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Executive

Loads

OFFSHORE TECHNOLOGY REPORT

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Loads

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FOREWORD

This document provides technical information previously contained in the Fourth Edition of the Health and Safety Executive's *'Offshore Installations: Guidance on Design, Construction and Certification'* (1990 edition plus amendments)(1). The 'Guidance' was originally published in support of the certification regime under SI289, the Offshore Installations (Construction and Survey) Regulations 1974(2). However, SI289 was revoked by the Offshore Installations (Design and Construction, etc) Regulations, 1996, which also introduced the verification provisions into the Offshore Installations (Safety Case) Regulations, 1992. The 'Guidance' was formally withdrawn in its entirety on 30 June 1998 (see HSE OSD Operations Notice 27(3)).

The withdrawal of the 'Guidance' was not a reflection of the soundness (or otherwise) of the technical information it contained; some sections (or part of sections) of the 'Guidance' are currently referred to by the offshore industry. For this reason, after consultation with industry, relevant sections are now published as separate documents in the HSE Offshore Technology (OT) Report series.

It should be noted that the technical content of the 'Guidance' has not been updated as part of the re-formatting for OTO publication, although prescriptive requirements and reference to the former regulatory regime have been removed. **The user of this document must therefore assess the appropriateness and currency of the technical information for any specific application. Additionally, the user should be aware that published sections may cease to be applicable in time and should check with Operations Notice 27, which can be viewed at http://www.hse.gov.uk/hid/osd/notices/on_index.htm, for their current status.**

1. INTRODUCTION AND SCOPE

1.1 SOURCE OF INFORMATION

This Offshore Technology (OT) Report provides technical information on loads and their assessment for Offshore Installations. It is based on guidance previously contained in Section 15 of the Fourth Edition of the Health and Safety Executive's 'Offshore Installations: Guidance on Design, Construction and Certification'(1) which was withdrawn in 1998. As discussed in the Foreword, whilst the text has been re-formatted for Offshore Technology publication, the technical content has not been updated. The appropriateness and currency of the information contained in this document must therefore be assessed by the user for any specific application.

1.2 EFFECTS OF LOADS

The principal categories of load are:

- Dead loads
- Imposed (operational) loads
- Hydrostatic loads
- Environmental loads
- Deformation loads
- Accidental loads.

Static, dynamic and fatigue effects of loads may need to be considered depending on the variation of the load with time and on the response characteristics of the structure.

2. DEAD LOADS

Dead Loads are fixed gravitational loads that can be varied significantly only by major alterations to the structures and / or the installed equipment. They comprise:

- The weight in air of the entire structure including all secondary structures, and the weight of all equipment and machinery installed on the Installation.

- Those gravitational loads imposed by conductors, risers and any other normally fixed items that do not directly form part of the Installation but which are supported by, and transfer loads to, the Installation.

3. IMPOSED LOADS

Imposed loads include all loads related to the operational use of the Installation. They are inherently variable in magnitude and / or disposition and, in certain cases, they have major horizontal components. Imposed loads include:

- **Loads arising from the functional activities of the Installation** eg. drilling, production and storage operations, helicopters landing and taking off, and loads arising from the transfer of persons and stores by the use of cranes or other means.
- **The weight of all variable and consumable stores and portable equipment used during operations**; also crew members, furniture, effects and living stores.
- **Loads arising from moving a mobile Installation and from maintaining it on station.** These include loads transferred to bollards, or equivalent, when the Installation is under tow, being manoeuvred or moored; the thrusts developed by propelling machinery or thrusters; and the hydrodynamic resistance due to movement through the water.
- **Loads developed in a mobile Installation from change of trim and / or mode of support**, including impact and straining forces caused by ballasting and changes to or from the floating mode.
- **Construction and installation loads** imposed on fixed structures, including the loads imposed at various construction stages, lifting forces, load-out forces and forces experienced during launching, towing, up-ending and / or sinking; also loads exerted on the permanent structure by construction plant during construction, alteration and repair.

  Construction loads also include those applied by temporary auxiliary buoyancy chambers and similar equipment associated with a fixed Installation and intended to facilitate movement to, and installation at, the permanent location.

  The effects of immersion of a fixed Installation to a greater depth than that at the permanent location should be allowed for when necessary for deck erection. In such circumstances, it may be appropriate to reduce the factor of safety. In the event of any such change in the criteria, it must be demonstrated that no permanent damage to the structure will result.
- **Operational impact loads** which may arise during operation of vessels in the vicinity. Members located in areas where vessels may be permitted to operate in close proximity to the Installation should be capable of absorbing the energy due to operational impacts by vessels, for example whilst they are berthing. Information on any areas where vessels are not permitted to operate in close proximity should be available to personnel on the Installation.

  The operational impact can be taken to be not less than that caused by a vessel of 2500 tonnes displacement coming into contact at a speed of 0.5 m/s and considering an added mass coefficient of 1.4 for sideways collisions and 1.1 for bow or stern collision. It should be assumed in this case that all the kinetic energy is absorbed by the fendering or Installation. Note that accidental loads are referred to in Section 7.2.

Consideration should be given to both maximum and minimum values of imposed loads, to determine the most unfavourable effect.

4. HYDROSTATIC LOADS

Hydrostatic loads act in a direction normal to the contact surface; they may be external or internal. Further information is given in Section 5. Hydrostatic loads have been treated separately because they can usually be determined with a high degree of accuracy, and when limit state design methods are used hydrostatic loads may justify a lower partial safety factor than imposed loads.

5. ENVIRONMENTAL LOADS

Environmental loads are random in character and extreme magnitudes can be predicted only on a probability basis.

Environmental loads result from:

- Wind
- Wave
- Current
- Marine growth
- Snow and ice.

Special considerations apply to thermal loads and these are included in Section 6.

5.1 WIND

The wind force developed on an Installation or its elements may be calculated by the methods recommended in British Standards Institution CP3(4), or on the basis of reliable wind tunnel observations which should always be made in respect of structures of unusual shape and / or size. Values of wind speeds are given in Offshore Technology Report OTO 2001 010, and the following averaging periods should be adopted:

- Category A (3 second): Individual members and equipment secured to them on open decks.
- Category B (5 second): Parts or the whole of the superstructure above the lowest still water level whose greatest dimension horizontally or vertically does not exceed 50m.
- Category C (15 second): Parts or the whole of the superstructure above the lowest still water level whose greatest dimension horizontally or vertically exceeds 50m.
- Category D (1 minute): The exposed superstructure regardless of dimension, to be used when determining the wind forces in combination with other design extreme environmental loads.

For slender members and dynamically sensitive structures consideration should be given to dynamic response and fatigue loading due to the wind gust spectrum and vortex shedding effects. Further information can be found in Report OTO 88 021(5).

It should be noted that the wind values given in OTO 2001 010 are based on the logarithmic profile with height, whereas information given in BS8100(6) and CP3 are based on power law profiles. The logarithmic profile is more soundly based for use on offshore Installations; however the forces resulting from the use of either profile are similar.

5.1.1 Wind loads on flare booms/towers

For towers located on fixed or mobile Installations the wind loads may be calculated on the basis of BS 8100(6). However, BS 8100 is limited to land based towers and consequently additional criteria are required to account for items such as gust response, wind structure over the sea, safety factors, interference with wave/topsides, etc.

Special consideration should be given to the interaction effects of maximum wind loading on flare booms and loadings due to the accelerations produced by motions of mobile Installations.

5.2 WAVES AND CURRENT

The hydrodynamic phenomena which give rise to loading on structural members are complex, especially in view of the random nature of wave and current conditions in the sea. The methods evolved to estimate these loads involve simplifying assumptions. The methodology in this section is based on widely used practice and in the case of overall structure load involves a ‘package’ of inter-dependent assumptions which are considered to provide estimates of sufficient accuracy for design purposes.

The development of more advanced methods which aim to rationalise these assumptions is to be encouraged. Attempts to rationalise any particular aspect should only be made with due consideration of the implications of the ‘package’ as a whole, ie. to ensure that there will be no systematic and unjustified reduction in overall factors of safety inherent in the methods described here.

When assessing the fluid loading on a structure, combinations of the following should be considered in order to identify the worst load effects associated with a 50 year return period (see also OTO 2001 010):

- **Wave or seastate height.**
- **Wave length (wave period), or mean zero crossing period.** The ratio of wave length to the spacing of structural members affects the phasing of loading on different parts of the structure. Wave length also affects the decay of water particle orbit size and hence wave loading with depth. The ratio of wave frequency to structural natural frequencies affects the dynamic magnification of the structure’s response. Consequently, total forces and member forces can be very sensitive to these parameters which should be selected with care.
- **Wave phase angle** (location of wave crest relative to the structure).
- **Wave direction**.
- **Current speed, direction and profile**. Current significantly increases the extreme total loading on some structures.
- **Water level**. The choice of water level should take account of the effect of water level on: wave kinematics, maximum possible wave height when wave height is limited by water depth and the amount of structure subject to fluid loading.
- **Wind speed and direction.**

When assessing loadings for fatigue analysis, studies indicate that, in general, current velocities have little effect on fatigue life and may be ignored except in areas of high current velocity.

The calculated load on the structure based on the above parameters should include the total load given by Morison’s equation (or diffraction loading if applicable), buoyancy, vortex shedding, impulsive wave slam or slap and wind loading.

Owing to the lack of correlation of the vortex shedding loads over the structure, it will usually only be necessary to consider the fluctuating effect of vortex shedding for local member design and adjacent member interaction. The same is also true of impulsive wave slam or slap loads.

The initial response to impulsive wave slam or slap usually occurs before a member is significantly immersed. Therefore, other fluid loading on a member need not be applied with the impulsive load. However, structural continuity will result in simultaneous loading on other members affecting the impulsively loaded member (ie. include stresses caused by space frame deflections when assessing a member).

Detailed technical information on wave and current loads is given below for rigid structures, ie. for structures in which structural deflections do not alter the hydrodynamic loads. For slender members and compliant structures further considerations of relative movement apply, and these are not addressed in this report.

The treatment of hydrodynamic loading and the analysis procedure for determining structural response to the loading are inextricably linked, therefore the remainder of this section also includes information on deterministic and probabilistic analysis and the prediction of extreme and fatigue responses to wave and current loads.

5.2.1 Determination of particle kinematics

When choosing the design seastate, advantage may be taken of the predominant direction of the extreme wave if the directional distribution can be predicted with confidence. For the purposes of determining particle kinematics, the seastate can be modelled by regular or random waves. However, particular care is required for steep waves and in the free surface zone.

a) Regular waves

An appropriate regular wave theory to be used for the calculation of particle kinematics may be selected using Figure 1 or Figure 2.

b) Random waves

A random sea may be represented by a time history of water surface elevation having the required spectral characteristics or, in the frequency domain, by a spectral density function of surface elevation with random phases between the components. The spectral density function can be represented either as a ‘continuous’ function of frequency or as a number of discrete regular linear waves.

c) Wave and current combination

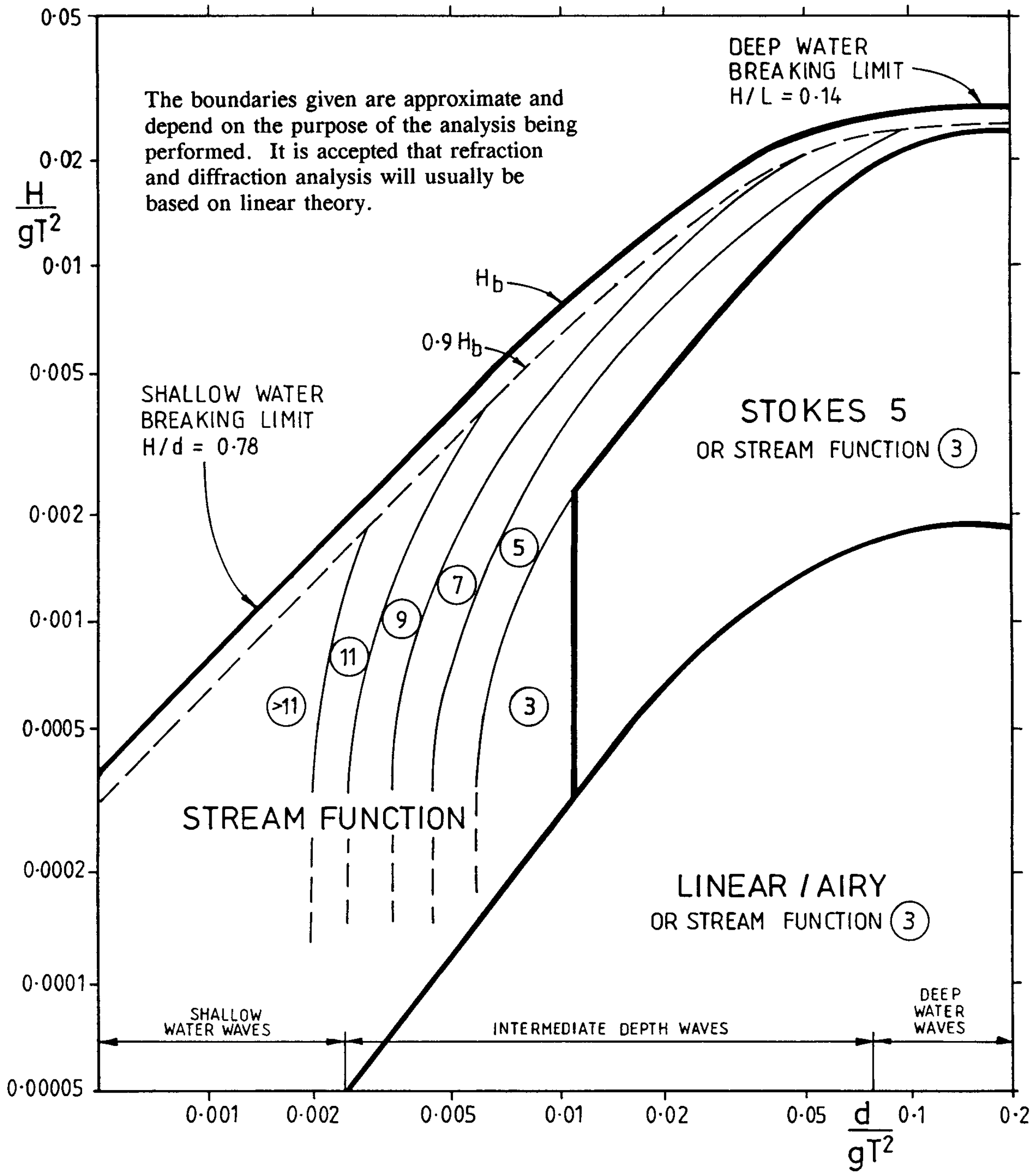
Current profiles are given in OTO 2001 010.

A variety of techniques exists for modifying the current profile in the presence of a wave. These are described in the background documents (OTH 89 299(7) and OTH 89 300(8)).

Wave particle velocities and current velocities should be added vectorially. The modification of the wavelength/wave period relationship by currents is generally small and may therefore be ignored.

d) Breaking waves

Since breaking waves may give rise to high local slap pressures and severe overall loads, the likelihood of exposure to breaking waves should be determined (see OTO 2001 010).

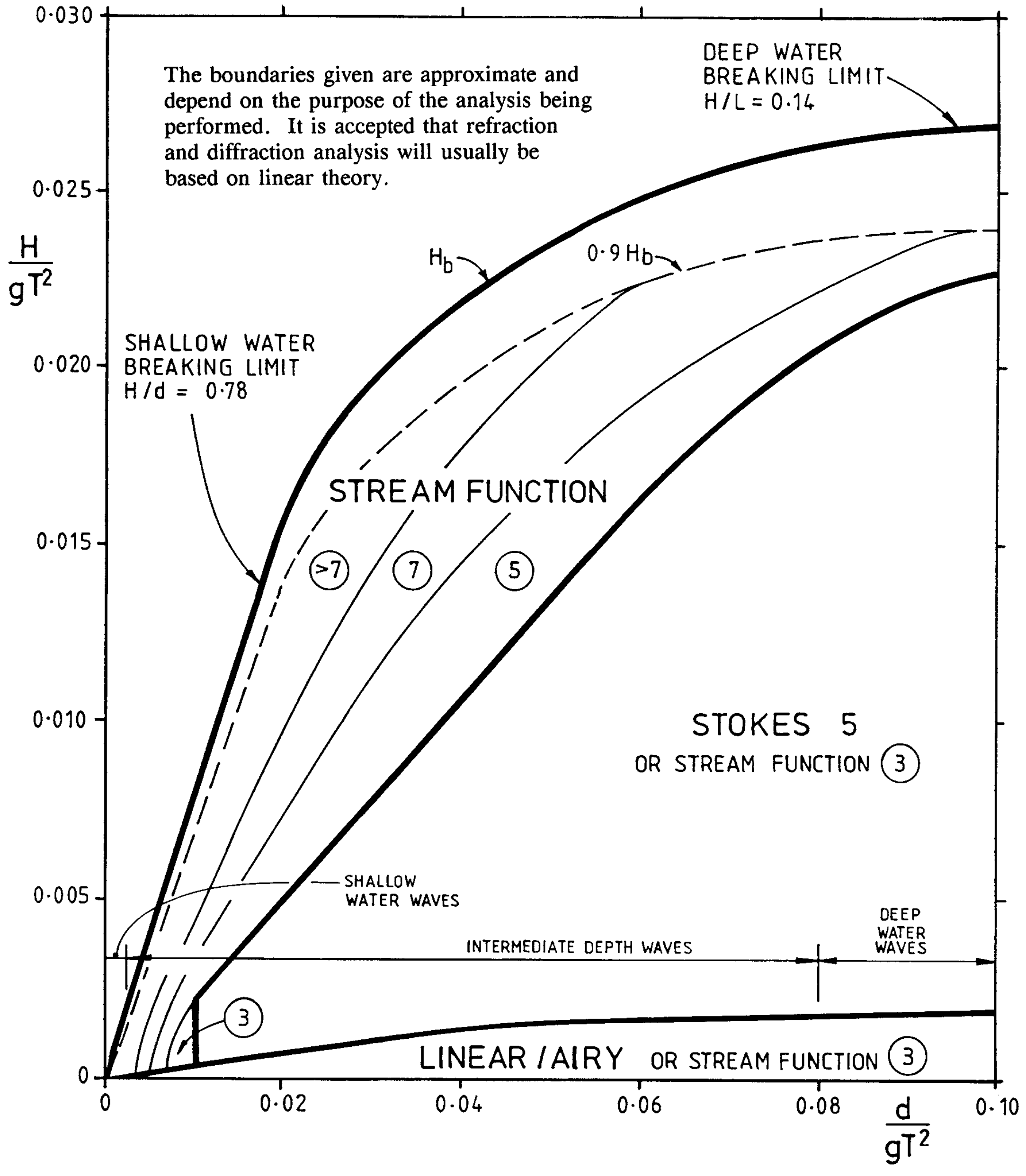


The boundaries given are approximate and depend on the purpose of the analysis being performed. It is accepted that refraction and diffraction analysis will usually be based on linear theory.

Nomenclature for Figures 1 and 2

H/gT^2 = Dimensionless wave steepness
d/gT^2 = Dimensionless relative depth
H = Wave height (crest to trough)
H_b = Breaking wave height
d = Mean water depth
T = Wave period
L = Wave length (distance between crests)
g = Acceleration due to gravity

Figure 1 Regular wave theory selection diagram (log scales)



The boundaries given are approximate and depend on the purpose of the analysis being performed. It is accepted that refraction and diffraction analysis will usually be based on linear theory.

Figure 2 Regular wave theory selection diagram (linear scales)

Notes for Figures 1 and 2

1) None of these theories is theoretically correct at the breaking limit
2) Wave theories intended for limiting height waves should be referenced for waves higher than 0.9 H_b when stream function theory may underestimate the kinematics.
3) Stream function theory is satisfactory for wave loading calculations over the remaining range of regular waves. However, stream function programs may not produce a solution when applied to near breaking waves or deep water waves.
4) The order of stream function theory likely to be satisfactory is circled. Any solution obtained should be checked by comparison of the results with a higher order solution.
5) The error involved in using Airy theory outside its range of applicability is discussed in the background document OTH 89 300(8).

5.2.2 Member hydrodynamic and hydrostatic loading

When assessing the hydrodynamic and hydrostatic forces on an individual member, the following should be considered:

- Average drag forces over a vortex shedding cycle
- Inertia forces (or Froude Krylov and diffraction forces)
- Average lift forces over a vortex shedding cycle
- Fluctuating drag and lift forces due to vortex shedding
- Wave reflection
- Slam forces
- Slap forces
- Hydrostatic and hydrodynamic pressure

a) Drag (mean) and inertia forces

Drag forces are caused by viscosity resulting in flow separation and the shedding of vortices from the member. The mean drag force over a vortex shedding cycle is represented by the drag term in Morison's equation (see below).

Inertia forces are related to the acceleration of the incident flow and the modification of the incident wave pattern by the member. They are usually calculated assuming inviscid irrotational flow. In practice the viscosity of the fluid can modify the inertia force from the value calculated for inviscid flow. This change may be taken into account by using experimental results.

If the member cross-section dimension is less than about one fifth of the wave length then the structure has a negligible effect on the incident wave pattern and the acceleration is approximately uniform in the vicinity of the structure. In this case the inertia force can be calculated using the inertia term in Morison's equation below.

b) Morison's equation

$$F = F_d + F_i = \tfrac{1}{2} C_d \rho \, D \left| U \right| U + C_m \rho \, A \, \dot{U}$$

where:

F is the instantaneous combined drag plus inertia force per unit length resolved normal to the member axis (N/m)

F_d is the instantaneous drag force per unit length resolved normal to the member axis (N/m)

F_i is the instantaneous inertia force per unit length resolved normal to the member axis (N/m)

C_d is the drag coefficient

ρ is the density of water (kg/m^3)

D is the member diameter or characteristic cross-sectional dimension (m)

$|U|$ is the modulus of the instantaneous velocity of the incident flow resolved normal to the axis of the member (m/sec)

U is the instantaneous velocity of the incident flow resolved normal to the axis of the member (m/sec)

C_m is the inertia coefficient

A is the member cross-sectional area (m^2)

$\dot{U}$ is the instantaneous acceleration of the incident flow resolved normal to the axis of the member (m/sec^2).

Note: D and A should include an allowance for marine growth where applicable.

c) *Selection of drag and inertia coefficients for circular cylinders for use with Morison's equation*

Research has shown C_d and C_m to be affected in a complex way by Reynolds number, Keulegan-Carpenter number, surface roughness, type of flow (steady or oscillating) and member inclination. A discussion of these aspects can be found in the background document (OTH 89 300(8)) together with recommended values of C_d and C_m based on research findings.

In practice C_d values significantly lower than those predicted from research may be selected for design in order to compensate for over-conservative assumptions which are made elsewhere in the design process.

If the following conservative assumptions are made:

i) Waves are long crested (i.e. unidirectional)
ii) Water particle motions are calculated by regular wave theories
iii) No shielding effects on the structure are included
iv) Independent extreme values of wave and current are combined (extreme loading only)

then drag coefficients lower than those predicted by research may be used but they should not normally be less than the following:

- $C_d = 0.7$ (marine growth)
- $C_d = 0.6$ (no marine growth)
- $C_m = 1.7$ (extreme conditions)
- $C_m = 2.0$ (fatigue conditions).

For extreme loading the low value of C_d is balanced mainly by item (iv) above. This is satisfactory for global horizontal loading, but because the overestimate of current has little effect on vertical loads, these may be underestimated. Consideration should, therefore, be given to using more realistic values of C_d for the vertical loading on horizontal and inclined members.

For fatigue loading the low C_d value is partly balanced by the use of a higher than realistic C_m value and partly by the conservative assumptions (i) to (iii) above.

If a more advanced analysis is attempted which removes one or more of the simplifying assumptions, (i) to (iii) above, then more realistic C_d and C_m values should be considered. (Information is given in the background document to assist the selection of more realistic values.)

d) Diffraction effects

Members having solid cross-sectional dimensions greater than one fifth of a wave length will diffract the incident waves. The effect on the structural loading should be estimated by linear diffraction analysis as the sum of a Froude Krylov and diffraction force.

The Froude Krylov force is found by integrating the pressures, calculated to be within the incident wave, over the surface of the structure without allowing for the effect of the structure on the incident wave.

The diffraction force is the additional force that is exerted on a fixed structure in inviscid flow by the local modification of the flow pattern around the member and the changes in the wave pattern caused by the presence of the member.

In deep water the results of a linear diffraction analysis may be applied directly. For steep waves in intermediate and shallow water depths the results may not be directly applicable, owing to the limitations of linear wave theory (which underestimates accelerations and overestimates wave length). Therefore, some correction should be applied.

Some structures have small members (D/L less than 5) as well as larger members (D/L greater than 5) which diffract the waves. It is then necessary to consider the effect on kinematics of diffraction due to the larger members when calculating loads on the smaller members using Morison's equation.

The effect of a current is usually small and is often ignored. Diffraction calculations do not include drag loading on the diffraction members. These loads, if significant, should be calculated on the basis of Morison's equation and the incident (not diffracted) waves.

Diffraction loading may be calculated using Morison's Equation with the inertia coefficient modified, to allow for diffraction, on the basis of published data. If based on data for a single member, but applied to a structure composed of several members, then the method does not allow for interference effects which may be important. It should be noted that this method does not allow for the change in phase of the loading which occurs when the member diameter is large.

e) Interference Effects

Interference effects between groups of members may increase or decrease the load on the group as a whole and on individual members within a group.

Interference effects may be associated with the incident flow on some members being directly modified by the presence of other members in the group. Generally interference effects on the total load acting on a group of members need not be considered. However, the possibility of increased load on individual members, such as risers, conductors and attachments, should be taken into account when checking those members.

If an attachment does not stand off from a member then the member should be treated as having a modified shape which includes the attachment.

It is accepted practice to take account of anodes by increasing the C_d value for members with anodes attached.

f) Lift forces and fluctuating drag forces

Lift and drag forces are caused by a periodic shedding of vortices from the member. Unlike the drag force the average lift force, for a symmetrical member, is usually zero. The fluctuation in drag and lift forces, as vortices are shed, may cause slender members (e.g. caissons, risers and conductors) to vibrate. Resonant oscillations may occur if a member has a natural frequency, f_n, close to a vortex shedding frequency.

The oscillations may be either in-line with the flow or transverse to the flow, depending on the value of the incident velocity. In-line oscillations may occur for incident velocities in the range $1.2f_nD$ to $3.5f_nD$. Transverse oscillations may occur for incident velocities in the range $3.5f_nD$ to the onset of the next mode of oscillation. Several modes may need to be investigated. The response of the member to vortex shedding depends on its damping characteristics.

Vortex-shedding-induced oscillations are likely to become significant if the incident velocity exceeds the design current.

Whilst there is some experimental evidence that waves may induce vortex shedding oscillations, no problems have been found on existing jacket structures and at present there is no generally accepted procedure for assessing the resulting response amplitude. The effect of wave induced vortex shedding on jacket structures may therefore be ignored.

Attachments may cause high, steady, lift forces on the member to which they are attached. This force may be of similar magnitude to the drag force on the member over the length of the attachment.

Attachments and members may also be subject to buffeting by vortices shed from other parts of the structure.

g) Wave reflection

Wave reflection will occur when the wave length is smaller than the member size. It may, however, be treated as a special case of diffraction.

h) Wave slam and slap

Slam forces occur when a wave engulfs a horizontal or gently sloping member, causing a volume of water to be decelerated by the member. Slap forces are similar to slam forces but refer to a breaking wave front meeting an approximately parallel member. Both types of loading are impulsive and the member responds dynamically. The dynamic amplification of the response to the impulsive force and the number of stress cycles for each wave slam or slap should be taken into account.

Loading and dynamic responses from wave slam and slap may be assessed by reference to NMI Report OTR 82113(9), or the background document (OTO 89 300(8)) which contains information from the NMI report.

i) Hydrostatic and hydrodynamic pressure

Hydrostatic pressure is ρgz where z is the depth from the still water surface to the point being considered.

The resultant hydrostatic force on a member is the buoyancy force. However, if member stresses are to be calculated, it is preferable to work from the hydrostatic pressure distribution.

Free flooding members near the free surface may not be capable of flooding and emptying during a wave cycle. Any additional loading from these effects should be allowed for in the analysis.

Hydrodynamic pressure on constantly immersed surfaces may be taken as the sum of the Froude Krylov force, diffraction effects and pressures associated with flow separation which cause drag and lift forces.

Pressures from wave slam and slap are difficult to determine and are subject to considerable scatter. Damage has been observed to columns of semi-submersibles showing that considerable pressures can occur and that local and overall integrity of the structure should be checked (see also the background document OTO 89 300(8).)

j) Loads on items in the air gap

The effects of possible fluid loading on items situated in the air gap should be considered as follows.

In lieu of a more detailed analysis, it may be assumed that the particle kinematics in the air gap are the same as for the crest of a 50-year return period wave.

The local effects of fluid loading on all items in the air gap should be considered using the factor of safety appropriate for storm conditions.

Global effects of fluid load on items in the air gap need only be considered if the item is substantial in relation to the main structural members immediately below the air gap. In such cases reduced safety factors may be used provided the probability of structural failure is kept to an acceptable level.

k) Methods of calculating response to extreme loading

Deterministic methods are the simplest techniques to use for the analysis of extreme loads and they are adequate for the majority of offshore structures.

Other methods are:

- Semi-probabilistic
- Spectral
- Random wave time history.

A detailed discussion of these can be found in the background document (OTO 89 200(8)).

A deterministic analysis is based on extreme waves having the 50 year return height and a range of wave periods and directions in conjunction with a 50 year current. In a deterministic analysis the following maximum forces are identified by analysing the wave passing through the structure:

- Maximum horizontal force applied to the whole structure

- Maximum overturning moment applied to the whole structure
- Maximum vertical forces on horizontal frames.

When a steep wave loads a structure it is possible to obtain more than one peak load during the passage of a wave. In these cases it is necessary to identify the largest peak load.

It is normal practice to base the structural checks on these maximum load cases. However, maximum load effects in individual members at phases other than those for peak overall loading should be considered if these are likely to be significant.

It should be noted that there may be realistic combinations of wave height and period other than those associated with the normally specified return period wave height which can generate large loads on the structure. These cases will require a more detailed investigation.

l) Methods of calculating response to fatigue loads

Fatigue analysis requires the calculation of the long term stress range distribution.

For fatigue calculations, it is necessary to select wave or sea state heights, periods and direction, current speed and direction and water level. The fatiguing effects of Morison or diffraction loading, vortex shedding, wave slam and wave slap need to be added together. The effect on fatigue life of the relative timing of the various load types should be taken into account (i.e. the total stress range, taking into account the various load types, should be used to assess the fatigue life).

When fatigue damage arises from other loading conditions, such as transportation, this should be added to the in-situ fatigue damage.

m) Deterministic fatigue analysis

Deterministic methods represent the random sea by a number of regular waves. Each wave has a height, period and defined number of occurrences per year.

The distribution of wave heights from each of typically 4 to 8 directions relative to the structure is found from the environmental data (see OTO 2001 010). The height range is divided into a number of bands and a wave period is chosen as representative of each wave height band.

Ideally the representative wave period should be selected to give the same damage as the range of periods of the waves in that height band, though in most cases it is only possible to choose periods which represent the waves and not the fatigue damage caused by them. This may produce inaccuracies because of the sensitivity of all types of hydrodynamic loading to wave length and period.

The structure is analysed statically, or if appropriate dynamically, for the stress range associated with each representative wave and the fatigue life calculated.

n) Semi-probabilistic fatigue analysis

The semi-probabilistic method is a more advanced deterministic analysis method in which the random sea is replaced by its constituent waves. It overcomes the problem associated with the simple deterministic method of choosing suitable wave periods by using an individual wave scatter diagram showing occurrences of individual wave heights and periods. A range of wave periods is selected, then wave heights and occurrences are calculated which will represent the fatigue damage occurring at each wave period.

This method is suitable for the fatigue analysis of the effects of Morison loading, diffraction loading, vortex shedding and wave slap. However, the occurrences vary rapidly in the breaking area and, therefore, the estimates for wave slap should be treated cautiously.

If wave induced resonance is considered to be significant, the spectral method is preferable.

o) Spectral fatigue analysis

The method calculates the long term distribution of stress range by maintaining the randomness of the real sea and the structural response throughout the calculations.

The method assumes that:

- The effects of different wave frequencies in a sea state can be combined by linear superposition.
- For any given wave frequency and direction within a sea state, the load effect is linearly proportional to wave amplitude (or height). Therefore a relationship between load effect per unit wave amplitude and wave frequency (known as a transfer function) may be defined.

Conveniently, fatigue damage is dominated by small waves in which drag loading plays a smaller part than in extreme waves. Nevertheless, drag loading will still be significant for many structures and the wave height, chosen for the generation of the transfer functions, should represent the amount of drag loading that is causing fatigue damage.

p) Comparison of fatigue analysis methods

The spectral method is the only method that can take into account directional spreading within a sea state. In addition when there is a resonant dynamic response of the structure it is the only method which can properly take into account the filtering effect of the sharp peak in the mechanical admittance function (i.e. dynamic response divided by static response). However, where shallow water effects are important for fatigue waves a deterministic analysis may well be more accurate than a spectral method. (See OTO 2001 010 for conditions when shallow water effects need to be considered).

5.3 MARINE GROWTH

Information on the extent of marine growth is given in OTO 2001 010.

Extensive marine growth will increase the section area of a member and alter its surface characteristics, both changes tending to increase resistance to waves and currents and to alter the values of drag and inertia coefficients (see Section 5.2).

5.4 SNOW AND ICE

Information on the accumulations of snow and ice on Offshore Installations is given in OTO 2001 010. Account should be taken of the consequential increase in gravity loading, effect on stability and increase in area and drag factors in wind.

5.5 COMBINATIONS OF ENVIRONMENTAL PARAMETERS FOR DESIGN

In considering the appropriate combination of environmental parameters for determining extreme load conditions, account should be taken of the guidance given in OTO 2001 010 on the simultaneous occurrence of the several extreme parameters, subject to the following notes:

- Information on the combination of wave effects and current effects when calculating hydrodynamic loads is given in Section 5.2.
- Both minimum and maximum values of certain parameters may need to be considered to establish the critical design cases.
- The wind used in combination with the extreme wave and current load is the one minute mean speed, Category D (see Section 5.1).

6. DEFORMATION LOADS

Deformation loads are loads associated with imposed deformations and imposed strains.

Thermal stress and deformations result from temperature differences between different areas of the structure. Under North Sea conditions gradients of up to 40°C (corresponding, say, to the difference between the external structure at -10°C and adjacent internal accommodation or machinery space at 30°C) might coincide with severe wave conditions in a winter storm (see OTO 2001 010). An extreme temperature gradient of approximately 45°C may arise if hot oil is stored in a compartment that is externally in contact with sea water. For thermal effects on concrete, see UEG (UTN9) 1976(10) and UEG (URM) 1980(11)). For temperature effects on steel structures, see Ossowska, (1964)(12) and the US Department of Commerce(13).

For loads associated with shrinkage and creep in concrete, see Offshore Technology Report OTO 2001 046.

Deformation loads also result from certain construction sequences, lack of fit during fabrication and weld shrinkage.

Deformation loads are static loads which induce self-cancelling internal loads. For structures with adequate ductility these loads have reduced or negligible effect on structural integrity. For non-ductile components the full effect of deformation loads should be considered in design.

7. ACCIDENTAL LOADS

7.1 GENERAL

Offshore Installations should be planned with due regard to the possibility of accidental loading and damage arising from accidental events, such as collision, dropped objects, fire and explosion and other abnormal events.

The Installation should be so designed and, if necessary, protected that the consequences of damage are acceptable and that an adequate margin of safety against collapse is maintained.

7.2 VESSEL COLLISION

Accidental damage should be considered for all exposed elements of an Installation in the collision zone. The vertical extent of the collision zone should be assessed on the basis of visiting vessel draft, maximum operational wave height and tidal elevation.

7.2.1 Accidental impact energy

a) Total kinetic energy

The total kinetic energy involved in accidental collisions can be expressed as:

$$E = \tfrac{1}{2} amV^2$$

where

m = vessel displacement (kg)
a = vessel added mass coefficient
= 1.4 for sideways collision
= 1.1 for bow or stern collision
V = impact speed (m/s).

The total kinetic energy, E, should be taken to be at least:

- 14 MJ for sideways collision or
- 11 MJ for bow or stern collisions

which corresponds to a vessel of 5000 tonnes displacement with an impact speed of 2 m/s. A reduced impact energy may be acceptable in cases where the size of visiting vessels and / or their operations near the Installation are restricted. In this instance a reduced vessel size and / or reduced impact speed may be considered.

The reduced impact speed, V, in metres per second may be estimated numerically from the empirical relation:

$$V = \tfrac{1}{2} H_s \ \text{(m/s)}$$

where H_s = maximum permissible significant wave height in metres for vessel operations near to the Installation (see OTI 88 535[(14)]).

b) Energy absorbed by the structure

The energy absorbed by the Installation during a collision impact will be less than or equal to the total impact kinetic energy, depending on the relative stiffness of the relevant parts of the Installation and the impacting vessel that come in contact, the mode of collision and vessel operation. These factors may be taken into account when considering the energy absorbed by the Installation.

For a fixed steel jacket structure it is recommended that the energy absorbed by the Installation should not be taken to be less than 4 MJ, unless a study of the collision hazards and consequences specific to the Installation demonstrates that a lower value is appropriate. Examples could be small occasionally manned and infrequently supplied Installations, or where there is a restriction on the size of visiting vessels.

If the vessel size is less than 5000 tonnes displacement then the minimum energy to be absorbed by the Installation may be reduced to a value given by:

$$0.5 + m^2(4.2 \times 10^{-7} - 5.6 \times 10^{-11}\, m) \;\; \text{MJ}$$

where m is the displacement of the vessel in tonnes (see OTI 88 535[(14)], Section 5.7.2.).

The energy absorbed by the Installation may be taken to be less than this value if the stiffness of the impacted part of the Installation is very large in comparison to that of the impacting part of the vessel, as for example in collisions involving concrete Installations or fully grouted Installation elements. In such cases the effects of impact loading should be considered, as detailed below.

7.2.2 Accident impact loading

In cases where the stiffness of the impacted part of the Installation is very large in comparison to that of the impacting part of the vessel, as for example in collisions involving concrete Installations or fully grouted elements, the impact energy absorbed locally by the Installation may be very low and it is important to examine damage caused by the impact force.

In such cases, the impact force, F, may be taken as:

$$F = P_o \text{ or } V\sqrt{(cam)}, \text{ whichever is the less}$$

where

P_o = the minimum crushing strength (or punching shear as appropriate) of the impacting part of the vessel and the impacted part of the Installation (MN)

c = stiffness of the impacting part of the vessel (MN/m)

V, m and a are as defined in Section 7.2.1(a).

7.2.3 Consequences of damage

The primary structure should be designed to ensure that accidental damage does not cause complete collapse. Damaged members should be considered to be totally ineffective unless it can be shown by analysis or tests that they retain residual load-carrying capacity.

8. LOADS IN COMBINATION

8.1 GENERAL

The structure should have adequate resistance to sliding, overturning and structural failure under the most adverse combination of dead, imposed, hydrostatic, environmental, deformation and accident loadings that may occur on the structure, as detailed below. Account should be taken of the augmented stresses due to dynamic loading. Each variable load should be assumed to have that value and position within its possible range that will minimise the margin of resistance to the mode of failure under examination.

8.2 EXTREME CONDITIONS

Guidance on the coincidence of environmental conditions to be assumed in design is set out in Section 5. The extreme environmental conditions should be combined with dead, imposed, hydrostatic and, where appropriate, deformation loads. Advantage may be taken of any possibility of reducing loads significantly by suspending operations or by taking other measures.

8.3 OPERATING CONDITIONS

The owner may specify the most severe environmental conditions during which operations will be allowed to continue. These environmental conditions should be combined with the consequent dead, imposed, hydrostatic and, where appropriate, deformation loads. Otherwise the guidance for extreme conditions will apply.

8.4 ACCIDENT CONDITIONS

The accidental loads set out in Section 7 should be combined with dead, imposed, hydrostatic, environmental and, where appropriate, deformation loads. The environmental conditions and operational conditions should be consistent with the assumed accidental event.

In the post-accident condition the dead, imposed, hydrostatic, environmental and deformation loads are to be combined. After a design case accident the structure should be able to withstand environmental loads with a return period of at least 1 year.

9. OPERATIONAL DATA (LOADS)

The following items referring to loads should be available to personnel on the Installation:

- Any limits to or other precautions about additional loading arising from functional activities of the Installation, such as drilling, production and storage.
- Any limits on the weight and disposition of variable and consumable stores, number of people on board and their personal effects and living stores.
- Limiting weather conditions, sea states, speed, trim, load, etc.
- The increased diameter allowed for marine growth in the design.
- Information in respect of fixed installations on the suspension of operations or other measures which can be taken to reduce loading under severe combinations of environmental conditions.
- Information in respect of mobile Installations on altering loads, trim, freeboard, orientation and mooring systems while afloat, so as to minimise loading due to severe combinations of environmental conditions.
- The maximum variable load that may be carried by a mobile Installation in transit, its disposition on board and the draft appropriate to specific wind / sea states.

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