# Cathodic Protection of Reinforced Concrete Maritime Structures

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## The Marine Environment

- Water, oxygen and chlorides
  - The perfect recipe for the corrosion of ferrous and other metals
- Living organisms
  - Attach to the metal surface, damage coatings, make inspection difficult
  - Microbial activity can lead to severe corrosion in areas which are normally protected
- Weathering
  - Abrasion and attrition by wave action and sand
  - For concrete, salt damage and chemical attack by sulfates plus corrosion of the reinforcement



## The Marine Environment

## Reinforced Concrete in a Marine Environment

- Reinforced concrete offers the advantage of a good level of self protection against the environment
  - Chlorides & Biomass
    - Needs to be designed to resist sulfates
  - Impact & Abrasion



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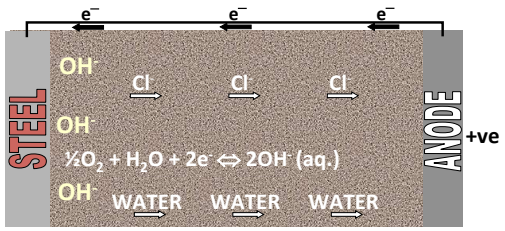
- The mass of concrete can also be beneficial in resisting service loads, especially for free standing structures
- Cathodic protection (CP) offers the opportunity to extend service in new and existing structures
  - CP already widely used on iron and steel marine structures such as jetties, piers and sheet pilings
  - CP now commonly applied to reinforced concrete infrastructures such as bridges and tunnels
    - Typically for remediation rather than for new



## CP of Reinforced Concrete in a Marine Environment

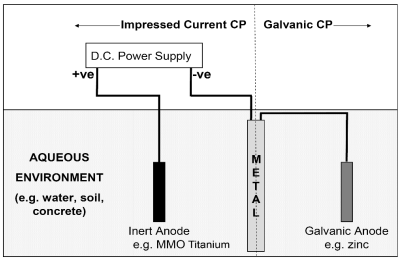
- CP can be beneficial in providing corrosion protection to the reinforcement of marine structures for:
  - Old structures where the chlorides are starting to reach the depth of the reinforcement
  - Damaged structures as part of a durable repair
  - New structures where extended, maintenance-free service lives are required

## CP in Reinforced Concrete






## Cathodic Protection - Impressed or Galvanic?






## Cathodic Protection - Impressed or Galvanic?

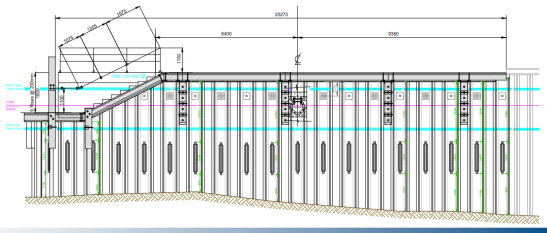
- IMPRESSED
  - Generally simpler to design based on existing standards and codes of practice
  - Requires monitoring and maintenance but can be adjusted
  - Long lives (50 years and over) can be achieved
- GALVANIC
  - Very long track record (193 years)
  - More difficult to design as standards and guidance for steel in seawater are not appropriate
  - Design relies on trials to establish performance characteristics
  - Long lives require large masses of sacrificial metal
    - e.g. 150 tons of aluminum to protect 1 mile of seawall for 50 years

## CP of Reinforced Concrete vs Ferrous Structures

- CP of steel, cast and wrought iron marine structures can only provide full protection to the permanently wetted areas plus some protection to the tidal zone
  - Tidal and splash zones typically require additional measures (e.g. coatings or corrosion allowance)

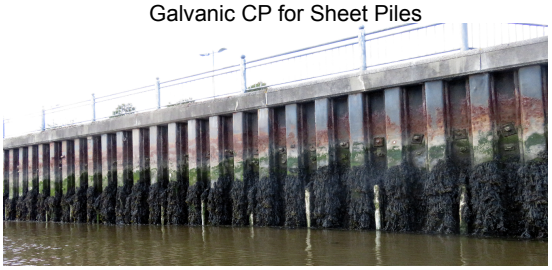


## Galvanic CP for Sheet Piles





## Galvanic CP for Sheet Piles



## Galvanic Anodes
- at installation



## Galvanic Anodes
- at replacement



## CP of Reinforced Concrete vs Ferrous Structures

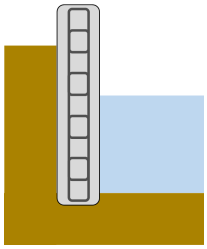
- CP of steel, cast and wrought iron marine structures can only provide full protection to the permanently wetted areas plus some protection to the tidal zone
  - Tidal and splash zones typically require additional measures (e.g. coatings or corrosion allowance)
- CP of reinforced concrete works with the existing cover to provide full cover to approximately 1m (3ft) above mid-tide level
  - Additional protection can be provided to the splash zone by 'conventional' reinforced concrete CP (discrete anodes, ribbon, mesh and overlay, cassettes)

CP of Reinforced Concrete - Options

- CP can be applied to reinforced concrete marine structures in several ways:



Reinforced Concrete Harbor Wall

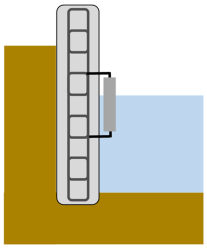




CP of Reinforced Concrete - Options

- CP can be applied to reinforced concrete marine structures in several ways:
  - Galvanic CP
    - Trials required to refine design
    - Large installations may require support frames

Option 1:
Galvanic CP

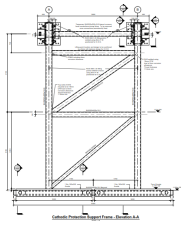


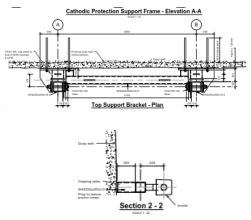


Aluminum
Galvanic
Anodes
- Concrete
Encased Piles



Galvanic Anode Support Frame

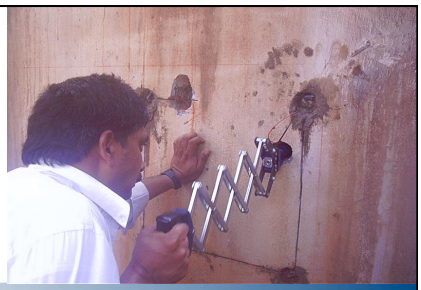




Galvanic Anodes for Trial Installation



Cored-In Galvanic Anodes





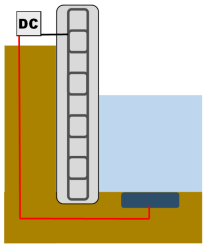
Cored-In Galvanic Anode CP

## CP of Reinforced Concrete - Options

- CP can be applied to reinforced concrete marine structures in several ways:
  - Galvanic CP
    - Trials required to refine design
    - Large installations may require support frames
  - Impressed CP
    - Marine anodes plus RC anodes if required
    - RC anodes to protect the splash zone

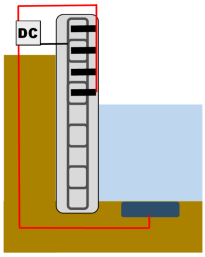


## Option 2: Impressed CP – Marine Anodes





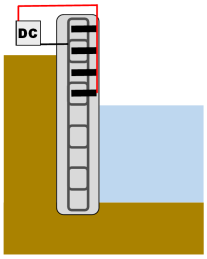

## Option 3: Impressed CP – Marine & RC Anodes



Marine Anodes plus Discrete Anodes in Splash Zone



Option 4: Impressed CP – Splash Zone Only



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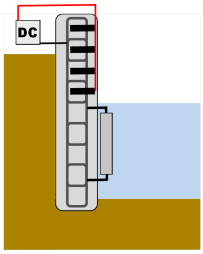
  - Galvanic CP
    - Trials required to refine design
    - Large installations may require support frames
  - Impressed CP
    - Marine anodes plus RC anodes if required
    - RC anodes to protect the splash zone
  - Hybrid Systems
    - Galvanic plus impressed working together

## Option 5: Hybrid CP – Impressed & Galvanic Anodes






## Access for Investigation and Installation

- Special provisions are likely to be required to achieve safe access during the investigation and installation phases
  - Sequencing works to the tides
  - Additional safety provisions for working over water



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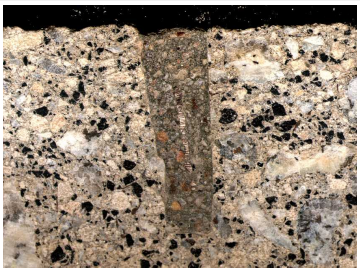
  - Sequencing works to the tides
  - Additional safety provisions for working over water
- Curing of repairs and anode grouts needs to be timed to avoid wash-out
  - May require temporary protection
  - Some designs more suitable than others

## Impressed Ribbons in Slots



## Impressed Ribbons in Slots





## To Conclude

- CP can be applied effectively to reinforced concrete marine structures
- Impressed, galvanic and hybrid systems can all be employed
  - Likely to require trials to determine optimum design
- Tidal conditions make access more challenging
  - Also makes interpreting monitoring results more difficult



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