Numerical Investigation of Storm Surge in Kong Port in the Persian Gulf

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Abstract

Storm surge is generated by the integration of waves, tide and wind setup that is resulted in unwanted mean sea level rise and coastal flooding. The estimation of accurate storm surge is essential for the engineering design of coastal structures. In this study, we estimated the respond of mean sea level winds, tide, waves, and sea-level rise using a local coastal model. A fully coupled hydrodynamic and wave model was implemented to obtain storm surge from different phenomena. The simulations of water level fluctuations due to these parameters were analyzed with the wind forces identified with tidal observations in the Port of Kong. Extreme value analysis was performed to determine the fluctuations associated with different return periods. These data were combined by sea-level rise projections are combined with resulted value. The worst and best scenario of storm surges for each return period were determined for engineering design purposes.

Keywords: Storm Surge, Numerical Modeling, Wave setup, Wind Setup, Tidal fluctuations, Kong.

1- Introduction

Storm Surge is formed by the force of wind and waves on the surface of the oceans and seas. Due to the complexity and randomness of meteorological processes and wind generation, the waves generated by them are also complex and random in nature. On the other hand, the influence of storm surge on all coastal and marine activities causes the first step in identifying the factors affecting marine environments and coastal areas are to determine the patterns of waves. In coastal zones, waves also play an important role in determining the geometry and shape of the shores, and determining the wave conditions in coastal zones (determining altitude, period and direction of waves) is essential for estimating the forces exerted by the waves on the coastline. These waves integrate with tide and wind setup and form storm surge which causes coastal flooding in the coastal region.

Kong port is one of the fishery ports in Hormozgan province, located 6 km east of the Port of Lengeh and about 150 km southwest of Bandar Abbas. The Port of Kong, one of the most important ports in the Province, is owned by the Iranian Fishery Organization. In this study, in order to understand present conditions, results of studies conducted in previous phases of the “Monitoring and Modeling Study of Hormozgan Coasts” project are employed, and results of various effective hydrodynamic phenomena simulation are presented. In Addition, using numerical models, flow separation lines, flooding levels, and the vortex formation area were investigated and the mean sea level for different storm return periods was estimated in Kong Port on the northern coast of the Persian Gulf.

2- Method

In order to determine storm surge in Kong Port, wave characteristics, involving significant wave height, peak wave period and mean wave direction, have been extracted from wave propagation modeling report of Monitoring and Modeling Studies of Hormozgan Province for a point in front of Kong station with a depth of 10m. The investigation, identification, and characterization of waves in shallow and coastal waters of Hormozgan province was part of the Monitoring and Modeling Studies of Hormozgan Province. Prior to conducting this phase of studies, a series of comprehensive studies were conducted to determine the pattern of wind and deep-water waves whose output, deep-water wave information including energy spectrum, altitude, period, and wave direction. In the present study, the deepwater waves obtained from the Monitoring and Modeling Studies of Hormozgan Province project were transmitted to the coasts of by regional models, MIKE21 SW software, a third-generation model capable of using a triangular computing network, was used to transmit the waves.

In these studies, for each modeling range, the validation and in-depth modeling were carried out using information obtained from the measurement stations in the coastal area of Hormozgan province. The results were compared with the results of the ISWM project and the results of the deep-water model. Figure 1 shows the probability and returns period of wave height for each prevailing direction based on optimum distribution. Variations in significant wave height versus peak wave period have been presented in Figure 1.

The Mike21 FM Coupled model is part of the Mike21 series developed at the Danish Hydraulic Institute. This model simulates the resonance, deterioration, and transmission of winds and waves in offshore and coastal areas. This model has two different formulations:

- Directional parametric formulation
- Fully spectral formulation

The parametric formulation is based on a parameterization of the wave continuity equation. The parameterization is performed in the frequency range assuming that the zero and first moments of the wave spectrum are dependent variables (Holthuigsen (1989)). According to Cushen et al. (1994) and Young's hypothesis, the spectral formulation is based on the wave continuity equation, where the wave direction spectrum is a dependent variable. The first formulation is faster than the second formulation but has some limitations. The first formulation does not consider wave growth and deterioration and only transmits the wave. In the second formulation, in addition to wave transmission, wind growth and deterioration due to phenomena such as White Capping are also considered.

In order to simulate the mean sea level variations due to waves, a two-dimensional MIKE21 FM Coupled has been developed. Bathymetry and mesh for Kong port models have been provided in Figure 3.

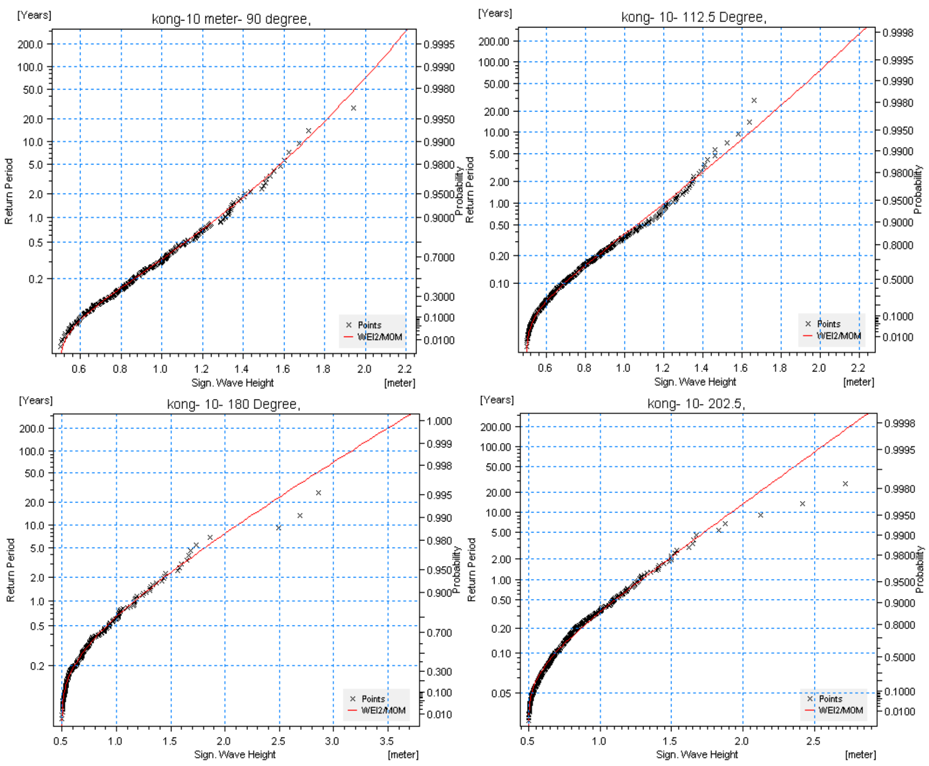

Figure 1: The probability and return period of wave height from four directions in a point in front of Kong station with a depth of 10m

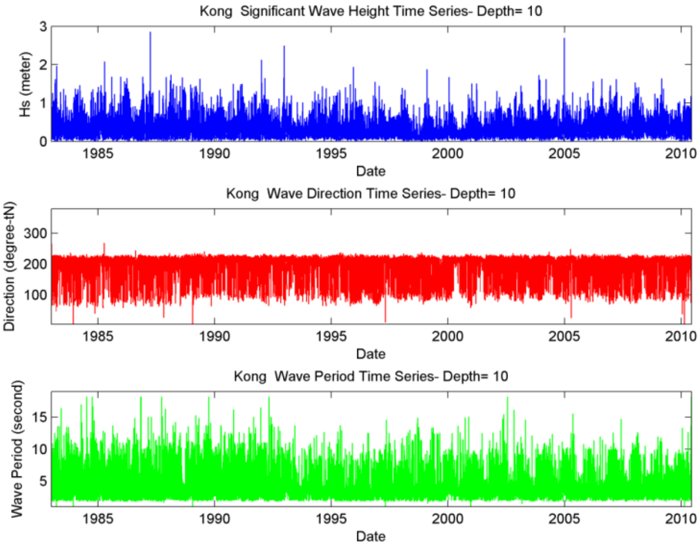

Figure 2: wave height, Period and direction for the port of Kong in 10m depth

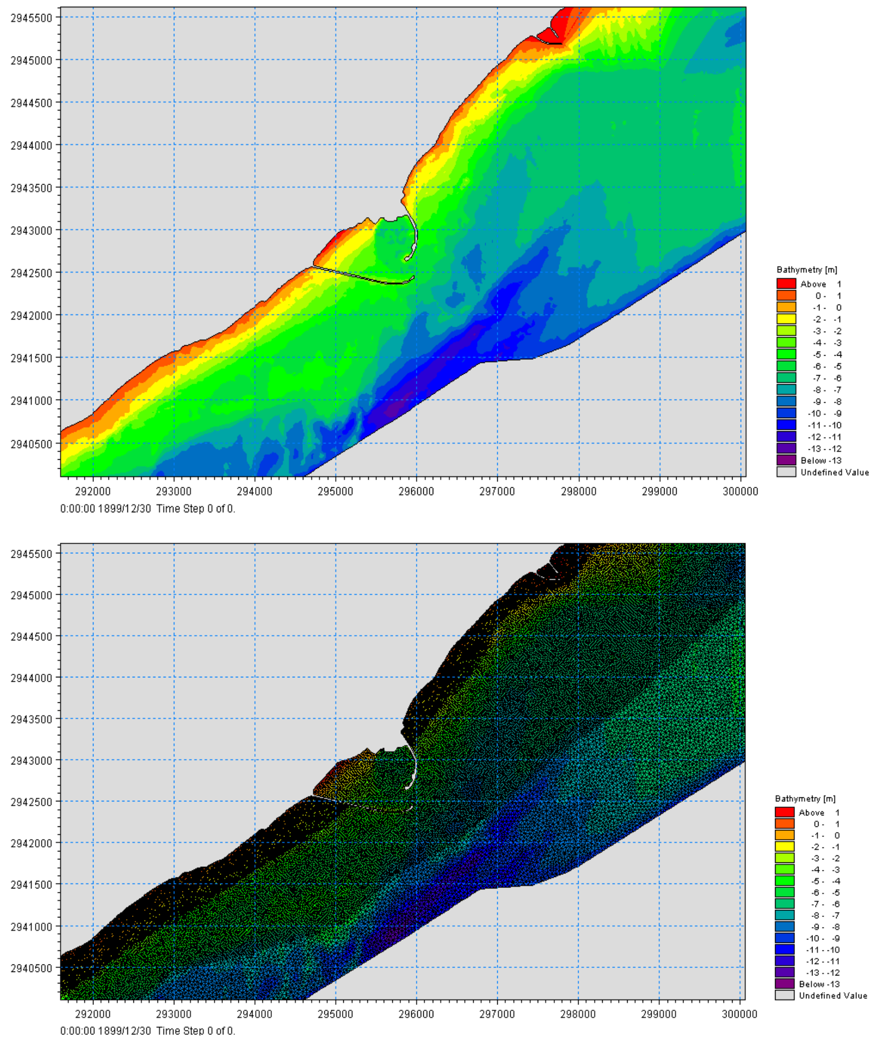

Figure 3: bathymetry and mesh which used in Kong Port water level variation due to wave model

3- Results

Table 1 represents the results of the wave setup calculation. As can be seen, the maximum of wave setup for return periods of 50 and 100 years is 17 cm and 23 cm in cross-shore direction, respectively. Wave setup variations across the Kong Port for the return period of 100 years and different directions are shown in Figure 4. As can be seen, the maximum setdown is 2 centimeter and the setup amounts are negligible for the depths higher than 3m. The wave setup suddenly increases for the depth lower than 3m.

Table 1: Results of maximum wave setup in front of Kong 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)
		2	1.35	6.30	0.09
		5	1.56	6.59	0.10
		10	1.69	6.75	0.10
90	Weibull	20	1.84	6.93	0.11
		50	1.95	7.05	0.12
		100	2.05	7.15	0.13
		2	1.28	6.20	0.09
		5	1.49	6.50	0.10
		10	1.63	6.68	0.11
112.5	Weibull	20	1.80	6.88	0.13
		50	1.92	7.02	0.13
		100	2.04	7.15	0.14
		2	1.31	6.24	0.10
		5	1.76	6.84	0.12
		10	2.08	7.19	0.15
180	Weibull	20	2.50	7.60	0.16
		50	2.82	7.88	0.18
		100	3.14	8.14	0.20
		2	1.39	6.36	0.12
		5	1.69	6.76	0.13
		10	1.90	6.99	0.14
202.5	Weibull	20	2.16	7.27	0.15
		50	2.36	7.46	0.16
		100	2.55	7.65	0.17
		2	1.69	6.75	0.13
		5	1.97	7.07	0.14
		10	2.15	7.26	0.15
All Directions	Weibull	20	2.38	7.48	0.17
		50	2.55	7.64	0.18
		100	2.71	7.79	0.20

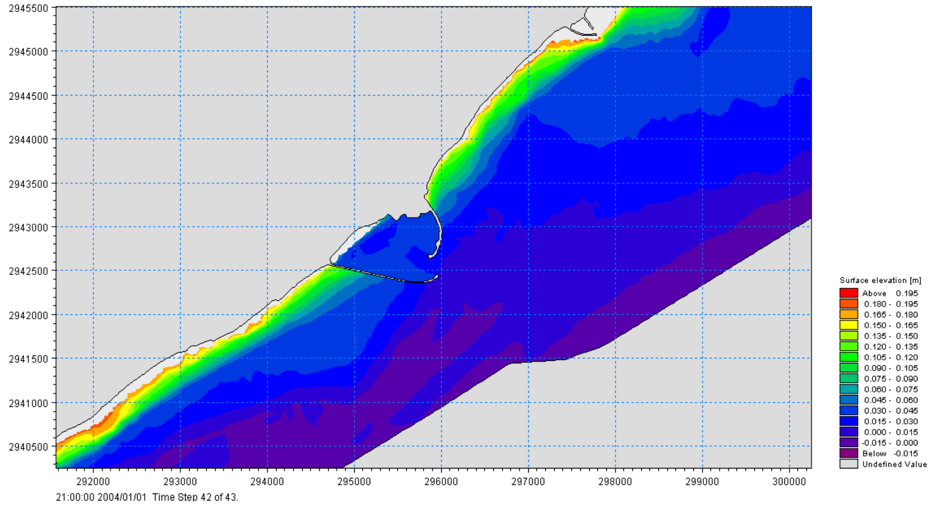

Figure 4: Wave setup variations across the Kong port area for all direction and the return period of 100 years

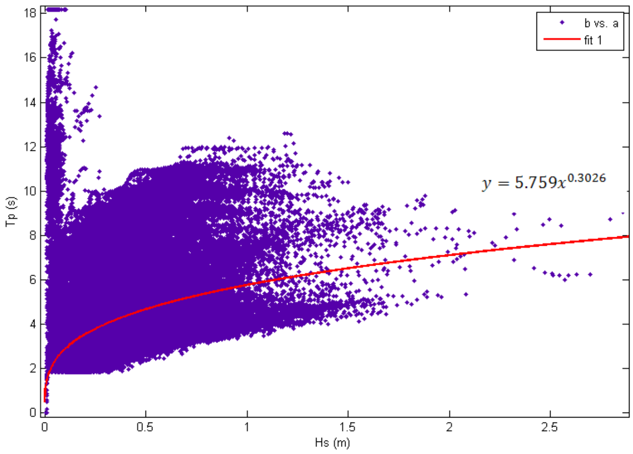

Figure 5: Significant wave height versus peak wave period for a point in front of Kong station

In order to determine tidal water levels, water level variations have been extracted from tidal modeling for a point in front of Kong station with a depth of 10m. Figure 6 shows the time series of water level variations for this point. Tidal datums and parameters obtained 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 2 and Table 3, respectively.

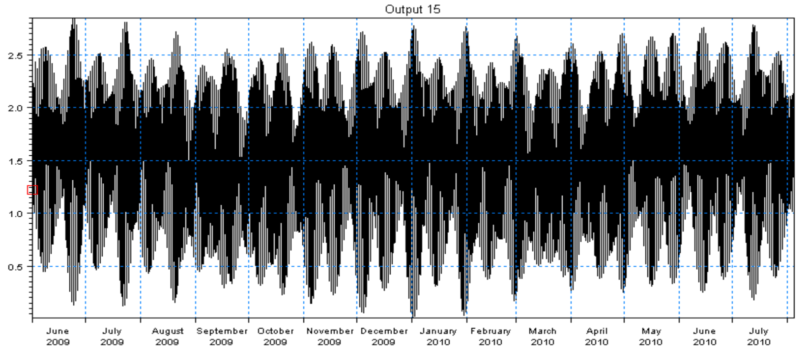

Figure 6: Time series of water level variations for a point in front of Kong station with a depth of 10m

Table 2: Tidal datums for a point in front of Kong station with a depth of 10m

Level	LLW	HHW	MSL	MHHW	MLHW	MHLW	MLLW
Height(m)	0.14	2.87	1.52	2.66	1.6	1.44	0.38

Table 3: Tidal parameters period for a point in front of Kong station with a depth of 10m

Z0	S2	M2	O1	K1
1.52	0.24	0.61	0.23	**0.30**

In order to determine wind setup and setdown, water level variations have been extracted from wind-induced water level variations modeling for a point in front of Kong station with a depth of 10m. Figure 7 shows the 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 4 represents the final results of wind setup and setdown calculation.

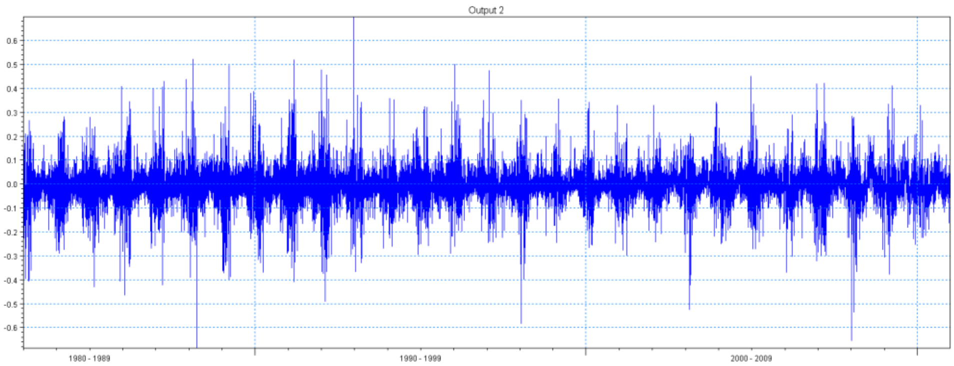

Figure 7: Time series of water level variations for a point in front of Kong station with a depth of 10m

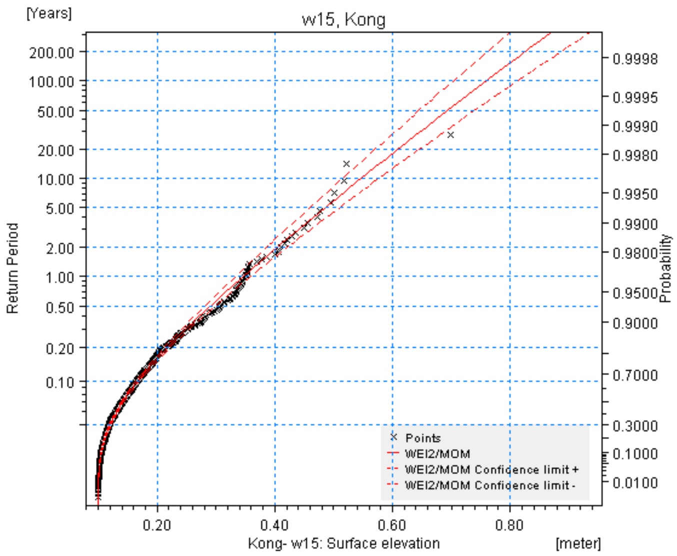

Figure 8: The probability and return period of water level variations for a point in front of Kong station with a depth of 10m

Table 4: Results of wind set up for a point in front of Kong station with a depth of 10m

Return Period (years)	Set-Up (meter)	Set Down (meter)
2	0.38	0.38
5	0.48	0.47
10	0.54	0.54
20	0.61	0.60
50	0.69	0.67
100	0.76	0.73

The final step is to determine an integrated storm surge induced by all phenomena. Several methods for determining total storm surge levels have been defined in Coastal Engineering and Marine structures depend on their objective and application. In this section, all the possible storm surge levels have been represented based on the application of structures or designing criteria of codes and standards. Finally, Table 8 represents the worst and the best scenario for storm surge in Kong Port for different return Periods.

Table 5: The setup and setdown due to wave and wind for different return periods in Kong station

Return Period (years)	Wave Setup (m)	Wave Setdown (m)	Wind Setup (m)	Wind Setdown (m)
2	0.10	0.01	0.38	0.38
5	0.12	0.01	0.48	0.47
10	0.15	0.01	0.54	0.54
20	0.16	0.02	0.61	0.60
50	0.18	0.02	0.69	0.67
100	0.20	0.02	0.76	0.73

Table 6: Tidal levels in Kong port

Level	LLW	MLLW	MHLW	MSL	MLHW	MHHW	HHW
Height(m)	0.14	0.38	1.44	1.52	1.6	2.66	2.87

Table 7: maximum, average and minimum predicted levels of sea-level rise in Kong port according to IPCC reports

The Years Later (years)	Sea Level Rise (m)		
	Lower bound	**Medium**	**Upper bound**
2	0.01	0.01	0.01
5	0.01	0.02	0.04
10	0.02	0.05	0.07
20	0.05	0.10	0.14
50	0.12	0.24	0.36
100	0.24	0.48	0.72

Table 8: The worst and best scenario of storm surge in Kong Port for the return periods

Return Period (years)	Storm Surge Best Scenario (m)	Storm Surge Worst Scenario (m)
2	3.15	3.36
5	3.27	3.51
10	3.37	3.63
20	3.48	3.78
50	3.65	4.10
100	3.86	4.55

4- Conclusions

In order to estimate storm surge in Kong Port, comprehensive and exhaustive studies of wave propagation and tidal levels modeling are performed. Considering more importance of Kong in fishery activities in the Persian Gulf, setup and setdown estimation have been performed in this position.

Wave Setup and setdown due to wave, tide, wind for the return period of 2 to 100 years were calculated for the worst and best scenarios. A comparison between results shows that the maximum wave set up in this region for a 100-year period is 0.20m and the maximum amount of wind setup for the same period is 0.76m in Kong Port. Based on IPCC sea-level projection data, in the worst scenario a 4.55m storm surge, relative to lowest mean sea level, will be observed in a 100-year period in Kong Port. In the best scenario, the maximum storm surge in the same period will be 3.86. Based on the structure importance the suitable value for storm surge should be used between the range presented in Table 8.

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