PIANC APAC 2024
3RD PIANC ASIA PACIFIC CONFERENCE
27-30 AUGUST 2024
SYDNEY, AUSTRALIA
www.piancapac.com
Connecting Asia Pacific ports in a changing world

SUSTAINABLE LONG-TERM PROTECTION OF REINFORCED CONCRETE PORT STRUCTURES

Andrew Dickinson

Vector Corrosion Technologies

Concrete Preservation and Sustainability

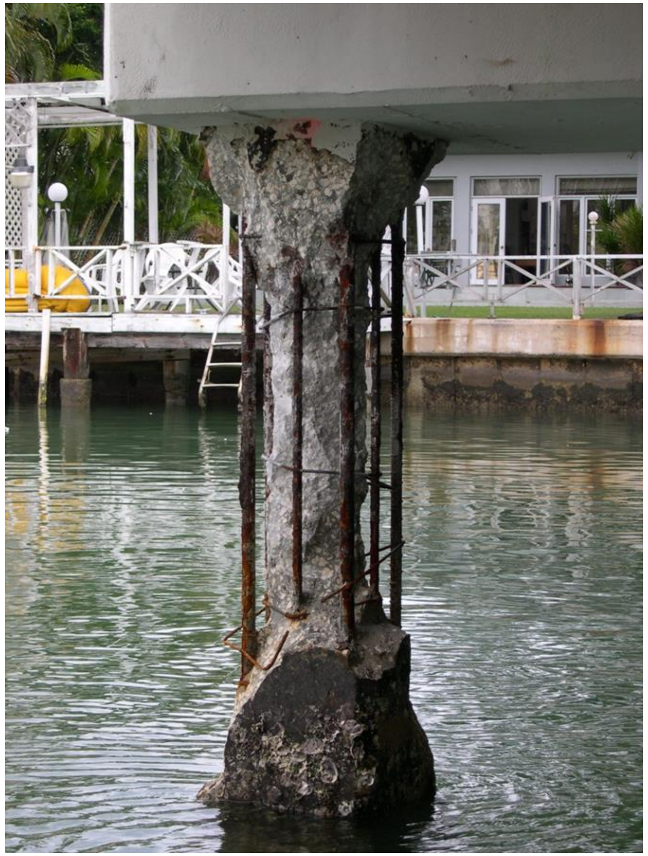
It is estimated that up to 40% of solid waste derives from construction and demolition.

For every 10,000 m3 of concrete preserved :

- 24,000 mt of rubble is kept from the landfill and a similar amount of natural resources are conserved.
- Conserves enough potable water to fulfill the daily needs of 3,000 people
- Avoids carbon dioxide generation equivalent to the annual emission of 1,600 people

Corrosion Preservation Economic Impact

A 2002 federal study, initiated by NACE stated that
Corrosion Costs and Preventive Strategies in the United States, backed by the U.S. Federal Highway Administration, estimated annual costs at the time of **$276 billion.**



The cost of corrosion-related maintenance of infrastructure (e.g. Ports and Bridges) in Australia is currently estimated to be **$A8 billion**. (Sept 2020, ACA)

Options to extend the life of the asset

- Do nothing – regular monitoring
- Localised spalling repairs
- Discreet anodes in patch repairs to extend the repairs life
- Distributed Galvanic Cathodic protection
- Impressed Current Cathodic Protection (ICCP)
- Two stage protection – ICCP and Galvanic cathodic protection combined
- Chloride Extraction
- Protection Coatings eg Silanes

* Options selection all depend on condition of asset, life extension desired and budget available

Installed Distributed Anode

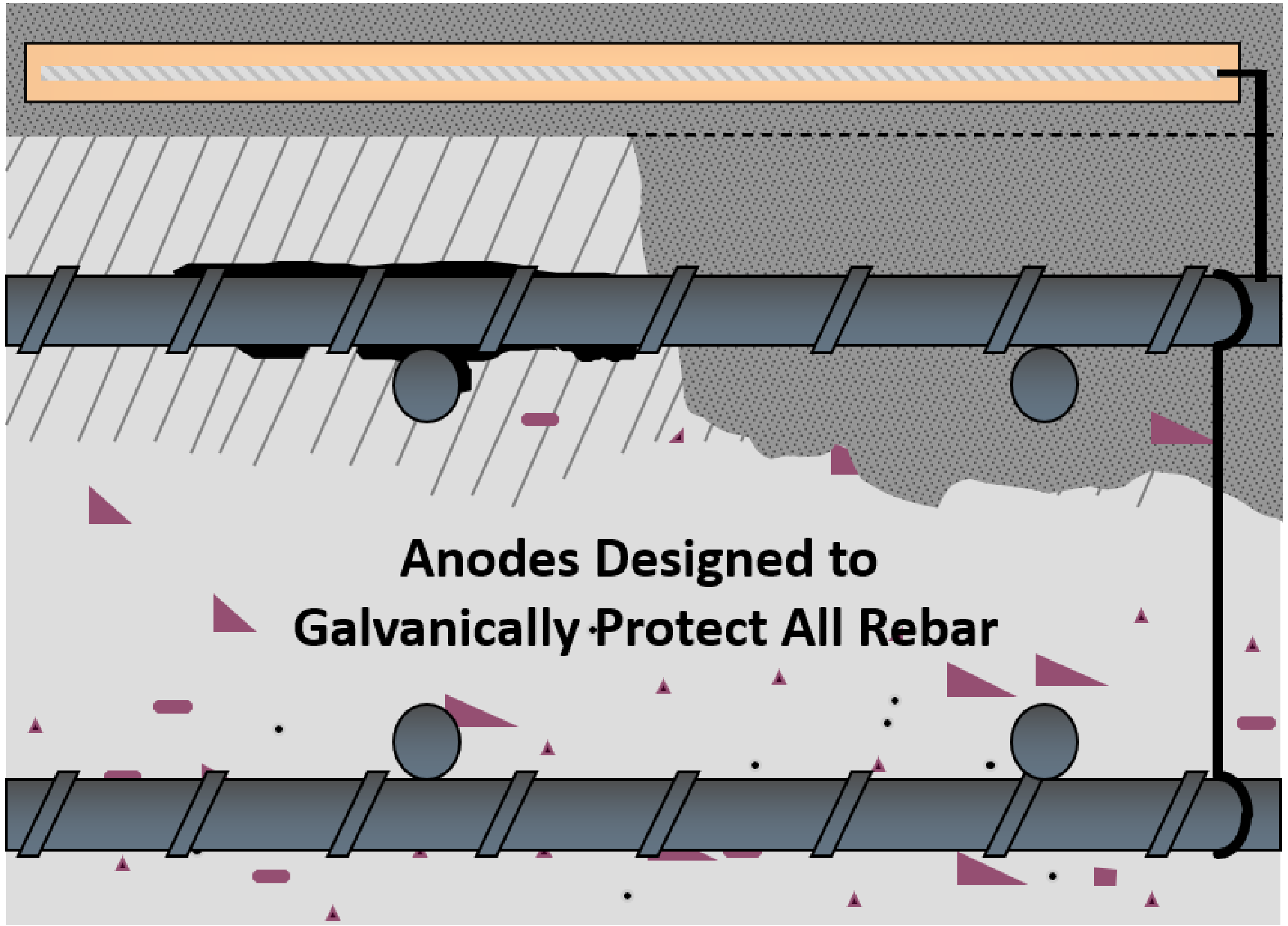
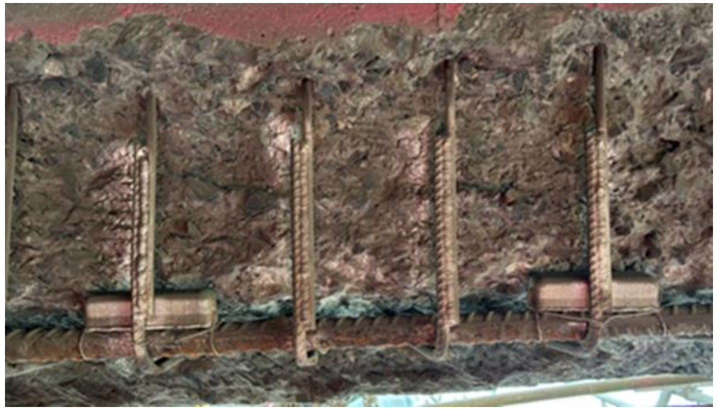


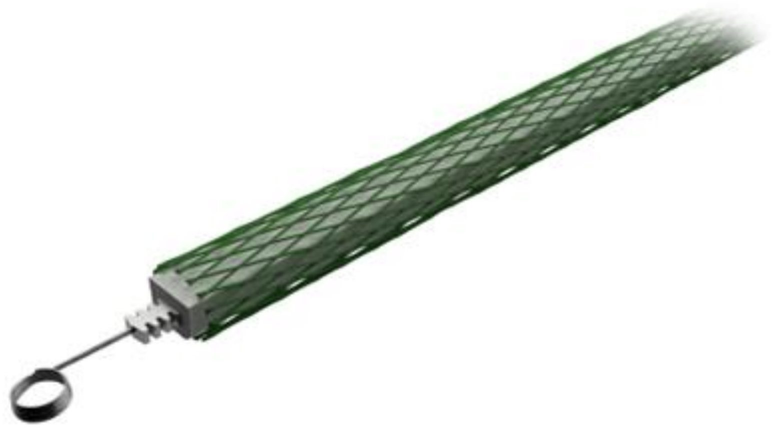
Table 2: Practical Galvanic Series in Seawater

Metal	Volts vs. Cu-CuSO$_4$
Active or Anodic End	
Magnesium	–1.60 to –1.75
Zinc	–1.10
Aluminum	–1.05
Clean Carbon Steel	–0.50 to –0.80
Rusted Carbon Steel	–0.20 to –0.50
Cast/Ductile Iron	–0.50
Lead	–0.50
Steel in Concrete	–0.20
Copper	–0.20
High Silicon Iron	–0.20
Carbon, Graphite	+0.30
Noble or Cathodic End	



Applications for Distributed Protection

- Joint Repairs
- Large beam repairs
- Deck widening or extensions (new to old joint interfaces)
- Concrete overbuilds such as headstocks and pile caps
- Galvanic cathodic protection jackets for piles



North Otter Creek Bridge, Ontario

- Pre-cast anode DAS anodes 12mm x 50mm 2.4M length installed at 300mm spacings
- A carbon fibre mesh was used to prevent or reduce shrinkage cracks in the concrete overlay.
- Each junction box contained a system on/off switch and a precision resistor. This arrangement and the installed MEP allowed the anode current to be measured and the current density generated by the anodes

Completed Project

Long Term Monitoring since 2003

Highway 9 North Otter Creek Bridge DAS

Time (days)	Temp (oC)	Current Density (mA/m2)	Depolarization (mV)
13	7	6.5	273
33	10	6.1	238
61	11	3.5	57
222	20	3.8	271
258	23	2.6	220
267	21	2.5	260
336	23	1.7	211
426	8	1.4	230
486	-20	0.55	142
571	3	1.4	293
676	20	1.8	313
766	8	1.3	284
859	-7	0.8	167
942	10	1.4	330
1165	7	1.24	281

Time (days)	Temp (oC)	Current Density (mA/m2)	Depolarization (mV)
1299	-3	1	201
1573	0	7.6	322
1649	3	1.1	314
1755	20	1.6	421
2000	-5	0.65	273
3174	22	1.8	278
3646	23	1.13	128*
4300	25	1.08	432
5140	23	0.6	202
5383	20	0.57	181
5770	23	0.66	212
6150	23	0.23	185
6554	22	0.59	174
6825	24	0.53	141
7239	28	0.58	161
Average	13.0667	1.877	226.3

The last monitoring was on August16，2023

- The values were averaged to determine a polarization value for the system.
- All embedded instrumentation was backfilled with concrete containing the typical amount of chloride found in the deck (at the reinforcement level).
- Except for winter months when the bridge deck froze and current and corrosion potential readings were not reliable,
- Sufficient current was being supplied by the anodes to meet the 100 mV criteria as per AS2832.5 & NACE criteria
- Exceptions are readings in winter when bridge was frozen

Port of Canaveral North Cargo Piers

North Cargo Piers Restoration, Port of Canaveral, Cape Canaveral, Florida

- 4 cargo piers
  - Bulk cargo: cement, slag, salt, lumber, automobiles
  - 626 meters of docking space with 11,000 m2 total
- Major restoration with 20-year design life
- April 2005 to December 2006

Corrosion Induced Damage

Scope of Repair works

- Pile Caps
- Prestressed Piles
- Precast Deck Units

Pile Cap Repair

- 2,000 meters of pile cap repair
- Remove bottom 20 cm
- Install distributed strip anodes
  - 4 cm x 4 cm x 2.5 m
- Form and Pour Repair

Distributed Anode Strips for Pile Caps

Pile Repair

- 668 Prestressed Piles
  - 450 mm square
- Remove damaged concrete
- Install Galvanic Jackets
  - 56 cm and 71 cm square
  - 2 to 10 meters in length
  - Stay-in-place FRP Form
  - 7.8 kg/m2 zinc mesh anodes
  - 22 kg bulk zinc anodes
- Concrete is pumped into ports from the bottom up

North Cargo Piers Sustainability outcomes

- 6651m3 of reinforced concrete were preserved with concrete repair and galvanic cathodic protection.
- 15,952 tons of solid waste avoided
- 15,464 tones of natural resources were not used including cement, aggregate and steel.
- 814,748 Litres of potable water were not used, enough for the daily needs of 2,201 people
- 20,744 GJ of heat generation was avoided, enough to boil 26 Olympic-size pools
- 18,848 pounds of NO2 and SO2 pollution were avoided
- 4,310 tons of CO2 production was prevented

CONCRETE PRESERVATION IMPACT STATEMENT
NORTH CARGO PIERS REHABILITATION
PORT CANAVERAL, FLORIDA, USA

Based on the information provided, preserving and extending the service life of this structure will provide the following benefits:

- 17618 tons of solid waste will be kept out of landfills.
- 17128 of new natural resources will be conserved, including cement, aggregate and steel.
- 220120 gallons of potable water - enough for the daily needs of 2201 people - will be conserved.
- 20746 GJ of heat generation - enough to boil 26 Olympic-size pools - will be conserved.
- 10848 pounds of NO_x and SO_2 pollution is avoided.
- 4756 tons of CO_2 production - the equivalent to the annual emissions of 1081 people - is prevented.

Inputs

Volume of concrete to be preserved	8700	yd3	6651	m3

Outputs

Emissions

Concrete C02	2290	US tons	2075	metric tons
Steel C02	2466	US tons	2235	metric tons
Total Carbon Dioxide	4756	US tons	4310	metric tons
Equivalent to annual CO2 emission of:	1081	people	1078	people
NOx (as NO2)	8480	lbs	3782	kg
SO2	2368	lbs	1056	kg
Total Pollutants	952429	lbs	431492	kg

Waste Generation

Solid Waste (Rubble)	17618	US tons	15962	metric tons
Energy (heat generation from cement production, cement hydration, and steel production)	20746	GJ	19691	GJ
Equivalent energy to boiling	26	Olympic Pools	24	Olympic Pools

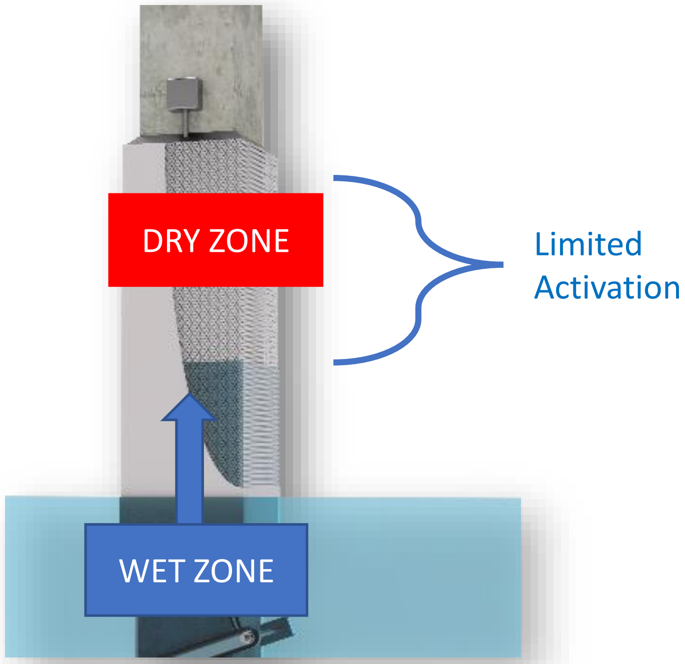
Natural Resources Required

Fine aggregate	4581	US Tons	4150	metric tons
Coarse aggregate	7223	US Tons	6545	metric tons
Cement	3915	US Tons	3492	metric tons
Steel	1409	US Tons	1277	metric tons
Total tons	17128	US Tons	15464	metric tons
Potable Water	220120	gal	814748	liters
Equiv. daily water usage for:	2201	people	2037	people

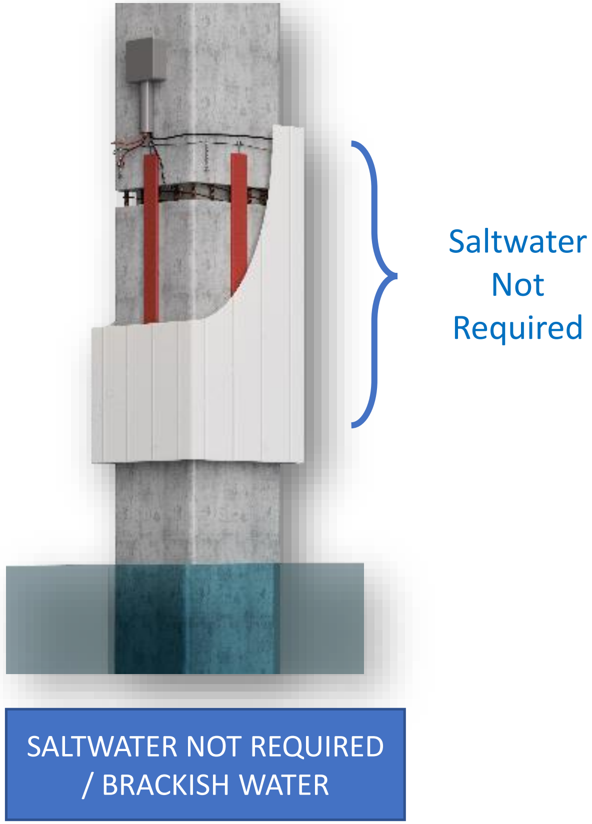
VECTOR

Jacket Evolution

1st Gen Tidal (Mesh)



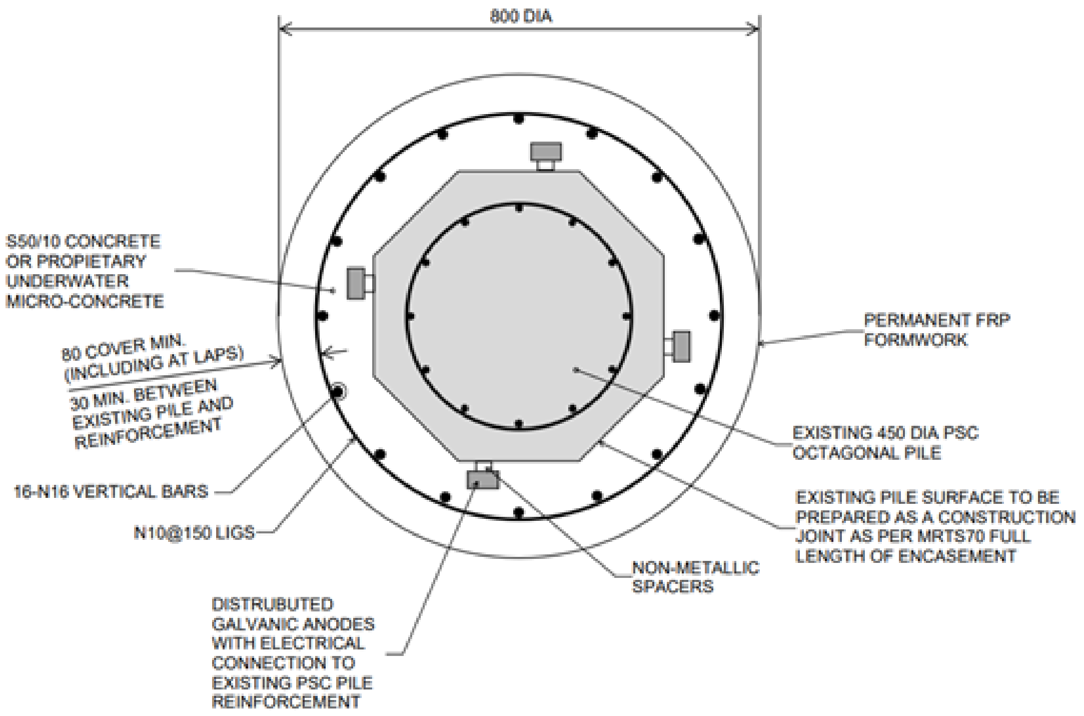
Alkali Activated
Dry Areas Land / Marine



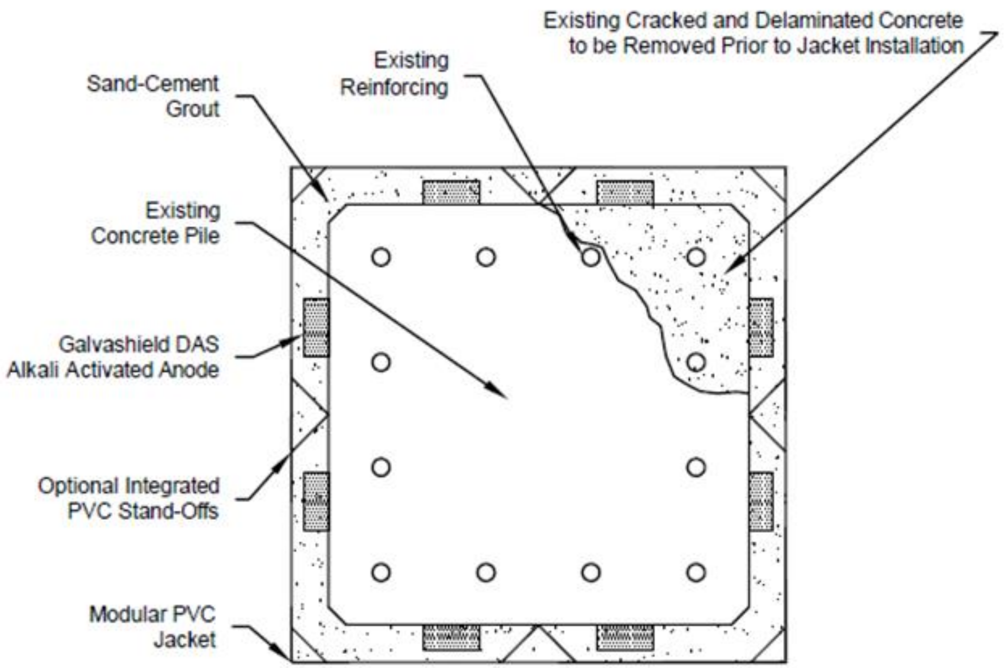
Alkali Activated Anodes used in:

- Saltwater
- Brackish water
- Fresh water and
- Dry land applications.

Typical Layouts



PILE ENCASEMENT - TYPICAL SECTION



Pile Protection with Marine DAS
HMAS Platypus (2012)

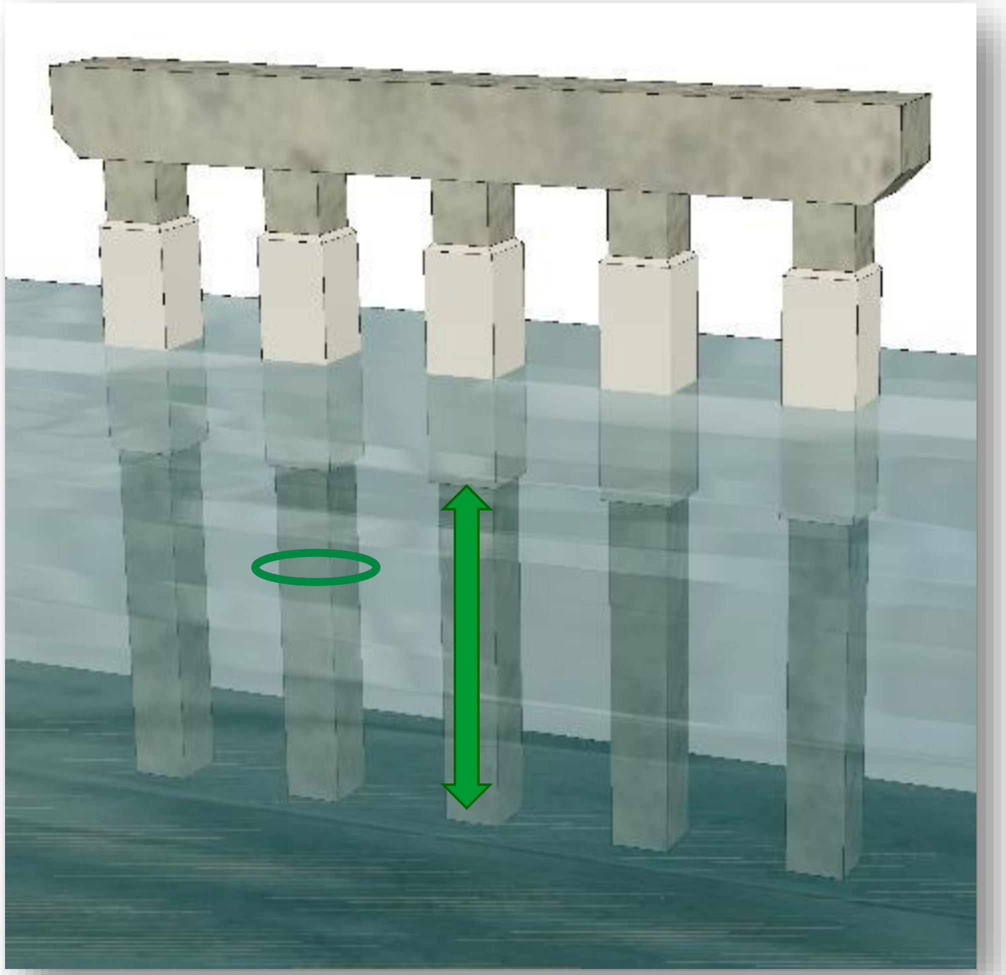
Applications on pile caps in overbuilds

M Ali, H. Madrio, S Salek 2023 “Case Study of Sacrificial Anode Cathodic Protection with Concrete Encasement” 2023, ACA conference, Perth

Bulk Anode Underwater

Design Considerations?

- Can a different alloy be utilized as a bulk anode
- What size of anode should be used?
- Considerations in design
  - Continuity of piles
  - Condition of piles
  - Spacing - are piles in close proximity?
  - Amount of steel to protect
  - Design life required



Bulk Water Anode

Environmental Concerns?

Zinc Toxicity

- Zinc is a heavy metal, but is also an important nutrient
- Toxicity develops when you have too much in the environment
  - Different species metabolize zinc differently,
  - Toxic concentration varies by species
- Excessive concentrations buildup in ports, shipyards, near point sources like foundries

EPA Limits

- Acute: saltwater exposure 170 μg/L max; Varies with hardness in fresh water
- Chronic: saltwater exposure for 24 hr. 58 μg/L; freshwater exposure for 24 hr., 47 μg/L
- Aluminum not toxic, not regulated

Bulk Anode Selection

Conclusions

- Alkali-activated distributed anodes have been used on reinforced concrete structures throughout North America for 20 years and in Australia for nearly 15 years.
- The anodes have been used in a variety of environments de-icing salts to marine exposure and have been installed in nearly all states in Australia
- They do not require an external power source to energize the system or ongoing means it can provide a safer, easier and potentially more cost-effective option
- No ongoing maintenance or monitoring commitment for the Port owner
- Long term monitoring has demonstrated that the anode systems can be designed to satisfy AS2832.5 & NACE 0216-2023 cathodic protection criteria while providing low maintenance cathodic protection for up to 30 years.
- Galvanic cathodic protection systems can provide a sustainable, low maintenance and cost-effective option for asset owners to extend the service life of corroding reinforced concrete structures compared to replacement.

Thank You – Questions?

Andrew Dickinson
andrewd@vector-corrosion.com
www.vector-corrosion.com