Concrete Manhole & Wastewater Facility Structure Rehabilitation: Keys to a Successful Project

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Dewberry®

Corrosion and infiltration are BIG problems that significantly affect manholes and wastewater structures

- A primary cause of failure in wastewater systems, which are mostly made of concrete
- Causes billions of dollars of damage and increased operating costs annually
- Out-of-site, out-of-mind asset management approach not helping!

ASCE assigned a grade of “D+” to our nation’s wastewater infrastructure in 2021.

Wastewater Systems Are In Trouble!

The EPA estimates that there are more than 20 million manholes throughout the US!

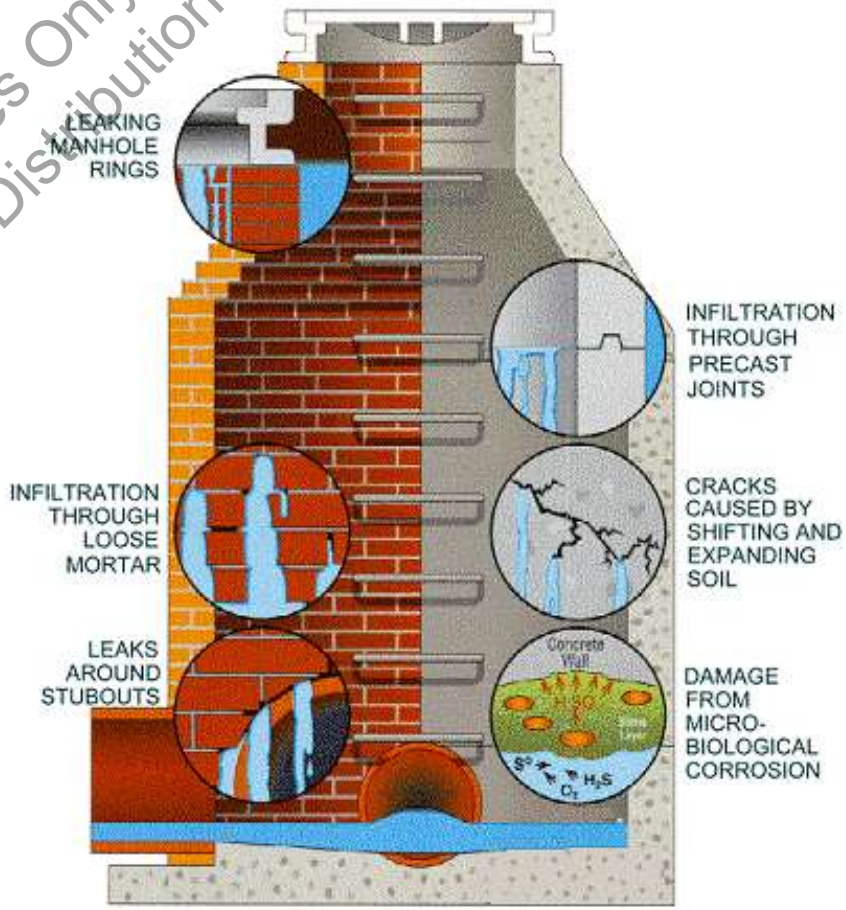
- Approx. 9 million manholes in US are over 30 years old
- Estimated 3.5 million of these manholes are likely in very poor condition and in need of immediate attention.
- Treatment plant structures are facing problems similar to what is happening in collection systems
- Concrete manholes and wastewater structures are under attack!

Common causes of degradation can include:

Infiltration
- Leaking through precast joints
- Leaking around stub outs
- Leaking around cracks
- Leaking manhole rings

Fatigue
- Traffic Loading
- Shifting and expanding soil
- Hydrostatic pressures
- Temperature changes (freeze-thaw)

Microbial-Induced Corrosion (MIC)
- Hydrogen sulfide
- Warm/humid environments
- Long retention times, Force mains



The big culprit: Microbial-Induced Corrosion (MIC)

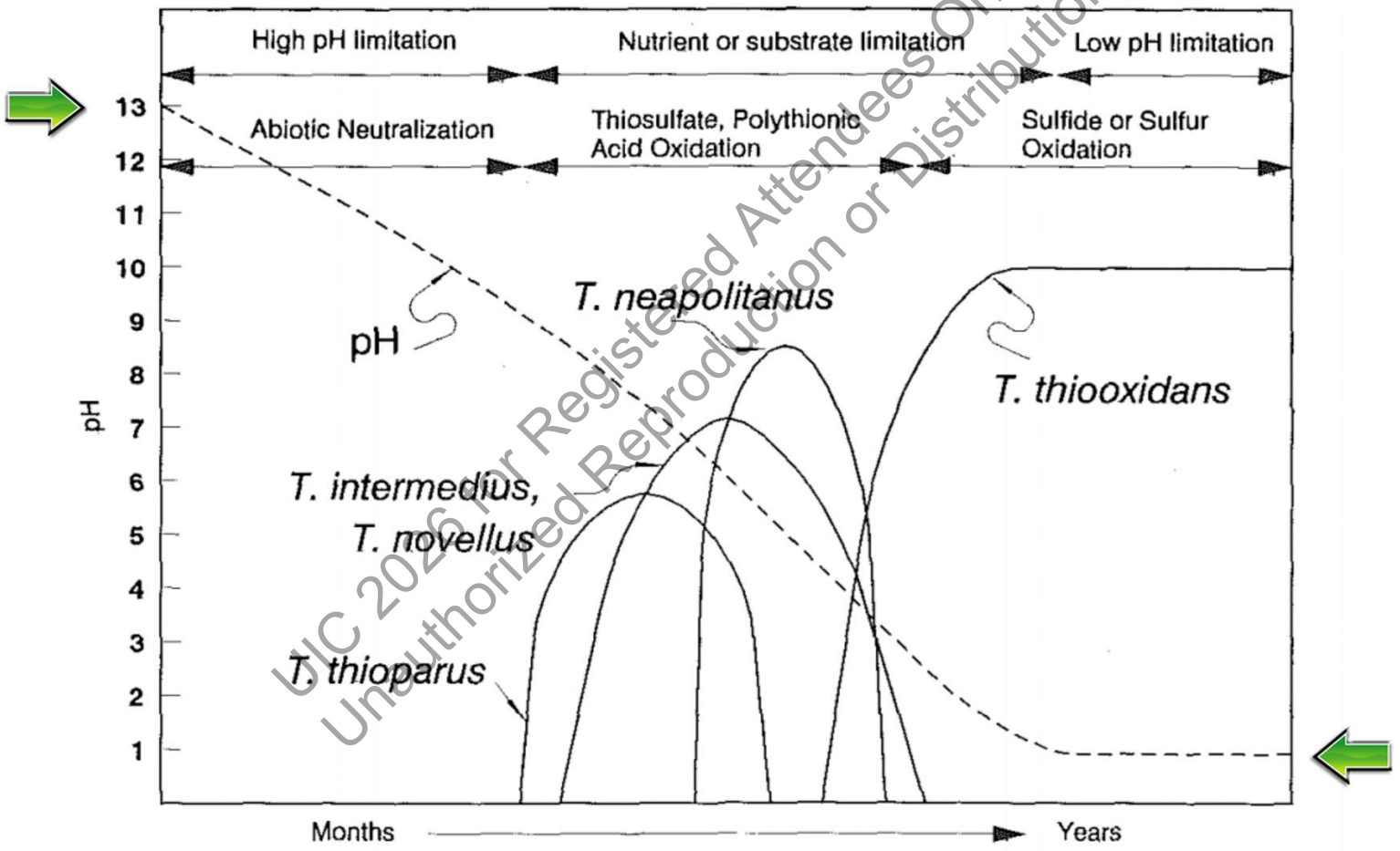
Deterioration of wastewater structures from microbial induced corrosion

- Headspace (vapor phase) environments above flow of the waste stream
- Characterized by elevated hydrogen sulfide (H_2S) levels
- Biological oxidation of H_2S to H_2SO_4 within headspace areas of enclosed wastewater structures

$$H_2S + O_2 \xrightarrow{\textit{Thiobacillus}\ \text{SOB}} H_2SO_4$$

- H_2SO_4 attacks the matrix of the concrete above the waterline *(i.e. pipe crowns, manhole barrels, clarifers, etc)*

MIC Corrosion Bacterial Progression on Concrete



Courtesy of Islander et al. 1991, Environ. Eng. 117

Microbial-Induced Corrosion (MIC)
Corrosion in concrete sewer manholes & structures

Microbial-Induced Corrosion (MIC)
Corrosion in lift stations & treatment facilities

What can corrode in wastewater systems?

Does Corrode:

- Unlined concrete manholes, pipes, facility structures
- Steel & metallic pipe, structures, components
- Mortar in brick manholes & pipes

Does Not Corrode:

- PVC, HDPE & plastic materials
- Fiberglass/ FRP, composite materials
- Clay pipe & bricks
- High performance coating/ lining materials
- Polymer concrete

Typical wastewater corrosion hotspots

Elevated H2S levels & MIC are common in:

- Force main outfall locations
- Locations with turbulent flows
- Areas with poor air handling
- Drop manholes
- Junction structures
- Wet wells
- Clarifiers
- Siphons
- Headworks areas
- Larger systems
- Areas with higher temperatures

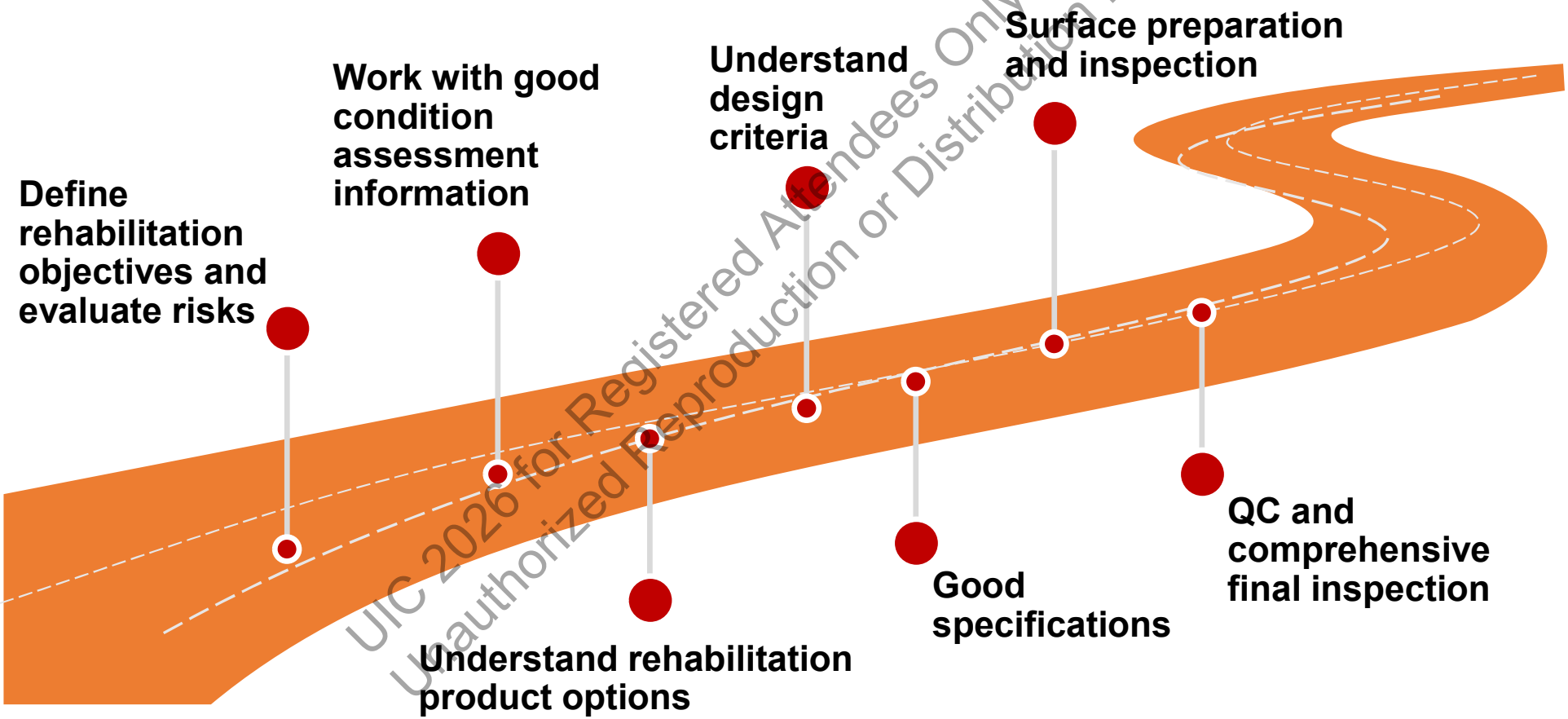
So what can we do? Rehabilitation vs. Replacement

- Trenchless concrete rehabilitation is cost effective
  - ✓ ***Typically much lower than replacement cost***
- Less disruptive and faster than replacement
- Most manholes are good candidates for rehabilitation

vs.

Rehabilitation of concrete manholes and wastewater structures sounds great, but how do I ensure that it will be successful for my project?

Keys to a Successful Concrete Rehabilitation Project



Define your rehabilitation objectives

- What kind of problems are your wastewater structures facing?
  - Corrosion?
  - Inflow and infiltration, exfiltration?
  - Structural issues?
  - Industrial waste issues?
  - Poor construction?
- Evaluate risk and consequence of failure
- Understanding the problems will help guide rehabilitation approach
- Define rehabilitation objectives to address identified problems

Work with good inspection information

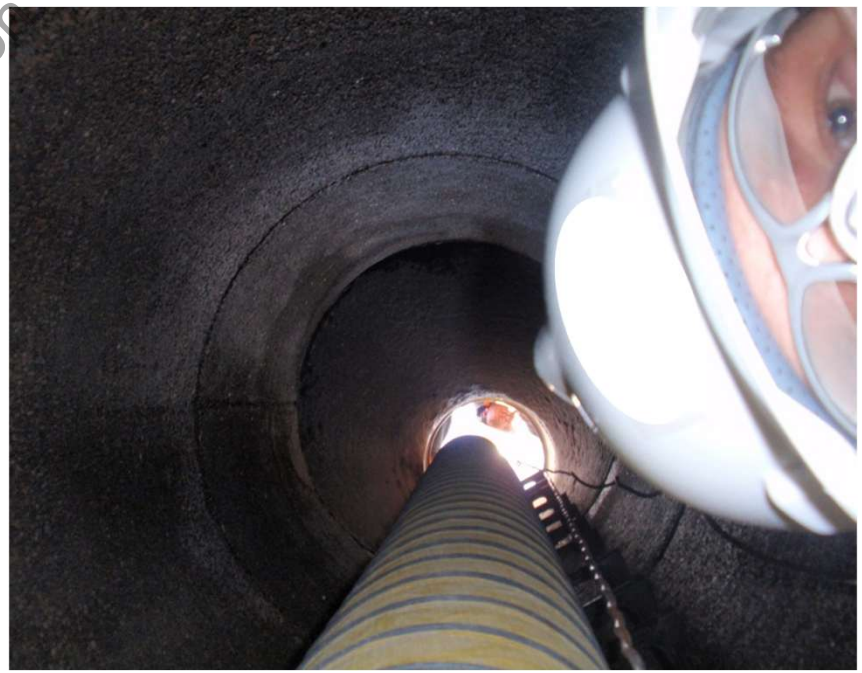
- Detailed inspections identify & quantify condition of concrete
- Entry inspections by qualified inspectors are most accurate
- Systematic & detailed documentation, including photos, top to bottom within manhole or structure
- NASSCO MACP, AMPP (NACE) certified inspectors are recommended

Safety is key during any inspection process!

Work with good inspection information

Inspection and condition assessment info is only as good as the expertise of the people doing the actual inspection work and subsequent data assessment

Proper training, experience & safety is essential!



With so many different rehabilitation products available, what ones will meet my objectives?

- Understand what problems can be remedied by the various types of rehabilitation products available
- Research product information and references
- Review and consider independent testing data
  - *(CIGMAT, TTC, LA County Redner Study, Greenbook, etc)*
- Compare concrete rehabilitation material properties, chemical resistance, bond strength, and hydrostatic pressure performance
- Discuss & share information with other municipalities

Consult ***experienced*** engineers and ***good*** contractors

Concrete Rehabilitation Product Types

- Resin-based polymer coating/lining systems
  - ✓*Epoxies, poly-ureas, polyurethanes*
- Cementitious coatings/linings
  - ✓*Calcium aluminate mortars, microsilicas, geopolymers*
- Prefabricated Insert Systems
  - ✓*Fiberglass inserts, polymer concrete units*
- I&I Elimination products
  - ✓*Chemical grout, chimney seals*

Resin Based Coating/Lining Materials

100% solids epoxies

- Suitable for aggressive environments (pH<2)
- Select products with no VOC's
- Bis A chemistry most common (~50% sulfuric acid resistant)
- Bis F chemistry (novolacs) are more expensive but more chemically resistant and heat tolerant (~98% sulfuric acid resistant)
- Typical thickness is 125 mils (1/8") for wastewater applications
- Typically needs buildback and resurfacing prior to application
- Important to use compatible buildback and water stop products
- Typically more moisture tolerant compared to other polymeric coating/lining materials
- Curing time is several hours

Resin Based Coating/Lining Materials

Polyureas and Poly-urethanes

- Suitable for aggressive environments (pH<2)
- Polyureas are often more flexible, poly-urethanes more rigid
- Common specified thickness is 250 mils for wastewater applications
- Often needs less buildback and resurfacing compared to epoxies
- Significantly more moisture reactive compared to epoxies
- Curing time is several minutes
- Typically lower adhesion strength to substrate compared to epoxies
- Caution with isocyanate chemistries

What About Stand-Alone Cementitious Coating/Lining Materials?

Geopolymers, Calcium Aluminates, Cementitious Mortars

- Suitable for moderate environments (pH>2)
- Specified thickness must be ½" or more for wastewater applications
- Can be trowel applied or spray applied
- Less expensive than epoxies & polymeric high performance coating/linings
- More moisture tolerant than polymeric coating/linings
- Curing time is several hours
- Verify 100% CAM, XRF and XRD composition analysis for geopolymers

But not all products are created equal…

Concrete rehabilitation products each have their unique strengths & limitations

- Select the right product or system for your circumstances and design appropriately. **Compatibility is critical!**
- Material properties & performance can differ greatly
- Significant cost differences exist
- A good rehabilitation product applied by a bad contractor will likely result in a poor job
- Be cautious with approval of “or-equal” products

Well-written Specifications are Critical

Specifications must meet rehabilitation objectives and be developed for the unique needs of your project

- Specs need to be fair to both owner and contractor
- Clear & concise, performance-based specs preferred
    - If substrate build-back for an epoxy or polyurethane is needed, is this specified? Thickness needed?
    - Are surface preparation requirements well-defined?
    - Are bond strength requirements specified?
    - QA/QC and inspection requirements?
    - Flow management?

Good Specifications & Project Documents

- Beware of cut & paste specifications and specifications "borrowed" from other municipalities
- Understand the standards referenced (ASTM, AMPP, ICRI) and make sure the design methodology used is appropriate
- Measurement & payment section needs to be well-defined and consistent
- Applicable design criteria and QA/QC requirements

Good Specifications & Project Documents

Unit price contracts help define quantities & control costs

- Performance specs & unit-price contracts account for unknowns
  - ✓Chemical grout for infiltration control (per gallon basis)
  - ✓Substrate build-back material (per kit or per bag basis)
- Be specific with unit price measurement & payment items
- Estimated quantities will provide a basis for contractor bids
- Quantities tracked and rectified at end of project
- Provides a better basis for project budgeting

Owner gets what they pay for, contractor paid for what they install

Understanding Concrete Rehabilitation Design

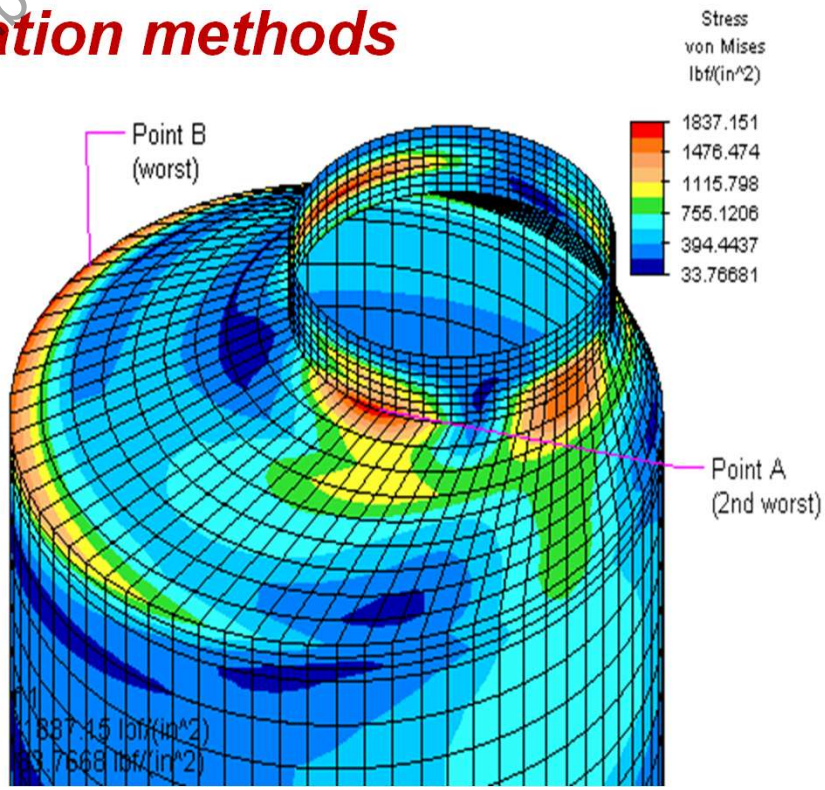
Significant differences exist between structural, semi-structural & non-structural rehabilitation methods

Coatings & linings:

- ✓ Semi-structural for high build applications
- ✓ Non-structural for thin DFT applications

Structural rehabilitation solutions:

- ✓ H-20 load rated composite inserts
- ✓ Polymer concrete systems
- ✓ New manholes or prefabricated structures
- ✓ Other systems proven by FEA



Choose H-20 or other load rated products that are truly fully structural for structural applications

Structural means it can stand completely on its own and resist loading both vertically and horizontally

Strength of “semi-structural” coatings & linings is dependent on individual product material properties and bond to substrate to create an interactive system

“Semi-structural” will need to rely on some degree of structural integrity of the host substrate-interactive

“Fully structural” design needs to be approached like any other structural engineering problem:

Make them prove it!

The Importance of Surface Preparation

- The **most important step** during the concrete rehabilitation process
- Most rehabilitation failures are attributed to improper surface preparation
- Especially critical for bonded coatings/linings and close-fit liners, less so for structural pre-fabricated insert systems

Surface Preparation Process Begins With Visual Inspection

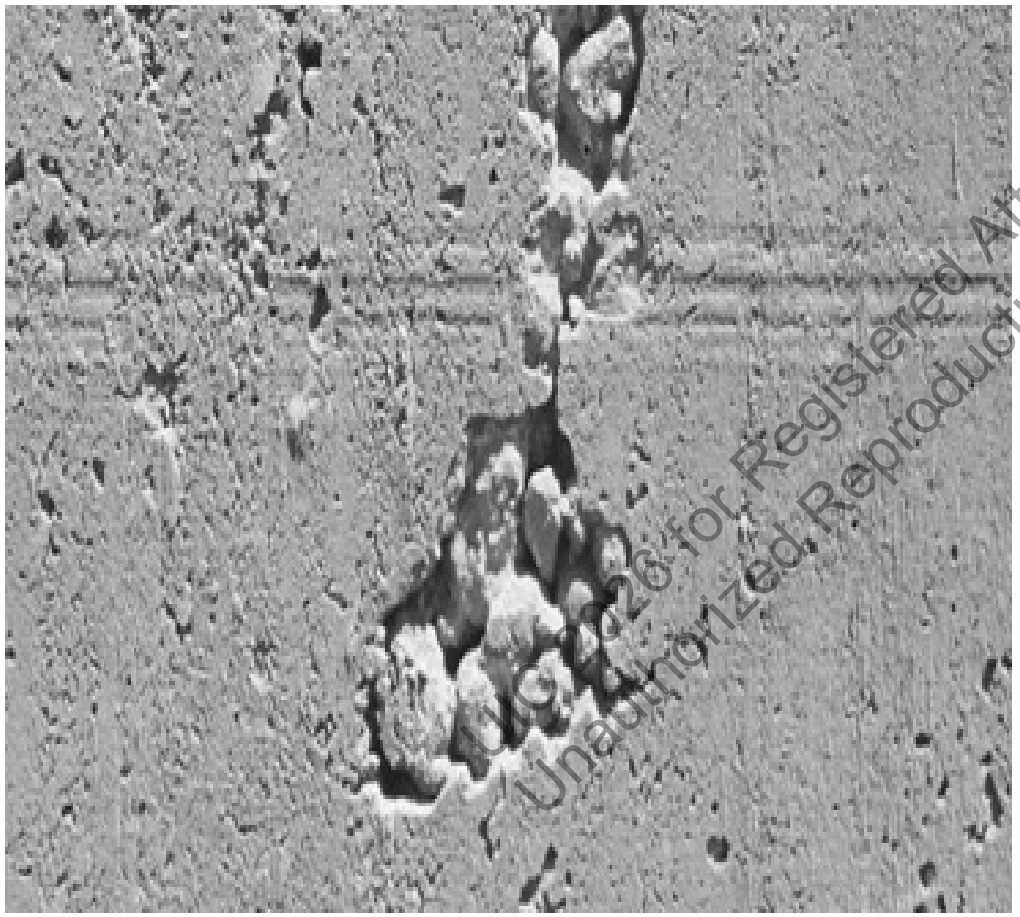
All concrete surfaces need to be visually inspected for defects, physical damage, corrosion, chemical contamination, and excess moisture

Inspection Procedures Prior to Surface Preparation:

The condition of the concrete will determine the appropriate cleaning, preparation & subsequent rehabilitation approach(es):

1. Verify Concrete Cure (hydration) – *for new concrete installations*
2. Visual Inspection
3. Identify Concrete Defects – Extent of Damage
   - Physical Damage or Defects
   - Severity of Corrosion
   - Chemical Damage and Contamination
4. Moisture Situation

Examples of defects



Addressing chemical damage and contaminants

Concrete can be attacked by a variety of chemicals, including acids, that may affect adhesion and performance of the specified coating system.

Contaminants include all materials that may affect adhesion and performance of coating applied.

Chemical damage and contamination may be detected or identified using visual inspection, pH test, or other analytical testing.

Chemically damaged surfaces shall be tested using test patch to see if contamination affects the adhesion & performance of coating.

pH measurement can be used to determine complete removal of contaminants

- If used, pH testing should be specified in the procurement documents
- Can be used during initial inspection to assess severity of environment
- Can be used to help ensure all contaminants are removed after preparation

Moisture on concrete should be inspected to determine if it is within limits of the intended coating/lining system

- Assessment of moisture on substrate
  - Adequate concrete hydration (evaporation of free water)
  - Infiltration issues
- Other forms of moisture, such as water infiltration of cracks from hydrostatic pressures, should be inspected and noted prior to proceeding to surface preparation
- Some rehabilitation systems are more sensitive than others
- Excessive moisture to be addressed using compatible water stop material and/or grout

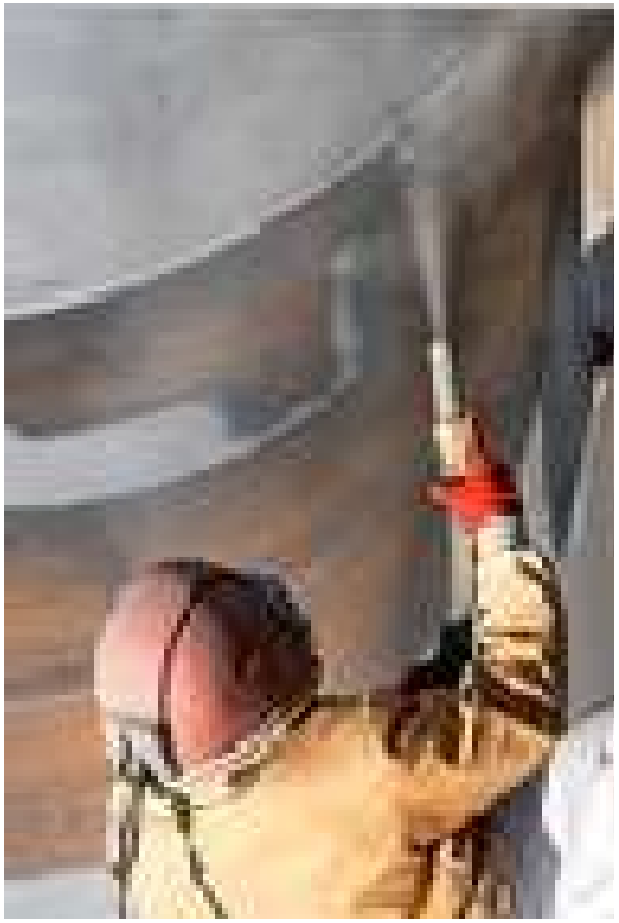
Surface Preparation – Consistency is Critical

- High pressure water blasting, abrasive blasting, and acid etch are commonly used
- Removal of soft, corroded concrete, contamination, debris down to clean and sound substrate
- Surface roughness requirements well defined

✓ ICRI No. 310.2R-2013,

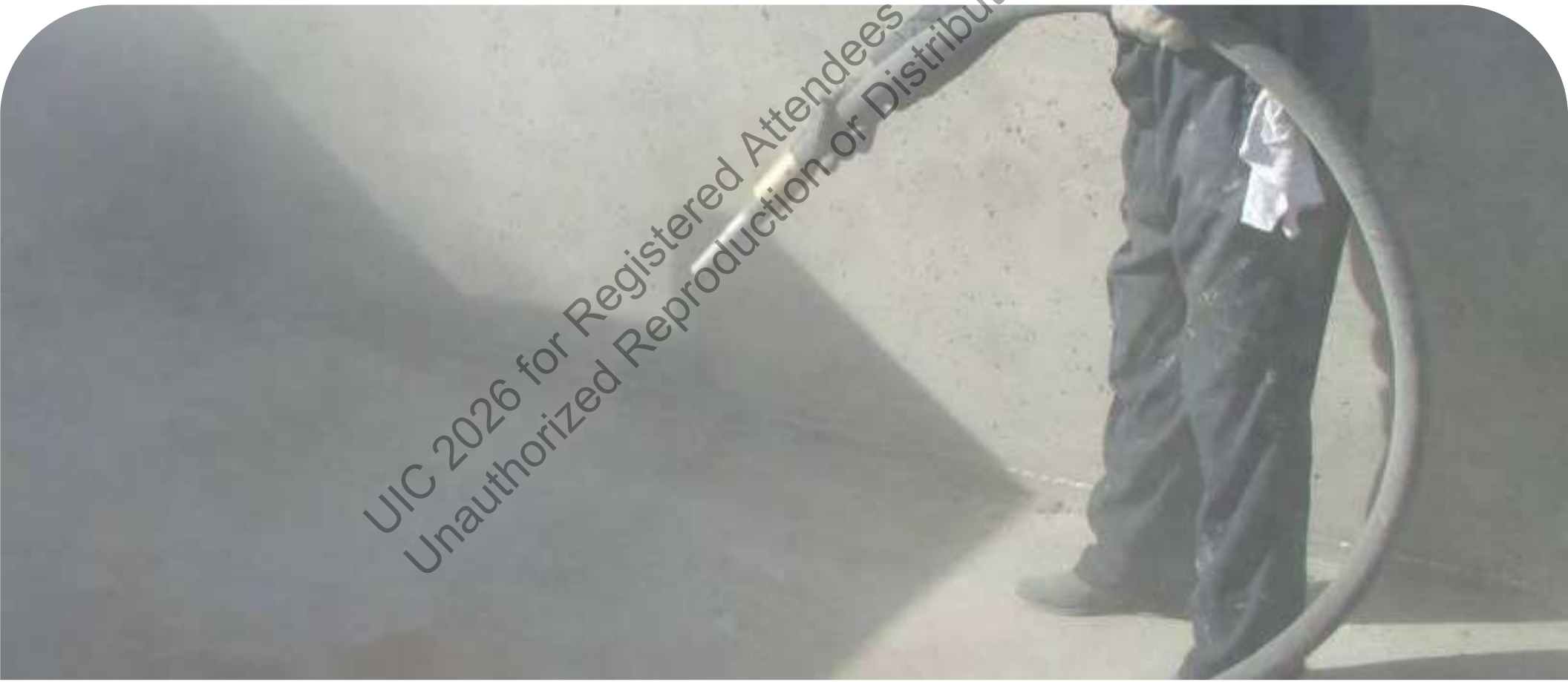
✓ AMPP (NACE No. 6/SSPC SP-13)

Abrasive blasting should be specified & required

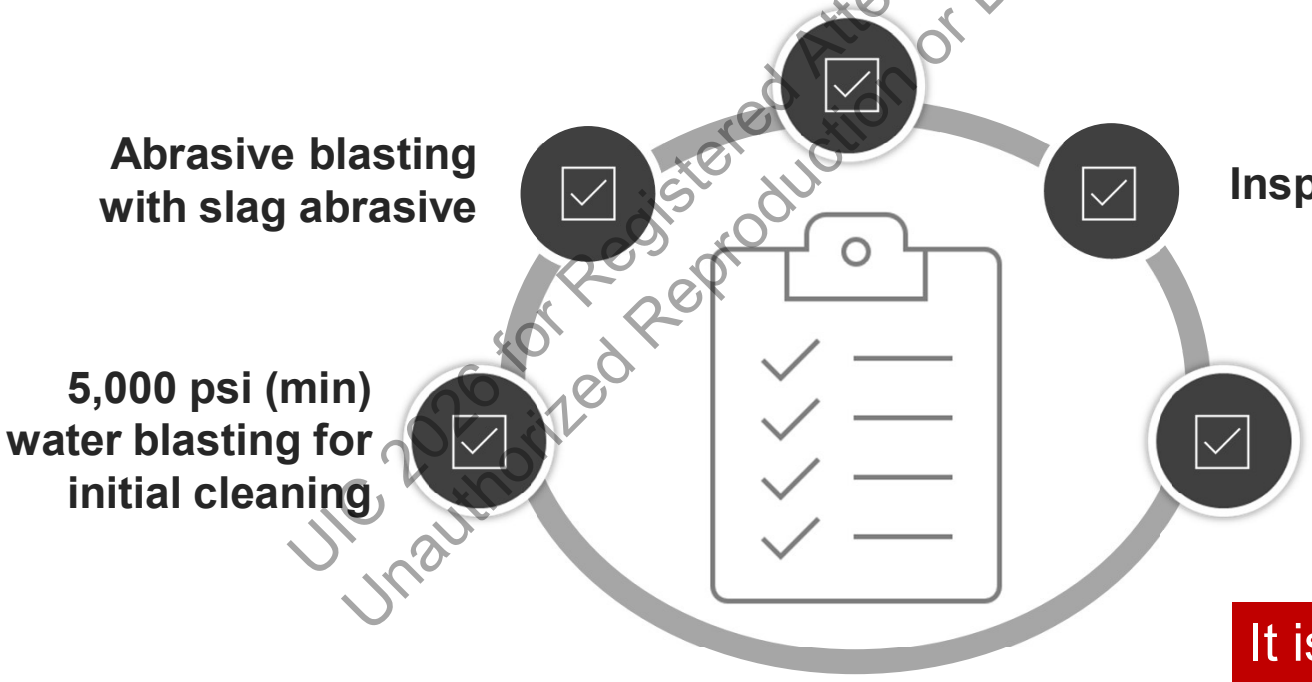


Example of high pressure water blast surface cleaning (pre-cleaning) at 5,000 psi (min)

Example of dry-abrasive blasting
(Typically uses a slag abrasive blast media)

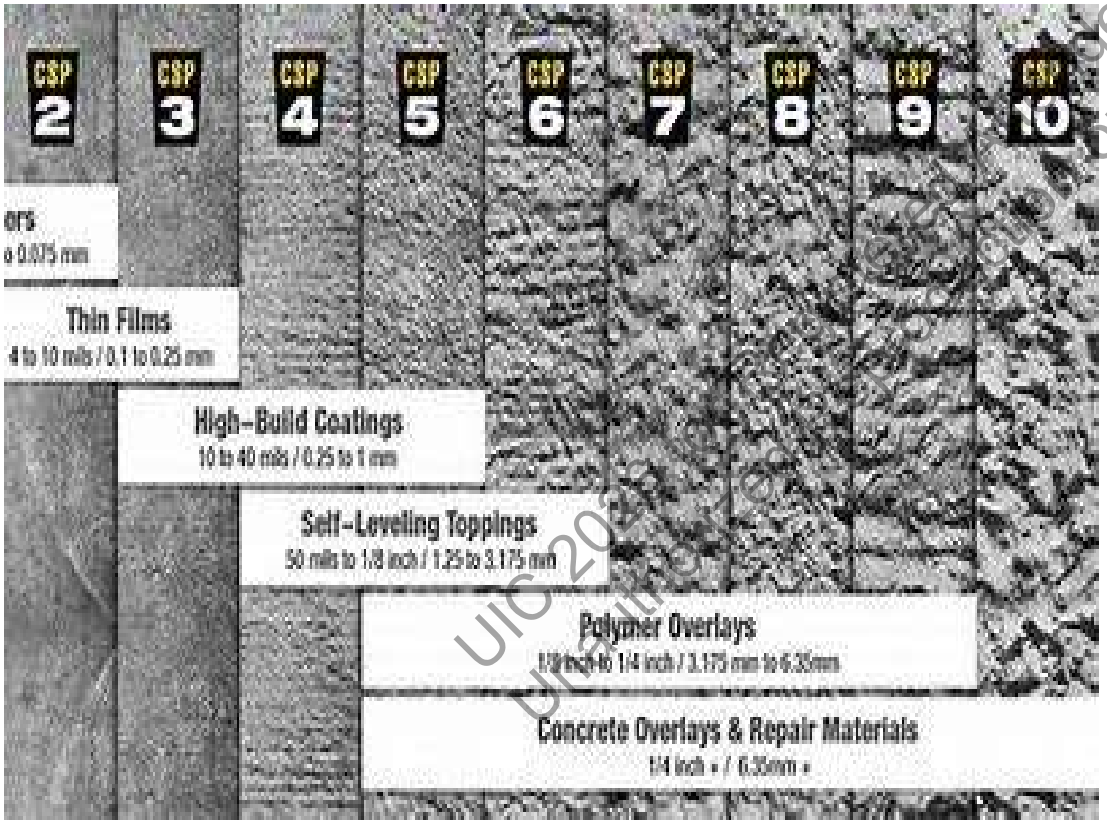


How can you make sure that surface preparation is performed correctly and consistently?



It is best not to rely on just water blasting alone!

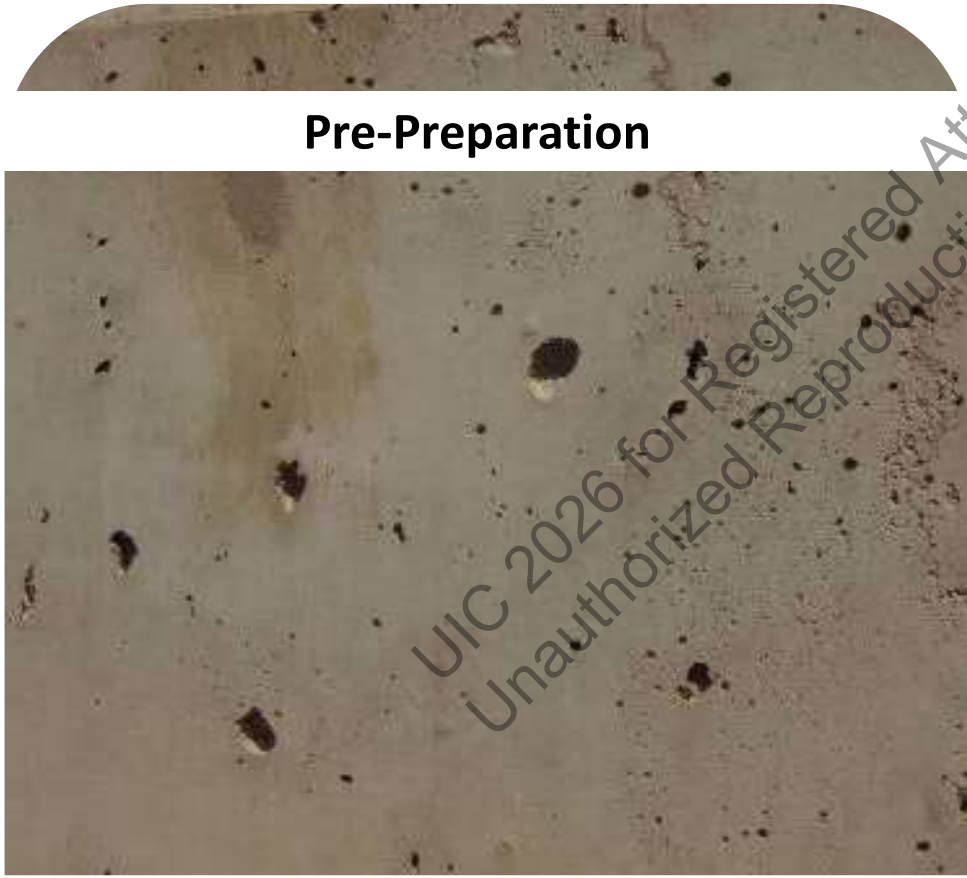
ICRI CSP surface profile comparators are useful tools for surface preparation inspection (ICRI No. 310.2R-2013)



ICRI CSP surface profile comparators are useful tools for surface preparation inspection and verification (ICRI No. 310.2R-2013)

- ICRI CSP surface roughness profiles from CSP-1 to CSP-10
- CSP-4 or CSP-5 profiles commonly specified for wastewater applications

New concrete: Example of removal of laitance & weak concrete through abrasive blast to expose subsurface voids and to produce a sound concrete surface with adequate profile and porosity



Pre-Preparation

Post-Preparation

Concrete must be adequately cured prior to coating/lining

<u>Concrete Cure</u>:

- Concrete should be cured using the procedures described in ACI 308R *Guide to Curing Concrete*
- Maintaining moisture & temps for a minimum period
- Insufficiently cured or low-strength concrete may create an excessively coarse surface profile, overall weakness, or removal excessive concrete

Require 28 day (min) cure for new concrete

Product Application Best Practices

- For coatings/linings: Ensure proper thickness is being applied
  - ✓Specify and use wet mil thickness gauges (ASTM D4414)
  - ✓Typical minimum thicknesses for resurfacing material = ½” (13 mm)
  - ✓Typical thickness for coating/lining topcoat = 125 mils (~ 3.18 mm)
- Make sure environment is appropriate for application
- Make sure all active infiltration is stopped
- **Line the manhole inverts or ensure proper terminations**
- Use appropriate and well functioning application equipment & PPE

Safety first! Beware of exposure to hazardous chemicals

A coating/lining application without proper concrete restoration will not provide long-term protection

- Inconsistent coating/lining application
- Thin areas
- Pinholes (concrete offgassing)
- Bughole-induced offgassing

Substrate resurfacing, patching and repairs

All gouges, surface air voids, and other surface anomalies need to be repaired to a level required by the coating system as specified

All repair material must be approved by coating manufacturer

Materials must be compatible!

Process establishes a "paintable surface"

- Film integrity and consistency
- Monolithic lining
- Chemically-resistant lining

All considered part of the protective lining ***system***

- Substrate prep
- Optimum Adhesion
- Optimum Performance

Cementitious resurfacing materials must be applied at proper thickness & most are not suitable as thin overlays

Many cementitious repair mortars can form a weak laitance layer, if applied too thin or as a parge coat

- Calcium aluminate-based mortars
- Micro-silica mortars
- Portland-based mortars
- Acrylic-based mortars

More material is needed, comparatively, if cementitious is used compared to epoxy-modified resurfacing material

Minimum of ½" thickness needed for cementitious materials to develop self-strength, and must be compatible with top coat!

Thin overlays can create a smooth, consistent surface for topcoating, without the need for high build application

Profile view showing a thin overlay applied to concrete to create contiguous surface for application of a monolithic protective liner.

Profile view showing the monolithic application of a high-performance protective liner over a smooth substrate.

Now we're ready for the coating/lining application!

Stringent QA/QC & Inspection is a Good Investment

- QC & inspection ensures specifications are being met throughout the rehabilitation process
- QC expert is highly recommended and provides knowledge & experience throughout project
  - ✓*Independent third party or in-house expert (i.e. AMPP certified)*
- Agreed upon inspection & quality control testing provides valuable feedback
- Increases contractor accountability and protects owner
- Makes sure the job is done right!

Hold points allow inspectors to confirm quality and specifications are being met

- ✓Surface preparation hold point
- ✓Application hold point
- ✓Final inspection

- Inspector should have authority to stop project if there are issues
- Review process in pre-construction meeting
- Communication is key to procedural conformity

When things go wrong... Failure of a protective lining due to insufficient anchor profile on existing concrete surface, no resurfacing

Failures frequently occur without proper surface preparation!

Failure of a protective liner due to insufficient removal of the laitance layer from a new concrete surface

Don’t take shortcuts: Failure due to direct-to-aggregate application without proper surface preparation & adequate resurfacing of substrate

Commonly Specified QC and Inspection Procedures

- ✓ Visual inspection of surface preparation prior to coating/lining installation (ICRI 310.2R-2013)
- ✓ Ensure AMPP (SSPC-SP 13/NACE No. 6) standards are being followed throughout
- ✓ Observation of coating/lining installation & verification of thickness (wet mil gauge testing ASTM D4414)

Specific to resin-based polymer coatings and linings:

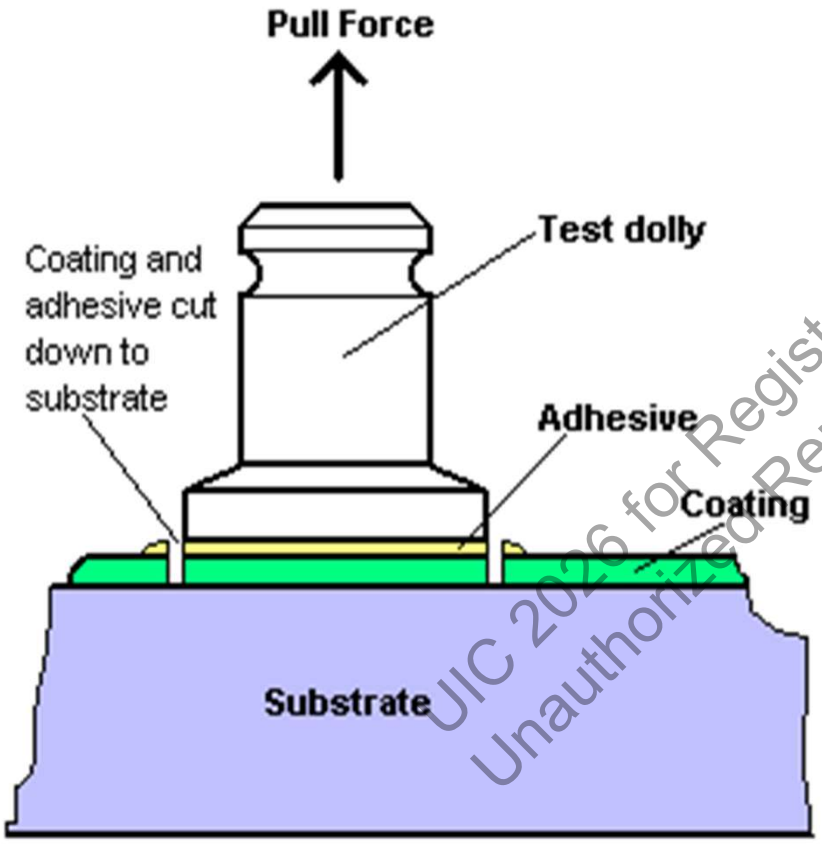
- ✓ Once cured, holiday (spark) test on all coated/lined surfaces (NACE SP0188)
- ✓ Adhesion testing to verify bond strength (ASTM D7234)
- ✓ Comprehensive final visual inspection

Provide written verification of inspection process

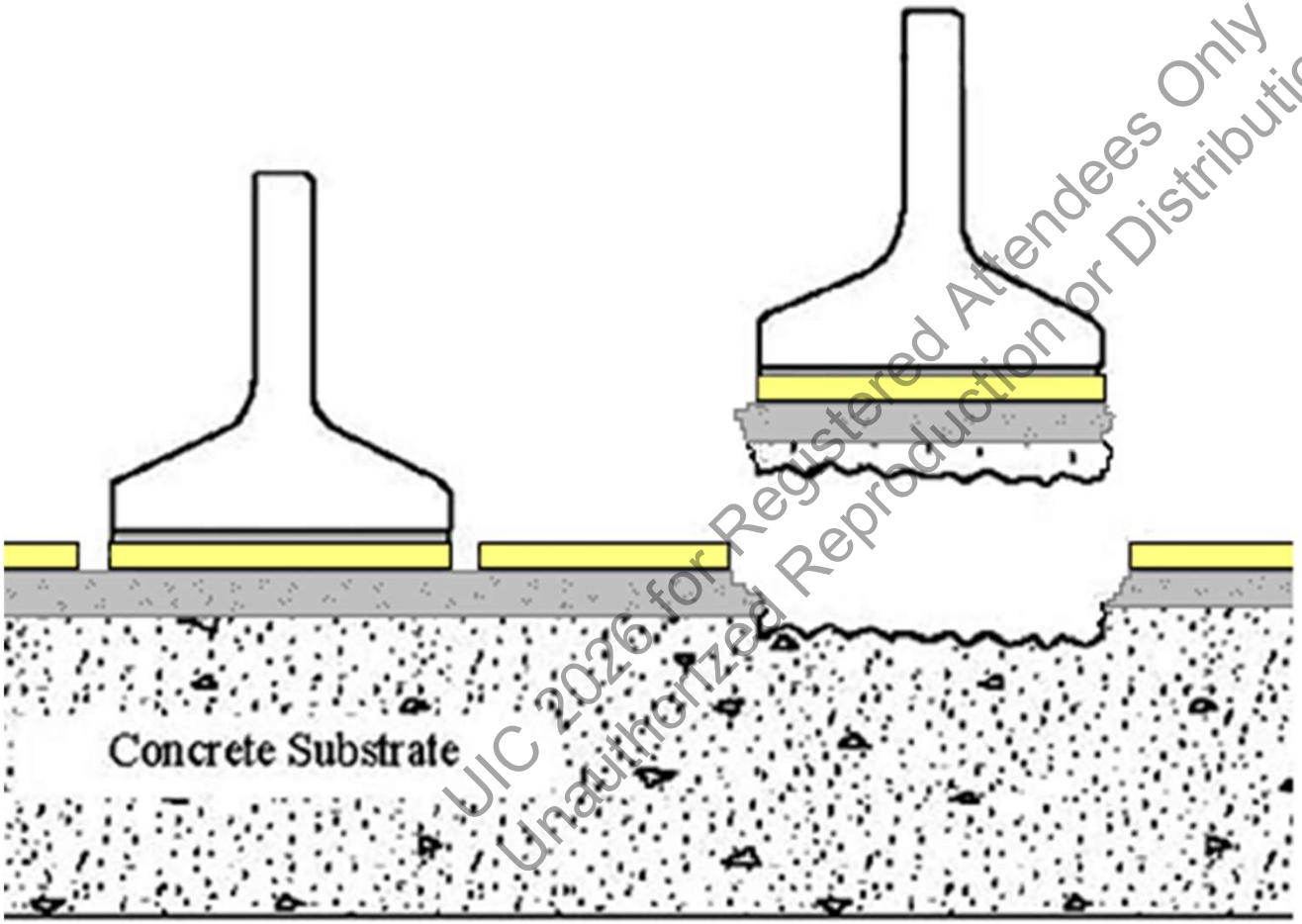
QC & Inspection Procedures Commonly Specified

Holiday (spark) test on all coated/lined surfaces
AMPP (NACE SP0188) at 100 volts/mil

QC & Inspection Procedures Commonly Specified



Bond Strength Testing per ASTM D7234 Standard



- Typically a minimum of 250 psi+ adhesion strength
- Be sure to calibrate test unit for dolly size (10mm, 20mm, 50mm)

So when the process is done correctly…

Before

After

Final Inspection – Looking Good!

Concrete rehabilitation is a less disruptive and cost-effective alternative to replacement

It is important to understand differences in rehabilitation products & methods

Rehabilitation requires unique design and planning considerations

Surface preparation is the most important step. This must be done right!

Quality control & inspection are critical

Help Save Your Concrete!

Concrete Rehabilitation is a Winning Strategy:

- *Minimize disturbance*
- *Save money*
- *Save time*

Questions?

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