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ICRI 2021 Fall Convention

Evaluation of Chemical Attack to a Semi-Elliptical Concrete Conduit

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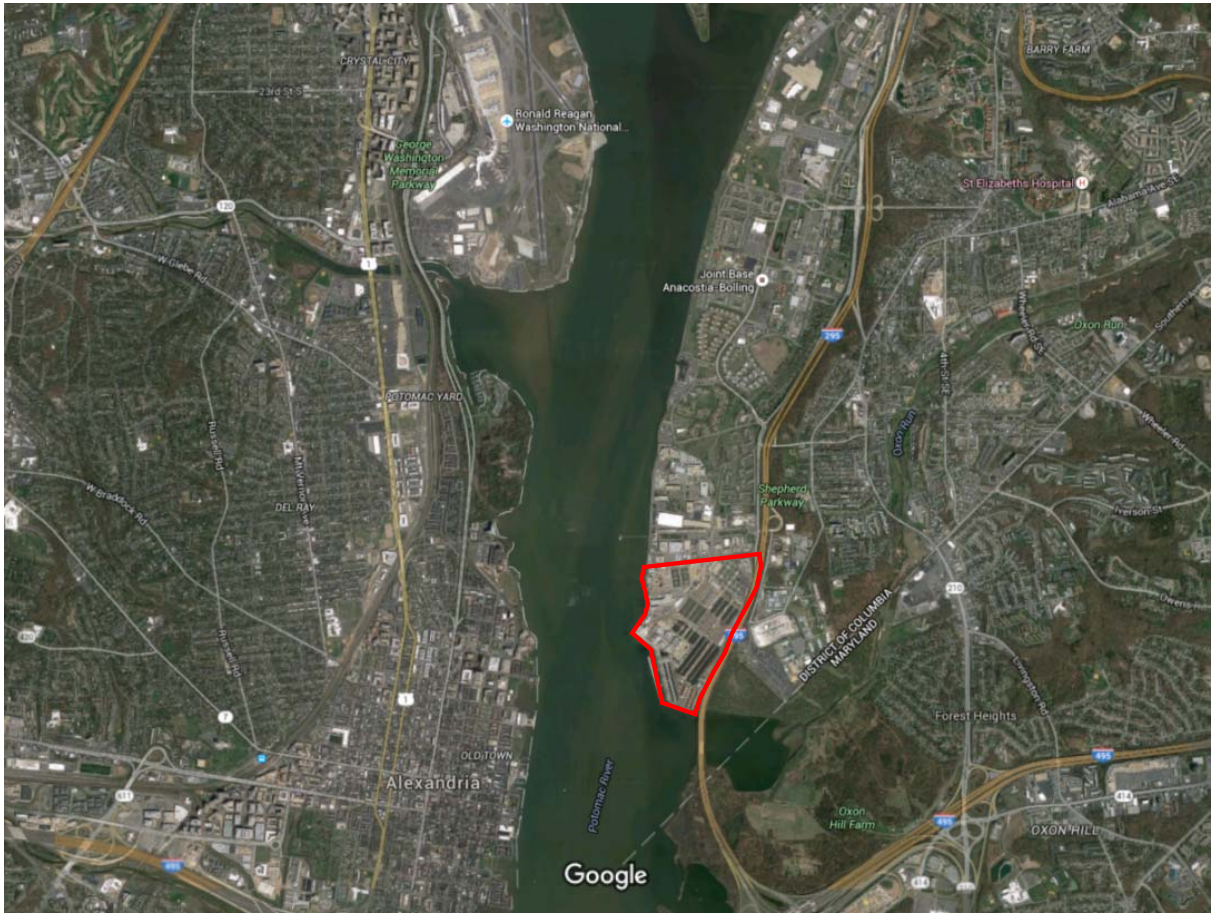
ICRI CONCRETE REPAIR
Restore | Repurpose | Renew

Outline

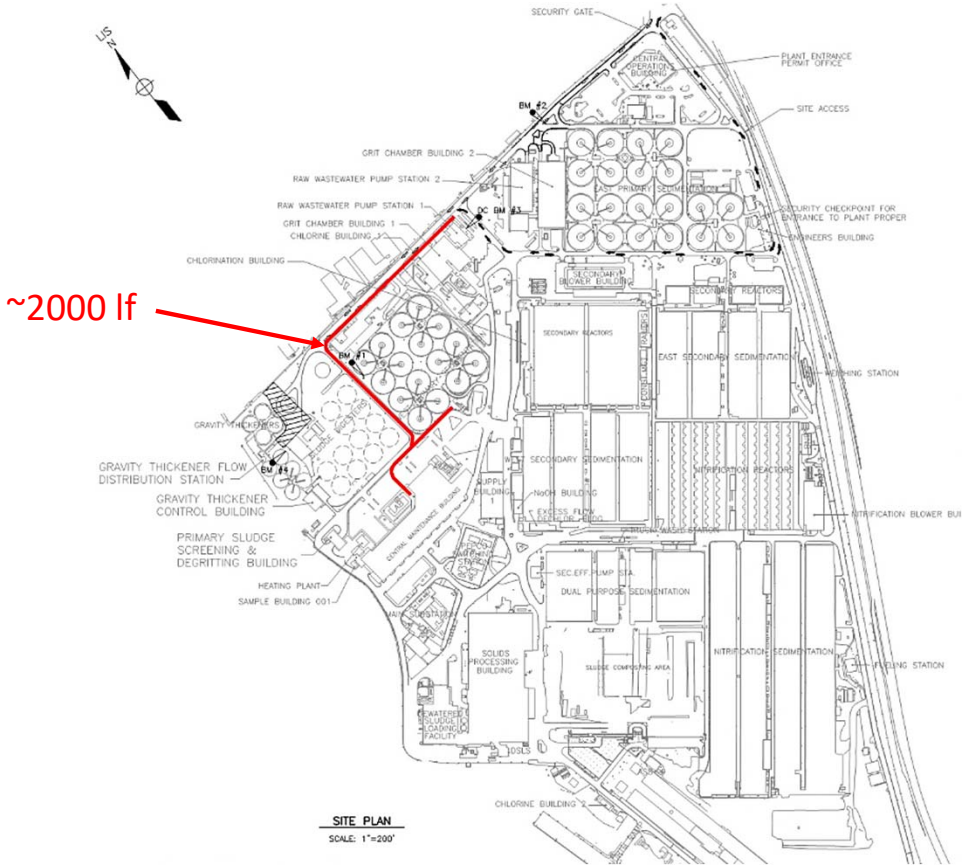
- Project Description
- Evaluation of Chemical Attack to Semi-Elliptical Conduit
- Conduit Repair Methods
- Summary & Questions

Project Description



Project Description

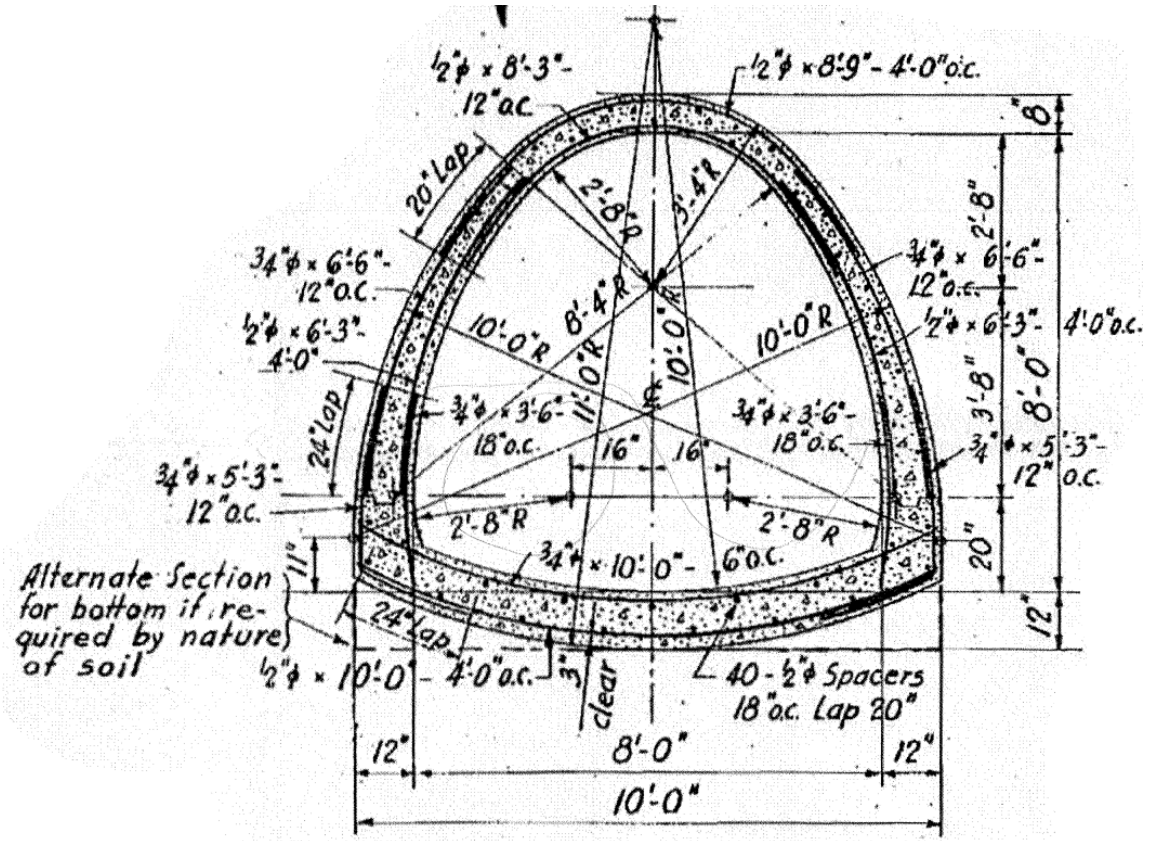
- Site Plan



Project Description

- Cast-in-place semi-elliptical concrete conduit, 8 ft vert. dia.
- Constructed circa 1935
- Originally an emergency overflow for transporting raw sewage
- No longer used for raw sewage transport in 2006
- Current uses:
  - Portions of plant site drain into it
  - Some active storm water inlets
- Project Delivery: Design Build
- Objective: Repurpose for storm drainage

Project Description



DISTRICT OF COLUMBIA
SEWAGE TREATMENT PLANT
NON-FEDERAL PUBLIC WORKS PROJECT 9200
CONTRACT DRAWINGS

GREASE SEPARATING TANKS
PRELIMINARY SEDIMENTATION TANKS
PLANT BY-PASS AND EFFLUENT CONDUIT

1935

METCALF & EDDY
ENGINEERS
BOSTON, MASS.

UNIT 2

General notes
indicate 2” cover

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Project Description

- Previous Investigation Work
  - 1987 Dive Report
  - 2013 Engineering Report
- Findings:
  - Crown Deterioration
  - Debris

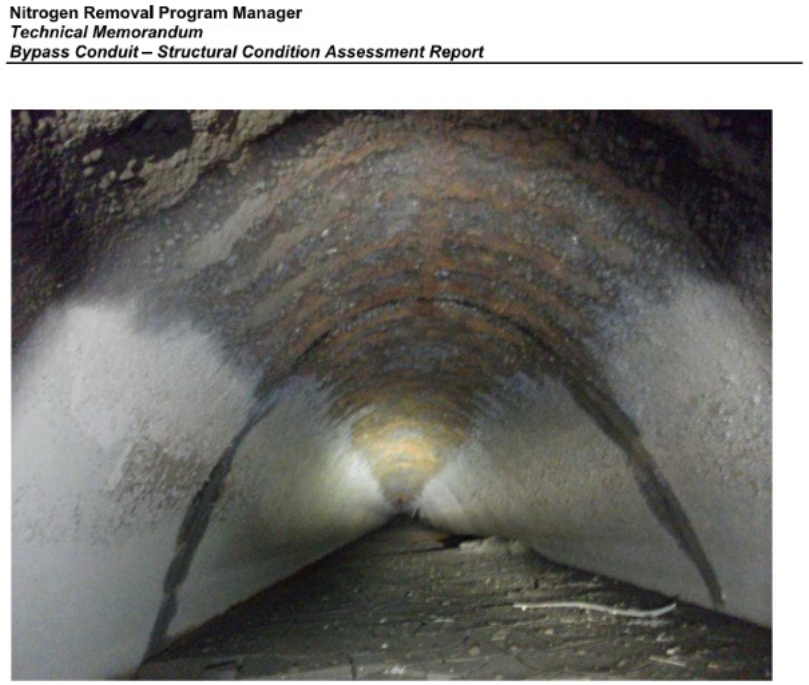


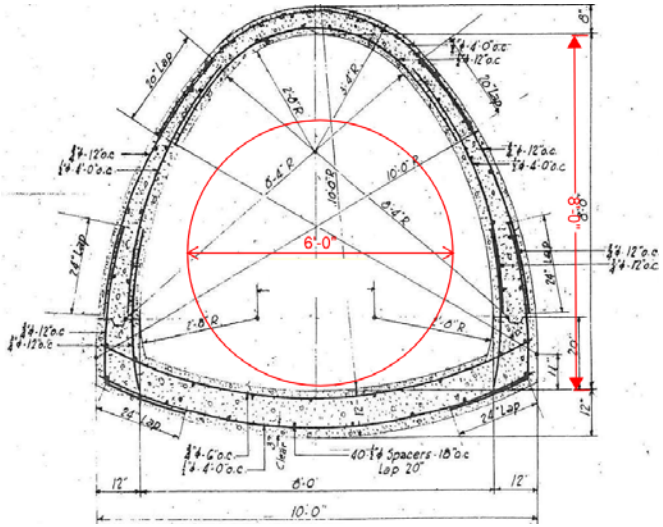
Photo 10: Example of hydrogen sulfide corrosion.

Project Description

- Original Repair Concepts

1. Scenario 1: Two 36” dia. FRP pipes + flowable fill
2. Scenario 2: 72” dia. steel pipe with welded joints + flowable fill
3. Scenario 3: Cut out 140 ft section, install CIP box “culvert” section

All scenarios assumed the existing conduit provided no strength



Project Description

- After winning project, Design-Build Contractor cleaned the conduit
- Contractor noted areas of severe deterioration and “good” areas
- Structural Group performed initial investigation (Nov 2014) to determine whether conduit could be repaired
- Repair (instead of abandonement) had potential cost-savings
- Questions:
  - How much of the conduit could be repaired?
  - Are portions of conduit too badly damaged to be repaired?
  - What type of repair is necessary?
  - Constructability concerns with repairs

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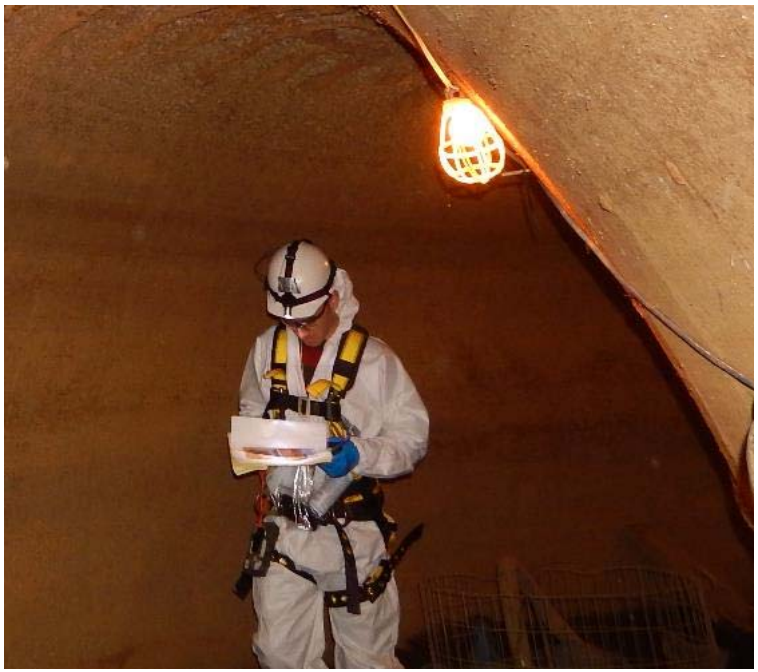
Project Description

- A note about safety
  - Investigation required confined-space entry (CSE)
  - Contractor developed written Safety Plan and drafted CSE Permit
  - Safety equipment: Tyvek, rubber boots, body harness, gas meter, lighting, radios



Project Description

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Project Description

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Structural Evaluation

- Phased approach
  - Preliminary Assessment and then Detailed Investigation
  - Limiting risk
- Preliminary Assessment goals:
  - Spend limited effort to learn as much as possible
  - Obtain concrete cores for material testing
  - 2-day Walk-Through: visual and limited sounding
  - Try to characterize relative amount and nature of deterioration
- Decide whether to repair after obtaining preliminary information

Structural Evaluation

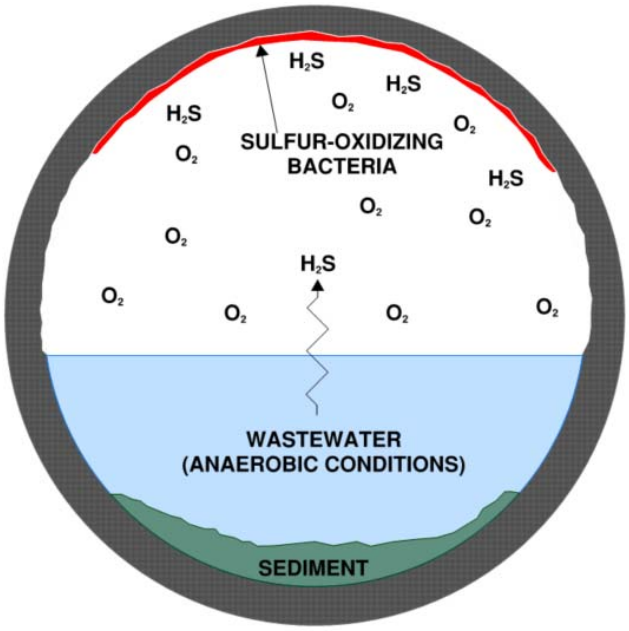
- Obtained 8 core samples for material testing
  - Compressive Strength (ASTM C42)
  - Petrographic Examination (ASTM C856)
  - Chemical Testing for Sulfate Content and pH (ASTM C114)
- Why these tests?
  - Crown deterioration documented previously (acid attack)
  - Always test compressive strength
  - What is depth of carbonation (pH test)?

Structural Evaluation

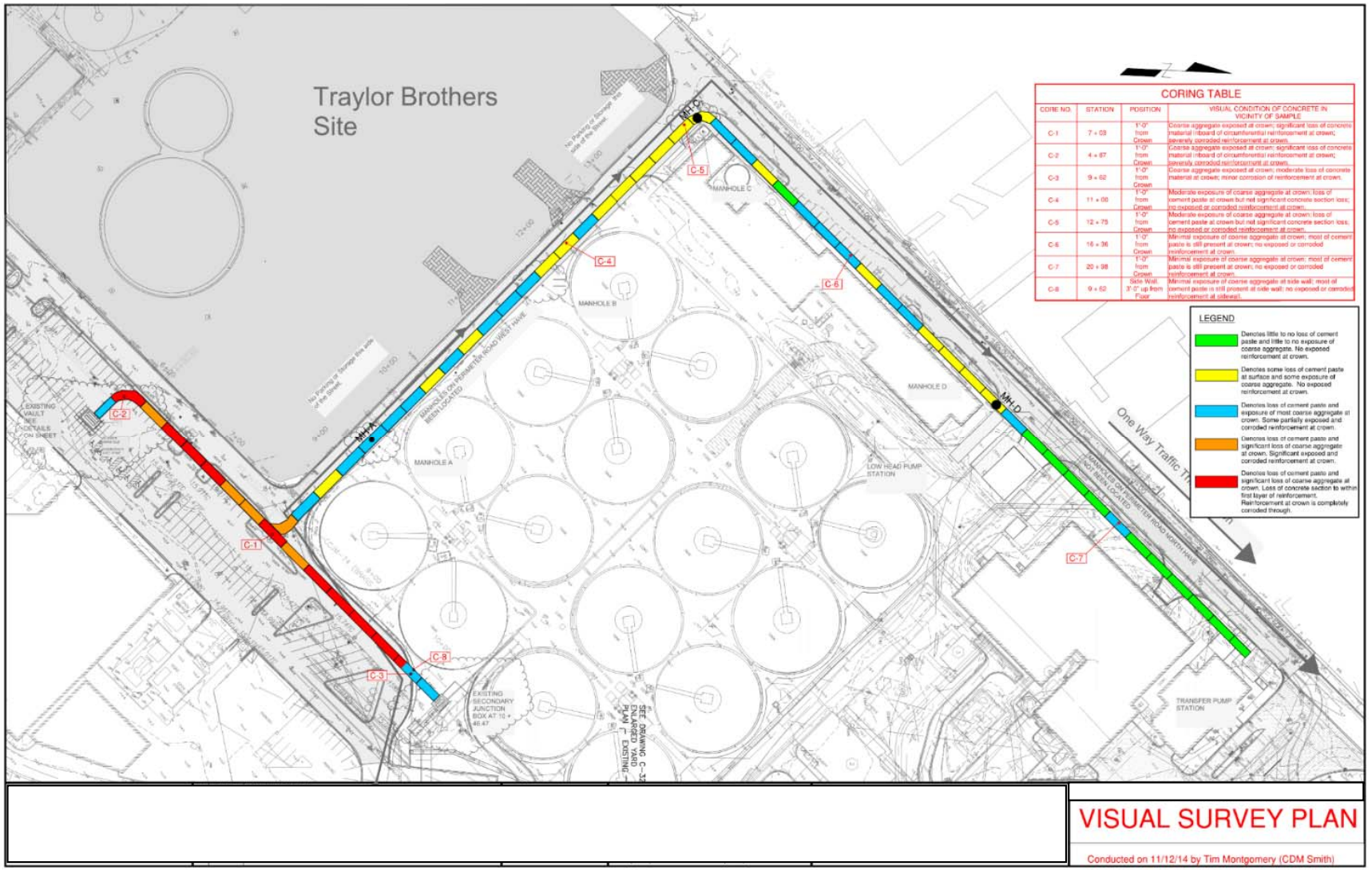
- Sidewalls
  - Minor spalling or hollow sounds
  - Some erosion of concrete cover (bottom)
- Floors
  - Some erosion of concrete cover
- Crown
  - Condition highly variable
  - Developed Visual Survey Plan to characterize relative condition
  - Each 30 ft segment assigned one of five visual survey categories

Structural Evaluation

- Acid Attack
  - Typical in water-treatment structures
  - Anaerobic bacteria produce hydrogen sulfide gas (H_2S)
  - H_2S oxides in presence of moisture to form sulfuric acid
  - Sulfuric acid degrades concrete (paste)
- Sulfate Attack
  - Sulfate salts produced by reaction, further degrade concrete



CONCRETE SEWER PIPE



VISUAL SURVEY PLAN

Conducted on 11/12/14 by Tim Montgomery (CDM Smith)

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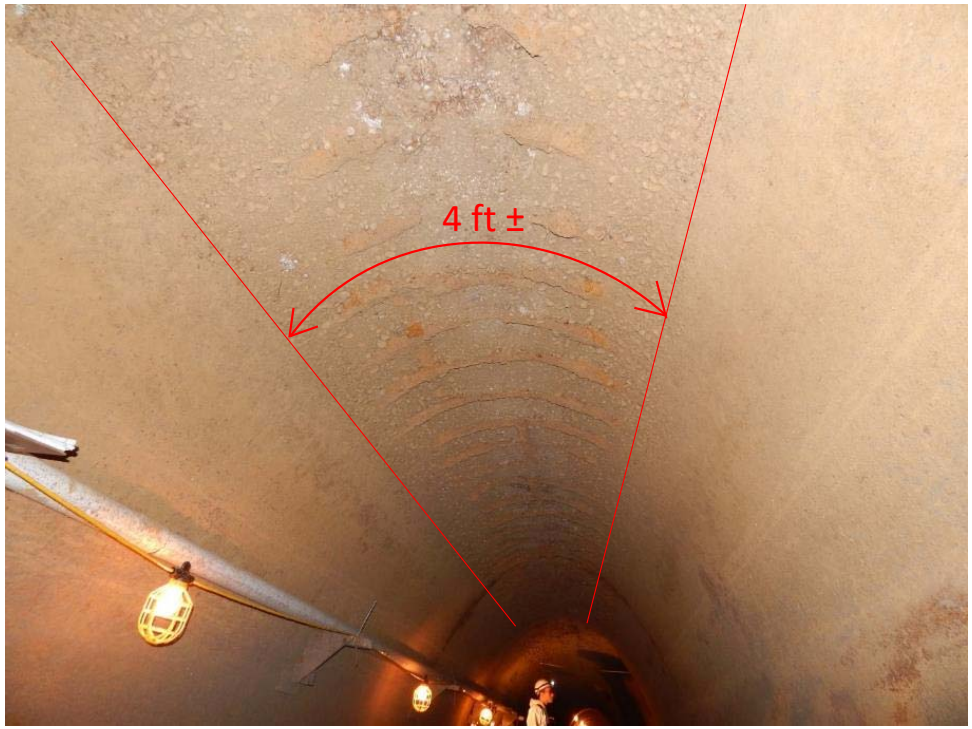
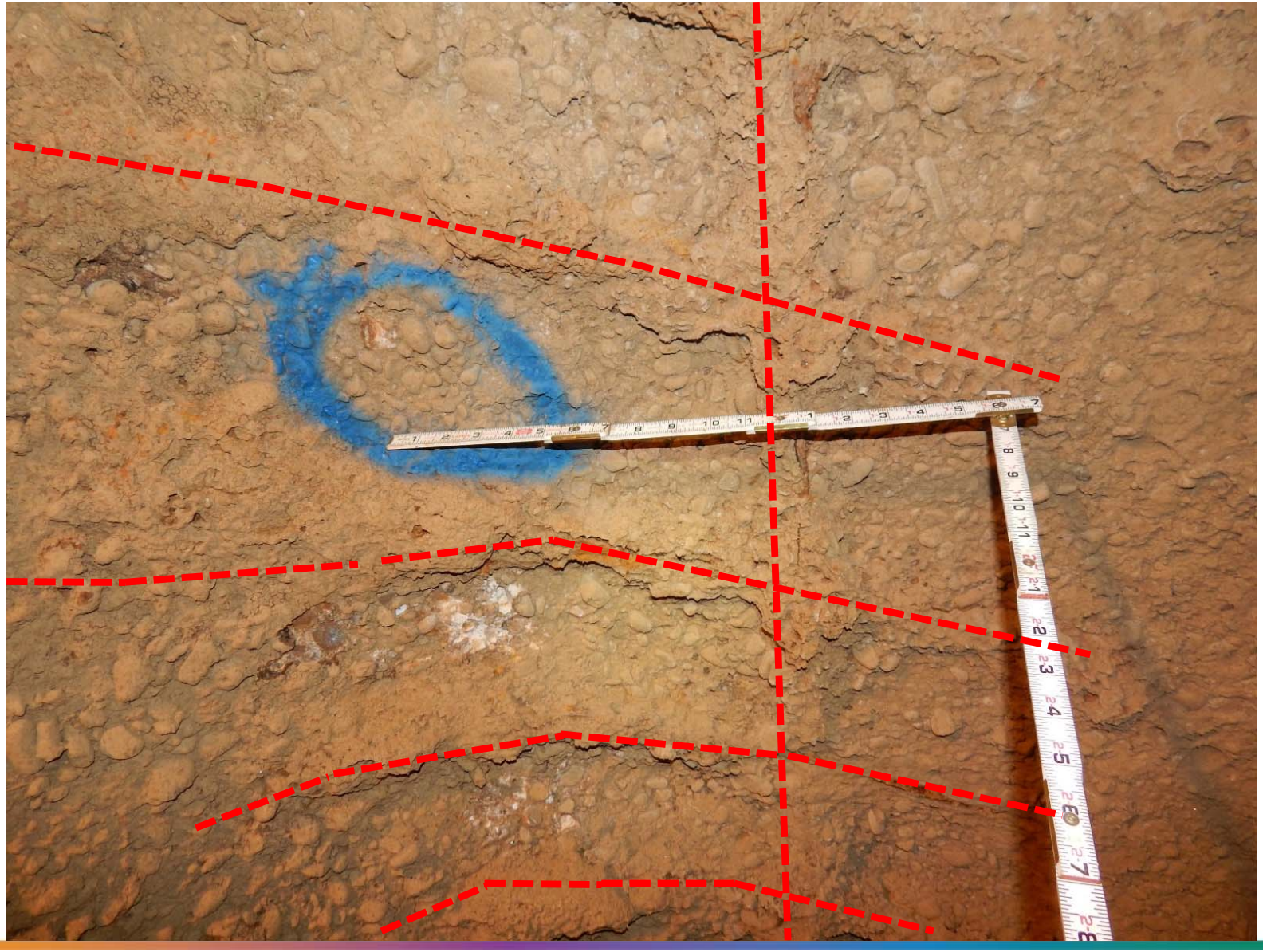
Structural Evaluation



RED Segment

- Loss of 3” – 4” of crown concrete
- Complete section loss for most rebar
- Sweep of visible deterioration ~4 ft ±



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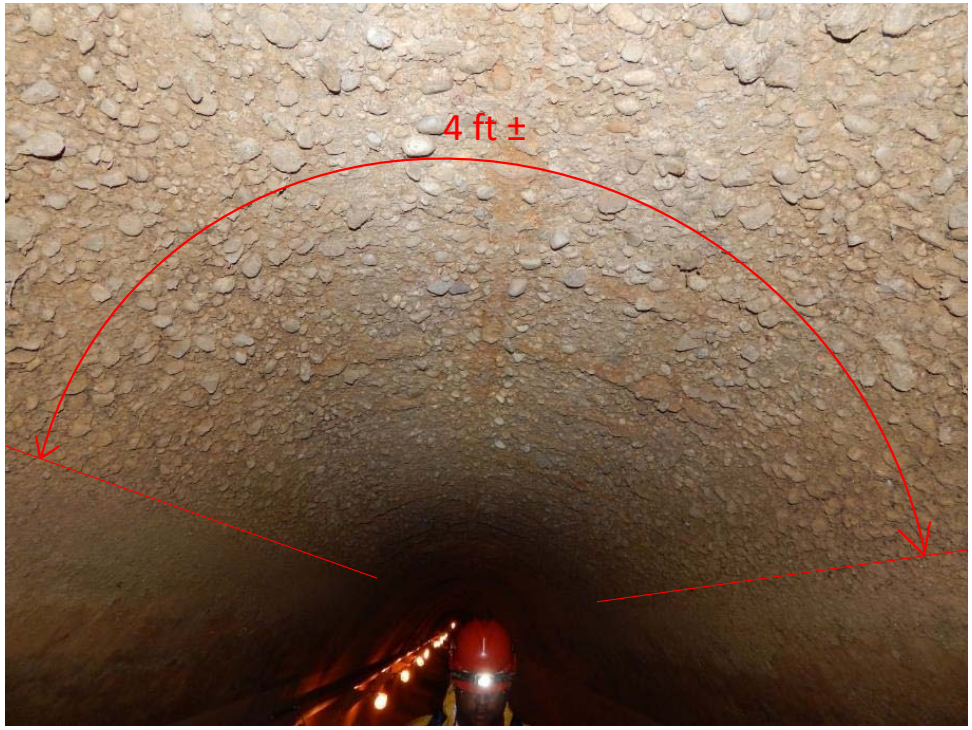
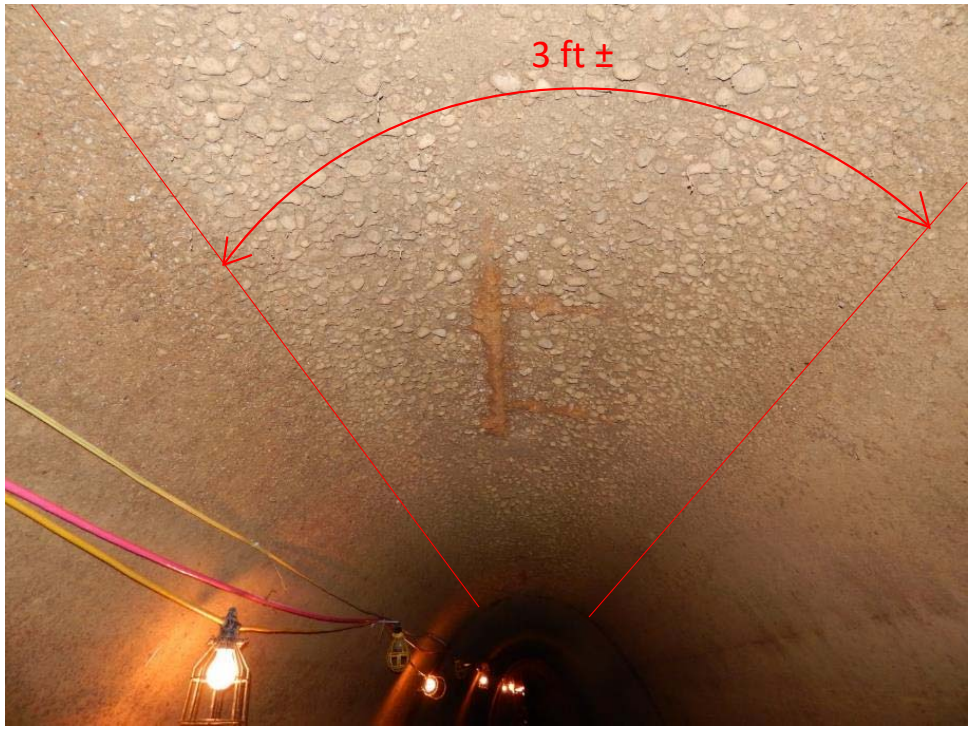
Structural Evaluation



ORANGE Segment

- Loss of 2” – 3” of crown concrete
- Crown rebar is exposed and corroded
- Crown rebar has some (not full) section loss
- Sweep of visible deterioration ~4 ft ±

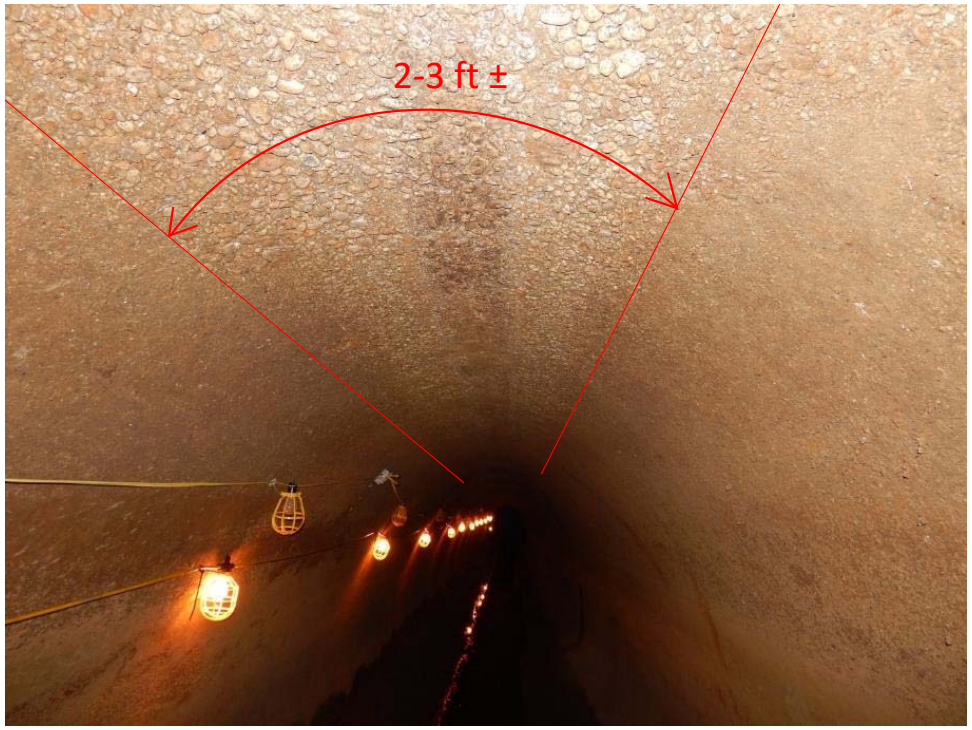
Structural Evaluation



BLUE Segment

- Loss of 1” – 2” of crown concrete
- Intermittent exposure of rebar at crown
- Sweep of visible deterioration narrower (~3 ft ±)

Structural Evaluation



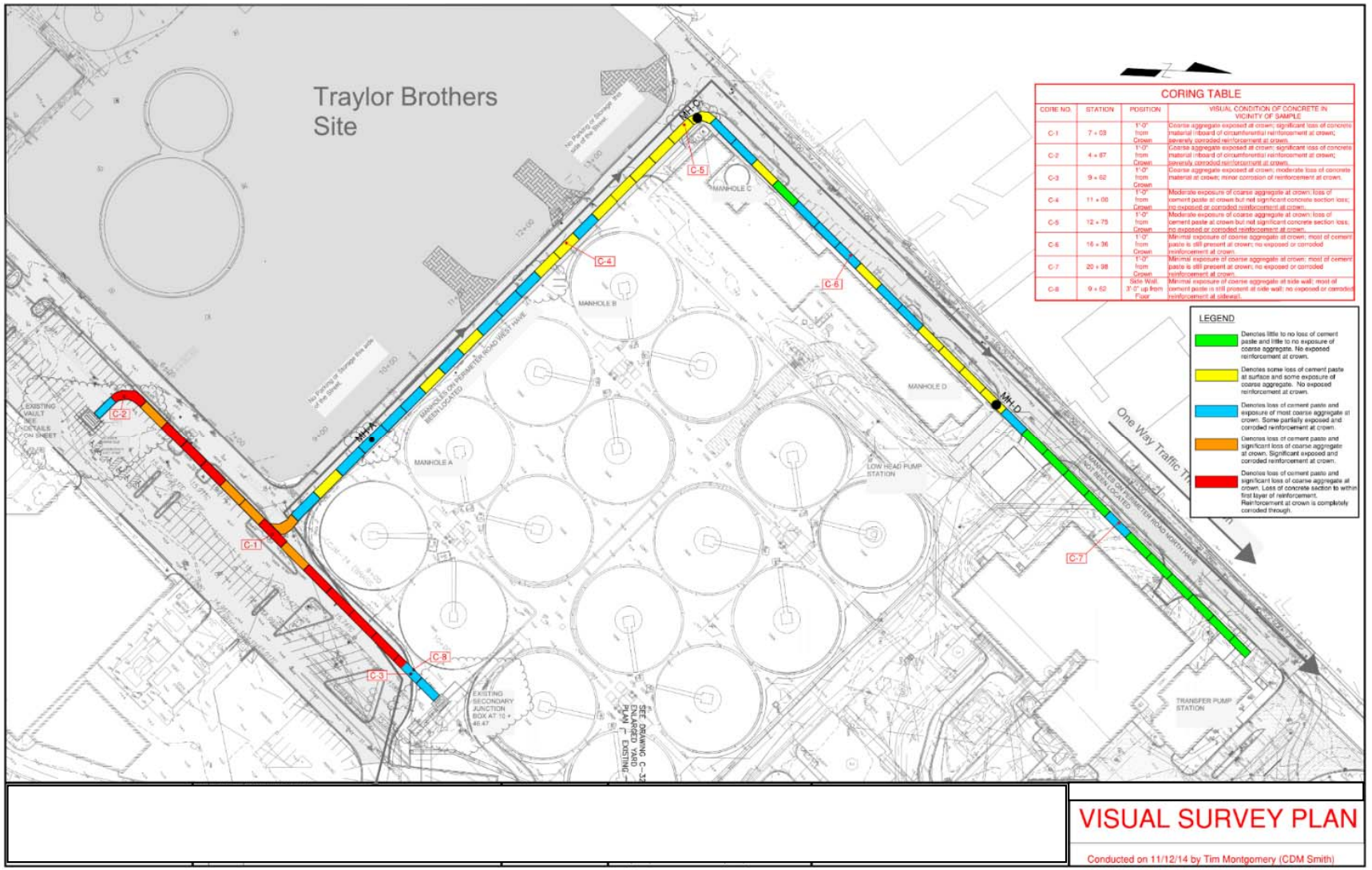
YELLOW Segment

- Loss of 1”± of crown concrete
- Coarse aggregate exposed at crown; no rebar exposed
- Sweep of visible deterioration ~2 to 3 ft

Structural Evaluation

GREEN Segment

- Little to no visible loss of crown concrete
- No rebar exposed



VISUAL SURVEY PLAN

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Structural Evaluation

Joints

- Many joints leaking
- Some staining at joints
- Concrete deterioration visible at several joints

Structural Evaluation

Penetrations

- Some typical penetrations
- Loose masonry
- Exposed rebar
- Evidence of sediment and water infiltration through annular space

Structural Evaluation

Invert Slabs

- Only edge visible
- Some erosion of surface paste
- No visible spalls or exposed rebar

Structural Evaluation

Test Results

- Compression Tests – 3 cores
- Petrographic Examination – 2 cores
- Chemical Testing – 4 cores
  - Sulfate Content
  - pH and Depth of Carbonation

Structural Evaluation

- Compression Tests (ASTM C42) – Cores C-4, C-5, C-7
  - Average strength **5,560 psi**

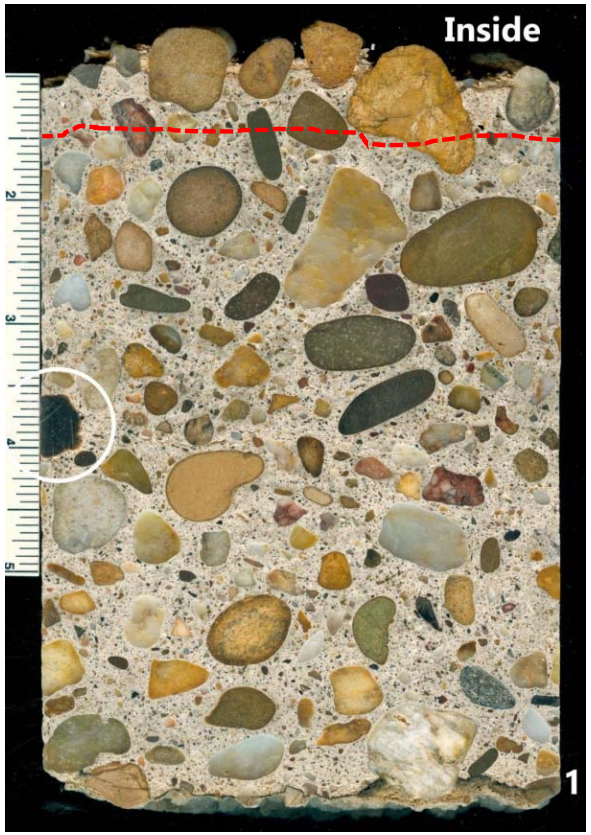
Core	Length (in.)	Width (in.)	Area ($in.^2$)	L/D	Compressive Strength		Type Fracture
					Total Load (lb.)	Corrected (psi)	
3	4.5	4.20	13.85	1.07	91130	5840	3
4	4.5	4.20	13.85	1.07	77465	4960	3
7	4.5	4.20	13.85	1.07	91635	5870	3

Structural Evaluation

- Petrography (ASTM C856)
  - Core C-1
    - Taken from significantly deteriorated crown area
    - C-1 mortar deterioration due to sulfuric acid attack; depth of deterioration 3/4 in. below surface
  - Core C-8
    - Taken from sidewall (good area), “control” sample

Structural Evaluation

- Core C-1 section



Structural Evaluation

- Chemical Testing
  - Sulfate content
  - Depth of carbonation

Table 3 – Sulfate (as SO_3) profiles for the cores. Depths are from the inside face of the cores.

Sulfate intrusion ~1”

Depth (in.)	Sulfate (as SO_3)			
	Core 2	Core 3	Core 5	Core 6
0 – 1/2	0.36	1.03	0.94	0.69
1/2–1	0.68	0.90	0.89	0.71
1–1 1/2	0.67	0.71	0.52	0.75

Table 4 – Summary of depths of carbonation and pH.

Core	Depth of Carbonation (in.)(1)	pH(2)
2	1/2	12.5
3	3/8	12.5
5	1/2	12.5
6	1/2	12.5

(1) Inside surface. Measured from top of the most protruding aggregate particle.

(2) Tested in non-deteriorated areas.

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Structural Evaluation

- Additional Chemical Testing (powder samples)
  - Sulfate content
  - pH
- Test positions

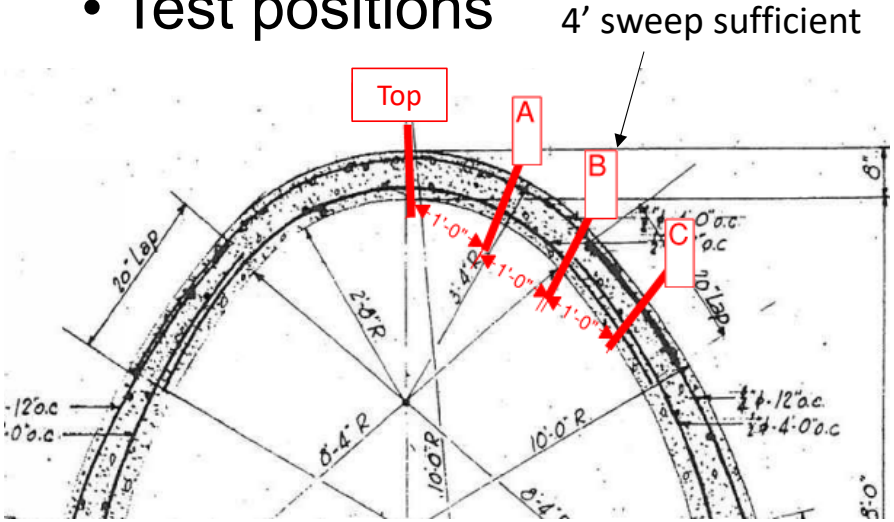

Table – pH, and sulfate contents (ASTM C114) for the powder samples. Drilled samples reported to be from concrete depths of 3/8 to 3/4-inch. (DC Water Facility, Concrete Elliptical Tunnel).

Core	pH	Sulfate (as SO_3), %
10+50 Top	13.0	2.28
C	13.0	0.68
12+00 Top	13.0	2.51
B	13.0	0.69
14+00 Top	13.0	0.83
B	13.0	0.59
16+00 Top	13.0	0.67
B	13.0	0.61
18+00 Top	13.0	0.57
C	13.0	0.63
20+00 Top	13.0	0.55
B	13.0	0.53

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Structural Evaluation

- Presented preliminary assessment findings to Owner in April 2015; submitted report in May
- Provided conceptual level repair alternatives
- Design-Build Team obtained preliminary pricing on repair alternatives; cost estimated to be about half of original estimate
- Owner provided authorization to pursue repair alternatives
- Detailed assessment completed in October 2015
- Repair drawings released for construction March 2016

Structural Evaluation

Detailed Assessment

- Similar to the preliminary assessment, but refined approach and confirmed our initial findings
  - Detailed hammer sounding of each 30 ft segment
  - Estimated repair quantities
  - Catalogued each penetration through Conduit
  - Further sulfate testing at crown and shoulder
  - Measured concrete cover at sidewalls (GPR & drill holes)

Conduit Repairs

- How to develop repairs recognizing that not all areas of conduit are deteriorated equally (depth and breadth)?
- Developed three repair approaches
  1. Hydrodemolition/Shotcrete Repairs – moderate deterioration
  2. Cast-in-Place (CIP) Liner – severe deterioration
  3. Remove conduit, direct-bury 96” dia. steel pipe – severe deterioration
- Perform localized repairs at joints, penetrations
- Abandon some areas of conduit; provide bulkheads and back-fill abandoned space

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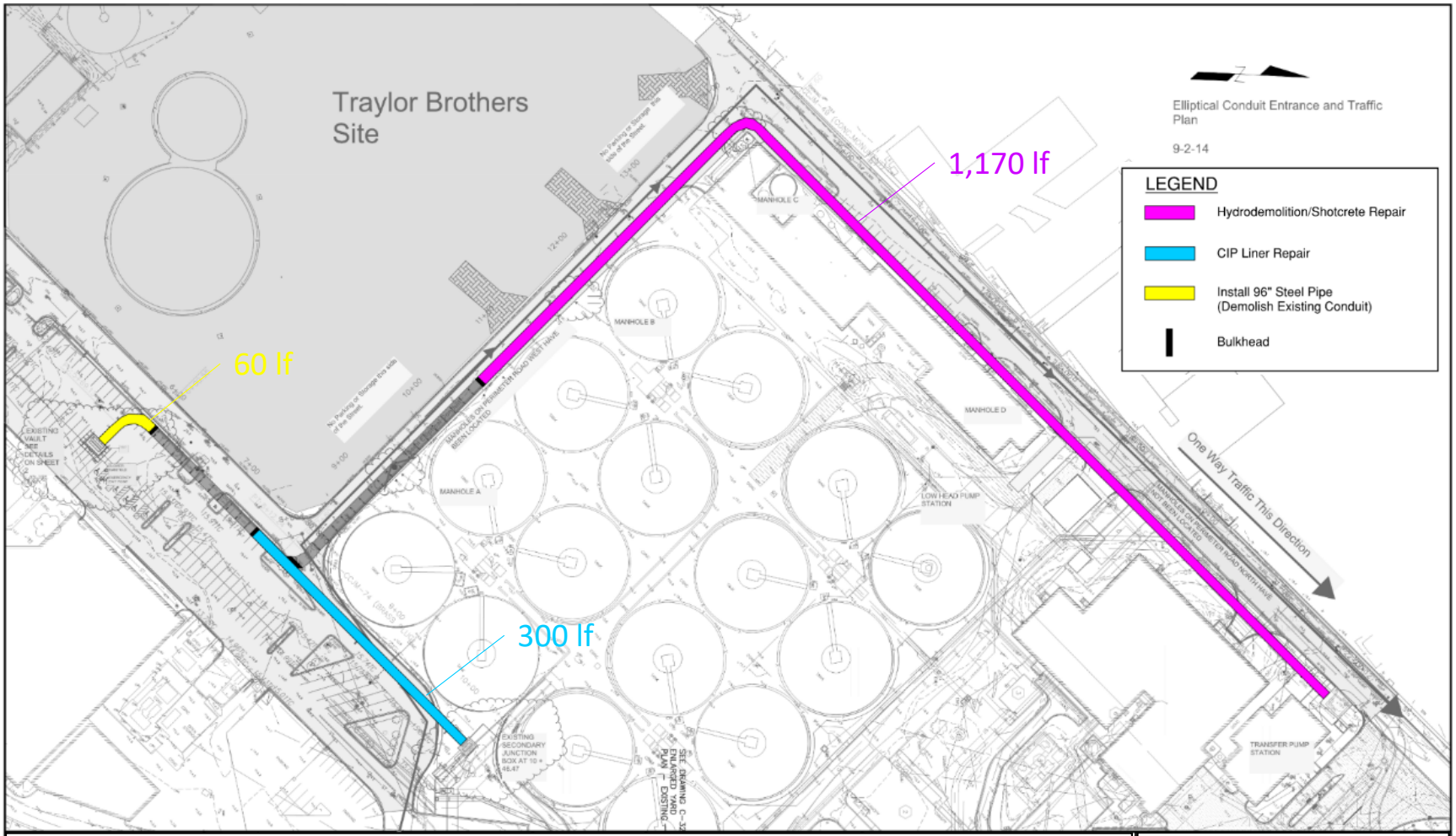
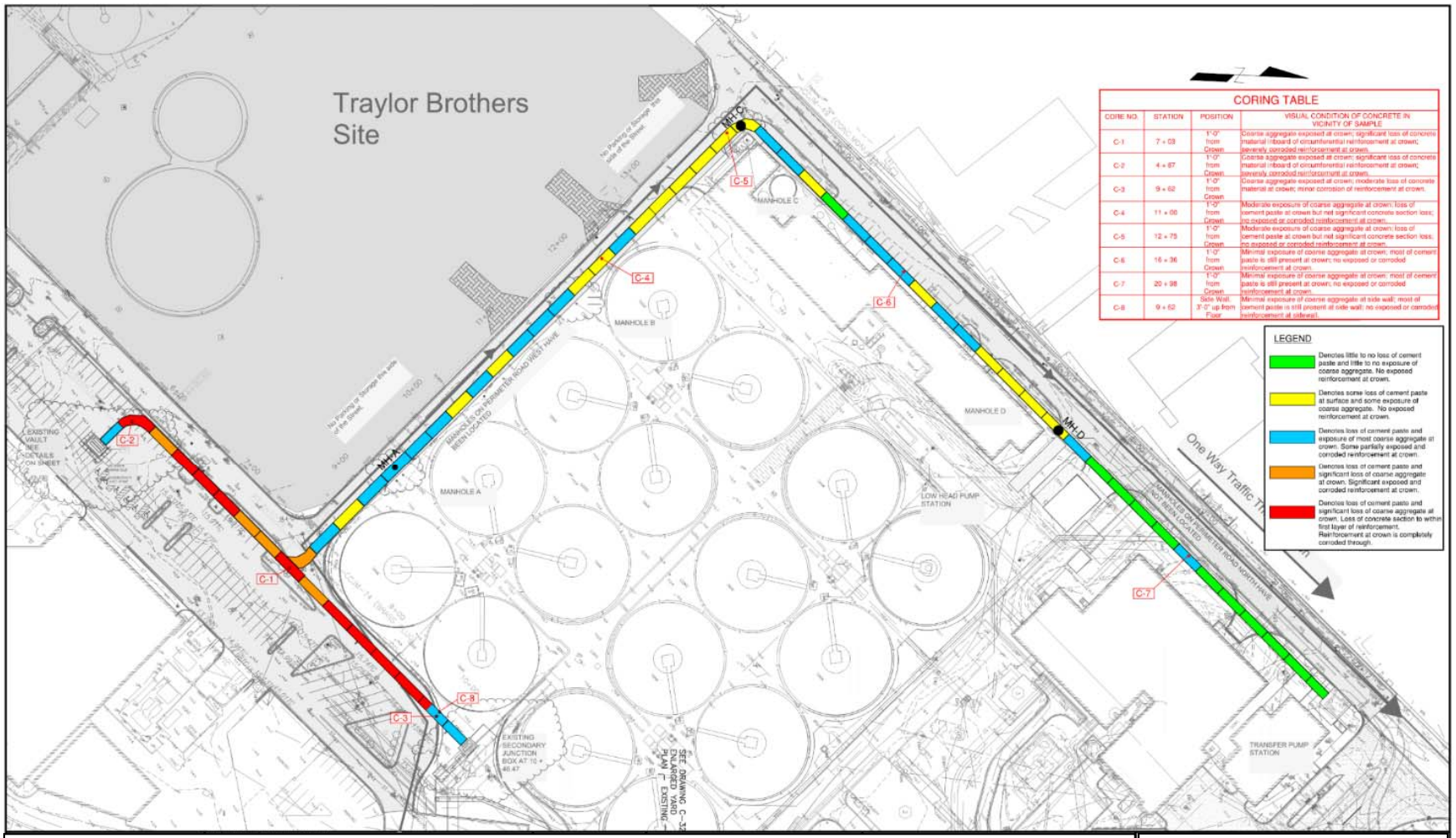


CONCRETE REPAIR PLAN

ICRI CONCRETE REPAIR



VISUAL SURVEY PLAN

Conducted on 11/12/14 by Tim Montgomery (CDM Smith)

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Conduit Repairs

- Robotic Hydrodemolition
  - Ultra-high pressure: 20,000 psi +
  - Controlled overhead removal depth and sweep
  - Cleans reinforcement
  - Prepares surface; minimizes microcracking
  - Electric-powered motor to run hydraulics
  - Cutting head made of aluminum (reduce weight)
  - 3’x2’ cutting head coverage area

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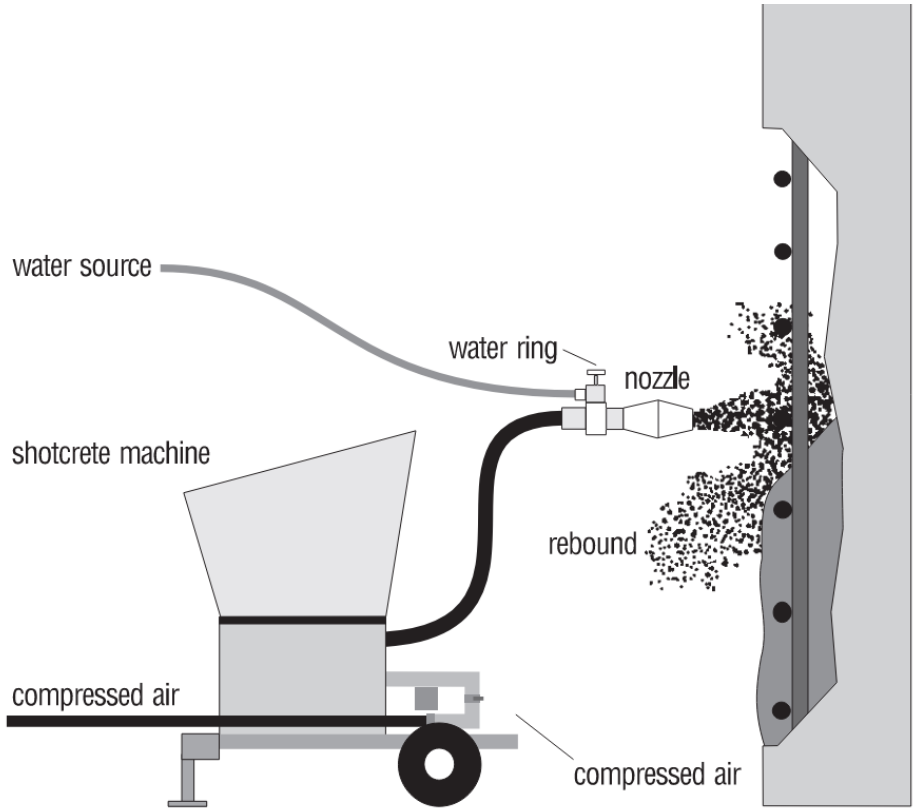
Conduit Repairs

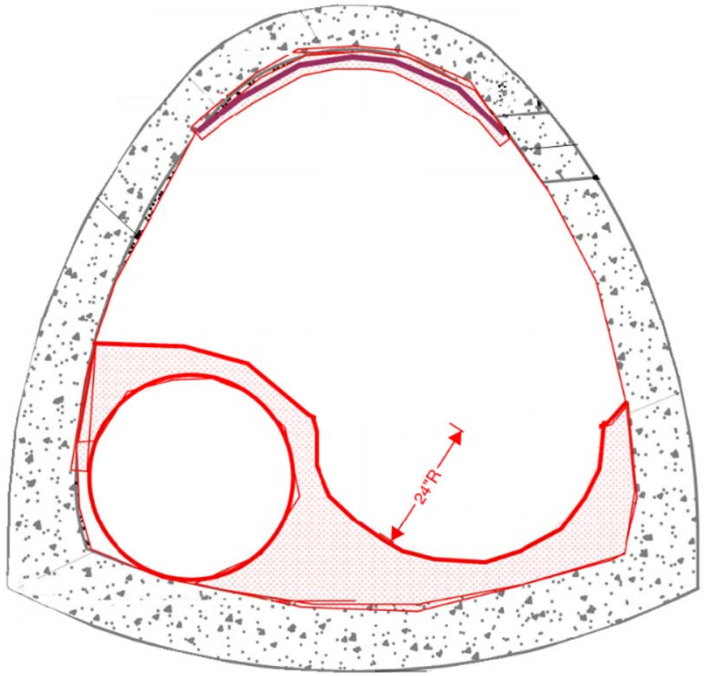
- Fiber-Reinforced Shotcrete (Dry Mix)
  - Enhanced with silica fume
  - Low w/c ratio (0.40)
  - Want to minimize shrinkage cracking
  - Micro-synthetic polypropylene fiber mesh



Source: ICRI Guideline No. 03731 – Guide for Selecting Application Methods for the Repair of Concrete Surfaces

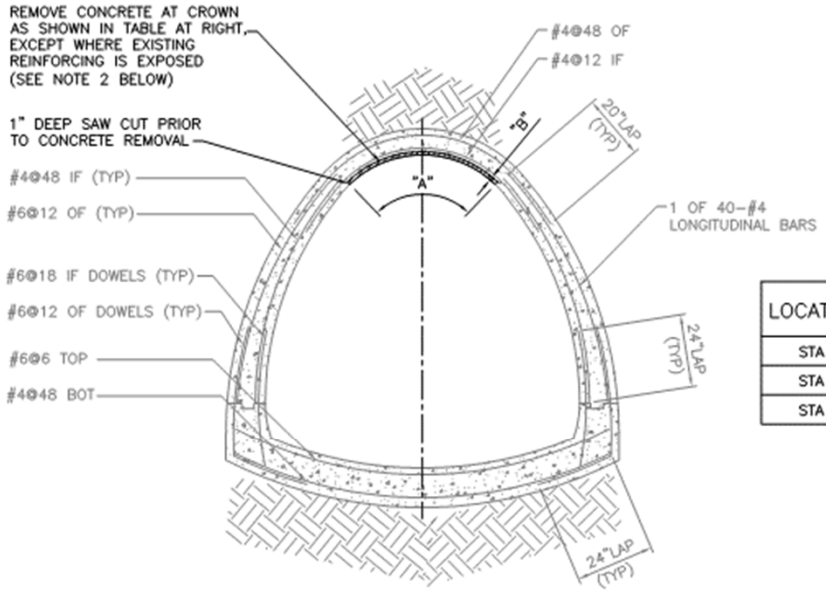
Conduit Repairs

- Shotcrete repair to crown
  - Saw-cut edges of repair
  - Provide 2” min. cover
  - Provide supplemental rebar (if needed)
- Re-contour invert with CIP concrete
- 36” dia. pipe encased in concrete



Conduit Repairs

- Crown Removal Details



LOCATION IN CONDUIT	"A" DIMENSION	"B" DIMENSION
STA 10+80 TO 17+59	5'-0"	1"
STA 17+59 TO 18+55	3'-0"	1"
STA 18+55 TO 22+10	3'-0"	1/2"

NOTES:

1. AFTER CROWN REMOVAL, CROWN SHALL BE REPAIRED PER SECTION S-241B. IF EXISTING REINFORCEMENT IS EXPOSED PER NOTE 2 BELOW, CROWN SHALL BE REPAIRED PER SECTION S-241C.
2. WHERE MORE THAN HALF A BAR DIAMETER OF EXISTING REINFORCING BARS IS EXPOSED DURING INITIAL HYDRODEMOLITION REMOVAL, REMOVE ADDITIONAL CONCRETE TO 3/4" BEHIND LAYER OF REINFORCING NEAREST TO THE SURFACE OF THE CONCRETE (SEE SECTION S-241C)

SECTION S-241A
CROWN DEMOLITION C-54, C-55

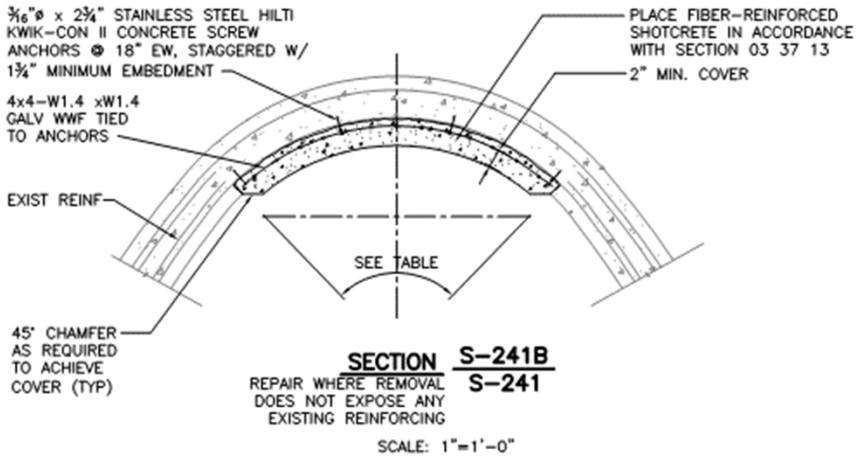
SCALE: 1/2"=1'-0"

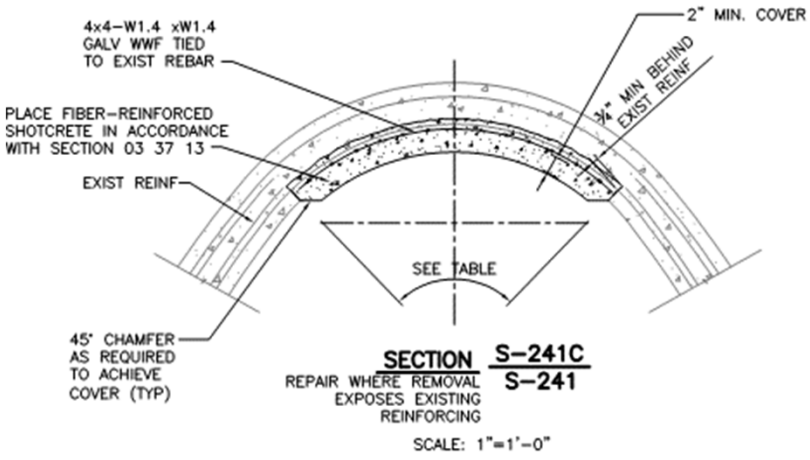
Conduit Repairs

- Hydrodemolition and saw cut edge

Conduit Repairs

- Crown Repair Details





Conduit Repairs

- Hydrodemolition

Conduit Repairs

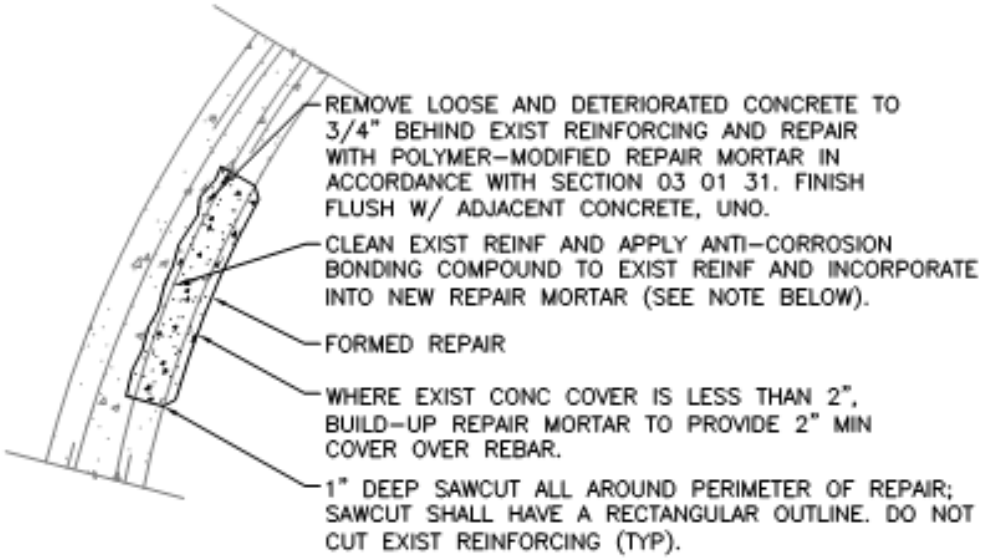
- Finished Shotcrete Crown Repairs

Conduit Repairs

- Conventional concrete repairs
  - At Joints
  - Around penetrations (interceptors)
- Polyurethane chemical gro injection at actively leaking joints/cracks

Conduit Repairs

- Partial-Depth Concrete Repairs



NOTE: BARS TO REMAIN IN PLACE WHICH ARE FOUND TO HAVE LOST MORE THAN 15% CROSS SECTIONAL AREA DUE TO CORROSION OR WHICH ARE DAMAGED BY THE CONCRETE REMOVAL PROCESS SHALL BE REPLACED WITH NEW BARS OF THE SAME SIZE. NEW BARS SHALL BE SPLICED WITH INTACT BARS AND MAY REQUIRE REMOVAL OF ADDITIONAL CONCRETE TO ACHIEVE SPLICE.

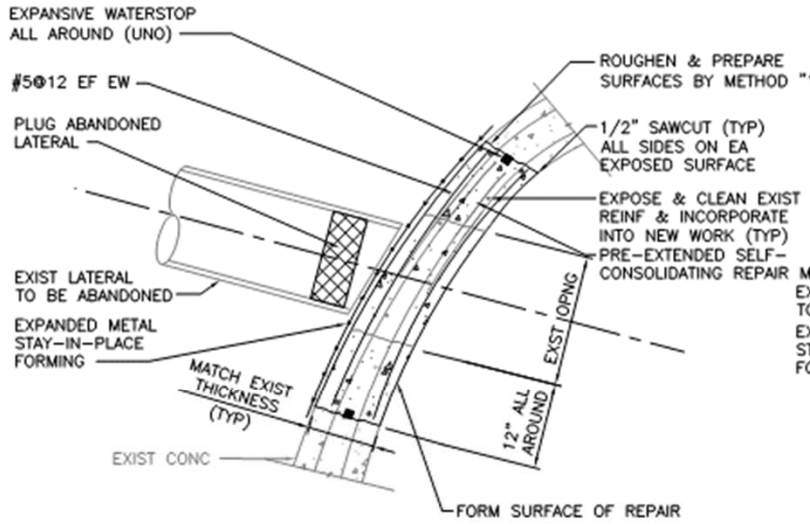
SECTION S-241E / C-55

REPAIR OF SPALLED/ DETERIORATED CONCRETE

SCALE: 1"=1'-0"

Conduit Repairs

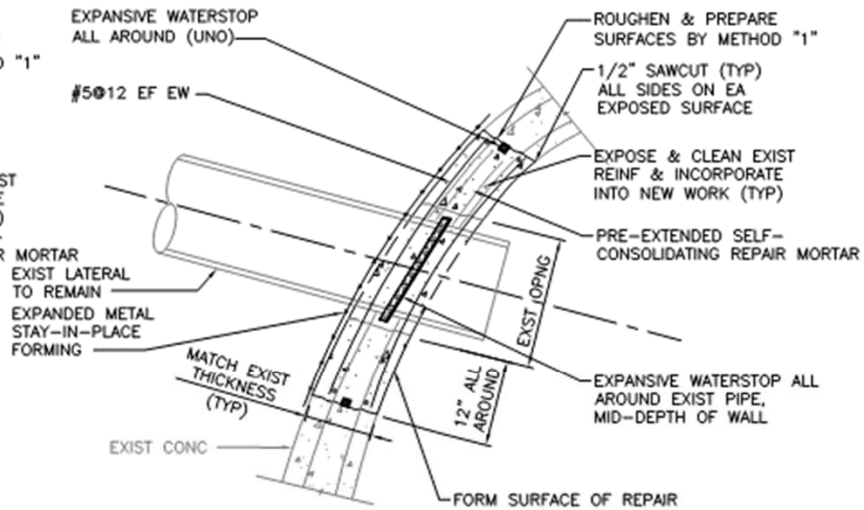
- Repairs at Penetrations: two conditions



NOTE: SEE CIVIL DRAWINGS FOR IDENTIFICATION OF LATERALS TO BE ABANDONED.

DETAIL 1S-240 / S-240

SCALE: 1"=1'-0"



NOTE: SEE CIVIL DRAWINGS FOR IDENTIFICATION OF LATERALS TO REMAIN.

DETAIL 2S-240 / S-240

SCALE: 1"=1'-0"

Summary

- With minimal up-front testing and assessment costs, the Semi-Elliptical Conduit could be repaired (instead of abandoned) at lower cost.
- When deterioration is present over large areas, material testing can be effectively used to develop precise repair methods and quantities.
- Preliminary evaluations can be beneficial to limit risk and develop repair/rehabilitation costs early in the project.
- Design-Build projects can provide unique opportunities to find cost savings, even mid-project

ICRI CONCRETE REPAIR

Questions?

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