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On

The Maintenance of Buoys and Small Aids to Navigation Structures

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1. Introduction

This guideline provides information to help plan the inspection and maintenance of small aids to navigation (ATON). These include floating buoys and small fixed structures, which some authorities refer to as beacons. Guidance is provided for the physical components of the buoys and structures themselves, as well as for associated equipment such as mooring hardware, signal equipment, and power systems. This document begins by presenting some general issues for consideration, and follows with guidance on specific items of ATON hardware and equipment. Maintenance and disposal should be considered in the design process of ATON hardware and systems. Attention at the initial design stage can significantly reduce the cost of these activities, and thus the overall life cycle cost of the hardware and systems.

1.1 Location of work

ATON maintenance work is carried out on station and at on-shore maintenance facilities. Although a large proportion of maintenance work has traditionally been carried out on station, the high cost of transporting and maintaining staff at buoys and structures generally makes it more cost-effective to return ATON equipment to the maintenance facility for repair or refurbishment whenever possible. Work can then be carried out in a controlled environment, possibly by a specialist subcontractor, within a reasonable time and with planned quality control. Much depends on the environmental conditions and location of the aid station. In warm dry climates where the aid is close to the shore side maintenance base, considerable on-station maintenance may be practical within predictable timeframes. In cold climates and rough seas, on the other hand, almost no on-station maintenance may be possible, and there may only be enough time to exchange complete buoys, daymarks, or power systems in the short periods of suitable working weather. The concept of "repair at base station" does require that a sufficient amount of spares be maintained to allow for breakdown repair and planned maintenance. The cost of these spares must be incorporated in the overall maintenance plan.

1.2 Inspection

Regular, planned inspections should be carried out on all types of fixed and floating ATON. This is of particular importance to the planning of future maintenance and the development of maintenance policy. Those carrying out these inspections must receive relevant training in the systems to be inspected and methods of recording the data. All items that wear, degrade, corrode, or have a finite working life should be included in these inspections. Typical areas of concern would be chain wear, paint failure, corrosion, marine growth, damaged solar modules, salt encrustation on lanterns, etc. This list is certainly not all-inclusive, and more detailed guidance is provided in later sections of this document. One item of particular importance is the inspection of the access arrangements (ladders, working platforms, fall arrest systems, etc.) on buoys and structures to ensure safe and easy access for maintenance personnel.

1.3 Cleaning

Cleaning is generally required each time an aid is serviced. Cleaning covers those actions required to maintain the signal colour; to remove marine growth for reasons of colour retention or for reduction of drag or weight on floating ATON; and to remove salt, dirt, or bird droppings from lanterns and solar panels. Modern pressure washing equipment is particularly suitable for these processes in the field, as all contaminants can be removed without introducing solvents or detergents into the environment. Care must be taken to ensure that correct pressures are used, as excessive pressure may result in the paint coating being removed, damage being caused to solar panels, mortar being removed from masonry structures, or other similar problems. Although manual scraping can also be used to remove marine growth from buoys, this can easily damage the coating system, and should be avoided if possible.

1.4 Maintenance intervals

The maintenance budget is considerably influenced by the time interval between maintenance visits and the length of time spent on station at each visit. Decisions on maintenance intervals depend on the shortest "maintenance life" period of each individual component of the ATON and any associated structure. Maintenance visits can be planned based on these intervals, and other work carried out at subsequent visits. Cost savings can be achieved by extending the maintenance period for a particular ATON. This is accomplished by increasing the working life of the component with the shortest maintenance period. One example would be replacing a primary battery system with a solar power system. The maintenance visits would then extend from every six months to change the primary battery to every year or more to clean and inspect the solar modules and the lantern. As another example, changing conventional paint systems on a buoy to modern high performance paints could extend the on-station life of the buoy from two years to five years or more, assuming that the moorings and other buoy systems can operate for this extended period.

2. Steel buoys

2.1 Maintenance on shore

Steel buoys must be brought ashore periodically for repair and refurbishment and made ready to return to sea. In areas with extreme climates, this may be an annual event (e.g., when buoys are removed when winter ice sets in, and replaced with refurbished buoys in the summer). In more benign areas, buoys can usually stay on station much longer between overhauls. Typical reasons for relieving a buoy from station would be collision damage, failure of the paint system, or to remove excessive marine growth if authorities do not have servicing vessels with adequate lifting capacity to clean the buoy on site.

Steel buoys will require periodic blast cleaning. For proper paint application, a painting facility with controlled temperature and humidity will be needed. Blasting and painting both require a significant investment in worker health and safety equipment and procedures. Buoy overhaul may be carried out by subcontractors - local shipyards may be suitable. In this case, detailed specifications should be prepared for this work, along with inspection procedures for all stages of the overhaul process.

2.1.1 Blast cleaning

Servicing units should remove the majority of fouling to the greatest extent possible before dropping buoys off at the maintenance facilities. This avoids transporting marine growth from one environmental area to another. Also, heavy fouling should not be allowed to dry on the buoy. Dried fouling is very difficult to remove, and it creates a strong and unpleasant odour. Fouling may be removed by high-pressure water washing or by scraping. Special attention should be given to removing the fouling from underneath the counterweights of flat-bottom buoys, and from inside whistle tubes. Any remaining fouling should be removed by the buoy maintenance facilities prior to blasting, since fouling can clog up and damage the blasting equipment when continuous grit recycling systems are used. In addition, removing the fouling prior to blasting will reduce the amount of residual blast waste that must be disposed of as hazardous material. Heavy accumulations of oil, grease, and dirt should also be removed from the buoy prior to blasting. Foreign material of this type will become embedded in the steel during blasting, and will prevent the paint from sticking.

Components that could be damaged by blasting should be removed from the buoy before blasting. Examples include electrical wiring, signal equipment, bells, gongs, and whistles. In addition, vent valves should be removed and the vent lines plugged. All threaded surfaces should be covered for protection.

All exterior surfaces of the buoy hull, and the inside surfaces of whistle tubes and battery pockets, should be blasted to near-white metal. If a high performance epoxy system has been used on the buoy, a partial blast may be satisfactory. This partial blast would include removing damaged paint and lightly blasting the remainder of the buoy to create a surface profile suitable for overcoating. Blasting media should be of a recyclable variety, such as steel shot, steel grit, garnet grit, etc. Ultra high pressure water blasting is another option if full paint removal is required. Coal slag, sand, or crystalline silica should not be used due to the negative health and environmental effects of the dust created by these materials.

The surface profile after blasting should comply with the paint manufacturer's recommendations. After blasting, the surface to be painted should have the following characteristics: free of rust and scale except for slight shadows, streaks, or discolouration; free of blasting grit, weld spatter, and slag; free of old paint, oil, grease, and dirt. Painting should follow immediately after blasting to avoid the onset of corrosion.

2.1.2 Painting

The type of coatings used on steel buoys vary from Authority to Authority, depending on product availability, operating conditions, and the level of environmental regulation in the region. Regardless of the type of coatings used, they should be high-performance products designed for use in the marine environment. Paints are normally applied by brush, roller, or spray, depending on the surface area involved and the facilities available. All of the paints applied to a given buoy should be from the same manufacturer. This is to provide compatibility between coats, validate the manufacturers' warranties, and ensure the Authority receives adequate technical support to correct problems and increase productivity.

Follow the manufacturer's instructions for correct application of the coating system. This includes complying with temperature, humidity, and dew point restrictions; storage, mixing, and induction time requirements; and specific requirements related to equipment and application techniques. All welding, machining, cutting, drilling, forming, or any other operation that would damage the coating system should be performed prior to painting. Sharp corners, edges, and other hard-to-coat areas should be pre-coated before each full coat is applied, to ensure adequate paint thickness in these areas.

Implement appropriate worker safety procedures for the application of the coating system, and ensure the procedures are strictly followed.

2.1.3 Repair of steel hulls and appendages

Buoy hulls should be repaired or replaced when the hull thickness reaches the minimum allowable level (varies depending on the buoy design and Authority policy). Buoy hull thickness can be easily measured with ultrasonic equipment. Any damage that penetrates the hull should be repaired. Severe dents and creases should be repaired, returning the buoy body to its approximate original shape. Be aware that combustible gases could be present in a buoy hull. Before beginning any "hot work" (cutting or welding) on a steel hull, test for combustible gases with a combustible gas monitor or explosive meter. If combustible gases are detected, purge the hull with compressed air to displace the combustible atmosphere. If workers must enter a buoy hull to effect repairs, ensure that appropriate safety requirements for confined space entry are followed. Buoy hulls and battery pockets that have been repaired should be pressure tested prior to repainting to ensure airtight integrity.

Bent counterweight tubes should be replaced. The welds at the junction of the tube and the buoy body should be inspected and repaired as necessary. Bent mooring arms should be straightened or replaced if they do not function properly. Bent tower legs should be straightened. Radar reflector panels should not exceed three degrees from a right angle, and should be straightened if necessary. Lantern mounting surface and lantern ring should be parallel to the waterline.

Battery pocket closures should be inspected, and the battery pocket cover gaskets should be replaced. Vent lines should be inspected for damage or obstructions that would impede air flow or allow flooding of battery pockets, and repaired or replaced as necessary. Crossover vent tubes within battery pockets should be inspected for damage or obstructions that would impede air flow. Make sure the tubes are free of blast grit, paint chips, dirt, or other foreign material.

The integrity of lifting eyes is vital to the safety of buoy handling operations. Lifting eyes are subjected to repeated heavy loads while in service, which can weaken the weld and the surrounding metal. Failure of a lifting eye could lead to serious injury of the ships' crew or the shoreside maintenance personnel. Therefore, it is paramount to ensure the fitness for use of this critical component. Load testing is the preferred method of demonstrating lifting eye integrity. Non-destructive inspection (e.g., magnetic particle method) is also used by some Authorities for this purpose.

Worn mooring eyes should be repaired or replaced. Mooring eyes can be repaired by building them up to their original size by welding, or by inserting sleeve bushings. Hardfacing material should be used when weld build-up is the chosen repair method. Ensure that this material is compatible with the shackles that will be used in service.

2.2 Maintenance on station

2.2.1 Hulls

Buoys should be checked for flooding and inspected for damage that could affect their watertight integrity. Cutting or welding may be required to repair this damage on station. Extreme care must be exercised because combustible gases could be present in a buoy hull. Before beginning any "hot work" (cutting or welding) on a steel hull, test for combustible gases with a combustible gas monitor or explosive meter. If combustible gases are detected, purge the hull with compressed air to displace the combustible atmosphere. Remove the battery pocket covers and batteries prior to beginning hot work.

2.2.2 Appendages

Battery pocket closures should be inspected for damaged flanges, covers, swingbolts, and gaskets. The vent valves should be inspected to ensure that the balls are free to move. The tower legs and feet should be inspected for cracks and broken welds. Swing arms, mooring pins, and mooring eyes should be inspected for excessive wear. Any problems with these items should be repaired if possible, or the buoy brought ashore for an overhaul.

2.2.3 Painting

Painting on station is not recommended. However, touch-up painting is sometimes done to restore the proper signal colour of the buoy. Prior to painting on station, prepare the buoy surface by wire brushing, scraping, or high-pressure water washing to remove as much dirt, rust, guano, fouling, loose paint, grease, and salt as possible. If high-pressure water washing is used, follow the manufacturer's recommendations for a pressure setting that will clean the buoy thoroughly but will not damage the underlying coatings. The surface must be dry before painting. Wet surfaces shall be blown dry with compressed air or wiped off. Care should be taken when scraping so as not to damage the buoy's coating system. Follow the manufacturer's instructions for the correct application of all paints. Ensure that the paint has properly cured in accordance with the manufacturer's recommendations before redeploying the buoy in the water.

2.2.4 Removal of fouling

Fouling from marine growth may be so severe that the buoy will have to be lifted and cleaned at regular intervals if suitable lifting capacity is available on scene, or returned to the depot if not.

3. Synthetic buoys

Synthetic buoys can be grouped in the following four categories, based on their primary material of construction: glass-reinforced plastic (GRP), moulded thermoplastic, urethane-coated foam, and all foam. Each of these will be addressed below. In general, maintenance of these buoys will be performed on shore. Maintenance on station would usually be limited to the removal of fouling, and possibly some minor touch-up painting to restore the signal colour. The steel components of all types of synthetic buoys will require painting or re-galvanising, and in the case of mooring eyes, re-surfacing. The integrity of any internal load bearing structure must be regularly monitored to ensure handling safety, as components may suffer corrosion, fatigue, or abrasion damage.

Synthetic buoys can have a wide range of lifting eye configurations, depending on the specific buoy design. The integrity of these eyes is vital to the safety of buoy handling operations. It is recommended that Authorities have testing procedures in place to ensure the fitness for use of these critical components over the full service life of the buoy. Consult the buoy manufacturer for guidance on suitable testing procedures.

3.1 GRP

GRP is the usual abbreviation for glass reinforced plastic (fiberglass), which in its most common form consists of glass matte bonded by polyester resin. Repair of GRP is usually straightforward, but does require standards of cleanliness and high working temperatures that may be difficult to achieve. Effective drying of damaged laminates or foam cores may also be difficult in cold climates. It may be necessary to use infrared heaters to warm and dry damage areas and to ensure effective curing of the repair. The use of laminating resins and solvents is subject to increasing control by health and safety regulations.

3.1.1 Hull repair

When a GRP buoy has been in service for any length of time, the gelcoat will begin to fade from exposure to ultraviolet (UV) radiation. Loss of gloss and "chalking" can also occur, where the surface gradually breaks down to a powder. Polishing with marine grade wax polish may delay this, but eventually a paint system may be needed to protect the gelcoat surface and provide the required glossy colour finish. If the gelcoat is extensively grazed, flaking, blistering, or contains many bubbles, then the gelcoat should be removed by power sanding or grit blasting. This should be undertaken by experienced personnel to ensure that the glass fibre structure of the buoy is not damaged. The buoy should then be pressure washed with fresh water and allowed to thoroughly dry in conditions of controlled temperature and humidity. Coatings of solvent-free epoxy are then applied, again in controlled climatic conditions, to form an impermeable barrier on the surface of the GRP moulding. Four or five coats are usually necessary, and these may be followed by colour coats in areas where the signal colour of the buoy is required. More guidance on painting is provided in the following paragraphs.

3.1.2 Painting

Prior to painting, the surface must be prepared to ensure proper adhesion of the coating system. Special releasing agents are used during the manufacturing process to allow the removal of the buoy from its mould. It is essential that these agents be removed from the surface before painting. The buoy must be cleaned with a degreasing agent, which can be obtained from the paint manufacturer. This is usually left on the buoy for 10-20 minutes before washing off. Afterward, wash the surface again with fresh water. If the surface is completely clear of grease, the water will spread out evenly on the surface. If grease is still present, the water will form small droplets, which indicates more cleaning is necessary with the degreasing agent. Any minor cracks and blemishes can be filled with an epoxy filler. Only epoxy-based fillers should be used to ensure long-term adhesion and water resistance. To ensure good adhesion of the paint, the surface must be abraded with a fine grade abrasive paper. Wet and dry abrasive paper may be used if a high gloss finish is required. All sanding dust should be removed before painting proceeds.

For the best long term protection, a coat of an epoxy primer should be applied prior to the selected finish coat. If the surface is in very good condition, it may not be necessary to apply a separate primer as the undercoat for the paint will provide the necessary adhesion. If the surface has become "chalked," it can absorb solvents from the paint system, which can cause microblistering problems later. To avoid this, an epoxy primer system should be applied to the surface. This will seal the surface and provide a stable base for the paint system. Submerged areas of the buoy that do not form part of the colour daymark may be painted with at least three coats of an underwater epoxy system to provide a water barrier for the GRP structure. All of these paints can be applied by brush, roller, or spray, depending on the surface area involved and the facilities available.

All coatings should be high-performance products designed for use in the marine environment. All of the paints applied to a given buoy should be from the same manufacturer. This is to provide compatibility between coats, validate the manufacturers' warranties, and ensure the Authority receives adequate technical support to correct problems and increase productivity. Follow the manufacturer's instructions for correct application of the coating system. This includes complying with temperature, humidity, and dew point restrictions; storage, mixing, and induction time requirements; and specific requirements related to equipment and application techniques. Implement appropriate worker safety procedures for the application of the coating system, and ensure the procedures are strictly followed.

3.2 Thermoplastic

Buoys of this type are typically fabricated from polyethylene plastic (either linear or cross-linked). Typical fabrication processes include rotational moulding and extrusion.

3.2.1 Hull repair

The polyethylene skin can be difficult to repair. If linear polyethylene is used, it can be melted and hence repaired by hot air welding. Another option is to resurface the buoy by flame spraying new plastic onto the surface of the original moulding. This involves using a spraying system which projects plastic powder through a gas flame to deposit a molten layer of new plastic. Materials of any colour can be sprayed on, and a considerable thickness can be built up as required.

Large roto-moulded thermoplastic buoys are generally modular in construction, so it is possible to salvage parts of these buoys that are still in good condition and reuse them to replace damaged parts and extend the life of other buoys. Other repair and recycling options may be available from the buoy manufacturer.

3.2.2 Painting

Painting of thermoplastic buoys is not usually successful due to surface adhesion problems. This is because polyethylene is naturally slippery. Some success has been obtained by abrading the surface of the plastic with a medium grade abrasive paper or using flame treatment, and then painting with an appropriate coating. The effectiveness of this process may vary depending on the grade of polyethylene used in the manufacture of the buoy. The flame spraying process described in paragraph 3.2.1 can also be used to restore or change the colour of plastic buoys.

3.3 Urethane coated foam

These buoys typically consist of a thick (up to 10mm) flexible urethane elastomer skin on a flexible closed cell foam core. The urethane may be repaired with two component pouring or towelling compounds. Correct working conditions are critical (temperature and humidity), and detailed health and safety precautions must be observed.

3.4 All foam

These buoys are usually constructed by wrapping closed-cell foam sheets around a central structural core, the layers of foam being heat sealed together during the wrapping process. A typical material for this application would be foam made from ionomer resin.

Foam buoys generally require very little maintenance. A foam buoy hull can sustain considerable damage or loss of material without sinking, and still provide the proper signal to the mariner. Cuts, tears, gouges, shredding, or even missing chunks of foam will rarely be enough to affect the performance of the buoy. Foam buoys will lose their colour over time through fading, chalking, sunburn, and the accumulation of foreign materials (salt, dirt, guano, etc.). Usually, cleaning the surface of the buoy with high-pressure washing is enough to restore a proper colour. The metalwork of a foam buoy will deteriorate over time through corrosion and normal wear-and-tear, or there may be damage from collisions. The important considerations are whether the metalwork can continue to hold the buoy together, and whether the buoy remains safe to lift and handle.

To achieve the lowest life cycle cost for these buoys, they should be kept on station as long as possible, provided they remain serviceable and continue to present the required signal to the mariner. In other words, the steelwork should be intact, the buoy should be safe to handle, the colour should be recognizable; the daymark shape should be identifiable as a can or nun; and the buoy should have sufficient stability and freeboard to provide the required visual range for the aid. If the buoy fails to meet one or more of these requirements, it should be relieved and disposed of. Since these buoys are generally modular in construction, it is possible to salvage parts of these buoys that are still in good condition and reuse them to replace damaged parts and extend the life of other buoys. Other repair and recycling options may be available from the buoy manufacturer.

4. Moorings

The life of a mooring (chain, rope, shackles, swivels, sinkers, anchors) will depend on local operating conditions; i.e., the sea state, water depth, type of sea bed, abrasive particles in the water, current speed, etc. The most rapid wear will be in the thrash zone (where the chain meets the seabed). The authority must plan to lift and replace worn components to keep the mooring in safe working order or to remove the entire mooring before it is worn to unsafe levels. If the Authority has a suitable vessel to lift and inspect the mooring, then worn components and sections of the mooring may be renewed at planned intervals. If the mooring cannot be lifted for inspection, then a working life will have to be predicted and the mooring replaced or abandoned on the seabed at the end of this period. Historic inspection information is invaluable in establishing practical working periods in specific locations.

4.1 Chain

A chain mooring consists of three parts: the riser chain, which hangs in the water column; the thrash (chafe) section, which moves against the sea floor as the buoy moves; and the bottom chain, which remains on the sea floor. Since the thrash section typically experiences the greatest wear, it is the most important area to inspect. Depending on the length of time between mooring inspections and the severity of the environment, it may be prudent to bring the entire mooring aboard for inspection. When inspecting chain, it is important to know its condition at the time of the last mooring inspection. Annual wear rates for a given buoy station can be estimated by keeping records of the chain measurements at each inspection. This information can be used to plan the frequency of mooring inspection visits that will be necessary for a given buoy station.

Inspect for chain wear by measuring the smallest parts of the most worn links, using a calliper. Replace the chain if it has worn down to the minimum useable diameter for the buoy type on station, or if any of the links are deformed, stretched, bent, or twisted.

When replacing sections of worn chain, enough chain should be removed on either side of the worn section to ensure that shackles do not ride in the thrash when the replacement chain is connected to the mooring. If a mooring has sufficient scope and only a short section of chain is worn, it may be possible to remove the worn section and join the riser and bottom sections without replacing any chain. If conditions permit, either the entire mooring or certain sections of the chain can be cut and "end-for-ended." This action will put "good" chain in the thrash section and shift the worn chain to an area of less wear, such as in the riser or the bottom. This method can be utilized where chain is worn, but not to the extent that it needs to be replaced. Chain that is worn below the useable diameter for a given buoy type may be "downgraded" and used on a buoy that requires a smaller chain size.

4.2 Synthetic rope

Some Authorities use synthetic rope made from a wide variety of materials: nylon, polyester, polypropylene, and other advanced fibres. Regardless of the type of material used, there are a number of factors to consider with regard to the use and maintenance of these moorings. These include the need for proper material specifications, termination specifications, handling procedures and equipment, and mooring system design.

Personnel safety is a major concern when using synthetic moorings. The energy stored in the rope when under tension may be considerable, and suitable precautions must be taken to ensure that no personnel will be in any area that may be swept by the end of a broken rope.

Chafe and cutting are the greatest dangers to a rope mooring. It is easily demonstrated that a sharp knife will rapidly cut through a piece of rope, and any sharp edges presented by rocks, sea shells, or the servicing ship's own capstan can rapidly cause permanent damage to the surface of the rope. Allowing the rope to slip on the drum of a capstan or pulling it through an unsuitable fairlead may not only result in abrasive damage, but also in localised heating such that the surface fibres of the rope may melt, resulting in significant weakening.

When lifting a mooring for removal or inspection, two areas need special attention:

- Any fairlead that the rope runs over must be of sufficient diameter for the rope used, be of the roller type, and present no sharp edges.

- The winch or capstan must be designed for handling rope, and must not allow the rope to slip on the winch drum when under load.

Conventional capstans may be capable of recovering a rope mooring; however, their tendency to allow the rope to slip on the capstan drum will result in considerable heat being generated that can damage the rope. Successful techniques have been developed using spooling winches where the rope is wound onto a large rotating drum. However, this technique is limited by the length of rope, and hence the number of moorings that can be carried on the drum at any one time. If a large number of rope moorings are to be handled, the preferred method is to use a specialised rope hauling winch. These can be installed at the vessel's deck edge so that the rope can lead directly to the winch without a fairlead being required. The winch consists of an arrangement of large rubber wheels, which grip the rope without causing damage to the surface fibres. The rope usually only passes over a segment of hauling wheel rather than being wrapped around a drum, and can thus be placed in, or removed from, the hauling winch as may be necessary. This type of winch placed on the deck edge also has the advantage that there is no rope under load passing across the vessel's deck, which may present a serious hazard should the rope break.

Consult the rope manufacturer for specific guidance on the installation, inspection, and maintenance of the rope and the rope terminations (i.e., thimbles and splices).

4.3 Connecting hardware

Shackles and swivels that are excessively worn, deformed, stretched, bent, or twisted should be replaced. Swivels should be replaced if they have "seized up" and fail to rotate.

4.4 Sinkers

Concrete sinkers should be replaced if the mooring eye has worn to less than one-half of its original diameter, of if the concrete is eroded or broken away. Cast iron sinker mooring eyes may be repaired or replaced, if economically viable.

5. Structures

This section provides guidance for assessing the physical condition of ATON structures. The purpose is to evaluate the structural integrity of the aid to ensure the safety of servicing personnel who must climb it, and to identify what repairs might be needed.

5.1 Overall condition assessment

The following are things to look for to get an overall impression of the structure's condition, and to ensure the structure is safe to climb before proceeding with a more complete assessment.

Check horizontal and vertical alignment. Is the structure out of plumb? Do any of the vertical members appear bent or misaligned? Does the structure vibrate or move when the boat berths against it? Does the structure deflect from wind gusts or waves? Are there signs of damage caused by vessel impact, ice, logs, or other debris? Is the water under the structure deeper than originally designed, or deeper than reported at the previous inspection?

Check ladders for corrosion, broken, bent or missing rungs, loose or failed connections, and malfunctioning fall arrest systems. Is the ladder misaligned? Does the ladder vibrate or move from the current, waves, or when the boat berths against it? Check for bolt corrosion or loosening of bolts as indicated by wear marks from moving members, misalignment of mating surfaces, and by looseness or distortion of structural members. Loose bolts will typically move when hit with a hammer.

Check the extent of steel member corrosion in the splash zone. Hammer the surface corrosion to remove corrosion by-products and expose the steel below. Removal of the corrosion scale does not affect the structural integrity, and may expose severe corrosion defects.

5.2 Piles

5.2.1 Timber

Timber members have traditionally been used for construction and maintenance of aid structures due to their availability, economy, and ease of handling relative to other construction materials. Timber damage is caused by fungal rot/decay, marine borer and insect attack, connector corrosion and bolt loosening, abrasion.

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. If the aid is a multi-pile structure, are the piles angled toward each other evenly? Is the mast out of plumb?

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

5.2.2 Steel

Steel is used in the construction of ATON structures due to ease of connection, fabrication, and splicing, ductile behaviour, and the ability to drive steel piles through hard soil. There are six major types of steel structure deterioration to watch for in the marine environment: corrosion and coating loss; abrasion; loosening of structural connections, missing bolts; fatigue (broken or cracked welds); overloading; loss of foundation material.

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 easily measured with ultrasonic equipment.

Check for deformation, distortion, or deflection. Check for abrasion as indicated by a worn, smooth, or polished appearance. Inspect welds for signs of corrosion, cracking, or breakage.

Inspect coating for any peeling, blistering, etc. Check for loss of foundation material and/or scour.

5.2.3 Concrete

Reinforced concrete is a construction material for ATON structures due to its relatively low cost and durability. 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. Deterioration of concrete appears in the following forms: corroded steel reinforcing; abrasion wear, which is usually only significant in poor quality concrete; chemical deterioration accelerated by continuous exposure to saltwater, causing soft friable concrete (which can be pulled apart by hand or with hand tools); spalling and/or cracking with rust stains, which usually indicates the reinforcing steel is corroding; overloading damage as noted by cracking, spalling, or concrete breakage; shrinkage cracking.

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 prestressing strands (embedded high strength wire cable).

Check for evidence of chemical deterioration, abrasion wear, and overload damage. Sound the piling with a hammer to detect any loose layers of concrete or delaminating. 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 below.

5.3 Other construction materials

5.3.1 Masonry

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).

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. Is a portion of the originally straight wall bowing outward? Has a portion of the structure settled?

Detailed guidance on the inspection and repair of masonry structures is available from the United States Parks Department at the following Internet address: http://www.cr.nps.gov/maritime/handbook.htm

5.3.2 Non-ferrous metals

ATON structures can be made entirely from marine-grade aluminium or stainless steel, or a combination of both. Also, these metals are used for the secondary portions of structures, such as platforms, marker masts, solar panel mountings, and guard railings.

With regard to aluminium, check 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. Check for abrasion and wear. Aluminium is much softer than steel, and will wear if subject to rubbing with other objects. Check for cracked welds.

5.3.3 Fiberglass

Many structural shapes, ladders, and gratings are available in fiberglass composites that can be well suited to ATON structures.

Check for broken members. Fiberglass is prone to impact damage, particularly in extremes of hot and cold weather and with aging after prolonged UV exposure. Check for loose connections. Fiberglass members are usually connected together using stainless steel bolts, which can loosen over time. Check for damage to the surface finish. Weathering and ultraviolet light (UV) can degrade the surface finish, which can cause fiberglass splinters to develop and present a hazard for servicing personnel.

5.3.4 Plastics

Various grades of polyethylene plastics are used in ATON structures. These may be in the form of sheets attached to the boat fendering of the structure, or polyethylene plastic piles and dimension "lumber," with or without internal reinforcing. The internal reinforcing is now mostly fiberglass rebar or fibers, though internal steel reinforcing has been used as well.

Check for broken or damaged members. Plastics are prone to impact damage, particularly in extremes of hot and cold weather and with aging after prolonged UV exposure. Check for cracking. This can result from the manufacturing process itself, or by corrosion of embedded reinforcing steel. Check for loose bolted connections.

5.3.5 Rubber

There are several types of rubber that are often used in boat fendering on ATON structures. The rubber will degrade over time after prolonged UV, ozone, and petroleum exposure. Ozone and UV will result in a hardened surface and rubber cracking with age. Petroleum exposure will swell and soften many types of rubber. The rubber deterioration should be monitored with each inspection, and the parts replaced when damaged. Check for rubber deterioration (i.e., hardening, cracking, swelling, softening).

5.4 Structure components

5.4.1 Ladders

Check ladders for corroded, broken, bent, or missing rungs. Check horizontal and vertical alignment. Is the ladder misaligned? Does the ladder vibrate or move from the current or waves, or when the boat berths against it? Are there signs of damage caused by vessel impact, ice, logs, or other debris?

Check for corroded, loose, or failed connections. Loose bolts can be indicated by wear marks from moving members, misalignment of mating surfaces, and by looseness or distortion of the ladder. If bolt washers move, then there is no tension in the bolt to clamp the fastened members together. Inspect welds for signs of corrosion, cracking, or breakage. If the ladder has been deformed from an impact, then adjacent welds on rungs and mounting brackets may have been cracked.

If the ladder is equipped with a ladder safety device or fall arrest system, this must be inspected and maintained in accordance with the Authority's national health and safety requirements.

5.4.2 Platform

Inspect the platform decking or grating for structural integrity and soundness. Check the railings for deterioration and parts that are broken, severely bent, or otherwise unsafe.

5.4.3 Tower

Visually inspect all structural members and connections of the towers for evidence of corrosion, deformation, signs of fatigue, and cracks. Look for excess corrosion at the bolts and joints that are bolted together, and for missing, loose, or damaged bolts.

Check the plumb (straightness) of the tower. All towers must be plumb (straight up and down). A simple visual inspection is sufficient. If the tower looks crooked, use a straight edge as a sight and be sure it is not an optical illusion. You may even find towers that zig-zag. Improper construction or damage at specific section connections can cause one section of the tower to be out of plumb with the rest of the structure. Question any unexplained distortion. If the tower is leaning, something is wrong. Find out why it is leaning.

On hollow-section structural members, rust damage on the interior surfaces might not be obvious. Each member of such a tower should have drain holes at the bottom to prevent water from collecting and causing damage. Check these drain holes to make sure they are not obstructed and are doing their job. Visible rust flakes or rust staining may be an indication of interior rust damage. Steel member thickness can be easily measured with ultrasonic equipment.

5.5 Foundations

5.5.1 Concrete foundations

Inspect the concrete foundation above ground level for signs of cracking or spalling. If conditions of the concrete above ground level are poor, an area adjacent to the foundation should be excavated to check the condition of the concrete below ground level. Inspect the soil surrounding the structure foundation for evidence of settlement or upheaval. Inspect the anchor bolts connecting the concrete foundation to the steel tower for deformation, loose nuts, corrosion, or defects. Inspect for exposed reinforcing bars. For inspecting foundations which are underwater, divers or remote operated cameras can be used.

5.5.2 Guy anchors and hardware

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. Preformed guy grips should be checked to ensure there is no change in surface appearance of the guy strand immediately next to these grips. A change in surface appearance may indicate slippage. Ensure turnbuckles are properly moused with safety wire to prevent inadvertent turning of the turnbuckles. Also, turnbuckle threads should be coated with a light coat of petroleum-based grease to prevent corrosion and binding. Inspect structural guys for signs of strand separation, corrosion, fatigue, deformation, and broken strands. In weather conditions where there is no wind, a slack guy wire can be an indication that something is wrong. Verify that safety tie wires are installed on all turnbuckles, shackles, and pins. Inspect steel anchor hardware for corrosion, including steel surfaces in contact with the ground.

6. Signal equipment

6.1 Lanterns and lamps

Visually inspect the lantern lens and base for cracks, crazing, holes, etc. Replace if necessary. Check the level and focus of the lantern. Check operation of the daylight control and signal character.

Filament lamps must be replaced before their working life is exceeded. Buoys and structures with lamp changers will need to have their lamps replaced before the last lamp is consumed. Replace all extinguished lamps and the operating lamp. Rotate remaining good lamps to the forward positions and use new lamps to fill the remainder of the lamp changer. Wipe lamps with a clean rag dampened with denatured alcohol. Rotate the turret to the first position. Those undertaking the replacement of lamps must appreciate the importance of correctly sealing the lantern after the new lamps have been installed and then functionally testing the light. Manufacturers will provide some guidance on lamp replacement intervals, but the local operating environment will affect lamp life. Feedback from inspection reports will enable practical lamp change periods to be established.

LED lanterns have the considerable advantage of requiring little or no maintenance over their service life. When LED lanterns are used, the need to visit the station to remove bird fouling or salt deposits may control the period of time between maintenance visits.

6.2 Electronic sound signals

Turn off power to the sound signal. Visually inspect the housing for cracks, crazing, holes, etc. Repair or replace if necessary. Inspect the emitter openings for debris or dirt and clean if necessary. Apply power to the sound signal, command the fog detector to turn the horn on (if so equipped), and note if all emitters are operating, emitting a pure tone, and sounding on rhythm.

6.3 Wave-activated sound signals

Bells, gongs, and mounting hardware should be inspected for wear, cracks, excessive rust, missing shock pads, and loose hardware. Bells and gongs that are excessively worn should be rotated or replaced. Bell and gong stands should be inspected for cracks, and repaired or replaced as necessary. Hammer hinges should be checked for wear and free movement. Hammer heads should be adjusted to properly impact the bell or gong, and replaced if necessary. Hammer heads that are worn should be rotated or replaced. Replace hammer bars if they are broken or severely bent.

Whistle balls should be replaced each time the buoy is overhauled. The ball valves on whistles should be checked for free operation and cleaned of salt and dirt. The air gap should be adjusted.

6.4 Dayboards

Faded, damaged, or missing dayboards should be replaced.

6.5 Retroreflective material

Any retroreflective material which is peeling or faded should be replaced.

6.6 Topmarks

Repair or replace topmarks and mounting hardware as necessary.

7. Power equipment

7.1 Solar

When solar systems are considered, the power system should operate for more than five years on station, assuming the site has suitable solar radiation.

7.1.1 Solar panels

Test the power output if a system fault is suspected. Check to be sure that the tilt angle is properly set for the aid. Check the solar panel framework and mounting hardware for corrosion. Check the solar panel for broken glass, and for evidence of water intrusion around the edges of the glass. Discolouration of the solar cells and potting material are typical signs of water intrusion. Inspect wiring for cuts, abrasion, and UV degradation. Where plugs and sockets are used, check for water ingress or corrosion. Clean the solar pane with glass cleaner. Replace the panel if necessary.

7.1.2 Secondary batteries

Secondary batteries will need to be replaced before the end of their efficient working life. This is difficult to specify accurately as it will depend on the combination of annual charging regime, annual variation in load and the operating environment. Operational experience is necessary to determine precise battery life, which may vary considerably depending on battery type, charge regime, and climatic extremes.

Inspect battery boxes for damaged flanges, covers, gaskets, vent valves, and securing hardware. All accessible wiring and connections should be visually checked for cracking, deterioration, and corrosion. Wire retaining clips should be checked to ensure the wiring is secure. Stuffing tubes should be inspected.

7.2 Primary batteries

Primary batteries will have to be changed before their capacity is exhausted by the electrical load (lantern, fog signal, racon etc.) or perhaps before winter weather sets in that may make battery changing impractical.

7.3 Gas cylinders

Information may be found in the IALA Practical Notes for the Safe Handling of Gases, October 1993.

Appendix - References

There is extensive information available in existing IALA publications on relevant maintenance issues:

- Recommendation E107 on the design of moorings (May 1998)
- Recommendation E108 for surface colours used on visual AtoN (May 1980, amended June 2004).
- Practical Notes on the use of mooring chains for floating AtoN (1989)
- Practical Notes on the safe handling of gasses (1993)
- IALA Guidelines on plastic buoys (1997)
- IALA Guidelines on painting aids to navigation buoys (May 2001)
- IALA Practical guide on surface colours for aids to navigation.
- IALA Guidelines on synthetic mooring lines (December 2001).
- IALA Practical Notes for the Safe Handling of Gases (October 1993).
- IALA Guidelines on Power Sources and Energy Storage for AtoN (June 2004). [if approved]