Guidelines for Design Basis of Marine Energy Conversion Systems

Foreword

This document has been prepared in consultation with The European Marine Energy Centre Ltd (EMEC) and with other interested parties in the UK marine energy community. It is one of twelve publications in the *Marine Renewable Energy Guides* series, as detailed in the following figure.

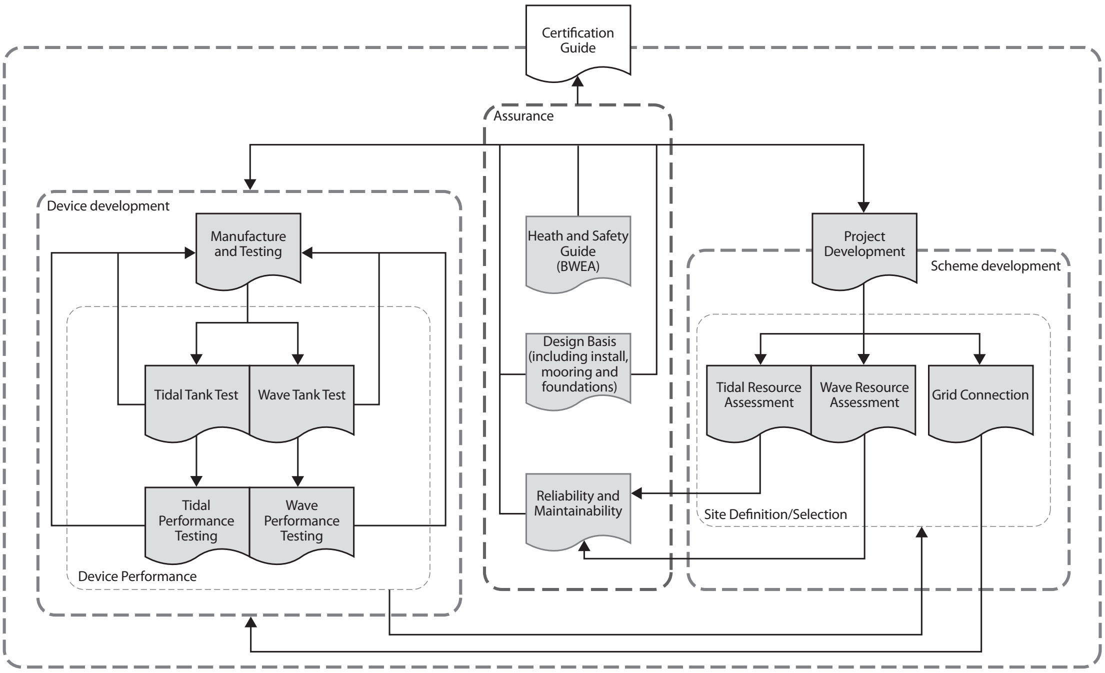

Figure 1 — Marine Renewable Energy Guides

Acknowledgements

This document was written by Peter Davies, Lloyd's Register EMEA under contract from the European Marine Energy Centre Ltd (EMEC).

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Guidelines for Design Basis of Marine Energy Conversion Systems

Marine Renewable Energy Guides

EMEC ORKNEY™
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Introduction

The design process covered by this guideline does not consider the concept design. It is assumed that the designer has undertaken the formative steps in the development of the wave or tidal device and has determined the general layout and operational functions, conducted numerical and physical modeling tests (scaled and/or full size prototypes) and undertaken performance assessments. Therefore, it is assumed that the developer is in the position to develop and optimize the device for manufacture and ultimately to achieve certification.

It is noted that there are many different concepts for marine renewable energy devices both tidal stream and wave. In order to develop a document that covers many different design ideas it is necessary to have a generic model which could cover any concept. Figure 2 below illustrates a generic model of a marine renewable energy device. This generic model is used in this document.

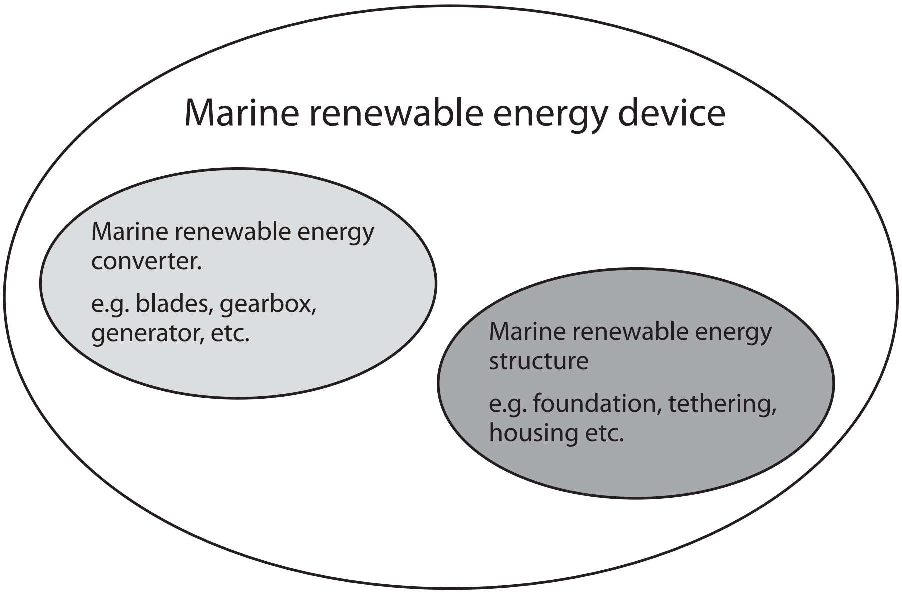

Figure 2 — Generic model for marine renewable energy device

It is assumed that the marine renewable energy device will have two main parts. These are the marine renewable energy converter and the marine renewable energy structure.

It might be a legislative requirement for the device to be independently certified (or a requirement from underwriters or financial institutions). The application of this guideline will assist in achieving certification; see *Guidelines for Marine Energy Certification Schemes* for more details.

The interaction between the various elements of the design process is shown in Figure 3.

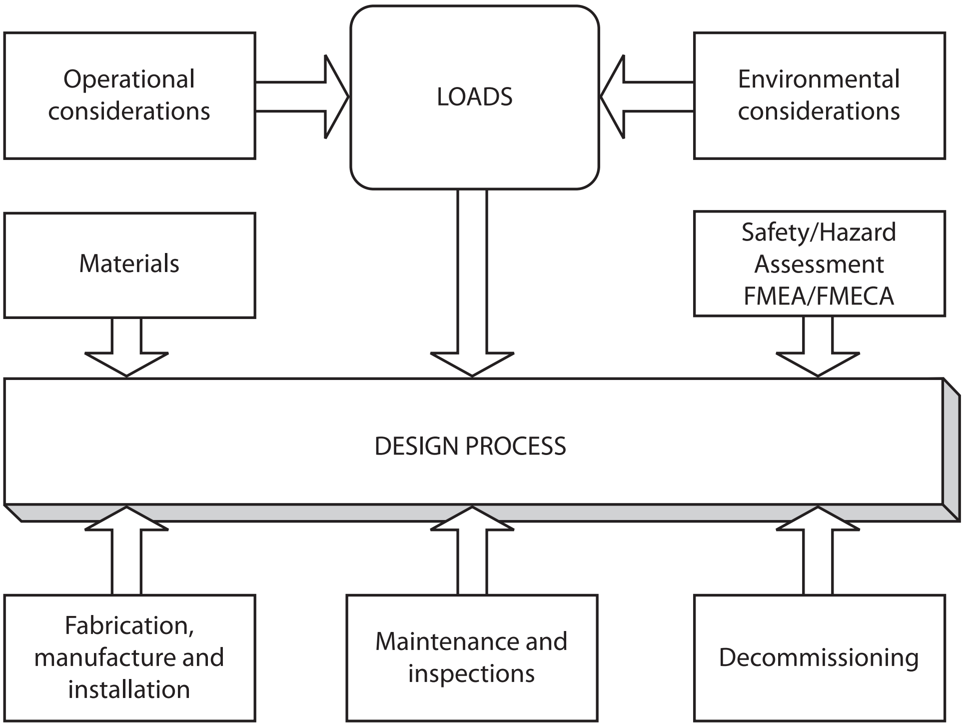

Figure 3 — Elements affecting the design of a device

The typical process for developing a basis of design document is shown in Figure 4. The relevant clause numbers of this document are shown in brackets on this figure.

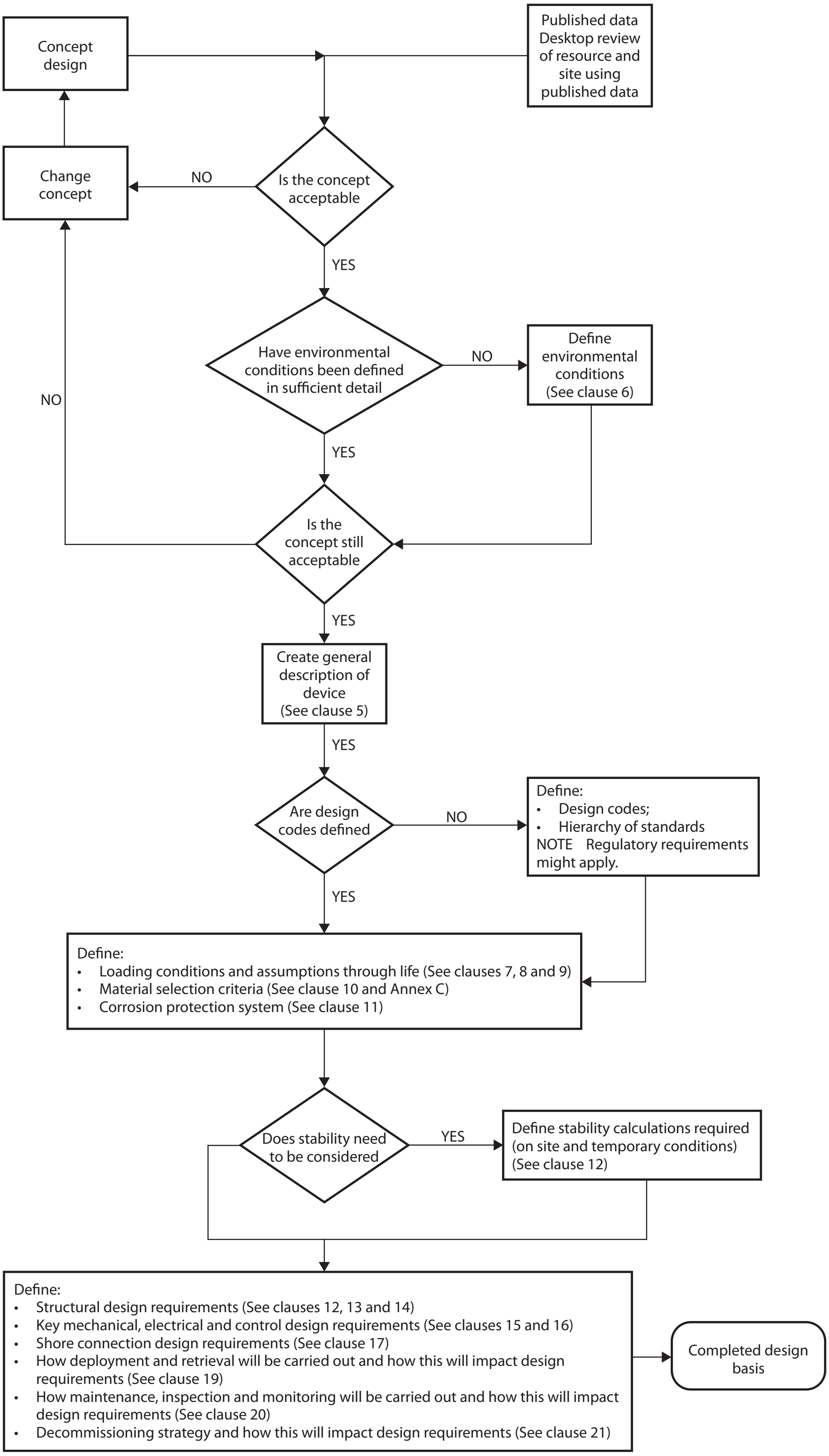

Figure 4 — Typical process for developing a design basis document

1 Scope

This document establishes general principles for producing a design basis document for a device. The aim of the document is to provide simple step by step guidance that can be followed by a device designer, in order to understand the factors that influence the design of a device, and design procedures that can be followed. By following the guidance in this document, it is not only hoped the designer will have a conforming design but will also be in a position to comply with the Certification Scheme.

This document is applicable to both wave and tidal stream energy converters.

It is applicable to all stages from the prototype design stage (after the initial concept has been proven to work) up to the final design.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN ISO 19901-1:2005, *Petroleum and natural gas industries — Specific requirements for offshore structures — Metocean design and operating considerations*

IEC 61508-3:2002, *Functional safety of electrical/electronic/programmable electronic safety-related systems — Software requirements*

IEC 61506:1997, *Industrial-process measurement and control — Documentation of application software*

IEC 60812:2006, *Analysis techniques for system reliability — Procedure for failure mode and effects analysis (FMEA)*

ISO/IEC Guide 2:2004, *Standardization and related activities — General vocabulary*

Guidelines for Reliability, Maintainability and Survivability of Marine Energy Conversion Systems, EMEC, 2009

Guidelines for Health & Safety in the Marine Energy Industry, BWEA, 2008

API RP 2A, *WSD Recommended Practice for Planning, Design and Constructing Fixed Offshore Platforms Working Stress Design*.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

3.1.1
atmospheric zone
area of the device above the splash zone which is therefore exposed to atmospheric conditions

3.1.2
buried zone
area of the device below the seabed

3.1.3
business critical system or component
computer, structural element, electronic, electromechanical or mechanical system/component whose failure might have an unacceptable impact on business objectives

3.1.4
Campbell diagram
method of illustrating the natural frequency of an object and its common exciting forces

NOTE It is drawn as a graph with speed of the device on the horizontal axis (normally expressed as rpm) and natural frequency on the vertical axis (Hz). The forcing frequencies are plotted on the Campbell diagram. When the natural frequencies coincide with a forcing frequency then a resonance could occur.

3.1.5
CAPEX capital expenditure
costs associated with manufacturing and installing a device

3.1.6
classification societies
organizations that establish and apply technical standards in relation to the design, construction and survey of marine related facilities including ships and offshore structures

NOTE For the purpose of this guideline it is assumed that such organizations are members of IACS.

3.1.7
corrosion fatigue
fatigue which occurs in a corrosive environment

EXAMPLE Seawater is an example of a corrosive environment.

NOTE Corrosion fatigue strength is usually less than the fatigue strength in air.

3.1.8
damping coefficient
measure of the amount of damping in a dynamic system

NOTE When the damping coefficient = 1 then the system is critically damped and when the damping coefficient = 0 then the system is not damped.

3.1.9
device
marine renewable energy device

3.1.10
factors of safety
permissible value divided by the actual value

NOTE The actual value can be calculated or measured.

3.1.11
failure mode and effects analysis (FMEA)
procedure for analysis of potential failure modes within a system for the classification by severity or determination of the failure's effect upon the system

3.1.12
failure mode, effects, and criticality analysis (FMECA)
procedure, which is an extension of a FMEA, that in addition includes a criticality analysis that is used to chart the probability of failure modes against the severity of their consequences

3.1.13
internal rate of return
discount or interest rate at which the net present value of an investment is equal to zero over the lifetime of the project

NOTE Ascertaining the internal rate of return can be used as a method for evaluating the financial viability of a project.

3.1.14
inter-tidal zone
area of the device that is exposed to atmospheric conditions during high spring tides and submerged conditions during low neap tides

3.1.15
life cycle costs
summation of whole life OPEX and CAPEX costs

3.1.16
marine renewable energy converter
device consisting of a number of components that together convert either tidal or wave energy into electrical energy

3.1.17
marine renewable energy device
device consistsing of two main parts: a marine renewable energy converter and a marine renewable energy structure

3.1.18
marine renewable energy structure
structure or system that supports a marine renewable energy converter in order to keep it on station

NOTE The structure might also provide some protection to the marine renewable energy converter.

3.1.19
net present value
present value of net cash flows

3.1.20
non-substantial failures
failure that would not result in a risk to life, collapse of the device or substantial pollution

3.1.21
OPEX operating expenditure
costs associated with operating the device

EXAMPLE Examples of these costs include whole life maintenance and decommissioning.

3.1.22
procedure
specified methodology with which to carry out an activity or a process

3.1.23
process
set of interrelated or interacting activities that transform inputs into outputs

3.1.24
quality
degree to which a set of inherent characteristics fulfils requirements

3.1.25
quality management
co-ordinated activities to direct and control an organization with regard to quality

3.1.26
quality management system
management system to direct and control an organization with regard to quality

3.1.27
requirement
need or expectation that is stated, generally implied or obligatory

3.1.28
safety critical system or component
computer, electronic, electromechanical, or mechanical system or component whose failure might cause injury or death to human beings

3.1.29
significant wave height
statistical measure of the height of waves in a sea state

NOTE The significant wave height was originally defined as the mean height of the highest one-third of the zero upcrossing waves in a sea state. In most offshore data acquisition systems the significant wave height is currently taken as $4\sqrt{m_0}$ (where m_0 is the zeroth spectral moment) or 4σ, where σ is the standard deviation of the time series of water surface elevation over the duration of the measurement, typically a period of approximately 30 min.

[ISO 19901-1:2005, definition 3.30]

3.1.30
splash zone
area of the device that whilst not completely submerged will not be kept dry during normal operation

3.1.31
standard
document, established by consensus and approved by a recognized body, that provides for common and repeated use, rules, guidelines and characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context

NOTE Standards should be based on the consolidated results of science, technology and experience, and aimed at the promotion of optimum community benefits.

[ISO/IEC Guide 2:2004, definition 3.2]

3.1.32
submerged zone
area of the device below the splash zone

3.1.33
substantial failures
failure which would result in a risk to life, collapse of the device or substantial pollution

3.1.34
spectral peak period
period at the maximum (peak) energy density in the spectrum

NOTE In practice there is often more than one peak in a spectrum.

[ISO 19901-1:2005, definition 3.32]

3.2 Abbreviated terms

AISC	American Institute of Steel Construction
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers

BS	British Standard
CSA	Canadian Standards Association
EMEC	European Marine Energy Centre
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode, Effects, and Criticality Analysis
FOS	Factor of Safety
GBS	Gravity Based Structures
IACS	International Association of Classification Societies
IMO	International Maritime Organization
IP	International Petroleum
IRR	Internal Rate of Return
ISO	International Organization for Standardization
MCP	Measure, Correlate, Predict
NPV	Net Present Value
NS	Norwegian Standard
QA	Quality Assurance
RPM	Revolutions Per Minute
UV	Ultraviolet

4 Managing the design process

4.1 Quality assurance

4.1.1 General

The design basis shall establish and maintain a Quality Assurance (QA) system appropriate to the level of design being undertaken. The design process shall be carried out in accordance with an audited QA system similar to that specified in ISO 9000. Some aspects shall be given special attention during the design process, as outlined below:

- The design practices of the designer's organization shall be identified including departmental instructions to ensure the orderly and controlled preparation of design and subsequent verification.
- Provision shall be made for the identification, documentation and appropriate approval of all design change and modifications – both during the design and manufacturing stages.
- Methods shall be prescribed for resolving incomplete, ambiguous or conflicting requirements.
- Design inputs shall be identified such as sources of data, preferred standard parts or materials and design information and procedures shall be provided for their selection and review by the manufacturer for adequacy.

4.1.2 Software – calculation

Any software used in the design process shall be controlled so that verification and revision control or configuration management can be easily audited.

4.1.3 Software – system control

Software that forms part of the device converter which is safety or business critical shall conform to IEC 61508-3. Other software should comply with IEC 61506.

4.2 The use of prototype components

A device should not have prototype components within it where possible, especially if the device is a prototype, to best facilitate the identification of errors and issues.

NOTE The use of proprietary off-the-shelf products which have a proven history will accelerate the design process.

4.3 FMEA/FMECA

As part of the design process the risks associated with the design of the device shall be identified.

Safety or business critical risks and failure modes over the design life of the device may be carried out by means of an FMEA or an FMECA. These studies should identify all failure modes and evaluate whether they are substantial or non-substantial. These studies should be carried out at as early a stage as practical in the design process. Reference should be made to *Guidelines for Reliability, Maintainability and Survivability of Marine Energy Conversion Systems* which covers FMEA. Reference should also be made to IEC 60812.

NOTE These risks could be critical to personnel (assessment of safety risks) or to assessment of business performance such as loss of income.

4.4 Health and safety

As with any construction projects, health and safety is paramount and a system of work shall be in place which covers all phases from initial design to decommissioning.

NOTE 1 As well as following best practice, attention is drawn to the fact that legislative requirements exist which will affect the project development both at the manufacturing location and at the location where the device will be installed, which might or might not be within the UK.

NOTE 2 See also the relevant Marine Renewable Energy Guide: *Guidelines for Health & Safety in the Marine Energy Industry*.

NOTE 3 For guidance a simple hazard risk assessment form is included in Annex A. This form has been developed to best assist designers to design out or specify mitigation, where possible, for all risks identified during the design process.

4.5 Environmental impacts

As part of the design process the environmental impacts due to the installation of the device shall be understood.

4.6 Consultations, permissions and consents

The stakeholders who could be impacted, or have a vested interest, by the installation of a device (or a farm of several devices) shall be identified. These stakeholders shall be consulted as it might be necessary to gain permissions or consents.

NOTE 1 The majority of the stakeholders and consultees will have been identified during the environmental impact assessment undertaken prior to the installation of the device.

Other less obvious generic stakeholders should also be consulted.

NOTE 2 The following is a list (although not exhaustive) of other stakeholders:

- recreational users of sea such as yachting clubs;
- commercial users of sea such as shipping companies;
- military users of sea;
- navigation authorities such as local ports authority or lighthouse authority.

4.7 Standard hierarchy

The following list gives the hierarchy that should be followed when there are various standards that impact a design device.

1. International standards (e.g. ISO, IEC)
2. National standards
3. These guidelines

NOTE Attention is drawn to legislative requirements at the place of manufacture and at the intended location of the installation of the device.

5 General description of device

5.1 General

This clause outlines the general aspects of the device that should be known prior to design.

The design basis shall highlight the need to consider all loadings associated with the construction, deployment, operation, maintenance, retrieval and decommissioning phases.

NOTE The provisions in this clause will ensure all assumptions and information relating to the operation of the device are established as part of the design process.

5.2 Description of device

The description of the device shall include:

- equipment layout;
- details of support structure or mooring system;
- proposed or typical location of device;
- details of a possible device farm arrangement;
- operational functions of the device (i.e. will it pitch, or vertically displace along a support structure?);
- information of any numerical and physical modelling work undertaken to date – particularly operational loadings and survivability and reliability studies;
- identification of failure modes (see 4.3);
- outline deployment methodology (including vessels or equipment that will be needed for deployment);
- outline operation and deployment activities which have health and safety implications (such as lifting);
- outline methods for marking (if necessary) submerged structures or converters using buoys etc.;
- outline methods for marking key components of the devices so that they can be uniquely identified for maintenance;
- outline inspection and maintenance methodology (intervals, methodology and means of access);
- outline decommissioning methodology.

5.3 Design life

The design basis shall define the design life of the device.

The notional design life of a device should range between 10 and 30 years although the actual period should be determined by the design basis.

With the exception of prototype machines, design life can be taken as the minimum period of time for the project to be considered financially viable. This will take into account CAPEX, OPEX and income from electricity etc. Typically internal rate of return (IRR) or net present value (NPV) are used to determine project financial viability. A design life longer than this minimum is advantageous but this will have an impact on the inspection and maintenance requirements of the device.

NOTE 1 The design life will have a direct impact on the economic feasibility of the project and the maintenance regime.

NOTE 2 For a prototype the design life will normally be much less than 10 years.

6 Environmental guidance

6.1 General

This clause describes the various environmental phenomena which the device will be exposed to and therefore is fundamental to the design of a device. This clause highlights the key processes or data that shall be considered prior to the design process.

NOTE It is at this point that a designer might find that additional data is required before developing the concept design and, if this is the case, this clause provides direction on how to obtain such data. Much of this information might be covered in related standards (i.e. within the relevant Marine Renewable Energy standards *Assessment of Tidal Energy Resource* or *Assessment of Wave Energy Resource*). Additionally other useful standards and documents are referenced in the Bibliography in particular ISO 19901-1.

The design basis shall identify just how significant the various environmental considerations are in the design of the device.

EXAMPLE For instance if the wind loading contributes only a small amount of the total loading then the accuracy of the predicted wind loadings might be less significant than, say, current or wave loadings. In addition it might also be important to consider the impact the device can have on the environment (such as noise). This will be covered in related standards.

6.2 Bathymetry/coastal topography

The bathymetry and topographic features can impact the performance of a device, therefore the design basis should take these factors into account. As such, a detailed review of the bathymetry and topographic features of the proposed installation site should be conducted.

6.3 Geotechnical considerations

The design process shall ensure that the seabed geotechnical features at the proposed location of deployment that are critical for the design and installation of the support structure or mooring system are understood.

NOTE 1 An insufficient understanding of the features could either lead to an inadequate design or an over-engineered design, based on greater factors of safety, which would be more costly than necessary.

There is an obvious economic trade-off to be made, in which the cost of a site investigation together with the CAPEX costs resulting from a lean design should be assessed against the CAPEX costs associated with an over-engineered design.

NOTE 2 This trade-off would become more apparent if the designer were to conduct an economic assessment for a farm of devices in which a single expansive site investigation could facilitate the lean design of a large number of devices.

NOTE 3 Clauses 12 and 13 deal with the installation of the structure of the device in greater detail.

6.4 Meteorology and climatology

6.4.1 General

This subclause describes the meteorological and climatological processes that the design basis should consider.

NOTE Although not all will be necessarily applicable to a specific device, the following key processes have been identified to assist the developer's understanding of the key environmental considerations and their potential impacts.

6.4.2 Wind – general

Wind loading shall be considered in the design process, particularly if part of the device extends above the water surface.

The design basis shall apply the 1-hour wind speed, plus wind gust spectrum.

The wind gust spectra formulation specified in API RP 2A should be adopted for the time varying component. Other published spectra formulations may be used, see Bibliography.

If some historical data is available and is to be used the design process shall specify whether its accuracy is sufficient.

NOTE 1 Wind data will also assist in the forecasting of wave parameters in the absence of recorded offshore wave data.

NOTE 2 The historical data might be fairly general and not take account of local effects.

6.4.3 Wind – prediction methodology

If it is necessary to estimate the wind forces and moments for the design analysis, the design basis should specify a suitable methodology. Typically such a regime should follow a measure, correlate, predict (MCP) methodology as detailed below:

- Measure: measurements should be carried out using an anemometer at the proposed site. This data should be collected for a minimum of 1 year. Co-current data measured at a met station should also be obtained. The measurements should be carried out at a height which is close to that experienced by the device.
- Correlate: these two sets of data should be correlated.
- Predict: the correlation can then be used to predict a period (reflecting the design life) from some historical data recorded at the met station.

6.4.4 Air and water conditions

Estimates shall be made of minimum and maximum air temperatures which might influence the structural design of the device – particularly exposed elements.

The design basis should consider atmospheric conditions at the device location such as humidity and rainfall.

In addition, the water quality at the proposed device location should be defined, i.e. its salinity, pollution and the amount of silt present. Water temperature might also have an influence on the design and historical data for the device location should be obtained.

NOTE For the accuracy needed for the design, historical data can be obtained from the UK Meteorological Office (or similar elsewhere).

6.5 Water level

6.5.1 General

This subclause describes the various ways water levels can change. The design basis shall consider these as they could influence the type, response and geometry of the support structure or system.

6.5.2 Tide levels

If data on tide levels exists and is to be used the design process shall define whether the accuracy of the available data is sufficient. If no suitable information is available, then measurements should be taken over a suitable time period of at least 1 year.

NOTE The necessary data for the proposed location can be obtained from many sources such as the Admiralty Charts in the UK (or similar elsewhere), or by requesting recorded data from the local port or harbour authorities.

6.5.3 Storm surge

The design process shall consider the combined effects of high tide levels, storm surges and also waves .

NOTE Storm surges, caused by a storm and the change in atmospheric pressure, can raise water levels which can raise the water surface above normal tide levels. This is a particularly important consideration if the storm surge were to occur during high tides. Historical data from the Meteorological Office in the UK (or similar elsewhere) will give an indication of previous storm surges and the impact on water levels.

6.5.4 Sea level rise

The actual values are difficult to quantify but the design basis should consider the possibility of changing sea levels. Predictions of sea level rise should be treated with caution as the accuracy of such predictions is uncertain. However, the design basis should consider the sensitivity of the design to sea level rise.

6.6 Currents

Design current velocities shall be established, taking account of all relevant components including the following:

- tidal stream currents;
- circulation currents;
- wind driven currents;
- storm surge generated currents;
- current turbulence.

NOTE Refer to the Marine Renewable Energy Guide, *Assessment of Tidal Energy Resource*. In addition, the design basis could consider the increase in the water particle velocities due to the excitation of passing waves (see 6.7).

6.7 Waves

The basis of design shall specify how the action of the waves and the wave loading will impact the device.

EXAMPLE Actions of waves that could affect the device could be slam forces, overtopping, wave processes etc.

NOTE See also the Marine Renewable Energy Guide *Assessment of Wave Energy Resource*.

6.8 Marine life

The design basis shall take into account the build-up of marine growth on the mooring lines, and/or the structure (floating or fixed), and the resulting increase in load and damping. The thickness of marine growth taken into account shall be stated in the Operations Manual and shall not be exceeded in service.

NOTE Marine growth can increase loads on structures and mooring lines through increasing weight, surface roughness and the obstruction to flows. The extent of marine growth that can be expected will vary from one location to another.

6.9 Sea ice and icebergs

The design basis for devices that will be located in regions subject to sea ice or icebergs should take into account how the device will be impacted.

NOTE The following are some areas which might need to be considered:

- impact of ice on support structure or system;
- quick release mooring systems;
- impact of ice on the converter (i.e. tidal turbine blades).

Guidance on zones susceptible to seaborne ice, thickness of ice and ice properties are shown on sea ice charts which are available from various sources such as the National Snow & Ice Data Centre. A general reference on design for propellers and floating structures operating in ice can be found in IACS Unified Requirement UR I.

7 Loading guidance

7.1 General

During the design life of the device the loading imposed by the environment will not be constant and so the design basis shall take account of extreme storm events which the device can reasonably be expected to experience during its design life.

Although not exhaustive, the following types of loadings shall be considered with respect to the design life of the device:

- permanent (dead) loads such as self weight of the structure and permanent ballast;
- variable functional (live) loads that vary in magnitude, position and direction such as on-board personnel or equipment, berthing loads and operational loads (i.e. thrust and torque loads from turbine units);
- accidental loads include collisions with vessels or debris, flooding of buoyant compartments, failure of mooring lines and breakage of blades. Many of these loads might have been estimated during previous reliability, maintainability and survivability studies;

- loads induced by thermal expansion and contraction of materials;
- loads due to entrained mass (of water);
- loads induced by transient phases such as load-out or installation.

NOTE The design basis will ensure that the annual probability of a substantial failure will not exceed that derived from the FMEA or FMECA studies.

7.2 Design conditions

7.2.1 General

The design basis shall define a recognized design code so that the design load cases can be identified.

7.2.2 Dynamic loads

Dynamic loads will in general be dominated by the device response to the environment (wind, waves and current) and so care shall be taken in selection of the design environments to determine the maximum combination of loads that could be imposed on the device during its design life.

Where the loads are dominated by one environmental parameter (for example, current speed) then statistical methods may be used to estimate the critical design load case based on assessment of environmental data. Where the loads are influenced by several environmental parameters then the loads shall be calculated using measured (or hindcast) environmental data and statistical methods shall be used to estimate the design cases from the calculated load data.

NOTE 1 Care in selection of the design environments is particularly important for floating structures since the loads are sensitive to wave period and the directionality of the environment.

NOTE 2 In some cases a device might operate in an environment where the magnitude of the individual parameters is not large. However, this might result in large loads because of the directionality and period.

7.3 Design concepts

7.3.1 General

The following concepts may be used to determine the suitability of the design of the device.

NOTE Attention is drawn to local regulatory requirements.

7.3.2 Working stress design for strength

In general, the structural design of the device shall be based on the elastic method of design (also known as working stress design). The permissible stresses in the structure shall be based on the use of a permissible usage factor that effectively reduces the characteristic strength of a material to determine the permissible (or allowable) stress. Appropriate codes of practice should be consulted for details of the design philosophy, permissible usage factors and critical load cases.

7.3.3 Limit state method of design for strength

The design basis shall specify the design philosophy, partial factors and recommended critical load cases within acceptable codes of practice and shall be agreed with the certifying body of the device.

NOTE 1 See the *Guidelines for Marine Energy Converter Certification Schemes*.

NOTE 2 A traditional approach to design, the limit state method of design (also known as load and resistance factor design) is based on the use of a combination of partial load and resistance factors to amplify destabilizing loads and to reduce stabilizing loads and material resistance properties.

7.3.4 Plastic method of design for strength

When the plastic method of design based on the ultimate yield strength is proposed for the device, the load factors should be in accordance with an acceptable code of practice, (see Bibliography) and shall be agreed with the certifying body of the device.

7.3.5 Fatigue design

All units shall be capable of withstanding the fatigue loading to which they are subjected. The minimum design fatigue life of a device shall be the design life (see 5.3) unless a longer life is specified by the design basis.

NOTE For more detail on fatigue design see clause 8 (in particular 8.1.3).

8 Fatigue design guidance

8.1 Fatigue considerations

8.1.1 General

The design shall take into account all fatigue loadings and the resulting stresses. Any calculation method shall include all relevant loads on the complete system under all permissible operating conditions. Consideration shall be given to the dimensions and arrangements of all components.

NOTE 1 Fatigue loading (i.e. cyclical loading) is any loading which results from a force or moment which is not applied continuously. This loading could result from a harmonic response (see clause 9).

NOTE 2 The aim of the design is for the device to perform satisfactorily during its intended life with an acceptable factor of safety. The use of proprietary off-the-shelf products which have a proven history will accelerate the design process.

8.1.2 Fatigue loading

The most appropriate method of fatigue analysis will depend on the characteristics of the device as shown in Table 1 below. In general floating structures and devices making use of resonant responses should be analysed using spectral or time domain methods. Dynamic stresses should be minimized by good design based on the following:

- large separation between the natural periods of the structure and the exciting forces;
- reducing exciting forces;

  EXAMPLE An example of how to reduce exciting forces is to minimize loads due to vortex shedding.
- good detail design.

Table 1 — Fatigue analysis methods

Method	Applicability
Deterministic (Including weibull and semi-probabilistic.)	• Not suitable for dynamically sensitive structures (including floating structures) unless calibrated. • Suitable where there are significant non-linearities.
Frequency domain (spectral)	• Suitable for dynamically sensitive structures. • Not suitable where there are significant non-linearities.
Time domain	• Suitable for dynamically sensitive structures. • Suitable where there are significant non-linearities.

8.1.3 Fatigue life

The fatigue strength may be calculated using S/N curves following a suitable standard such as BS 7608. If required the inspection interval and acceptable defect size may be calculated following a suitable standard such as BS 7910.

8.2 Factors of safety for fatigue

In defining the applicable minimum factor of safety for fatigue first the consequences of failure for the component in question shall be established. An FMEA shall be carried out in order to establish the consequences of failure.

NOTE 1 The factors of safety will be defined in the design code identified by the design basis.

NOTE 2 For further information on FMEA see *Guidelines for Reliability, Maintainability and Survivability of Marine Energy Conversion Systems*.

9 Harmonic response

9.1 General

The design basis shall take into account the harmonic response both for structural and mechanical elements.

There are two types of device: ones that exploit a resonant response, in order to maximize the power captured, and those that do not.

- For devices that exploit a resonant response (in order to maximize the power captured) the design basis shall pay close attention to the fatigue stresses and the fatigue life.
- For devices that do not exploit a resonant response the design basis shall either:
  - ensure the natural frequency of the structural and mechanical elements are sufficiently separated from the forcing frequency;
  - or ensure that there is sufficient damping in the design such that the fatigue stresses induced are not significant.

9.2 Forcing frequencies

The design basis shall ascertain on which part of the device all forcing forces or moments are acting and in which plane.

NOTE For any device there are forces or moments applied which are of a cyclical nature. The frequency at which these forces occur can be considered as forcing frequencies with respect to the harmonic response. These frequencies can be fixed, random or a function of another frequency. The most significant are fluid acting on the support structure, waves and the cyclic passing of turbine blades (or other moving components of the converter). Some of the excitation can be termed broadband excitation as it comprises more than one frequency.

9.3 Natural frequencies

Both structural and mechanical elements will have many natural frequencies. All natural frequencies which could be excited by forcing frequencies shall be identified. The mode shapes of all natural frequencies shall be considered so that it is understood how such frequencies can be excited.

NOTE Where it is intended to avoid operating at a natural frequency the three most common approaches taken are to:

- ensure that the stiffness of the structural or mechanical elements is low such that the natural frequency will occur sufficiently below the forcing frequency;
- ensure that the stiffness of the structural or mechanical elements is relatively high such that the natural frequency will occur above the forcing frequency; and
- ensure that there is sufficient damping of the structural OR mechanical elements such that the response to a forcing frequency will not result in the fatigue stresses induced being significant in comparison to the mean stresses.

Using the first approach results in the lowest cost as the amount of material is reduced in order to achieve a lower level of stiffness. However, the designer needs to be careful that whilst the first natural frequency is below any forcing frequency, the second (or third etc.) mode of natural frequency is also not close to any forcing frequency. The second approach is the simplest method of avoiding a harmonic response but is not a cheap option. The third approach is difficult to achieve unless a separate damping component is added.

9.4 Analysis

Any analysis shall have three parts to it.

1. The natural frequencies shall be identified together with the mode shapes.
2. The forcing frequencies shall be identified.
3. The relationship between the two shall be clarified.

The simplest way of identifying the relationship between the natural frequencies and the forcing frequencies is by means of a Campbell diagram. The Campbell diagram should also indicate the forcing frequencies associated with various operating (or running) conditions of the device.

Any points where the natural frequencies and the forcing frequencies coincide shall be noted. For the design to be acceptable the margin between natural frequency and operating speed range shall be at least ± 20%.

NOTE 1 See Annex B, REF 1.

However, if a natural frequency is found to be within ± 20% of the operating speed range then a forced response calculation which takes into account the damping of the system shall be carried out. Ideally the model should be for all six degrees of freedom. It is recommended that any natural frequencies that are found within ± 20% of operating speed range shall have a damping coefficient greater than 0.4, or an amplification factor less than 2.5.

NOTE 2 See Annex B, REF 2.

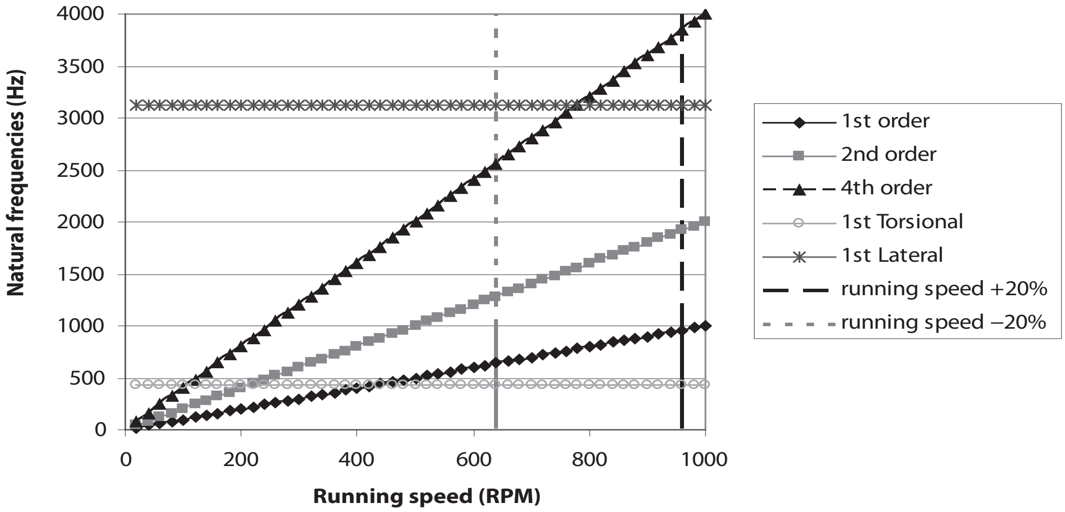

Figure 5 — Typical Campbell diagram

10 Material standards and testing

In order to ensure consistency, materials should wherever possible be referenced against a standard, some suitable standards are listed in the Bibliography (see also 4.7). For instance terms such as 'mild steel' should be avoided, as the term might have different meanings within different organizations and locations.

Depending on location and reputation of sub-suppliers, consideration should also be given for the testing process to be witnessed by an independent third party.

NOTE 1 To achieve uniformity in material supply, testing might need to be specified. Also testing might be necessary to ensure certain material properties are achieved.

NOTE 2 Please see Annex C for more information regarding material selection.

11 Corrosion protection

11.1 General

As the device will be working in the highly corrosive marine environment the material shall be suitably protected or the impact of corrosion shall be negated by other means.

The corrosion zones may be classified as follows:

- atmospheric;
- splash;
- inter-tidal;
- submerged;
- buried.

The designer shall identify which zone each component of the device will exist within before being able to best consider forms of corrosion protection during design.

NOTE 1 Corrosion is a term applied to the degradation of a material as a consequence of a chemical reaction with the surrounding environment, normally due to a combination of oxygen and moisture. Corrosion is further amplified in the marine conditions due to the presence of salt in seawater.

NOTE 2 For marine applications, the rate of corrosion will vary due to the differing oxygen/moisture content in the various zones.

11.2 Concrete

The design of each concrete member shall ensure that prestressing tendons and rebars are sufficiently protected against the environmental conditions that represent the corrosion zone in which it is to exist.

The casting of concrete elements shall also be in accordance with design drawings and specification documents of concrete members to ensure the work is carried out to design. In addition, an inspection procedure should be implemented during the casting of the elements to ensure workmanship is undertaken to adopted QA systems.

NOTE 1 Corrosion protection of prestressing tendons and reinforcement bars (rebars) is an important aspect of the design of concrete structures. Generally corrosion protection is provided through the detailed specification of a durable mix design through consideration of chemical exposure such as chlorides and sulphates and also freeze-thaw damage. In addition, the specification of a sufficient cover thickness (i.e. the thickness of concrete between the free surface of the member and rebar) and the limitation of the allowable size of cracking to minimize the amount of moisture that attacks the tendons and rebars.

NOTE 2 The structural design and specification of concrete members is a mature science and is well documented in a number of reference documents and design standards such as BS 8110 parts 1, 2 and 3, BS 5400-5 and BS 5328-2.

11.3 Structural steel

11.3.1 General

When considering the methods used for corrosion protection the following points shall be considered:

- corrosion allowance incorporated in the design;
- inspection regime to be employed.;
- stress in the component (both mean stress and fatigue) and calculated factor of safety (FOS);
- location of the component relative to the seawater surface;
- areas subject to wear.

For areas not protected against corrosion (or with ordinary paint coating only), an additional corrosion allowance shall be considered.

NOTE BS 6349 also provides advice on free corrosion for steel in maritime structures.

11.3.2 Corrosion rates

The corrosion rates should be determined based on previous similar service experience. In the absence of accurate information the design basis should define a code of practice which defines corrosion rates.

Consideration should also be given to aggressive local corrosion (pitting and grooving). The inspection regime should confirm the corrosion rates assumed in the design.

11.3.3 Cathodic protection

Cathodic protection is particularly effective for the submerged zone and should be designed for a period commensurate with the design life of the structure or the dry docking interval. It should be capable of polarizing the steelwork to a sufficient level in order to minimize corrosion.

NOTE Cathodic protection can be achieved through use of impressed current anodes or sacrificial anodes, or a combination of both, that are attached directly to the device.

11.3.4 Protection after launching and during outfitting

Where protection is primarily by an impressed current cathodic protection system, sufficient sacrificial anodes shall be fitted, capable of polarizing the critical regions of the structure from the time of initial immersion until full commissioning of the impressed current system.

11.3.5 Coating systems

Cathodic protection should only be used for areas which are continuously submerged. For areas that are not continuously submerged (such as the splash zone), suitable protection should be provided through the application of protective coatings which have good abrasion and ultraviolet (UV) resistance attributes.

NOTE Protective coatings include the use of hop dip galvanizing or epoxy based paint systems. Such coating systems generally have design lives in the order of 5 to 10 years and will therefore need to be reapplied. Also, there might be limitations in the size of structural components able to be hot dip galvanized.

11.3.6 Sacrificial thickness

It is possible to mitigate the effects of corrosion through the use of thicker steel sections based on corrosion rates and the design life of the structure. In effect, this approach provides a sacrificial thickness of steel which, if corroded over time, will ensure that the remaining cross section of the section still provides sufficient structural integrity as the device nears the end of its design life. However, consideration should also be given to aggressive local corrosion (pitting and grooving). The inspection regime should confirm the corrosion rates assumed in the design.

11.3.7 Galvanic corrosion considerations

When selecting materials for the device the possibility of galvanic corrosion should be considered.

NOTE As devices will be either partially or wholly submerged the interaction between different materials can lead to unintentional galvanic corrosion.

11.4 Mooring system

The chain size chosen shall exceed that required to satisfy the FOS to allow for the corrosion and wear which can occur over the intended service life of the anchor chain or associated component. Additional greater margins may be required where chains are subjected to high wear rates.

12 Floating structures (and structures floated during installation)

12.1 General

Reference should be made to *Guidelines for Health & Safety in the Marine Energy Industry*.

The following aspects should be considered in the design basis:

- required buoyancy or ballasting of the structure;
- pumping arrangements (perhaps temporary) to achieve the required buoyancy or ballasting of the structure;
- strength of the structure (taking into account the loading imposed over the lifetime of the installation);
- potential loss of watertight integrity and how this could affect the buoyancy or ballasting of the structure;
- potential sources of fire (e.g. hydraulic oil under pressure) and mitigation of any risks of fire.

As a general reference for the design of floating structures the rules of a classification society may be used.

NOTE It is assumed that the device will be mostly unmanned (except during maintenance activities). Therefore many of the requirements in classification society rules for ships or floating offshore structures which are related to safety might not be applicable.

12.2 Stability of floating devices

Stability calculations should be carried out for devices which are of the floating type or which might be floated during installation. The acceptable environmental conditions for the device for installation and/or operation should be derived from these calculations.

NOTE This will confirm the acceptable environmental conditions defined in the basis of design.

EXAMPLE Examples of environmental conditions are currents and sea state.

13 Design of foundation and support structure (if applicable)

13.1 General

For devices which are not of the floating type, there are the two generic types of support structures that should be considered, these being:

- gravity type foundations;
- pile foundations.

With regard to the design of these support structures, the design basis shall consider the structural integrity and global stability of the support structure in addition to the geotechnical design of the founding seabed strata, as defined in 15.2.

13.2 Geotechnical design parameters

Whilst it might be advantageous for a device to have a common foundation design, a thorough site investigation of the proposed deployment area shall be performed to confirm that the foundation design is suitable at a specific location – unless an over-engineered approach is adopted as per 6.3. The site specific investigation should confirm the following parameters:

- soil resistance to axial pile load;
- soil shear strength;
- uniformity of soil and seabed conditions;
- strata layer thickness;
- representative ground parameters for each strata.

13.3 Design of pile foundations

In selection of the piled foundation and thereafter, the design basis shall consider the following:

- seabed conditions – geotechnical conditions at the proposed site;
- depth of water at the proposed site (including superposition of tidal levels, surges and waves);
- all loads imposed on the support structure and the critical load cases;
- the operation and maintenance needs of the converter (i.e. whether the converter will need to move along the support structure to facilitate access);
- the proposed installation, recovery and decommissioning methodologies.

An experienced marine installation contractor should be consulted at an early stage of design development to discuss possible installation methods currently available on the market to suit the programme aspirations of the design base – which may be the critical factor in the type of support structure considered.

NOTE 1 Piles have been used for many years to support offshore wind turbines and within oil and gas installations throughout the world and such experience can be used for the benefit of the marine renewable energy industry. The use of piles as a support structure can be generally classified as either a single monopile or a group of piles which can be installed by driving, suction or drill and socket techniques. The type of piled foundation, and the design, is dependant on the environmental and geotechnical conditions at the proposed location, the operation considerations of the converter and the proposed installation methodology.

NOTE 2 There is a great amount of experience in the design of piled foundations and there are numerous standards that can be consulted as well as consulting an experienced marine installation contractor.

13.4 Design of gravity foundations

The design basis shall identify the coefficient of friction between the structure and the seabed at the location that the device is to be installed.

Towing of the GBS should be a design case considered by the design basis. Such a design case should identify the weather and sea state conditions which will be acceptable for the tow.

NOTE Gravity foundations or gravity base structures (GBS) have been used for supporting offshore wind turbines and oil and gas platforms. GBS can also be be used to support marine renewable energy devices. GBS structures are usually configured to have a cellular arrangement, similar to a 'tray', so that they have sufficient buoyancy to allow them to be towed by vessel to the installation location and then infilled with a ballast material (i.e. water, grout or iron ore) in order to be sunk into place on the seabed. Once in place, the ballasted GBS will be designed to have sufficient weight to resist overturning and sliding forces imposed by extreme destabilzing loads.

Once in place, a number of integral legs, generally piles, can be connected to the GBS in order to extend vertically to support the device.

13.5 Stability of seabed

The design basis shall consider the stability of the seabed and in particular the slope stability of the seabed.

Where possible historical data for the proposed site should be obtained so that these considerations can be quantified.

NOTE Another concern might be moving sandbanks or shifting sediments. This can be a particular concern for seismically active areas.

13.6 Scour protection

One of the following methods may be used to prevent scour:

- rock dumping;
- bottom protection with integrated geotextile fabrics and concrete block mattresses;
- protection wall with concrete filling;
- seabed improvement by gluing the sand.

The environmental impact of some of these solutions should also be considered as part of the design process.

NOTE Piled foundations, in sandy soils, can be susceptible to scour. Scour is a type of erosion caused by the effect of the foundation on the local flow pattern and velocities. Scour can cause a significant section of the soil around the pile to be removed. It is more significant at sites with high tidal currents. A paper on scour protection is referenced in the Bibliography.

14 Design of mooring system (if applicable)

14.1 General

As a general reference for the design of the mooring system the rules of a classification society may be used.

NOTE Mooring systems are typically characterized in one of the following configurations:

- **Catenary mooring** – A mooring system which derives its compliancy mainly from the catenary action of the mooring lines. Some additional resilience is provided by the characteristic axial elasticity of the mooring lines.
- **Taut-leg mooring** – A mooring system based on lightweight mooring lines pre-tensioned to a taut configuration with no significant catenary shape at any unit offset, and applying vertical and horizontal loads at the anchor points. With this type of system, compliancy is derived from the inherent axial elastic stretch properties of the mooring line.
- **Single-point mooring** – An offshore mooring facility based on a single buoy or single tower.
- **Spread mooring** – A multi-line mooring system designed to maintain an offshore unit on an approximately fixed heading.

14.2 Mooring equipment

The mooring system should consist of the following components, as relevant:

(a) anchor points:

- drag embedment anchors;
- anchor piles;

- suction anchor piles;
- gravity anchors.

(b) mooring lines;

(c) mooring line fittings:

- shackles;
- connecting links/plates;
- rope terminations;
- clump weights;
- anchor leg buoyancy elements.

(d) fairleads/bending shoes;

(e) chain or wire rope stoppers;

(f) winches or windlasses.

14.3 Loadings

Refer to environmental conditions (clause 6) which outlines loading upon the device and also forces directly on the mooring system (i.e. wave and current). The design basis shall consider marine growth on the mooring system as the diameter influenced by the loadings might increase.

14.4 Design of mooring system

Generally clauses 6 and 7 give the necessary guidance in respect of the design of the mooring system.

14.5 Anchor design

14.5.1 General

The following are the types of anchors that may be used for a device:

- drag embedment anchors;
- anchor piles;
- suction anchor piles;
- gravity anchors.

The design of the anchors shall take into account the seabed soil conditions at the site where the device will be located – ensuring the proposed locations of all anchor points are considered. For all anchors the holding capacity shall be clearly defined for all foreseeable conditions.

All anchors should follow a process outlined either in a recognized international standard or following the design principles outlined by an International Association of Classification Societies (IACS) member.

14.5.2 Drag embedment anchors

The manufacturing process for these anchors, from foundry to completion, should be witnessed and inspected by an independent third party. As an alternative the anchors may be manufactured at a works that has been audited by an IACS member.

NOTE Notwithstanding the above, attention is drawn to the separate requirement of some national authorities for proof load testing of anchors.

14.5.3 Anchor piles

Anchor piles should be either driven or drilled and grouted into the seabed or installed by suction, to provide resistance to axial, lateral and torsional loading. Piles installed by vibrating hammers are not recommended where axial loading is significant.

NOTE Anchor piles are characterized by being relatively long and slender and having a length to diameter or width ratio generally greater than 10.

14.5.4 Suction anchor piles

Suction anchor piles should be installed by suction to achieve the required penetration into the seabed to provide resistance to axial, lateral and torsional loading. Suction should be applied by creating a reduced water pressure within the pile compared to the external ambient water pressure.

NOTE Suction anchor piles can be retrieved from the seabed by reversing the suction process. Suction anchor piles are characterized by having a large diameter and a length to diameter ratio generally less than 8 and are essentially caisson-type foundations if it is less than 3.

14.5.5 Gravity anchors

This subclause applies to anchors which are either a gravity frame or deadweight block anchors, which rely on their self weight to provide resistance to vertical, lateral and torsional loading. Gravity anchors may be provided with skirts which penetrate the seabed to provide increased lateral resistance through mobilization of additional seabed strata.

15 Marine renewable energy converter (electrical and mechanical design)

15.1 General

The design basis shall identify the operating environment and required design life of mechnical and electrical components.

Some components such as gearboxes or generators within the marine renewable energy converter should be designed to comply with existing international standards.

NOTE In order to establish the general functional specification for the marine energy converter within the design basis it is necessary to define the design conditions which are applicable. The purpose of this clause is to provide general guidance on the design, selection and installation of electrical and mechanical components. There are many standards associated with this aspect and only the most generally applicable have been listed in the Bibliography.

15.2 Definition of design environment

Clauses 6 and 11 of this document outline the environment conditions which should be considered in the design basis. In addition electrical, control and mechanical equipment might be subject to factors which could have a detrimental impact on performance for example:

- vibration; and
- inclination (both during operation and damaged condition, see 12.1).

The FMEA will identify any such factors; and the design basis should list any factors which could impact the performance of electrical, control or mechanical equipment.

If active marinization techniques are used then the systems which have a safety function should continue to operate if the active marinization fails.

NOTE It is possible to provide protection using an active marinization technique such as the provision of a dry desalinated atmosphere.

15.3 Design life of components

Some components might be replaced during the design life of the device. Thus the design life of some components may be less than the design life of the device. The design life needed for components should be defined by a reliability, maintainability and survivability study.

NOTE Refer to *Guidelines for Reliability, Maintainability and Survivability of Marine Energy Conversion Systems* for further details.

15.4 Electrical and control equipment

15.4.1 General

Electrical equipment shall be suitable for operation in the environmental conditions experienced by the marine energy converter.

The design basis shall identify which standards should be specified for equipment in the device. Also national/regional regulations are to be complied with (e.g. EC Electromagnetic Compatibility (EMC) directive).

NOTE Standards for testing electrical and control equipment to demonstrate suitability are listed in the Bibliography.

15.4.2 Emergency safety systems

The design of the marine energy converter shall include details of emergency safety systems which shall include typical single line diagrams and arrangements, showing the location of equipment and cable routes to be employed for:

- emergency and navigation lighting;
- fire detection, alarm and extinction systems (if applicable);
- watertight doors, and other electrically operated closing appliances (if applicable).

Any electrical systems which provide a safety function shall be capable of battery operation and shall be provided with suitable batteries.

15.4.3 Major items of equipment

The electrical design of the marine energy converter shall include a general arrangement plan showing the location of major items of electrical equipment, for example:

- generators;
- transformers;
- switchboards;
- emergency batteries;
- cable routes between equipment.

In addition the design basis should address the need for earthing, cable standards and cable connections.

NOTE Standards for the design of electrical equipment are included in the Bibliography.

15.4.4 Grid connection

The design basis shall define the following parameters both at the device and the grid connection point:

- voltage;
- frequency; and
- functionality of any voltage or frequency converter.

NOTE Attention is drawn to national and regional regulations for grid connection arrangements. Some UK standards are referenced in the Bibliography.

15.5 Mechanical equipment

15.5.1 Inclinations

All mechanical equipment shall be capable of operating at all inclinations both static and dynamic that the device could experience. If there are any mechanical components which are safety or business critical then these shall remain operating at all inclinations both static and dynamic that could occur if the device is damaged.

15.5.2 Material considerations

The design basis should consider the material degradation of mechanical equipment.

NOTE This material degradation could be caused by creep, changes in hardness or fatigue. For further details of design in respect of fatigue see clause 8.

15.5.3 Force transmitting components (shafts, linkages etc.)

Force transmitting components shall comply with clauses 8, 9 and 15.5.1 of this document and ISO 76, ISO 281 and ISO 6336.

15.5.4 Pressure retaining equipment

Items of mechanical equipment which are pressure retaining should comply with a recognized standard (see Bibliography) if any of the following conditions are exceeded:

- Group 1 gases $P < 200$ and $V < 1$

  OR $PV < 25$

- Group 2 gases $P < 1000$ and $V < 1$

  OR $P * V$ is less than 50

- Group 1 liquids $P < 500$ and $V < 1$

  OR $PV < 200$
- Group 2 liquids $P < 1000$ and $V < 10$

  or $PV < 10000$

Where:

Group 1 comprises those fluids classified as:

- explosive;
- extremely flammable;
- highly flammable;
- flammable (where the maximum allowable temperature is above flashpoint);
- very toxic;
- toxic;
- oxidising.

Group 2 comprises all other fluids including steam.

P = Maximum allowable Pressure in bar

V = Volume in litres

NOTE Attention is drawn to regulatory requirements such as the Pressure Equipment Directive (PED) that might be applicable.

15.6 Piping systems

15.6.1 General

The materials used for pipes, valves and fittings shall be suitable for the fluid and the service for which the piping is intended.

The piping material, pipe sizing and construction details shall follow the design concepts laid out by a recognized international standard. The application of these standards shall be consistent.

EXAMPLE 1 Examples of standards could be ANSI/ASME B31.3 or the rules of an IACS member.

EXAMPLE 2 For instance it is not permissible to use the allowable stress for a material from one standard and the stress formulation from another standard.

NOTE Attention is drawn to the existence of regulatory requirements such as the Pressure Equipment Directive that might be applicable.

15.6.2 Flexible piping

The materials used for flexible pipes shall be suitable for the fluid and the service for which the piping is intended. The materials and construction of the hoses, and the method of attaching the end fittings together, shall be subject to satisfactory prototype testing witnessed by an organization independent of the manufacturer (see Bibliography for applicable standards).

All flexible hose assemblies shall be satisfactorily prototype burst tested to an international standard to demonstrate they are able to withstand a pressure of not less than four times the maximum working pressure without indication of failure or leakage.

Where flexible hoses are intended for conveying flammable fluids in piping systems that are in close proximity to hot surfaces, electrical installation or other sources of ignition, the risk of ignition due to failure of the hose assembly and subsequent release of fluids shall be mitigated as far as practicable by the use of screens or other suitable protection.

The installation of flexible hose assemblies shall be in accordance with the manufacturer's instructions and use limitations with particular attention to the following:

- orientation;
- end connection support (where necessary);
- avoidance of hose contact that could cause rubbing and abrasion;
- minimum bend radii.

15.6.3 Nonmetallic rigid piping (plastic)

Pipes and fittings shall be of robust construction and shall comply with a national or other established standard, consistent with the intended use.

NOTE Attention is drawn to the fact that the use of plastics pipes might be restricted by statutory requirements of the National Authority where the device is installed. Some useful guidance is also given in the *Guidelines for the Application of Plastic Pipes on Ships* contained in IMO Resolution A.753(18).

16 Instrumentation and control systems

16.1 General

NOTE This clause provides general guidance on the requirements for instrumentation and control systems. There are many standards associated with this aspect and the most widely applicable are referenced in the Bibliography.

16.2 Definition of design environment

Clause 6 of this document outline the environmental conditions that the design basis should consider.

If active marinization techniques are used then the systems which have a safety or business critical function shall continue to operate if the active marinization fails.

NOTE It is possible to provide protection using an active marinization technique such as the provision of a dry desalinated atmosphere.

16.3 Design of systems

The instrumentation and control systems which are safety critical or business critical should be identified by the FMEA.

The FMEA should also identify the required reliability for the instrumentation and control systems.

NOTE See *Guidelines for Reliability, Maintainability and Survivability of Marine Energy Conversion Systems* of this series for further details.

16.4 General requirements for control systems

Machinery, safety and control system faults shall be indicated. The presence of unrectified faults shall be clearly indicated at all times.

Failure of any power supply to the alarm system shall operate an alarm.

The alarm system should be designed with self-monitoring properties. Insofar as practicable, any fault in the alarm system should cause it to fail to the alarm condition.

Control systems should be designed to 'fail-safe'. The characteristics of the 'fail-safe' operation shall be evaluated on the basis not only of the control system and its associated machinery, but also the complete installation.

The control system shall be be designed such that normal operation of the controls cannot induce detrimental mechanical or thermal overloads in the machinery.

When control systems are provided with means to adjust their sensitivity or set point, the arrangements shall be such that the final settings can be readily identified.

Failure of a control system shall not result in the loss of ability to provide control to safety and business critical systems by alternative means. This may be achieved by manual control or redundancy within the control system or redundancy in machinery and equipment.

16.5 Requirements for safety and business critical control systems

Safety systems shall operate automatically in case of serious faults endangering the machinery, and personnel so that:

- normal operating conditions are restored;

  EXAMPLE 1 This can be done by the starting of standby machinery.

- the operation of the machinery is temporarily adjusted to the prevailing conditions;

  EXAMPLE 2 This can be done by reducing the output of the machinery.

- the machinery is protected from critical conditions by shutting off the fuel or power supplies thereby stopping the machinery.

16.6 Alarm and safeguards

The design basis should list the minimum alarm setting points which have been identified in the FMEA or FMECA.

17 Cable connection to shore

17.1 General

Underwater connections and connectors operating in a marine environment should be technology which has demonstrated satisfactory service of at least 5 years in similar applications. As an alternative, underwater connections and connectors which have not demonstrated satisfactory service should undergo a testing regime to demonstrate the suitability of the technology. Such testing should be witnessed by an organization independent of the manufacturer.

The connectors should:

- not be of a push fit type, but have a positive locking mechanism such as bayonet fitting;
- be arranged so that they cannot be connected in the wrong position, a keyed arrangement or similar method should be employed.

NOTE See also 15.4.4.

17.2 Installation

In considering the routing of the cables the following should be taken into account:

- submerged hazards, such as wrecks;
- fishing grounds;
- fish breeding grounds; this might be dependent on the time of year;
- shipping lanes;
- areas of high tidal stream velocities;
- shifting sands;
- stability of seabed;
- environmental conditions, see clause 6.

Some of these hazards may be mitigated by burying the cable or creating a trench to protect the cable.

17.3 Loading

The design basis shall determine the loading the cable can withstand both in tension and flexing. These loads shall be considered both during installation and during operation.

NOTE The operating loads are expected to be more severe on floating devices where the cable will be subjected to dynamic loads and continuous movement.

17.4 Design

In addition to the loading mentioned in 17.3 cables and umbilicals shall be capable of transmitting the required power and signals without any loss of function for the service life of the device as replacement will probably not be cost-effective. In considering possible degradation the following factors shall be considered:

- material compatibility in the marine environment;
- operating temperature (max, min and mean);
- terminations or interfaces of cables and umbilicals.

NOTE Refer to the Bibliography for relevant standards for umbilicals.

17.5 Terminal boxes

Standard terminal boxes should be used in the device. However, the design basis should take into account the ingress protection that is necessary for the location of the terminal boxes.

If the device is designed so that it can be disconnected then this should be reflected in the terminal box design.

17.6 Umbilicals and cables

Refer to the Bibliography for relevant standards for umbilicals and cables.

18 Fabrication, manufacture and commissioning

Refer to *Guidelines for Manufacturing, Assembly and Testing of Marine Energy Conversion Systems*.

19 Deployment and retrieval

In order that the life cycle costs are minimized the following phases shall be given careful consideration. They might also have an impact on the design of the device.

NOTE The deployment and retrieval phase of the life cycle of the device could have a very significant impact on the life cycle costs.

The design basis shall consider the following phases:

- weather conditions necessary for deployment or retrieval;
- time needed for deployment or retrieval;
- tidal and sea state conditions needed for deployment or retrieval;
- specialist equipment or contractors needed for deployment or retrieval;
- availability of vessels needed for deployment;
- loadings on device during deployment or retrieval;
- marine operators' requirements;
- risk assessment for deployment or retrieval.

The design basis should clearly state what assumptions have been made for the deployment or retrieval phase.

Health and safety should be carefully considered when planning deployment or retrieval. Reference should also be made to *Guidelines for Health & Safety in the Marine Energy Industry* document of this series.

NOTE Attention is drawn to the fact that there might be local regulatory requirements.

20 Maintenance, inspection and monitoring

20.1 General

The design basis shall consider the operational phases in order to minimize costs.

NOTE The maintenance, inspection and monitoring of the device will have an impact on the OPEX costs.

The design basis shall consider the following:

- Maintenance methodology (for both minor and major maintenance activities).

  EXAMPLE Will adopted maintenance intervals be based on:

  — regular time intervals?

  or

  — condition based intervals?

  or

  — will a risk based strategy be employed (such as reliability centred maintenance)?

- Will maintenance, inspection and monitoring be done:

  — in-situ whilst at sea?

  or

  — will it be necessary to recover the device from site and bring it back ashore?

- How will maintenance, inspection and monitoring be influenced by weather conditions and environment loads? If maintenance, inspection and monitoring tasks are postponed due to weather this could reduce the availability of the device and might compromise its survivability.
- Risk analysis of these activities shall be undertaken during these phases.

Reference should be made to *Guidelines for Reliability, Maintainability and Survivability of Marine Energy Conversion Systems.*

20.2 Access arrangements

Access for maintenance of the device shall be defined in the design basis.

The design basis shall define how access for maintenance will be achieved; for instance will it be through use of a helicopter, a rigid inflatable boat or a pilot boat?

EXAMPLE Examples of typical issues that need to be addressed by the design basis include:

- How will safe access be achieved?
- How will fall arrest be achieved?
- How will fall prevention be achieved?

21 Decommissioning

To ensure that the impacts of the decommissioning phase of the device are minimized, the design basis shall give this phase careful consideration.

The design basis should consider the following during this phase and during disposal of the device:

- weather conditions necessary for decommissioning;
- length of time required for decommissioning;
- tidal and sea state conditions needed for decommissioning;
- specialist vessels, plant, equipment and contractors needed for decommissioning;
- seabed conditions;
- risk assessment for decommissioning;
- environmental impact both during and after decommissioning and disposal;
- health and safety impacts.

NOTE 1 The decommissioning phase of the device could have a significant impact on life cycle costs and the environmental impact assessment, therefore the viability of a project. Furthermore, the decommissioning requirements might also have an impact on the actual design of the device. For example the environmental impact assessment might encourage the use of a scarified GBS to promote colonization of marine organisms long after the decommissioning of the device.

NOTE 2 A useful reference document is the DTI guide for offshore decommissioning; details are in the Bibliography.

Annex A – Hazard risk assessment

The following is taken from The BERR product standards document, 'Essential health and safety requirements relating to the design and construction of equipment and protective systems intended for use in potentially explosive atmospheres'.

	Requirement	How Requirement has been met
A	Equipment and protective systems must be designed and manufactured after due analysis of possible operating faults in order as far as possible to preclude dangerous situations.	
B	Any misuse which can reasonably be anticipated must be taken into account.	
C	The materials used for the construction of equipment and protective systems must take into account foreseeable operational stresses.	
D	Materials must be so selected that predictable changes in their characteristics and their compatibility in combination with other materials will not lead to a reduction in the protection afforded; in particular, due account must be taken of the material's corrosion and wear resistance, electrical conductivity, impact strength, ageing resistance and the effects of temperature variations.	
E	Equipment and protective systems must be so designed and manufactured as to: (a) avoid physical injury or other harm which might be caused by direct or indirect contact; (b) assure that surface temperatures of accessible parts or radiation which would cause a danger, are not produced; (c) eliminate non-electrical dangers which are revealed by experience; (d) assure that foreseeable conditions of overload shall not give rise to dangerous situations.	

	Requirement	How Requirement has been met
F	Dangerous overloading of equipment must be prevented at the design stage by means of integrated measurement, regulation and control devices, such as over-current cut-off switches, temperature limiters, differential pressure switches, flowmeters, time-lag relays, overspeed monitors and/or similar types of monitoring devices.	
G	Equipment and protective systems must be so designed and constructed as to be capable of performing their intended function in full safety, even in changing environmental conditions and in the presence of extraneous voltages, humidity, vibrations, contamination and other external effects, taking into account the limits of the operating conditions established by the manufacturer.	
H	Equipment parts used must be appropriate to the intended mechanical and thermal stresses and capable of withstanding attack by existing or foreseeable corrosion.	
I	Safety devices must function independently of any measurement or control devices required for operation.	
J	As far as possible, failure of a safety device must be detected sufficiently rapidly by appropriate technical means to ensure that there is only very little likelihood that dangerous situations will occur.	
K	For electrical circuits the fail-safe principle is to be applied in general. Safety-related switching must in general directly actuate the relevant control devices without intermediate software command.	
L	In the event of a safety device failure, equipment and/or protective systems shall, wherever possible, be secured.	

	Requirement	How Requirement has been met
M	Emergency stop controls of safety devices must, as far as possible, be fitted with restart lockouts. A new start command may take effect on normal operation only after the restart lockouts have been intentionally reset.	
N	In the design of software-controlled equipment, protective systems and safety devices, special account must be taken of the risks arising from faults in the programme.	
O	Manual override must be possible in order to shut down the equipment and protective systems incorporated within automatic processes which deviate from the intended operating conditions, provided that this does not compromise safety.	
P	When the emergency shutdown system is actuated, accumulated energy must be dispersed as quickly and as safely as possible or isolated so that it no longer constitutes a hazard.	
Q	Equipment and protective systems must be fitted with suitable cable and conduit entries.	
R	When equipment and protective systems are intended for use in combination with other equipment and protective systems, the interface must be safe.	

Annex B – References

THE FOLLOWING ARE REFERENCES LISTED WITHIN THIS DOCUMENT.

1. A separation margin of 20% between critical speed and operating speed is a common margin. This can be found in several published documents; for instance in API 618 section 2.5.3.

2. A minimum damping coefficient of 0.4 (or maximum allowable amplification factor = 2.5) is referenced in several published documents; for instance in API 617 section 2.6.1.2 and API 616 Appendix section D.1.5.

Annex C – Material selection

C.1 General

During the design process it will be necessary to specify the material and manufacturing process for each component of the device. In some instances the choice of material is completely dominated by the required properties. For example if low electrical resistance is required then high conductivity copper is an obvious choice.

However, in the majority of cases there will be more than one material which is suitable. This annex covers some of the considerations that form the material selection process.

C.2 Factors effecting material selection

There can be many factors effecting material selection as shown in the list below. This list is not exhaustive and in some cases not all of the factors will be relevant.

- component shape;
- dimensional tolerances required;
- mechanical properties (e.g. fatigue strength, shear strength, tensile strength);
- corrosion properties;
- density;
- life cycle cost (e.g. cost of material, cost of manufacture, cost of maintenance and cost of installation and removal).

These factors can not be viewed in isolation as there is a complex interaction between them.

C.3 Interaction between manufacturing and material

As outlined above there are several factors which affect material selection and many of the factors interact. Probably the most significant interaction is between the manufacturing process and the material. The size and shape of a component will influence the choice of manufacturing process and hence materials. Also the required dimensional tolerances will have an impact on the choice of manufacturing process.

Life cycle costs will be influenced by the material and manufacturing process chosen. For example: a complex shape using a cast metal might be deemed a possible choice. However, if a good dimensional tolerance is also required in a component some casting processes might have further problems (for example, sand casting would need to be followed by a machining process to achieve a good dimensional tolerance).

C.4 Cost–benefit analysis

When the possible materials for a component have been identified a process for final selection of a material is necessary. Life cycle cost will be a major factor influencing material selection. It is necessary to consider all possible materials and the associated manufacturing and other life cycle costs. When the costs for all possible material and manufacturing life cycle permutations have been evaluated the material and manufacturing process which gives the lowest overall cost can be selected.

There are several methods for cost–benefit analysis; a website providing more information is listed in the bibliography.

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