STUDY OF DESIGN WATER LEVEL ELEVATIONS IN HOTSPOTS OF HORMOZGAN COASTLINE

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Abstract

In this paper, design water level elevations due to wave, tide, wind and barometric pressure are calculated in hotspots including the ports of Kong, Lengeh, Shahid Rajaiee, Kuhmobarak, Sirik and Khuran. The effect of global water level rise is also considered. This modelling is performed utilizing MIKE21 developed by DHI Water and Environment. In order to calculate wave and tide setup, comprehensive and exhaustive studies of wave propagation and tidal levels modelling, which have been performed in last parts of Monitoring and Modeling Project of Coastal Zones of Hormozgan, are used. Also, wind-induced water level variations model is developed to calculate wind setup in various return periods. The results of the study present values of setup due to above mentioned phenomena which can be used in marine structures designs.

Introduction

Sea level is a measurable quantity and it can be generally defined as the results of some influences, including tides, waves, atmospheric pressure, winds, thermal effect, seismic activity (tsunami), vertical land movement, oceanographic effects such as El Niño, etc., which affect the height of sea surface (Aung et al. 1998). The study of coastal erosion, the gradual change of coastline, the cross-shore profile change and the safe design of coastal structures such as groins and jetties is a function of design water level in coastal areas.

Zervas (2001) analyzed monthly mean sea level (MSL) variations for 117 stations of the National Ocean Service's (NOS) National Water Level Observation Network (NWLON) having between 25 and 146 years of data. In this study, monthly MSL data up to the end of 1999 are used to calculate linear trends, and to obtain the average seasonal cycle, the residual time series, and the autoregressive coefficient of the residual with accurate estimates of standard errors. Bondar (2007) have been analyzed the water budget of the Black Sea and the sea level variations at different coastal zones for highlighting the influence of the river – sea interactions. Huang et al. (2008) evaluated GEV model for frequency analysis of annual maximum water levels in the coast of United States.

In this paper, study of design water level elevations in hotspots of Hormozgan coastline is performed utilizing MIKE21. The values of setup due to wave, tide, wind and barometric pressure, along with setup due to global sea level rise are calculated in the return periods of 2,

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As the waves approach the breaking point there will be a small progressive set down of the mean water level below the still water level. This setdown is caused by an increase in the radiation stress owing to the decreasing water depth as the waves propagate toward the shore. The setdown is maximum just seaward of the breaking point. In the surf zone, there is a decrease in radiation stress as wave energy is dissipated. This effect is stronger than the radiation stress increase owing to continued decrease in the water depth. The result is a progressive increase or setup of the mean water level above the still water level in the direction of the shore. This surf zone setup typically is significantly larger than the setdown that occurs seaward of the breaking point.

In this study, a one-dimensional numerical model called LITPACK-LITDRIFT has been used to calculate wave-induced setup. In fact, this model investigates nearshore sediment transportation rate and nearshore currents due to wave. Meanwhile, other applications of this software are wave transfer along the cross-shore profile and calculation of water level variations as the result of wave breaking in coastal areas. In this software, wave –induced water level variations are determined from integrated momentum equation along cross-shore:

$$-\frac{1}{\rho} \frac{\partial \bar{S}_{xx}}{\partial x} = g(D + b) \frac{\partial b}{\partial x} \quad (1)$$

Where S_{xx} is cross-shore radiation stress; D is water depth; b is wave-induced water level variations; g is gravitational acceleration and ρ is water density [9].

The inputs of the model are bathymetry profile and wave characteristics including significant wave height, peak wave period and mean wave direction. After extracting time series of wave characteristic in each hotspot from the wave propagation model at 10m depth, time series of significant wave height are saved as dfs0 file. In next step, significant wave height values based on prevailing direction in each point are calculated for return periods of 2, 5, 10, 20, 10, 20 and 100 years by utilizing one-dimensional EVA module of Mike Zero software. Then, corresponding peak wave periods are determined. This wave data along with bathymetry profile is applied to LITDRIFT model. The model transfers each wave toward the coastline and calculates water level variation due to wave along the profile.

Tide setup

The tide is the rise and fall of sea levels generated by the gravitational attraction of the sun and moon on the oceans and the equal and opposite centrifugal forces owing to the rotation of the earth–sun–moon system. In the Persian Gulf and the Oman Sea, the major water level variations are due to tidal phenomenon. The rise in water level due to tide is defined as tide setup. Water level variations are significantly affected by nearshore hydrography, bottom friction, Coriolis acceleration, and resonant effects. Water and land elevations in the coastal zone are referenced to a variety of tidal datums in different regions of the world and for different purposes. Some of these datums are [9]:

MSL: The average height of all tide elevations (usually on an hourly basis) averaged over a 19-year period

LLW: The lowest of the low water levels

HHW: The highest of the high water levels

MHHW: The 19-year arithmetic mean of only the higher of each pair of high water levels in a mixed tide

MLHW: The 19-year arithmetic mean of only the lower of each pair of high water levels in a mixed tide

MHLW: The 19-year arithmetic mean of only the higher of each pair of low water levels in a mixed tide

MLLW: The 19-year arithmetic mean of only the lower of each pair of low water levels in a mixed tide

Each lunar and solar component has a period that has been determined from astronomical analysis and a phase angle and amplitude that depend on local conditions and are best determined empirically. Eight major lunar and solar components with their common symbol, period, approximate relative strength (depending on location), and description are listed in Table 1. The components combine in different ways at each coastal location and are affected by local hydrography, bottom friction, resonance and so on, to produce the local tide.

Table 1) Tidal parameters

Symbol	Period(hour)	approximate relative strength	Sources
M2	12.42	100	Main lunar, semidiurnal constituent
S2	12.00	46.6	Main solar, semidiurnal constituent
N2	12.66	19.2	Lunar constituent due to monthly variation in moon's distance
K2	11.97	12.7	Soli-lunar, semidiurnal constituent
K1	23.93	58.4	Soli-lunar constituent
O1	25.82	41.5	Main lunar, diurnal constituent
P1	24.07	19.4	Main solar, diurnal constituent

Many numerical models have been developed for hydrodynamic studies in last decades. In present studies, Mike21 has been used because of its wide facilities and reliable results. Moreover, some parameters such as Coriolis force, wind forcing, bed friction, and Eddy viscosity can be considered in calculations.

To obtain tidal levels, first, tidal parameters of O1, K1, S2, M2, Z0 have been calculated by utilizing tidal option of Mike 21 toolbox. In this stage, time series of surface elevation, obtained from the tidal model in last parts of monitoring and modeling project of coastal zones of Hormozgan, have been used as model input. After obtaining the tidal parameters, chart datum (CD), low low water (LLW) and high water (HHW) can be calculated by using below equations.

National Cartographic Center (NCC) of Iran is using a "modified" Indian Spring Low Water (ISLW) as CD. Its formula is [7]:

$$CD = Z0 - 1.1(M2 + S2 + K1 + O1) \quad (2)$$

Also, following equations have been used to obtain LLW, HHW, MHHW, MLHW, MHLW, and MLLW [9].

$$LLW = Z0 - (M2 + S2 + K1 + O1) \quad (3)$$

$$HHW = Z0 + (M2 + S2 + K1 + O1) \quad (4)$$

$$MHHW = Z0 + (M2 + K1 + O1) \quad (5)$$

$$|MLHW = Z0 + |M2 - (K1 + O1)| \quad (6)$$

$$MHLW = Z0 - |M2 - (K1 + O1)| \quad (7)$$

$$MLLW = Z0 - (M2 + K1 + O1) \quad (8)$$

Usually MHHW is used as tide-induced setup in design of marine structures.

Wind setup

A wind system over nearshore shallow coastal waters or shallow inland water bodies can generate large water level fluctuations if the wind system is sufficiently strong and the water body is shallow over a large enough area. Wind system can cause both a rise (setup) and fall (setdown) of the water level at different locations and times. Setup is commonly predominating in vertical magnitude, lateral extent, and duration. This occurs when the

forward velocity of the wind is close to the celerity of a shallow water wave over which the wind system is traveling. It takes time for this wave to develop so the wind must travel for a significant period of time.

In order to calculate wind setup, the wind-induced water level variations model is developed using MIKE21 Flow FM-HD. Parameters' characteristics of model are as follows:

Table 2: The calibration parameters of the water level variations model

Parameters	Description
Density	Barotropic state equation
Eddy viscosity	Smagorinsky formulation with constant coefficient of 0.28
Bed resistance	Constant Manning number in domain equal to 32 ($\frac{0.1}{m/s}$)
Coriolis forcing	Varying in domain
Wind forcing	Varying in time and domain

Also, wind friction values have been considered about 0.001255 and 0.00245 for wind speeds of 7 and 25 (m/s), respectively. When the wind speed is between mentioned values, wind friction is calculated by linear interpolation. More details about these models can be found in references [4]

After running the model for 28-years period, time series of water level variations in the study area are extracted from the model and saved as dfs0 file (Mike21 time series format).

In the next step, values of water level variations in various return periods must be calculated by using statistical methods. Hence, wind setup values in return periods of 2, 5, 10, 20, 50 and 100 years are calculated by utilizing one-dimensional EVA module of Mike Zero software.

Setup due to barometric pressure

The effect of barometric pressure on sea level variations is calculated by using following formula

$$\Delta p = \Delta h \rho g \quad (9)$$

and substituting the typical values. Here Δp represents atmospheric pressure difference ρ is density of seawater, g is acceleration due to gravity and Δh is the change of sea level height due to pressure. The seawater density and standard atmospheric pressure at sea level is taken $1.025 \frac{g}{ml}$ and 1009.28 hPa, respectively.

The depression of the water surface under high atmospheric pressure, and its elevation under low atmospheric pressure, is often described as the inverted barometer effect (Crowder 1995). The water level does not adjust itself immediately to a change of pressure and it responds to the average change in pressure over a considerable area. Changes in sea level due to barometric pressure seldom exceed 30 cm (Aung et al. 1998). It is also to be noted that a decrease of barometric pressure by 1hPa may cause a ~1 cm rise in sea level and vice versa.

In this study, setup due to barometric pressure is calculated using the measured data sets of barometric pressure in Lengeh, Queshm, Bandar-e- Abbas and Jask synoptic stations. The location of these stations and a sample of pressure changes are presented below.

Fig.2) Location of Synoptic stations in the study area

Fig.3) Pressure changes from first of June 2009 to 31th of October 2010 in Lengeh synoptic station

To calculate setup due to barometric pressure in each station, at first the mean barometric pressure for each station are calculated, then barometric pressure variations than the mean pressure are computed for total duration of pressure data. Finally, the water level corresponding to the barometric pressure variations are calculated by using 3-14 formula.

In the next step, values of setup in various return periods must be calculated in each synoptic station by using statistical methods. Hence, setup values in return periods of 2, 5, 10, 20, 50 and 100 years are calculated by means of EVA module of Mike Zero software.

Global sea level rise

There are two main factors affect the volume or mass of the ocean, leading to long-term changes in eustatic sea level. The first is thermal expansion: as ocean water warms, it expands. The second is from the contribution of land-based ice due to increased melting. The major store of water on land is found in glaciers and ice sheets.

Sea level rise is one of several lines of evidence that strongly support the view that the climate has recently warmed. It is very likely that human-induced (anthropogenic) warming was responsible for the sea level rise observed in the latter half of the 20th century. The average sea level rise rate is considered 4.8mm/year [1] which is equal to following values in return periods of 2, 5, 10, 20, 50 and 100 years:

Table 3) Global sea level rise

Return Period (years)	Sea Level Rise (m)
2	0.010
5	0.024

10	0.048
20	0.096
50	0.240
100	0.480

Results and conclusion

In this study, setup due to wave, tide, wind and barometric pressure, along with setup due to global sea level rise were calculated in hotspots of Hormozgan coastline, including the ports of Lengeh, Suza, Kong, Kuh Mobarak, Rajaie, Sirik and Khuran. Below sections presents results of setup study in the Port of Sirik.

Wave setup

In order to determine wave setup, wave characteristics, involving significant wave height, peak wave period and mean wave direction, have been extracted from wave propagation modelling for a point in front of Sirik station with depth of 10m. Fig.5 represents bathymetry profile of this point. Moreover, Table 4 represents final results of wave setup calculation. As can be seen, the maximum values of wave setup for return periods of 50 and 100 years are 65cm and 71cm, respectively.

Fig.4) The time series of Wave height, Period and direction for port of Sirik in 10m depth

Fig.5) Bathymetry profile used for a point in front of Sirik station

Table 4) Results of maximum wave setup in front of Sirik station for wave of 10m depth for various return periods

Direction (degree)	Type of Distribution	Return Period (years)	Hs (m)	Period (sec)	Wave Setup (m)
202.5	Weibull	2	1.08	5.96	0.14
		5	1.27	6.40	0.16
		10	1.39	6.67	0.17
		20	1.54	6.97	0.18
		50	1.65	7.19	0.19
		100	1.76	7.39	0.20
225	Weibull	2	1.12	6.07	0.18
		5	1.35	6.58	0.20
		10	1.50	6.89	0.21
		20	1.69	7.25	0.23
		50	1.83	7.51	0.24
		100	1.97	7.75	0.25
247.5	Weibull	2	1.86	7.58	0.27
		5	2.37	8.41	0.33
		10	2.71	8.91	0.37
		20	3.13	9.50	0.42
		50	3.45	9.91	0.46
		100	3.77	10.30	0.50
270	Weibull	2	2.82	9.08	0.41
		5	3.65	10.16	0.52
		10	4.21	10.81	0.59
		20	4.92	11.56	0.62
		50	5.44	12.09	0.65
		100	5.97	12.59	0.71
292.5	Weibull	2	0.74	5.06	0.15
		5	0.94	5.62	0.18
		10	1.08	5.96	0.19
		20	1.25	6.37	0.21
		50	1.38	6.65	0.23
		100	1.51	6.92	0.24
All Directions	Weibull	2	2.78	9.02	0.40
		5	3.50	9.97	0.50
		10	3.98	10.55	0.57

		20	4.60	11.23	0.65
		50	5.05	11.70	0.67
		100	5.51	12.15	0.71

Tide Setup

In order to determine tide setup, water level variations have been extracted from tidal modelling for a point in front of Sirik station with depth of 10m. Fig.6 shows time series of water level variations for this point. Tidal datums and parameters obtain from Matlab programming and Mike 21 toolbox. In order to provide standard results, chart datum (CD) is subtracted from values of tidal datums and parameters. The results of tidal datums and parameters have been represented in Table 5 and Table 6, respectively. Mean higher high water (MHHW) will be used as tide setup in this point for later calculations.

Fig.6) Time series of water level variations for a point in front of Sirik station with depth of 10m

Table 5) Tidal datums for a point in front of Sirik station with depth of 10m

Level	LLW	HHW	MSL	MHHW	MLHW	MHLW	MLLW
Height (m)	0.18	3.76	1.98	3.35	2.23	1.57	0.45

Table 6) Tidal parameters period for a point in front of Sirik station with depth of 10m

Z0	S2	M2	O1	K1
1.98	0.34	0.89	0.22	0.34

Wind Setup

In order to determine wind setup, water level variations have been extracted from wind-induced water level variations modelling for a point in front of Sirik station with depth of 10m. Fig.7 shows time series of water level variations for this point. The probability and return period of water level variations based on Weibull distribution has been presented in Figure 8. Also, Table 7 represents final results of wind setup calculation.

Fig.7) Time series of water level variations for a point in front of Sirik station with depth of 10m

Figure 8) The probability and return period of water level variations for a point in front of Sirik station with depth of 10m

Table 7) Results of wind setup for a point in front of Sirik station with depth of 10m

Return Period (years)	Wind Setup (m)
2	0.29
5	0.34
10	0.38
20	0.42
50	0.47
100	0.51

Sea level variations due to barometric pressure

The nearest synoptic station to this hotspot is Qushm station; so, the measured barometric pressure values in this station during a 15-months period are used to calculate corresponding sea level variations. The probability and return period of sea level variations based on Weibull distribution has been presented in Figure 9. Also, Table 8 represents values of setup due to barometric pressure. It should be mentioned that determining long return interval design data has large uncertainty for such a short record length.

Figure 9) The probability and return period of sea level variations due to barometric pressure in Sirik station

Table 8) Results of setup due to barometric pressure in Sirik station

Return Period (years)	Sea level variations due to barometric pressure (m)
2	0.21
5	0.24
10	0.26
20	0.29
50	0.31
100	0.33

The sum of setup

The sum of setup due to wave, tide and wind with and without setup values due to barometric pressure in Sirik station is presented in Table 9.

Table 9) The sum of setup due to wave, tide and wind with and without sea level variations due to barometric pressure in Sirik station (to CD)*

Return Period (years)	Wave Setup (m)	Tide Setup (m)	Wind Setup (m)	Setup due to barometric pressure (m)	Sum of Setup with barometric pressure (m)	Sum of Setup without barometric pressure (m)
2	0.40	3.35	0.29	0.21	4.25	3.83
5	0.50	3.35	0.34	0.24	4.43	3.95
10	0.57	3.35	0.38	0.26	4.56	4.04
20	0.65	3.35	0.42	0.29	4.71	4.13
50	0.67	3.35	0.47	0.31	4.8	4.18
100	0.71	3.35	0.51	0.33	4.9	4.24

*These values have obtained without water level rise rate

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