Corus Construction & Industrial

A corrosion protection guide

For steel bearing piles in temperate climates

Steel bearing piles – surface protection

This document is intended to provide guidance on the corrosion and protection of H-section universal bearing piles used for the foundations to all types of structures. In the majority of circumstances steel bearing piles can be used in an unprotected condition, however, in more aggressive environments, additional protection may be required to achieve the desired design life of the structure. This publication outlines the corrosion performance of steel piling in various environments, and reviews the protective measures that can be taken to increase the life of steel piles where necessary.

Corrosion of piling in various environments

In determining the effective life of unprotected piles, the selection of piling section and the need for protection, it is necessary to consider the corrosion performance of bare steels in the different environments normally encountered in service. The corrosion rates given in this section are per exposed face. To determine the reduction in section thickness, the cumulative losses from all relevant faces need to be considered. The corrosion rates quoted are based on those given in BS 8002(1), BS 8004(2), BS 6349(3) or are derived from the corrosion allowances given in EN 1993 – 5 (Eurocode 3: Part 5)(4). Mean or guidance values are given by the references and are considered to be most relevant to the design and performance of most steel foundations. However, in some circumstances the designer may wish to take account of higher values and in these circumstances upper limits are given for marine environments in BS 6349.

Underground corrosion of steel piles

Natural soils

The underground corrosion of steel piles has been studied extensively. A review(5) of published data, outlining mainly overseas experiences, concluded that, unless the soils are strongly acidic (pH<4), the underground corrosion of steel piles driven into undisturbed soils is negligible, irrespective of the soil type and characteristics. The insignificant corrosion attack was attributed to the very low oxygen levels present in undisturbed soils.

Research on instrumented driven steel piles(6) shows that the greatest proportion of load resistance is derived from the lowest 25% of pile length in the zone immediately above the pile tip, where the risk of corrosion is normally lowest. This also has relevance to piles driven into fill soils. Pitting corrosion in the water table zone is frequently reported in the literature, but nowhere is this regarded as affecting the structural integrity of piling, except for excessive pitting found in some Norwegian marine sediments(7). Evaluations by British Steel(8-12) of piles extracted from UK sites, ranging from canal and river embankments to harbours and beaches, also confirm negligible underground corrosion losses. A further evaluation in Japan(13) of test piles driven, at ten locations, into natural soils which were considered to be corrosive, gave a maximum corrosion rate of 0.015mm/side per year after ten years' exposure. An aspect of underground corrosion that can arise is that of microbial corrosion by sulphate-reducing bacteria, which is characterised by iron sulphide-rich corrosion products. Although this form of corrosion has been observed on buried steel structures, e.g. pipelines, there is no evidence from the literature(5) or within Corus experience that this is a problem with driven steel piles.

Guidance on corrosion allowances for piles in natural soils is given in BS 8002 where the maximum corrosion rate of 0.015mm/year/side is advised and no other protection is required. This is within the range quoted by BS 8004 and consistent with the corrosion rates derived from Eurocode 3.

Fills and industrial soils

More recent trends have been to redevelop brownfield sites that may consist of recent-fill soils, industrial waste tips, or contaminated land where conditions could be more corrosive to steel. Traditionally, corrosivity has been evaluated on the basis of the physical and chemical characteristics of the soil. These parameters are scored individually in terms of influence on corrosion severity, and then collated to provide an empirical guide as to the likely corrosivity of the soil. Such general correlations continue to provide guidance for materials selection but are too general to allow the accurate prediction of damage at specific sites. More recently, corrosion rates can be derived from the corrosion allowances published in Eurocode 3 for service lives up to 100 years in non-aggressive and aggressive non-compacted fills (long-term rates approximately 0.02mm/year/side and 0.06mm/year/side respectively). Recent work by Corus[14] has further refined these guidelines by showing that certain soil parameters, e.g., pH, resistivity, soluble salt content, internal drainage, can be can be used to classify a soil as non-aggressive or aggressive so that the appropriate corrosion rate can be applied.

In a compacted 'controlled fill' (i.e., selected granular fill, as referred to in Highways Agency document BD 42/00), the same corrosion rates as in natural undisturbed soils can be assumed.

Atmospheric corrosion

At inland sites, piles used for foundation work may also be used as support structures above ground level. In such cases bare steel will corrode in the atmosphere at a rate that depends upon the site environment. This can be broadly classified as rural, urban or industrial. Similarly, piling at coastal sites may be subject to a marine atmospheric environment. BS EN ISO 12944-2 gives short-term (1 year) corrosion rates for these various environments. In the UK, the average rate of atmospheric corrosion can be taken as that recommended in BS 8002, i.e. 0.035mm/year/side. More specifically, the guidance value given in Eurocode 3 for what is classified as 'normal atmospheres' (0.01mm/year/side) is more typical of long term values for rural or urban conditions. Higher corrosion rates may be experienced, as given in BS 8004, when localised conditions and pollution produce very aggressive microclimates. However, the incidence of severe industrial conditions is diminishing with the progressive reduction in sulphur dioxide emissions experienced throughout the UK and Europe.

Corrosion in fresh waters

Fresh waters are very variable and can contain dissolved salts, gases or pollutants that may be either beneficial or harmful to steel. The term 'fresh waters' is used to distinguish these from sea or estuarine brackish waters. The corrosion of steel in fresh waters depends upon the type of water, although pH has little effect over the range pH 4 to pH 9, which covers the majority of natural waters. Corrosion losses from fresh water immersion generally are lower than for seawater and effective lives are normally proportionately longer. However fresh waters are very variable and these variable conditions are reflected in the corrosion rates derived from Eurocode 3 (approximately 0.02 – 0.05mm/year/side). These are broadly in line with the rates given in BS 8004. Considerably higher corrosion rates have been experienced in situations where there is a roughly constant water level and in these cases appropriate methods of protection are recommended.

Corrosion in marine environments

Marine environments normally encompass several exposure zones of differing aggressivity and the corrosion performance of marine structures in these zones requires separate consideration.

Below the bed-level

Where piles are below the bed-level very little corrosion occurs and the rate given for underground corrosion is applicable, i.e. 0.015mm/year/side.

Seawater immersion zone

Above the bed-level and depending upon the tidal range and local topography, there may be a continuous seawater immersion zone in which, with time, piling exposed to unpolluted waters acquires a protective blanket of corrosion products and marine growth, the latter consisting mainly of seaweeds, anemones and seasquirts. Corrosion of steel piling in immersion conditions therefore is normally low, with a mean corrosion rate of 0.035mm/year/side.

Tidal zone

This zone lies between the low-water neap tides and high-water spring tides and tends to accumulate dense barnacle growths with filamentous green seaweeds. The marine growths can again protect the piling by sheltering the steel from wave action between tides and by limiting the oxygen supply to the steel surface. The presence of macro-cells where the tidal zone is cathodic to the low water zone, may also limit the corrosion rate of steels to a level similar to that of immersion zone corrosion, i.e. 0.035mm/year/side.

Low water zone

In the low water zone, which is anodic to the tidal zone, higher corrosion rates are often experienced. It has been established that, for piles in tidal waters, the low water level and the splash zone are regions of highest thickness losses, where a mean corrosion rate of 0.075mm/year/side occurs. Localised corrosion, leading to significantly higher corrosion rates than this value, is sometimes encountered at the low water zone because of specific local conditions. Further details on the mechanisms of this form of concentrated corrosion are discussed in BS 6349-1. Corus recommends that periodic inspections of this zone are undertaken.

Splash and atmospheric zones

Above the tidal zone are the splash and marine atmospheric zones, the former being subject to wave action and salt spray and the latter mainly to airborne chlorides and is less aggressive. Unlike the tidal zone, these areas are not covered with marine growths. Corrosion rates in the splash zone are similar to the low water level, i.e. 0.075mm/year/side. In this zone thick stratified rust layers can develop, however, it should be borne in mind that rust has a much greater volume than the steel from which it is derived and steel corrosion losses may amount to no more than 10% to 20% of the rust thickness.

The boundary between the splash and atmospheric zones is not well defined; however, corrosion rates diminish rapidly with distance above peak wave height and the mean atmospheric corrosion rate of 0.035mm/year/side can be used for this zone.

Methods of increasing effective life

The effective life of unprotected steel piling, depends upon the combined effects of imposed stresses and corrosion. Where possible, the structure should be designed so that low corrosion rates exist at positions of high imposed stresses. Measures for increasing the effective life of a structure, where necessary, are covered in BS 8002 and BS 6349; these can be used separately or in combination and are outlined below:

(a) Use of a heavier section
(b) Use of a high yield steel at mild steel stress levels
(c) Apply a protective organic coating
(d) Apply cathodic protection
(e) Use concrete encasement where practicable

Use of a heavier section

Effective life can be increased by the use of additional steel thickness as a corrosion allowance. The pile thickness can be increased locally by the addition of steel plates. The extra steel thickness required depends upon the working life and environment of the piling structure. The corrosion rates of steel piling in various service environments have been discussed previously and in many circumstances, the use of a corrosion allowance can be a cost effective method of increasing effective life.

Suggested coatings for immersed conditions or soils

Coating	Surface preparation	No. of coats	Nominal dry film thickness (microns)	Comments[3]	Typical areas of use	Relative Costs[5]	Typical times to first maintenance (Years)[1, 2]
PC3	Blast Clean ISO 85101-1 Sa 2½	1	400	Epoxy[4]	Piers, jetties, bearing piles in corrosive soils	140	20+
PC4				Glass flake epoxy	Piers, jetties, bearing piles in corrosive soils. For soils and immersion conditions that also require abrasion resistance	160	20+
PC5				Glass flake polyester/vinyl ester	Piers, jetties, bearing piles in very corrosive soils where abrasion resistance and chemical resistance are required	165	25+

Notes

1. Estimated durability is for environment categories Im2 (sea or brackish water), and Im3 (soil), based on BS EN ISO 12944 and ISO 9223. A longer time to first maintenance may be expected for bearing piles in Im1 (fresh water) environments.
2. These will vary considerably and will depend upon workmanship, environment etc. The period given relates to reasonable freedom from corrosion which might lead to a weakening of the structure, and assumes no mechanical damage during installation.
3. PC3/PC4/PC5, are available in a range of colours. These coatings are subject to superficial surface degradation termed 'chalking', but can be overcoated on-site with a finish coat, e.g. an aliphatic polyurethane, which has good colour and gloss retention.
4. Upon request, a coal tar epoxy (PC2) may also be available as an alternative to an epoxy. Although this is likely to be cheaper (relative cost = 100), it is currently being phased out for health and safety reasons, and is not recommended.
5. Relative costs are based on a typical bearing pile (305x305x126) and contract size (75T), in 2005.

Use of a high yield steel

An alternative approach to using mild steel in a heavier section is to use a higher yield steel and retain the same section. Although both types of steel have similar corrosion rates, the provision of grade S355 piles to EN10025-2 that are designed for grade S275 stresses will allow an additional 30% loss of permissible thickness to be sustained without detriment. This method, in effect, builds in a corrosion allowance and gives an increase of 30% in effective life of a steel piling structure for an increase of only about 7% in steel costs.

Organic coatings

Suggested coating systems for protection of steel exposed to atmospheric environments are given in a separate Corus document[17]. Coatings suggested for the protection of steel in immersed conditions or soils are given in the table above.

These high build durable coatings have been tested in a range of environments including bioreactor tests in the presence of bacteria and have shown good protection against localised corrosion at the low water level in Europe[15] and Japan[16].

Coatings that are shop applied under controlled conditions are more durable than site applied coatings. Coatings can be damaged during transport, handling and pitching and appropriate on-site remedial treatment may be required. Driving in certain types of soil, e.g. gravels, may cause removal of some types of coatings, and this aspect should be considered when selecting an appropriate coating.

Cathodic protection

Cathodic protection (CP) can be applied to buried or marine structures, but appropriate design can be a complex operation requiring the knowledge and experience of specialist firms. The principles involved are discussed in the appropriate Standard[18] and are outlined below. Two systems are employed, utilising either sacrificial anodes or impressed DC currents. In normal electrochemical corrosion all metal loss occurs at the anode and both types of CP system impart immunity from corrosion by rendering the steel structure cathodic to externally placed anodes.

For a steel piled structure of large surface area, the total current required for CP could be considerable. If piles are suitably coated then current requirements, and hence running costs, are considerably reduced. Deterioration of the protective coating occurs with time, though this is counteracted to some extent, by the deposition of protective calcium and magnesium salts on bare areas of the steel piling and the growth of marine organisms. However, in the long term, an increase in total current may be necessary and the CP system should be designed with an appropriate margin of capacity to cover this situation.

Not all protective coatings can be used in conjunction with CP. The coating should be of high electrical resistance, as continuous as possible, and resistant to any alkali, which is generated by the cathodic reaction on the steel surface. The high build durable coatings recommended in the table can be used with cathodic protection.

When considering CP it should be borne in mind that this method is considered to be fully effective only up to the half-tide mark. For zones above this level, including the splash zone, alternative methods of protection are required. Sacrificial anode or impressed current alone or in conjunction with CP compatible protective coating systems have been evaluated and recommended as a method of protection against localised corrosion at the low water level in both Europe[15] and Japan[16]. These evaluations include bioreactor tests in the presence of bacteria.

Concrete encasement

Concrete encasement can be used to protect steel piles in soils or marine environments. In marine environments, often the use of concrete encasement is restricted to the splash zone. However, in some circumstances, both splash and tidal zones are protected by extending the encasement to below the lowest low water level. Corus experience has shown that where the splash zone is only partially encased, a narrow zone of increased corrosion can occur at the steel-concrete junction, as a result of electrochemical effects at this junction.

In soils and seawater, concrete is not itself always free from deterioration problems. The concrete should have the correct composition and compaction with a depth of cover appropriate for the environment as recommended in the appropriate standard.

Summary of suggested measures for various environments

Underground exposures

Steel piles driven into undisturbed ground (pH>4) require no protection irrespective of the soil types encountered. This also applies to piles driven into harbour, river and sea beds. For piling driven into recent fill soils and particularly industrial fill soils some protection may be necessary. Where protection is required, a durable protective organic coating or CP should be applied.

Fresh water and marine environments

Normally the corrosion rate of steel exposed to these environments is low enough to give acceptable steel loss over the design life of a piling structure; therefore bare steel can be used with an appropriate corrosion allowance. Alternatively, paint coatings or cathodic protection can be used.

In non-tidal situations, corrosion can occur at the water line, e.g. canals, where there is roughly a constant water level. In such cases it is recommended that a protective organic coating is applied to a depth of 1m above and below the water level.

In the marine splash zone, protections can be employed in the form of organic coatings or concrete encasement. With the former it is suggested that the coating should extend to at least 1m below mean high water level. It should be borne in mind that, in the absence of good borehole data, it is often difficult to estimate beforehand the driven depth of piling. In such cases more of the pile length may have to be coated to ensure that the piles insitu are protected in the splash zone. Where the tidal range is small, concrete encasement can also be used. With this method the encasement should be extended to a minimum of 1m below mean high water level and the highest quality concrete used.

Atmospheric exposures

Piling exposed to rural, urban or industrial atmospheres is usually painted for aesthetic reasons. A variety of coatings can be used depending upon requirements[17]. The marine atmosphere zone of a piling structure is normally considered on the same basis as the splash zone and if protections are used on the splash zone, then they are normally extended to protect the atmospheric zone.

References

1. Code of practice for earth retaining structures, BS 8002: 1994, BSI.
2. Code of practice for foundations, BS 8004:1984, BSI
3. Code of practice for maritime structures, BS 6349-1:2000, BSI.
4. Eurocode 3: Design of Steel Structures – Part 5: Piling, ENV 1993-5
5. J. Morley: 'A Review of the Underground Corrosion of Steel Piling', Report T/CS/1114/1/78/C, British Steel Technical, Teesside Laboratories, 1978.
6. Steel Bearing Piles Guide, Publication Number P156, 1997, The Steel Construction Institute
7. L. Bjerrum: 'Norwegian Experiences with Steel Piles to Rock', Geotechnique, 1957, Vol. 7, pp 73 – 96.
8. J. Morley: 'A Corrosion Examination of Extracted Larssen Piles', Report T/CS/906/3/77/C, British Steel Technical, Teesside Laboratories, 1977.
9. J. Morley and D. W. Bruce: 'A Corrosion Examination of an Extracted H-Bearing Pile: Scotswood Bridge', Report T/CS/906/5/78/C, British Steel Technical, Teesside Laboratories, 1978.
10. J. Morley: 'A Corrosion Examination of Extracted Piles from Beach Groynes', Report T/CS/906/6/78/C, British Steel Technical, Teesside Laboratories, 1978.
11. J. Morley and D. W. Bruce: 'Survey of Steel Piling Performance in Marine Environments', ECSC Final Report No. 7210-KB/8O4, 1983.
12. D. W. Bruce: 'Corrosion of Steel Piles at B.T.P. Tioxide Site at Hartlepool', Technical Note No. T/CS/TN/19/79/D, British Steel Technical, Teesside Laboratories, 1979.
13. Y. Osaki: 'Corrosion of Steel Piles Driven in Soil Deposits', Soils and Foundations, Vol 22, No. 3, September 1982.

14 E. Marsh and W. T. Chao: 'The durability of steel in fill soils and contaminated land', Report no. STC/CPR OCP/CKR/0964/2004/R, Corus Research, Development & Technology, Swinden Technology Centre

15. Moulin et al: 'Prevention of Low-Water Corrosion on Steel Piling Structures due to Microbially Influenced Corrosion Mechanisms', Draft Final Report, ECSC Agreement 7210-KB/503, KB/825, KB/130, KB/826, KB/337, February 1998.
16. 'Corrosion Protection and Repair Manual for Port and Harbour Steel Structures', 1998, The Overseas Coastal Area Development Institute of Japan.
17. A corrosion protection guide, For steelwork exposed to atmospheric environments, Corus Construction & Industrial, 2004.
18. Cathodic Protection, Part 1: Code of practice for land and marine applications, BS 7361:Part 1:1991, BSI.
19. B Linder: 'Cathodic Protection of Steel Sheet Piling in Sea Water, Containing Sulphate Reducing Bacteria (SRB), Particularly with Respect to Accelerated Low Water Corrosion (ALWC)', Swedish Corrosion Institute Report No. 55467, 1/6/99.

Further information

Details of universal bearing pile sizes and section properties are given in our brochure 'Structural Sections to BS4: Part 1: 1993 and BS EN10056: 1999.'

www.corusgroup.com

Designed and produced by
Orchard Corporate Ltd.

Corus Construction & Industrial
Technical Sales and Marketing
PO Box 1
Brigg Road
Scunthorpe
North Lincolnshire
DN16 1BP
T +44 (0) 1724 405060
F +44 (0) 1724 404224
E tsm@corusgroup.com
www.corusconstruction.com

English language version

CC&I:CD:F:3000:UK:02/2005