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Dealing with Corrosion : Helical Piling

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Carbon Steel & Galvanised Steel Screw Piles

What is corrosion?

Steel produced from naturally occurring iron ore requires vast amounts of energy to transform it from oxides into malleable, ductile, mouldable and weldable forms that are able to resist compressive, tensile and torsional forces.

From the day that it was smelted steel will always try to return to its natural low energy (oxide) form.

This spontaneous process is termed **CORROSION**

A metal surface will have discrete areas with differences in potential caused by variations in surface characteristics, inclusions, moisture or from being embedded in variable soils.

These small surface variations set up **anodic** and **cathodic** sites.

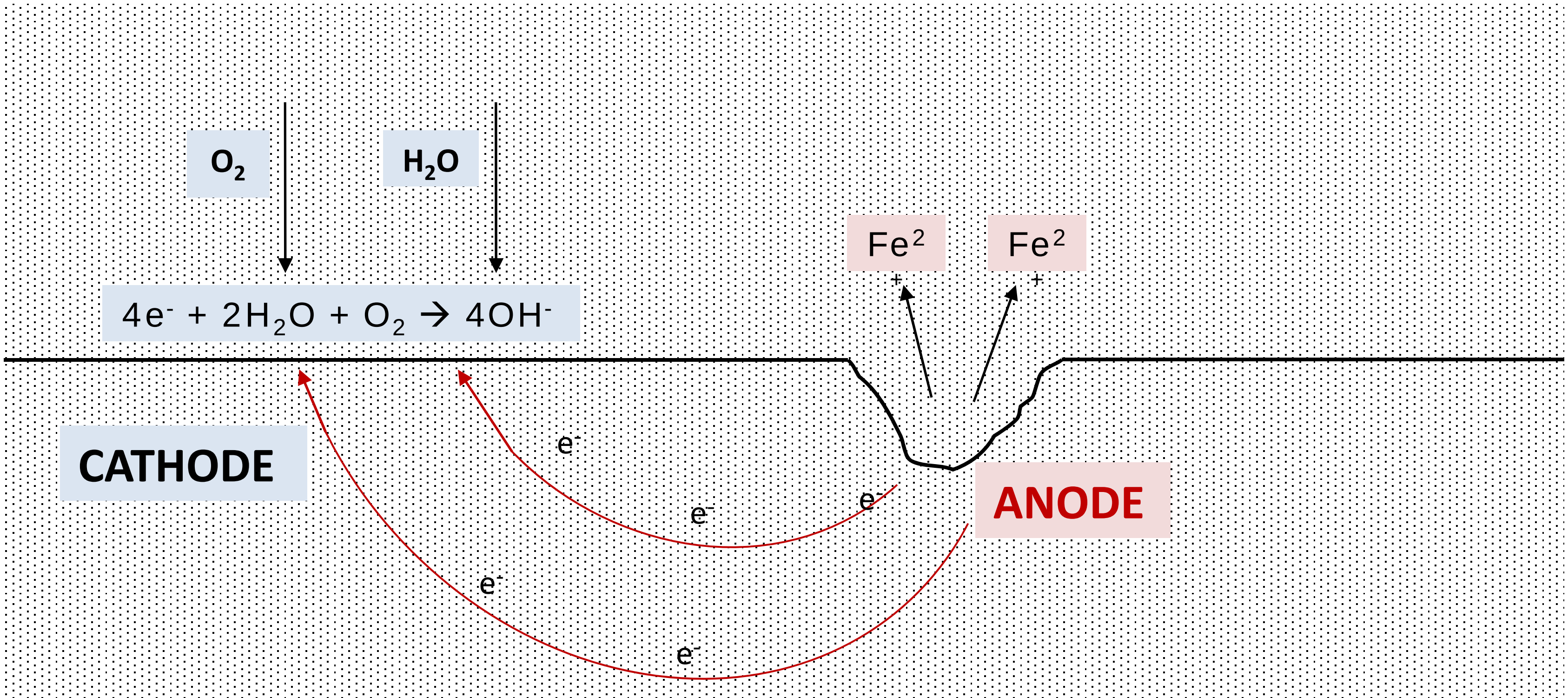
At the **anode** the iron molecules pass into solution releasing electrons.

$$Fe \rightarrow Fe^{2+} + 2e^{-}$$

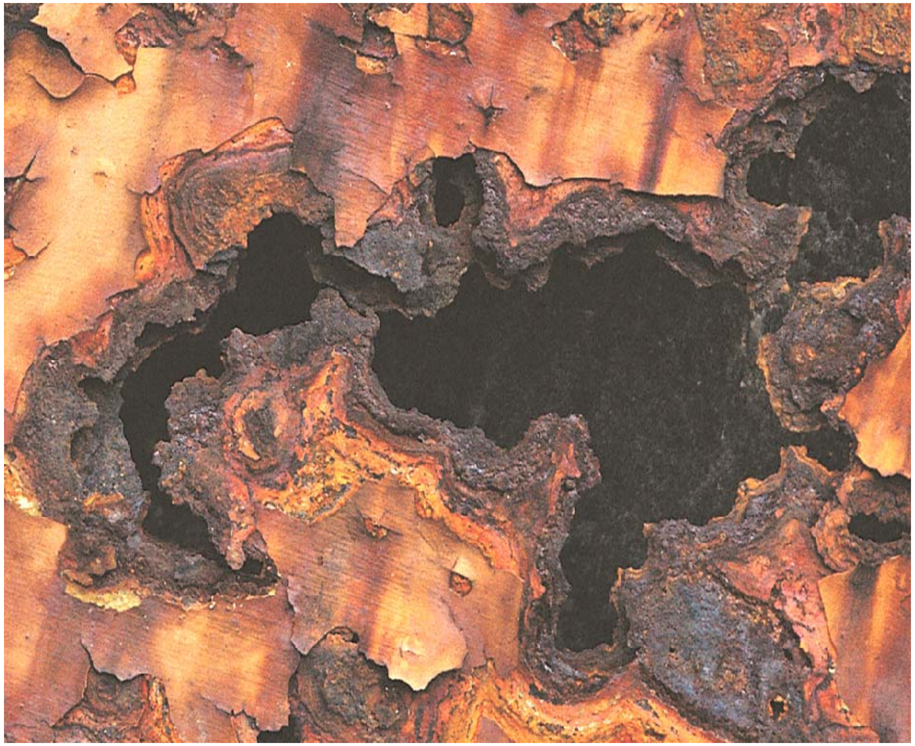
These electrons travel through the steel to cathode area(s) where they react with oxygen and moisture to form hydroxyls.

$$4e^{-} + 2H_2O + O_2 \rightarrow 4OH^{-}$$

Corrosion (as dissolution of the iron) occurs at the **ANODE**. As the electrochemical reaction takes place, differences in the surface potential also changes with time and the **ANODE** can move to another location, one that may even have previously been a **CATHODE**. The result therefore is an appearance of '**GENERAL CORROSION**'.



Corrosion As the electrochemical reaction takes place, differences in the surface potential also changes with time and the **ANODE** can move to another location, one that may even have previously been a **CATHODE**. The result therefore is an appearance of all-over '**GENERAL CORROSION**'.



Sometimes the **ANODE** may stay in one location resulting In concentrated corrosion also known as **PITTING.**

The Rate of Corrosion is heavily influenced by the nature of the soil

The resistivity of the soil is a measure of the soil characteristics that can enhance or restrict these electrochemical **corrosion** reactions. The more conductive the soil is, the more it enhances the **corrosion** reactions. Conversely, the higher the soil resistivity is, the lower the **corrosion rate**

The **pH** of the soil also has an important effect on **corrosion rate.** Lower pH value soil (acidic) enhance the corrosion process. High pH soils (alkaline) tend to reduce corrosion rates

Other factors which can affect the **corrosion rate** of steel in soil include; presence of anaerobic bacteria, dissolved salts (particularly chlorides), moisture content, oxygen availability, stray currents and electrical connection of the structure to a dissimilar metal.

Corrosion rates of steel in soils have been studied in fairly great detail over the years and the importance to buried steel structures is now fairly well understood and quantified.

Tables and listings have been developed to assist with design methodology for **corrosion control**.

Site investigations to determine the soil conditions likely to affect the corrosion of buried steel, helical or screw pilings are needed to develop the most effective and cost economic method of catering for anticipated **corrosion**.

All steel pilings in soil will corrode – but at differing rates

Knowing the soil type, resistivity, pH, moisture content and extent and type of contamination is useful to predict **corrosion rates** so that counter measures for can be implemented

Electrical resistivity of the soil is best measured on site using the Wenner 4-pin method in accordance with ASTM G57-06. This test measures the electrical resistance of soil 'blocks' to any realistic known depth by judicial spacing of the four pins. The resistance results provide **Electrical resistivity** (ohms.cm) by using simple conversion formula.

pH can be determined from recovered soil samples. The testing procedures are covered in ASTM G51-95(2005).

Chloride and sulphate contamination levels can be determined by laboratory measurement techniques on samples recovered from the site.

The presence of **sulphate reducing bacteria** can be determined by a number of methods including serial dilution and now more sophisticated DNA and other testing. Soil testing of Redox potentials.

Generally Accepted - Soil Classifications

Resistivity Range (Ohm.cm)	Corrosivity
Less than 1,000	Very severe
1,000 to 2,000	Severe
2,000 to 5,000	Moderate
5,000 to 10,000	Mild
Greater than 10,000	Very Mild

Source:R Revie "Uhlig's Corrosion Handbook, Section 20

AWWA (American Water Works Association C-105) has produced a corrosion grading for relating corrosivity to soil conditions. It is quite complicated and involves site testing bringing into play:

- **Soil resistivity**
- **pH**
- **Redox potential**
- **Sulphide concentration**
- **Moisture content**
- **Drainage conditions**

It assigns a points system to each parameter, totals the sum to provide a corrosion scale

Another example (and there are a number) was formulated by the **American Iron & Steel Institute** (AISI) for galvanised steel pipe. Provided the **soil resistivity** and **pH** is known, or can be realistically estimated the corrosion rate to perforation can be derived for various thicknesses of steel. Most soils have a pH value of between 6.5 and 8.0.

These following Tables are modified for 1.6mm and 3mm thick corrugated steel with 45µm galvanised layers. The modified graphs show the anticipated time to perforation of galvanised steel pipe.

These data can be transferred across to steel piling.

One design method for catering for corrosion of steel piling involves assuming the **worst case scenario** and design the steel piling accordingly.

This may however not always be economic.

If we could at least investigate the **SOIL RESISTIVITY** and **pH** and be reasonably sure of the results, then it may not necessary to design for the worst case scenario and a better engineering approach can be taken.

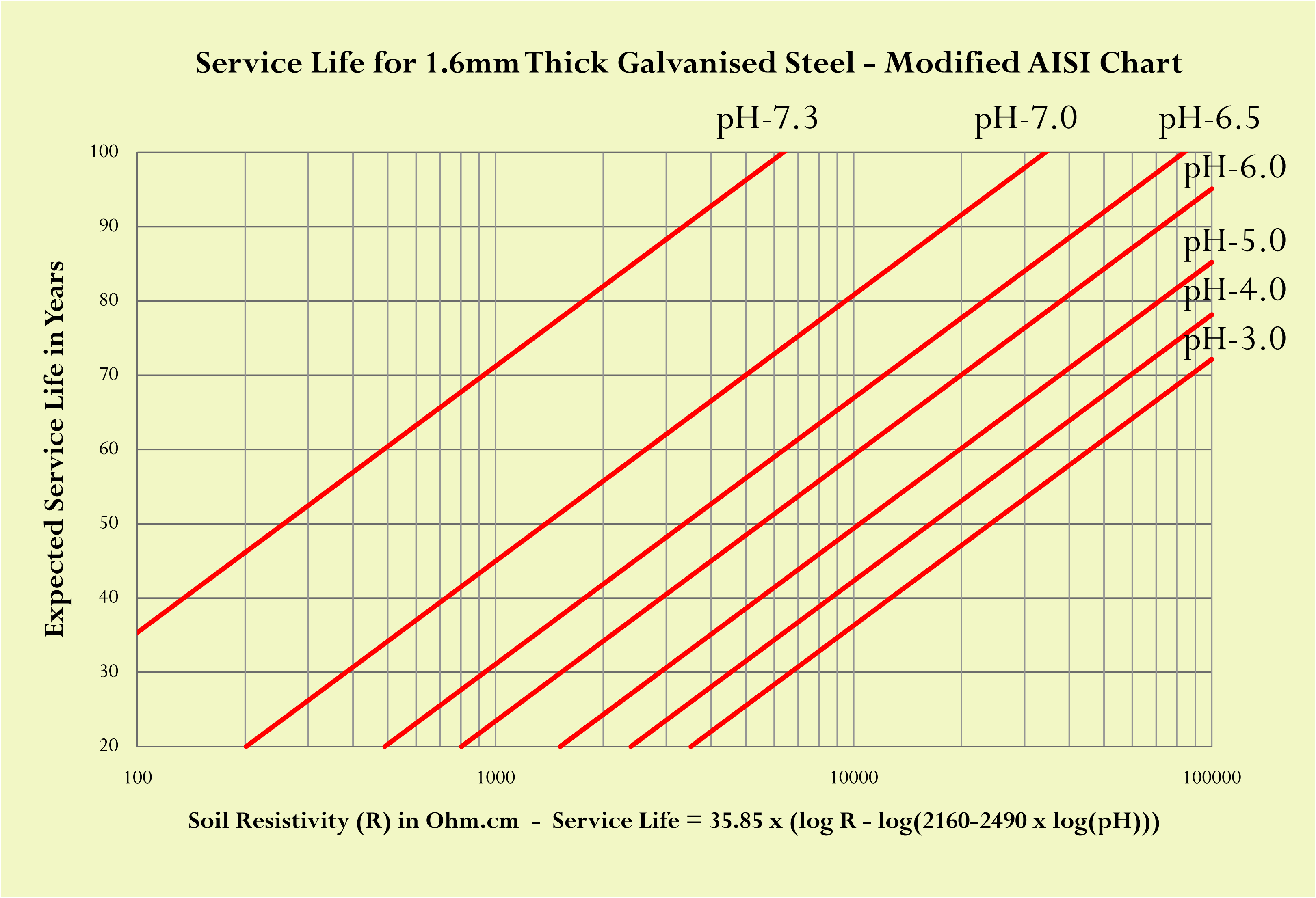
Simplified relationship (Tables) have been developed that relate **SOIL RESISTIVITY** and SOIL **pH** to anticipated **CORROSION RATES**

National Corrugated Steel Pipe Association CSP Durability Guide

- Provides data on service life expectancy from buried galvanised steel pipe materials.
- Derived formulae for predicting time to perforation of 1.6mm thick steel with 40-50μm zinc galvanising coating.
- **American Iron & Steel Institute** (AISI) derived a formula for service life

  $= 35.85 \times (\log_{10}R - \log_{10}(2160-2490 \times \log_{10}(pH))$

  (where R = soil resistivity in ohm cm, pH = pH of soil)
- They also provide factors for thicker or thinner steel.
- This data can be shown can be shown in graphical form and has relevance to any buried galvanised steel component.


Service Life for 1.6mm Thick Galvanised Steel - Modified AISI Chart
pH-7.3
pH-7.0
pH-6.5
pH-6.0
pH-5.0
pH-4.0
pH-3.0
Expected Service Life in Years
100
90
80
70
60
50
40
30
20
100
1000
10000
100000
Soil Resistivity (R) in Ohm.cm - Service Life = 35.85 x (log R - log(2160-2490 x log(pH)))

Service Life for 3mm Thick Galvanised Steel – Modified AISI Chart

Corrosion Rates of Uncoated Steel in Soil

- If **soil parameters** are not known then use worst case scenario to estimate loss of steel to corrosion.
- Tables of corrosion rates have been produced.
- Many are based on work carried out by Romanoff detailed in a report in 1957 and rereleased in 1982.
- This is well documented on the internet and reference can be made easily to this work.

Worst Case Scenario – Design Corrosion Rates of Steel Pilings in Soil

Corrosion Rate (µm/yr)	Source (Reference)
0.030mm (30 µm/yr)	K Fisher & B Bue - ASTM Publication T41
Up to 0.050mm (50 µm/yr)	BGB Projects Ltd – Singapore Trials (2001)*
0.025mm (25 µm/yr)	California Department of Transportation
0.015mm (15 µm/yr)	Corus (Correlates with BS8004)
0.012mm (12 µm/yr)	A B Chance - Screw Pile Design Manual 2003
0.014 to 0.033mm (14 to 33 µm/yr)	Uhlig 2nd Ed for non-corrosive and corrosive soils respectively
Soil dependent	See Eurocode EN 1993-Part 5 - 2007

Eurocode 1993 - Part 5 – 2007
UK National Annex – Table 4.1
Uncompacted (Disturbed) Soils

Corrosion Rate (µm/yr)	Soil Type with or without groundwater (interpretation)
0.012mm (12 µm/yr)	Undisturbed natural soils (sand, silt, clay, schist)
0.030mm (30 µm/yr)	Polluted natural soils & industrial sites
0.030mm (30 µm/yr)	Aggressive natural soils (swamp, peat, marsh)
0.020mm (20 µm/yr)	Non-compacted & non-aggressive fills (sand, silt, clay, schist)
0.050mm (50 µm/yr)	Non-compacted aggressive fills (ashes, slags)

Actual Measurement of Corrosion Rates in Singapore

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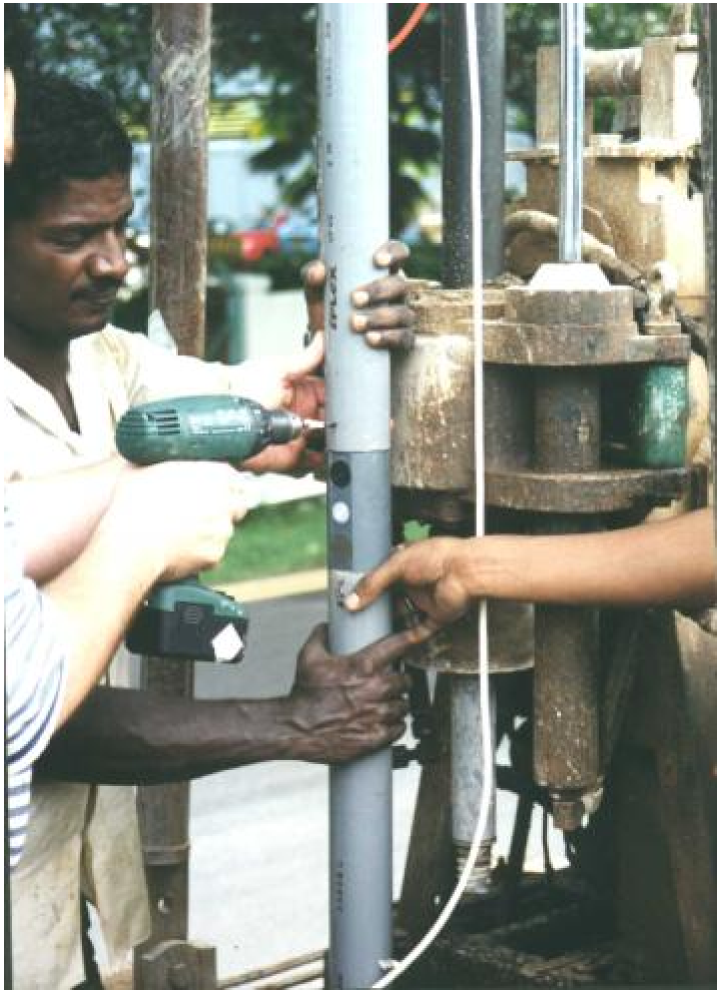
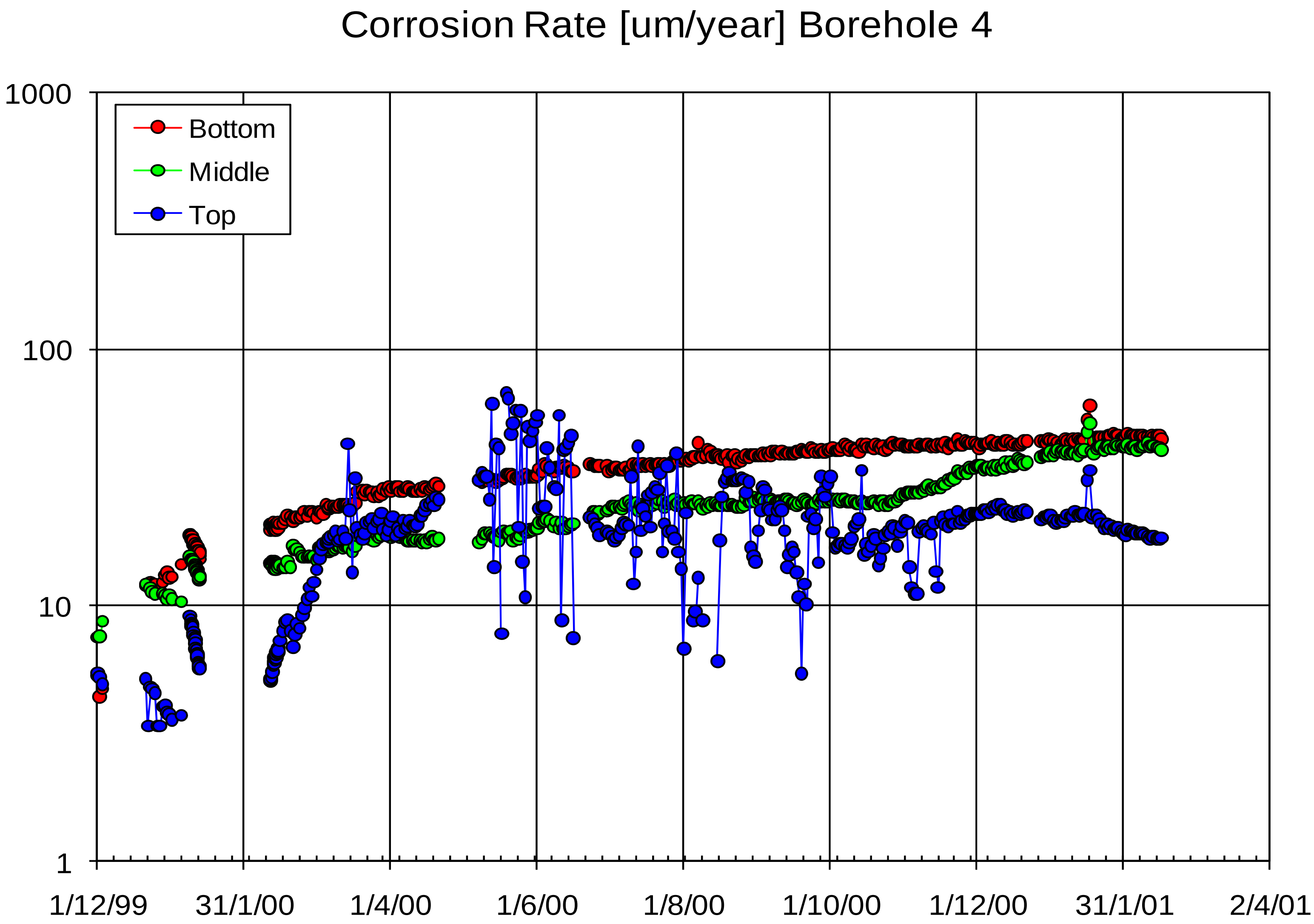


Corrosion Rate testing using linear polarisation testing (LPR) method at 1.5m, 4m, and 8m depths

Measurement of Corrosion Rates in Singapore



Corrosion Control Measures

- Corrosion (metal loss) allowance if carbon steel
- Galvanising of steel surfaces – zinc metal coatings
- Special corrosion resistant materials
- Coatings
- Cathodic Protection (galvanic or impressed current)

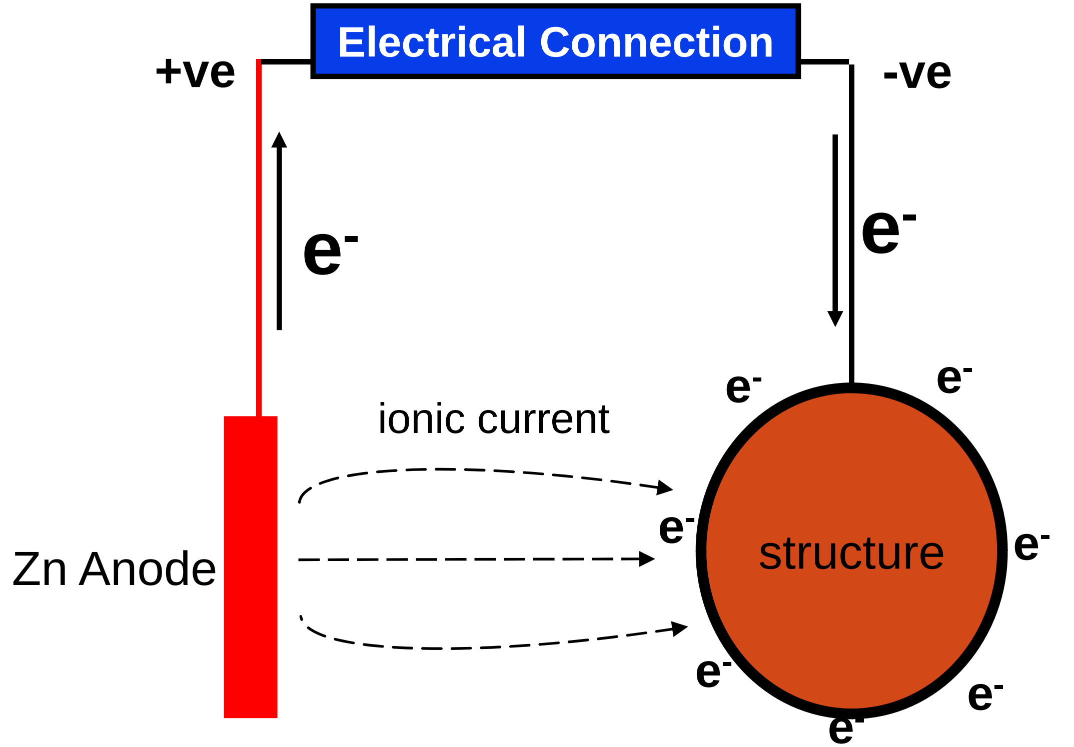
Corrosion

ANODE

$Fe \rightarrow Fe^{2+} + 2e^-$

$4e^- + 2H_2O + O_2 \rightarrow 4OH^-$

CATHODE



$Zn \rightarrow Zn^{2+} + 2e^-$

$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

Anode

Buried Steel

Screw Pile?

Cathodic Protection

Undisturbed soils vs Disturbed Soils

- Corrosion rates are higher in disturbed soils than in undisturbed soils **why?**
- Because of the oxygen availability mainly
- Screw piling disturbs the soil more than driven piling
- **EN 1993-Part 5 suggests corrosion rates in compacted (ie undisturbed soils) are approximately half that quoted in the previous tables for disturbed soils**
- It would be expected that after installation piling would be mostly in undisturbed soil – except for top 1m or so.

Example : Corrosion Allowance for Bare Steel Pile

Assuming soil resistivity is tested and found to be 1,200 to 1,500 ohm cm

Worst case corrosion rate from EN 1993 – Part 5 - Table 4.1 (naturalised for UK) for soil type - undisturbed (screw pile) and considered to be aggressive

Assumed corrosion rate – worst case is 0.030mm/yr/side – i.e. all around the tube and both sides of the flights

Allow factor of safety (fos) = 1.5

Service design life of 75 years (Particular Highways Agency application)

Corrosion allowance is therefore - 75 years x 0.030mm/yr x 1.5 = **3.4mm**

Same Example - Using Galvanised Steel

FHWA-SA-96-072 lists the following corrosion rates for hot dipped galvanising

15µm/yr for the first two years
4 µm/yr thereafter until the galvanised layer has been consumed.

Normal hot dipped galvanising to ISO 1461 results in a galvanising layer of between 75-100 µm thick. - Assume 85 µm

The period to expiry (total consumption) of the galvanised layer is therefore

$$2 + ((85 - (2 \times 15))/4) \text{ years} \sim 15 \text{ years}$$

Corrosion allowance for previous steel screw piling is

$$(75 - 15) \text{ years} \times 0.030\text{mm/yr} \times 1.5 \text{ (f.o.s.)} = \underline{2.7\text{mm}}$$

Design (Corrosion) Measures

One recent approach adopted by Screwfast™ in UK for a fast pile foundation installation where site testing was regulated by 'possessions' and investigation time was limited --- was to:

- Conduct in situ resistivity testing (4-pin Wenner at 1.0m and 3.0m pin spacings). **This was feasible within the time scheme**
- Categorise the soil condition **'based only on resistivity results'**
- Use the following **'Table'** to determine the corrosion control measures to be implemented on a case-by-case basis
- NOTE: Results in a conservative design approach

Design (Corrosion) Measures – Example Used in UK

Resistivity Range (Ohm.cm)	Corrosion Measure
> 10,000	Shaft of screw pile to be 8.0mm minimum wall thickness
5,000 to 10,000	Shaft of screw pile to be 8.0mm minimum wall thickness plus…… upper 2m length to be hot dipped galvanised
1,000 to 5,000	Shaft of screw pile to be 9.5mm minimum wall thickness plus…… upper 2m length to be hot dipped galvanised
500 to 1,000	Shaft of screw pile to be 9.5mm minimum wall thickness plus upper 2m length to be hot dipped galvanised plus 1 or 2 x 20kg (350mm long x 50mm thick bracelet) zinc galvanic anode welded to top section
Less than 500	Considered to be too severe for steel helical piles if >20 year service life required

In Aggressive Soils

In really aggressive soils additional sacrificial zinc can be added. One example used in UK is bracelet zinc anodes pre-formed onto a carbon steel annular ring be welded to the steel screw pile shaft on site prior to installation as required.

Assuming the additional corrosion protection is required following in situ Wenner 4-pin resistivity testing and a low resistivity results being obtained, zinc bracelet shaped anodes can be welded to the uppermost shafts to provide additional corrosion protection.

In Aggressive Soils – Design of Zn Anode

Assume the helical (screw) pile has:

- 4m length of 114mm diameter x 8.0mm thick steel tube
- 1m length of 140mm diameter steel tube
- 1m length of 170mm diameter steel tube

Assume design life of anode = 30 years (before corrosion allowance is required)

Total Pile Surface Area (6m length) = $\underline{2.41m^2}$
Current density needed for cathodic protection = $20mA/m^2$ (bare steel)
Current needed from galvanic anode = $\underline{0.048A}$

$$\text{Net weight of zinc anode} = \frac{0.048A \times 30 \text{ years} \times 8766 \text{ hrs/year}}{780 \text{ A/hrs/kg} \times 0.80 \text{ uf}}$$

$$= \underline{20.3kg}$$

Typical Zinc Galvanic Anode

Typical Zinc Galvanic Anode

Helical Pile Foundations for Corrosion Example

Screw piled foundation with helical piles to support steel grillage. Low soil resistivity.

Design life = 60 years (Client's requirements)

Difficulties relating to time on site, decisions had to be made quickly and this will inevitably result in over design.

Zoning of Helical Pile Foundations for Corrosion : Specific Example

Zone 1: Portion of the structure above the ground (atmospheric corrosion)

Carbon steel thickness = 8.0mm
Galvanised steel thickness = 85μm (nom)

Solution : Galvanised layer to ISO 1461 to provide >30 years life before start of consumption of the steel corrosion allowance. Corrosion rate <3μm/yr.

Assuming **steel corrosion rate** of 0.035mm/yr (Corus publication 'A Corrosion Protection Guide for Steel Bearing Piles in Temperate Climates', 2002 the loss over the next 30 years will be: 0.035mm/yr x 30 years = 1.05mm

Remaining theoretical thickness after 60 years = (8.0 – 1.05mm) = <u>6.95mm</u>

Zoning of Helical Pile Foundations for Corrosion : Specific Example

Zone 2: Interface Zone (Top 2.0m of the soil)

Carbon steel thickness = 9.5mm
Galvanised steel thickness = 85µm (nom)
Galvanic zinc bracelet anode = 20kg (welded to upper 2.0m shaft)

Solution :
Weld galvanic anode 20kg to provide 30 years corrosion free life
Galvanised layer to ISO 1461 to provide 15 years life before start of consumption of the steel corrosion allowance.

Assuming steel corrosion rate of 0.050mm/yr loss over the next 15 years will be - 0.050mm/yr x 15 years = 0.75mm

Remaining theoretical thickness after 60 years = <u>8.75mm</u> (Adequate)

Zoning of Helical Pile Foundations for Corrosion Specific Example

Zone 3: Portion of the piled foundation below the aerobic layer (basically in undisturbed soil more than 2.0m below ground level.

Carbon steel thickness = 9.5mm

Solution :

Assuming steel corrosion rate of 0.015mm/yr loss over the next 60 years will be: 0.015mm/yr x 60 years = 0.9mm

Remaining theoretical thickness after 60 years = 8.6 mm (Adequate)

Zoning of Helical Pile Foundations for Corrosion
Specific Example

Zone 4: Internal chamber within the tubular piles

Carbon steel thickness = 9.5mm

Solution :
Internal chambers are sealed so oxygen availability limited within reasonably short time period.

Initial corrosion processes consume the oxygen.

Once the oxygen is depleted the corrosion rate slows to very low levels ($<5\mu m/yr$).

Minimal corrosion (~ 0.30mm) internally throughout 60 year life.

Actual Installation Using Zinc Galvanic Anodes

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Other Considerations

Stray current corrosion from; electrified railway systems or high powered cathodic protection systems in the vicinity

Anaerobic corrosion caused by sulphate reducing bacteria in the soil

Bi-metallic electrical connection to dissimilar metals, for instance; stainless steel structures, galvanised steel railway gantries, copper based earthing beds and cabling management systems

High proportion of coals/coke contamination in soil

Localised ponding/river course

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