DETERMINATION OF DESIGN AND OPERATIONAL ENVIRONMENTAL PARAMETERS FOR OFFSHORE STRUCTURES

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ABSTRACT

This paper describes in brief the state of art for the determination of design and operational environmental parameters for offshore structures. Procedures for the determination of design wave, wind, current and tide for the Indian coastal waters have been discussed. Since instrument recorded data on waves and winds are not available for Indian coastal areas, hence Wilson's technique for the analysis of cyclones, is the best technique for getting the design wave and wind conditions. The design current at the site can be determined by using the techniques of Ekman, Stokes and Airy combined with a few months instrument recorded data.

The techniques of presentment of data in the form which will be useful for offshore operations have been discussed. Areas in which further research is needed have been highlighted.

INTRODUCTION

A huge literature is available giving the damages to offshore structures due to severe environmental conditions. In order to give an idea of damages caused by a single cyclonic storm, two typical case histories have been cited below:

(a) Hurricane Hilda moved through the central Gulf of Mexico in October 1964 causing complete destruction to at least 13 offshore structures, and three others damaged to such an extent that major repairs and replacement were necessary.

(b) Hurricane Betsy, September 1965, was the most damaging storm that had ever struck the Gulf of Mexico coast. Two single-well structures in 41 m of water and two multiwell structures in 65 m of water were destroyed. A multiwell structure in 90 m of water was so badly damaged that it had to be salvaged.

A review of the above two case histories show that the detailed knowledge of the environment is essential before any offshore structure can be designed. A few of the important environmental factors which must be considered before the design of the offshore structures are:
1. Wave 4. Tide

2. Wind 5. Other oceanographic parameters like sea temperature, salinity, oxygen, density, etc.


In the present paper the first four parameters, will be discussed in detail while the fifth will be briefly described. Soil conditions on the sea-bed and their utility in the design of offshore structures have not been covered in this paper.

Besides, for the design purpose, environmental data is also needed for offshore operations.

The prediction of daily or weekly average environmental condition determines how efficiently operations can be carried out and which, in the long run, has a profound effect on the return of investment.

DESIGN ENVIRONMENTAL FACTORS

The designer of offshore platforms, pipelines or mobile drilling rigs, etc. will like to have the maximum survival probability for its structures while keeping the cost to a minimum. The determination of design environmental factors can be divided into two major steps, environmental parameters determination and selection of design parameters. The basic data on meteorological and oceanographical parameters for an area can be collected from the following process:

(i) Hindcast from synoptic meteorological charts based on data collected for a number of years.

(ii) Install equipment on the site and collect the data for severe climatic seasons.

(iii) Collect available historical data from the areas surrounding the site.

The next step in the process is to extrapolate extreme values from the data collected for various meteorological and oceanographical parameters. The design values are selected from the extreme values on the basis of safety factor and probable life of the structure.

DETERMINATION OF ENVIRONMENTAL PARAMETERS

(a) Waves

The extreme value for waves in an area can be determined from any one or a combination of the techniques discussed below:

1. Extrapolate from hindcast data

The three important wave forecasting/hindcasting techniques available in the published literature are:

(a) Sverdrum-Munk-Bretscheider and Wilson technique

(b) Pierson-Neumann-James technique

(c) Darbyshire technique

(a) Sverdrup - Munk - Bretscheider and Wilson (SMBW) technique

From a study of the processes by which the energy is transmitted from wind to wave, Sverdrup and Munk have derived the energy relations correlating significant height (H) and velocity (C) with wind velocity (U),
duration of wind (td) and fetch (F) and have drawn the forecasting curves. Bretschneider reconstructed these curves to fit more recent data. Later Wilson suggested analytical relations which are a better fit to the data presented by Bretschneider. Using these relations, Wilson has plotted relations between dimensional variables H, F, T and td. This graph is referred to as Ht-FT diagram, and can be used for forecasting deep water waves.

(b) Pierson-Neumann-James (PNJ) technique

The authors have made a mathematical representation of the complex sea surface of short crested waves. The elevation of surface at any instant can be given as a combined effect of an infinite number of sine waves, with completely random phases. Neumann proposed that a unique energy spectrum of the waves will result if the wind blows for an infinite time and over a large enough area to generate a fully developed steady state condition. If the duration is limited or the fetch is limited the spectrum will not reach a steady state. Neumann has developed formulae for these cases and has drawn a series of curves which can be used for forecasting purposes.

(c) Darbyshire Technique

Darbyshire has derived a formula correlating significant height of waves with wind velocity and fetch. In practice the height is computed on the basis of the wave spectrum i.e. during growth waves of different periods are considered separately and at the end of the fetch these wave components are combined to give the actual conditions.

For the determination of design wave we need to know the maximum possible waves generated in the area due to cyclones. During cyclones windspeed changes frequently both in space and time. Wilson's graphical technique gives an accurate forecast for situations in which the wind speed frequently changes, hence Wilson's technique is generally used for forecasting cyclone waves.

Wilson's wave forecasting curves are used to get the significant height, significant period and the time of occurrence of the highest wave, by choosing various generating points in the wind field diagram. The effect of decay of the waves while travelling from generating area to the point of interest (deep waters) is determined by using Sverdrup-Munk decay curves. The wave height is further modified as they approach the shallower areas, due to refraction, shoaling and bottom friction. Refraction diagrams are drawn for different periods and directions using the technique of Terry and Herlich. Using the coefficients obtained by refraction diagrams the deep water wave characteristics are corrected for shoaling, refraction and bottom friction. Some of the deep water waves break before reaching the point of interest, where the offshore structure is stipulated to be constructed. These waves are filtered out. Thus we get the extreme wave condition which can occur by cyclones during fifty or hundred years period depending upon the 50 year or 100 year cyclones being analysed.
2. **Extrapolate from measured area**

The most accurate, though the costliest procedure for getting the design wave in an area is to collect the real-time data at the site for a couple of years, preferably covering the cyclone periods. One of the best wave recording equipment available in the market is Data-Well telemetering wave buoy (Fig. 1). Twenty minutes wave records are taken every three hours and processed to determine significant wave height and significant wave period. The data is further analysed to get the cumulative percentage of time that a wave is likely to exceed a specified value. The calculated values are plotted on probability – logarithm graph (Fig. 2). From this graph the design wave for a particular period is determined.

3. **Extrapolate from ship reported data (Visual observations).**

The only data which is easily available for Indian coastal areas is the ship reported data. Visual estimates of wave height, period and direction are reported by various naval and merchant vessels traversing the area. The wave height thus reported is considered to be the significant wave height while the period and direction reported is taken to be the average occurring at the site. These data are analysed to determine the cumulative percentage frequency distributions for various height classes. After this the probability technique described above is used for determining the extreme wave condition. It is important to note that the data reported by ships is random, both in horizontal plane and time, hence the design values so obtained should be used with caution. More so the ships will normally avoid the rough weather areas, particularly the vicinity of cyclones, hence the reported data will tend not to report very high waves.

4. **Design-storm technique**

In this technique a design storm is used and cartesian component of wind field for this storm are determined. The components of wind fields thus determined are used together with wave forecasting relationships to generate components of wave fields, which are then combined to obtain stationary cyclone wave fields. The design cyclones for our coastal areas have not yet been worked out. It will be advantageous for offshore engineers if research is done to develop design storms for various areas of our coastline. From hurricanes occurring in the Atlantic Ocean, Bretschneider has developed procedures for getting wave conditions of a design hurricane from wind field diagrams. He has also developed techniques, modifying the wave data calculated for a stationary design storm for a moving system. The design wave parameters for an area can be determined by analysing a design storm.

(b) **Winds**

The determination of design wind for an area can be determined by one or a combination of the following techniques.

1. **Extrapolate from hindcast data**

Surface synoptic charts for severe cyclonic periods are obtained from the India Meteorological Department. The highest wind which can occur
Fig. 1 Data well wave rider buoy
in the area during 50 or 100 year period is determined from the above charts, by the techniques as outlined in the section on waves.

2. **Extrapolate from coastal measurements**

Coastal observatories of the India Meteorological Department have been collecting wind data at specified times since a number of years. All the available wind data from the observatories nearer to the site is collected. These data are corrected for the offshore site by using suitable conversion factors. From the data so obtained cumulative frequency
distribution of winds is determined for different wind speed classes. As discussed earlier, the design wind can be obtained from this data by using the log probability - logarithm graphs.

3. *Extrapolate from ship reported data*

In using the ship reported data for wind for getting the design wind in an area, the same technique is followed as for waves.

4. *Design storm technique*

Bretschneider (1959) has presented a hurricane wind model in a dimensionless form. This model is based on an exponential related model pressure field. Graphs have been prepared which can be used for getting the design wind if a design cyclone is available for the site.

The design wind calculated from the above four techniques gives the average wind recorded for about 3 to 5 minutes. The conversion factors to calculate average winds for different periods from five minutes average wind are as follows:

1. 1 hour average wind = 5 minutes average x 0.86
2. 10 minutes average wind = 5 minutes average x 0.94
3. 1 minute average wind = 5 minutes average x 1.07
4. 5 seconds average wind = 5 minutes average x 1.27

(c) *Currents*

The extreme current at any place can be caused by one or a combination of the following forces:

1. Extreme tidal currents
2. Design-storm wind driven currents
3. Design wave induced currents
4. General circulation

1. *Extreme spring tide*

Tidal currents are predominant in semi-enclosed bodies of water with higher tidal ranges. For the determination of tidal currents in an area it is essential that current meters, preferably self recording, should be installed for a period of about one month during the calmest season. Tidal and wind data in the area is also collected simultaneously. From the data so collected tidal component of the current is sorted out. A relationship is developed between the tidal current and the tidal range in the area. Using value of maximum tidal range in the area the maximum possible current in the area is determined.

2. *Design storm wind*

Wind causes a shear stress at the air-water interface and the air drags water along. Ekman has given a theoretical relation between the wind speed and the wind driven currents at different depths. The equations derived by Ekman will have to be modified when the depth of water is limited. Using these relations the maximum probable wind driven current is determined for design storm wind.

3. *Design wave*

For determination of wave induced current the following theories are used wherever they are applicable:
(a) Stoške’s Vth order
(b) Airy’s
(c) Solitary wave

It is important to note that the wave induced currents will be changing direction every few seconds, depending upon the period of the wave, hence the current meters normally do not record them.

4. General Circulation

The magnitude of general circulation in the area can be estimated only if long term data is available for the area. For semi-enclosed bodies it is normally less than 0.05 m/s.

The maximum current speed obtained from the techniques 1, 2 & 4 is combined vectorially to get the design current in the area. The results obtained from technique No. 3 are depicted separately and are used for calculating the total forces on offshore structures.

(d) Tides

The tides in an area can be caused by astronomical forces and cyclonic storms. For the determination of extreme astronomical tide in an area in situ tidal data is collected for at least one month. A correlation is established between the tidal ranges at the site to the tidal ranges at the nearest port for which daily predicted tides are available. The mean spring tide in the area of study can be obtained by multiplying the mean spring tidal range by suitable factor established for the nearest port.

The storm tide in the area are caused by the low barometric pressure and associated high wind velocities of cyclonic centres. Detailed techniques for the calculation of storm surges are presented in the manual on-shore protection of U. S. Army Corps of Engineers.

In areas where tide is not the most critical parameter the total extreme tides frequently taken as the sum of maximum annual astronomical tide and the storm tide calculated for the design storm having the specified recurrence interval. A more rigorous approach is to calculate the probability distribution function for the combined tide from the independent distribution functions for astronomical and storm tides.

(e) Other Oceanographic Parameters

Seasonal maximum and minimum values of the oceanographic parameters like Ph, oxygen and salinity are needed for designing the anti-corrosive measures. The knowledge of the variation of parameters like nitrate, phosphate, etc. are needed for designing the anti-fouling measures. Seasonal variations of parameters like sulphate, chloride etc. are needed for choosing a suitable cement for offshore work.

OPERATIONAL ENVIRONMENTAL CONDITIONS

The operational environmental conditions for an area can be broadly divided into two parts, construction period and long term use.
(a) **Construction period**

The environmental conditions expected during construction depends on the period of the year in which construction occurs. To get the extreme conditions during the construction period it is necessary that five or ten year recurrence values be utilized. The wind and wave data for this purpose are analysed for a number of years and are presented to the operators in the form of rose diagrams or exceedence graphs.

A typical wind rose diagram and exceedence graph for the Gulf of Kutch are presented in Figs. 3 and 4. From the above diagrams it can be seen that December to March
are the calmest months in the area with winds exceeding 39 kmph for about one per cent of the time. A similar study is made to determine the periods when the wave activity is negligible and the occurrence of cyclones and depressions are minimum. After considering the above facts the best construction period is judiciously selected.

The different types of currents and their magnitudes and directions expected during the construction period are calculated for the probable maximum wind and waves during the construction period. Various techniques to be adopted for this purpose have already been discussed while discussing the design current.

(b) Long term use

For the determination of environmental conditions expected during long term use 25 to 30 years data is analysed. The persistence of winds and waves (cumulative frequency) above selected values, for different periods, are determined and presented in tabular form. Longer period wave data for Indian coastal areas are seldom available. In such cases seasonal normal frequency of wave heights, periods and directions are hindcast from normal winds in the area.

The current data for long term use are determined by using the normal winds and waves.

Tidal variations in the area are determined by using the tidal predictions for a nearby coastal station.

CONCLUSION

In this paper the importance of environmental data for the design, construction and operation of the offshore structures have been discussed. Procedures for the calculation of design conditions for various oceanographic parameters have been discussed. Practically no real time data on winds and waves are available for Indian coastal areas, hence Wilson's technique for the analysis of cyclones, is the best technique for getting the design wind and wave conditions. The design current in the location can be calculated by using the techniques of Ekman, Stockes and Airy combining with a few months real time data collection in the area.

The presentation of data in the form which can be of direct use to the operators of offshore structures have been discussed. A few of the problems in oceanographic studies which need further research have also been pointed out.

Acknowledgement: The author is highly grateful to Dr. A.K. Manna for his keen interest in this work.

REFERENCES


Fig. 3-A.
Fig 3-b
NOTES—

1. SOURCE—INDIA METEOROLOGICAL DEPARTMENT.
2. BASED ON OBSERVATION BY SHIPS PLYING IN THE REGION LATITUDE 21°-25° N. AND LONGITUDE 67° E. TO COAST LINE.
3. FIGURE IN THE CENTRE OF EACH DIAGRAM INDICATE THE NUMBER OF OBSERVATIONS.

Fig. 3-E
### Season Wise Frequency Tables of Wind

#### Gulf of Kutch

#### December to March

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<th>Wind Direction from North</th>
<th>Total</th>
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Fig 3-F

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