9.5.2.6 Load effect and environmental conditions for time-dependent material properties

The sustained load effect values or the fatigue load effect values (if relevant) and the sustained environmental values shall be used for the time-dependent material properties.

9.5.2.7 Load effect and environmental conditions for fatigue analysis

All load effect fluctuations imposed during the entire design life shall be taken into account when determining the long-term distribution of stress or strain ranges. The fatigue load effects shall be combined with the sustained environmental values for the fatigue analysis.

9.5.2.8 Direct combination of loads

The combination of load effects and environmental conditions shall be used. If transfer functions and structural analysis are linear, loads or moments can be combined.

9.5.2.9 Safety, model and system factors

The safety provisions based on consequences of failure and service classes (frequency of service interruptions or restrictions caused by service limit state (SLS) modes of failure) shall be based on the safety methodology for the device and types of failure. The selection of partial safety (model and system) factors shall be based on selected safety level.

Partial load effect factors, γ_F shall be applicable to the characteristic values of the local response of the structure. The uncertainties in the local response are associated with the uncertainties on the loads applied to the structure through the transfer function.

Partial resistance factors, γ_M account for uncertainties associated with the variability of the strength. The combined load effect and resistance factor, γ_{FM} may be taken as the product of γ_F and γ_M. The safety factor γ_{FM} depends on the following:

- target reliability level, expressed in terms of annual probability of failure;
- characteristic values for load effects and resistance; and
- type of distribution function for load effects and resistance.

The partial load effect and resistance factor $\gamma_{FM} = \gamma_F \times \gamma_M$ and may be calibrated against different target reliabilities. The target reliabilities shall correspond to annual probabilities of failure.

The required target reliability level depends on the following:

- the limit state (ULS or SLS);
- the safety level; and
- the failure type (brittle, plastic or ductile).

The target safety levels shall be selected as per Clause 5. A simplified set of partial safety factors may be used whenever a satisfactory probabilistic representation of the load effects is not available.

Load model factors, γ_{Sd} shall account for uncertainties and inaccuracies in the transfer function, the analysis methods and dynamic effects.

Resistance model factors, γ_{Rd} shall account for differences between true and predicted resistance values given by the failure criterion. A summary of typical model factors is given in Table 10.

Table 10 – Summary of model factors

Failure criteria	Model factors γ_{Rd}
Fibre failure	1,0
Matrix cracking	1,0 to 1,15
Delamination	1,0 to 2,0
Yielding	1,0
Ultimate failure of orthotropic homogeneous materials	1,25
Displacements	1,0
Stress rupture	0,1 to1,0
Fatigue	0,1 to1,0

A system effect factor, γ_S is given for the entire system. Depending on how the components are connected to form a system, the target probability of failure for individual components may need to be lower than the target probability of failure of the entire system. If the system effect is not relevant, γ_S = 1,0. A value of γ_S = 1,10 can be used as a first approach. In certain cases, a system may consist of parallel components that may support each other and provide redundancy, even if one component fails. In this instance, a system factor smaller than 1 may be used if it is based on a rigorous structural reliability analysis.

9.5.3 Joints and interfaces

Structural requirements for composite material joints and interfaces are based on achieving the same level of reliability as the structure. If metal components are part of a joint or interface, the metal components shall be designed to be compatible with the composite structure.

Joints are load-bearing connections between structures, components or parts. The following three basic types of joints shall be considered:

- Laminated joints are joints fabricated from the same constituent materials as the laminates that are joined, such as over-laminations, lap joints, and scarf joints. These joints can use either primary or secondary bonds.
- Adhesive joints are joints between laminates, cores or between laminates and other materials for example metals that utilize a specialty adhesive matrix.
- Mechanical joints use fasteners and bolted connections.

Material selection and fabrication environment critically affect the durability of structural joints. The effects of time, thermal stresses, fatigue and long-term creep shall be considered for all joints and interfaces.

10 Electrical, mechanical, instrumentation and control systems

10.1 Overview

The electrical, mechanical, instrumentation and control systems of a MEC include all equipment installed in each device up to and including the MEC point of common connection with the grid. The designer shall consider failures in the electrical, mechanical, instrumentation and control systems that can have critical impacts on the integrity of the MEC primary structure.

10.2 General requirements

Faults, as well as normal operation, can influence loading on the primary structure and give resonant response of both structural and mechanical elements (both passively and actively).

Therefore, the designer shall carry out a FMECA for the electrical, mechanical, instrumentation and control systems to ensure that none of the failure modes can critically increase the resonant response of the structural, mechanical or electrical elements (see 5.9).

The impact of the electrical, mechanical, instrumentation and control systems upon the loading of the primary structure when positioning the control system elements shall be addressed.

The electrical, mechanical, instrumentation and control systems of a MEC and every component such as converters, controllers, generators, transformers and cables shall comply with applicable regional regulations. The design of the electrical system shall take into account the fluctuating nature of power generation from MECs and effects of the marine environment, such as humidity, corrosion, bio-fouling, motion and inclination.

The lightning protection of a surface piercing or floating MEC shall be designed in accordance with IEC 62305-3. All MEC protection system circuits that could possibly be affected by lightning and other transient overvoltage conditions shall be protected according to IEC 61643-11.

Any part of the electrical system that can excite the MEC generator shall automatically be disconnected from the grid and remain safely disconnected in the event of loss of power at the MEC, subject to local grid requirements.

Isolation from all sources of supply will be particularly important when using permanent magnet or other types of generator capable of self-excitation, and where work or testing on the device, subsea cable system or connectors is likely to require electrical isolation from the generator as well as from the shore supply. Isolation requirements shall be considered at the design stage. If remotely operated equipment is selected for isolation purposes, it will require careful design to ensure firstly that it can be confirmed that the remote equipment has operated correctly to provide isolation and secondly that the equipment can be secured in the isolated position.

10.3 Abnormal operating conditions safeguard

The MECs control methodology requirements shall be summarized in a functional design specification that describes the objectives and attributes of the electrical, mechanical, instrumentation and control systems in terms of functional capability at locations (on-board, electrical substation, control centre, etc.).

Within the functional design specification, the designer shall demonstrate that all necessary precautions have been taken to prevent the MEC transitioning into an abnormal condition or state due to conditions such as, but not limited to:

- loss of the control system;
- electrical and/or mechanical component failure;
- loss of communication with the device;
- loss of load; and
- over-speed.

If an abnormal condition or state occurs, the MEC electrical, mechanical and control system shall transition to an offline safe condition or state.

The primary structure shall be designed for loads arising from such abnormal conditions.

11 Mooring and foundation considerations

11.1 Overview

11.1.1 General

Clause 11 includes additional requirements for the consideration of station keeping of major structural elements of MECs, including the design of the geotechnical interface.

The design of moorings and foundations for MECs has unique challenges over conventional offshore structures and these shall be considered to ensure the appropriate design and mechanical integrity of such structures. In particular, there are unique technical challenges that depend on the type of MEC being considered. In many cases, established mooring and foundation methods for conventional marine structures are not appropriate.

11.1.2 Unique challenges for wave energy converters

a) Wave-induced response

   Wave energy converters may have structures designed to amplify wave loads and induce a motion response to absorb energy from the prevailing wave climate. This structural loading and motion response shall be resisted by the foundation and moorings systems in extreme wave conditions.

b) Shallow deployment sites exposed to ocean wave climates

   For economic power export, WECs are deployed close to the market for energy, usually meaning structures are deployed in water depths within the range 15 m to 100 m. As such, the applicability of deep-water assumptions (λ/d > 0,5) does not often apply for extreme waves. Such waves can have amplified horizontal water particle excursions and non-linear phenomena including wave breaking are more prevalent.

   Designing mooring systems to comply with ever-larger horizontal excursions induced by shallow water extreme waves is difficult owing to the small vertical spans available in relatively shallow-water tether mooring systems to accommodate such compliance.

   In shallow water, there is significant wave-induced hydrodynamic shear at the seabed with the consequent effect of:

   – loading on seabed foundation structures; this is especially the case for low-density gravity base structures (e.g. self-installing gravity base structures), where such large volume structures can attract significant wave loading on the foundation itself;

   – lack of stable sediment accumulations for drag embedded anchors owing to seabed scour; and

   – severe scouring of the seabed and undermining of foundations.

11.1.3 Unique challenges for tidal energy converters

Where TECs are deployed in tidal streams exposed to ocean waves, similar issues to those described above for wave energy converters apply, especially for floating installations. The issues of lack of seabed sediment due to strong currents exist, as sediments can be mobilized and transported away from the site and rocky seabeds and large boulders are common geotechnical issues. Wave-induced loading on foundation structures also apply and wave loading on any turbine ducting shall also be considered.

11.2 Tethered floating structures

Tethered floating structures are supported by their own buoyancy forces and are tethered to the seabed for the purpose of station-keeping such that there is a degree of compliance to dynamic environmental loading on the structure. Tethered station-keeping systems will comprise of one or more tethers to connect the floating structure to an anchor in a fixed earth reference.

Tethers will generally be made of steel chain, steel wire, synthetic fibre rope, or elastomeric cable elements. The tether may also include buoyant elements and/or clump weights.

Anchors will comprise drag anchors, anchor piles (driven, jetted, suction, drilled or grouted), and other anchor types, such as gravity anchors, suction anchors and plate anchors.

When orientation is important for safety or operational considerations, the station-keeping system shall be designed to maintain adequate position reference and directional control. Passive station-keeping systems include catenary mooring, taut-line mooring, spring buoy and tension leg systems. Active systems include dynamic positioning using thrusters or motorized winches to change mooring line tensions.

The adequacy of the station-keeping systems for moored floating structures shall be demonstrated by adhering to the requirements of IEC TS 62600-10.

11.3 Fixed structures

The structural analysis of the foundation of a fixed offshore MEC shall be performed in accordance with the ISO offshore structural design standards cited in this subclause or other recognized offshore design standards. If offshore design standards other than the ISO standards are used, it shall be demonstrated that at least the same level of structural reliability with respect to ultimate strength and fatigue is obtained.

The design load cases (see Clause 7) and associated load and resistance factors (see Clause 9) shall be used as the basis of the structural design of the foundation. Note in particular that the conversion of waves and tidal currents through controllable PTO machinery can result in significant dynamic loading that shall be considered in the load cases as prescribed in Clause 7.

The foundation design and analysis shall comply with ISO 19900. Geotechnical and foundation specific requirements that are applicable to a broad range of offshore structures are based on ISO 19901-4. The design of piled foundations that have a traditional association with fixed steel structures is detailed in ISO 19902. Particular requirements for the design of shallow gravity foundations that have a traditional association with fixed concrete structures are detailed in ISO 19903. Where appropriate, the principles for concrete gravity bases can also be applied to steel gravity base solutions, which may be desirable to reduce environmental loading on the gravity base itself in shallow water.

The foundation shall be designed to carry static and dynamic (repetitive as well as transient) actions without excessive deformation or vibrations in the structure. Special attention shall be given to the effects of repetitive and transient actions on the structural response, as well as on the strength of the supporting soils. The possibility of movement of the sea floor against foundation members shall be investigated. The loads caused by such movements, if anticipated, shall be considered in the design.

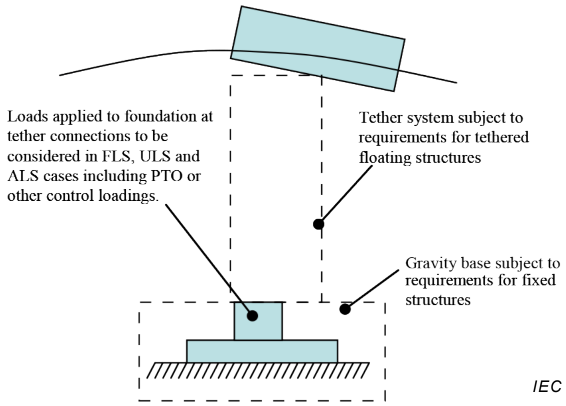
Loads acting on the foundation during transport and installation shall be taken into account. For piled structures, an analysis shall be undertaken to calculate the fatigue damage sustained by the pile as it is driven into the seabed. The fatigue analysis shall consider the loads associated with pile driving impact, taking account of the structural dynamics of the pile and stress increases due to the details of the pile design and the pile driving process.

11.4 Compound MEC structures

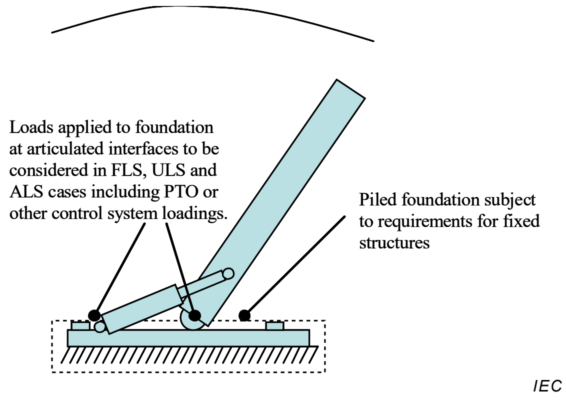
Compound MEC structures combine the function of station-keeping with other MEC functions, such as:

- the provision of a reaction to PTO forces that permits energy conversion from wave induced or current induced loads;

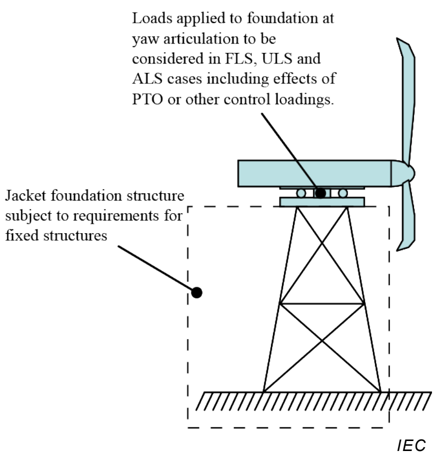
- where controllable power conversion machinery (e.g. hydraulic cylinders, linear generators, hose-pump elements) transfers the environmental loads from the primary wave-activated structure to the anchor reference point, forming an essential part of station-keeping for a large portion of the MEC structure; and
- attitude control – a controllable actuator delivers loads between the foundation and the MEC to affect optimal orientation of the structure to enhance energy conversion.



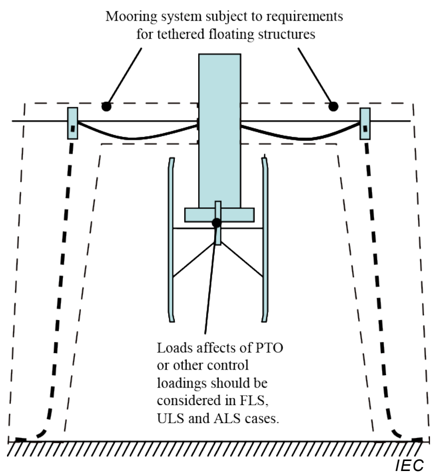
a) WEC using tether to transmit wave loads from wave-activated buoy to a reaction given by a gravity base foundation. The tether could also connect to a controllable PTO, included either within the foundation or buoy.



b) A flap type wave energy conversion device with a piled foundation base. Articulations permit the flap kinematics and provide a PTO reaction for a hydraulic cylinder.



c) Fixed horizontal axis tidal energy conversion turbine with yaw articulation



d) Free-floating, compliantly moored vertical axis tidal energy conversion turbine.

Figure 2 – Examples of compound position mooring systems for wave (a, b) and tidal (c, d) energy conversion systems

The resulting compound station keeping systems (see Figure 2) can depend on a combination of tether, fixed and articulated structural elements as well as controllable power conversion elements. In such cases, the issue of station keeping is less clearly divisible from the general structural integrity of the MEC and the provisions in 11.2 to 11.4. The considerations for fixed foundations and the station keeping of compliantly moored floating structures shall all apply, as follows:

a) Compound structures with tethers

Where tether elements are included in the MEC such that their failure would result in a loss of station keeping for all or a portion of the MEC structure, the requirements for tethered floating structures (see 11.2) shall be applied for the purpose of designing all tethers and associated attachments. The requirements of tethered floating structures shall also be used to determine the required design safety factor at interfaces to other parts of the structure (either the fixed part of the structure or free floating part of the structure) and the corresponding interface loads shall be included for the assessment of load combinations under Clause 7. Consideration shall be given to ALS load cases, including provision for redundancy due to failed tether elements. Where the MEC includes active control systems (such as power conversion hydraulics, linear generators, etc.) such that the load in the tether and its attachments are influenced significantly, then the control response shall be considered in any tether or fixed foundation load assessment allowing for all applicable operating scenarios, control settings and possible control ALS failure conditions (see Clause 7).

b) Compound structures with articulations

Where articulations are included in the MEC such that their failure would result in a loss of station keeping for a proportion of the MEC structure, the design load cases and associated load and resistance factors specified in Clauses 7 and 9 shall be used to ensure the integrity of articulated joints and associated attachments. Partial failure conditions of joints and articulations shall be considered in load cases to determine ALS foundation load cases. Where the articulation elements include active control systems such that loads applied to the foundation are influenced significantly, then the control response shall be considered in the foundation load and resistance assessments allowing for all applicable operating scenarios, control settings and possible ALS failure conditions (see Clause 7).

12 Inspection requirements

12.1 General

The manner in which a marine energy converter (MEC) is operated and maintained will have a significant impact on the integrity of the primary structure and functionality throughout its design life. In order for any maintenance and inspection to be effective, it shall be considered in a holistic manner throughout the design, construction, commissioning and operation of the MEC.

The requirements for a robust inspection and maintenance strategy will vary according to the type of MEC and the offshore environment in which it is working. Given the harsh environmental conditions which MECs experience, access for inspection and maintenance and in-situ working can be difficult to achieve in a safe manner, hence it will be necessary in many cases to recover the MEC back to shore or harbour prior to undertaking any inspection and maintenance work.

Maintenance and inspection activities can expose workers to a number of potential hazards. The planning stage of maintenance or inspection activities shall identify all potential hazards and identify means of reducing or eliminating exposure to these hazards. The maintenance strategy shall identify all local and national health, safety and environmental requirements that may apply to ensure the proposed activities comply.

12.2 Consideration during the design stage

The planned inspection and maintenance strategy shall be considered during the design stages to ensure that it is practical, economic and safe. The safety of personnel engaged in inspection and maintenance is paramount and should be considered through the undertaking of appropriate risk assessments to eliminate, or limit, the need to expose personnel to dangerous working environments. However, human safety is outside the scope of this document and designers should refer directly to local and national regulations.

The opportunity to use monitoring of structural integrity and other systems to provide a safe and continuous assessment of MEC structural integrity and functionality shall be evaluated at the design stage and, where feasible, adopted.

12.3 Inspection and maintenance planning

The designer shall give due consideration to the individual subsystems and components that may have a much reduced design life compared to the MEC system. Such a strategy shall consider three main categories as a minimum:

- time-based maintenance (where maintenance intervals are prescribed for the MEC system, subsystems, equipment and components);
- condition-based maintenance: this involves monitoring the condition of the MEC system, subsystems, equipment and components and maintenance is scheduled when certain conditions are met; and
- risk/reliability based maintenance (where maintenance intervals are determined based on the risk to and reliability of the MEC system, subsystems, equipment or components).

The designer shall identify the risks associated with the design, operation and maintenance activities as well as the mitigating measures using recommendations defined in Clause 7. The inspection and maintenance strategy shall be developed once these risks and mitigating measures are identified to ensure any requirements are considered from a risk perspective and the risk of human injury, significant environmental pollution or very high economic or political consequences are reduced to an acceptable level. The strategy shall satisfy appropriate local and national codes and regulations.

The developer shall communicate the inspection and maintenance strategy within a MEC specific Operation and Maintenance (O and M) manual that shall be issued to the owner/operator. In detailing the strategy and general operational requirements, the O and M manual shall include, but not be limited to the following:

- any maintenance or inspection activities that require special training;
- safe operating limits and system descriptions that consider local site conditions;
- maintenance inspection periods and procedures;
- for parts subject to wear: criteria for replacement;
- procedures for functional check of protection subsystems;
- start-up and shut-down procedures;
- an alarms action list;
- emergency procedures plan; and
- compliance with appropriate occupational health and safety regulations and marine regulations.

12.4 Data management

All inspection and maintenance activities shall be documented to reflect the requirements of the governing strategy specified in the O and M manual and shall include the reporting of the following information, as applicable:

- MEC identification;
- subsystem, equipment or component identification;
- operating hours to date, including operational modes that factor into fatigue analysis, such as energy produced;
- shut-down hours to date;
- date and time of fault reported;
- date and time of service or repair;
- nature of failure, fault or service (random or systematic);
- details of tests and inspections;

- recording of remedial action taken (part replacement, repair, identified for further monitoring);
- review of outstanding issues from previous activities; and
- details of personnel and equipment used.

Data shall be reported in an objective manner and shall justify its conclusions and include photographic documentation as considered appropriate. Relevant data from the design, construction and commissioning stages shall be available and understood to act as a baseline for in-service inspection and maintenance activities.

Feedback from in-service inspection and maintenance activities can provide valuable information to inform the following:

- possible revision/amendment to the governing strategy and hence the O and M manual;
- develop a greater understanding of component reliability and the degradation of structures or structural elements in the real sea environment and whether they continue to comply with the governing basis of design;
- highlight any findings or deviations reported during previous inspection and maintenance activities that have been remedied or not dealt with; and
- identify possible issues for future structural integrity monitoring.

Data shall be obtained during the in-service life in a systematic way that will enable an industry wide involvement of manufacturers, technology developers, operators, certification organizations and regulatory agencies.

12.5 Condition assessment and integrity evaluation (against performance requirements)

The findings from the inspection/maintenance carried out during the in-service life are to be compared with the expected behaviour of the structure and equipment identified during the design and commissioning phases.

Inspection and maintenance shall focus on detecting signs of degradation (corrosion, wear, cracks, tolerances, leaks). Degradation shall be limited to the range expected in the design. Findings deviating from the expected range require investigation. This could be, but not limited to, reviewing the design methodology and reviewing the actual conditions of operation.

At the early stage of technology development, the level of uncertainties on the design methodology and actual conditions of operation are much larger than what is observed in conventional and well-established technologies. Thus, an essential part of the technology development is the assessment of the condition of the structure and equipment during operation. Monitoring combined with results from inspection provides a full understanding of the technology (failure modes and degradation).

For MECs, the use of risk assessment is an adequate way to identify the areas of uncertainty and associated risk level for the technology to perform as required. As risk management is a continuous process, monitoring and inspection should feed back into the risk management and technology development to recalibrate the risks and effort required during the in-service life.

When planning and recording the monitoring and inspection activities, data collection is a key step in the identification of performance, failures, and reliability (see 12.4).

12.6 Maintenance execution

All inspection and maintenance activities shall be carried out in accordance with the O and M manual and shall be performed by personnel suitably trained or instructed in this activity. Access for inspection and maintenance of a MEC will be a key consideration. Because of the nature of MEC and the harsh environment, it might be necessary to recover the MEC to shore prior to undertaking any maintenance work due to limited safe access for inspection and in-site working. Where in-site maintenance is considered, consideration shall be given to provision of refuge areas for personnel on the MEC. An appropriate risk assessment, or similar, shall be undertaken to determine safe methods of undertaking the work.

An emergency procedures plan shall be defined as part of the O and M manual and the required actions of the operating personnel prescribed. The plan shall require that where there is a fire or apparent risk of structural damage to the MEC or its components, no one should approach the MEC unless the risk is specifically evaluated.

13 Life cycle considerations

13.1 General

The designer shall consider the entire life cycle of the MEC and the effects of both frequent and infrequent operations on the integrity of the primary structure. Fabrication, transportation and installation phases for MECs are significantly different than the operational phase and decommissioning phase. Each of these phases can impose loads on the primary structure that can affect the engineering integrity of the collective system. Careful planning is required to provide an appropriate level of protection against damage from all hazards that may lead to failure of the primary structure, injury to personnel, damage to equipment or damage to the environment.

The designer shall consider the rigging, lifting and movement of components, assemblies and modules during fabrication. Transportation planning shall consider all logistics and loads associated with movements at the fabrication site, road transport, pier-side activity, lift transfers and water transport. Due consideration shall be given to weight, height, width, length, in-water draft, and overhead clearance. Installation planning shall consider all associated operations including removal and reinstallation for maintenance and decommissioning. Changes in state, such as on-land to floating, floating to submerged and submerged to bottom shall be considered. The designers of a MEC shall provide an installation manual clearly describing the fabrication, transportation and installation requirements for the MEC, moorings, power cables and anchoring system. The installation of MECs shall be performed by personnel trained or instructed in these activities.

The designer shall consider and provide operational procedures, to include maintenance, inspection, and decommissioning to the owners/operators. The designer shall consider fatigue and degraded material condition during design and permitting for removal and decommissioning at end of useful life.

The site of a marine energy facility shall be prepared, maintained, operated and managed so that work can be performed in a safe and efficient manner in accordance with appropriate regulations and permitted requirements. This shall include:

- marking of individual structures, or fields of structures;
- installation of power cables between individual MECs, transformer stations, and shore;
- monitoring of the facility by the operator;
- procedures to prevent unauthorized access, where appropriate; and
- contingency plans to address the possibility of individual MEC units breaking loose and becoming floating or submerged hazards.

Detailed installation engineering and planning shall be carried out. Checklists of planned activities shall be prepared and comprehensive records shall be maintained during construction and commissioning to provide as-built data. Planning and independent reviews shall consider:

- design, testing and certification of lift points;

- movements on land;
- route considerations, including contingency mooring and anchoring locations;
- cross-section related current, wave and wind forces with respect to available tug capabilities and backup tugs;
- tug contact points; and
- centre of gravity, stability and risk of capsizing (static and dynamic stability requirements).

The transportation plan, including the towing plan, shall consider all aspects of MEC movement, launch, placement and mooring, including:

- weather windows for transportation and installation;
- damage control contingencies and monitoring systems;
- lashing and sea fastening for inertial loads;
- modularity and assembly at sea;
- freeboard of hatches and maintenance openings and risk of down-flooding;
- role of independent surveyor prior to movements on land and to sea;
- role of harbour and coastal pilots;
- launch considerations:
  - clearance of submerged hazards; and
  - dynamics and irreversible/unstoppable launching procedures;
- transitions in centre of gravity and centre of buoyancy and associated risks of capsizing:
  - physics of floating device;
  - physics of submerged device;
  - physics of bottomed device;
  - transitions between states;
  - limbering of tanks;
  - abnormal hydrostatic pressures;
  - lifts at sea:
    - snap loads; and
    - entrained mass of water;
  - tensioning the mooring; and
  - power cable connections.

When appropriate, installation personnel shall use approved personal protective equipment, such as eye, feet, hearing, and head protection. Fire safety issues shall be considered during all aspects of the MEC life cycle, especially during confined entry activities. All personnel climbing or working above ground or water level shall be trained in such work and shall use approved safety belts and safety climbing aids. Personnel working on or near the water shall wear approved life jackets at all times. Consideration shall be given to the use of survival suits in cold climates when risk of immersion is imminent.

All equipment shall be kept in good repair and be suitable for the task for which it is intended. Cranes, hoists and lifting equipment, including all slings, hooks and other apparatus, shall be periodically tested and approved for safe lifting.

Particular consideration shall be given to avoid installation of the MECs under unusual conditions, such as: hail, lightning, high winds, earthquake, icing, high waves, and extreme tidal conditions.