EUROPEAN MARINE ENERGY CENTRE LIMITED (EMEC)
STANDARDS PROJECT

DRAFT STANDARD ON BASIS OF DESIGN OF MARINE ENERGY CONVERTERS

00	**14/01/08**	**PGD**	**RB**		
Rev	**Date**	**By**	**Reviewed**	**Approved**	**Notes**

Lloyd's Register
LIFE MATTERS

Table of Contents

Foreword

Date of publication; June 08
Committee responsible for drafting this standard; EMEC is responsible for developing this standard.
Relationship between standards: This document is one of a number of documents dealing with Marine Renewable Energy Devices. Fig 2 below shows the Renewable Energy Standards Relationship.
Legal context: compliance with this Standard cannot confer immunity from legal obligations.

It is noted that there are many different concepts for Marine Renewable Energy Devices both tidal stream and wave. In order to develop a standard which covers many different design ideas it is necessary to have generic model which could cover any concept. Figure 1 below illustrates a generic model of a Marine renewable energy device. This generic model is used in this draft standard.

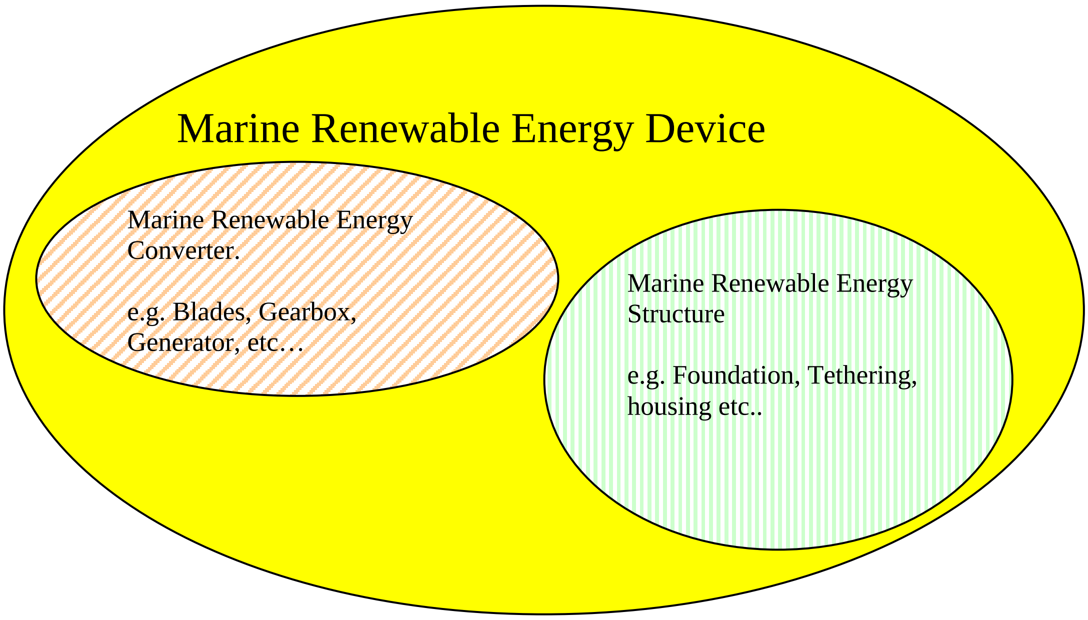

Figure 1 ***Generic model for Marine Renewable Energy Device***

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.

Some components such as gearbox or generators within the Marine Renewable Energy Converter should be designed to comply with existing international standards.

1 General

1.1 Objective

This Design Basis Standard will be applicable for both wave and tidal stream energy converters. 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, the merits

and drawbacks of various materials and design procedures that can followed. It is not the intention for this standard to be prescriptive in form.
By following this standard, it is not only hoped that the designer will have a conforming design but will also be in a position to follow the Certification Scheme.

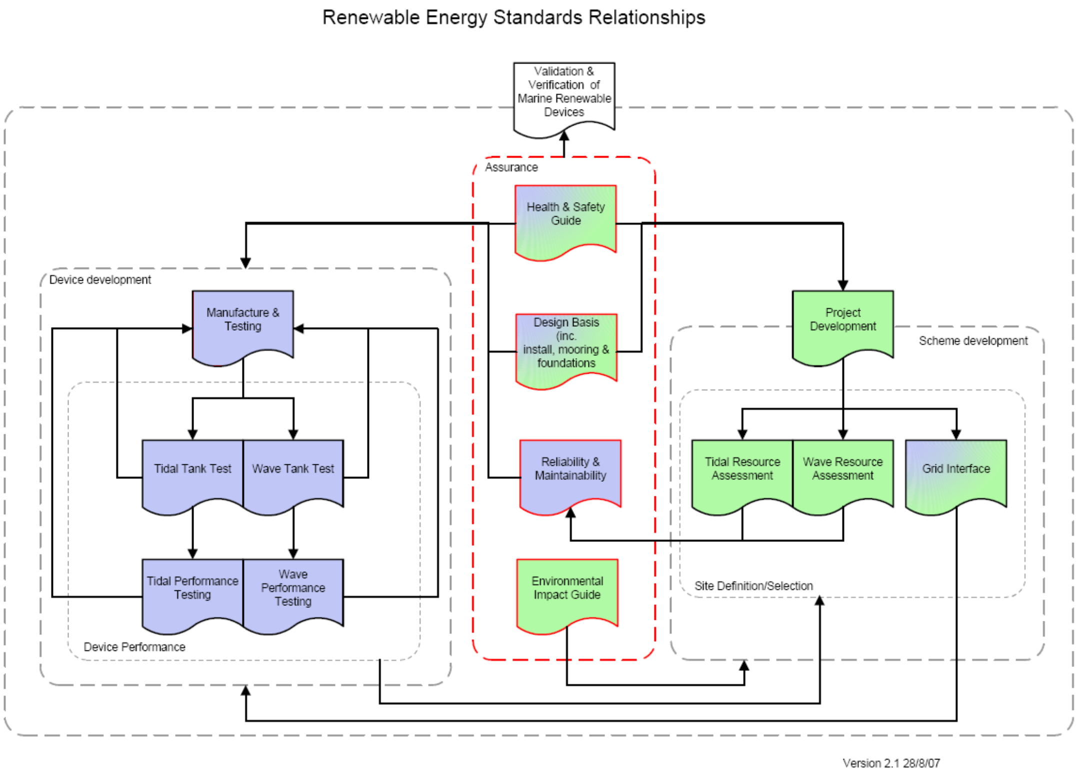

Figure 2 ***The (Marine) 'Renewable Energy Standards Relationship'.***

1.2 Scope Statement

This standard applies to the design of Marine Energy Converters (wave and tidal stream).
This standard is not a full design procedure but provides simple step by step guidance to design considerations principles. The interaction between the various parts of this standard and how they interact with the design process is shown in Fig 3.
Reference shall be made to other recognized national and international standards including those within the same suite of 'Renewable Energy Standards' (see Fig 2).
Devices for extracting energy from changes in tidal height (such as tidal barrages) are NOT within the scope of this document.

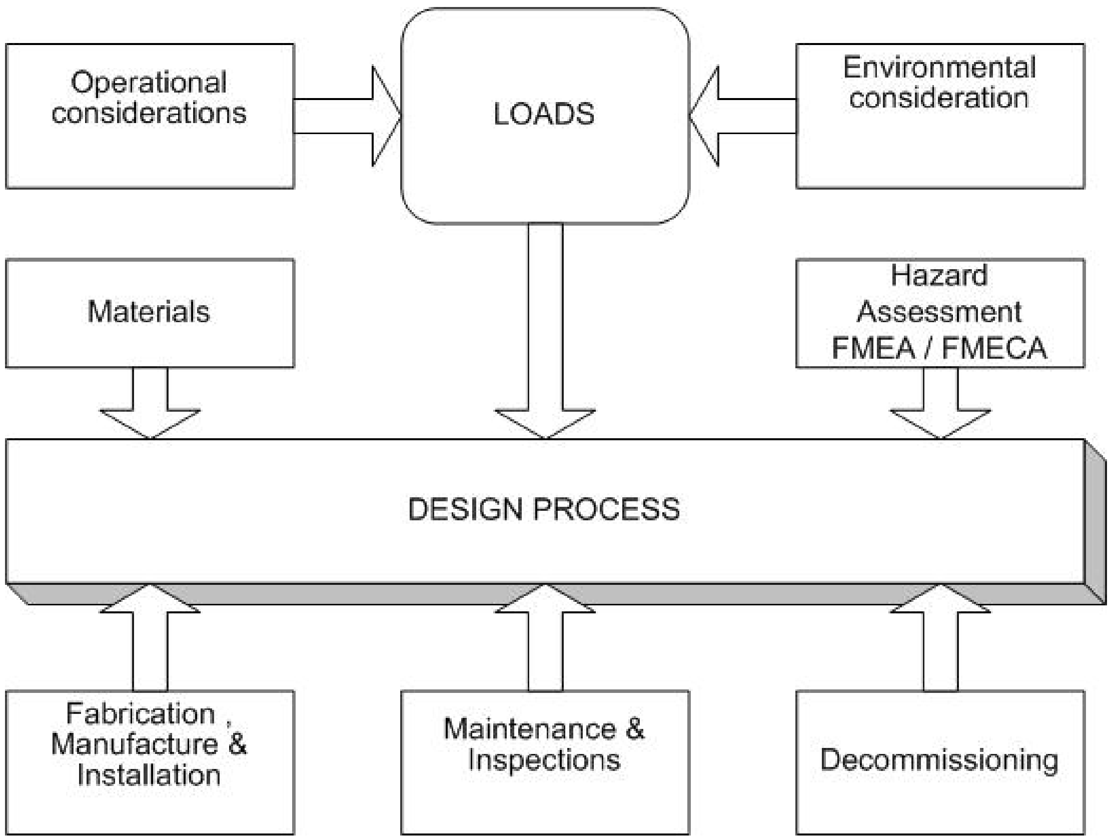

Figure 3 ***Elements affecting the design of a device***

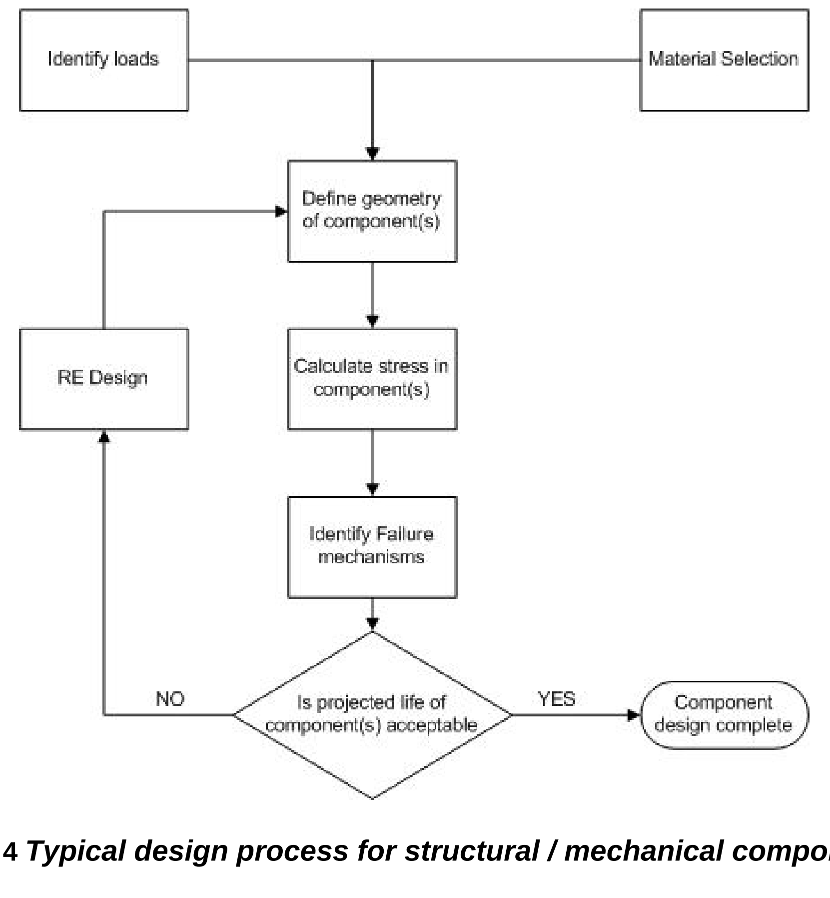

Figure 4 ***Typical design process for structural / mechanical components.***

1.3 Normative References

There are no documents that are ‘indispensable’ to the full compliance with this standard.
All informative references (i.e. those which provide supplementary information or guidance) are in a separate section entitled a “Bibliography”. The Bibliography follows the Annex.

1.4 Definitions

Business Critical system / component : A computer, electronic or electromechanical system or mechanical system / component whose failure may have an unacceptable impact on business objectives.
CAPEX Capital expenditure – The costs associated with manufacturing and installing a device.
Campbell Diagram: A Campbell diagram is a method of illustrating the natural frequency of an object and its common exciting forces. 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.
Classification societies: Non-governmental organizations that promote the safety and protection of the environment of ships and offshore structures. For the purpose of this standard it is assumed that such organizations are members of IACS.
Corrosion fatigue: Fatigue which occurs in a corrosive environment (such as sea water). Note Corrosion Fatigue strength is usually less than the Fatigue strength in air.
Damping Coefficient: Sometimes called the damping ratio is a measure of the amount of damping in a dynamic system. When the *Damping Coefficient* = 1 then the system is critically damped and when the *Damping Coefficient* = 0 then the system is not damped
Device a Marine renewable Energy device
FMEA - Failure Mode and Effects Analysis is a 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.
FMECA - Failure Mode, Effects, and Criticality Analysis is a procedure which is an extension of FMEA. In addition to the basic FMEA, it includes a criticality analysis, which is used to chart the probability of failure modes against the severity of their consequences.
Life cycle costs = OPEX + CAPEX
Marine Renewable Energy Device This will have two main parts. The Marine renewable energy converter and the Marine renewable energy structure
Marine renewable energy converter is a number of components which together convert either tidal or wave energy into electrical energy
Marine renewable Energy structure contains / supports the Marine renewable energy converter and keeps it at the desired location. Also the structure provides protection for the Marine renewable energy converter.
NON Substantial failures A failure which would NOT a substantial failure.
Factors of safety The limiting stress divided by the calculated stress
OPEX Operating expenditure – The costs associated with operating the device such as maintenance and including decommissioning
Process ‘Set of interrelated or interacting activities which transforms inputs into outputs’.
Procedure ‘Specified way to carry out an activity or a process’.
Quality ‘Degree to which a set of inherent characteristics fulfils requirements.’
Quality management ‘Co-ordinated activities to direct and control an organization with regard to quality’.
Quality management system ‘Management System to direct and control an organization with regard to quality'
Requirement ‘Need or expectation that is stated, generally implied or obligatory’.
Substantial failures A failure which would result in a loss of life; collapse of the device or substantial pollution.

Safety Critical system / component: A computer, electronic or electromechanical system or mechanical system / component whose failure may cause injury or death to human beings.
Significant wave height, as defined in ISO 19901-1
Splash zone The area of the device which whilst not completely submerged will not be kept dry during normal operation.
Wave peak period, as defined in ISO 19901-1

1.5 Symbols & Abbreviations

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.
DIN	Deutsches Institut für Normung
EMEC	European Marine Energy Centre
FEM	Federation Europeenne de la Manutention.
FOS	Factor of Safety
IACS	International Association of Classification Societies
IP	International Petroleum.
IMO	International Maritime Organisation
ISO	International Standards Organisation.
NACE	National Association of Corrosion Engineers.
NS	Norwegian Standard.
NFPA	National Fire Protection Association.
UKOOA	United Kingdom Offshore Operators Association.

2 Managing the Design Process

2.1 Introduction

The design process covered by this standard is not 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.
It is assumed that the developer is in the position to develop and optimize the device for fabrication and to achieve certification.
This standard is applicable to all stages from the prototype design stage (after the initial concept has been proven to work) up to the final design. The typical design process is shown in Figure 4.

2.2 Certification

It is noted that it may be a legislative requirement for the device to be independently certified (or a requirement from underwriters or financial institutions). The application of this standard will assist in achieving certification; see the Marine renewable Certification Scheme for more details.

2.3 Quality Assurance

The manufacturer is to establish and maintain a design control system appropriate to the level of design being undertaken. Ideally the design process should be carried out following Quality Assurance principles similar to those laid down in ISO 9000: 2000. It is noted that some aspects do need special attention during the design process and these are outlined below:
(a) identify the design practices of the manufacturer’s organization including departmental instructions to ensure the orderly and controlled preparation of design and subsequent verification;
(b) make provision for the identification, documentation and appropriate approval of all design change and modifications;

(c) prescribe methods for resolving incomplete, ambiguous or conflicting requirements; and
(d) identify design inputs such as sources of data, preferred standard parts or materials and design information and provide procedures for their selection and review by the manufacturer for adequacy

2.3.1 Software – calculation

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

2.3.2 Software – system control

Software that forms part of the Marine renewable energy device which is Safety OR Business Critical will conform to IEC 61508 part 3.
Other software should comply with IEC 61506.

2.4 Health & Safety

As with any construction projects, health and safety is paramount and a system of work must be in place which covers all phases from design to decommissioning. See also the relevant (Marine) Renewable Energy standard for Health and Safety.
For guidance a simple hazard risk assessment is included in annex A. This will allow designers to ‘design out’, where possible, all risks identified during the design phase.

2.5 Environmental Impacts

As part of the design process it will be necessary to understand the environmental impact of the installation of the device. See also the relevant Renewable Energy std Environmental Impact Guide.

2.6 Standard Hierarchy

It should be noted that there may be more than one standard which impacts the design of a device. Some standards or legislation may take precedence over other standards. The following is the hierarchy that should be followed:

- Local Regulations
- International standards (e.g. ISO, IEC, etc)
- National standards
- This standard

3 Operational Considerations

3.1 General

This section outlines the general aspects of the device that should be known prior to design. This section will ensure that all assumptions and information relating to the operation of the device are established as part of the design process.
It is important to highlight the need for the designer to be aware that the design is to consider loadings associated with the construction, deployment, operation, maintenance, retrieval and decommissioning phases.
Lastly it is important to undertake a FMEA and FMECA to identify Safety OR Business Critical components and failure modes over the life-time of the device. These studies should identify if failure modes are substantial or non substantial (see definitions). Reference should be made to the relevant (Marine) Renewable Energy standard ‘Reliability & Maintainability’ which covers FMEA and IEC 60812.

3.2 Description of Device

The description of the device will typically include:
- Description of the device.
- General Arrangement Plan Drawings.
- Elevation Drawings.
- Equipment Layout.
- Details of support structure / anchoring arrangement.
- 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 modeling work untaken to date – particularly operational loadings and survivability/reliability studies.
- Outline deployment methodology.
- Outline maintenance methodology (intervals, methodology and means of access).
- Outline decommissioning methodology.

3.3 Design Life

It is necessary in the design process to define the design life of the device. This will have a direct impact on the economic feasibility of the project and the maintenance regime.
It is expected that the notional design life of a Marine Renewable Energy Device range between 10 and 30 years although the actual period is to be determined by the designer.

4 Environmental Considerations

4.1 General

This section describes the various environmental phenomena which the device is to be exposed and therefore is fundamental to the design of a device. This section highlights the key processes/data that are to be considered prior to the design process.
It is at this point that a designer may find that additional data is required before design and, if this is the case, this standard provides direction to obtain such data.
Much of this information may be covered in sister standards (i.e. within the relevant (Marine) Renewable Energy standards “Tidal resource assessment” or “Wave resource assessment”). Additionally some useful standards and documents are referenced in the Bibliography in particular ISO 19901-1.
It is important for the device designer to identify how significant the various environmental considerations are in the device of the design. For instance if the wind loading contributes only a small amount of the total loading then the accuracy of the predicted wind loadings may not be significant.

4.2 Bathymetry/ Coastal Topography

The performance of the device will be significantly affected by the bathymetry and coastal topographic features of the area of deployment. For this reason it will be necessary to understand how the bathymetry and topographic features could change the performance of the device. It will also be necessary to carry out a review of the bathymetry and topographic features of the proposed installation site.

4.3 Geotechnical Considerations

It is important to understand the Geotechnical features that are necessary for installation and the Geotechnical features of the proposed site. It will be necessary to carry out a review of the Geotechnical features of the proposed installation site.
Sections 10 & 11 deal with the installation of the structure of the device.

4.4 Meteorology and Climatology

This section describes the meteorological and climatological processes that should be considered. Although not all may be applicable to a specific device, the following key processes should be briefly described to ensure that the designer is aware of their impact.

4.4.1 Wind - General

Wind loading is an important consideration, particularly if part of the device extends above the water surface. Wind data will also assist in the forecast of wave parameters in the absence of recorded offshore wave data.
The 1-hour wind speed, plus wind gust spectrum, will normally require to be applied in design. The following wind gust spectra formulations can be adopted for the time varying component:

• API RP 2A
• Other published spectra formulations may be accepted,
see Bibliography.

For many locations some historical data may be available. This may be fairly general and not take account of local effects. The designer must decide of the accuracy of the historical data is sufficient.

4.4.2 Wind – prediction methodology

If it is necessary to estimate the wind forces and moments for the design analysis. A suitable methodology is to be used. Typically such a regime would follow a Measure Correlate Predict methodology. The three stages are as follows:

- **MEASURE**: measurements are carried out using an anemometer at the proposed site. This data needs to be collected for a minimum of 1 year. Co-current data measured at a met station is also needed. The measurements should be carried out at a height which is close to that experienced by the device.
- **CORRELATE**: these two sets of data are then 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.

4.4.3 Air/Water temperatures

Estimates to be made of minimum and maximum air temperatures which may influence the structural design of the device – particularly exposed elements.
For the accuracy needed for the design historical data can be obtained from the Meteorological Office in the UK (or similar elsewhere).

4.5 Water Level

4.5.1 Tide Levels

The necessary data can be obtained from Admiralty charts in the UK (or similar elsewhere) OR harbour authorities for recorded data. The designer must decide of the accuracy of the available data is sufficient for the design process. If no suitable information is available, then measurements would need to be taken over a suitable time period of at least 1 year.

4.5.2 Storm Surge

Wind from a storm can raise water levels and if this coincides with a high tide then the sea level can rise above the normal high tide level. This is known as a storm surge. 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.

4.5.3 Sea Level Rise

The possibility of changing sea level should be considered. However, the actual values of such changes are difficult to quantify.

4.6 Currents

Design current velocities are to be established, taking account of all relevant components including the following:
• Tidal currents.
• Circulation currents.
• Wind driven current.
• Storm surge generated current.
Refer to (Marine) Renewable Energy standard 'Tidal Resource Assessment'.

4.7 Waves

The design of most devices will need to take into account the action of the waves and the wave loading (e.g. slam, overtopping, wave processes etc).
See also the relevant (Marine) Renewable Energy standard 'Wave Resource Assessment'.

4.8 Marine Life

Account is to be taken in the design of build-up of marine growth on the anchor lines, and/or the structure (floating or fixed), and the resulting increase in load and damping. The thickness of marine growth taken into account is to be stated in the Operations Manual and is not to be exceeded in service.
The impact of the Marine Renewable Energy Device on Marine life is covered in the relevant (Marine) Renewable Energy standard 'Environmental impact guide'

4.9 Sea ice and icebergs.

The design philosophy of units intended to be moored in regions subject to sea ice or icebergs should consider the need for any quick-release mooring system arrangements.

4.10 Design conditions

The design load cases for strength normally consider the following combinations. The joint probabilities of occurrence of the loads are considered.

- Static loads only
- Static loads + Dynamic loads (annual probability of occurrence of 10E-2)
- Static loads + Rare dynamic loads (annual probability of occurrence of 10E-4)
- Static loads + Dynamic loads + Accidental loads (annual probability of occurrence of 10E-4)

Generally the design load case for strength in a recognised design code should be suitable.

4.10.1 Dynamic loads

The design environments in the design code being used should be checked to ensure they are suitable.
The dynamic loads will in general be dominated by the response to the environment (wind, waves and current). Care must be taken in selection of the design environments to ensure the environments result in the maximum loads. This is particularly important for floating structures since the loads are sensitive to wave period and the directionality of the environment. In some cases an environment where the magnitude of the individual parameters is not large may result in large loads because of the directionality and period.
Where the loads are dominated by one environmental parameter (for example, current speed) then statistical methods may be used to estimate the design cases from the environmental data (extrapolate the environmental data). Where the loads are influenced by several environmental parameters then it is recommended the loads are calculated using measured (or hind cast) environmental data and statistical methods used to estimate the design cases from the load data (extrapolate the load data).

5 Loading Considerations

5.1 General

During the design life of the device the loading imposed by the environment will not be constant. The design needs to take account of storm conditions which the device can reasonably be expected to experience during the design life period.
In addition the following types of loadings need to 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 onboard personnel/ equipment, berthing loads and operational loads (i.e. thrust loads from turbine units)
- Accidental Loads include collisions with vessels/debris, failure of mooring lines and breakage of blades. Many of these loads may have been estimated during previous survivability/reliability studies.
- Loads induced by thermal expansion and contraction of materials
- Loads induced by transient phases such as load-out or installation

The device should be designed such that the annual probability of a substantial failure should not exceed 10E-5.

5.2 Design concepts

In the absence of local regulatory requirements the following can be used to determine the suitability of the design of the device.

5.2.1 Elastic method of design

In general, the approval of the structure of the device will be based on the elastic method of design (also known as working stress design) and the permissible stresses in the structure are to be based on the minimum factors of safety defined in 5.3.

5.2.2 Limit state method of design

When the limit state method of design (also known as Load resistance factor design) is proposed for the structure the design methods, load combinations and partial factors are to be agreed with the certifying body of the device. See the Marine renewable Certification Scheme.

5.2.3 Plastic method of design

When the plastic method of design based on the ultimate strength is proposed for the device, the load factors are to be in accordance with an acceptable Code of Practice, see Bibliography. Also to be agreed with the certifying body of the device.

5.2.4 Fatigue design

All units are to be capable of withstanding the fatigue loading to which they are subjected. The minimum design fatigue life of a device is to be 20 years unless a longer life is specified by the device designer. FOR MORE DETAIL SEE SECTION 6.

5.3 Factors of safety

In defining the applicable MINIMUM factor of safety it is first necessary to establish the consequences of failure for the component in question. It is necessary to carry out a FMEA in order to establish the consequences of failure.

		Business Critical failure	Non substantial failure	Substantial failure
Can component be inspected OR repaired?	Yes	1	1	2
	Yes but only underwater	2	2	4
	NO	5	5	10

Table 1 ***Minimum Factors of Safety***

For further information on FMEA see the relevant Renewable Energy std 'Reliability & Maintainability' Standard

6 Fatigue Design Considerations

6.1 Basis of Design

The aim of the design is for the device to perform satisfactory during its intended life with an acceptable factor of safety. Factors of safety are dealt with in section 5.3

6.2 Fatigue Considerations

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 section 7). The design is to take into account all such fatigue loadings and the resulting stresses.
Any calculation method is to include all relevant loads on the complete system under all permissible operating conditions. Consideration is to be given to the dimensions and arrangements of all components.

6.2.1 Fatigue Loading

The most appropriate method of fatigue analysis will depend on the characteristics of the device as shown in Table 2 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 minimised by good design including the following:

- Large separation between the natural periods of the structure and the exciting forces
- Reducing dynamic loads. For example, minimise loads due to vortex shedding.
- Good detail design.

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

Table 2 ***Fatigue analysis methods***

6.2.2 Fatigue life

The fatigue strength can be calculated using S/N curves following a suitable standard such as BS7608.

If required the inspection interval and acceptable defect size may be calculated following a suitable standard such as BS7910.

7 Harmonic Response

7.1 General

In designing the device the harmonic response needs to be considered both for structural and mechanical elements. Normally structural design avoids operating in a regime where a structural natural frequency can be excited.

However, some devices may exploit a resonant response in order to maximize the power captured. For such devices careful attention must be paid to the fatigue stresses which are induced and the fatigue life.

For devices which are NOT intended to exploit a resonant response it is desirable to either ensure that the natural frequency of the structural and mechanical elements are separated from the forcing frequency or ensure that there is sufficient damping in the design such that the fatigue stresses induced are not significant in comparison to the mean stresses.

7.2 Forcing Frequencies

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 may be fixed, random OR a function of another frequency. The most significant are fluid acting on the marine renewable structure, waves and passing of turbine blades (or other marine energy converter components).

For all forcing forces or moments acting on the device it is important to understand where the forces or moments are acting and in which plane.

7.3 Natural Frequencies

Both structural and mechanical elements will have many natural frequencies. It is important that all natural frequencies which could be excited by forcing frequencies are identified. The mode shapes of all such frequencies are to be considered so that the designer can understand how such frequencies can be excited.

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

- Ensure that the stiffness of the structural OR mechanical elements is low such that the natural frequency will occur 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
- Ensure that there is sufficient damping of the structural OR mechanical elements such that the response to a forcing frequency will not result 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. However, the designer needs to be careful that whilst the first natural frequency is below any forcing any forcing frequency the second (or third etc.) natural frequency is 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.

7.4 Analysis

Any analysis must have three parts to it.

- The natural frequencies are to be identified together with the mode shapes.
- The forcing frequencies are to be identified.
- The relationship between the two is to 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 show the operating speed of the device.

Any points where the natural frequencies and the forcing frequencies coincide are to be noted. For the design to be acceptable the margin between Natural frequency and operating speed range is to be at least + / - 20%.
If any natural frequencies are found within + / - 20% of operating speed range then a forced response calculation which takes into account the damping of the system is to be carried out. Ideally the model should be for all six degrees of freedom. For a design to be considered acceptable any natural frequencies are found within + / - 20% of operating speed range are to have a damping coefficient greater than 0.4.

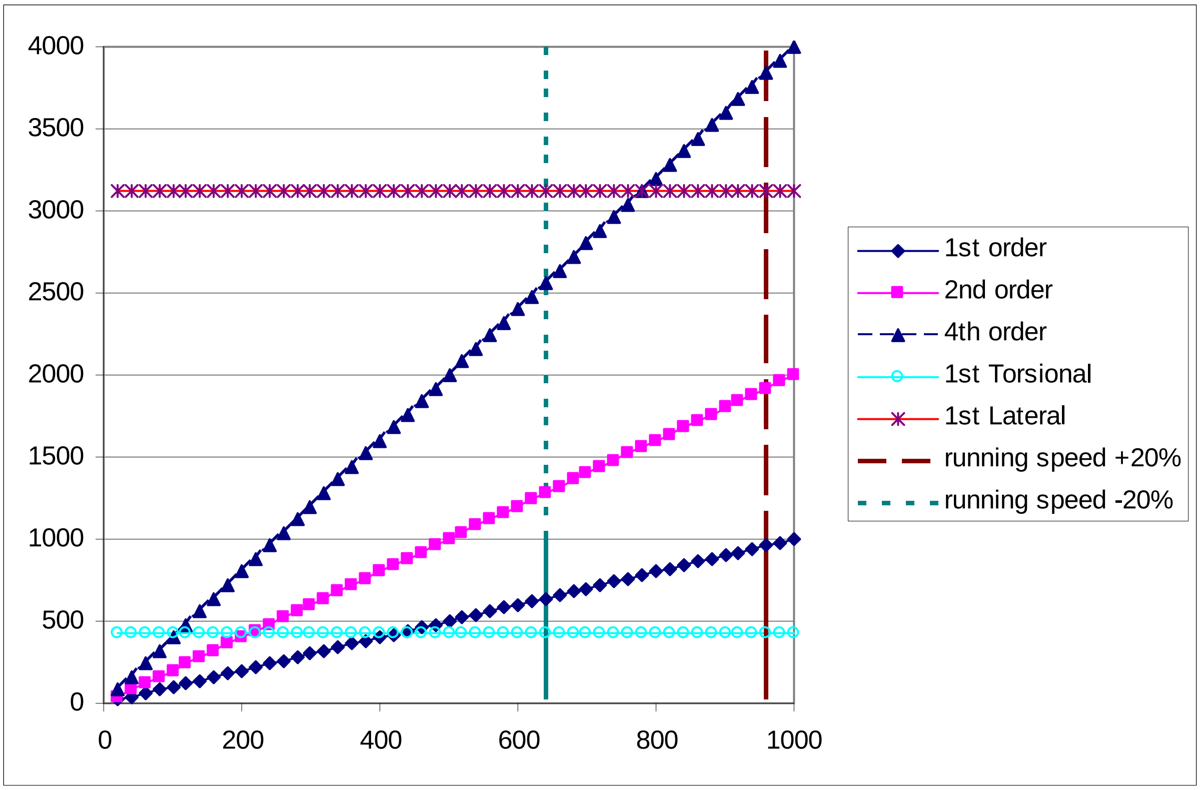

Figure 5 ***Typical Campbell diagram***

8 Materials

8.1 General

There are many types of materials that could be used to construct the device. It is important that a correct selection of the material(s) which the device is to be fabricated is important due to durability and behavior characteristics and cost.

8.2 Concrete

Tests are to be made on all proposed materials prior to construction. The tests are to be carried out by an independent laboratory which is acceptable to the certifying authority. Appropriate trials on proposed concrete and grout mixes will also be required. The testing shall generally be carried out in accordance with recognized National Codes or Standards, and is to be agreed with the certifying authority. Suitable standards are listed in the Bibliography.

8.3 Structural Steel

Structural steel is often used in the marine environment with suitable corrosion protection (see section 9). Structural Steel is frequently used because of the ease of fabrication and strength. It is available in various shapes and forms (piles, beams, plates and columns etc). It is recommended that standard forms are used when ever possible to reduce cost.
Suitable standards are listed in the Bibliography.

8.4 Bronzes

Bronzes (particularly Nickel Aluminum Bronze) have good corrosion fatigue strength. It is for this reason that they are used extensively for ships propellers.

8.5 Stainless Steel

Stainless steel is used in the marine environment because of its resistance to corrosion. Additionally it has reasonable corrosion fatigue strength and good impact properties. For this reason it is often used for ships propellers which will experience ice loading.

8.6 Composites Materials etc.

In some applications it may be advantageous to use materials other than those outlined above. Composites such as Glass Reinforced Plastic and Carbon fiber reinforced plastic have good strength to weight ratios. The disadvantage of Carbon fiber reinforced plastic is that it can accelerate corrosion of any metal components when in sea water.
Rubber has low stiffness and good damping properties. For this reason it can be used to minimize damage from parts of a device that experience oscillating force, or to tune a vibration resonance.
The experience of using such materials in a marine environment is fairly limited therefore it is recommended that specialist advice is sought.

9 Corrosion Protection

9.1 General

As the device will be working in a corrosive environment it is important that either protection is employed to minimize corrosion OR the impact of corrosion is negated by another means.

9.2 Concrete

The concrete is to be configured so that the pre-stressing tendons and reinforcement bars (rebars) are protected by the concrete against corrosion. However, if this is not possible or if damage occurs which expose pre-stressing tendons OR rebars then corrosion protection will need to be provided.

9.3 Structural Steel

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

- Corrosion allowance incorporated in the design
- Inspection regime to be employed
- Stress in the component (both mean stress and Fatigue) and calculated FOS
- Location of the component relative to the sea water surface
- Areas subject to wear

For areas not protected against corrosion (or with ordinary paint coating only), an additional corrosion allowance shall be considered. BS6349 also provides advice on free corrosion for steel in maritime structures.

9.3.1 Corrosion Rates

The corrosion rates are to be determined based on previous similar service experience. In the absence of accurate information the following corrosion rates are to be considered in the design for components in the splash zone.

- Uncoated surfaces which are internally heated the corrosion rate = 3mm per year.
- Uncoated carbon steel corrosion rate = 0.3mm per year

Consideration should also be given to aggressive local corrosion (pitting and grooving).

9.3.2 Cathodic Protection

The cathodic protection system for the external submerged zone is to be designed for a period commensurate with the design life of the structure or the dry docking interval and it should be capable of polarizing the steelwork to a sufficient level in order to minimize corrosion.
This may be achieved using either sacrificial anodes or an impressed current system or a combination of both.

9.3.3 Protection after launching and during outfitting

Where protection is primarily by an impressed current cathodic protection system, sufficient sacrificial anodes are to 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.

9.3.4 Coating Systems

It is to be noted that cathodic protection is only suitable for areas which are continuously submerged. For areas which are not continuously submerged (such as the splash zone) a suitable coating is to be used.

9.3.5 Sacrificial Thickness

It is possible to mitigate the effects of corrosion by the use of thicker steel sections based on corrosion rates and the design life of structure. However, consideration should also be given to aggressive local corrosion (pitting and grooving).

9.4 Mooring System

The chain size chosen should exceed that required to satisfy the Factor of Safety to allow for the corrosion and wear which can occur over the intended service life of the anchor chain or associated component. A size margin over and above the minimum chain size required to satisfy Rule factor of safety requirements is to be included to the minimum margins shown in Table 2 below are recommended.

Region of anchor chain	Margin (mm per year service life, on chain diameter)
Splash zone	0,3
Catenary	0,2
Touch down zone and sea bed	0,4

Table 3 ***Chain corrosion factors***

Additional margins greater than those indicated in the Table may be required where chains are subjected to high wear rates.

10 Floating structures

It is assumed that the device will be mostly un-manned (except during maintenance). Therefore many of the requirements related to safety for a conventional ship or floating offshore structure will not be applicable.
However the following aspects should be considered in the design.

- Required buoyancy / ballasting of the structure.
- Pumping arrangements (perhaps temporary) to achieve the required buoyancy / 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 due to collision OR corrosion and how this could effect buoyancy / 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.

11 Design of Foundation and Support Structure (if applicable)

11.1 General

For devices which are not floating type the two basic types of foundations that can be used are:

- Gravity type foundations.
- Pile foundations (driven & suction)

It is important to consider the structural design and global stability of the foundation as well as the stability of the founding sea bed soils.

11.2 Geotechnical Design Parameters

Whilst it may be advantageous for a device to have a common foundation design, site investigation is necessary to confirm that the foundation design is suitable at a specific location. The site specific investigation should confirm the following parameters:

- Soil resistance to axial pile load
- Soil shear strength
- Uniformity of soil and seabed conditions

11.3 Design of Pile Foundations

Piled foundations have been used for supporting offshore oil and gas platforms throughout the world and could be used for Marine Renewable Energy Structure. There is well established design codes / guidelines for the design of piles (these are listed in the Bibliography).

There are several methods of installing piles:

- Drill-drive
- Drill and grout
- Above-surface steam, hydraulic or vibration hammers
- Underwater hydraulic hammers

The choice of pile could be affected by the following

- Weather conditions needed to install
- Soil conditions need to install
- Forces / accelerations needed to install

11.4 Design of Gravity Foundations

Gravity foundations or gravity base structures (GBS) have been used for supporting offshore oil and gas platforms. GBS could be used for Marine Renewable Energy Structure. GBS are usually configured so that they have sufficient buoyancy to be floated out for, tow and installation and are then ballasted so that they have sufficient weight to resist overturning (usually ballasted with water, grout or iron ore). The GBS is usually a number of cells (open and or closed) that form the base and a number of integral legs these can support any structure located above the water line.

11.5 Stability of Seabed

The stability of the seabed and in particular the slope stability of the sea bed is to be considered in the design. This may be a particular concern for seismically active areas.

11.6 Scour Protection

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 can be removed. It is more significant at sites with tidal currents.

There are several methods of preventing scour :

- Rock dumping,

- Bottom protection with integrated geotextile and concrete block mattresses
- A protection wall with concrete filling.
- Seabed improvement by gluing the sand

A paper on scour protection is referenced in the bilbliography.

12 Design of the Mooring System (if applicable)

12.1 General

Mooring system are typically characterized in of the following configurations:

- **Catenary mooring.** A mooring system which derives its compliancy mainly from the catenary action of the anchor lines. Some additional resilience is provided by the characteristic axial elasticity of the anchor lines.
- **Taut-leg mooring.** A mooring system based on light-weight anchor 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 anchor 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.

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

12.2 Mooring Equipment

Mooring system will consist of the following components, as relevant:

(a) Anchor points:

- Drag embedment anchors.
- Anchor piles.
- Suction anchor piles.
- Gravity anchors.

(b) Anchor lines.

(c) Anchor 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.

12.3 Loadings

Refer to environmental conditions (section 4) which outlines loading upon the device and also forces directly on the mooring system (wave and current). Marine growth on the mooring system is to be considered as the diameter influenced by the loadings may increase.

12.4 Design of Mooring System

Generally sections 4 & 5 give the necessary guidance in respect of the design of the mooring system.

12.5 Anchor Design

The following are the types of anchors that could be used for a device.

- Drag embedment anchors
- Anchor piles

- Suction anchor piles
- Gravity anchors

The design of the anchors should take into account the soil conditions at the site where the device will be located. For all anchors the holding capacity is to be clearly defined for all foreseeable conditions.
All anchors are to follow a process outlined either in a recognized international standard OR following the design principles outlined by an IACS member.

12.5.1 Drag embedment anchors

It is recommended that the manufacturing process for these anchors, from foundry to completion is to be witnessed and inspected by an independent third party. An alternative would be for the anchors are to be manufactured at a works that has been audited by an IACS member.
Notwithstanding the above, attention is drawn to the separate requirement of some National Authorities for proof load testing of anchors.

12.5.2 Anchor piles

Anchor piles are either driven or drilled and grouted into the sea bed to provide resistance to axial, lateral and torsional loading. Piles installed by vibrating hammers are not recommended where axial loading is significant. Anchor piles are characterized by being relatively long and slender and having a length to diameter or width ratio generally greater than 10.

12.5.3 Suction anchor piles

Suction anchor piles are installed by suction to achieve the required penetration into the sea bed to provide resistance to axial, lateral and torsional loading. Suction is applied by creating a reduced water pressure within the pile compared to the external ambient water pressure. Suction anchor piles can be retrieved from the sea bed by reversing the suction process
Suction anchor piles are characterized by having a large diameter and a length to diameter ratio generally less than eight and are essentially caisson-type foundations if it is less then three.

12.5.4 Gravity anchors

This section applies to anchors which are either a gravity frame or block anchors, which rely on their mass to provide resistance to vertical, lateral and torsional loading. Gravity anchors may be provided with skirts which penetrate the sea bed to provide increased lateral resistance.

13 Marine Renewable Energy converter (Electrical and Mechanical Design)

13.1 General

This section 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.

13.2 Definition of Design Environment

Sections 4 & 9 of this document outline the environment conditions which need to be considered in the design.
It is possible to provide protection using an active marinisation technique such as the provision of a dry de-salinated atmosphere. If active marinisation techniques are used then the systems which have a safety function are to continue to operate if the active marinisation fails.

13.3 Design Life of Components

The design life needed for components should be defined by a Reliability & Maintainability study. Refer to ‘Reliability & Maintainability’ Standard for further details.

13.4 Electrical Equipment

Electrical equipment should be suitable for operation in the environmental conditions experienced by the Marine Energy Converter. Also national / regional regulations are to be complied with (e.g. EC Electromagnetic Compatibility (EMC) directive).

13.4.1 Emergency safety systems

The design of the Marine Energy Converter is to include details of emergency safety systems which are to include typical single line diagrams and arrangements, showing the location of equipment and cable routes to be employed for:

- emergency & 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 are to be capable of battery operation and are to be provided with suitable batteries.

13.4.2 Major items of equipment

The electrical design of the Marine Energy Converter is to include a general arrangement plan showing the location of major items of electrical equipment, for example:

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

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

13.4.3 Grid connection

National / regional regulations are to be complied for Grid connection arrangements some UK standards are referenced in the Bibliography.

13.5 Mechanical Equipment

13.5.1 Inclinations

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

13.5.2 Fatigue

For further details of design in respect of fatigue see section 6.

13.5.3 Force transmitting components (shafts, linkages etc.)

Force transmitting components are to comply with sections 5.2.4, 6 &13.5.1of this document and the standards referenced in the Bibliography.

13.5.3 Pressure retaining equipment

The designer is in addition to comply with any regulatory requirements such as the Pressure Equipment Directive (PED) that may be applicable.

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 gasses** P less than 200 & V is less than 1
  OR P * V is less than 25
- **Group 2 gasses** P less than 1000 & V is less than 1
  OR P * V is less than 50

- **Group 1 liquids** P less than 500 & V is less than 1
  OR P * V is less than 200
- **Group 2 liquids** P less than 1000 & V is less than 10
  OR P * V is less than 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

13.6 Piping systems

The materials used for pipes, valves and fittings are to be suitable for the fluid and the service for which the piping is intended.
The piping material, pipe sizing and construction details are to follow the design concepts laid out by a recognised international standard such as ANSI/ASME B31.3 Or the rules of an IACS member. It is important that the application of these standards is consistent. For instance it is NOT permissible to use the allowable stress for a material from one standard and the stress formulation from another standard.
The designer is in addition to comply with any regulatory requirements such as the Pressure Equipment Directive that may be applicable.

13.6.1 Flexible Piping

The materials used for flexible pipes, are to 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 are to subject to satisfactory prototype testing witnessed by an organisation independent of the manufacturer (see Bibliography for applicable standards).
All flexible hose assemblies are to 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 is to be mitigated as far as practicable by the use of screens or other suitable protection.
The installation of flexible hose assemblies is to be in accordance with the manufacturer's instructions and use limitations with particular attention to the following:
(a) Orientation.
(b) End connection support (where necessary).
(c) Avoidance of hose contact that could cause rubbing and abrasion.
(d) Minimum bend radii.

13.6.2 Non metallic rigid Piping (plastic)

Pipes and fittings are to be of robust construction and are to comply with a National or other established Standard, consistent with the intended use. It should be noted that the use of plastics pipes may 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).

14 Instrumentation and Control Systems

14.1 General

This section 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.

14.2 Definition of Design Environment

Sections 5 & 9 of this document outline the environment conditions which need to be considered in the design.
It is possible to provide protection using an active marinisation technique such as the provision of a dry de-salinated atmosphere. If active marinisation techniques are used then the systems which have a safety or business critical function are to continue to operate if the active marinisation fails.

14.3 Design of Systems

The Instrumentation and control systems which are safety critical or business critical should be identified by the FMEA (see 'Reliability & Maintainability' Standard for further details). The FMEA should also identify the required reliability for the Instrumentation and control systems.

14.4 General requirements for Systems

Machinery, safety and control system faults are to be indicated. The presence of unrectified faults is to be clearly indicated at all times.
Failure of any power supply to the alarm system is to 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 are to be evaluated on the basis not only of the control system and its associated machinery, but also the complete installation.
The control system is to 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 are to be such that the final settings can be readily identified.
Failure of a control system is not to result in the loss of ability to provide control to Safety / 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.

14.5 Requirements for Safety / Business Critical Systems

Safety systems are to operate automatically in case of serious faults endangering the machinery, so that:

- normal operating conditions are restored, e.g. by the starting of standby machinery, or
- the operation of the machinery is temporarily adjusted to the prevailing conditions, e.g. by reducing the output of the machinery, or
- the machinery is protected from critical conditions by shutting off the fuel or power supplies thereby stopping the machinery.

14.6 Alarm & Safeguards

This section should has lists of typical alarm points.

ITEM	ALARM
Hydraulic system pressure	Low
Hydraulic oil supply tank level	Low
Hydraulic oil temperature	High (Where an oil cooler is fitted)
Bus-bar voltage	High and Low
Bus-bar frequency	Low
Generator cooling air	High For closed air circuit temperature water cooled machines
Bearing lubricating oil tank level	Low
Bearing temperature	High

Table 4 Typical Alarm points

15 Cable Connection to Shore

15.1 General

Underwater connections and connectors operating in a marine environment shall be technology which has demonstrated satisfactory service of at least 5 years in similar applications. It is recommended that the connectors used are:

- Are not of a push fit type (but have a positive locking mechanism such as bayonet fitting)
- The connector is to be arranged so that it can NOT be connected in the wrong position (a keyed arrangement or similar method is to be employed).

15.2 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 may be dependent on time of year)
- Shipping lanes
- Areas of high tidal speeds
- Shifting sands

Some of these hazards may be mitigated by burying the cable.

15.3 Loading

The designer is to determine the loading the cable can withstand both in tension and flexing. These loads are to be considered both during installation and during operation. The operating loads are expected to be more severe on floating devices.

15. 4 Design

In addition to the loading mentioned in section 15.3 cables and umbilicals are to 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 are to be considered:

- Material compatibility in the marine environment
- Operating temperature (max, min and mean)
- Terminations / interfaces of cables / umbilicals

Refer to the Bibliography for relevant standards for Umbilicals

15.5 Terminal Boxes

It is recommended that standard terminal boxes are used in the device. However, the designer should take into account the ingress protection that is necessary for the location of the terminal boxes.

15.6 Umbilicals & Cables

Refer to the Bibliography for relevant standards for Umbilicals & Cables.

16 Fabrication, Manufacture & Commissioning

Refer to (Marine) Renewable Energy standard ‘Manufacturing & Testing Guide’.

17 Deployment and Retrieval

The deployment and retrieval phase of the life cycle of the device could have a very significant impact on the life cycle costs. In order that costs are minimized it is necessary to give these phases careful consideration. Further these phases may also have an impact on the design of the device.
The following needs to be considered during these phases:

- Weather conditions necessary for deployment / retrieval
- Time needed for deployment / retrieval
- Tidal conditions needed for deployment / retrieval
- Specialist equipment / contractors needed for deployment / retrieval
- Loadings on device during deployment / retrieval
- Risk assessment for deployment / retrieval

Health & Safety should be carefully considered when planning Deployment OR Retrieval. As well as considering local regulatory requirements reference should also be made to (Marine) Renewable Energy standard ‘Health & Safety Guide’.

18 Maintenance, Inspection and Monitoring

The maintenance, inspection and monitoring of the device will have an impact on OPEX . Thus these operational phases needed to be carefully considered in order to minimize costs. The following to be considered during design:

- Maintenance methodology (for both minor and major maintenance activities) will maintenance intervals be based on: Regular time intervals ?
  OR
  Condition based intervals ?
  OR
  Will a risk based strategy be employed (such as Reliability Centered Maintenance)?
- Will maintenance, inspection and monitoring be done in-situ
  OR
  Will it be necessary to remove the device from the site.
- How will maintenance, inspection and monitoring be influenced by weather conditions/ environment loads. If maintenance, inspection and monitoring tasks are postponed due to weather this could reduce the availability of the device.
- Risk analysis of these activities is to be undertaken during these phases.

Reference should be made to the relevant (Marine) Renewable Energy standard for Reliability & Maintainability.

19 Decommissioning

The decommissioning phase of the life cycle of the device could have a very significant impact on the life cycle costs. In order that costs are minimized it is necessary to give these phases careful consideration. Further this phase may also have an impact on the design of the device. The following needs to be considered during this phase and during disposal of the device:

- Weather conditions necessary for decommissioning
- Time needed for decommissioning
- Tidal conditions needed for decommissioning
- Specialist equipment / contractors needed for decommissioning
- Risk assessment for decommissioning
- Environmental impact both during and after decommissioning and disposal

Reference should also be made to the relevant (Marine) Renewable Energy standard for Environmental impact and the Bibliography.

Annex A - Hazard risk assessment.

THE FOLLOWING IS TAKEN FROM "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.	
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	

	Requirement	How Requirement has been met
	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.	
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	

Bibliography

A selection of relevant standards

Pressure vessels/heat exchangers:

ASME Section VIII, Div. 1 and 2 Rules for Construction of Pressure Vessels.
PD 5500 Unfired Fusion Welded Pressure Vessel.
TEMA Tubular Exchangers Manufacturers Association.

General structural items :

ISO 19900 General requirements for offshore structures (Petroleum and natural gas industries)
ISO 19902 Fixed steel offshore structures (Petroleum and natural gas industries)
ISO 19904-1 Floating offshore structures -- Part 1: Monohulls, semi-submersibles and spars (Petroleum and natural gas industries)
ISO 19901-4 Specific requirements for offshore structures-- Part 4: Geotechnical and foundation design considerations (Petroleum and natural gas industries)
ISO 19901-2 Specific requirements for offshore structures-- Part 2: Seismic design procedures and criteria (Petroleum and natural gas industries)
AISC Manual of Steel Construction – Allowable Stress Design.
AISC LRFD Manual of Steel Construction - Load and Resistance Factor Design
API RP 2A – WSD Recommended Practice for Planning, Design and Constructing Fixed Offshore Platforms Working Stress Design.
API BUL 2U Design of Flat Plate Structures.
BS 7608 Code of practice for fatigue design and assessment of steel structures
BS 7910 Guide to methods for assessing the acceptability of flaws in metallic structures
BS 5950 Structural Use of Steelwork in Building.
BS 2853 The Design and Testing of Steel Overhead Runway Beams.
BS EN 1993 Eurocode 3: Design of Steel Structures.
BS 6399-2 Loads for Buildings, Code of Practice for Wind Loads
BS 8118 Structural Use of Aluminium
BS 8100 Lattice Towers and Masts.
BS 6349 Maritime structures. Code of practice for general criteria

Bearings:

ISO 281: Dynamic Load Ratings and Rating Life of Rolling Bearings.
ISO 76: Static Load Ratings for Rolling Bearings.

Metocean:

ISO 19901-1 Petroleum and natural gas industries -- Specific requirements for offshore structures -- Part 1: Metocean design and operating considerations.
API RP 2A Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms.
Environmental Parameters for Extreme Response: Inverse Form with Omission Factors, Winterstein et al, ISBN No. 9054103571

Codes for concrete structures:

ISO 19903 Fixed concrete offshore structures (Petroleum and natural gas industries)
BS 8110 Structural Use of Concrete, Parts 1, 2 and 3.
NS 3473 Concrete Structures – Design Rules.
CSA S471 General Requirements, Design Criteria, the Environment and Loads.
CSA S474 Concrete Structures, Offshore Structures.

Mechanical equipment:

ISO 6336: Calculation of load capacity of spur and helical gears.
ISO 1328: Gear quality grade.
ISO 6802 Rubber and plastics hoses and hose assemblies – Hydraulic pressure impulse test without flexing.
ISO 6803 Rubber and plastics hoses and hose assemblies – Hydraulic pressure impulse test with flexing.
ISO 10380 Pipework – Corrugated metal hoses and hose assemblies
ANSI/ASME B31.3 Process Piping
IMO Resolution A.753(18) Guidelines for the Application of Plastic Pipes on Ships

Electrical equipment:

IEC 60502 Power cables with extruded insulation and their accessories
IEC 60439 Low voltage switchgear and control gear assemblies;

IEC 60298 AC Metal enclosed switchgear and control gear for rated voltages above 1 kV and up to and including 72.5 kV;
IEC 60466 AC insulated-enclosed switchgear for rated voltages above 1 kV and up to and including 38 kV;
IEC 60255 Electrical relays
IEC 60947-2 Low voltage switchgear and Control gear Pt 2: Circuit-breakers;
IEC 62271-100 High-voltage switchgear and control gear - Pt 100: High-voltage alternating-current circuit breakers;
IEC 60470 High-voltage alternating current contactors.
IEC 60269 Low-voltage fuses;
IEC 60282-1 High voltage fuses Pt 1: Current-limiting fuses;
IEC 60092–350 Low-voltage shipboard power cables. General construction and test requirements
IEC 60092–353 Single and multicore non-radial field power cables with extruded solid insulation for rated voltages 1 kV and 3 kV
IEC 60092–354 Single and three-core power cables with extruded solid insulation for rated voltages 6 kV, 10 kV and 15 kV
IEC 60092–375 Shipboard telecommunication cables and radio frequency cables – General instrumentation, control and communication cables
IEC 60092–376 Shipboard multicore cables for control circuits
IEC 60702 Mineral insulated cables with a rated voltage not exceeding 750 V
API 17E / ISO 13628 Specification for Subsea Umbilicals

Grid Connection:

Electricity Safety, Quality and Continuity Regulations (2002) (Section J – Generation). Publication reference URN 02/1544.
G59/1 Recommendations For The Connection Of Private Generating Plant To The Regional Electricity Companies (RECs)
G75 Recommendations for the Connection of Embedded Generating Plant to Public Electricity Suppliers Distribution Systems (above 20kV or with outputs over 5MW).

Software:

IEC 61508 part 3. Functional safety of electrical/electronic/programmable electronic safety-related systems - Software requirements
IEC 61506. Industrial-Process Measurement and Control - Documentation of Application Software

MISC

Offshore Technology Report 2001/032 Decommissioning Topic Strategy ISBN 0 7176 2054 9
Offshore Technology Report 2000/099 Generic design framework pile foundations (fixed steel structures) ISBN 0 7176 2039 5
“Scour protection: a necessity or a waste of money?” M.B. Zaaijer, J. van der Tempel,
http://www.iacs.org.uk/ International Association of Classification Societies (IACS)
http://www.iacs.org.uk/explained/members.aspx List of IACS members

List of Figures

List of Tables