15	2.20

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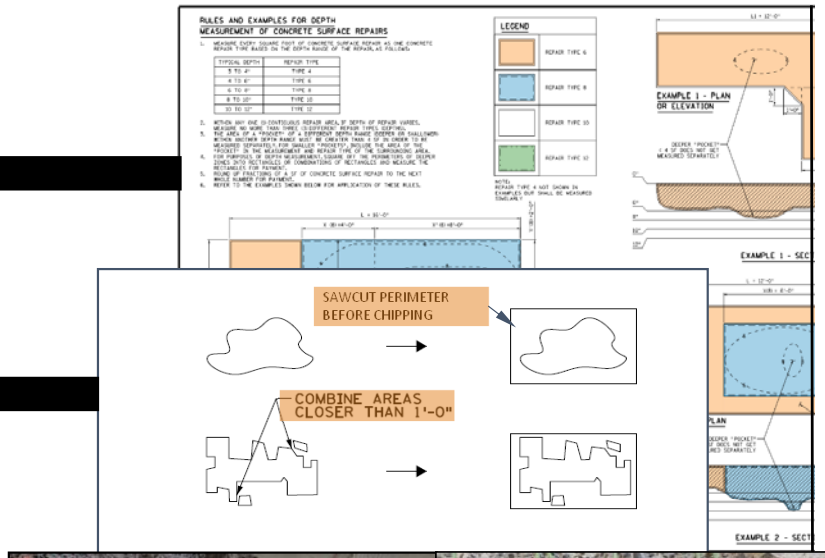
Controlling Repair Quantities During Construction

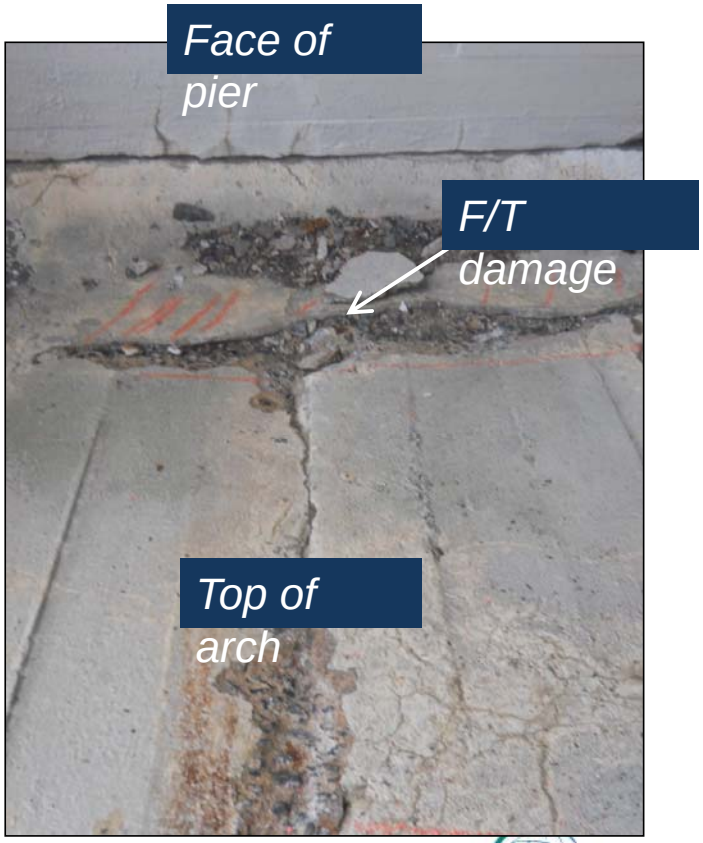
- Fair, clear, and doable repair measurement and payment procedures (area and depth)
- Sawcut before chipping; do not combine areas more than 1 foot apart; use good repair geometries (see ICRI guidance)
- Engineers experienced in historic concrete repairs present during marking, measuring and excavation of repair areas (control growth); track repair quantities in real-time



3. How to Address Deep Freeze-Thaw Damage

Deep F/T below drain

Deep F/T at arch springline



F/T at arch groin

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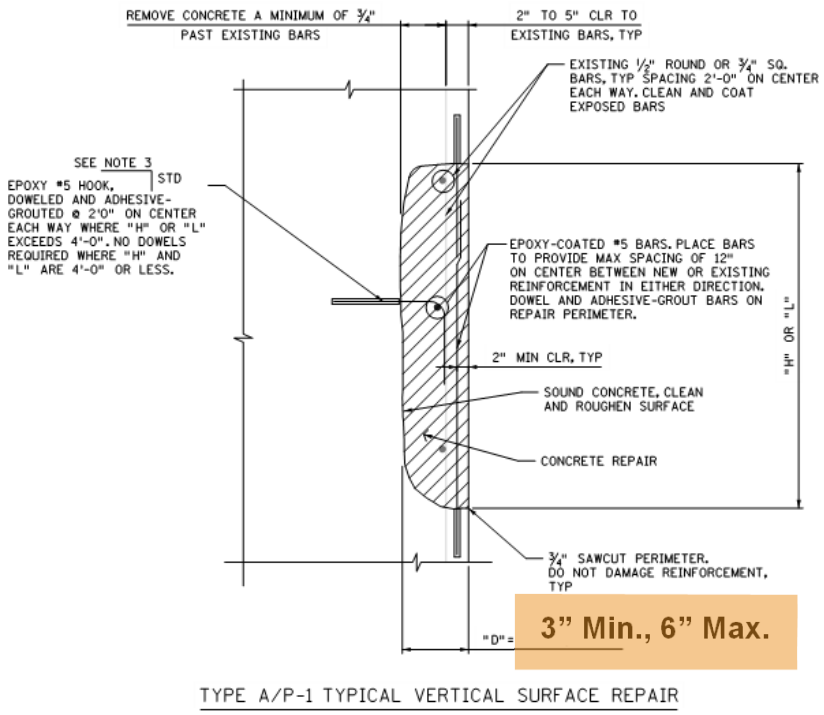
Typ. Surface Repair (6” Max.)

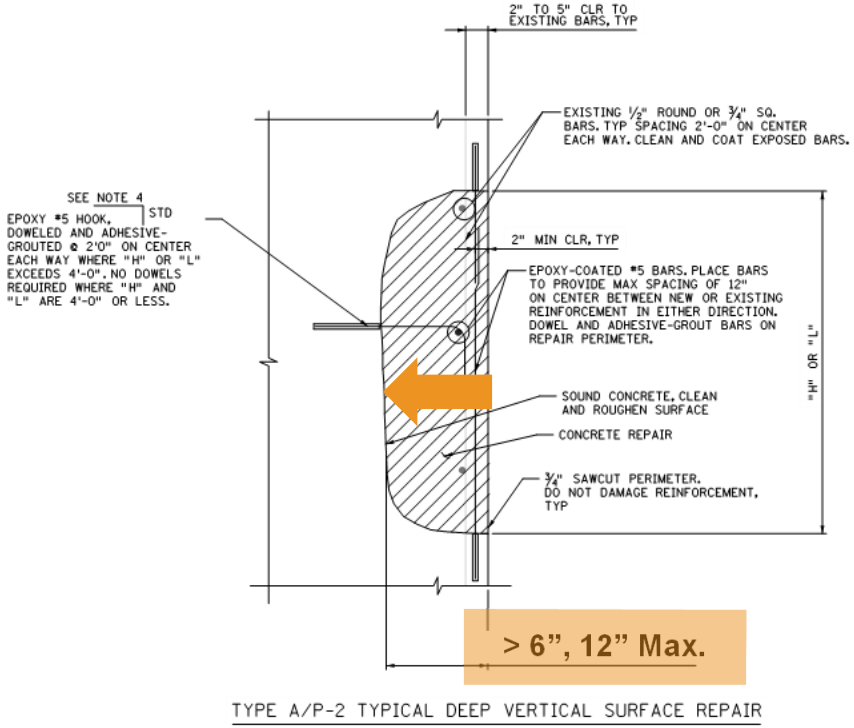


TYPE A/P-1 TYPICAL VERTICAL SURFACE REPAIR

Key points:

- Concrete removal behind bars
- Up to 6 inches depth
- Supplemental bars & dowels

Deep Repair (8, 10, 12” Max.)

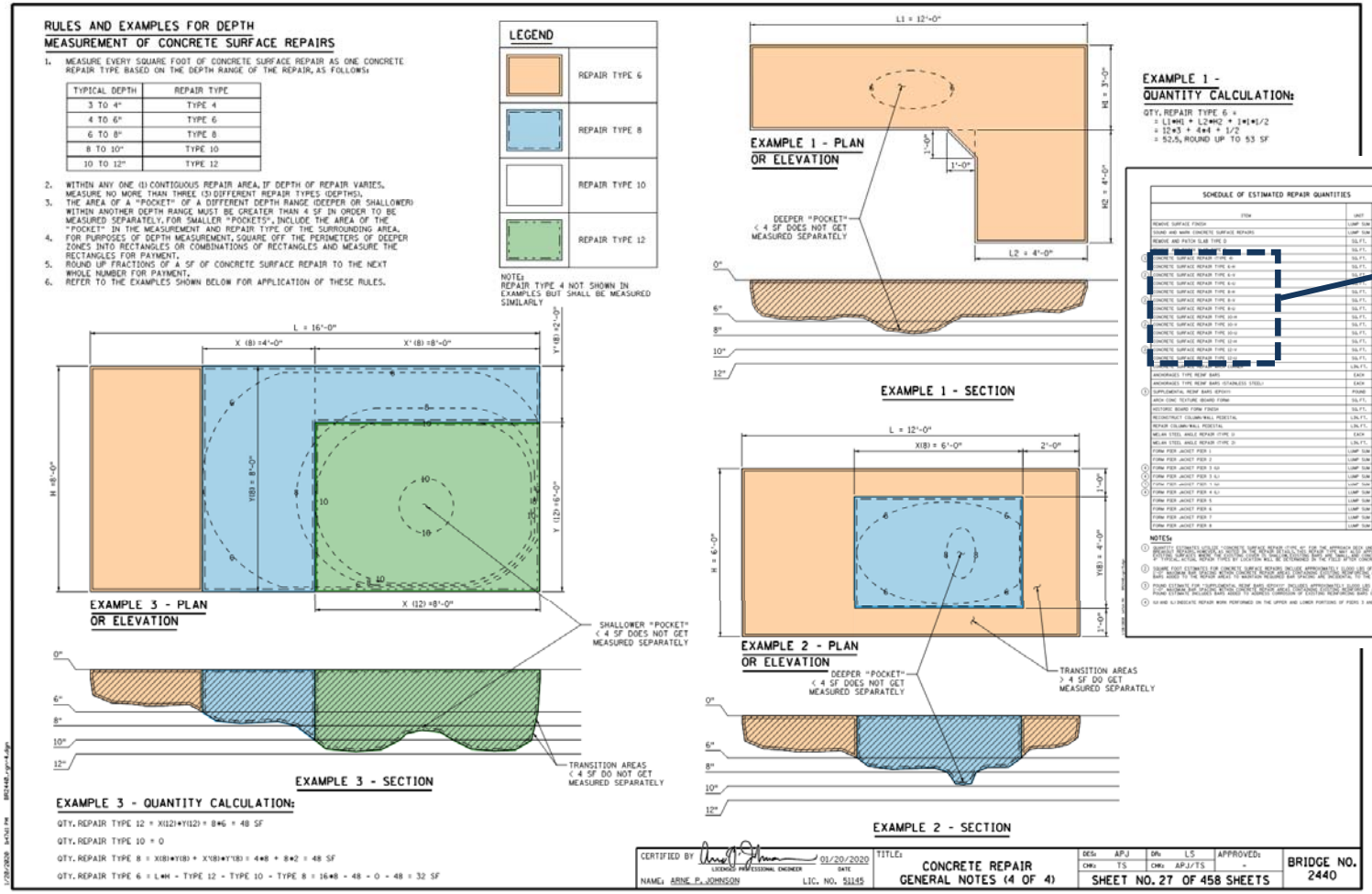


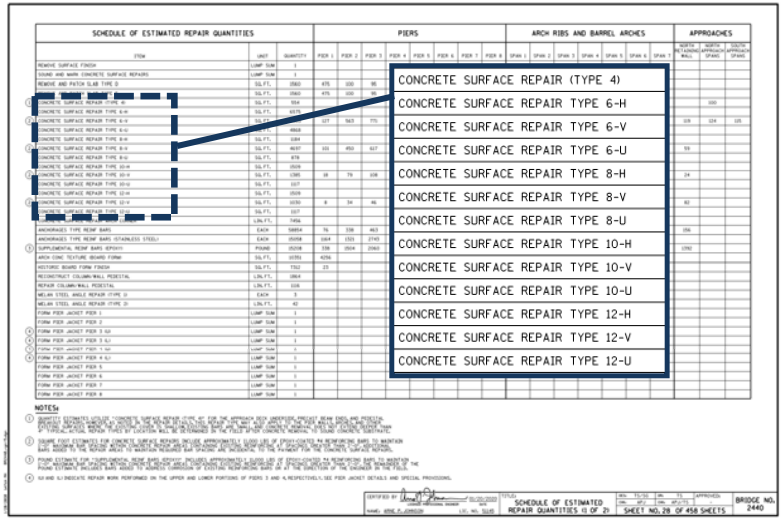
TYPE A/P-2 TYPICAL DEEP VERTICAL SURFACE REPAIR

Key points:

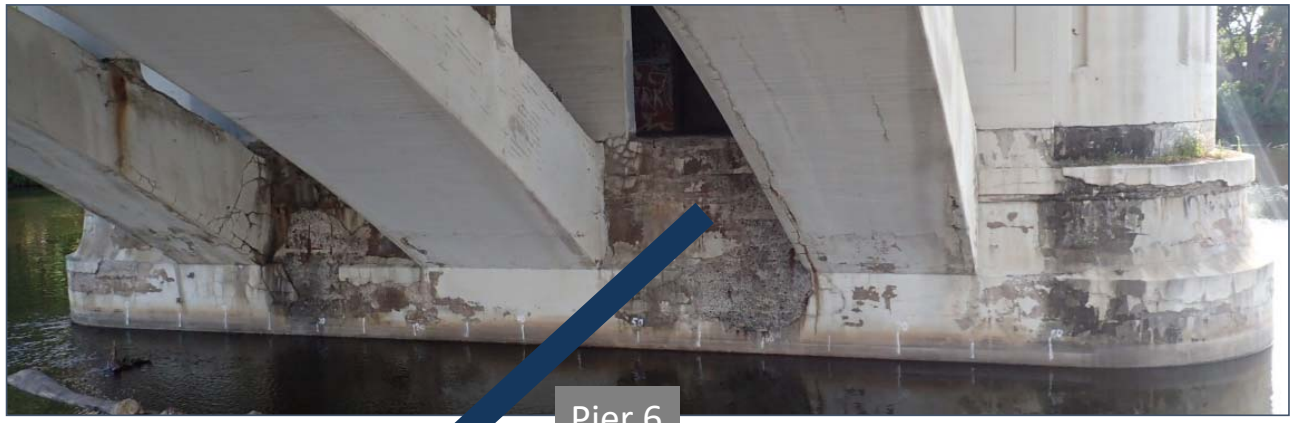
- Excavate incrementally deeper until reach sound substrate
- 8”, 10”, 12” payment depths

Define Measurement and Payment



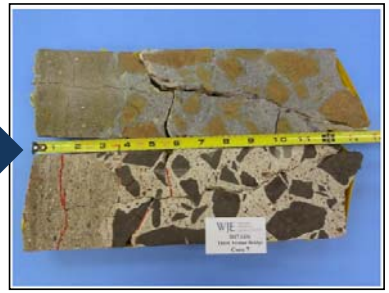


Very Deep F/T Damage at Pier Bases



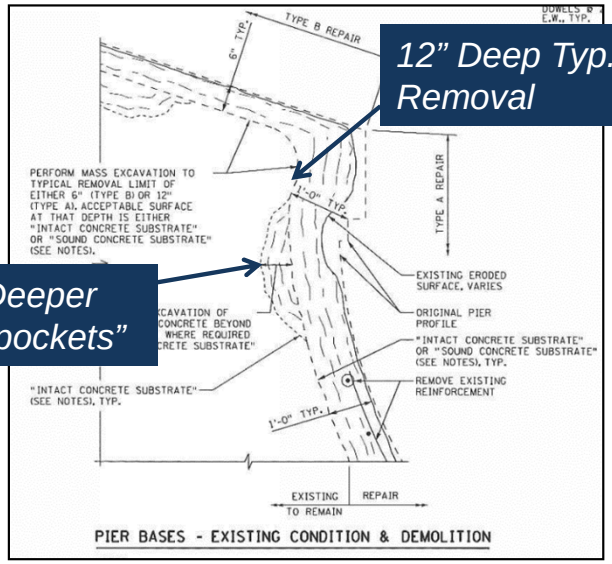
- Freeze-thaw damage near waterline and below drain discharges
- Approx. 2 feet deep max. (erosion plus F/T beyond)

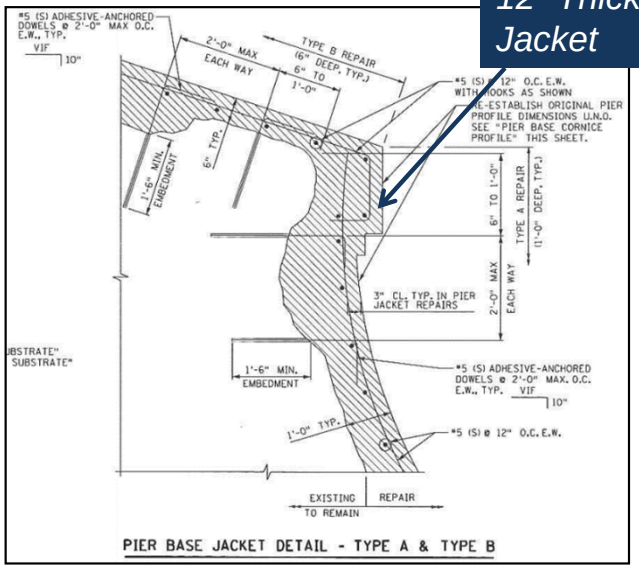
- Max. erosion depth of 17”

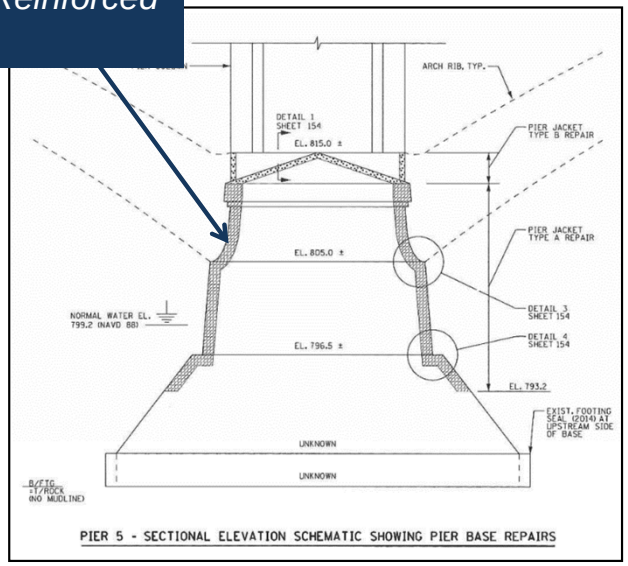


- Max. F/T damage beyond erosion 8”

Repair Approach - Pier Base Jackets







- Remove 12” typical, plus deeper in isolated “pockets” to reach “intact concrete substrate” (not necessarily to “sound substrate”)
- Install new anchorages deeply embedded into sound concrete below F/T damage, install new reinforcing steel in jacket concrete
- Cast new self-consolidating concrete to match original profile lines

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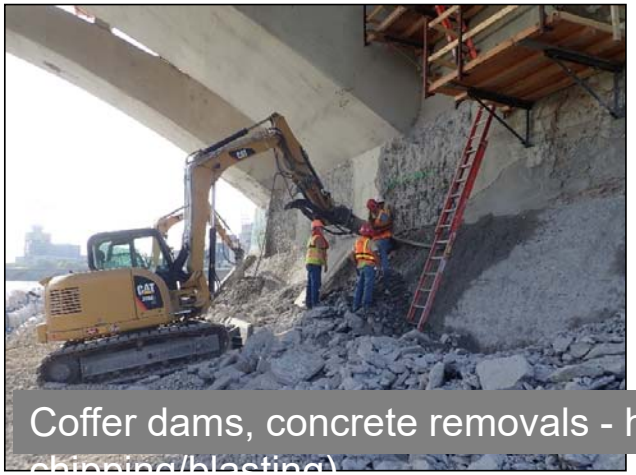
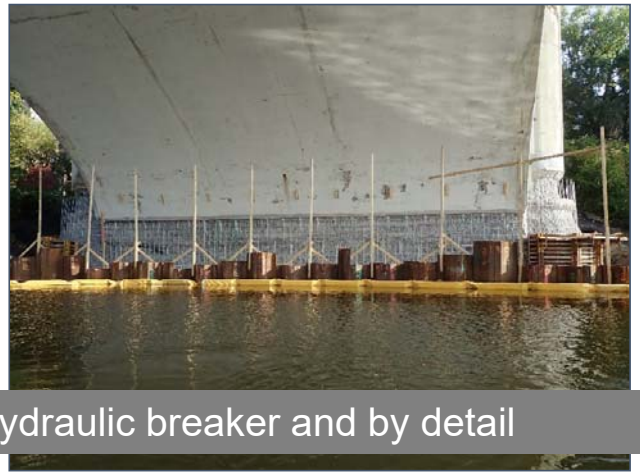
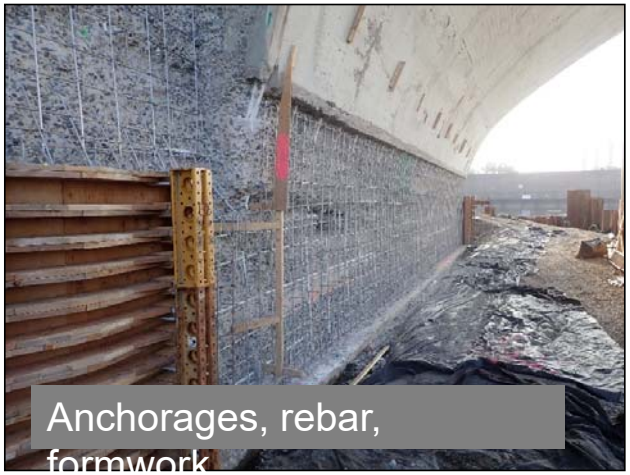
Pier Base Jacket Construction

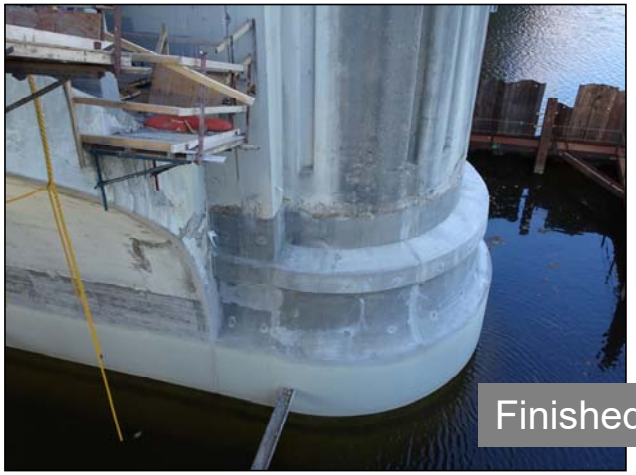




Coffer dams, concrete removals - hydraulic breaker and by detail chipping/blasting)



Anchorages, rebar, formwork



Finished product

Drone View

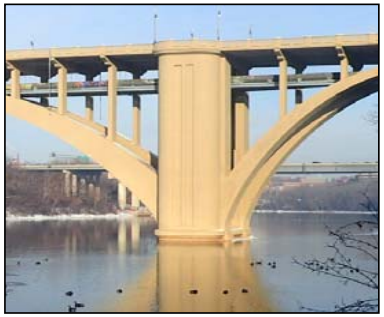
4. Mitigation of Freeze-Thaw Damage and Reinforcing Steel Corrosion (i.e., Extending Service Life)

For freeze-thaw and corrosion mechanisms:

- Both are moisture-driven mechanisms, so overarching goal is to keep water out of the concrete
- High-quality repairs to limit cracking
- Reduce and improve expansion joints
- Coatings and sealers

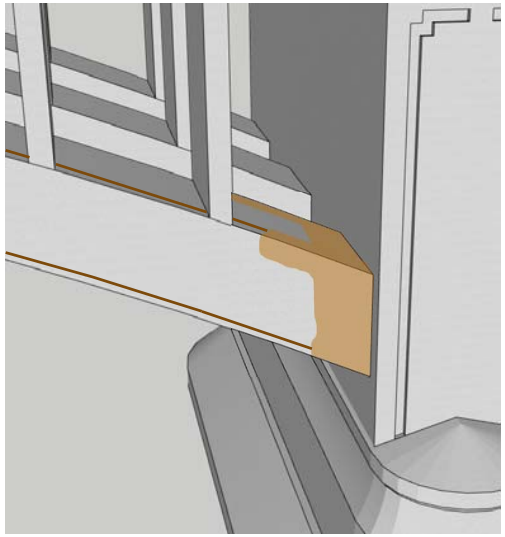
For corrosion mechanism only:

- Cathodic protection

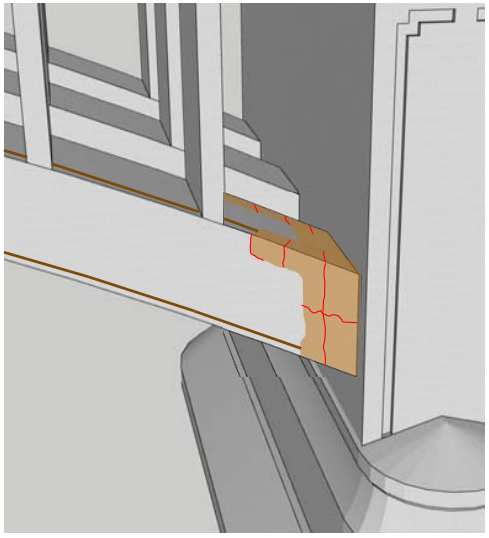


Full Coating, Enhanced Water Barrier in Critical Zones

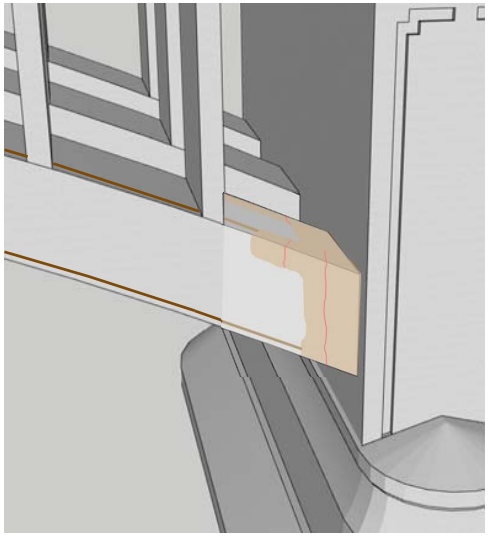
- Research showed 3rd Avenue Bridges had various surface treatments in history
- Original concrete extremely vulnerable to future deterioration if water penetrates
- Historic agencies accepted water-resistant coating for all original surfaces



1. Concrete surface repairs, cast-in-place material required, anodes between corner repairs



2. Extended cure-out period (6 months min.), almost all shrinkage cracks and bond line separations occur



3. Silane treat surfaces – 100% solids, two coats to refusal (seals cracks <10 mils)

ICRI CONCRETE REPAIR

Full Coating, Enhanced Water Barrier in Critical Zones

- Research showed 3rd Avenue Bridges had various surface treatments in history
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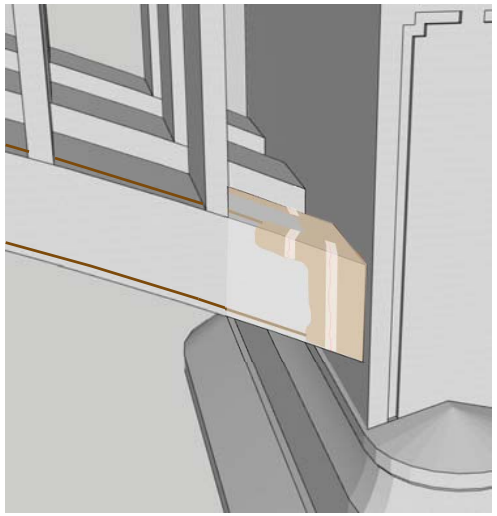
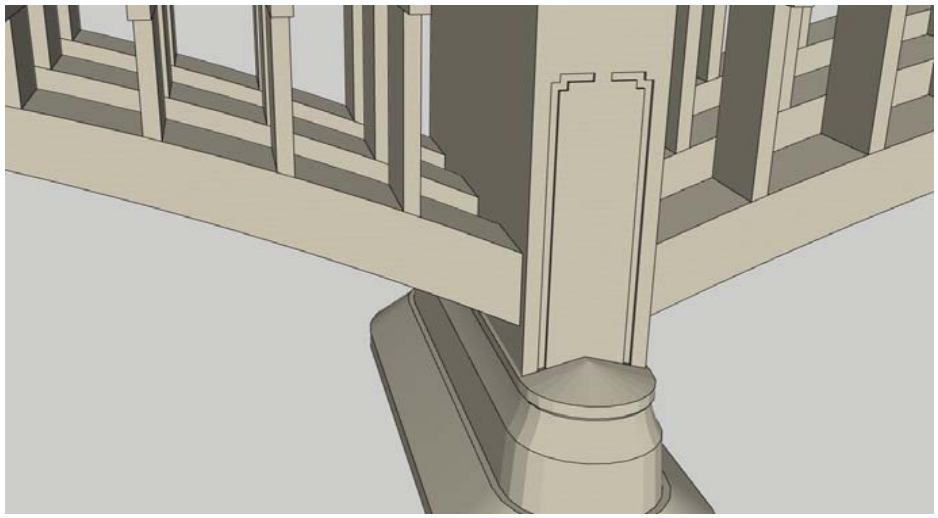


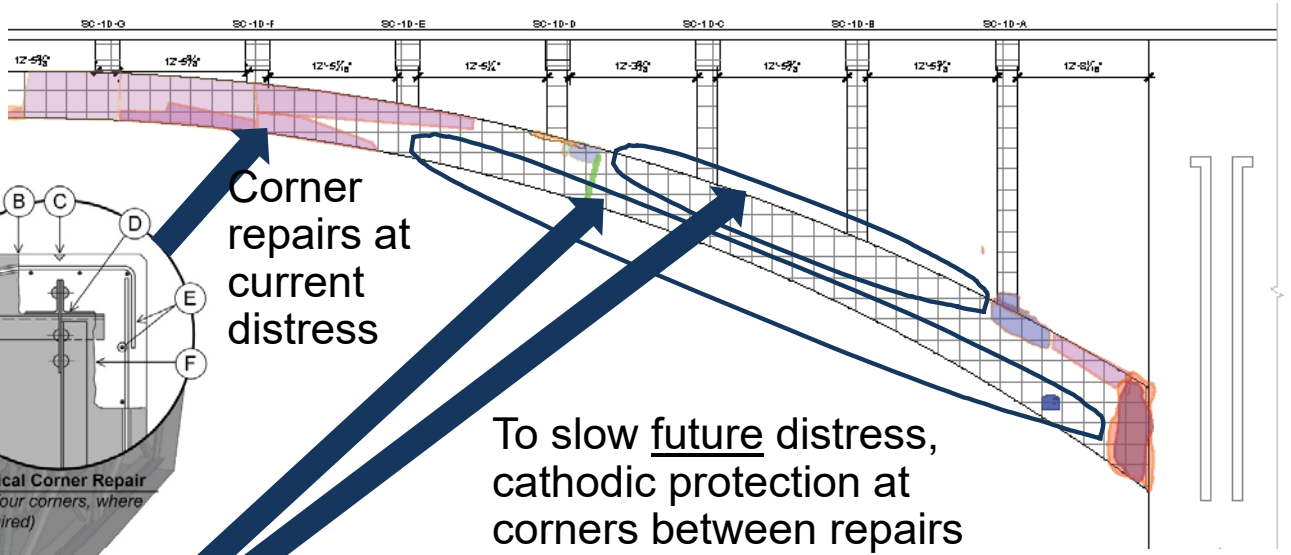
4. Rout and seal all wider and moving cracks; pre-stripe cracks with elastomeric patching compound

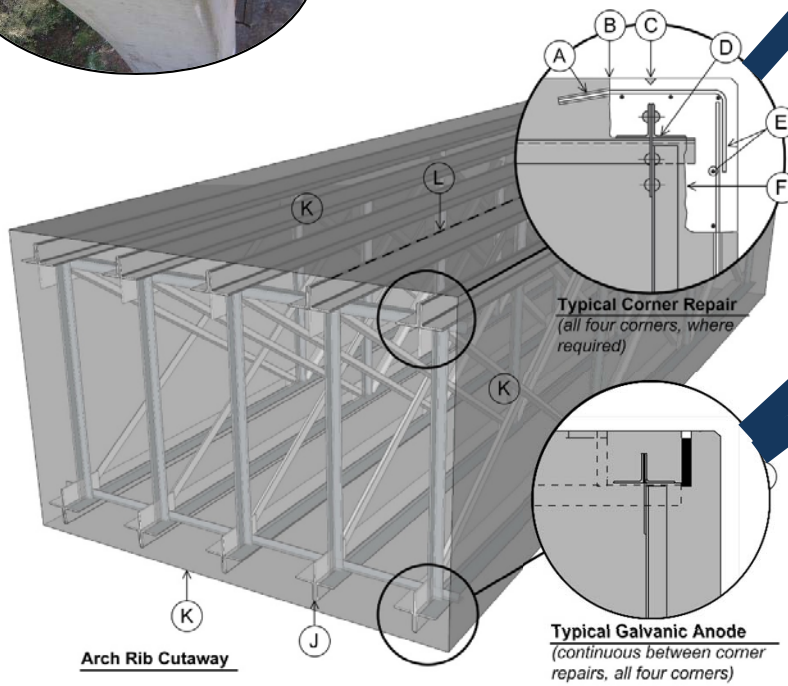


5. Coat all surfaces with elastomeric surface coating colored to match original concrete (MnDOT Special Surface Finish II)

ICRI CONCRETE REPAIR

Targeted Cathodic Protection





Corner repairs at current distress

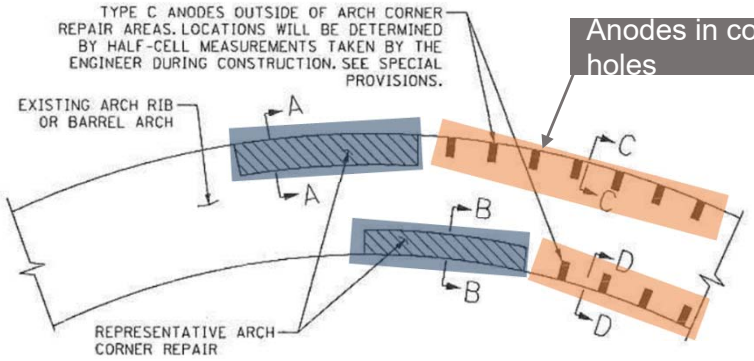
To slow <u>future</u> distress, cathodic protection at corners between repairs

Furthermore:

Cathodic protection anodes will be located in the field only where half-cell testing shows active corrosion is occurring

ICRI CONCRETE REPAIR

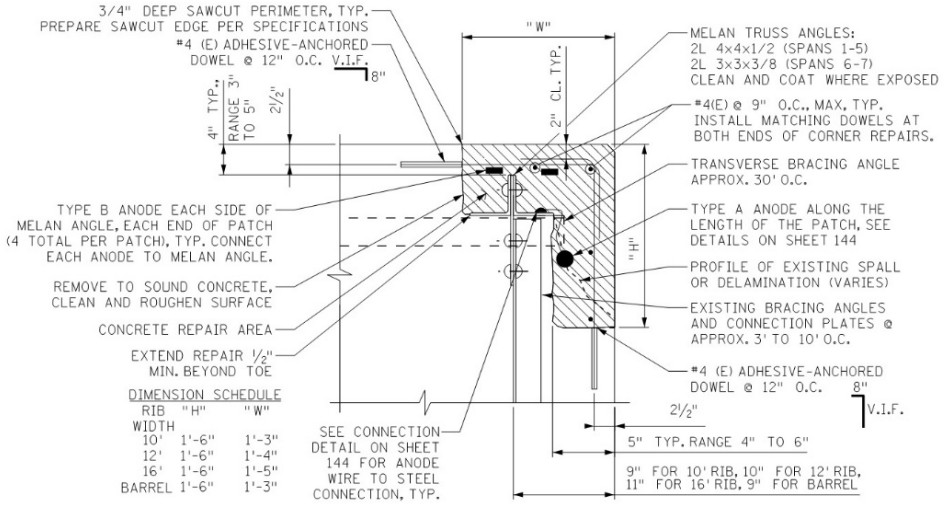
Targeted Cathodic Protection



Anodes in cored holes

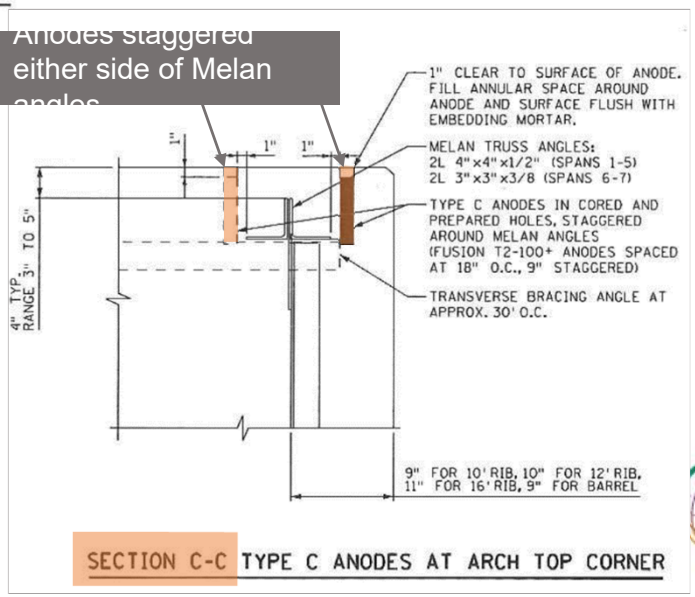
Cylinder-shaped anodes

REPRESENTATIVE ARCH ELEVATION



SECTION A-A ARCH TOP CORNER REPAIR

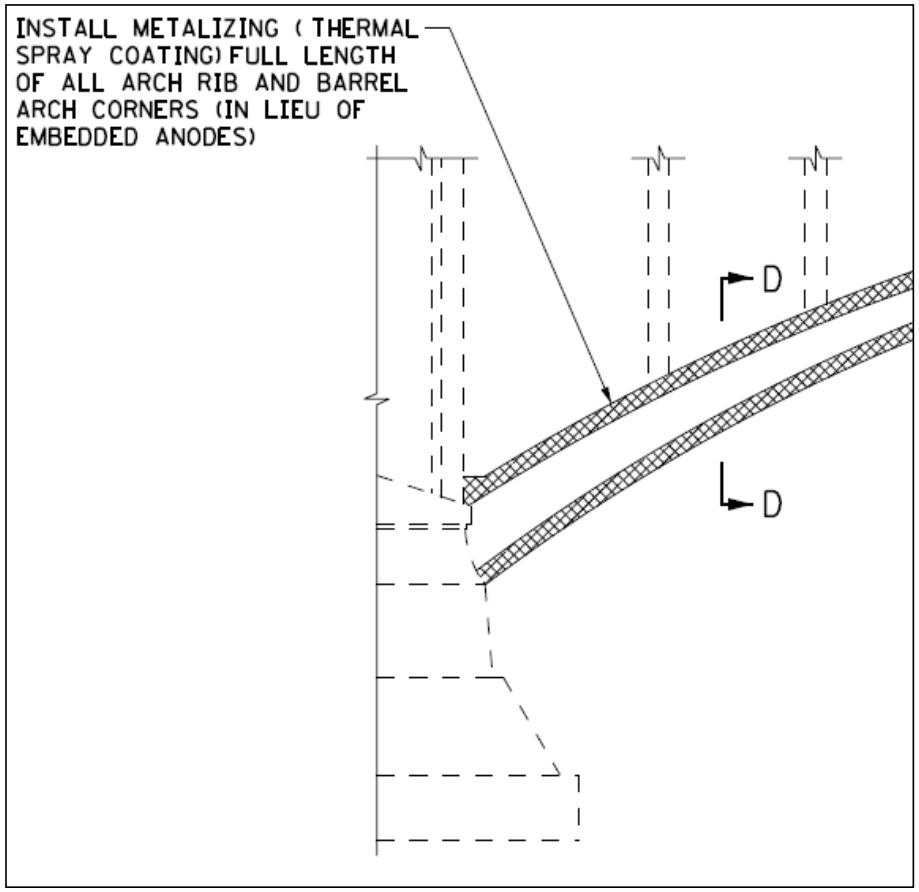
Anodes staggered either side of Melan angles

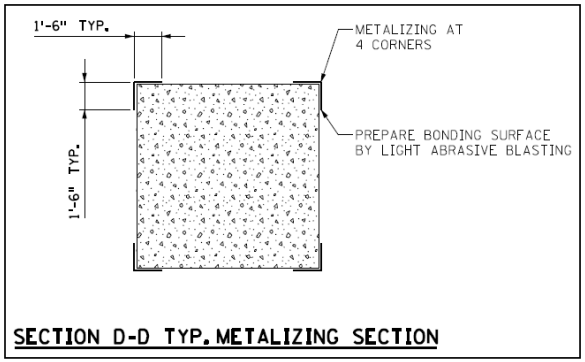


SECTION C-C TYPE C ANODES AT ARCH TOP CORNER

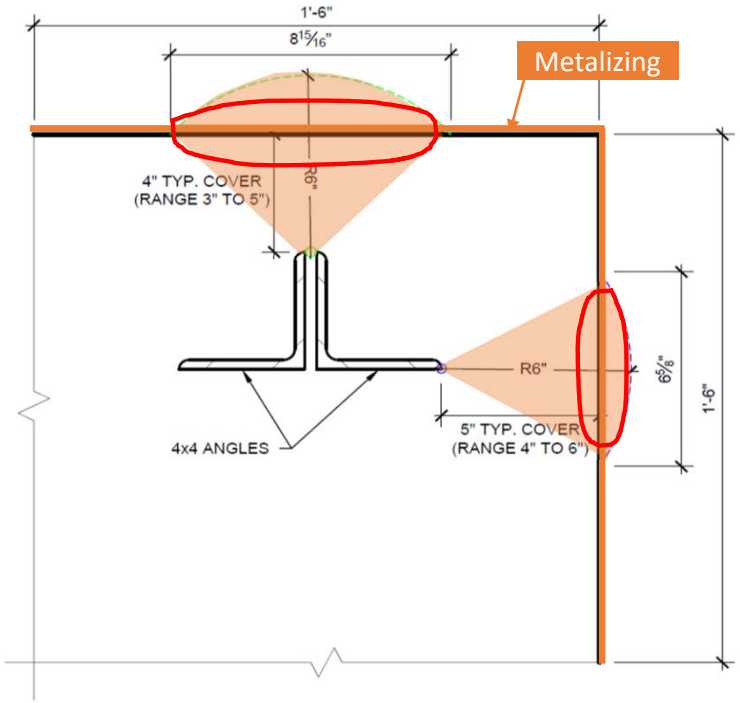
ICRI CONCRETE REPAIR

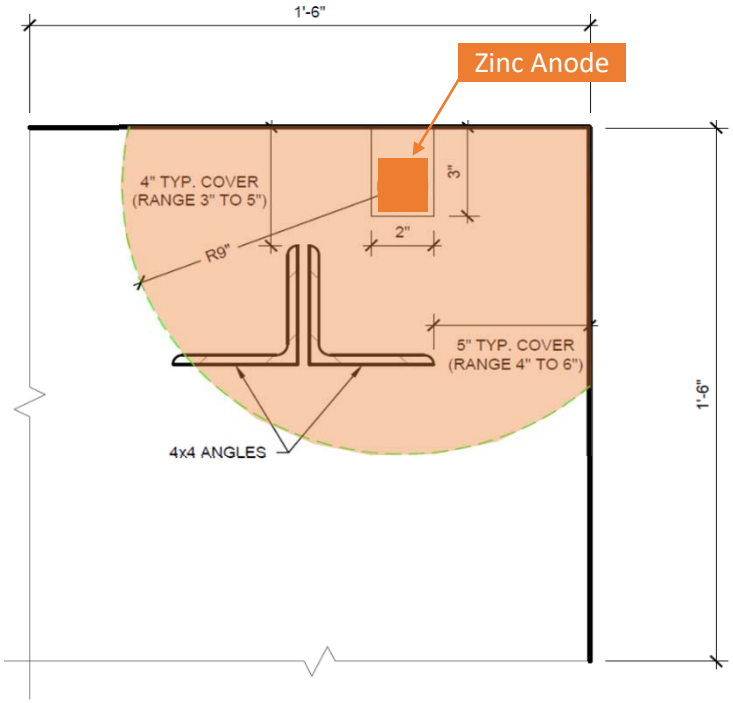
What About Metalizing (Thermal Spray Coating) at Arch Corners?





Determined Inadequate “Throw Distance” from Metalizing to Melan Angles in this Case





Metalizing:

- Typical maximum effective current throw distance is 4” to 5”
- Consider 6” radius here
- Only narrow “strips” of metalizing are effective

Embedded Zinc Anode System:

- Effective maximum current throw distance is up to 15”
- Consider 9” radius here
- Entire embedded anode is effective

5. Matching Concrete Repairs to Original Concrete Texture and Color

- A primary goal of preserving historic concrete is to match the texture, profile, and color of the original concrete
- Various techniques can be used to create “board-form” texture in repair concrete (shown here from another project)

ICRI CONCRETE REPAIR

Mockups During Construction

Table 1. Mock-up Types, Numbers, Requirements, and Purpose

Mock-up Repair	Type of Mock-up	Mock-up Requirements	Purpose
Remove Non-Adhering Coatings and Surface Treatments	Trial Repair	For each type of removal process planned for use, perform Mock-up in three areas selected by Engineer to include a range of existing coating conditions	Demonstrate effectiveness of removal and protection of original concrete surfaces from damage
Concrete Surface Repair	Field sample	For each material type (conventional ready-mix, self-consolidating ready-mix, pre-packaged for formed repairs, and shotcrete) and placement method planned for use, perform Mock-up for the following including board-form finish: 1. Arch - top (horizontal) 2. Arch - side (vertical) 3. Arch - bottom (horizontal underside)	Demonstrate conformance of materials and placement methods, as well as appearance of board-form finish
	Trial repair	For each of following types of repair, perform Mock-up using the material type and placement method planned for use and include board form finish: 1. Arch - top corner 2. Arch - side 3. Arch - bottom corner 4. Arch - top 5. Arch - bottom (underside) 6. Pier - vertical face Perform pull-off testing as outlined in SB-13.29.1 *Concrete Surface Repair* for each type.	Demonstrate conformance of materials, preparation (including cleaning, coating of exposed steel truss member and reinforcing bars, dowel installation), placement and curing methods, as well as appearance of board-form finish
Galvanic Anodes	Trial repair	Perform Mock-ups for the anode types as follows: 1. Type A - Distributed galvanic anode for concrete surface repair: Incorporate into arch corner trial repairs for Concrete Surface Repair 2. Type B - Discrete galvanic anode for concrete surface repairs: Incorporate into arch corner and pier vertical face trial repairs for Concrete Surface Repair 3. Type C - Discrete galvanic anode for sound concrete: Install on top of arch at location identified by Engineer	Demonstrate conformance of materials, preparation (including anode-to-steel connection and anode securing methods) and placement methods for embedding mortar
Concrete Crack Repair (Types 1 through 5)	Trial repair	For each of following types of crack repair, perform Mock-up using the material types planned for use: 1. Type 1 Crack Repair 2. Type 2 Crack Repair 3. Type 3 Crack Repair 4. Type 4 Crack Repair 5. Type 5 Crack Repair Mock-ups to include Special Surface Finish II Base Coat.	Demonstrate conformance of materials, preparation and placement methods, as well as appearance of crack repairs

Specifications for mockups on 3rd Avenue Bridge

3 steps recommended, as appropriate:

1) Shop samples – made in shop, transported

2) Field samples- made at site next to point of placement, serve as mobile

3) Trial repairs – made on structure, left in place if accepted

Drone Flyover Showing Current Status

Questions?

Arne Johnson
Principal
Wiss, Janney, Elstner Associates, Inc.
ajohnson@wje.com
847.274.7400

Dan Enser
Associate Vice President
HNTB Corporation
denser@hntb.com
763.852.2100