IALA GUIDELINE

1007

LIGHTHOUSE MAINTENANCE

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DOCUMENT REVISION

Revisions to this IALA Document are to be noted in the table prior to the issue of a revised document.

Date	Page / Section Revised	Requirement for Revision
December 2005	Entire document	Reformatted to reflect IALA Hierarchy documentation

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1 INTRODUCTION

The IALA Guidelines on Lighthouse Maintenance provides guidance and advice on lighthouse maintenance, refurbishment, repair, protection from the environment, and the addition of helicopter platforms. It was taken as a task by the IALA Engineering Committee as a result of interest expressed in the subject during the 1990 and 1994 IALA Conferences.

The Guideline endeavours to summarise the experiences contributed by several lighthouse authorities (see the Bibliography) in selected areas of interest, in a way which will permit other services to benefit from the experience while avoiding the pitfalls.

1.1 PRELIMINARY NOTE

The structures considered in this handbook are lighthouses in the strict sense of the word, and their surroundings. Much of the information provided is in the context of civil engineering.

2 STRUCTURAL COMPOSITION

2.1 PRELIMINARY NOTE

Regular preventative maintenance will ensure a long life for most lighthouse structures. With the exception of metal constructions, very little maintenance is required on a routine basis. Major renovation works on the other hand will be required if the original structure is not built strongly enough to cope with the local conditions. It is imperative therefore to make a comprehensive survey to take in all environmental factors such as wind and sea conditions, ambient temperature, as well as foundation, soil and boundary factors to reliably establish the structural requirements. From this a suitable renovation concept will emerge.

2.2 MASONRY CONSTRUCTION [6]

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 one was able 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.

To properly preserve and maintain our lighthouses we need to study 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.

We also need to understand the reasons for changes in concept which have emerged over the years. While the original design is a major consideration, we need to understand the historical importance of the alterations our lighthouses have undergone over the years as they continued to be modified and adapted to house new equipment. The primary function of our lighthouses has been the housing of the light itself, and any other emerging function was always secondary.

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 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. Reference has been made 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 as one moves 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.

2.3 MASONRY TOWERS

Many towers otherwise built of rubble 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 thus 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: conservation may not be needed for years to come.

However, three problems can be anticipated: spalling, cracking and staining from rust and exfoliation if iron dowels or cramps were used; fire damage can be as extensive with granite as with other building stones; and movement caused by weakening or instability of the foundation may be drastic and for which there may be no remedy. It is spalling that will most likely be encountered.

One potential example of this is the detail common in many lighthouses where iron handrail posts were placed in pockets cut in the granite base, which were then sealed with molten lead: damage from sea-water rusting the iron may cause some cracking. The volume of iron in relation to the size of the surrounding stones may not be sufficient to rupture the stone. Serious problems may also be caused by the corrosion of iron beams set into masonry structures.

Many of the lights which incorporate such a feature appear to rely less on iron cramps and more on interlocking the masonry. However, it is possible that several early lights do contain numerous iron cramps. Whilst these might rust in time, one would have expected the problem to have manifested itself by now even where the cramps are set in lead. Repair of damage caused by rust expansion can be very difficult and expensive, again the depth at which the iron lies and its volume in relation to the bulk of the granite or other dense stone may limit the damage that can occur.

The introduction of electric power generation at remote rock towers resulted in many cases in a surplus capacity. This surplus capacity has been utilized for electric heating to protect the sensitive electronics demanded by automation and has had the additional benefit of helping to preserve the structure of the building.

Accommodation at offshore locations has to be maintained, and in colder climates be capable of being heated so as to allow maintenance staff to remain on site for extended periods if necessary. Arguably, the heating is now more convenient than in the pre-electrification days when there were keepers who would have to rely on individual stoves. At the many rock stations with towers separate from accommodation, the tower area was sometimes far removed from the nearest stove, although the light itself in the lantern would generate some heat and thus cause ventilation. In the vertically arranged rock towers, heat from the keeper's stoves would tend to percolate to the upper parts of the structures.

There are examples of lighthouses being on mains electricity where any additional consumption has a cost, or where there is no surplus from the generation plant without increasing the fuel consumption. In such cases there is a tendency to ignore any heating requirement and this in turn can lead to deterioration in the structure of the lighthouse.

Lighthouse stations are often good locations for solar and wind-generated power and increasingly Lighthouse Authorities are adopting this new technology. It is to be hoped that these alternative power sources which are at present of quite low capacity, will be developed further. If we can reach the point where there is again a surplus of power, heating or dehumidification can be provided to stave off deterioration of the structure.

2.4 EXTERNAL FINISHES

Initially, the earliest lighthouses were either unpainted or lime washed. The use of lime wash for boundary walls and outbuildings continued until relatively recently.

With regard to offshore tower lights which are obviously hard to paint, these remained their natural stone colour for many years. Obviously the structure was not easily visible in daytime and gradually the practice of painting them took hold. There were a number of colour schemes which gained popularity, perhaps the most common of which was the red and white horizontal bands. As granite provides a relatively receptive and stable base for alkyd paints, and given the difficulties of painting on such remote sites with short weather windows, oil-based paints were used on rock towers from the beginning.

2.5 STONE DRESSING

The detailing of stonework is generally simple and robust. However, where attractive dressed stone has been used, this should be protected. Grit blasting of textured finishes, especially where the stone is not robust enough to take such treatment should be avoided. Alternative remedies are:

- reconsider whether it is really necessary to remove all paint in the first place;
- use other techniques on moulded or finely tooled stonework such as water washing or chemical poultices;
- employ firms skilled in conservation work for such tasks, not direct labour or contract labour selected solely on price;
- train some in-house maintenance staff in conservation techniques.

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 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.

3 CONCRETE CONSTRUCTIONS

In civil engineering circles until relatively recently it was claimed that reinforced concrete structures were robust enough to have a long life. Experience has proved this to be a bold and erroneous statement. However, the reasons for concrete failure were mainly a lack of proper procedures during construction and an underestimation of the demands the environment would place on the structure.

A case study may give a good example:

Shortly after the Second World War a reinforced concrete lighthouse, with a focal height of 65 m above the mean sea level, was erected. The lower part was octahedral on the outside whilst the upper part was cylindrical in outline. The inside was a hollow cylinder over the total height.

Some 40 years after construction it was noticed that there was cracking at several levels of the lowest outward part and evidence of rust staining weeping from the cracks. The cracks were most pronounced on the octahedral surfaces towards and opposite the prevailing wind directions which evidenced dynamic deformation of the tower.

A total survey was set up:

3.1 DEFORMATION MEASUREMENTS

With the lighthouse being situated in an urbanized area, it was relatively easy to refer to exactly surveyed landmarks.

Several surveys were carried out, both in calm and stormy conditions. The survey indicated that there were of course movements of the upper part of the construction resulting from wind loading, but the amplitude of these oscillations increased over time under the same wind conditions. Furthermore, after windy conditions, the lighthouse tower did not return to the vertical again. This permanent deformation appeared to be mainly to the leeward of the prevailing wind direction.

3.2 INVESTIGATION ON THE CONCRETE ITSELF

Two types of testing method were used:

- a non-destructive test that measures the compressive strength of the concrete involved;
- a destructive test to monitor concrete used.

  This consists in drilling several cylindrical cores that are afterwards analysed in a laboratory.

Both tests showed that density 'soundness', cement content and durability of the concrete were excellent. What was the problem then?

3.3 ARCHIVES RESEARCH

This research confirmed the cement chosen at the time was capable of withstanding the marine environment concerned. However, the construction technique of a moving formwork was very new. Where a uniform concrete cover of 6 cm was called for in the design, it was found at one side there was only 2.5 cm whilst on the opposite side there was 9.5 cm. This meant the protective concrete layer scarcely existed on one side due to eccentric casting of the original structure.

The concrete covering layer is very important as it protects against aggressive chlorides reaching the steel reinforcing bars. These bars expand as they corrode which in turn cracks the concrete cover. This cracking leads to more water ingress, further corrosion and deterioration of the structure continues at an ever accelerating pace.

3.4 RECALCULATION OF THE STRUCTURE

Since the construction of the lighthouse, standards on wind loadings have changed. Taking into account the new standards, recomputing of the tower's overall stability showed a lack of transverse reinforcement bars.

3.5 RENOVATION WORKS

To make a complete and lasting restoration of the lighthouse structure it would be necessary to remove the concrete cover layer from the whole of the octahedral section of the structure.

This has to be carried out during the calm weather season and doing only small areas at a time to preserve the towers stability.

After removing the outer concrete layer, additional transverse rebars were added.

Afterwards the area involved was restored with shotcrete, to become a uniform concrete layer of approximately 8 cm.

3.6 IMPORTANT RECOMMENDATIONS FOR THE USE OF MORTAR AND CONCRETE

These recommendations apply to both new building and for restoration works.

- the minimum concrete cover on rebars is to be at least 5 cm;
- the minimum content of cement is to be at least 350 kg per m^3 of fresh concrete;
- it is important to choose a good quality cement. This means preferably very fine-grained cements with a good chemical composition.

The cement should not contain more than 46.5% of CaO, which means that a 'plain' Portland cement should not be used. A high resistance Portland cement though can cope, as soon as its ratio Al2O3/Fe2O3 is smaller than 0.64.

4 REINFORCED POLYESTER CONSTRUCTIONS [13]

As defined these are prefabricated light weight constructions that are generally not suited to be placed on a site that is very exposed to massive green water wave attacks. 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). The only economically and mechanically suitable reinforcement for polyester resins used for lighthouse constructions is glass fibre.

Except for repainting, the constructions mentioned demand no further maintenance.

References [8] and [9] mention respectively the weatherproof characteristics of fibre reinforced plastics (FRP) on one hand and the problems relating to static electricity on the other.

According to the first reference FRP has been used for lighthouse construction in Japan since 1978, and tested ever since. The parameters that are monitored are compression, bending and tensile strength and colour changes.

The FRP's used for lighthouses are generally of the glass fibre reinforced type. The reinforcing materials are uniformly distributed in the resin which cures at room temperatures.

The Japanese Authority has provided information on test pieces taken from the lighthouse structure at periods after one year's exposure.

The compressive strength depends on the direction of the load applied relative to the axis of reinforcement.

No substantial change of the retention rate of compression strength was observed in the normal direction while that in the parallel direction decreased remarkably beginning one year after exposure, and its rate of compressive strength five years after exposure fell to approximately 70% and 65% for the test pieces with and without gelcoat, respectively.

The compressive strength in the parallel direction ten years after exposure improved to approximately 88% and 76% for the test pieces with and without gelcoat, respectively.

4.1 STRENGTH VARIATION IN BENDING

The test pieces with gelcoat maintained the same strength even ten years after exposure while the retention of bending strength of those without gelcoat gradually decreased to approx. 80% of the initial value.

4.2 STRENGTH VARIATION IN TENSILE TEST

The tensile strength of the test pieces both with and without gelcoat varied little during the exposure time, indicating 95-100% of their original strength.

4.3 COLOUR VARIATION

The fading of colour, lightness and chromaticity of each colour is shown below.

4.3.1 Red colour

- the colour tends to approach the red violet area as time elapses;
- the lightness increases slightly as time elapses;
- the chromaticity tends to decrease until the fifth year of exposure, but increases a little in the tenth year of exposure.

4.3.2 White colour

- the colour changes as time elapses. However, it is not a visible change due to saturation close to zero;
- there is no remarkable change of lightness as time elapses;
- there is no remarkable change of chromaticity as time elapses.

4.3.3 Green colour

- the colour in the first year of exposure is remarkably yellowish, and then returns to the original colour. The hue in the fifth year is less yellowish compared to that of the original colour. It tends to be a bit more yellowish in the tenth year of exposure;
- the lightness continues to be constant after the third year of exposure;
- the chromaticity decreases a little and tends to approach white colour as time elapses.

Reference [9] examines the effect of static electricity on FRP towers. It was found that lighting equipment installed in the aids using FRP light towers suffer a number of failures due to the static electricity generated in the FRP. It was thus necessary to take countermeasures to solve this problem.

It is thought that the static electricity, with which the FRP light towers become charged, is generated by natural phenomena such as lightning and snow. Consequently, a lighthouse installed on the Sea of Japan was selected for this survey as lightning and snow are frequently observed on the Sea of Japan, especially in winter. It is impossible to prevent the generation of static electricity in FRP light towers, thus, we come to the conclusion that the solution lay in having the static electricity grounded at a faster rate than it could charge.

Based on this conclusion, all the metal fixtures inside FRP towers have been earthed. This has completely circumvented the problems caused by static electricity charging.

Five German lighthouses were built from GRP between 1972-1981. They are between 10 and 47m high.

4.3.4 Chromaticity

- severe bleaching of red and black gelcoat: required painting with special paint after special surface treatment/preparation.

4.3.5 Structural damage (Fissures etc.)

- none so far.

4.3.6 Stiffness

- the slender 47m tower oscillated severely, induced by wind.

  This is now dampened by a mechanical compensating device.

4.3.7 Longevity

- no information could be gathered about long term behaviour, probable deterioration or changing characteristics/material properties.

  Therefore, production of GRP lighthouses was abandoned in 1981.

5 METAL CONSTRUCTION

Steel Lattice Structures In Use In South Africa [16]

5.1 BACKGROUND

Only 5 steel lattice lighthouse towers remain in use in South Africa. In the past, a considerable number of these towers were in use, both as lighthouse towers and radio masts.

5.1.1 Problems Areas

Over the years, due to high maintenance costs and general deterioration, most of them have either been done away with or been replaced by aluminium towers. The majority of the towers were erected in the 1920s and 1930s and were galvanized. When painted, they were good for many years, but unfortunately, when the paint deteriorated, chipping hammers were used to remove the loose paint and this damaged the galvanizing. With time, rust had set in and maintenance became more and more difficult to perform.

5.1.2 Coating

Due to the remote positions of these towers it is not always feasible to sandblast the structures before painting. Because of this a paint schedule was drawn up and found to work very well under the ost harsh conditions, giving at least 5 years between painting visits.

5.1.3 Heavy Formation of Rust on Steel Constructions

All impurities, mill scale, oxidation, grease etc. must be removed by abrasive blasting.

NOTE: It is vital determine the nature of the coating to be removed so that adequate protection can be provided to workers to meet local health and safety requirements.

The surface must be cleaned to at least SA 2,5, with a necessary degree of roughness of Ra 6.3 (=N9 B Rugatest N°3).

The degree of cleanness and the degree of roughness specified by the paint manufacturer must be followed to get the required cathodic protection of a zinc rich painting systems (cold). There is an intimate contact required between the zinc coating and the steel substrate. This treatment gives the permanent advantage of reloading and automatic repairing of the cathodic protection system.

To achieve the maximum life from a paint system the manufacturers' instructions must be followed in detail.

5.2 REPAIR AND MAINTENANCE OF ZINC PAINT COATING DAMAGED CONSTRUCTION

If there is no other layer of paint on the zinc coating, the damaged places should be cleaned before repairing with zinc coatings.

If there is a layer of paint on top of the zinc coating, first clean the damaged places before putting on a new layer of zinc coating, if necessary blast or brush with a steel brush.

5.2.1 Weathered constructions

If there is no protective layer of paint on the zinc layer, the old zinc layer must be completely removed, and will need to be cathodically 'reloaded'. Total cleaning of the surface is strictly necessary and it is vital to perform the recoating before there is any formation of rust.

5.2.2 Repair and Maintenance of Thermal Zinc Metal

Coated and Metallised Constructions

5.2.2.1 Old Constructions

The surface should be cleaned before the application of the new zinc paint system. It is normal to repair zinc coated structures by the application of new zinc paint. The zinc painting reloads the old active cathodic layer and repairs the weathered layer.

5.2.2.2 New Constructions

Any new areas of zinc metal that are damaged must be lightly abraded to ensure good adhesion of subsequent paint coatings.

Only after complete recoating of the zinc coating will the layer of zinc take over the cathodic action. The zinc metal coated steel becomes anodic.

6 STAINLESS STEEL CONSTRUCTIONS

Behaviour and Prevention of Different Forms of Corrosion

6.1 ATMOSPHERIC CORROSION

This form of general corrosion is caused by chemical degradation due to reactions with the marine atmosphere and is mostly marked by surface discolouration. The corrosion is slow and gradual, resulting in a visual degradation of the metal. There is no danger of unexpected failure. This corrosion is not directly dangerous.

6.2 GALVANIC CORROSION

This corrosion is the more serious resulting from the potential difference that may exist between the stainless steel and other materials (see schedules of electro-chemical corrosion).

Concrete and stainless steel seem to be good in combination (e.g. stainless steel cramp irons).

In all cases where contact of dissimilar materials can not to be avoided, the local contact is to be isolated with for example acid free grease, isolation barriers, insulation tape, etc.

6.3 PITTING

Locally there is a development of porosity, that deepens quickly into the material, whereby the structural integrity can be severely damaged. This corrosion appears mostly in a marine atmosphere and can only be avoided by the choice of correct grade of stainless steel (usually high molybdenum content) for use in the marine environment.

6.4 CREVICE CORROSION

In the presence of a wet environment corrosion appears in crevices and openings of the construction, where an insufficient amount of air (oxygen) can circulate to repair the passivity of the surface of the stainless steel. This form of corrosion necessitates a change of design to remove the crevices.

7 CAST IRON CONSTRUCTION [14]

There are ten lighthouses built in Germany about 90 years ago from grey cast iron elements bolted together. This was once a common lighthouse construction method when lighthouses were shipped abroad from Europe in component from.

In the German service the outside is painted about every 15 years, not for protection, but as a daymark. Otherwise they do not demand any maintenance. Several cast iron lighthouses have never been painted inside and still do not rust. The cast iron is not prone to corrosion, thanks to its high carbon content, see analysis below. According to present day classification in the German DIN 1691 standard, the material is called flake graphite cast iron, and the material code number is 0.6015.

Like other metal structures, cast iron lighthouses tend to condense humidity inside. This can be corrected by natural ventilation or, in the case of unattended lighthouses, by dehumidifiers if suitable power is available.

Fabrication cost was kept low by using the same moulds to cast elements for a number of lighthouse varying only in height.

Table 1 Cast Iron Chemical Analysis of Six Samples (Two Lighthouses), Average

	%
C	3.32
P	1.12
S	0.12
N	0.01
Mn	0.38
Al	0.001
Si	2.06
Cr	0.025

7.1 MAINTENANCE OF CAST IRON STRUCTURES IN USE IN SOUTH AFRICA [18]

7.1.1 Background

The first cast iron lighthouse structure in South Africa was erected in 1864. Thereafter another 8 were established, the last one being erected in 1919. The towers range in height from 8 metres to 33 metres. A few of these structures were designed by Mr Alexander Gordon, a civil engineer to the Board of Trade, London. Mr Gordon also supplied towers for various lighthouse installations in the British Colonies and dependencies.

7.1.2 Coating and Maintenance

In the past and at the time of erection, cast iron towers on the coast of South Africa were primed with a coat of red lead and then, when the tower was completed, the final cover coat of enamel (oil based) paint was applied. When painting maintenance was to be carried out to a cast iron structure, the good paint was cleaned of all dirt and salt deposits and where the paint had failed and rust was showing through, a flame descaling apparatus was used to remove the rust and to dry out the metal. Immediately, while the metal was still warm, a coat of red lead was applied and when dry, the colour finishing coat was applied. If the above maintenance was carried out regularly, every two years (the normal life time of the paint in harsh conditions), then no problems were experienced.

If the maintenance was not carried out for some reason or other rust would take hold in such a way as to be almost unnoticeable. It has been found on occasion that if the metal is chipped with a chipping hammer to clean it, the metal keeps on coming away until a hole is formed right through whatever it is you are cleaning. One of the towers on the coast had, in fact, to be encased in concrete because of just such a problem. This tower was situated in Durban which is in the sub-tropics where the humidity can be very high. In our modern times, almost any suitable paint system produced by a reputable company can be used on these towers as long as the maker’s directions are followed closely.

By experience though, it has been found that under no circumstances should the tower be sandblasted. Any descaling or rust removal should be done by hand or by means of a needle scaling gun. Once a small portion has been cleaned (not more than one square metre), it should be heated by means of a gas flame and while still slightly hot, the paint should be applied immediately as recommended by the suppliers.

Surface preparation of the cast iron is of the utmost importance. If this is done thoroughly and no damp, salt laden air allowed to come into contact with the iron, results will be good and painting may only be needed every 5 years or so.

8 RECENT FULLY ENCLOSED ALUMINIUM LIGHTHOUSE TOWERS BUILT IN THE PHILIPPINES [15]

For corrosion resistance and lighter weight, the new towers should be designed in modules of hexagonal and octagonal cross sections using Aluminium Alloy (5083) of International Designation System for Wrought Aluminium and Wrought Aluminium Alloys. Design for wind velocity and wind pressure should be in accordance with National Structural Codes. The tower of major and medium lighthouses/beacons should be designed to be equipped with internal stairs while small light beacons should have an external ladder and platform on top, in order to allow easy maintenance. The solar panel for medium and small lighthouses/beacons should be installed on a platform and its storage battery to be kept within the tower. The material for fixing bolts and nuts should be Stainless Steel SIS316 and nyloc type nuts should be used for main members.

The foundation shall be designed to have sufficient strength to withstand against external and gravity loads. Bidders shall be required to conduct site surveys and geotechnical investigations as part of their design requirements. The design shall take into account security and safety measures to prevent access by unauthorized persons and pilferage of equipment and structures.

The finish shall be aluminium etching primer with epoxy 3 coat paint system. All fixing bolts, nuts and washers are stainless steel coated with anticorrosive plastic shielding, to minimize long term electrolytic action between the bolts and the aluminium castings and sheet fabrication of the lighthouse tower sections.

Sealing shall be done in accordance with the following procedure:

8.1 PREPARATION ADJUSTMENT OF JOINTS

It is absolutely essential that surfaces of joints are sufficiently dried. Chips, cracks and imperfect welded joints should be completely corrected. Also, moisture, oils, etc. which prevent adhesion must be completely removed.

8.2 CLEANING WORKING SURFACES

Since a high performance is required for silicone sealant as compared to other sealing materials, sufficient care should be taken for cleaning of joints, removing moisture, laitance and oils. Where working surfaces are wet or where oils, laitance or dirt is present, there is a consequent decrease in adhesiveness of interface separation. Working surfaces are to be cleaned of dust and dirt by air-spraying or wiping with a cloth. Also, when surfaces have smeared badly, wipe with a cloth using a suitable solvent.

8.3 APPLICATION OF MASKING TAPE

To prevent smearing in the area and to ensure a clean finish of sealant filled portions, apply masking tape to both sides of joints, full pressure shall be applied so as to ensure adhesion of tapes. Care should be taken to avoid tape intrusion into joints.

8.4 PRIMER APPLICATION (ALUMINIUM PRIMER)

The liquid primer is applied uniformly with a brush or spray and allowed to dry.

8.5 FILLING OPERATION

Cut nozzle to desired size at 45°angle and puncture inner seal base of nozzle and then insert cartridge into caulking gun. Apply sealant with gun as directed by supplier.

8.6 TOOLING

After filling joints with sealant, tooling is to be carried out. This operation is to make sealant hermetically adhere to the aluminium structure for complete adhesion and to avoid cavities.

8.7 REMOVAL OF MASKING TAPE

After the completion of tooling, remove masking tapes quickly before the silicone dries. Remove tapes by winding using a bar shaped object with a large diameter.

8.8 CURING

After the completion of the operation, joint surfaces are to be cured with sufficient care until completely hard. Sealant begins to cure upon contact with air and moisture. The curing progresses inwards from the surface of the rubber. Curing time therefore depends on the rubber thickness, cure temperature, and relative humidity. When left at 25℃, 50%RH, the surface skins in 20 to 30 minutes and cures into a resilient rubber after 15 to 16 hours. Maximum adhesive strength is reached in 3 days. In case of electrical properties, it takes 7 days.

8.9 ALUMINIUM ALLOY A5083 – MECHANICAL PROPERTIES

Table 2 Aluminium Alloy A5083 – Mechanical Properties

Symbol		A5083P
Temper grade		0
Tensile test	Thickness mm	Over 0.8, up to & including 40
	Tensile test MPa	275 minimum, 353 maximum
	Proof stress MPa %	127 minimum, 196 maximum
	Elongation %	16 minimum
Bend test	Thickness mm	0.5 & over, up to & including 12
	Inside radius	Thickness x 2

Table 3 Aluminium Alloy A5083 – Chemical composition

Alloy No.	A5083P
Cladding & base material chemical composition	0
Si	0.40 maximum
Fe	0.40 maximum
Cu	0.10 maximum
Mn	0.40 to 1.0
Mg	0.40 to 1.0
Cr	0.05 0.25
Zn	0.25 maximum
Zr, Zr+Ti, Ga, V, Ti	0.15 maximum
Others each	0.05 maximum
Others total	0.15 maximum
Al	Remainder

8.9.1 Disadvantages of Plated Towers

- high cost of manufacture as extruded sections and special bolts are needed;
- full 360°insulation membrane must be provided to isolate the aluminium tower from the concrete base;
- final painting must be delayed until joint sealant has cured.

8.9.2 Advantages of Plated Towers

- low weight of individual components allows easy transport and assembly;
- solid extruded aluminium tower provides large painted surface giving good daylight visibility and an excellent radar response;
- smooth exterior profile may allow safe operation in winds up to 260 Km/hour.

9 ALUMINIUM LATTICE STUCTURES IN USE IN SOUTH AFRICA [17]

9.1 BACKGROUND

From 1963 to 1980 almost all the new lighthouses built in south Africa consisted of a 'self-supporting' aluminium lattice structure supporting a platform with a standard 250 mm Stone Chance optic and lantern house. The weight of the lantern house and optic is approximately 1 ton. In all, 13 such lighthouses were constructed of which 9 were built to a four legged design and 4 were built with 3 legs. The towers range in height from 10 to 23 metres.

Apart from the lighthouses, a number of minor lights, harbour leading lights and radio masts have also been established using this type of structure. The reasons for the change to aluminium from the more traditional building material were numerous, but the most important at the time were:

- that most new lighthouses were to be built in remote locations where the light weight and easily handleable sections of an aluminium structure would be a definite advantage;
- the lattice structure is relatively inexpensive;

- ease and speed of erection.

9.2 CONSTRUCTION

All the structures are manufactured from marine grade aluminium of angle and channel cross section, bolted together and left unpainted. Nine of the towers use aluminium nuts and bolts to fasten the sections together. These nuts and bolts are tightened up to a pre-determined torque. The rest of the towers are fastened with stainless steel nuts and bolts of 316 grades.

9.2.1 Disadvantages

It has been found that the advantages of light weight, ease of erection and economy do not outweigh the disadvantages of poor visibility as a daymark from the sea, lack of room for equipment in the lantern house, constant vibration of the tower in any wind (this is most likely due to poor design) and metal fatigue in critical areas of the construction (one tower was lost in a wind storm when the feet fractured and the tower was blown over). These towers are now being systematically replaced with concrete towers of similar height.

9.2.2 Problem Areas

Some problems have been encountered over the years with the aluminium bolts coming loose due to incorrect torque having been applied during the construction of the towers. Once a bolt comes loose the vibration of structure soon enlarges the hole and when the bolt is replaced the hole has to be reamed out for a bolt of larger diameter to be fitted.

Generally, apart from loose bolts and metal fatigue, the only other problems encountered with these towers are the corrosion of the underside of the balcony and the lantern house floor. The cause of this corrosion has been traced to dissimilar metals having been used where cables pass through the floor and to humidity and the growth of plant life (moss and lichen) under the balcony. One other problem is the corrosion of the underside of the tower feet where they come into contact with the concrete foundation. The rectification of these problems was accomplished by simply keeping the underside of the balcony clean, changing the effected part of the floor to an insulating material and by changing the tower feet to stainless steel.

9.3 MAINTENANCE

Due to these structures never having been painted, little maintenance is required. Regular inspections are recommended to establish if there are any loose bolts, or signs of corrosion especially on the feet of the towers or due to dissimilar metals.

10 ACCESSIBILITY AND MEANS OF TRANSPORTATION

10.1 COASTAL LIGHTHOUSES ACCESSIBLE BY LAND TRANSPORT

In the case of such lighthouses, one can accept that the stock of construction or repair materials on the site can be reduced to the strict minimum, particularly taking into consideration that certain products are liable to deterioration (paints, mortars, sealants, …); manufacturers' 'shelf life' information should be strictly adhered to.

Furthermore, the chance of accidental damage to the lighthouse is minor, due to their rather protected siting, and if sudden gale or lightning damage occurs it well be very quickly noticed or monitored. This certainly is the case for mainland lighthouses. If furthermore they are staffed or at least minimally heated (to prevent condensation) one should only consider stocking minor repair products.

Heavier construction materials like sand, mortar, gravel, re-bars, quarry stone etc. could then be carried by lorry to the lighthouse as needed. In the case of major damage to a masonry construction of hard rock quarry stone, it would be very difficult to have each type of stone in stock. The stone should then be cut to size according to a working drawing in a wold consider a greater level of preventive maintenance. Major works are to be carried out in the calm of a workshop, to be transported later to the lighthouse. For the case of coastal lighthouses at cliff bases the accessibility is of course more difficult. Works during windy and cold seasons should be limited to minor or emergency repairs.

Lighthouses on flat coasts are mostly placed in well protected areas when they are accessible by land transport, even very near to urban areas. In the latter case one could accept to have no material stock at all on the site.

10.2 COASTAL LIGHTHOUSES WHICH ARE EITHER INACCESSIBLE BY LAND TRANSPORT OR VERY REMOTE

The inaccessibility may be due to several reasons: no access road possible, seasonal influences (snow, flooding …), periodical tidal influences, a tiny isolated island or platform, …

In such a case a well pre-planned maintenance scheme must be followed. Accidental damage can only be noticed by passing vessels or remote monitoring. If such problems occur in the inaccessible season for land transport, one should then reach the site by air transport, taking into account that there is a weight limit to this means of transport. Therefore, heavy materials needed for regular maintenance may have to be stored on the site.

10.2.1 Program Civil Elements Description

(Example) Identification of Buildings and Structures

In order to provide a standard uniform means of identification and reference, and for the future possibility of mechanized data processing, a code of digits is to be established.

10.2.2 Preventative Maintenance Procedures [12]

These procedures are identified by routine codes. This code refers to the procedures to be followed when carrying out a site inspection.

The work operations are not completely detailed but are intended, generally to serve as a guide to the personnel performing the operation.

It is intended that the routine work procedures will be performed by personnel qualified to recognize and evaluate the physical condition of the structure.

The abbreviations used under the heading frequency are as follows:

SA	Semi-annual
A	Annual
2Y	Every Two Years
3Y	Every Three Years

A copy of these procedures should be reduced and made into a book form and supplied to all Field Personnel for their personal reference guide.

10.2.3 Site Inventory Form

This form is an inventory of all structures and property for each specific site. It also has a general description of these structures, which is to be retained on the site file in the maintenance supervisor's office.

10.2.4 Site Record Form

This form contains site specific information for each individual site such as: type of structures; routines to be followed for site inspections or maintenance; and the frequency of these visits. The comment column is to be used for any special considerations or conditions at that particular site.

This form is to be held in the office file:

- Semi-Annual Site Inspection;
- Annual Site Maintenance;

- 2 Year Site Maintenance;
- 3 Year Site Maintenance.

These forms are check lists for all site inspection or maintenance.

They are to be supplied to all field inspectors for each site visit. When each structure has been inspected, as per the routine procedures, the inspector is to check the status column.

The comments column is to be used to identify any work required, emergency repairs carried out, etc. Should additional space be required the forms for corrective maintenance or emergency repairs are to be used.

These forms should also include the date of inspection and signature of the inspector.

On a semi-annual inspection the inspector will take this form only to the site.

On an annual site maintenance visit the inspector will carry out a semi-annual inspection and annual site maintenance.

On a two-year maintenance visit the inspector will carry out a semi-annual site inspection and annual site maintenance and so on.

10.2.5 Corrective Maintenance Required

This form is to be used on a site visit to identify any work required on a future visit to the site. It should also include a description of the materials required to carry out that work.

These forms should be supplied to the field personnel in bulk.

10.2.6 Corrective Maintenance Completed

This form is to be used on a site visit where maintenance work has been carried out. It should identify structures where work has been carried out, what work was carried out and time required to carry out work. All structures, work and time should be listed for that particular site.

This form is to be completed by the maintenance foreman at the site and returned to the maintenance supervisor's office to be placed on the site file for further reference.

These forms should also be supplied to the field personnel in bulk.

10.2.7 Form Distribution

All inspection and maintenance forms are to be supplied to the inspector and maintenance staff in triplicate. Upon completion these forms are to be distributed as follows:

1 Maintenance supervisor.

2 Inspector.

3 Site.

Note: Although the structure and site clean-up has been included as a Civil Maintenance Procedure it still does not alleviate the work team of the responsibility of clean-up after carrying out work at any site.

10.2.8 Inspection/Maintenance Schedule

This form is to be used by the maintenance department as a guide for scheduling inspection tours of all sites. It should list all sites in the maintenance program and dates of inspections (to several years in advance) and a check that inspections have been completed.

This could be a rigid board mounted on the wall of the maintenance supervisors' office.

[11] can be consulted for examples of sheets to be used for: 3-year site maintenance, civil inspection/maintenance schedule, corrective maintenance required and corrective maintenance completed.

[12] gives very extensive civil maintenance preventative procedures.

10.3 HELICOPTER PLATFORMS [1] [7] [19]

10.3.1 INTRODUCTION

Four types of helicopter platforms are in use:

- the mass concrete or asphalt pad used when sufficient ground space is available, for providing a level landing area;
- a fabricated stainless steel structure built on ground or rocks adjacent to lighthouse base;
- a fabricated steel/aluminium structure built over the lighthouse lantern;
- a fabricated reinforced concrete structure built over the lighthouse lantern.

The geometry, eventual orientation and implantation are described in the ICAO (International Civil Aviation Organisation)-guidelines. The first type of helicopter pad needs no further explanation in the framework of this chapter.

The latter two are mostly used for lighthouses situated on isolated rocks or platforms. A distinction must be made between helicopter pads used for landing people or supplies by winching down or for landing the aircraft itself. This makes quite a difference in the safe working load of the platform, and the size and the geometry of the helipad.

In fact, whatever structure is chosen, one should avoid drastically altering the silhouette of the lighthouse. In any case this alteration must be mentioned in the following edition of Pilot Books in the area and also in the Notices to Mariners.

Obviously neither the lantern itself, fog signals nor radio navigational aids can be obscured or disturbed by the new construction.

The new structure or prefabricated parts of the structure will probably have to be transported themselves by helicopter. This means that there is a weight limit to every part (say for instance 3.5 tons for a Sea King type of helicopter).

The following provides a good example of a prefabricated metal construction as it has been erected on the Needles Lighthouse – Isle of Wight (United Kingdom). [1].

10.3.2 GENERAL DESIGN CRITERIA [1]

A steel supporting framework would be founded on the granite lighthouse gallery, of such a form to provide the minimum possible obstruction to the navigation light, rising to clear the lantern roof. At this level a framework of horizontal steel joists would carry an aluminium landing deck.

Although the standard helicopter in service use is a Bolkow 105D with a weight of 2.300 kg, the platform was designed to accept a maximum weight of 3.600 kg, to cater for use of an alternative larger helicopter should operational reasons dictate, or in an emergency.

To maximize available space, and to conform to the circular plan of the lighthouse, the steel support structure was designed on a sixteen sided figure in plan. Additionally, no single component of the structure was to exceed 350 kg in weight, as it was intended to utilize the service helicopter to deliver components to the lighthouse, and this figure was the maximum permissible underslung load in this instance.

The diameter of the landing deck was to be 8 metres, using perforated aluminium decking panels to reduce wind resistance.

Decking panels outside the periphery of the main support structure were to be secured by aluminium shear pins, which would shear under excessive wind/sea forces permitting the panel to detach rather than causing damage to the structure.

The periphery of the landing area would be surrounded with safety netting.

To minimize obscuration of the light source, previous calculation had shown that the support structure passing through the focal plane should be inclined.

In this way the obscuration of the light source due to the superimposed structure was kept down to about 20%, which was considered acceptable.

To provide access from the deck to the lighthouse, three access hatches and ladders were to be provided. It is impossible to predict exactly where a helicopter will land on the deck as this is dependent on wind direction. Experience has shown that with three hatches located at 90 degrees to each other above the lighthouse gallery, one is always unobstructed by the helicopter.

A fourth hatch was to be provided for the future installation of an oil and water delivery facility, used in conjunction with pillow tanks delivered by helicopter.

10.3.3 Outline Programme for Work

1 Office Work

Preparation of design, drawings and specification. Invitation and acceptance of tenders from manufacturers.

2 Preparatory Site Works

Lantern roof modification, gallery alterations, preparation of foundation, erection of temporary staging.

3 Manufacture

Fabrication, trial erection and painting under factory conditions.

4 Delivery

Transfer from works to holding store, onward delivery from store via operational site to lighthouse, dependant on site work progress.

5 Erection

On site erection.

10.3.4 Temporary Access Platform

As scaffolding is required to undertake the alterations to the lantern roof, this is designed so that it can be used on completion of the temporary works to provide a level timber decked platform above the lantern.

This provides a convenient delivery point for the helideck components taken to site as helicopter underslung loads.

To provide the minimal obstruction to the available working area on the lighthouse gallery, this scaffold structure is built tight against the murette.

10.3.5 Description of Structure

For design and construction purposes, the steel support structure was divided into five sections vertically, and sixteen sections horizontally. This arrangement permitted conformity of the structure to the circular plan shape of the lighthouse gallery, and restriction of the maximum weight of the heaviest member to less than the 350 kg restriction passed by the helicopter for under slinging.

The lower section consists of vertical support members with horizontal bracing, which also formed an enclosure to the lantern gallery in place of the original parapet wall.

The next two sections, formed from 'X' shaped (cruciform) members, give a diamond pattern when assembled to provide the minimum obscuration to the light source.

The present navigation light has its focal plane level with the centre line of the first row of cruciform units, the second row was provided to cater for the future installation of an emergency beacon as part of the automation scheme. The fourth section again had vertical support members with horizontal bracing: this being at lantern roof level.

The fifth section provided the transition from the support structure to the deck joists, and incorporates a cantilever arm facing outward to extend the deck away from the support structure.

At this uppermost level, horizontal joists provided interconnection between the sixteen bays of the support structure, and formed the supports for the 60 mm deep perforated aluminium decking panels.

10.3.6 Landing Platform

The landing deck was designed to be made from a commercially available aluminium decking plank, 60 mm thick.

Due to the weight restrictions for transport to the lighthouse, and the sixteen sided shape, the deck was designed to be constructed from a series of rectangular and angled edge panels which abut each other and are secured by stainless steel fastenings to deck joists.

10.3.7 Corrosion Protection

To provide maximum protection to the steelwork in the aggressive marine environment, all steelwork was grit blasted after manufacture in accordance with Swedish Standard SIS O5 5900, SA3, to give a blast profile maximum amplitude not exceeding 100 microns.

Immediately after grit blasting the steelwork was zinc metal sprayed to a nominal thickness of 200 microns. A paint system was then applied consisting of an etch primer, a zinc phosphate primer and a single finish top coat.

All aluminium used was of marine grade HE30, and received no further finish except where necessary to mark out the perimeter of the helideck.

All steel/aluminium contact surfaces were insulated using a neoprene gasket, and stainless steel bolts were used for connection between the two.

10.3.8 Concrete Structures

Examples of concrete support structures for helicopter landing are only to be found where the platform was incorporated in the original overall design of lighthouses recently erected.

11 ACCOMMODATION FACILITIES

11.1 GENERAL SURVEY ABOUT MAINTENANCE OF LIGHTHOUSES

The outer appearance of the structure is defined by the IALA guidelines and the conservation or upkeep depends on three major factors:

- in an unmanned lighthouse only structural maintenance is needed;
- in a manned lighthouse the social aspect of interior decoration is to be taken into account;

  The lighthouse is inhabited for X days a week by the same staff:
- a lighthouse with public access should have adequate facilities (publicity, mobility of the visitor).

In general lighthouses can be considered as being technical spaces that don't need any extra or special maintenance when not inhabited.

During the periodic inspection of the A to N equipment small maintenance jobs can be done without additional costs being incurred.

11.2 ELEMENTARY MAINTENANCE

The husbandry includes:

- dust the monitors and (when existing) the electronic equipment;

- cleaning of the rooms monthly, dusting and other wet cleaning;
- clean windows monthly and when necessary (winter months);
- cleaning of the lenses (yearly maintenance);
- staircases (see rooms).

The preceding points must be carried out more frequently when inhabited or regularly visited. The inhabitants do inevitably create dirt, but they can clean up during their period of stay and do small jobs and repairs to the building.

If access to the tower is available to visitors, more maintenance will be required and it may be necessary to employ private contractors to look after:

- dirt in staircases;
- frequent use of toilets;
- possibly a souvenir-shop;
- dumping of litter (placement of a container);
- inevitably there must be a cleaning team at work at least weekly.

11.3 MAINTENANCE OF FURNITURE AND HOUSEHOLD EFFECTS

11.3.1 Painting Maintenance Works

Outside painting: see section 2 (structural composition).

11.3.1.1 Inside

- for an uninhabited lighthouse one can limit maintenance painting to the structural maintenance needed for the preservation of the building;

  The rooms that are used as an emergency workshop or as storage need only are to be maintained using a 'simple painting system'
- in an inhabited tower there is a social factor: to consider;

  The lighthouse is inhabited for a number of days a week by the same watch. Some rooms must be arranged for living and even the storage rooms must be given some aesthetic consideration.
- for a lighthouse open to visitors the building must have a completely different accommodation.

  The function of the working and storage areas will be kept, but in the other rooms there must be space for exhibitions. These rooms and the staircase must be constantly tidy and therefore require more up keep.

11.3.2 Maintenance of Furniture

The arrangement and the choice of the furniture of the lighthouse depends on the three above mentioned factors:

- in an uninhabited lighthouse the furniture is limited to utility items and storage racks, and these require little maintenance;
- with an inhabited tower a completely different approach is required because one has to arrange and maintain domestic facilities;

  The furniture will consist mainly of normal household items which can be maintained by the inhabitants without further costs.
- for a lighthouse open to the public the furniture will consist mainly of exhibition furniture.

Public access increases the number of repairs and renewals that are needed but this can be included in the lighthouse management system.

11.4 UTILITY SUPPLIES

11.4.1 ELECTRICAL INSTALLATION

The arrangement of the electrical installation will depend on the siting of, and access to the lighthouse.

- if the lighthouse is always accessible by road and connected to the mains supply there will be little difficulty; the maintenance can be as for a normal industrial installation, according to the ruling electrical installation standards.
- if the lighthouse is built on a remote site the maintenance and repairs must be supported by air or water transport. If there is no mains electricity at hand, power must be provided by locally generated means.

  The supply of material and staff for repairs is restricted by the carrying capacity of the available transport (weight of the fuel, tools and items for repair). However, there is the advantage of difficult access in that the lighthouse is not liable to unauthorized access by the public.

11.4.2 HEATING

Here one has the same problems as for the electrical installation. An unstaffed tower need only be kept dry and free of frost whereas an inhabited or manned tower must have an average heating of 18°C in the living areas.

11.4.3 SANITATION

The sanitation is complex as one has to take into account the environment and the type of sewage facilities required to meet local regulations.

- when the lighthouse is unmanned there may be no sanitation necessary however it may still be necessary to install facilities for visiting maintenance personnel.
- with a manned lighthouse that is accessible to the public the problem is different.

  If the lighthouse is close to main drains, drainage can be connected to the public system. But when the lighthouse is at a remote site there must be storage and some form of sewage treatment plant. It may even be necessary to transport sewage from site in special tanks. The storage areas must be pre-planned in the layout of the building. The transports of the tanks are one of the main problems, given the limits (of weight) by air transport. Even if sewage is treated and disposed of locally it will still be necessary to bring freshwater to site by some means of transport. These problems are generally limited to mainland lighthouses as remote offshore lighthouses are not accessible to tourists.

11.4.4 LITTER

The litter problem can be serious for a lighthouse open to the public the litter production is large, and requires the placement of litter containers and the subsequent removal of litter from the site.

11.5 PROTECTION AGAINST WEATHER CONDITIONS AND VANDALISM

11.5.1 STORM AND RAIN DAMAGE

Permanent protection of the lighthouse against storm and rain damage is practically impossible. Regular control and immediate repair of any minor damage of roofs and windows will prevent more serious damage at a later date. For remote and difficult to reach lighthouses there is the possibility of monitoring the humidity via a telemetry system. The installation of temperature sensors that monitor any large oscillations in a measured time, can be used to warn of storm damage (the breaking of windows, ventilators etc.).

11.5.2 Fire Detection

The fire detection can be installed in different areas with different sensors activated by smoke or temperature rise. Temperature monitoring is usually combined with smoke detection. These sensors work on a low current and activate an alarm which in turn can activate a fire suppression system.

11.5.3 Fire Suppression System

National regulations define the type of fire suppression medium that can be used. The system will usually be installed and maintained by a specialist contractor.

11.5.4 Burglary Protection

The protection of the lighthouse space can be accomplished by means of electronic detectors that work on radar and/or infra-red. The apparatus must not be sensitive to the frequency of fluorescent lights and certainly not to light level changes from night to daytime.

11.6 GENERAL NOTICES

The above mentioned observations and specifications vary in importance according to the function of the lighthouse building. The frequency of maintenance changes with the occupation and the use of the accommodation. Elementary maintenance of the building (on yearly basis) can vary but can be combined with the periodical inspection of the A to N installation of the lighthouse.

- in a manned tower the risk of fire an associated smoke is most probable because there are cooking and heating appliances, however the risk of burglary and vandalism are low when a lighthouse keeper is present;
- for a tower open to the public the risk of burglary and vandalism is much more likely because these lighthouses are more easily accessible and they contain information, documentation and exhibition material;
- when the tower is unmanned guarding need only be elementary, but if the tower is situated in a tourist centre one needs all the precautions suitable for public access lighthouses;

  The maintenance of the security system depends on the location and it may be necessary to deter vandalism.
- if the lighthouse is easy to access and it is provided with a telephone line it is possible to install alarms via a modem;
- when there is no phone line available the following solutions are possible:
  - if the distance from a lighthouse to a fixed mark is less than 1 km, one could utilize an online connection by infrared (not to be recommended);
  - by cellular communication system;
  - by dedicated radio link.

11.7 REFURBISHMENT AND MAINTENANCE OF INFRASTRUCTURE

11.7.1 Access

If the lighthouse is reached by a public road, then this will be maintained by the local public authority.

If the road is owned by the lighthouse authority or if there are driveways at the lighthouse site, these will have to be fully maintained by the lighthouse authority. If public access is allowed, then suitable sign posts and safety fences have to be provided.

11.7.2 Parking

The construction and maintenance of a car park is only necessary when the tower is accessible to public. This requires an estimation of the number of visitors and hence the number of spaces and possibly staff.

The maintenance of the parking area is another cost go be charged against the management of the lighthouse.

12 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.

12.1 REVIEW OF EFFECTS

12.1.1 Organic Effects

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

12.1.2 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 Suns radiation is the normal maintenance as is the use of microporous 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.

12.1.3 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.

12.1.4 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.

12.1.5 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.

12.1.6 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.

12.2 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 key holders;
- 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 ladder;.
- 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.

12.3 HUMIDITY [2] [4]

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

12.3.1 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.

12.3.2 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.

12.3.3 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.

12.3.4 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.

12.3.5 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.

12.3.6 CELLAR INUNDATION

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

13 A TYPICAL MAINTENANCE SCHEME

Referring to [10], which gives a fair example of the way Canadian authorities deal with extensive maintenance programs, the following subdivision can be made for an overall maintenance scheme:

- Inspection;
- preventative maintenance;
- corrective maintenance;
- renewal.

Part of the previously mentioned reference is repeated here:

> This practice describes a plan for carrying out scheduled preventative maintenance on lighthouse sites. This plan is designed to provide written preventative maintenance work orders at scheduled intervals from a central record filing location.

Preventative maintenance involves servicing or replacement of components parts or an installation of equipment on a regular basis, often before signs of deterioration are evident. This practice minimizes the incidence of costly and possibly dangerous situations that may arise from the unexpected deterioration or failure of a component.

Preventative maintenance of lighthouse facilities is usually limited to replacement of parts of electrical, mechanical and electronic equipment, but such work as regular painting and site work may be considered a form of preventative maintenance. Replacement of structural members is undertaken only after evidence of deterioration has been discovered and is therefore not classified as preventative maintenance but as corrective maintenance.

This program will prove effective only if all maintenance data is kept up to date and all procedures are followed accordingly

13.1 RECORDS

Some key objectives which must be considered in regards to the amount and type of information to be retained are:

- ease with which data can be used to perform analysis and help the decision making process;
- ease with which the information can be accessed and maintained;
- security of data to protect its integrity by preventing unauthorized access and manipulation.

Records should show:

- inventory related to the technical description of the facility;
- activity data, related to the various activities performed upon these facilities (e.g. inspections, maintenance, repairs, etc.).

13.2 INVENTORY FILE

The inventory file must be created when a new facility is built and remains unchanged until a major rehabilitation or replacement of the structure is completed. It records all pertinent information of that facility.

Updating has to take place whenever an inspection or maintenance work is done at a facility or whenever a status change is made with respect to a facility (e.g. change detailed inspection frequency from Quarterly to Semi-annually).

13.3 SCHEDULING

Timely inspection of structures and equipment serves to monitor the performance of construction materials and equipment parts with time and help to ensure the early detection of material deterioration or equipment breakdown.

Inspections forming part of a routine program are conducted roughly every three months, six months, or yearly. (e.g. at times when deterioration on a structure is likely to be most pronounced from environmental effects). To determine the inspection date for each facility a master schedule is drawn up based on historical data such as weather conditions, availability of manpower, availability of transportation and travel distance.

The maintenance section is responsible for seeing that the necessary routines are scheduled in order that their frequencies meet the equipment manufacturers recommendations and the preventative maintenance program is carried out in a safe, economical and satisfactory manner.

13.4 INSPECTIONS

An inspection involves a complete systematical examination of structures and equipment and must be made up of an inspection team who have a good working knowledge of the facilities and their operation.

A detailed itinerary of the proposed inspection tour should be prepared.

Inspection data covers the visual, routine, detailed and special inspections and should include:

- type of inspection;
- observation of components (current condition) especially deficiencies;
- recommendations and comments;
- date of inspection;
- signature of inspector.

Field observations are transferred from the field reports to general file held in office. The inspection files are updated after each inspection and contain the observations and comments of the inspection team to permit evaluation of the input data in the Regional office.

14 MAINTENANCE AND PRESERVATION OF HISTORIC LIGHTHOUSES

Reference is made throughout this document to maintenance issues associated with historic lighthouses. More detailed information regarding specific examples of lighthouse preservation is available in the United States Coast Guard Historical Lighthouse Preservation Handbook. [19]

15 DEFINITIONS

The definition of terms used in this Guideline can be found in the International Dictionary of Marine Aids to Navigation (IALA Dictionary) at http://www.iala-aism.org/wiki/dictionary.

16 ACRONYMS

A	Annual
Al	Aluminimum
Al_2O_3	Aluminium oxide
C	Carbon
C	Celsius (previously Centigrade)
CaO	Calcium oxide
cm	centimetre
Cr	Chromium
Cu	Copper
DIN	Deutsches Institut für Normung, the German Institute for Standardisation
Fe	Iron
Fe_2O_3	Ferrous oxide
FRP	Fibre Reinforced Plastics
Ga	Gallium
GLA	General Lighthouse Authority(ies)
GRP	Glass Reinforced Plastic (fibreglass)
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities - AISM
ICAO	International Civil Aviation Organization
IEG	Information Exchange Group (GLA)
kg	kilogram

Km	kilometre
m	metre(s)
m^3	cubic metre(s)
Mg	Magnesium
mm	millimetre(s)
Mn	Manganese
nm	nanometre(s)
P	Phosphorous
Ra	Roughness average
S	Sulphur
SA	Semi-annual
SA	Swedish sand blasting standards
Si	Silicon
Ti	Titanium
UV	Ultra Violet (light) (10 – 380 nm)
V	Vanadium
Zr	Zirconium
2Y	Every Two Years
3Y	Every Three Years

17 REFERENCES

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[5] Coastal Erosion-Effect on Lighthouse Structures, Hawaii Conference paper

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[8] Weatherproof characteristics of FRPs (fibre reinforced plastics) in Japanese Maritime Safety Agency

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[13] Reinforced Polyester Constructions

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[15] Recent Aluminium Lighthouses Built in the Philippines

17.7 BY PORTNET, SOUTH AFRICA (MR. JAMES COLLOCOTT)

[16] Steel Lattice Structures in Use in South Africa

[17] Aluminium Lattice Structures in Use in South Africa

[18] Maintenance of Cast Iron Structures in Use in South Africa

[19] Upgrading of Roman Rock Lighthouse

17.8 ADDITIONAL TECHNICAL INFORMATION ON LIGHTHOUSE PRESERVATION

[20] USCG Historic Lighthouse Preservation Handbook