



ADVISORY NOTE #42.1

HOT DIP GALVANIZED STEEL EMBEDDED IN SOIL

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TABLE OF CONTENTS

Contents

| | |
|--|----|
| Introduction | 1 |
| Hot Dip Galvanizing | 1 |
| Soil Characteristics | 2 |
| pH | 2 |
| Sulfates and Acid Sulfate Soils | 2 |
| Location of acid sulfate soils | 2 |
| Potential acid sulfate soils | 3 |
| Actual acid sulfate soils | 3 |
| Resistivity | 3 |
| Moisture | 3 |
| Chlorides | 3 |
| Oxygen Content | 4 |
| Soil Corrosion Rates | 4 |
| Introduction | 4 |
| Australian Standards | 4 |
| Durability Allowance | 5 |
| Simplified Durability Design | 5 |
| Detailed Durability Design | 6 |
| AASHTO specifications | 9 |
| Exposure testing | 9 |
| Adapted German Gas and Water Works Engineers' Association Method | 10 |
| Increasing Durability | 12 |
| Preventing Ponding | 12 |
| Additional Barrier Protection | 12 |
| Using a Select Fill | 14 |
| Ramming Posts or Compacting Backfill | 14 |
| Zinc in Nature | 15 |
| Introduction | 15 |
| Environment | 15 |
| Human Health | 16 |
| Crops | 16 |
| Summary | 16 |
| Appendix A. Romanoff Data Examples | 18 |

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Hot Dip Galvanized Steel Embedded in Soil

INTRODUCTION

Hot dip galvanizing (HDG) is commonly embedded in soil in a range of applications, with both partial and full embedment having many successful examples. Numerous different soil compositions exist in Australia, with the differences in physical and chemical properties between soils leading to corrosion rates that are rarely uniform between locations. In drained soils the typical average HDG loss rates are from 2 to 6 $\mu\text{m}/\text{year}$, and the typical steel loss rate once the HDG coating is expended is from 10 to 20 $\mu\text{m}/\text{year}$.

Zinc is a naturally occurring element in the earth's crust and essential for human health. The natural background levels of zinc in surface water, soil and rock vary over a wide range of concentrations, although the variable range is relatively consistent from place to place. Run-off from embedded galvanized items to the native soil is usually at low levels and can be ignored.

This Advisory Note gives general information on factors influencing the corrosivity of different soils, provides guidance on estimating corrosion rates of galvanized steel and bare steel using Australian Standards, and provides recommendations which aim to prolong the life of hot dip galvanized steel members in soil. It also introduces the effect of zinc on soils. This document is not intended to replace any information or advice given by a professional, who should be consulted to perform site inspection and testing when hot dip galvanizing is embedded in soil.

HOT DIP GALVANIZING

HDG is widely used to provide corrosion protection to steel articles. The process involves dipping steel in a molten zinc bath, which results in a metallurgical reaction between the zinc and steel. While submerged in the bath, metallurgically bonded alloy layers are created which are much harder than the base steel, giving excellent resistance to erosion and mechanical damage. The coating provides barrier protection to the steel, blocking corrosive species such as oxygen and moisture from reaching the steel's surface. If the barrier is compromised, the base steel is still protected by surrounding zinc as it corrodes sacrificially to protect the steel. The outer zinc layer also forms a natural patina, a thin protective barrier of oxides and carbonates that greatly slows corrosion. Combining these protective properties with a corrosion rate of zinc between 20 and 40 times slower than steel in the atmosphere, it is no surprise that galvanizing is a commonly used protective coating to provide longer service lives without maintenance.

Numerous Australian Standards exist for galvanizing, using different processes and resulting in different coating thicknesses. Batch hot dip galvanizing to AS/NZS 4680 produces the thickest galvanized coating and will provide the best durability when embedded in soil.

Table 1 gives the minimum average coating thickness for hot dip galvanized members (AS/NZS 4680). The coating thickness is directly related to the thickness of the base steel, and a thicker zinc coating provides better durability as the zinc corrodes naturally over time. Thicker coatings than the ones listed in Table 1 may be achievable depending on the steel's thickness and chemical composition, and specifications such as HDG900 (125 μm) for increased durability must always be discussed with and agreed to by the galvanizer at the time of purchase.

ADVISORY NOTE #42

Table 1. Coating thickness and mass on batch hot dip galvanized steel complying to AS/NZS 4680

| Steel thickness range (mm) | Minimum average coating thickness (μm) | Minimum average coating mass (g/m ²) |
|----------------------------|--|--|
| > 6 | 85 | 600 |
| > 3 to ≤ 6 | 70 | 500 |
| > 1.5 to ≤ 3 | 55 | 390 |
| ≤ 1.5 | 45 | 320 |

SOIL CHARACTERISTICS

Soil is a complex mixture of minerals, liquids, gases, organisms, and organic matter which forms the surface of most of Earth's land. The corrosion mechanism differs from that in the atmosphere, where humidity, temperature and chloride levels are usually the key factors. Typically, soil is made up of three phases; the solid phase which mainly consists of weathered rock, the liquid phase that holds the soil's water, and a gas phase which is held in the soil's pores. The soil's components can vary greatly between locations and have a large influence on its corrosivity. The following characteristics are known to influence the corrosion rates of galvanized coatings in soil.

pH

Highly acidic or alkali soils can be quite corrosive to steel and hot dip galvanizing. Given the pH of soil is location dependant and can vary between 2.6 to 12 depending on the soil constituents and organic content (such as decomposed plant matter), the pH of soil should be tested before embedding articles. The pH of soil has been widely researched in Australia in the agricultural sector due to its effect on crop growth, and many of the Australian State Governments provide fact sheets addressing the pH of soils. Soil maps from the Australian Soil Resource Information System and reports by the CSIRO can be used to give a regional estimation of soil pH.

Sulfates and Acid Sulfate Soils

Sulfates present in the soil can lead to particularly aggressive conditions for zinc, steel, concrete and some aluminium alloys unless preventative actions are taken. Acid sulfate soils are naturally occurring soils that most commonly occur near the coast or in areas which were once coastal, where bacteria have converted sulfate from tidal waters and iron from the organically rich and waterlogged sediments to iron disulfide (iron pyrite). When exposed to air, iron sulfides oxidise and produce sulfuric acid.

The iron sulfides in acid sulfate soils are contained in a layer of waterlogged soil, which is usually clay, loam or sand. The water creates an anaerobic environment that prevents oxygen in the air reacting with the iron sulfides and the soil typically has a near neutral pH. When the iron sulfides are exposed to air they produce sulfuric acid, which moves through the soil and can acidify the soil, the groundwater, and eventually surface waters.

Metal ores are also commonly rich in sulfides. These metal sulfides may be exposed to oxidation during mining, quarrying or excavation operations leading to acid rock drainage (the generation of sulfuric acid and dissolved metals in water in and around a mine site).

Location of acid sulfate soils

Most acid sulfate soils in Australia are found in low-lying areas several kilometres inland from the current coast and where the surface elevation is less than five metres above the mean sea level in wetlands, back-swamps, estuaries, salt marshes and tidal flats. They also occur in locations of excessive groundwater pumping and inland in agricultural areas well away from the coast in response to rising water tables and land salinisation.

ADVISORY NOTE #42

During development of Australia's infrastructure many soils rich in iron sulfides have been drained, converting them into acid sulfate soils on contact with air. Some of the acid sulfate soils that were drained 100 years ago are still releasing acid today. In clay soils the oxidation process is very slow and can take centuries due to the difficulty of penetration by air. Oxidation of sandy materials can be quite rapid, sometimes taking less than a week depending on the air circulation within the soil. Testing of soils should include testing for potential and actual acid sulfate soils, as dormant iron sulfides may be activated during construction.

More information on acid sulfate soils is available from the Australian Government [here](#). The CSIRO's [Atlas of Australian Acid Sulfate Soils](#) is also a useful resource.

Potential acid sulfate soils

Acid sulfate soils which have not been oxidised by exposure to air are known as potential acid sulfate soils. While contained in a layer of waterlogged soil, the iron sulfides in the soil are stable and the surrounding soil pH is roughly neutral (6.5–7.5). The soil contains unoxidised iron sulfides and are usually soft, sticky, gel-like muds that are saturated with water.

Actual acid sulfate soils

When potential acid sulfate soils are disturbed or exposed to oxygen, the iron sulfides are oxidised to produce sulfuric acid and the soil becomes strongly acidic (usually below a pH of 4). These soils are then called actual acid sulfate soils. Actual acid sulfate soils vary in texture and often contain jarosite (a yellow mottle produced as a by-product of the oxidation process).

Resistivity

Soils that can better resist the flow of current usually result in greater durability of embedded items. As the resistivity of soil increases and conductivity decreases, less electrons flow from the corroding area of the material and corrosion slows. The resistivity can vary widely depending on the soil, from tens of ohm centimetres ($\Omega\cdot\text{cm}$) to hundreds of thousands of $\Omega\cdot\text{cm}$, making it an important parameter to test. The main factors influencing the resistivity of soil are the moisture content and the chloride concentration, with higher values of each increasing the conductivity and making the soil more corrosive.

Moisture

The moisture content of the soil has a direct influence on its conductivity, with higher moisture leading to higher conductivity. Typically, the soil particle size determines how well the soil will hold or drain water, with soils containing fine particles, such as clays, tending to have higher moisture contents. Conversely, soils made up of larger particles, such as sands, tend to have more space between particles and allow draining, leading to lower moisture content. A simplified list of typical soil types in *AS 1726 – Geotechnical Site Investigations* can be seen in Table 2.

Chlorides

When the moisture content of the soil reaches around 20%, the chloride concentration begins to have a large influence on soil conductivity. Higher concentrations of dissolved salts in the soil lead to higher conductivity and corrosivity. Some of the most corrosive soils in Australia are in desert regions that don't receive a lot of rainfall, as corrosive salts, such as chlorides, aren't removed by the rain and can build up in very large concentrations. In coastal areas, airborne chlorides can become deposited at the interface between the galvanizing and soil, and these areas requiring additional protection of the galvanizing to protect against corrosion.

ADVISORY NOTE #42

Table 2. Different soil types, their grain size and typical moisture content

| Soil type | Grain size | Typical moisture content |
|--------------------------------------|------------|--------------------------|
| Gravel or sandy gravel | Coarse | Low |
| Sand or gravelly sand | | |
| Clayey gravel or clayey-sandy gravel | Medium | Medium |
| Clayey sand or clayey-gravelly sand | | |
| Silty sand or silty-gravelly sand | | |
| Clay, silt | Fine | High |

Oxygen Content

The amount of oxygen present at the surface of the metal has an influence on the corrosion rate, with increased oxygen allowing easier oxidation of the zinc or steel. Generally, less oxygen is present as soil depth increases, and less corrosion occurs over time when galvanizing is embedded deeply. Research has shown that corrosion occurs at a slower rate when steel is either driven into the ground or the back fill is compacted, slowing the supply of oxygen to the metal surface. In corrosive soils, a shallow buried or partially buried steel item will require additional protection to the HDG coating to counter the effects of increased oxygen availability at the surface.

SOIL CORROSION RATES

Introduction

Long-term in-situ investigations in Australia and overseas of over 50,000 buried corrugated metal structures and other steel items allow the durability of hot dip galvanized (HDG) coatings and steel structures to be estimated with some confidence. Galvanizing usually performs well in soil that is sufficiently free draining to maintain a moisture content below 20%, with typical average HDG loss rates from 2 to 6 $\mu\text{m}/\text{year}$ and steel loss rates once the HDG coating is expended from 10 to 20 $\mu\text{m}/\text{year}$. As time passes the corrosion products usually build up on the surface of the galvanizing, leading to a slower corrosion rate after the first couple of years. This effect continues when the last of the zinc has corroded, leaving the underlying steel with a slower corrosion rate than steel that was not initially galvanized. Zinc also corrodes slower than steel in soil and prevents insidious pitting corrosion which commonly occurs on bare steel.

Australian Standards

Two Australian and New Zealand Standards are of interest when determining how exposure to soils will affect corrosion rates. AS/NZS 2041.1 provides in-depth information on the soil's corrosivity to buried metal corrugated structures (including galvanized steel) and how engineers can design for durability in the soil's environment. AS 2159 provides requirements for the durability design of piles, using a similar method to AS/NZS 2041.1.

AS/NZS 2041.1 contains both simplified and detailed approaches to designing for durability in soil, with an overview of general durability design procedures included below. If a steel corrosion allowance is included, the design should take into account the design requirements from AS 4100. This overview is included as a guide only and should not be used to perform durability design for embedding galvanized steel in soil in place of AS/NZS 2041.1.

ADVISORY NOTE #42

Durability Allowance

The durability allowance required on bare steel is given explicitly when using the simplified design method from AS/NZS 2041.1 and can also be calculated from the estimated life of the zinc coating and steel loss rate using the detailed design method. A steel loss of 1 mm is commonly used in industry for structures before structural integrity is compromised, but the allowable steel loss should be determined by the engineer for each design. The thickness of the steel can be modified to ensure the member will meet the required service life, and the galvanized coating is usually thicker and provides extra durability when the thickness of the steel is increased.

Simplified Durability Design

The simplified method is designed to be used for buried corrugated metal structures where the conditions of the installation and soil are known in general, but testing hasn't been carried out on the site (the soil pH can be estimated using simple methods). If there is any uncertainty as to whether the conditions for using the simplified durability design are met, the detailed durability design procedure should be used. Table 3 lists the requirements for using the simplified method with galvanized steel, as well as whether a durability allowance is required for the base steel and Table 4 is used to determine the metal loss for this method.

Table 3. Requirements to use the simplified design method and resulting durability allowance

| | No durability allowance | 1 mm durability allowance |
|------------------------|--|--|
| Structure importance | Lesser importance, < 1.5 m in height or width and not expensive to replace | Lesser importance, < 3 m span and not expensive to replace |
| Design working life | ≤ 30 years | ≤ 50 years |
| Saline conditions | Not exposed to airborne salts, salt, or brackish water within 20 km of the coast and not on an estuary | |
| Corrosive run-off | No corrosive run-off from mines/industry in the area | |
| Fill material draining | Usually dry and free draining | |
| Fill material pH | In the range of 5 to 8 | |
| Local (native) soil pH | In the range of 5 to 8 | |
| Local (native) soil | Not saline nor containing sulfates | |

Table 4. Corrosion rates for zinc and steel in soil

| Soil type | pH | Resistivity (Ω·cm) | Galvanizing loss rate (μm/y) | Steel loss rate (μm/y) |
|-------------------|--------|--------------------|---|------------------------|
| Non-Corrosive | 5 – 12 | ≥ 10,000 | 15 for first 2 years and 4 subsequently | 12 |
| Normal Conditions | 6 – 10 | 2,000 – 10,000 | | |
| Mildly Corrosive | 5 – 8 | 1,500 – 2,000 | Seek specialist advice and assume aggressive soil in the detailed procedure | |
| Corrosive | 5 – 10 | > 1500 | | |

Example 1. A galvanized culvert with a 1 metre diameter is being buried in non-reactive gravelly sand with a pH of 7, resistivity of 6,000 Ω·cm and requires a 30 year design life. The culvert is located far from the coast in an area that is known to be low in chlorides and sulfates based on past testing undertaken when installing nearby culverts.

The simplified durability design can be used, as the culvert is a buried corrugated metal structure and satisfies the requirements of Table 3. No durability allowance is required for the culvert.

ADVISORY NOTE #42

Example 2. A galvanized corrugated structure in a residential area has a design life of 50 years and the free-draining fill available for the site is expected to have a pH of 7 with an estimated resistivity of 7,000 $\Omega\cdot\text{cm}$. The native soil does not contain significant chlorides or sulphates and has a pH of 6. The initial galvanized coating thickness is measured at 85 μm .

The simplified durability design can be used and a steel durability allowance of 1 mm is required.

Detailed Durability Design

The detailed durability design process is used when the object is not a buried corrugated metal structure or when the conditions in Table 3 and Table 4 aren't met. For piling situations higher corrosion rates might exist if the steel is in contact with groundwater or if cut and fill installations disturb potential acid sulfate soils.

The corrosion rates for hot dip galvanizing and steel are given for pH and resistivity ranges in Table 4. If the pH or resistivity is outside the ranges provided in Table 4 or the site is subject to ponded water or wet silt specialist advice should be sought.



Figure 1. Corrosion of galvanized steel in aggressive soil.

If the fill material is outside the limits given in Table 4, it is considered aggressive and additional protection is recommended. In these cases, a suitable fill material should be used that can be isolated from the corrosive surrounding native soil, or by making design changes such as adding a barrier coating.

In mining environments, the concentration of elements in the soil must be checked, and specialist advice sought if runoff will increase the corrosion rate. When the pH and resistivity are near the limits given in Table 4, the soil may be aggressive and the concentrations of chloride ions and sulfate ions must be checked using the limits of Table 5.

Table 5. Concentration tests when soil is near the limits of Table 4

| Chloride concentration (mg/kg) | Sulfate concentration (mg/kg) | Procedure |
|-----------------------------------|----------------------------------|--|
| ≤ 200 | ≤ 1000 | Non-aggressive, use Table 4 |
| > 200 | — | Aggressive, use the worst case out of Table 6 and Table 7 for galvanizing, and Table 8 for steel |
| — | > 1000 | |

Table 6. Loss rate of galvanizing by pH in aggressive soil

| Soil pH | Range of average galvanized coating loss rate ($\mu\text{m}/\text{y}$) | |
|---------|---|-----------------|
| | Drained Soils | Undrained Soils |
| < 4 | > 6.5 | > 20 |
| 4 – 4.9 | 2.6 – 5.2 | 6.7 – 13.3 |
| 5 – 7.9 | 2.2 – 4.3 | 5.5 – 11 |
| 8 – 9 | 3.3 – 6.5 | 6.1 – 12.1 |
| > 9 | > 8.6 | > 17.2 |

ADVISORY NOTE #42

Table 7. Loss rate of galvanizing by soil resistivity in aggressive soil

| Soil Resistivity ($\Omega \cdot \text{cm}$) | Range of average galvanized coating loss rate ($\mu\text{m}/\text{y}$) |
|--|---|
| < 500 | > 3.5 |
| 500 – 1,000 | 1.5 – 3.5 |
| 1,000 – 2,000 | 1.3 – 1.5 |
| 2,000 – 5,000 | 0.9 – 1.5 |
| > 5,000 | < 0.9 |

Note: Use the worst-case value corresponding to the soil conditions out of Table 6 and Table 7 and do not add the values together.

Table 8. Loss rate of bare steel in aggressive soil

| Fill or soil conditions | | | Steel corrosion allowance from AS/NZS 2041.1 ($\mu\text{m}/\text{y}$) | | Uniform steel corrosion allowance from AS 2159 ($\mu\text{m}/\text{y}$) | |
|-------------------------|------------------|---|---|--------------------|---|---|
| pH | Chlorides (%) | Resistivity ($\Omega \cdot \text{cm}$) | Drained soils | Undrained soils | Low permeability soils ¹ | High permeability soils ² |
| > 5 | < 0.5 | > 5,000 | < 10 | < 10 | < 10 | < 10 |
| 4 – 5 | 0.5 – 2 | 2,000 – 5,000 | < 10 | 10 – 20 | < 10 | 10 – 20 |
| 3 – 3.9 | 2 – 5 | 1,000 – 2,000 | 10 – 20 | 20 – 40 | 10 – 20 | 20 – 40 |
| < 3 | > 5 | < 1,000 | 10 – 40 | 40 – 300 | 20 – 40 | 40 – 100 |

Notes:

1. Low permeability soils are silts and clays or all soils **above groundwater**
2. High permeability soils are sands and gravels that are **in groundwater**

Where sulfate levels are more than 1,000 ppm (0.1%) in piling situations, sulfate-reducing bacteria may be present and active, which sometimes leads to microbiologically induced corrosion. In such cases, corrosion rates for low permeability soils should be assumed to be 10 to 20 $\mu\text{m}/\text{y}$ and corrosion rates for high permeability soils should be assumed to be 20 to 40 $\mu\text{m}/\text{y}$. If the internal face of a steel pile is fully sealed, the corrosion rate on that face can be assumed to be negligible.

Example 3. A galvanized structure in a residential area has a design life of 50 years and the free-draining fill available for the site has a resistivity of 1,500 $\Omega \cdot \text{cm}$, a pH of 7 and chlorides have been measured at 1.2%. The native soil does not contain significant chlorides or sulphates and has a pH of 6. The initial galvanized coating thickness is measured at 85 μm . The steel durability allowance is 1 mm. The total alkalinity of the soil is 50 mg/kg (as CaCO_3) and the alkalinity at pH 7.3 is 3 mg/kg (as CaCO_3).

Using the detailed procedure of AS/NZS 2041.1, the pH of the soil governs the corrosion rate of the galvanizing and the rate is selected at 4.3 $\mu\text{m}/\text{year}$. From this, the galvanized coating will be expected to last 19 years. For steel, the corrosion rate is governed by the resistivity and is selected at 20 $\mu\text{m}/\text{year}$. Therefore the corrosion loss over the next 31 years is expected to be 0.62 mm, which is well less than the 1 mm corrosion allowance.

The durability of the galvanized structure is expected to be more than 50 years and is suitable for use.

ADVISORY NOTE #42

Example 4. Galvanized screw piles with a steel thickness above 6 mm are used in a clayey sand soil. The geotechnical survey reveals a soil pH of 6.0 and a resistivity of 2,500 $\Omega\cdot\text{cm}$. Using Table 4, this puts the soil under normal conditions. Since the pH is close to the limit, the chloride concentration and sulfate concentration are tested and found to be 150 mg/kg and 500 mg/kg respectively. Since these are lower than the limits for galvanizing shown in Table 5, the corrosion rate of 15 $\mu\text{m}/\text{y}$ for the first 2 years and 4 $\mu\text{m}/\text{y}$ subsequently from Table 4 is used, with the steel loss taken as 12 $\mu\text{m}/\text{y}$ using the same table.

The screw piles require a life of 30 years, and the steel section is more than 6 mm thickness. Table 1 indicates a minimum average coating thickness of 85 μm . Using the calculated loss rates, 30 μm of zinc is consumed in the first 2 years, leaving 55 μm of galvanized coating. The remaining coating will then be lost at a rate of 4 $\mu\text{m}/\text{y}$, lasting 13 years. This gives an estimated zinc life of 15 years.

The durability allowance of the steel is required to give 15 years of life (30 yrs – 15 yrs = 15 yrs). Using the loss rate of steel this equates to $15 \text{ y} \times 12 \mu\text{m}/\text{y} = 180 \mu\text{m}$ (0.18 mm) of extra steel material. In practice, this small a durability allowance is unlikely to be used and a value around 1mm will be chosen to incorporate a safety factor in case conditions change.

If HDG 900 was specified and agreed to by the galvanizer, the zinc coating life would be at least 25 years, a large improvement over the life of a HDG 600 coating.

Example 5. Galvanized H piles with a thickness above 6 mm are driven into silt. The geotechnical survey reveals a soil pH of 5.0 and a resistivity of 1,700 $\Omega\cdot\text{cm}$, and the soil does not drain freely. Using Table 4, this puts the soil under mildly corrosive conditions, and specialist advice should be sought (with an estimate of a loss rate given using the worst case out of Table 6 to Table 11). Being relatively close to the coast, the chloride concentration is tested and found to be 300 mg/kg.



Figure 2. Galvanized steel embedded in concrete with a paint coating around the embedded length to provide additional protection and prevent accelerated corrosion.

ADVISORY NOTE #42

The zinc loss rate is taken as 11 $\mu\text{m}/\text{y}$, the worst case value from the tables which appears in Table 6. This gives a HDG 600 zinc life of $85/11 = 7$ years. The durability allowance of the steel is then required to deliver the remaining 43 years of life. The worst case for the steel loss rate occurs when taking the corresponding rate to the resistivity of 1,700 $\Omega\text{-cm}$ from Table 8, which is a loss rate of 40 $\mu\text{m}/\text{y}$. The durability allowance required is thus $43 \times 40 = 1,720 \mu\text{m}$ (1.72 mm).

When a durability allowance of this magnitude is required, alternative solutions such as providing extra protection for the galvanizing (e.g. by painting or using a tape/wrap system), using a controlled backfill, or embedding in concrete should be explored. Note that the pH of the soil may affect the concrete durability and this should be checked separately.

Exposure testing

Laboratory measurements made on soils are not strictly comparable to similar measurements made in the field, due to varying moisture and other uncontrolled factors, such as variation in corrosion products, film formation and polarization. For these reasons, Romanoff and Denison performed extensive exposure testing of bare steel and metallic coatings between 1920 and 1950. Hot dip galvanized zinc coatings were applied to steels and iron of different compositions and production methods, with a total of 1,312 specimens of galvanized pipe or sheet buried between 1922 and 1924. Specimens were buried in 47 different soils, with the majority being loams, but also including clays and fine sands. The exposure testing lasted up to 13 years for galvanized steel, bare steel, and zinc in soils with pH ranging from 2.6 to 9.4 and resistivity ranging from 62 to 17,800 $\Omega\text{-cm}$. Further testing was undertaken in 1937 to investigate the corrosion of thicker hot dip galvanized coatings in highly aggressive soils, with an additional 300 hot dip galvanized steel pipes buried.

A summary of the exposure testing results can be seen in Appendix A.

AASHTO specifications

The American Association of State Highway and Transportation Officials (AASHTO) have codified the expected loss rates for galvanized steel in their bridge design specifications. These are similar to the Australian design guidelines shown in Table 3.

Table 9 AASHTO metal loss rates for zinc and steel

| Metal Loss Rates Material | Loss Rate |
|--------------------------------------|----------------------------|
| Zinc (first 2 years) | 15 $\mu\text{m}/\text{yr}$ |
| Zinc (subsequent years to depletion) | 4 $\mu\text{m}/\text{yr}$ |
| Carbon steel (after zinc depletion) | 12 $\mu\text{m}/\text{yr}$ |

Table 10 AASHTO limits for soil properties

| Electrochemical Requirements Property | Value |
|---------------------------------------|--|
| Resistivity | $\geq 3000 \text{ ohm-cm}$ (at saturation) |
| pH | 5-10 |
| Chlorides | $< 100 \text{ ppm}$ |
| Sulfates | $< 200 \text{ ppm}$ |

There are only minor differences between the values in Tables 9 and 10 and those in the Australian Standards (Tables 4 and 5), with the Americans settling on lower sulfate and chloride levels for design.

ADVISORY NOTE #42

Adapted German Gas and Water Works Engineers' Association Method

An alternative method developed by the German Gas and Water Works Engineers' Association provides a method for quickly estimating the risk of a soil being corrosive. Adaptions to the formula were made by the International Zinc Association to more accurately predict the suitability of galvanizing in the soil, instead of steel and iron.

The method uses the values in Table 11 as a quick check of likely corrosivity and performance and provides no information about expected corrosion rates. In Example 3, the application of the German method returns a value of -4 for hot dip galvanized steel, likely to have a fair performance and for low risk applications may well provide all the information required.

The corrosivity of a soil can be assessed by adding together all the ratings in Table 11 and comparing below.

$$S = A + B + C + D + E + F + G + H + I + J$$

$S > 0$ – Non corrosive soil

$S < -10$ – Corrosive soil

The probable performance of galvanized steel is given by adding some of the ratings in Table 11 and comparing to the values below.

$$P = C + E + F + G + H$$

$P > 1$ – Satisfactory

$1 \geq P \geq -4$ – Fair

$-5 \geq P \geq -8$ – Borderline

$P < -8$ – Unsatisfactory



Figure 3. Galvanized steel posts after about 35 years service. While the galvanizing had been fully consumed, the steel losses were reported at around 0.3 mm.

ADVISORY NOTE #42

Table 11. Modified German Gas and Water Works parameters and ratings

| Value | Parameter | Description or Range | Rating |
|-------|---|------------------------|--------|
| A | Type of Soil | Chalk or Sand | 2 |
| | | Loam or Clayey sand | 0 |
| | | Clay or Humus | -2 |
| | | Peat, Mud, or Bog | -4 |
| B | Soil Condition | Uniform soil | 0 |
| | | Dissimilar soil | -3 |
| C | Soil Resistivity ($\Omega \cdot \text{cm}$) | >10,000 | 0 |
| | | $\leq 10,000 - >5,000$ | -1 |
| | | $\leq 5,000 - >2,000$ | -2 |
| | | $\leq 2,000 - >1,000$ | -3 |
| | | $\leq 1,000$ | -4 |
| D | Water Content (%) | <20 | 0 |
| | | ≥ 20 | -1 |
| E | pH Value | >9 | 2 |
| | | >5.5 - ≤ 9 | 0 |
| | | ≤ 5.5 | -3 |
| F | Total Alkalinity mg/kg (as CaCO_3) | >100 | 2 |
| | | >20 - ≤ 100 | 1 |
| | | ≤ 20 | 0 |
| G | Alkalinity at pH 7.3 mg/kg (as CaCO_3) | <2.5 | 0 |
| | | $\geq 2.5 - <5$ | -2 |
| | | $\geq 5 - <10$ | -4 |
| | | ≥ 10 | -6 |
| H | Sulphide mg/kg | <5 | 0 |
| | | $\geq 5 - <10$ | -3 |
| | | ≥ 10 | -6 |
| I | Chloride mg/kg | <100 mg/kg | 0 |
| | | ≥ 100 mg/kg | -1 |
| J | Sulphate mg/kg | <200 | 0 |
| | | $\geq 200 - <500$ | -1 |
| | | $\geq 500 - <1,000$ | -2 |
| | | $\geq 1,000$ | -3 |

ADVISORY NOTE #42

INCREASING DURABILITY

Numerous steps can be taken to help a galvanized steel member embedded in soil reach the required service life. Some or all the following measures may be required depending on the corrosivity of the soil and potential issues identified during the design process.

Preventing Ponding

When water can pool at the interface between the galvanized steel and soil, a localised corrosion cell can form which results in higher than expected corrosion rates. Ponding can be minimised by building up soil (or concrete) around the interface to promote a natural water run-off, and by preventing water from running down the member to the interface. If ponding cannot be avoided through a design change, additional barrier protection is recommended at the interface.

Additional Barrier Protection

When only part of the member is embedded in soil or the member crosses a soil/groundwater interface, applying an additional coating is recommended to give enhanced corrosion resistance. At an interface between soil and the air there is a risk of accelerated corrosion from the level of compaction and oxygen availability, higher microbial activity in the first 200 to 300 mm below the natural soil levels, detritus build-up around the base causing higher levels of contamination and wetness, and exposure to chemicals such as herbicide, fertiliser or animal urine. Accelerated corrosion of the galvanized coating and pitting corrosion of the steel can occur, especially in aggressive atmospheres and wet environments.

For these reasons, where a steel structure is only partially buried, it is recommended designers consider additional protection for the first 250 mm below and above the natural surface. Many protection methods can be applied over galvanizing to provide additional protection, including epoxy mastic coatings, very high build epoxy coatings, ultra-high build epoxy coatings, powder coating, elastomeric polyurethane or polyurea coatings, bituminous paint (these are often not suitable for UV exposure), corrosion inhibiting fabrics (wrapping tapes), or high-density polyethylene (particularly for piling).

Specialist advice should be sought to ensure the chosen system is suitable for above and below ground use, forms a complete seal against moisture being drawn between the coating and galvanizing by capillary action, and will have excellent long-term adhesion to the galvanized coating.

Galvanizing can also be embedded in concrete footings to extend its life in aggressive soils and provide a higher tolerance to a member's overturning moment. The concrete/soil/steel/air interfaces should be designed and built correctly, including extending the concrete at least 250 mm below the soil level, ensuring the concrete extends above the natural soil level and slopes away from the steel at a 30° angle (at least) to prevent ponding, and adding additional barrier protection when the exposed atmospheric corrosivity category is C3 or above. Concrete, bricks and mortar are susceptible to corrosion in acid sulfate soils and will not provide significant protection in these circumstances. The best solution is to modify the fill and/or increase the cover if concrete use is required.

ADVISORY NOTE #42



Figure 4. New galvanized steel ground stubs with additional barrier protection applied near soil interface.



Figure 5. Used galvanized steel ground stubs after excavation.

Many Australian Utility companies and Roads Authorities publish their recommended technical information about their steel pole practices and several examples are provided in Table 12.

Table 12. Examples of the requirements of different utility companies and roads authorities for installation of galvanized steel poles

| Company/Authority | Recommendation or Requirement |
|---------------------------------|---|
| Main Roads (WA) | Requires a properly engineered reinforced concrete foundation and additional corrosion protection at the ground line |
| Energex/Ergon (QLD) | Specify a corrosion resistant coating on direct buried streetlight poles, extending 200 mm above and approximately 400 mm below the ground line |
| Powercor/Citipower (VIC) | Specify a “high film protective coating” for the buried portion of the streetlight poles to 250 mm above the ground line |
| VicRoads (VIC) | Similar to above but allow three coating options; powder coating, epoxy coating or heat shrink sleeves |
| AusGrid | Require an additional below ground protective coating from the bottom end to 300 mm above the ground line |
| NZ Transport Agency | Additional below ground protective coating to 100 mm above the ground line |

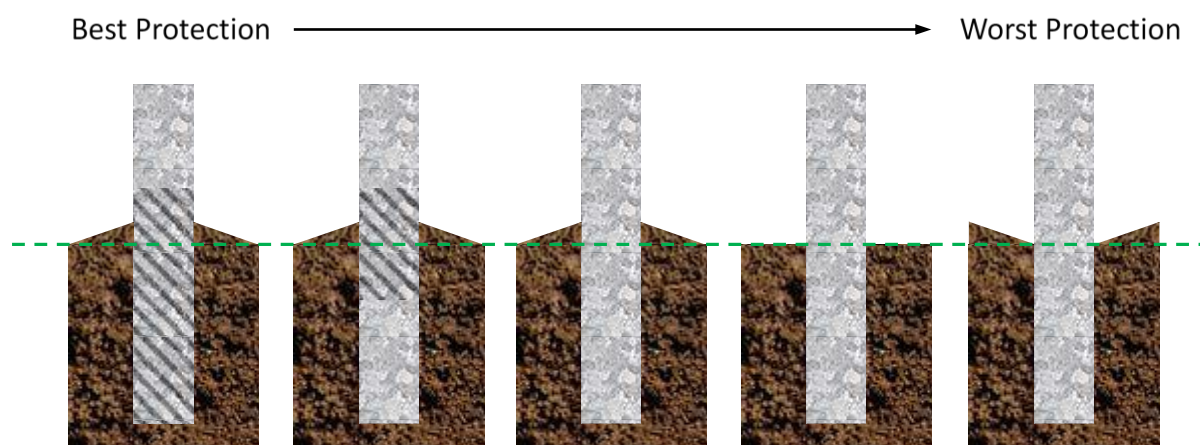


Figure 6. Diagram of best practices for partially embedding galvanized steel in soil.

ADVISORY NOTE #42

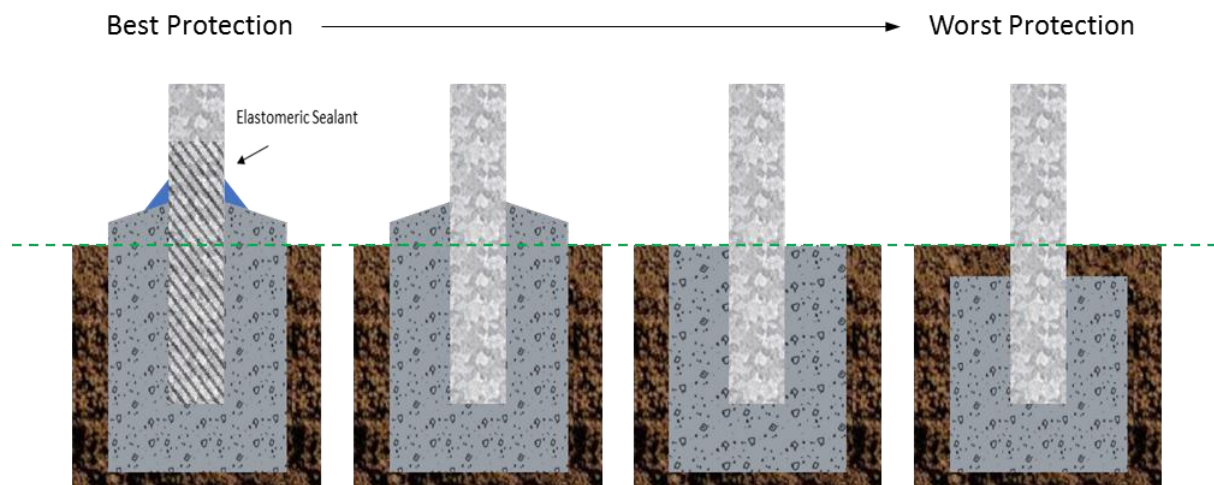


Figure 7. Diagram of best practices for partially embedding galvanized steel in concrete and soil.

Using a Select Fill

Where the soil is deemed unsuitable for galvanizing, a select backfill can be used to extend the life of galvanizing. Fills that satisfy the requirements of AS/NZS 2041.2 are usually within the acceptable pH and resistivity values and are free draining, maintaining a moisture content below 20%. Care should be taken to ensure the select fill zone is large enough and isolated from the aggressive native soil to ensure the fill material remains suitable for steel and galvanized steel.

Ramming Posts or Compacting Backfill

When less oxygen is supplied to submerged sections of galvanized steel lower corrosion rates are observed. Leaving the soil compacted by ramming posts or compacting the backfill will slow the diffusion of oxygen and result in higher durability of galvanized steel. Ramming posts into the soil may avoid activating dormant acid sulfate soils by preventing oxygen from coming into contact.



Figure 8. Additional barrier coating compromised potentially due to poor quality, aggressive conditions and/or constant moisture from plant matter.

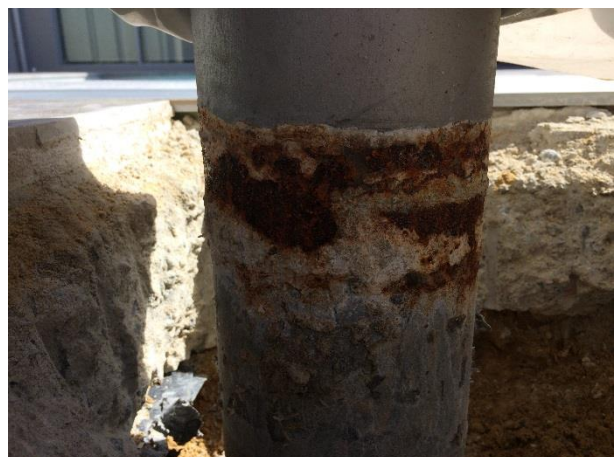


Figure 9. Corrosion below the concrete line from capillary action drawing moisture between the galvanizing and concrete.

ADVISORY NOTE #42

ZINC IN NATURE

Introduction

Zinc is the 24th most abundant element in the Earth's crust and has been present ever since the planet formed its surface. It is an essential mineral of "exceptional biologic and public health importance" and is considered a "Life Saving Commodity" by the United Nations.

Zinc moves constantly throughout the environment by a process called natural cycling. Rain, snow melt, ice, solar heat, and wind erode zinc from rocks and soil. Wind and water carry minute amounts of zinc to lakes, rivers and the sea, where it collects on organic material and eventually settles into the sediment. Other natural phenomena, such as volcanic eruptions, forest fires, dust storms and sea spray, contribute to the continuous cycling of zinc.

The concentration of zinc in nature without the additional influence of human activities is called "natural background." The natural background levels in surface water, soil and rock vary over a wide range of concentrations, although the variable range is relatively consistent from place to place. The natural amount of zinc in rivers has been measured from less than 5 to over 100 micrograms per litre. These ranges are consistent across different regions and have been comprehensively documented throughout the world. The zinc contained in soils directly influences background concentrations found in rivers. Natural levels in soil can range from less than 10 to over 1000 milligrams per kilogram.

Environment

It is estimated that natural emissions, including the mobilization of zinc due to uptake by plants, collectively amounts to over 10 million metric tons of zinc each year. Human activities do not add to the overall zinc amount on a global scale, but mining, production of goods and the use of zinc create situations where emissions to the atmosphere, soil and water can occur. These are known as anthropogenic emissions. Over the last few decades, zinc emissions from zinc manufacturing and processing have been reduced substantially by process improvements and the progressive implementation of more efficient emission abatement techniques. As a result, present-day emissions from industrial processes are limited and are estimated to be only 10% of the total emissions from the natural cycling of zinc from erosion, sea spray, volcanic eruptions, etc. Members of the [International Zinc Association](https://www.zinc.org/) adopted a set of commitments to sustainability as set out in their Sustainability Charter. For more information visit www.zinc.org/sustainability.

The environmental impact of zinc – and of all essential elements – cannot be assessed in the same way as man-made chemical compounds. Because zinc occurs naturally, eliminating it from the environment would not be possible. Moreover, because zinc is essential to life, achieving such a goal would ultimately lead to detrimental effects throughout an ecosystem. In other words, 'less' is not necessarily 'better'.

For essential elements such as zinc, environmental concentrations and their effects must be considered within the context of an organism's natural ability to regulate (uptake and excretion) and maintain a certain level of homeostasis. Organisms have evolved mechanisms to supply their needs independent of the external concentration by regulating an essential element to a constant internal level. Environments containing zinc at very low or very high concentrations may produce undesirable effects and the range between the minimum and maximum is often called the optimal window of essentiality.

ADVISORY NOTE #42

Human Health

Zinc is essential for human health and is found in all parts of the body. It is a component in more than 300 enzymes, plays a key role in the human metabolism and influences hormones. Zinc is vital for the stabilisation of DNA and the expression of genes as well as for the transfer of nerve signals.

Zinc is important for activating normal growth and neurological development in infants, children and teenagers. It accelerates cell division and enhances the immune system. It is also important in protecting the body from illnesses and fighting infections, such as reducing the duration and severity of a common cold and halting diarrhea.

Zinc deficiency is a major health problem in developing countries, especially among young children. Zinc deficiency weakens their immune system and leaves them vulnerable to conditions such as diarrhea, pneumonia and malaria. Due to the impact zinc can have in saving children's lives, the former UN Secretary General Ban Ki-Moon named zinc a "life-saving commodity". In light of this global health issue, the zinc industry, through [International Zinc Association](#), launched the Zinc Saves Kids initiative in support of UNICEF's global micronutrient supplementation program to address zinc deficiency for at-risk children. For more information on the Zinc Saves Kids initiative visit zincsavekids.org.

Crops

As well as being key for human health, zinc is a beneficial micronutrient for crops and zinc deficiency takes an enormous toll on both humans and agricultural crop productivity.

Zinc is lacking in 50% of the world's soils and is recognized as the most common micronutrient deficiency in crops. Zinc deficiency in soils creates reductions in crop yield, crop quality and nutritional value. Adding zinc to soils is a sustainable approach to significantly increasing crop yield, boosting nutritional value in humans and improving farmer incomes.

For more information on about the sustainability of zinc and its role in nature, download the International Zinc Association's [Zinc – A Sustainable Material, Essential for Modern Life](#).

For more information about zinc in the environment, see the International Zinc Association's [Zinc in the Environment: Understanding the Science](#).

SUMMARY

Hot dip galvanizing is commonly used as a durable corrosion protection for steel articles embedded in soil, with typical average HDG loss rates from 2 to 6 $\mu\text{m}/\text{year}$ in drained soils. Soil properties can vary greatly between locations and many factors have a large influence on the corrosion rate of galvanizing and steel in soil. Run-off from embedded galvanized items to the native soil is usually at low levels and can be ignored. For this reason, durability design should be undertaken before galvanizing is embedded in soil to determine whether methods to increase the durability are required. In aggressive conditions correct detailing is essential and using additional barrier protection or select fill can help the steel reach the desired service life.

ADVISORY NOTE #42

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ADVISORY NOTE #42

APPENDIX A. ROMANOFF DATA EXAMPLES

The results of the 1922 to 1924 testing showed a large variation in the galvanized coating's condition after being buried for 10 or 12 years, with some specimens showing little corrosion and pure zinc still present on the surface and others experiencing severe pitting corrosion of the underlying steel. Estimating an average loss rate over the length of the test is difficult, as around half of the specimens lost more than just the weight of the zinc coating during exposure. For the 20 least corrosive soils the coating remained intact, and an average loss rate of 14 g/m² per year (2 µm per year) was observed. Table 13 shows the percentage of specimens with no base steel exposed after the exposure period of 10 or 12 years.

Table 13. Percentage of specimens with zinc or zinc-iron alloy layers intact (no base steel exposed)

| Coating mass average (g/m ²) | Exposure time (years) | Percentage of specimens with no base steel exposed |
|---|--------------------------|---|
| 247 | 10 | 21 |
| 302 | 10 | 35 |
| 327 | 10 | 33 |
| 552 | 12 | 38 |
| 861 | 10 | 54 |

Results from the 1937 tests of galvanized pipe with a coating thickness of 940 g/m² showed that in the most aggressive soils exposure of the base steel is common and additional protection would be required to protect galvanized steel. Most specimens that had been hot dip galvanized had lower maximum pit depths compared to bare steel or pure zinc alone (graphs showing examples of weight loss and pit depth are in Appendix A). The reason behind the pitting resistance was investigated in the lab and found to be mechanical in nature, with the deposition of a white film on the surface of the specimen. X-ray powder diffraction revealed the film consisted primarily of zinc silicate.

The results obtained from the Romanoff and Denison studies are the basis for many of the predictive corrosion models currently used.

ADVISORY NOTE #42

The following graphs show the weight loss and maximum pit depths of four different types of soil studied in the Romanoff exposure tests. From top to bottom the soils are: 1) Soil 66, Inorganic oxidising soil. 2) Soil 70, Inorganic reducing soil. 3) Soil 59, Organic reducing soil. 4) Soil 67, Cinders.

