Simulation of Tidal Currents in the Persian Gulf

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ABSTRACT

The developed 2D hydrodynamic model has been already applied and calibrated for the Persian Gulf to simulate the tidal currents in the Gulf. The location of Hormuz island at the Strait of Hormuz is suitable to represent the water level entering the Persian Gulf. Tidal elevations at different locations of the Persian Gulf are available. The simulation results show that after the first week of the February, a non-prevailing southeastern wind front took place. The verification of current hydrodynamic model was carried out with several case studies. Results were compared with available analytical solution or laboratory measurements. The results show the capabilities of this model for simulating the flow pattern in simple and complex geometry. The detailed of this hydrodynamic model including governing equations, solution techniques and verification tests is presented in authors' previous works. The tidal current in the Gulf is made by imposing tidal fluctuation to the main open boundary at Hormuz Strait (26°39'N 55°53'E). After providing the model input data, it could be applied to simulate the tidal current. To evaluate the model output, a check point has been chosen and the results of numerical model have been compared with observed data.

Keywords: Persian Gulf, Tidal Currents, Simulation, Modeling.

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Introduction

The Persian Gulf has long been an important water body for economic, environmental, and military reasons (Fig 1). It is a large, shallow basin located in the heart of the Middle East Its notable importance during recent decades stems from several factors. Countries bordering the

Persian Gulf are rich in oil reserves. Consequently there is considerable oil industry shipping through the Gulf as well as a large industry investment in marine drilling and production platforms. Desalinization plants along the Gulf shores provide fresh water for the arid lands in the region. The Gulf is productive biologically, with numerous marsh areas and an active fishery. As a result of these factors coupled with extended political turbulence in the region, a number of previous studies have been conducted. Tidal characteristics at a number of coastal measurement sites in the Persian Gulf and Gulf of Oman are summarized by the National Ocean Service (NOS) of the U.5 Apartment of Commerce and the British Hydrographer of the Navy. Th. NOS annually publishes high and low water predictions and information on tide range (e.g. U.S. Department of Commerce 1990). The NOS archive of tidal measurements includes data from some Persian Gulf stations. The data are in a variety of forms, as discussed in this paper. The Hydrographer of the Navy (1989) provides amplitudes and phases for 4 tidal constituents at many stations dispersed around the Gulf.

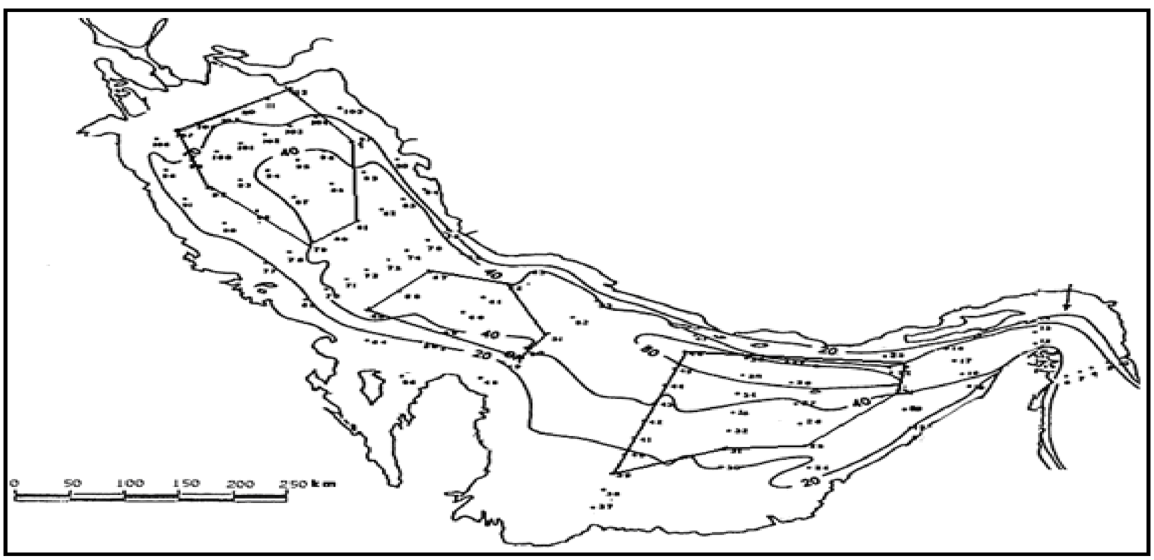

Fig 1: Study location

Tidal Regime in the Persian Gulf

Cotidal[1] and Corange[2] lines are very useful for showing the general tidal response of a large

[1] Cotidal line: a line passing through places having the same cotidal hour. Cotidal hour is the average interval between the Moon's transit over the Greenwich meridian and the time of the following high water at any place.
[2] Corange line: a line passing through places of equal tide range.

body of water. Tidal constituents in the Persian Gulf develop counterclockwise rotations. The pivotal points for rotation are referred to as "Amphidromic points." Semidiurnal constituents have two Amphidromic points in the Persian Gulf (Fig 2). The location of these points is about the same for all semidiurnal constituents. Diurnal constituents have only one Amphidromic point, more centrally located in the Gulf than those for the semidiurnal constituents.

Bogdanov (1987) discusses tides in the Persian Gulf and presents tidal charts for the M_2, S_2, K_j, and O_l constituents. His Cotidal lines differ from other published results and should be considered suspect another two-dimensional model of tidal hydrodynamics, including transport, is given by Chu et al. (1988).

Tidal and wind-driven circulations in the Persian Gulf were modeled by Lardner et al. (1989) and Al-Rabeh et al. (1990), including some discussion of vertical flow structures. Lardner et al. (1989) includes circulation results for a 12.9 m/s (25 knots) wind blowing from the southwest In Al-Rabeh et al.'s (1990) study, tidal forcing was provided by nine tidal constituents. The constituent amplitudes and phases imposed along the model boundary in the Strait of Hormuz are given. Measured and model constituent amplitudes and phases for surface elevation are listed for six sites along the Saudi Arabian coast. Cekirge et al. (1989) focused strictly on wind-induced three-dimensional circulation in the Persian Gulf, presenting an example of surface currents in response to a 12.9 m/s (25 knots) wind from the northwest.

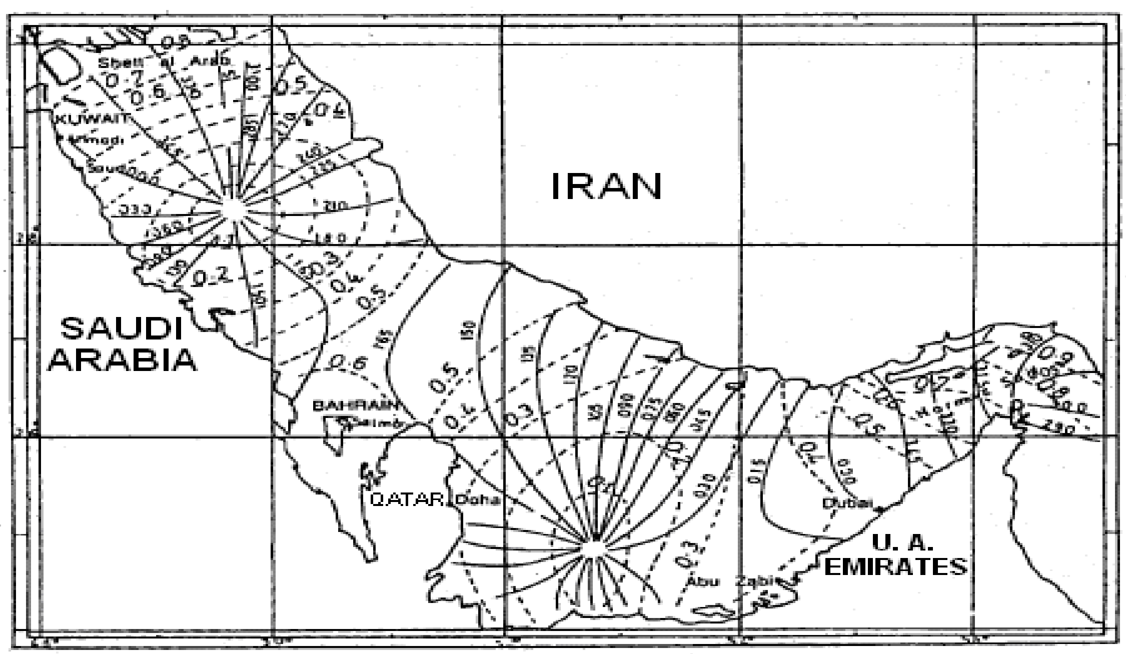

Fig 2: Amphidromic points and tidal current gauge sites

Measurements and harmonic analyses of tidal currents in the western Persian Gulf were reported by John (1992). Gauges were located off the Saudi Arabian coast near Bandar Mishab and Ras Tanura. The gauge sites are in the vicinity of Amphidromic points for semidiurnal and diurnal tidal constituents (Fig 2). A total of six gauges were operated at four sites for a time period of one month (Table 1). The hourly vector mean at stations CM1, CM3, and CM4 was separated into north and east components.

Each component time series was subjected to harmonic analysis. Amplitudes and phases are given for the M_2, S_2, K_L, O_l, M_4, and MS_4 tidal constituents.

Table 1: Tidal Current Gauges (John 1992)

Gauge	*Gauge Depth*	*Water Depth (m)*
CM1	Near surface	30
CM1	Near bottom	30
CM2	Mid depth	5
CM3	Near surface	30
CMS	Near bottom	30
CM4	Mid depth	5

Material and Methods

The POM numerical model known as the ADvanced CIRCulation model (ADCIRC), Version 8.01, was used in this study for simulating water levels and currents due to long wave hydrodynamic processes. The model is based on the equations of mass and momentum conservation. The equations are integrated over water depth; flows are assumed to be uniform in the vertical dimension. It is additionally assumed that flows are incompressible, vertical accelerations are negligible, and pressures are hydrostatic. Bottom stress is parameterized by a standard quadratic expression. The Newtonian equilibrium potential for astronomical tide is expressed as given by Princeton University. The influence of wind is represented as a stress applied to the free surface. Other forcing functions are atmospheric pressure gradients, Coriolis effects, and tidal forcing along the seaward boundary.

The ADCIRC model equations are solved by a finite element approach. However the equations are reformulated mathematically to a form with much improved numerical solution characteristics. The new form, referred to as the Generalized Wave Continuity Equation (GWGE), is solved for surface elevation and velocity on a standard finite element grid consisting of linear triangular elements. The ADCIRC solution procedure and FORTRAN coding are designed to maximize computational speed and efficiency.

Tidal Forcing

The astronomical tide is created by gravitational pull of the moon and sun, and to a much lesser extent other astronomical bodies, on the earth. Since the astronomical bodies have cyclic, predictable motions, frequencies associated with tidal forcing are very predictable. The frequency components are referred to as "tidal constituents" Although NOS identifies 37 tidal constituents in standard analyses of tide data, the great majority of tidal energy at most locations can be represented by a small number of constituents.

Astronomical tides can be modeled in ADCIRC in two ways. One option is to include the tidal potential forcing function acting directly within the Persian Gulf. This function is essential to proper modeling of large regions. However, the Gulf is small enough that the internal tidal potential forcing can be neglected.

Another optional input to ADCIRC is the specification of astronomical tidal forcing on the seaward or open grid boundary. For each tidal constituent to be modeled, an amplitude and phase must be provided at each node on the open boundary. The constituent frequency is also required.

The primary tidal constituent forcing the Persian Gulf is the semidiurnal principal lunar tide, commonly referred to as the M_2 tide. Amplitudes and phases for the M_2 tide in the Arabian Sea and Gulf of Oman are included in the global tide model results of Schwiderski (1979). Amplitudes and phases at the ADCIRC open boundary nodes were obtained by interpolation of the global model results. The same approach was used to develop the required input for the other seven tidal constituents included in this study. Included are four semidiurnal constituents (with cycles of approximately 12 hr) and four diurnal constituents.

Wind Forcing

The ADCIRC model requires wind forcing to be specified as the ratio of both horizontal components of wind stress to water density at each node. An atmospheric pressure, expressed as the ratio of pressure to the product of water density and gravitational acceleration, must also be specified at each node.

Four grids were developed during the course of this study. Software for semi-automated grid development (Turner and Baptista 1993) was in an eariy stage. However, with assistance from the developers, the software was used successfully in this study. The grids represent successive stages of refinement. The initial grid, using a Mercator projection, was relatively coarse. It covered the Persian Gulf and a small part of the Gulf of Oman. Subsequent grids were based on a spherical projection. The next two grids extended to longitude 59° E. Grid 2 contained finer resolution than Grid 1 and the resolution was nearly uniform. Grid 3, referred to as the refined grid, was obtained by refining the Grid 2 resolution in shallow areas (Fig 3).

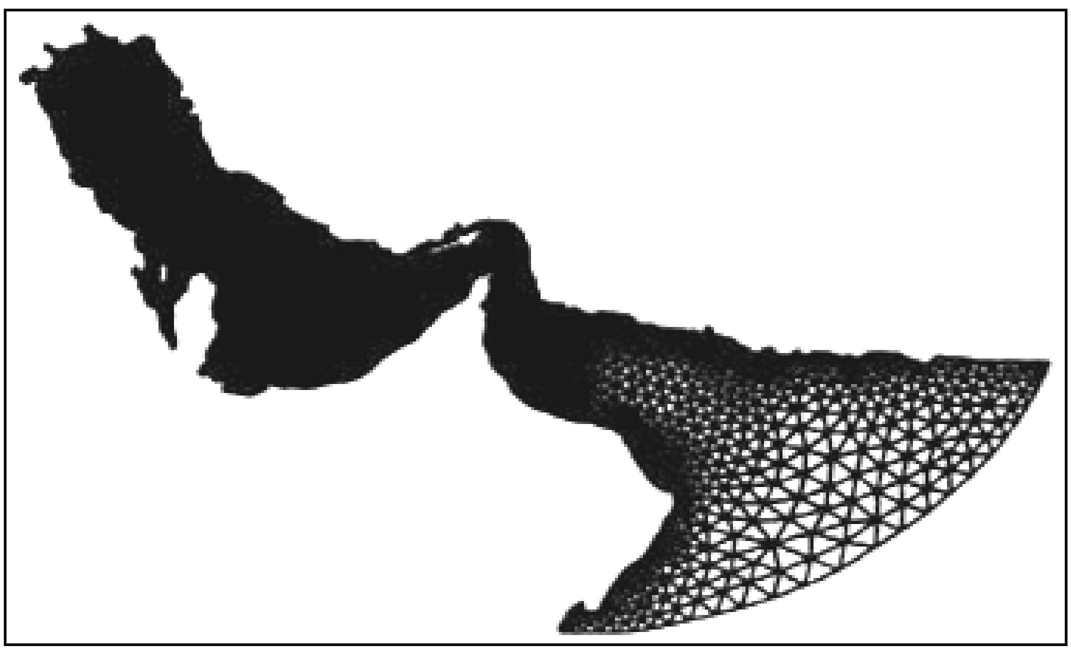

Fig 3: Expanded finite element grid

Conclusions and Recommendations

The grid used in this study was designed to concentrate resolution in shallow areas or constricted regions where strong flow velocities can be expected. There was no effort to increase resolution at a specific hypothetical site. The model is applied in the following two ways:

a. Force with astronomical tides to create tidal constituent amplitudes and phases for water levels and currents.
b. Force with wind field to estimate water level and current response.

Based on this study and the related study by Thompson and Hadley (1994), the following recommendations are made:

1. Water levels and currents in the Persian Gulf and Gulf of Oman should be given further consideration to include the following enhancements to the present study.
2. An updated version of the ADCIRC model should be used.
3. The detailed grid should be extended into the Arabian Sea to ensure that tidal forcing on the seaward boundary is free of distortions induced by shallow water and land.
4. Effects of vertical variation in currents should be considered.
5. Wind forcing should be studied in more detail, including more complete verification and coupling with the wind fields of Bratos and Farrar (1994) to estimate climatological water levels and currents.

The resulted simulations of tidal currents in the case study zone are shown in (Fig 4).

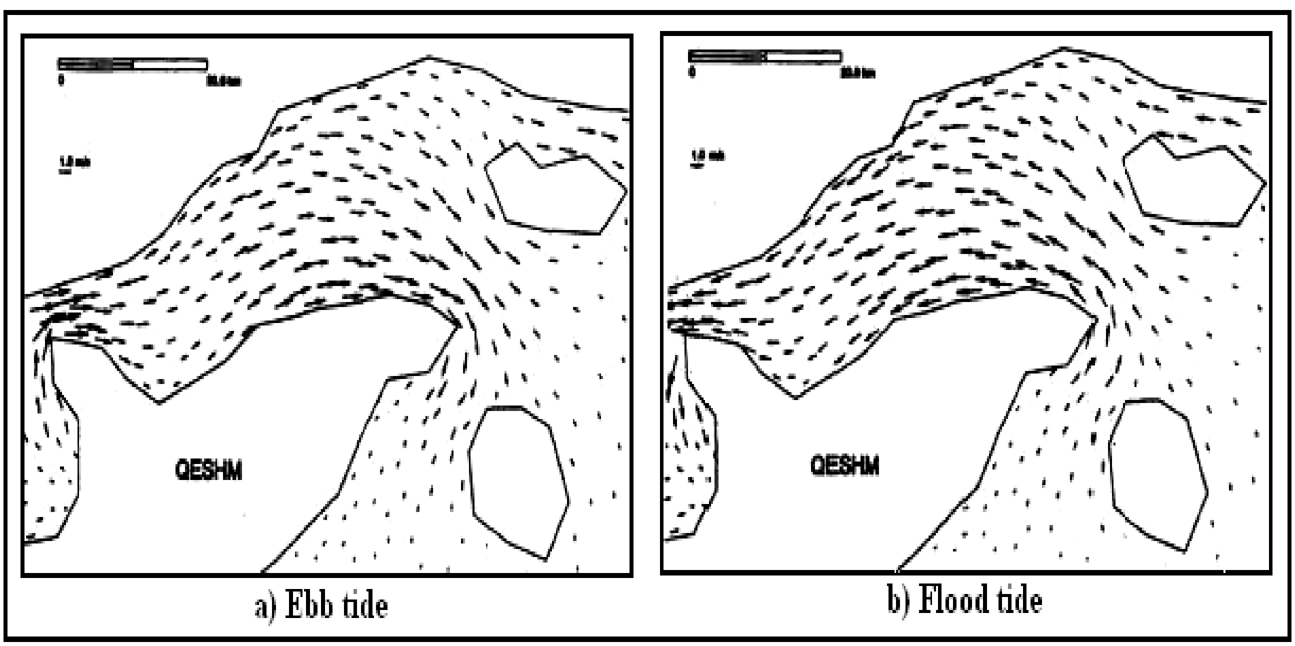

Fig 4: simulations of tidal currents in the case study zone (a. Ebb tide b. Flood tide)

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