A Numerical Simulation for Predicting Sea Waves Characteristics and Downtime for Marine and Offshore Structures Installation Operations

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Abstract
In this paper, a numerical simulation of sea wave characteristics and operation downtimes of offshore structures is presented. The simulation was based on available wind data and seawater temperature recorded by an oceanography buoy installed in the Caspian Sea. Wave characteristics were simulated for deepwater parts of the Caspian Sea by applying the Bretschneider spectrum and equations using following recorded data: wind velocity, wind duration, fetch length, and water/air temperature differences. Since recorded wave data were only available for a one-year period, they were solely used for validation of the simulation results with recorded data but for not the simulation itself. Some practically established thresholds for wave velocity, wave period, and wind velocity were considered as constrains, limiting the operation of offshore installations. The numerical simulation model revealed that it is possible to operate offshore installations for 250 days per year in the southern parts of the Caspian Sea. A worst-case scenario showed that the maximum waiting time for restarting the offshore installations is 17 days. Considering the swell parameter, it was concluded that the annual downtime period of offshore installation operations in southern parts of the Caspian Sea is about one third of a year and the maximum waiting time for this operation is about two third of a month.

Keywords: Simulation, Bretschneider, Wave Height/Period, Caspian Sea, Marine

Introduction
In order to design, calculate, construct, and install coastal, port, marine, and offshore structures, environmental data are needed, in particular wave and wind data. To determine wave data, simulation models, measuring devices, and remote sensing by satellites are used. Obtaining valuable and long-term environmental data by measuring devices or satellites is time consuming and very expensive. In addition, these types of data are not available for all regions.

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Because of the above-mentioned drawbacks of the direct measuring methods, simulation models are widely used in establishing environmental data. They are easy to use and are applicable for every geographical area, provided valid equations and spectrums are chosen, calibrated, and well adapted to the specific situation. To predict the wave characteristics in lakes, gulfs, seas, and oceans, the equations and spectrums of Sverdrup-Munk-Bretschneider (S.M.B), Bretschneider, Pierson-Moskowitz, and JONSWAP (Joint North Sea Wave Project) are mainly used. These models can be adapted to every point in any water depth in the sea waters (Sadeghi 2001).

To evaluate the validity of the Bretschneider spectrum, a case study was carried out by the author for the Caspian Sea. The Bretschneider spectrum was selected for this study because its equations and spectrums consider the very important parameter of water/air temperature differences.

The Caspian Sea was chosen as study area, since sufficient wave characteristics data are not available for some parts of the Caspian Sea allowing the evaluation of sensitive operations such as installations of offshore petroleum platforms and the like. Simulation of wave characteristics was carried out based on available wind data recorded by Khazar Oceanography Buoy (KEPCO 2001). This buoy is located in the south-eastern part of Caspian Sea, 30 km from Neka Harbour at a water depth of 35 m and operated by KEPCO (Iranian Company for Exploration of Oil in Caspian Sea).

Wave characteristics were simulated for deep water parts of the Caspian Sea based on recorded wind data using the Bretschneider spectrum (Bhattacharyya 1972, Cold Bay Study [CBS] 1999) and various modeling equations (U.S. Army Coastal Engineering Research Center 1980, Sadeghi 1989, 2001). Wind duration, wind velocity, fetch length, and water/air temperature differences were considered in the simulation. Some constrains for wave velocity, wave period and wind velocity were used as limitation criteria for offshore installation operations. It is important to mention that only one-year wave data were available for the study area. Thus, these data have only local validity and are not valid for other points of the Caspian Sea, particularly for deep-water areas. Therefore, the recorded wave data were only used for comparison purpose and were not applied in the simulation.

**Information and data used**

General information on environmental conditions (wave, wind, current, etc.) obtained from literature were used for general consideration and overall engineering judgments (U.S. Army Coastal Engineering Research Center 1980, Sadeghi 1989, 2001). The data used in the wave characteristic simulations were taken from KEPCO (2001).
Formulas used in this study

The Bretschneider equations and spectrum were applied to predict forecasting the wave characteristics (U.S. Army Coastal Engineering Research Center 1980, Sadeghi 1989, 2001, CBS 1999). The Bretschneider equations take the effects of wind blowing duration, wind velocity, air-sea temperature difference, and fetch length into account.

Summary of assumptions and analysis approach


Following assumptions and analysis steps were applied:

a. Since there is lack of wind data for all points in south Caspian Sea, the wind data recorded in the location of the above-mentioned buoy were used for all points of the south Caspian Sea considering different fetch lengths. Comparing the wind data for different parts of the south Caspian Sea presented in literature (Kosarev & Yablonskaya 1994) showed that this assumption could be considered as a valid.

b. A summary of used formulas based on the Bretschneider spectrum is presented.

c. Data on seawater temperature, wind velocity, direction of wind, wind duration, and air temperature were taken from KEPCO Engineering Department measured by the KEPCO buoy (KEPCO 2001) and were used for the numerical simulation of wave characteristics of the south Caspian Sea. It is to be underlined that the available one-year data covers only a certain period (1988/1989).

d. In the available data (KEPCO 2001), the period of each set of record is three hours. It is important to note that this 3-hour period is not necessarily the wind blowing duration. Therefore following criteria were used for evaluating the wind duration:

  - If the directions of wind for two consecutive sets of recorded data were different, the wind duration is considered as $1.5 \times 3$ hours (because of difference between measuring period and real wind duration by considering minimum probable duration of 4.5 hours).
If the differences among wind directions between every two consecutive periods of recorded data were less than 7 degrees, the consecutive accumulated wind measuring duration were considered as wind blowing duration (t). In this case the average wind velocity was also used.

e. With regard to wind velocity and blowing duration, the required related minimum fetch was calculated from the Bretschneider equation which should be less than maximum effective fetch existing in the south Caspian Sea (i.e. 450 km).

f. Based on the Bretschneider spectrum, the ratio of maximum wave height over significant wave height is normally bigger than two. In this study the Rayleigh ratio for $H_{\text{max}}/H_s$ was used for the benefit of simplicity (i.e. $H_{\text{max}}/H_s = 1.85$) (DNV Classification Notes 2000, Sadeghi 2001).

g. Significant wave height, significant wave period, and peak period were calculated based on the Bretschneider equation considering the air-sea water temperature difference.

h. Constraints for the limitation of installation operation were defined as follows:
   - Maximum wind velocity equal to 20 Knots
   - Maximum wave height equal to 2 meters
   - Maximum wave period equal to 8 seconds
   - Installation operation duration equal to 5 days (This duration is considered for mooring and installation operation of the Iran-Alborz semi-submersible drilling platform in water depth of 970 m in the Caspian Sea).

Wave characteristics simulation results

Comparison of simulated and recorded wave characteristics
Simulated wave height and period for the south Caspian Sea were compared with recorded wave height and period for a distinct point in this sea (30 km from Neka Harbour, at 35 m water depth). It is important to note that the results of simulated values were different from that of existing recorded values at that certain point. The reason is that the reference point in this study was located at the south-east corner.
of Caspian Sea and thus, the fetch will be different from other points at southern basin of Caspian Sea.

Figures 1, 2, 3, and 4 present the maximum wave height ($H_{\text{max}}$ in meters) versus time (sets of 3 hours registered data). In the horizontal axis of these figures, 40 means $40 \times 3$ hours that equals to five days and 720 means $720 \times 3$ hours equaling three months.

Figures 5, 6, 7 and 8 show the recorded values of $H_{\text{max}}$. As it can be seen from these figures the simulated values are generally well adopted with the recorded values but a little bigger than them due to longer fetches.

![Figure 1. Simulated maximum wave height for months 11, 12, year 1988 and month 1, year 1989.](image)

As shown in figures 7 and 8 for an about two-month periods, the wave heights were not recorded, but for the time period, the wave heights were simulated and are presented in figures 3 and 4.

Figures 9, 10, 11 and 12 show the simulated peak period ($T_{\text{m}}$) versus time (sets of 3 hours registered data).

On the above-mentioned figures, the limitation criteria are shown by full block lines and also the non-operational days are presented. It is to be mentioned that the recorded and simulated wave periods were moderately different. This is mainly due to the swell effect that has not been considered in Bretschneider formula and as a result of the numerical simulation.
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Figure 2. Simulated maximum wave height for months 2, 3 and 4, year 1989.

Figure 3. Simulated maximum wave height for months 5, 6 and 7, year 1989.
Figure 4. Simulated maximum wave height for months 8, 9, 10 and 11, year 1989.

Figure 5. Recorded maximum wave height for months 11, 12, year 1988 and month 1, year 1989
Figure 6. Recorded maximum wave height for months 2, 3 and 4, year 1989.

Figure 7. Recorded maximum wave height for months 5, 6 and 7, year 1989.
Figure 8. Recorded maximum wave height for months 8, 9, 10 and 11, year 1989.

Figure 9. Simulated peak period for months 11, 12, year 1988 and month 1, year 1989.
Figure 10. Simulated peak period for months 2, 3 and 4, year 1989.

Figure 11. Simulated peak period for months 5, 6 and 7, year 1989.
Conclusion
Due to the limitation of the existing recorded data (only one year available data for a certain point near the shoreline), this simulation can be considered only as a guide for evaluation of situations and can be used only for preliminary estimations.

Considering the operational constraints ($H_{\text{max}} = 2$ m, $T_m = 8$ s and gust velocity = 20 Knots) used for numerical simulation, an installation operation of 250 days per year is possible. The maximum waiting time for restarting the installation operation is estimated to last 17 days.

As only the seas are simulated and due to lack of data and information for swell, it can be in general concluded that the installation operation is possible for 2/3 of the year and the maximum waiting time for this operation is about 2/3 of months.

References
Cold Bay Study [CBS], 1999. Section IV (Climatology).


