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# Management of accelerated low water corrosion in steel maritime structures

Prepared under contract to CIRIA by Mott MacDonald in partnership with BAC Corrosion Control Ltd, Nuttall John Martin and the Corrosion and Protection Centre at the University of Manchester

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# Summary

ALWC is an aggressive and localised form of low water corrosion which can occur in tidal and brackish waters on steel maritime structures. Corrosion rates in regions affected by ALWC can be 1 mm/side/year or more and design corrosion allowances will, therefore, be exceeded quickly. This process will rapidly compromise the integrity of affected structures and will lead to significant costs for repair or replacement, in addition to having serious implications for the safe operation of the structure.

This book provides a comprehensive guide to the phenomenon of ALWC and its management, condition appraisal, repair, protection and monitoring. It is aimed at infrastructure owners, operators and their advisors, specialist engineers and asset and maintenance managers in ports, harbours and other marine locations. An executive summary gives an overview of the book and answers key questions. More in-depth information can be gained from reading the whole book, particular chapters of interest or the detailed information in the appendices.

The book is based on a detailed review of published literature and infrastructure owner's procedures, consultation with experts and practitioners from a cross-section of fields of expertise and case studies demonstrating good practice.

**Management of accelerated low water corrosion in steel maritime structures**

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The book sets out good practice in the management, condition assessment, repair, protection and monitoring of steel maritime structures affected by ALWC.

Following CIRIA's usual practice, the research project was guided by a Steering Group which comprised:

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Other organisations contributed to the book by reviewing drafts and specific text. They include the British Ports Association Engineering Dredging Group, Arup worldwide via their intranet, and the ICE Maritime Board.

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## Health and Safety

Construction activities, particularly those on construction sites, have significant health and safety implications. These can be the result of the activities themselves or can arise from the nature of the materials and the chemicals used in construction. This book gives some reference to relevant health and safety issues. However, other published guidance on specific health and safety issues in construction should be consulted as necessary to ensure up-to-date legislation is applied and appreciated, especially the requirements of national legislation and those of infrastructure owners.

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Dr Lyon is a Reader in Corrosion Science and Engineering at the Corrosion and Protection Centre at the University of Manchester. His research interests include: accelerated testing and analysis of materials performance, advanced paints and coatings for materials protection, engineering failure analysis and advanced electrochemical methods.

# Executive summary

**Who is the book for?** The target audience is:

- port infrastructure owners and operators and their advisors
- specialist engineers – experts in marine activities
- asset and maintenance managers.

Owners and operators of other structures such as coastal defences will also find the book valuable.

**What is it about?** Accelerated Low Water Corrosion (ALWC) is a particularly aggressive and localised form of low water corrosion which can occur in tidal and brackish waters on steel maritime structures. This book aims to provide a comprehensive guide to the phenomenon of ALWC and its management in ports and harbours and other marine locations.

**Why should I read this book?** Corrosion rates in regions affected by ALWC can be 1 mm/side/year or more and design corrosion allowances will, therefore, be exceeded quickly. ALWC could lead to a loss of 33 to 66 per cent of the asset value. This process will rapidly compromise the integrity of affected structures and will lead to significant costs for repair or replacement, in addition to having serious implications for the safe operation of the structure.

**How is this book structured?** You do not have to read this guide in any particular order. It is structured so that you can obtain as little or as much information as you may need on ALWC and its management. Although this approach is designed to help the reader, it inevitably results in some repetition.

A first level of understanding can be gained by reading this summary in combination with those found at the end of each of the main chapters and Chapter 10 "Recommendations for good practice". Greater understanding can be obtained from reading the whole book or those chapters of interest which are augmented by more detailed information to be found in the cross-referenced appendices.

**Chapter 1** of this book is a general introduction to ALWC. It covers the types of structures at risk, the implications of its occurrence and a brief overview of relevant health and safety and environmental issues.

**Chapter 2** describes traditional marine corrosion mechanisms and associated corrosion rate data for steel maritime structures exposed to tidal influences in order to put ALWC into context. It expands on the basic ideas outlined in Chapter 1, providing more detailed information on identification, damage patterns, proposed mechanisms and reported rates of metal loss for ALWC.

**Chapter 3** concerns the geographical distribution of ALWC and the surveys carried out to date, including the questionnaire survey, as part of this work.

**Chapter 4** introduces the general principles of asset management in a maritime environment with particular emphasis on ALWC.

**Chapters 5 and 6** deal with the interrelated subjects of condition appraisal, repair and protection.

**Chapters 7 and 8** look at monitoring the performance and procurement of remedial methods relevant to ALWC.

**Chapter 9** focuses on areas requiring funding for further research into the problem, its identification and treatment.

**Chapter 10** gives guidance on general good practice in dealing with ALWC.

The bibliography and cited references provide a comprehensive list of both technical and commercial literature relevant to ALWC. The glossary of terms will assist the reader in understanding the multidisciplinary terms associated with the phenomenon of ALWC.

**What causes ALWC?** The detailed mechanism of ALWC is still unclear, but it involves a combination of microbiological and corrosion processes, which may explain the unpredictability of its occurrence.

**Where does it occur?** ALWC typically occurs just above the area of lowest astronomical tide (LAT) although it has recently been reported as present below this level. The distribution of ALWC is both highly variable (some elements of a structure will have it while their neighbours will not) and consistent (it will often occur at the same location for particular pile or other element geometries, irrespective of geographic location).

**Will I get it?** No reliable predictive model is currently available for assessing the risk of ALWC appearing at any particular location. Therefore, there is currently no location where the possibility of it occurring can be ruled out.

The extent and spread of the ALWC problem is a source of ongoing debate. Some claim that the problem is exaggerated with only relatively few locations being affected. Others claim that it is already widespread and even if a structure is not currently being affected, it is only a matter of time (or diligence in looking for it) before all experience it, unless appropriate protection measures are taken. Diligence in inspection and maintenance should, therefore, be a priority.

A recent survey, initiated as part of this study, indicated that of the 70 questionnaires returned, 57 per cent stated that ALWC was present while 23 per cent reported no significant corrosion. A more comprehensive and widespread survey of steel maritime structures by experienced personnel familiar with ALWC is required in order to obtain a definitive answer as to the scale of the problem within the UK.

**How do I know if I have ALWC?** Currently the only reliable method of detecting ALWC is by visual inspection (either by boat at very low spring tides or using divers) together with residual wall thickness measurements. ALWC occurs as localised patches of damage, identified by a characteristic, poorly-adherent orange corrosion product over a 'soupy' black (iron sulfide rich) underlayer associated with rapid metal thinning (the substrate steel surface exhibiting a bright, clean and shiny appearance with extensive pitting). An area exhibiting this visual characteristic alone but without the local high rates of attack is not confirmation of ALWC.

**How can I manage ALWC and what will it cost me?** The strategy for management of ALWC will depend on whether a structure is new build (where the aim will be to take measures to minimise the risk of ALWC occurring) or an existing structure in the early, intermediate or advanced stage of attack (where the aim will be to take appropriate action to ensure it remains operational for the required remaining service life). Design, inspection, structural analysis, repair, protection and on-going monitoring of maritime structures must now be done taking ALWC into account with due regard to relevant health and safety legislation and environmental responsibilities.

The corrosion protection measures that are currently applicable to ALWC are those based on conventional corrosion control methods which have a track record of protecting steelwork from other forms of corrosion in a marine environment, notably cathodic protection (CP) and coatings of various types. The criteria for optimal protection are not as clearly understood as for 'normal' marine corrosion, but all can be expected to contribute to the protection against ALWC to a greater or lesser degree. The real challenge with ALWC, as with most corrosion problems, is to obtain safe and long-lived service for the lowest overall cost. ALWC only affects a small percentage of total exposed surface area on a structure, and an area for future research is developing remedial techniques aimed specifically at treating ALWC in a more focused way.

In the absence of an accurate predictive model, it is prudent to assume that ALWC will occur at all locations. In general, the adage "a stitch in time saves nine" applies and the sooner corrosion control measures are installed, the lower the overall cost will be. The cost of a combined corrosion protection system, ie CP and coating, generally recommended for new build structures, typically accounts for some two to 10 per cent of overall construction costs. A life cycle cost analysis should be performed to compare the actual financial implications of candidate corrosion control options for particular structures. Installing corrosion control to an existing structure will typically cost three to 10 times as much, while repair of a badly corroded structure will eventually become more expensive than replacement with a new structure. Subsequently the proper maintenance of the corrosion control system is also essential for cost effective performance and should be properly resourced and managed.

As with all significant assets, a whole life costing and asset management approach should be adopted in order to minimise the total cost of ownership of the asset. Taking into account the probability of ALWC, the provision of corrosion control should significantly reduce the overall cost, whether installed at the outset or as a retrofit.

**How will it impact on my business?** If ignored, ALWC can result in extensive, unbudgeted and costly repair and maintenance works at an unexpectedly early stage in the life of a structure. The damage caused by ALWC is not obvious. It occurs below the low water mark and, unless you look for it, the first sign of the problem is liable to be loss of containment of backfill resulting in the collapse of surfaces above. ALWC in an advanced stage could also potentially lead to the collapse of a structure. By the time holing happens any repair is likely to be expensive, not only in terms of the direct cost of the repair process itself but also, and probably more significantly, in terms of the loss of operational usage. Repairs disrupt operations. In contrast, early identification and remedial treatment will be relatively inexpensive and can often be managed to minimise disruption.

**Can I delay spending money?** Providing the structure has been analysed by a competent design engineer who has determined an acceptable remaining serviceable life without the need for immediate repair and/or protection, major spending on remedial measures can be deferred. However, this does not mean completely avoiding spending money – regular inspection should be continued, especially on critical elements in the areas subject to ALWC. Furthermore, as the degradation of the structure proceeds, the eventual repair costs will mount. Therefore, regular inspections followed by early remedial measures are recommended. The sooner ALWC is detected and addressed, the cheaper the remedial solutions will be.

**How do I go about it?** Owners should consider corrosion protection, including from ALWC, on all maritime structures, both new build and existing. They should be fully aware of their technical, commercial and legal responsibilities for managing operational, financial, environmental and health and safety risks. The following recommendations are made:

**For new build structures:**

- include cathodic protection in any design (it can protect against other forms of corrosion in addition to ALWC. ALWC may cause the loss of up to two thirds of design life if not protected against)
- if CP is not included initially, ensure electrical continuity is provided between all elements of the structure to facilitate its installation if required at a later stage
- apply a heavy duty, protective coating system to at least the exposed part of the structure in the atmospheric, splash and tidal zones and preferably the retained face. (This will reduce the CP current requirement for protection which, in the case of galvanic CP will reduce the number and weights of anodes required or prolong anode life, and will provide protection in the regions where CP is ineffective)
- record all design data including specific minimum thickness requirement at the critical low water zone
- institute a monitoring programme to confirm the efficacy of the protection applied and determine maintenance timing.

**For existing structures:**

- where necessary, seek independent, professional advice for guidance on the most appropriate and cost effective remedial strategy and when to apply it for the particular structure
- inspect all structures as soon as possible and establish the presence of any locations showing high rates of metal wastage or holing (particularly on critical elements) and pattern of such attack. Confirm the cause and treat appropriately. Note that competent inspection is required for the accurate identification of ALWC
- if ALWC is the cause, identify the generalised (ideally maximum) levels of steel loss. It is important that a consistent approach to measurement be adopted from the outset to allow future comparison. Calculate the rate of loss for forecasting purposes when setting a detailed inspection programme
- for the attack found, re-analyse the factor of safety against overstress, instability or collapse. Note that modern analytical techniques may find useful redundancy, but you should not rely on the structure's apparent ability to withstand collapse, even with holes
- establish a priority work programme. Keep and update regularly a condition database for all parts of all structures and use risk management techniques, as appropriate
- propose a programme of remedial measures and an appropriate budget and calculate potential loss of asset value at collapse or for reduced loading use
- report to Budget-holders/management making clear their Health and Safety responsibility and establishing full board level backing appropriate to the importance of the matter
- carry out priority repairs (holes > excessive thinning > overstress). Make emergency repairs a priority over all but initial inspection
- repair operations can be combined with inspection and save cost. Remobilisation is often a wasted expense. Working in the dry environment of a limpet dam for quality results is often advisable
- do not let holes occur since they complicate the repair work and waste money
- continue to monitor repairs and protection systems.

*Remember:*

- failure to implement appropriate measures for the monitoring and control of corrosion can expose an organisation and its management to the full severity of Health and Safety and Environmental Legislation if a fatal incident, pollution release or harm to the public occurs
- following and documenting the procedures identified in this guide and carrying out the investigation, design and construction work arising from them will demonstrate that an owner and his technical and commercial management have intended to meet their legal responsibilities for health and safety, and the environment.

# Abbreviations

| | |
|---|---|
| AC | Alternating electrical Current |
| ACOP | Approved Code of Practice |
| ALARP | As Low As Reasonably Practicable |
| ALWC | Accelerated Low Water Corrosion |
| APB | Acid Producing Bacteria |
| ASTM | American Society for Testing Materials |
| CD | Chart Datum |
| CDM | Construction (Design and Management) Regulations 1994 |
| CP | Cathodic Protection |
| DC | Direct electrical Current |
| DFT | Dry Film Thickness |
| HAZ | Heat Affected Zone |
| H&S | Health and Safety |
| HSWA | Health and Safety at Work Act (1974) |
| ICCP | Impressed Current Cathodic Protection |
| ICE | The Institution of Civil Engineers |
| ILW | Intertidal Low Water |
| ISO | International Organisation for Standardisation |
| LAT | Lowest Astronomical Tide |
| MHWS | Mean High Water Spring |
| MHWN | Mean High Water Neap |
| MIC | Microbiologically Influenced Corrosion |
| MLWS | Mean Low Water Spring |
| MLWN | Mean Low Water Neap |
| NACE | National Association of Corrosion Engineers, USA |
| NLWC | Normal Low Water Corrosion |
| O&M | Operating and Maintenance |
| PWC | Preferential Weld Corrosion |
| QRA | Quantitative Risk Assessment |
| QUENSH | Quality, Environment, Safety and Health |
| SCE | Saturated Calomel reference Electrode |
| SOB | Sulfur Oxidising Bacteria |
| SRB | Sulfate Reducing Bacteria |
| SLS | Serviceability Limit State |
| ULS | Ultimate Limit State |
| VOC | Volatile Organic Content |

# 1 Introduction

## 1.1 Background

ALWC (accelerated low water corrosion), sometimes also referred to as "LAT (lowest astronomical tide) corrosion", is a particularly aggressive form of localised corrosion defined in the British Standard for Maritime Structures (BS 6349-1: 2000) as a type of low water "concentrated corrosion". It has become a high profile problem, associated with unusually high rates of metal wastage and holing (see Plate 1.1) on unprotected, or inadequately protected, steel maritime structures. Average corrosion rates in the range of 0.3 to 1.0 mm/wetted side/year are typically reported but higher instantaneous rates are probable once ALWC has initiated on a structure. If timely action is not taken, this rapid form of attack can result in extensive, unbudgeted and costly remedial repair and maintenance works at an unexpectedly early stage in the life of a structure. ALWC in an advanced stage could also potentially lead to the collapse of a structure. It is not surprising, therefore, that the occurrence of ALWC was described as "a matter of national importance" at a conference organised by the ICE on the subject in London, October 1998.

ALWC can occur in tidal waters on steel maritime structures and is most commonly found just above LAT, although it has been reported at areas below this level. The level at which it occurs means that, unless efforts are made to survey the structure in the susceptible zones, it can remain undetected. ALWC has a recognisable appearance (see Plate 1.2), typically showing patches of lightly adherent, bright orange and black (iron sulfide rich) deposits over a clean, shiny and pitted steel surface. As the pits deepen, become more numerous and overlap, this produces a dishing effect in the metal surface, which ultimately develops into a hole.

The detailed mechanism of ALWC continues to be a matter of some debate but the evidence (see Chapter 2, Section 2.3.3 and Appendix 3) is that ALWC is associated with bacterial activity and it is, therefore, a form of microbially influenced corrosion (MIC). Although localised (or accelerated) corrosion on steel maritime structures at low water can be caused by other mechanisms, a defining characteristic of ALWC is that it usually conforms to a specific pattern of damage on steel sheet piled structures. While attack is often seen to be random both within and between installations, the pattern of damage is usually similar for particular pile geometries, irrespective of the geographic location. The presence of poorly adherent orange and black (iron sulfide rich) patches of surface deposit and local high rates of metal loss occurring together often confirms ALWC but not if one of these features is absent (see Chapter 2, Section 2.3.1).

There has been some confusion in defining ALWC in the past, both in literature and from the maritime industry. Some have rightly acknowledged it as a discrete corrosion phenomenon and a form of MIC. Others such as BS 6349-1: 2000, have referred to it collectively, with other corrosion mechanisms that can give high rates of attack in the low water and submerged zones, as "concentrated corrosion". However, others have used the latter term to define the problem in the low water zone specifically in terms of macro concentration cells, principally differences in oxygen concentration, with no acknowledgement to the role of MIC (OCDI 1998). Even a recently published maritime inspection guidance document (PIANC, 2004), which acknowledged the possible contribution of MIC to low water corrosion, does not refer to the ALWC phenomenon.

An early reference to the existence of black (iron sulfide rich) deposits, indicative of MIC, occurring on corroded steel structures immersed in seawater appears in a South African technical paper (Copenhagen 1934). A subsequent paper by the same author twenty years later (Copenhagen 1954) describes a specific low water corrosion problem on steel sheet piling at Cape Town Docks. Corrosion rates of 1.25 mm/side/year were observed, associated with black, sulfide rich deposits reported to be "due to the action of sulfate reducing microorganisms". The author at that time stated that "this underwater type of marine corrosion is far more common than has been hitherto suspected" and considered the problem "to be of sufficient importance to examine bottom muds of harbours from different parts of the world for sulfide content". These included samples taken from English ports (Port of London and Southampton Docks). However, this would appear not to be the first recorded incident of what is now commonly – although not universally – referred to as ALWC. An identical or very similar incident was reported occurring on steel-joist piles in Hong Kong harbour back in 1914 (Ellis, 1914). The problem was described by the author at the time as occurring "in a rather curious and alarming manner" being restricted to surfaces at and below the low water zone. Pits and "saucer shaped depressions" filled with black iron sulfide were found on relatively new structures, associated with corrosion rates estimated at 2 mm/ wetted side/year. The generation of hydrogen sulfide by "certain marine growths" was cited by the author as a possible causative agent.

According to more recent literature, the existence of ALWC is first reported as being identified in the UK in the early 1960s (Morley, 1978) but was not widely recognised as being present in UK waters until the 1980s (BS 6349-1, 2000). In a survey of UK ports and harbours carried out in 1980 (Doughty, 1980) no unusual corrosion behaviour was reported in the low water zone. While the authors suspected the possibility of MIC occurring in ports and harbours at this time, little evidence for this had been forthcoming from the survey itself. Since then, however, the number of reported cases of ALWC on maritime steel structures appears to have increased significantly both within the UK and worldwide. It is now recognised that such localised (accelerated) corrosion, by whatever means, does unquestionably occur on steel maritime structures at or around LAT.

Consequently, to minimise the risks of failure of marine structures, infrastructure owners, operators and engineers should now plan design, inspection and maintenance taking into account the possibility of ALWC (and any other localised corrosion mechanism) occurring in the susceptible zones. Ignorance would be no defence against any charges of negligence for structures failing from ALWC, or other localised corrosion attack, through lack of maintenance or deficient design provision.

**See Plate 1 *ALWC holing at low water on typical maritime structure* and Plate 2 *Close up of typical ALWC patch* on page 98.**

## 1.2 Purpose and scope of work

This guide is aimed at three main user groups:

- infrastructure owners and operators, and their advisors
- specialist engineers – experts in marine activities
- asset and maintenance managers.

The book addresses the technical issues associated with ALWC in design, condition appraisal, repair, maintenance and protection. It promotes managerial and engineering best practice to reduce the impact of ALWC on steel maritime structures. It is based on:

- a detailed review of published technical and commercial literature
- consultation with experts and practitioners within a cross-section of fields of expertise
- information obtained from a questionnaire-based survey
- case studies demonstrating good practice.

The purpose of the book is to:

- provide an independent overview of ALWC and associated problems – both nationally and globally
- increase awareness and enable early identification and repair of ALWC, thereby permitting early action to minimise health and safety risks to users of maritime structures
- improve protection/reduce risk of failure of steel marine structures
- recommend appropriate design, maintenance and repair strategies in order to reduce whole life costs
- combine previous research with current good practice in one document.

Some chapters will have more relevance to some practitioners than to others, however all will gain an insight into the factors that govern the management of ALWC by reading the whole book.

## 1.3 Applications and types of structure at risk

Any unprotected, or inadequately protected, steel structure exposed to tidal or impounded marine or brackish environment is susceptible to ALWC which can occur on any wetted surface of any pile type and/or fittings, such as ladders, chains, fenders, etc. This document is applicable to the following types of structure at risk from the effects of ALWC:

- Skeletal structures, with steel tubular, box and H etc pile sections:
  - jetties
  - piers
  - dolphins
  - wharves.

- Solid structures, with steel retaining structures, including:
  - wharves
  - quays
  - cellular cofferdams
  - retaining walls
  - canal and river walls in estuarine areas, including bank protection structures
  - dolphins
  - lock gates and sluices
  - dams
  - coast protection works
  - bulkheads
  - breakwaters
  - flood defence structures
  - barrier walls in cooling water system intakes/outlets.

Steel sheet piling is widely used in the construction of many types of maritime structures and there are, therefore, many kilometres of sheet piling potentially at risk from ALWC attack. Steel piling was introduced as a successor to cast iron at the beginning of the 20th century. Steel sheet piling consists of hot-rolled or cold formed steel sections that can be interlocked to produce structures ranging from a simple continuous corrugated wall (where individual pieces are driven side by side) to "combi walls" made up of king piles and intermediate sections. The Universal pile system (based on connected universal joists) was created in 1907 with a lighter version, the Simplex system, following in 1912. The types commonly used today (see Figure 1.1) were first introduced in the UK in the 1920s (ie U piles) and in the late 1930s (ie Z piles).

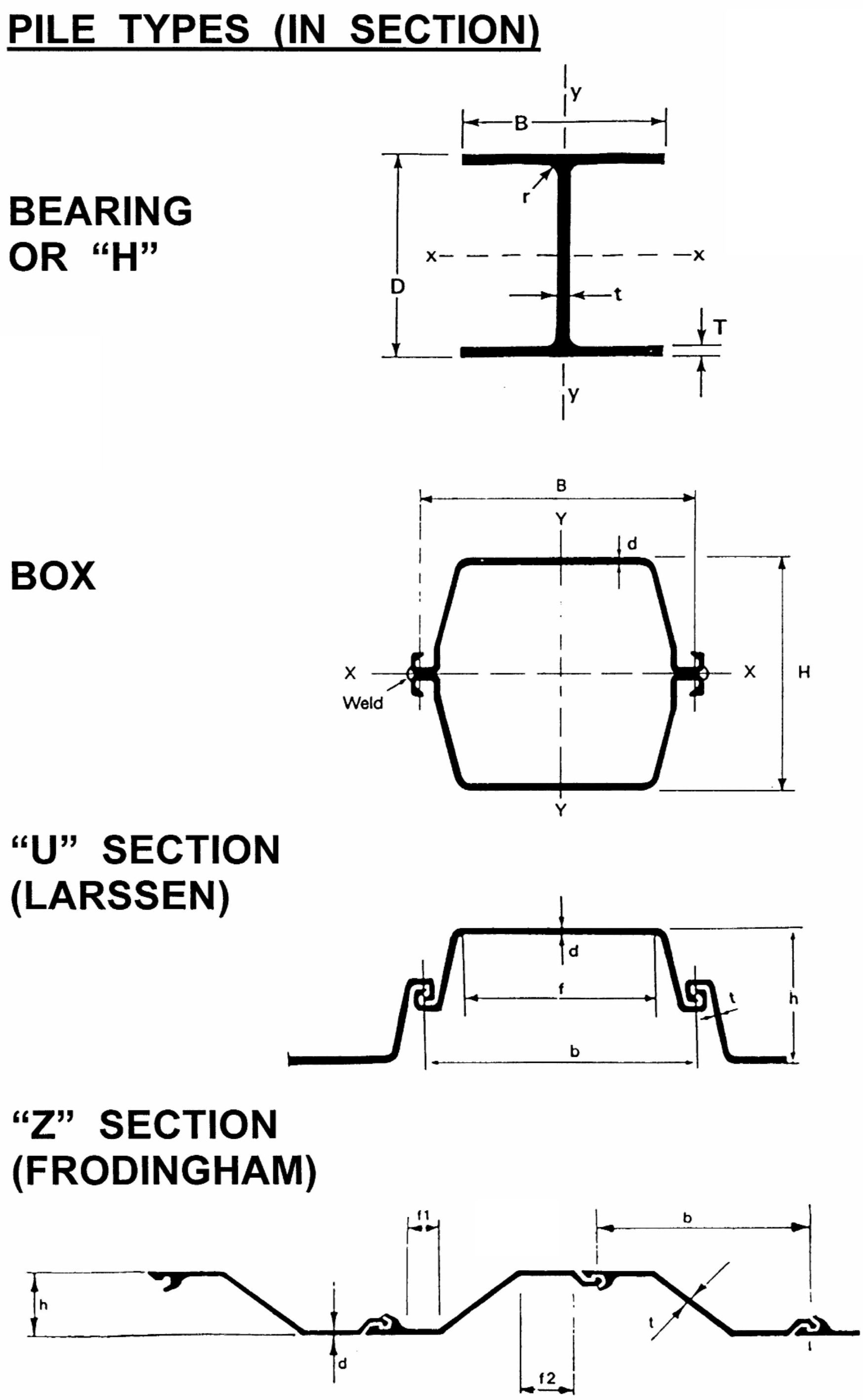


Figure 1.1 Pile types commonly used in maritime construction

Other unprotected steel members also at risk from ALWC in the low water zone include:

- steel repair plate
- angle members
- mooring chains
- ladders
- steel elements of fendering systems.

## 1.4 Implications of ALWC to structures

ALWC produces rapid, local metal thinning which can, if left unchecked develop into:

- serious holing and the need for urgent repairs
- premature structural failure leading to partial or complete reconstruction of a structure or even total shutdown of a facility.

Such features have been observed after a service life of as little as 20 years on structures that were originally designed to give 40 to 120 years. Clearly structures designed with thinner steel sections could be at greater risk. However, it is not yet possible to accurately predict if a structure will suffer the problem or at what stage in the life of a structure the problem will initiate (Gubner, 1998).

The forms of failure caused by ALWC are:

- **Loss of containment or stability**; BS6349-1:2000 warns that loss of backfill material through a holed sheet pile wall can lead to the collapse of pavement surfacing above or structures supported on the backfill. Uneven surfaces in themselves can also prove hazardous. In the case of ports and harbours, significant loss of fill material can, in extreme circumstances, reduce the navigable depth of a berth creating a potential hazard to transport, cargo and maintenance services.

  Loss of containment producing voids behind a steel sheet piled wall will become apparent during inspection, either planned or following the failure of the adjacent supported pavement. The impending loss of containment will be indicated by local thinning or initial holing of steel forming the retaining structure. Often local clouding of the water on a falling tide caused by loss of silty material can warn of a hole.

**See Plate 3 *Holed Z section pile showing loss of backfill material* on page 99.**

- **Loss of strength or structural failure**; loss of structural section can weaken the affected structure, potentially leading to failure or the need to place loading restrictions on it. Although ALWC only affects a small percentage of total exposed surface area, it has potentially serious implications to structures where the resultant loss in section from ALWC corresponds to areas of maximum stress. Structural failure has fortunately been rare and sometimes does not occur even when detailed analysis suggests that it should have done so. Nevertheless, it is essential for the owner to be confident that a structure is operating safely and can carry the loads that will be imposed on it.

  A potential reduction in the load carrying ability of the structure may be identified by loss of section and/or holing. The structure should be analysed by a competent designer, either:

  - to prove the adequacy of the structure and assist in determining the remaining serviceable life without protection
  - to determine the extent of necessary repairs and protection strategies.

Simply replacing the backfill before carrying out remedial works may cause over-stress of a steel sheet piled wall already weakened by ALWC. Allowing the structure to hole before suitable remedial works are performed often complicates and increases the cost of carrying out such repair works.

## 1.5 Brief overview of Health and Safety legislation

All activities related to ALWC, in common with all workplace activities, are covered by the Health & Safety at Work Act 1974. In almost all cases – except perhaps the most basic inspection and survey work, such as "taking levels, making measurements and examining a structure for "faults" – inspections, surveys, repair and protection work associated with ALWC affected structures and new build will be covered by CDM Regulations (HMSO, 1994). However, even with basic inspection and survey work, the addition of any significant work to clean off marine biofouling from surfaces would appear to bring the work into the scope of the regulations. It would, therefore, be wise in view of the potential risks to follow guidance given in the regulations.

The Approved Code of Practice (ACOP) "*Managing Health and Safety in Construction: Construction (Design and Management) Regulations 1994*", HSG224 (Health and Safety Commission, 2001), issued by the Health and Safety Executive provides advice and guidance on the application of the Regulations which encompass building, civil engineering and engineering construction work, including cleaning, maintenance, repair, renovation and demolition.

The CIRIA publication "*CDM Regulations – Practical guidance for clients and clients' agents*" (CIRIA C602) provides information on when and where CDM applies and the roles and responsibilities of parties under CDM. The associated CIRIA publication "*CDM Regulations – work sector guidance for designers*" (CIRIA C604) provides general guidance to designers on the identification of hazards in relation to the health and safety of construction workers and those affected by construction work. It is important for all parties to understand their responsibilities under CDM and, in particular, to recognise that the term "designer" can encompass a number of activities including temporary works and surveys.

There are many potential hazards associated with repair and protection work for structures affected by ALWC that may need to be considered. The following list gives examples but is not exhaustive:

- ensuring stability of the weakened structure at all stages of the work
- working under, over and adjacent to water
- interaction with facility operations – shipping and road/rail traffic
- working at height
- blasting and coating work within a confined area
- lifting of heavy or awkward items (eg anodes, steel repair plates, etc)
- use of hazardous materials with potential to cause harm (eg fuel, cement, organic solvents, biocidal washes, etc)
- use of ultra high pressure water jetting
- leptospirosis.

Designers should give particular consideration to the means of safe access to undertake future inspection and maintenance on their structures, particularly where these features (eg access ladders) can be included as part of the construction work or added during repairs.

## 1.6 Environmental responsibilities

Environmental legal requirements will vary between countries but will almost certainly have an impact on the:

- design and form of construction of the structure
- materials incorporated in the permanent works
- control of the process by-products
- selection and use of plant and equipment.

There are many potential environmental hazards associated with protection systems for new build structures and repair and protection work for structures affected by ALWC which need to be considered. The following list gives examples but is not exhaustive:

- coating systems (see Appendix 10, Section 1.1)
- jet/blast cleaning activities (see Appendix 10, Section 1.4)
- proper waste disposal from all works
- galvanic anodes for cathodic protection of structures at locations where there are already high concentrations of heavy metals in the seawater from whatever source (see Appendix 10, Section 2.0).

In many cases, environmental impact studies may be required and licences first obtained before work can commence, usually under strict terms of the authorities involved. In general, the repair and protection work associated with ALWC will be subject to the same environmental controls as any other similar work at that particular location.

Within the UK, the extent of the statutory controls will depend on the location, extent and magnitude of the work. The legislation given below may apply in addition to any requirement for a Harbour Works Licence. Application is made to the Marine Consents and Environment Unit (MCEU), a central facility for receipt and administration of applications to undertake works in tidal waters below MHWS and at sea. In considering applications the MCEU will consult with various governing bodies, agencies, and departments, including those shown below.

- **Coast Protection Act 1949**

  Imposes restrictions on works which may be detrimental to the safety of navigation or have potential environmental effects.

  Consultees: Environment Agency, English Nature, Countryside Council for Wales, Crown Estate, English Heritage, Local Authority via the planning department, Sea Fisheries Committees and competent navigation authorities.

- **Harbour Works (Environmental Impact Assessment) Regulations 1999**

  Applies to Coast Protection Act applications involving harbour works.

  Consultees: English Nature, Countryside Council for Wales, Environment Agency, Countryside Agency, DEFRA and local authorities.

- **Food and Environment Protection Act (FEPA) 1985**

  Controls the deposit of articles or materials in the sea or tidal waters and primarily aims to protect the marine ecosystem, human health, and minimise interference to others by considering any potential hydrological effects, possible interference with marine activities, turbidity, noise, drift of fine materials to smother seabed flora and fauna and adverse implications for designated conservation areas. In Scotland, an FEPA Licence is obtained from the Scottish Executive.

Consultees: Government agencies and departments with navigational interests, maritime and coastguard agency, Corporation of Trinity House, SEPA, local harbour authorities, fishermen's organisations and leisure interests.

The following statutory controls may also apply to work in, or adjacent to, protected or conservation areas:

- **Conservation (Natural Habitats &c.) Regulations 1994**

  If the work is in, or adjacent to, a European Site Special Protected Area (SPA) or candidate SPA, or Special Area of Conservation (SAC) or candidate SAC the MCEU may also consult with English Nature, the Countryside Council of Wales and the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) to determine whether it is likely to have a significant effect, and to determine any mitigation measures to be put in place.

- **Countryside and Rights of Way Act 2000**

  If the work is in or adjacent to a Site of Special Scientific Interest (SSSI) the MCEU may also consult with English Nature to determine whether the works are likely to potentially affect the species or features protected by the site and to determine necessary conditions to be included within any consent.

Depending on the specific location and level of the work, other more specific acts such as the Land Drainage Act 1991 may also apply.

Certain remedial works and operations may be exempt from particular requirements. For example, exemption from the Food and Environment Protection Act may be granted where remedial works are to refurbish or replace parts of existing structures or facilities with materials or articles of a similar nature (essentially "like-for-like" replacement) to extend the serviceability of the structure or continue its purpose. However, this will not apply if the remedial works will significantly enhance, alter, or extend the existing structures or facilities, or if the remedial works require additional temporary works to be constructed adjacent to the existing site.

CIRIA have produced two guidance documents providing good practice guidelines for construction and maintenance work.

- "*Coastal and marine environmental site guide*" (C584) published in 2003 addresses issues in the marine environment
- "*Environmental good practice on site handbook*" (C502) published in 1999 addresses issues in the freshwater and terrestrial environments.

## Summary

- ALWC is a high profile problem that can produce rapid rates of localised attack on steel maritime structures, typically just above LAT. It is a discrete corrosion phenomenon and a form of MIC (see Chapter 2)
- if ALWC is left unchecked, the consequences are loss of stability and/or gradual weakening of the affected structure potentially leading to structural failure
- any unprotected, or inadequately protected, steel structure (eg steel sheet piled walls, tubular piles and so on) exposed to tidal marine environment is susceptible to ALWC
- since the 1980s the number of reported cases of ALWC on steel, maritime, structures have notably increased both within the UK and worldwide (see Chapter 3)
- this book addresses the management of ALWC to reduce its impact on maritime structures (see Chapter 4) and highlights the technical issues. It proposes methodologies for condition appraisals (Chapter 5), repair and protection for new build and existing structures (Chapter 6), monitoring (Chapter 7) and procurement of remedial methods relevant to ALWC (Chapter 8). Areas requiring funding for further research into the problem, its identification and treatment are presented in Chapter 9. Finally, guidance on general good practice in dealing with ALWC is given in Chapter 10.