PILE DRIVING CONSTRUCTION

Sheet Pile Corrosion Protection

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WHAT IS CORROSION

Corrosion Affecting Design Life of Piling Infrastructure

American Association of State Highway Transportation Officials (AASHTO) *Load and Resistance Factor Design (LRFD) Bridge Specification* requires a 75-year structure design life.

How is Corrosion Defined

Site specific corrosion investigations are needed to determine the corrosivity of a site and to provide appropriate corrosion mitigation measures to obtain the desired design lives.

What are the Factors that Contribute to Corrosion

- the presence of soluble salts,
- soil and water resistivity,
- soil and water pH, and
- the presence of oxygen.

Characterization of Corrosion is a Complicated Process

Corrosion of metals is an electrochemical process involving oxidation (anodic) and reduction (cathodic) reactions on metal surfaces. For metals in soil or water, corrosion is typically a result of contact with soluble salts found in the soil or water. This process requires moisture to form solutions of the soluble salts. Factors that influence the rate and amount of corrosion include the amount of moisture, the conductivity of the solution (soil and/or water), the hydrogen activity of the solution (pH), and the oxygen concentration (aeration). Other factors such as soil organic content, soil porosity, and texture indirectly affect corrosion of metals in soil by affecting the other factors listed above.

STEEL GRADES AND IMPACT ON CORROSION

ASTM Steel Grades Typically Used in Piling Applications

A572 covers the standard requirements for Grades 42, 50, 55, 60, and 65 of high-strength low-alloy columbium-vanadium structural shapes like sheet piles. The alloy shall conform to the required contents of columbium, vanadium, titanium, and nitrogen. Permissible values for the product thickness and size is given. Tensile requirements (including yield point, tensile strength, and minimum elongation) and alloy content are also specified.

A690 specification deals with the standard structural quality of high-strength low-alloy nickel, copper, phosphorus steel piling for use in the construction of dock walls, bulkheads, excavations, and like applications in marine environments. The steel shall be semi-killed or killed and shall be exposed to the washing action of rain and the drying action of wind or sun, or both to determine its atmospheric corrosion resistance. Material specimens shall undergo product analysis, heat analysis, and tension testing and shall conform to the required chemical composition, tolerance, tensile strength, yield point, and elongation specifications.

A588 is a high-strength low-alloy steel which is resistant to atmospheric corrosion over regular carbon steel which develops a protective oxide film on the steel surface which slows corrosion. These steels have been used in a variety of applications such as bridges, transmission towers, and cranes since the steel can be used in these unpainted applications to reduce on maintenance costs such as coatings. A588 material can be substituted for A572 steel however ASTM has different welding practices between to the two grades.

Sacrificial Thickness / Higher Strength Steel

- Additional steel thickness is used to meet the corrosion loss over a defined period thus ensuring the structure can perform as intended over its design life.
- Higher strength steel, similar to sacrificial thickness, builds a corrosion allowance guaranteeing the structure performs as intended with steel loss
- The above methods may be used depending on the soil conditions and/or the level of corrosiveness of the environment

COATINGS FOR STEEL SHEET PILING

Overview

- The classic corrosion protection for steel sheet piling is surface coating. Coating systems are used to protect against corrosion as well as providing an aesthetic appeal.
- A **coating system may consist of one or two primers followed by a top coat**. A **zinc primer** is often chosen for its good corrosion-inhibiting properties. The top coat is chosen for chemical resistance and or for resistance to mechanical damage such as abrasion during installation or in service.
- Generally **epoxies are used for sea water immersion and chemical resistance,** polyurethanes for color and gloss retention.
- Steel sheet piles continuously or partially immersed in seawater require careful attention. Abrasion and impact (direct or indirect) may damage the coating system and soluble salts will accelerate the rate of corrosion at the damaged areas. For long term performance in seawater immersion there should be no compromise on quality. Surface preparation must be good, the application must be properly carried out and of course, the coating must be of high quality and chosen for its specific mechanical properties.

Properties for a Quality Coating

- Excellent **resistance to water/seawater**
- Good **impact** resistance
- Excellent **flexibility, hardness, and adhesion**
- High build **16 to 26 mils** (406 to 660 microns) in one or two coats
- Touch **dry relatively quickly** (approx.3 hours at 77°F (25°C)
- Can **be brush or spray** applied
- **Environmentally** friendly
- Exceeds **Corp** of Engineers **C-200, C200a**
- Exceeds **AWWA C-210** for exterior

Polyamide based coating systems will offer a viable less carcinogenic replacement for base coal tar epoxy.

Coatings - Options

- International Coatings:
  - Intercure 200 Primer: Rapid cure two component epoxy zinc
  - Interzone 505 Intermediate: Glass flake epoxy
  - Interthane 990 Top Coat: Two component polyurethane finish

- ICE Devoe
  - Bar Rust 235 Primer: Two component epoxy semi gloss coating
  - Devguard 238 Intermediate: Anti abrasion glassflake coating
  - Devthane 379 Top Coat: Urethane gloss finish

- Sherwin Williams
  - Duraplate 235 Primer: Two component epoxy
  - Duraplate 154 Intermediate: Two component amine epoxy coating
  - Acrolon 218 Top coat: Acrylic polyurethane

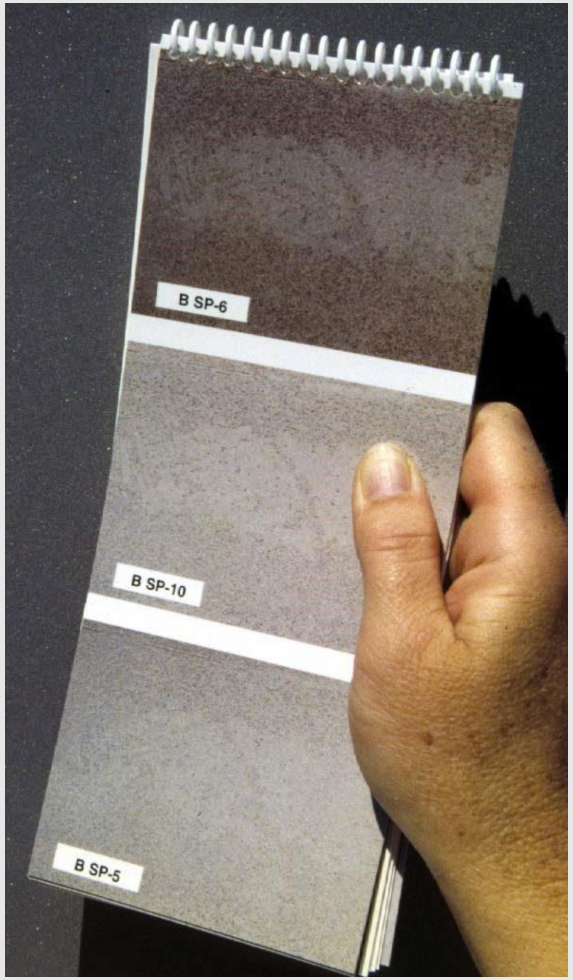
Coatings - Options

- US Coatings:
  - Epoxy Grip 2100 Primer: Rapid cure epoxy
  - Epoxy Grip 2200 Flake Glass Intermediate: Glass flake epoxy
  - Uregrip 3000 top coat: Acrylic urethane finish
- Ameron
  - Amercoat 385 primer: Two component polyamide cured epoxy
  - Amercoat 400 Intermediate: High solids epoxy
  - Amercoat 450 Top Coat: Urethane top coat
- Jotun
  - Primastic AV: Two component epoxy mastic
  - Baltoflake Eco Life Intermediate: Abrasion resistant glass flake polyester coating
  - Hardtop urethane enamel: Polyurethane top coat

Surface Preparation

- Hot rolled steel has a surface oxide layer known as **millscale.** The very high surface temperature combined with high roller pressures result in a smooth, bluish grey surface layer. This **bluish oxide laye**r is brittle and only partly adherent to the steel surface. When exposed to air and water corrosion will spread under the millscale causing it to flake off. If millscale is coated corrosion will take place under the coating eventually causing the coating to break down. **Abrasive blasting** to a recognized standard is the most efficient and recognized way for cleaning steel. The blasting also roughens the steel surface providing a good bond for the adhesion of the coating.

SSPC-SP 10 near-white metal blast cleaning (NACE No. 2) is a standard used for near-white metal blast cleaning put forth by the Society for Protective Coatings (SSPC) and NACE International Standard. ... SSPC-SP 10/NACE No. 2 removes all dust, coating, and mill scale.



Coating Types

1. **Coal Tar Epoxy**

   For decades, the most popular method to protect sheet piles has been coal tar epoxy coatings due to the low cost, high resistance to exposure in sea-water, oil and chemicals. These coating systems are very much still in use however environmental concerns along with performance constraints have led to the markets embrace of improved coal tar epoxy coatings and newer alternatives to coal tar epoxies.

   Coal tar epoxy problems can arise during the application such as delamination between multiple coats, poor adhesion, and long cure times. These issues can hinder the applicator’s production rates and lead to premature coating failures once the sheet piles are in service.

Coating Types

2. **Polyamide Coatings**

   Newer coal tar replacement coatings are provided by a number of manufacturers and are typically based on a polyamide chemistry. These are designed as environmentally friendly alternatives to hazardous coal tar epoxies.

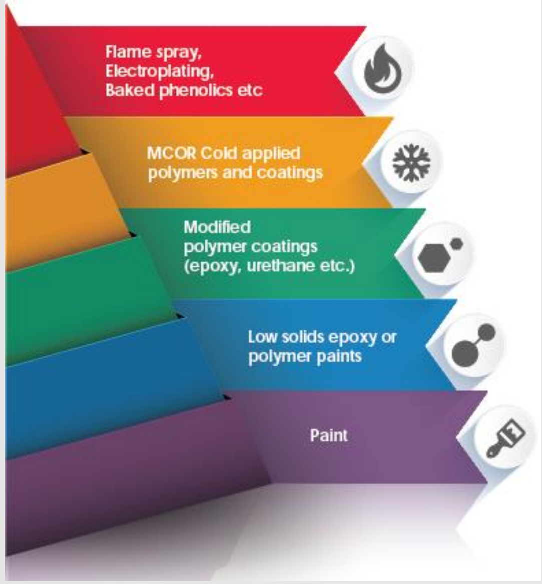
3. **Glass Flake Epoxy Coatings**

   Glass Flake coatings are ideal for applications where there is expected to be impact and high abrasion exposure conditions.

Coating Types

3. **Epoxy and Polymer Cementitious Coatings**

   Other coating combinations are offered by some manufacturers for improved performance such as an epoxy and polymer modified cementitious coatings. These incorporate the benefits of copolymer and epoxy resin by combining them into a water based cementitious system to give a hard, durable coating with excellent resistance to water, chloride ions, oxygen and aggressive chemicals.

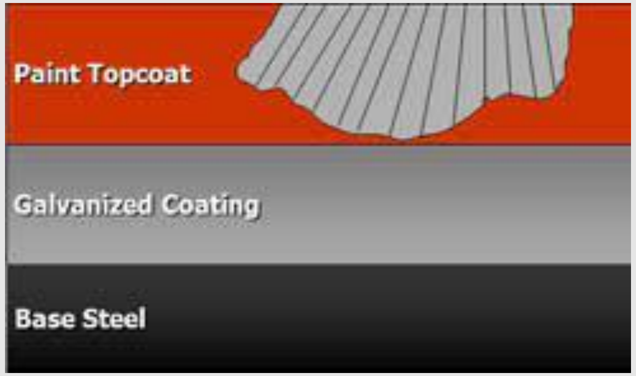


Higher Performance

4. **Duplex Coating System**

   Duplex coatings consist of a combination of hot dip galvanization and traditional epoxy coating systems.

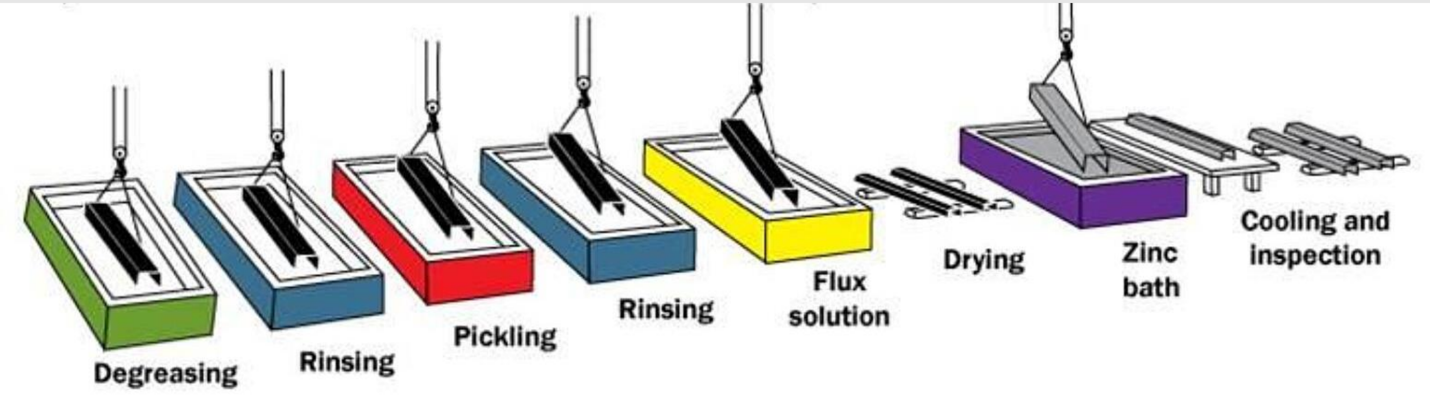
   While it is not a standard application, it might be required on special projects.



HOT DIP GALVANIZING FOR CORROSION PROTECTION

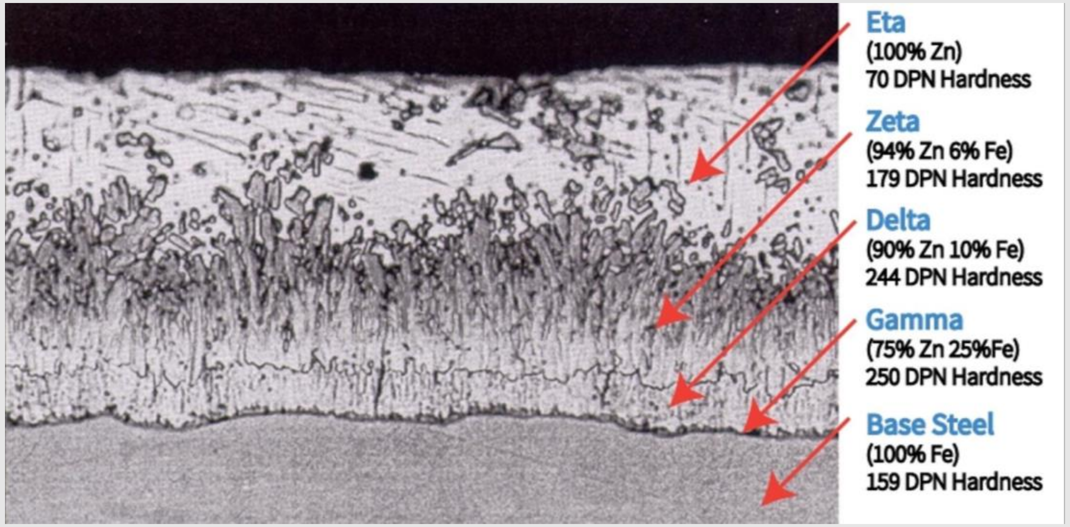
The Process

- Steel is cleaned in a three part method. **Caustic cleaning** removes contaminants. Steel is then inserted into a **pickle bath** to remove mill scale and oxides. The third step is **pre-flux** where an acidic solution provides a protective layer to prevent oxide formation prior to immersion into the galvanizing bath.
- The steel is then completely **immersed into a 98% pure zinc bath** at a temperature of **815 F**. The steel is lowered by a crane hoist at an angle and at around 3 feet per minute rate. This is to allow air to escape as the molten zinc displaces the air. After approximately 5 -7 minutes of complete immersion the steel reaches the bath temperature and the metallurgical reaction is complete. A magnetic thickness gauge is used to verify thickness.



Galvanized Coating

- A cross section of the galvanized coating shows the various layers. The **first layer is approx. 75% zinc** and 25% steel. The **next layer is 90% zinc** and 10% steel. The **third layer, 94% zinc** and 6% steel followed by the last layer which forms as the steel is withdrawn from the zinc bath.



The reaction that takes place is a diffusion reaction between the steel and the zinc. A crystalline structure forms perpendicular to the surface. A benefit of this is that corners have as thick a layer as flat surfaces.

Galvanized Coating – Marine Environments

- Galvanizing provides a **barrier against corrosion** by forming a layer of less noble metal that will sacrifice itself to protect the steel until it is consumed by corrosion. The **zinc becomes anodic to the steel** thus **cathodically protecting** the steel surface.

  The zinc will form a **corrosion layer or 'patina'** that slows the corrosion process particularly in atmospheric conditions. The formation of the patina is critical in delivering long term corrosion protection.

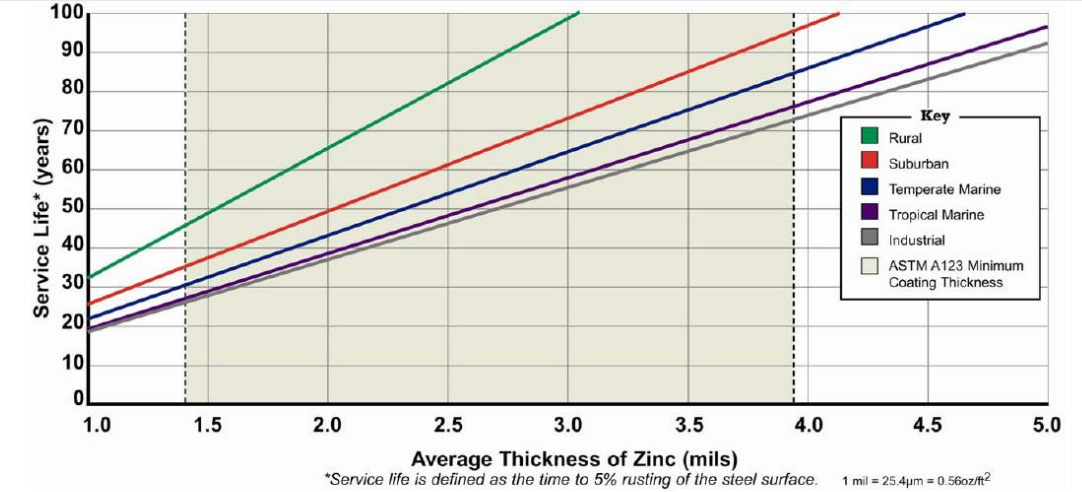
- The exception to this is in a marine environment where the **patina may not be able to form completely** due to **chloride contamination** or is consistently prevented from forming for example, due to **wave action** in the splash zone of a sea wall. Without the protection of a patina layer the zinc thickness will be quickly consumed allowing the steel to corrode.

- The following plot of service life against galvanized thickness is based on a patina layer remaining intact throughout the steel's life.

Service Life Estimate

- A galvanized structure in an inland environment according to ASTM A123 (standard specification for hot-dip galvanizing), steel with a 0.25 inch thickness will require a galvanized thickness of 3.9 mils.
  Other ASTM standards relating to hot-dip galvanizing are A153 (steel hardware) and A767 (rebar for concrete reinforcement).

For atmospheric exposure zones only



Galvanizing Cost/Recommendations

- **Galvanizing Cost**

  Hot-dip galvanizing **costs can comparable to typical polyamide coating systems** and thus can be considered as a competitive alternative to a coating application where conditions are favorable for its use. One advantage for hot-dip galvanizing, in the correct application, is its lifespan compared to a coating system. A typical coating will have a service life of 10-20 years whereas the life of hot-dip galvanizing can be considerably longer in atmospheric exposure conditions.

- **Galvanizing Specification / recommendations**

  Hot-Dipped Zinc Galvanizing **meets ASTM A123**.
  Recommended for non-tidal, fresh water applications.
  Salt water negates corrosion prevention.
  Galvanize sheet piles in full length. Lengths greater than 40 ft require ‘double dipping’ which increases cost.
  Not cost effective for longer/heavier sheet piles due to cost based on weight vs coating area.

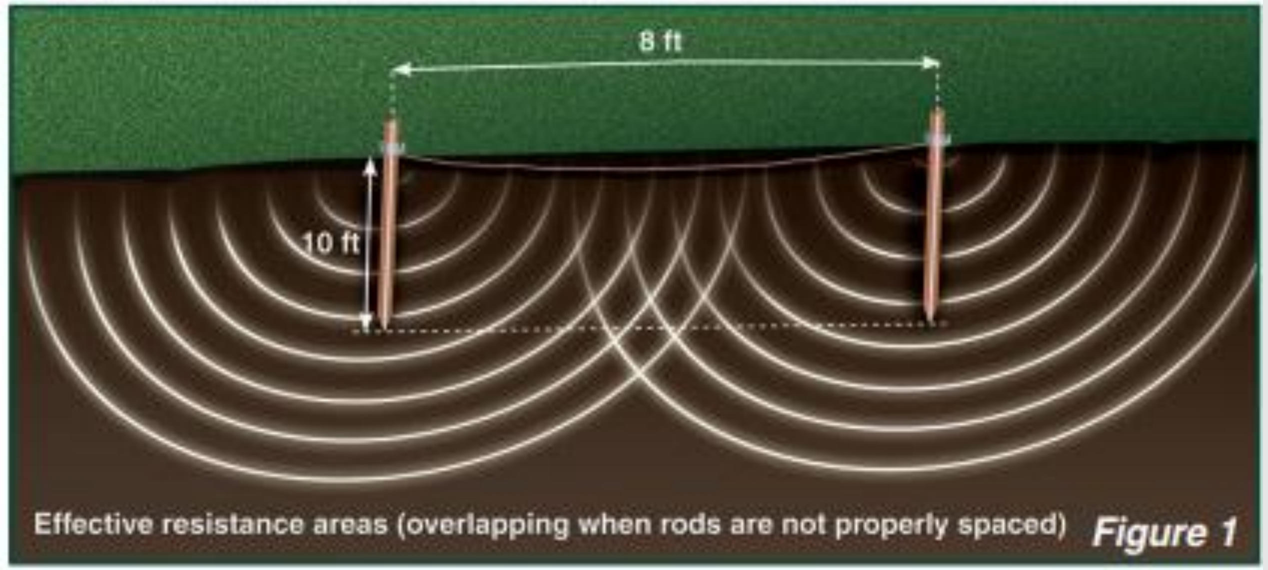
RESISTIVITY

pH – soil type-drainage-contaminated soils-soil resistivity-chemical composition of soils

Resistivity – pH and Contaminated soils

- Soil resistivity has a direct impact on the degree of corrosion of buried steel structures.
- Vulnerability among **buried steel components**, pipelines and piling where corrosion seen during excavation.
- Some **failures recorded for tension systems** such as Rock-bolts, Soil nails and permanent Ground anchors
- Resistivity is believed the cause and has become a criteria for establishing steel corrosion measures.
  - AASHTO T 288 & 289 for resistivity
  - ASTM G57 (Wenner) & G51 for pH

Resistivity testing - Apparatus



Resistivity – pH and Contaminated soils

Type of Soil or water	Typical Resistivity (Ω / m)
Sea Water	2
Clay	40
Ground well and spring water	50
Clay and Sand mix	100
Shale, Slates, Sandstone	120
Peat, Loam and Mud	150
Lake and Brook Water	250
Sand	2000
Morane Gravel	3000
Ridge Gravel	15000
Solid granite	25000
Ice	100000

Soil resistivity (ohm cm)	Corrosivity Rating
>20,000	Essentially non-corrosive
10,000 to 20,000	Mildly corrosive
5,000 to 10,000	Moderately corrosive
3,000 to 5,000	Corrosive
1,000 to 3,000	Highly corrosive
<1,000	Extremely corrosive

Implication from these tables is that typical soil types for piling installation such as Sand, Gravel Clay, Shale or Sandstones vary from corrosive to extremely corrosive.

Resistivity – pH and Contaminated soils

- No standards for interpretation and application of test results for resistivity
- Wide variations can exist between Min resistivity and In-situ resistivity – but no guidelines exist whether to use average pH or worst case factors.
- TRB research document *NCHRP 21-06*
  - Correlates soil resistivity and pH measurements with soil corrosivity
  - Validates usefulness of measuring soil resistivity for soil corrosivity
  - Low resistivity indicates aggressive Chlorides or Sulfates

Resistivity – pH and Contaminated soils

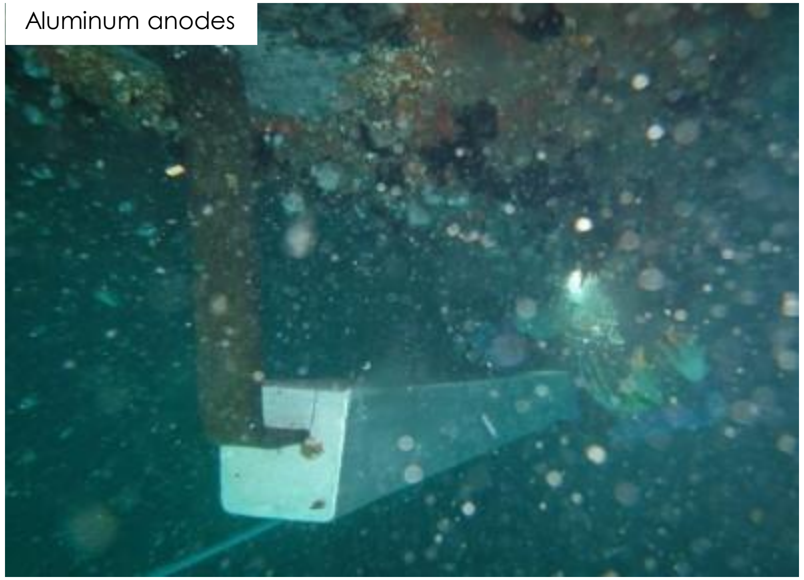
- But **recommendations only highlight aerated or disturbed soils** and typical specifications dictate that **where resistivity is low and soils are very corrosive then maximum protection on the steel piling is required**.
- But research by Romanoff and others has clearly shown that in general, ***soil type, drainage, soil resistivity, pH or chemical composition of soils are of no importance in determining the corrosion of steel piling driven in undisturbed soils.***
- The corrosion of the driven pile is wholly dependent on whether the piles are driven into undisturbed soils. If so then oxygen content is quickly consumed and corrosion tapers to a stop.
- **In disturbed soils** usually just below grade or in backfilled soils protection of the steel is required and **resistivity values are applicable**.

CATHODIC PROTECTION

WHAT IS CATHODIC PROTECTION?

Cathodic protection extends design life of steel that is submerged below the water line. Replacement of consumed sacrificial anodes can be carried out much more easily than reapplication of typical corrosion protection coatings.

Aluminum anodes



GALVANIC SERIES CHART

CORRODED END (Anodic or active)		Magnesium Zinc Aluminum **Mild Steel, Cast Iron** Lead Tin Brass, Bronze Copper Stainless steel (passive) Silver Gold Platinum
PROTECTED END (Cathodic or Passive)	↕	

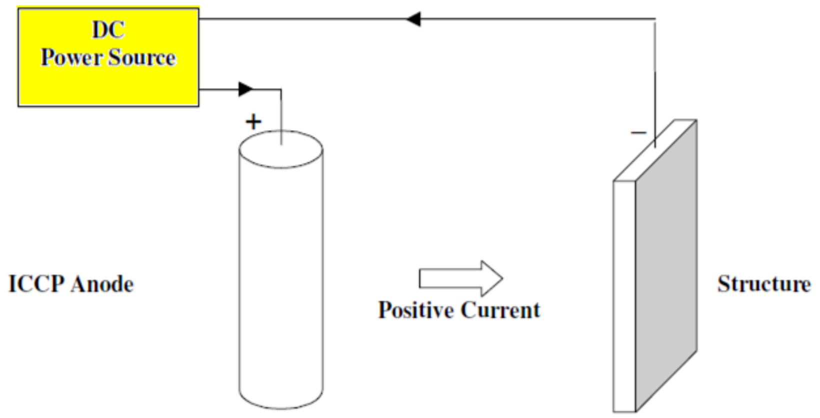
- **Anode** – more active site
- **Cathode** – less active site

TWO METHODS OF APPLYING CATHODIC PROTECTION

- Impressed current cathodic protection (ICCP)
- Sacrificial (or galvanic) anode cathodic protection (SACP)

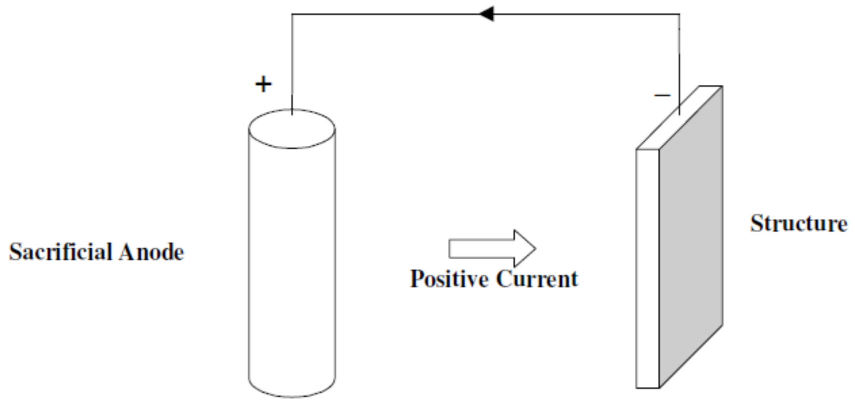
IMPRESSED CURRENT CATHODIC PROTECTION (ICCP)

- Connected to an external power source or a DC power supply
- Needs **lesser** number of anodes compared to SACP
- Used in structures with high protection requirements



SACRIFICIAL (OR GALVANIC) ANODE CATHODIC PROTECTION (SACP)

- **Simple and easy to install**
- **Independent** of any external power source
- Used on smaller surface areas like a **sheet pile wall system**



COMMON ANODE MATERIALS

- **Magnesium –** soils and freshwater; can be ribbon or rod type
- **Zinc –** salt water; used in ship hulls
- **Aluminum –** saltwater and brackish water; commonly used for sheet pile walls

Aluminum anodes

Zinc anodes

Magnesium anodes

CATHODIC PROTECTION CAN PROTECT:

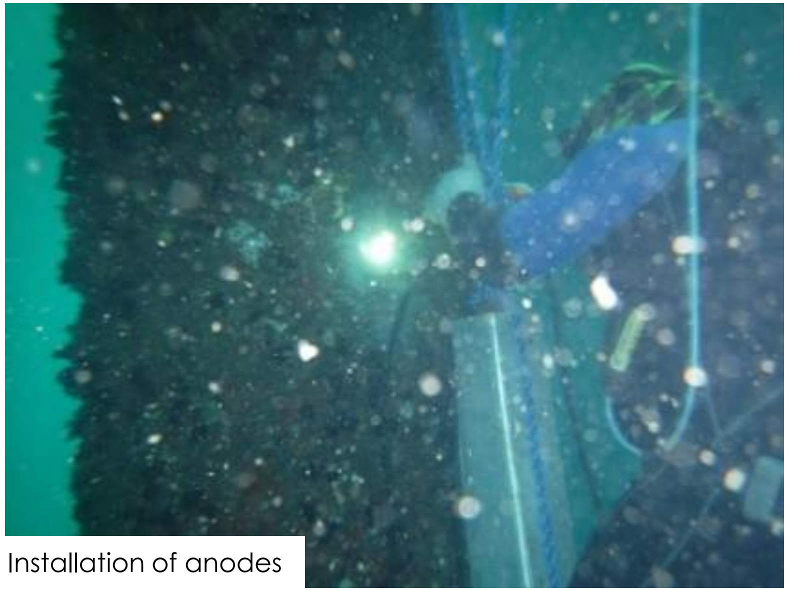
- Steel structures
- Pipes
- Buried tanks, vessels, condensers
- Well casings
- Steel piles
- Vessels
- Marine structures such as jetties or wharfs

FACTORS TO CONSIDER IN CATHODIC PROTECTION DESIGN

- Design life of the system
- Coating thickness (if any)
- Surface area to be protected
- Degradation of coating in the ground
- Coating degradation rate
- Salinity
- Seawater Resistivity
- Highly/poorly aerated waters
- Tidal flow rate
- Temperature
- Electrochemical capacity (Ah/kg)

INSTALLATION, COMMISSIONING AND MAINTENANCE

- **INSTALLATION**
  - Standoff type can be welded or bolted
  - The anode needs to be electrically connected to the steel to work
  - Must be submerged



Installation of anodes

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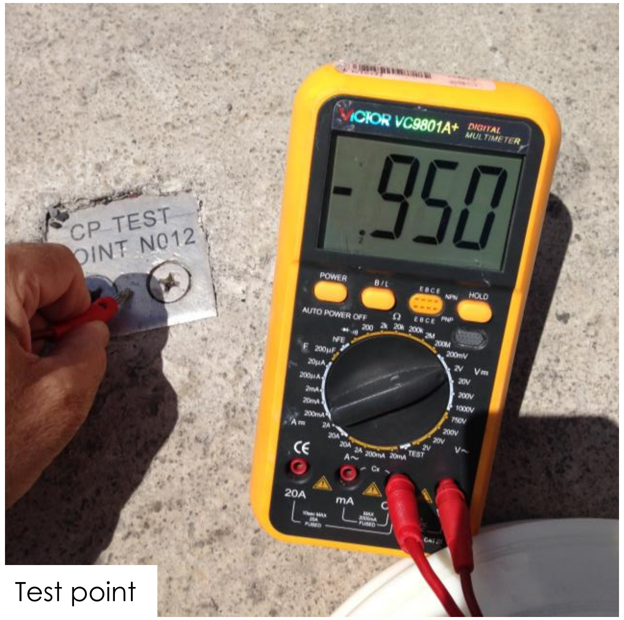
INSTALLATION, COMMISSIONING AND MAINTENANCE

- **COMMISSIONING AND MAINTENANCE**
    - Pre-commissioning survey
    - Commissioning survey
    - Post-commissioning survey
    - Annual potential survey
    - Post installation visual inspection
    - Rectification instruction



Test point

RELEVANT STANDARDS

- **DNV RP B401** Cathodic Protection Design Rules & Standards
- **BS EN 13174** Cathodic Protection of Harbor Installations
- **Other sources:**
  - NACE RP 0176
  - NACE RP 0386
  - NORSOK M503
  - BS EN 12473, 12495, 13173

THANK YOU.