INTERNATIONAL JOURNAL OF
COASTAL & OFFSHORE ENGINEERING

IJCOE Vol.5/No. 3/Summer 2021 (49-53)

Available online at: www. Ijcoe.org

Simulation of Tide in Khowr-e Musa by Using the TELEMAC Numerical Model

Nadia Talebpour[1], Mohammad Akbarinasab[2*], Masoomeh Rasoolian[3], Abolfazl Delbari[4]

[1] *MSc., Faculty of Marine and Oceanic Sciences, University of Mazandaran, Iran; n.talebpur@stu.umz.ac.ir*
[2*] *Associate Professor, Faculty of Marine and Oceanic Sciences, University of Mazandaran, Iran; m.akbarinasab@umz.ac.ir*
[3] *MSc., Faculty of Marine and Oceanic Sciences, University of Mazandaran, Iran; m.rasoolian@stu.umz.ac.ir*
[4] *Assistant Professor, Department of Physical Oceanography, Faculty of Marine Science, Khorramshahr University of Marine Science and Technology, Khorramshahr, Iran; abolfazl_delbari@yahoo.com*

ARTICLE INFO

Article History:
Received: 16 Nov. 2020
Accepted: 19 July. 2021

Keywords:
Khowr-e Musa
Tide
Water Level
TELEMAC Model

ABSTRACT

Khowr-e Musa at the northwestern terminus of the Persian Gulf sedimentary basin is the widest and longest inshore marine outcrop in the entire coast of the iran at present. In this research, the tidal Current velocity and tidal water level in the Khowr-e Musa estuary was modeled in a 15-day period from 18th of November 2006 by using the Telemac two-dimensional hydrodynamic software. For this purpose, the irregular mesh in two dimensions was selected from the smallest mesh of 70 meters to the largest mesh of 210 meters. The topography of the area was added to the grid of mesh by using an interpolation method. Then TPXO database tidal data applied along the boundary of model. The friction coefficient was calculated using the Stickler theory with the value of 40 m1/2s-1 and the model was executed with a time step of 10 seconds. After Sensitivity analysis and calibration, the model was validated by using measurement data that's provided by the ports and maritime organization. The results showed a good correlation of 94% between the results of the water surface level of modeling the tidal and measurement data and correlation of 73% between the results of the current velocity of modeling the tidal and measurement data, so the TELEMAC two-dimensional hydrodynamic model is suitable for studying the tidal current.

1. Introduction

In order to perform any engineering project or marine environment study, the prediction of currents is an essential task. Water currents in the Khowr-e Musa estuary are formed due to tidal fluctuations in Persian Gulf as well as the complicated geometric features of this multi branch estuary. Therefore, there are no regular streams in this multi branch estuary and the interaction between periodical behavior of tides of the Persian Gulf and the geometrical complexities of this estuary provides difficulties for prediction of the time dependent streams in the branches of the Khowr-e Musa [1].

Today Pacific basin scale and global scale tidal models are available on tidal inversion software or online sites (OTIS & FES) [2, 3, 4]. The global scale tides are suitable for describing the tides in large scale systems such as the Indian Ocean. However, in local or regional sites, the observation or ocean modeling of tides are still needed [5, 6, 7, 8, 9, 10, 11, 12].

Several researchers have used numerical modeling to assess tidal stream energy resources. Carballo et al. applied a two-dimensional horizontal finite element model to evaluate the tidal stream energy resources in the Ria de Muros, which is in the northwestern coast of Spain [13]. Sadrinasab and Shoaib employed a three-dimensional hydrodynamic model (COHERENS) to assess the tidal power of the Doragh estuary. Their simulation indicated that using one basin project at the estuary, where the average tidal range is 5 meters, can obtain about 30 MW of electrical power [14]. Blunden and Bahaj applied a two-dimensional tidally driven hydrodynamic numerical model (TELEMAC-2D) to estimate the available tidal stream energy resources at Portland Bill, UK [15]. Hashemi et al. investigated the influence of waves on tidal resource at Anglesey, showing that extreme wave-current interactions can reduce the tidal resource by 20% [16]. Wang et al. studied the seasonal variations of four principal tidal constituents [17]. Also, some studies have been conducted assessing locations for the available tidal

[DOI: 10.52547/ijcoe.5.3.49]

energy resource and the suitability for tidal stream extraction such as Robins et al., 2015 [18], Lewis et al., 2015 [19] and Neill et al., 2014 [20].

2. Objective

In this study, hydrodynamics tide of the Khowr-e Musa estuary modeled by TELEMAC-2D. Telemac-2D is an open-source computer numerical model that solves the shallow water equations using a finite element method [21] and also it has been carried out with Blue-Kenue (BK). BK is a pre and post-processor visualization program developed by the Canadian Hydraulics Centre of the National Research Council Canada [22].
The process of resource assessment involves the following stages:

1. Geometric layout and computational mesh preparation
2. Boundary condition definitions
3. Parameterisation of model
4. Model execution
5. Post-processing and analysis of output (Calibrate and validate by comparison with measurement data)

Figure 1 shows the process to undertake a resource assessment.

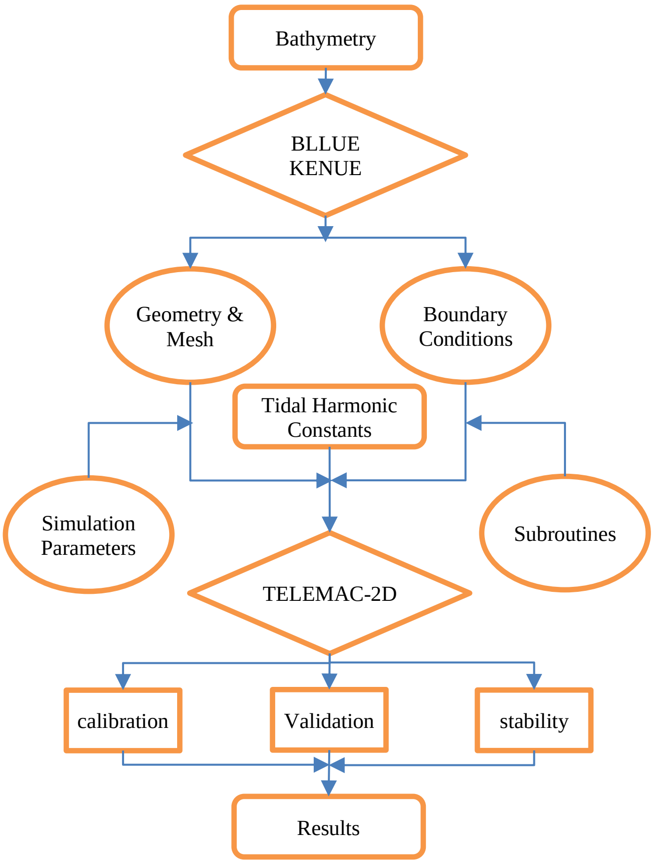

Figure 1: Model process with BK and Telemac-2D [23]

3. Site Description

Khowr-e-Musa estuary is located in the south-west of Iran and in the north-west of the Persian Gulf, at the approximate coordinates 30°28′ N 49°11′ E (Figure 2). The approximate area of Khowr-e Musa is 1350 km^2 [24]. The port of Imam Khomeini, the port city of Mahshahr and several important industrial enterprises are located in the vicinity of this estuary.

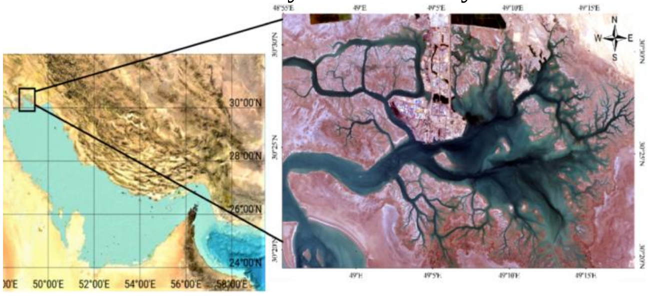

Figure 2: The position of the Khowr-e Musa estuary

4. data Description

Tidal data was received from the OSU[1] TPXO Tide Models [25]. The tidal level from the TPXO can be collected as predicted values, in which the tidal level is deduced from the harmonic constants, or observational values.
The bathymetry used to produce the mesh was provided by International Hydrographic Organization of Iran. Data resolution varies between 60 and 400 meters for Khowr-e Musa estuary with UTM coordinates system. The datasets used for the water level and flow velocity analysis are acquired from Iran Ports and Maritime Organization (PMO) at longitude 49.1° and latitude 30.42° for 15 days from 18-Nov-2006. Table 1 shows a summary of the input data.

Table 1. Input data

Initial data	Type of Data	Database	Time/ Duration	Resolution
Bed Bathymetry	Longitude	IHO	-	varies between 60-400 m
	Latitude			
	Depth			
Tidal data	Velocity components in the x and y directions	TPXO database	2006/11/18 15 days	178 km
	Water height (h) Harmonic constants			
Measurement data	Flow velocity	PMO	2006/11/18 15 days	-
	Water level			

4. Methods

Numerical model

The TELEMAC-2D code solves the second-order partial differential equations for depth-averaged fluid flow derived from the full three-dimensional Navier–Stokes equations. They are also called the Barre de Saint-Venant Equations. This gives a system consisting of an equation for mass continuity and two force-momentum equations. The equations at constant density are averaged over the vertical by integrating

[1] Organ State University

[DOI: 10.52547/ijcoe.5.3.49]

from the bottom to the surface. The averaged form of the continuity equation is:

$$\frac{\partial h}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hv)}{\partial y}=0 \qquad (1)$$

The average forms of the momentum equations are:

$$\frac{\partial (hu)}{\partial t}+\frac{\partial (hUU)}{\partial x}+\frac{\partial (hUV)}{\partial y} = -gh\frac{\partial z}{\partial x}+\frac{\partial}{\partial x}\left[h\nu_e\frac{\partial U}{\partial x}\right] + \frac{\partial}{\partial y}\left[h\nu_e\frac{\partial U}{\partial y}\right]+hF_x \qquad (2)$$

$$\frac{\partial (hv)}{\partial t}+\frac{\partial (hVV)}{\partial y}+\frac{\partial (hUV)}{\partial x} = -gh\frac{\partial z}{\partial y}+\frac{\partial}{\partial x}\left[h\nu_e\frac{\partial V}{\partial x}\right] + \frac{\partial}{\partial y}\left[h\nu_e\frac{\partial V}{\partial y}\right]+hF_y \qquad (3)$$

where *U* and *V* are depth average velocity components in *x* and *y* Cartesian directions, *h* is the depth, ν_e is the coefficient of momentum diffusion (m^2s^{-1}), *g* is the gravitational acceleration, *t* is the time, *Z* is the elevation of free surface (m), *Fx* and *Fy* are some source terms of the momentum equation in *U* and *V*, respectively, which include friction, coriolis, and wind force.

The bed friction is represented as quadratic function of velocity, $\vec{\tau}=\rho C_f|U|\vec{U}$; where $\vec{U}=(U\cdot V)$. The friction coefficient (C_f) can be parameterised in terms of Strickler friction coefficients applying the respective equations (S is the Strickler coefficient) [26].

$$C_f=\frac{2g}{S^2h^{\frac{1}{3}}} \qquad (4)$$

5. Results and Discussion

In the simulation, a mesh should be used that is able to properly simulate the geometric complexities of the bed and the environment. For this purpose, the mesh and the open boundary were made using the Blue-Kenue and are shown in Figure 3. At the mesh generation process, the optimal scale of the mesh was determined using the sensitivity of the network density by performing the model for different mesh scales for the whole area with a ratio of 1 to 3 and a minimum inter-node distance of 70m has been defined at the entrance of Khowr-e Musa to have a higher resolution for more accuracy and computation nodes near the open boundary. In areas farther from the open boundary and at the end of the estuary the grid size has been set up to 210 m to reduce the computation time. The final network used in the form of triangular irregular mesh consists of 75479 elements and 39745 nodes, which the depth is loaded in the mesh using linear interpolation. The model was run in a 15-day period from 18th of November 2006 with a time step of 10 s. The friction coefficient was calculated using the Stickler theory with the value of 40 m1/2s-1.

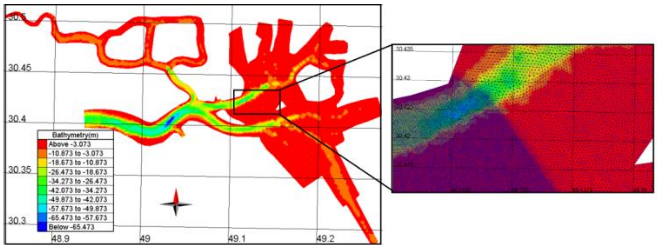

Figure 3: Bathymetry, open boundary and mesh of the study area

In order to achieve the desired accuracy and computational time, it is necessary to sensitize the model to the dimensions of the mesh and thus determine the optimal mesh. Table 2 shows the sensitivity of the model to the mesh and its execution time.

Table 2: sensitivity of the mesh

Mesh dimensions	20-60	40-120	60-180	70-210	80-240
Number of nodes	463214	117950	53142	39745	30693
Number of elements	912425	229017	101812	75479	57964
Running time	6 d	3 d	6 h	3 h	2 h
water level correlation	0.91	0.92	0.93	0.94	0.93
RMSE error of water level	0.3	0.28	0.26	0.25	0.26
current speed correlation	0.57	0.93	0.69	0.71	0.47
RMSE error of current speed	0.106	0.077	0.069	0.065	0.069

The tasks of both model calibration and validation require actual field (observed) data to complete. For calibration and validation of the model, one-hour time series data for water level and flow velocity were received from Iran Ports and Maritime Organization (PMO) at longitude 49.1° and latitude 30.42°, near the port of Imam Khomeini, for 15 days from 18-Nov-2006. Calibration is accomplished by changing the input parameters of the model for the purpose of having a simulation output similar to the observed values. For calibration, four coefficients including velocity range, tidal range, sea level and friction were investigated. Table 3 shows the selected coefficients for calibration.

Table 3: Selected calibration coefficients

Calibration coefficients	Value
velocity range	1.1
tidal range	2.7
sea level	3.26
friction	40

In order to evaluate the accuracy of the results of the numerical model, water surface levels and velocity values at a point in the middle of the estuary near the port of Imam Khomeini were compared with the field measurement data (Figures 4 and 5).

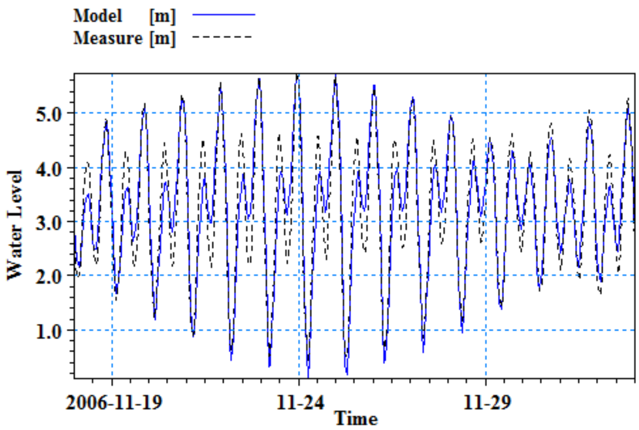

Figure 4: The result of the water surface level of the model compared with the measurement

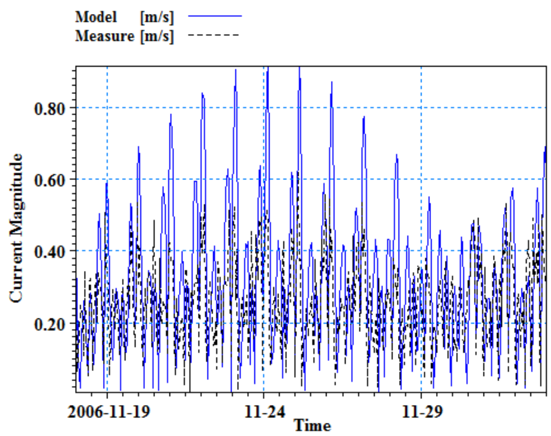

Figure 5: The result of the current velocity of the model compared to the measurement

Figures 6 and 7 show the correlation between measurement and results of the numerical model, water surface levels and current velocity values.

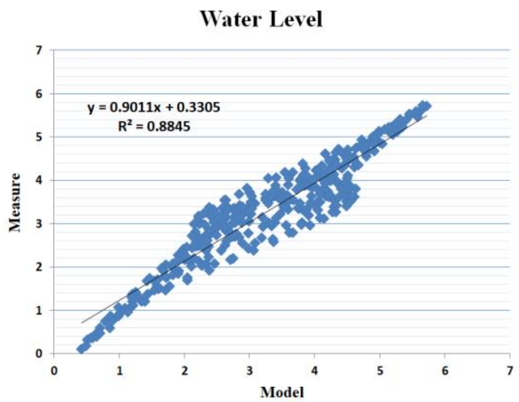

Figure 6: The correlation between measurement and the result of water surface level of model

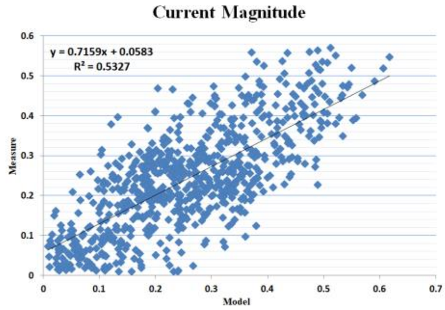

Figure 7: The correlation between measurement and the result of current velocity of model

6. Conclusions

In this study, the water surface levels and current velocity of the tidal currents was modeled by the two-dimensional hydrodynamic model TELEMAC in the Khowr-e Musa estuary region and the sensitivity and calibration of the model were investigated, then the model results were compared with the observed measurement data. The results showed that:

-The model is sensitive to the dimensions of the mesh, so mesh sensitivity is important in modeling and should be analyzed in the modeling process.

- The results of the numerical model presented in this study show a good correlation of 94% between the results of the water surface level of modeling the tidal and measurement data and correlation of 73% between the results of the current velocity of modeling the tidal and measurement data, so the TELEMAC two-dimensional hydrodynamic model is suitable for studying the tidal current.

8. References

1- Hashemi Aslani, Z., Niksokhan, M. H., and Montazeri Namin, M., (2017), *Assessment of the potential of harnessing tidal energy in the Khowr-e Musa estuary in the Persian Gulf*, Environmental Energy and Economic Research, 1(1), p.15-22.

2- Egbert, G. D., Bennett, A. F and Foreman, M.G.G., (1994), *TOPEX/POSEIDON tides estimated using a global inverse model*, J. Geophys. Res. 99, p.24821-24852.

3- Egbert, G. D., and Erofeeva, S. Y., (2002), *Efficient inverse modeling of barotropic ocean tides*. Journal of Atmospheric and Oceanic technology, 19(2), p.183-204.

4- Carrère, L., Lyard, F., Cancet, M., Guillot, A., Roblou, L., (2012), *A New Global Tidal Model Taking Advantage of Nearly 20 Years of Altimetry*, In Proceedings of the Meeting 20 Years of Altimetry, Venice, Italy, p.24–29.

5- Mayer-Gürr, T., Savcenko, R., Bosch, W., Daras, I., Flechtner, F., and Dahle, C., (2012), *Ocean tides from satellite altimetry and GRACE*, Journal of geodynamics, 59, p.28-38.

6- Pelling, H. E., Green, J. M., and Ward, S. L., (2013), *Modelling tides and sea-level rise: To flood or not to flood*, Ocean Modelling, 63, p.21-29.

[DOI: 10.52547/ijcoe.5.3.49]

7- Kumar, S. S., and Balaji, R., (2015), *Tidal Hydrodynamics along Gulf of Khambhat*, West Coast of India. Aquatic Procedia, 4, p.41-48.
8- Othmani, A., Béjaoui, B., Chevalier, C., Elhmaidi, D., Devenon, J. L., and Aleya, L., (2017), *High resolution numerical modelling of the barotropic tides in the Gulf of Gabes, eastern Mediterranean Sea (Tunisia)*, Journal of African Earth Sciences, 129, p.224-232.
9- Tazkia, A. R., Krien, Y., Durand, F., Testut, L., Islam, A. S., Papa, F., and Bertin, X., (2017), *Seasonal modulation of M2 tide in the Northern Bay of Bengal*, Continental Shelf Research, 137, p.154-162.
10- Pringle, W. J., Wirasaet, D., Suhardjo, A., Meixner, J., Westerink, J. J., Kennedy, A. B., and Nong, S., (2018), *Finite-element barotropic model for the Indian and Western Pacific Oceans: Tidal model-data comparisons and sensitivities*, Ocean Modelling, 129, p.13-38.
11- Deng, F., Jiang, W., Valle-Levinson, A., and Feng, S., (2019), *3D modal solution for tidally induced Lagrangian residual velocity with variations in eddy viscosity and bathymetry in a narrow model bay*, Journal of Ocean University of China, 18(1), p.69-79.
12- Setiawan, I., HaditiarA, Y., Ikhwan, M., Nufus, Z., Syukri, M., Ismail, N., and Rizal, S., (2020), *Modeling of M2-TIDE in the western waters of Aceh, Indonesia*, Journal of Sustainability Science and Management, 15(8), p.122-135.
13- Carballo, R., Iglesias, G., and Castro, A., (2009), *Numerical model evaluation of tidal stream energy resources in the Ría de Muros (NW Spain)*, Renewable Energy, 34(6), p.1517-1524.
14- Sadrinasab, M., and Shoaib, N., (2011), *The Potential of Tidal Power from the Doragh Estuary*, in 9 th Europaen wave and tidal energy conference.
15- Blunden, L. S., and Bahaj, A. S., (2006), *Initial evaluation of tidal stream energy resources at Portland Bill*, UK, Renewable Energy, 31(2), p.121-132.
16- Hashemi, M. R., Neill, S. P., Robins, P. E., Davies, A. G., and Lewis, M. J., (2015), *Effect of waves on the tidal energy resource at a planned tidal stream array*, Renewable Energy, 75, p.626-639.
17- Wang, D., Pan, H., Jin, G., and Lv, X., (2020), *Seasonal variation of the principal tidal constituents in the Bohai Sea*, Ocean Science, 16(1), p.1-14.
18- Robins, P. E., Neill, S. P., Lewis, M. J., and Ward, S. L., (2015), *Characterising the spatial and temporal variability of the tidal-stream energy resource over the northwest European shelf seas*, Applied Energy, 147, p.510-522.
19- Lewis, M., Neill, S. P., Robins, P. E., and Hashemi, M. R., (2015), *Resource assessment for future generations of tidal-stream energy arrays*, Energy, 83, p.403-415.
20- Neill, S. P., Hashemi, M. R., and Lewis, M. J., (2014), *Optimal phasing of the European tidal stream resource using the greedy algorithm with penalty function*, Energy, 73, p.997-1006.
21- Hervouet, J. M., (2007), *Hydrodynamics of free surface flows: modelling with the finite element method*, John Wiley and Sons.
22- Canadian Hydraulics Centre of the National Research Council Canada. Blue Kenue. [Online]. Available: http://www.nrccnrc.gc.ca/eng/solutions/advisory/blue_kenue_index.html.[Accessed: 12-Dec-2012].
23- Pérez-Ortiz, A., Pescatore, J., and Bryden, I., (2013, September), *A systematic approach to undertake tidal energy resource assessment with Telemac-2D*, In 10th European Wave and Tidal Energy Conference (EWTEC) (p. 9). Denmark: Aalborg.
24- Dehghan Madiseh, S., Esmaily, F., Marammazi, J. G., Koochaknejad, E., and Farokhimoghadam, S., (2012), *Benthic invertebrate community in Khur-e-Mussa creeks in northwest of Persian Gulf and the application of the AMBI (AZTI's Marine Biotic Index)*, Iranian Journal of Fisheries Sciences, 11(3), p.460-474.
25- OSU TPXO Tide Models, Service Home Page, Available online: https://www.tpxo.net/
26- Nolivos Alvarez, I., Choudhur, A., and Manbaliu, J., (2009), *N 2d hydrodynamic modelling of a tidal inlet using telemac, case study of "de ijzermonding*, Bachelor's thesis, Vrije Universiteit Brussel Belgium.

[DOI: 10.52547/ijcoe.5.3.49]