ANALYSIS OF EXTREME WAVES IN THE GULF OF OMAN

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INTRODUCTION

The south Iranian coastline is extended along the Persian Gulf, Strait of Hormuz, and the Gulf of Oman (Figure 1). Among these water bodies, the Gulf of Oman experiences Tropical Cyclones (TCs) infrequently, but there has been an observed increase in their intensity in recent years (Ranji et al., 2020). Gonu (2007), which is the most intense TC on record, and Shaheen/Gulab (2021), with its rare track that propagated close to the Iranian coastlines, are examples of recent TCs that resulted in significant damage to the coastal infrastructures.

Several studies have considered the design wave in the Gulf of Oman. Danish Hydraulic Institute (DHI) performed an analysis on wave and storm surge conditions caused by TCs in 1976 to facilitate the design of the Chabahar Naval Base. A comprehensive review of wind and wave data for the area was conducted in 2005 by a joint venture between Sazeh Pardazi Iran and Royal Haskoning (SPI-RH, 2005). The study concluded that the wave dataset from the British Meteorological Organization (BMO) is the most reliable due to its extensive spatial coverage and long recording period. As part of the broader development of a wave climate for the southern coastal regions of Iran, Baird & Associates (2007) carried out a thorough examination of wave conditions caused by TCs in the Gulf of Oman. Monte Carlo numerical simulations were employed to artificially generate TC waves. This approach was used as a means to compensate for the limited availability of reliable historical data.

Given the increasing intensity of tropical cyclones (TCs) in the Gulf of Oman in recent years, it is imperative to conduct a comprehensive review of extreme waves and define the design waves in the region. This serves as the primary objective of the present study.

METHODOLOGY

A reliable long-term dataset is needed for Extreme Value Analysis (EVA) of storm waves. This can be acquired either by the global re-analysis data or hindcast data, extracted from regional numerical models.

The dominant coastal design wave condition in the Gulf of Oman is attributed to TC waves along the north coastline of the Gulf of Oman, particularly in the central and eastern sections. This is due to the fact that the maximum wave heights originating from TCs can surpass those generated by other meteorological phenomena, such as northerly Shamal winds coming from the Persian Gulf and monsoons. Since the availability of reliable TC data in the vicinity of Iranian coasts begins after Gonu (2007), a hindcast wave data spanning 20-year period from 2000 to 2020 is performed in this study.

NUMERICAL MODELING

A regional wave model is developed to reproduce the hindcast data along the Gulf of Oman using the Spectral Wave (SW) module of MIKE21 (DHI, 2017). The surface wind forcing to the wave model is extracted from ERA5 reanalysis data (Hersbach et al., 2020).

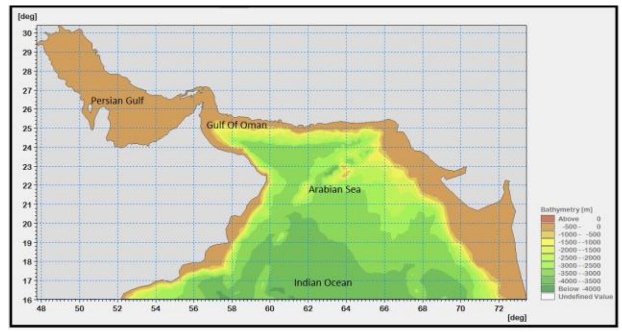

Figure 1 - Study area

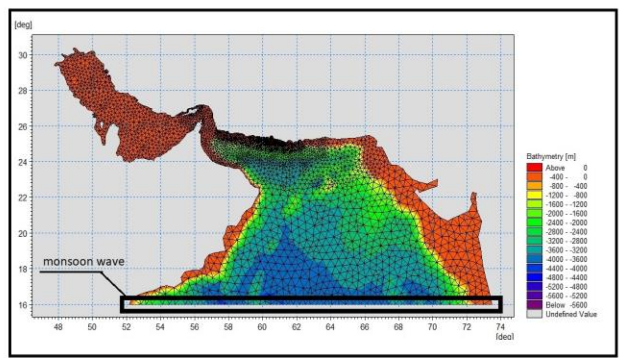

Figure 2 - Computational grid of the wave model

Figure 2 shows the computational grid of the numerical model. Bathymetry consists of ETOPO 1 min (Amante and Eakins, 2009) together with local 1:25 and 1:100 k hydrographic maps at some ports and coastal areas along the north coastline by National Cartographic Center of Iran (NCC). ETOPO effectively projects the compatible depth, particularly in shallow waters, comparing to GEBCO 30 s gridded data (Sandwell et al., 2002). Wave characteristics from the ERA5 are also applied at the south open boundary to include the incoming swell waves in the numerical modeling (Figure 2).

Some parametric models were also examined to enhance the accuracy of the input data for reproducing the wind field of TCs. A comparison between the wind field generated by the parametric models, and the wind field derived from ERA5 revealed a notable level of agreement among them in this particular area. As a result, ERA5 data was selected for the complete temporal coverage of the modeling process.

RRESULTS AND DISCUSSION

Sensitivity analyses are performed on the input

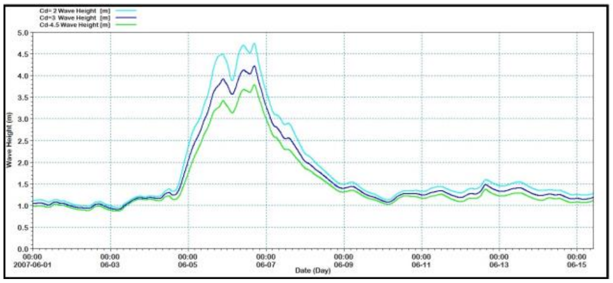

Figure 3 - Sensitivity of the wave height to the wind drag coefficient at Chabahar during Gonu (2007)

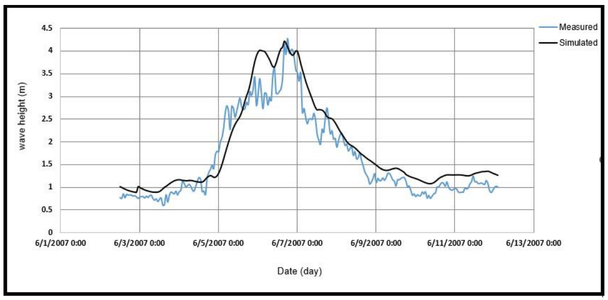

Figure 4 - Comparison of simulated (Black) and measured (blue) wave heights at Chabahar during Gonu (2007)

Figure 5 - Selected coastal locations for the outputs of EVA

Table 1 - EVA results at Chabahar

Return Period (years)	Wave Height (m)			
	Weibull	Gama P (T3)	Log P (T3)	Lognormal
2	4.1	4.1	4	4
5	5	4.9	5	5
10	5.6	5.5	5.7	5.9
50	7.14	6.7	7.7	8.2
100	7.8	7.2	8.8	9.3

parameters to account for uncertainties in the wave model. Some important effective factors are wind drag coefficient, roughness coefficient, number of discretization in directional domain, wave breaking coefficient, grid size, and white-capping coefficient. One such example is illustrated in Figure 3, which demonstrates the sensitivity of wave height to variations in the wind drag coefficient during Gonu (2007).

Figure 4 demonstrates a favorable agreement between the measured and simulated wave heights during Gonu (2007) using the wave data in front of Chabahar Bay (Dibajnia et al., 2010).

The calibrated wave model is employed to extract the hindcast data for twenty years (2000-2020). Different approaches of EVA (e.g., univariate and multivariate) can be implemented to provide the best return values for coastal infrastructural design. Figure 5 shows 27 selected stations for EVA along the north coastline. As an example of the output results for different distributions, Table 1 displays the calculated return values in Chabahar for various return periods.

The performed EVA revealed that the design wave heights can reach up to 10 meters in certain locations for a return period of 100 years. The eastern part of the coastline exhibits the highest design waves, while the values gradually decrease as one moves westward towards the Strait of Hormuz. This pattern can be attributed to the protective nature of the Arabian Peninsula, which partially shields the region from the majority of TCs.

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