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Modeling Khowr-e Musa Multi-Branch Estuary Currents due to the Persian Gulf Tides Using NASIR Depth Average Flow Solver

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Abstract

The depth average module of NASIR finite volume solver was applied to study the tide induced currents in Khowr-e-Musa estuary. The model computes water level variation and velocity components in horizontal plane solving depth average continuity and momentum equations considering the hydrostatic pressure distribution. The software takes into account the bed and wall geometric complexities and resistances. In the present work, the option of cell vertex finite volume method of the software was applied for discretizing the governing equations. The descritized equations were solved on a triangular unstructured mesh. The solution domain was descretized using Delauni triangulation method. For damping out numerical oscillations of explicit solution procedure, an artificial viscosity formulation suitable for the triangular unstructured meshes was applied. After verification of the accuracy of the software with analytical solution of tidal currents in a dead end channel, the efficiency of the results was assessd by simulating flow on Khowr-e-Musa multi-branch estuary.

Keywords: *Multi-Branch Estuary, Khowr-e-Musa Currents, NASIR Depth Average Solver, Persian Gulf Tides*

1. Introduction

Khowr-e-Musa estuary is located in the north-west of PERSIAN GULF (Figure 1). The port city of Mahshahr and several important industrial enterprises are located in the vicinity of this estuary. Therefore, not only sedimentation in the main branch of this estuary (as an important navigation root) has been the subject of many engineering studies, but also the marine pollution due to discharge from regional industries into this dead ended water body has been a matter of interest for environmental studies. In order to perform any engineering project or marine environment study related to this estuary, the prediction of currents is an essential task.

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Water currents in the Khowr-e-Musa estuary are formed due to tidal fluctuations in PERSIAN GULF (Figure 1) as well as the complicated geometric features of this multi branch estuary (Figure 2). Furthermore, as a consequence of the tidal stream complexities and bed erosions, the bed elevation of the main branches of this tree shaped estuary present irregular bed elevations. 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.

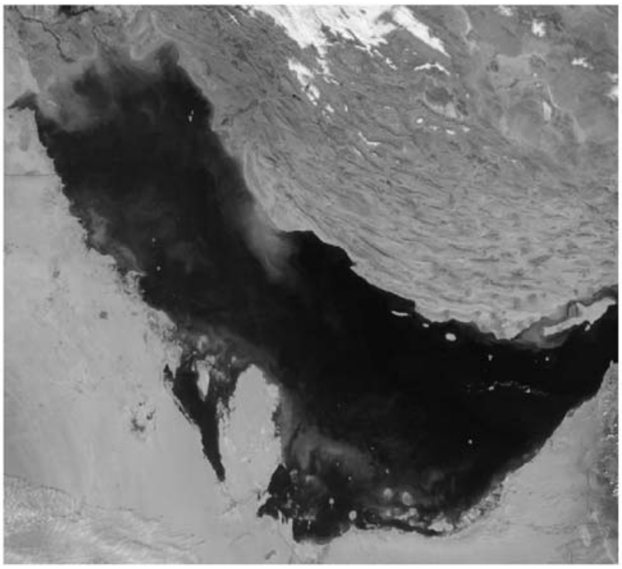


Fig 1. Location of the Khowr-e-Musa at north-west end of the PERSIAN GULF

Fig 2. Geometric complexities of the Khowr-e-Musa multi branch estuary

Application of advanced numerical methods and utilization of powerful computers may help overcome complexities of many present day problems. The first author has succeeded in developing NASIR[1] solver which is able to solve governing equations of many civil engineering problems on unstructured finite volumes. The various modules of this numerical model have been verified and applied for solving many engineering problems in the field of fluid flow and solid dynamics. The problems related to the marine environment of the PERSIAN-GULF are some of the issues that the NASIR software has managed to deal with from the modeling point of view. This software was able to deal with the salinity changes due to the fresh water influx from the main rivers as well as the huge volume of salty water introduced to the PERSIAN GULF due to considerable evaporation from its water surface (Sabbagh-Yazdi, 2004). The ability of the developed software for simulation of oil slick has been successfully tested (Sabbagh-Yazdi, 2005). The accuracy and efficiency of the depth average solver is examined for solution of tidal constituents in PERSIAN GULF (Sabbagh-Yazdi et al., 2007). In another numerical research, this computational model was utilized to study the effects of PERSIAN GULF islands on formation of flow patterns (Sabbagh-Yazdi and Zounemat-Kermani, 2007). In another application of this numerical tool, the effect of turbulent modeling on the depth average solution of tidal currents on three dimensional bed surface of the PERSIAN GULF was investigated (Sabbagh-Yazdi and Zounemat-Kermani, 2008).

In the present work, the depth average module of NASIR finite volume solver was applied for solution of tidal currents in Khowr-e-Musa estuary after verification of the accuracy of the software by solution of the tidal currents in a dead ended channel for which analytical solution was readily available.

2. Hydrodynamic Model

Considering hydrostatic pressure distribution, the depth-averaged equations (SWE) were chosen as the governing equations. The source term in continuity equation included evaporation and

[1] Numerical Analyzer for Scientific and Industrial Requirements

rainfall effects. The source term in these equations covered bed and surface global stresses which represented the general diffusive influence of the turbulent phenomena. The Coriolis forces were considered negligible due to limited water volume. Consequently, the governing equations were written in vector form as follows:

$$\frac{\partial}{\partial t}(h)+\frac{\partial}{\partial x_j}(hu_j)=q_z \qquad (j=1,2) \qquad (1)$$

$$\frac{\partial}{\partial t}(hu_i)+\frac{\partial}{\partial x_j}(hu_iu_j)+\frac{\partial}{\partial x_i}\left(\frac{1}{2}gh^2\right)=S_i \qquad (j=1,2) \qquad (2)$$

Where, h is the flow depth, u and v the horizontal components of velocity, q is the sum of evaporations and rain falls and the source term S contains the source and sink terms of bed slops and global stresses due to bed frictions and turbulent effect in i direction.

3. Numerical Simulations

Application of unstructured mesh facilitates considering the effects of geometrical irregularities of coastal boundaries. Therefore, the governing equations were explicitly solved using Cell Vertex Finite Volume Method on triangular unstructured meshes. This method ends up with the following formulation (Sabbagh-Yazdi et al., 2007):

$$W_n^{t+\Delta t}=W_n^t-\frac{\Delta t}{A_n}\left[\sum_{k=1}^{m}\left(\overline{G_1}\Delta y-\overline{G_2}\Delta x\right)+S_i^tA_n\Delta t\right] \qquad (3)$$

Where W_i represents conserved variables at the center of control volume Ai. $\overline{G_i}$ is i direction the mean values of convective fluxes on the boundary sides of control volume. Δt is the minimum time step of the domain (proportional to the minimum mesh spacing and wave speed of the equations). Efficiency of the model was improved by applying Edge-Base algorithm, Residual Smoothing, and Runge-Kuta Multi Time Stepping techniques (Sabbagh-Yazdi et al., 2007).

4. Verification Test Case

In order to assess the ability and efficiency of the software used to simulate tidal flows, the wave propagations due to sinusoidal fluctuation of water surface at the inflow boundary of a dead end channel were numerically modeled. For this test case, since the imposed boundary condition oscillations were periodical in nature, the analytical solution of the flow parameters could be simulated by a periodic equation. The analytical solution of this one-dimensional flow test case, is given by Ippen (1966) in the form of two sinusoidal equations which are dependant on time and space representing the oscillation of water surface and the velocity as (Balas and Ozhan, 2001; Casulli and Walters, 2000):

$$\eta = a\cos(kx)\cos(\omega t) \qquad (4)$$

$$u=\frac{ac}{h}\sin(kx)\sin(\omega t) \qquad (5)$$

Here, u: velocity of tidal wave in the direction of x axis, η: level of water surface, a: tidal wave amplitude, k= ω/c: wave number, ω= 2π/T: angular frequency, $c=(gh)^{0.5}$: wave celerity,
T: wave period. The solution above mentioned equations for the periodical flow in a dead end channel with length of 10 km, width of 6 km and depth of 15m with frictionless bed conditions is used for verification of the utilized two dimensional solver, considering the parameters of the wave: T=12 hr, a=25 cm. The boundary conditions for x= 0 is u=0 and for x= L is

$$\eta = a\cos(\omega t) \qquad (6)$$

In the initial condition (t=0), the water surface level was considered to be the maximum at x=L and the velocity equal to zero. Both numerical and analytical solutions were obtained for frictionless flow conditions due to the periodical fluctuation of the water surface at the open end of the channel.

In order to evaluate the accuracy of the results of the numerical model for solution of the periodical flow, water surface levels and velocity values at a point in the middle of the channel length were compared with the analytical solutions (Figures 3 and 4).

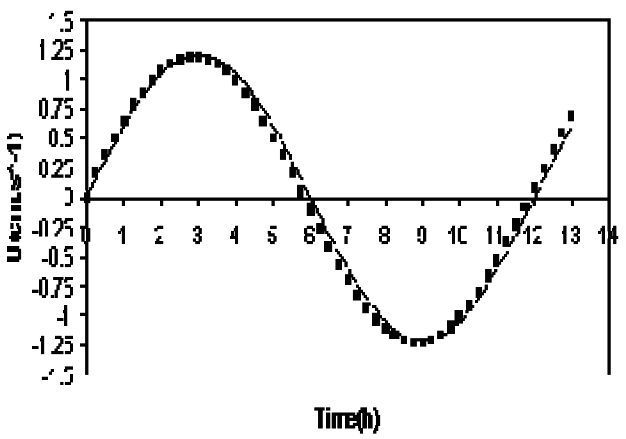


Fig 3. The x direction values velocity values the middle of the channel (solid line is numerical solution and the square points are analytic solution)

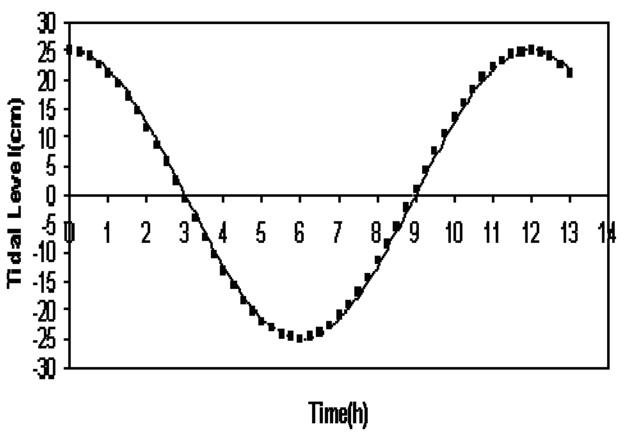


Fig 4. The water surface level in the middle of the channel (solid line is numerical solution and the squares are analytic solution)

As shown in Figures 3 and 4, the results of the numerical model were similar to the analytic solution. The maximum difference of analytical and numerical solutions for the water surface level was 0/006m. Considering the analytical solution of the water surface level in the middle of the channel as

$$\Delta\eta_{centre} = a\cos(kx) = 0.25\, m\,,$$

the error of the computed water level was equal to

$$E_{\eta} = {}^{0.0006}\!/_{0.25} = 0.24\%$$

For the velocity in the middle of the channel with the maximum difference analytical solution and numerical results was 0/0059 m/s, and therefore, considering the analytical solution of the velocity as

$$\Delta u_{centre} = {}^{ac}\!/_{h}\sin(kx) = 0.0125\; m/s$$

in the middle of the channel, the error in velocity computation was

$$E_{v} = {}^{0.0059}\!/_{0.00125} = 4.75\%$$

5. Computational Results

The geometric modeling of the computational domain of Khowr-e Musa estuary was completed in two stages. First, the flow domain was discredited using unstructured mesh generated by Delaney Triangulation Technique (Thompson et al., 1999) by using the boundary curves representing coastal boundaries. The bed elevation of the flow domain was digitized at a number of points along some digitized contour lines. Then, the bed elevation was set for the every node of the mesh by interpolation of the elevations between surrounding digitized points and the two dimensional mesh was converted to a three dimensional flow domain bed surface (Figure 5).

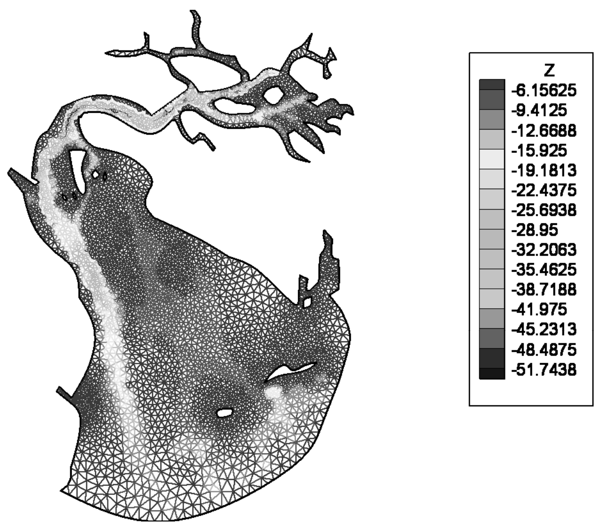


Fig 5. Unstructured triangular mesh including bed elevation data

The hydrodynamic model was used to simulate flow patterns in Khowr-e Musa for a tidal period. As the tidal inflow-outflow boundary condition, only the fluctuations of water surface elevation from tidal predictions at MUSA-Bar (obtained from the harmonic analyses data) was calibrated by Easy Tide Prediction software (Easy tide prediction)) for any arbitrary period of time Figure 6).

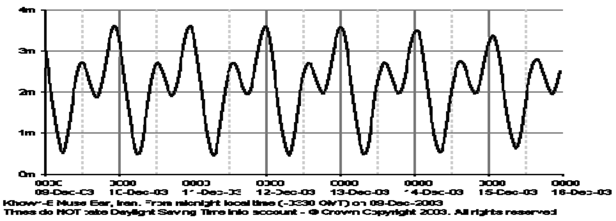


Fig 6. Water surface fluctuations imposed at far field boundaries of computational domain (predicted by the harmonic analyses data which is calibrated by Easy Tide Prediction)

Therefore, the velocity components were extrapolated from inside the computational domain. At coastal boundary lines, free slip boundary condition was applied by imposing zero normal velocity and keeping tangential computed velocities at wall boundaries. Application of free slip velocity condition provided considerable savings on computational efforts. Having applied the above mention model, water surface fluctuation could be computed at any desired location of the estuary, i.e. Mahshahr Mahshahr port (Figure 7).

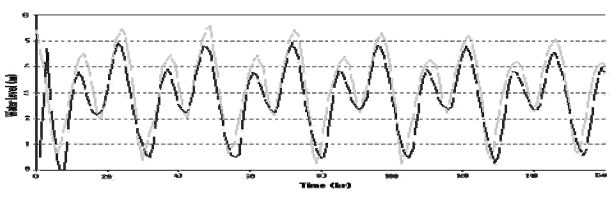
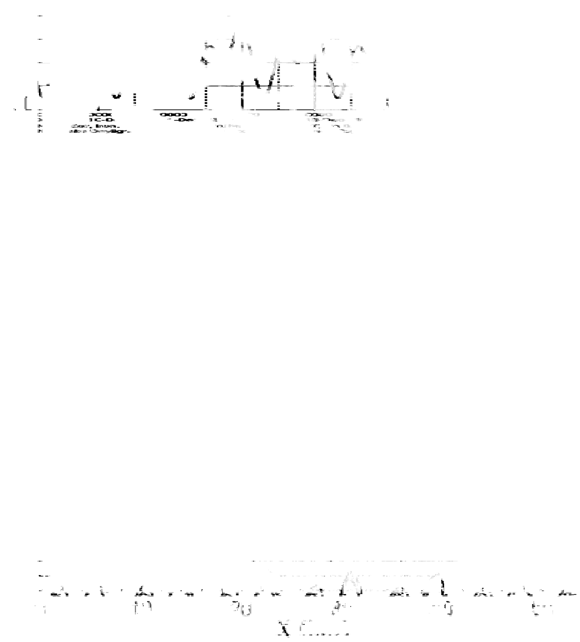


Fig 7. Water surface level in MAHSAHR Port Thick line is the numerical solution and light line is the Easy Tide Prediction software

Some of the sample results presented in terms of the water level fluctuations of the model is appeared few days warm up period. The following plots represent sample computed water level and flow patterns (Figure 8).



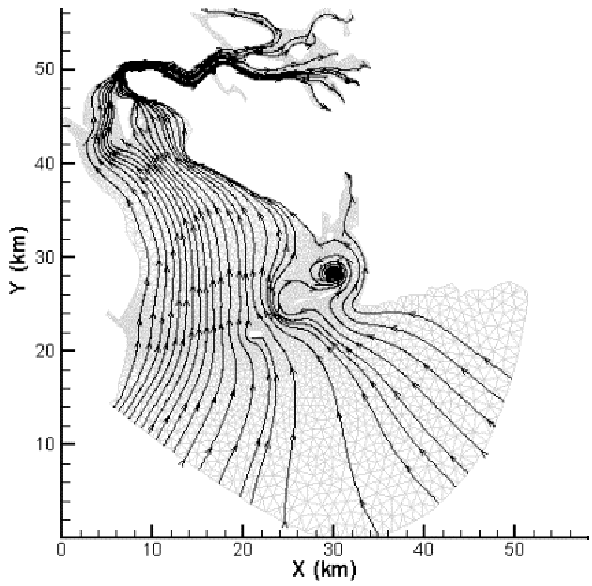


Fig 8. Typical Computed results in an arbitrary day Stream traces in the form of flood tide and ebb tide

6. Conclusion

In this study, an attempt was made to assess the accuracy of the depth average module of NASIR finite volume solver for computation of fluctuating water level and periodical variations of velocity values in a dead-ended channel with sinusoidal water surface variation. Comparison of the numerical model results with the analytical solution of the case presented less than. 25% and 5% errors in computation of water surface level and velocity values at the middle of the frictionless channel. Although no friction was considered in the two dimensional solutions, neither oscillations nor damping was observed in the computed results.

Having assessed the accuracy of the software, its efficiency was examined for solution of tidal current in a multi-branch estuary with geometrical complexities. The comparison of the results of successful numerical modeling with the measured water level at Mahshahr port located at an end point of the one of the main branches of the estuary proved the accuracy of the modeling strategy and the software used.

References

Balas, L. and Özhan, E., 2001. Three-dimensional modeling of stratified coastal waters. Estuarine. Coastal and Shelf Science. Vol. 54, 75-87.

Casulli, V. and Walters, R.A., 2000. An unstructured Grid Three-dimensional model based on the shallow water equation. Int. J. Numerical Methods in Fluids. Vol. 32,331-348.

Sabbagh-Yazdi, S.R., 2004. Numerical modeling of Persian Gulf salinity variations due to tidal effects. International Journal of Environmental Science and Technology, Vol.1, 41-48.

Sabbagh-Yazdi. S.R., 2005. Coupled solution of oil slick and depth averaged tidal currents on three dimensional geometry of the Persian Gulf. Journal of Environmental Science and Technology. Vol.2 , No.4, 309-317.

Sabbagh-Yazdi, R.S. and Zounemat-Kermani, M. and Kermani A., 2007. Solution of depth averaged tidal currents in Persian Gulf on unstructured overlapping finite volumes. International Journal for Numerical Methods in Fluids, Vol.55, 81-101.

Sabbagh-Yazdi, S.R. and Zounemat-Kermani, M., 2007. Numerical investigation of island effects on depth averaged fluctuating flow in the Persian Gulf. International Journal of Engineering (Transaction A: Basics), Vol.20, No.2, 117-127.

Sabbagh-Yazdi, S.R. and Zounemat-Kermani, M., 2008. Vertex base unstructured finite volume solution of depth averaged turbulent tidal currents on 3D Bed. Iranian Journal of Science & Technology. Transaction B: Engineering. Vol. 13, No. B5. 563-570.

Thompson Joe, F., Soni, B.K., and Weatherill, N. P., 1999. Hand book of grid generation. CRC Press. New York.