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ISO/DIS 19901-1

Oil and gas industries including lower carbon energy — Specific requirements for offshore structures —

Part 1: Metocean design and operating considerations

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

This document was prepared by Technical Committee ISO/TC *67] Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 7, *Offshore structures*

This third edition cancels and replaces the second edition (ISO 19901-1:2015), which has been technically revised.

The main changes compared to the previous edition are as follows:

— Clarification on the role of the metocean expert (Section 5.2 and Annex A.5.2)

— Additional information related to the determination of associated criteria (Section 5.3 and Annex A.5.3)

— Additional information related to the estimation of extreme/abnormal conditions (Section 5.7 and Annex A.5.7)

— Alignment of the wind normative and informative sections with API RP 2MET (Section 7 and Annex A.7)

— Additional information related to breaking/non-breaking wave kinematic estimation (Section 8.4.3 and Annex A.8.4.3)

— Expansion to section on additional environment factors to be considered (Section 10 and Annex A.10)

— Introduction of Normative and Informative text related to the verification of weather forecast information (Sections 12 and Annex A.12)

— Update to Offshore Canada Regional Annex (Annex D)

— Update to Sakhalin/Sea of Okhotsk Regional Annex (Annex E)

— Update to Caspian Sea Regional Annex (Annex F)

— Introduction of Mediterranean Sea Regional Annex (Annex H)

— Introduction of Brazil Regional Annex (Annex I)

— Re-introduction of US Gulf of Mexico Regional Annex (Annex J)

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— Re-introduction of Coast of California Regional Annex (Annex K)

— Re-introduction of Overview of Regions Excluding Gulf of Mexico and California Regional Annex (Annex J)

A list of all parts in the ISO 19901-1 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

The series of International Standards applicable to types of offshore structure, ISO 19900 to ISO 19906, constitutes a common basis covering those aspects that address design requirements and assessments of all offshore structures used by the petroleum and natural gas industries worldwide. Through their application the intention is to achieve reliability levels appropriate for manned and unmanned offshore structures, whatever the type of structure and the nature or combination of the materials used.

It is important to recognize that structural integrity is an overall concept comprising models for describing actions, structural analyses, design rules, safety elements, workmanship, quality control procedures and national requirements, all of which are mutually dependent. The modification of one aspect of design in isolation may disturb the balance of reliability inherent in the overall concept or structural system. The implications involved in modifications, therefore, need to be considered in relation to the overall reliability of all offshore structural systems.

The series of International Standards applicable to types of offshore structure is intended to provide a wide latitude in the choice of structural configurations, materials and techniques without hindering innovation. Sound engineering judgement is therefore necessary in the use of these International Standards.

The overall concept of structural integrity is described above. Some additional considerations apply for metocean design and operating conditions. The term “metocean” is short for “meteorological and oceanographic” and refers to the discipline concerned with the establishment of relevant environmental conditions for the design and operation of offshore structures. A major consideration in the design and operation of such a structure is the determination of actions on, and the behaviour of, the structure as a result of winds, waves and currents.

Environmental conditions vary widely around the world. For the majority of offshore locations there are little numerical data from historic conditions; comprehensive data often only start being collected when there is a specific need, for example, when exploration for hydrocarbons is being considered. Despite the usually short duration for which data are available, designers of offshore structures need estimates of extreme and abnormal environmental conditions (with an individual or joint probability of the order of 1×10^{-2}/year and 1×10^{-3} to 1×10^{-4}/year, respectively).

Even for areas like the Gulf of Mexico, offshore Indonesia and the North Sea, where there are over 30 years of fairly reliable measurements available, the data are insufficient for rigorous statistical determination of appropriate extreme and abnormal environmental conditions. The determination of relevant design parameters has therefore to rely on the interpretation of the available data by experts, together with an assessment of any other information, such as prevailing weather systems, ocean wave creation and regional and local bathymetry, coupled with consideration of data from comparable locations. In particular, due account needs to be taken of the uncertainties that arise from the analyses of limited datasets. It is hence important to employ experts from both the metocean and structural communities in the determination of design parameters for offshore structures, particularly since setting of appropriate environmental conditions depends on the chosen option for the offshore structure.

This part of ISO 19901 provides procedures and guidance for the determination of environmental conditions and their relevant parameters. Requirements for the determination of the actions on, and the behaviour of, a structure in these environmental conditions are given in ISO 19901-3, ISO 19901-6, ISO 19901-7, ISO 19902, ISO 19903, ISO 19904-1, ISO 19905-1 and ISO 19906.

Some background to, and guidance on, the use of this part of ISO 19901 is provided in informative Annex A. The clause numbering in Annex A is the same as in the main text to facilitate cross-referencing.

Regional information, where available, is provided in the Regional Annexes B to I. This information has been developed by experts from the region or country concerned to supplement the guidance provided in this part of ISO 19901. Each Regional Annex provides regional or national data on environmental conditions for the area concerned.

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Oil and gas industries including lower carbon energy — Specific requirements for offshore structures —

Part 1: Metocean design and operating considerations

1 Scope

This part of ISO 19901 gives general requirements for the determination and use of meteorological and oceanographic (metocean) conditions for the design, construction and operation of offshore structures of all types used in the petroleum and natural gas industries.

The requirements are divided into two broad types:

— those that relate to the determination of environmental conditions in general, together with the metocean parameters that are required to adequately describe them;

— those that relate to the characterization and use of metocean parameters for the design, the construction activities or the operation of offshore structures.

The environmental conditions and metocean parameters discussed are:

— extreme and abnormal values of metocean parameters that recur with given return periods that are considerably longer than the design service life of the structure,

— long-term distributions of metocean parameters, in the form of cumulative, conditional, marginal or joint statistics of metocean parameters, and

— normal environmental conditions that are expected to occur frequently during the design service life of the structure.

Metocean parameters are applicable to:

— the determination of actions for the design of new structures,

— the determination of actions for the assessment of existing structures,

— the site-specific assessment of mobile offshore units,

— the determination of limiting environmental conditions, weather windows, actions and action effects for pre-service and post-service situations (i.e. fabrication, transportation and installation or decommissioning and removal of a structure), and

— the operation of the platform, where appropriate.

NOTE Specific metocean requirements for site-specific assessment of jack-ups are contained in ISO 19905-1, for arctic offshore structures in ISO 19906 and for topside structures in ISO 19901-3.

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.

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ISO 19900, *Petroleum and natural gas industries — General requirements for offshore structures*

ISO 19901 (all parts), *Oil and gas industries including lower carbon energy — Specific requirements for offshore structures*

ISO 19902, *Petroleum and natural gas industries — Fixed steel offshore structures*

ISO 19903, *Petroleum and natural gas industries — Concrete offshore structures*

ISO 19904-1, *Petroleum and natural gas industries — Floating offshore structures — Part 1: Ship-shaped, semi-submersible, spar and shallow-draught cylindrical structures*

ISO 19905-1, *Oil and gas industries including lower carbon energy — Site-specific assessment of mobile offshore units — Part 1: Jack-ups: elevated at a site*

ISO 19906, *Petroleum and natural gas industries — Arctic offshore structures*

WMO-No 306, *Manual on Codes*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 19900 and the following apply.

3.1
abnormal value
design value of a parameter of abnormal severity used in accidental limit state checks in which a structure is intended not to suffer complete loss of integrity

Note 1 to entry: Abnormal events are typically accidental and environmental (including seismic) events having probabilities of exceedance of the order of 10^{-3} to 10^{-4} per annum.

3.2
chart datum
local datum used to fix water depths on a chart or tidal heights over an area

Note 1 to entry: Chart datum is usually an approximation to the level of the lowest astronomical tide.

Note 2 to entry: Chart datum may differ from one chart to another and care is required if cross referencing sites that are not on the same chart.

3.3
conditional probability
conditional distribution
statistical distribution (probability) of the occurrence of a variable A, given that other variables B, C, … have certain assigned values

Note 1 to entry: The conditional probability of A given that B, C, … occur is written as $P(A|B,C,...)$. The concept is applicable to metocean parameters, as well as to actions and action effects.

EXAMPLE When considering wave parameters, A may be the individual crest elevation, B the water depth and C the significant wave height, and so on.

3.4
design crest elevation
extreme crest elevation measured relative to still water level

Note 1 to entry: The design crest elevation is used in combination with information on astronomical tide, storm surge, platform settlement, reservoir subsidence and water depth uncertainty and is derived using extreme value analysis. Where simplified models are used to estimate the kinematics of the design wave, the design crest elevation may be different from (usually somewhat greater than) the crest elevation of the design wave used to calculate actions on the structure. In reality, the wave with the greatest trough-to-crest height and the wave with the highest crest will be different waves.

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3.5
design wave
deterministic wave used for the design of an offshore structure

Note 1 to entry: The design wave is an engineering abstraction. Most often it is a periodic wave with suitable characteristics (e.g. height *H*, period *T*, steepness, crest elevation). The choice of a design wave depends on:

— the design purpose(s) considered,

— the wave environment,

— the geometry of the structure,

— the type of action(s) or action effect(s) pursued.

Note 2 to entry: Normally, a design wave is only compatible with design situations in which the action effect(s) are quasi-statically related to the associated wave actions on the structure.

3.6
expert
<metocean> individual who through training and experience is competent to provide metocean advice specific to the area or topic in question.

3.7
extreme water level
EWL
combination of design crest elevation, astronomical tide and storm surge referenced to either LAT or MSL

3.8
extreme value
representative value of a parameter used in ultimate limit state checks

Note 1 to entry: Extreme events have probabilities of the order of 10^{-2} per annum.

3.9
gravity wave
wave in a fluid or in the interface between two fluids for which the predominant restoring forces are gravity and buoyancy

Note 1 to entry: Wind-generated surface waves are an example of gravity waves.

3.10
gust
brief rise and fall in wind speed lasting less than 1 min

Note 1 to entry: In some countries, gusts are reported in meteorological observations if the maximum wind speed exceeds approximately 8 m/s.

3.11
gust wind speed
maximum value of the wind speed of a gust averaged over a short (3 s to 60 s) specified duration within a longer (1 min to 1 h) specified duration

Note 1 to entry: For design purposes, the specified duration depends on the dimensions and natural period of (part of) the structure being designed such that the structure is designed for the most onerous conditions; thus, a small part of a structure is designed for a shorter gust wind speed duration (and hence a higher gust wind speed) than a larger (part of a) structure.

Note 2 to entry: The elevation of the measured gust should also be specified.

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3.12
highest astronomical tide
HAT
level of high tide when all harmonic components causing the tides are in phase

Note 1 to entry: The harmonic components are in phase approximately once every 19 years, but these conditions are approached several times each year.

3.13
hindcasting
method of simulating historical (metocean) data for a region through numerical modelling

3.14
infra-gravity wave
surface gravity wave with a period in the range of approximately 25 s to 500 s

Note 1 to entry: In principle an infra-gravity wave is generated by different physical processes but is most commonly associated with waves generated by nonlinear second-order difference frequency interactions between different swell wave components.

3.15
internal wave
gravity wave which propagates within a stratified water column

3.16
Joint North Sea Project Spectrum
JONSWAP
version of the Pierson-Moskowitz spectrum which accounts for the continued development of the spectrum through non-linear wave-wave interaction over time and space

3.17
long-term distribution
probability distribution of a variable over a long time scale

Note 1 to entry: The time scale exceeds the duration of a sea-state, in which the statistics are assumed constant (see **3.35 short-term distribution**). The time scale is hence comparable to a season or to the design service life of a structure.

EXAMPLE Long-term distributions of:

— significant wave height (based on, for example, storm peaks or all sea-states),

— significant wave height in the months May to September,

— individual wave heights,

— current speeds (such as for use in assessing vortex-induced vibrations of drilling risers),

— scatter diagrams with the joint distribution of significant wave height and wave period (such as for use in a fatigue analysis),

— a particular action effect,

— sea ice types and thickness,

— iceberg mass and velocity,

— storm maximum significant wave height.

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3.18
lowest astronomical tide
LAT
level of low tide when all harmonic components causing the tides are in phase

Note 1 to entry: The harmonic components are in phase approximately once every 19 years, but these conditions are approached several times each year.

3.19
marginal distribution
marginal probability
statistical distribution (probability) of the occurrence of a variable *A* independent of any other variable

Note 1 to entry: The marginal distribution is obtained by integrating the full distribution over all values of the other variables *B*, *C*, ... and is written as *P*(*A*). The concept is applicable to metocean parameters, as well as to actions and action effects.

EXAMPLE When considering wave conditions, *A* may be the individual crest elevation for all mean zero-crossing periods *B* and all significant wave heights *C*, occurring at a particular site.

3.20
marine growth
living organisms attached to an offshore structure

3.21
mean sea level
MSL
arithmetic mean of all sea levels measured over a long period

Note 1 to entry: Seasonal changes in mean level may be expected in some regions and over many years the mean sea level may change.

3.22
mean wind speed
time-averaged wind speed, averaged over a specified time interval and at a specified elevation

Note 1 to entry: The mean wind speed varies with elevation above mean sea level and the averaging time interval; a standard reference elevation is 10 m and with an averaging time of 10 min. See also **3.11 gust wind speed** and **3.46 sustained wind speed**.

3.23
mean zero-crossing period
average period between (up or down) zero-crossing waves in a sea-state

Note 1 to entry: In practice the mean zero-crossing period is often estimated from the zeroth and second moments of the wave spectrum as $T_z = T_2 = \sqrt{m_0(f)/m_2(f)} = 2\pi\sqrt{m_0(\omega)/m_2(\omega)}$.

3.24
monsoon
seasonally reversing wind pattern, with associated pattern of rainfall

Note 1 to entry: The term was first applied to the winds over the Arabian Sea which blow for six months from northeast and for six months from southwest, but it has been extended to similar winds in other parts of the world.

3.25
most probable maximum
value of the maximum of a variable with the highest probability of occurring

Note 1 to entry: The most probable maximum is the value for which the probability density function of the maxima of the variable has its peak. It is also called the mode or modus of the statistical distribution.

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3.26
operating conditions
most severe combination of environmental conditions under which a given operation is permitted to proceed

Note 1 to entry: Operating conditions are determined for operations that exert a significant action on the structure. Operating conditions are usually a compromise: they are sufficiently severe that the operation may generally be performed without excessive downtime, but they are not so severe that they have an undue impact on design or safety.

3.27
polar low
depression that forms in polar air, often near a boundary between ice and sea

3.28
residual current
residual water level
part of the total current or water level that is not constituted from harmonic tidal components (i.e. the tidal stream or tidal height)

Note 1 to entry: Residual currents are caused by a variety of physical mechanisms and comprise a large range of natural frequencies and magnitudes in different parts of the world.

3.29
return period
average period between occurrences of an event or of a particular value being exceeded

Note 1 to entry: The offshore industry commonly uses a return period measured in years for environmental events. For a rare event, the return period in years is equal to the reciprocal of the annual probability of exceedance of the event.

3.30
scatter diagram
joint probability of two or more (metocean) parameters

Note 1 to entry: A scatter diagram is especially used with wave parameters in the metocean context (for example in fatigue assessments). The wave scatter diagram is commonly understood to be the probability of the joint occurrence of the significant wave height (H_s) and a representative period (T_z or T_p).

3.31
sea floor
interface between the sea and the seabed and referring to the upper surface of all unconsolidated material

3.32
sea-state
condition of the sea during a period in which its statistics remain approximately stationary

Note 1 to entry: In a statistical sense the sea-state does not change markedly within the period. The period during which this condition exists depends on the particular weather condition at any given time, however it is often assumed to be three hours in extra-tropical conditions, however it may be as short as 1 hour in tropical cyclonic conditions.

3.33
seabed
materials below the sea in which a structure is founded, whether of soils such as sand, silt or clay, cemented material or of rock

3.34
seiche
oscillation of a body of water at its natural period

3.35
short-term distribution
probability distribution of a variable within a short interval of time during which conditions are assumed to be statistically stationary

Note 1 to entry: The interval chosen is most often the duration of a sea-state.

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3.36
significant wave height
statistical measure of the height of waves in a sea-state

Note 1 to entry: The significant wave height was originally defined as the mean height of the highest one-third of the zero up-crossing waves in a sea-state. In most offshore data acquisition systems the significant wave height is currently taken as $4\sqrt{m_0}$, (where m_0 is the zeroth spectral moment, see 3.38 spectral moment) or 4σ, where σ is the standard deviation of the time series of water surface elevation over the duration of the measurement, typically a period of approximately 30 min.

3.37
site-averaging
averaging extreme values from a number of individual sites

Note 1 to entry: used to take account of the localised extent of phenomena such as tropical cyclones or meso-scale eddies e.g. warm core rings in the Gulf of Mexico

3.38
site-pooling
concatenating datasets from several sites into a single dataset for extremal analysis, with the length of the dataset equating to the sum of the individual datasets

Note 1 to entry: used to take account of the localised extent of phenomena such as tropical cyclones or meso-scale eddies e.g. warm core rings in the Gulf of Mexico

3.39
soliton
solitary wave or wave packet travelling on an internal density discontinuity which, as a result of the cancellation of nonlinear and dispersive effects, maintains its shape and speed over extended distances

EXAMPLE Internal tides which form on the density gradient within the water column may interact with the continental slope and form internal solitary wave packets.

3.40
spectral moment
n^{th} spectral moment
integral over frequency of the spectral density function multiplied by the nth power of the frequency, either expressed in hertz (cycles per second) as $m_n(f) = \int_0^\infty f^n S(f)\,df$ or expressed in circular frequency (radians/second) as $m_n(\omega) = \int_0^\infty \omega^n S(\omega)\,\mathrm{d}\omega$

Note 1 to entry: As $\omega = 2\,\pi f$, the relationship between the two moment expressions is: $m_n(\omega) = (2\pi)^n\, m_n(f)$.

Note 2 to entry: The integration extends over the entire frequency range from zero to infinity. In practice the integration is often truncated at a frequency beyond which the contribution to the integral is negligible and/or the sensor no longer responds accurately. Care should be taken when utilizing moments of order higher than 2, as for standard spectral models, the 4th moment will not converge; the value is in effect determined by the choice of truncation.

3.41
spectral peak period
period of the maximum (peak) energy density in the spectrum

Note 1 to entry: In practice there is often more than one peak in a spectrum.

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3.42
spectral density function
energy density function
spectrum
measure of the variance associated with a time-varying variable per unit frequency band and per unit directional sector

Note 1 to entry: Spectrum is a shorter expression for the full and formal name of spectral density function or energy density function.

Note 2 to entry: Within this part of ISO 19901, the concept of a spectrum applies to waves, wind turbulence and action effects (responses) that are caused by waves or wind turbulence. For waves, the spectrum is a measure of the energy traversing a given space.

3.43
squall
strong wind event characterized by a sudden onset, a duration of the order of minutes and often, a sudden decrease in speed

Note 1 to entry: A squall is often accompanied by a change in wind direction, a drop in barometric pressure, a drop in air temperature and heavy precipitation.

Note 2 to entry: The WMO classification of a squall requires the wind speed to increase by at least 8 m/s and attain a top speed of at least 11 m/s, lasting at least one minute in duration.

3.44
still water level
abstract water level used in the calculation of elevations at which actions are applied.

Note 1 to entry: still water level is typically used for the calculation of:

— wave kinematics for global actions,

— wave crest elevation for minimum deck elevations,

— maximum elevation of ice actions.

Note 2 to entry: Still water level, also referred to as storm water level, is an engineering abstraction calculated by adding the effects of tides and storm surge to the water depth but excluding variations due to waves (see Figure 1). It may be above or below mean sea level.

3.45
storm surge
change in sea level (either positive or negative) that is due to meteorological (rather than tidal) forcing

3.46
sustained wind speed
time averaged wind speed with an averaging duration of 10 min or longer at a specified elevation

3.47
swell
wave that was wind-generated but has travelled out of its generation area and has no relationship with the local wind

3.48
track-shifting
method of perturbing the track (intensity, radius) of historical tropical cyclones to increase the duration of the record artificially

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3.49
tropical cyclone
closed atmospheric circulation around a zone of low pressure that originates over the tropical oceans

Note 1 to entry: The circulation is counter-clockwise in the northern hemisphere and clockwise in the southern hemisphere.

Note 2 to entry: At maturity, the tropical cyclone may be one of the most intense storms in the world, with wind speeds exceeding 90 m/s and accompanied by torrential rain.

Note 3 to entry: In some areas, local terms for tropical cyclones are used. For example, tropical cyclones are typically referred to as hurricanes in the Gulf of Mexico and North Atlantic, while in the East Asian Sea and NW Pacific they are called typhoons. In the South Pacific and South Indian Ocean, however, they are commonly referred to as cyclones.

Note 4 to entry: The term cyclone is also used to refer to a tropical storm with sustained wind speeds in excess of 32 m/s (Beaufort Force 12).

Note 5 to entry: In the Australian region the term 'tropical cyclone' refers to a warm-cored, non-frontal low-pressure system of synoptic scale developing over warm waters, and having organised convection and a (10-minute mean) wind speed of at least 34 knots (17,4 m/s), extending more than half way around near the centre and persisting for at least six hours.

3.50
tsunami
long period surface waves caused by displacement of a large volume of a body of water, normally an ocean

Note 1 to entry: The vertical movement of the sea floor is often associated with fault rupture during earthquakes or with seabed mud slides.

3.51
units
SI units are used throughout this document

3.52
water depth
vertical distance between the sea floor and still water level

Note 1 to entry: As there are several options for the still water level, there may be several water depth values. Generally, design water depth is determined to LAT or to mean sea level.

Note 2 to entry: The water depth used for calculating wave kinematics varies between the maximum water depth of the highest astronomical tide plus a positive storm surge, and the minimum water depth of the lowest astronomical tide less a negative storm surge, where applicable. The same maximum and minimum water depths are applicable to bottom-founded and floating structures, although water depth is usually a much less important parameter for floating structures. Water depth is, however, important for the design and analysis of the mooring system and risers for floating structures.

3.53
wave spectrum
measure of the amount of energy associated with the fluctuation of the sea surface elevation per unit frequency band and per unit directional sector

Note 1 to entry: The wave frequency spectrum (integrated over all directions) is often described by use of some parametric form such as the Pierson-Moskowitz or JONSWAP wave spectrum.

Note 2 to entry: The area under the wave spectrum is the zeroth spectral moment m_0, which is a measure of the total energy in the sea-state; m_0 is used in contemporary definitions of the significant wave height.

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3.54
wave steepness
characteristic of individual waves defined as wave height divided by wave length

Note 1 to entry: For periodic waves, the concept is straightforward as H / λ. For random waves, the definition is normally used with the significant wave height (H_s) and the wavelength that corresponds with the mean zero crossing period (T_z) of the wave spectrum in deep water. The significant wave steepness is then defined as $H_s / \lambda_z = H_s / [(g/2\pi)\ T_z^2]$.

3.55
wind spectrum
measure of the variance associated with the fluctuating wind speed per unit frequency band

Note 1 to entry: The wind spectrum is an expression of the dynamic properties of the wind (turbulence). It reflects the fluctuations about and in the same direction as a certain mean wind speed, usually the 1 h sustained wind speed. There is hence no direction variable associated with the wind spectrum within this part of ISO 19901.

Note 2 to entry: As the sustained wind speed varies with elevation, the wind spectrum is a function of elevation.

4 Symbols and abbreviated terms

4.1 Symbols

$D(\theta)$	wave directional spreading function
$D(f,\theta)$	general form of the wave directional spreading function
d	water depth
$F_{coh}(f;P_1,P_2)$	coherence function between turbulence fluctuations at $P_1(x_1, y_1, z_1)$ and at $P_2(x_2, y_2, z_2)$
f	frequency in cycles per second (Hertz)
f_1	mean wave frequency of the wave spectrum ($f_1 = 1/T_1 = \omega_1 / (2\pi)$)
f_a	apparent wave frequency ($f_a = 1/T_a = \omega_a / (2\pi)$)
f_e	encounter wave frequency ($f_e = 1/T_e = \omega_e/ (2\pi)$)
f_i	intrinsic wave frequency ($f_i = 1/T_i = \omega_i/ (2\pi)$)
f_p	peak or modal frequency at the peak of the spectrum ($f_p = 1/T_p = \omega_p/ (2\pi)$)
f_z	average zero-crossing frequency of the water surface elevation ($f_z = 1/T_z = \omega_z/ (2\pi)$)
g	acceleration due to gravity
H	height of an individual wave
H_b	breaking wave height
H_N	maximum height of an individual wave having a return period of N years. Both H_{max} and H_{mp} are also used in this context
H_s	significant wave height
$I_u(z)$	wind turbulence intensity at z m above mean sea level
k	wave number = $2\ \pi\ /\ \lambda$
m_n	n^{th} spectral moment (either in terms of f or ω). In particular, m_0 is the zeroth spectral moment and is equivalent to σ^2, the variance of the corresponding time series

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S	spectral density function, energy density function
$S(f)$, $S(\omega)$	wave frequency spectrum
$S(f, \theta)$, $S(\omega, \theta)$	directional wave spectrum
S_{JS}	JONSWAP spectrum for a sea-state
S_{PM}	Pierson-Moskowitz spectrum for a sea-state
S_{OH}	Ochi-Hubble spectrum for a total sea-state consisting of a combination of two sea-states with a general formulation
T	wave period; also period in general
T_0	standard reference time-averaging interval for wind speed of 1 h = 3 600 s
T_a	apparent period of a periodic wave (to an observer in an earth-bound reference frame)
T_e	encounter period of a periodic wave (to an observer in a reference frame that moves with respect to earth as well as the wave; the frame is usually fixed to a moving vessel)
T_i	intrinsic period of a periodic wave (in a reference frame that is stationary with respect to the wave, i.e. with no current present)
T_p	modal or peak period of the spectrum
T_z	mean zero-crossing period of the water surface elevation in a sea-state
T_1	mean period of the water surface elevation in a sea-state, defined by the zero and first-order spectral moments
t	Time
U_c	free stream current velocity
U_{c0}	surface current speed at $z = 0$
U_{ref}	reference wind speed, $U_{ref} = 10$ m/s
$U_c(z)$	current speed at elevation z ($z < 0$)
$U_w(z,t)$	spatially and temporally varying wind speed at elevation z above mean sea level and at time instant t
$U_w(z)$	mean wind speed at elevation z above mean sea level averaged over a specified time interval
$U_{w,1\,h}(z)$	1 h sustained wind speed at elevation z above mean sea level
$U_{w,T}(z)$	sustained wind speed at elevation z above mean sea level, averaged over time interval $T < 1$ h
U_{w0}	1 h sustained wind speed at 10 m above mean sea level (the standard reference speed for sustained winds)
$u_w(z,t)$	fluctuating wind speed at elevation z around $U_w(z)$ and in the same direction as the mean wind
$V_{in\text{-}line}$	component of the current velocity in-line with the direction of wave propagation
x,y,z	coordinates of a right-handed orthogonal coordinate system with the xy-plane at the undisturbed still water level (for waves and currents) or mean sea level (for winds) and the $z$axis positive upwards

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z	vertical coordinate [measured upwards from the still water level (for waves and currents) or mean sea level (for winds)]
z_r	reference elevation for winds above the mean sea level, z_r = 10 m
z_s	stretched vertical coordinate for waves and currents (measured upwards from the still water level)
γ	shape parameter of the peak enhancement factor in the JONSWAP spectrum
η	water surface elevation above still water level as a function of time and location
θ	wave direction angle
$\bar{\theta}$	mean wave direction
θ_c	direction of the current velocity relative to the wave direction
Λ	wavelength or Ochi-Hubble spectrum peak enhancement factor
σ	standard deviation of the water surface elevation in a sea-state
σ_a, σ_b	parameters in the peak enhancement factor of the JONSWAP spectrum
σ_{sw}	parameter defining the width of the symmetric swell spectrum (equals the standard deviation of the Gaussian function)
ϕ	directional spreading factor
ω	angular frequency (radians per second $\omega = 2\pi f$)

4.2 Abbreviated terms

HAT	highest astronomical tide
LAT	lowest astronomical tide
MSL	mean sea level
PSU	practical salinity unit
UI	uncertainty interval
VIV	vortex-induced vibration

5 Determining the relevant metocean parameters

5.1 General

The owner or operator of an offshore installation is responsible for the selection of the environmental conditions applicable to specific design situations or for particular operations.

The selection shall consider:

— the type of structure being designed or assessed,

— the nature of the operation to be undertaken (e.g. construction, transportation, installation, drilling, production, etc.),

— the limit state considered (e.g. ultimate, fatigue, accidental),

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— any additional company or regulatory requirements.

NOTE In addition to accidental events, the accidental limit states relate to abnormal environmental events, including abnormal level earthquakes (ALE), see ISO 19900.

The type of metocean information that may be required includes:

a) extreme and abnormal metocean parameters, which are required to develop extreme and abnormal environmental actions and/or action effects. These parameters are used to define design situation(s) while the extreme and abnormal environmental actions and/or action effects are used to perform design checks for ultimate limit states and accidental limit states respectively.

b) long-term distributions of metocean parameters in the form of cumulative conditional or marginal statistics. These parameters are used:

   — to define design situation(s) and to perform design checks for the fatigue limit state, or

   — to make evaluations of downtime/workability/operability during a certain period of time, for the structure or for associated items of equipment.

c) long-term time series of metocean parameters for use in response-based analyses.

d) short-term environmental conditions, which are required:

   — for carrying out checks for serviceability limit states,

   — for developing actions and action effects to determine when particular operations may safely take place, and

   — for planning construction activities (fabrication, transportation or installation) or field operations (e.g. drilling, production, offloading, underwater activities).

Depending on the geographical region and the offshore operations involved, other environmental conditions may be required for specific design situations or for particular operations.

5.2 Expert development of metocean criteria

Reliable estimates of (very) low probability environmental events may be made using a number of different approaches, including analysis of all data values, annual or monthly maxima, or peak-over-threshold events. Implicit in the use of each approach are assumptions about the data used, the statistical procedures applied, and the interpretation of the results.

Metocean experts are specialists who have knowledge spanning the areas of meteorological and oceanographic processes, data gathering techniques, data interpretation, statistical methods and offshore design practices to enable them to develop reliable criteria appropriate for differing types of designs or operations. Development of environmental conditions and associated metocean parameters for designs where actions (action effects) with long return periods are required shall be developed by or in consultation with a metocean expert.

For regions subject to continuous, seasonal or periodic ice events such as sea ice and icebergs, metocean experts should be supplemented by experts in the relevant ice hazards.

5.3 Selecting appropriate parameters for determining design actions and action effects

Environmental actions and associated action effects used in the design and assessment of offshore structures are dominated by one or more metocean parameters depending on factors including:

— the structural form (e.g. fixed jacket, semisubmersible or monohull),

— the geographical location (e.g. regions where strong currents may be present),

— the exposure of individual structural elements to wind, wave, current or ice action,

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— the limit state being addressed.

Information on the metocean parameters appropriate to each structural form is presented in the relevant structure-specific standards in the ISO 19900 series of publications. The final choice of metocean parameters to be used to determine design actions or action effects should be carried out in consultation with structural engineers.

Where wave actions dominate, the wave condition(s) to be considered for a particular design situation may be specified through:

a) long-term statistical distributions of the oceanographic parameters describing the wave climate at the location of interest over many years;

   Where adequate data are available, the statistical distributions may reflect the joint occurrences of oceanographic parameters. Alternatively, only marginal distributions are provided. From these long-term distributions, appropriate oceanographic design parameters should be derived that are compatible with the design situations involved.

b) short-term descriptions of one or more design sea-states, in conjunction with one or more design values of winds and currents;

   A design sea-state should be described by a wave spectrum in terms of a significant wave height, a representative frequency or period, and a mean wave direction. Where appropriate, the wave spectrum may be supplemented with a directional spreading function, see 8.3. A design current is specified by a surface velocity and its velocity profile over the water column, including its direction, see Clause 9.

c) one or more individual design waves, in conjunction with one or more design winds and currents.

   A design wave shall be specified by its height and period, together with an appropriate wave theory from which the wave kinematics may be derived, as well as (an) associated direction(s), see Clause 8. A design current is specified by a surface velocity and its velocity profile over the water column including its direction, see Clause 9.

The above descriptions shall be supplemented by associated meteorological conditions that are relevant for the particular design situation considered. For strongly correlated parameters, whilst simple linear or non-linear regression models may be used to identify a most-probable or median associated value of other parameters, more advanced method (see A.5.3) better reflect the extremal correlation structures between two or more parameters. This approach also allows estimation of the conditional distribution of the associated parameter given the occurrence of the return period (RP) event. For sensitivity analyses, this allows a percentile range of the conditional distribution of the associated parameter to be used e.g. 2,5 % to 97,5 %.

For weakly or un-correlated parameters, the chances of simultaneous occurrence of extreme events of both parameters are very small. In this case, the return period event together with exploration of the action effects of a percentile range of the unconditional distribution of an associated parameter, again such as 2,5 % to 97,5 % should be used.

The selection of the most appropriate specification a), b) or c) above depends on the data that are available for the location of interest, the type of structure concerned, the design situation involved and the limit state considered. It is entirely appropriate that a different selection is made to suit different structure types, different design situations and different limit states.

If the current is known to dominate design actions on the structure, the selection of associated wave heights and wind speeds for a given current velocity should be considered.

If ice in the form of sea ice, icebergs etc. could occur, relevant design situations shall be defined and environmental parameters shall be developed in accordance with ISO 19906. ISO 19906 also includes provisions for other environmental phenomena encountered in arctic and cold regions, such as snow and ice accretion, and ice encroachment.

Where environmental actions for structural design are not dominated by wave, current or ice conditions (but, for example, by wind or earthquakes), special consideration shall be given to the selection of the relevant metocean parameters in combination with those other events.

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5.4 The metocean database

A site-specific metocean database shall be established containing information on:

— significant wave heights, periods, directions and spreading,

— current speeds and directions at a number of depths throughout the water column,

— wind speeds and directions,

— sea ice, icebergs, snow and ice accretion,

— water levels, and

— other relevant metocean parameters (air and water temperatures, water salinity, etc.).

The database may be established either by site-specific measurements over a period of years or by numerical modelling (hindcasts) of historical events. If numerical simulations are used, the simulated results shall be calibrated (or verified) against appropriate measurements.

Where possible, the database should be sufficiently long to encompass all the physical processes which may be encountered during the lifetime of the structure. Where this is not possible, the metocean criteria derived directly from the database should be modified appropriately.

5.5 Storm types in a region

General information on the various types of storms which may affect the structure shall be used to supplement available data.

When determining the appropriate environmental conditions, it is important to separate storms of different types, for example, monsoons and typhoons, before performing an extreme value analysis. Furthermore, it may be necessary to set operating limits for a particular structure for particular storm types and seasons.

5.6 Directionality

In some locations, representative storm tracks and topographic features may provide fetch limitations on wave heights from specific directions, or tidal or general circulation currents may be in a predominant direction. For design in such situations, different wave, wind and/or current magnitudes may be used for different approach directions, provided that sufficient reliable data are available to derive them. However, the owner of the structure shall ensure that the overall reliability of the structure is not compromised by the use of such lower directional environmental conditions.

If reliable directional information is not available, conservative assumptions shall be made with respect to relative directions of winds, waves and current.

5.7 Extrapolation to extreme and abnormal conditions

Designers require metocean parameters at (very) low probabilities or recurrence rates, e.g. with a return period of 100, 1 000 or 10 000 years. Where data covering such long periods are not available, an extrapolation of existing data is necessary. Many extrapolation methods are used and there is no universally accepted method; expert advice should be sought, and the following key elements of the extrapolation methodology are important to consider:

— Extrapolations based on continuous frequency distributions are strongly discouraged. Peaks-over-threshold (storm-based) or block maxima approaches support statistical independence for the data points in the extrapolated data set.

— For water levels and currents, extrapolation should be carried out on the nondeterministic (residual) component only. The deterministic (tidal) components should be added to the extrapolated residual component on the basis of joint-probability analyses if sufficient data exists. If insufficient data exists for

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the tidal component, add the Mean High-Water Spring for diurnal and semi-diurnal tidal locations; or, for mixed tidal locations, add the Mean Higher High Water.

In general, the longer the data set the more accurate the extrapolation will be. However, even with long data sets, estimates of (very) low probability parameters can still depend to a considerable degree on the extrapolation method and sampling variability. Confidence intervals can be estimated to assess the uncertainty due to sampling variability.

For some phenomena for which the area of most extreme conditions in an event is quite limited compared to the overall area of the region in which they occur, such as tropical cyclones in the Gulf of Mexico and offshore Northwest Australia, or the Loop Current and warm core rings (eddies) in the Gulf of Mexico, site-averaging (calculating extremes at individual sites, and averaging the results together) or site-pooling (concatenating the hindcast data from several sites into one set, with length of the combined set equal to the length of the hindcast period multiplied by the number of sites) is recommended for the determination of extremes. These techniques serve to smooth out local variability in extremes determined at single locations resulting from the limited area of affect of these phenomena. An important consideration in applying site-averaging or site-pooling is to choose sites which are far enough apart such that they provide independent realizations of the local conditions, but not to choose sites which are so far apart that true spatial variations in extremes are smoothed over. For tropical cyclones, where site-averaging or site-pooling is not feasible due to proximity to irregular coastlines or the presence of islands, track-shifting may be applied, whereby the tracks of historical storms are randomly perturbed, assuming the population of storms repeats over time. Care should be taken in inferring great reductions in uncertainty when site pooling (or tracking shifting), for while the effective length of the data set is multiples of the length of the hindcast record, a key assumption is made that the overall regional climate will repeat multiple times with little variation, i.e. no events more severe than those observed will occur, and those that do occur, will follow tracks or paths similar (but not completely identical) to those observed historically.

Monte Carlo methods can also be used to create synthetic databases of phenomena like tropical cyclones or warm-core rings associated with boundary current features, for the assessment of extreme (100 years) and abnormal (10,000 years) conditions. Care should be taken to ensure an adequate historical record of the parameters needed to characterize the phenomena is used in developing the synthetic model.

5.8 Metocean parameters for fatigue assessments

The fatigue limit state may govern the design of individual structural components in fixed and floating offshore structures in several parts of the world.

Fatigue is an accumulation of damage caused by the repeated application of time-varying stresses which may result from the environmental actions to which the structure is exposed.

Fatigue limit state assessment of a structure requires specification of all environmental conditions that are expected to occur during the entire period of the structure's exposure, i.e. its construction phase, including transportation, and its design service life. The specification of the environment is given by the long-term distribution(s) of one or more metocean parameters. The metocean parameters relevant for the fatigue assessment depend on the type of structure and the location under consideration. The distribution(s) of the relevant parameter(s) shall be determined from the metocean database, taking due account of the requirements for the structure being considered.

When computing the cumulative fatigue damage over the life of the structure using the distribution of relevant parameters, it should be kept in mind that this is an estimate of the expected long-term fatigue damage. In such assessments, by their very nature, rare events are weighted with a low probability of occurrence. In some cases, however, it should be considered how much damage a structure may accumulate during a rare event which imposes a relatively low number of very large amplitude stress cycles. Such “low-cycle fatigue assessments” ensure that the occurrence of a single extreme or abnormal event does not consume a significant proportion of the overall fatigue life of a structural system.

For some components and types of structures, cyclic stresses due to vortex-induced vibrations (VIV) in steady currents or winds should also be considered.

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Structures in ice environments may experience dynamic ice actions and ice-induced vibrations that should be considered in accordance with ISO 19906.

Information on the metocean parameters appropriate to the fatigue assessment of different forms of offshore structure is presented in the relevant structure specific standard in the ISO 19900 series of publications.

5.9 Metocean parameters for short-term activities

Transportation, installation, maintenance and removal of a structure are scheduled activities that are weather-sensitive. Operation of a structure includes regular and routine activities that are also weather-sensitive. Some of these activities are sensitive to high winds, while others are sensitive to currents, swell, wave heights, wave periods, wave directions or combinations thereof.

Examples of weather-sensitive scheduled short-term activities are:

a) transportation of the structure over a relatively short distance,

b) installation of fixed steel offshore structures, including;

   1) lifting, launching, upending and placement on the seabed,

   2) the period following placement but prior to and during piling, and

   3) the period following piling but prior to and during pile grouting and until the grout sets,

c) installation of fixed concrete offshore structures, including;

   1) placement on the seabed, and

   2) the period following placement but prior to and during any grouting and until grout setting,

d) establishment/re-establishment of a floating structure at the operating location, including the setting of mooring systems,

e) installation and foundation pre-loading for jack-ups,

f) topsides installation,

g) underwater operations, including inspection and repair, and

h) removal for decommissioning or reuse.

As well as being critical and expensive, these activities usually require a weather window with low environmental conditions for significant durations, e.g. sufficient to allow for all piling and pile fixing. Consequently, the accuracy of short-term forecasting may be as important as the values of the metocean parameters.

Examples of routine activities that are weather-sensitive include:

— use of cranes for lifting to and from supply boats;

— use of cranes for moving items around decks;

— under-deck access;

— use of drilling derrick, particularly derrick movements;

— helicopter movements;

— personnel transfer operations by boat.

These activities generally have different weather sensitivities.

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Limiting criteria shall be established for each activity. In many cases the limitations are established by considering the safety of personnel.

It is useful in the planning of a development or the planning of a specific activity to know that the probability of the metocean parameters exceeding the criteria for particular activities is sufficiently low for sufficient time to complete these activities. The probability of sufficiently calm conditions for a given location typically varies on a seasonal basis.

Predictions of the variation in the relevant metocean parameters should be made from the metocean database. Predictions should provide either the proportion of time and the durations for which metocean parameters are expected to remain within limiting criteria, or the probability of the values of certain metocean parameters being exceeded. Seasonal variations (by month or by quarter) should be reported if these are significant. In addition, it should be considered and made clear to users of such criteria that in addition to seasonal variations in operational conditions, there may be significant year-to-year variations.

In order to identify an appropriate weather window within which to perform the short-term activity, a weather forecast will be required. This shall be provided by a competent organisation. Section 12 provides details concerning the verification of forecast products.

5.10 Metocean parameters for medium-term activities

Medium-term activities such as tows and transportation of a structure or structural members, particularly when involving long exposed tows, are scheduled activities which are weather sensitive but which have durations significantly longer than the length of the available weather forecast; typically in excess of 72 hours. For such activities, certain design criteria may be required, such as sea-fastening load criteria.

For transportation, the design criteria should be defined, consisting of the design wave, design wind and, if relevant, design current. Where the transportation transits through different geographical areas, the maximum wave and maximum wind may not occur in the same area, in which case it is necessary to check the extremes in each area, to establish governing load cases.

To derive return period metocean extremes for ocean-going tows, an industry recognised methodology (e.g. SafeTrans) or other certified methods or standards should be used.

Weather forecasts play an important role in the planning and execution of medium-term activities. As such, a weather forecast shall be provided by a competent organisation.

6 Water depth, tides and storm surges

6.1 General

The water depth at the site, including variations in the water depth, shall be determined where significant for the type of structure being considered.

The range of water depths at a particular site is important for the design of structures as it affects several parameters, including:

— environmental actions on the structure,

— elevations of boat landings, fenders, and cellar deck on bottom-founded structures,

— riser length/stroke on floating structures, and

— mooring forces for taut or vertically moored floating structures.

For the purpose of design or assessment, the water depth may be considered to consist of a more or less stationary component, this being the water depth to a reference chart datum (e.g. LAT or MSL), and variations with time relative to this level (see Figure 1). The variations are due to the astronomical tide (see 6.2) and to the wind and atmospheric pressure, which may create storm surges (which may be positive or negative) (see 6.3). Other variations in water level may result from long-term climatic variations, sea floor subsidence or

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episodic events such as tsunamis. Water level variations may have a relatively minor impact in deep water, but may be considerably more important in shallow water.

It is important for the design of all structures (and in particular bottom-founded structures in shallow water) to have a good knowledge of the joint distribution of the tide, the storm surge height and the crest and trough elevations of the waves.

6.2 Tides

Tidal variations are the result of the gravitational and rotational interaction between the sun, moon and earth and are regular and largely predictable; they are bounded by the highest astronomical tide (HAT) and the lowest astronomical tide (LAT) at the site.

The variations in elevation of the daily astronomical tides determine the elevations of boat landings, fenders, splash-zone treatment, conductors and risers, and the upper limits of marine growth for bottom-founded structures.

At latitudes where the inertial period is close to the diurnal and semi-diurnal periods, the inertial energy may cause inaccuracies in the tidal harmonic analysis. This may particularly affect the latitudes close to 30 degrees in both the northern and southern hemispheres.

Tidal levels shall be established from a minimum of 6 weeks, preferably 12 months of high quality, site specific, water level measurements. Harmonic analysis shall be undertaken to establish the HAT and LAT, using a prediction over a period of 18,6 years.

The residual water levels shall be determined as the deviation of the predicted water levels from the measured water levels.

6.3 Storm surges

Storm surges are meteorologically generated. Since the generation of surges is unrelated to tides, their occurrences are randomly superimposed on tidal variations. In deep and modest water depths, tidal and storm surge elevations may be arithmetically added to good approximation. In shallow water, tide and surge may interact due to nonlinear bottom friction effects. Since surges cause water level variations additional to tides, total still water levels above HAT and below LAT may occur.

6.4 Extreme water level

The extreme water level is derived through a combination of 'design crest elevation', astronomical tide and 'storm surge' referenced to either LAT or MSL.

The combination is best calculated by using the joint probability of occurrence of tide, surge and wave crest. However, if there are insufficient data to model this reliably, conservative assumptions may be used, e.g. summation of the ‘design crest elevation’ and the ‘still water level’ of the same return period. Note that the method described in ISO 19902 for determining the deck height in Section A.6.3.3.2 is indicative and should not be used for final design purposes.

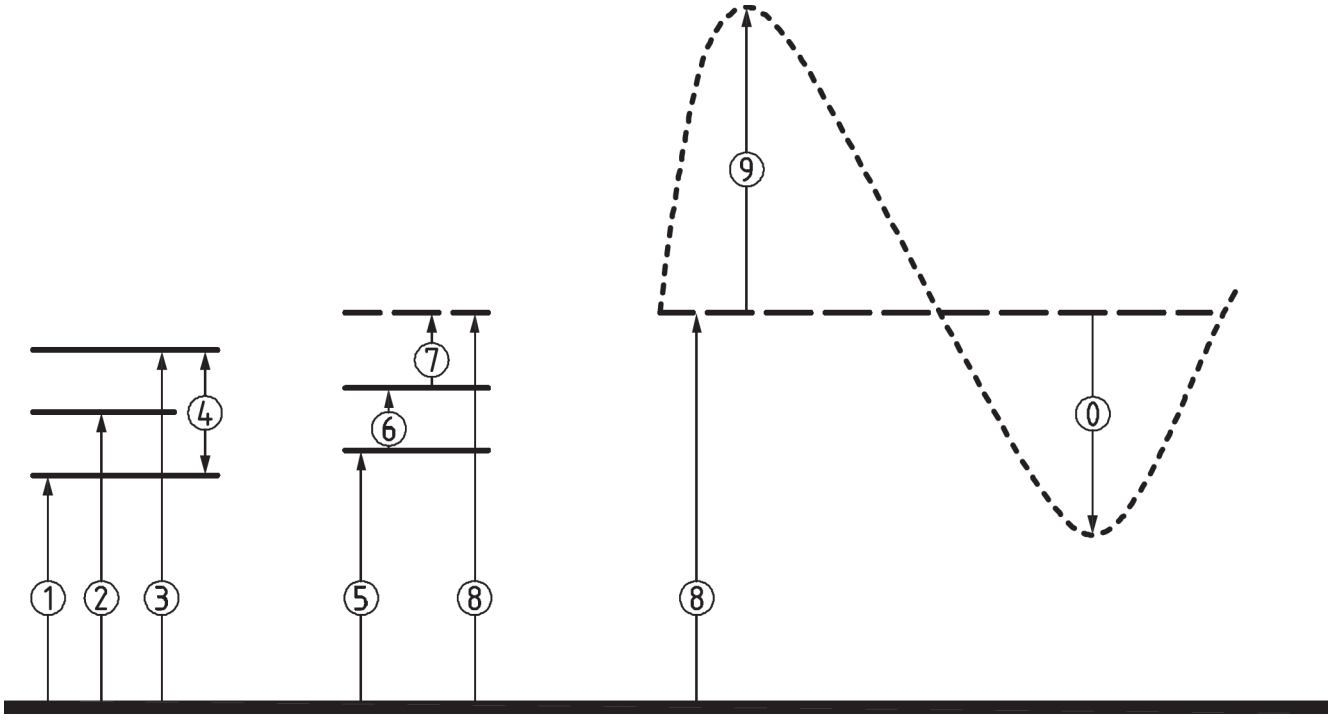
The effects of climate change on mean sea level over the lifetime of a structure should be assessed, especially for projects with 30+ year life spans. The latest Intergovernmental Panel on Climate Change (IPCC) provides recommendations on sea level rise that may be adopted. Alternatively, site-specific data may be collected and analysed.

Extreme water level is a starting point for ascertaining the minimum height of the main deck of a bottom-founded structure. Allowance should also be made for platform settlement, reservoir subsidence and water depth uncertainty.

Structures with large diameter columns may modify the incident wave field, resulting in changes to the extreme water level (and other wave properties) estimated in the absence of wave/structure interactions. Such changes may need to be addressed as part of the design process.

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a) Tides **b) Tide + storm surge = still water level** **c) Wave profile superimposed on water level**

Key

Key to distance elevations

1	Lowest astronomical tide (LAT)	6	Tide associated with storm (shown positive but may be positive or negative)
2	Mean sea level (MSL)	7	Storm surge (shown positive but may be positive or negative)
3	Highest astronomical tide (HAT)	8	Still water (or 'storm water') level
4	Tidal range	9	Crest elevation
5	Tidal datum (commonly LAT or MSL but may be other)	0	Trough elevation

Key line types

▬▬▬	Seafloor
———	Tide levels
— — —	Surge or surge+tide levels
-------	Wave profile

Figure 1 — Water depth, tides and storm surges

7 Wind

7.1 General

Wind speed and direction vary in space and time. Normally, wind speed time-series data at a site are only available at a single elevation. It is unusual to have multiple measurements on the tens to hundreds of metres horizontal-length scales relevant to offshore structures. Furthermore, time series are often only available at time scales much longer (e.g. 10 min to 3 h) than the natural response periods of most structures. On length scales typical of even the largest offshore structures, the mean and standard deviation of the wind speed, averaged over durations of the order of an hour, do not vary horizontally, but they do change with elevation (wind profile). For averaging durations shorter than 1 h, there will be periods with higher mean speeds and increased spatial variation. As such, typical practice is to specify wind criteria at a clearly specified averaging interval and reference elevation. The most commonly used reference elevation is 10 m above mean sea level. Wind profile factors, gust factors, auto- or coherence spectra appropriate to the local wind

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regime may then be applied in conjunction with the reference winds to appropriately account for fine-scale spatial and temporal effects.

Wind speeds are classified as either:

— sustained wind speeds, or

— gust wind speeds.

The elevation and averaging interval of any wind speed or gust should always be reported.

Extreme gusts occur due to a variety of phenomena. These include squalls, thunderstorms, downbursts, tornados, water spouts, all of which are relatively short-lived. The ratio of maximum gust wind speed to hourly mean wind speed at any one location in these examples may be large.

However, gusts also occur during periods of high hourly mean wind speed due simply to turbulence, but in this case the ratio of maximum gust wind speed to hourly mean wind speed over the sea is typically less than about 1,5.

Wind conditions shall be determined by proper analysis of wind data. Guidance on collecting wind data is given in A.7.1.

To determine appropriate design situations for offshore structures with regard to wind, the extreme, abnormal and operationally relevant wind conditions shall be specified in accordance with the type of structure and the nature of the structure's response. Wind turbulence in gusts has three-dimensional spatial scales related to their duration. For example, 3 s gusts are coherent over shorter distances and therefore affect smaller components of a structure than 15 s gusts. For structures (structural components) that are subject to appreciable dynamic response, it may be necessary to take the time variation of actions caused by wind into account.

Further guidance is provided below, while procedures for determining actions and action effects caused by wind for different types of structure shall be in accordance with the relevant structure-specific standard in the ISO 19900 series of publications.

7.2 Wind actions and action effects

Wind acts on the topsides and that portion of the structure that is above the water, as well as upon any equipment, deck houses, bridges, flare-booms and derricks that are located on the topsides. As the wind speed varies with elevation, the height of the component shall be taken into account. A vertical wind profile that may be used is discussed in 7.3 and provided in A.7.3.

For the design of offshore structures that respond globally in a nearly static fashion, global actions caused by wind are generally much less important than those caused by waves and currents. However, for the local response of certain parts or of individual components of these structures, the action effects caused by wind may be significant. Global actions on structures shall be determined using a time-averaged design speed in the form of a sustained wind speed. For the design of individual structural components, a time-averaged wind speed may also be adequate, but the averaging duration shall be reduced to allow for the smaller turbulence scale that may affect individual components. Local actions on individual components shall therefore be determined using a gust wind speed. Guidance on the selection of appropriate averaging times is given in A.7.2.

For the design of offshore structures (or structural components) that are subject to appreciable dynamic response, the time and spatial variation of the wind speed needs to be accounted for. A dynamic analysis of a structure (or structural components) is generally necessary when the wind field contains energy at frequencies near the natural frequencies of the structure (structural components). Such analyses require detailed knowledge of the wind turbulence intensity, the wind frequency spectrum and its spatial coherence (see 7.4).

A special case of dynamic response is the VIV of relatively slender structures subjected to steady winds in which alternate vortex shedding excites components. Components of fixed steel offshore structures may

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be exposed to VIV during construction and transportation. Flare structures and telecommunication towers may also be susceptible to VIV throughout their lives.

Wind should be considered in detail for compliant bottom-founded structures and floating structures.

7.3 Wind profile and time-averaged wind speed

The vertical profile of the mean wind speed in storms is usually expressed by a logarithmic function. Adjustments to the wind profile at a particular location or under certain conditions may be made when appropriate measured data from an offshore location are available (i.e. measured data for the kind of event used in design).

7.4 Wind spectra

If a structure (or a structural component) exhibits appreciable dynamic response due to wind action, the temporal and spatial variations of the wind speed shall be considered. Turbulent wind may be viewed as an evolving field of vortices being swept past the structure. Additional turbulence is generated by the structure itself. The most accurate wind actions are derived from physical testing in a boundary-layer wind tunnel, or by using computational fluid dynamics. Useable results may be obtained from a time series of wind velocity generated by adding spectral frequency components (mathematically as described below for waves) to the mean wind speed. In the absence of three-dimensional wind modelling, only the speed fluctuations in the mean wind direction may be described. An appropriate form of the frequency spectrum for wind speeds in the mean direction is given in A.7.4. The spatial variation of the wind speed in the mean direction between two points in space is expressed by means of a coherence function (see A.7.4).

The concept of a wind spectrum is only applicable to stationary wind conditions. As squalls are transient (non-stationary), the temporal and spatial variations of the wind speed in a squall cannot be described by a wind spectrum. Analysis of actions and action effects caused by squalls requires the specification of a time series of wind velocity, which captures the transient squall peak.

8 Waves

8.1 General

Surface waves are generally very important for the design of offshore and coastal structures. Facility design requires the specification of the operational wave statistics and extreme and abnormal return-period wave conditions comprising spectral and/or deterministic wave height and period parameters, direction of wave propagation and the spread of the directions.

Ocean waves are irregular in shape, vary in height, length and speed of propagation, and travel in many directions. In general, small waves in deep water may be regarded as the linear superimposition of many small individual sinusoidal components, each of which is a periodic wave with its own amplitude, frequency and direction of propagation; with linear waves the components have random phase relationships with respect to each other. Linear superposition of waves may be described as a wave spectrum defining the amplitude of waves for frequencies and directions.

For larger waves, generally occurring at low probabilities (long return periods), waves are not linear. Interactions of wave components of differing frequencies and directions change the shape of the waves, an effect being that higher wave crests occur compared to those estimated using linear wave assumptions. In intermediate and shallow water depths, the nonlinearity of the waves increases and becomes very important.

Waves may be described as either:

— a sea-state, defined by either the frequency-direction wave spectrum or the frequency spectrum (see 8.3) or

— an individual wave, defined by wave height (or crest height), period and water depth (this wave is also called a deterministic or single wave) (see 8.4).

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In a sea-state, the wave energy may be distinguished into two broad classes: wind-seas and swells. Wind-seas are generated by the local wind, while swells consist of wind-driven waves that have travelled out of the generation area, and have no relationship with the local wind.

The range of wave conditions that may occur at the site of the structure shall be specified. For operational conditions, details of the occurrence and joint occurrence of wave heights, periods, directions, spectral shape and spreading of waves shall be specified. For extreme or abnormal conditions, the return-period values of waves shall be specified. Associated values and ranges of wave periods and water depths shall also be specified.

It may be required to partition the wave energy spectrum into swell and wind sea components.

In determining the operational, extreme or abnormal wave conditions, the physical processes which lead to the wave forms at the site shall be considered. In this respect, nonlinear effects may be significant (e.g. breaking).

The response of a structure to waves depends on, among other things, its dynamic response characteristics. Structures with significant dynamic response (i.e natural periods around the wave frequencies or their second-order components) require wave energy spectra or time series of the surface elevation for their analysis. These may be specified in a number of ways; a common approach is to use a sea-state defined by a standard wave frequency spectrum, with a given significant wave height, a representative frequency/period, a mean wave direction and, sometimes, a directional spreading function. It is important to define the range of wave conditions which may be experienced at the facility site.

For structures that only respond in a quasi-static manner, it may be sufficient to use individual periodic waves. The most important wave parameters required to describe a single, periodic design wave are its height, crest elevation above still water level, period and direction of travel. The wave kinematics properties may then be estimated using the local still water depth. The distribution of individual waves in a given sea-state may be estimated from statistical wave parameters, such as the significant wave height and the mean zero-crossing period.

In some applications, periodic or regular waves may be used as an adequate abstraction of a real sea for design purposes. Periodic waves are also the building blocks for the linear random wave model. Where closer agreement to real waves is required, fully nonlinear wave models are available for use, but require careful calibration for application to design conditions to ensure consistent structural reliability levels are achieved.

It is often desirable to specify the duration associated with sea-states. Traditionally, 3 h durations are often specified. However, durations actually depend on the particular weather situation and how the criteria will be applied to design. In differing parts of the world, significant wave heights near the peak of a storm may be nearly constant over durations that could either be significantly shorter or significantly longer than 3 h. Furthermore, if the intention of specifying a duration is to design to a response at a given *N*-year target return period level, then the duration necessary to achieve this response shall be carefully considered. The *N*-year response is not necessarily achieved during the peak of the *N*-year sea-state. The most rigorous way to ensure that the *N*-year response is achieved is through a response-based design approach.

8.2 Wave actions and action effects

Wave conditions shall be specified in an appropriate way for the type of structure under consideration, for extreme, abnormal and normal (operating) conditions.

The linear spectral model for waves is presented in 8.3. Regular periodic wave models are presented in 8.4. The height of the highest wave crests in extreme and abnormal metocean conditions may be of special significance, see 8.7.

Procedures for determining actions and action effects caused by waves for different types of structure shall be in accordance with the relevant structure-specific standard in the ISO 19900 series of publications.

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8.3 Sea-states — Spectral waves

8.3.1 Wave spectrum

The sea-state may be described in terms of the linear random wave model by specifying a wave spectrum, that defines the energy in different frequency and/or direction bands. In most cases, the wave spectrum is represented by empirical equations defining the distribution of energy over frequency and/or direction. Parameters typically required for defining a wave spectrum for design are the significant wave height and a representative frequency or period. For many applications, wave direction, wave spreading and peakedness of the wave spectrum are also required.

There are several standard wave-frequency spectra in use; the most appropriate spectral form depends on the geographical area, the severity of the sea-state and the application concerned.

Wave spectra may be determined from site-specific measurements and numerical wave modelling. Use of wave spectra from measurements generally provides the more accurate description of the spectral content of the sea-state, and should be used in preference to numerical models to define ambient spectral shapes and extreme spectral shapes. Spectral fitting to measured spectra is generally required for application to design, though in some cases this will not be adequate and measured spectra should be recommended for direct application to design (e.g. where the wave spectrum is used to drive response models within a response-based approach).

Spectral fitting should be used to define spectral shapes with parametric forms of wave spectrum, and the parameters of the selected spectral shape should be defined as part of the ambient and extreme design metocean conditions.

Further discussion and guidance on wave spectra and the most common parametric forms for the wave spectrum are given in A.8.3.1.

8.3.2 Directional spreading

As the water surface elevation in a sea-state is in reality three-dimensional (short-crested), the wave frequency spectrum may be supplemented by a directional spreading function. Parametric forms for the wave directional spreading function are given in A.8.3.2.

8.3.3 Wave periods

The spectral description of waves requires specification of a representative wave period, for example, the peak spectral wave period. Other wave periods (e.g. the average zero crossing period) or a range of periods may also be required to support specific forms of analyses.

8.3.4 Wave kinematics — Velocities and accelerations

Linear (or Airy) theory is a first-order approximation for real waves. It is based upon a linearization of the free-surface boundary conditions and as such is only valid for waves of low steepness.

Wave kinematics may be determined from a wave spectrum by linear superposition of the individual components of wave velocity and acceleration. However, extrapolation of the kinematics associated with the higher frequency components into the crest of a wave may lead to significant errors. This is often referred to as ‘high frequency’ contamination. Commonly applied engineering approximations avoid this by stretching the kinematics to the instantaneous free surface; for example, using linear stretching [also known as Wheeler stretching or Delta stretching (see A.8.4.2 and A.9.4.1)]. These approximations may be non-conservative and so should only be used where their application may be shown to be justified.

Better approximations are recommended and are provided by nonlinear wave models (see 8.6).

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8.4 Regular (periodic) waves

8.4.1 General

A single regular (periodic) wave may be defined by characteristic parameters, for example, height and period. Water depth is also required. The characteristic parameters should be chosen to suit both the wave theory to be applied and the loading recipe. For example, when applying a 'Stokes 5th wave theory' approach within the context of the API RP 2A loading recipe (for fixed jacket platform design), the height and period should be the zero-downcrossing height and period.

For determination of actions by individual waves on structures, a nonlinear periodic wave theory may be used with a calibrated loading recipe. Calibrated loading recipes for drag-dominated structures are coded in typical loading software. Stokes 5th wave theory is commonly used for these types of structure. Other wave theories, such as Extended Velocity Potential and Chappelear theory, may also be used, if used with a loading recipe calibrated for these wave theories. An appropriate order of numerical solution shall be selected as appropriate to the water depth, wave height and wavelength.

As an alternative to periodic wave theories, representative waves from a random sea derived with wave theories such as New-wave theory may be used.

In addition, realistic representation of ocean waves is possible with fully nonlinear numerical wave models, but their use in the calculation of design actions shall be calibrated.

8.4.2 Wave period

The period of the regular (periodic) wave should be established to be consistent with the sea-state(s) in which the wave is likely to exist.

8.4.3 Wave kinematics — Velocities and accelerations

Wave particle velocities and accelerations for periodic waves may be calculated using an appropriately selected wave theory.

Discussion on the wave theories, range of convergence and references is given in A.8.4.

Most periodic wave theories do not account for wave directional spreading in their kinematics. Where appropriate, directional spreading may be approximately modelled in periodic waves by multiplying the horizontal velocities and accelerations by a wave directional spreading factor ϕ (see A.8.3.2.2).

The choice of whether to determine wave kinematics on the basis of non-breaking wave or breaking wave kinematics should normally be made on the basis of the wave being assessed. However, the extra effort required to calculate breaking wave kinematics may not be warranted if it may be demonstrated that the associated actions represent an insignificant contribution to overall actions being assessed.

8.4.3.1 Non-Breaking Waves

Away from a wave crest, or if the waves are not highly nonlinear or breaking, simpler models may be used which may be delineated by the effective water depth. This may be defined in terms of kp.d, where kp is the wave-number corresponding to the spectral peak, and d is the water depth. In the case of:

— Intermediate and deep water (kp.d ≥ 1,2), second-order irregular wave theory should be used.

— Intermediate to shallow water when the waves remain in the dispersive regime (0,6 ≥ kp.d ≥ 1,2), very few simple wave models are accurate, Molin Stretching should be used.

— Shallow water where the waves are non-dispersive (kp.d ≤ 0,6) a high order Stream function solution should be used.

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Alternative solutions that neglect either the irregularity or nonlinearity of waves, and that do not consider wave breaking, may be used, including:

— Wheeler stretching, or

— Delta stretching, or

— Stokes V solutions.

Note All simpler models or alternative solutions may underestimate the velocities in the crest of a wave. However, they may be appropriate provided that the design recipe has been calibrated for the conditions to which these approximations are being applied.

8.4.3.2 Breaking Waves

Waves in the ocean are irregular, nonlinear, directionally spread and may break through spilling or plunging. The occurrence of wave breaking is not restricted to shallow water and may occur in any water depth.

Wave breaking may result in a large increase in water particle velocities at high elevations in the crest of a wave.

Note The inclusion of wave breaking is important for calculating wave-in-deck loads, local loading on elements high in the water column and wave slamming on columns.

In instances where wave-breaking provides the governing load case and is not already accounted for in the design recipe, breaking wave kinematics calculation may be based on one or more of the following methods:

— fully nonlinear wave models; and/or

— computational fluid dynamics (CFD); and/or

— laboratory testing; and/or

— full scale measurements.

Validation could be through comparisons with laboratory test results or by comparison with independent CFD models.

8.4.4 Intrinsic, apparent and encounter wave periods

Wave periods appear to differ depending on the relative velocities of wave propagation and the reference frame of an observer. This is due to the Doppler effect. For example, an observer moving against the direction of the waves encounters successive wave crests more quickly than an observer travelling in the same direction as the waves.

When waves are superimposed on a (uniform) current, the intrinsic reference frame for the waves travels at the speed and in the direction of the underlying current.

Three particular situations are as follows.

a) An observer travelling at the same speed and in the same direction as the current is stationary with respect to the intrinsic reference frame and will therefore measure the intrinsic wave period T_i.

b) An observer on a fixed structure is stationary relative to the seabed and measures the apparent wave period, T_a. If the waves are travelling in the same direction as the current, approaching wave crests pass the structure more quickly than if there was no current and consequently the apparent period is shorter than the intrinsic period. Similarly, if the waves are travelling against the current the apparent period is longer than the intrinsic period. If there is no current, the fixed structure is stationary with respect to the intrinsic reference frame and hence $T_a = T_i$.

c) An observer on a moving vessel (having a velocity relative to the seabed) measures the encounter wave period, T_e. The difference between T_e and T_i depends on the relative speeds and directions of the moving vessel and of the current. If the moving vessel is travelling at the same speed and in the same direction as the current, then $T_e = T_i$.

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See A.8.4.4 for the relationship between T_i, T_a and T_e.

Wave kinematics for the calculation of actions caused by waves shall be derived from the intrinsic wave period (or the intrinsic wave frequency).

8.5 Maximum height of an individual wave for long return periods

If regular (periodic) waves are adequate for use as a design wave for an offshore structure, the height of an individual wave with a specified return period (e.g. H_{100}) shall be used.

The data derived from measurement programmes or provided directly from hindcasts are typically time series of significant wave height (Hs) and representative periods such as mean zero-crossing period (Tz) or spectral peak period (Tp). The required long-term individual wave height for a return period of N years, H_N, should be established by convolution of long-term distributions derived from these data with a short-term distribution of individual wave heights in a sea state. This can either be done using numerical integration or Monte Carlo approaches. Calculation of the wave in this manner differs from the calculation of the expected maximum wave in a sea state, which, if determined for the N year sea state, will be less than the true N year individual maximum wave height (or crest).

For deep and intermediate water depth locations, the Forristall distribution generally provides a good estimate of the wave heights in many sea states although some experimental results indicate that where non-linear effects are significant it may under-estimate the maxima. For shallow water, the Forristall distribution tends to be conservative for large sea states as it does not include the effects of wave breaking. For locations dominated by long-period swell, the Rayleigh distribution may provide the best characterization of the wave heights.

Further details are presented in A.8.5.

8.6 Linear and non linear wave models

Either linear spectral waves or periodic waves are commonly applied in the design of offshore and coastal facilities. However, these representations are an abstraction of real ocean waves. Linear spectral representations ignore the nonlinear interactions between waves of different frequencies and directions, whereas periodic waves ignore the irregular nature of waves. The linear random wave models and regular waves most often used for design and analysis are convenient approximations. However, they are not always very accurate in defining the position of the free surface, kinematics beneath the surface or, in consequence, local or global actions. Neither regular nor linear random wave theories give the correct elevation of the wave crest or kinematics over the water column.

Real ocean surface waves are random, broad-banded, directionally spread and nonlinear. Thus, for many purposes, a more accurate nonlinear carefully calibrated random wave model may be helpful, or even essential.

In practice, the extension of spectral representations to second order may provide an adequate approximation of the surface profile and kinematics of moderately steep waves when considering global loads on a bottom-founded structure. However, where waves become steep and/or break the kinematics in the vicinity of the crest of the wave will be significantly larger than those derived using standard linear or second order wave models. Therefore, in cases where these wave crests impact topside components or other structural elements (such as Emergency Shut-Down Valves or caissons), the loading will be much higher, and a fully nonlinear model shall be used to calculate the loading.

8.7 Wave crest elevation

Distributions of extreme and abnormal crest elevations which account for the nonlinear nature of large-amplitude waves are required for setting minimum deck heights on bottom-founded structures and for assessing the probability of green water intruding onto the topsides of all types of structures, decks and hulls which are intended to be kept above the waves.

For structures where there can be significant wave-structure interaction (e.g. for structures with a caisson or with very large diameter legs), the possible enhancement of the crest elevation due to the presence of

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the structure shall be considered. This enhancement often does not lead to large increases in the global actions on the structure, but can impose significant local pressures on items located on the underside of the topsides. It can also impede operations (particularly under-deck) and local measures to reduce its effect can be necessary.

The statistics of the wave crest elevation component of the total water level (i.e. the combination of crest, tide and surge) should be determined both for a single point in space (i.e. point statistics) and also for an area equivalent to that covered by the lowest topsides structural element (i.e. area statistics). The latter approach accounts for short-crestedness of seas and reflects the increased chance of a crest impacting somewhere on the deck as its area increases.

For structures which are sensitive to exceedance of airgap, consideration should be given to the increased probability of exceedance associated with the effect of area statistics when assessing structural reliability against the target implied by the relevant code and the calculation of local loading on safety critical elements that sit below the design total water level.

In shallow water and for gently-sloping seabeds of gradients less than 1 in 100, the non-linear behaviour of waves should be considered.

9 Currents

9.1 General

Currents affect the design, construction and operation of offshore structures in various ways. In addition to their impact on the environmental actions and action effects on the structure, they affect the location and orientation of boat landings and fenders, may create sea floor scouring, and often have an adverse effect on operating practices. All of these factors may influence the structure's design.

The current velocity generally varies through the water column. Information on the vertical profile is given in 9.3. Where currents co-exist with waves, the current profile is stretched and compressed with the water surface elevation; guidance on current profile stretching is provided in 9.4. Currents may also be modified by partly transparent structures, see 9.5.

9.2 Current velocities

Like wind, current speeds vary in space and time but at much lower rates. Therefore, currents may generally be considered as a steady-flow field in which velocity is only a function of depth.

The total current velocity is composed of tidal currents, resulting from astronomical forcing, and residual currents. The components of the residual current may include circulation and storm-generated currents, as well as short- and long-period currents generated by various phenomena such as density gradients, wind stress and internal waves.

Depth-averaged tidal currents are regular and predictable. Circulation currents are relatively steady, large-scale features of the general oceanic circulation. Examples include the Gulf Stream in the Atlantic Ocean and the Loop Current in the Gulf of Mexico, where surface velocities may be in the range of approximately 1 m/s to 2 m/s. While relatively steady, these circulation features may meander and intermittently break off from the main circulation feature to become large-scale eddies or rings, which then drift at a speed of a few kilometres per day. Velocities in such eddies or rings may approach or exceed that of the main circulation feature. These circulation features and associated eddies occur in deep water beyond the shelf break, but in some areas of the world they may affect shallow water sites.

Storm-generated currents are caused by the wind stress and atmospheric pressure gradient throughout a storm. Storm current velocities are a complex function of the storm intensity and meteorological characteristics, bathymetry and shoreline configuration, and water density profile. In deep water along open coastlines, surface storm currents may be roughly estimated to have velocities up to 3 % of the 1 h-sustained wind speed during storms. As a storm approaches the coastline and shallower water, the storm surge and current may increase, and after a storm has passed inertial currents may persist for some time.

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Currents may be intensified and directionality steered close to shore and in deepwater near steep bathymetry (e.g., Sigsbee Escapement). When using regional current measurements to develop criteria for a specific site, the bathymetry surrounding the measurement sites shall be compared to the bathymetry of the site for which criteria is being developed, and if there are significant differences the implications of the differences shall be established.

In the surf zone, breaking wave action sets up a longshore current. This effect shall be explicitly addressed for pipeline landfall criteria and other infrastructures in the surf zone.

Sources of information about the statistical distribution of currents and their variation with depth through the water column are generally scarce in most areas of the world. To avoid encountering problems during early phases such as exploration drilling, concerted measurement campaigns are required to acquire the data, particularly in remote, deep water areas near the edges of continental shelves. In deep water areas (water depths typically greater than 200 m) such as in the Gulf of Mexico, the West of Shetlands region and along the northern and eastern coasts of South America, currents are a major consideration in carrying out offshore operations and in the design of structures.

The variation of current velocity with depth shall be determined by an experienced metocean expert.

9.3 Current profile

The variation of current speeds and directions through the water column shall be determined for the specific location of the structure, taking into account all available information. In general, current profiles vary in strength and direction through the water column. Where the density does not vary significantly through the water column, the direction of the current velocities over the full water column is usually relatively uniform and simple profiles are appropriate; guidance is provided in A.9.3. Where the density varies through the water column, or different water masses flow into the region, more complex current profiles are common.

9.4 Current profile stretching

Current speeds and current profiles are determined for still water conditions, although in some situations they are applicable to storm conditions. The current profile is modified by the presence of waves, with a component of the current being present throughout the water column from sea floor to free water surface (between wave crest and wave trough).

Wave kinematics, adjusted for directional spreading where appropriate, shall be vectorially combined with the current velocities, and adjusted for blockage where appropriate (see 9.5). As the current profile used in design is specified only up to the storm still water level, the profile to the local instantaneous wave surface shall be modified by some means, see A.9.4.

9.5 Current blockage

The current velocity around and through a structure is modified by blockage. The presence of the structure causes the incident flow to diverge, with some of the flow going around the structure rather than through it. For structures that are more or less transparent, the current velocities within the structure are reduced from the free-stream values.

The degree of blockage depends on the type of structure. For dense, fixed-space frame structures it will be large, while for some types of transparent floaters it will be very small. More specific advice for the treatment of current blockage for different types of structure is given in the relevant structure-specific standard in the ISO 19900 series of publications.

9.6 Tidal Currents

Inertial currents at latitudes where the inertial period is close to the diurnal and semi-diurnal periods may cause inaccuracies in the harmonic analysis of measured current velocities in the same way as for water levels (Section 6.2). Internal tide effects may also cause problems as they may modify and smear the periods of the pure tidal fluctuations.

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10 Other environmental factors

10.1 Marine growth

Marine growth on submerged structural components and other parts of a structure may have a significant influence on the hydrodynamic actions to which the structure is exposed.

The influence of marine growth on hydrodynamic actions is due to increased dimensions and increased drag coefficients due to roughness, as well as to the increased mass and its influence on dynamic response and the associated mass inertial forces. Where sufficient information is available, the loading coefficients may be selected based on the nature of the marine growth.

Structural components may be considered hydrodynamically smooth if they are either above HAT or sufficiently deep such that marine growth is sparse enough to allow its effect on roughness to be ignored. However, caution should be exercised, as a small increase in roughness may cause an increase in the drag coefficient to a level similar to that corresponding to a rough surface.

The type and thickness of marine growth varies with depth and depends on location, the age of the structure and the maintenance regime. Experience in one area of the world cannot necessarily be applied to another. Where necessary, site-specific studies shall be conducted to establish its likely type, thickness and depth dependence.

More specific advice for the different types of structure is given in the relevant structure-specific standard in the ISO 19900 series of publications.

10.2 Tsunamis

Tsunamis are water waves caused by impulsive disturbances that displace a large water mass in the sea. The main disturbances causing tsunamis are earthquakes, but they may also be generated by seabed subsidence, landslides, underwater volcanic eruptions, nuclear explosions, and even impacts from objects from outer space (meteorites, asteroids and comets). Their wavelength is several tens of kilometres and they have periods in the range of 5 min to 100 min. Their speed of propagation across the ocean is a function primarily of water depth; in the deepest oceans tsunami waves may travel at speeds of several hundred kilometres per hour.

In deep water, tsunamis have a low height and very long period and pose little hazard to floating or fixed offshore structures. Tsunamis contain more energy when they are generated in deeper water, and may be extremely destructive when they impact the coast. When they reach shallow water, the wave form pushes upward from the bottom to create a rise and fall of water that may break in shallow water and wash inland with great power.

The greatest hazard to offshore structures from tsunamis results from inflow and outflow of water in the form of waves and currents. These waves may be significant in shallow water, causing substantial actions on structures. Currents caused by the inflow and outflow of water may cause excessive scour problems.

Tsunamis travel great distances very quickly and may affect regions that are not normally associated with the disturbances that cause them. The likelihood of tsunamis affecting the location of the structure shall be considered.

10.3 Seiches

Coastal measurements of sea level in semi-enclosed bodies of water often show seiches with amplitudes of a few centimetres and periods of a few minutes due to oscillations of the local harbour, estuary or bay, superimposed on the normal tidal changes. Normally, variations are small enough offshore that they may be ignored, but if a structure is located in shallow partly enclosed seas, the effect of seiches should be considered.

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10.4 Sea ice and icebergs

Sea ice and icebergs may affect the design and operation of structures. Before commencing design for, construction of, or operations on, structures in areas that are likely to be affected by sea ice and icebergs, adequate data shall be collected in accordance with ISO 19906, and may include:

— seasonal distribution of sea ice,

— distribution and probability of ice floes, pressure ridges and/or icebergs,

— effect of ice-gouges on the seabed from icebergs or ice ridges,

— type, thickness and representative features of sea ice,

— drift speed, direction, shape and mass of ice floes, pressure ridges and/or icebergs, and

— strength and other mechanical properties of the ice.

These data shall be used to determine design characteristics of the structure, as well as possible evacuation procedures.

For specific provisions for sea ice and icebergs, see ISO 19906.

10.5 Snow and ice accretion

Where relevant, snow accumulation and ice accretion shall be considered in the design of structures.

An estimate shall be made of the extent to which snow may accumulate on the structure and topsides, and of its possible effect on the structure.

Topsides icing may increase the diameter of structural components and may lead to a substantial increase in actions caused by wind and gravity, particularly for long, slender structures such as flares. Topsides snow and icing may also adversely affect the stability of floating structures and the operation of emergency equipment.

Icing from sea spray, freezing rain or drizzle, freezing fog, or cloud droplets shall be considered in the design.

For specific provisions for snow and ice accretion, see ISO 19906.

10.6 Thunderstorms and Lightning

Where required, thunderstorm and lightning occurrence should be based on meteorological observations, with observations that represent each day of the observation period uniformly. Care shall be taken to avoid biased databases which are observed only at particular times of the day.

Lightning occurrence shall be determined from lightning sensor measurements. Alternatively satellite and onshore measurements may be used.

Where required, monthly and seasonal occurrences of thunderstorms and lightning shall be provided.

10.7 Rainfall

Where required, total rainfall for each month of the year and/or season shall be given with daily average and daily maximum rainfall. The number of rain days each month shall be provided as well as the number of rain days which exceed prescribed levels of rainfall (e.g. number of days with rainfall exceeding 10 mm).

Rainfall intensity shall be prescribed on a return period basis.

10.8 Squalls and Downbursts

A squall is defined as a sudden increase of wind speed of at least eight metres per second (16 knots), the speed rising to 11 metres per second (22 knots) or more and lasting for at least one minute.

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Where required, site specific quality controlled measured data shall be used to provide the occurrence rate and return period conditions of squall wind speeds.

Guidance on the vertical profile of squall winds is given in A.10.8.

Return period values of squall wind speeds shall normally be provided for 1, 10, 100 or 10,000 year return periods depending on the specific application. Return period analysis shall be undertaken in accordance with Section 5.7 of this document; and for squall winds return period values of the 3 s and 1-minute wind duration speeds are required. The 10-minute or 1-hour wind speeds for squalls shall not be quoted.

For specific applications, representative time histories may be required scaled to the appropriate return period, typically 100 or 10,000 years.

10.9 Internal Waves and Solitons

Internal waves/solitons are likely to occur, to some extent, whenever a thermocline is present. Where required, satellite data or historic measured data may be used to establish the likely presence, seasonal occurrence and inter-annual variability of internal waves. Satellite data may be used qualitatively and but should not be used to set design criteria.

Specialist modelling may be used to quantify likely current strengths in some types of internal waves.

Quantitative estimates of the presence or absence of internal waves and solitons, should be determined where possible through a minimum of 12 months of through water column current and temperature measurements (at approved spacing through the water column). A sampling interval of at least 1 min of the vector average current speed and direction, and temperature is recommended.

Total current should be decomposed into component vectors and tidal signal removed prior to extrapolating non-tidal current velocity to extreme values. Crest length should be determined.

For fatigue analysis, the occurrence and duration of solitons should be determined, for example from the half-life of the peak of the soliton current.

10.10 Shelf Waves and Eddies

If it is apparent from site-specific current measures and/or associated sea water temperatures that shelf-waves and/or ocean eddies are likely to be present, the phenomena may be characterised from examination of satellite observations.

The frequency of occurrence should be established in the region using the combination of measurements, satellite data and ocean circulation modelling.

The spatial scales (horizontal and through water column) of the features should be described.

Estimates of through water column current should be prepared for both shelf waves and eddies.

10.11 Infragravity Waves

For facilities in coastal waters which are sensitive to infra-gravity waves, site specific measurements of water surface elevation and current speed and direction should be undertaken for a minimum period of 12 months.

The measurements should be taken as continuous measurement of the average water level over a duration of a minimum of 5 seconds each 5 seconds.

Numerical modelling of infra-gravity waves should be undertaken to determine if facilities (ship motions at a wharf) will be subject to unacceptable effects from infra-gravity waves. Numerical models should be verified against measurements of infra-gravity wave events. Short stormy periods may be modelled for these numerical model assessments.

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10.12 Seawater Temperature

Both through the water column and near the seabed water temperatures are required for facility and pipeline designs. Long term databases shall be accessed, if available, to provide long term statistics. Site specific measurements of sea water temperatures shall be undertaken for a minimum of 12 months to determine seasonal variation where this is not available through existing records.

10.13 Miscellaneous

Depending on circumstances, other environmental factors may affect operations and may consequently influence the design of structures. Appropriate data shall be compiled, including, where appropriate, records and/or predictions of:

— air temperature (maximum and minimum where appropriate),

— barometric pressure,

— cloudiness and cloud base levels,

— humidity,

— lightning,

— precipitation,

— salinity,

— seawater composition,

— solar radiation

— heat stress

— visibility,

— wind chill,

— phenomena specific to arctic and cold regions, see ISO 19906.

11 Collection of metocean data

11.1 General

Offshore metocean monitoring systems may vary from simple weather stations for aviation purposes, to complete data acquisition systems incorporating a wide range of sensors and sophisticated data processing, display, storage and transmission features. By providing real-time information for operational use and long-term records for engineering design purposes, offshore metocean monitoring systems play an important role in ensuring safe offshore operations.

This part of ISO 19901 is intended as an initial reference for offshore operators when planning metocean monitoring equipment on offshore installations. It provides guidance on both possible statutory requirements and the operator's own requirements, spanning applications such as weather forecasting, climate statistics, helicopter traffic, tanker loading, marine operations, etc.

The collection of metocean data is normally the result of requirements imposed by a regulator or other authority, and the operator's own needs. When specifying a metocean data collection system, the operator shall cater for the requirements of each of these organizations where they differ from those presented in this part of ISO 19901.

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11.2 Common requirements

11.2.1 General

Procedures which ensure the proper functioning of the measuring and recording systems described in this part of ISO 19901, as well as instrument accuracy and calibration, shall be established and maintained.

Qualified personnel shall carry out observations, select, install, check and maintain the equipment and repair any faults or malfunctions. Service and calibration intervals on equipment shall be a maximum of one year. When new types of instruments are introduced, notification shall be given to all regular receivers of data.

Time references given in local or UTC (universal time coordinate) shall be recorded together with the measured data or derived parameters. The time reference should not be dependent on a manual resetting following a temporary cessation in operation of the system. Local user interfaces should clearly show both UTC and local time.

11.2.2 Instrumentation

The accuracy, range, type and location of the instruments should be determined with due regard to the purpose of the recordings.

11.3 Meteorology

11.3.1 General

Information concerning instrument accuracy and calibration requirements shall be established.

Data that cannot be measured by means of instruments shall be obtained by observation by qualified observers. Observers shall have completed relevant meteorological observer training. Consideration shall be given to suitable refresher training for observers to comply with local regulations.

11.3.2 Weather observation and reporting for helicopter operations

The specifications provided in this part of ISO 19901 address only metocean conditions, and do not constitute a complete system for offshore helicopter operations. The relevant local helicopter regulations shall be applied in order to ensure all necessary aspects are covered.

A complete aviation routine weather report is specified in WMO-No. 306, under code FM 15-XV Ext. METAR. The data are transmitted in a ‘message’ which consists of information derived from instrumental measurements and manual observations taken by a qualified observer.

The parameters included are:

— wind direction,

— wind speed,

— visibility [according to METAR specifications, and runway visual range (RVR) if available],

— weather,

— cloud,

— dew-point temperature,

— air temperature,

— air pressure (QNH – barometric pressure adjusted to sea-level),

— significant wave height, and

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— sea surface temperature.

The wind measurements from the top of derrick are normally not representative for the wind field at the helicopter deck. A separate wind sensor shall be installed near the helideck to measure values representative for the wind field at the helicopter deck. This requirement may be waived if it may be clearly demonstrated that this is not necessary.

11.3.3 Weather observation and reporting for weather forecasting services

A complete weather observation report is specified in WMO-No. 306 under code FM 13-XIV Ext. SHIP. The message consists of information derived from instrumental measurements and manual observations taken by a qualified observer.

The parameters included are:

— wind direction,

— wind speed,

— air pressure,

— air temperature,

— sea surface temperature,

— humidity,

— wave height,

— wave period,

— clouds,

— visibility (MOR – meteorological optical range),

— weather, and

— icing.

Observations shall be made at standard synoptic hours, expressed in terms of UTC at which, by international agreement, meteorological observations are made simultaneously throughout the globe. Standard synoptic hours are 00, 03, ... 21 UTC. The observations shall be recorded in accordance with WMO-No. 306, under code FM 13-XIV Ext. SHIP (Section A, pp. 7-24).

11.3.4 Weather observation and reporting for climatological purposes

In addition to the data collected for the weather report (SHIP-format), the wave parameters of maximum wave height, peak period and wave direction shall be included if available. The normal recording interval shall be 1 h as a minimum, though more frequent recording is recommended, and the resolution of the data shall be in accordance with the instrument accuracy.

11.4 Oceanography

11.4.1 General

In the context of this part of ISO 19901, the term oceanography shall encompass

— ocean currents at specified depths,

— water level,

— sea temperature at specified depths,

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— salt content (salinity) at specified depths,

— oxygen content at specified depths,

— icebergs, their size and drift,

— sea ice.

Ocean waves and sea surface temperature are defined as part of meteorology, and covered in 11.3.

Apart from ocean currents and water level, the measurements and observation of oceanographic parameters are not commonly included in platform metocean systems. The operator shall, however, consider his own need for collecting such data contingent upon the natural conditions at the location, the inadequacy of the database, the type of structure or installation, and the operational situation of the facility.

11.4.2 Measurements and observations

Ocean currents should be measured at fixed depths (or bins), and include at least three depths in shallow waters: near-surface, mid-depth and near-bottom. For measurements in deeper waters, more measurement depths are recommended to capture the spatial variability of currents with depth. The observation of sea ice and icebergs (size and drift), may be performed by combining e.g. manual observations, instrument recordings and remote sensing.

11.5 Data quality control

Procedures shall be established to ensure that collected data are processed and standard analyses carried out in such a way that the quality of the data may be verified. The analyses should be sufficiently extensive to allow all significant errors to be discovered. The data should be compared to other recorded data, to the extent this is practicable.

Local regulations may require the provision of metocean data and/or reports to a regulatory body or agency at regular intervals. Careful consideration shall be given to how these requirements will be met by the observation system and its operation.

12 Verification of Weather Forecast Information

12.1 General

In planning and undertaking operations which are sensitive to one or more metocean parameters, it is essential to understand the ability of the weather forecast organisation to provide a forecast that meets the clients' requirements.

Understanding forecast performance is important when planning and taking action based on forecast information, or when choosing a forecast provider. Forecast verification - comparison of the forecasts against observations - should be undertaken routinely in order to quantify the forecast performance. While the overall forecast performance is important and should be determined, special consideration should be given to those aspects of the forecast which are of most relevance, and forecast verification focus on these elements.

13 Information concerning the annexes

13.1 Information concerning Annex A

The clauses in Annex A provide additional information and guidance on clauses in the body of this part of ISO 19901. The same numbering system and heading titles have been used for ease in identifying the subclause in the body of this part of ISO 19901 to which it relates.

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13.2 Information concerning the Regional Annexes

The annexes subsequent to Annex A present an overview of various regions of the world for which information has been developed by experts on each region, and is intended to supplement the provisions, information and guidance given in the main body and Annex A of this part of ISO 19901. They also provide some guidance relating to the particular region dealt with in each annex, as well as some indicative values for metocean parameters which may be suitable for conceptual studies. However, site- or project-specific metocean parameters shall be developed for structural design and/or assessment.

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Annex A
(informative)

Additional information and guidance

A.1 General

Environmental conditions generally have a significant influence on the design and the construction of offshore structures of all types. In some areas of the world, the prevailing environmental conditions may also have an influence on the operational aspects of a structure, which in turn may affect the design of the structure.

The environmental conditions and metocean parameters discussed herein relate to the pre-service, the in-service and the removal phases of structures.

It is beyond the scope of this part of ISO 19901 to provide detailed instructions that may be followed to produce reliable estimates of extreme or abnormal conditions in all areas and in all cases.

Requirements for the calculation of environmental actions on offshore structures and the resulting action effects are given in ISO 19902 for fixed steel structures, ISO 19903 for fixed concrete structures, ISO 19904-1 for floating structures (monohulls, semi-submersibles and spars), ISO 19905-1 for site-specific assessments of jack-ups, ISO 19906 for arctic offshore structures and ISO 19901-3 for topsides structures.

A.2 Determining the relevant metocean parameters

A.2.1 General

The design parameters should be chosen after considering all of the relevant service and operating requirements for the particular type of structure.

Selection of environmental conditions and the values of the associated parameters should be made after consultation with both the structure designer and appropriate experts in oceanography, meteorology and related fields. The sources of all data should be noted. The methods used to develop available data into the desired metocean parameters and their values should be defined.

General information on the various types of environmental conditions that may affect the site of the structure should be used to supplement data developed for normal conditions. Statistics may be compiled giving the expected occurrence of metocean parameters by season, direction of approach, etc.

Of special interest for the planning of construction activities, platform operations and evacuation are the duration, the speed of development, the speed of movement and the extent of storm conditions. The ability to forecast storms in the vicinity of a structure is very important.

If the amount of metocean data available is very limited (particularly in the early phases of a project), the extreme and abnormal metocean conditions should be derived conservatively. If, in the judgement of the metocean expert, there is considerable uncertainty in the data, the extremes should be set too high rather than too low. A subsequent increase in extreme values later in a project may have both safety and economic consequences [1].

Figure A.1 presents an overview of the process involved in developing metocean parameters.

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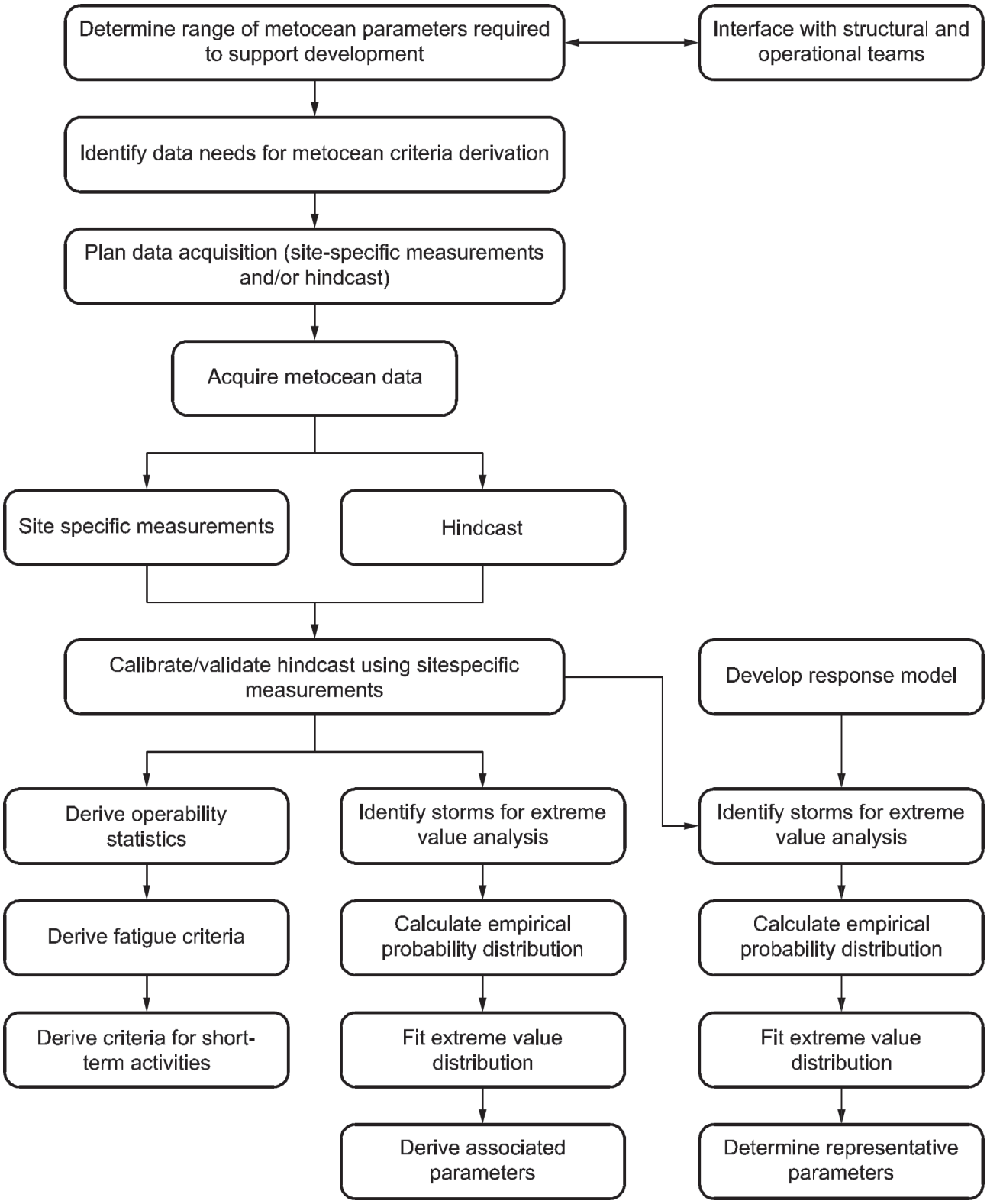


Figure A.1 — Overview of the process of producing metocean parameters

A.2.2 Expert development of metocean criteria

It is important to select a metocean expert(s) with experience in all facets of the process; this includes the hardware and software associated with data gathering (*in situ* or remote sensing), hindcasting procedures, data sampling and analysis procedures, and extreme statistical analysis techniques. Additionally, it is important that the metocean expert understands the purpose for which criteria are intended such that

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appropriate criteria cases are provided and to highlight limitations to use or areas of particularly high uncertainty such that the criteria will be properly applied in design.

The approach used to determine metocean parameters is often dictated by the available data (measured, continuous, storm hindcasts, satellite, radar, etc.). Understanding of the methods used to record and analyse the data is critical; as is knowledge of how these methods and data may influence the selection of an analysis approach or possibly bias the result. A sound understanding of the data techniques is necessary in order to be able to account for them during interpretation of the datasets and to apply any corrections that could be necessary to the final estimates.

Given a suitable database of measured and/or hindcast data, it is important to investigate the sensitivity of estimates to the use of different datasets (measured or hindcast) and statistical analysis

procedures. It is important that the design engineer who will use the metocean parameters is aware of the uncertainty (preferably by a quantitative assessment) in the parameters provided. Relatively small changes in design estimates may significantly affect the reliability of offshore structures. Engagements between the metocean expert and the design team throughout the design process may help ensure proper application of criteria and that proper account has been taken of uncertainties associated with the development of metocean criteria.

A.5.3 to A.5.10 provide brief general descriptions of the principal considerations for deriving safe, reliable metocean parameters to support the design and operation of different types of offshore structures.

A.2.3 Selecting appropriate parameters for determining design actions or action effects

The design or site assessment of structures is often governed by extreme actions or extreme action effects caused by the local environment conditions. The conditions appropriate to design or site assessment are usually quantified in terms of the metocean parameters (e.g. a combination of extreme wave height, current and wind velocity) or the action effect (e.g. global bending moment on a hull).

The traditional approach to offshore structural design and assessment required the use of a predetermined set of metocean parameters (e.g. 100-year wave plus associated current). This type of approach is still widely used, its advantage being that the metocean parameters are well defined and understood, they may be determined prior to the detailed structural model being finalized, and the design process is simplified (in particular, the metocean parameters do not normally need to be revisited during detailed design). The disadvantages are that it does not tend to provide an optimized structure, nor does it facilitate the use of reliability- or risk-based approaches.

The shift in emphasis towards reliability-based approaches has led to the increased use of response-based methods. These require the determination of the *N*-year response or action effect (e.g. the 100-year overturning moment of a jacket structure or the bending moment of a drilling riser). An appropriate set of metocean conditions that result in the 100-year response may then be determined.

Reliability-based approaches provide a more rational basis on which to design or assess any structural form, in particular those that respond to complex combinations of metocean actions. However, they usually require a closer interaction between the metocean and structural models and experts, and if used to their full potential, the development of detailed structural response models. In addition, it is essential that appropriate account is taken of both aleatory and epistemic sources of uncertainty both in respect of the metocean and loading aspects of the analyses.

The term “100-year storm” has no meaning except as an informal description of a set of conditions that introduce the parameter or action effect.

The return period in years, for larger values of return period, may be taken as the inverse of the annual probability of exceedance of a parameter (e.g. a wave height or wind speed).

Parameters appropriate to the design or assessment of different forms of offshore structure are provided in the relevant ISO publication:

— ISO 19901-3 for topside structure;

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— ISO 19902 for fixed steel offshore structures;

— ISO 19903 for fixed concrete offshore structures;

— ISO 19904-1 for floating offshore structures;

— ISO 19905-1 for site-specific assessment of mobile offshore units;

— ISO 19906 for arctic offshore structures.

Four methods are discussed below for defining an environment that generates the extreme direct action and, generally, also the extreme action effect, caused by the combined extreme wind, wave and current conditions. The methodologies may be applied for a case in which any return-period parameter dominates the action effect, but the examples given below are for the wave-dominated loading cases. Other methods are possible.

a) Specified return-period wave height (significant or individual) with "associated" wave period, wind and current velocities. A similar methodology may be applied where a parameter other than wave height dominates the action effect.

   This has been the established practice for deriving wind and current extremes occurring simultaneously with the wave height in some areas (e.g. USA). The specified return period is usually 100 years. It has also been used for deriving secondary parameters (such as wave periods) in the North Sea. The "associated" wave period, current, or wind is the value estimated to co-exist with the specified return-period wave height. The method is applicable if:

   — there is a statistically significant correlation between the associated value and the specified return-period wave height, and

   — the extreme global environmental action on the structure is dominated by waves.

   Where there is a correlation between the parameter and wave height simple regression models have historically been used to determine an absolute or in-line component of associated parameters. Whilst these linear or non-linear regression models may be applied, when extrapolation is being carried out to long return periods, there are better statistical methods available. These methods explicitly model the extremal correlation structure between parameters.

   One method, described in Heffernan & Tawn,[2] allows for associated values of one or more conditional parameters (e.g. Tp or wind speed) to be described for large values of a main conditioning parameter (e.g. Hs). As for the GPD for a single parameter, the approach outlined in reference [2] produces a description of the conditional parameters' probability distributions which is asymptotically correct for large values of the conditioning variable. The approach depends on first applying an Extreme Value Analysis to the marginal distributions of parameters and then fitting the asymptotic model to estimate the correlation structure. The fit that is produced is similar to a simple regression model but is more flexible and accounts for the simultaneous correlation structure between extremes of the main parameter and all of the associated parameters being considered. The approach also allows the estimation of environmental contours or 95 % ranges for associated parameters.

   If there is not a strong correlation between parameters or if the global environmental action is not dominated by a single parameter, then there is no explicit confirmation in any of these methods that the combination of the primary metocean parameter (e.g. wave height) and its associated parameters (e.g., current and wind velocities) will approximate to the return-period event for any global environmental action on a structure. In these circumstances, and if a response-based approach is not feasible, the most appropriate approach is to explore a selected percentile range of the distribution of associated parameters (typically, 2,5 % to 97,5 %) since no particular values of the associated parameter are more likely than others to occur at the time of large values of other parameters.

   Where tidal effects are relevant, it should also be recognised that although there may be a reasonable degree of correlation between Hs and surge, the correlation between Hs and total current/water level may be much weaker. In these circumstances, the best option may be to derive surge using a correlation method and then add on a tidal component separately taking into account the length of time for which the surge events persist.

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When the present method is used for structures that are sensitive to wave period, the most onerous combination of wave height and period may be at a different period from that associated with the maximum specified return period wave height. Consequently, a reasonable range of variations in both period and wave height should be investigated to determine the most onerous combination of wave height and period with the same, or higher probability of occurrence than the specified return period.

b) Specified return-period wave height combined with the wind speed and the current velocity with the same specified return period, all determined by extrapolation of the individual parameters considered independently.

This method has been used in the North Sea and many other areas of the world, normally with a return period of 50 years or 100 years. A modified version, using the 100-year wave height and the 100-year wind speed combined with the 10-year current velocity, has been used in Norway.

The method is simple, independent of the structure, and may be determined from separate (marginal) statistics of waves, currents and wind. It always yields results that are conservative compared to either of the two other methods for the same specified return period when used to determine design actions for fixed structures, but is not appropriate for floating and other types of structure with significant dynamic response. By contrast, method c) below, when correctly applied, will always provide a good estimate of the specified return-period global environmental action.

c) 'Response-based analysis' which requires any “reasonable” combination of wave height and period, wind speed and current velocity that results in:

— the global extreme environmental action on the structure with the specified return period, or

— a relevant action effect (global response) of the structure (base shear, overturning moment, floater displacement, etc.) with the specified return period.

This method typically involves calculating one or more combinations of wave height (as the dominant parameter) and associated current and wind speed, which deliver one or several critical structural response functions (action effects), such as base shear or overturning moment on a fixed structure or horizontal displacement of a floating structure.[3],[4],[5] Directional effects of wind, wave and current, and water-depth fluctuation due to tide and surge, are fully accounted for. Storms are treated as independent events and short-term variability is taken into account. The long-term distribution of the structural response is then determined and from this its extreme and abnormal values. The same structural response function may be used to determine combinations of metocean parameters leading to the desired return-period extreme and abnormal responses. It should be noted that a set of parameters is not unique: several other related sets will produce the same result. In addition, the statistics may be used in the development of partial factors for environmental actions (action effects) as described below. Reference [3] describes the procedure in some detail.

Although this method may involve time and cost in developing software, it may provide a realistic set of design parameters — even if there is little correlation between waves, winds and currents. Thus, defining the specified return-period action or action effect has a significant advantage over defining the specified return-period wave height, either with associated or with specified return-period values of wind and current. The definition of the action or action effect should not use an arbitrary set of related wave, wind and current values that satisfies the specified return-period global environmental action or action effect, but should make a “reasonable” (expected) choice so as to correctly model the probable spatial distribution of global hydrodynamic actions over the structure. Reasonably accurate combinations of metocean parameters may be deduced from observing the combinations that cause the greatest responses in the storms used in developing response statistics.

Care should be taken in the application of a response-based approach where the final concept remains to be fully defined. As noted above, it is essential that appropriate account is taken of both aleatory and epistemic sources of uncertainty both in respect of the metocean and loading aspects of the analyses.

d) Environmental contours. Although a long-term response-based analysis is preferable, it is not always possible to derive the response reliably for a large number of combinations of input parameters. Where the dominant structural responses and their main contributing parameters are all known, and the effect of short-term variability is relatively small, the “environmental contour” approach may be used

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