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| IALA Guideline |

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Maintenance of AtoN Structures

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# INTRODUCTION

This guideline is intended to assist those involved in the maintenance of AtoN structures. Users of the guideline should recognise that the maintenance of AtoN structures should take into account their 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.

# PURPOSE

This Guideline on the Maintenance of AtoN Structures provides general guidance and advice on the types of structures, their 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.

# MAINTENANCE PRINCIPLES

## 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 emerged over the years. 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.

## Maintenance Strategy

Structures used for AtoN purposes vary considerably in terms of their component materials, their location, the environment in which they are located and their exposure to environmental and climatic conditions. Routine maintenance will ensure a long life for most AtoN structures. Generally, most structures constructed of masonry, concrete and composite materials require minimal maintenance, whereas, structures comprising iron, metal, steel and similar constructions require more frequent action to ensure a long service life.

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 on periodically. It is also advisable to carry out comprehensive structural surveys taking into account 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.

## 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.

## Maintenance of Historic Lighthouses

Lighthouses may have statutory designations applied to them such as historic lighthouses/buildings, protected structures, listed buildings, or similar. Particular 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.

# STRUCTURES, BUILDINGS AND CONSTRUCTION MATERIALS

## Lighthouse

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

## 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

## 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.

## Construction 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);
* combination of some of the above materials.

# MATERIALS

## Masonry (including stone, brick, etc.)

### 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 varied. 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,’ and the corrosion of the connecting dowels may allow blocks to fall out of the structure. The joints between blocks may be left open (called dry masonry construction) or may be 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. Interlocking granite ashlar in towers is likely to prove one of the longest lasting forms of construction the world has known.

### 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-born 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 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.
* 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 assemblage 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 a number of 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.
* Installation of electric storage 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.

### 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.

### 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 point out 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 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 if a portion of the structure is exhibiting any evidence of settlement;
* check for evidence of structural cracking;
* check for evidence of any water ingress.

### 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.

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 really 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;
* training some in-house maintenance staff in conservation techniques.

## Timber

### Material description and properties

Timber is a building material used in lighthouse construction. Easily shaped by sawing, planing, carving, and gouging, timber was used for many components of lighthouses. Timber towers were generally timber frame construction covered with sheathing. All other lighthouse components such as door and window surrounds, cornices, doors and windows were also constructed of timber. The use of timber in lighthouse construction, however, was not limited to the AtoN structure. Timber was also used in the construction of ancillary buildings as building components and in roof structures. 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 and structural capabilities of the timber are compatible.

### 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 puddle 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.
* attack by fungus, insects, or other pests.

### 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.

### 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, typically referred to as ‘woodworm’, 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.

### 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.

## Concrete

### 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. It gets its name from the fact that it does not have any steel reinforcing bars. Unreinforced concrete, however, is relatively weak.
* **Reinforced concrete** is concrete strengthened by the inclusion of steel 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.

### 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.

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.

### 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 and bleeding. If cement content is reduced, then at fixed water/cement ratio the workability will 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 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.

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.

Paint coatings have traditionally been applied to concrete structures to provide the AtoN daymark. External coatings provide a 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.

### Condition Assessment

Before any visual inspection is carried out, all 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.

### Repair Techniques

Repair of cracking in concrete 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 have 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 is 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 has to 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 ‘grouts’.

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 or not the remaining area of reinforcement is adequate to cater for the required loading. Options for restoring the original structural capacity could include the following:

* additional prestressing consisting of adding external stresses to modify the stress state of a structure with dry process shotcrete together with steel reinforcement applied externally to a structure by using a stream of compressed air to spray dry material through a nozzle, with hydration optimised at the nozzle.
* dry process shotcrete together with steel reinforcement applied externally to a structure by using a stream of compressed air to spray dry material through a nozzle, with hydration optimised at the nozzle.
* Fibre Reinforced Polymer (FRP) composites (such as carbon fibre or Kevlar) bonded to the concrete using resin 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.

Protective surface coatings are primarily used to protect new or repaired concrete surfaces from future chemical attack and the ingress of aggressive liquids. There are 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.

## Composite Materials (including plastics)

### Material description and properties

Modern composite materials provide a variety of fibres to be used as reinforcement in polyester resins, such as glass fibre, carbon fibre and poly-aramide fibre (Kevlar). Glass fibre is a common reinforcement for polyester resins used for AtoN structures. These are prefabricated light weight constructions that are generally not suited for exposed wave washed sites. Many structural shapes, ladders, gratings and other components are available in glass reinforced plastic (GRP) composites that can be well suited to AtoN structures.

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 now mostly fibreglass rebar or fibres, though internal steel reinforcing has been used as well.

Fibre Reinforced Polymer (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.

### Behaviour and Risks/Issues

Fibre reinforced plastics are prone to impact damage, particularly in extremes of hot and cold weather and with ageing after prolonged UV exposure. Damage to fibre reinforced plastics generally manifests itself in one or all of 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 also the surface finish, which can cause splinters to develop and present a hazard for maintenance personnel. Gelcoat is the outer surface layer on fibre reinforced plastics and is fairly durable, but it can become dull or faded as it weathers. Sunlight and air combine to oxidize the gelcoat surface, fading it and making the surface dull.

### Preventive Maintenance

GRP structures require little or no maintenance. A fibreglass sealer can be used to restore the dull or faded surface condition. The fibreglass sealer penetrates into 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.

### Condition Assessment

Check for broken or damaged members and components.

Check for loose connections. GRP members are usually connected together 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.

### Repair Techniques

Repair of fibreglass structures in remote locations may be undertaken using polyester, vinyl ester, or epoxy resin systems. Epoxy repairs are more robust and exothermic in nature, and 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 GRP 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.

## Ferrous Metal

### 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, steel, galvanised steel and stainless steel. In lighthouses, the most widely used alloy was cast iron. Iron was also used for the production of architectural features such as balcony brackets and prefabricated lantern components. Other iron alloys such as steel, galvanised 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.
* **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, sulfur, oxygen, manganese, silicon, aluminum, 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 more base zinc occurs, 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. Given the complexity of the issues and potential application, the selection of the proper grade of stainless steel for use in a marine environment requires careful evaluation by an Engineer.

### 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 iron lighthouse components. Often called oxidation, it is the chemical reaction of a metal with oxygen or other substances. The deterioration of iron 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 iron 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 as a result of imperfections in the original manufacturing process. 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.

### 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 primed and painted with a primer and top coat 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 take into account in selection of primers and coatings is the variety of conditions affecting existing and new materials on a particular structure. When selecting high performance coatings, it should be recognised that these coatings tend to have a high gloss finish that can be slippery when wet. When painting balconies and other iron or steel walkways, anti-slip surface treatment may need to be installed 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 suitable separated to prevent galvanic corrosion. In some instances, galvanised steel can be painted to provide daymark colouring and also additional protection to the steel component. Galvanised steel elements should be etch primed or similar pre-treatment prior to application of coating systems.

Cathodic protection is a recognised method of protecting metalwork against corrosion, where structural components are in direct contact with severe environmental conditions, such as seawater.

### 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 a number of factors including the age of the structure, the location, environmental conditions and the importance of 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, 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.

### 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 zinc rich primers.

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

## Non-Ferrous Metal

### Material description and properties

Non-ferrous metals primarily include aluminium, copper, brass, lead, zinc, brass and bronze. Their main advantage over ferrous materials is their malleability. They have no iron content and are non-magnetic, giving them a higher resistance to rust and corrosion making them ideal for outdoor use. Traditional AtoN structures can include various combinations of non-ferrous materials. Lighthouse lanterns often include cast iron base plates or walkways and gutters, bronze lantern astragals and wrought iron dome frame 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. All non-ferrous metals display better corrosion resistance than ferrous metals, but are often more costly.

* **Aluminum** is lightweight, soft and low strength. It is easily moulded, forged, machined and welded. It is not suitable for high-temperature environments.
* **Copper** is red in color, highly ductile, malleable and has high conductivity for electricity and heat. Copper is used in sheet roofing and domes of lighthouses.
* **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.
* **Zinc** is a medium to low strength metal with a very low melting point. It can be machined easily, but heating may be required to avoid cleavage of crystals. Zinc is most widely used in galvanizing, the process of applying a protective zinc coating to iron or steel to prevent rust.
* **Brass** is an alloy of copper and zinc.
* **Bronze** is an alloy of copper and tin.

### Behaviour and risks/issues

Non-ferrous materials offer many advantages over ferrous metals, not least corrosion resistance in the marine environment. However, they are generally less ductile than ferrous metals and are therefore more prone to impact damage, resulting in cracks and dents.

Care must be taken to avoid galvanic corrosion when using a combination of dissimilar metals.

Aluminium structures offer lightweight construction, which helps ease and speed of erection and handling. It is essential to select the correct grade of aluminium appropriate for the intended application.

### Preventive maintenance

Paint systems used on non-ferrous metals will require a build-up of different coats, but primer coats must be compatible with the particular parent metal concerned.

Aluminium can prove difficult to paint successfully in the field due to the rigorous preparation and the curing regimes required.

### 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 a number of 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.

### 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.

# HAZARDOUS MATERIALS (ENG 5 Note: to be completed)

## Asbestos Containing Materials

Asbestos can be found in any building built before the year 2000 (houses, factories, offices, schools, hospitals etc) and causes many deaths every year. Asbestos still kills more people working in the construction industry than the number of people killed in road traffic accidents. However, asbestos is not just a problem of the past. It can be present today in any building built or refurbished before the year 2000. 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:

1. 'blue asbestos' (crocidolite),
2. 'brown asbestos' (amosite) and
3. 'white asbestos' (chrysotile).

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

### Material description and properties

When materials that contain asbestos are disturbed or damaged, fibres are released into the air. When these fibres are inhaled they can cause serious diseases. These diseases often take a long time to develop, but once diagnosed, it is often too late to do anything. This is why it is important that you protect yourself now. Asbestos can cause Mesothelioma, Asbestos-related lung cancer, Asbestosis and Pleural thickening.

### Material description and properties

As long as the asbestos-containing material (ACM) is in good condition, and is not being or going to be disturbed or damaged, there is negligible risk. But if it is disturbed or damaged, it can become a danger to health, because people may breathe in any asbestos fibres released into the air. It can be difficult to identify asbestos, as it is often mixed with other materials.

### Material description and properties

Asbestos can found in a many of the common materials used in the building trade. Some of these materials should only be worked on by a licensed contractor.

## Silica

To be completed

## Lead Based Paints

To be completed

## Mercury

To be completed

# BUILDING ENVIRONMENT MANAGEMENT

## ?????

To be completed.

## ?????

To be completed.

# OTHER PHYSICAL AND ENVIRONMENTAL EFFECTS

## ?????

To be completed.

## ?????

To be completed.

# CONTROL MECHANISMS - ENVIRONMENTAL CONTROLS – BUILDING CONDITIONING (EXISTING GUIDELINE 1076)

Environmental conditions at coastal sites reflect the influence of a large body of salt-rich seawater with generally high ambient atmospheric humidity conditions combined with atmospheric moisture that contains a variety of salts. In order to formulate a successful management strategy it is important to have a sound understanding of the factors that regulate these parameters and the nature of their interaction with buildings and the materials that comprise them. It is also important to accept that it is not possible to stop all water ingress into buildings with a resultant emphasis on minimising and managing the natural water/moisture load of the structure. Note: Reference IGC5 Task Group Report in Guideline 1076.

## Behaviour of Water Vapour in Air

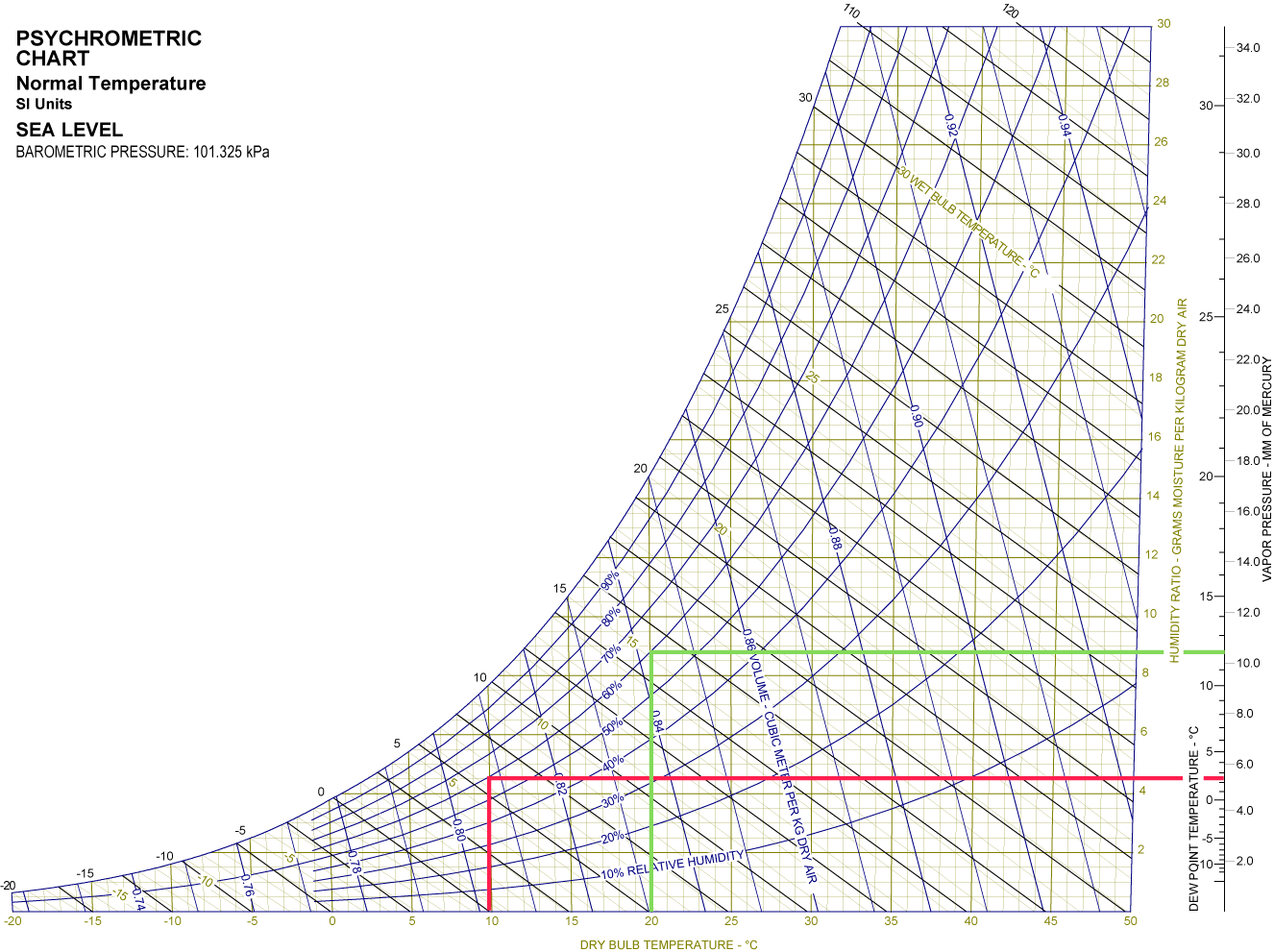
At a given temperature air is capable of containing a limited amount of water as invisible vapour; the warmer the air the more water vapour it can contain. If moisture laden air comes into contact with a colder surface, either inside the building or an interface within the building fabric, condensation 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).

**

1. Part of a Psychrometric Chart showing relationship between air temperature, vapour pressure and relative humidity.

The curved lines in Figure 3 show percentage relative humidity (RH) resulting from the combination of temperature and vapour pressure. Percentage relative humidity is a good indicator of the risk of condensation, mould growth and the degradation of absorbent materials. As a general rule, where air remains around or above a 70% RH value for lengthy periods there is a high risk of condensation development and mould growth on some part of the internal fabric.

The arrows shown in Figure 3 indicate that the risk of condensation development can be reduced by increasing the temperature, decreasing the vapour pressure or by a combination of these two factors. A blank Psychrometric Chart is included in Appendix 2. Excess atmospheric moisture and the associated absence or reduction in ventilation within structures, are the main factors that lead to a decline in the internal condition of structures and their fabric and furnishings.

This Psychrometric Chart allows the calculation of dew point based on certain known air temperature and relative humidity (RH) parameters. For example, air at 10°C with a RH of 60% has a dew point of 2.5°C and moisture content of 4.5g/kg dry air (red line) while air at 20°C with the same RH value of 60% has a dew point of 12°C and moisture content of 8.75g/kg dry air (green line)

1. Psychrometric Chart

## Causes of Condensation

There are two types of condensation:

* **surface or visible condensation** – this type of condensation develops on visible surfaces within the building;
* **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.

Most materials will absorb water vapour from the environment and this can take the form of atmospheric humidity, construction water and moisture derived from the presence and action of human occupants (cooking, cleaning, breathing etc.).

### Causes of Surface Condensation

Surface condensation will occur on surfaces that are at or below the dew point temperature of the air immediately adjacent to them. As shown in Figure 3 the two parameters that control this effect are the temperature of the surface and the vapour pressure of the air.

The temperature of a surface depends upon the following factors:

1. Type(s), amount, time and rate of heating of the building.

Buildings heated on a 24/7 basis rarely show evidence of condensation even in the absence of ventilation. In such cases all surfaces are maintained at the temperature of the heated air with no intervals of cooling that might allow a thermal differential to develop between material surfaces and the air. However, 24/7 heating is expensive, environmentally unsustainable and not possible in many remote locations where there is no mains electricity and power generation is limited and primarily directed towards the Aids to Navigation. Intermittent or partial heating can be problematic with the development of condensation through the creation of a time lag before temperature equalisation occurs between material surfaces and the overlying air due to differences in thermal properties (see below).

1. Cold bridging in the building fabric.

Cold bridges are sections through the building fabric of significantly lower thermal resistance than the rest of the construction. These occur particularly around openings and at the junction of walls and floors and walls and roofs. For example, condensation can occur at the base of externally connecting walls. Concrete and steel framed buildings are particularly prone to cold bridging unless these elements are individually insulated. Cold bridging usually becomes apparent through specific patterns of staining whereby the cold bridge because of the temperature differential attracts moisture as surface condensation, which in turn attracts dirt and dust and can facilitate mould growth. The overall effect of cold bridging is to reduce the effectiveness of any insulation within the building. Cold bridge condensation can also occur on internal structures such as un-insulated cold-water tanks.

1. Thermal properties of the material and its surface finish.

Different materials have different thermal properties that reflect a material’s ability to absorb and conduct heat energy. For example, the thermal or specific heat capacity of a material refers to the quantity of heat energy required to increase the temperature of a material by a particular amount. Brick, stone and concrete have much higher specific heat capacities than air which means that they take longer to heat than air but they hold onto that heat and will release it relatively slowly back into the building in comparison to air which heats and cools quickly. The significance of differences in thermal properties between materials is the creation of a ‘lag effect’ when the temperature of walls, floors etc. lags behind that of heated air creating conditions conducive to the formation of condensation when warmer air overlies comparatively cooler surfaces.

1. Nature and rate of ventilation.

The absence of, or reduction in, ventilation within a building can raise the potential for the development of condensation because the greater the amount of time a body of moist air is in contact with cooler surfaces such as walls and ceilings the greater the time available for moisture within the air to condense out onto the surface of the material in question. Inadequate ventilation can result in the formation of ‘pockets’ of static air at wall corners and in rooms where connecting doors have been closed. Prior to automation lighthouse keepers ensured adequate ventilation of towers and associated buildings on a daily basis but this is no longer the case with buildings effectively closed up for long periods between maintenance visits. In such circumstances full use should be made of structural features such as fireplaces and chimney flues, which in the absence of an actively maintained airflow, allow for some limited ventilation.

1. Temperature conditions of the external environment.

In the absence of heating, a building’s internal temperature primarily reflects external temperature conditions although it may be somewhat modified by aspect-related heating of rooms by the sun shining through windows. Reverse condensation or summer condensation is a product of external temperature conditions and is most frequently observed when the sun shines on damp walls. This is most likely to be encountered in thin masonry walls, walls of an absorbent nature or on walls that remain saturated because of their exposure. It is caused by the moisture within the wall being vaporised by the heating effect of the sun with the resulting pressure difference driving the water vapour towards the inside of the building. The risk of reverse condensation may be reduced by the application of a weatherproofing treatment or system to the outside walls of the building. Reverse or summer condensation can commonly occur on basement floors especially if the basement space is ventilated. Outside air tends to have high moisture content during warm weather and the dew point temperature of this air may also be relatively high but as uninsulated basement floors may be colder than the dew point of this outside air then condensation will form.

The vapour pressure of the air is determined by:

1. Production of water vapour.

The potential for condensation development within a building can be significantly increased by human occupation and associated activities. For example, moisture can be brought in directly on wet clothes and materials, it can be released from the burning of gas in cookers and heaters, it can also be released from the act of cooking food, boiling a kettle and through the use of washing machines and unvented driers. Finally, the simple act of breathing can also introduce considerable quantities of water vapour into the internal atmosphere of a building.

1. Nature and rate of ventilation.

Well established airflow decreases the time that moisture-laden air is in contact with cold internal surfaces and thus reduces the potential for condensation development. Passive ventilation through the utilisation of structural features such as the stack effect in tall buildings and the natural draw of air through fireplaces and chimney flues has the advantage of requiring no additional energy input but may lead to the formation of static pockets of air. Active ventilation requires energy input but in comparison to passive systems will be more efficient in terms of air movement and is therefore more likely to be effective in reducing or preventing surface condensation. Possible solutions to this problem include the introduction of solar powered fans and wind catcher units.

1. Moisture content of the replacement ‘fresh’ air.

Because of their coastal environmental settings, lighthouses and associated buildings are exposed to the effects of naturally moisture-laden and salt-rich air. In addition, the moisture burden can be increased by wave splash and spray and coastal fog. The importation of moisture-rich air could be reduced by use of ‘smart’ positive ventilation systems whereby ventilation is restricted or deactivated during periods when the external humidity is high (e.g. more than 75%RH) and reactivated when RH values fall.

1. Direct penetration of the building fabric by water.

The central tenet of good building management is to keep the ‘weather’ out. However, there are many sources from which water can be derived especially in regularly unoccupied buildings where the effects of relatively minor damage or poor/delayed maintenance can accumulate to cause significant damage. Building fabric defects that can lead to the ingress of water include (examples of these defects are shown in Section 4):

1. Badly fitting lantern glazing may facilitate the ingress of rain into the lantern and from there into the body of the tower.
2. Damaged glazing and cracked window putty may facilitate the ingress of driven rain.
3. Degradation of mortar and pointing can create a route for moisture penetration, which once established within masonry, can be extremely difficult if not impossible to eliminate.
4. Penetration of groundwater can occur in buildings that have compartments below ground level with inadequate tanking.
5. Rising damp is a problem associated with many old buildings constructed without a damp-proof course (DPC). The extent and severity of the problem will primarily depend on the nature of the building materials and the bedrock and foundation characteristics.
6. Where a damp proof course is present it may provide a route for moisture penetration across the DPC from external to internal wall surfaces.
7. Cracks in asphalt (flat roofs) and parapet walls.
8. Damage to roof tiles/slates and lead/copper flashing.
9. Damaged or blocked rainwater goods can lead to prolonged periods of dampness on adjacent walls. In salt-rich marine environments corrosion of lead and copper pipes within masonry walls can result in the significant leakage and spread of water within walls.
10. Close proximity of vegetation and mosses to buildings can lead to moisture retention and can degrade materials/structure by root penetration.
11. Water absorbency of building fabric and contents.

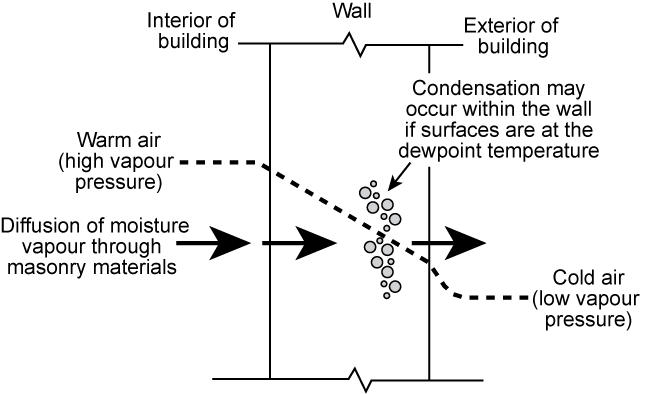
The ability of the building fabric and contents to absorb water vapour (sponge effect) will reduce or increase the vapour pressure within the building depending on whether the building is cooling or warming.

### Causes of Interstitial Condensation

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 dew point within the fabric of the building resulting in condensation. This form of condensation is called interstitial condensation and can result in the potentially serious hidden deterioration of materials and is often associated with spalling/loss of decorative surfaces. The movement of moist air through the fabric of a building can occur by leakage and/or diffusion:

* Diffusion;

Diffusion involves the movement of water vapour through building material from locations of high moisture content towards a location of comparatively lower moisture content (Figure 5). The rate of moisture diffusion will vary depending on the permeability characteristics of the material through which it is moving and the vapour pressure gradient between internal and external conditions. Diffusion can be combated by the use of less porous materials vapour barriers such as films and paint systems.



1. Process of moisture diffusion through a wall

* Leakage.

Leakage of moist air can occur through cracks or fissures in materials. These may be present as material flaws or may have been created, for example, by the drilling of holes in walls and window frames to accommodate electrical cables and drains for dehumidifiers. The rate of leakage will depend on the nature and extent of potential access points for moisture-laden air and also on the vapour pressure differences. Air leakage can only be addressed by judicious maintenance with the sealing of cracks, fissures and openings in interior walls.

In addition to the effects within masonry structures, interstitial condensation has been found to be a major problem within lanterns where double skins are used to form the cast iron murette. Ventilation and, in severe cases, condensate management should be provided to reduce the problem as much as possible by opening up the internal ventilators. Introduction of ventilation within the walls themselves may also help to remove or lessen moisture within masonry and reduce the potential for development of condensation. Such a system is being trialled at North Foreland by Trinity House (TH site 13 in Figure 9) where moisture loading within the masonry is excessive (Figure 6).



1. Damp control surface vents

Damp control surface vents inserted at regular intervals in the lower part of walls. These vents may be connected to ceramic tubes inserted into the wall creating an airflow pattern that facilitates the formation of a cold bridge leading to condensation of moisture from within the masonry, which is then drawn out and away in the form of water vapour. Once painted these surface vents should not be visually intrusive.

## 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**;

The effects of condensation can range from the relatively minor comprising the presence of condensate only on kitchen and bathroom windows to the more problematic extensive presence of condensate on walls and floors. The former is more of a nuisance and is of limited significance while the latter may have serious implications for the longevity of furnishings, fabrics and internal surfaces and components.

* **mould growth**;

Mould spores are naturally present and abundant in the atmosphere. Within occupied buildings that are well heated and ventilated they rarely cause a problem. The main factor that is essential for the growth and spread of mould is the persistent presence of moisture on surfaces and within materials. As a general rule if the average relative humidity within a room stays above 70% for prolonged periods of time, sufficient moisture will be available to support the growth and spread of moulds. Once established moulds can actually retain moisture within their structures exacerbating surface wetness. Aside from the implications of mould growth for deterioration of fabrics and fittings it also has serious implications for human health and is therefore a major Health and Safety issue for personnel required to spend time on station.

* **generalised dampness**;

Fabrics and furnishing stored within a damp building will absorb moisture, which will ultimately lead to their gradual degradation. Sustained exposure to damp may contribute to the decay of timber, plasterboard and corrosion of metal fittings.

* **salt damp**;

Moisture penetration with salt can result in staining of interior surface finishes as salts reabsorb moisture from the atmosphere when relative humidity rises. This dampness will also tend to attract dust and may facilitate mould growth which will further exacerbate the surface discoloration.

* **salt accumulation**.

The significance of high relative humidity and associated condensation, particularly in a salt-rich environment, is that it provides a mechanism for the wet-deposition, surface accumulation and gradual penetration of salts into the fabric of the building. One of the most commonly occurring salts in these coastal environments is halite (sodium chloride: NaCl). Halite is a strongly hygroscopic salt meaning that it attracts moisture from the atmosphere (in a kitchen salt cellars frequently clog up) and is therefore said to be deliquescent. Different hygroscopic salts exhibit particular threshold relative humidity values above which they start to deliquesce. Above the equilibrium relative humidity value (75% for NaCl), hygroscopic salts will exhibit deliquescence but if the ambient relative humidity decreases below this value the salt solution will become saturated and with a continued decline in relative humidity salt crystallisation will begin. With the accumulation of salt, regular episodes of salt crystallisation followed by periods of deliquescence allow salts in solution to penetrate and exploit naturally occurring weaknesses within masonry material (for further information see Appendix 3). The accumulation of salts resulting from condensation will also have adverse implications for any exposed metal fittings and electronics that are prone to corrosion. Salt accumulation can also occur as a result of the interaction between fumes from inadequately vented internal fuel storage tanks and salt rich moisture within masonry materials. The volatile hydrocarbons from the fumes combine with sodium salts to form a suite of particularly aggressive sulphate salts.

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. Table 1 gives some more specific examples of the hazardous effects of condensation within lighthouses and associated buildings.

1. Common effect of condensation on interior fittings and fixtures of lighthouses and associated buildings

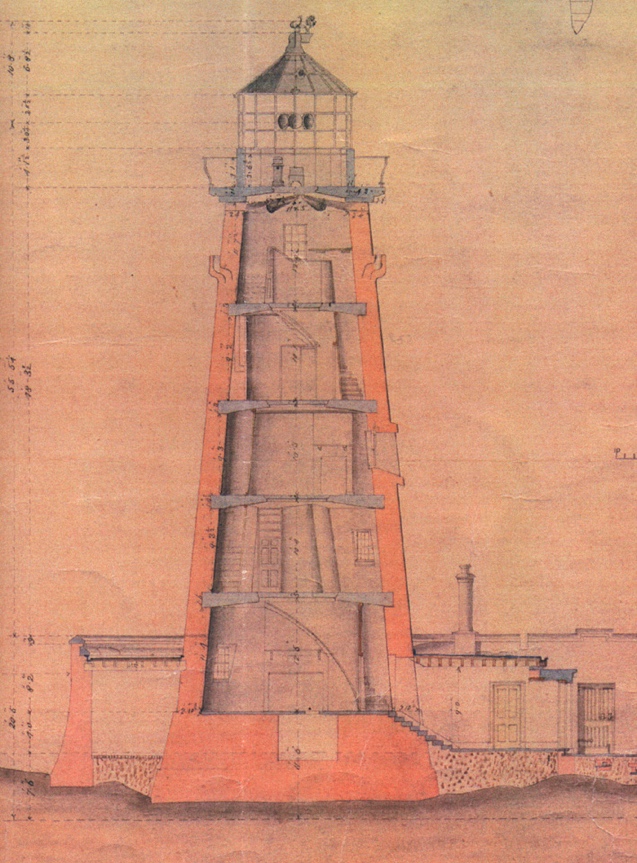
|  |  |
| --- | --- |
| **Hazard** | **Effect** |
| **Mould growth** | **Health impacts**: the presence of mould spores can have serious effects on human health when inhaled, especially for personnel with chronic health disorders such as asthma and bronchitis. (N.B. Health and Safety Legislation requires that the working and accommodation environments should not be hazardous to the health of personnel)  **Soft furnishings**: mould growth within damp furnishings can lead to the staining, breakdown or rotting of fabrics. Mould can also cause foxing of paper  **Timber**: penetration of timber joints by moisture facilitates the ingress of spores and development of mould that can lead to the breakdown and rotting of the timber  **Painted surfaces**: extensive and well-established mould growth results in unsightly discoloration of painted surfaces |
| **Corrosion** | **Metal fittings** (e.g. handrails, screws and nails etc): condensation and associated salt accumulation can lead to rapid corrosion  **Electrical items**: condensation and high humidity can lead to corrosion of electrical contacts, printed circuit boards and where surfaces are damp, increases the risk to personnel of electric shock |
| **Damage to surface finishes** | **Wallpaper**: Under conditions of condensation wallpaper will become stained and will start to peel away from the wall  **Soft distempers**: these are liable to breakdown through flaking when exposed to repeated wetting and drying  **Paint**: when moisture penetrates behind painted surfaces this will often result in the creation of blisters with the eventual fragmented loss of the painted surface  **Plaster**: under extreme conditions plaster may become unstable and break away from the underlying surface  **Lath and plaster detachment**: corrosion of nails fixing lath and plaster to wall-mounted wooden batons can result in its destabilisation and eventual detachment |
| **Fogging** | Condensation can form on lantern glazing resulting in a fogging of the light. In exceptional conditions condensation can also affect lenses with significant implications for light generation |

## 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)

Building design can have a significant influence on factors such as ventilation, heating and moisture movement. For example, a tall tower will benefit from natural ventilation developed through the ‘stack’ effect with warm air rising and drawing in replacement air. The efficiency of this natural form of ventilation will depend on the internal structure of the tower with features such as floors, staircases and closed doors inhibiting airflow. The presence of structural features such as fireplaces and chimney flues will also facilitate ventilation within a building provided they are not closed up (Figure 7). Another significant factor is the presence or absence of a damp-proof course.



1. Section drawing of Longstone lighthouse

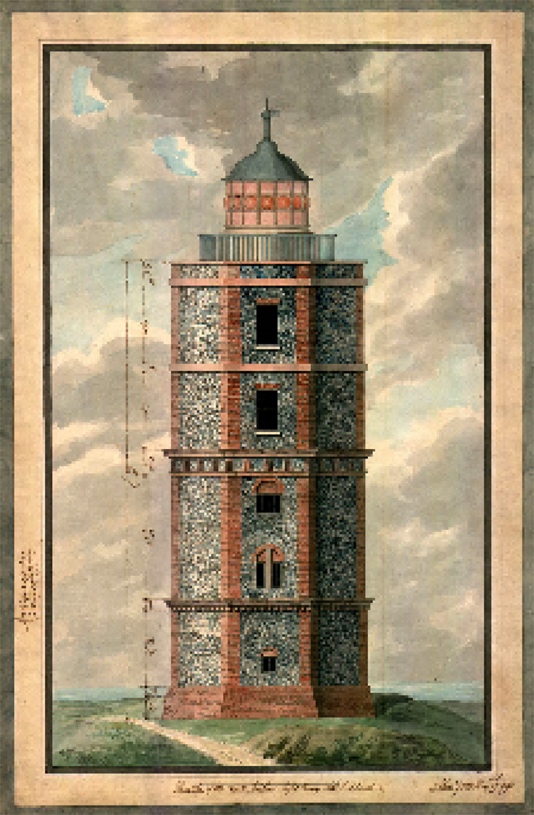
Figure 7 shows chimney flues and outlets within the external walls on the 4th and 5th floors (TH site 3 in Figure 9)

### The history of the building(s)

In historic structures, present-day management is often heavily influenced by a legacy of past events. For example, major storm damage in the past, which may have resulted in the ingress of seawater, can leave masonry materials contaminated with salt and moisture and initiate the cycle of salt weathering and corrosion-related damage. In addition, as many of these structures are more than 100 years old, the gradual aging and degradation of the masonry components of the building can reduce their efficiency in preventing moisture penetration.

### Materials used in construction

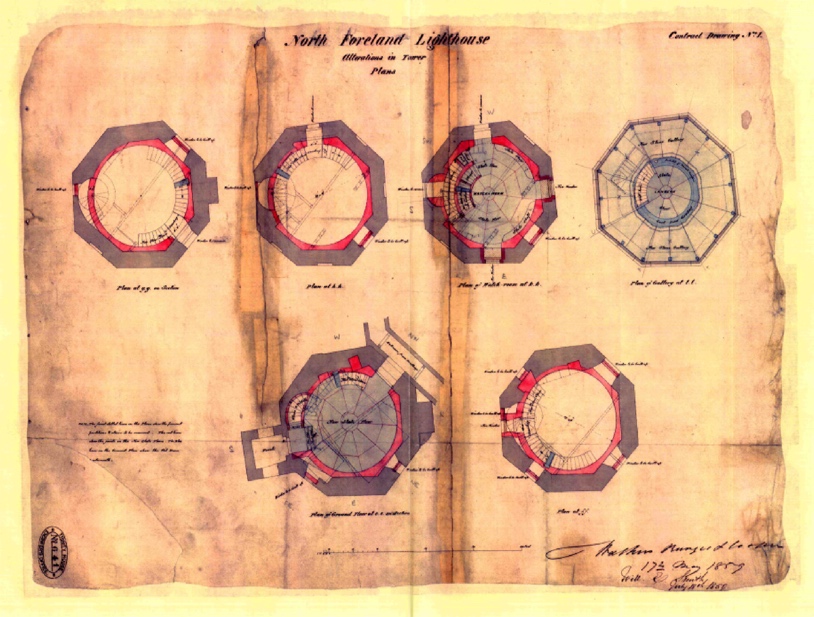
Materials used in building construction can greatly influence long-term building condition. For example, different materials have different permeability and thermal characteristics, which can lead to the creation of cold-bridging and increase the potential for condensation when buildings are unheated. In addition, certain building materials are more prone to the long-term effects of salt and moisture than others. Because of their age, many lighthouses have undergone significant structural modification that has introduced different building materials and methods. Consequently, knowledge of the construction history of the structure is extremely important in condition management with referral to archive drawings and plans e.g. North Foreland (Figure 8a–c) (TH site 13 in Figure 9). In addition, poor specification of material used in repairs and/or replacement can be the source of significant problems with the most common example being the replacement or repair of lime mortar with ‘hard’ cement, which lacks the flexibility and breathability of the original lime mortar.



*a*



*b*



*c*

1. Historic plans and drawings of North Foreland lighthouse

Figure 8 provides a valuable record of significant structural changes that have had a major impact on present-day building conditioning. (a) The original flint and brick finish of the tower, (b) subsequent rendering of the exterior of the tower and, (c) construction of a rounded internal structure within the original octagonal tower which has given rise to considerable stresses between different masonry materials and problems related to moisture movement and reduced breathability.

### Exposure characteristics of the building’s location.

Lighthouses and their associated structures are by their very nature exposed to extreme environmental conditions. However, the extremity of these conditions varies from site to site and, in general, those located on the western, north-western and south-western coasts are exposed to the harshest conditions in terms of driven rain and high wind-speeds. In addition to the effects of wind-driven rain, many lighthouses such as Orfordness (TH site 12 in Figure 9) are increasingly at risk from the effects of coastal erosion, sea-level rise and the increased severity of storm events associated with climate change (Figure 7). In the next 50 years this will become an increasingly significant issue with regard to building conditioning because of the associated impact of rising groundwater and storm surges.

### Available energy for conditioning

Building location also has an impact on the energy available for conditioning with those stations located off-shore and away from mains electricity being dependent on energy generated by other sources. This may result in an unavoidable energy shortfall for building conditioning as the primary call on available energy is for the operation of the Aids to Navigation.

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1. Orfordness Lighthouse

Orfordness Lighthouse is located on a shingle spit which is undergoing significant coastal erosion that will eventually jeopardise the structural stability of the tower.

It is important to remember that in situations where internal building condition has been deteriorating for some time, through the accumulation of salts, salt damage and moisture in materials, there will be no ‘quick-fix’ when attempting to improve condition. Improvement in condition under such circumstances may take time involving a period of gradual improvement as the building adjusts to moisture control measures.

## Methods of building conditioning

In terms of building conditioning, it is important to recognise that there is no single prescribed approach. Each station will require individual assessment and the development of a strategy appropriate for that particular station’s needs reflecting factors such as the station layout, energy availability, the current condition of the station, 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 have to be considered:

* Station Asset Plan & identification of operational category (1–4);
* provision of ventilation;
* provision of heating;
* dehumidification;
* use of specialist building systems and finishes.

### Station Asset Plan and Identification of Operational Category

The first step in the compilation of a strategy for building conditioning is the development of a Station Asset Management Plan in association with a Property Plan, a Risk Register statement and an Environmental Designation (examples of these are shown in Appendix 5). The Asset Management Plan forms the basis of a 10-year work plan for the station and should identify the long-term operational category of the station in question (categories 1–4) which is central to defining short (2-year) to medium-term (5-year) condition management goals and work programmes for each building within the station complex.

### Provision of Ventilation

In this post-automation era, one of the most challenging issues with regard to building conditioning is ventilation or more accurately, insufficient ventilation. The primary effect of ventilation is to control humidity levels and reduce the potential for condensation development by keeping moist air moving over cold internal surfaces thereby preventing it from cooling and condensing. Ventilation can be either:

* Natural – structural characteristics of buildings can facilitate natural airflow;

The prime example of this is the through flow of air generated by the stack effect in a tall building where warm air rises from the base, is expelled from the top of the tower and replaced by air drawn in from outside. Natural ventilation may be insufficient in certain buildings to maintain adequate airflow and it is important to note that this form of ventilation will only occur if vents exist for the drawing in and expellation of air. If ventilation in a building is reliant on natural processes, then it is important that connecting doors within the building are left open unless the risk of fire is considered to be high

* Forced – forced or fan assisted ventilation requires power and maintenance but produces a regulated airflow that can be controlled by humidistats;

Forced ventilation systems may be necessary to supplement natural airflow and thus avoid the development of static pockets of stale, damp air that lead to localised condensation.

* Positive pressure – natural through flow ventilation may not always be practical for lighthouses and associated buildings.

An alternative method of ventilation, which has found favour with many Local Authorities and Housing Associations is Positive Pressure Ventilation using systems such as the Daisy Combi Positive Pressure Ventilation Unit. This is an extension of the intake ventilation concept. This rate of ventilation is very low, half an air change per hour, and is designed to be continuous. The concept underlying this method is that outside air is usually drier than inside air, BS5925 (1991 Section 4.5; Control of Internal Humidity) states that ‘The contribution made by ventilation is to lower the moisture content of the internal air by dilution with the outside air which has a lower moisture content.’ Whether this last statement reflects what happens in lighthouses is debatable. Positive Pressure Ventilation introduces dryer air into the dwelling where it is mixed with the internal air lowering the total moisture content and gently removing the moist air by forced natural leakage around doors, windows and chimneys. If the building is sealed and draught proofed it may be possible to fit devices to allow the air to escape or devices that open and close automatically depending on temperature, moisture content or both. The air at ceiling level is usually up to 8°C warmer than at lower levels as heated air naturally rises. This stratification was evident in rooms where heavy smoking occurred where heated air rose to ceiling level creating a barrier for the cigarette smoke, which visibly hung some distance below ceiling level. In a domestic environment positive pressure ventilation mixes this wasted heat at higher level, with the dryer outside air and circulates it, firstly across the room at ceiling level, then to the rest of the room volume without any noticeable draughts. As dry air costs less to heat than moist air, and the room air is de-stratified, this form of ventilation should reduce heating bills, despite bringing in a small amount of outside air, which may be below the internal air temperature at certain times of the year.

* Ventilation heat exchangers.

In cold weather, the provision of heating and the provision of ventilation give rise to a conflict of interests. In order to maintain a certain temperature or temperature difference, increased ventilation (either natural or forced) increases demands on energy input. In heating terms, an airflow rate of 60 l/s costs 72W/ºC sustained temperature difference. This flow rate is about half an air change per hour for a medium sized tower (20m high x Ø5m). One solution to this problem is ventilation with heat recovery, whereby supply and extract ventilation are provided by a device that incorporates a heat exchanger. The extracted air gives up heat to the supply air at an effectiveness that can be as high as 80%. There is a small energy penalty for this heat recovery that is equivalent to the airflow resistance through the heat exchanger. Using heat recovery ventilation, about 50W/ºC could be recovered for a fan energy input of about 40W, irrespective of temperature difference. A temperature difference of 5ºC above ambient would be sufficient to combat condensation problems. Using the same sized tower as an example, energy input without heat recovery would be 360W, 150W with 70% heat recovery.

### Provision of Heating

To minimise surface condensation, the timing and amount of heating should be regulated to ensure that surface temperatures inside the building are kept above the dew point temperature. The aim should be to maintain an air temperature difference of ideally 5°C above ambient in all parts of the building but 3–5°C may be more realistically achievable. There are many different types of heaters and their choice will primarily depend on energy available and the area to be heated. It is important to remember that the requirement for heating will be dictated by the operational status of the building with, for example, Category 4 buildings left unheated.

### Dehumidification

The aim of dehumidification is to reduce and control the moisture content of air below 70% and ideally around 60%. There are many types of systems available to reduce atmospheric moisture but all require power and regular maintenance and need to be sited judiciously in order to avoid localised deterioration of joinery, masonry materials and associated surface paint finishes as dehumidification forces the crystallisation of surface salts.

With the exception of accommodation, establishing adequate ventilation is more important in terms of overall building conditioning than dehumidification. However, in buildings where personnel accommodation necessitates the storage of furniture and soft furnishings such as bedding, curtains etc., dehumidification in a confined space such as a bedroom in association with good ventilation will be important for preventing damp and mould growth.

### Use of Specialist Building Systems and Finishes

Certain measures can be taken to design against condensation problems. The two aspects of the building to be considered in terms of paint are external and internal surfaces.

External surfaces - historically, many buildings have been externally rendered using cement, which although hardwearing and protective, does not allow masonry materials to breathe. This, combined with the widespread use of impervious, non-breathable paint systems has created a situation whereby the lack of external breathability prevents moisture escaping from the interior of the structures. Replacing a paint system may not be cost-effective but may sometimes need to be considered in situations where there are significant problems of excessive moisture content in the interior environment and within masonry materials. With regard to external paint systems there are three options:

**Option 1** – continue using the traditional alkyd, acrylated, epoxy, masonry (e.g. ‘Weathershield’) or polyurethane paint systems. The main disadvantage associated with these is that they do not allow masonry surfaces to breathe and do not bridge structural movement cracks.

**Option 2** – repair defective coatings and overpaint with elastomeric systems for crack bridging. These paints have a certain level of breathability but this decreases over time when additional coats of paint are applied.

**Option 3** – remove existing coating and replace with a breathable system such as Kiem system (mineral) or with ‘Option 2’ to give flexibility as well as breathability to facilitate water vapour release.

It is important to remember that where primary colours are required for day-mark identification, breathable paint systems are less flexible with regard to colour choice.

Internal surfaces – where buildings are unoccupied, particularly towers, it is preferable to remove paint so that masonry surfaces can breathe, although paint systems such as ‘Kiem’ can be applied after, which allows the passage of water vapour. Paint films can be allowed to degrade naturally and peel or flake off but this can often look unsightly and can be a health issue as most of the old coatings could contain lead. Moisture removal from masonry materials can be assisted by good ventilation and the use of specialist masonry humidity regulating systems such as natural damp courses. However, it is important to note that where relevant, listed building approval may be required before such systems can be fitted.

In some situations, condensation has to be accepted as inevitable for example around windows, but its impact can be lessened by using historic drainage channels to trap and carry any moisture away from masonry surfaces (normally found blocked with paint) or by improving insulation by dry-lining with for example, dense insulation/plaster-board materials. This again may require listed building approval.

## Some Basic DO’S and DON’TS of 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 power available to achieve these. However, there are some basic DO’S and DON’TS that should be followed in the conditioning of any building:

DO:

* 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 around the 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;
* consider the type and quality of soft furnishings left on station in the context of the condition status of the buildings.

DON’T:

* import excess moisture in wet clothing, as steam from cooking, kettles etc.;
* cover up sources of damp – identify and rectify the problem as quickly as possible;
* expect a station to remain in pristine condition unless 24/7 heating is provided.

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.

## Physical and Environmental Effects

These include sun, rain, snow, frost, salt, sand, humidity, flood, wind, organic influences as mould, insects, woodworm, mice etc. Furthermore, soil instability, earthquake, iceberg and snow- or mud slides, air pollution, bird excrements, oil or chemical pollution and vandalism.

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.

## Review of Effects

### Organic Effects

Organic effects such as mould, insects, woodworm and mice are only important for unprotected wood on the external walls (windows).

### Timber Work

Problems with internal timber work are usually related to humidity and will be considered further on. Ultraviolet radiation (U.V.) on wood causes the loss of natural oil protection, cracks, and speeds the effects of organic influences.

Classic wood protection, especially on the side with most of the Sun’s radiation is the normal maintenance as is the use of microsporous coating such as wood oil and wood stain. In the early life of the construction the wood must be protected frequently, later once a year is normal. The wood surface must be inspected after every summer. Eradication of wood decay is more expensive than regular protection.

If normal protection is still insufficient, consider wood replacement by more resistant or tropical wood species.

### Snow or Mud Slides

If snow or mud slides are still problems after consideration in the design phase, the building of a small protection wall together with an extra ditch may be a solution.

### Bird Excrement

The problem of bird excrement can be reduced by preventing the landing of the animals on the lighthouse. This can be done by installing stretched rustproof wires. Suitable attachments may be expensive and harmful to a watertight roof. The protection could be worse than the inconvenience! Care to remove bird food or nesting material can also be effective.

### Lightning

Protection against lightning is usually essential for a high exposed construction such as a lighthouse. Lightning rods and conductors should be present and maintained in good condition. After visual inspection for corrosion or interruptions in the lightning conductor measurements of electrical conductivity and earth capacity should be made.

Electronic surge protection arrestors can prevent or reduce damage to expensive electronic equipment.

### Air Pollution

Air pollution is a problem affecting the lantern glazing. The consequent light obstruction can only be reduced by regular window cleaning, and therefore some light obstruction is generally accepted. One can investigate systems as used for windshields, in vehicles or chemical products that reduce the adhesion of pollutants.

## Protection Against Vandalism

It is appropriate to consider the usual protection measures for remote buildings. Some of these systems will require costly maintenance which may be more expensive than accepting some level of vandalism.

One should consider the following before deciding on the level of protection to be used:

* frequency of visits;
* is public access allowed?
* use of special keys, reduced numbers of keys and keyholders;
* control procedure when leaving the building, locking doors, windows etc.;
* do not leave valuables on station;
* facilities such as oil tanks, emergency electric equipment, vehicles (bicycles) could be hidden inside buildings;
* remove external aids for intruders such as outside emergency ladders;
* install barriers against intruders such as fences, bars at the lower windows, extra locked doors, use of shockproof glass (lexan polycarbonate);
* reduce numbers of access routes, place trespassing warnings and fences on the access road long before reaching the lighthouse, use of private access road;
* installation of alarm systems;
* simulation of presence of a guardian by switching the internal lights on/off.
* use of anti-graffiti paint and anti-climbing paint where appropriate.

## Humidity (2)\* (4)\*

This is the most important effect on the building structure and its effects can be caused directly by: frost, snow, flooding, rainwater.

There are also the results of humidity such as mould, presence of insects, woodworm, and soil instability related to changes in ground water levels.

Humidity can also considerably increase the damage caused by the presence of salt, poor quality of mortar, insufficient layers of protective coatings and poor general quality of building materials.

The problem can be greatly increased by the fact that the lighthouse is generally not inhabited, and there is insufficient heating or ventilation.

The presence of electronic systems also adds to the importance of preventing a build-up of condensation.

The original design and coatings specifications should avoid humidity problems. Incorrect maintenance can cause new problems if protective coatings are used on the outside walls, where most visual damage occurs, then moisture can be trapped within interior coatings. Insulation layers without ventilation capacity can also cause condensation inside the wall cavities.

Correct maintenance starts with a good survey: when notes should be made of: presence of smells, splash, water folding level marks, salt stains, mould and mould stains, stains or colour changes near windows and underneath the roof. Crumbling of plaster, wallpaper, wall tiles. Rust stains of internal iron bars. Loss of mortar from joints, efflorescence, crumbling of jointing mortar. Loss of the outer protection layer of the concrete. Presence of water or moisture in the electric conduits, frequent short circuiting.

After a survey of the humidity problems it is necessary to consider the ways of preventing ingress of water. The maintenance needed is classified as follows by means of water entry. It is usually good to improve ventilation. Heating may be the only solution to moisture problems.

### Water Through the Flat roof

The watertight layers are often no longer stuck to the supporting structure but lifted by water bubbles. The damaged watertight layers must be all removed and replaced. Cheaper solutions will only increase damage already in place.

### Water Through Windows & Doors

Check and if needed replace locks, hinges and any window or door seals. Consider installation of double (glazed) windows, replacement of swing type windows by fixed windows.

### Rise of Ground Water by Capillary Action

* remove moss, clay or mud around outside walls;
* lower ground water levels by improved draining of surroundings;
* injection with specialist products closing the capillarity channels.

### Water Absorbed in Materials

* check amount of water penetration;
* repair joints, especially any external vertical ones. The latter are less compressed than the horizontal joints and therefore are more porous;
* repair waterproofing systems.

### Condensation in the Walls

* remove any wet plaster, wallpaper, or wall tiles;
* remove water logged insulation;
* ventilate the wall;
* apply watertight screeds on the inside wall, only after extensive study.

### Cellar Inundation

* lower ground water levels by improved draining of surroundings;
* fix waterproof layers on the cellar walls;
* install automatic pump.

## Location surveys: erosion, cliff stability, tide

Content required.

## Structure surveys (frequency)

Content required.

7.13 Local weather conditions monitoring

Content required.

# CONTENT

## Content

Content required.

# ACRONYMS

ASR Alkali-silica reaction

AtoN Aid(s) to Navigation

DPC Damp-proof course

FRP Fibre Reinforced Polymer

g gram

GRP Glass Reinforced Plastic (fibreglass)

IGC5 section 7

kg kilogram

kPa kiloPascal

NaCl sodium chloride

nm nanometer

RH Relative Humidity

SI International System of Units

TH Trinity House

UV Ultra Violet (light) (10 – 380 nm)

VOC Volatile Organic Carbons (paints and solvents)

# REFERENCES

1. aa

**Appendix A**

(ENG5 Note: Consider moving to an Appendix, so as not to lose information?)

These are either made in quarry stone or brickwork. Either type can be built strongly enough to withstand very high wind forces and massive green water wave attacks.

The most important difference in these two constructions is that in the case of quarried stone labyrinth joints which may not require mortar were often used.

The choice between bricks or quarried stone depended on the location of the lighthouse. On alluvial coast, where no rock is at hand, brick construction would be chosen. On a rocky coastline it was possible to take quarried stone, however not every type of stone is building material. It is now a fact that economic and environmental pressures often point to reinforced concrete as the most suitable building material, particularly where environmental conditions dictate massive strength.

A brief understanding of the essential form of the lighthouse tower itself is needed. Several of the earliest surviving towers from the classical and medieval periods were polygonal or round with vertical, or near vertical walls. This could be interpreted as being a practical design to show the light round a large are of view. However, these lights were not wave-washed and could in reality have been any shape to carry out their basic function of providing a light platform at a suitable elevation.

It should however be born in mind there was a need to make them easily recognizable from different directions and to do this from seaward favoured a symmetrical form. A round form may be preferred where there are no other buildings to relate to; also the vertical sides could incorporate a defensive function and make it easier to hoist fuel for the open fires of those early lights.

In the eighteenth century, straight tapered sides began to appear as standard as the concept was growing of building a tower streamlined against wind. As the positions of the lights became more exposed, and as the light towers became higher, the taper was adopted to increase the stability of the structure. Again, few of the lighthouses with this shape had to withstand the battering of waves.

Later came the parabolically curved taper which was adopted for many subsequent wave-washed lighthouses, and which also crept into the design of towers beyond the range of wave damage. This curve became less pronounced as the nineteenth century wore on, and stepped masonry was introduced at the base of wave-washed towers to deflect heavy seas from the tower. Straight sided towers were sometimes used in conjunction with stepped bases.

Eventually the craftsmen based and labour-intensive interlocking load bearing ashlars construction was abandoned in favour of slip-formed concrete, precast concrete or prefabricated steel, all of which favoured a pure cylindrical form for the tower.

The above brief account is inevitably simplified, and there are exceptions. Some lights took other forms altogether, notably the medieval mobile lever arm or ‘swape’ lights which were not buildings in the true sense, and the coal light platforms on vaulted cottages which had no towers.

However, for the most part our traditional lighthouse has a tower, whether wave-swept or not: and this will usually be the focus of concern in both the archaeology and the conservation of a lighthouse station, but not to the exclusion of the station as a whole.

We have already differentiated between two basic types of tower: one that must withstand being wave-swept, and one founded higher above sea level, or further back that need only withstand the normal rigours as any building in a harsh coastal environment.

The history of lighthouses engineered to withstand the full brunt of the sea begins properly in the eighteenth century. Later still the engineering principal of massive interlocking stone blocks, with dovetailing on five out of the six faces of each stone was introduced. Interlocking stone became the tried and tested solution to the construction of offshore towers throughout the great lighthouse building era of the nineteenth century.

Interlocking solved the main problems of resisting displacement by the impact of waves, and eliminated gross water penetration as it was unable to follow the labyrinthine paths which the construction incorporated. The complexity of this design called for the pre-erection of the stonework in workshops, or on any nearby land. The interlock between stones was so effective that one was confident that the lighthouse would stand without mortar bonding although pointing was still required to prevent erosion of the joints. Later the stones became so precisely cut that each stone would be shipped out to site in a packing case to protect its edges.

The dominant nineteenth-century core of our lighthouse population can be seen as a product of the Industrial Revolution both because cast iron and other prefabricated components and materials associated with this era were used, and because their architecture as a whole conveys the spirit of the time.

The towers were essentially the work of engineers: many rock towers were pre-erected on the mainland first, with few decisions being left to be made on site. Lanterns were prefabricated in factories and generally had all the hallmarks of the precision that had entered other fields of endeavour. Granite blocks were used on the tower lights because, with their self-weight and durability, they were the right components in an engineering equation. In a different context with a different brief, engineers might equally have turned to iron. Several iron lighthouses were in fact built, some for export. These could be prefabricated and then dismantled for shipment, and they did not have the volume or weight penalty of granite. Because most lighthouses were built of stone rather than iron, they are not usually perceived as products of the Industrial Revolution.

Lighthouse stands somewhat apart from the generality of buildings meriting conservation, but not completely so. We have referred to the minority of pre-nineteenth century, non-wave-washed lights that are built of lime mortar and rubble: here the conservator can usually turn to familiar lime-based techniques. Much else is familiar also: the principles of good maintenance, the exclusion of water and dampness, ensuring good ventilation, etc. But, moving on to the nineteenth century lighthouses, often now confidently sited close to waves and salt water, more exceptional circumstances may apply to any work on them:

* exceptional exposure to sea-water, and windblown, hygroscopic sea-salt;
* difficulty, or extreme difficulty, in gaining access to undertake repairs;
* difficulty in undertaking repairs because of the need to keep key stations functioning;
* the use of interlocking masonry, dowels, trenails, and other engineered reinforcement;
* pozzuolanic mortars used in the initial construction, not easily available today;
* many years of subsequent use of cement technology;
* highly engineered environments, where the interface between equipment and building is a major element to be conserved.

It should be noted that work on lighthouses by a Lighthouse Authority is normally exempt from Statutory Building Regulations. This usually applies to the domestic facilities of a lighthouse station as well as the light tower. Presumably this exemption ceases when a light is discontinued and sold.