



Guidance for Long-term Hydro-structure Calculations

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**Rule Note
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GENERAL CONDITIONS

1. INDEPENDENCE OF THE SOCIETY AND APPLICABLE TERMS

- 1.1 The Society shall remain at all times an independent contractor and neither the Society nor any of its officers, employees, servants, agents or subcontractors shall be or act as an employee, servant or agent of any other party hereto in the performance of the Services.
- 1.2 The operations of the Society in providing its Services are exclusively conducted by way of random inspections and do not, in any circumstances, involve monitoring or exhaustive verification.
- 1.3 The Society acts as a services provider. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty. The Society is not and may not be considered as an underwriter, broker in Unit's sale or chartering, expert in Unit's valuation, consulting engineer, controller, naval architect, designer, manufacturer, shipbuilder, repair or conversion yard, charterer or shipowner; none of them above listed being relieved of any of their expressed or implied obligations as a result of the interventions of the Society.
- 1.4 The Society only is qualified to apply and interpret its Rules.
- 1.5 The Client acknowledges the latest versions of the Conditions and of the applicable Rules applying to the Services' performance.
- 1.6 Unless an express written agreement is made between the Parties on the applicable Rules, the applicable Rules shall be the Rules applicable at the time of entering into the relevant contract for the performance of the Services.
- 1.7 The Services' performance is solely based on the Conditions. No other terms shall apply whether express or implied.

2. DEFINITIONS

- 2.1 "Certificate(s)" means classification or statutory certificates, attestations and reports following the Society's intervention.
- 2.2 "Certification" means the activity of certification in application of national and international regulations or standards, in particular by delegation from different governments that can result in the issuance of a Certificate.
- 2.3 "Classification" means the classification of a Unit that can result or not in the issuance of a classification Certificate with reference to the Rules. Classification is an appraisalment given by the Society to the Client, at a certain date, following surveys by its surveyors on the level of compliance of the Unit to the Society's Rules or to the documents of reference for the Services provided. They cannot be construed as an implied or express warranty of safety, fitness for the purpose, seaworthiness of the Unit or of its value for sale, insurance or chartering.
- 2.4 "Client" means the Party and/or its representative requesting the Services.
- 2.5 "Conditions" means the terms and conditions set out in the present document.
- 2.6 "Industry Practice" means international maritime and/or offshore industry practices.
- 2.7 "Intellectual Property" means all patents, rights to inventions, utility models, copyright and related rights, trade marks, logos, service marks, trade dress, business and domain names, rights in trade dress or get-up, rights in goodwill or to sue for passing off, unfair competition rights, rights in designs, rights in computer software, database rights, topography rights, moral rights, rights in confidential information (including know-how and trade secrets), methods and protocols for Services, and any other intellectual property rights, in each case whether capable of registration, registered or unregistered and including all applications for and renewals, reversions or extensions of such rights, and all similar or equivalent rights or forms of protection in any part of the world.
- 2.8 "Parties" means the Society and Client together.
- 2.9 "Party" means the Society or the Client.
- 2.10 "Register" means the public electronic register of ships updated regularly by the Society.
- 2.11 "Rules" means the Society's classification rules and other documents. The Society's Rules take into account at the date of their preparation the state of currently available and proven technical minimum requirements but are not a standard or a code of construction neither a guide for maintenance, a safety handbook or a guide of professional practices, all of which are assumed to be known in detail and carefully followed at all times by the Client.
- 2.12 "Services" means the services set out in clauses 2.2 and 2.3 but also other services related to Classification and Certification such as, but not limited to: ship and company safety management certification, ship and port security certification, maritime labour certification, training activities, all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board. The Services are carried out by the Society according to the applicable referential and to the Bureau Veritas' Code of Ethics. The Society shall perform the Services according to the applicable national and international standards and Industry Practice and always on the assumption that the Client is aware of such standards and Industry Practice.
- 2.13 "Society" means the classification society 'Bureau Veritas Marine & Offshore SAS', a company organized and existing under the laws of France, registered in Nanterre under number 821 131 844, or any other legal entity of Bureau Veritas Group as may be specified in the relevant contract, and whose main activities are Classification and Certification of ships or offshore units.
- 2.14 "Unit" means any ship or vessel or offshore unit or structure of any type or part of it or system whether linked to shore, river bed or sea bed or not, whether operated or located at sea or in inland waters or partly on land, including submarines, hovercrafts, drilling rigs, offshore installations of any type and of any purpose, their related and ancillary equipment, subsea or not, such as well head and pipelines, mooring legs and mooring points or otherwise as decided by the Society.

3. SCOPE AND PERFORMANCE

- 3.1 Subject to the Services requested and always by reference to the Rules, the Society shall:
- review the construction arrangements of the Unit as shown on the documents provided by the Client;
 - conduct the Unit surveys at the place of the Unit construction;
 - class the Unit and enter the Unit's class in the Society's Register;
 - survey the Unit periodically in service to note whether the requirements for the maintenance of class are met.
- The Client shall inform the Society without delay of any circumstances which may cause any changes on the conducted surveys or Services.
- 3.2 The Society will not:
- declare the acceptance or commissioning of a Unit, nor its construction in conformity with its design, such activities remaining under the exclusive responsibility of the Unit's owner or builder;
 - engage in any work relating to the design, construction, production or repair checks, neither in the operation of the Unit or the Unit's trade, neither in any advisory services, and cannot be held liable on those accounts.

4. RESERVATION CLAUSE

- 4.1 The Client shall always: (i) maintain the Unit in good condition after surveys; (ii) present the Unit for surveys; and (iii) inform the Society in due time of any circumstances that may affect the given appraisalment of the Unit or cause to modify the scope of the Services.
- 4.2 Certificates are only valid if issued by the Society.
- 4.3 The Society has entire control over the Certificates issued and may at any time withdraw a Certificate at its entire discretion including, but not limited to, in the following situations: where the Client fails to comply in due time with instructions of the Society or where the Client fails to pay in accordance with clause 6.2 hereunder.
- 4.4 The Society may at times and at its sole discretion give an opinion on a design or any technical element that would 'in principle' be acceptable to the Society. This opinion shall not presume on the final issuance of any Certificate or on its content in the event of the actual issuance of a Certificate. This opinion shall only be an appraisal made by the Society which shall not be held liable for it.

5. ACCESS AND SAFETY

- 5.1 The Client shall give to the Society all access and information necessary for the efficient performance of the requested Services. The Client shall be the sole responsible for the conditions of presentation of the Unit for tests, trials and surveys and the conditions under which tests and trials are carried out. Any information, drawing, etc. required for the performance of the Services must be made available in due time.
- 5.2 The Client shall notify the Society of any relevant safety issue and shall take all necessary safety-related measures to ensure a safe work environment for the Society or any of its officers, employees, servants, agents or subcontractors and shall comply with all applicable safety regulations.

6. PAYMENT OF INVOICES

- 6.1 The provision of the Services by the Society, whether complete or not, involve, for the part carried out, the payment of fees thirty (30) days upon issuance of the invoice.

6.2 Without prejudice to any other rights hereunder, in case of Client's payment default, the Society shall be entitled to charge, in addition to the amount not properly paid, interests equal to twelve (12) months LIBOR plus two (2) per cent as of due date calculated on the number of days such payment is delinquent. The Society shall also have the right to withhold Certificates and other documents and/or to suspend or revoke the validity of Certificates.

- 6.3 In case of dispute on the invoice amount, the undisputed portion of the invoice shall be paid and an explanation on the dispute shall accompany payment so that action can be taken to solve the dispute.

7. LIABILITY

- 7.1 The Society bears no liability for consequential loss. For the purpose of this clause consequential loss shall include, without limitation:
- Indirect or consequential loss;
 - Any loss and/or deferral of production, loss of product, loss of use, loss of bargain, loss of revenue, loss of profit or anticipated profit, loss of business and business interruption, in each case whether direct or indirect.
- The Client shall defend, release, save, indemnify, defend and hold harmless the Society from the Client's own consequential loss regardless of cause.
- 7.2 Except in case of wilful misconduct of the Society, death or bodily injury caused by the Society's negligence and any other liability that could not be, by law, limited, the Society's maximum liability towards the Client is limited to one hundred and fifty per-cents (150%) of the price paid by the Client to the Society for the Services having caused the damage. This limit applies to any liability of whatsoever nature and howsoever arising, including fault by the Society, breach of contract, breach of warranty, tort, strict liability, breach of statute.
- 7.3 All claims shall be presented to the Society in writing within three (3) months of the completion of Services' performance or (if later) the date when the events which are relied on were first discovered by the Client. Any claim not so presented as defined above shall be deemed waived and absolutely time barred.

8. INDEMNITY CLAUSE

- 8.1 The Client shall defend, release, save, indemnify and hold harmless the Society from and against any and all claims, demands, lawsuits or actions for damages, including legal fees, for harm or loss to persons and/or property tangible, intangible or otherwise which may be brought against the Society, incidental to, arising out of or in connection with the performance of the Services (including for damages arising out of or in connection with opinions delivered according to clause 4.4 above) except for those claims caused solely and completely by the gross negligence of the Society, its officers, employees, servants, agents or subcontractors.

9. TERMINATION

- 9.1 The Parties shall have the right to terminate the Services (and the relevant contract) for convenience after giving the other Party thirty (30) days' written notice, and without prejudice to clause 6 above.
- 9.2 In such a case, the Classification granted to the concerned Unit and the previously issued Certificates shall remain valid until the date of effect of the termination notice issued, subject to compliance with clause 4.1 and 6 above.
- 9.3 In the event where, in the reasonable opinion of the Society, the Client is in breach, or is suspected to be in breach of clause 16 of the Conditions, the Society shall have the right to terminate the Services (and the relevant contracts associated) with immediate effect.

10. FORCE MAJEURE

- 10.1 Neither Party shall be responsible or liable for any failure to fulfil any term or provision of the Conditions if and to the extent that fulfilment has been delayed or temporarily prevented by a force majeure occurrence without the fault or negligence of the Party affected and which, by the exercise of reasonable diligence, the said Party is unable to provide against.
- 10.2 For the purpose of this clause, force majeure shall mean any circumstance not being within a Party's reasonable control including, but not limited to: acts of God, natural disasters, epidemics or pandemics, wars, terrorist attacks, riots, sabotages, impositions of sanctions, embargoes, nuclear, chemical or biological contaminations, laws or action taken by a government or public authority, quotas or prohibition, expropriations, destructions of the worksite, explosions, fires, accidents, any labour or trade disputes, strikes or lockouts.

11. CONFIDENTIALITY

- 11.1 The documents and data provided to or prepared by the Society in performing the Services, and the information made available to the Society, are treated as confidential except where the information:
- is properly and lawfully in the possession of the Society;
 - is already in possession of the public or has entered the public domain, otherwise than through a breach of this obligation;
 - is acquired or received independently from a third party that has the right to disseminate such information;
 - is required to be disclosed under applicable law or by a governmental order, decree, regulation or rule or by a stock exchange authority (provided that the receiving Party shall make all reasonable efforts to give prompt written notice to the disclosing Party prior to such disclosure).
- 11.2 The Parties shall use the confidential information exclusively within the framework of their activity underlying these Conditions.
- 11.3 Confidential information shall only be provided to third parties with the prior written consent of the other Party. However, such prior consent shall not be required when the Society provides the confidential information to a subsidiary.
- 11.4 Without prejudice to sub-clause 11.1, the Society shall have the right to disclose the confidential information if required to do so under regulations of the International Association of Classifications Societies (IACS) or any statutory obligations.

12. INTELLECTUAL PROPERTY

- 12.1 Each Party exclusively owns all rights to its Intellectual Property created before or after the commencement date of the Conditions and whether or not associated with any contract between the Parties.
- 12.2 The Intellectual Property developed by the Society for the performance of the Services including, but not limited to drawings, calculations, and reports shall remain the exclusive property of the Society.

13. ASSIGNMENT

- 13.1 The contract resulting from to these Conditions cannot be assigned or transferred by any means by a Party to any third party without the prior written consent of the other Party.
- 13.2 The Society shall however have the right to assign or transfer by any means the said contract to a subsidiary of the Bureau Veritas Group.

14. SEVERABILITY

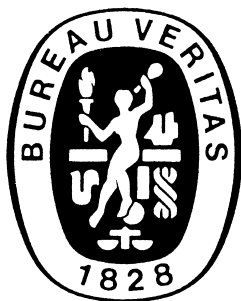
- 14.1 Invalidity of one or more provisions does not affect the remaining provisions.
- 14.2 Definitions herein take precedence over other definitions which may appear in other documents issued by the Society.
- 14.3 In case of doubt as to the interpretation of the Conditions, the English text shall prevail.

15. GOVERNING LAW AND DISPUTE RESOLUTION

- 15.1 These Conditions shall be construed and governed by the laws of England and Wales.
- 15.2 The Parties shall make every effort to settle any dispute amicably and in good faith by way of negotiation within thirty (30) days from the date of receipt by either one of the Parties of a written notice of such a dispute.
- 15.3 Failing that, the dispute shall finally be settled under the Rules of Arbitration of the Maritime Arbitration Chamber of Paris ("CAMP"), which rules are deemed to be incorporated by reference into this clause. The number of arbitrators shall be three (3). The place of arbitration shall be Paris (France). The Parties agree to keep the arbitration proceedings confidential.

16. PROFESSIONAL ETHICS

- 16.1 Each Party shall conduct all activities in compliance with all laws, statutes, rules, economic and trade sanctions (including but not limited to UN sanctions and EU sanctions) and regulations applicable to such Party including but not limited to: child labour, forced labour, collective bargaining, discrimination, abuse, working hours and minimum wages, anti-bribery, anti-corruption, copyright and trademark protection, personal data protection (<https://personal.dataprotection.bureauveritas.com/privacypolicy>).
- Each of the Parties warrants that neither it, nor its affiliates, has made or will make, with respect to the matters provided for hereunder, any offer, payment, gift or authorization of the payment of any money, directly or indirectly, to or for the use or benefit of any official or employee of the government, political party, official or candidate.
- 16.2 In addition, the Client shall act consistently with the Bureau Veritas' Code of Ethics. <https://group.bureauveritas.com/group/corporate-social-responsibility>



GUIDANCE NOTE NI 638

NI 638 Guidance for Long-Term Hydro-structure Calculations

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SECTION 1

GENERAL

1 Introduction

1.1 Context

1.1.1 In the design process of ships and offshore units, long-term direct hydro structure analysis, as defined in [2.1], are widely used to assess the robustness of a given design regarding the possible failure modes. Several methods can be used to assess the extreme stress in the structural members or the fatigue damage, depending on the loads to be considered and the type of response to compute.

1.2 Application

1.2.1 This Guidance Note describes various methods and tools that can be used for the direct calculations of the hydro-structural response of ships and floating or fixed offshore units.

1.3 Scope

1.3.1 The main purpose of the present Guidance Note is to present several approaches to perform a long-term analysis and to provide the associated theoretical background. This Guidance Note mainly focus on the tools and background of the long-term analysis itself, however it also provides information on environmental conditions and hydro-structure models respectively in Sec 2 and Sec 3.

2 Long term analysis

2.1 Definition

2.1.1 A long-term analysis consists in simulating the ship or offshore unit behaviour over a very long period of time (several years), where the vessel will encounter many different environmental conditions. The objective of the long-term analysis is to compute:

- the extreme response over that period of time (extreme stress, motion or load)
- the accumulated fatigue damage over that period of time.

These results are obtained from the combination of the short-term results for the different environmental conditions. A secondary output of the long-term analysis is the list of the short-term conditions (heading, sea-state) having the highest contribution to the extreme response or to the fatigue damage.

2.2 General methodology

2.2.1 Input data and model

A complete description of the environmental conditions is needed to perform a long-term analysis. This description can come from hindcast data or from a scatter diagram (see Sec 2 and App 1).

To compute the hydro-structure unit response on every sea-state of the environmental conditions, the first step is to build a representative model of the unit (see Sec 3) and to define the expected operational profile (see Sec 2).

If directionality information is available for both the operational profile (heading) and the environmental conditions (wave direction), it should be combined in order to obtain a relative wave direction for each short-term condition.

Note 1: For turret moored offshore units, this relative wave direction can be the outcome of a heading analysis.

If either the vessel heading or the wave direction information is not available, a probability distribution of relative wave direction is to be set, thus increasing the number of short-term conditions to be considered. Equiprobability of the relative wave direction is considered in the absence of detailed information.

2.2.2 Characterization of the short term distributions

Short term statistics are used to characterize the short-term distribution of the response cycles. The knowledge of this distribution, or at least of the tail of the distribution, is necessary to perform the long-term analysis. The different approaches used to perform short-term statistics are presented in Sec 4 and Sec 6.

2.2.3 Characterization of long term distributions

Several methods can be employed to perform a long-term analysis. The most complex ones simulate all the life-time unit response, while the simplified methods, under given assumptions, focus on a limited number of simulation cases. All these methods are presented in Sec 6.

2.3 Different strategies for long-term analyses

2.3.1 A summary of the different strategies available to determine the long-term extreme response and damage is presented in App 3 with references to the different Sections of the Guidance Note for the detailed methods and definition.

SECTION 2

ENVIRONMENTAL AND OPERATING CONDITIONS

Symbols

H_s	: Significant wave height, in m
T_p	: Peak period, in s
T_z	: Zero up-crossing period, in s
β	: Wave heading relative to the unit axis, in degree. For head seas: $\beta = 180^\circ$, and $\beta = 90^\circ$ for waves coming from star-board
ω	: Wave angular frequency, in rad/s

1 General

1.1 Purpose

1.1.1 The present Section defines environmental and operating conditions, considered as the input data for long-term analysis, i.e. the environmental conditions that the unit will encounter during its lifetime, including wave, wind, current as well as its operational profile.

1.2 Description of environmental conditions

1.2.1 Three main natural phenomena may contribute to structural damage or operation disturbances:

- current
- wind
- waves.

These phenomena are described by physical variables of statistical nature, both on the short and the long-term. Considering their potential effects on the design, there is a need for reliable data, representative for the area of operation and/or navigation, on a sufficiently long period.

1.2.2 If a reliable simultaneous database exists, the environmental phenomena can be described by joint probabilities. For vessels operating world-wide or in different zones, data from particularly hostile areas can be considered (North Atlantic for instance).

1.2.3 Reliable data defining correctly wave, wind and current and their joint probabilities for specific areas may be difficult to obtain. In the absence of multi-dimensional scatter diagrams, the long-term methodology described in this Guidance Note cannot be correctly developed. Considering that wave, wind and current are fully uncorrelated is a simplifying assumption that may be highly incorrect and could lead to unrealistic results. In the offshore industry, the environmental contours (see App 1) approach, with estimated associated value between the different parameters, are often used since the effect of wind and current cannot be neglected (in the evaluation of mooring line tensions for instance).

For ships, wind and current do not usually represent a relevant contribution to extreme stress or fatigue, hence only the wave (H_s , T_p and direction) are considered.

The main part of this Guidance Note focus on wave contribution.

1.3 Measurements

1.3.1 General

Different types of techniques exist in order to measure or generate the set of data required to describe the environment at a specific location. Some of these techniques are briefly presented hereafter.

1.3.2 Human observation at sea

As it is the simplest method to implement in order to derive wave data, this technique has been the earliest method used to build the first tabulation of wave height.

Thanks to the improvements made in measurements techniques, this method has been replaced by several more accurate techniques of measurement.

1.3.3 Buoy measurements

Moored buoys are frequently used to capture environmental data, as they are a practical solution capable of recording several type of information such as wind speed and direction, air and sea temperature, and wave energy spectra from which significant wave height, dominant wave period, and average wave period can be derived.

These type of buoys can be installed in both coastal and offshore waters. Generally using accelerometers, they capture the buoy motions and accelerations. Several methods of analysis are then available to derive the wave data.

1.3.4 Sensors on offshore structures

As per moored buoys, sensors can be installed on offshore structures in order to measure wind speed and direction, current speed, etc.

For wave measurements, several sensors may be used such as pressure gauge to derive wave height and period.

1.3.5 Satellite Altimeters

The satellite altimeters, that are used to measure surface geostrophic currents, also measure wave-height. Altimeter data are used to produce monthly mean maps of wave-heights and the variability of wave energy density over time and space.

1.3.6 Synthetic Aperture Radars on Satellites

Synthetic Aperture Radars (SAR) tend to map the radar reflectivity of the sea surface (spatial resolution from 6 to 25 meters). Depending on the conditions, synthetic aperture radars may lead to really good measure of the wave field, based on reflexivity analyses.

1.4 Hindcast data

1.4.1 According to the World Meteorological Organization (WMO), hindcasting refers to the diagnosis of wave information based on historical wind data. Hindcast wave data from numerical wave models are produced operationally and archived by many major meteorological services.

In other words, hindcasting techniques are used to provide statistical wave data over a large area in a short period of time. Wave data can be derived from wind field information using different methods, ranging from simple formulae to complex numerical models.

2 Waves

2.1 General description

2.1.1 In order to properly describe the sea-states that the ship or offshore unit will face over its lifetime, two descriptions are used:

- the short-term description
- the long-term description.

The short-term description, as defined in [2.2], is used to define one specific wave condition over a short duration (usually 3 hours) where the sea-state is considered as stationary.

The long-term description, as defined in [2.3], is used to define all the different wave conditions that can occur over a long period of time, usually several years, corresponding to the lifetime of the ships or offshore units.

2.2 Short-term wave conditions

2.2.1 Description

The description of short-term wave conditions may be given by:

- wave spectra, or
- wave statistics.

2.2.2 Wave spectrum

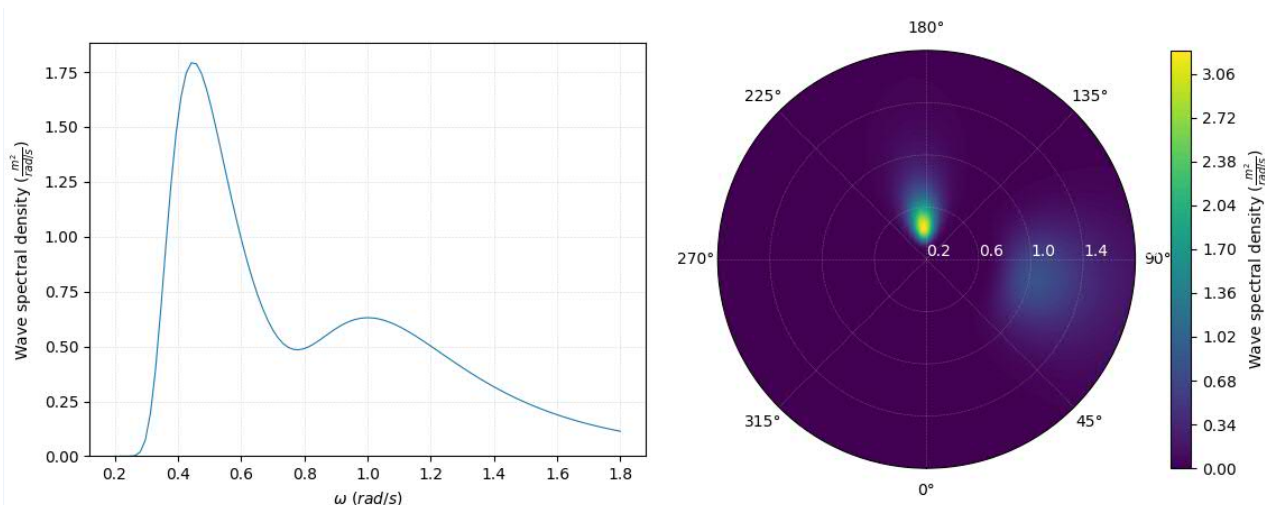
A short-term sea-state is described by a wave energy density spectrum, (see Fig 1) which is the power spectral density function of the vertical sea surface displacement. Wave spectra are often given in the form of an analytical formula.

Directional short-crested wave spectra $S_{\eta}(\omega, \beta)$ may be expressed in terms of a unidirectional wave energy density spectrum $S_{\eta}(\omega)$ multiplied by an angular spreading function $G(\beta)$:

$$S_{\eta}(\omega, \beta) = S_{\eta}(\omega) \cdot G(\beta)$$

For a two-peak spectrum expressed as a sum of a swell component and a wind-sea component, each component may have its own spreading function (see [2.2.7] and [2.2.8]). Different spectra can be found in the literature, such as Pierson-Moskowitz (see [2.2.4]), Jonswap (see [2.2.5]), Ochi-Hubble (see [2.2.6]), etc.

Figure 1 : Examples of wave spectral density



2.2.3 Spectral model

The spectral model are characterized by some of the following characteristics:

- spectrum moments

$$m_n = \int_0^\infty \int_0^{2\pi} \omega^n S(\omega) D(\omega, \beta) d\beta d\omega$$

- standard deviation

$$\sigma = \sqrt{m_0}$$

- significant height

$$H_s = 4\sqrt{m_0}$$

- mean up-crossing period

$$T_z = 2\pi \sqrt{\frac{m_0}{m_2}}$$

- mean crest period

$$T_c = 2\pi \sqrt{\frac{m_2}{m_4}}$$

- bandwidth

$$\varepsilon = \sqrt{\left(1 - \frac{m_2^2}{m_0 m_4}\right)}$$

2.2.4 Pierson-Moskowitz spectrum

The Pierson-Moskowitz spectrum is frequently applied for wind seas. It was originally proposed for fully-developed seas. It describes the wind-sea conditions that often occur for the most severe sea-states. The Pierson-Moskowitz spectrum is given by:

$$S_\eta(\omega) = \frac{5\omega_p^4 H_s^2}{16\omega^5} \cdot \exp\left[-1, 25\left(\frac{\omega_p}{\omega}\right)^4\right]$$

where:

ω_p : Peak angular frequency.

$$\omega_p = \frac{2\pi}{T_p} = \frac{2\pi}{1,408 T_z}$$

2.2.5 JONSWAP spectrum

The JONSWAP spectrum is formulated as a modification of the Pierson-Moskowitz spectrum for a developing sea-state in a fetch limited situation. It includes a peak-enhancement factor, the effect of which is to increase the peak of the Pierson-Moskowitz spectrum. The JONSWAP spectrum is given by:

$$S_{\eta}(\omega) = A \cdot \frac{5\omega_p^4 H_s^2}{16\omega^5} \cdot \exp\left[-1,25\left(\frac{\omega_p}{\omega}\right)^4\right] \cdot \gamma^{\left[\exp\left(\frac{-(\omega-\omega_p)^2}{2\sigma^2\omega_p^2}\right)\right]}$$

where:

γ : Peak enhancement factor. For $\gamma = 1$ the JONSWAP spectrum corresponds to a Pierson-Moskowitz spectrum

σ : Relative measure of the peak width. In the most cases:

- for $\omega < \omega_p$: $\sigma = 0,07$
- for $\omega > \omega_p$: $\sigma = 0,09$

$$A = \frac{1}{5(0,065\gamma^{0,803} + 0,135)}$$

2.2.6 Ochi-Hubble spectrum

Combined wind-sea and swell may be described by a double peak frequency spectrum, i.e. where wind-sea and swell are assumed to be uncorrelated. The Ochi-Hubble spectrum is a general spectrum formulated to describe bimodal sea-states.

The spectrum is a sum of two gamma distributions, each with 3 parameters for each wave system:

$$S_{\eta}(\omega) = \frac{1}{4} \sum_{i=1}^2 \left\{ \left[\omega_{p,i}^4 \left(\lambda_i + \frac{1}{4} \right) \right]^{\lambda_i} \cdot \frac{H_{s,i}^2}{\Gamma(\lambda_i) \omega^{4\lambda_i+1}} \cdot \exp\left[-\left(\lambda_i + \frac{1}{4}\right)\left(\frac{\omega_{p,i}}{\omega}\right)^4\right] \right\}$$

where:

$\omega_{p,i}$: Peak angular frequency, in rad/s, of component i

$H_{s,i}$: Significant wave height, in m, of component i

λ_i : Spectral shape parameter of component i.

2.2.7 Spreading function with 'cos n' formulation

The most commonly used directional spreading function is:

- when $|\beta - \beta_0| \leq 90^\circ$:

$$G(\beta) = \frac{\pi}{180} \cdot \frac{\Gamma(n/2 + 1)}{\sqrt{\pi} \Gamma(n/2 + 1/2)} \cdot \cos^n(\beta - \beta_0)$$

- when $|\beta - \beta_0| > 90^\circ$:

$$G(\beta) = 0$$

where:

β_0 : Main wave heading relative to the ship bow, in deg

n : Spreading parameter specified according to the metocean data.

2.2.8 Spreading function with 'cos 2s' formulation

An alternative formulation for the directional spreading function is:

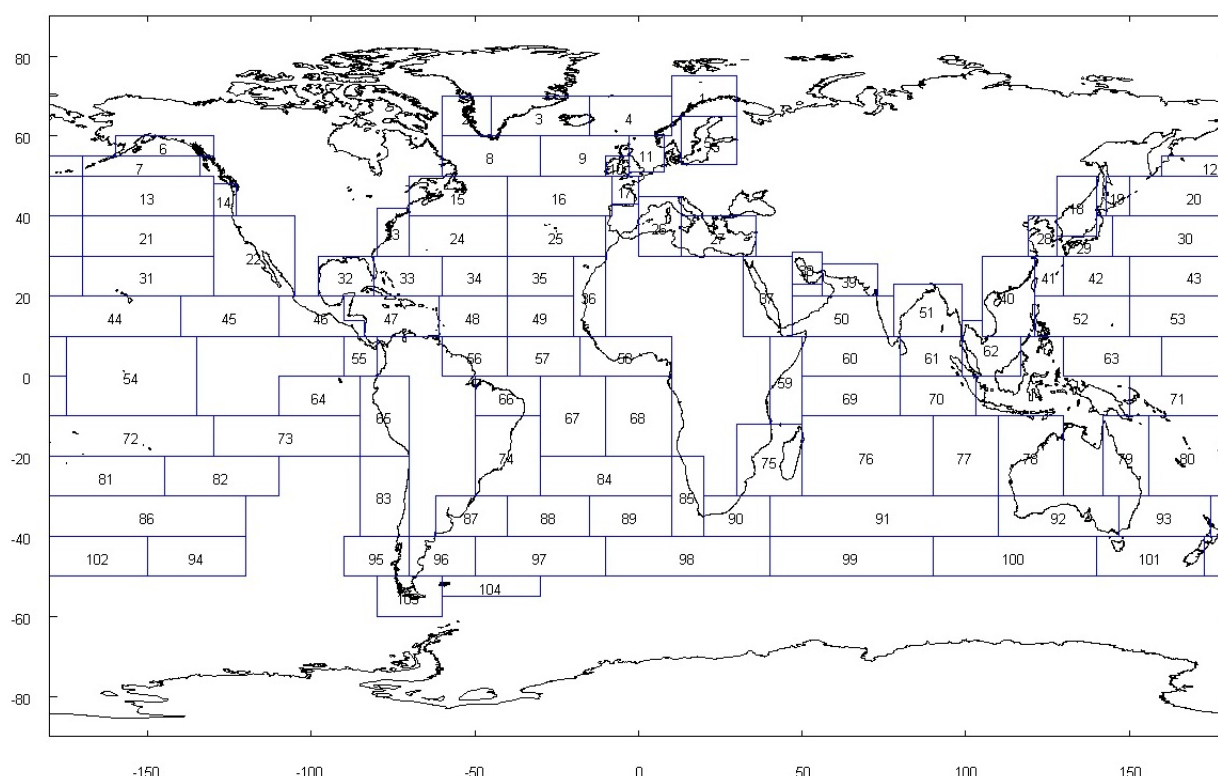
$$G(\beta) = \frac{\pi}{180} \cdot \frac{\Gamma(s + 1)}{2 \sqrt{\pi} \Gamma(s + 1/2)} \cdot \cos^{2s}\left(\frac{\beta - \beta_0}{2}\right)$$

where:

β_0 : Main wave heading relative to the ship bow, in deg

s : Spreading parameter specified according to the metocean data.

Figure 2 : Areas of the global wave statistics



2.3 Long term wave conditions

2.3.1 Description

The description of long-term wave conditions may be given by:

- scatter diagrams (see [2.3.2], [2.3.3] and [2.3.4])
- list of sea-states (see [2.3.5])
- envelope sea-states (see [2.3.6]).

2.3.2 Wave scatter diagram

A wave scatter diagram is a description of the joint probabilities of wave heights and wave periods. This description is made for a given geographical area. The scatter diagrams are usually based on visual observations and hindcast data, which are merged and extrapolated, using some analytical functions. The global wave statistics atlas provides scatter diagrams for 104 areas in the world, including some seasonal and directional information (see Fig 2). The scatter diagrams generally used for the design of ships without any specific sailing area are those provided in [2.3.3] and [2.3.4].

It is important to note that field measurements lead to scattered data from limited duration. They usually cannot be used for extreme calculations.

2.3.3 IACS scatter diagram

The IACS scatter diagram has been defined from the winter data of areas 8, 9, 15 and 16 (North Atlantic). This scatter diagram is the basis of many standard long-term analyses since the North Atlantic is considered as the most severe area in the World (considering the wave heights).

The IACS scatter is defined according to the following probability density function:

$$P_{IACS}(H_s, T_z) = \frac{\beta}{\alpha} \left(\frac{H_s - \gamma}{\alpha} \right)^{\beta-1} \exp \left[- \left(\frac{H_s - \gamma}{\alpha} \right)^{\beta} \right] \frac{1}{T_z \sigma \sqrt{2\pi}} \exp \left(- \frac{(\ln(T_z - \mu))^2}{2\sigma^2} \right)$$

where:

$$\alpha = 3,041$$

$$\beta = 1,484$$

$$\gamma = 0,66$$

$$\mu = 0,7 + 1,27 H_s^{0,131}$$
$$\sigma = 0,1334 + 0,0264 \exp (-0,1906 H_s)$$

The sea-states are to be modeled by a Pierson-Moskowitz spectrum and a ‘cos n’ spreading function with n = 2, as defined in [2.2.4] and [2.2.8]. Equiprobability of the main wave direction is to be considered.

2.3.4 Worldwide scatter diagram

The worldwide scatter diagram is representative of wave conditions for worldwide trips is defined according to the following probability density function:

$$P_{ww}(H_s,T_z) = \frac{\beta}{\alpha} \left(\frac{H_s-\gamma}{\alpha}\right)^{\beta-1} \exp\left[-\left(\frac{H_s-\gamma}{\alpha}\right)^{\beta}\right] \frac{1}{T_z\sigma\sqrt{2\pi}} \exp\left(-\frac{(\ln(T_z-\mu))^2}{2\sigma^2}\right)$$

where:

$$\alpha = 1,807$$
$$\beta = 1,217$$
$$\gamma = 0,83$$

$$\mu = -0,1 + 2,847 H_s^{0,075}$$
$$\sigma = 0,161 + 0,146 \exp (-0,683 H_s)$$

The sea-states are to be modeled by a Pierson-Moskowitz spectrum and a ‘cos n’ spreading function with n = 2, as defined in [2.2.4] and [2.2.8]. Equiprobability of the main wave direction is to be considered.

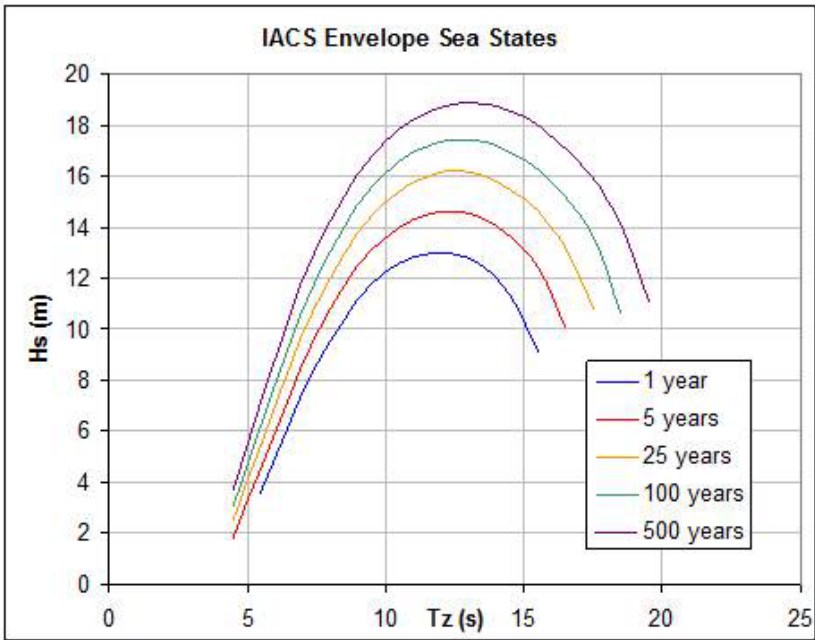
2.3.5 List of sea-states

Lists of sea-states may be used as input data for certain analyses. They are based on hindcast or measured data at specific location and give a precise description of the short-term spectrum. The list may contain information on current, wind and multiple wave systems, each with their own properties like direction and magnitude.

2.3.6 Envelope sea-states

The envelopes sea-states are based on the Inverse First Order Reliability Method (I-FORM), as detailed in App 1, [2.2.1]. They are derived from the analytical formulation of the scatter diagram and are defined by a short-term duration (usually 3 hours) and a given long-term return period (see Fig 3).

Figure 3 : IACS envelope sea-states



3 Operating conditions

3.1 Vessel operational profile

3.1.1 Loading conditions

The definition of the loading conditions allows to calculate hydrostatic data such as draft, trim, displacement, position of the center of gravity, GM value, etc.

In order to perform extreme or fatigue calculations, it is necessary to correctly define the loading conditions and the percentage of time that the vessel intends to be loaded in each condition.

As an example, the following loading conditions are usually defined: full load, alternate, normal ballast, heavy ballast in either transit, site or hull damaged conditions (non exhaustive list).

3.1.2 Ship speed and heading

The ship speed and heading generally depend on the sea-states encountered by the ship.

Involuntary speed reduction may occur due to several factors such as added resistance or wind resistance.

Voluntary speed reduction may be a consequence of captain decision in order to avoid damaging the ship or the cargo (severe slamming, extreme motions, propeller emergence).

3.1.3 Wave relative heading

The wave relative heading is a key point when performing calculations to assess the design of the vessel. This wave relative heading is driven by two parameters:

- vessel direction
- wave direction.

Particular attention is to be paid for the signs and referential system used for both the vessel and the wave directions.

3.1.4 Rules

Usually, class rules give specific recommendations to account for the speed for extreme and fatigue calculations.

SECTION 3 HYDRO-STRUCTURE CALCULATIONS

1 General

1.1 Objective

1.1.1 The objective of hydro-structure calculations is to compute the behaviour of the ship/offshore unit when facing a given environmental condition.

Different outputs can be computed through hydro-structure calculations such as:

- motions and accelerations
- pressures on the hull and inside the tanks
- hull girder loads.

1.2 Evaluation of the response

1.2.1 A good evaluation of the structural response of a ship in waves needs a proper coupling between a hydrodynamic model, which describes the hydrodynamic interaction between the ship and the waves, and a structural model, which describes the structural response to the wave induced loads. Several levels of assumptions can be chosen for the hydrodynamic model and the structural model, depending on which physical behaviour is expected to be reproduced.

From the hydrodynamic analysis point of view, see [2.1], the loads can be considered as:

- linear (valid only for the smallest sea-states), as described in [2.1.1]
- weakly non-linear (e.g. Froude-Krylov loads as described in [2.1.2], or Morison loads as described in [2.1.3])
- highly non-linear or impulsive (e.g. slamming loads, as described in [2.1.4]).

From the structural analysis point of view, see [3], the response can be considered as:

- quasi-static, which means that the structural response is strictly proportional to the applied loads. This model is described in [3.1]
- dynamic, if a dynamic amplification or a resonant response occurs. This model is described in [3.2]
- non-linear (e.g. large deformation, contact, friction).

2 Loads

2.1 Hydrodynamic loads

2.1.1 Linear loads

The linear part of the hydrodynamic loading is calculated by a validated numerical sea-keeping code. The use of codes based on the Boundary Element Method (BEM) is recommended. In the case of linear calculations, the mesh contains the mean under-water part only. The mesh size is to be chosen so that the minimal wave length (defined on the basis of encounter frequency) is covered by at least eight panels. Alternatively, a special treatment of the high frequency calculations can be used in order to avoid the numerical inaccuracies inherent to the BEM method. In any case, the problem of irregular frequencies is to be properly solved.

2.1.2 Froude-Krylov non-linear loads

When non-linear hydrodynamic simulations are performed, the minimum non-linear loads that should be included are based on the so called Froude-Krylov approximation. The pressure of the undisturbed incoming wave is applied to the hull on every wet panel, and not only under the mean waterline as it is the case in the linear computation. The non-linear hydrostatic restoring forces are also included by taking into account the real position of the ship in the integration of the hydrostatic pressure. The mesh used to integrate the pressure loading is to include the part of the hull above the mean waterline.

2.1.3 Morison non-linear loads on slender elements

The Morison loads on slender structural elements, mainly of offshore units, can be introduced in non-linear hydrodynamic simulations. The general expression for these loads is:

$$dF_M = \frac{1}{2}\rho C_D D \left(v - \frac{dx}{dt} \right) \left| v - \frac{dx}{dt} \right| dl + \rho \frac{\pi D^2}{4} \left[(1 + C_M) \frac{dv}{dt} - C_M \frac{d^2x}{dt^2} \right] dl$$

where:

- ρ : Fluid density, in kg/m³
- D : Diameter of the slender element, in m
- C_D, C_M : Drag and added mass coefficients, respectively
- $v, dv/d\tau$: Local fluid velocity and acceleration, respectively in m/s and m/s², perpendicular to the slender element axis
- $dx/dt, d^2x/dt^2$: Local velocity and acceleration, respectively in m/s and m/s², of the slender element due to the units motions.

2.1.4 Slamming

For ships (e.g. bow slamming on container ships), if slamming loads are considered in the simulation, the slamming pressures are to be computed using either a Computational Fluid Dynamic (CFD) code or a BEM code, provided that these codes are properly validated and coupled with the sea-keeping code. The slamming pressures are to be properly transferred to the Finite Element (FE) model at each time step of the time domain simulation.

2.2 Internal liquid loads

2.2.1 General

Different assumptions can be used for taking the liquids in tanks into account on the structural model (see Tab 1). The validity of the different models depends on the following criteria:

- a) the pressure exerted by the liquid in the tank has no direct influence on the response of the considered structure
- b) the liquid in the tank have a significant hydrostatic effect (significant free surface effect impacting the unit motions at sea)
- c) the liquid in the tank have a significant hydrodynamic behaviour (sloshing in the sense of dynamic liquid motions, not covering impacts).

The risk of dynamic fluid behaviour depends on the dimensions of the tank and on the presence of structural elements inside the tank capable of preventing or strongly damping such motions (e.g. in a double hull of double bottom tank).

In any case, the choice of a model for the liquid in tank is to be carefully reflected in the structural model as well as in the hydrodynamic model, in order to keep the consistency between the two models for the sake of the structural model balance in the hydro-structure coupling procedure.

2.2.2 Tank mass

If the liquid in tank fulfils the criteria a) and b) of [2.2.1], then it can be simply represented as a mass matrix.

On a FEM model, the mass matrix element is to be attached to the tank boundaries by means of special elements which do not introduce any rigidity in the model (interpolation elements). Modelling the mass of the liquid with lumped masses directly located on the tank boundaries is not recommended as it creates some overestimated mass moments of inertia with very limited options to adjust them.

The mass, centre of gravity and mass moments of inertia resulting from the modelling of the liquid as a mass in the structural model are to be used in the hydrodynamic model.

Table 1 : Models for liquids in tanks

Mass model	Mass matrix	
	Linear model	Non-linear Model
Hydrostatic model	simplified pressure model (see [2.2.3])	simplified pressure model (see [2.2.3], valid only for $p_{liq}>0$)
Hydrodynamic model	linear hydrodynamic computations	CFD computations

2.2.3 Simplified pressure model

A simplified pressure model can be used when the liquid in tank fulfills the criterion c) of [2.2.1]. In this case, the effect of the fluid is modeled as a pressure defined with the following analytical formulae:

- if $z \leq z_F$ $p_{liq} = \rho [(x - x_F) \gamma_x + (y - y_F) \gamma_y + (z - z_F) \gamma_z]$
- if $z > z_F$ $p_{liq} = 0$

where:

(x, y, z) : Location where the pressure is evaluated, in m

(x_F, y_F, z_F) : Location of the centre of the tank liquid free surface, in m

ρ : Liquid density, in kg/m^3

$(\gamma_x, \gamma_y, \gamma_z)$: Local acceleration at the tank centre of gravity, in $\text{m}\cdot\text{s}^{-2}$.

The acceleration at the tank centre of gravity is deduced from the ship accelerations at the motion reference point, using the rigid body kinematic rule. The ship accelerations include the terms due to the influence of gravity when the unit pitches and rolls.

In case of a fully filled tank, the same pressure formulation can be used, setting the 'centre of liquid free surface' at the uppermost point of the tank, or at the centre of the liquid free surface for a 'almost fully filled tank'. However, z_F is to be chosen so that $z_F \geq z$ whatever z , in order that no free surface effect occurs.

The tank is to be introduced in the hydrodynamic model in a way fully consistent with the loads exerted on the structural model according to the above formulae. To this effect, the terms of the tank hydrostatic restoring matrix and mass matrix can be determined considering unitary motions, determining the liquid pressure resulting from the above formulae and integrating this pressure on the tank boundary.

2.2.4 Hydrodynamic tank pressure

If a significant fluid dynamic behaviour is expected, then the pressure exerted by the liquid is to be determined by means of a hydrodynamic computation and transferred to the structural model. As a general rule, the hydrodynamic model used for the external problem related to sea pressure is also to be used for solving the tank hydrodynamic problem.

3 Structural ship/offshore unit response

3.1 Quasi-static response

3.1.1 Once the hydrodynamic sea-keeping problem is solved, the different loading cases for FE model analysis need to be constructed.

Each loading case is composed of the hydrodynamic pressure loading on the wet panels, the inertial and the gravity loading on each finite element and the additional damping loading. The perfect equilibrium of the overall loading needs to be ensured. In general, the hydrodynamic and structural meshes are different, and special care is to be given to the pressure transfer.

The structural problem is solved using FEA software for each loading case. The structural response is supposed to be static and linear. In order to ensure equilibrium of the coupled model, the mass distribution of the FEA model shall be equivalent to the mass distribution used for the hydrodynamic analysis. Adjustment of material density in FE model may be found necessary in order to match with lightship condition of the unit.

3.2 Dynamic response

3.2.1 If a dynamic ship response is anticipated, a coupled hydro-elastic model should be used.

The first step of the dynamic analysis is the modal FEM model analysis in dry condition (i.e. without liquid added mass effect), which is to be done with care. Local structural modes are to be removed. The first ten dry eigen modes are normally considered to be sufficient.

Once the dry modes are obtained, the modal displacements are to be transferred from the structural model to the hydrodynamic model and the corresponding hydrodynamic problems are to be defined. Once the hydrodynamic problems are solved, a fully coupled dynamic equation is solved, giving both the rigid body motions and the structural response in terms of modal amplitudes.

The modal reduction of the structural response is usually not fully satisfactory for strength or fatigue verification, since the number of modes in the base is not sufficient to capture the full distortion of the structure, in particular regarding the quasi-static response of the transverse structure. Therefore, the structural response needs to be evaluated by a quasi-static approach, in which the pressure and inertia loads arising from the hydro-elastic dynamic equation are applied in a static way on the FEM model. Alternatively, the motion equation results can be separated into a quasi-static part and a dynamic part. The quasi-static part of the response is then calculated using the quasi-static method while the dynamic part of the response is calculated by summing up the dynamic contribution of each mode.