1. Introduction

1.1 General

1.1.1 This Classification Note gives guidance for description of important environmental conditions as well as giving guidance for arriving at environmental loads.

Environmental conditions are described in clauses 2–4 while environmental loads are described in clauses 5—7.

1.2 Environmental conditions

1.2.1 Environmental conditions cover natural phenomena which may contribute to structural damages, operation disturbances or navigation failures. Phenomena of general importance are:

- Wind
- Waves
- Currents.

Phenomena which may be important in specific cases are:

- Ice
- Earthquake
- Soil conditions
- Temperature
- Fouling
- Visibility
- Tides.

1.2.2 The phenomena are usually described by physical variables of statistical nature. The statistical description should reveal the extreme conditions as well as the long- and short-term variations.

1.2.3 The environmental design data should be representative for the geographical areas where the structure will be situated, or where the operation will take place. For ships and other mobile units which operate world-wide, environmental data for particularly hostile areas, such as the North Atlantic Ocean, may be considered.

1.2.4 Empirical, statistical data used as a basis for evaluation of operation and design must cover a sufficiently long time period.

For operations of limited duration, seasonal variations must be taken into account. For meteorological and oceanographical data, 3–4 years is a minimum. Earthquakes must be based on long-term historical data.

1.3 Environmental loads

1.3.1 Environmental loads are loads caused by environmental phenomena.

Environmental loads to be used for design are to be based on environmental data for the specific location and operation in question, and are to be determined by use of relevant methods applicable for the location/operation taking into account type of structure, size, shape and response characteristics.

2. Wind conditions

2.1 Average wind

2.1.1 Wind velocity changes both with time and with height above the sea surface. For this reason the averaging time and height must always be specified.

Common height level is $z = 10$ metres. Common averaging times are 1 minute, 10 minutes or 1 hour.

Wind velocity averaged over 1 minute is often referred to as *sustained* wind velocity.

2.1.2 The average wind speed and the wind height profile may be estimated by the formula

$$U(z,\ t) = U(z_r,\ t_r)\left(1 + 0{,}137 \ln \frac{z}{z_r} - 0{,}047 \ln \frac{t}{t_r}\right)$$

where

z = height above the still water sea surface level.
z_r = reference height = 10m.
t = averaging time.
t_r = reference time = 10 minutes.
$U(z,\ t)$ = average wind speed by specified z and t.
$U(z_r,\ t_r)$ = reference wind speed.

The ratio $U(z,\ t) / U(z_r,\ t_r)$ is given in Table 2.1 for:

Table 2.1 Wind speed ratios.

z (metres)	*Time*					
	3 seconds	*5 seconds*	*15 seconds*	*1 minute*	*10 minutes*	*60 minutes*
1,0	0,934	0,910	0,858	0,793	0,685	0,600
5,0	1,154	1,130	1,078	1,013	0,905	0,821
10,0	1,249	1,225	1,173	1,108	1,000	0,916
20,0	1,344	1,320	1,268	1,203	1,095	1,011
30,0	1,399	1,375	1,324	1,259	1,151	1,066
40,0	1,439	1,415	1,363	1,298	1,190	1,106
50,0	1,469	1,445	1,394	1,329	1,220	1,136
100,0	1,564	1,540	1,489	1,424	1,315	1,231

2.1.3 The statistical behavior of the average wind speed $U(z,\ t)$ referred to a fixed height and averaging time may be described by the Weibull distribution given as:

$$\Pr(U) = 1 - \exp\left[-\left(\frac{U}{U_o}\right)^c\right]$$

where

$\Pr(U)$ = cumulative probability of U.
U = $U(z,\ t)$ = wind speed.
U_o = Weibull scale parameter.
c = Weibull slope parameter.

2.1.4 The most probable largest wind speed for an exposure time, T, may be obtained by:

$$U_{max}(z,\ t) = U_o\left(\ln\frac{T}{T_s}\right)^{1/c}$$

where

T = exposure time.
T_s = average time period of constant wind speed, usually 3 hours.

2.2 Gust wind

2.2.1 In the short time range the wind may be considered as a random gust wind component with zero mean value, superposed upon the constant, average wind component.

2.2.2 Gust wind cycles with period shorter than about 1 minute, may be desribed by the gust spectrum

$$f{\cdot}S(f) = 4\,\kappa\,U^2(z,\ t)\frac{\tilde{f}}{(2+\tilde{f}^2)^{5/6}}$$

where

S = power spectral density (m²/Hz).
f = frequency (Hz).
$\tilde{f}$ = non-dimensional frequency, $\tilde{f} = f{\cdot}L\,/\,U(z,\ t)$.
L = length scale dimension (m); may be chosen equal to 1800m.
κ = surface drag coefficient; may be chosen equal to 0,0020 for rough sea and 0,0015 for moderate sea.
$\ddot{U}(z,\ t)$ = average wind velocity.

2.2.3 Gust wind velocity, defined for instance as the average wind velocity during an interval of 3 seconds, may normally be assumed to follow the Weibull distribution law, see 2.1.3--2.1.4.

3. Wave conditions

3.1 Wave theories

3.1.1 Wave conditions which are to be considered for design purposes, may be described either by deterministic design wave methods or by stochastic methods applying wave spectra.

By deterministic methods the seas are described by regular, periodic wave cycles, characterized by wave length (period), wave height and possible shape parameters.

The deterministic wave parameters may, however, be predicted by statistical methods.

3.1.2 The kinematics of regular waves may be described by analytical or numerical wave theories. Among these may be mentioned:

- *Linear* wave theory, by which the wave profile is described as a sine function.
- *Solitary* wave theories for particularly shallow water.
- *Cnoidal* wave theories which cover the waves above as special cases.
- *Stokes* wave theories for particularly high waves.
- *Stream-function* waves which are based on numerical methods and accurately describe the wave kinematics over a broad range of water depths.

By spectral description of random seas, the linear wave theory is almost always used.

For most practical purposes, the following wave theories are recommended:

- Solitary wave theory:

$$\frac{h}{\lambda} \leq 0{,}1$$

- Stokes' 5th order wave theory:

$$0{,}1 \leq \frac{h}{\lambda} \leq 0{,}3$$

- Linear wave theory (or Stokes' 5th order):

$$0{,}3 \leq \frac{h}{\lambda}$$

where

h = water depth.
λ = wave length.

3.2 Short term wave conditions

3.2.1 Short term stationary irregular sea states may be described by a wave spectrum; that is, the power spectral density function of the vertical sea surface displacement.

Wave spectra may be given on table form, as measured spectra, or on parametrized, analytic form.

3.2.2 The Jonswap spectrum and the Pierson-Moskowitz spectrum are most frequently applied. The spectral density function is:

$$S(\omega) = \alpha\, g^2 (2\pi)^{-4}\,\omega^{-5}\exp\left[-\frac{5}{4}\left(\frac{\omega}{\omega_p}\right)^{-4} + e^{-\frac{1}{2}\left(\frac{\omega-\omega_p}{\sigma\,\omega_p}\right)^2}\ln\gamma\right]$$

where

ω = angular wave frequency, $\omega = 2\pi f = 2\pi/T$.
f = wave frequency, $f = 1/T$.
T = wave period, $T = 1/f$.
ω_p = angular spectral peak frequency $\omega_p = 2\pi f_p = 2\pi/T_p$.
g = acceleration of gravity.
α = generalised Phillips' constant.
σ = spectral width parameter.
= 0,07 if $\omega \leq \omega_p$.
= 0,09 if $\omega > \omega_p$.
γ = peakedness parameter.

The Pierson-Moskowitz spectrum appears for $\gamma = 1$.

3.2.3 The Pierson-Moskowitz spectrum is generally applied for open, deep waters and fully developed seas. The Jonswap spectrum is normally used for fetch-limited, growing seas and without swell.

3.2.4 The peak period T_p may be related to the average zero-crossing wave period T_z by

$$T_z = T_p\left(\frac{5+\gamma}{11+\gamma}\right)^{1/2}$$

The parameter α is given by

$$\alpha = \frac{5}{16}\,\frac{H_s^2\,\omega_p^4}{g^2}\,(1-0{,}287\ln\gamma)$$

where

H_s = significant wave height.

If no particular values are given for the peakedness parameter γ, the following value may be applied:

$$\gamma = 5 \text{ for } \frac{T_p}{\sqrt{H_s}} \leq 3{,}6$$

$$\gamma = e^{5{,}75 - 1{,}15T_p/\sqrt{H_s}} \text{ for } 3{,}6 \leq \frac{T_p}{\sqrt{H_s}} \leq 5$$

$$\gamma = 1 \text{ for } 5 \leq \frac{T_p}{\sqrt{H_s}}$$

where T_p is in seconds and H_s is in metres.

If the period is not given for a particular sea-state, a tentative estimate

$$T_z = 6\, H_s^{0{,}3}$$

where T_z is in seconds and H_s is in metres.

3.2.5 The spectral moments M_n of general order n is defined as

$$M_n = \int_0^\infty \omega^n\, S(\omega)\, d\omega$$

where

n = −1, 0, 1, 2, ...

The Jonswap spectrum above has approximately

$$M_{-1} = \frac{1}{16} H_s^2 \omega_p^{-1} \frac{4{,}2 + \gamma}{5 + \gamma}$$

$$M_0 = \frac{1}{16} H_s^2$$

$$M_1 = \frac{1}{16} H_s^2 \omega_p \frac{6{,}8 + \gamma}{5 + \gamma}$$

$$M_2 = \frac{1}{16} H_s^2 \omega_p^2 \frac{11 + \gamma}{5 + \gamma}.$$

Quantities that may be defined in terms of spectral moments are among others:

- Significant wave height:

$$H_s = 4\sqrt{M_0}$$

- Average wave period:

$$T_z = 2\pi \left(\frac{M_0}{M_2} \right)^{1/2}$$

- Significant wave slope:

$$S = \frac{2}{\pi g} \frac{M_2}{\sqrt{M_0}} \simeq \sqrt{\frac{\alpha}{\pi}}$$

- Spectral width:

$$\eta = \left(\frac{M_0 M_2 - M_1^2}{M_1^2} \right)^{1/2}$$

3.2.6 If the power spectral density S(f) is given as a function of the frequency f rather than as the function $S(\omega)$ of ω, the relationship is

$$S(f) = 2\pi\, S(\omega)$$

Similarly, if the moments of the circular frequency spectrum S(f) are denoted $M_n(f)$, the relationship to M_n in 3.2.5 is

$$M_n(f) = \int_0^\infty f^n\, S(f)\, df = (2\pi)^{-n} M_n$$

3.2.7 Directional short-crested wave spectra may be derived from the nondirectional wave spectra above as follows:

$$S(\omega, \alpha) = S(\omega)\, f(\alpha)$$

where

α = angle between direction of elementary wave trains and the main direction of the short-crested wave system.

$S(\omega, \alpha)$ = directional short-crested wave power density spectrum.

$f(\alpha)$ = directionality function.

Energy conservation requires that the directionality function fulfills the requirement

$$\int_{\alpha_{min}}^{\alpha_{max}} f(\alpha)\, d\alpha = 1$$

The directional function $f(\alpha)$ may have the general form

$$f(\alpha) = \text{const.} \cdot \cos^s \alpha \qquad \text{where } 2 \leq s \leq 8$$

Due consideration is to be taken to reflect an accurate correlation between the actual seastate and the power constant, s.

The main wave direction may be set equal to the prevailing wind direction.

3.2.8 The statistical distribution of individual wave crests Z in an irregular short-term stationary seastate may usually be described by the Rayleigh distribution. The cumulative probability function P(Z), that is the probability that a crest shall be equal or lower than a value Z, is

$$P(Z) = 1 - e^{-\left(\frac{Z}{A_Z}\right)^2}$$

where

$A_Z = H_s/\sqrt{8}$

The highest wave-crest Z_{max} within a time t is

$$Z_{max} = \frac{1}{\sqrt{8}} H_s \sqrt{\ln N}$$

where

$N = t/T_z$.

To the first approximation one may put

$$Z_{max} \simeq H_s$$

3.2.9 The peak-to-trough wave height H of a wave cycle is the difference between the highest crest and the deepest trough between two successive zero-upcrossings.

The wave-heights are Rayleigh distributed with cumulative probability function

$$P(H) = 1 - e^{-\left(\frac{H}{A_H}\right)^2}$$

where

$$A_H = \frac{H_s}{\sqrt{8}} \cdot 2\,(1 - c^2 \eta^2)^{1/2}$$

c = a constant $\simeq 1.0$.

The highest crest-to-trough wave height H_{max} within a time t is

$$H_{max} = \frac{1}{\sqrt{2}} H_s \sqrt{(1 - c^2 \eta^2) \ln N}$$

where

$N = t/T_z$.

To the first approximation one may put

$$\eta = 0{,}43$$

$$c = 1{,}0$$

$$H_{max} \simeq 1{,}8\ Z_{max}$$

3.2.10 In evaluation of the foundation's resistance against cyclic wave loading, the temporal evolution of the storm should be taken into account. This should cover a sufficient part of the growth and decay phases of the storm.

If data for the particular site is not available, the storm profile in Fig. 3.1 may be applied.

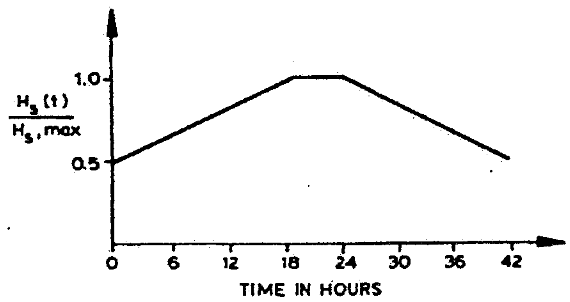

Fig. 3.1
Significant wave height relative to maximum value as a function of time during a storm.

3.3 Long-term wave statistics

3.3.1 The long-term variation of the seas may conveniently be described by a set of seastates, each characterized by the wave spectrum parameters, that is, (H_s, T_z) or (α, T_p, γ) defined in 3.2.5 and 3.2.4 respectively.

3.3.2 There are currently three ways to describe the marginal long-term probability distribution of the significant waveheight:

a) The three-parameter Weibull distribution with probability density:

$$f(H_s) = \frac{j}{H_1 - H_0}\left(\frac{H_s - H_0}{H_1 - H_0}\right)^{j-1} e^{-\left(\frac{H_s - H_0}{H_1 - H_0}\right)^j}$$

$(H_0 < H)$

This distribution has evident advantages in connection with extreme seastate prediction.

b) The generalised gamma distribution with probability density:

$$f(H_s) = \frac{j}{\Gamma(b)\, H_1}\left(\frac{H_s}{H_1}\right)^{bj-1} e^{-\left(\frac{H_s}{H_1}\right)^j}$$

$\Gamma(b)$ is a complete gamma function.

This distribution is most convenient for establishing long-term distribution for individual crest-heights.

c) The log-normal/Weibull distribution with probability density function:

$$f(H_s) = \frac{j}{H_1}\left(\frac{H_s}{H_1}\right)^{j-1} e^{-\left(\frac{H_s}{H_1}\right)^j} \quad H_2 < H_s$$

$$f(H_s) = \frac{1}{\sqrt{2\pi}\,\sigma_{\ln H}\, H_s} e^{-\frac{1}{2}\left(\frac{\ln H_s - \mu_{\ln H}}{\sigma_{\ln H}}\right)^2} \quad 0 < H_s < H_2$$

There are also constraints on the parameters of the two parts such as to give continuity in cumulative probability and in probability density at $H_s = H_2$.

This distribution is convenient for extreme seastates and in prediction of persistence of low and medium seastates.

The two-parameter Weibull distribution is obtained by:

- Putting $H_0 = 0$ in a).
- Putting $b = 1$ in b).
- Putting $H_2 = 0$ in c).
- $\mu_{\ln H}$ and $\sigma_{\ln H}$ are parameters fitted to the asymptotic parts of the empirical data.

3.3.3 To establish an extreme design storm in a time span t (order 20 years), it is convenient to agree upon a design storm duration τ, usually 3, 6 or 12 hours, in advance. The number m of short-term intervals in the time span τ is then

$$m = \frac{t}{\tau}$$

The significant wave height in the extreme design storm is then

a) By the three-parameter Weibull distribution:

$$H_{s,max} = H_0 + (H_1 - H_0)\,(\ln m)^{1/j}$$

b) By the generalised gamma distribution (approximate formula):

$$H_{s,max} = H_1\left(\ln \frac{m}{\Gamma(b)} + (b-1) \ln \ln \frac{m}{\Gamma(b)}\right)^{1/j}$$

c) By the log-normal/Weibull distribution:

$$H_{s,max} = H_1\,(\ln m)^{1/j} \qquad H_2 < H_{s,max}$$

The other spectral parameters of the extreme seastate may be chosen as advised in 3.2.

Design storms with a preferred value for the storm duration are advised in 3.3.4 and 3.3.5 below.

3.3.4 If the time t covers a total of N wave cycles, a long-term marginal distribution of the individual wave crests are preferably obtained in terms of a general gamma distribution. The probability density is

$$f(Z) = \frac{k}{\Gamma(d) D}\left(\frac{Z}{D}\right)^{dk-1} e^{-\left(\frac{Z}{D}\right)^k}$$

A two-parameter Weibull distribution is obtained for $d = 1$. Two methods may be advised, viz.

- The optimised elementary method.
- The saddle-point method.

3.3.5 The optimised, elementary method is based on two-parameter Weibull distributions.

The design storm duration advised is:

$$\tau = N^{\frac{j}{2+j}}\, \bar{T}_z$$

where