Corrosion Issues for Port Facilities

Presented by

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Vector Corrosion Services

Outline

- Corrosion background
    - How and why does it happen
- Reinforced concrete structures
    - Deterioration process
    - Special considerations
- Steel structures
    - Deterioration process
- Corrosion mitigation solutions
    - Galvanic and impressed current cathodic protection

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Corrosion Background

ASCE Report Card (2017)

- Port Infrastructure
  - C+
- Inland waterways
  - D
- Funding Provided $22 Billion USD
- Investment Needed $37 Billion USD
- Deficit of $15 Billion USD

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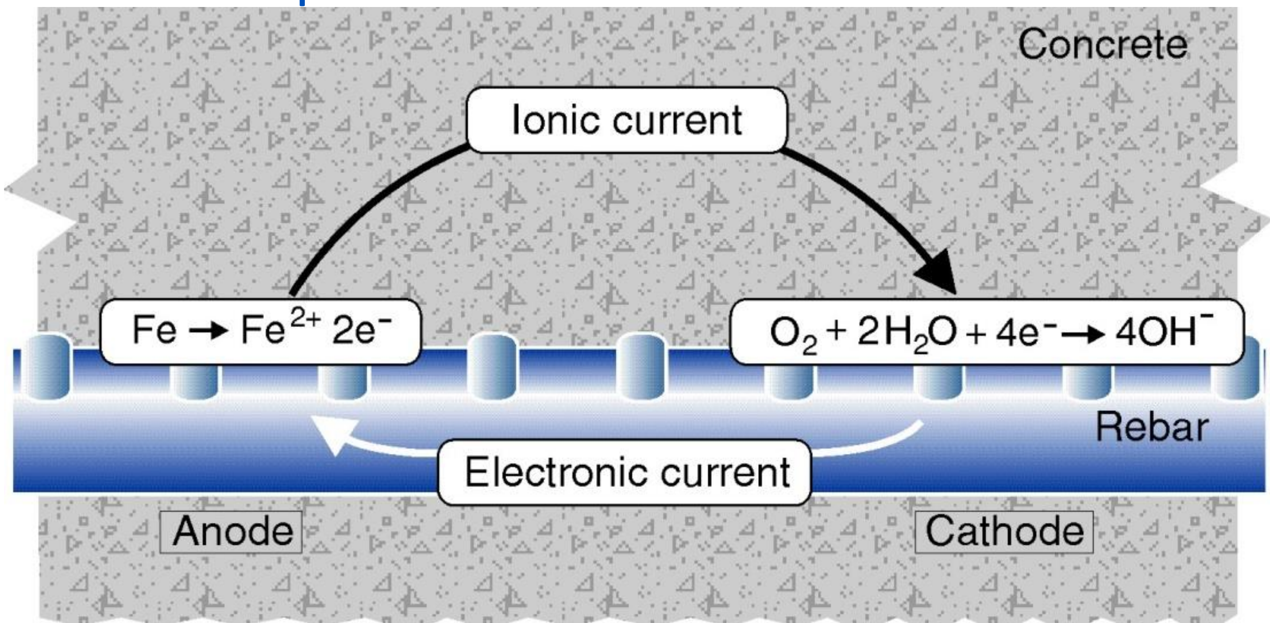
NACE Cost of Corrosion (2002)

- Infrastructure
  - $22.6 Billion USD
  - Waterways and Ports
    - $0.3 Billion USD
- Transportation
  - $29.7 Billion USD
  - Ships
    - $2.2 Billion USD

Corrosion

- Electrochemical reaction
- Requires
  - Moisture
  - Electrolyte – water or concrete
  - Metallic path – steel
- Anode
  - Where rust is formed
- Cathode
  - No section loss



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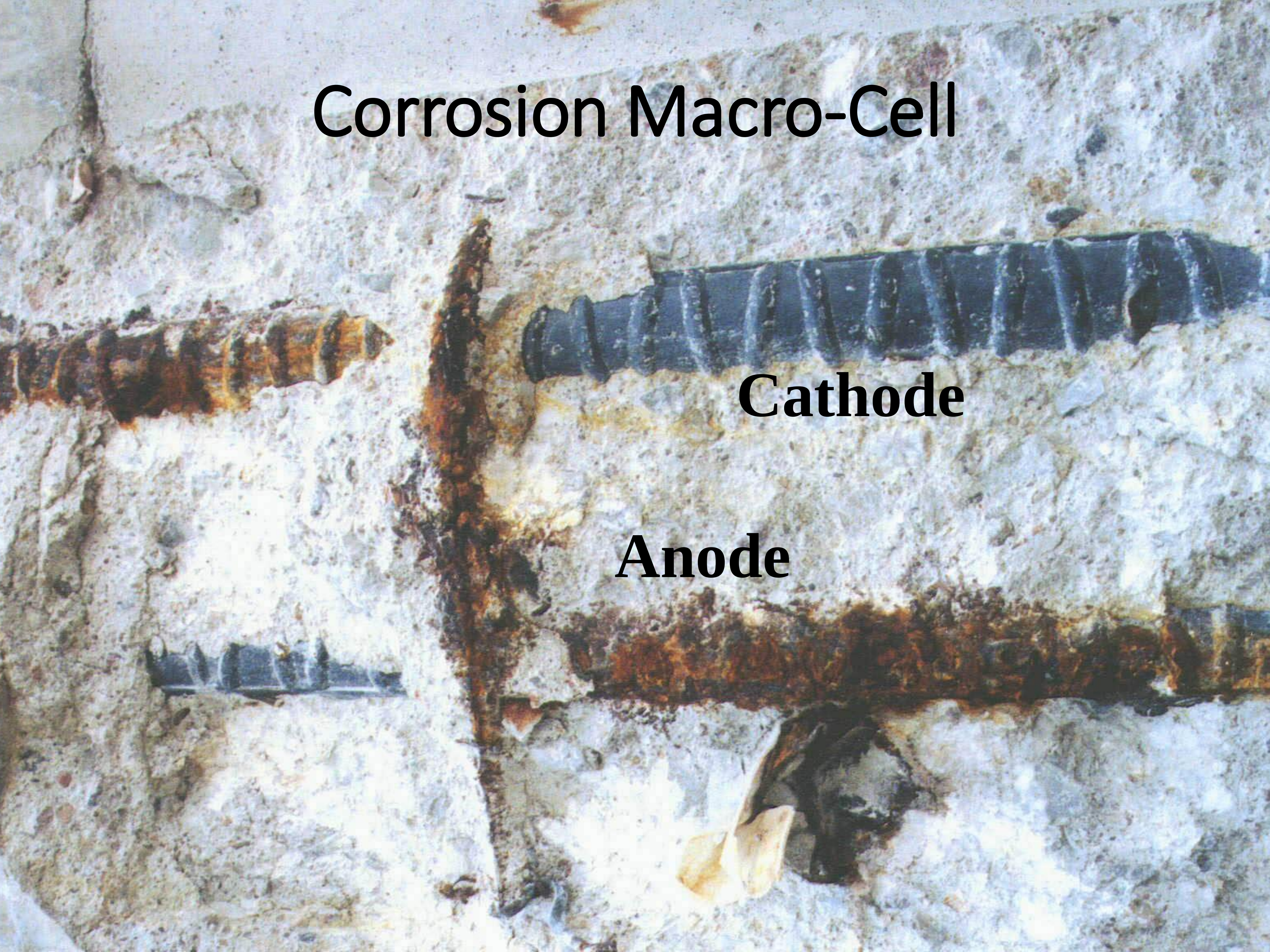
Corrosion Macro-Cell



Reinforced Concrete Structures

Corrosion of Reinforced Concrete

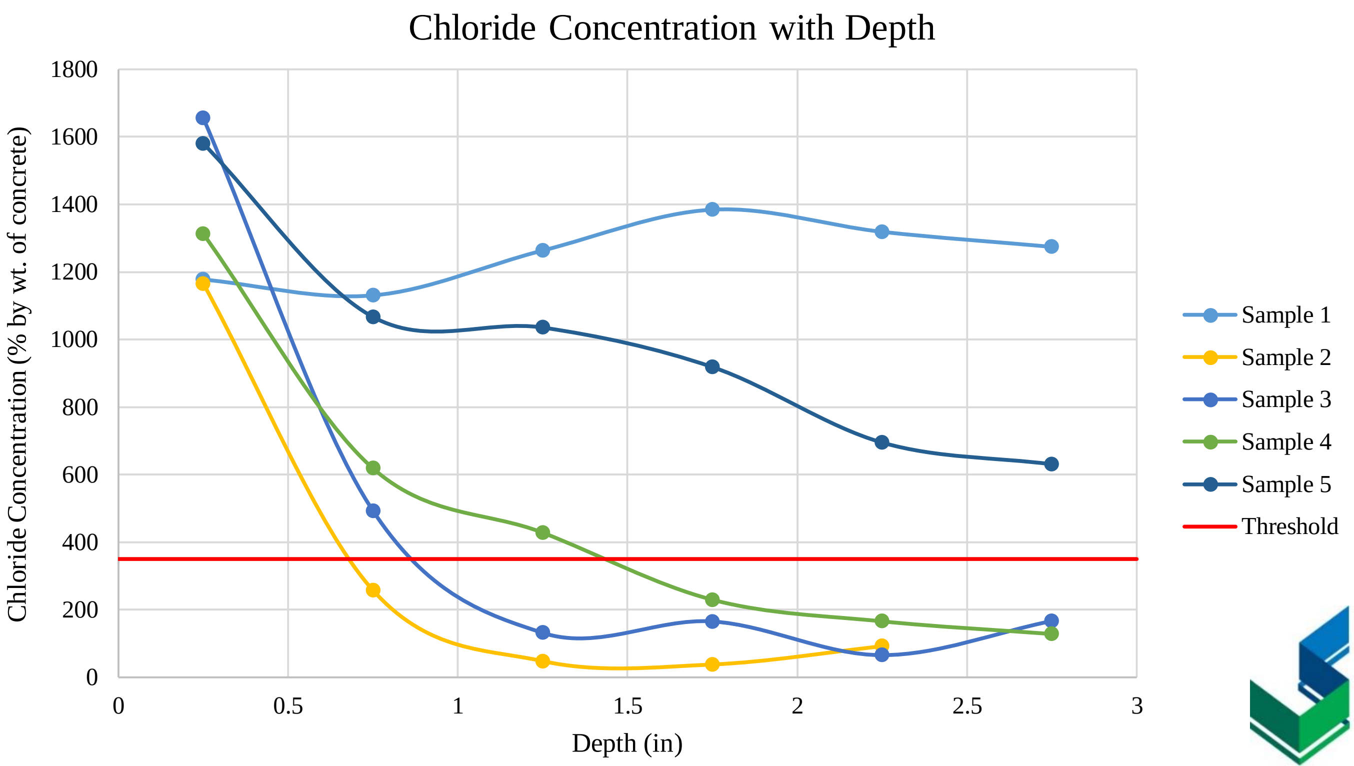
- Concrete is naturally alkaline
  - pH of about 13
- Steel is naturally passive at this alkalinity
  - Formation of passive layer
- Passive layer can be destroyed by;
  - Chlorides
  - Carbonation

Chloride Induced

- Chloride ions diffuse into concrete and destroy steel's passive layer
- Source of chlorides
  - Marine environments
  - De-icing salts
  - Chemical/processing plants
  - Cast into concrete
- Chlorides are not consumed in corrosion reaction, therefore, once threshold concentration reached, corrosion can occur unabated

Chloride Concentration Threshold

- Generally accepted chloride thresholds
  - 350 ppm of ***concrete***
  - 0.035% by mass of ***concrete***
  - 1 .5 lbs per cubic yard of ***concrete***
  - 3000 ppm by mass of ***cement***
  - 0.3% by mass of ***cement***



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Carbonation

- Carbon dioxide permeates into concrete
- Reduces pH of concrete
  - CO_2 reacts with free lime, $Ca(OH)_2$, resulting in $CaCO_3$ and H_2O
- Reduced pH de-passivates steel
- Often seen when
  - Concrete permeability is high
  - Industrial sites
  - Very old structures – carbonation is a result of time and exposure

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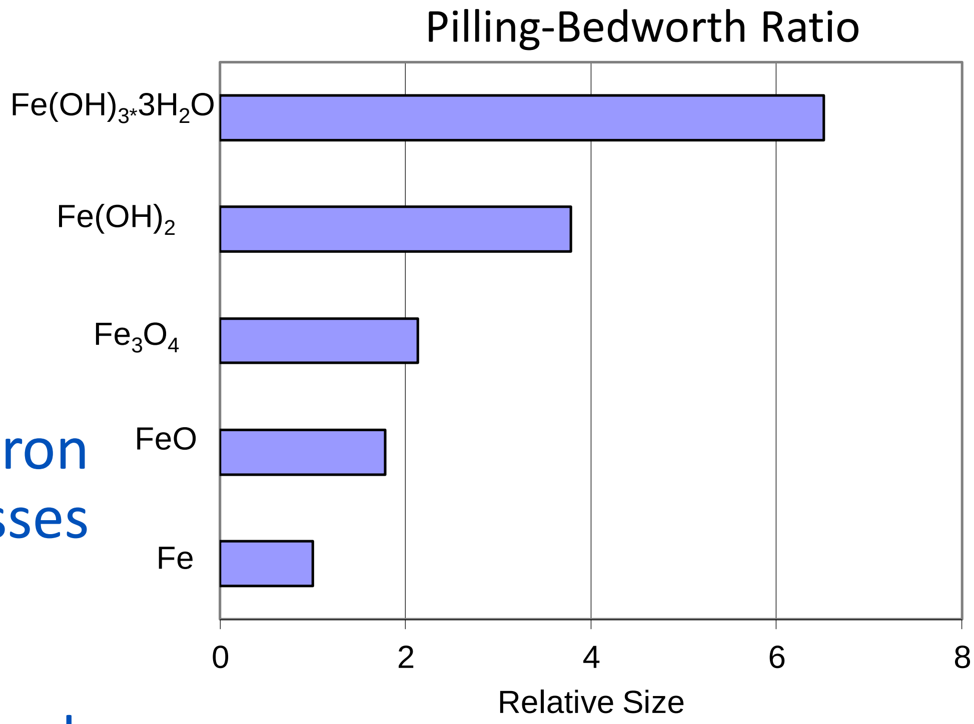
Corrosion Induced Damage

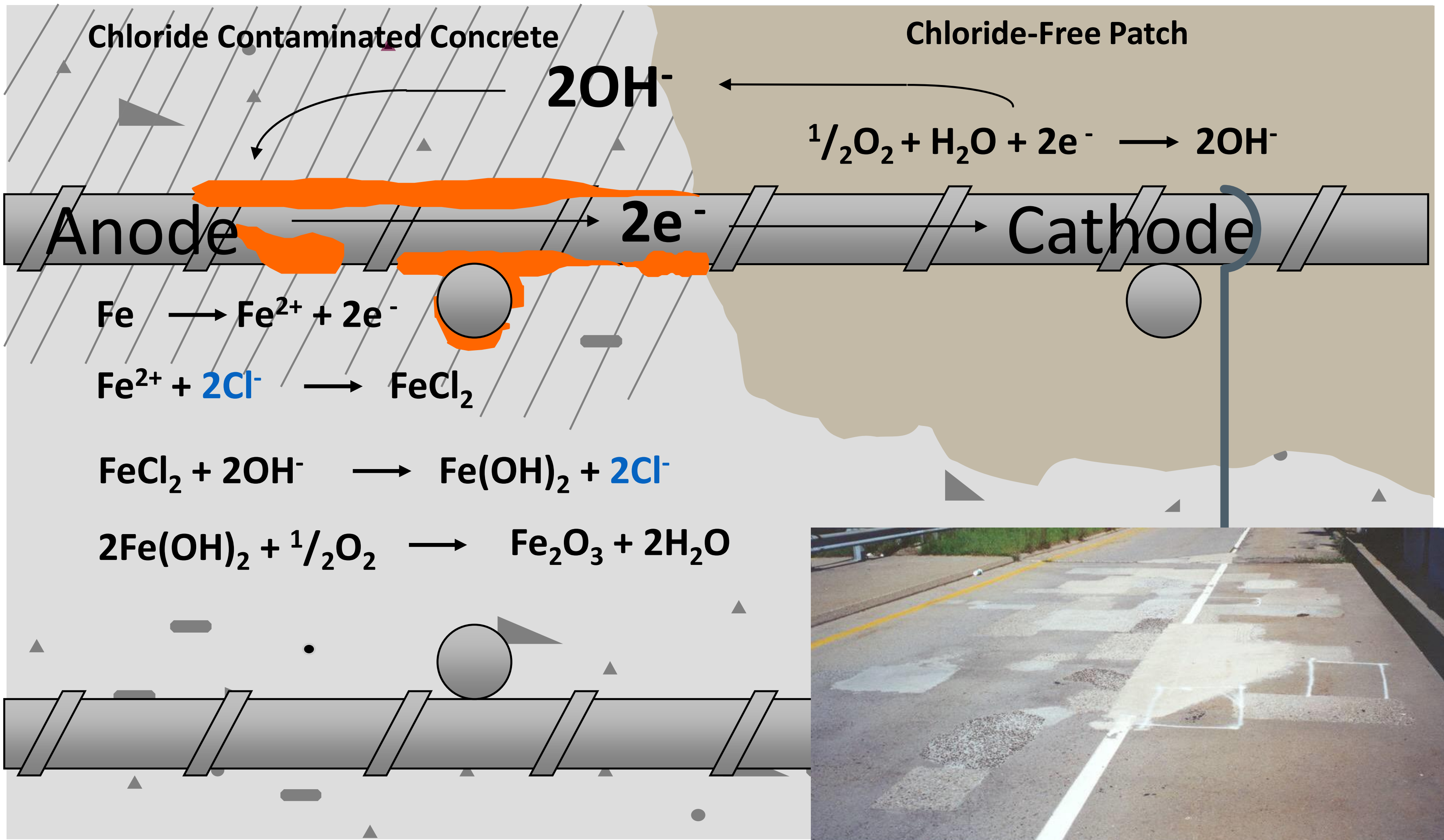


- Damage resulting from
  - Metal section loss and
  - Formation of iron oxide (rust)
  - Expansive properties of iron oxide create tensile stresses in concrete
  - Leads to cracking, delamination, and eventual spalling

Corrosion Induced Damage

- Conventional mild reinforcing bar
  - In most cases loss of steel section not primary concern
  - Damage to concrete becomes significant and observable prior to severe section loss
- High strength steel
  - Minor section loss can have significant effect on strength
  - Can have significant section loss without significant concrete damage

Patch Accelerated Corrosion



Steel Structures

Steel Structures

- Directly exposed to environment
- Primary factors affecting corrosion
  - pH
  - Temperature
  - Moisture
    - Wetting drying cycles
  - Ion content
    - Chlorides, sulfates, etc.
  - Oxygen Content
  - Water Velocity

Source – techknowserv.com

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Dissimilar Metals – Galvanic Corrosion

- Dissimilar metals in direct electrical contact with each other will result in the less noble metal corroding
  - Principal used in galvanic cathodic protection to protect a metal while sacrificing another metal.

Table 1.1 Partial Standard emf Series of Metals

Half-cell	Metal	Standard Electrode Potential E_o(volts) vs. SHE*
Au/Au^{+++}	Gold	+1.498
Pt/Pt^{++}	Platinum	+1.200
Cu/Cu^{++}	Copper	+0.345
$H_2/2H^{+}$	Hydrogen	0.000
Pb/Pb^{++}	Lead	–0.126
Ni/Ni^{++}	Nickel	–0.250
Fe/Fe^{++}	Iron	–0.440
Zn/Zn^{++}	Zinc	–0.763
Al/Al^{+++}	Aluminum	–1.662
Mg/Mg^{++}	Magnesium	–2.363

Less Noble Metal

*** Standard Hydrogen Electrode***

Corrosion Mitigation

Cathodic Protection

- Cathodic protection (CP) is a method of corrosion control through the application of direct current to a metal under protection, forcing it to become a cathode
  - Anode is where rust occur and the cathode is protected from section loss
- Two main types of CP
  - Galvanic
  - Impressed current

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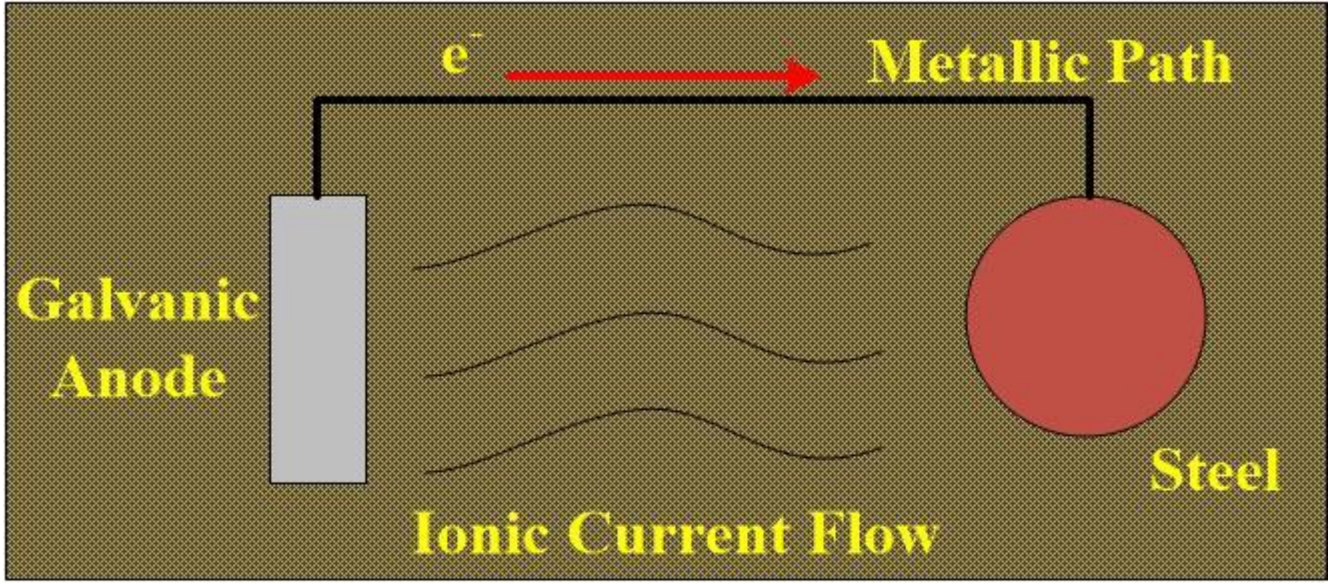

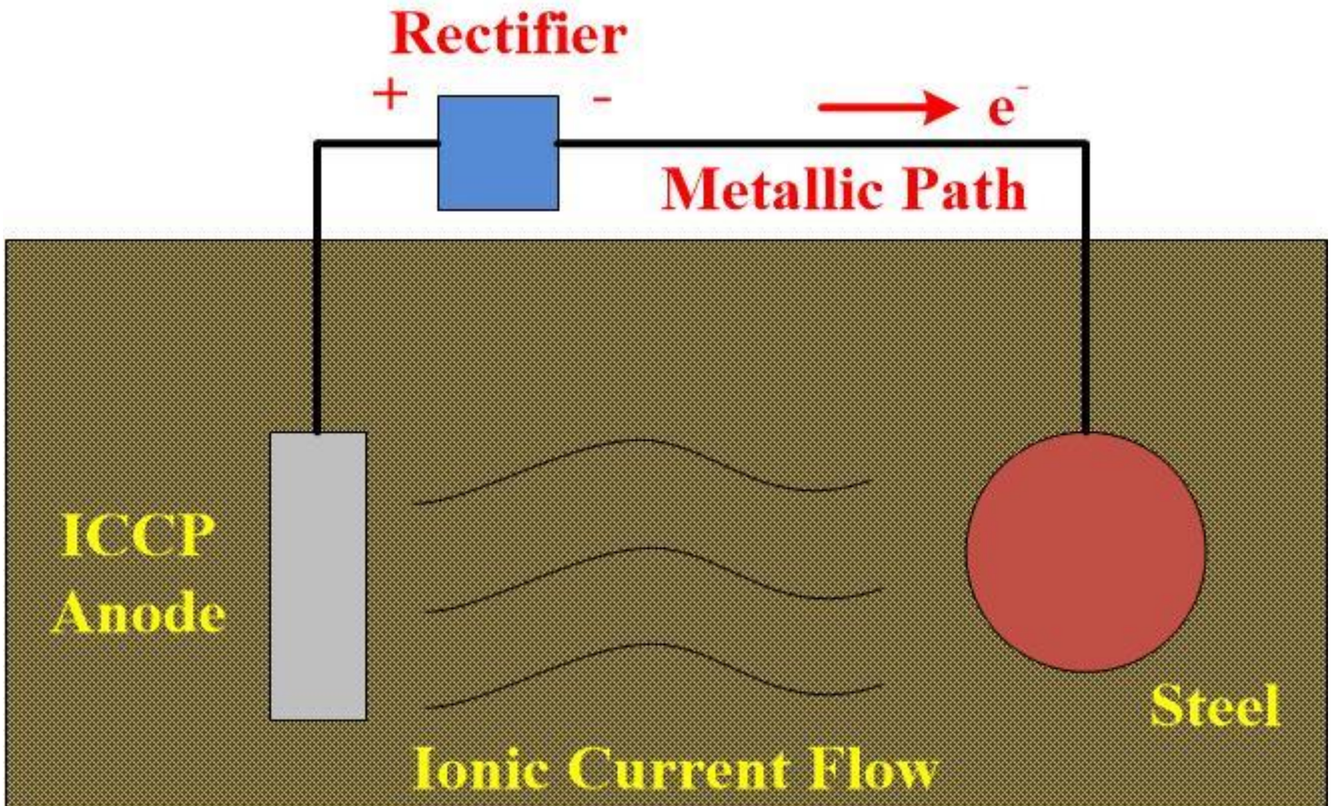

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Impressed vs Galvanic

- Galvanic
  - Typically very low maintenance
  - Self regulating current output based on environment
    - Current output limited
  - Typically less expensive
    - Not always though
  - Limited life span – between 10 to 30 years
- Impressed
  - Provides significantly more current
    - Can reduce number of anodes
  - Long life span
    - Can be over 50 years depending on application
  - Requires maintenance

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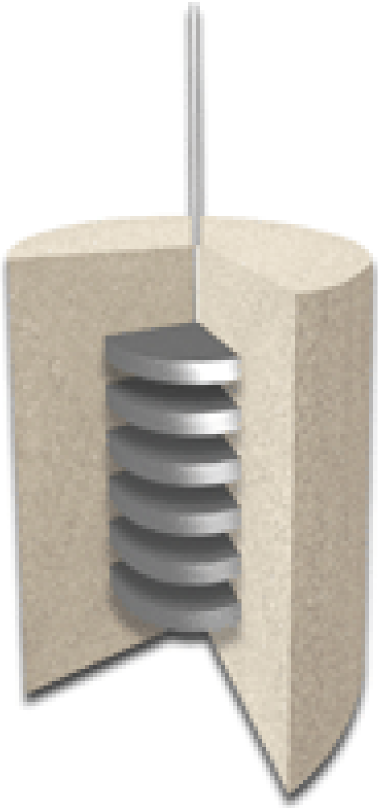
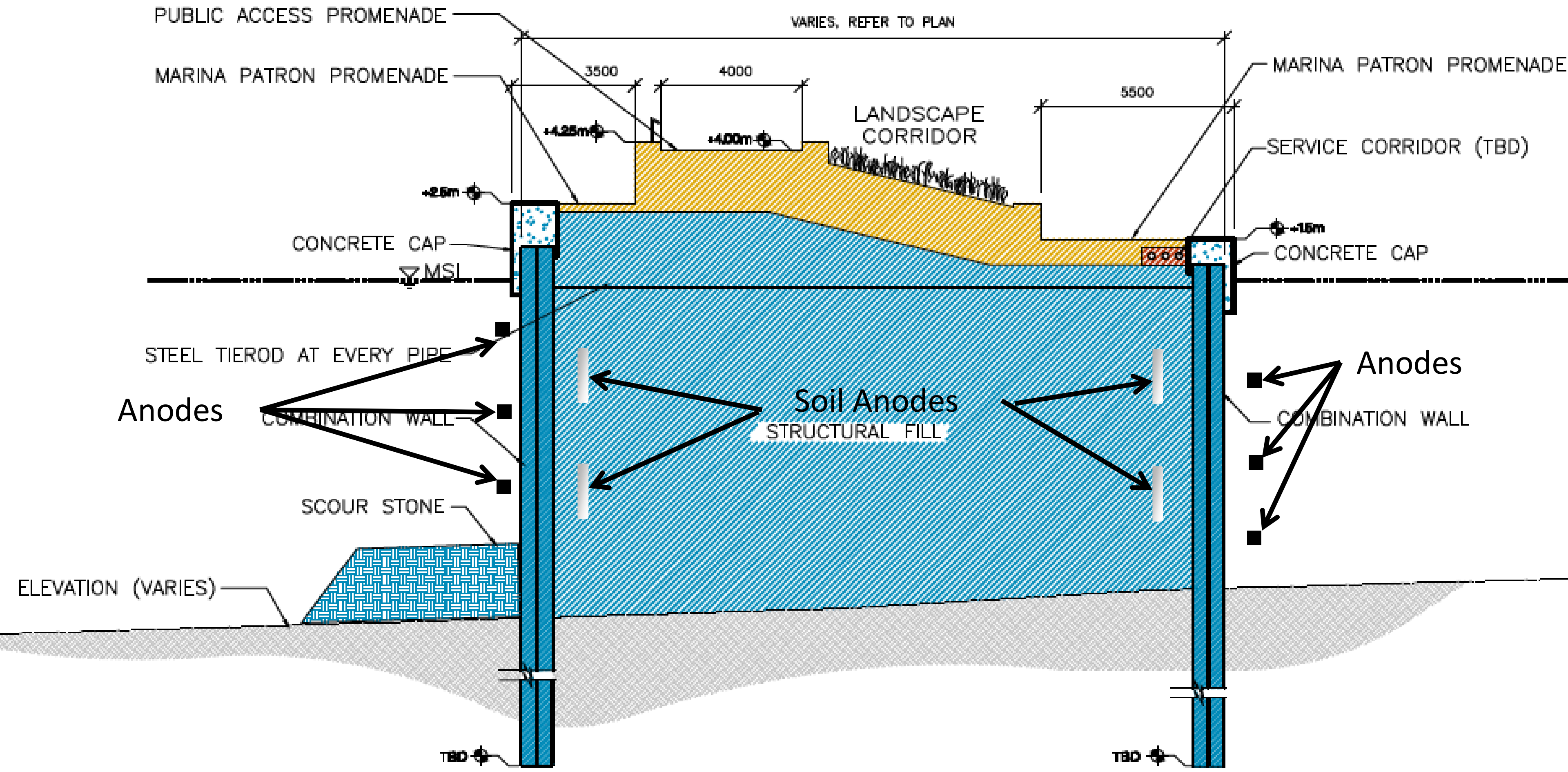
Galvanic CP

- Uses the concept of dissimilar metal corrosion in order to protect steel reinforcing.
  - Anode types;
    - Zinc
    - Aluminum
    - Magnesium
  - All are less noble than steel



Steel Sheet Pile Construction



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Sheet Pile Galvanic CP

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Piles

- Jacketing is the most common repair strategy
  - Critical to have cathodic protection in jackets
  - FDOT discovered accelerated corrosion in jackets without CP
    - Hartt, W.H. and Rapa, M., "Condition Assessment of Jackets Upon Pilings for Florida Bridge Substructures," Final Report, WPI No. 0510803, Florida Department of Transportation, Tallahassee, Florida, April 13, 1998

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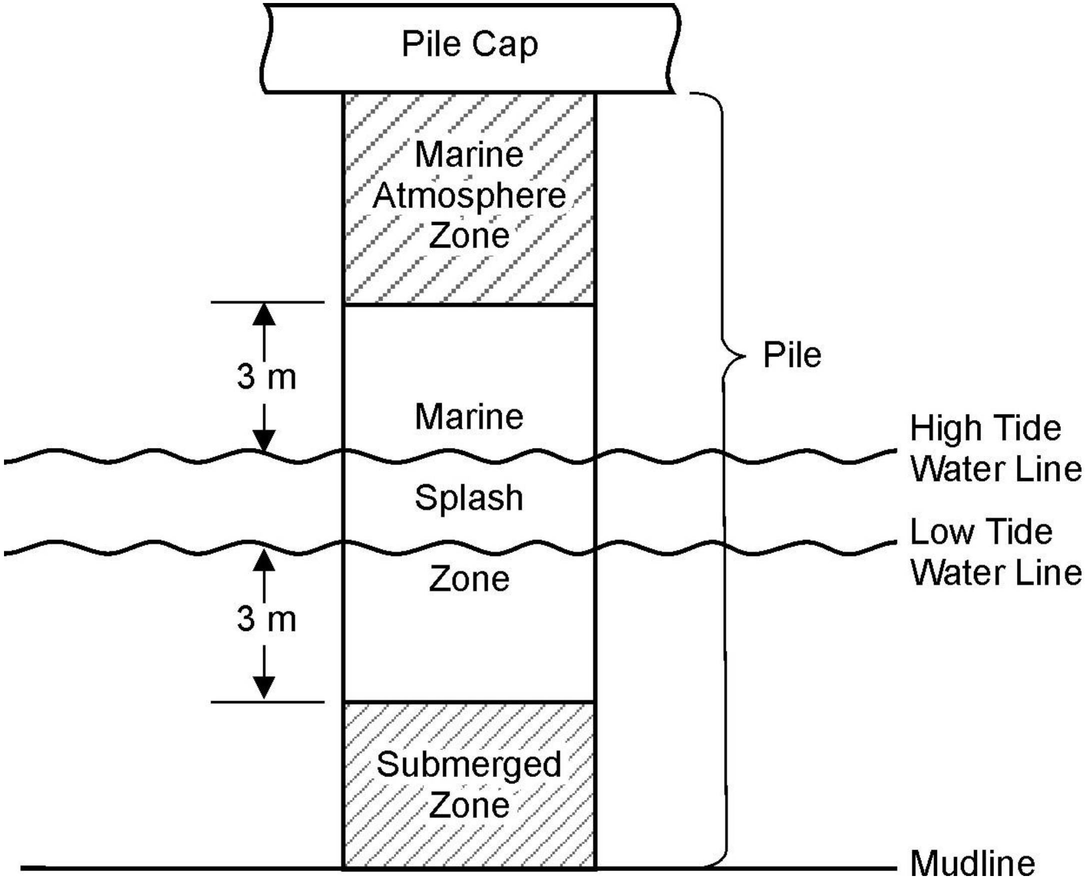
Galvanic CP – Pile Jackets

- Several different types of jackets
- Dependent on the environment
  - Chloride content of water
  - Tidal range



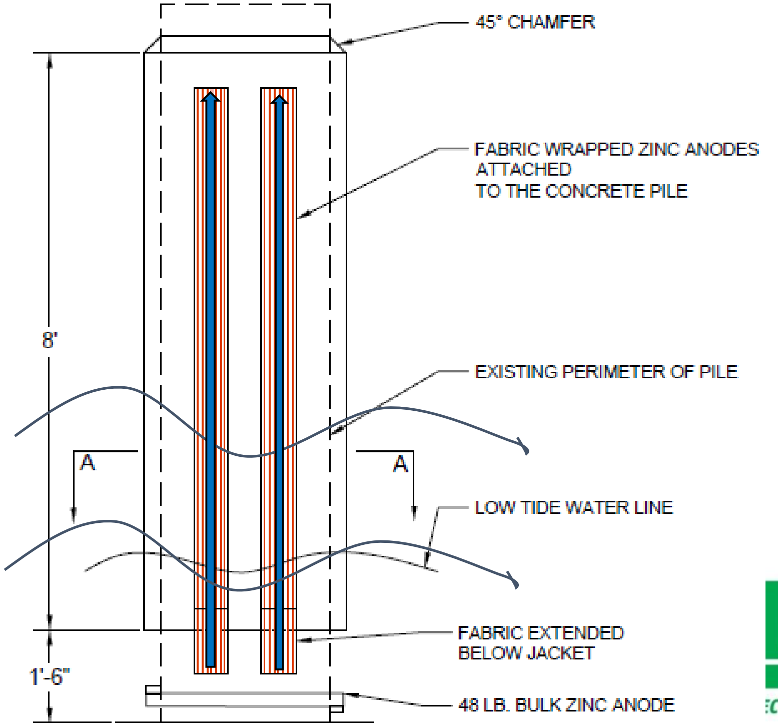
Jacket Installation

Zinc Mesh – Tidal Jacket

- Used only in salt water environments where most of the pile lenght is within the tidal region
  - Requires constant exposure to salt water to keep zinc active

Above Tidal Jacket

- Commonly referred to as "wicking" jackets
- Zinc wrapped in absorbent fabric
  - Draw salt water above tidal region to keep zinc active
- Still uses a bulk anode below the water line



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Alkali Activated Jackets

- Can be used in salt water, above tidal, brackish, freshwater, or non marine environments
    - Uses pH of mortar to activate zinc instead of salt water

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Jacket Research

- VCS in partnership with Vector Corrosion Technologies and Florida Department of Transportation have been trialing new jacket methods on a bridge in the gulf.

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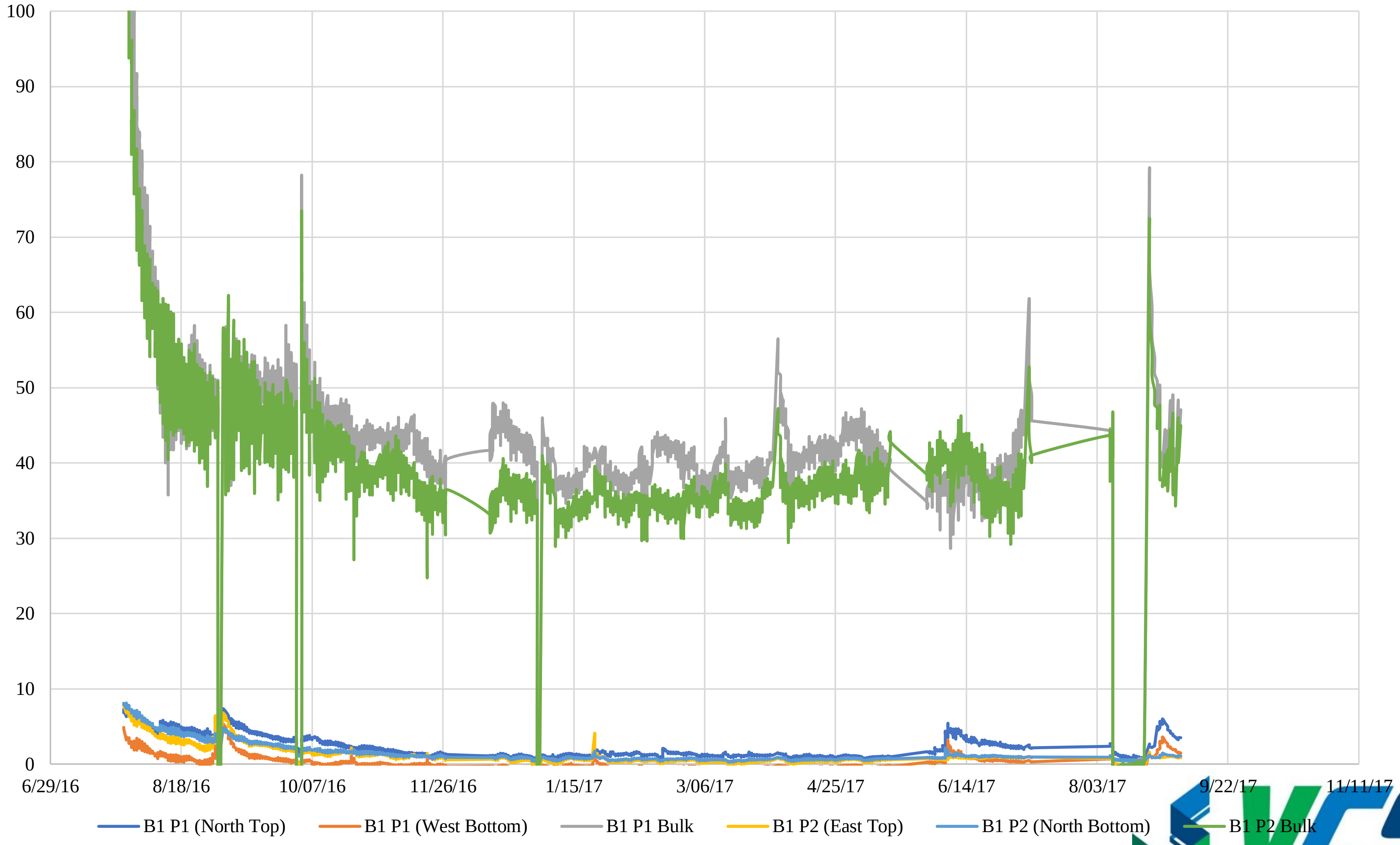
Zinc Mesh



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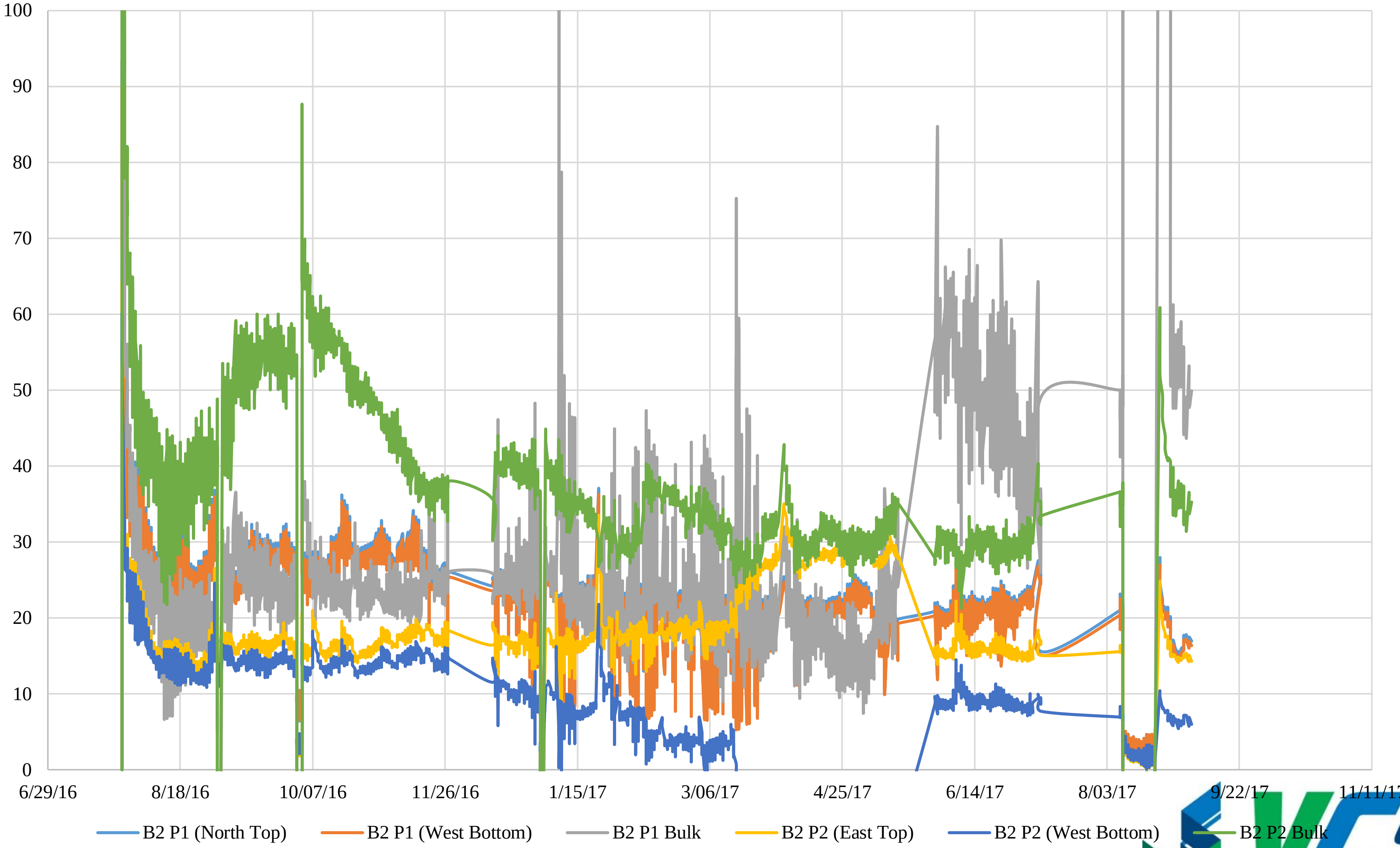
Wicking Jackets



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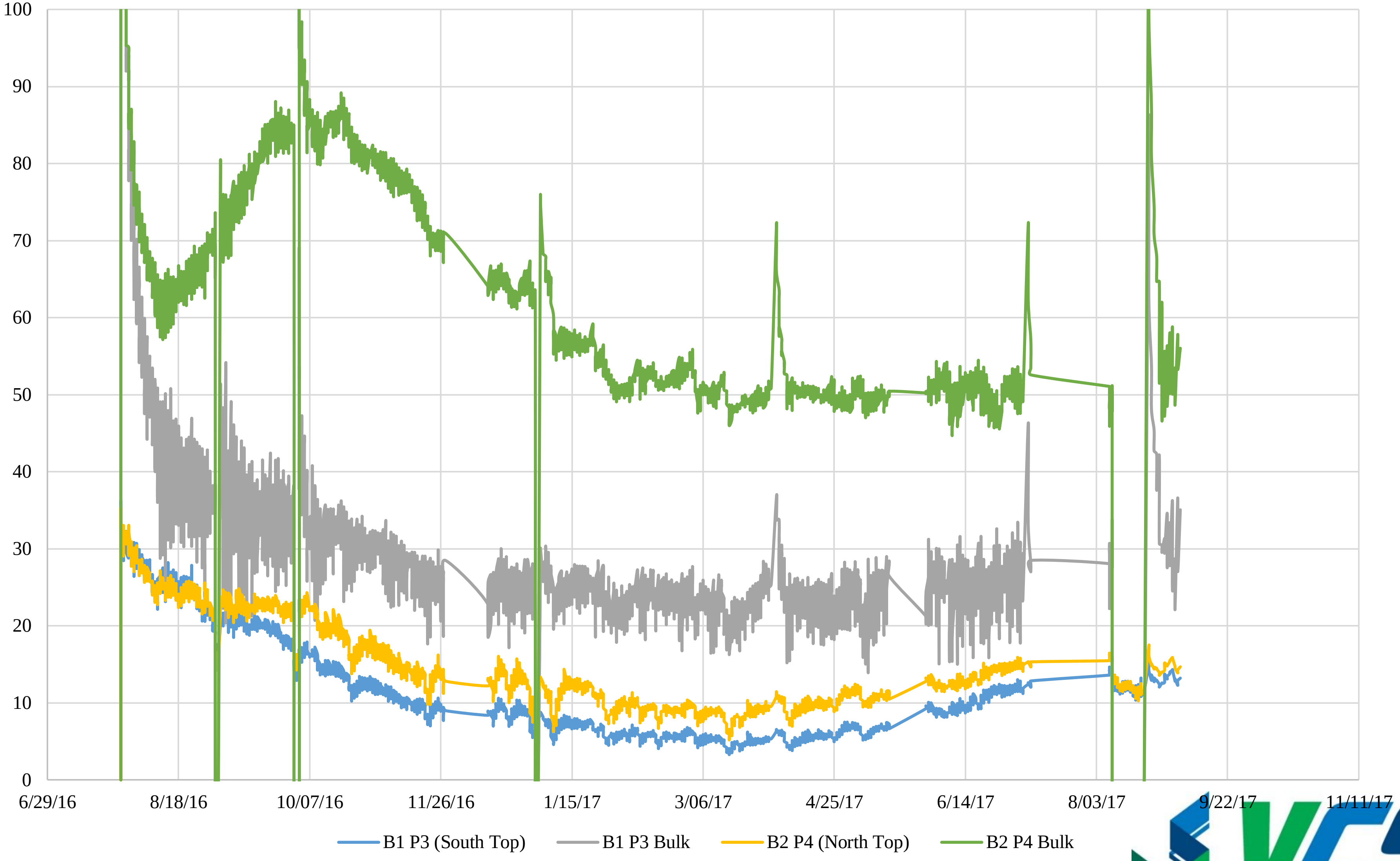
Alkali Activated



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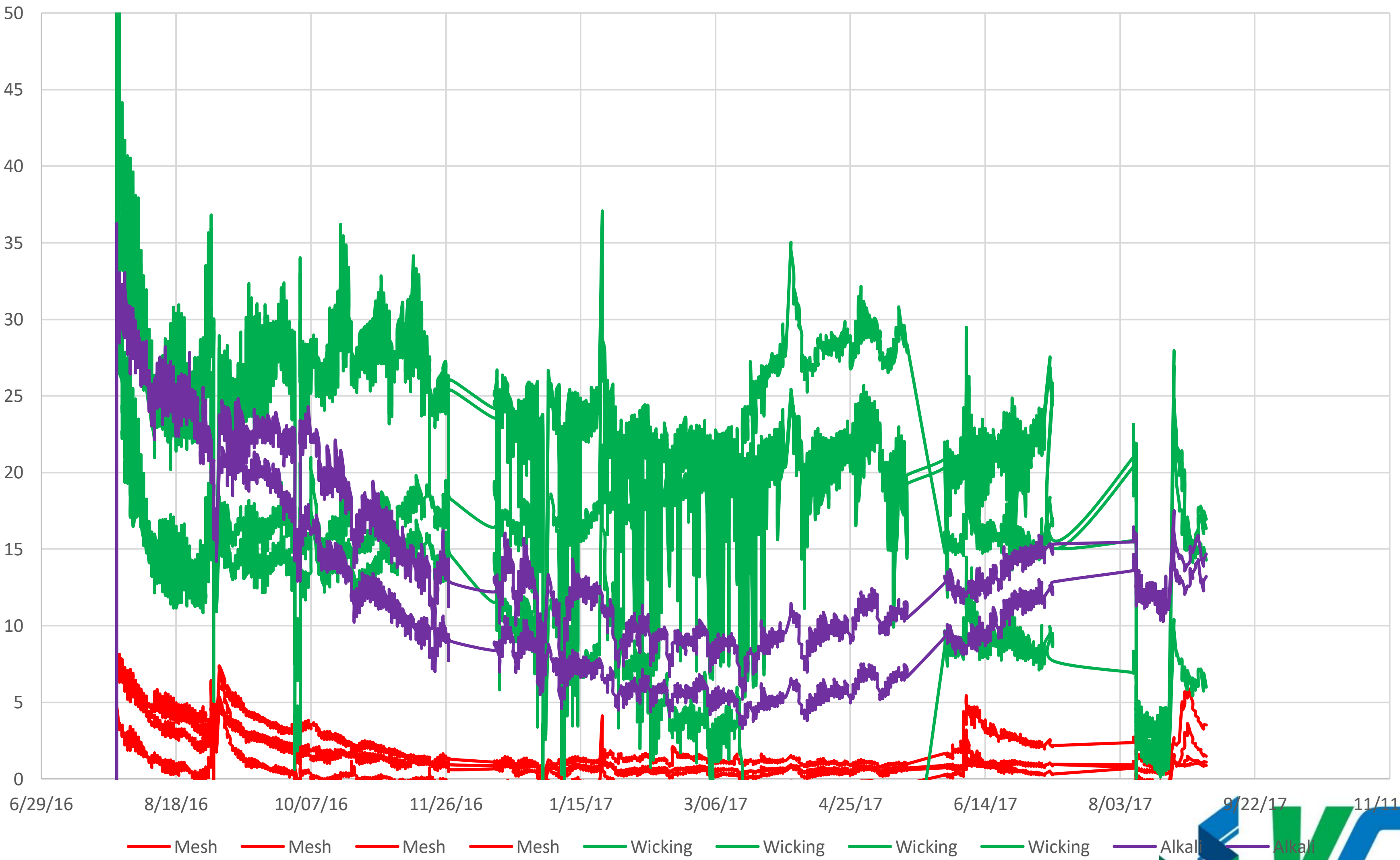
Comparison



50
45
40
35
30
25
20
15
10
5
0
6/29/16
8/18/16
10/07/16
11/26/16
1/15/17
3/06/17
4/25/17
6/14/17
8/03/17
9/22/17
11/11/17
Mesh
Mesh
Mesh
Mesh
Wicking
Wicking
Wicking
Wicking
Alkali
Alkali

Metalizing
Both Galvanic and Impressed

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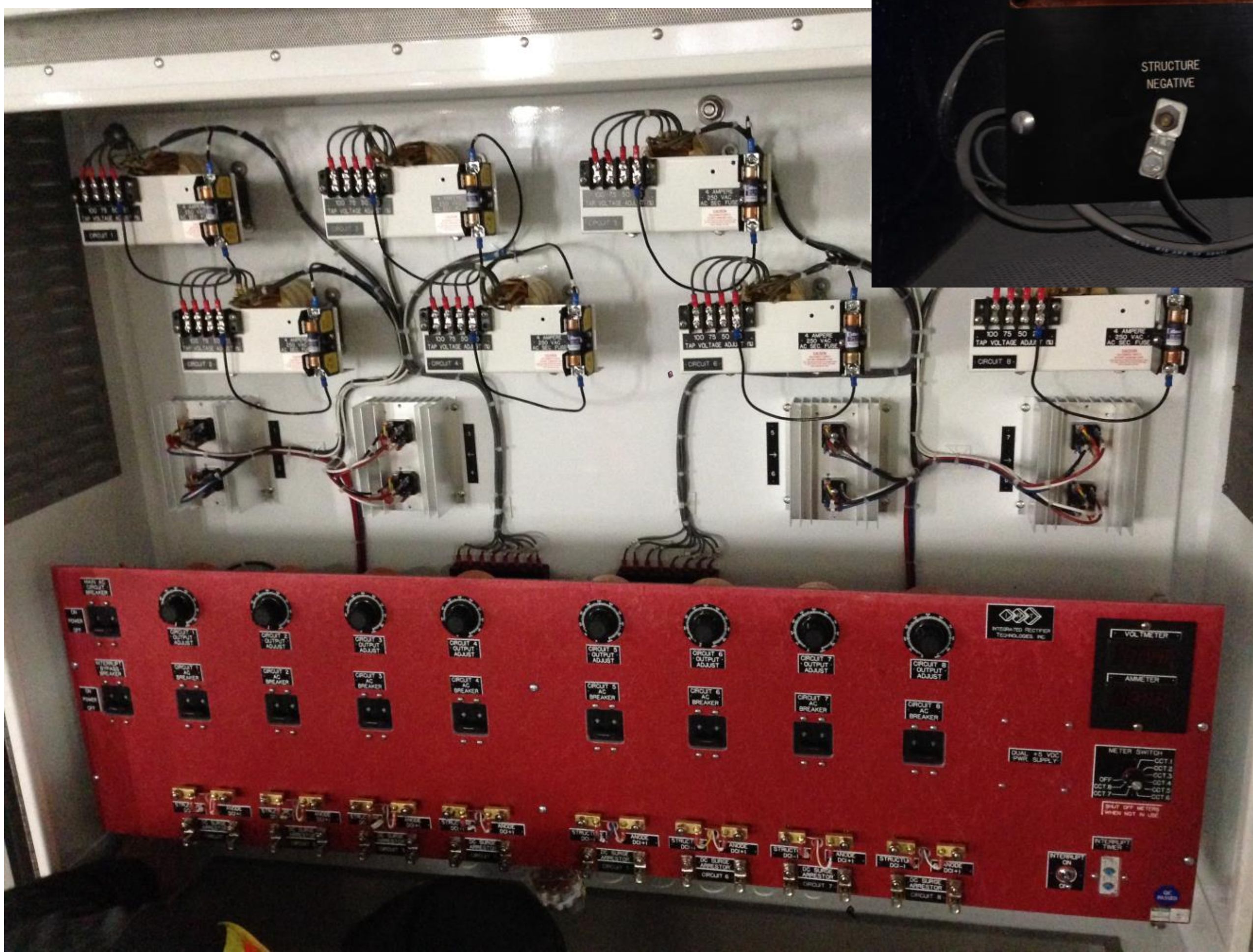
Impressed Current

- Steel elements
  - Bulk anodes
  - Submerged or buried applications
- Concrete elements
  - Ribbon anodes
  - Discrete rode anodes

Power Source



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Questions