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MAINTENANCE OF ATON STRUCTURES

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1. INTRODUCTION

This Guideline is intended to assist those involved in the maintenance of Aids to Navigation (AtoN) structures. Users of this Guideline should recognise that AtoN structure maintenance regimes must consider the intended use, the resources available to the property owner or manager, and any statutory or legal designation applied to the structure. The Guideline is intended to be used as a reference to identify maintenance issues and assist in the development of appropriate solutions.

2. PURPOSE

This Guideline provides general guidance and advice on the types of structures, component materials, maintenance, refurbishment and repair techniques. Much of the information provided is in the context of civil engineering and building construction technology. Further information and specific case studies are available on the IALA Wiki.

3. MAINTENANCE PRINCIPLES

3.1. CONTEXT

To properly preserve and maintain AtoN structures, particularly lighthouses, it is necessary to understand the original design concept. Whilst such information for very old lighthouses may be difficult to trace, many more recent ones have good reports as they are the work of known individual, or teams of, professional architects/engineers.

It is also beneficial to understand the reasons for changes in the original design concept which have taken place during the life of the structure. While the original design is a major consideration, it is necessary to understand the historical importance of alterations that structures have undergone, including de-manning and automation, and as they continue to be modified and adapted to house new systems and modern equipment.

3.2. MAINTENANCE STRATEGY

Structures used for AtoN purposes vary considerably in terms of their design, component materials, their location, the environment in which they are located and their exposure to environmental and climatic conditions. Routine maintenance is essential to maximise the life of AtoN structures. Generally, most structures constructed of masonry, concrete and composite materials require a minimal maintenance regime, whereas, structures comprising iron, metal, steel and similar constructions require more frequent action to ensure a long service life. Noting that most structures consist of a variety of materials, it is important to tailor maintenance regimes accordingly.

Maintenance of any structure begins with scheduled inspections and routine maintenance. Scheduled inspections are the most basic form of maintenance and are critical in the long-term preservation of AtoN structures. The inspection process is a method for identification of maintenance issues and should be carried out periodically. It is also advisable to carry out comprehensive structural surveys considering environmental factors such as geographic location, wind and sea conditions, ambient temperature, as well as foundation, soil and boundary factors to reliably establish maintenance and refurbishment solutions.

3.3. MAINTENANCE MANAGEMENT SYSTEMS

Computerised maintenance management systems are available to assist authorities in the management and maintenance of their AtoN structures and building assets. These systems are designed to help schedule, plan, manage and track maintenance activities and keep a historical record of work performed.

3.4. MAINTENANCE OF HERITAGE AND HISTORIC LIGHTHOUSES

Lighthouses may have statutory designations applied to them such as historic lighthouses/buildings, protected structures, listed buildings, or similar. Care is required in the selection of materials, products and repair techniques, together with suitably qualified personnel in the repair and maintenance of such structures or buildings. Careless maintenance methods used on historic lighthouses can result in irreparable damage to the valuable material of the structure.

4. STRUCTURES, BUILDINGS AND CONSTRUCTION MATERIALS

The Guideline covers the following AtoN infrastructure:

4.1. LIGHTHOUSE

A tower, or substantial building or structure, erected at a designated geographical location to carry a signal light and to assist marine navigation.

4.2. BEACON

A fixed artificial navigation mark that can be recognised by its shape, colour, pattern, topmark or light character, or a combination of these. It may carry various additional aids to navigation

4.3. ANCILLARY FACILITIES

All structures at a lighthouse station, other than the lighthouse tower, which can include dwellings, equipment rooms, outbuildings, boat landings, etc. necessary for facilities to support the AtoN services.

5. MATERIALS

Materials typically used in the construction of lighthouses, beacons and ancillary facilities include:

- masonry (stone, brick, etc.);
- timber;
- concrete;
- iron (wrought and cast);
- steel (including galvanised steel, stainless steel, duplex steel);
- non-ferrous metal (e.g., aluminium, brass, copper, etc.);

- composite materials (e.g., GRP); and
- a combination of some of the above materials.

5.1. MASONRY (INCLUDING STONE, BRICK, ETC.)

5.1.1. MATERIAL DESCRIPTION AND PROPERTIES

Masonry is the most commonly used building material in lighthouse construction. Because of the harsh conditions associated with the locations of most lighthouses, brick and stone masonry was chosen for its durability. The masonry used in lighthouse construction was typically quarried (in the case of stone) or made (in the case of bricks) as close to the site as possible. The quality of the materials used for lighthouse construction varies. Stone masonry structures can be built using many different types of stone block configurations and using irregular or rectangular cut stone blocks. Precast concrete block masonry is typically built using rectangular blocks which may or may not be reinforced. The blocks may be connected with iron or steel dowels or large “staples”. The joints between blocks may be left open (called dry masonry construction) or maybe mortar filled (pointed joints). Many lighthouse towers had their cornice course built of interlocking or dowelled granite or similarly hard stone where it provided an anchor for the lantern; this construction detail is likely to be encountered frequently in lighthouse conservation work in some parts of the world; Interlocking granite ashlar in towers provides one of the longest lasting forms of construction and requires little maintenance. Other lighthouses were built using limestone or sandstone, which are some of the softest masonry materials available and require careful specialist maintenance as they reach an extended age.

5.1.2. BEHAVIOUR AND RISKS/ISSUES

Masonry is subject to attack by a host of forces. The success of a lighthouse resisting these pressures depends on how well it was designed, constructed, and maintained. Causes of deterioration can include the following:

- excessive moisture within the masonry that gives rise to the destructive crystallisation action of soluble salts as well as freeze-and-thaw expansion-and-contraction actions;
- water ingress through walls can lead to differential settlement, deterioration of adjacent materials (e.g., rusting iron or rotting window lintels), erosion of mortar, debonding of linings, the emergence of algae growth on internal surfaces due to a damp environment and other structural problems;
- use of mortars that have a high compressive strength, i.e., are harder than the brick or stone;
- abrasion by the wind and wind-borne solids;
- differential expansion that places internal stresses on the structure when one part responds to thermal stresses more than another or; differential settlement or movement because of weaknesses in the soil, foundations, or structure;
- cracking and spalling of masonry due to corrosion of iron or steel embedded in the stone. Typical examples include iron handrail posts set in the stone with molten lead and iron beams set into masonry structures.
- impact caused by the installation of equipment;
- chemical disintegration caused by pollutants in the atmosphere;
- inadequate ventilation that causes a build-up of moisture on the inside of the tower; and
- coating of internal walls with impermeable paint that does not allow the structure to breathe or moisture to escape.

When considering the factors contributing to deterioration of stonework in lighthouses, it is important to recognise the complex nature of stone response to environmental conditions. At the outset it is important to stress that stone affected by the presence and action of salts cannot be returned to its original “quarry fresh” condition or the condition it was in at the time of construction. Remedial intervention is therefore aimed at controlling and slowing rates of deterioration with avoidance of well-intentioned but overly aggressive or inappropriate treatments that can accelerate rates of pre-existing deterioration or trigger the decay sequence by destabilising previous stable stonework.

In lighthouses and associated structures, salt decay is enhanced by the progressive accumulation of marine salts through condensation. The effects of salts can be made more complex by the presence of sulphates which give rise to the formation of particularly aggressive salts such as sodium sulphate. Sulphates can be derived from emissions from overcharged lead acid batteries, emission of volatile organic carbons (VOCs) from inadequately sealed fuel tanks or introduced through the use of cement-based mortar repairs.

Where lighthouse towers are normally closed, salt-related deterioration of stonework can be accelerated in response to several factors:

- reduced airflow over stone surfaces has decreased evaporation and can lead to a significant increase in condensation and hence longer periods of wetness. These longer periods of surface wetness may facilitate salt penetration to greater depths within the stone by keeping salts mobile for a longer time;
- the installation of electrical dehumidifiers has locally accelerated decay by forcing cyclic salt crystallisation. Typically, this is manifest as efflorescence on stone surfaces and associated release of debris; and
- installation of heaters can superimpose an additional number of wetting and drying cycles that take advantage of the increased condensation to accelerate the crystallisation of salts at or near the stone surface. Because the capacity of the heaters is limited, they tend to have a localised effect with decay concentrated around them.

5.1.3. PREVENTIVE MAINTENANCE

Within all lighthouses and associated structures, steps should be taken to ensure a consistent airflow as a means of reducing condensation arising from static moisture laden air remaining in contact with cold stone/masonry surfaces for prolonged periods of time. To ensure airflow within towers, ventilation will be required at the base and top of each tower, but it is recognised that this may require the design of a system shielded from seawater and driving rain. However, an approach of minimum intervention is initially recommended through the use of existing structural characteristics of the tower that can be employed to facilitate improved airflow, e.g., opening of old chimney flue systems, use of existing windows, dome ventilators, etc.

In the planning and implementation of stone management strategies, it is important to remember that because of the range of site-specific factors that can influence the extent and severity of stone deterioration, it will be necessary to tailor control measures and/or remedial action to meet the specific needs of each lighthouse rather than searching for a single prescriptive answer.

Joints in masonry towers can be susceptible to erosion, thus exposing the structure elements to possible degradation and water infiltration. The integrity of the masonry joints is essential for the durability of the structure. Sealing of joints ensures the water tightness of the structure.

Paint coatings have traditionally been applied to masonry structures to provide the AtoN daymark. External coatings can also provide an additional barrier to protect the masonry and the joints from being eroded.

The provision of electric power generation at offshore towers in the past has resulted in many cases in a surplus capacity. This surplus capacity was utilised for electric heating to protect the sensitive electronics demanded by automation and had the additional benefit of helping to preserve the fabric of the structure. With the conversion to renewable energy technologies (solar, wind, etc.), opportunities for providing electric heating is no longer feasible and natural ventilation is considered the preferred solution for protection of the structure's internal fabric.

5.1.4. CONDITION ASSESSMENT

Condition assessment surveys can be carried out by a maintenance team familiar with the structure and its maintenance requirements. Visual surveys will quickly identify any obvious deficiencies to a well-trained eye with observations being documented. The following are typical aspects to be inspected to get an overall impression of the structure's condition:

- check for missing or displaced blocks, usually due to mortar deterioration, loss of wedging stones, or corrosion of iron/steel dowels between blocks;
- check for eroded, worn, cracked, or crumbling blocks, typically evident in aged sedimentary stone structures
- check for wall movement, usually noted by a portion of the masonry structure having vertical and/or horizontal misalignment that varies from the design drawings or adjacent portions of the structure;
- check for evidence of settlement or subsidence of the structure, or any part of the structure;
- check for evidence of structural cracking; and
- check for evidence of any water ingress.

5.1.5. REPAIR TECHNIQUES

The detailing of stonework is generally simple and robust. Individually damaged, cracked or spalled stones should preferably be removed and replaced with matching stone. An alternative is to refasten loose stones using techniques such as the insertion of stainless steel or bronze pins. This is preferable to using cement repairs that tend to have a short life and which may themselves accelerate the erosion of the stone by trapping salts and moisture, and/or chemically attacking the stone.

Pointed joints can be repaired using different grades of hydraulic lime or cementitious mortars with or without additives. Hydraulic lime mortars are generally more appropriate to preservation of heritage structures. The selection of the repair mortar should be considered carefully and be appropriate to the structure and consistent with the other masonry elements in the structure.

The re-painting of masonry structures and its associated preparation work should be carefully considered. Where attractive dressed stone has been used in the construction, this should be protected. Grit blasting or high-pressure water jetting of textured finishes, especially where the stone is not robust enough to take such treatment should be avoided. Alternative approaches that could be adopted include:

- reconsidering whether it is necessary to remove all paint in the first place;
- using other techniques on moulded or finely tooled stonework such as water washing or chemical poultices;
- employing firms skilled in conservation work for such tasks; and
- training some in-house maintenance staff in specialist conservation techniques.

5.2. TIMBER

5.2.1. MATERIAL DESCRIPTION AND PROPERTIES

Easily shaped by simple hand and power tools, timber was used for many components of lighthouses. Timber towers were generally timber frame construction covered with sheathing. Many other lighthouse components such as door and window surrounds, cornices, doors and windows were also constructed of timber. The use of timber was not limited to the AtoN structure, it was also used in the construction of ancillary buildings as structural components and in roofing. Many masonry and iron lighthouses were fitted with timber components. Timber piles have been used to support AtoN platforms and equipment. Timber members have traditionally been used for construction and maintenance of AtoN structures due to their availability, economy, and ease of handling relative to other construction materials. The durability of timber is generally related to the species of wood from which it comes. The choice of timber to be used for repairs is of critical importance. A match in timber type should be obtained, for instance oak for oak and red deal for red deal, so that the physical performance, structural capabilities, and heritage value of the timber are compatible.

5.2.2. BEHAVIOUR AND RISKS/ISSUES

Causes of timber damage and decay include the following:

- inherent design flaws or missing/damaged features that allow for the exposure of wood end grain to moisture or allow water to pool or collect on wooden components;
- lack of trim elements and metal flashings to protect the timber elements;
- failed coating systems that allow raw timber to come in contact with moisture;
- dry rot and wet rot; and
- attack by fungus, insects, marine life or other pests.

5.2.3. PREVENTIVE MAINTENANCE

Preservation treatment systems can be used to protect the integrity of the timber. Protective surface coatings are essential with appropriate surface preparation and correct application of the paint system. Where enclosed lighthouses are constructed of timber, the provision of adequate ventilation should be considered in order to ensure that environmental conditions within the structure protect the timber from physical and biological decay.

5.2.4. CONDITION ASSESSMENT

Inspect structural elements and timber components in lighthouses to verify the integrity of the timber members. Cracking in timber elements could suggest excessive loading on the member. Evidence of fungal growth can be an indication of either dry rot or wet rot in the timber, with dry rot having the more serious effect on the timber member. Evidence of insect infestation, such as woodworm, termites, etc., can threaten the structural integrity of the timber member because the insects use wood as a food source and eventually eat away enough of the material that the structural strength is compromised, and can eventually lead to failure.

In relation to timber piles, check the tops of piles for physical damage, dry rot, and termite or pest infestation and determine the depth of deterioration. Check for cracked, rotted, loose, or worn piles or connecting braces. Visually examine piling in the tidal zone for marine borer damage. The tidal zone is the area between high and low tide and is likely to be the most damaged. Clear a section of the structure of all marine growth and visually inspect for surface deterioration. Sound the piles with a hammer and carefully probe with a thin-pointed tool such as an ice pick to look for internal decay and soft timber. Check for member damage due to overload or impact. Check pile and mast alignment.

Check also for corrosion of steel fasteners, including bolts, drift pins, and wire rope. Steel fasteners embedded in wet timber usually corrode faster inside the timber, which may not be apparent from visual inspection. Strike the bolt ends with a hammer to check for internal corrosion failure. Wire rope is often used to wrap timber pile cluster structures to hold the pile heads together. This wire rope typically corrodes internally at a faster rate than externally and may be structurally compromised even when the exterior of the wire appears only lightly corroded.

5.2.5. REPAIR TECHNIQUES

Damaged structural elements should be replaced in their entirety or part replaced using splicing techniques.

As new timber is often placed in an area previously affected by timber decay, fungicidal or insecticidal pre-treatment of the timber should always be considered and only omitted if there is a good reason for doing so. New timber should not be placed in direct contact with damp masonry, but should be isolated from it, either by supporting the timber on new brackets away from the wall or by placing a damp-proof layer between the timber and masonry.

More extensive repairs can be made using modern mechanical fasteners such as tooth plate connectors, split rings and steel brackets. Introducing a new structural member to reinforce the existing structure or even supersede it, is often a viable option and can usually be designed to avoid the removal of the failed original timber.

The use of other more specialist repair techniques, such as resin-fixing steel or carbon fibre plates to existing timbers, or fixing plates or tensile rods within the timber, requires specialist knowledge and expertise in their design and specification.

5.3. CONCRETE

5.3.1. MATERIAL DESCRIPTION AND PROPERTIES

Concrete is a construction material used for AtoN structures due to its relatively low cost and durability. Types of concrete include:

- *Unreinforced concrete* is a composite material containing aggregates (sand, gravel, crushed shell, or rock) held together by a cement combined with water to form a paste. Unreinforced concrete does not have any steel reinforcing bars. Unreinforced concrete is relatively weak, other than in direct compression.
- *Reinforced concrete* is concrete strengthened by the inclusion of steel (mild or stainless) or FRP reinforcing bars, which increase the tensile strength of concrete.

  Both unreinforced and reinforced concrete can be either cast in-situ or precast.
- *Cast in-situ concrete* is poured on site into previously erected formwork that is removed after the concrete has set.
- *Precast concrete* is moulded offsite into building components. These are transported to and assembled on site to form the structure.
- *Prestressed concrete* is concrete that has had internal stresses introduced to counteract the tensile stresses that will be imposed in service. The stress is usually imposed by tendons of individual hard-drawn wires, cables of hard-drawn wires, or bars of high strength alloy steel. Prestressing may be achieved either by pre-tensioning or by post-tensioning.
- *Ultra-high performance fibre reinforced concrete* is a type of reinforced concrete with exceptional performance. Its mix design makes use of superplasticisers, specific types of aggregate, ultrafine particles and fibres (metal or polymer). Its high strength and low permeability to aggressive agents is achieved by a considerable reduction in porosity, making it very useful in the marine environment.

5.3.2. BEHAVIOUR AND RISKS/ISSUES

Deterioration of concrete can be caused by environmental factors, inferior materials, poor workmanship, inherent structural design defects, and inadequate maintenance. Typical signs of concrete deterioration include:

- *Cracking* occurs over time in virtually all concrete. Cracks vary in depth, width, direction, pattern, location, and cause. Cracks can be either active or dormant (inactive). Active cracks widen, deepen, or migrate through the concrete. Dormant cracks remain unchanged. Some dormant cracks, such as those caused by shrinkage during the curing process, pose no danger, but if left unrepaired, they can provide convenient channels for moisture penetration, which normally causes further damage.
- *Spalling* is the loss of surface material in patches of varying size. It occurs when reinforcing bars corrode, thus creating high stresses within the concrete. As a result, chunks of concrete break off from the surface. Similar damage can occur when water absorbed by porous aggregates freezes. Paints or sealants, which trap moisture beneath the surface of the impermeable barrier can also cause spalling.
- *Deflection* is the bending or sagging of concrete beams, columns, joists, or slabs, and can seriously affect both the strength and structural soundness of concrete. It can be produced by overloading, by corrosion, by inadequate construction techniques, or by concrete creep (long-term shrinkage).
- *Erosion* is the weathering of the concrete surface by wind, rain, snow, and salt air or spray. Erosion can also be caused by the mechanical action of water channelled over concrete by inadequate drainage.
- *Corrosion,* the rusting of reinforcing bars in concrete, can be a serious problem. Normally, embedded reinforcing bars are protected against corrosion by being buried within the mass of the concrete and by the high alkalinity of the concrete itself. This protection, however, can be destroyed in two ways:
    - First, by carbonation, which occurs when carbon dioxide in the air reacts chemically with cement paste at the surface and reduces the alkalinity of the concrete.
    - Second, chloride ions from salts combine with moisture to produce an electrolyte that effectively corrodes the reinforcing bars. Chlorides may come from seawater additives in the original mix, or from prolonged contact with salt spray. This is typically the failure mode seen in marine and coastal structures.

  Regardless of the cause, corrosion of reinforcing bars produces rust, which occupies significantly more space than the original metal, and causes expansive forces within the concrete. Cracking and spalling are frequent results. In addition, the load-carrying capacity of the structure can be diminished by the loss of concrete, by the loss of bond between reinforcing bars and concrete, and by the decrease in thickness of the reinforcing bars themselves. Rust stains on the surface of the concrete may be an indication that internal corrosion is taking place.

- *Aggregate segregation* in concrete results from inadequate compaction of the concrete during the placing operation.

5.3.3. PREVENTIVE MAINTENANCE

The durability of concrete in the marine environment is highly dependent on the quality of concrete mix used. It is not unusual to find relatively new concrete structures in poor condition, while adjacent older structures are in better condition. Concrete can be affected in the hardened state by factors such as weathering, chemical attack, abrasion and freeze/thaw attack. It is important that the thickness of concrete covering steel reinforcement (or “cover”) is sufficient to prevent the ingress of moisture and air, which may lead to corrosion. Some countries may have defined standard specifications for concrete applications in the marine environment.

When designing concrete structures to resist aggressive environments, a strong, dense concrete with low permeability is necessary. For a structure to resist deterioration, the right blend of design, materials and quality of construction is needed. Factors that should be considered during construction include:

- *Cement content* – concrete mix must be designed to ensure cohesion and prevent segregation. If cement content is reduced, then at fixed water/cement ratio, the workability can be reduced leading to inadequate compaction. However, if water is added to improve workability, the water/cement ratio increases resulting in highly permeable material.
- *Compaction* – proper compaction of the concrete is essential to minimise embedded voids caused by inadequate compaction.
- *Curing* - it is important to permit proper strength development and to ensure hydration process occurs completely.
- *Cover to reinforcement* - thickness of concrete cover must comply with codes of practice for specific applications.
- *Permeability* - higher permeability is usually caused by higher porosity. Therefore, proper curing, sufficient cement content, proper compaction and suitable concrete cover should provide a low permeability concrete.
- *Reinforcement* – typically mild steel reinforcement is used in reinforced concrete. Consideration could be given to using stainless steel or FRP reinforcement which is more resistant to corrosion effects and can prolong the lifespan of the structure. There is an increased cost associated with the use of stainless steel reinforcement. Development of FRP reinforcement bars in recent years has been significant, and its light weight combined with the elimination of the possibility of corrosion makes it increasingly attractive for use in marine environments.
- *Coatings* – application of a coating system can have a major benefit in resisting the ingress of CO2 and chloride ions which cause corrosion of steel reinforcement.

Alkali-silica reaction (ASR) is the most common form of alkali-aggregate reaction. It occurs when the alkaline pore fluid and siliceous minerals in some aggregates react to form a calcium alkali silicate gel. This gel absorbs water, producing a volume expansion which can disrupt the concrete. The main external evidence for damage to concrete due to alkali silica reaction is cracking. Aggregate specifications to limit alkali content and reactive aggregates in the manufacture of the concrete should prevent the occurrence of ASR.

Cathodic protection is a widely used and effective method of corrosion control. Cathodic protection can be applied to reinforced concrete structures to either prevent or arrest the problem of corrosion of the reinforcement. Cathodic protection may be an economical alternative to patch repairs in chloride-damaged structures, not only because it provides a long-term solution but also because it obviates the need for extensive removal and replacement of contaminated concrete. Hybrid anode systems can offer an alternative solution for remote locations.

Paint coatings have traditionally been applied to concrete structures to provide the AtoN daymark. External coatings also provide a significant first line of defence against the prevailing weather and sea conditions. External coatings should be renewed on a periodic basis to maintain their integrity, depending on the nature of the structure and its location. Good quality surface preparation is essential to ensuring good adhesion for new coatings and to achieving the expected lifespan for the coating.

5.3.4. CONDITION ASSESSMENT

Before any visual inspection is carried out, any relevant structural drawings should be reviewed to gain an understanding the structure design.

Inspect for cracks, spalling, corrosion of reinforcing steel and visual signs of rust staining. Solid reinforcing bars are much more tolerant of corrosion than are pre-stressing strands (embedded high strength wire cable).

Check for evidence of chemical deterioration, abrasion wear and overload damage.

Check for efflorescence, which could indicate water infiltration.

Check previous repair patches as these repairs are signs of past damage or deterioration.

Concrete in the structure can be checked with a hammer to detect any loose layers of concrete or delamination. A sharp ringing noise indicates sound concrete. A soft surface will be detected, not only by a sound change, but also by the change in rebound, or feel, of the hammer. A thud or hollow sound indicates a delaminated layer of concrete, most likely due to the corrosion expansion of internal reinforcing steel. Loose delaminated concrete may be removed to inspect the extent of reinforcing corrosion underneath.

More intensive investigations to determine the strength and condition of hardened concrete can include the taking of core samples for laboratory analysis, the taking of concrete samples for petrographic analysis and the use of non-destructive techniques such as Schmidt Rebound Hammer test, radiographic testing, infrared thermography, etc.

5.3.5. REPAIR TECHNIQUES

Prior to repair of cracking in concrete, it should be assessed to determine whether it is structural or cosmetic. Active structural cracks will move as loads are added or removed. Thermal cracks will move as temperatures fluctuate. Thus, expansion-contraction joints may need to be introduced before repair is undertaken. Active cracks may be filled with sealants that will adhere to the sides of the cracks and will compress or expand during crack movement. Large cracks or spalling may require reconstruction of the affected area.

There are a range of industrial products available on the market for use in concrete repairs. These include pure cement-based products, cementitious mortars, polymer-modified repair mortars and epoxy-based repair materials. The range includes products appropriate for general purpose repairs, rapid setting mortars, waterproofing mortars, mortars for marine applications and mortars suitable for wet and dry spray application. The choice of mortar for concrete repairs should be selected to suit the repair works being undertaken, the environment of the work and any specific requirements. Manufacturer’s instructions should be followed to ensure correct application of the repair mortar.

Hand placed concrete repair mortars should normally be pre-batched, cement-based mortars possibly modified for improved strength or resistance with polymers and/or other additives or special graded sands and aggregates. Hand applied concrete repair mortars are applied by gloved hands or trowels and finished by trowel to match the original line and profile of the parent concrete. They are ideal for patch repairs and repairs to concrete spalling in areas of locally corroding reinforcement.

Machine applied or sprayed concrete repair mortars are generally supplied pre-batched and, like hand placed concrete repair mortars, they can also be modified with polymers and other additives to improve their performance, particularly the cohesion of the sprayed mortar, which can reduce the amount of rebound and wastage. Machine applied concrete repair mortars are primarily designed for use where large volumes of the repair mortars are needed, or where a significant volume must be applied as fast as possible to suit local conditions. Machine applied or sprayed concrete repairs are a specialist area requiring specialist sprayed concrete equipment, operative training and materials.

Poured or flow applied concrete repair materials are frequently used where there is difficult access or around congested reinforcement. These concrete repair materials are also modified with polymers and super-plasticisers that improve their flow and ensure a good surface finish. Concrete repair products used for flow application in smaller scale repair or re-casting situations are also known as mortar.

Bonding primers are used in concrete repair works to increase the adhesion or bond of the subsequent concrete repair mortar to the cleaned and prepared existing concrete substrate. These materials improve the ‘wetting’ of the profiled surface, filling troughs in the concrete surface profile, reduce suction due to the concrete porosity and lubricating the interface to ensure a fully homogenous bond and optimum adhesion.

Steel reinforcement primers or protective coatings are important in complete concrete repair and protection systems, where they are designed to provide additional protection and act as a barrier to prevent any future water penetration and corrosion of the steel surfaces. The steel reinforcement primer is applied to any exposed steel reinforcement that has been cleaned and prepared, preferably by mechanical blast-cleaning, once the damaged concrete and any contaminants such as chlorides have been removed.

Steel reinforcing bars can exhibit a reduction in their section size as a result of corrosion. This needs to be assessed from a structural perspective to determine whether the remaining area of reinforcement is adequate to cater for the required loading. Options for restoring the original structural capacity could include the following:

- Welding of new sections of reinforcing bar to the existing reinforcing matrix to ensure adequate section size.
- Fibre Reinforced Polymer (FRP) composites (such as carbon fibre or Kevlar) bonded to the concrete using resin or mortar can provide a reliable and durable reinforcement solution. Its use in a marine environment situation should be carefully considered to ensure the site conditions are suitable for the application of the FRP composite.
- several specialised methods exist for reinforcing concrete using external stresses and sprayed concrete type replacement material.

Protective surface coatings are primarily used to protect new or repaired concrete surfaces from future chemical attack and the ingress of aggressive liquids. There is a wide range of different protective concrete coating products and systems available on the market. In addition, hydrophobic impregnations are effective concrete protection and generally based on Silanes, Siloxanes or Siliconates, or blends of these materials. Due to their small molecular size and penetrating ability, together with their unique water-repelling or hydrophobic properties, they can penetrate completely into the surface pores and capillaries of concrete thereby creating a water repellent (hydrophobic) surface, but without any significant residual surface film.

5.4. COMPOSITE MATERIALS (INCLUDING PLASTICS)

5.4.1. MATERIAL DESCRIPTION AND PROPERTIES

Modern composite materials, or Fibre Reinforced Polymers (FRP), are constructed using a variety of fibres as reinforcement in a polymer resin. Fibres such as glass, carbon and poly-aramide (Kevlar) are commonly used. Typical resins are polyester, vinylester, or epoxy based. Glass fibre is a common reinforcement for polyester resins used for AtoN structures. These are prefabricated light-weight constructions that are well suited to a range of applications with the exception of exposed wave washed sites. Many structural shapes, ladders, gratings and other components are available in fibre reinforced polymer (FRP) composites that can be well suited to AtoN structures.

FRP composites such as carbon fibre or Kevlar can be bonded to concrete using resin to provide a reliable and durable reinforcement solution, where the capacity of the existing steel reinforcement has been compromised.

Different combinations of fibre and resin provide different properties and usage scenarios; whilst outside the scope of this Guideline, there is substantial technical information available to assist AtoN maintainers. For general AtoN maintenance usage, glass fibre and epoxy resin will yield the most successful outcome.

Various grades of polyethylene plastics are used in AtoN structures and ancillary facilities. These may be in the form of sheets attached to the boat fendering of the structure, polyethylene plastic piles and plastic ‘lumber,’ with or without internal reinforcing. The internal reinforcing is typically fibreglass rebar or chopped fibres, though internal steel reinforcing has been used as well.

5.4.2. BEHAVIOUR AND RISKS/ISSUES

FRP can be prone to impact damage, particularly in extremes of hot and cold weather and with ageing after prolonged UV exposure. Damage to FRP generally manifests itself in one or all the following ways depending on the severity of the impact or failure:

- *Tear* - resulting when the tensile strength of the composite part has been exceeded and the laminate has failed. This typically results in a fracture which extends completely through the substrate;
- *Perforation or puncture* - typically resulting from an impact or cutting. Holes and punctures are sometimes limited to surfacing layers or skins;
- *Crushed core* - applying to composite parts containing sandwich core materials. It is typically the result of an impact which forces the composite skin of the laminate to deflect, but not fail, causing the sandwich core material to collapse;
- *Delamination* - resulting in layers of the material separating from each other. It is typically caused by impact or stress between or across the layers.

Weathering and UV can degrade the colour and the surface finish, which can cause splinters to develop and present a hazard for maintenance personnel. Gelcoat is the outer surface layer on FRP systems and is more durable than the internal layers, but it can become dull or faded as it weathers. Sunlight and oxygen combine to oxidize the gelcoat surface, fading it and making the surface dull.

5.4.3. PREVENTIVE MAINTENANCE

FRP structures require little or no maintenance. An FRP sealer can be used to restore the dull or faded surface condition. The FRP sealer penetrates the gelcoat surface, filling in the microscopic holes and crevices to prevent future oxidation. The sealer provides a barrier between the environment and the gelcoat, cutting off the chemical reaction which creates oxidation. FRP structures can also be painted using modern coatings to add additional weather protection; this is often the case where the structure serves as a daymark.

5.4.4. CONDITION ASSESSMENT

Check for broken or damaged members and components.

Check for loose connections. FRP members are usually connected using stainless steel bolts, which can loosen over time.

Check for damage to the surface finish. Check for cracking, tears and perforations. This can result from the manufacturing process itself, by corrosion of embedded reinforcing steel or as a result of an impact.

Check the surface colour for degradation and fading.

5.4.5. REPAIR TECHNIQUES

Repair of fibreglass structures in remote locations may be undertaken using polyester, vinylester, or epoxy resin systems. Epoxy repairs are more robust and have a far higher bond strength than other materials. Cured epoxy tends to be very resistant to moisture absorption. Epoxy resin will bond dissimilar or already-cured materials which makes repair work that is very reliable and strong. Epoxy bonds to many types of fibres very well and offers excellent results in repair-ability when it is used to bond two different materials together. Epoxy repairs must be coated to prevent UV damage to the repaired area.

Delamination of foam cores to the laminate can be repaired by pouring epoxy resin into the void between the core and skin laminate. Care should be taken in repair of mixed resin systems. Epoxy resins will bond over vinyl ester and polyester resins. Polyester and vinyl ester resins may not cure over epoxy repairs.

Structurally weak areas, such as the corners of door or hatch openings in GRP structures, should be repaired to the original thickness and strength. Any cracks in the laminate should be removed prior to repair with FRP mat and resin. Minor damage to the gelcoat can be repaired by grinding away the damaged area then recoating with gelcoat.

Manufacturer’s instructions should be followed to ensure correct surface preparation and application of the repair components.

5.5. FERROUS METAL

5.5.1. MATERIAL DESCRIPTION AND PROPERTIES

Ferrous metal (iron) is a common material used in AtoN structures. Iron is used in a variety of its commercially manufactured alloys: wrought iron, cast iron, mild steel, and stainless steel. In lighthouses, the most widely used alloys were cast iron and wrought iron. Iron was also used to produce architectural features such as balcony brackets and prefabricated lantern components. Modern ferrous materials such as mild steel, and stainless steel are mostly found in modern additions such as handrails, equipment brackets, security doors, etc. Steel is used in the construction of AtoN structures due to ease of connection, fabrication, splicing, ductile behaviour, and the ability to drive steel piles through hard soil.

- *Wrought iron* is relatively soft, malleable, tough, fatigue-resistant, and easily worked by forging, bending, rolling and drawing. Until steel was available, wrought iron was used structurally for beams and girders as it had strength in both tension and compression. During the late 19th and early 20th centuries, it was not unusual to find a mixture of cast iron columns and wrought iron or steel beams in the same structure.

- *Cast iron* is one of the oldest ferrous metals used in construction. It is an iron-carbon alloy and has a relatively high carbon content of 2% to 5%. It is hard, brittle, non-malleable (i.e., it cannot be bent, stretched or hammered into shape) and more fusible than steel. Its structure is crystalline, and it fractures under excessive tensile loading with little prior distortion. Cast iron is, however, very good in compression. Cast iron was a common material in AtoN construction as structural elements could be readily bolted together. Some AtoN structures can consist solely of cast iron, but many structures will contain a combination of cast iron elements and components manufactured from different metals. Cast iron is generally resistant to corrosion, however, when combined with other materials, can corrode due to galvanic action of dissimilar metals.

- *Mild steel* is an alloy of iron and carbon that contains not more than 2% carbon and is malleable in block or ingot form. Steel may include phosphorus, sulphur, oxygen, manganese, silicon, aluminium, copper, titanium, molybdenum and nickel. The properties of steel can vary greatly in relation to the chemical composition and the type of heat treatment and mechanical working used during manufacture. Characteristics affected by these differences include strength, hardness, ductility, resistance to abrasion, weldability, machinability and resistance to corrosion. A grade of medium carbon steel is typically used for most AtoN applications today such as handrails, equipment brackets, new light support structures, etc.

- *Galvanised steel* - hot dip galvanising is the immersion of clean steel in molten zinc to apply a protective coating to the steel. A series of zinc-iron alloy layers are formed by a metallurgical reaction between the steel and zinc, providing a robust coating which is an integral part of the steel. A major advantage of zinc coating on steel is that if the zinc is worn away or broken down and the steel is exposed to the atmosphere, galvanic corrosion of the zinc occurs, as it is more base than steel, thus protecting the more noble steel.

- *Stainless steel* is defined as a steel containing sufficient chromium, or chromium and nickel, to render it highly resistant to corrosion. Stainless steel is malleable, hardened by cold working, and resistant to oxidation, corrosion and heat. It has characteristics of high thermal expansion and low heat conductivity, and can be forged, soldered, brazed, and welded. Because of its relatively inert properties, stainless steel bolts are frequently used where the possibility of galvanic corrosion could occur. Stainless steel is available in various grades with SS316 being the most commonly used in the marine environment. Given the complexity of the issues and potential application, the selection of the proper grade of stainless steel for use in a particular application requires careful evaluation by an Engineer.

5.5.2. BEHAVIOUR AND RISKS/ISSUES

Possible forces that can act on a ferrous AtoN structure component and lead to its failure include:

- *Corrosion*, in one form or another, is the major cause of the deterioration of ferrous lighthouse components. Often called oxidation, it is the chemical reaction of a metal with oxygen or other substances. The deterioration of ferrous lighthouse components is a complex process because the type and degree of corrosion is affected by minor variations in environment, contact with other metals and materials, and the composition of the component itself. The main forms of corrosion include:
    - *Oxidation* or rusting occurs rapidly when the ferrous component is exposed to moisture and air. Localised pitting is a development of porosity that deepens quickly into the material, whereby the structural integrity can be compromised. This corrosion appears mostly in a marine atmosphere and can be mitigated by the choice of correct surface coatings or by using stainless steel as an alternative.
    - *Galvanic corrosion* is an electrochemical action that results when two dissimilar metals react together in the presence of an electrolyte, such as water containing salts or hydrogen ions. In all cases where contact of dissimilar materials cannot be avoided, the local contact should be isolated with, for example, acid free grease, isolation barriers, insulation tape, etc.
    - *Graphitisation of cast iron*, a less common problem, occurs in the presence of acid precipitation or seawater. As the iron corrodes, the porous graphite (soft carbon) corrosion residue is impregnated with insoluble corrosion products. As a result, the cast iron element retains its appearance and shape but is weaker structurally.
    - *Crevice corrosion* is a localised form of attack, where there is a breakdown of the surface passive layer, in crevices or on 'shielded' areas beneath surface deposits. In the presence of a wet environment, corrosion appears in crevices, where an insufficient amount of air (oxygen) can circulate to repair the passivity of the surface of stainless steel. Good design and fabrication to prevent the creation of crevices will mitigate this form of corrosion.
- *Inherent flaws* - castings may also be fractured or flawed because of imperfections in the original manufacturing process such as air pockets, porosity, or cooling stresses. Brittleness is another problem occasionally found in old cast iron elements. It may be a result of excessive phosphorus in the iron or of cooling during the casting process.
- *Mechanical breakdown* - components can also fail from purely physical causes such as abrasion, metal fatigue, overloading or a combination of physical and chemical attack, such as weathering and stress corrosion cracking.
- *Weathering* - ferrous components subjected to the weather are exposed to various chemical and physical agents singly and in combinations of several at one time. The result is a kind of synergism where the total effect is greater than the sum of the individual effects taken separately. For example, the rate of corrosion accelerates with increases of temperature, humidity and surface deposits of salts, dirt and pollution.
- *Connection failure* - the failure of the connections of ferrous components, especially structural members, can also be caused by a combination of physical and/or chemical agents. The most common type of connections used for ferrous structural elements include bolting, riveting, pinning and welding. These connections can fail through the overloading, fatigue or corrosion of the connectors.

5.5.3. PREVENTIVE MAINTENANCE

The most common and effective way to preserve ferrous components is to maintain a protective paint or coating on the metal. The effective protective lifespan of an existing paint or coating can be greatly increased by routinely touching up areas of deterioration. A small break in the protective finish can lead to accelerated corrosion of the underlying ferrous material. Areas, where the paint or coating has been damaged by mechanical impact or blistering, should be addressed promptly. These areas should have all loose paint and rust scale removed using recommended methods. Hand tool cleaning and low-pressure grit blasting are most effective for this scale of paint removal. The bare metal should then be painted with a coating system that will adhere to both the bare metal and the existing paint or coating system.

The types of paints available for protecting iron have significantly changed over the years as a result of regulations that prohibit or restrict the manufacture and use of products containing toxic substances such as asbestos, lead and zinc chromate, as well as volatile organic compounds and substances (VOC or VOS). Availability of paint types varies, and manufacturers continue to change product formulations to comply with current environmental regulations.

A key factor to consider in selection of coating systems is the variety of conditions affecting existing and new materials on a particular structure. As a safety note when selecting high performance coatings, it should be recognised that many coatings tend to have a high gloss finish that can be slippery when wet; when painting balconies, stairs, and walkways, anti-slip surface treatment may need to be used for safety reasons.

Stainless steel and galvanised steel components generally require little or no maintenance, other than checking to ensure that the various connections are secure and that contact with different metals are suitably separated to prevent galvanic corrosion. In some instances, galvanised steel can be painted to provide daymark colouring and additional protection to the steel component. Galvanised steel elements should be etch primed or similar pre-treatment prior to application of coating systems.

Stainless steel should be passivated to create a durable oxide layer on the surface of the metal. Passivation is typically done during fabrication; however, care should be taken during maintenance works where modifications are made to stainless structures to re-passivate the metal. Passivation can be done with a pickling solution.

Cathodic protection is a recognised method of protecting metalwork against corrosion, where structural components are in direct contact with saltwater. Typically zinc, aluminium, or magnesium anodes are bolted or welded to the structure below LAT to provide a sacrificial material.

5.5.4. CONDITION ASSESSMENT

Regular inspections and periodic maintenance are important to ensure the integrity of ferrous AtoN structures and components is maintained. The frequency of inspections required may depend on several factors including the age of the structure, the location, environmental conditions and the importance of the AtoN.

Inspections should check for deformation, distortion or deflection. Check for abrasion evidenced by worn, smooth, or polished appearance. Inspect welds for signs of corrosion, cracking or breakage.

Inspect surface coating for any peeling, blistering, or other damage, etc.

Check the integrity of foundations and for any scouring effects.

Inspect guy anchors and hardware. Look for any disturbance in the ground around the foundation of the guy. Inspect guy (wire rope) anchors, turnbuckles, thimbles, shackles, preformed dead end guy grips, shear pins, and cotter pins for signs of corrosion, deformation and fatigue.

Check for corrosion evidence - rust, scale and holes, especially in the splash zone and at extreme low water level. Hammer the surface corrosion to expose the steel below for inspection. Steel member thickness can be measured with ultrasonic equipment.

5.5.5. REPAIR TECHNIQUES

Repairs to ferrous AtoN structures can include replacement of the affected component, installation of additional support or bracing to maintain structural integrity or surface restoration with suitable coating systems.

In certain instances, major cracks or corrosion damage can be repaired on site by brazing or welding and should be carried out using experienced welders.

5.6. NON-FERROUS METAL

5.6.1. MATERIAL DESCRIPTION AND PROPERTIES

Non-ferrous metals used in AtoN construction primarily include aluminium, copper, lead, zinc, brass and bronze. Each specific material has properties that make its use advantageous in a variety of applications. Traditional AtoN structures can include various combinations of ferrous and non-ferrous materials. Lighthouse lanterns often include cast iron base plates or walkways and gutters, bronze lantern astragals and wrought iron dome frames clad in sheet copper. Modern AtoN structures can be made entirely from marine-grade aluminium or combined with other ferrous materials. Non-ferrous metals are also used for elements of structures, such as platforms, marker masts, solar panel mountings and guard railings.

- *Aluminium* is lightweight and provides good structural capacity when used in a suitable design. It is easily extruded, forged, machined and welded. Aluminium is often used as a sacrificial metal in the form of anodes for underwater protection.
- *Copper* is red in colour, highly ductile, malleable and has high conductivity for electricity and heat. Copper is used in sheet roofing and domes of lighthouses and is used for electrically conductive components.
- *Lead* is a soft, heavy, malleable metal with a low melting point and low tensile strength. It can withstand corrosion from moisture and many acids. Lead is widely used in building construction, however, its use must be considered carefully due to its toxic nature
- *Zinc* is a medium to low strength metal with a very low melting point and can be machined easily. Zinc is most widely used as a sacrificial metal in galvanizing or zinc plating, or as an anode for underwater protection.
- *Brass* is an alloy of copper and zinc. It is used most often for decorative purposes, and for items such as hinges and latches
- *Bronze* is an alloy of copper and tin. It is often used for bushes, bearings, and decorative items.
- *Magnesium* is a soft reactive metal. It is often used for anodes used in freshwater environments.

5.6.2. BEHAVIOUR AND RISKS/ISSUES

The variety of differing non-ferrous metals available makes generalising about their properties and inherent risks a difficult exercise. Choice of correct alloys of these very different metals is crucial to ensure that they perform as intended in the specified application. Care must be taken to avoid galvanic corrosion when using a combination of dissimilar metals whether ferrous or non-ferrous.

Galvanic corrosion will occur where metals of differing galvanic potential are connected directly in the presence of an electrolyte such as saltwater. The risk of corrosion is highest, where a small component with a high galvanic potential is connected to a large structure with a low potential – for example, a galvanised bolt in a stainless steel structure will corrode quickly, whereas a stainless steel bolt in a galvanised structure will cause minimal localised corrosion. Where dissimilar metals are used, care should be taken to adequately isolate them from each other with insulating washers or similar. The following Figure 1 lists the galvanic potential of different metals.

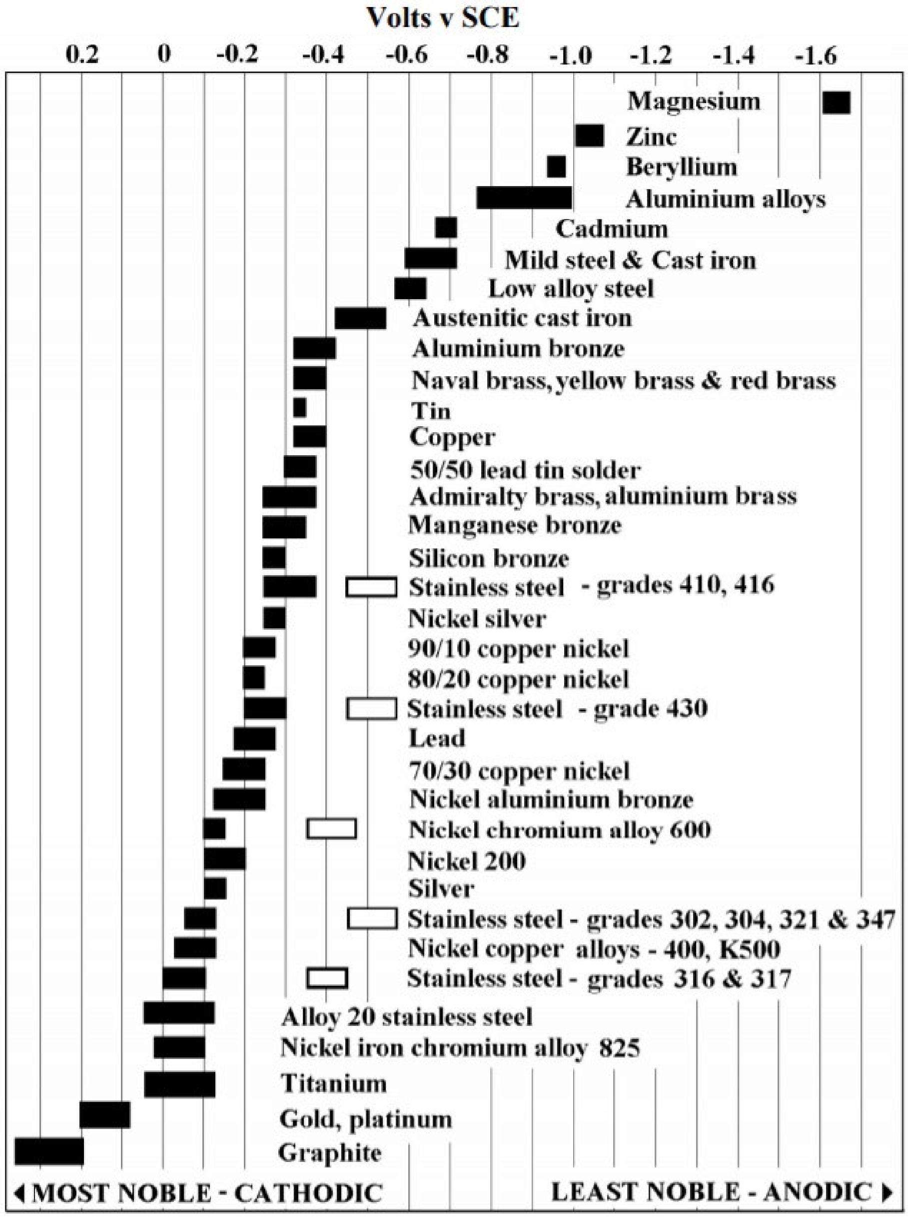

Figure 1 Galvanic potential of different metals

5.6.3. PREVENTIVE MAINTENANCE

Paint systems used on non-ferrous metals will require specific systems intended for the specific material.

Aluminium can prove difficult to paint successfully in the field due to the rigorous preparation and the curing regimes required. Aluminium forms an oxide layer that offers good corrosion resistance but makes coating application difficult.

5.6.4. CONDITION ASSESSMENT

As for ferrous materials, it is prudent to regularly inspect non-ferrous metal structures, but it may be observed that less remedial works are required. The frequency of inspections required may depend on several factors including the age of the structure, the location, environmental conditions and the importance of AtoN.

Aluminium components should be checked for corrosion, particularly if the aluminium is in direct contact with steel, concrete or mortar. Aluminium should be separated from these materials, typically using plastic spacers or other appropriate isolation material. Check for abrasion and wear, as aluminium is much softer than steel, and may be subject to mechanical wearing if rubbing against other metals. Check for cracked welds.

Similarly, copper and brass items should be inspected for signs of deterioration resulting from contact with dissimilar metals.

Check for corrosion evidence, such as efflorescence, gel and salt-like deposits and ultimately metal breakdown, at structural connections and in areas where the structure is in contact with other materials.

Sacrificial anodes of zinc, aluminium, or magnesium should be inspected regularly and replaced when substantially depleted.

5.6.5. REPAIR TECHNIQUES

Weld repairs to moulded materials in the field is difficult. Repairs using fish-plates and screws/bolts may be more successful. An alternative solution may involve replacement of affected component.

Welding of damaged aluminium can also prove difficult in the field. Solutions may require parts to be temporarily removed to effect workshop repairs prior to being re-installed. Alternatively, affected parts could be replaced with new components.

Damaged copper and brass components can be more easily repaired in-situ, with appropriate preparation of the parent material and selection of replacement materials compatible with the existing.

Often it is easier to replace parts than to attempt to make repairs where parts are easily removable, however heritage considerations must be made.

5.7. PROTECTIVE COATINGS

Protective coatings of one type or another have been used on AtoN structures since AtoN structures were first developed. Coating technology has changed dramatically over the years and many high-performance coatings now exist that can aid in maintaining structures to a high standard. Coatings fall into several broad categories as follows.

5.7.1. SACRIFICIAL METAL COATINGS

Fabricated steel structures can be treated by applying a sacrificial metal coating that will degrade in place of the steel. Examples of this include hot dip galvanising and hot aluminium spray. Each system works differently and has different applications. Hot dip galvanising is widely used on new steel fabrication whereas hot aluminium spray is typically used in refurbishment works.

5.7.2. PROTECTIVE WRAPS

Protective wraps are often applied to steel piles within the intertidal zone. Protective wraps are typically chemically impregnated material, titanium foil wrapping or polymer tapes, that are wrapped tightly around a pile or other structural element. The mode of protection is achieved by completely isolating the steel from oxygen and moisture and therefore preventing oxidisation from occurring.

5.7.3. PAINT COATING SYSTEMS

5.7.3.1. Chemically protective coatings

Chemically protective coatings work by protecting the substrate using a sacrificial or reactive process. Examples of this type of coating are zinc phosphate primers, and lime wash coatings.

5.7.3.2. Barrier coatings

Barrier coatings work in a similar way to protective wrap in creating a barrier to moisture and oxygen but are applied as a liquid coating. Examples of barrier coats include; high build epoxy paints suitable for use on steel and concrete structures, and acrylic based paints suitable for use on masonry structures.

5.7.3.3. Aesthetic coatings

Visual signal coatings are those that are applied not primarily for protection of the structure, but for the visual appearance that they provide to the AtoN. Examples of Visual Signal Coatings are Polyurethanes and Polysiloxanes, that have excellent UV and fade resistance. These products are often used over a suitable barrier coat, but many also provide a barrier coat as a secondary advantage.

6. HAZARDOUS MATERIALS

Awareness of hazardous materials has changed over the years since lighthouses were first constructed. International and national legislation regulates the use of certain materials in modern construction. However, many of these materials can remain in lighthouse constructions. The predominant hazardous materials known to exist at lighthouses can include:

- asbestos containing materials;
- silica;
- lead based paints; and
- mercury.

6.1. ASBESTOS CONTAINING MATERIALS

6.1.1. WHAT IS ASBESTOS?

Asbestos can be found in many buildings built pre-2000 (houses, factories, offices, schools, hospitals, etc). Prolonged inhalation of asbestos can cause serious and fatal illnesses.

Before its harmful qualities were known, asbestos was widely used because of its desirable physical properties – including sound absorption, tensile strength, resistance to fire, heat, electricity and its general affordability. Use of asbestos was eventually restricted, phased out or banned by the 1990s. As such, there is a possibility it is still present in buildings that were built or refurbished before that period.

In many countries it is a legal requirement for building owners to identify and manage Asbestos Containing Materials that may be present within their buildings.

There are three main types of asbestos that can still be found in premises, commonly called:

- 'blue asbestos' (crocidolite);
- 'brown asbestos' (amosite); and
- 'white asbestos' (chrysotile).

All of them are dangerous carcinogens, but blue and brown asbestos (amphiboles) are more hazardous than white.

6.1.2. RISK OF EXPOSURE

Asbestos may be found in several different structure components;

- thermal insulation in tamping or flocking (projection);
- woven or braided asbestos for thermal insulation of pipelines, personal protective equipment (PPE), electrical cables;

- asbestos in the form of sheets of paper or cardboard of variable thickness (5 to 50 mm) was used for the thermal insulation of heating equipment, false ceilings, joints;
- incorporated in the form of powder into mortars, plasters, mortar glues etc.;
- mixed with cement for the fabrication of structural elements - corrugated plates, facade elements, ventilation ducts, pipes;
- a mineral filler incorporated into paints, varnishes, sealants, insulation foams;
- mixed with plastics or elastomers for the fabrication of joints, coatings;
- floor tiles and their adhesives; and
- the asbestos incorporated in bitumen's was used for the waterproofing of roofs.

It is the interaction with these components, during refurbishment, removal or maintenance, that may expose the worker to the risk of inhalation.

6.1.3. HEALTH EFFECTS

All asbestos varieties are carcinogenic. But inhalation of asbestos fibres can also lead to several other, well documented diseases. The asbestos fibres are made up of bundles of fibrils which easily separate when manually handled or manipulated, forming a cloud of very fine dust, often invisible to the naked eye. These fibres are easily inhaled and are retained in the lungs. The manifestation of the after-effects of this process are very progressive and do not detect easily at an early stage. It is therefore necessary to firstly avoid manual interaction with asbestos tainted materials as much as possible and avoid any inhalation at all.

6.1.4. REGULATIONS

There are applicable international and national regulations and standards relating to asbestos removal. Local regulations must be adhered to when planning how to deal with an asbestos issue.

6.1.5. PREVENTION OF ASBESTOS RISK

Where it is necessary to remove asbestos from an AtoN site or utility building, there are two possible solutions. These are:

- encapsulate the asbestos materials so that they do not emit any more fibres (temporary solution);
- remove the asbestos materials (final solution, and most often prescribed).

The assessment of the risks by each of the tasks involved in the operation must lead to the choice of processes and working methods to reduce all risks, particularly controlling fibre emissions. It must also make it possible to define the collective and individual protection measures best suited to the protection of the workers involved, but also the rules for the protection of persons working in the vicinity of the site.

Processes for treating materials containing asbestos are selected to:

- limit exposure of workers to asbestos fibres during construction;
- to reduce to the lowest possible level the emission of fibres in the environment of the site;
- facilitate the removal of debris and disposal of asbestos-containing materials, depending on the nature and geometry of the support; and
- to reduce to an acceptable level the physical burden of employees given the difficulty and constraints of these work sites.

Every time maintenance or maintenance work on materials containing asbestos is scheduled, whatever the level of risk that can be determined, it is necessary to resort to a combination of measures, both work organization, collective protection by risk reduction and individual protection of operators.

All wastes containing asbestos are subject to strict packaging and transport conditions.

Where asbestos is to remain in-situ, it is necessary to maintain, label and record the presence of those items on a register.

6.2. SILICA

6.2.1. WHAT IS SILICA?

Silica is a material that exists in the free state in crystalline or amorphous form, and in the combined state in the form of silicates. It occurs naturally in many rocks (sandstone, granite and sand) and as such can be present in structures built predominantly from masonry. Due to its physical properties, it is also commonly added as an additional material in products such as concrete, mortars and façade plasters.

6.2.2. RISK OF EXPOSURE

The risk of exposure to inhalation of silica is during the following activities:

- stone cutting;
- manufacture of dentures;
- manufacture of bricks and tiles;
- production of concrete, mortars and plasters; and
- general construction works.

6.2.3. HEALTH EFFECTS

The health effects of crystalline silica can be particularly severe and disabling (especially silicosis). Occupational exposures should therefore be reduced to the lowest possible level. The route of penetration of crystalline silica into the body is inhalation via the respiratory tract. Dust particles become deposited in the lungs. Crystalline silica dust can induce eye and respiratory irritation, chronic bronchitis and irreversible pulmonary fibrosis called silicosis. This severe and debilitating pulmonary disease usually only occurs after several years of exposure and its evolution continues even after the exposure ceases.

6.2.4. REGULATIONS

Crystalline silica is considered a hazardous chemical agent. There are therefore applicable international and national regulations and standards relating to silica removal. Local regulations must be adhered to when planning how to mitigate the risk of working with silica. Suppliers of silica or silica fume will also be able to provide guidelines for safe handling and work.

6.2.5. RISK PREVENTION

The main preventive measures in the presence of silica dust are as follows:

- when working conditions require it and collective protective measures are not sufficient to eliminate the risk (e.g., on construction sites), provide personnel with suitable PPE: respiratory protection device (depending on the exposure use of a free or assisted ventilation device equipped with a class 3 anti-particle filter or an insulating device), type 5 disposable hooded suit, goggles;
- regularly check the dustiness of the working atmosphere and every important change in operating procedures; and
- implement medical monitoring of exposed employees and post-professional monitoring.

6.3. LEAD

6.3.1. WHAT IS LEAD?

Lead is a metal that has been used since ancient times in many applications. Very resistant to corrosion, it has long been used for the manufacture of water pipes, flashings, and as pigment for paints despite its long-term toxicity.

Regular exposure to lead can lead to many serious health problems.

6.3.2. RISK OF EXPOSURE

The risk of exposure to lead is most common during the following activities:

- removal or repair of lead-based paint systems on buildings, pipes or other parts of the structure, etc.;
- cutting or sanding of metal structures coated with anti-corrosion paint; and
- roofing work (lead soldering, use of lead foil, etc.).

6.3.3. HEALTH EFFECTS

Lead can be ingested through inhalation (dust, smoke) or the mouth (contaminated hands, food, etc). It cannot however be absorbed through the skin.

Lead causes health issues as it accumulates in the body, especially in the bones, where it can remain several decades. It is eliminated very slowly.

The effects of lead are:

- direct effect on the nervous system, including disorders of mood and memory, deterioration of intellectual capacity, impairment of peripheral motor nerves;
- kidneys: disruption of elimination functions, chronic renal failure;
- blood: decrease in the number of red blood cells (anaemia); and
- in the digestive system: lead colic (abdominal pain).

6.3.4. REGULATIONS

Since lead compounds are classified as toxic for reproduction, there are applicable international and national regulations and standards that administer its use.

Safe work procedures should be developed to guard against lead contamination.

These should be consulted when planning how to mitigate the risk of working with lead.

6.3.5. RISK PREVENTION

Guarding against lead contamination can be summarized as follows:

- replacement of products containing lead with less toxic products;
- identify potential points of exposure and mitigate them;
- prevent the production of lead in a form that can be inhaled (aerosols and dust); and
- prevent ingestion of lead (hands, water or contaminated food).

In the case of the building, any work on paints containing lead (or in which lead can be suspected) requires specific prevention measures appropriate to the level of risk. This can range from very simple measures for limited interventions (such as drilling holes for the passage of cables or pipes) to heavy measurements for paint removal sites.

6.4. MERCURY

6.4.1. WHAT IS MERCURY?

Mercury is the only metallic element that is liquid at standard conditions for temperature and pressure. It is a dense, silvery white liquid and is insoluble in water.

6.4.2. RISK OF EXPOSURE

The main risk of exposure to mercury at an AtoN site is in traditional optics where a mercury bath is used as a rotating system. Maintenance of the rotation system often requires draining, cleaning, and refilling the mercury bath. Mercury vapours can be present in lantern rooms where Mercury baths are present.

6.4.3. HEALTH EFFECTS

Mercury and most of its compounds are extremely toxic and must be handled with care. It can be absorbed through the skin and mucous membranes or inhaled. Mercury can cause both chronic and acute poisoning, severe neurological disorders and pose risks to fertility.

6.4.4. REGULATIONS

There are applicable international and national regulations and standards that administer the use of mercury and limit the maximum concentrations that is permitted in air, water, soil, food and drugs.

Whenever mercury is present on an AtoN site, the first option should be removal, unless it is technically necessary to utilize. Removal should be planned carefully or carried out by removal experts. In the event it must remain utilized, maintenance procedures should very clearly identify the risks associated and provide suitable means of mitigating them and protecting the health of workers.

6.4.5. RISK PREVENTION

Where the use of mercury is technically necessary, exposure of workers should be reduced to the lowest possible level. Strict risk-prevention and protection measures are required when storing and handling these substances. The main methods could include:

- set up general ventilation of the premises, without recirculation of the air;
- personal protective equipment should always be worn when handling the product: protective clothing, safety glasses, non-porous impervious gloves;
- inform employees about the risks involved and how to protect them; and
- thorough spill response and clean up.

7. BUILDING ENVIRONMENT MANAGEMENT

7.1. INTRODUCTION

Environmental conditions at coastal sites generally feature high humidity and salt laden moisture in the air, strong winds, and varied temperature extremes dependant on location. It is important to understand how these conditions interact with, and affect, buildings and the materials in them. It is also important to accept that it is often not possible to stop all moisture ingress into buildings and instead focus on minimising and managing the natural moisture load of the structure.

Prior to automation, maintenance of internal and external condition was achieved through the daily actions of keepers who ensured good ventilation of structures and up-keep of the structural fabric. Any problems were promptly dealt with and/or reported creating a regime whereby building conditioning was guaranteed through a proactive process of relatively minor daily maintenance actions and occasional major works when required. In recent decades, automation and the associated de-manning of stations had major implications for the long-term condition of structures.

It may be necessary to implement measures to manage and control moisture levels within the structure.

7.2. BEHAVIOUR AND RISKS/ISSUES

7.2.1. CONDENSATION

At a given temperature, air can contain a limited amount of water as invisible vapour; the warmer the air the more water vapour it can contain. If moisture laden air comes into contact with a colder surface, either inside the building or an interface within the building fabric, condensation will occur at the temperature at which the air becomes saturated (Dewpoint). Water vapour in the air exerts a pressure (the Vapour Pressure) and so air containing a large mass of water vapour has a higher vapour pressure than drier air. This pressure will cause vapour to diffuse from high to low pressure areas. The term usually used to describe whether the air is dry or water laden is Relative Humidity (RH).

7.2.1.1. Causes of condensation

There are two types of condensation:

Surface or visible condensation – this type of condensation develops on visible surfaces within the building

Surface condensation will occur on surfaces that are at or below the dewpoint temperature of the air immediately adjacent to them.

Interstitial condensation – this type of condensation develops within or between the layers of the building envelope and can be potentially hazardous because serious damage to building materials such as timber can often go undetected, it is also often associated with spalling/loss of decorative surfaces.

The interior of buildings during the winter will usually be warmer and the air will hold more moisture in vapour form than the outside. Because most building materials are permeable to some extent, they do not obstruct the movement of moist air through the fabric of the structure. This warm moist air will eventually cool when it comes into contact with concealed surfaces that are below its dewpoint within the fabric of the building resulting in condensation.

7.2.1.2. Effects of high relative humidity and condensation

In coastal locations high background humidity levels are to be expected and good moisture management strategies are central to the long-term maintenance of building condition. However, in such environments atmospheric humidity is difficult to control and there are many features that are indicative of inadequate management:

- condensate;
- mould growth;
- generalised dampness; and
- salt accumulation.

The persistence of excess moisture within a building will quickly make its presence known through many of the above features. Prompt intervention can prevent a relatively minor problem developing into a major issue with widespread adverse implications throughout a structure.

7.3. FACTORS INFLUENCING BUILDING CONDITION

Successful condition management of structures exposed to marine environments is extremely challenging and reliant on an understanding of the complex interactions between factors such as:

- the design of the building(s);
- the history of the building(s);
- materials used in construction;
- exposure characteristics of the building's location;
- available energy for conditioning; and
- knowledge and experience of maintenance personnel.

7.4. METHODS OF BUILDING CONDITIONING

In terms of building conditioning, it is important to recognise that there is no single prescribed approach. Each building will require individual assessment and the development of a strategy appropriate for tits needs reflecting factors such as layout, energy availability, current condition, its operational category and any associated operational restrictions. Increasingly, greater reliance is being placed on the use of energy from renewable energy sources to cover building conditioning requirements, especially on off-shore stations where mains electricity is not available.

When compiling a building conditioning strategy several factors must be considered:

- station Asset Plan & identification of operational category;
- provision of ventilation;
- provision of heating;
- dehumidification; and
- use of specialist building systems and finishes.

7.5. GOOD PRACTICE FOR BUILDING CONDITIONING

Building conditioning of lighthouses and associated structures may require compromises to be made between the best conditions that can be established and the resources available to achieve these. However, the following provides some practical guidance for managing building conditioning:

- ensure that the external fabric of the building is sound with no structural weaknesses through which moisture can penetrate;
- address any problem of rising damp;
- ensure that all glazing is watertight;
- regularly check that all wooden window frames are sound and free from rot;
- ensure that all external finishes are sound;
- check for leaks at the interfaces of different materials, such as around the balcony/gallery as many cast-iron murettes, because of their age, are showing signs of deterioration and, in some cases, are starting to leak;
- check that where buildings have concrete roofs the differential expansion cracks between the roof soffits and the walls are properly sealed;

- ensure adequate ventilation exists for the method being used to provide conditioning;
- provide notices informing visiting personnel which internal connecting doors are to be left open for ventilation purposes when leaving the station;
- expect the walls of naturally ventilated stations to occasionally show signs of condensation – protect electronic items with suitable enclosures or by using marine grade materials; and
- consider the type and quality of soft furnishings left on station in the context of the condition status of the buildings.

It is important to remember that each structure is unique in terms of its construction, exposure to extreme events, history of occupation and long-term maintenance. Consequently, there is no single prescription for building conditioning with the result that building conditioning strategies that work well at one location may not be successful elsewhere.

8. OTHER PHYSICAL AND ENVIRONMENTAL CONSIDERATIONS

8.1. GENERAL

Factors such as sun/UV, rain, snow, frost, salt, sand, humidity, flood, wind, organic influences as mould, insects, woodworm, pests, soil instability, earthquake, iceberg and snow or mud slides, air pollution, bird excrements, oil or chemical pollution, tourism, and vandalism, can all have an effect on AtoN maintenance considerations

Some of these influences such as soil instability, earthquake, icebergs, snow and mud slides should be considered principally in the design phase of the lighthouse so as not to create maintenance problems at some later date.

8.2. EROSION, CLIFF STABILITY, TIDE

Coastal erosion is the wearing away of land and the removal of beach or dune sediments by wave action, tidal currents, wave currents, or high winds. Waves, generated by storms, wind, or fast moving motor craft, can cause coastal erosion, which may take the form of long-term losses of sediment and rocks, or merely the temporary redistribution of coastal sediments; erosion in one location may result in accretion nearby. Storms can cause erosion hundreds of times faster than normal weather.

Before and after comparisons can be made using data gathered by surveying techniques or imagery captured by satellite or drone technology.

8.3. LOCAL WEATHER CONDITIONS

Local weather conditions can have a significant effect on the structure, the site location and the capacity to fulfil maintenance activities. General meteorological information can be obtained from local meteorological authorities. When more site specific information is required, local environmental monitoring can be utilised.

8.4. LOCATION AND ACCESS

Maintenance activities and programmes may also need to take into consideration the following challenges:

- environmentally protected zones;
- prevention of the transfer of invasive species to site;
- challenging terrain and tides;

- land owner rights;
- local indigenous consultation;
- security controlled zones;
- logistical arrangements and available facilities for maintenance personnel.

8.5. TOURISM

Tourism can have an impact on the maintenance regime of AtoN due to the following:

- additional wear and tear on the structures resulting in a requirement for more frequent maintenance;
- additional safety and logistical considerations for public access;
- theft and vandalism;
- reduced access; and
- additional stakeholder management.

9. DEFINITIONS

The definitions of terms used in this Guideline can be found in the *International Dictionary of Marine Aids to Navigation* (IALA Dictionary) at http://www.iala-aism.org/wiki/dictionary and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

10. ABBREVIATIONS

ASR	Alkali-silica reaction
AtoN	Marine Aid(s) to Navigation
DPC	Damp-proof course
FRP	Fibre Reinforced Polymer
g	gram
GRP	Glass Reinforced Plastic (fibreglass)
kg	kilogram
kPa	kilopascal
LAT	Lowest Astronomical Tide
NaCl	sodium chloride
nm	nanometer
RH	Relative Humidity
SI	International System of Units
UV	Ultraviolet (light) (10 – 380 nm)
VOC	Volatile organic compounds (paints and solvents)