IEC TS 62600-10

Edition 1.0 2015-03

TECHNICAL SPECIFICATION

colour inside

Marine energy – Wave, tidal and other water current converters –
Part 10: Assessment of mooring system for marine energy converters (MECs)

IEC TS 62600-10:2015-03(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.140

ISBN 978-2-8322-2431-1

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IEC TS 62600-10, which is a technical specification, has been prepared by IEC technical committee 114: Marine energy – Wave, tidal and other water current converters.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
114/140/DTS	114/150A/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

This technical specification defines rules and assessment procedures for the design, installation and maintenance of mooring system with respect to technical requirements for floating marine energy converters.

The proposed work will aim to bring together expert knowledge from the marine energy power and offshore engineering industries in order to formulate a guideline specification of the design, installation and maintenance requirements for mooring system of floating MECs.

In addition to safety and ocean environmental requirements, this technical specification focuses on the strength requirements of mooring systems for MECs.

MARINE ENERGY – WAVE, TIDAL AND OTHER WATER CURRENT CONVERTERS –

Part 10: Assessment of mooring system for marine energy converters (MECs)

1 Scope

The purpose of this Technical Specification is to provide uniform methodologies for the design and assessment of mooring systems for floating MECs (as defined in TC114 scope). It is intended to be applied at various stages, from mooring system assessment to design, installation and maintenance of floating MEC plants.

This technical specification is applicable to mooring systems for floating MEC units of any size or type in any open water conditions. Some aspects of the mooring system design process are more detailed in existing and well-established mooring standards. The intent of this technical specification is to highlight the different requirements of MECs and not duplicate existing standards or processes.

While requirements for anchor holding capacity are indicated, detailed geotechnical analysis and design of anchors are beyond the scope of this technical specification.

2 Normative references

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

IEC TS 62600-1, *Marine energy – Wave, tidal and other water current converters – Part 1: Terminology*

ISO 17776:2000, *Petroleum and natural gas industries – Offshore production installations – Guidelines on tools and techniques for hazard identification and risk assessment*

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

ISO 19901-7:2013, *Petroleum and natural gas industries – Specific requirements for offshore structures – Part 7: Stationkeeping systems for floating offshore structures and mobile offshore units*

API RP 2SK, *Design and Analysis of Station keeping Systems for Floating Structures*, 3rd Edition, October 2005

API RP 2I, *In-Service Inspection of Mooring Hardware for Floating Structures*, 3rd Edition, 2008

3 Terms and definitions

For the purposes of this document, the following terms and definitions as well as those given in IEC TS 62600-1 apply.

3.1
anchor
device that provides a holding point at the seabed for a mooring line connected to a floating MEC

3.2
catenary mooring
mooring system where restoring forces are provided by the distributed weight of mooring lines

3.3
connectors and accessories
hardware used to join various components in the mooring system not including the structures fixed to the MEC or the anchor

3.4
design criteria
quantitative formulations that describe the conditions to be satisfied with each limit state

3.5
design service life
assumed period for which a structure or a structural component is to be used for its intended purpose with anticipated maintenance, but without substantial repair being necessary

3.6
design limit
set of physical conditions during a certain reference period for which the structure member will demonstrate that relevant limit states are not exceeded

3.7
dynamic response
acceleration and resulting motion of a MEC with mooring system as it is subject to assorted loads

3.8
floating device
structure supported by buoyancy

3.9
limit state
condition for which a system or a component is at its limit of performance of its intended function

3.10
mobile mooring
temporary anchoring arrangement at a specific location for a short period of time

3.11
mooring components
general class of devices and hardware used in the mooring of floating structures

3.12
mooring line
string of components connecting a MEC to an anchor

3.13
mooring system
compliant configuration that consists of mooring lines, components, and anchors

3.14
resistance
capacity to withstand loads and motions

3.15
return period
inverse of the annual probability

3.16
single point mooring
mooring system that consists of a single connection point to the MEC

3.17
spread mooring
mooring system that consists of multiple connection points to the MEC

3.18
stiffness
ratio of change in restoring forces to change in displacement

3.19
semi-taut mooring
mooring system comprised of attributes of both taut and catenary forms

3.20
taut-line mooring
mooring system where the restoring action is provided by elastic deformation of mooring lines

3.21
axisymmetric
floating structure that is symmetric about an axis of rotation

3.22
umbilical
compliant and slender structure that is used to transport fluid, electricity, data, or other material from a MEC to another location

3.23
proof loading
test procedure that applies loads at some fraction of design load to confirm adequate structural response

3.24
consequence class
classification that correlates to the potential for damage in the event of failure with an associated set of design factors

3.25
design factor
factors that amplify loading and stresses that are used to compensate for uncertainty and the potential for damage in the event of failure in accordance with the associated consequence class

4 Abbreviated terms

ALARP	As low as reasonably practicable
ALS	Accidental limit state

API	American Petroleum Institute
ASF	Adjusted safety factor
CALM	Catenary anchor leg mooring
CFD	Computational fluid dynamics
DP	Dynamic positioning
DF	Design factor
FLS	Fatigue limit state
HAZID	Hazard Identification
HHP	High holding power
IEC	International Electrotechnical Commission
ISO	International Organisation for Standardisation
LTM	Long term mooring
MBL	Minimum breaking load
MEC	Marine energy converter
MEP	Marine environmental protection
MPM	Most probable maximum
PTO	Power take-off
PT	Project team
ROV	Remotely operated vehicle
SALM	Single anchor leg mooring
SF	Safety factor
SLS	Serviceability limit state
SPM	Single point mooring
ULS	Ultimate limit state
UV	Ultraviolet
VIM	Vortex induced motion
VIV	Vortex induced vibration

5 Principal element

5.1 General

This clause provides an overview of the content of this technical specification.

5.2 Mooring and anchor systems

An overview of existing mooring designs, components, and anchors is provided for reference.

5.3 Design considerations

Understanding the design inputs and limitations shall be considered when designing a mooring system and selecting anchor types for MECs. Fundamental design considerations include limit state categories, metocean and external conditions, external load effects, and mooring line component and anchor hardware related considerations.

5.4 Safety and risk consideration

Understanding risk factors is important in quantifying the consequence class of the mooring design. The consequence class dictates the required level of safety of the mooring design.

5.5 Analysis procedure

The limit states influence the mooring design process. The potentially complex nature of MEC dynamic behaviour and external loading effects mean that careful consideration of the limitations of analysis techniques shall be made.

5.6 Inspection and maintenance requirements

The integrity of a station keeping system and its serviceability throughout the design service life are not only strongly dependent on a competent design, but also on the quality control exercised in manufacture, supervision on-site, handling during transport and installation, and the manner in which the system is used and maintained.

6 Types of moorings and anchoring systems

6.1 General

This clause provides an overview of mooring and anchor types that may be used with floating MECs. Floating structure station keeping systems vary depending on the characteristics of the structure and on the environmental conditions. Single point moorings are frequently used for floating structures where greater freedom in motion is required, while spread moorings are used mostly on structures when maintaining a particular orientation is important. Another type of station keeping system is dynamic positioning (DP). Dynamic positioning uses actively controlled thrusters as part of the station keeping capability. Thruster-assisted moorings can be used to reduce mooring line tensions or to control heading.

The mooring components, anchor types, and sizing depend on the site requirements, design, and MEC power capture considerations.

6.2 Mooring systems

6.2.1 General

Examples of existing mooring system types for floating structures are described in the following subclauses. These examples are not exhaustive.

6.2.2 Spread moorings (catenary, taut-line and semi-taut-line)

Spread moorings are often used when weathervaning, or rotation movement of a floating structure such that it aligns to a wind or current load so as to minimize drag loading, is not desirable. Spread moorings can incorporate chain, wire rope, synthetic rope, or various combinations of materials. Spread mooring systems may use taut, semi-taut, or catenary systems. A spread moored configuration can be seen in Figure 1.

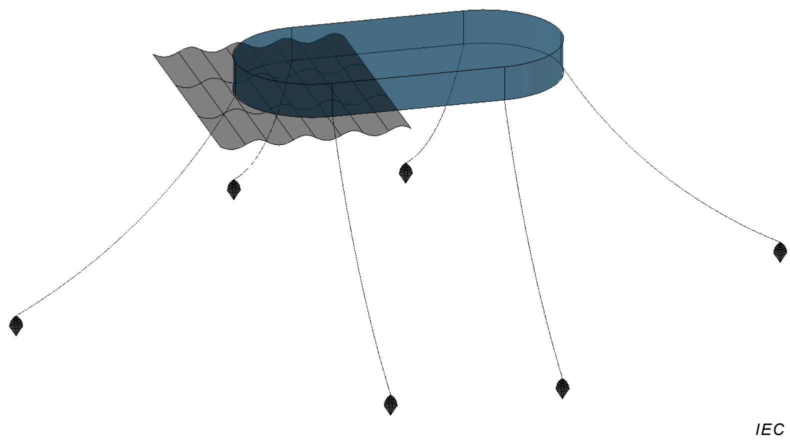


Figure 1 – Spread mooring configuration

6.2.3 Single point moorings (SPM)

Single point moorings allow floating structures to weathervane. A floating structure may directly connect to the mooring system or to an intermediary moored buoy. There is wide variety in the design of single point moorings but they all essentially perform the same function. Examples of typical single point mooring systems are described below.

a) Catenary anchor leg mooring (CALM)

A CALM system consists of a large buoy that supports a number of catenary mooring lines. The floating structure is connected to the buoy by a single connection point as indicated in Figure 2.

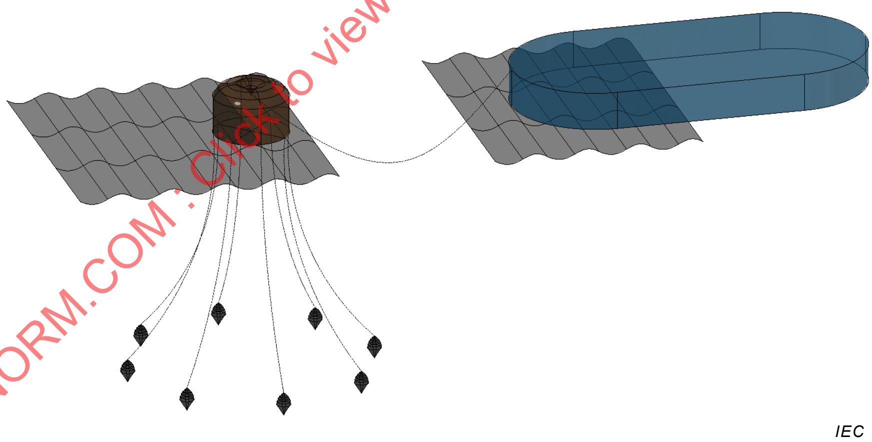


Figure 2 – Catenary anchor leg mooring configuration

b) Single anchor leg mooring (SALM)

A SALM system consists of a large buoy that supports a single taut vertical mooring line. The buoy floatation induces tensions that tend to restore the buoy to the vertical position. The floating structure is connected to the buoy by a single connection point as indicated in Figure 3.

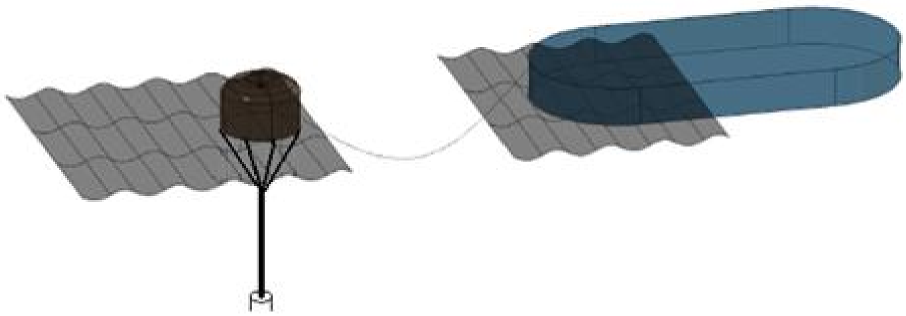


Figure 3 – Single anchor leg mooring configuration

c) **Turret mooring**

A turret mooring system consists of lines that are attached as in a CALM or SALM buoy system. The turret is attached to the floating structure via a bearing joint or other linkage that allows relative yaw motion as indicated in Figure 4.

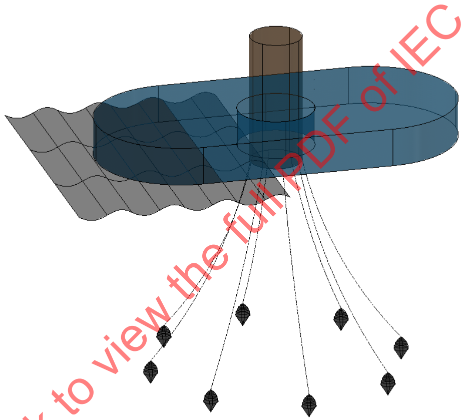


Figure 4 – Turret mooring configuration

6.3 Mooring line components

6.3.1 General

Mooring lines for floating structures are usually made up of wire rope, chain, synthetic fibre rope or a combination thereof. Many possible combinations of line type, size and location, and size of clump weights or buoys can be used to achieve the required mooring performance. The following subclauses provide an illustration of common mooring components.

The selection of mooring components shall be based on design objectives. The mooring components should meet material, manufacture, and testing requirements specified in applicable certification rules. Mooring component properties (e.g. MBL, weight, etc.) shall be based on manufacturer specific data. An adequate inspection and maintenance program shall be developed to monitor for loss of integrity in-service. The components suitability for mobile or long term mooring (LTM) deployments shall be considered. More information on aspects of component selection can be found in A.1.7 and A.11.1 of ISO 19901-7:2013.

6.3.2 Chain

Chain size is defined by the bar diameter of the chain links. Diagrams of studless and studlink chain can be seen in Figure 5. Various grades of chain are available from U-grades (normally used for ship chain) to the higher grade of ORQ, R3, R3S, R4, R4S, and R5.

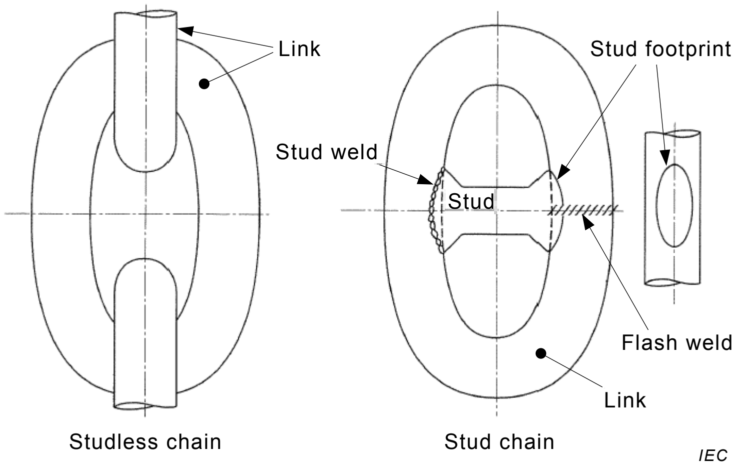


Figure 5 – Studless and studlink chain

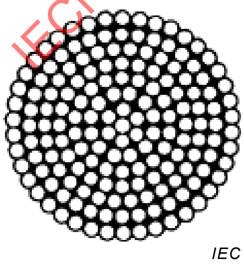
The length of chain links have been standardised with an overall length of 6 times the nominal bar diameter and 3,6 and 3,35 times the bar diameter for overall width for studded and studless chain, respectively. To facilitate connection to other items, both chain types are often terminated in slightly larger end links which are matched to LTM shackle designs.

When selecting chain, the choice of studded versus studless can be a key aspect. While studded has greater fatigue life, a lost, damaged, or misaligned stud can reduce fatigue life to less than that of studless chain. Studless chain can be easier to handle compared to studlink since there is room in the link to attach a lifting point.

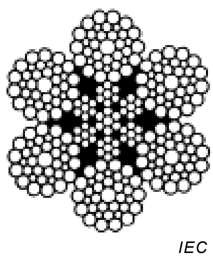
Corrosion allowance should be taken into account for LTM systems. Consideration of the location of the system should be factored as it has been noted that the corrosion rate of chain can be high in highly oxygenated environments. This corrosion will lead to a loss of strength which shall be accounted for in the design.

6.3.3 Wire rope

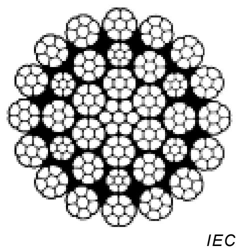
Wire rope has a lower weight per unit length than chain, lower stiffness, and similar breaking loads. Common wire ropes used in offshore mooring lines are six strand, spiral strand, and multi-strand as seen in Figure 6. The wire rope is terminated with a socket for connection to the other components in the mooring system. Special consideration is required to protect wire rope components from coming in contact with the sea bed, from abrasion damage and corrosion.



a) Spiral strand



b) Six strand



c) Multi-strand

Figure 6 – Typical wire rope construction

The different constructions of wire rope behave differently, especially with regards to the torque and twisting response and hence should not be used in the same mooring leg. The spiral strand wire is torque balanced and does not twist appreciably under load, whilst six strand rope will twist significantly.

The six strand wire is susceptible to corrosion, whereas spiral strand wire has significantly greater longevity, especially if supplied with an external sheath.

6.3.4 Synthetic rope

Synthetic rope offers an alternative to chain and wire rope where weight per unit length, elasticity, and corrosion are of specific concern. The most common materials used for offshore moorings are Polyester, Aramid, and Dyneema. Synthetic rope is generally made up of individual yarns in either a plaited or parallel fiber construction terminated with a thimble or spool and shackle for connection to the other components in the mooring system. Synthetic ropes have unique material properties and failure modes that require special consideration. The load-elongation properties of these ropes can be non-linear and depend on loading rate and loading level. In addition, limited information may be available on fatigue performance of some materials, although the most common material, Polyester, exhibits fatigue resistance well in excess of chain and wire.

Special consideration shall be required to protect rope components in contact with the sea bed from abrasion damage and sediment ingress especially in strong tidal environments where the profile of the rope, in particular leeward lines, will be driven by the current. Marine growth, UV degradation, and fish bite damage shall also be considered. Wire rope and synthetic rope should not be used in the same mooring leg due to risk of damage via twisting. More information on mooring with synthetic rope can be found in ISO 19901-7.

6.3.5 Clump weights

Concentrated or distributed weights can be added to mooring lines to produce desired performance characteristics. Using clump weights in a mooring line design shall require consideration of potentially adverse effects, such as increased use of connecting hardware, installation complexity, dynamic response and possible interaction with the seabed which can result in damage or loss of the clump weight.

The addition of a clump weight may cause a large angle change to the mooring line at a single point and thus localised wear may be significantly increased. This should be accounted for in the design.

6.3.6 Buoyancy aids

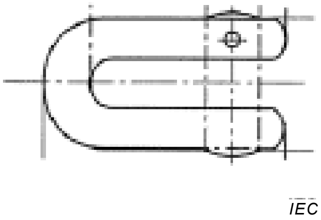
Concentrated or distributed buoyancy aids can be added to mooring lines to produce desired performance characteristics. The depth rating of the buoyancy module shall be considered to avoid damage or loss of buoyancy through compressive creep or water absorption. Loss of buoyancy can have a significant impact on the performance of the mooring system.

Using buoyancy aids in a mooring line design shall require consideration of potentially adverse effects, such as increased use of and complex loading on connecting hardware, installation complexity, and dynamic effect of the buoy on the mooring, drag forces, and navigation hazard of shallow or partial submergence.

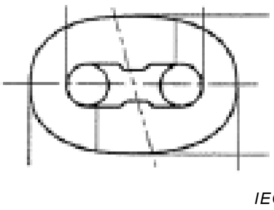
6.3.7 Connectors and accessories

The number of connectors should be minimized for safety, fatigue, and operational and maintenance considerations. Connectors with the designation LTM are used for permanent mooring systems and are of a more robust design.

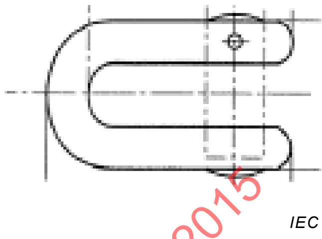
Failure modes due to connector interaction and other accessories, such as material hardness, contact area, and electric potential differences, as well as interaction with the seabed, shall be considered. Several examples of connectors can be seen in Figure 7. It should be noted that some of these items, such as Kenters, Baldt, and swivel shackles, may not be suitable for LTM in excess of 1 to 2 years due to poor fatigue performance.



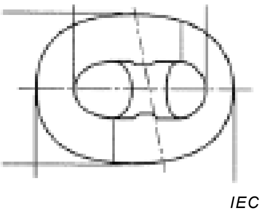
a) Joining shackle type D



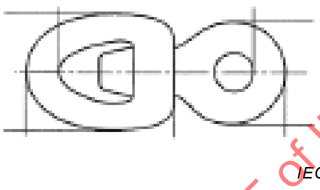
b) Joining shackle type Kenter



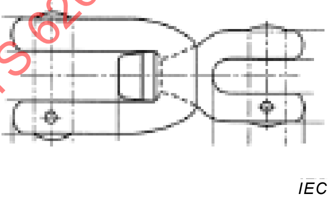
c) Anchor shackle type D



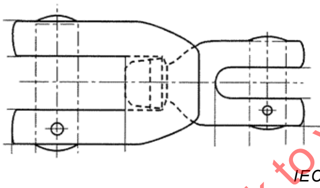
d) Anchor shackle type Kenter



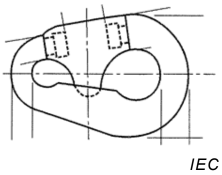
e) Swivel



f) Swivel shackle



g) Swivel shackle ASW



h) Baldt detachable anchor connecting links

Figure 7 – Types of connectors

6.4 Anchors types

6.4.1 General

The type of anchors used shall take into account the seabed and geotechnical conditions for each anchor point at the site where the floating structure will be located. Anchor type selection considerations are presented in 7.7.

6.4.2 Drag embedment anchor

A drag embedment anchor is designed to penetrate into the sediment as it is pulled horizontally along the seabed. Two fundamental types of drag anchor are the stockless and the High Holding Power (HHP). The stockless anchor is traditionally used as a ships anchor as it is easy to deploy and recover but limited in holding capacity. The HHP anchor requires careful positioning but generates a high holding capacity due to the large surface area bearing against the soils when embedded.

By design, when employing drag embedment anchors, the mooring line should generally not have any uplift at the anchor location in order to avoid a reduction in holding capacity, which may cause the anchor to dislodge from the sediment. In addition, out of plane lateral loading can also cause the anchor to fail. An example of a HHP drag embedment anchor can be seen in Figure 8.

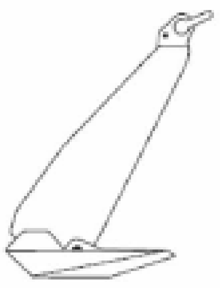


Figure 8 – HHP drag embedment anchor

The holding capacity is a function of the soil, with stiffer soils giving higher load capacity. If the soils are very hard, or rock, the anchor may only partially embed, resulting in reduced holding capacity or failure to embed.

6.4.3 Pile anchor

A pile anchor is a rod or pipe that is driven into the seabed by a piling hammer, vibrator, drilling, or other means. The holding capacity of the pile is generated by the friction of the sediment along the pile, lateral sediment resistance, or a grouted bond with the rock. A capacity to resist both out of plane lateral and vertical loads is possible depending on pile design. A schematic of a pile anchor can be seen in Figure 9.

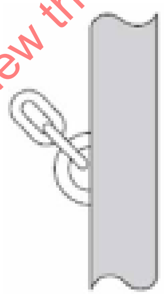


Figure 9 – Pile anchor

Design of pile anchors requires knowledge of the strength of the sediment and therefore core samples are usually required to ensure the pile can be installed to the required depth. The size of the installation equipment required should be considered early in the design, since the cost of the hammers or drills and ships to deploy them may be prohibitively expensive.

6.4.4 Suction anchor

The suction anchor is forced into the seabed by the pressure differential created by pumping out the seawater from the caisson during installation. This pressure differential is limited to the depth of the water above the anchor and so installation in shallow water can prove difficult. Suction anchors are generally not suitable for hard, rocky, or gravel seabed.

The holding capacity of the suction anchor is generated by the friction of the sediment along the caisson wall, lateral sediment resistance, and reversed end bearing effects. A capacity to resist both out of plane lateral and vertical loads is possible depending on suction anchor design. A schematic of a suction anchor can be seen in Figure 10.

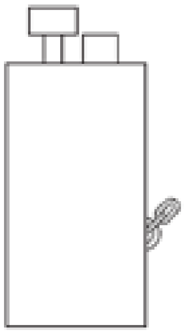


Figure 10 – Suction anchor

6.4.5 Gravity installed anchor

Gravity installed anchors are installed as projectiles that penetrate the sea floor under velocity. The holding capacity of the anchor is generated by the friction of the sediment and lateral sediment resistance. A capacity to resist both out of plane lateral and vertical loads is possible depending on anchor design. A schematic of a gravity installed anchor can be seen in Figure 11.

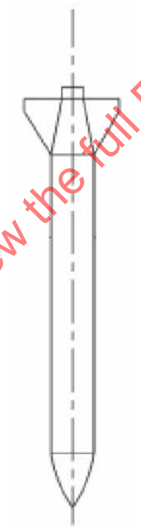


Figure 11 – Gravity installed anchor

Gravity installed anchors rely on high velocity to achieve sufficient penetration and hence are generally used in deep water with a sand or soft clay seabed and are not suitable for very hard, rocky, or gravel soils.

6.4.6 Gravity anchor

The holding capacity of a gravity anchor is generated by the submerged weight of the anchor material used and by the friction from the seabed. Steel, concrete, and confined rubble are examples of materials that may be used. A schematic of a gravity anchor can be seen in Figure 12.

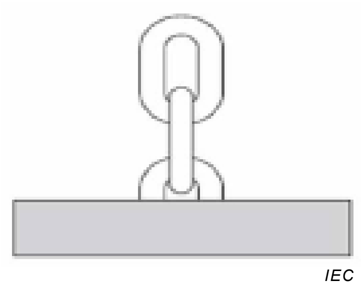


Figure 12 – Gravity anchor

The dimensions of the gravity anchor may be significantly larger than many other designs and in shallow water or in areas with strong currents, environmental loading from wind and waves may have a significant impact on holding capacity.

6.4.7 Plate anchor

Plate anchors can be installed by drag embedment or by being vertically driven into place followed by a keying process. The holding capacity of the plate anchor is generated by sediment resistance against the plate surface. Significant vertical holding capacity is possible. A capacity to resist out of plane lateral loads is possible depending on plate anchor design. A schematic of a plate anchor can be seen in Figure 13.

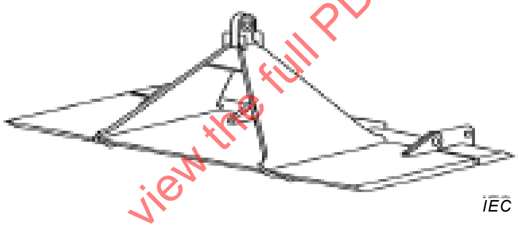


Figure 13 – Plate anchor

6.4.8 Screw anchor

A screw anchor may be used for particular sediment types and for special applications. Holding capacity is generated by friction and lateral sediment reaction against the anchor surface. Depending on the screw anchor design, vertical and out of plane lateral holding capacity is possible.

A schematic of a screw anchor can be seen in Figure 14.

Figure 14 – Screw anchor

7 Design consideration

7.1 General

This clause describes basic considerations for parameters and data needed to design a mooring system.

7.2 Limit states

7.2.1 Ultimate limit state (ULS)

This limit state corresponds to the intact mooring system's resistance to extreme expected actions, such as those arising from design environmental events. Consideration for the ULS shall be made to determine whether the extreme response corresponds to the MEC configured in survival or operational mode.

7.2.2 Accidental limit state (ALS)

The purpose of this limit state is to ensure the system has necessary redundancy in case of a single mooring system component failure. Consideration for the ALS shall be made to determine whether the extreme response corresponds to the MEC configured in survival or operational mode.

7.2.3 Serviceability limit state (SLS)

This limit state represents mooring system installation, MEC installation and connection with mooring system, and operation and maintenance modes of the MEC. The effect on mooring components from commissioning, decommissioning, and delivery of MECs should be considered. If the duration of time the MEC is not connected is considerable, more detailed analysis of the mooring system in this configuration may be necessary.

7.2.4 Fatigue limit state (FLS)

The fatigue limit state refers to cumulative damage in the system components of the MEC due to environmental cyclical action. Consideration of the effect of the PTO on the FLS shall be made.

7.3 External conditions

7.3.1 General

External conditions include metocean and other environmental factors that will vary based on region and should be considered on a site specific basis.

7.3.2 Metocean conditions

Wind, wave, current, water elevation variations, snow and ice load, and other conditions at each site shall be considered. Guidelines for determining metocean conditions can be found in ISO 19901-1.

7.3.3 Marine growth

The type and accumulation rate of marine growth at a specific site can affect mass and hydrodynamic properties and therefore the dynamic response of the MEC and mooring lines. This shall be taken into consideration for mooring systems designed without any regular marine growth removal or protection plan.

7.3.4 Marine life

The presence of marine life can affect the mooring through damage such as from fish bite and should be considered.

7.3.5 Environmentally sensitive and protected areas and marine animals

Selected sites for MECs can be located near sensitive or protected habitats. Any device located in such a habitat can impact the ecology and environment via direct contact or indirectly by harassment. Mooring systems can have impact without a failure event. Consequences can include bottom scour due to normal mooring motion, marine life entanglement with mooring components, and habitat damage from anchor placement and installation activities. In addition, noise produced by strum, mooring line interaction with the seabed, and mooring component rattle can be considered harassment.

7.3.6 Nearshore impact

Nearshore impact is defined as impacts associated with any developmental activities related to the installation or operation of MECs that can take place in the area between the shoreline and the area defined as the offshore zone. Nearshore impacts can have unintended consequences that can be financial, environmental, or societal. Nearshore impacts may include but are not limited to the following, listed in Table 1.

Table 1 – Potential nearshore impacts

Impact type	Description of impact
Noise	Noise generated during installation, recovery, or other operations involving the mooring system that can disturb marine life
Proximity	Dredging operations in coastal zones can disrupt MEC moorings or umbilical systems

7.3.7 Vandalism and misuse

Vandalism is the deliberate defacement, destruction, or theft of an existing MEC mooring system or mooring components. The misuse of floating structures as temporary tie-off buoys for sport and commercial vessels is common in nearshore areas. Accessibility of mooring components and connections should be considered.

7.3.8 Marine traffic

The type and frequency of other marine traffic traversing the site should be considered. For example, local or commercial fishing vessels can accidentally entangle in the MEC mooring system that could lead to failure. In addition, any restriction within the water column to mooring line components with regards to safe keel clearance regardless of limit state shall be considered.

7.4 Assorted loading

7.4.1 General

The assorted loading on the MEC and mooring system, including the anchors, shall be resisted by the mooring system. A range of possible combined loads may result:

a) Low frequency current, wind and wave drift loads
b) Wave frequency loading
c) High frequency VIV, seismic, PTO, ice and ship impact

The combined assorted loadings, including those from winds, currents, and waves, on the MEC and mooring system are required to determine the motion response and mooring loads. The assorted loadings may be determined by relevant analytical, numerical, or experimental methods. Some loading can only be determined through the use of experimental methods or specialist software. Interaction between and directionality of wind, current, and waves shall be examined.

7.4.2 Low frequency loads

7.4.2.1 Mean current and wind loads on mooring components

The effect of current actions on mooring lines and umbilical cables shall be evaluated. Actions on these entities due to currents can be calculated as a drag force.

7.4.2.2 Mean current and wind loads on MECs

As a guideline, the mean wind and current loading can be estimated with a drag force approximation.

7.4.2.3 Mean wave drift loads on MECs

The mean wave drift load is a time average load that arises from the effects such as but not limited to reflection of ocean waves on the floating MEC hull.

7.4.2.4 Low frequency wind, current, and wave loads on the MEC

The wave drift force can vary at low frequencies and can have effects proportional to the difference between frequencies of waves present in the spectrum. The geometry of the MEC can interact with prevailing wind direction to produce low frequency loading. The motion of the MEC and mooring system can also interact with prevailing current direction to produce low frequency loads. If the MEC mooring system has any low natural frequency, large motions and mooring loads can result. For example, in existing floating structure systems, low frequency yaw motions can result with a single point mooring system.

7.4.3 Wave frequency loads on mooring components

Wave frequency loading on mooring components are a function of wave orbital velocities and accelerations and may cause dynamic loading on the mooring system.

7.4.4 Wave frequency loads on MEC

If the MEC geometry is large relative to the ocean wavelengths present, wave radiation and diffraction loading will have a significant influence on the MEC motion and mooring system response.

7.4.5 High frequency loading

7.4.5.1 Vortex induced vibrations of mooring system and vortex induced motions of MECs

For mooring lines and umbilicals, the possibility of vortex induced vibrations (VIV) in areas with prevailing current should be considered due to potential impact on fatigue life. Vortex induced motions (VIM) of the MEC with mooring system should be investigated.

7.4.5.2 High frequency wave loads

Loading proportional to the sum of the frequencies of waves present in the spectrum can exist and should be considered in determining the response of systems with high natural frequencies.

7.4.5.3 MEC PTO response

The PTO system may have a significant influence on the dynamic response of the MEC and mooring system. The dynamic loading from the PTO on the system shall be considered.

7.5 Mooring line components

7.5.1 Component strength

The MBL of components can be provided by supplier technical specification sheets or from experimental measurements. Consideration should be given to flexural and chafing effects of mooring components on MEC surfaces. As mooring line components wear, corrode, and fatigue, the minimum break load, MBL, of the line components will decrease. Consequently, the reduction in MBL during the system's design life should be considered during the design of the mooring system otherwise planned replacement of the affected components may be required during the design life.

The dynamic MEC motion and consequent complex mooring interaction may require special consideration of selection of mooring components.

7.5.2 Component fatigue life

The fatigue damage accumulated in mooring components is the result of cyclic loading. Underestimated fatigue damage may result in the premature failure of the mooring line. Specific guidance for determining fatigue life can be found in Clause A.9 of ISO 19901-7:2013. However, an increased factor of safety fatigue life may be warranted based on various factors such as inaccessibility of components for inspection, site specific environmental loading and unique PTO operational characteristics. Specific guidance for determining fatigue life can be found in Clause A.9 of ISO 19901-7:2013.

7.5.3 Redundancy

All mooring configurations shall be designed to ULS and ALS considerations. Single point mooring systems shall have special consideration to address ALS assessments.

7.5.4 Clearance

Contact between mooring lines and other mooring lines, the umbilical, the MEC and adjacent structures in all limit states should be avoided. The required clearance can be determined on a case by case basis, but the minimum value should be considered on the basis of consequences of impact.

7.6 Umbilical considerations

7.6.1 Umbilical response

A key output of the mooring analysis is the offset of the MEC for input to the design of the umbilical. The design of the mooring and umbilical may require an iterative approach to determine a suitable configuration for both items.

7.6.2 Umbilical strength

The umbilical strength and allowable bending radius can be provided by the manufacturer. Specific consideration shall be given to reduce stress concentration at umbilical termination.

7.6.3 Umbilical offset and clearance limits

The offset due to MEC movement in all limit state conditions shall be considered. The clearance between the umbilical and the mooring lines, sea bed, MEC, and other potential hazards shall be considered. The installation and hook-up of umbilicals should be planned in consideration of any temporary mooring, jack leg deployment, or live manoeuvring required by any maintenance or installation vessels.

7.7 Anchors

7.7.1 Type selection

In selecting the appropriate anchor type, consideration shall be given to the mooring system configuration and design characteristics (load, out of plane lateral, and uplift), site-specific seabed conditions, direct loading from current and wave action, removal and installation constraints. The above considerations as well as the site specific risk profile will dictate anchor selection.

7.7.2 Holding capacity

For all anchors, the design load and holding capacity shall be clearly defined for all limit state conditions. Holding capacity is the maximum force that can be resisted by the anchor and can be determined from anchor manufacturer or standard design tables and semi-empirical models. Generic manufacturer holding capacity curves may not be a conservative approach. Sample anchor data can be found in A.10.4 of ISO 19901-7:2013. Site specific anchors or standard anchors in areas of unusual bottom conditions require holding capacity analysis based on site geotechnical properties. This type of analysis is typical for driven, drilled and grouted piles and other anchor systems where design optimization is required.

Holding capacity may also be derived from scaled or full size field tests in the site seabed conditions.

Particular consideration should be given to possible dynamic and direct environmental loading on the anchor and the influence on sediment and rock conditions.

7.7.3 Sediment and rock conditions

Site-specific sediment and rock data should be obtained in order to evaluate the performance of the anchors. Installation calculations and ultimate holding capacity calculations should utilize the lower and upper bound site-specific data to develop anchor performance envelopes.

7.7.4 Fluke setting

Some anchor types have an adjustable fluke feature allowing the angle or exposed area of fluke to be adjusted for various sediment conditions. The fluke setting features and installation implications should be considered.

7.7.5 Installation

Each anchor type has different installation techniques to consider. A detailed installation plan, including allowable tolerances, should be prepared during the design phase. The field layout and surrounding infrastructure should be considered when planning the installation. As the time of year may indicate the installation weather windows, the necessary anchor setup time should also be specified and taken into account.

7.7.6 Proof loading

Some anchor types require proof loading as an integral part of the installation process to ensure proper embedment. It is important that the minimum required proof load is determined for each application and included in the installation plan.

7.7.7 Directional anchor loading

Structural and geotechnical capacities should be considered for each design based on the maximum expected out of plane lateral, uplift, and horizontal loading in all limit states. Some deployments may require multiple attachment points to a single anchor and all loading combinations shall be considered and the possible geotechnical effect to the seabed or sediment.

7.7.8 Failure mode

The failure mode of the anchor and the implications in ALS should be considered on a site specific basis.

7.7.9 Environmental loading

Anchors for a MEC system may be large or placed in shallow water or areas subject to tidal and wave action. The loading from environmental effects including wind and waves shall be considered as it may have a significant effect on holding capacity.

8 Safety and risk considerations

8.1 Overview

This clause provides guidance for the consideration of safety and risk associated with MEC mooring systems. Fundamental aspects of determining probability of a mooring failure and the associated consequences are discussed. The goal is to identify potential risks before the mooring system design is finalized and installed. Identifying site-specific risks facilitates the selection of a consequence class and the associated design factors to be used for the mooring system.

8.2 Risk

8.2.1 General

A basic description and background of risk is provided in the following subclauses for introductory purposes from API RP 2SK. Acceptable risk levels vary from region to region depending on governing body regulations and requirements. Consideration shall be given to ensure compliance with all applicable rules for the region and operation.

8.2.2 Definition

Risk is the potential of an adverse event occurring that leads to an undesirable outcome or consequence. In general, a risk assessment should study the probability of event occurrence, related consequences, and potential risk mitigation measures.

Risk = [Probability of an undesirable event occurring] × [Anticipated consequence if that event occurred] (1)

Mooring risk scenarios can be complex and involve multiple events in succession. In a situation with multiple risk events, the total risk is the sum of the risks for each different accident, provided that the consequences are of the same type:

Risk = For all accidents ∑ ([Probability of an undesirable event occurring] × [Anticipated consequence if that event occurred]) (2)

8.2.3 Consequence types

In general, the types of consequence to be considered in MEC mooring system risk assessments, at a minimum, include:

a) Health and safety effects
b) Damage to MEC, mooring components, or other assets
c) Environmental effects
d) Financial loss
e) Damage to corporate or industry reputation

A mooring system failure can include any single or multiple mooring component or anchor structural or geotechnical failure. When considering adverse MEC events as a result of a mooring failure, the immediate surface, subsurface, and device itself, along with all appurtenances, should be considered. The surrounding surface and subsurface region of the MEC location should be considered to cover reasonable consequence scenarios.

8.2.4 General risk mitigation

When performing a MEC mooring risk assessment, it is important to understand the risk exposure for each specific location and system. Risk may be reduced to tolerable levels by decreasing the probability of an undesirable event occurring and/or by minimizing the consequence should that event occur. Acceptable or tolerable risk levels for a particular MEC mooring project may be based on industry, corporate, certifying authority, and/or government criteria depending on the location. It is up to the responsible party to ensure all potential risks are considered and mitigated during design (i.e. before installation) to tolerable levels that are as low as reasonably practicable (ALARP).

8.2.5 ALARP principle

With regards to the design, planning, and operations, thorough consideration should be given to make sure the risk of a MEC mooring failure is ALARP. It may be shown that the benefit of further risk reduction is outweighed by the effort or resources required to implement the mitigating measure. The magnitude of consequence due to a mooring failure can vary considerably based on many site-specific elements, and therefore so may the risk level of what is considered to be ALARP.

8.3 Risk assessment methodology

8.3.1 General

This subclause provides information on the basic considerations and methodology of a risk assessment relating to the mooring of a MEC. The fundamental considerations in determining the probability of a mooring failure and the related consequence are discussed. This subclause is not intended to specify exactly how to perform the risk assessment or limit the user to any specific format for analysis and results.

8.3.2 Methodology flowchart

The purpose of the risk assessment methodology described herein is to give some level of guidance in assessing the probability of a MEC experiencing a mooring failure and the related consequences of such an event. The consequences of a mooring failure to the MEC itself can vary based upon the type of MEC and is the responsibility of the owner and operator to properly consider.

Figure 15 illustrates the general methodology used to evaluate the risk associated with a MEC mooring failure with regards to assets of value at risk. Assets of value may be related to loss of income or property, environmental impact, or endangering human life.

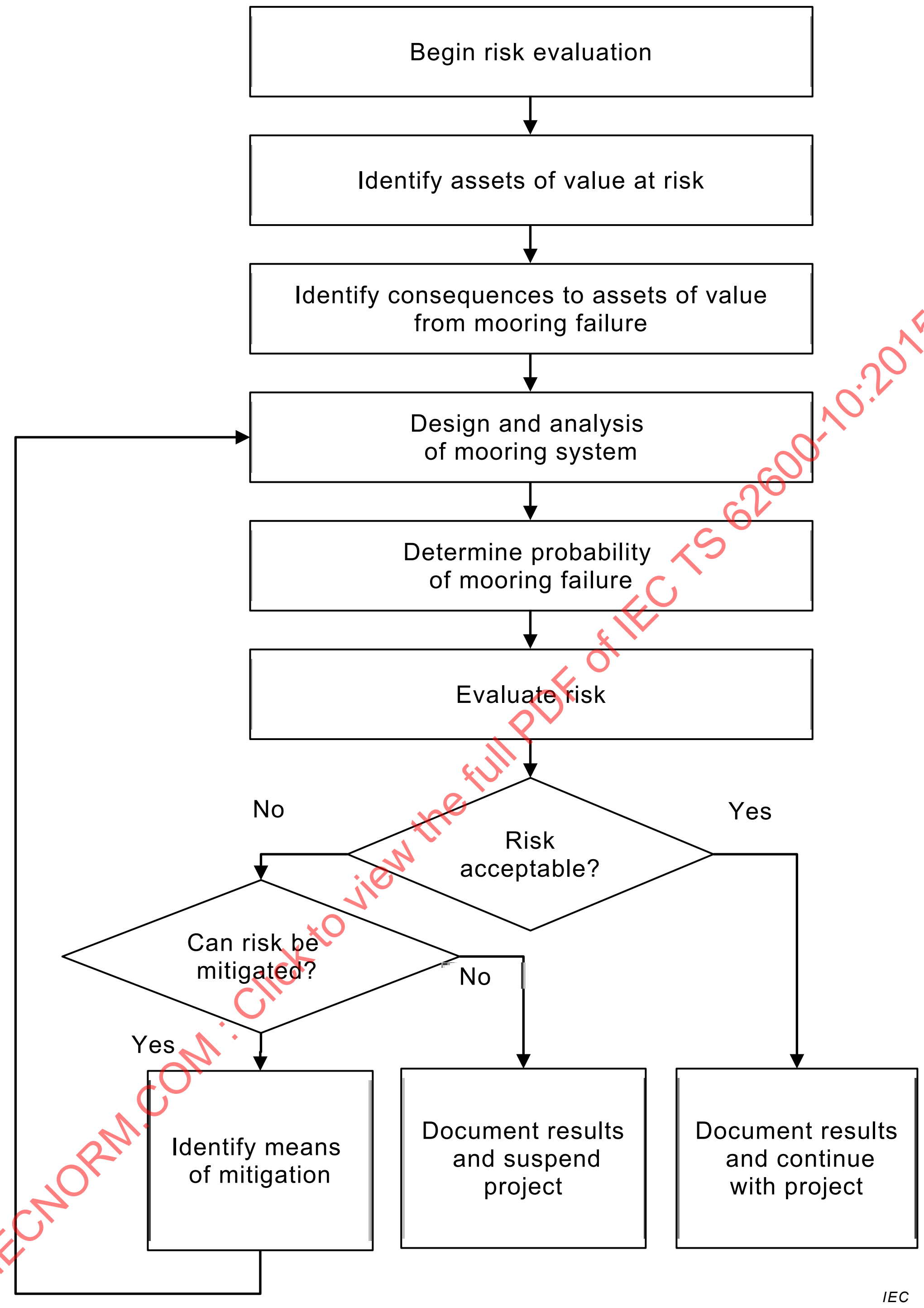


Figure 15 – General risk methodology flowchart

8.3.3 Basic considerations

Generally, risk assessments can be carried out on a qualitative or quantitative basis. This technical specification outlines the approach for a quantitative risk assessment. A Hazard Identification (HAZID) study should still be completed to identify broad risks and develop measures to mitigate those risks for any operation. Typically, a HAZID is a qualitative assessment of consequence events using some form of Risk Matrix to categorize the events based on the probability of occurrence. For guidelines on performing HAZID studies, see ISO 17776.

8.3.4 Probability assessment

Determining the probability of the initial event and then subsequent events is a crucial part of determining the risks involved with a moored MEC. For a moored MEC risk assessment, the initial event is mooring failure.

The probability of the initial mooring failure occurring is the inverse of the return period of environmental condition that results in failure. Alternatively, the probability of the initial mooring failure can be calculated through reliability analysis. The detail level of such an analysis can vary, but at a minimum, the uncertainty in mooring component strength and environmental loads should be considered.

8.3.5 Consequence classification assessment

For each location, it is important to fully understand and consider the possible consequences in the event of a mooring failure. Quantitatively, consequences are usually considered from a financial loss perspective. Some consequences, such as loss of life, are difficult to quantify, but should be considered in any comprehensive risk study. Multiple successive consequences should be considered to the extent practical.

8.4 Consequence considerations for mooring failure

Consequence considerations should be taken into account during the design phase. The considerations should be focused on the identification of the consequences to assets of value in the event of mooring system failure. Consequences can be categorized based on the description of the exposure or hazard and can be defined by the following, see Table 2.

Table 2 – Consequence categories

Consequence category	Possible related consequence
Person	Injury or fatality
Financial	Loss of production, cost of repair, compensation
Property	Damage to device or third party property
Environmental	Possible injury, harassment, or death of local ecosystems
Societal	Negative public perception

Each consequence category should be assessed for each consideration. Considerations for consequence assessment are addressed below.

8.5 Consequence classification

8.5.1 General

The purpose of increased minimum design factor requirements for higher consequence systems is to reduce the probability of a mooring failure. MEC consequence classifications include Class 1, 2, and 3. An example of consequence class levels for life safety is indicated in Table 3.

Table 3 – Consequence class

Life safety category	Consequence class		
	High consequence	**Medium consequence**	**Low consequence**
Manned non-evacuated	3	3	3
Manned evacuated	3	2	2
Unmanned	3	2	1

General guidance for selecting mooring consequence class based on consequence categories previously defined is listed below. The most limiting of any single consequence category shall determine the consequence class of the mooring system location.

For consequence class 3, possible outcomes of a mooring system failure may include loss of human life, significant damage to marine environments, blockage of high traffic navigable waterways, and substantial financial or third party property damage.

For consequence class 2, possible outcomes of a mooring system failure may include serious injury, damage to marine environment, blockage of navigable waterway, and financial or property damage.

For consequence class 1, possible outcomes of a mooring system failure may include minimal human injury, minimal environmental impact, minimal navigable waterway impact, and minimal financial or property damage.

8.5.2 Consequence impact considerations

8.5.2.1 General

There are many factors that should be considered when determining the level of consequence, some of which are identified in the following subclauses.

8.5.2.2 Subsurface infrastructure, pipelines, umbilical, cables

Subsurface infrastructure can be considered as any man made structure placed on the bottom surface, including pipelines, subsea cables, etc. A mooring failure can result in dragging mooring line components or anchors across the bottom surface, causing damage or destruction to surrounding subsurface infrastructure or areas of environmental or archaeological importance. The probability of subsurface infrastructure damage, in the event of a mooring failure, can be affected by:

a) Distance away from MEC site.
b) Anchor and mooring components choice.
c) Diameter of pipeline or cables.
d) Mooring system robustness.
e) Concentration of infrastructure in an area.

An example of how probability is affected can be explained by distance away from the MEC site. The greater the distance from the MEC mooring location to a pipeline or cable can indicate a lower probability of dragging an anchor and/or mooring components and causing damage to the infrastructure. The consequence assessment of these events may include the cost of repair or replacement, delay of production, and possibly causing an environmental incident.

8.5.2.3 Surface structures

Surface risk can include damage to surface asset systems such as moorings or damage associated with any hull to structure interaction. The probability of complete structure loss may not be as high for MECs due to the smaller target of the structure compared to its mooring. The probability of surface structure damage can be based on the location and the distance to the asset.

The financial consequence of interacting and colliding with other surface structures such as vessels, or other MECs may be considered. Both direct collision to these structures and interaction damage to the associated ancillaries such as the moorings, risers, power cables, etc., may be accounted for in the cost impact. Replacement or repair, delay of production, or causing a possible environmental incident may be included in the consequence assessment.

8.5.3 Waterway navigation impacts

There are consequences associated with the failure of mooring of any man-made offshore structure in navigable waters. Mooring failure can physically affect:

a) Commercial shipping.
b) Governing authority operations.
c) Recreational boating.
d) Fishing (commercial and recreational).

The consequences can vary depending on the project phases, including installation, operations and decommissioning.

8.5.4 Environmentally sensitive and protected sites

Partial and complete mooring failures can cause the MEC to move into and through a sensitive or protected habitat.

8.5.5 Archaeological sites

A bottom surface hazard survey should be completed prior to the installation of the MEC. The requirement of a hazard survey may vary from region to region. In regions where archaeological finds are protected, a discovery of manmade debris may indicate the presence of a shipwreck or a find of archaeological importance. Minimum clearance distances for anchor placement or grounded lengths of the mooring system from an archaeological find may be determined by the governing body of a region to minimize disturbance.

8.6 Risk mitigation considerations

8.6.1 Mitigation overview

Mitigation should be used to minimize risk to tolerable levels. The following subclauses address the reduction of risk event probability and consequence.

8.6.2 Probability reduction

The probability of mooring system failure can be reduced through various design strategies that achieve higher return periods at the required factor of safety for the respective consequence class.

8.6.3 Consequence reduction

Consequence class is defined by the location of the MEC and the associated consequence categories previously discussed. A careful consideration of available locations and their associated consequence categories should be completed before selecting the final location.

8.7 Risk acceptance

8.7.1 Acceptance overview

After identification of all risks involved, it shall be decided whether each particular risk is tolerable or not. Regardless, risk reduction measures should always be considered and evaluated for each identified risk. Depending on the geographical region, ruling authorities may have their own acceptance and approval criteria. Acceptable levels of MEC mooring failure risk can generally be based on the experience and level of acceptability established by other offshore systems and industries. Stakeholders may have different internal risk acceptance criteria based on the type of consequence. Determining what level of risk is tolerable may be based on consideration and weighing of known requirements and the benefits versus cost/effort/resources of additional risk mitigating measures.

The risk assessment process can be iterative. It should be repeated each time with consideration to the proposed mitigating measures until the risk level is acceptable. Both preventative (e.g. strengthening the mooring system to reduce failure probability) and mitigation (e.g. choosing a synthetic line component to reduce severity of consequence in the event of a failure) measures can be used to reduce risk to tolerable levels.

It is also important to recognize that a risk reduction measure for one scenario can actually increase risk associated with another scenario in some cases.

8.7.2 Documentation

The basis, assumptions, and results of the risk assessment shall be thoroughly documented with full traceability. Conclusions and all measures taken to reduce risk shall be clearly explained. The fundamentals and results of the analysis should be clear, even to persons that may not be familiar with the project.

9 Analysis procedure

9.1 General

This clause provides an overview of modelling considerations and analysis procedures to design moorings for MECs.

9.2 Basic considerations

Four limit states have been defined and are used to assess the mooring design considered. Each mooring design will be a function of the site specific environmental conditions and specific MEC characteristics. Determining the mooring design that satisfies the limit states may not be obvious and may require an iterative process. Static, quasi-static, and dynamic analysis procedures can apply. A finalized mooring design should be checked in a manner that considers full coupled mooring effects with the MEC, including the effect of the PTO and umbilical cable. The considerations in the following subclauses arise due to a range of challenges for mooring MEC systems. Some of these challenges include:

a) High energy density and the likelihood of shallow water conditions.

b) Tidal range in relation to mean water depth.

c) Complex and highly dynamic motion characteristics.

d) Interrelation between PTO and mooring system.

The following subclauses elaborate on specific considerations for mooring design for MECs as well as clarifying analysis procedures.

9.3 Analysis procedure overview

ULS, ALS, FLS, and SLS requirements shall be satisfied by the analysis procedure used. A recommended analysis procedure is summarized by the flow chart seen in Figure 16. This procedure is based on analysis processes presented in ISO 19901-7. This procedure can be summarized as follows:

a) Determine metocean and external conditions for the location.

b) Establish a conceptual mooring pattern. Properties of the mooring components shall be established. Mooring pretension should be considered.

c) Determine external loads on the mooring and MEC due to metocean and external conditions.

d) Complete an analytical or static analysis using mean environmental loading to allow rapid initial iteration on mooring components, pretensions, and mooring envelope. Iterate and modify the mooring design as needed.

e) Perform a dynamic analysis on the mooring system for each of the limit states considered.

f) If the resulting design criteria for any limit state are not satisfied, iterate on the mooring design concept or restart the process with a new mooring design concept.

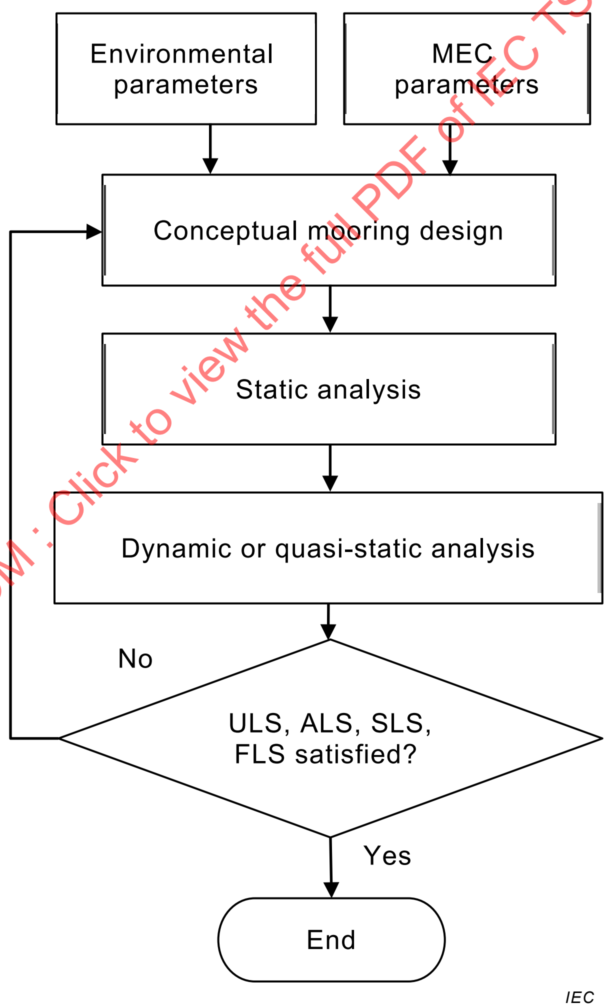


Figure 16 – Conceptual mooring analysis procedure

9.4 Modelling consideration

9.4.1 General

This subclause provides information on various modelling techniques that are used to study the dynamics of floating structures. Special care is required in understanding the capabilities and limitations of the modelling method used due to the additional complexity introduced by MECs.

9.4.2 Mooring and umbilical models

9.4.2.1 General

Nonlinear behaviours shall be considered to gauge the most appropriate mooring model to use to determine the dynamic mooring system response. Some examples of nonlinear behaviours in mooring systems include variation in mooring geometry due to extreme storm conditions or shallow operating depths, mooring component material properties, mooring drag and damping induced by viscous hydrodynamic effects on the lines, and seabed contact. Installation tolerances shall be considered in the model.

9.4.2.2 Static catenary

A static catenary solver can be used to initially produce mooring position and tension based on the distributed weight and stiffness of the line. This model cannot address dynamic effects such as mooring inertia or viscous damping effects on the MEC. The effect of strong tidal flow on the catenary profile shall be assessed, as in certain conditions this can have a major influence on the design.

9.4.2.3 Discrete models

These models discretize the mooring lines and umbilicals. These models may be based on finite segment, finite difference, or finite element techniques. Care should be taken to ensure accurate and converging results are achieved as the discretization density increases. The effects of internal axial, bending, and torsion loads of the mooring components and umbilical can be considered. Most dynamic effects and nonlinearities can be addressed by discrete models. The limitations of the model coupling between the MEC fairlead and mooring model should be considered.

9.4.3 Floating unit numerical models

9.4.3.1 General

A model may consist of limited degrees of freedom ranging from a single motion mode to all six degrees of freedom. If the system has an articulated mechanism, the degrees of freedom considered may be more than six. The floating unit model shall include all degrees of freedom that affect the motion of the system and induce significant mooring reaction loads.

9.4.3.2 Small body approximation and Morison-type hydrodynamic loading

When a MEC representative dimension is small relative to the incident wavelengths present in the ocean, wave diffraction effects can be neglected and viscous and inertia effects dominate. The Morison equation produces hydrodynamic loading on the MEC as a function of relative velocity, acceleration, and hydrodynamic drag and added mass coefficients for the structure of interest. Hydrodynamic coefficients for common geometric shapes are available in the literature and standards. Ideally, coefficients can be determined through numerical or experimental methods.

Wave radiation effects may not be insignificant but in general they act as a damping mechanism and as a result it may be considered conservative to neglect them for the purpose of a mooring design.

9.4.3.3 Linearized hydrodynamic loading

When a MEC representative dimension is large relative to incident wavelengths, diffraction effects will dominate. It is common to resolve diffraction loads through a numerical solver based on potential flow theory. Potential flow solvers that use a strip-theory approach can only be applied to slender floating structures. On the other hand, potential flow solvers that use a panel method approach are not subject to any such geometric constraint. Diffraction loads can change significantly if the MEC has a relative speed to the water. Potential flow solutions usually do not account for strong viscous effects like flow separation or skin friction which may be accounted for by other means. Other assumptions, limitations, and linearization of a wave radiation and diffraction solver should be checked with the particular requirements of a MEC unit for validity.

9.4.3.4 Nonlinear hydrodynamic and hydroelastic loading

Computational fluid dynamics (CFD) techniques that account for viscous and rotational effects in more detail than potential theory are evolving. Principally, CFD could solve the fluid dynamics problem fully and directly in some situations. However, these techniques can be extremely computationally intensive and in many cases are impractical to use for design purposes due to their complexity and long simulation run times.

9.4.4 Coupled and uncoupled analysis

An uncoupled analysis considers a floating MEC response either neglecting the mooring and umbilical restoring forces or using a linear stiffness to represent them. The resulting MEC motion response is then used to determine maximum mooring loads accordingly. In contrast, a coupled or global response analysis directly incorporates the mooring and MEC models. An uncoupled analysis is usually less complex due to the ability to compartmentalize the floating device and mooring models. When nonlinear mooring dynamic behaviour begins to have a substantial influence on MEC and PTO response, a coupled analysis shall be used. In shallow water conditions or when significant water elevation changes relative to water depth occur, significant mooring variations are expected and a coupled analysis shall be used.

9.5 Analysis procedure considerations

9.5.1 Metocean directionality

Wind, wave, and current heading may be applied in co-linear fashion. However, depending on site-specific conditions or specific MEC characteristics, the combination of wind, wave, and current headings consistent with the metocean conditions at the site that results in the most severe response and mooring loads should be considered.

9.5.2 Resonant response

Due to the potential complexity of MEC dynamic response, the environmental conditions that produce the most extreme response and mooring loads may not be obvious and may even be counter intuitive. Therefore, a screening process should be performed to determine whether a particular wave period, which may be less than that associated with extreme conditions, generates the highest loads.

9.5.3 Dynamic mooring analysis

In comparison to static and quasi-static modelling, dynamic modelling considers the acceleration and velocity of all components in the system. Inertia, damping, and stiffness of the MEC and mooring as well as PTO effects may be incorporated in the dynamic model. Dynamic modelling may be coupled or uncoupled and performed in the frequency domain or the time domain. For time domain modelling, the simulation time duration and time step should be considered such that all pertinent dynamic effects are captured. Adequate time domain simulation realizations shall be generated for each sea state to ensure consistent statistics of extreme peak responses. The frequency domain analysis may not accurately capture the peak resonance response of the system due to challenges incorporating nonlinear mooring response and loading effects in this technique.

9.5.4 Design situations of ULS

Extreme metocean conditions should be used. The mooring system shall have acceptable strength when subjected to extreme combinations of wind, wave, and current at various worst-case combination loading directions. If applicable, the extreme metocean conditions corresponding to MEC PTO resonant conditions shall be considered.

9.5.5 Design situations of ALS

The environmental design situations for ULS shall be applied to ALS together with the following considerations. The effect of failure of any one mooring system component shall be considered to determine the effect of progressive failure in remaining mooring line components as well as the effect on MEC motion envelope.

9.5.6 Design situations of FLS

Computing fatigue life for a MEC mooring requires extensive knowledge of the occurrence and distribution of environmental conditions at the MEC installation location. The occurrence of significant wave height, peak period, wind, and currents over a range of headings is required to accurately assess the fatigue life. Loading cycles in the mooring system may be affected by the MEC PTO operation in nominal conditions and shall be considered. The sediment and rock characteristics may also change due to the nature of the cyclical loading from MEC operations and may require consideration to determine the change in holding capacity. Fatigue life of the system can be determined through a cumulative damage technique such as Miner's rule.

9.5.7 Design situations of SLS

Design situations for maintenance, commissioning, and decommissioning, should be considered. The SLS may consist of a variety of design situations in a range of environmental conditions, including MEC response while towing to site, MEC response with PTO active during limiting conditions, MEC response without PTO active during limiting conditions, and MEC response to transient docking operations. Limiting environmental conditions will be specified by the limiting sea state allowing intervention for the purposes of maintenance or installation. The SLS conditions shall be considered carefully due to the potential for loss of life during human interface. Transient cases should be considered to assess the additional dynamic load on the mooring system and any umbilicals present.

9.6 Mooring design criteria

9.6.1 Design return period

The environmental return periods for ULS and ALS shall be 100 years. The environmental return periods for SLS should consider a spread of wind, wave, and current conditions that are suitable for operations and maintenance. The FLS considers a range of wind, wave, and current conditions up to the design return period to establish fatigue life.

9.6.2 Consequence class design factor

The corresponding design factors to be used for each consequence class are listed in Table 4. The design factors are used to determine acceptable mooring line component and anchor capacity. Limited station keeping experience for MEC systems inhibits accurately defining consequence class design factors, but values of 1,3 and 1,5 for consequence class 2 and 3, respectively, can be considered.

Table 4 – Consequence class associated design factors

Consequence class	Design factor (DF)
3	1,5
2	1,3
1	1,0

9.6.3 Mooring line component failure

For each case to be studied, acceptable mooring component strength is achieved when the following relationships are satisfied:

$$ASF = SF \times DF \quad (3)$$

$$MBL / Design Tension > ASF \quad (4)$$

The tension is based on the Most Probable Maximum (MPM) dynamic tension. The safety factor shall be used from Table 5. The design factor (DF) for the appropriate consequence class shall be used from Table 4. The resulting factor guarding against failure is the adjusted safety factor (ASF). The MBL associated with the expected corroded line size shall be used when assessing the strength criteria.

Safety factors are a function of fundamental inherent uncertainties while design factors are a function of risk exposure defined by the consequence classes. Sources of uncertainty may include environmental data as well as in limitations of dynamic analysis tools to predict response of the system. In addition, the quasi-static approach to mooring analysis has a wide range of accuracy, and as a result the safety factors used are higher when compared to dynamic analysis methods. The safety factors in Table 5 originate from ISO 19901-7, which is a design standard for station keeping of vessels. Mooring design safety factors for MECs may modify with time as data becomes available.

Table 5 – Safety factors for ULS and ALS conditions

Design condition	Analysis method	Safety factor (SF)
ULS	Dynamic	1,67
	Quasi-static	2,00
ALS	Dynamic	1,25
	Quasi-static	1,43

Quasi-static analysis may be used for preliminary permanent mooring analysis but it should be noted that quasi-static techniques can produce misleading results for some MEC applications. Final permanent mooring installations shall be designed using dynamic analysis methods and corresponding safety factors.

9.6.4 Anchor holding capacity

The holding capacity of anchors depends on sediment conditions and performance characteristics of the anchor. Safety factors for different anchor types are listed in Tables 6, 7, and 8. Design factors indicated in Table 4 shall be used. Acceptable anchor holding capacity is achieved when the following relationship is satisfied:

$$Anchor holding capacity / Design tension at anchor > ASF \quad (5)$$

Table 6 – Safety factors for holding capacity of drag anchors factors

Conditions	Quasi-static	Dynamic
Permanent mooring		
Intact condition	n/a	1,5
Redundancy check	n/a	1,0
Temporary mooring		
Intact condition	1,0	1,0
Redundancy check	Not required	Not required

Table 7 – Safety factors for holding capacity of anchor piles and suction piles

	Permanent mooring		Temporary mooring	
Analysis condition	Axial loading	Lateral loading	Axial loading	Lateral loading
Intact condition	2,00	1,60	1,50	1,20
Redundancy check	1,50	1,20	1,20	1,00

Table 8 – Safety factors for holding capacity of gravity and plate anchors

Analysis condition	Gravity anchors				Plate anchors	
	Permanent mooring		Mobile mooring		Permanent mooring	Mobile mooring
	Axial	Lateral	Axial	Lateral		
Intact condition	2,00	1,60	1,50	1,20	2,00	1,50
Redundancy check	1,50	1,20	1,20	1,00	1,50	1,20

10 In-service inspection, monitoring, testing, and maintenance

10.1 General

This clause gives a brief overview for maintenance and inspection requirements. Existing offshore standards should be considered for appropriate rigorous and complete inspection regime such as API RP 2I.

Rigorous and effective inspection of mooring hardware is required because mooring failures can result from corroded or physically damaged mooring components, defective connecting hardware, or mooring components of inferior quality.

The measures to be considered in the design of a permanent mooring system to minimize component deterioration generally include means to address corrosion and bending stresses.

Suitable means to address corrosion include:

a) Cathodic protection of major components (e.g. chain, wire rope, connecting hardware, submersible buoys and anchors).
b) Sheathing of wire rope.
c) Jacketing and filtering of ropes.
d) Protective coatings.

e) Galvanization of components (in particular wire ropes).

f) Electrical bonding or isolation between dissimilar materials.

g) Oversizing and/or replacing components based on expected corrosion rates.

Suitable means to minimize bending stresses in the mooring lines:

h) Adequate sizes of bending shoes and/or fairleads.

i) Bend stiffeners near terminations.

More detailed information, including photographic examples, is available in API RP 2I.

10.2 Mooring system proof loading

All moorings shall be subject to load testing after initial installation. For systems where the mooring line is attached to the anchor below the mudline, the load testing is completed to embed anchor, establish reverse catenaries through the sediment, and straighten the mooring. Following any substantial changes, whether by intent, environment, or accident, a further load test may be required subject to the outcome of a risk assessment. Specific test procedures for permanent and mobile moorings can be found in 10.4.6 of ISO 19901-7:2013.

10.3 Component replacement

A specification for the inspection, inspection intervals, and discard criteria for mooring line components should be considered.

Outline procedures for the replacement of any components should be considered as part of the spares and maintenance strategy.

10.4 In air and splash zone mooring line sections

All mooring components and hardware that are located above water, where an interface is made with the floating structure, should be inspected visually. Deterioration from interaction with the mooring components with the MEC structure, seawater or other external effects may occur. Some examples of deterioration include corrosion, marine growth, bending fatigue failure at mooring or umbilical terminations, broken wire rope strands, and chain link wear, fatigue cracking, and loose studs.

10.5 Submerged mooring line sections

The submerged hardware, terminations, and section of mooring line that extends from the MEC to a connector within surface diving limits can be inspected using surface divers, by an ROV using an underwater video camera, or other appropriate inspection methods. The remaining sections of mooring line can be inspected using an ROV with a video camera system. The inspections shall be recorded for later analysis and to form a baseline for assessing the degradation of the system.

In case where an ROV is not available, there should be a plan to inspect subsurface components. Where sheathed mooring lines are installed, it is not possible to determine the condition of the material beneath the sheath. The purpose of this inspection is then to verify the integrity of the sheath to ensure that it is not cracked, torn, or chafed. For electrically isolated components, the integrity of anodes should be monitored.

The entire length of chain components should be inspected to check for abrasive wear, corrosion, and missing studs, where possible.

Chain near the sea bed is subject to greater wear and abrasion due to contact. An allowance for this possibility may be made by increasing the diameter of this section of chain.