



Exploration & Production

GENERAL SPECIFICATION

SURVEYS

GS EP GEO 504

Comprehensive evaluation of metocean conditions

05	10/2009	General review
04	10/2007	General review
03	10/2005	Update, with guidance about persistence analysis. Merge with GS GEO 503 - Addition of "EP" root to GS identification
02	10/2004	General review
01	10/2003	General review - Change of Group name and logo
00	02/2001	First issue
Rev.	Date	Notes



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1. Scope

The objective of the metocean study is to provide a comprehensive evaluation of meteorological and oceanographic environmental conditions at the offshore/onshore location. Some guidance for developing simplified metocean criteria for basic design studies is also given in section 4.7.

The metocean study shall result in best estimates of both extreme and normal/operational metocean design criteria for the project.

The analysis shall be based on available and suitable data sources, which may consist of:

- Published papers and reports
- Metocean data from specialist providers, including hindcast data, satellite observations, etc.
- Data from site surveys.

Suitable analysis methods shall be used. A general description of applicable methods is given in Section 5. Alternative methods may be proposed if they result in more accurate or more reliable results: they shall be fully described by the CONTRACTOR and approved by the COMPANY.

The design criteria that result from the metocean study shall be adequate for following design studies:

- Design of offshore/onshore installations with respect to extreme environmental conditions
- Design of offshore/onshore installations with respect to fatigue due to environmental conditions
- Design and planning of marine operations.

The metocean study comprises three phases:

1.1 Data collation

The objective of this phase is to identify and acquire the data sets required for the study.

This phase includes an investigation of all available data, following which a selection of adequate data to be acquired for the study shall be drawn up and submitted to COMPANY for review.

Then, after COMPANY approval, the suitable data are acquired for further analysis.

1.2 Data analysis and complementary studies

This phase covers the statistical analysis of collected data, including the extreme value analysis, and the complementary analyses that are necessary to develop the metocean design criteria. The complementary analyses may be limited, for example, to the derivation of maximum wave and crest height from extreme significant wave height and period. It may also be more complex and include, for example, wave propagation modelling or tidal and current simulations.

1.3 Preparation of metocean design criteria

This phase consists of the interpretation of the results of the metocean study and the development of metocean design criteria for the project.



All data, all results and all information provided by CONTRACTOR in the final report and during the course of the study shall first be checked and approved internally by a recognised metocean expert and then submitted to COMPANY's metocean expert for approval.

2. Reference documents

The reference documents listed below form an integral part of this General Specification. Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published at the EFFECTIVE DATE of the CONTRACT.

Standards

Reference	Title
ISO 19901-1, 2005	Petroleum and natural gas industries - Specific requirements for offshore structures - Part 1: Metocean design and operating conditions
ISO 19906, 2007	Arctic Offshore Structures

Professional Documents

Reference	Title
WMO no. 49 Vol.1 – 1988	General meteorological standards and recommended practice
API RP 2A-WSD 21st Ed. - Dec. 2000	Recommended practice for planning, designing and constructing fixed offshore platforms
API RP 2N, 2nd Ed. - Dec. 1995	Recommended Practice for Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions

Regulations

Reference	Title
Not applicable	

Codes

Reference	Title
Not applicable	

Other documents

Reference	Title
Not applicable	



Total General Specifications

Reference	Title
Not applicable	

3. Definitions, abbreviations, conventions

3.1 General

The terms and definitions given in [ISO/DIS 19900-1](#) and the following apply.

Special consideration shall be paid to the definition of **direction**:

- The direction (wind, wave, current, etc.) must be based on a **vector average**. An arithmetic average of direction data that included values either side of North would be in error (e.g. $(359 + 001)/2 = 180$)
- **Oceanographic convention** is that winds and waves approach from the given direction, whilst currents flow towards the given direction.

Unless otherwise specified in the Particular Technical Specification, the **directional sectors** to be considered by CONTRACTOR for the analyses are 16 sectors of 22.5° width centred on True North (N), North-Northeast (NNE), Northeast (NE), East-Northeast (ENE), East (E), East-Southeast (ESE), Southeast (SE), South-Southeast (SSE), South (S), South-Southwest (SSW), Southwest (SW), West-Southwest (WSW), West (W), West-Northwest (WNW), Northwest (NW), North-Northwest (NNW).

Calms: Periods of calm conditions, where no wind or wave or current is detected, or when the parameter value is less than the data source minimum resolution. Periods of calms shall be clearly indicated (as a percentage or number of events). When the occurrence of non-zero events in tabulated distributions are summed and added to the occurrence of calms, the result is 100% (allowing for rounding).

When not specified otherwise, the appellation “**mean wind speed**” refers to the 1 hour mean wind speed, and wind characteristics refer to its value at 10 m above ground or mean sea level.

The required **system of units** is the S.I. (Metric) system. In case other units are used, the conversion factors shall be given. All units, directional and other conventions and frames of reference for all parameters shall be clearly defined.

Time references shall be given in UTC.

All location **co-ordinates** shall be given with the system employed (geodetic datum, spheroid, grid system, origin of projection, false easting, false northing, scale factor).

3.2 Water levels

CD = Chart datum: local datum used to fix water depths on a chart or tidal heights over an area. Chart datum may be an approximation to the level of the Lowest Astronomical Tide.

Tide periodicity: Tides repeat themselves exactly with a period of approximately 18.6 years.

HAT = Highest Astronomical Tide: level of high tide when all harmonic components causing the tides are in phase.

LAT = Lowest Astronomical Tide: level of low tide when all harmonic components causing the tides are in phase.

Note: The harmonic components are in phase once per tide periodicity but these conditions are approached several times each year.

MSL = Mean Sea Level: arithmetic mean of all sea levels measured at hourly intervals over a long period, ideally the tide periodicity

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

In semi-diurnal waters, the following mean tide levels are applicable, averaged over a period time preferably equal to the tide periodicity:

- **MHWS = Mean High Water Spring:** mean of the high water at spring tide
- **MHWN = Mean High Water Neap:** mean of the high water at neap tide
- **MLWN = Mean Low Water Neap:** mean of the low water at neap tide
- **MLWS = Mean Low Water Spring:** mean of the low water at spring tide.

In mixed waters, the following mean tide levels are applicable, averaged over a period time preferably equal to the tide periodicity:

- **MHHW = Mean Higher High Water:** mean of the higher of the two daily high water
- **MLHW = Mean Lower High Water:** mean of the lower of the two daily high water
- **MHLW = Mean Higher Low Water:** mean of the higher of the two daily low water
- **MLLW = Mean Lower Low Water:** mean of the lower of the two daily low water.

4. Metocean design criteria

The metocean design criteria that shall be derived from the study are listed hereunder:

4.1 Climatology

A general description of meteorological and oceanographic conditions at considered location shall be provided. This description shall include information on wind regime, wave regime, current regime and other metocean parameters with indication on seasonal variations. Probability of rare phenomena shall also be mentioned.

Rare phenomena include:

- Cyclones, squalls, tornadoes, etc.
- Internal waves
- Tsunamis.

4.2 Extreme conditions

As a minimum, the extreme values shall be specified for following return periods: 100, 10 and 1 year. In addition, a method permitting the derivation of extremes for intermediate return periods shall be given.

If requested in Particular Specification, 1000 and 10000 years return period values could be requested for some parameters.

4.2.1 Extreme winds

Omnidirectional and per directional sector:

- 1 hr mean wind speed (m/s)
- Range of wind speeds and gusts including but not limited to 10 min mean, 1 min mean, 15 s mean, 3 s gust
- Wind profile applicable for each of these extreme conditions.

The most probable period of the year for extreme winds shall be indicated and the following monthly (or at least seasonal) directional extremes shall be given:

- 1 hr mean wind speed, together with 10 min, 1 min, 15 s and 3 s mean wind speeds (or if relevant, conversion factors for the calculation of the latter from the 1 hr mean wind speed).

Additional criteria may be required for certain applications or regions. In such cases these shall be individually agreed by COMPANY for each study. Examples include:

- Wind energy spectra
- Description of extreme events such as squalls, tropical cyclones, etc.

4.2.2 Extreme Waves

Omnidirectional and per directional sector:

- Extreme significant wave height (m), associated peak wave period (s) and mean wave period (s)
- Extreme significant wave height and peak period contours
- Maximum wave height (m), period associated with the maximum wave (s) - most probable and range
- Maximum wave crest elevation (m)
- Frequency-direction wave energy spectrum for the extreme sea states (or one-dimensional wave energy spectrum with directional spreading).

The most probable period of the year for extreme waves shall be indicated and the following monthly (or seasonal) directional extremes shall be given:

- Extreme significant wave height (m)
- Associated peak wave period (s).

If justified by the analysis of the data, and if possible, extreme wave conditions as described above for the total sea-state will also be computed for the swell and the local wind sea partitions.

The number of directional sectors could be reduced for determination of extreme significant wave height and peak period contours.

Maximum wave height and maximum crest shall be derived using recommendation from section 5.3.6.

4.2.3 Extreme Current

Omnidirectional and per directional sector:

- Tidal current
- Residual current (where appropriate including the effects of wind drift, storm surge, water density variations, oceanic currents, internal waves, river flow, etc.)
- Combined extreme current (tidal + residual)
- Current profiles.

The most probable period of the year for extreme currents shall be indicated and the following monthly directional extremes shall be given:

- Residual current
- Combined extreme current.

4.2.4 Extreme water levels

The tidal regime shall be briefly described (diurnal, semi-diurnal, mixed, etc.). Following tidal levels shall be given, with respect to Chart Datum:

- HAT
- MHWS/MHHW
- LAT.

The extreme water levels shall be given as follows:

- Yearly and monthly positive and negative storm surge and anomalies, for the above specified return periods
- Maximum wave crest elevation (see section 5.3.6)
- Total combined (usually MHWS/MHHW + storm surge + crest elevation, but preferably with adequate correlation)
- Safety margin as per international recommendations
- Minimum safe height above C.D.

4.2.5 Combined extreme parameters

As a minimum, the following combination shall be provided for the different return periods:

- Wind speed and current speed associated to extreme significant wave conditions
- Significant wave height and current speed associated to extreme wind conditions
- Significant wave height and wind speed associated to extreme current conditions.

More detailed information can be requested as specified in section 5.3.

4.3 Operational data

The data, which mainly consists in distributions useful for fatigue studies and marine operational data, shall be representative of an "Average Year".

4.3.1 Winds

- Monthly maximum, minimum, mean values, standard deviation and quantiles of mean wind speed, with associated wind direction
- Monthly histogram and percentage exceedence diagram of mean wind speed
- Monthly wind speed/direction tabulated frequency distributions and wind roses
- Persistence statistics of wind speed above and under selected thresholds (usually 5, 10, 15, 20, 25 m/s, to be specified in the Particular Technical Specification). Guidance about persistence statistics shall be discussed with COMPANY.

Annual summaries for the values above.

4.3.2 Waves

- Monthly maximum, minimum, mean values, standard deviation and quantiles of significant wave height, with associated wave direction
- Monthly maximum, minimum, mean values, standard deviation and quantiles of peak wave period with associated wave direction
- Monthly histogram and percentage exceedence diagram of significant wave height
- Joint distribution of significant wave height and peak wave period (wave scatter diagram), omnidirectional and for directional sectors
- Monthly significant wave height/direction tabulated frequency distributions and wave roses
- Persistence statistics of significant wave height above and under selected thresholds (usually 0.5, 1, 1.5, 2, 2.5, 3 m to be specified in the Particular Technical Specification). Guidance about persistence statistics shall be discussed with COMPANY.

Annual summaries for above values and for following data.

- Joint distribution of individual wave height and period, per class intervals of 0.5 m x 1 s, for a one year period
- Joint distribution of individual wave height and direction, per class intervals of 0.5 m x directional sector width, for a one year period, with the most probable associated period for each height/direction couple.

4.3.3 Currents

- Monthly maximum, minimum, mean values, standard deviation and quantiles of current speed, with associated current direction
- Monthly frequency table, histogram and percentage exceedence diagram of current speed
- Monthly current speed/direction tabulated frequency distributions and current roses

- Persistence statistics of current speed above and under selected thresholds (usually 0.2, 0.4, 0.6, 0.8, 1.0 m/s to be specified in the Particular Technical Specification). Guidance about persistence statistics shall be discussed with COMPANY.
- Variation with depth (Current profiles).

Annual Summaries for the values above.

4.3.4 Tide and water levels

Standard Tidal Levels with respect to Chart Datum:

- HAT
- MHWS/MHHW
- MHWN/MLHW
- MSL
- MLWN/MHLW
- MLWS/MLLW
- LAT
- Seasonal changes of MSL.

4.4 Ice

In cold regions such as the Arctic area, structures shall be designed against ice conditions, as described in [API RP 2N](#) and [ISO 19906](#). The present section lists the main parameters that shall be developed by CONTRACTOR. The database used and methods applied by CONTRACTOR for such analysis shall be fully documented.

4.4.1 Icing

- Density (kg/m^3) versus elevation above sea level
- Thickness (mm) versus elevation above sea level
- Probability of occurrence by month.

4.4.2 Ice cover & concentration

- Dates of the stable ice formation
- Dates of ice clearance in the area
- Ice period duration in the area
- Ice-free period duration in the area
- Ice cover extent of the general area by months (%)
- Ice cover extent of the regional area by months (%)
- Front ice position by months
- Probability of ice presence by months (%)

- Probability of ice presence by months and by ice age categories (%)
- Total ice concentration by months (%)
- Concentration by ice age categories by months (%)
- Ice floes statistics: Frequency of occurrence by months (%); Diameter (km) and area (km²); Thickness (m).

4.4.3 Ice morphology

- Physical characteristics: Thickness by months (m); Temperature averaged by ice thickness (°C); Snow thickness on the ice by months (cm); Density (kg/m³); Simultaneous data for porosity, salinity, temperature
- Mechanic characteristics (by ice age categories and total ice): Compressive ice strength (MPa) (effect of porosity); Flexural ice strength (MPa) (effect of porosity).

4.4.4 Ice ridges and hummocks

- Frequency per km and km²
- Frequency by months
- Physical characteristics: Sail height and keel draft (m); Total length (m); Sail and keel width (m); Ratio sail/keel; Total thickness (m); Sizes (length, width, thickness) of blocks composing the hummocks (m); Angle of sail & keel slope (deg); Size of consolidated layer (m); Snow thickness in ice ridges by months (cm); Ice density (kg/m³); Simultaneous data for porosity, salinity, temperature
- Mechanic characteristics (by ice age categories and total ice): Compressive strength of ice from ice ridges (MPa) (effect of porosity); Flexural strength of ice from ice ridges (MPa) (effect of porosity).

4.4.5 Ice drift

- Ice drift velocity (m/s)
- Ice drift direction (deg).

4.4.6 Icebergs

- Generation sources
- Boundaries of iceberg spreading
- Iceberg characteristics: Height (sail), length, width, keel draft (m); Masse (tonne); Ice density (kg/m³); List of shape existing in the area (tabular, blocky, etc.); List of size existing in the area (bergy bit, small iceberg, etc.)
- Iceberg drift: Direction (deg); Velocity (m/s)
- Compressive ice strength (MPa)
- Probability of iceberg occurrence in the area by size (%)
- Probability of iceberg collision with platform and platform closing in (%).

4.4.7 Simultaneity of events

Simultaneity of wind, wave and current with iceberg presence or earthquake occurrence shall be documented by CONTRACTOR showing the combination of extreme events. For instance, the following combinations might be considered, corresponding to different seasons or events:

- Associated wave, current and wind to extreme iceberg presence (such as 100-year or even 10,000-year return period)
- Associated iceberg presence to extreme wave, current or wind occurrence (100-year return period)
- Extreme ice cover (100-year or 10,000-year return period) with no wave but associated wind and current.

Whenever possible, joint probability distributions of the main metocean and ice parameters will be proposed.

Additionally, operating conditions of wind, wave and current or ice will be considered, as described in the [API RP 2N](#) (section 6.5) and [ISO 19906](#) (section 7.2.3).

4.5 Other Metocean Parameters

General climatologic parameters characterizing the site:

- Average monthly maximum, minimum, mean values and standard deviation, extreme monthly maximum and minimum of:
 - Air temperature
 - Air pressure
 - Relative humidity
 - Visibility: cloud ceiling, fog, snow whiteouts (i.e. blowing snow with low contrast lighting), etc.
 - Rainfall
 - Solar radiation
 - Sea temperature profiles with depth
 - Salinity profiles with depth
 - Density profiles with depth
 - Dissolved oxygen
 - Ice: sea ice cover, concentration and morphology (physical & mechanical properties), ice ridges and hummocks characteristics, ice drift velocity & direction, iceberg characteristics, properties and drift, etc.
- Marine growth: thickness versus depth profiles, type, density, evolution with time, etc.

4.6 Tsunami

If a tsunami hazard has been identified: estimate of tsunami wave return period and intensity.

4.7 Preliminary criteria for a basic study

The metocean design criteria specified in above sections may be too comprehensive for a basic design study such as:

- Basic design of offshore installations with respect to extreme environmental conditions
- Selection of design concept
- Basic design and planning of marine operations.

The Particular Technical Specification will clarify the level of detail needed for the data analysis and processing. It is very likely however that, at the stage of basic design, the following data will **not** be requested:

- For the extreme conditions in general (section 4.2):
 - Directional extreme values: instead, only omni-directional extreme values may be required, with indication of the most probable direction of the extreme event
 - Monthly extreme values.
- For operational data in general (section 4.3):
 - Persistence statistics.
- For the waves (sections 4.2.2, 4.3.2, 5.2.3):
 - Frequency-direction wave energy spectrum
 - Partition between swell and wind sea
 - Individual waves statistics.
- For the current (sections 4.2.3, 4.3.3, 5.3.9):
 - Full profiles through water depth: only three depth levels may be required, typically surface, seabed and mid-depth.
- For the other metocean parameters (section 4.5)
 - Visibility and solar radiation
 - Dissolved oxygen
 - Detailed ice characteristics (section 4.4)
 - Marine growth (section 5.3.10)

Regarding the methods used to develop this data, it is also very likely that:

- Little or no site measurements will be available for validation/calibration purposes
- Simplified information about the correlation of metocean parameters (section 5.3.2) or interannual variability (section 5.3.3) will be requested
- Only a simplified wave propagation model might be needed, which would neglect non linear interactions in wave spectra, changes of direction due to refraction, wind/tide/current effects on wave propagation, etc.
- Similarly, a simplified hydrodynamic model might be sufficient, with for instance little consideration to wave radiation effects or wind forcing.

5. Methods

The data analysis to be carried out, as well as the necessary complementary studies, depends on the nature and the quality of available data and also depends on the site location and characteristics (for instance, deep water or shallow water location, tropical or extratropical weather conditions, etc.).

The standard analysis and studies are specified hereunder. They may be completed or amended by the Particular Technical Specification.

5.1 Data collation

CONTRACTOR shall investigate all available sources of data necessary for evaluation of extreme conditions and derivation of normal conditions.

Data sources may consist of, but are not necessarily limited to:

- International data banks of climatological data and climatological statistics, covering wind and meteorological parameters, waves, currents, tides and oceanographic parameters
- Specialized data providers of satellite observations, wind and wave hindcast data, tide and current from oceanic models, etc.
- COMPANY provided site measurements and observations
- Oil industry archives
- University or scientific archives
- General bibliography.

It should be recognised that use of long term measured data is of highest priority where available.

Then, CONTRACTOR shall perform a comprehensive evaluation of the available data with regard to:

- Quality: COMPANY requests that, where possible, data used in the analysis, such as satellite data or hindcast data, are validated or calibrated against site measurements
- Accuracy: COMPANY requests that data accuracy is checked with respect to all available information
- Duration covered by the data: COMPANY requests to use satellite data covering at least 10 years of observations and hindcast data covering at least 15 years of simulations
- Relevance to the Site Conditions: COMPANY requests that the relevance of data for the site location is checked, for example when deep water data are used in view of an analysis of a shallow water location.

Based on this evaluation, CONTRACTOR shall prepare recommendations on the most suitable data and on the methods of analysis with regard to:

- Reliability and accuracy of the results
- Cost
- Delivery time.



CONTRACTOR shall report and submit the results of the investigation to COMPANY. The report on data collection shall contain:

- The description of the requested work
- The list of data sources analysed by CONTRACTOR
- The evaluation of the quality of these sources
- The cost and the delivery time
- The recommendations on data to be acquired and on methods of analysis to be applied
- The description of the results that can be obtained with confidence.

After COMPANY approval, and at COMPANY request, CONTRACTOR shall proceed with the acquisition of relevant metocean data. These data will remain the property of COMPANY and shall be provided by CONTRACTOR to COMPANY in electronic files, in an ASCII format compatible with PC based computer programs. The ASCII file shall be self describing with all necessary information to permit a proper use of the data in the future without need for external documentation.

5.2 Data analysis

The data analysis generally consists of following:

5.2.1 Statistical analysis

The statistical analysis generally consists in a simple empirical analysis of metocean parameters in order to derive statistical values (mean, maximum, minimum, standard deviation, etc.) histograms, percentage exceedences and joint distributions specified in Section 4.3.

The results of the statistical analysis shall be given and discussed in the report.

5.2.2 Extreme value analysis

The extreme value analysis generally consists in a sophisticated analysis based on the fitting of empirical distributions by standard distribution models (Weibull, Gumbel, Generalised Extreme Value (GEV), etc.) followed by extrapolation.

Several methods are available for extreme value analysis and the method applied by CONTRACTOR shall be fully documented.

When sufficient time series data are available, the Peaks Over Threshold (POT) method shall be applied in addition to Cumulative Frequency Extrapolation (CFE). In the case of CFE, statistical fits to varying data distribution tails shall be tested.

An assessment shall be made of the goodness of fit, e.g. by varying thresholds.

When specified by COMPANY, confidence intervals shall be associated to each calculated extreme value, for instance based on the method of Extreme Bootstrap Percentile.

The parameters of the fitted distribution shall be given and discussed in the report, as well as the results of extrapolation for specified return periods (usually 1, 10, 100 years).

Method to estimate directional extreme values shall be documented and agreed with COMPANY.



5.2.3 Spectral analysis

The spectral analysis generally consists in a standard frequency analysis of a metocean parameter (wave elevation, wind speed, current speed, etc.) in order to derive the spectral properties of the parameter.

The method applied for spectral analysis shall be based on standard Fast Fourier Transform (FFT) method, or on other alternative method. In particular, the frequency range shall be selected with respect to the physics of phenomena, and the method shall take into account possible aliasing effects. The method applied by CONTRACTOR shall be fully documented.

When the recorded data allow for it, directional spectra shall be computed, on the same basis.

The results of the spectral analysis shall be given and discussed in the report.

5.2.4 Harmonic analysis

Harmonic analysis shall be employed to derive the tidal harmonic constituents from tide/water level measurements or from current measurements.

A standard recognized method shall be applied for harmonic analysis. It shall be fully documented by CONTRACTOR.

Depending on the duration of measurements, the number of harmonic constituents to be derived from the analysis may vary from about 17 constituents (1 month data) to about 60 constituents (1 year data). The harmonic constituents shall be given and discussed in the report.

The harmonic constituents derived from the analysis shall be checked versus available constituents at reference ports close to the location, from US, UK, French or other Hydrographic offices.

The harmonic constituents derived from the analysis shall be used to filter the water level and current records in order to derive tide level and storm surge variations as well as tidal currents and residual currents.

5.2.5 Analysis of specific events

COMPANY may require specific analysis of particular events, in addition to standard data analysis specified above. This will generally consist in the analysis of particular storms or specific oceanographic conditions. For such analysis, the method applied by CONTRACTOR shall be fully documented.

5.3 Complementary studies

The complementary studies requested to fulfil the project requirements, as specified in Section 4, may be of different kind, depending on the project, on the site location (deep water, shallow water, shore approach, land) and on the maritime area (for instance, risk of cyclones or not). Hereunder are listed usual studies that have to be performed in addition to the data analysis:

5.3.1 Specific wave parameters and wind parameters

The wave and wind data analysis is often limited to the main wave and wind parameters: significant wave height, peak period and mean wind speed for example. Other wind and wave parameters shall also be characterized for design, such as maximum wave height and



associated wave period and crest height, partitions of swell and local wind sea, or wind gust, for example.

This should be done with specific analysis from site measurements or from general formulae developed from similar environmental conditions where site specific data is unavailable.

The methods and formulae applied by CONTRACTOR for such analysis shall be submitted to COMPANY approval prior to analysis and fully documented in the final report.

5.3.2 Correlation of metocean parameters

The study of correlation between several metocean parameters (for example between wind and waves (or more specifically between wind and local wind sea), between wind and surge, between currents at several depths, or between temperature and humidity for the design of air-conditioning systems) may be requested in the Particular Technical Specification to refine design studies.

In such studies, a part of the analysis is related to specific data analysis such as regression analysis. In addition, the physical processes must be investigated to explain the relation between the parameters.

When extreme joint conditions have to be derived from the analysis, this must be done carefully in order to avoid any underestimation in environmental loads. Inverse First Order Reliability Method (Inverse FORM) is a sophisticated method recommended to obtain extreme joint conditions.

The methods and procedures applied by CONTRACTOR for such analysis shall be fully documented and submitted for review and approval to COMPANY.

In the final report, CONTRACTOR shall warn future reader that extreme metocean conditions could not correspond to extreme design conditions. Investigation for design conditions shall be done by design engineers.

5.3.3 Interannual variability

Metocean data statistics provided for fatigue studies and for marine operations are representative of average conditions. The study of variations of climatic data from one year to another is sometimes requested to refine design studies, particularly in the preparation of marine operations.

The objective is to characterize severe metocean conditions with respect to marine operations, for example the worst monthly conditions that may occur once every 10 years. For such analysis, the data base shall be adequate for the purpose and the methodology shall be adapted.

The methods applied by CONTRACTOR for such analysis shall be fully documented.

5.3.4 Specific shallow water wave analysis

The available wave data are generally for deep water locations. When wave criteria shall be evaluated in shallow water, specific analysis shall be carried out to derive shallow water wave conditions from deep water waves.

A wave propagation model shall be applied to derive wave spectral characteristics at shallow water location from deep water wave spectral characteristics, this for selected wave conditions. The wave propagation model shall include following effects:

- Wave refraction and shoaling caused by the local bathymetry and by the currents
- Bottom friction
- Wave breaking caused by the local bathymetry and by the currents
- Non linear interactions in wave spectra when necessary
- Wave diffraction, if any
- Wave reflection, if any.

Special attention shall be paid to changes of direction between deep water and shallow water conditions, due to refraction for instance. In particular, the outputs at the shallow water location shall be presented by reference to the resulting directions, after wave propagation.

In addition, in some case, following effects must also be considered:

- Wind effects. The correlation between wind and wave shall be accounted for when selecting likely associated wind/deep water wave conditions for the simulations
- Tide and current variations during wave propagation.

The method applied by CONTRACTOR for such analysis shall be fully documented, in particular:

- The features of the wave propagation model
- The deep water wave conditions used in the analysis, as well as the associated tides, currents and winds
- The bathymetry, as well as the bottom friction coefficients used in the model and the other parametric formulas
- The dimension of the modelled area and the size of the mesh
- The boundary conditions
- The water level taken as a reference for the model.

In the Final Report, CONTRACTOR shall describe calibration and validation performed on the model as defined in section 5.3.7.

Extreme conditions in shallow water may be derived by propagating extreme deep water conditions, or by calculating the extreme values from the propagated deep water distributions/time series. CONTRACTOR shall assess and compare both solutions.

5.3.5 Specific shallow water tide and current analysis

In shallow water, tide and current conditions vary with the bathymetry and for specific projects such as pipeline projects, tide level as well as current speed and direction shall be specified for a large area. Usually, tide and current conditions are not available on the whole area and specific tide and current modelling shall be carried out to derive the required tide and current data.

A hydrodynamic model shall be applied to derive tide and current characteristics over the whole area from tide and current characteristics at given locations, this for selected tide and current conditions, generally spring tide conditions and extreme current conditions.

The hydrodynamic model shall include following effects:

- Tide and current variations at the boundary of the model
- Tide and current variations caused by the local bathymetry
- Bottom friction
- Input from river flow, if any.

In addition, in some case, following effects must also be considered:

- Wave radiation effects
- Wind forcing.

The methods applied by CONTRACTOR for such analysis shall be fully documented, in particular:

- The features of the hydrodynamic model
- The tide and current conditions used as boundary conditions
- The other boundary conditions, and particularly the river flow, if any
- The bathymetry, as well as the bottom friction coefficients used in the model and the other parametric formulas
- The dimension of the modelled area and the size of the mesh.

In the Final Report, CONTRACTOR shall describe calibration and validation performed on the model as defined in section 5.3.7.

5.3.6 Estimate of maximum wave height and extreme wave crest

Many different methods have been used for estimating maximum wave and crest heights. The choice of method has a big effect on extreme values. It is very important to specify accurate methods that are fit for purpose.

COMPANY have recently made a review of available methods and a summary of the recommendations is presented here below. The full report will be made available to CONTRACTOR if such an analysis is requested.

5.3.6.1 Wave Height Distribution

The Forristall (1978) empirical distribution is recommended as the short term wave height distribution for storm waves in deep and intermediate depths.

Unusually broad or narrow spectra will have slightly different wave height distributions. Several theories have been developed to deal with those cases. The most complete and best verified is that of Tayfun (1981) but it might not be applicable everywhere.

There is more uncertainty about wave height distributions in shallow water. Wave breaking in shallow water makes high waves less likely. The Ursell number is a measure of the tendency toward breaking in shallow water. Shallow water effects appear to be important for $U_r > 0.5$. For

$0.5 < U_r < 1.0$, use of the Battjes distribution to find wave height distributions is recommended. For $U_r > 1.0$, a fitted Weibull distribution found in the LoWish project is recommended.

5.3.6.2 Crest Height Distribution

The available evidence shows that second order simulations agree well with measured crest height distributions. The Forristall (2000) parametric description, based on a fitted Weibull distribution, gives a good fit to simulations of JONSWAP spectra. It is recommended for most design cases.

The recommendation is different when the design spectra are unusually broad or narrow. The Prevosto (2000) equations are slightly more complicated than those of Forristall (2000), but they have the advantage of explicitly accounting for varying amounts of directional spreading. That is particularly important when the design spectra are unusually broad or narrow.

The Forristall and Prevosto equations do not account for spectra with bimodal directional distributions. Bimodal directional distributions can be dealt with by simulations. But for those cases, it is more efficient to use the spectral response surface method described by Tromans and Vanderschuren (2004).

Over the long term, more accurate distributions for all cases will come from fully nonlinear simulations.

5.3.6.3 Combining Short and Long Term Distributions

The recommended method for combining short and long term distributions is based on finding maxima in storms. This method is explicitly recommended in the [ISO 19901-1](#). The Borgman integral is used to find the most probable maximum in each storm. An extreme value distribution is fit to the set of most probable maxima. The statistical short-term variability of the most probable maxima is accounted for by Tromans and Vanderschuren (1995). This variability must be included because it increases the expected maxima by 5% - 7%.

5.3.7 Calibration, Validation of Numerical Models

Calibration and validation of numerical models are crucial steps prior to derivation of extreme and operational metocean conditions.

The following list of tables and figures shall be provided to justify calibration and validation of numerical models of for wind and wave:

- Times series of numerical models and measurements during selected storms for wave significant height, direction, peak period mean period, wind speed and wind direction
- Comparison of cumulated probability distributions for wind speed, wave significant height, mean wave period and peak wave period for the complete dataset but also per directional sector and per season
- Quantile-quantile plots of models versus measurements for wind speed, wave height and period for the complete dataset but also per directional sector and per season
- Comparisons of wind and wave roses for the complete dataset and per season

- Derivation of the following coefficients: bias, standard deviation, scatter index and correlation coefficient for significant wave height, wind speed, mean period and peak period
- Conclusions on wave and wind calibration.

If current modelling is performed, the following tables and figures shall be provided:

- Times series of numerical models and measurements during strong currents periods for currents speed and direction
- Comparison of cumulated probability distributions for residual speed for the complete dataset but also per directional sector and per season
- Quantile-quantile plots of models versus measurements for current residual speed for the complete dataset but also per directional sector and per season
- Comparisons of residual current roses for the complete dataset and per season
- Comparison of tide coefficients (as a minimum 8 first ones)
- Comparison of current spectra from measurements and models
- Derivation of the following coefficients: bias, standard deviation, scatter index and correlation coefficient for residual current speed
- Conclusions on current calibration.

The conclusions on calibration shall be approved by COMPANY.

5.3.8 Analysis of cyclone induced extreme conditions

The risk of cyclone occurrence must be carefully investigated, even in areas where cyclone occurrence is low. The risk must be analysed in relation with cyclone intensity and cyclone strength in a wide area around site location.

The intensity of the most severe cyclones that may affect the site location shall be analysed. The spatial distribution of cyclone tracks over the wide area shall be investigated. The risk of extreme winds and waves over the area shall be derived from the analysis. And the extreme winds and waves at site location shall be specified for the given return periods.

For such analysis, a careful investigation of all historical cyclones that passed through the wide area around site location shall be conducted. Specific wind and wave modelling from available cyclone information shall be carried out. Adapted statistical analysis shall be performed.

The methods applied by CONTRACTOR for such analysis shall be fully documented.

5.3.9 Analysis of current profiles for deep water developments

As mentioned in section 5.3.2 and when possible, CONTRACTOR shall indicate the level of correlation between currents at various depth levels, as extremes may not occur simultaneously at all depths. Additionally, sheared or out-of-plane current profiles may occur and shall be identified. In some cases, extreme profiles may only be obtained by response-based methods, which are not described in the present General Specification and which require the description by COMPANY of the system that is designed.

In some cases, a set of current profiles with their associated frequency of occurrence shall be developed. This analysis will usually be carried out by accounting for amplitude only, i.e. by



neglecting direction. Methods such as the sophisticated Empirical Orthogonal Functions (EOF) method or a simple count by classes of speed per depth level may be used.

The methods applied by CONTRACTOR for such analysis shall be fully documented.

5.3.10 Marine growth

When requested by COMPANY, the following elements shall be reported by CONTRACTOR for a given site: type of marine growth; thickness/density/spread; seasonal variations; rate of growth (in relation with rate of inspection and cleaning, to be discussed with COMPANY).

If possible, CONTRACTOR will indicate the correlation between marine growth characteristics and physico-chemical water properties (temperature, salinity, nutrients, biological parameters (chlorophyl, plankton, etc.), etc.): the use of model databases could enable the extrapolation, by analogy, of observations to unknown areas.

The database used and methods applied by CONTRACTOR for such analysis shall be fully documented.

5.3.11 Tsunamis

If a potential tsunami hazard is expected, a probabilistic and deterministic tsunami hazard assessment. Such study shall be performed with the seismic hazard assessment study.

6. Preparation of metocean design criteria

6.1 Comprehensive Design Criteria

The metocean design criteria specified in Section 4 shall be prepared from the results of metocean data analysis and complementary studies described in Section 5. They shall be prepared in accordance with the reporting specifications of Section 7.

In the preparation of metocean design criteria, CONTRACTOR shall pay careful attention to the following:

- Consistency of metocean design criteria
- No underestimation of extreme conditions
- No underestimation of fatigue data
- No underestimation of exceedence and persistence statistics.

The design criteria shall be prepared as specified in Appendix 1.

7. Final report

The final report shall be segregated in two parts: the metocean design criteria part as defined in section 4 and the methodology and data analysis part as defined in section 5. The final report, to be issued on completion of studies, shall provide all necessary information on the data available for the study, as specified in Section 5.1, on the data analysis and complementary studies, as specified in Section 5.2 and 5.3, and on the results of the studies.

The final report shall be prepared as specified in Appendix 1.



CONTRACTOR shall present in the report its conclusions on the quality and the reliability of the metocean data given in the report, with its recommendations to improve the quality and the reliability, if necessary.

One electronic copy of the draft final report shall be submitted to COMPANY at completion of studies. If the report is commented by COMPANY, CONTRACTOR shall revise it and submit the revision within two weeks after receipt of comments.

After approval, CONTRACTOR shall provide COMPANY with two hard copies of the final report with an electronic version (native files and pdf format). Contractor shall also provide COMPANY with electronic files of all data (as defined in section 5.1) acquired for the study and all the results.

The report shall comply with following specifications:

Language	English
Format	A4
Electronic format	Reports shall be delivered as non-encrypted portable document format (e.g. Adobe Acrobat .pdf) and as original source as appropriate (e.g. Word, Excel, Autocad, etc.)
Binding	4 Ring binder or special binding
Sketches & drawings	Maximum A3 size
Large drawings	Shall conform to standardized sizes: A0, A1, A2 and shall be folded and placed in special folder bound into the main report A reproducible copy shall be supplied A reduction to A3 size shall be supplied
Executive summary	Main results shall be gathered in a preliminary chapter to be put in the introduction of the report
Index	Contents of the report with page numbers shall be put at first page.
Frontispiece	A sketch of area with location shown shall be put as frontispiece. It shall include details of reference datum
Bibliography	Bibliography relevant to all names, titles, methods used or cited in the report shall be indicated at the end
Glossary	All technical terms shall be explained in a glossary
Appendices	Appendices to the report shall include all computation notes, listings, data sketches, weather maps, etc. not directly necessary for the comprehension of the main report. They shall be bound separately
Computer Programs	A description of the algorithms used in Computer Programs shall be given
Reference Number	Date of Report, Contract Reference, CONTRACTOR name shall be mentioned on each page



Appendix 1 Contents of final report

Part 1: Metocean Design Criteria

1. Introduction

Description of the area - Location map - Detailed map

Chart datum - Co-ordinates reference

Reference documents - Units and conventions.

2. Metocean design criteria

Description of general metocean/climatological conditions in the area.

Presentation of all metocean design criteria that are presented in the attached tables

Discussion of the results, by reference to the general conditions. When relevant, each analysis output (such as tables or plots) shall be commented and interpreted.

3. References

Appendices

Appendix 1 - Tables of metocean design criteria

- Main table of extreme criteria (omnidirectional data) for each return period
- Tables of directional and monthly extreme criteria for each return period
- Table of joint distribution of wind speed and direction
- Table of joint distribution of significant wave height and direction
- Table of joint distribution of significant wave height and peak or/and mean period - omnidirectional and by direction
- Table of joint distribution of individual wave height and direction, with the most probable associated period for each height/direction couple
- Table of joint distribution of individual wave height and period
- Table of joint distribution of current speed and direction, per depth level
- Tidal harmonic constituents
- Monthly distribution of wind speed
- Monthly distribution of significant wave height
- Monthly distribution of current speed, per depth level
- Monthly wind persistency statistics
- Monthly wave persistency statistics
- Monthly current persistency statistics
- Wind spectral model



- Wind profile model
- Wave spectral model
- Air and sea parameters.

Appendix 2 - Complementary tables of results

Other tables of metocean data statistics.

Appendix 3 - Figures

- Location map
- Wind, wave and current roses
- Wind, wave and current vs. direction scatter plots and iso-probability contours
- Wave (significant) vs. peak period scatter plots and iso-probability contours
- Percentage exceedence and persistence diagrams
- Current profiles
- Tidal current ellipses
- Empirical distributions and model fitting
- Wind spectra
- Wind profile
- Wave spectra.

Other relevant figures.

Part 2: Methodology and Data Analysis

1. Executive summary

General objectives of the study

Main results

2. Introduction

Aim of the study - Contractual requirements

Description of the area - Location map - Detailed map

Chart datum - Co-ordinates reference

Reference documents - Units and conventions

3. Metocean data sources

Sources of data

Quality and reliability

Limitations



4. Methodology for data analysis

Standard statistical analysis

Extreme value analysis

Spectral analysis

Harmonic analysis

Specific events

5. Methodology for complementary studies

(Depending on complementary analyses that have been performed)

6. Conclusions and recommendations

Quality and reliability of metocean design criteria

Recommendations for improvements if necessary

7. References

Appendices

Appendix 1 - Tables

- Relevant tables especially calibration/validation tables

Appendix 2 - Figures

- Empirical distributions and model fitting
- Figures relevant for calibration/validation

Other relevant figures.