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| IALA Guideline |

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Sustainable Structural Design of Marine Aids to Navigation

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# BACKGROUND

Recommendation *R1018 Responsible Design, Operation and Maintenance in the Provision of Marine Aids to Navigation* [1] states that Marine Aids to Navigation (AtoN) managers should:

* Implement systematic procedures for AtoN to meet or exceed the required performance.
* Use appropriate design and building codes and sound engineering principles to ensure fit for purpose assets.
* Seek to reduce environmental impact and improve safe working environments.

Undertaking AtoN design that complies with relevant national and international design regulations, codes, standards and best practice guidelines is considered fundamental to help achieve these recommended aims.

The complexity of AtoN design depends on various factors including focal height, foundation conditions and environmental loadings. It is important that the design complies with the regulations, codes, standards and guidelines, applicable for the geographical region and that these are incorporated into AtoN design and construction. It is particularly important in countries with extreme climatic conditions such as cyclones, extreme waves, or seismic induced activity, that AtoN are designed for relevant environmental conditions.

It is important that the AtoN manager understands:

* The requirement for and benefits of, appropriate AtoN design, using geographically appropriate design criteria.
* The value of identifying and providing clear AtoN design requirements that can be understood by suppliers and held with the AtoN records. This is referred to as “requirement traceability” in Guideline *G1033* [2].
* When there may be a need to request appropriately qualified assistance, to undertake the design and construction of new AtoN or structural assessment of existing AtoN.

Please note that definitions of various design guidance documentation are included in section 7.1 but for simplicity, within this Guideline the terms codes, regulations, guidelines and standards will be referred to collectively as codes, unless being described separately.

# PURPOSE

The purpose of this Guideline is to help the AtoN Manager:

* Understand the elements of AtoN structural design and assessment.
* Understand how design is undertaken in practice by illustrating some practical applications of design codes.
* Acknowledge where the complexity of the proposed AtoN structure requires external design assistance by appropriately qualified professionals.
* Feel confident to discuss the design principles of AtoN with external designers and suppliers and be able to ask appropriate questions regarding the suitability of design proposals.

The Guideline should also provide reassurance to external AtoN service providers and suppliers that AtoN managers understand the principles and application of design codes, thus facilitating good technical communication and the global implementation of harmonized AtoN solutions.

# SCOPE

## Within scope

This Guideline covers the principles of structural design and construction of new or appraisal of existing floating or fixed AtoN. There are several other guidelines that provide specific technical information on detailed light and floating AtoN design and these are listed in the References or Further Reading sections.

This Guideline introduces the generic elements of AtoN design and provides guidance to the AtoN manager when checking that AtoN will be designed and constructed to appropriate design and construction codes.

It is anticipated that this generic Guideline could also be used as a basis for providing further regional guidance for cyclonic regions. The regional guidance could describe the specific design codes used in the design and construction of typical AtoN and replicate the generic figures from this Guideline, with regionally applicable information. A proposed framework for regionally applicable information is detailed in annex B.

## Outside scope

Detailed guidance for the engineering design of major AtoN structures is beyond the scope of this Guideline.

The design of AtoN should be undertaken by those with the relevant qualifications and design experience, appropriate to the AtoN complexity and environmental setting.

This Guideline does not cover:

* The design of buildings such as VTS centres (although many of the design principles discussed will be applicable to the design of buildings).
* The design of light vessels or other major floating aids (see *R1001 The IALA Maritime Buoyage System* [3] for distinction between major and minor floating aids)
* Cladding or renovation of historic masonry lighthouse structures.
* Inspection or maintenance or AtoN. Extensive detail can be found on these topics in Guideline *G1151 Maintenance of AtoN Structures* [11].
* Methods of determining functional AtoN light requirements such as colour, characteristic and visibility. Extensive guidance can be found in IALA documentation associated with Standard *S1020 AtoN Design and Delivery* [35]
* Radio navigation equipment siting and licensing requirements.
* Electrical and other utility infrastructure.
* National or local, terrestrial or marine planning requirements.

The principles of good design practice detailed in this guideline do apply however, irrespective of the item being designed. The structural design of any AtoN infrastructure should be undertaken for the relevant environmental setting and using recognised codes. The Further Reading section also list several sources of reference that the reader can gather further information on the topics listed above.

# The AtoN structural design process

## The outline process

The structural design of new (or assessment of existing) AtoN includes consideration of characteristics including function, durability, sustainability, safety and quality. It is important that the AtoN manager is aware of how these characteristics are considered and appraised through the design process. They help form a checklist for design that the AtoN manager can discuss with suppliers and contractors to ensure a sustainable design approach will be taken. These characteristics are discussed in further detail in the following sections, with reference to additional IALA recommendations and guidelines.

Figure 1 summarizes the process and highlights key documentation that is produced or referenced during the process, with the relevant reference to the sections of this document.

Key design information includes:

* *AtoN manager’s specification* - The provision of a clear written specification means that the client can be sure, based on the supplier’s response, whether they can satisfy the client’s requirements. A specification is also a point of reference and ensures clarification on points of subsequent dispute.
* *Design codes* – these are discussed in greater detail in section 7 but use of the appropriate design codes relevant for the environment and geographical location is essential to producing a sustainable AtoN structural design.
* *Design statement* – The design statement is the designer’s confirmation of the relevant codes and criteria that they will use in the design. It combines a summary of the AtoN manager’s requirement with the appropriate values of design criteria. It is a reference for the designer of the parameters and values of those parameters to be used during the design and confirmation for the AtoN manager for future reference.
* *Design output documents* – these include design drawings, installation instructions, operation manuals and health and safety manuals. Together with the appropriate construction codes covering workmanship and site preparation they are used to construct the AtoN. It is also best practice (and required under some national regulations) that the designer should also undertake a designer’s risk assessment that assists identifying and mitigating risks that could be associated with the design. This may require several iterations before the design is finalized.

With reference to Figure 1, purchase of pre-designed AtoN products such as buoys or lights and light towers will not be subject to the same bespoke design procedure every time the product is purchased. The principles of Figure 1 still apply, however; the AtoN manager must state the requirement and performance criteria through a specification and the supplier should confirm that the products are appropriate for use in the geographical location and when subject to the anticipated environmental loadings for the location.

Diagram

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1. AtoN structural design process

## Principles of quality in AtoN design

### Quality in structural design

The use of the term quality can be open to interpretation. For some, it can mean the quality control of the finished product and for others a measure of how well the finished product meets the client’s expectations. It can also be reflected in how easy it is to find operational manuals or drawings, some years after installation. With reference to AtoN design, all these aspects apply.

Any project is a balance of cost, time and quality. It may not be cost effective to install the best quality AtoN but it may be applicable to install a fit for purpose AtoN that meets the required design life functional and technical requirements, when assessed under the appropriate codes for its geographical location. Each project will have its specific requirements.

### Quality management systems

It is recommended that the AtoN manager appoints designers, suppliers or contractors who undertake work within a quality management system (QMS), preferably based on the principles of ISO 9001: 2015 [15] . The principles of such a system include product traceability from design to decommissioning and consistency in their supply. This is particularly reassuring when AtoN managers may be purchasing off the shelf products such as beacons or buoys and expect the same quality of product or service at each purchase.

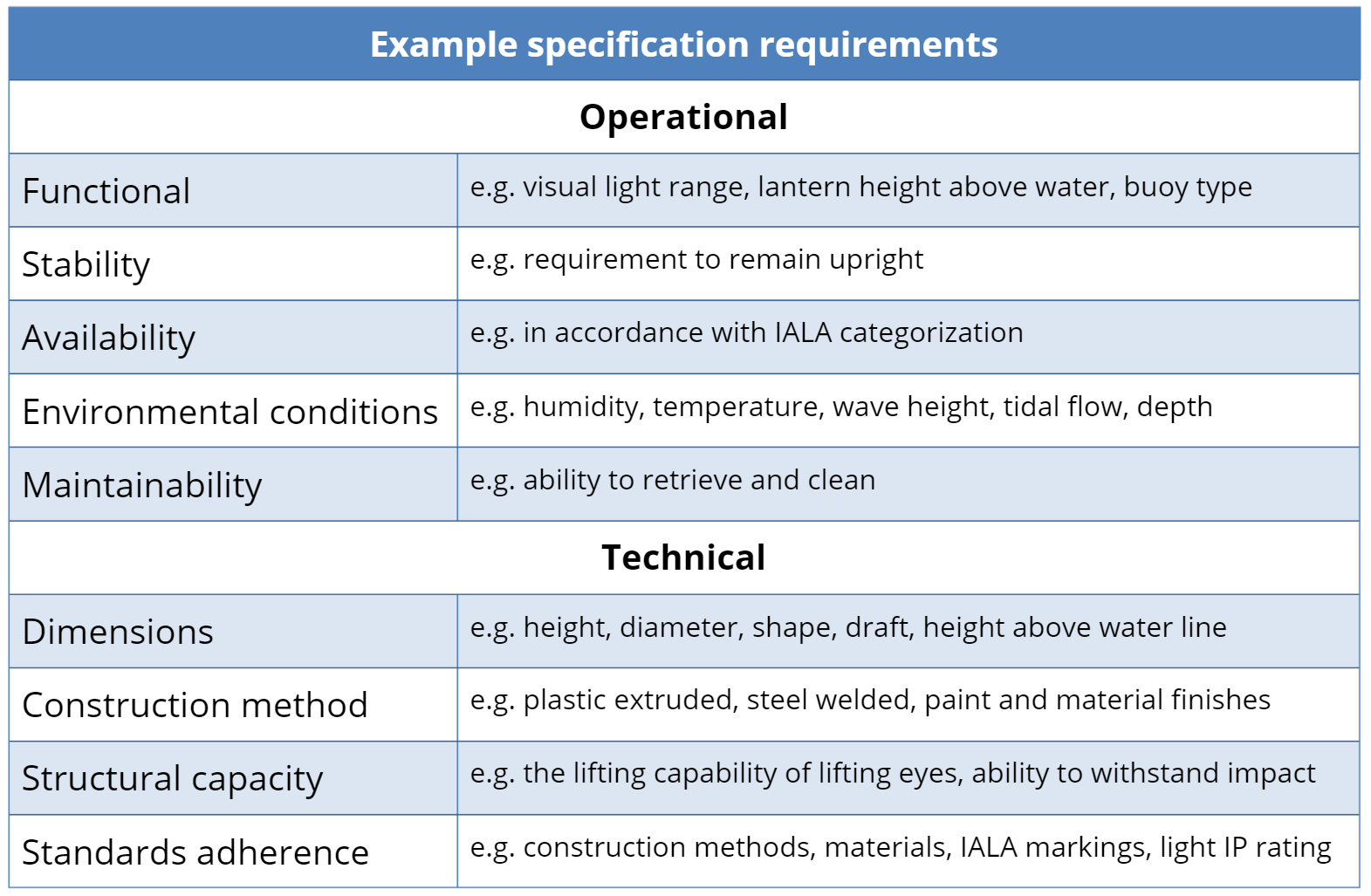
For bespoke AtoN provision, it is particularly important to have rigorous records of design statements or structural assessments, design changes, and a set of “as-built” documentation. Suppliers working to a QMS will have procedures for the issue of documentation and a means of document control that ensure the supplier receives the current version of all documents. Further information on the principles and characteristics of a QMS are included in *G1052 Guideline Quality Management in AtoN Service Delivery* [14].

# Specification

One key aspect in achieving quality in AtoN design solutions is the presence of a clear specification supplied by the AtoN manager. This principle is expressed in Guideline *G1133 Requirement Traceability* [2]

## Specification content

The provision of a clear written specification means that the AtoN manager can be sure, based on the supplier’s response, whether the supplier can satisfy the AtoN requirements. A specification is also a point of reference and ensures clarification on points of subsequent dispute. Figure 2 provides some examples of requirements that may be included in a specification:



1. Example AtoN specification requirements

A performance or output-based specification is where the supplier is given scope to propose solutions to an expected and known result within the boundaries of certain parameters specified by the AtoN manager.  It is important that the performance requirements are specified where appropriate for all design life stages of the goods or works including commissioning, operation, maintenance and decommissioning.

## Site investigations

On more complex AtoN projects, for example, the design of a 20m lattice tower with foundations, the AtoN manager may need to provide information about the site to facilitate the design. If the information is not available, the AtoN manager may be required to commission site investigations. Such investigations can include:

* Geotechnical investigation, to establish soil characteristics and ground conditions
* Topographical site survey, to establish ground levels and line of sight
* Services investigation, to identify utilities such as electricity or water supply infrastructure that could constrain the design
* Environmental impact assessments, to understand the effects of the installation on the local environment

Regulations, guidelines, standards or model specifications for undertaking geotechnical and topographic surveys are available in many countries and these are written to ensure the output data quality. Environmental impact assessment requirements are often stated within national regulations. It is important at an early stage to establish the required design information and the appropriate codes that should be used for the investigation (if conducted within the AtoN manager’s organization) or to specify to a site investigation contractor or consultant.

## Design statements

For more complex structural designs, once the designer has been appointed and provided with an adequate specification, the AtoN manager can then anticipate the receipt of a design statement from the designer. This document incorporates the requirements of the AtoN manager’s specification, states the elements that will be designed and confirms the relevant codes and loadings that will be used in the specific AtoN design. The design statement provides confirmation of one of the key requirements of appropriate AtoN design, which is, that the geographically appropriate codes have been used to design the AtoN. Section 9 provides more detail.

## Function

The primary purpose of any AtoN is to provide navigation safety related information to mariners. The type of information provided is derived from the attributes of the AtoN, such as its surface colour, geometrical shape (daytime) as well as the colour and rhythm of its light (during the night). The mariner must be able to detect and understand the signalling information provided within the operational range of the AtoN.

The physical size of the structure and the contrast of the surface colour against its surroundings determine the daytime range, while the intensity of the emitted light in the direction of the mariner determines range during the darkness. In both cases, the elevation of the signalling part of the AtoN (focal point) determines the possible geographical (line of sight) range.

The height of an AtoN structure, either fixed or floating, is therefore dictated by its fundamental functional requirement to act as a visible mark (either illuminated or unlit) or as a signal transmitter/receiver. The height of the structure line of sight above land or the seabed therefore will be a prime factor in its overall size and complexity. The level of design complexity will also depend on the structure’s foundation requirement and the nature of its environment.

Smaller daymarks or floating AtoN in shallow water may require minimal structural design scrutiny by the AtoN manager compared to a larger monopile or a lattice tower structure. Such items may be subject to regular purchase and as such, designed and manufactured to accepted standards. The specific colour, shape and topmark (where relevant) will be selected by reference to the IALA Maritime Buoyage System [3].

* Photo of Minsu’s leading light tower Korea
* Photo of groyne markers Thames estuary

For lit AtoN, the focal height of the light source is a critical functional requirement.

## Level of service and availability

Availability, in relation to AtoN, means the probability that the AtoN is performing its function at any time. There are IALA level of service categories for availability, expressed as a percentage of time that the AtoN is performing its function(s). The designation of a category is an indication of the criticality of the function of the AtoN. This in turn will influence the required reliability of the AtoN and the associated maintenance regime (see section 8.3). Guidance on selecting an appropriate category for a new AtoN is provided in Recommendation *R0130 Categorization and availability of Objectives for Short Range Aids to Navigation (0130)*[4].

Other requirement examples provided in Figure 2 will be discussed throughout sections 6 to 8.

# Loading of AtoN structural elements

The structural stability of an AtoN is essential to the functional performance of the AtoN and it is important that structural integrity is assessed through an appropriate design process.

## AtoN structural elements

There are common elements for which structural design and specification is undertaken, irrespective of the AtoN geographical location and specific codes used. These include:

* Steel elements, including member cross-sectional area, dimensions and fabrication.
* Concrete elements, including dimensions, strength, concrete durability and reinforcement.
* Timber elements, including dimensions, strength and moisture content.
* Connections between elements including welds and bolted connections.
* Foundations, where the designer considers the underlying soil properties and the ways the combined foundation and soil structure can fail.

The height of the AtoN determines the maximum achievable geometrical range and is a key design parameter that influences the design of the AtoN structural elements.

For AtoN, typical elements that require appropriate design and specification include the following, as illustrated in Figure 3: *(Mark up Figure 3 with the following elements where appropriate - Buoys, Moorings, Foundations, Shallow**, Piled, Steel elements e.g., lattice tower members, Concrete elements e.g., multi-pile beacon platforms., Monopiles, Connections, Welds, Bolts, Shackles, Lights)*

Diagram

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Drawing of buoy and mooring

1. Examples of AtoN design elements - marine monopile beacon, terrestrial lattice light tower and floating light

### Materials and their uses in AtoN

The AtoN designer will specify the use of material manufactured to certain quality and safety standards. Table 1 provides examples of materials commonly used in AtoN and the characteristics that are commonly specified through the design process:

1. Materials typically used for AtoNs and their key characteristics

|  |  |  |
| --- | --- | --- |
| Material | Typical AtoN uses | Key characteristics |
| Steel | * Tower members and fencing * Monopiles * Chains and shackles * Connection bolts and welds * Reinforcing bars and mesh | * Grade of steel (including tensile strength and thermal expansion properties) * Thickness * Welding methodology * Corrosion potential |
| Concrete | * Slab foundations * Piles (pre-formed and cast in-situ) * Marine platforms * Pre-cast units e.g., retaining walls, kerb stones | * Concrete mix i.e., water/cement/aggregate /additive ratio which defines:   + Compressive strength   + Workability * Flexural strength (increased by inclusion of reinforcement) * Reinforcement detail and cover to reinforcement |
| Timber | * Piles * Structural elements of platforms * Protective fenders | * Species * Source * Strength * Moisture content * Resistance to marine boring insects * Abrasion resistance |
| Plastic and rubber | * Buoys * Protective fenders * Insulating material for dissimilar metals | * Strength * Thickness * UV stability |
| Protective coatings and systems | * Buoys (steel):   + Paint * Piles:   + Paint   + Cathodic protection   + Tape wrappings for tidal zone * Tower elements and fencing   + Paint   + Galvanised coating | * Paint thickness, type and number of coats (paint system) * Environmental impact of product * Galvanised coating thickness * Method of coating application * Thickness and placement of tape wrappings |

## Loads, actions and forces

Irrespective of the specific size, material and structural requirements it is essential that any AtoN structural design considers the loadings to which it will be subject. It is important therefore that appropriate design codes are used (either by the supplier or by the AtoN manager’s design engineer) and that these will reflect actual loadings and environmental conditions. Not all AtoN designs will require extensive load analysis so the level of information that a supplier may provide will be reflective of the complexity of the AtoN.

Loads may be applied statically, for example the self-weight of the structure, or dynamically such as wind action. Dynamic loads can also be cyclical, that is they can be repetitive and regular, such as in the case of wave loading on monopiled structures. The effect of vibrations induced in the structure by such dynamic loads is dependent on the natural frequency of the structure and its ability to dissipate the vibrations. This ability is known as damping.

Wind loading is an important factor to incorporate in the design of AtoN and design standards appropriate to the geographical location should be used. It is also important to design connections for the anticipated loads as these can be the weakest link in the integrity of the structure. For example, a robust lattice tower could withstand high wind loads without deforming, but if the connections to its concrete foundation are insufficient, the structure may fail.

Modern design codes often refer to structural design loadings as “actions”. Assessment of the loads listed in the following sections are typically required by most structural design standards, irrespective of the national or international source. Live loads are generally considered as anything other than dead loads, but a third category of environmental loads is often used to describe loadings may act on a structure because of topographic or climatic conditions. Various codes have rules for the combination of loads in certain scenarios and how these should be applied to the structure in the design process.

Any design should incorporate the potential for climate change effects on environmental loads including sea level rise and increased storminess. The Intergovernmental Panel on Climate Change publishes updated assessments every five to seven years on the effects of climate change and many regions base updated guidance for environmental impacts on that guidance. For clarity, environmental loads are described in turn individually in paragraphs 6.2.4 to 6.2.11.

### Limit states and factors

It is useful to clarify some terms that are referred to often in structural design codes, namely ultimate limit state (ULS) and serviceability state. These describe what level of design is being undertaken and for what aspect of the design. Limit state design is a commonly used method of structural analysis

ULS is designing to limit the stresses in the materials to manage the probability of collapse. It involves the inclusion of combinations of safety factors and if all factored stresses are below the calculated resistances, it will satisfy the ULS design. The designer will check the structure for deformation of the structural members or stability, such as buckling of lattice tower structural members.

(Photo of:

* buckled lattice tower
* concrete cracking due to insufficient reinforcement)

Serviceability is the design process that manages the probability of the structure remaining fit for purpose without the need for repair. It is about the items that make the structure comfortable for the user or contribute to the durability of the AtoN. Exceedance of a serviceability state limit, therefore, may not result in structural failure but it may make the user experience less satisfactory. For example, certain strength wind loads may not cause a light tower structure to collapse, but it may cause the structural members to deflect sufficiently such that this translates to distracting vibration of the light, if deflection is not limited in the design.

Similarly, cracking in concrete foundations due to insufficient steel reinforcement (used to limit bending of the concrete under tension forces) will not cause immediate structural failure, but will cause deterioration of the structure over time due to the ingress of water and corrosion of the reinforcement. Serviceability loads may be applied with a safety factor of 1.0 (i.e., unfactored), depending on the codes used.

Note the distinction that serviceability, in the context of structural design, is not the same as maintainability. Serviceability is a specific set of structural analysis conditions related to the structure remaining fit for purpose without the need for repair. Maintainability is related to the ease of access and required frequency of repair of a structure. Designing for maintenance is discussed further in section 8.3.

### Dead loads/permanent actions

Dead loads (also referred to as permanent or static loads or permanent actions, depending on the codes) remain relatively consistent over time and include non-structural finishes. The main dead load is the self-weight of the AtoN structure. Although not technically static, allowance should be made when calculating the buoyancy of floating AtoN for the accumulation of marine growth, which can increase the dead load of a buoy between maintenance cleaning. Dead loads are calculated by calculating the volume of AtoN material and multiplying it by the relevant density of the material.

### Live loads/variable actions

Live loads (also referred to as imposed loads or variable actions) are loads created by dynamic forces such as pedestrians or machinery. They are usually temporary, changeable and dynamic. The weight of a maintenance engineer climbing a tower ladder would be considered a live load for the purpose of structural assessments. Live loads can be considered as uniformly distributed over an area, such as a group of engineers standing on a tower platform or as a point load such as the weight of machinery being lowered on a hoist from an AtoN structure.

Lighthouse visitors represent an important live load which must be taken into account.

### Wind

Wind loading is an essential environmental load used in AtoN design and is subject to specific and detailed calculation.

Typical design codes provide tables for a design wind speed estimation. These vary due to factors including the surrounding terrain and the geographical location. Alternatively, locally sourced meteorological information may be available for predicted maximum wind speeds. Where the designer has decided to collect wind data, certain standards may specify the methodology for collection.

Maximum anticipated wind speeds are then converted to wind pressure (a force per unit area) which is used to calculate the forces on the AtoN. Calculations for wind pressure consider the shape of the structure (for which a shape coefficient is included in the calculations) and its cross-sectional area.

### Ice/snow

In polar regions and areas prone to cold winters, the potential for accumulation of ice or snow on fixed AtoN structures should be considered over the design life of the structure. Both ice and snow can impose additional loading on lattice towered structures and the potential for additional load should be considered in the design.

In polar regions there may also be the potential for impact or static pressure from ice flows on marine based AtoN. The shape and wall thickness of floating AtoN should be designed with these loads in mind and alternative suggestions proposed within the AtoN system if it is anticipated floating AtoN may not be appropriate at a particular location.

### Seismic

Seismic loads are caused by the effects of earthquakes acting on structures. Certain regions of the world are more prone to seismic activity than others. The designer is required to use specific standards to calculate the loads and undertake specific checks. The derived loads are a function of geographical location, the type of structure, the geological conditions and statistical probability factors.

### Earth

If certain elements of land based AtoN are designed to retain earth, the loads imposed by the earth should be accommodated in the design of the element. For example, a boundary retaining wall for a tower site or a partially buried pad foundation. The loads imposed by the earth are a function of the soil properties, the retained height of earth and the natural level of water in the ground (the water table level). Consideration is also given to any vertical surface loading of the earth being retained, which is known as surcharge.

Soil properties are a key parameter in calculating the performance of concrete and piled foundations (see 6.2.12).

### Thermal

Daily and seasonal thermal changes can affect AtoN materials and an allowance for such effects should be incorporated into the design. This can be particularly important for steel component connections and for composite structures made from dissimilar materials, with differing thermal properties. Thermal differences will be moderated in a marine environment due to the cooling effect of a body of water.

### Wave

When designing marine based AtoN it is necessary to obtain the expected wave loadings as essential information in determining normal and extreme operating conditions. AtoN should be designed to withstand safely the effects of the extreme range of wave conditions expected during the design life of the structure.

For fixed marine AtoN, a design wave with a height and period is considered and used to calculate a force on the AtoN structure. The methodology used in the design calculation is related to the ratio of wave height to the submerged depth of the structure. For, floating AtoN the wave height is incorporated into the calculations for mooring forces and when considering stability in hydrostatic buoy design. Wave conditions are also a significant consideration during the installation of marine based AtoN and their consideration should be part of the designer’s and marine contractor’s risk assessments.

### Hydrostatic

Marine based AtoN should be designed to withstand safely the effects of the range of water levels from extreme low water to extreme high water expected during the design life of the structure. Hydrostatic pressure is considered to act linearly from a minimum at the water’s surface to a maximum at the seabed and is a function of water density and depth.

### Current/flow/Impact

The water loads imposed on marine based AtoN by tidal and wind-derived flows should be considered over the design life of the structure. Forces may act in different directions on a structure over a tidal cycle in a fast-flowing tidal estuary. The loads are a function of water density, water velocity and the shape of the structure. There is a possibility that debris can impact and/or accumulate on structures in estuaries and consideration should be given to the possibility that a “debris mat” can form which can act as an additional point load on a structure.

Although they are not generally also designed to act functionally as a vessel mooring or berthing structure, marine based AtoN can be subject to vessel impact. The risk and magnitude of such an impact should be considered in the design.

Diagram

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Drawing of buoy and mooring

1. Examples of loads to be considered in AtoN design - marine monopile beacon, terrestrial lattice light tower and floating light

### Forces and reactions

It is useful to state some of the forces that are experienced by AtoN structures under loading, to understand the common load combinations that structural design codes consider. With reference to Figure 5 below:

*Compression* forces crush a material by squeezing it together. In AtoN, compression may be seen for example, in a buoy being crushed by ice. Concrete is a very strong material when subject to compression forces.

*Tension* forces stretch a material by pulling its ends apart. In AtoN, tension forces might be seen by failure of a mooring chain. Concrete is reinforced with steel bars because it is very weak when subject to tension.

*Torsion* forces twist a material by turning the ends in opposite directions. In AtoN, this might be observed in a lattice tower secured at four corners on a base plate or steel walkways that are secured at both ends and subject to loadings in high winds.

*Bending* is a combination of tension and compression. In AtoN, this might be observed by deflection in a vertical pole or lattice tower member when it is subject to a combination of loads including wind or excessive additional equipment.

*Shearing forc*es tear a material by material being loaded in opposite directions at the same time. In AtoN, this might be seen by a bolt connecting two steel beams in a lattice tower being pulled apart by loads acting in opposite directions. Shear forces can also be observed by the movement of a foundation or retaining wall if the soil/structure is designed incorrectly

*Bearing forces* on soil or end of pile. A shallow foundation transmits loads from a structure (e.g., a lattice tower) to the soil over the area of a foundation. If this bearing pressure is too great for the bearing capacity of the soil, there is a risk the foundation will sink. Similarly, a deep end-bearing pile is designed to transfer the bulk of its load directly to the base or toe of the pile once a solid layer is penetrated.

A deep friction pile transfers its load along the entire shaft using friction between the pile and soil to achieve the required load when a solid layer cannot be penetrated. *Skin friction* is the resistance of the soil to the downward forces created when the pile is loaded by the structure upon it. If the skin friction is insufficient to support the loads the structure will not be supported.

Graphical user interface

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1. Typical design forces

Dynamically applied loads, particularly cyclical loads can have significant adverse effects on structural connections and the strength of structural members. In structural steel for example, microcracks in the material caused by dynamic cyclical tensile loads (such as those caused by wave action acting against a monopile) may gradually increase in a process called fatigue until the steel permanently deforms and fails. The ability of a material to return to its original size and shape once a load has been removed is known as its capacity for “elastic deformation.”

# codes

## Definitions of regulations, codes, standards and guidelines

Regulations or codes are generally mandatory requirements in construction and design that apply in individual countries. They are usually enacted by law and are regulated and enforced. The Fiji National Building code is such an example (full title Public Health (National Building Code) Regulations 2004 [17]).

Standards are developed using a consensus process that includes all stakeholders and publicised by a national or international organization such as Standards New Zealand, BSI or ISO. Standards are often referenced by codes as a requirement to be met but are not legally enforceable.

Map

Description automatically generated

1. Examples of national and international design standards in use

Approved Codes of Practice in some countries are recommended methodologies against which users will be scrutinised if there is a need to challenge the design.

Guidelines are generally examples of best practice to help achieve regulations and standards.

Including all relevant codes, regulations standards and guidelines into AtoN design will help the AtoN manager be reassured that the design is appropriate and compliant and help prove that in case of future challenge. Recording and justifying any deviation from normal practice is also useful to record in a design statement (see section 9).

## Typical standards

Irrespective of the global location, the regional design standards often cover common themes to assist designers, and compliance with such standards is generally considered to be best practice. In certain regions e.g., in Fiji The Insurance Council of Fiji requires insured buildings to be “cyclone certified” in accordance with Australian Standard AS4055 by an council-approved engineer [36]. Deviation from the standards is permissible but any deviation from normal design procedures or recommended data should be explicitly recorded in the design statement so that the decision can be referred to and justified if necessary.

Regional areas tend to use differing standards for structural design, but the aspects of the design standards are similar. Regional standards often include the following areas:

* Principles for design.
* Loadings
* Structural steelwork.
* Reinforced concrete.
* Geotechnics
* Piling
* Timber

Codes relating to the design of marine structures are also often specifically referenced by AtoN designers. These tend to complement regionally relevant codes for the specific areas above but with specific recommendations for loadings such as wave, debris and vessel berthing loads.

There are globally applicable standards for AtoN, such as IALA and PIANC guidance on buoy and mooring design. Two specific national codes that are often cited by PIANC in their published documents are British standard BS 6349 Maritime works (all parts) *(ref)* and the Australian standard AS 4997:2005 Guidelines for the design of maritime structures [19] .

The following sections describe generic standards that the AtoN manager may see reference to in design documents and records, including more detail about where they may be applied in the design of AtoN and the loadings that may be considered in the design.

### Loadings

Design criteria for loadings are often provided in a specific separate standard by many standards publishers. In many countries the permanent and variable actions as described in sections 6.2.2 to 6.2.8 are included within a specific document. Example documents are the European *Eurocode 1: Actions on Structures* [20] and the Indian *IS: 875 (Part-3)* [21].

Criteria and data for assessment of maritime specific variable actions (environmental loads) included in section 6.2.9 to 6.2.11 will often derive from specific documents such as *AS 4997* [19].

Loadings standards also provide guidance on combining loads for different situations and applying safety factors depending on the structural analysis methodology (see 6.2.1).

Wind loads are a critical environmental load in cyclonic areas and both wind and wave loadings should incorporate regional climate change predictions.

If the structures is likely to be exposed to loadings that could cause vibrations such as wind loading of monopoles or wave action on monopiles they will consider the potential for vibrations (see 6.2). Assessment of vibrations in structures is a specific and complex process, where the designer will try and limit the natural frequency of the structure by either making the structure stiffer or adding mass, in an iterative process.

### Structural steelwork

Steelwork elements of typical AtoN may include structural members of lattice towers or monopoles supporting land-based lights. The elements are assessed for how they work as a structure (globally) and on an individual element level (locally). The analysis method can depend on the cross-sectional dimensions of the steel and the method of connection.

The steel elements are assessed for stresses caused in the steel due to individual shear, bending and torsion forces and combinations of those. They are also assessed for deflection.

Connections are an important aspect of structural steel design. The capacity of both welds and bolts are calculated to withstand shear, *bearing* and tension.

Design of steel elements will also be accompanied by a statement about the grade of steel assumed or required. It described in terms of its thickness and strength.

Examples of structural steelwork codes include the Australian *Steel structures code AS 4100* [22] and the North American *AISC 360* [23]

### Reinforced concrete

Examples of reinforced concrete used in AtoNs includes pad foundations of tower bases, concrete piles and concrete platforms of multi-pile beacons.

The properties of concrete mix can change due to its composition, primarily the water to cement ratio but also the inclusion of other constituents to improve its workability, curing time or resistance to sulphate salts. The concrete design will have a specified mix of water, cement, aggregate and other constituents and be expected to have a certain value of compressive strength. It is therefore important that the design mix is recreated as specified if the concrete is being mixed on site, rather than delivered by a concrete company.

Concrete is often tested on a site by using the slump test which checks for the correct water/cement ratio. Any ready mixed concrete delivered from reputable firms will also have regular compressive test carried out on concrete samples The concrete is tested by creating a test cube or cylinder and its compressive strength tested after specific periods of time including seven days and 28 days.

Steel reinforcing bars are what provides the concrete with its tensile strength and stops it cracking under bending loads and shearing forces. Individual reinforcing bars are specified as a specific diameter at a certain spacing. These are arranged into “cages” in a specific sequence known as a bar bending schedule. Pre-welded reinforcing meshes are often used in slabs and shallow foundations.

The environment is a criterion used in concrete design. How exposed to aggressive chemical deterioration and physical abrasion the concrete will be is a factor in the concrete mix and the amount of “cover” required to the reinforcing bars. Steel reinforcement can be supplied galvanised or covered with other protective coatings.

Concrete can also be used in pre-formed units such as kerb stones or retaining walls. The principles of the design mix and reinforcement specification will all still apply. Additional on-site checks should be made that the precast units are installed to the manufacturer’s instructions and to the relevant tolerances.

Examples of concrete codes in use are the British National Annex for Eurocode 2, *BS EN 1992 Design of Concrete Structures* [25] and the New Zealand *Concrete structures standard* [26].

### Geotechnical, seismic and piling

The consideration of soil conditions is essential for any AtoN structural design. The way the structure and soil behave together is considered during design. For shallow or pad foundations the bearing capacity of the soil underneath the structure is considered. For piled foundations and monopiles the “skin friction” at the soil pile interface and the bearing capacity of the soil underneath the end of the pile are parameters that are checked during the structural analysis.

The location of the water table for land-based foundations is important as this can influence the soil properties. Examples of geotechnical and piling codes include Korean foundation design/canada foundation design.

Piles are checked during design for bending and deflection, and in the case of end bearing piles for the bearing capacity. The grade and thickness of steel will also be specified in the design. Marine based monopiles also must be designed for the hydrostatic and hydrodynamic forces of the sea or river, as well as the soil properties into which they are embedded. BS 8004:2015+A1:2020

The design of structures to consider seismic activity is often the subject of a separate national or international design standard. The purpose of the standard is to complement, the equivalent structural design codes with specific loads or actions and design criteria, to ensure the design of earthquake resistant structures. Examples include the Iranian standard *No.2800* [28] and the Brazilian Standard *NBR 15421:2006* [27].

### Timber

The use of timber in AtoN structures is common, particularly for simple marine based beacons. Timber is used for piles and timber posts. Commercial timbers are termed hardwood or softwood according to their botanical classification (rather than their physical strength). Timbers are often classified by their strength and their timber species to give an indication of structural strength.

There are design codes specifically for the design of structural elements, but the material considerations are equally important including moisture content, shrinkage potential, fire resistance and density. Resistance to marine boring insets and abrasion resistance are also important features. The assessment of bending, shear and torsion forces is similar to other structural elements and the assessment of connections also requires explicit consideration.

Many marine timbers used historically are tropical hardwoods and it is no longer considered sustainable to use many of these products. Any timber design specification should be for timbers that have been purchased through ethical trading and for which there is a validated “chain of custody” for their source and production.

### Marine/AtoN specific

The design of floating AtoN should be undertaken with reference to the several IALA documents listed in the references including *G1006* [30] *G1066* [29] and *G1099* [31]. PIANC also produce internationally applicable design guidelines for specific maritime installations, and these often cite some specific codes including the British Standards BS6349 and the Australian AS4997. Many other countries have also developed their own design guides for maritime structures.

In addition to referencing national structural guidelines these, maritime specific guidelines specify wave and hydrostatic loadings. In addition to AtoN design, they provide information for the design of vessel berths and fendering.

## Construction codes

Workmanship is an explicit aspect of many design codes and a specific example of quality control. The way in which the design is implemented at the construction stage is critical in ensuring the structural stability and durability aspects of the design are achieved. Many countries ensure the workmanship of the specified designed is incorporated into building regulations or codes. Examples include the placement of wet concrete to ensure adequate distribution within and around a reinforcing bar cage and the compaction of earth in appropriate layers before constructing a tower foundation, to reduce the potential for settlement of the structure. Some national organizations publish model project specifications for use in technical and contract documents.

The welding methodology and ultimate welding thickness on steel buoys may be an example of a construction detail that is specified by an AtoN manager

Ensuring compliant and consistent product quality can be particularly challenging in extreme climates. For example, high temperatures can lead to premature evaporation of water from concrete mixes which adversely affects the desired compressive strength. It can also lead to expansion of metals that can affect the connections of steel structures leading to stresses on joints if such expansion has not been accommodated in the design. Hot temperatures can also make steelwork difficult to handle and is generally debilitating for personnel, which again can lead to mistakes and hurried construction of AtoN elements.

Guideline G1136 *Providing AtoN Services in Extremely Hot and Humid Climates* [13] provides further commentary on the impacts and mitigation measures that can be undertaken to address the challenges of workmanship in hot climates.

Finally, the construction phase will also be accompanied by regulations or standards for temporary works. for example, temporary access platforms or concrete formwork.

# Non-structural design criteria

## Durability

Certain standards also specify the design of elements to resist the physical or chemical deterioration due to the environmental setting. AtoN structures and foundations installed within an estuarine or coastal waterway are particularly susceptible to deterioration due to the saltwater environment. Certain tidal levels, such as the low water area can be particularly detrimental for steel structures and can encourage microbial activity (Accelerated Low Water Corrosion, ALWC). The action of soils containing high concentrations of sulphate salts can be damaging for concrete.

Mechanisms for deterioration of AtoN also include wave erosion and windblown debris. The abrasive nature of cyclonic winds can be particularly damaging to structures. The design process will ensure specification of element characteristics to reduce the risk of deterioration. Some examples are:

* Member size – steel elements may be designed with a corrosion allowance to ensure minimum dimensional requirements are always maintained.
* Sacrificial protection such as a galvanised coatings and cathodic protection systems.
* Physical protection including the application of finishes or bituminous tape wrappings.
* Materials, for example the moisture content of structural timber or a concrete mix to resist sulphates in soil.
* Placement and fixing of e.g., in reinforced concrete the use of sufficient reinforcing bars to withstand tension forces that could induce unwanted cracks.
* Housing of electrical equipment, lights and batteries, from water and dust ingress and specification of ingress protection (IP) ratings.

## Sustainability

Sustainability is a core philosophy at the heart of any design process. Guideline *G1036 Environmental Management in Aids to Navigation* [5] provides numerous examples of how sustainability can be incorporated into AtoN design.

The whole life impact of AtoN should be considered in the design and the AtoN manager should feel confident in asking suppliers and designers how they have maximised the sustainability of any design solution. It may ultimately not be economically feasible to design structures for the worst-case loadings, for example, but it should be demonstrated that consideration of the options for sustainable design have been considered and compared over the design life of the AtoN. Sustainability considerations include those described in the following paragraphs.

### Design life of AtoN, whole life maintenance and decommissioning requirements

The design life is the period during which the item is expected by its designers to work within specified parameters. The robustness of the design to resist current and future climatic changes, including extreme weather is therefore important in ensuring the design life duration is realized. A more durable design may be more expensive as an initial solution but may remove the need for one or more replacement AtoN over its design life, thus reducing the manufacturing, installation, and disposal costs of additional AtoN.

An AtoN that is designed for durability may also require less maintenance and therefore have less impact due to the reduced use of materials and maintenance vessels and vehicles. This in turn will reduce the whole life carbon footprint of the design. Consideration should also be given to the decommissioning or replacement of AtoN structures and how they can be refurbished, recycled or disposed of. It is important to consider the extraction of piled structures within the river or seabed such that any legacy structures do not become a navigational hazard.

An example of typical design life of structure specified under the British National Appendix to Eurocode 0, Basis of design is included in appendix X but it must be noted that this is just an example and will change depending on the standards used and geographical location. Typical design life for AtoN structures could be 15 years for floating AtoN and 30 to 50 years for lattice towers. The actual life of the structure realized however, is very dependent on environmental exposure and maintenance regime

### Preferred technical solution

The preferred solution may be a compromise between cost, technical preference and environmental or societal impact. For example, the use of anchors for moorings in coral seabed habitats can be destructive and should be avoided, where possible [5] . Guideline *G1108* [32] provides an example of how the dimensions of a day board structure were adjusted to increase the rigidity and minimize the surface area resistance to the strong winds in Alaska (see Figure 7)

1. Example of structure modification to reduce risk of wind damage

Consideration should also be given to making AtoN temporarily demountable or stowable in extreme events, during which vessels may not be transiting (and therefore requiring AtoN services) or be at anchorage to await the passage of dangerous weather conditions. Although this approach means establishing and practising extreme event preparation procedures and the use of manual resources (and associated costs) to mobilize and demobilize after an extreme event, it may reduce the replacement costs of damaged AtoN.

### Waste reduction and alternative materials

It is essential to identify the opportunities for the reduction of waste materials for the whole life of the AtoN. The design should consider the use of:

* Alternative environmentally friendly products that will have no or minimal, potential toxic effects on the environment.
* Products that are easily recyclable or reusable at the end of their design life.
* Construction methodologies that will reduce the potential for waste and associated environmental impact. For example, this could include using prefabricated concrete products to minimise the potential for mixing too much concrete on-site and having to dispose of the excess.

### Materials storage

If potentially toxic products cannot be eliminated from the design, they should be stored to minimize impact in case of spillage or leakage This may mean creating a specific housing or bunded area to contain such materials.

### Stakeholder consultation

Undertaking timely and appropriate stakeholder management is a fundamental component of sustainable design. For example, the noise from generators or night-time illumination by lit AtoN could impact a local community and it is essential to understand any constraints on the selected AtoN solution at an early stage. Similarly, the timing of works could impact environmentally designated areas or interrupt seasonal recreational activities. Guideline *G1079 Establishing and Conducting User Consultancy by AtoN Authorities [12]* provides extensive information on identifying and consulting stakeholders.

Whilst stakeholder management is not a specific designer’s task, it is important that the designer and AtoN manager identify any issues that could impact or be impacted upon by stakeholders, for example timing, visual impact or the impact on environmentally designated habitats.

There are national and regional sources of information that can assist in stakeholder identification. National examples are the UK Magic Map [34]and the American EnviroMap, [33] both publicly available interactive map layer that can be interrogated for environmental designations and used therefore to help identify any local or regional groups that may have an interest in the construction or installation of AtoN.

### Renewable energy

Power requirements and the ability to employ renewable energy sources such as solar power are another sustainable consideration. It is important to consider the requirement for services within the design at an early stage. For example, it may be necessary to ensure ducting for electricity cables is accommodated in the concrete foundations of a tower base design to prevent the need for breaking out and relaying the concrete foundation at a later stage.

## Maintenance

As discussed in section 8.2, design for whole life maintenance involves the consideration of balance between sustainability and cost. Maintenance costs can be a significant consideration over the AtoN design life, so it is therefore important to consider the optimal balance of initial investment and durability of the selected AtoN, and maintenance costs together with the sustainability considerations highlighted in section 4.4. *Guideline G1035 Availability and Reliability of Aids to Navigation – Theory and Examples* [6] and Guideline *G1077 Maintenance of Aids to Navigation* [16] provides detailed guidance on establishing an optimised maintenance programme for AtoN with reference to functional availability and reliability requirements (see section 5.2).

The geographical location can impose its own constraints on the maintenance options and the maintenance regime anticipated at design stage should incorporate those. Physical accessibility to undertake monitoring, inspection and maintenance design life is an important consideration. Any design should consider the need to access all parts of the structure as appropriate and under any seasonal, climatic, or tidal limitations. These considerations should be explicitly recorded in a designer’s risk assessment document.

Guideline *G1023 The Design of Leading Lines [37]* provides information regarding the design of light platforms to facilitate access for maintenance.

It is important that technical design information such as “As-built” drawings or operating manuals are passed from the supplier to the AtoN manager and that this is easily accessible for inspection, health and safety purposes and in case of emergency.

The design should also consider the opportunity for remote monitoring or inspection and how that could optimise the sustainability of the preferred AtoN solution. Extensive guidance on the maintenance of AtoN, including the characteristics of typical AtoN materials can be found in Guideline *G1151 Maintenance of AtoN Structures* [11].

## Safety and security

### Safety

All persons have a duty to manage risk by eliminating health and safety risks so far as is reasonably practicable, and where removal is not feasible, to minimize the risk. Many national and regional regulations include the requirements for the designer to undertake a risk assessment for the construction, maintenance and decommissioning risks posed by their design. Even when this is not specifically required by national or regional interpretation it should be considered a best practice safety activity during the design process.

For example, if a functional requirement is that an AtoN light is situated 5m above ground level, the initial structural design may suggest a fixed pole structure with a top bracket to support the light. The maintenance requirement may be that a means of access is required to facilitate inspection and maintenance activities due to the height, and the design suggests a small access ladder attached to the structure. Personnel then need to be able to use the ladder such that the risk of falling from it is minimized.

Assessing the design risks will therefore include appraisal of whether an alternative design can remove the need for access at height, for example a mid-hinged tower that can be lowered to the ground. If it is not possible to remove the need for working at height, then consideration is made of whether alternative access to the top of the tower is achievable, such as the use of a mobile access platform. If this is not feasible due to access or availability issues, adequate structural design of the ladder and its connections to withstand the loadings imposed by its use is required. It is also necessary to consider features such as adequately sized work platforms or fall restraint systems that the personnel attach to when using the ladder.

Designing for safety is generally interpreted at a national or local level by governments or local authorities and an explicit requirement of many countries’ building codes and regulations. Guideline *G1092 Safety Management for AtoN Activities* [10] provides further overview and practical guidance to the management of AtoN at all stages of design life.

Other safety considerations include fire resistance properties (often an explicit part of structural design standards), adequate handrails and edge protection on walkways and platforms and safe access to facilities where work boats are used as the primary access.

Consideration should be given to facilities at remote sites for maintenance personnel for example shelters in case of bad weather or the installation of waterless toilets. Reducing the need for maintenance visits through sustainable design also reduces the safety risks.

Measures should be taken to protect persons and equipment from the effects of lightning on AtoN structures. Guideline *G1012 The Protection of Lighthouses and Other Aids to Navigation against Damage from Lightning* [7] provides extensive guidance on the assessment of the risk of lightning strikes and the requirements to protect structures, equipment and personnel from its effects.

### Security

It is important that the design incorporates security features to ensure maintenance of function and minimization of the need to reactively maintain or replace AtoN elements. Damage to AtoN can be caused by wilful actions or by the indirect activities of wildlife or climatic events. It is important, particularly on remote sites that the AtoN designer considers the security risks and suggests design features to mitigate the risks. It is also essential, as for any structural element that the design is undertaken with reference to appropriate codes and anticipated environmental conditions. Mitigating security features can include:

* Security fencing.
* Remote monitoring cameras.
* Anti-climb barriers and paint.
* Installation of bird spikes.
* Arrangement of desirable components positioned out of view or in relatively inaccessible areas.
* Use of collapsible bollards or concrete barriers to prevent unauthorized vehicular access.

It should be noted that national and local regulations should be consulted to ensure the use of compliant security features. For example, the use of anti-climb paint may require the installation of a visible sign warning that it has been applied to a tower structure. Guideline *G1109 Theft and Vandalism Deterrents* [8] provides further useful suggestions on the measures that can be incorporated into AtoN design to reduce the potential impacts of wilful damage. Guideline *G1091 Bird Deterrents and Bird Fouling Solutions* [9] similarly describes methods of deterring birds from nesting or congregating at AtoN sites.

# Design statements

On more complex AtoN projects, the AtoN manager can expect to receive a design statement from the designer. This document incorporates the requirements of the AtoN manager’s specification, states the elements that will be designed and confirms the relevant codes, loadings and other specific criteria that will be used in the AtoN structural design. The design statement provides confirmation of one of the key requirements of appropriate AtoN design, which is that the appropriate codes have been used to design the AtoN.

Not all works will be accompanied by a lengthy design statement, only where there is complexity of design. For a simple navigational buoy and sinker, the AtoN manager may simply require confirmation from the designer or supplier that it will perform in the environmental setting for its design life (as described in the AtoN manager’s Specification) and the details of any specific installation or maintenance instructions. For a 20m high lattice tower design, for example, the AtoN manager can expect to receive a specific document from the designer, listing the relevant design criteria and including confirmation that appropriate codes will be adhered to in the design.

Annex A contains an example of a design statement for the design of a monopile structure and an example checklist that AtoN managers can use when discussing designs with either suppliers or designers. For simple off-the-shelf purchases many of the specific queries will not apply, but basic questions regarding the use of the product for the environmental conditions anticipated are still relevant and important to satisfy.

*Repeat Figure 6 annotated with design codes used for the various elements e.g., can be UK for monopile and Australia for lattice tower.*

1. Typical design codes used in the UK and Australia respectively for AtoN elements

# Definitions

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

Serviceability limit state– the structural design conditions related to ease of use and potential for repair.

Maintainability - refers to the ease with which maintenance activities can be performed on an AtoN structure and the probability that an AtoN can be restored to normal operating conditions after undergoing maintenance.

Ultimate limit state (ULS) - ULS is designing to limit the stresses in the materials to manage the probability of collapse.

Curing

Cathodic protection systems – utilise the physical and chemical properties of seawater and a sacrificial metal to force the corrosion of anodes consisting of the sacrificial metal, *rather* than the steelwork of the marine structure to which they are attached. Systems can be passive, whereby the system relies on the dissimilar (see below) potential conductivity of the anode and the structure, or actively charged with an electrical current – impressed current cathodic protection (IPPC) – to provide additional current to force the corrosion of the anode.

Formwork

Cast in-situ

Cover

Dissimilar metals – All metals have a potential to corrode based on their atomic structure. Dissimilar metals describe the process whereby one metal is likely to corrode more quickly than another when they are placed together in the presence of water. The difference in potential for corrosion in different metals is the reason why for example, stainless steel (low potential) and aluminium (high potential) structural components would not be assembled in direct contact, without using an insulating material between them.

Shallow foundation – A type of building a foundation that transfers building loads to the earth very near to the surface, rather than to a subsurface layer or a range of depths Shallow foundations are constructed where soil layer at shallow depth can support the structural loads. The depth of shallow foundation is generally less than its width.

Piled foundation - A piled or deep foundation transfers building loads to the earth to a subsurface layer or a range of depths. A deep foundation is required to carry loads from a structure through weak compressible soils or fills on to stronger and less compressible soils or rocks at depth, or for functional reasons. Deep foundations are founded too deeply below the finished ground surface for their base bearing capacity to be affected by surface conditions, this is usually at depths greater than three metres below finished ground level. An end-bearing pile is designed to transfer the bulk of its load directly to the base or toe of the pile once a solid layer is penetrated, whereas a friction pile transfers its load along the entire shaft using friction between the pile and soil to achieve the required load when a solid layer cannot be penetrated.

Commissioning – To commission an AtoN structure, means to carry out all the necessary test and procedures, using industry codes where appropriate, to show that it is fit for the purpose for which it was designed. For AtoN structures, this includes checks that the focal height provides the functional requirements as identified in the AtoN manager’s specification.

Decommissioning – Decommissioning of an AtoN structure means the retirement from service of the structure and the necessary procedures to undertake this in a safe and sustainable way. In addition to recycling, refurbishment, dismantling or removal of the structure, decommissioning should include a risk assessment of the AtoN no longer performing a functional role (i.e., the navigational risk) and the health, safety and environmental risks of refurbishing or dismantling the structure.

# abbreviations

PIANC

VTS

# references

1. IALA. Recommendation R1018 Responsible Design, Operation and Maintenance in the Provision of Marine Aids to Navigation
2. IALA. Guideline G1133 Requirement Traceability
3. IALA. Recommendation R1001 The IALA Maritime Buoyage System
4. IALA. Recommendation R0130 Categorization and Availability Objectives for Short Range Aids to Navigation (0-130)
5. IALA. Guideline G1036 Environmental Management in Aids to Navigation
6. IALA. Guideline G1035 Availability and Reliability of Aids to Navigation - Theory and Examples
7. IALA. Guideline G1012 The Protection of Lighthouses and Other AtoN against Damage from Lightning
8. IALA. Guideline G1109 Theft and Vandalism Deterrents
9. IALA. Guideline G1091 Bird Deterrents and Bird Fouling Solutions
10. IALA. Guideline G1092 Safety Management for AtoN Activities
11. IALA. Guideline G1151 Maintenance of AtoN Structures
12. IALA. Guideline G1079 Establishing and Conducting User Consultancy by AtoN Authorities
13. IALA. Guideline G1136 Providing AtoN Services in Extremely Hot and Humid Climates
14. IALA. Guideline G1052 Quality Management in AtoN Service Delivery
15. International Organization for Standardization. (2015) Quality Management Systems – Requirements ISO 9001:2015
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17. Fiji Department of Health. (2004) Public Health (National Building Code) Regulations 2004
18. BS 6349 Maritime works Part 1-1: General – Code of practice for planning and design for operations
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28. Iranian Building Housing and Research Center. (2015) Iranian Code of Practice for Seismic Resistant Design of Buildings, Standard No. 2800, 4th Edition
29. IALA. Guideline G1066 The Design of Floating Aid to Navigation Moorings
30. IALA. Guideline G1006 Plastic Buoys
31. IALA. Guideline G1099 The Hydrostatic Design of Buoys
32. IALA. Guideline G1108 The Challenges of Providing AtoN Services in Polar Regions
33. EPA. [EnviroAtlas (epa.gov)](https://enviroatlas.epa.gov/enviroatlas/interactivemap/)
34. DEFRA. Magic Map
35. IALA. Standard S1020 AtoN Design and Delivery
36. Pacific Regions Infrastructure Facility. (2021) Regional Diagnostic Study of Constraints in the Application of Building Codes in the Pacific, Fiji Case Study
37. IALA. Guideline G1023 The Design of Leading Lines

# Further reading

1. Cobb, F. (2015) Structural Engineers Pocket Book Eurocodes, Third Edition
2. Pack, L. (2018) Australian Guidebook for Structural Engineers
3. PIANC Guidelines for Marina Design
4. BS EN 1990:2002 Eurocode basis of structural design
5. Maritime works –Part 1-1: General – Code of practice for planning and design for operations
6. Part 1-2: General – Code of practice for assessment of actions; 2)
7. Part 1-3: General – Code of practice for geotechnical design;
8. Part 1-4: General – Code of practice for materials
9. Part 4: Code of practice for design of fendering and mooring systems;
10. <https://www.construccionenacero.com/sites/construccionenacero.com/files/u11/ci38_38221_comparative_study_of_codes.pdf>
11. ocean engineering division united states coast guard Washington, D.C august 2013 specification for fabrication of steel ocean buoys specification no. 464 revision k
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# Index

**No index entries found.**

2. Design statement Example and checklist
   1. Design statement example
   2. Design statement checklist
3. Example of regional ATON structural design code information e.g. Souhwest Pacific REGION
   1. SPECIFIC CHALLENGES OF GEOGRAPHICAL AREA

Tropical storms, cyclones, earthquakes.

* 1. RELEVANT REGIONAL DESIGN CODES

Australian/New Zealand standards, national building codes translate those but mainly for buildings

* 1. INTERNATIONAL GUIDANCE IN USE IN REGION

IALA (This document)

PIANC referenced in AS 4997

* 1. LOCALLY MODIFIED OR ADOPTED STANDARDS

National building codes. Undergoing review in certain cases

* 1. SUMMARY of REGIONAL information FOR ATON DESIGN

The following structural design standards are available for use in the design of AtoN. These are either currently in general use or could be used in a supplementary manner (i.e., not in contradiction) to the primary recommended standards. The use of any standard is suggested as initial guidance and the AtoN manager should check the local building code requirements of the geographical location before deciding on the specific standards to apply. All standards included in the table are are referenced at the end of this document.

Design codes can be updated and amended regularly so it is wise to check that any reference is the most recent version. Web addresses are provided for the Australian, New Zealand and British Standards authorities in the Further Reading section.

|  |  |  |
| --- | --- | --- |
| Design element | Relevant documents | Specific Items |
| Actions[[1]](#footnote-2) (Loadings) | AS/NZS 1170.0:2011 Part 0 | General principles |
| AS/NZS 1170.1:2011 Part 1 | Dead loads (permanent actions). |
| AS/NZS 1170.1:2011 Part 1 | Live loads (imposed actions). |
| AS/NZS 1170.2:2011 | Wind actions. |
| NZS 1170.5:2004[[2]](#footnote-3) | Seismic actions. |
| AS 4997:2005 Guidelines for the design of maritime structures | Hydrostatic actions. |
| Wave loads. |
| Current loads. |
| Structural stability  (ULS and Serviceability) |  | Foundations. |
| AS 2159 | Piling. |
| NZS 3404 Parts 1 and 2:1997 Steel Structures standard | Steel. |
| NZS 3101.1&2:2006 (plus Amendments 1-3) Concrete Structures Standard  OR *(which is it, may come down to building codes?)*  AS 3600: 2018 | Concrete. |
| Tbc | Timber |
| Tbc | Connections. |
| Tbc | Stairs and walkways |
|  |  |
| Durability | tbc |  |
| Safety |  |  |
| Construction | NZS 3109:1997 Concrete construction (including Amendments 1 and 2) | Concrete and reinforcement mixing and placement on major works e.g., tower foundations. |
|  | NZS 3124:1987 Specification for concrete construction for minor works | Unreinforced concrete and concrete and reinforcement mixing and placement on major works e.g., post foundations |

* + 1. REGIONAL DESIGN EXAMPLES

Figure 8 replicated for a specific region e.g., Southwest Pacific

A red and white lighthouse

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1. Regional design examples

1. AS/NZS 1170.0 2011 and AS 4997:2005 also give guidance on combination of actions (load cases) [↑](#footnote-ref-2)
2. Note for Sarah – check modification made in Fiji Design Manual for Roads [↑](#footnote-ref-3)