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Erdöl- und Erdgasindustrie – Spezielle Anforderungen für Offshore-Anlagen – Teil 1: Grundsätze für die Auslegung und den Betrieb auf dem offenen Meer (ISO 19901-1:2005); Englische Fassung EN ISO 19901-1:2005

Petroleum and natural gas industries –
Specific requirements for offshore structures –
Part 1: Metocean design and operating considerations (ISO 19901-1:2005);
English version EN ISO 19901-1:2005

Industries du pétrole et du gaz naturel –
Exigences spécifiques relatives aux structures en mer –
Partie 1: Dispositions océano-météorologiques pour la conception et l'exploitation (ISO 19901-1:2005);
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Nationales Vorwort

Diese Europäische Norm wurde vom Technischen Komitee CEN/TC 112 „Materialien, Ausrüstungen und Offshore-Bauwerke für die Erdöl-, petrochemische und Erdgasindustrie“ erarbeitet, dessen Sekretariat von AFNOR (Frankreich) gehalten wird . Es handelt sich dabei um die unveränderte Übernahme von ISO 19901-1:2005, erarbeitet vom ISO/TC 67 „Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries“, Subkomitee SC 7 „Offshore structures“ (Sekretariat: Vereinigtes Königreich).

Von deutsche Seite erfolgte keine Mitarbeit bei der Erstellung dieser Norm.

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English Version

Petroleum and natural gas industries — Specific requirements for offshore structures — Part 1: Metocean design and operating considerations (ISO 19901-1:2005)

Industries du pétrole et du gaz naturel — Exigences spécifiques relatives aux structures en mer — Partie 1: Dispositions océano-météorologiques pour la conception et l'exploitation (ISO 19901-1:2005)

Erdöl- und Erdgasindustrie — Spezielle Anforderungen für Offshore-Anlagen — Teil 1: Grundsätze für die Auslegung und den Betrieb auf dem offenen Meer (ISO 19901-1:2005)

This European Standard was approved by CEN on 28 October 2005.

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Foreword

This document (EN ISO 19901-1:2005) has been prepared by Technical Committee ISO/TC 67 “Materials, equipment and offshore structures for petroleum and natural gas industries” in collaboration with Technical Committee CEN/TC 12 "Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries", the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by May 2006, and conflicting national standards shall be withdrawn at the latest by May 2006.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

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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 can 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 up to 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 specialists, 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. It is hence important to employ specialists 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, ISO 19905 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 normative text to facilitate cross-referencing.

A discussion on wave spectra is provided in informative Annex B.

Regional information, where available, is provided in informative Annex C.

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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:

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

b) 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 comprise

— 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 and action effects for the design of new structures,

— the determination of actions and action effects 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 tension leg platforms are to be contained in ISO 19904-2[1], for site-specific assessment of jack-ups in ISO 19905-1[2], for arctic structures in ISO 19906[3] and for topsides structures in ISO 19901-3[4].

2 Normative references

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

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

ISO 19902, *Petroleum and natural gas industries — Fixed steel offshore structures*[4)]

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

ISO 19904-1, *Petroleum and natural gas industries — Floating offshore structures — Part 1: Monohulls, semi-submersibles and spars*

4) To be published.

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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 Abnormal events have probabilities of the order of 10^{-3} to 10^{-4} per annum. In the limit state checks, some or all of the partial factors are set to 1,0.

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

NOTE Chart datum is usually an approximation to the level of the lowest astronomical tide.

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

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

EXAMPLE When considering wave parameters, A can 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 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 from an extreme value analysis. Because of the simplified nature of the models used to estimate the kinematics of the design wave, the design crest elevation can be different from, usually somewhat greater than, the crest elevation of the design wave used to calculate actions on the structure.

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

NOTE 1 The design wave is an engineering abstract. 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 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.

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3.6
extreme value
design value of a parameter used in ultimate limit state checks, in which a structure's global behaviour is intended to stay in the elastic range

NOTE Extreme events have probabilities of the order of 10^{-2} per annum.

3.7
gust
brief rise and fall in wind speed lasting less than 1 min

NOTE In some countries, gusts are reported in meteorological observations if the maximum wind speed exceeds approximately 8 m/s.

3.8
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 For design purposes, the specified duration depends on the dimensions and natural period of the (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 In practice, for design purposes, the gust wind speeds for different durations (e.g. 3 s, 5 s, 15 s, 60 s) are derived from the wind spectrum.

3.9
highest astronomical tide
HAT
level of high tide when all harmonic components causing the tides are in phase

NOTE The harmonic components are in phase approximately once every 19 years, but these conditions are approached several times each year.

3.10
hindcasting
method of simulating historical (metocean) data for a region through numerical modelling

3.11
long-term distribution
probability distribution of a variable over a long time scale

NOTE The time scale exceeds the duration of a sea state, in which the statistics are assumed constant (see short-term distribution in 3.29). 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,
- significant wave height in the months May to September,
- individual wave heights,
- current speeds (such as for the vortex induced vibrations of drilling risers),
- scatter diagrams with the joint distribution of significant wave height and wave period (such as for a fatigue analysis), or
- a particular action effect.

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3.12
lowest astronomical tide
LAT
level of low tide when all harmonic components causing the tides are in phase

NOTE The harmonic components are in phase approximately once every 19 years, but these conditions are approached several times each year.

3.13
marginal distribution
marginal probability
statistical distribution (probability) of the occurrence of a variable A that is obtained by integrating over all values of the other variables B, C, …

NOTE The marginal probability of A for all values of B, C, … 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 can be the individual crest elevation for all mean zero-crossing periods B and all significant wave heights C, occurring at a particular site.

3.14
marine growth
living organisms attached to an offshore structure

3.15
mean sea level
MSL
arithmetic mean of all sea levels measured at hourly intervals over a long period, ideally 19 years

NOTE Seasonal changes in mean level can be expected in some regions and over many years the mean sea level can change.

3.16
mean wind speed
time-averaged wind speed, averaged over a specified time interval

NOTE The mean wind speed varies with elevation above mean sea level and the averaging time interval; a standard reference elevation is 10 m and a standard time interval is 1 h. See also sustained wind speed (3.37) and gust wind speed (3.8).

3.17
mean zero-crossing period
average period of the (up or down) zero-crossing waves in a sea state

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

3.18
monsoon
wind which blows for several months approximately from one direction

NOTE The term was first applied to the winds over the Arabian Sea which blow for six months from north-east and for six months from south-west, but it has been extended to similar winds in other parts of the world.

3.19
most probable maximum
value of the maximum of a variable with the highest probability of occurring

NOTE 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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3.20
operating conditions
most severe combination of environmental conditions under which a given operation will be permitted to proceed

NOTE 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 can generally be performed without excessive downtime, but they are not so severe that they have an undue impact on design.

3.21
polar low
depression that forms in polar air, often near a boundary between ice and sea

3.22
residual current
part of the total current that is not constituted from harmonic tidal components (i.e. the tidal stream)

NOTE 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.

3.23
return period
average period between occurrences of an event or of a particular value being exceeded

NOTE The offshore industry commonly uses a return period measured in years for environmental events. The return period in years is equal to the reciprocal of the annual probability of exceedance of the event.

3.24
scatter diagram
joint probability of two or more (metocean) parameters

NOTE A scatter diagram is especially used with wave parameters in the metocean context, see A.5.8. 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).

3.25
sea floor
interface between the sea and the seabed

[ISO 19901-4:2003]

3.26
sea state
condition of the sea during a period in which its statistics remain approximately constant

NOTE In a statistical sense the sea state does not change markedly within the period. The period during which this condition exists is usually assumed to be three hours, although it depends on the particular weather situation at any given time.

3.27
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

NOTE The seabed can be considered as the half-space below the sea floor.

[ISO 19901-4:2003]

3.28
seiche
oscillation of a body of water at its natural period

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3.29
short-term distribution
probability distribution of a variable within a short interval of time during which conditions are assumed to be statistically constant

NOTE The interval chosen is most often the duration of a sea state.

3.30
significant wave height
statistical measure of the height of waves in a sea state

NOTE The significant wave height was originally defined as the mean height of the highest one-third of the zero 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 3.31) 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.

3.31
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 $m_n(\omega) = \int_0^\infty \omega^n S(\omega)d\omega$

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

NOTE 2 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.

3.32
spectral peak period
period of the maximum (peak) energy density in the spectrum

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

3.33
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 Spectrum is a shorthand expression for the full and formal name of spectral density function or energy density function.

NOTE 2 The spectral density function is the variance (the mean square) of the time-varying variable concerned in each frequency band and directional sector. Therefore the spectrum is in general written with two arguments: one for the frequency variable and one for a direction variable.

NOTE 3 Within this document 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.

3.34
squall
strong wind event characterized by a sudden onset, a duration of the order of minutes and a rather sudden decrease in speed

NOTE 1 A squall is often accompanied by a change in wind direction, a drop in air temperature and by heavy precipitation.

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NOTE 2 To be classed as a squall the wind speed would typically be greater than about 8 m/s and last for longer than 2 min (thereby distinguishing it from a gust).

3.35
still water level
abstract water level typically used for the calculation of wave kinematics for global actions and wave crest elevation for minimum deck elevations

NOTE Still water level is an engineering abstract calculated by adding the effects of tides and storm surge to the water depth but excluding variations due to waves (see Figure 1). It can be above or below mean sea level.

3.36
storm surge
change in sea level (either positive or negative) that is due to meteorological (rather than tidal) forcing

3.37
sustained wind speed
time-averaged wind speed with an averaging duration of 10 min or longer

3.38
swell
sea state in which waves generated by winds remote from the site have travelled to the site, rather than being locally generated

3.39
tropical cyclone
closed atmospheric or oceanic circulation around a zone of low pressure that originates over the tropical oceans

NOTE 1 The circulation is counter-clockwise in the northern hemisphere and clockwise in the southern hemisphere.

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

NOTE 3 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 South China 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 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).

3.40
tsunami
long period sea waves caused by rapid vertical movements of the sea floor

NOTE The vertical movement of the sea floor is often associated with fault rupture during earthquakes or with seabed mud slides.

3.41
water depth
vertical distance between the sea floor and still water level

NOTE 1 As there are several options for the still water level (see 3.35), there can be several water depth values. Generally, design water depth is determined to LAT or to mean sea level.

NOTE 2 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.

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3.42
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 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 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.

3.43
wave steepness
characteristic of individual waves calculated as wave height divided by wave length

NOTE For periodic waves, the concept is straightforward as H / λ. For random waves, the definition is used with the significant wave height (H_s) and the wave length that corresponds with the peak period (T_p) of the wave spectrum in deep water. The significant wave steepness is then defined as $H_s / \lambda_p = H_s / [(g/2\pi)\ T_p 2]$ and is typically in the range of 1/16 to 1/20 for severe sea states.

3.44
wind spectrum
measure of the variance associated with the fluctuating wind speed per unit frequency band

NOTE 1 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 document.

NOTE 2 As the sustained wind speed varies with elevation, the wind spectrum is a function of elevation.

4 Symbols and abbreviated terms

4.1 Main symbols

A	parameter in the Pierson-Moskowitz spectrum
B	parameter in the Pierson-Moskowitz spectrum
c	wave celerity (wave phase speed)
$D(\theta)$	wave directional spreading function
$D(\omega,\theta)$	general form of the wave directional spreading function
d	water depth
$F_{coh}(f;P1,P2)$	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_n	normalizing (scaling) factor for the JONSWAP spectrum
$F_{n,sw}$	normalizing (scaling) factor for the swell spectrum
F_s	stretching factor
f	frequency in cycles per second (hertz)
g	acceleration due to gravity
H	height of an individual wave
H_b	breaking wave height

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H_N	maximum height of an individual wave having a return period of N years
H_s	significant wave height
$I_u(z)$	wind turbulence intensity at z m above mean sea level, see Equation (A.4)
k	wave number = 2 π / λ
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
S	spectral density function, energy density function
$S(f)$, $S(\omega)$	wave frequency spectrum
$S(f, \theta)$, $S(\omega, \theta)$	directional wave spectrum
S_{gen}	general formulation of the spectrum for a sea state
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 (see Annex B)
$S_{sw}(f)$, $S_{sw}(\omega)$	swell spectrum
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 ($z \leqslant 0$)
$U_w(z,t)$	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

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$U_{w,1h}(z)$	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 in the undisturbed still water level (for waves and currents) or mean sea level (for winds) and the z-axis positive upwards
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 as a function of time and location
θ	wave direction angle
$\bar{\theta}$	mean wave direction
θ_c	direction of the current velocity with respect to the wave direction
λ	wave length
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	wave frequency; also circular frequency in general (radians per second $\omega = 2\pi f$)
ω_1	mean wave frequency of the wave spectrum ($\omega_1 = 2\pi / T_1$)
ω_a	apparent wave frequency
ω_e	encounter wave frequency
ω_i	intrinsic wave frequency
ω_m	modal frequency at the peak of the spectrum ($\omega_m = 2\pi f_m = 2\pi / T_p$)
ω_z	average zero-crossing frequency of the water surface elevation ($\omega_z = 2\pi / T_z$)

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4.2 Abbreviated terms

HAT	highest astronomical tide
LAT	lowest astronomical tide
MSL	mean sea level
PSU	practical salinity units

5 Determining the relevant metocean parameters

5.1 General

The owner of a platform is responsible for selecting the appropriate environmental conditions applicable to particular design and operating situations. The selection shall take regulatory requirements into account, where these exist.

General guidelines on metocean information are given in ISO 19900. Information about the following shall be determined.

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) and to perform design checks for ultimate limit states and accidental limit states.

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) Normal environmental conditions, which are required

   — for carrying out checks for serviceability limit states,

   — for developing actions and action effects to determine when particular operations can 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 can be required for specific design situations or for particular operations.

5.2 Expert interpretation of the metocean database

Reliable estimates of (very) low probability environmental events can be made using a number of different approaches, including analysis of all data values, annual or monthly maxima, 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.

The appropriate design parameters are also dependent on the structural form chosen, for example, different design parameters can be appropriate to fixed and floating structures.

Experts in meteorology and oceanography, familiar with the considerations, are needed to obtain reliable and appropriate design parameters. The experts shall be involved with the analysis of the data and its interpretation into the appropriate design criteria.

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5.3 Selecting appropriate parameters for determining design actions or action effects

Environmental actions and associated action effects for the design of offshore structures are usually, but not always, dominated by wave conditions.

The wave condition(s) to be considered for a particular design situation can be specified through either a), b) or c), as follows.

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 occurrence of the oceanographic parameters. Alternatively, the distributions can be marginal distributions for separate parameters. From these long-term distributions appropriate oceanographic design parameters shall be derived that are commensurate with the design situation involved.

b) Short-term descriptions of one or a number of different design sea states, in conjunction with one or more design currents. A design sea state shall be described by a wave spectrum together with the 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 8.7. 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 a number of individual design waves, in conjunction with one or more design currents. A design wave shall be specified by its height and period, together with an appropriate wave theory from which the wave kinematics can 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 (including wind) that are relevant for the particular design situation considered.

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 an associated wave height for a given current velocity should be considered. Where environmental actions for structural design are not dominated by wave or current 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.

5.4 The metocean database

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

— significant wave heights, periods and directions,

— 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 either be established by site-specific measurements over a period of years or as an alternative by numerical modelling (hindcasts) of historical events. If numerical simulations are used, the

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simulated results shall be calibrated (or verified) against measurements from a nearby location from which measurements exist. If such measurements do not exist, the hindcast model may be calibrated or verified against measurements from an analogous site with a similar metocean climate in a different ocean basin.

If measurements or hindcasts exist from a nearby location, the database from this location may be used, provided that conditions at the two sites are similar in water depth, fetch limits and overall climate.

For more detailed advice on sea ice, icebergs, snow and ice accretion, see ISO 19906[3].

When conducting metocean surveys at sea, safe practices should be followed.

5.5 Storm types in a region

General information on the various types of storms which can 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 can be necessary to set operating limits for a particular platform for particular storm types and seasons.

5.6 Directionality

In some locations, representative storm tracks and topographic features can provide fetch limitations on wave heights from specific directions, or tidal or general circulation currents can 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.

The possibility of the structure's orientation deviating from the design orientation shall be considered. Deviations can result from installation tolerances and from movements of floating structures. In locations where reliable directional data are not available, the directions of the wind, wave and current shall be assumed to coincide for determining extreme and abnormal actions and action effects.

For some structures, in particular floating structures, action effects can be greater with non-collinear wave, current and wind. In such cases special consideration shall be given to the selection of the most appropriate directions or combination of directions.

5.7 Extrapolation to rare 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. Since data covering such long periods are rarely available, an extrapolation of existing data is necessary. Many extrapolation methods have been used and, while some methods are clearly better than others, no single method is theoretically superior. In general, the longer a data set the more accurate the extrapolation will be. In some relatively homogeneous areas, hindcasts can be used to extend the time basis for estimating return period values at a particular site, thereby reducing the amount of extrapolation needed. However, even with long data sets, estimates of (very) low probability parameters can still depend to a considerable degree on the extrapolation method.

5.8 Metocean parameters for fatigue assessments

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

Fatigue is an accumulation of damage caused by the repeated application of time-varying stresses. The predominant cause of these time-varying stresses is the environment of the structure, particularly the wave environment for offshore structures. 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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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, see A.5.8.

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 platform 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

— transportation of the structure, particularly when involving long exposed tows,

— 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 grout setting,

— 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,

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

— installation and foundation pre-loading for jack-ups,

— topsides installation,

— underwater operations, including inspection and repair, and

— 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 can be as important as the values of the metocean parameters.

Examples of routine activities that are weather-sensitive:

— 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;

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— helicopter movements;

— personnel transfer operations by boat.

These activities generally have different weather sensitivities. 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 varies considerably through the year, usually with longer calmer periods occurring during the summer months.

Predictions of the variation of 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.

6 Water depth, tides and storm surges

6.1 General

The water depth at the site, including variations of 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

— the environmental actions on the structure,

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

— the 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 can be considered to consist of a more or less stationary component, this being the water depth to a reference 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 can create storm surges (which may be positive or negative) (see 6.3). Other variations in water level can result from long-term climatic variations, sea floor subsidence or episodic events such as tsunamis. Water level variations have a relatively minor impact in deep water, but can 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.

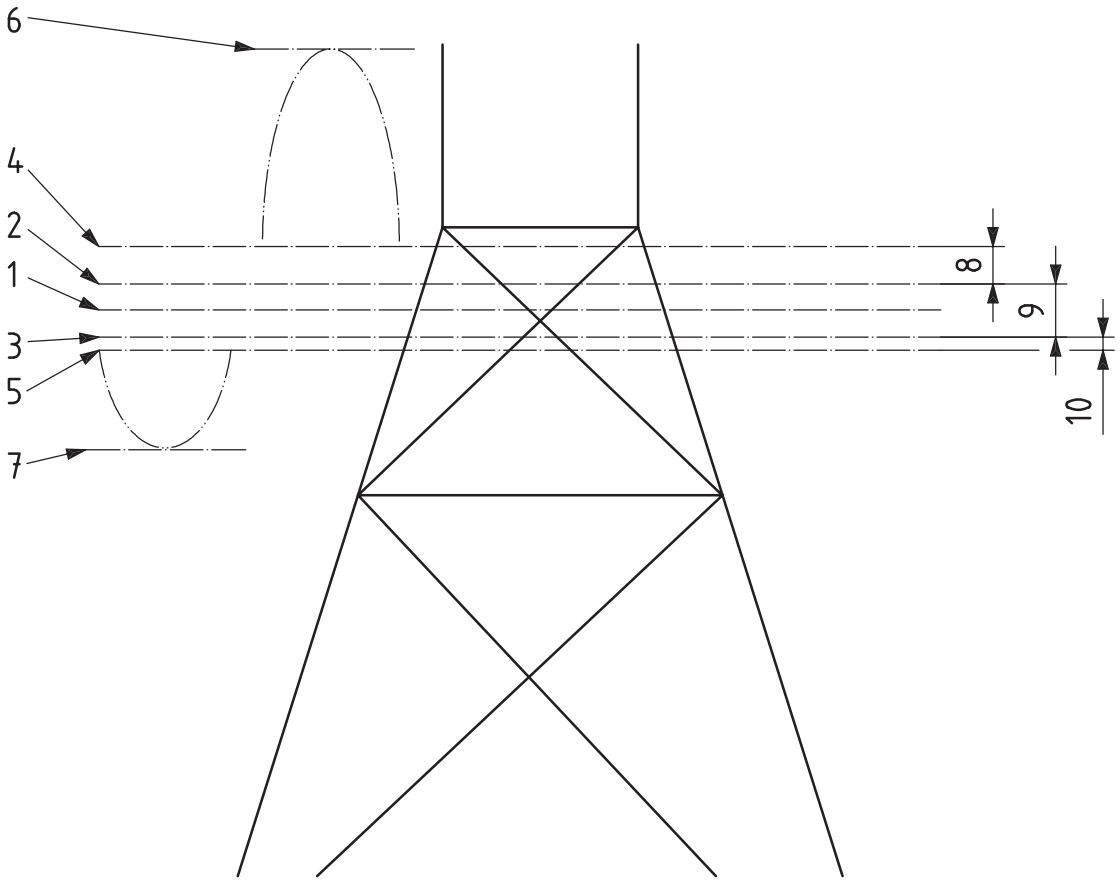
The variations in elevation of the daily astronomical tides determine the elevations of boat landings, fenders, splash-zone treatment, conductors and risers, and the upper limits of marine growth for bottom founded structures.

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6.3 Storm surge

Storm surges, which are meteorologically generated and hence essentially random, are superimposed on the tidal variations, such that total still water levels above HAT and below LAT can occur.



Key

1 mean sea level
2 highest astronomical tide (HAT)
3 lowest astronomical tide (LAT)
4 highest still water level
5 lowest still water level
6 maximum crest elevation
7 minimum trough elevation
8 positive storm surge
9 tidal range
10 negative storm surge

Figure 1 — Water depth, tides and storm surges

7 Wind

7.1 General

Wind speed and direction vary in space and time. There are normally insufficient data available to describe the spatial and time variations in great detail, while for most applications this is also unnecessary. Therefore, descriptions of the wind field are usually substantially simplified in that wind parameters are described in statistical terms, such as the mean and the standard deviation of the speed, as well as the mean direction. For the definition of such statistical parameters, both length scales and time scales are required.

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

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elevation (wind profile). For averaging durations shorter than an hour, there will be periods with higher mean speeds, while also the spatial variations will increase. Therefore, a wind speed value is only meaningful if it is qualified by its elevation as well as the duration over which it is averaged, and hence both elevation and averaging time interval should be specified. An elevation of 10 m above mean sea level is used as a standard reference height.

Wind speeds are classified as either

— sustained wind speeds, or

— gust wind speeds.

The elevation, duration and measurement period of a 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 can 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 normal 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 the durations. 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 can 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 ISO 19902 for fixed steel structures, ISO 19903 for fixed concrete structures and ISO 19904-1 for floating structures (monohulls, semi-submersibles and spars). See ISO 19904-2[1] for those relating to tension leg platforms, ISO 19905-1[2] for site-specific assessments of jack-ups, ISO 19906[3] for arctic structures and ISO 19901-3[4] for topsides structures.

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 can be used is discussed in 7.3 and provided by 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 can 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 can also be adequate, but the averaging duration shall be reduced to allow for the smaller turbulence scale that can 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 (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 (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.

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A special case of dynamic response is vortex induced vibration (VIV) of relatively slender structures subjected to steady winds in which alternate vortex shedding excites components. Components of fixed steel offshore structures can be exposed to VIV during construction and transportation. Flare structures and telecommunication towers can 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 specific 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 (a structural component) is subject to appreciable dynamic response due to wind action, the time and spatial variation 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 steady wind conditions. As squalls are not steady, the time and spatial variation 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.

8 Waves

8.1 General

Ocean waves are irregular in shape, vary in height, length and speed of propagation, and approach a structure from one or more directions simultaneously. These features of a real sea are best reflected by describing a sea state by means of a random wave model. The linear random wave model views the sea as the superimposition of many small individual frequency components, each of which is a periodic wave with its own amplitude, frequency and direction of propagation; the components have random phase relationships with respect to each other.

The wave conditions existing in a sea state can be distinguished into two broad classes: wind seas and swells. Wind seas are generated by the local wind in the area, while swells have no relationship with the local wind. Swells consist of wind-driven waves that have travelled out of the area in which they were generated.

In some applications, periodic or regular waves can be used as an adequate abstract of a real sea for design purposes. Periodic waves are also the building blocks for the linear random wave model.

For most geographical areas, waves are the major source of environmental actions on all offshore structures. The intensity and distribution of the actions caused by waves are usually the most important contribution to the action effects that govern the design of a structure. Actions caused by waves depend on combinations of several environmental parameters. The type, magnitude and interactions of these parameters are difficult to determine with any precision. For these reasons, the relevant wave conditions, the parameters to adequately describe these and the resulting actions and action effects shall be determined with great care. Procedures for determining actions and action effects caused by waves for different types of structure shall be in accordance with ISO 19902 for fixed steel structures, ISO 19903 for fixed concrete structures, ISO 19904-1 for floating structures (monohulls, semi-submersibles and spars), ISO 19904-2[1] for tension leg platforms, ISO 19905-1[2]

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for site-specific assessments of jack-ups, ISO 19906[3] for arctic structures and ISO 19901-3[4] for topsides structures.

For structures that only respond in a quasi-static mode, it can 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 can then be estimated using the local still water depth. The distribution of individual waves in a given sea state can be estimated from statistical wave parameters, such as the significant wave height and the mean zero-crossing period.

Structures with significant dynamic response 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.

The description of a sea state should include its duration; this is normally assumed to be 3 h but depends on the particular weather situation and how the design situation and associated criteria have been derived.

8.2 Wave actions and action effects

Waves shall be specified in an appropriate way for the type of structure under consideration, for extreme, for abnormal and for normal conditions (see 8.1).

Important features of periodic waves and their use are given in 8.3 to 8.5. Details of the linear random wave model are presented in 8.6 and 8.7. The height of the highest wave crests in extreme and abnormal environmental conditions can be of special significance in certain situations, see 8.8.

8.3 Intrinsic, apparent and encounter wave periods

Wave periods appear to be different 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.

All wave theories are developed using a reference frame which is a right-handed orthogonal coordinate system on a body of water without current. The horizontal xy-plane is the still water surface and the vertical z-axis points upward from the still water level. The wave direction is measured (in the horizontal plane) from the positive x-axis using the right-hand rule. This is the intrinsic reference frame for 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 the following.

— 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.

— 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 platform 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 $T_a = T_i$.

— 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 $T_e = T_i$.

See A.8.3 for the relationship between T_i, T_a and T_e.

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

8.4 Two-dimensional wave kinematics

For an intrinsic wave period (T_i), a specified wave height (H) and water depth (d), two-dimensional regular wave kinematics can be calculated using an appropriate periodic wave theory. Discussion on the wave theories, their applicability and references is given in A.8.4.

Linear (or Airy) theory is the basic periodic wave theory for all applications. However, as this is based on linearization of the physical process, the free surface boundary condition coincides with the still water level. The main drawback of Airy theory is therefore that it cannot describe the wave kinematics between the wave crest and the still water level. Moreover, it can be inaccurate in relatively steep wave conditions.

Where linearization can be justified, or if it is to be adopted in connection with overriding modelling assumptions (see 8.1), Airy theory may be used. If time series analysis is used, the kinematics should be stretched to the instantaneous free surface elevation using either linear stretching (also known as Wheeler stretching, see A.9.4.1) or delta stretching (see A.8.4).

For design waves and the determination of actions caused by waves on structures containing predominantly slender tubular components, such as fixed steel space frame structures, a non-linear periodic wave theory such as a suitable order of stream function theory is normally used. In many cases, Stokes 5th order wave theory will produce acceptable accuracy, while in some cases linear (or Airy) wave theory will even be adequate. Other wave theories, such as Extended Velocity Potential and Chappelear theory, may also be used if an appropriate order of solution is selected. 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. New-wave theory is a linear representation of the most probable maximum waveform in a (severe) random sea. To ensure approximate parity of actions caused by different design waves, the crest elevation in New-wave shall then be taken as 5/9 times the wave height used in Stokes 5th order or stream function theory. Delta stretching should be used with New-wave.

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 maximum height of an individual wave with the specified return period, H_N, (e.g. H_{100} for 100 year return period and 0,01 annual probability of exceedance) is the single most important wave parameter to be determined. The data provided by measurement programmes or hindcasts are time series of significant wave height and mean zero-crossing period (or spectral peak period). The required long-term, individual wave height, H_N, shall be established by convolution of long-term distributions derived from the data with a short-term distribution that accounts for the distribution of individual wave heights in a sea state.

8.6 Wave spectra

It is often useful or necessary to describe a sea state in terms of the linear random wave model by specifying a wave spectrum, which determines the energy in different frequency and/or direction bands. Parameters required for defining a wave spectrum 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 to be modelled and the application concerned.

Further discussion and guidance on wave spectra and the most common parametric forms for the wave frequency spectrum are given in A.8.6 and Annex B.

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8.7 Wave directional spreading function and spreading factor

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.8.7.

Two-dimensional regular wave theories do not account in their kinematics for irregularity in the wave profile shape nor for wave directional spreading. Where appropriate, directional spreading can be approximately modelled in periodic wave analyses by multiplying the horizontal velocities and accelerations from the two-dimensional periodic wave solution by a wave directional spreading factor ϕ, see A.8.7.

The wave directional spreading factor may be modified, if justified, to account for spatial effects.

8.8 Wave crest elevation

Knowledge of the distribution of extreme and abnormal crest elevations is 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 and 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 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 the underside of the topsides. It can also impede offshore (particularly under-deck) operations, and local measures to reduce its effect can be necessary.

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, can create sea floor scouring, and often have an adverse effect on operating practices. All of these factors can 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 can also be modified by partly transparent structures, see 9.5.

9.2 Current velocities

Like wind, current speeds also 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 the vector-sum of the tidal and residual currents. The components of the residual current can 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. Residual currents are often irregular, but at many locations the largest component of the residual current to be considered is the wind driven current.

Tidal currents are regular and predictable and the maximum tidal current precedes or follows the highest and lowest astronomical tides, HAT and LAT. They are generally weak in deep water outside the continental shelves, and generally stronger on broad continental shelves than on steep shelves. Tidal currents can, however, be strengthened by shoreline or sea floor configurations; strong tidal currents exist in many inlets and coastal regions, e.g. surface values of approximately 3 m/s occur in Alaska's Cook Inlet.

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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 can be in the range of approximately 1 to 2 m/s. While relatively steady, these circulation features can 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 can 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 can 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 strength and meteorological characteristics, bathymetry and shoreline configuration, and water density profile. In deep water along open coastlines, surface storm currents can 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 can increase, and after a storm has passed inertial currents can persist for some time.

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 greater than typically 200 m) such as in the Gulf of Mexico and along the northern and eastern coasts of South America, the effect of currents on offshore operations and the design of structures can be more important than the effect of waves.

The variation of current velocity and direction 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 account of all available information. For situations in which the direction of the current velocities over the full water column is the same and simple profiles are appropriate, guidance is provided in A.9.3.

9.4 Current profile stretching

Current speeds and current profiles are determined for still water conditions, although in some conditions 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, adjusted for blockage where appropriate (see 9.5). As the current profile in design environmental conditions 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 ISO 19902 for fixed steel structures, ISO 19903 for fixed concrete structures and ISO 19904-1 for floating structures (monohulls, semi-submersibles and spars). See ISO 19904-2[1] for procedures relating to tension leg platforms, ISO 19905-1[2] for site-specific assessments of jack-ups, ISO 19906[3] for arctic structures and ISO 19901-3[4] for topsides structures.

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10 Other environmental factors

10.1 Marine growth

The thickness and type of marine growth 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 the likely thickness and its depth dependence.

Marine growth on submerged structural components and other parts of a structure shall be considered. Due consideration shall be given to the influence of marine growth on hydrodynamic actions during its design service life, as well as to the increased mass and its influence on dynamic response and the associated mass inertial forces.

Marine growth thickness and type vary with depth. The influence of marine growth on hydrodynamic actions is due to increased dimensions and increased drag coefficients due to roughness. Structural components, conductors, risers and appurtenances shall be increased in cross-sectional area to account for marine growth thickness as appropriate. Components with circular cross-sections should be classed as either “smooth” or “rough”, depending on the thickness and type of marine growth expected to accumulate on them.

Structural components can be considered hydrodynamically smooth if they are either above HAT or sufficiently deep such that marine growth is sparse enough to ignore the effect of roughness. However, caution should be exercised, as a small increase in roughness can cause an increase of the drag coefficient corresponding to those of rough surfaces. Site-specific data should be used to establish the extent of the hydrodynamically rough zones. Otherwise, structural components should be considered as being rough down to the sea floor.

More specific advice for the different types of structure is 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 19904-2[1] for tension leg platforms, ISO 19905-1[2] for site-specific assessments of jack-ups, ISO 19906[3] for arctic structures and ISO 19901-3[4] for topsides structures.

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 can also be generated by seabed subsidence, landslides, underwater volcanoes, 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 to 100 min. Their speed of propagation across the ocean is a function primarily of water depth; in the deepest oceans the tsunami waves can 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 can be extremely destructive when they impact on the coast. When they reach shallow water, the wave form pushes upward from the bottom to create a rise and fall of water that can 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 can be significant in shallow water, causing substantial actions on structures. Currents caused by the inflow and outflow of water can cause excessive scour problems.

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

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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 can be ignored, but if a platform is located in shallow, partly enclosed seas, the effect of seiches should be considered.

10.4 Sea ice and icebergs

Sea ice and icebergs can affect the design and operation of platforms. Before commencing design for, construction of, or operations on, platforms in areas that are likely to be affected by sea ice and icebergs, adequate data shall be collected. In vulnerable areas the data shall include

— the seasonal distribution of sea ice,

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

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

— the 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 installation as well as possible evacuation procedures.

For more specific advice on sea ice and icebergs, see ISO 19906[3].

10.5 Snow and ice accretion

Where relevant, snow accumulation (e.g. on the roofs of buildings) and ice accretion (e.g. on lattice structures) shall be considered in the design of structures.

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

Topsides icing can increase the diameter of structural components and can lead to a substantial increase of actions caused by wind and gravity, particularly for long, slender structures such as flares. Icing from sea spray, freezing rain or drizzle, freezing fog, or cloud droplets shall be considered in the design.

For more specific advice on snow and ice accretion, see ISO 19906[3].

10.6 Miscellaneous

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

— air and sea temperatures,

— precipitation,

— humidity,

— fog,

— wind chill,

— salinity,

— the oxygen content of the sea water, and

— guano accumulations.

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Annex A
(informative)

Additional information and guidance

NOTE The clauses in this annex 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.

A.1 Scope

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 can also have an influence on the operational aspects of a platform, which in turn can 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 document to provide detailed instructions that can 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 19904-2[1] for tension leg platforms, ISO 19905-1[2] for site-specific assessments of jack-ups, ISO 19906[3] for arctic structures and ISO 19901-3[4] for topsides structures.

A.2 Normative references

No guidance is offered.

A.3 Terms and definitions

No guidance is offered.

A.4 Symbols and abbreviations

No guidance is offered.

A.5 Determining the relevant metocean parameters

A.5.1 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 platform designer and appropriate specialists 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.

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General information on the various types of environmental conditions that can affect the site of the structure should be used to supplement data developed for normal conditions. Statistics can 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 significant.

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 can have both safety and economic consequences[5].

A.5.2 Expert interpretation of the metocean database

It is important to select a metocean expert 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.

The approach used to determine metocean parameters will often be dictated by the available data itself (measured, continuous, storm hindcasts, ship's visual observations, 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 can 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 data sets 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 data sets (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 estimates of the design wave height (in particular) can affect the reliability of a fixed structure by an order of magnitude. However, given reliable long-term data sets, the various statistical approaches should tend to similar results.

It is recommended that the metocean experts are integral members of design teams, particularly when the environmental conditions and associated metocean parameters used for the design of proposed structures are based on design criteria for actions (action effects) with long return periods.

A.5.3 to A.5.9 provide brief general descriptions of the principal considerations for deriving safe, reliable metocean parameters to support the design of different types of offshore structures and associated operations.

A.5.3 Selecting appropriate parameters for determining design actions or action effects

The design of structures is often governed by extreme actions or extreme action effects caused by the environment. The design conditions are quantified in terms of a parameter (e.g. wave height) or action effect (e.g. global bending moment on a hull). Thus, 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, can be taken as the inverse of the annual probability of exceedance of a parameter (e.g. a wave height or wind speed).

Three 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. Other methods are possible.

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a) Specified return period wave height (significant or individual) with “associated” wave period, wind and current velocities.

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 expected 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.

Wave dominance will apply to the majority of the structures covered by this document. However, the correlation between current velocity and wave height is not significant in many geographical areas (e.g. areas where the current is dominated by tide).

One way of developing the associated value of a particular parameter is to find a (positive) correlation between the parameter and the wave height. For example, assume a model hindcast has been made in a region dominated by tropical storms. To find the associated current, one can develop a regression plot of the modelled significant wave height versus current velocity at or near the peak of each storm. To account for directionality, the current component in line with the significant wave height can be used. Assuming this plot shows that the current is statistically correlated with the wave, an equation can be developed for the in-line current as a function of significant wave height. The associated current is then the value given from the equation using the specified return period significant wave height.

If there is not a strong correlation between waves and current or if the global environmental action is not wave-dominated, then there is no explicit confirmation in this method that the combination of the primary metocean parameter (here, wave height) and its associated parameters (here, current and wind velocities) will approximate to the return period global environmental action on a structure. By contrast, method c) below, when correctly applied, will always provide a good estimate of the specified return period global environmental action.

When the present method is used for structures that are sensitive to wave period, the most onerous combination of wave height and period can 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 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 can be determined from separate (marginal) statistics of waves, currents and wind. It will always yield 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.

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c) 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 involves calculating an associated current and wind speed using the wave height and 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[6], [7], [8]. 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 uncertainty 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 can 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 can be used in the development of partial factors for environmental actions (action effects) as described below. Reference [6] describes the procedure in some detail.

Although this method can involve time and cost in developing software, it can 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 can be deduced from observing the combinations that cause the greatest responses in the storms used in developing response statistics.

Additional consideration should be given to obtaining extreme direct actions (action effects) for locations where there are strong currents that are not driven by local storms. Such currents can be driven by tides or deep water currents, such as the Loop Current in the Gulf of Mexico or the Gulf Stream. In this case, method a) can be acceptable if the storm-generated conditions are the predominant contributors to the extreme global environmental action (action effect) and if the appropriate “associated” value of tidal and circulation current can be determined. However, method c) is conceptually more straightforward and preferable. Method b) is the simplest method and ensures an adequate design environmental action (action effect); however, this can be very conservative compared to the true global environmental action (action effect) of the required return period.

For some areas, substantial databases are becoming available with which it is possible to establish statistics of joint occurrence of wind, wave and current magnitudes and directions. When sufficient data are available, method c) above should be used. The corresponding partial factors to be used in conjunction with the global environmental action (action effect) should be determined using reliability analysis principles, in order to ensure that an appropriate safety level is achieved. This approach provides more consistent reliability (safety) for different geographic areas than has been achieved by the practice of using separate (marginal) statistics of winds, currents, and waves.

Reference [9] contains an example of selecting appropriate wind factors for jack-ups.

A.5.4 The metocean database

There are various circumstances in which site-specific data from measurements or hindcasts should be analysed in order to produce metocean parameters, including the following:

— where regulatory requirements insist on the use of site-specific data;

— where the operator has field data in addition to the data used in producing the environmental conditions presented in standard guidance documents;

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— where environmental conditions are not provided in standard guidance documents or are otherwise deemed by an operator to be inappropriate;

— where an operator may wish to produce metocean parameters for return periods other than those available in standard guidance documents.

A well-controlled series of measurements at the location of an offshore structure is a valuable reference source for establishing design situations as well as operating conditions and associated criteria, although measurements taken over a short duration may give misleading estimates of long-term extremes. Extremes derived from short-term, site-specific measurements should only be used in preference to any indicative values presented in standard guidance documents if care is taken to adjust the records to reflect long-term variability, e.g. by analysing the record together with several years of measurements or hindcasts from a nearby site.

Where there are known or expected long-term climate cycles, the database should be long enough to include at least one full cycle.

Site-specific measurements should be taken consistently throughout the period considered and, when required, in a manner suitable for estimating climatological extremes. It should also be recognized that measurements made during a climatologically anomalous period can dominate a data set, and the data can therefore be atypical of the long-term climate at the location.

Climatic variations during the design service life of structures can result in changes to

— the water level (mean, tide, and/or surge),

— the frequency of severe storms,

— the intensity of severe storms, and

— associated changes in the magnitude and frequency of extreme winds, waves and currents.

Wave height depends on wind speed, direction and fetch, all of which are potentially affected by changes in intensity, frequency and track of weather systems. The analysis of meteorological observations is affected by homogeneity problems in historical weather maps; to date, it has not been possible to be definite about changes in wind or wave statistics or storm tendencies in general.

The various application(s) for the database should be considered when determining the type(s) of wave hindcast model calibrations which are most appropriate. For example, if a primary concern is to derive downtime estimates for tanker-offloading operations in a mild climate (e.g. through the use of persistence analyses), it is important to verify the accuracy of the database for low sea states with a broad range of wave periods and directions. If the database will also be used for deriving fatigue estimates on deep water fixed or on bottom founded compliant structures, the database should be verified for the full dynamic range of significant wave heights (H_s) and wave periods (T_p or T_z), in order to derive representative directional wave scatter diagrams — perhaps together with estimates of directional associated current profiles.

If the database will be used for establishing extreme design parameters, it is important to establish that the database is as long and as accurate as possible. A judgement should be made on the suitability of the design parameters that have been developed, e.g. with respect to how climatologically representative the available database is. Factors that need to be considered include the time over which the data have been collected, and whether this time was climatologically normal in terms of the frequency and strength of storms.

When extrapolating metocean databases to small probabilities of exceedance, it is assumed that the database is representative of long-term conditions. This hypothesis should continue to be tested and, if necessary, suitable allowances should be made to incorporate any residual uncertainty.

Reference [10] contains guidelines for safe practice for undertaking metocean surveys.

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A.5.5 Storm types in a region

The definition of environmental conditions and the associated metocean parameters that can occur in different storm types is an important part of understanding the workability of various offshore operations, as well as determining the process that will be needed to define the extreme and abnormal metocean parameters. For some areas, the definition of storm types is problematic, in particular in regions where tropical cyclones lose their identity and metamorphose into extratropical storms. Such storms can become very severe and their characteristics during the transition are not yet well understood[11]; the derivation of extreme and abnormal metocean parameters in such areas requires additional care.

A.5.6 Directionality

Where directional variations of parameters are used, the sectors should generally not be smaller than 45°. In addition, the environmental conditions should be scaled up such that the combined event from all sectors has the same probability of exceedance as the target return period, see Reference [12].

A.5.7 Extrapolation to rare conditions

The problem of determining low probability values of metocean parameters has become even more important because of the recent trend to use very rare events to directly calculate the failure probability of a structure. It is becoming increasingly common for owners and regulators to require consideration of the 1 000 to 10 000 year events, i.e. the 10^{-3} and 10^{-4} annual non-exceedance probability, respectively. Great caution should be used in extrapolating data to such extremely low probabilities.

There are two basic methods for calculating low probability values: the historical and the deductive methods.

The historical method takes data, either from measurements or model hindcasts, and fits the tail (low probability region) of the probability distribution with an appropriate extreme distribution such as Gumbel or Weibull. This historical method is the overwhelming favourite in the oil industry and is well documented in Reference [13].

The deductive method breaks a storm into a series of simplified sub-models with specified probabilities. The sub-models are eventually combined using probabilistic laws to develop events with much lower overall probabilities. Deductive models have been used to estimate extremes of earthquakes, storm surges and, to a lesser degree, winds and waves[14]. The method has recently received renewed interest because it can potentially provide more accurate extreme estimates than the historical method for very rare events having return periods from about 1 000 to 10 000 years.

Both methods have their strengths and weaknesses. The historical method is easy to apply. It requires simply using a curve-fitting routine (e.g. least squares or maximum likelihood) to fit an analytical expression (e.g. Gumbel, Weibull) to data originating from measurements or from a hindcast model. A disadvantage is that the statistical confidence in the extrapolated value rapidly decreases for return periods greater than two or three times the length of the database. It follows that extrapolations to very rare recurrence intervals of 1 000 years or greater are speculative given the length of commonly available data sets.

The deductive method begins by breaking the regional storm type into parameters whose probability can be determined from historical data, e.g. in the case of a hurricane this could be the radius to maximum wind, pressure deficit and forward speed. Synthetic storms are generated by combining the parameters accounting for their joint probability of occurrence. In the simplest case, where the parameters are statistically independent, the probability of a synthetic storm simply becomes the product of the probabilities of each of the storm's parameters. In this way very rare synthetic storms can be constructed using storm parameters with relatively high and statistically confident probabilities. Parameters that are statistically correlated complicate the analysis, but can be handled provided that the joint probability distributions can be deduced from the historical data. The main disadvantage of the deductive method is that it is time-consuming to apply, and in regions where storms are physically complicated it can be impossible to derive parameters that adequately describe the storms. The deductive method is applicable only if the extreme event is due to a rare combination of parameters which occur reasonably frequently within their individual distributions. Modelling such regions is a topic of ongoing research in the oil industry.

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Since the deductive method is relatively uncommon and its application in the oil industry is still in its infancy, the remainder of this subclause relates to the historical method. Reference [13] provides a detailed discussion of how to apply the historical method.

When extrapolating data sets, the following recommendations and considerations are relevant.

— It has been argued that some distributions are theoretically superior to others. However, experience has shown that the most robust extreme estimates are obtained by finding the distribution that fits a subset of a reasonable number of the more extreme data points most closely using an error-minimizing algorithm (e.g. maximum likelihood method).

— When fitting data, care should be taken not to mix data from one type of storm event (e.g. winter storms) with data from another type of storm event (e.g. hurricanes). The probability distributions of the two types of extreme event are often a strong function of the storm physics (storm type) and mixing storm types can lead to non-conservative estimates of the extremes; each storm type should be fitted separately and then the combined statistics computed.

— Fitting should include a sufficient number of storms to achieve statistical confidence in the fit.

— Care should be taken not to extrapolate too far beyond the length of the data set. A good rule of thumb is not to derive metocean parameters with return periods more than a factor of four beyond the length of the data set. For example, at least a 25 year data set should be used to estimate the 100 year storm parameters.

— Bias should be removed from the data, whether the data are from measurements or from hindcast modelling. Biased data can lead to substantial offsets in the estimates of rare events which can be non-conservative because of the extrapolation process. Scatter (noise) increases the confidence limits on the extrapolations and can introduce positive bias. The bias tends to increase as one extrapolates further beyond the data.

— It is preferable to extrapolate a noisy data set of longer duration rather than a shorter-duration cleaner data set. For example, a 50 year model hindcast data set to estimate the 100 year storm is preferred to a few years of measurements, even though the hindcast results may have more scatter than the measurements. This assumes that bias has been removed from both data sources. It is emphasized that any model used to extrapolate data should be carefully validated against available measurements.

— A variety of different techniques should be considered before deciding on an extreme value, e.g. the use of different thresholds, different distributions, annual maxima, peak-over-threshold (POT) and cumulative frequency distribution analyses.

— Estimates of rare events should be checked to make sure they do not exceed some limiting state imposed by physical constraints, e.g. the wave breaking limit in shallow water.

— Confidence in estimates of rare events can often be substantially improved by pooling data from nearby sites, especially in places where storms are sparse. Pooling is straightforward if the data source is a gridded hindcast model. There are other methods of reducing statistical uncertainty, such as averaging extreme estimates from adjacent sites, but research suggests that these can introduce bias and are inferior to pooling. Regardless of the method used, one should take great care to exclude sites that can be expected to be different from the site of interest because of a differing physical environment. For example, wave data from shallow water sites should not be pooled with wave data from a substantially different water depth.

A.5.8 Metocean parameters for fatigue assessments

A.5.8.1 General

Time-varying stresses in an offshore structure are due to time-varying actions caused by waves (with or without currents), gust winds and combinations thereof. Time-varying stresses for a fatigue assessment are characterized by the number of occurrences of various magnitudes of stress range (maximum stress minus preceding or following minimum stress), in some cases supplemented by the mean value of the stress range.

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Determination of the relevant metocean parameters should take due account of the required characterization for each case.

A.5.8.2 Fixed structures

Variable stresses during the in-place situation of fixed structures (either steel or concrete) are due to gust winds and waves, with or without the simultaneous presence of a current. The variable stresses caused by gust winds are normally small and, except for the design of some topsides components, can be neglected. The effect of current is normally not taken into account, for the following reasons:

— current velocities co-existing with waves in other than extreme or abnormal environmental conditions are usually small and not in the same direction as the waves;

— the influence of current on stress ranges is generally much smaller than the influence on the maximum stress experienced.

The minimum requirement for the fatigue assessment of a fixed structure during the in-place situation is therefore an appropriate description of the site-specific wave environment during its design service life. This is ideally provided by the long-term joint distribution of the significant wave height (H_s), a representative wave period (T_z or T_p), the mean wave direction ($\bar{\theta}$) and the directional spreading around the mean wave direction. However, adequate information on the joint occurrence of these four parameters is usually not available. The availability of data usually limits the options to providing a two-parameter wave scatter diagram. The wave scatter diagram gives the probability density $p(H_s, T_z)$ or $p(H_s, T_p)$ of the joint occurrence of H_s and T_z or T_p. Where adequate data exist, this can sometimes be extended to the three-parameter wave scatter diagram $p(H_s, T_z, \bar{\theta})$ or $p(H_s, T_p, \bar{\theta})$; otherwise, the mean wave direction $\bar{\theta}$ is specified by its long-term marginal distribution independent of H_s and T_z or T_p. Wave directional spreading is usually neglected or accounted for by a standard spreading function independent of the other three parameters, see A.8.7.

The long-term distribution should either cover the full duration of the design service life or the duration of a typical year. If annual distributions are used, it is assumed that the conditions during the typical year repeat themselves each year during the design service life. Seasonal distributions are not appropriate for fatigue assessments.

Where a deterministic fatigue assessment can be used for quasi-statically responding structures, the site-specific wave environment during the structure's design service life may be specified by the long-term marginal distribution of individual wave heights. This distribution can be derived from the wave scatter diagram.

Where vortex induced vibrations (VIV) due to currents in the in-place situation are important, the long-term marginal distribution of site-specific current speeds should also be determined.

For vortex induced vibrations due to wind action in the pre-service condition, the long-term marginal distribution of sustained wind speeds during the construction period should be made available.

Where variable stresses due to gust winds cannot be disregarded (e.g. for separate support structures for vent stacks or flare towers), the two- or three-parameter wave scatter diagram should be replaced by a three- or four-parameter scatter diagram of the joint occurrence of waves and winds. In such special cases the waves are as usual specified by H_s and T_z or T_p, supplemented if possible by $\bar{\theta}$, while the wind is normally specified by the sustained wind speed U_{w0} as being the representative parameter of gust winds, see A.7.4.

For slender structural components above water (e.g. drilling derricks, flare towers), the long-term marginal distribution of sustained wind speeds should suffice for a fatigue assessment due to excitation by both gust winds and vortex induced vibrations.

Requirements and guidance for the fatigue assessment of fixed steel and concrete structures are given in ISO 19902 and ISO 19903, respectively.

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A.5.8.3 Floating structures

In principle, the specification of all environmental conditions that are expected to occur during the floating structure's period of exposure is along similar lines as that for fixed structures. However, the behaviour of a floating structure under environmental actions is normally more complex than that of a fixed structure. Therefore, the long-term joint distribution of relevant metocean parameters should ideally comprise more parameters than for fixed structures.

Floating structures experience oscillatory motions in six degrees-of-freedom due to wave action. Additionally, floating structures are subjected to slow variations in their position and their orientation as a result of the simultaneous effects of wind, current and waves. These phenomena are not fully understood and can not often be reliably predicted in advance. This makes the determination of variable stresses in floating structures at the design stage very difficult. Consequently, a fatigue assessment of a floating structure normally uses pragmatic and experience-based procedures. The relevant metocean parameters and the way in which these are specified should suit the procedure being used. For requirements and guidance for the fatigue assessment of floating structures, see ISO 19904-1 for monohulls, semi-submersibles and spars, and ISO 19904-2[1] for tension leg platforms.

A.5.8.4 Jack-ups

The principal differences between jack-ups in their elevated condition and fixed structures regarding fatigue are

— that they are deployed at different sites during their working lives,

— that their period of exposure at one particular site is usually considerably shorter,

— at different sites at which the jack-up is deployed, the fatigue sensitive locations differ (primarily due to water depth variations),

— there are frequent opportunities to carry out non-destructive examinations of fatigue sensitive components, and

— periodic examinations are required by classification societies and coastal state authorities.

For requirements and guidance for the fatigue assessment of a jack-up during a site-specific application, see ISO 19905-1[2].

A.5.9 Metocean parameters for short-term activities

Almost all short-term offshore operations, and some offshore-related aviation operations, are sensitive to the accuracy, reliability and timeliness of weather forecasts. Planning prior to the operation is essential to enable safety plans to be properly completed, cost estimates to be accurately determined and any capacity limits on accommodation or transport to be defined.

The most common technique used in such planning exercises is the so-called “persistence” or “weather-window” analysis. This analysis is typically applied to a long time series (e.g. with a duration of 10 years) of a metocean variable such as significant wave height, mean wind speed or current speed. More sophisticated analyses of multiple parameters (including wave period) can be necessary, in particular for operations involving floating systems.

EXAMPLE In order to plan a required operation at an installation safely, the average number of occasions in the months June to August when the significant wave height at a specific location can be expected to be below 1,5 m for a period of 36 h or more, when at the same time the wind speed should be less than 10 m/s, and the spectral peak wave period is less than 9 s, can be evaluated. It could be necessary to modify an operation to allow the limiting criteria to be relaxed.

In all cases, weather forecasts are likely to be needed both before and during the operations and it is often worthwhile to collect real-time data on critical metocean parameters (such as wind speed and wave height/period) during the operation in order to assist with the accuracy and timing of the forecasts.

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References [5] and [15] provide examples of applications of operations requiring metocean data, and Reference [16] describes the types of metocean analyses which are often needed in studies to support the planning of floating systems operations.

A.6 Water depth, tides and storm surges

A.6.1 General

Changes in relative still water level comprise several components, including atmospheric tides, storm surge effects, changes in mean sea level, vertical movement of the earth's crust, settlement and subsidence. Records in areas such as northern Europe over the last 100 years show a downward trend in relative still water level because the crust in this area is lifting at a faster rate than the rise in actual sea level. Apart from sudden tectonic movements, such as earthquakes, changes in relative sea level from tectonics and isostasy are unlikely to be significant during the design service life of a structure. However, there can be significant local crustal movements over periods of decades or so caused by local effects, such as sediment compaction and subsidence, including the effects of reservoir compaction.

At present, the consensus of opinion for the rate of change of still water level due to climate change for the next century is about 5 mm per year[17]. However, this estimate is likely to change as knowledge increases. Any change in actual still water level is not expected to be uniform over the globe.

Changes in water depth due to changes in still water level will cause little change in tide and surge elevations unless depths are modified by many metres.

A.6.2 Tides

The best estimates of the water depth and of the fluctuations in water level (HAT, LAT, extreme surge elevation, and extreme total still water level) are derived from site-specific measurements with an offshore tide gauge measuring pressure from the sea floor. If the tidal signal is dominant, adequate estimates of the tidal range at a given site can be obtained from one month of measured data. However, accurate estimates of extreme tides, including HAT and LAT, require at least one complete year of high-quality data from one location. A method of analysing water level data requires

— conversion of pressure measurements to equivalent depths, using density/temperature/atmospheric pressure corrections,

— harmonic tidal analysis, giving values of all significant tidal constants and the mean water level,

— prediction of tides over 19 years (the harmonic constituent with the longest period) and extraction of HAT and LAT,

— subtraction of predicted tides from measured levels, giving time series of hourly storm surge elevations,

— separate statistical analyses of the tidal and storm surge elevations, and

— combination of the frequency distribution of tidal and surge elevations to give the required probabilities of total still water level.

When tide gauge measurements have not been made and water depth has been determined by local soundings, corrections should be made for the state of the tide by reference to published tide tables, co-tidal charts or the nearest available tide gauge.

A.6.3 Storm surge

Accurate estimates of the storm surge require a long data set (approximately 10 years), but if long-term measurements or hindcasts are available from an adjacent site, spatial techniques can be used and one to two years of data can provide workable estimates.

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A.7 Wind

A.7.1 General

When making wind measurements, the following is recommended.

— The height of the wind measurement above mean sea level should be known and should be sufficiently high to be clear of disturbances to the airflow from the wave surface or from the structure.

— The averaging time of the wind speed measurement should be known.

— The air and sea temperatures should be measured to enable an evaluation of the atmospheric stability which can affect the wind profile and the wind spectrum (see A.7.3 and A.7.4) in low wind conditions.

— The anemometer should not be aerodynamically shielded.

Reference [18] contains guidance on measuring instruments and their use.

Measurements at a location away from the site of interest can be misleading, e.g. because of a sharp gradient in wind speed near a coastline. If it is decided to use such measurements because site-specific measurements are not available, allowance should be made (e.g. by the use of numerical models) for such effects. Wind measurements made over land should be corrected to reflect over-water conditions.

Wind data should be adjusted to a standard elevation of 10 m above mean sea level (the reference elevation z_r) with a specified averaging time such as 1 h. Wind data can be adjusted to any specified elevation different from the base value using the wind profile given in A.7.3[19].

A.7.2 Wind actions and action effects

When determining appropriate design wind speeds for extreme and abnormal conditions, the projected extreme wind speeds in specified directions and with specified averaging times should be developed as a function of their recurrence interval. Data should be recorded for the following:

— the measurement site, date of occurrence, magnitude of measured sustained wind speeds, wind directions and gust wind speeds for the recorded data that were used during the development of extreme and abnormal winds;

— the projected number of occasions during the specified design service life of the structure when sustained wind speeds from specified directions are expected to exceed a specific threshold;

— the type of storm causing high winds, which is significant when more than one type of storm can be present in the region.

When determining appropriate design wind speeds for normal and short-term conditions, data should be recorded for the following:

— the frequency of occurrence of specified sustained wind speeds from various directions for each month or season;

— the persistence of sustained wind speeds above specified thresholds for each month or season;

— the probable gust wind speed associated with sustained wind speeds.

In some instances the spectrum of wind speed fluctuations about the mean should be specified. For example, floating and other compliant structures in deep water can have natural sway periods in the range of a minute or more, a period at which there is significant energy in the wind speed fluctuations. Data on wind spectra are given in A.7.4.

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For most purposes a relatively simple wind model consisting of the following scalar equation in the mean wind direction θ_w suffices:

$$U_w(z,t) = U_w(z) + u_w(z,t) \quad \text{(A.1)}$$

where

$U_w(z,t)$ is the spatially and temporally varying wind speed at elevation z above mean sea level and at time instant t;

$U_w(z)$ is the mean wind speed at elevation z above mean sea level, averaged over a specified time interval;

$u_w(z,t)$ is the fluctuating wind speed at elevation z around $U_w(z)$ and in the same direction as the mean wind.

The wind speed in a 3 s gust is appropriate for determining the maximum quasi-static local actions caused by wind on individual components of the structure, whereas 5 s gusts are appropriate for maximum quasi-static local or global actions on structures whose maximum horizontal dimension is less than 50 m, and 15 s gusts are appropriate for the maximum quasi-static global actions on larger structures.

When design actions due to wind need to be combined with actions due to waves and current, the following is appropriate:

— for structures with negligible dynamic response, the 1 h sustained wind can be used to determine quasi-static global actions caused by wind in conjunction with extreme or abnormal quasi-static actions due to waves and currents;

— for structures that are moderately dynamically sensitive, but do not require a full dynamic analysis, the 1 min mean wind can be used to determine quasi-static global actions caused by wind, again for wind in conjunction with extreme or abnormal quasi-static actions due to waves and currents;

— for structures with significant dynamic response to excitation with periods longer than 20 s, a full dynamic response analysis to fluctuating winds should be considered.

A.7.3 Wind profile and time-averaged wind speed

Measurements of representative offshore conditions, in strong, nearly neutrally stable atmospheric wind conditions, suggest that the mean wind speed profile $U_w(z)$ in storm conditions can be more accurately described by a logarithmic profile as given in Equation (A.2) than by the power law profile traditionally used:

$$U_{w,1h}(z) = U_{w0}\,[1 + C \ln(z/z_r)] \quad \text{(A.2)}$$

where

$U_{w,1h}(z)$ is the 1 h sustained wind speed at a height z above mean sea level;

U_{w0} is the 1 h sustained wind speed at the reference elevation z_r and is the standard reference speed for sustained winds;

C is a dimensionally dependent coefficient, the value of which is dependent on the reference elevation and the wind speed, U_{w0}. For z_r = 10 m, $C = (0{,}0573)\,(1 + 0{,}15\,U_{w0})^{1/2}$ where U_{w0} is in units of metres per second (m/s);

z is the height above mean sea level;

z_r is the reference elevation above mean sea level (z_r = 10 m).

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