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Corrosion Evaluation of Prestressed Piles in Refit Wharf #3

Naval Submarine Base
Kings Bay, GA, USA
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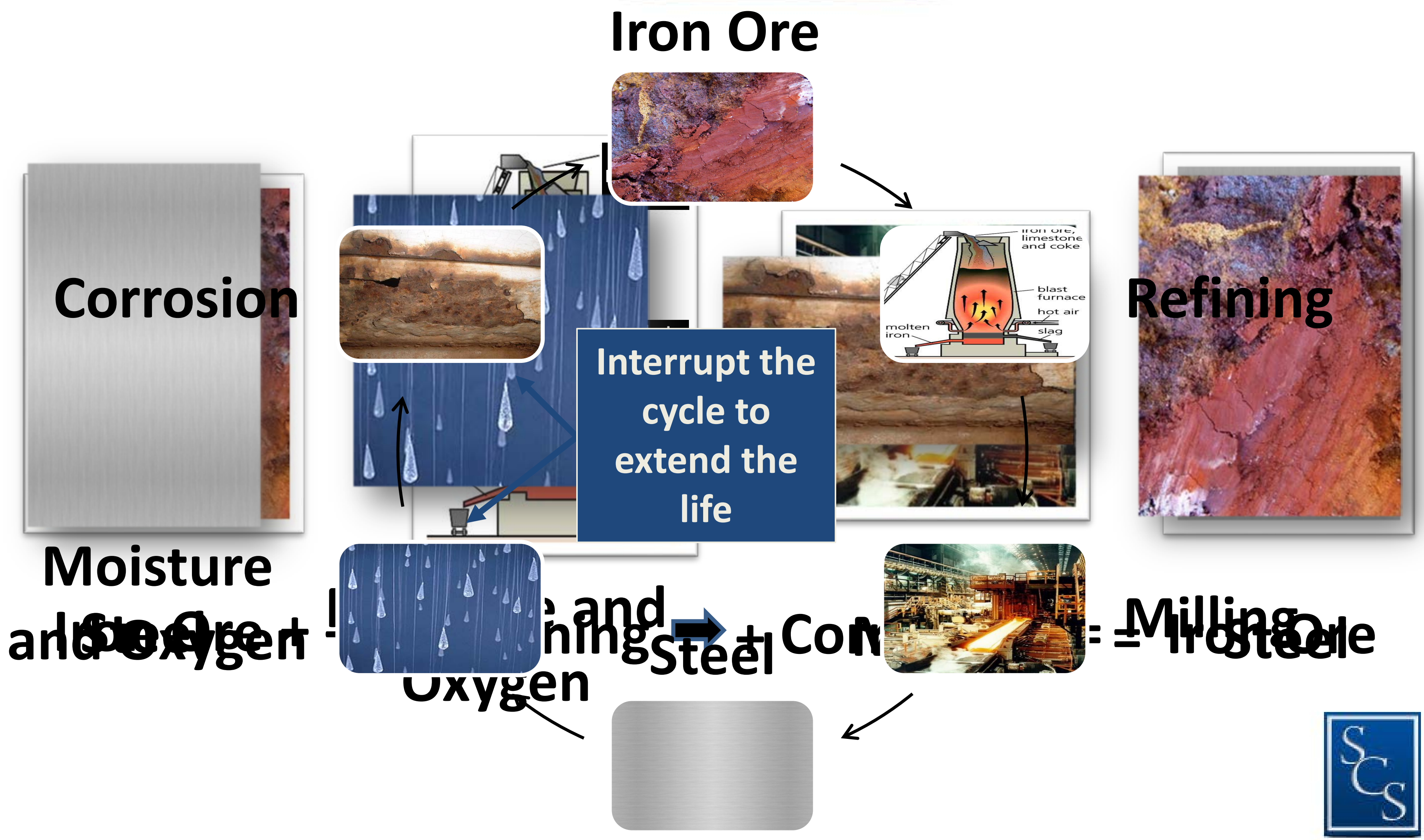
Siva Venugopalan
President, Principal Engineer
Siva Corrosion Services (SCS)
(610) 692-6551
Siva@SivaCorrosion.com
www.SivaCorrosion.com

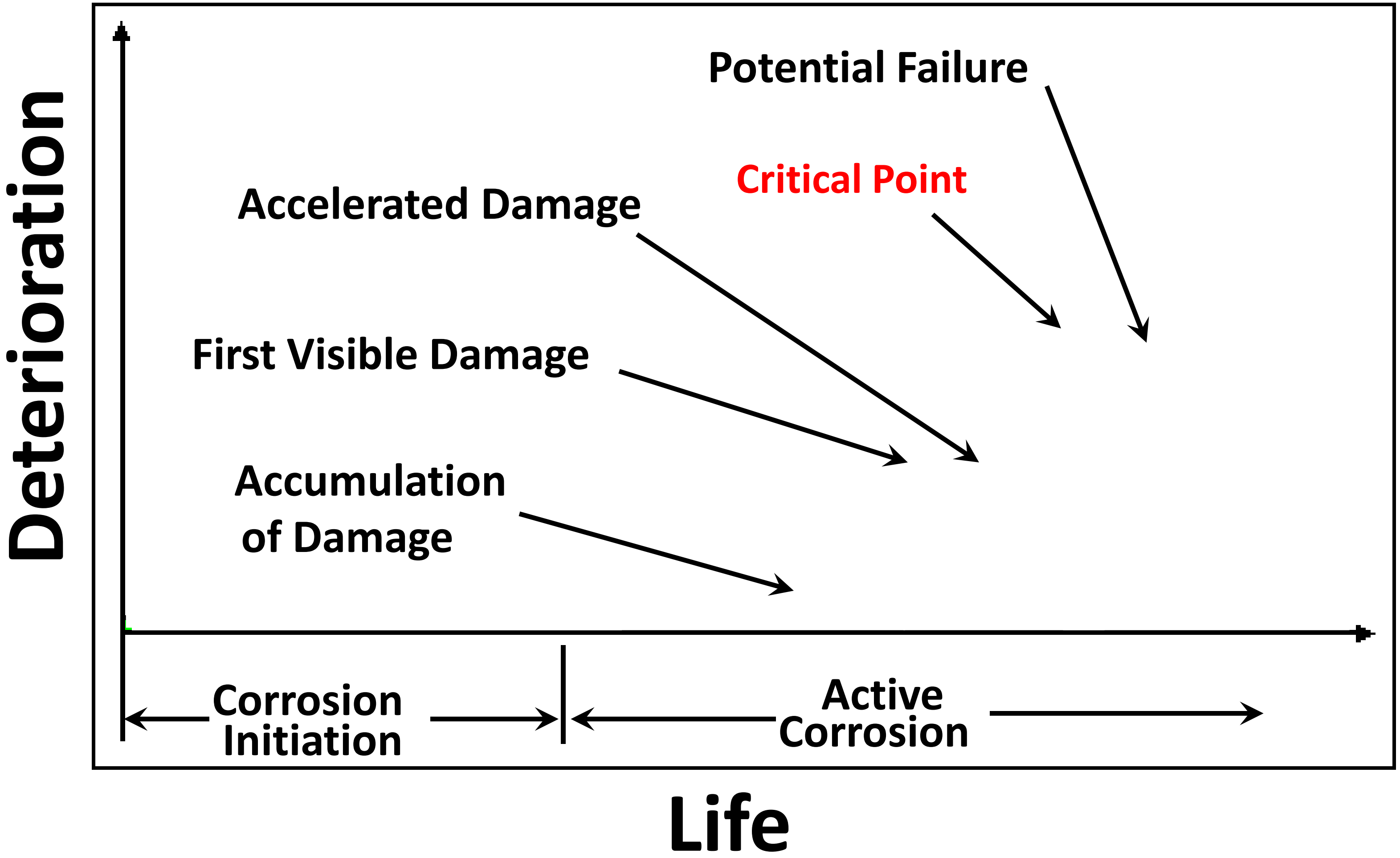
In This Presentation

- Project Outline
- Corrosion problems in Refit Wharf #3 Piles
- Corrosion inspection to *identify* and *quantify* problems in the piles
- **Solution**: Repair Options

Corrosion Cycle



Effects of Corrosion on Infrastructure



Benefits of Inspection

- Actual condition of Wharf is now known
- Corrosion problems can be addressed before repairs become too costly
- Determine optimal corrosion protection to extend the life of the marine structures by 20+ years
  - Prevent costly emergency repairs
  - Minimize interruption of service by avoiding unexpected/costly repairs

Scope of Work

1. Delamination and spall survey
2. Corrosion potential survey
3. Concrete cover survey over reinforcement
4. Chloride sampling
5. Electrical continuity between rebars and rebars/strands

Project Outline

- Corrosion was observed under Refit Wharf 3
- Stage 1: Inspect Pile Caps for corrosion
- Stage 2: Inspect Piles for corrosion
- Determine possible corrosion protection systems for Refit 3
- Compare repair options

Problems in Refit Wharf #3

- Salt water is a very corrosive medium
- Corrosion has led to concrete damage
- About two thirds of the pile caps have significant delaminations in the utility trench
- Almost 8% of the piles exhibit cracking or other concrete damage
- Loss of steel cross section; concrete – Reduced load capacity

Corrosion Evaluation of Piles

Inspections Performed:

- Visual Inspection
- Crack, Delamination and Spall Survey
- Concrete Cover Survey using Ground Penetrating Radar (GPR)
- Electrical Continuity Survey
- Corrosion Potential Survey
- Chloride Analysis

EVALUATION RESULTS

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Evaluation Results

Evaluation Results

Visual Inspection:

- 30 piles exhibited cracking
- Most cracks exhibited rust stains

Evaluation Results

Crack, Delam & Spall:

- 3 of 22 inspected piles exhibited significant concrete damage

Evaluation Results

Electrical Discontinuity:

- 5 of 22 inspected piles exhibited discontinuities

Evaluation Results

Corrosion Potential:

- Piles 85A, 88A and 88B exhibited high corrosion potential
- 8 out of 22 piles (36%) show active corrosion is taking place

Scope & Findings

- Visual Evaluation (396 Piles)
  - 30 Piles with Cracking
  - 3 Piles with Significant Damage
- Conc. Cover Survey (22 Piles)
  - Sufficient Cover for all Reinforcement
- Continuity Survey (22 Piles)
  - 5 out of 22 piles (23%) Exhibited Discontinuity
- Corrosion Potential (22 Piles)
  - 8 out of 22 piles (36%) Exhibited Active Corrosion

Scope & Findings

Typical Presentation of Results

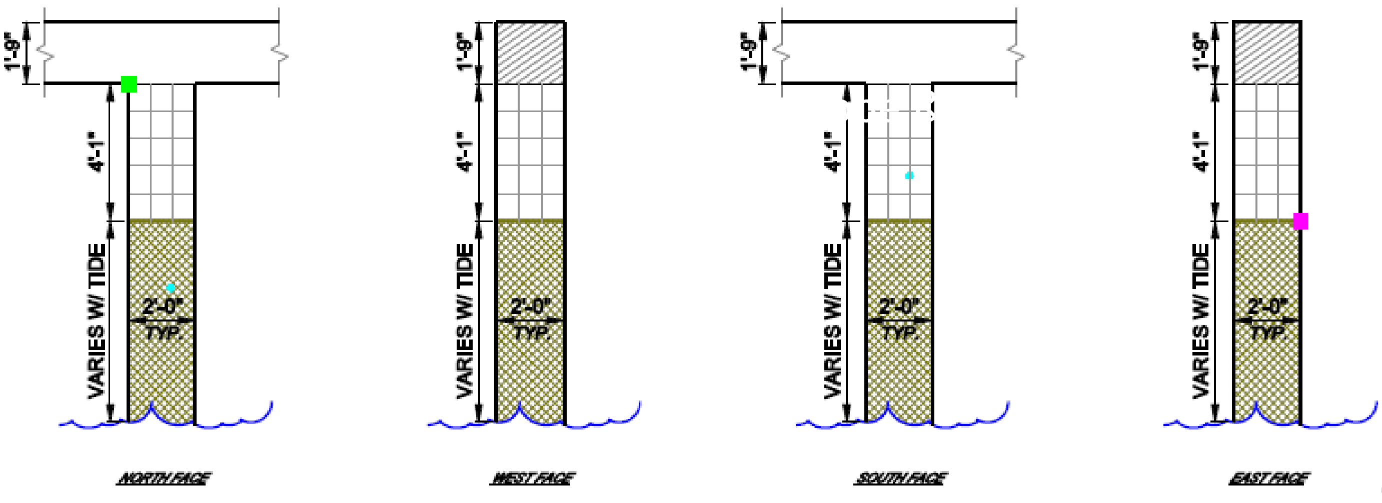
• CHLORIDE TESTING LOCATIONS AND RESULTS •		
LOCATION	DEPTH	Cl, WT % POWDER
PC83 - PD - NF (M)	0" - 1"	0.207
PC83 - PD - NF (M)	1" - 2"	0.128
PC83 - PD - NF (M)	2½" - 3½"	0.111
PC83 - PD - NF (M)	5" - 6"	0.047

* (M) DESIGNATES CHLORIDE TAKEN IN MARINE GROWTH AREA.

• CHLORIDE TESTING LOCATIONS AND RESULTS •		
LOCATION	DEPTH	Cl, WT % POWDER
PC83 - PD - SF	0" - 1"	0.319
PC83 - PD - SF	1" - 2"	0.193
PC83 - PD - SF	2¾" - 3¾"	0.020
PC83 - PD - SF	5" - 6"	0.005

LEGEND:

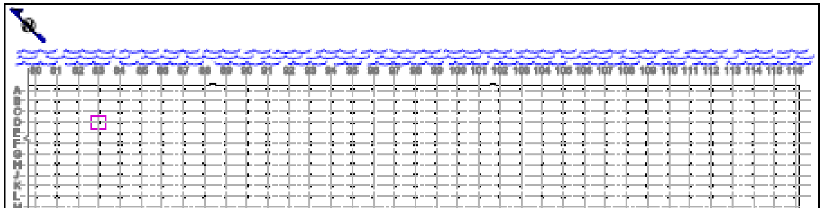
1) RED HATCHED AREA REPRESENTS DELAMINATION -
2) RED FILLED AREA REPRESENTS SPALLING -
3) BROWN HATCHED AREA REPRESENTS MARINE GROWTH AREA -
4) CYAN FILLED CIRCLE REPRESENTS CHLORIDE LOCATION -



BENT 83 - REFIT WHARF NO. 3
PILE D ELEVATION
N.T.S.

BENT 83 - PILE D											
POTENTIAL											
-177	-225	-175	-153	-175	-178	-178	-172	-149	-177	-183	-174
-245	-282	-213	-240	-304	-291	-278	-297	-257	-311	-277	-305
-234	-274	-251	-291	-298	-282	-312	-291	-297	-274	-297	-277
-375	-348	-380	-391	-392	-380	-415	-414	-422	-384	-372	-365
-443	-449	-445	-421	-432	-418	-462	-525	-461	-451	-393	-405

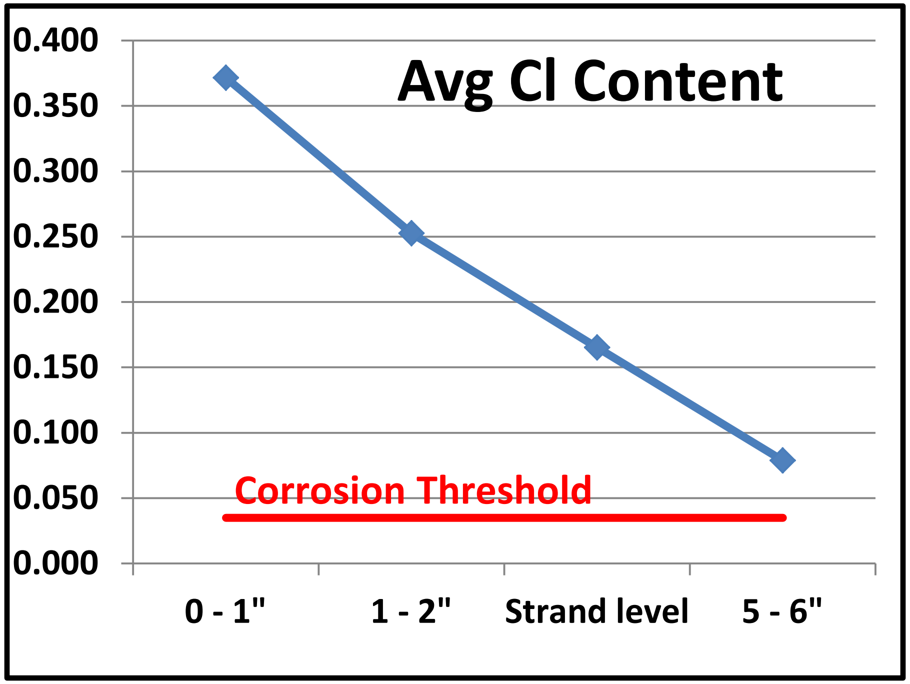
* POTENTIAL TAKEN FROM NORTH FACE OF PILE, WRAPPING COUNTER CLOCK-WISE, TO END OF EAST FACE OF PILE.
* POTENTIAL TAKEN FROM BOTTOM OF CAP TO TOP OF MARINE GROWTH. SOME AREAS OF MARINE GROWTH WERE CHIPPED FOR POTENTIAL READINGS WHERE SHOWN.



REFIT WHARF NO. 3 - BENT 83 - PILE D

* NO DELAM AND SPALL TESTING DONE IN MARINE GROWTH AREA.

Evaluation Results



Chloride Analysis:

- Cl^- content exceeded the threshold for corrosion at the reinforcement level in 41 of 44 samples

Summary of Findings

- Salt has diffused into the piles and initiated corrosion of the reinforcement
- The large cover has protected the reinforcement, slowing the ingress of chlorides to the reinforcement level
- If unaddressed, corrosion will accelerate and result in widespread concrete damage
- A proper combination of traditional and non-destructive testing enables *identification* and *quantification* of problems

Repair Solutions

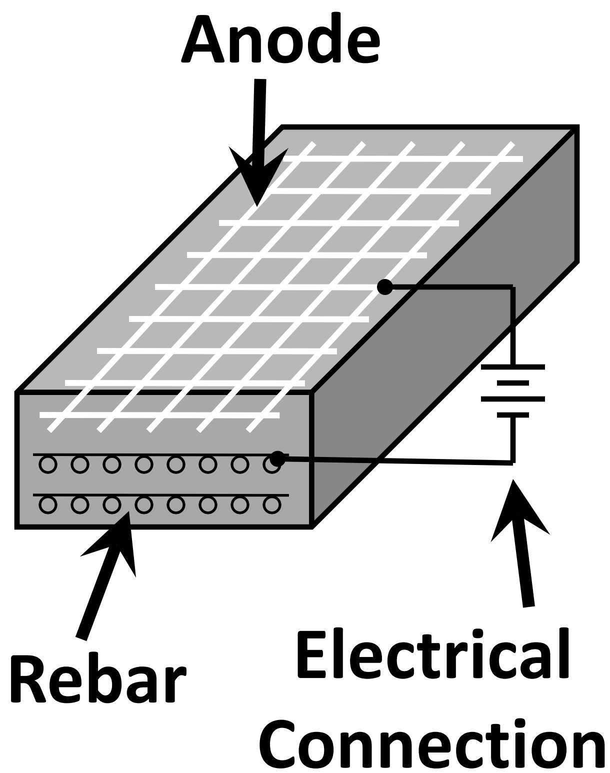
- **Patch Repair:** Repair damaged concrete only
- **Cathodic Protection**
  - Galvanic Cathodic Protection (GCP)
  - Impressed Current Cathodic Protection (ICCP)

Cathodic Protection

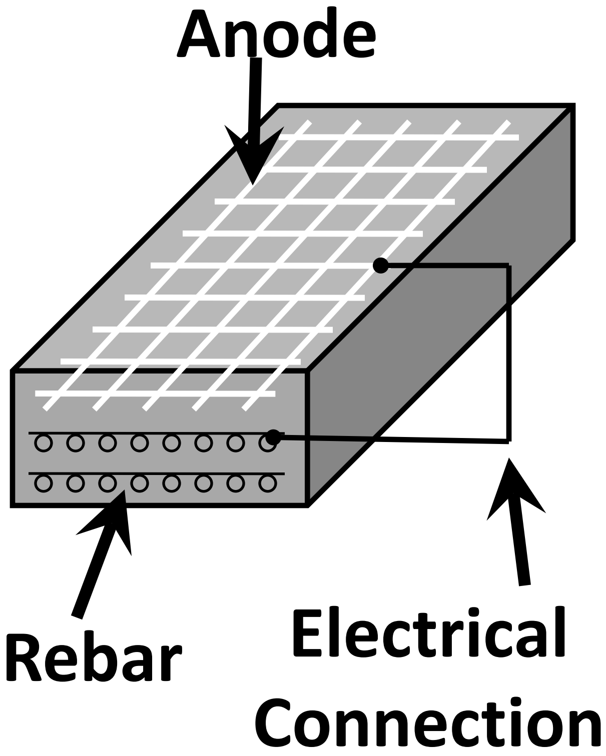
- Anode is embedded in the concrete
- Current flows from anode to cathode (steel)
- The current polarizes the steel and protects it from corrosion
- Can extend the life of the structure significantly

Cathodic Protection

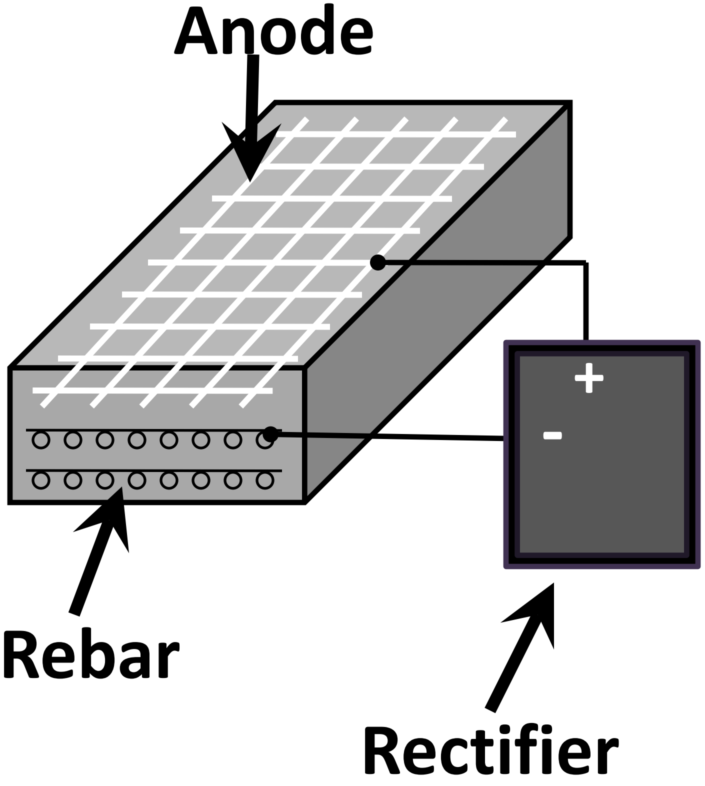
- Sacrificial anode is embedded in the concrete
- Current flows from anode to cathode (steel)
- The current polarizes the steel and protects it from corrosion
- Can extend the life of the structure by 15 (galvanic) to 50 (ICCP) years



Gavlanic Cathodic Protection (GCP)



Impressed Current Cathodic Protection (ICCP)



Recommendation

- Implement GCP system to extend pile service life
  - Make all reinforcements continuous
  - Repair all damaged concrete
  - Install GCP jacket on piles with concrete damage <5%
  - Install structural jacket with GCP on piles with concrete damage >5%
  - Install a bulk zinc anode system one foot below the low water level on all piles to address corrosion
- For Piles with >10% damage, install ICCP

Refit 3 Repair Options

Concrete Repair with GCP System (Opt. 1)

Advantages:

1. No External Power Source
2. No Maintenance or Operation
3. Reduction in Corrosion Rates
4. Lengthens Time of Full Repair

Disadvantages:

1. Galvanic Current is Limited & Not Adjustable
2. Limited Protection Against Highly Active Corrosion
3. 20 Year Anode Service Life
4. High Initial Cost

Refit 3 Repair Options

Concrete Repair with ICCP System (Opt. 2)

Advantages:

1. Protection Against Impending Corrosion Damage
2. Protection of Entire Reinforcement Within Selected Areas
3. Applied Current is Adjustable
4. Decreases Dependence on Concrete Patch Quality
5. Increased Repair Service Life

Disadvantages:

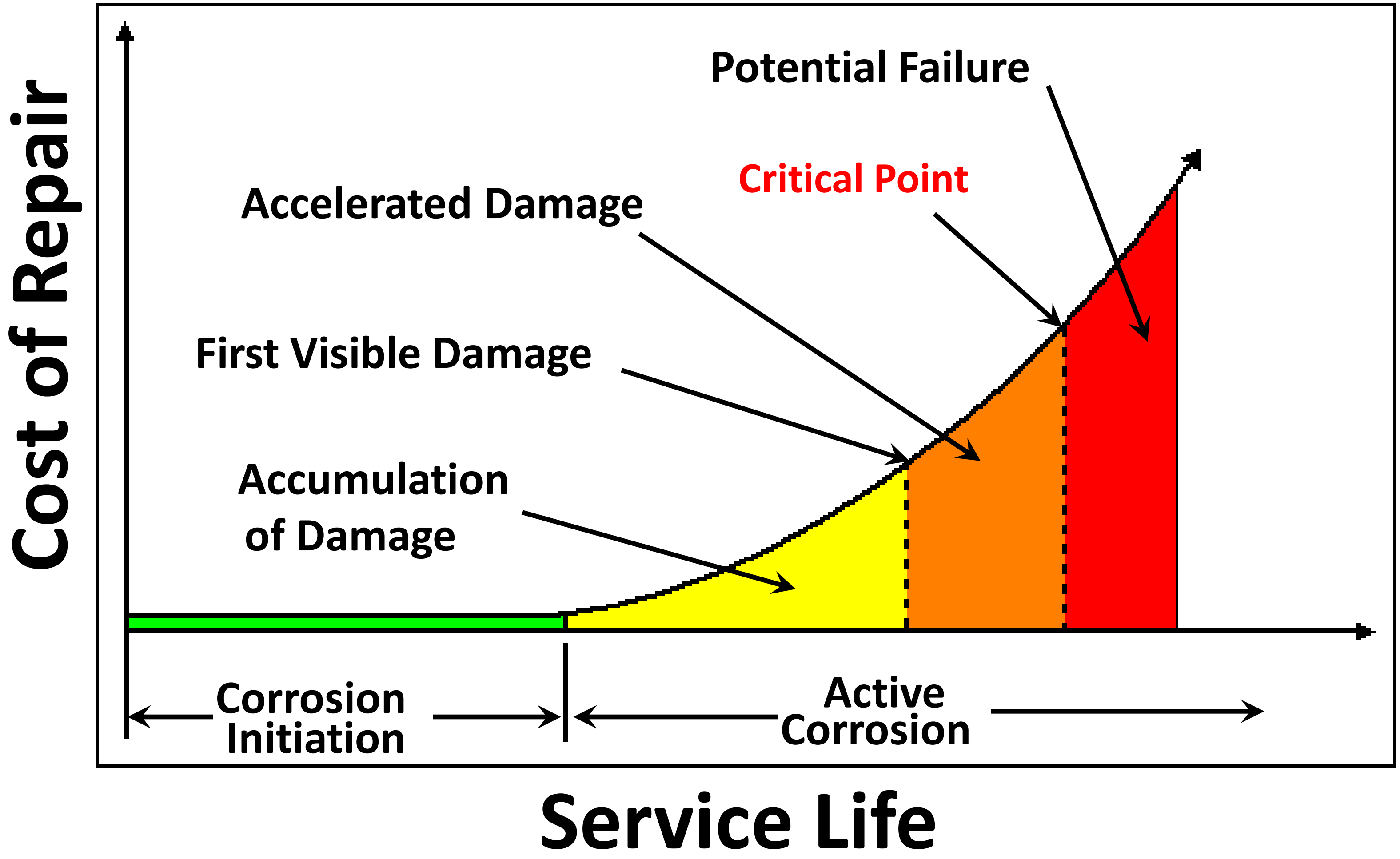
1. Requires Continuous External Power Source
2. External Power Source Subject to Failures
3. Requires Installation of Rectifiers
4. High Initial Cost
5. Requires Monitoring, Operation, and Maintenance

Refit 3 Repair Summary

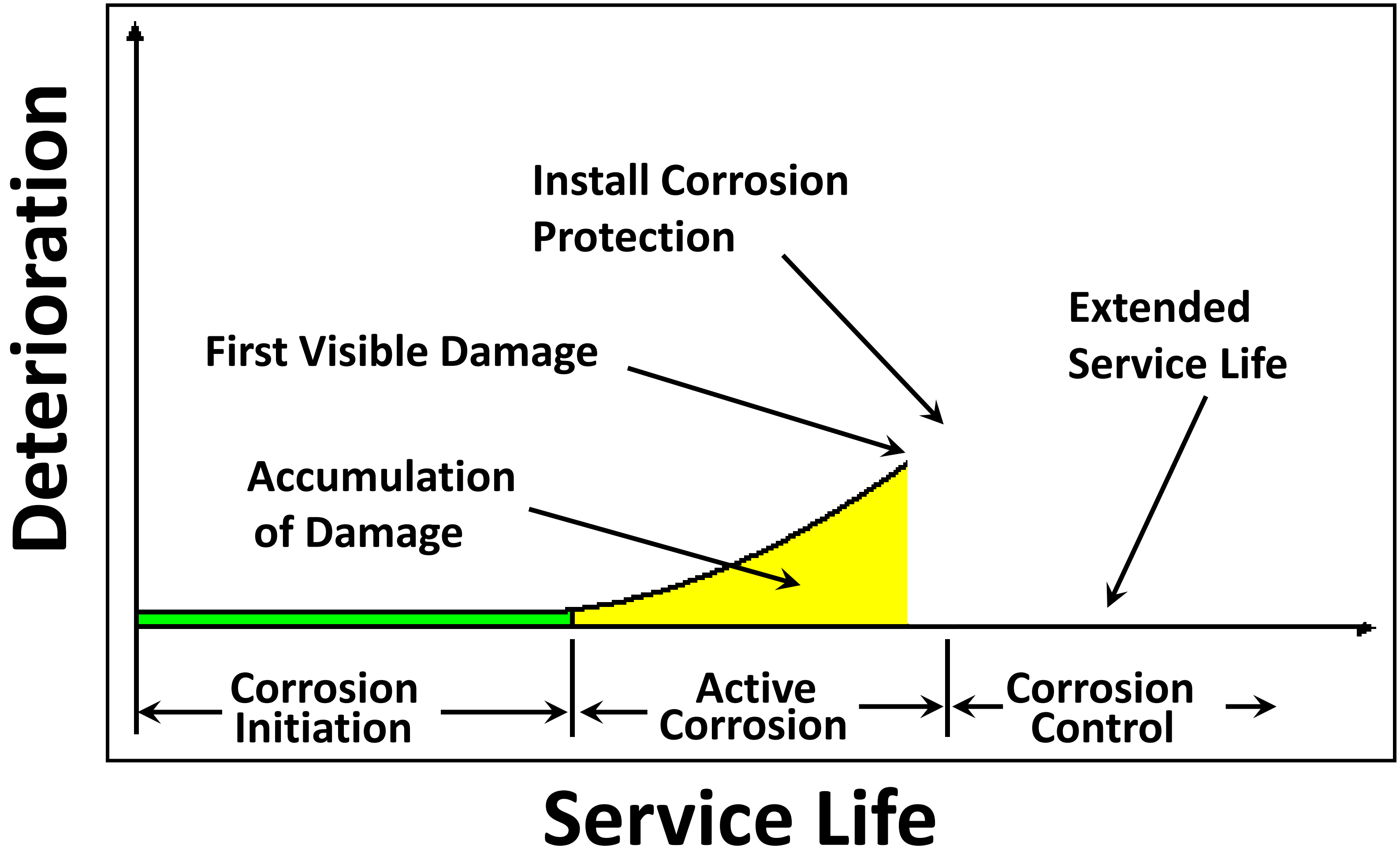
Table 1. Summary of Prestressed Pile Repair Options

Repair Option	Description	Advantages	Disadvantages	Repair Service Life
Option No. 1: Repair Damaged Conc., and Install GCP System with Pile Jackets. (RECOMMENDED)	Partial depth concrete repair of existing damaged areas. Installation of a Galvanic Cathodic Protection (GCP) system. Includes a stay-in-place form and anodic jacket. Includes installation of a bulk zinc anode below the mean low water (MLW). Repair 100% of existing damaged areas. Make all reinforcement in the pile electrically continuous. Apply corrosion protection to all areas.	1. Does not require an external power source. 2. No maintenance or operation required. 3. Reduction in corrosion rates at present and impending damage. 4. Protection against accelerated corrosion at concrete repair limits. 5. Installation of the bulk zinc anode below MLW prevents accelerated loss of the zinc mesh anode in the jacket. This extends the life of the primary GCP system. 6. Lengthens time to full repair of impending damage.	1. Galvanic current is limited and not adjustable. 2. Limited protection against highly active corrosion. 3. 20 year anode service life. 4. High initial cost.	20 Years
Option No. 2: Repair Damaged Conc. with Pile Jackets and Install ICCP System.	Partial depth concrete repair of existing damaged areas. Installation of an Impressed Cathodic Protection (ICCP) system supplying a direct low voltage current into the reinforcement. Includes a stay-in-place form and anodic jacket. Repair 100% of existing damaged areas. Make all reinforcement in the pile electrically continuous. Apply corrosion protection to all areas.	1 Protection against impending corrosion damage. 2 Protection against accelerated corrosion at conc. repair limits. 3 Protection of entire reinforcement within selected areas. 4 Applied current is adjustable. 5 Decreases dependence on quality of concrete patches. 6 Increased repair service life. 7 Limited concrete removal. 8 System can be rehabilitated to extend initial service life.	1. Requires a continuous external power source. 2. External power source is subject to failures. 3. Requires installation of rectifiers. 4. High initial cost. 5. Monitoring, operation and maintenance required.	30 Years
Option No. 3: Repair Damaged Conc. and Install Jackets on all Piles.	Partial depth concrete repair of existing damaged areas. Installation of a non-structural pile jackets on all piles. Repair 100% of existing damaged areas, no cathodic protection.	1. No maintenance or operation required. 2. Reduction in corrosion rates at currently present damage. 3. Protection against additional chloride penetration.	1. Limited protection against active and impending corrosion. 2. Limited service life between repairs. 3. Potential for loading limitations between repairs.	10 Years
Option No. 4: Repair Damaged Conc.	Partial depth concrete repair of existing damaged areas Repair 100% of existing damaged areas, no applied cathodic protection.	1. No maintenance or operation required. 2. Lowest initial repair costs.	1. Only applicable to existing damaged areas (does not address impending damage). 2. Very limited service life. 3. Potential for accelerated corrosion at repair limits. 4. Potential for loading limitations between repairs.	5 Years

Effects of Corrosion on Infrastructure



Benefits of Corrosion Control



Thank You

Questions?

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