Steel Corrosion Rates in Water and Soil

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Introduction

Guidance on typical corrosion steel rates in water and soil for design use is provided in the recently published NZS3404.1 *Steel Structures Standard - Materials, Fabrication, and Construction* (SNZ,2009). The design rates given are those to be used for long-term exposure, i.e. where the designer is calculating a required sacrificial thickness of steel in order to meet the specified design life. This article covers the background to the corrosion rates provided in NZS 3404.1.

Steel Corrosion Rates in Soil

Corrosion of steel in natural soils is electrochemical in nature and unless the soils are strongly acidic, i.e. pH <4, the corrosion of steel depends upon the simultaneous presence of oxygen and water.

Steel Corrosion Rates in Undisturbed, Natural Soils

In undisturbed natural soils, oxygen concentrations are very low at a very short distance below the ground surface. Steel corrosion rates are therefore very low in these circumstances, and are not related to the nature of the soil, its composition or its properties.

The principal research references used to derive the design data are a paper by Ohsaki entitled Corrosion of Steel Piles Driven in Soil Deposits (Ohsaki, 1982) and a report by Romanoff entitled Corrosion of Steel Pilings in Soils (Romanoff, 1962). The former describes tests on 130 steel piles driven into a wide variety of natural soil deposits at 10 test locations in southern and central Japan. The latter describes inspections on steel piles at 19 locations around the USA. A summary of the scope of the studies, soil conditions investigated and results are discussed in (Clifton, 1998).

Romanoff in his report concluded:
"… Undisturbed soils are so deficient in oxygen at levels a few feet below the ground or below the water table zone, that steel piles are not appreciably affected by corrosion, regardless of the soil types or the soil properties. Properties of soils such as type, drainage, resistivity, pH or chemical composition are of no practical value in determining the corrosiveness of soil on steel piles underground."

Ohsaki in his report concluded that the mean corrosion rate of piles after 10 years at the 10 locations was 0.005mm/steel surface/year, with a standard deviation of 0.003mm/steel surface/year. The maximum corrosion rate measured was 0.015 mm/steel surface/year.

The maximum corrosion rate is used in NZS3404.1 (SNZ, 2009). This is consistent with what has been used in (BSI, 1986; Clifton, 1998). A slightly lower rate of 0.012 mm/steel surface/ year is used in Eurocode 3, Part 5, *Design of Steel Structures – Piling* (BSI, 2007) for long term corrosion rate (100 years).

Steel Corrosion Rates in Fill Below the Permanent Water Table

The steel corrosion rates in fill materials may be slightly higher than those for steel in contact with undisturbed natural soil. This difference will not be significant. The typical bare steel design corrosion rate for use in design in NZS3404.1 is 0.015mm/steel surface/year.

Steel Corrosion Rates in Controlled Fill Above the Permanent Water Table
A controlled fill is an engineered granular fill, in which the nature of the fill material and the process of compaction is specified and controlled. These soils are as impervious to oxygen as an undisturbed natural soil and the same corrosion rate applies, i.e. 0.015mm/steel surface/year.

Steel Corrosion Rates in Uncontrolled Fill Above the Permanent Water Table
This represents the most severe corrosion condition for steel buried in the ground. The corrosion rate is broadly dependent on the type of fill materials and the soil pH and shows little dependence on any other soil properties. (Romanoff, 1957, 1962) The most significant zone of corrosion is in the top few metres of filled soils, where exposure to oxygen is greatest. New Zealand studies have been undertaken for steel pipe applications (Penhale, 1971 and 1984). This is discussed in (Clifton, 2001). The New Zealand studies covered corrosion after 20 years of mild steel plates buried horizontally at a depth of 0.9m at 33 sites with soil types ranging from sand to clay and peat. The results are in agreement with Romanoff's findings. Some of the American results show distinctly higher corrosion rates than the New Zealand results; however the American soils include a high number of low-resistivity soils. The New Zealand study findings are also in agreement with UK findings.

For steel above the permanent water table and in fill which includes more than small quantities of any or all of the following materials: cinders, flyash, slag from steel making or the residue from concrete making, coal or organic waste the typical corrosion rate for design is 0.050mm/steel surface/year for ground with pH ≥ 4 and 0.075mm/steel surface/year for ground with pH < 4.

For piles above the permanent water table and in fill which comprises soil material or concrete, brick and other inorganic building material rubble, the typical corrosion rate for use in design is 0.025mm/steel surface/year.

Steel Piles in Water
The principal sources in developing typical bare steel corrosion rates in water is (Biddle, 1997, 2005), which in turn draws on details from BS 6439 (BSI, 1988), BS 8002 (BSI, 1994) and BS 8004 (BSI, 1986). Rates used in these standards were primarily based around investigations done by Morley and Bruce (1978) of British Steel (now Corus) at that time. Morley and Bruce made an extensive survey of the extent of corrosion on steel piling in marine structures at various sites in the UK, Cyprus and United Arab Emeritus (Tomlinson et al, 2007). For a full listing of research reports refer to Corus publication *A Corrosion Protection Guide* (Corus, 2004)

Below the Sea Bed
The corrosion of steel below the sea bed has the same rate of corrosion as in undisturbed, natural soils. Therefore 0.015mm/steel surface/year is appropriate.

Permanent Immersion in Water
For steel permanently immersed in sea water, a design corrosion rate of 0.035mm/steel surface/year is appropriate. This will apply over the typical range of sea water temperatures experienced around New Zealand, as the warmer waters contain less oxygen than the colder waters. Therefore the potential increase in corrosion rate from the warmer temperatures is balanced by the decrease from reduced oxygen.

For steel permanently immersed in fresh water, lower rates apply (BSI, 1986) and a value of 0.025mm/steel surface/year is appropriate for design for lengths of the pile further than around 300mm below the surface of the water.

The corrosion rate is sometimes observed to be higher (BSI, 1986) over the zone of pile in the top 300mm depth of water and, for design purposes, a value of 0.050mm/steel surface/year should be used in this band. This band of increased corrosion occurs when the water level is constant and becomes less significant with greater fluctuation of the water level (BSI, 1986).

Low-Water Zone Corrosion
This narrow zone occurs at the bottom of the tidal range where a lack of marine growth occurs but oxygen is quite readily available. A rate of 0.075mm/steel surface/year is recommended by (BSI, 1994). Occasionally, higher corrosion rates are encountered because of specific local conditions and it is recommended that periodic inspection of this zone is undertaken.

Tidal Zone
Tidal zones tend to accumulate marine growths, which reduce the supply of oxygen to the steel surface, thus reducing the corrosion rate. A design value of 0.035mm/steel surface/year is recommended (Biddle, 1997; BSI, 1994 and BSI, 1988).

Splash and Marine Atmospheric Zones
These are above the tidal range, subject to wave action and high chloride concentrations. The height of the zone depends on the degree of shelter from wave action. A corrosion rate of 0.075mm/steel surface/year is recommended by (Biddle, 1997; BSI, 1994 and BSI, 1988), however higher rates can occur in localised conditions, especially where heavy wave action occurs. Upper range values are quoted in (BSI, 1988) for various conditions and can be as high as 0.14mm/steel surface/year.

Above peak wave height and where the pile is sheltered from direct wind flow (eg. underside of wharfs, above the wharf skirt), a rate of 0.035mm/steel surface/year can be used.

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