Calculating wave parameters of specified return periods by using WAM4 model

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Introduction

A new harbor is going to be built at Caofeidian (118° 30´E, 38° 55´N) in Bohai Sea. In order to obtain the design wave parameters for the engineer’s use in designing the harbor structures, we need to understand the wave climate (including extreme waves) in the harbor waters, which requires long-term wave data series exceeding twenty years. So we use the wave model WAM4 and the reanalysis wind field to reproduce 21 year (1981-2001) wave data.
red point is the location of Caofeidian harbor
Introduction

Also, wind observations at the coastal stations along Bohai Sea made every six hours are used to correct and validate the reanalysis wind field. In this presentation, description is given of the reproduction of the long-term hindcast wave data and the computation of design wave parameters.
Introduction

According to all kinds of available information about harbor waters, the engineering demands are to calculate design wave parameters of ENE, E, SE, S, SW, W directions with return periods of 50 year and 25 year at the appointed location. The design wave parameters include wave height and wave period of different accumulation probability H1%, H4%, H13%. The calculating process involves selection of driving wind field, simulation of deep water wave and computation of wave parameters of specified return period.
The whole process flow

1981-2001 year ECMWF reanalysis wind data

- correction

WAM4 model

21 years hindcast result

21 years series of annual extreme significant wave height

- wave parameter of 50 and 25 year return period

2002-2003 year reanalysis wind data

WAM4 model

verification
The wind field is derived from the 40-years reanalysis data of The European Centre for Medium-Range Weather Forecasts (ECMWF). The new reanalysis project ERA-40 will cover the period from mid-1957 to 2001 including the earlier ECMWF reanalysis ERA-15, 1979-1993. The aim of the reanalysis was to produce a dataset with no inhomogeneities by reconstructing the 45 years of data using the same numerical model throughout, and to promote the use of global analyses of the state of the atmosphere, land and surface conditions over the period.
The three dimensional variational technique is applied using the T159L60 version of the Integrated Forecasting System to produce the analyses every six hours.

The ERA-40 data, considered as high-quality data by the field of meteorology, is widely used in many aspects of Europe and internation climate research. It plays an important role in all meteorological service and scientific research.
Description and correction of reanalysis wind field

Though the reliability and accuracy of the ERA-40 wind field is widely accepted internationally, there is some limitation to the local region. The reason is:

1) The wind field of local region is frequently influenced by local circumstances, but much influence of local environment might be smoothed when running model to calculate the ERA-40 data;

2) For large scale, the resolution of 1.125 degree, is fine enough, but for local small region, this resolution could not reflect the particular structure of the wind field of local region.
Description and correction of reanalysis wind field

So far, meteorological station observations are considered the most reliable wind observation. As for Bohai Sea and its adjacent waters we concerned, there are a lot of data of many observation stations along coast and at islands, these materials were utilized in validating the ERA wind field of ECMWF. So with making use of much valuable material, we could correct the ERA data to improve its exactness.
Description and correction of reanalysis wind field

locations of operation spot and nine meteorological stations
While we corrected the ERA wind data, we found out those wind speed observations over 8m/s and the corresponding ERA wind data and obtained their ratios. Then for two situations, Summer and Winter, we averaged twenty-one years’ ratios and got the correction coefficients respectively. Figures of the ERA data in comparison with observations of operation spot and nine meteorological stations are showed as follows.
Description and correction of reanalysis wind field

wind speed comparison of Caofeidian in Aug, 1997
Description and correction of reanalysis wind field

wind speed comparison of Tanggu station in Aug, 1997
Description and correction of reanalysis wind field

Wind speed comparison of Laoting station in Aug, 1997
Description and correction of reanalysis wind field

wind speed comparison of Suizhong station in Aug, 1997
Description and correction of reanalysis wind field

Wind speed comparison of Longkou station in Aug, 1997
Description and correction of reanalysis wind field

wind speed comparison of Chengshantou station in Aug, 1997
Description and correction of reanalysis wind field

Wind speed comparison of Qingdao station in Aug, 1997
Description and correction of reanalysis wind field

Wind speed comparison of Shengsi station in Aug, 1997
WAM model

WAM is a third-generation wave model, which calculates the evolution of the wave energy spectrum by an explicit method, without any prior assumptions about its shape. It represents the physics of wave evolution in accordance with present day knowledge for the full set of degrees of freedom of the two-dimensional surface wave spectrum. It solves the action density balance equation, expressed in terms of wave energy, for the case of steady depths and currents. In deep water, the energy balance equation reads:

$$\frac{\partial F}{\partial t} + \rho_{g} \cdot \frac{\partial F}{\partial x} = S$$
where, $V_g$ is the group velocity, $F = F(f_w, \theta)$ is the wave spectrum described by the frequency $f_w$ and the wave direction $\theta$, $S$ is the source term given by

$$S = S_{in} + S_{nonl} + S_{ds} + S_{bot}$$

where the terms on the right hand side represent the physics of wind input, wave-wave interaction, dissipation due to whitecapping and bottom friction, respectively.
The calculated region of offshore wave is 116-128E, 30-42N, and the resolution is 0.25° x 0.25°. The water depth, derived from ETOP5, is revised by the newest sea chart of Bohai area. The driving wind field is obtained from ECMWF’s reanalysis wind field that is corrected and interpolated. The wind force is updated every six hours. The wave model is numerically solved by integrating the source term and advection term with the time steps of 10 and 20 minutes, respectively. The wave spectrum has 25 frequencies and 12 directions at each gridpoint. The time period is from 1981 to 2001. For ENE and E direction, we make a supplement to calculate the extreme wave process in 2002 and 2003.
WAM model

The calculated model results are compared with wave observations of Caofeidian. We could see that the wave model can reproduce big wave out Caofeidian harbor well.
WAM model

In Bohai sea on Oct 11, 2003, a simulated case caused by a very strong cold air is shown as figure. We also output every hour wave height out Caofeidian harbor.

significant wave height distribution on 18UTC October 11, 2003
WAM model calculated significant wave height from 20UTC October 8 to 02UTC October 14, 2003.
As example of $H_{1/100}$ wave height of ENE direction, it is shown as table that the series of annual extreme wave height from 1981-2003 out Caofeidian harbor. From this, we calculate the average annual extreme wave height $\overline{H} = 4.07\, m$, $C_v = 0.26$. 
Calculating offshore wave parameters of specified return period

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<th>year</th>
<th>$H_{13%}$</th>
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Calculating offshore wave parameters of specified return period

We get the best fitting curve of P-III type by adjusting $\frac{C_s}{C_v}$, shown as figure.
Calculating offshore wave parameters of specified return period

From this curve of P-Ⅲ type, wave heights of all kinds of specified return period could be obtained. The method is completely same for wave height of other directions and accumulation probability.
Conclusion

When we calculate the engineer’s wave height, especially in the situation of lacking long-term wave observations, we use the reanalysis wind field and wave model WAM4 to reproduce long-term wave data series. From discussion above, we could see the approach is feasible and practical.
Thank you!