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A Study of Tidal Water Circulation Using a Two-Dimensional Model in Jeddah Islamic Port, Red Sea

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Abstract. A two dimensional tidal depth averaged model was used to calculate the tidal currents in Jeddah Islamic Port which is the largest sea port in Saudi Arabia. The water circulation in Jeddah Port exhibits strong ebb to flood variability, reversing from west to east movement during both neap and spring tide respectively. Model results are compared with measured current meter data. The comparison showed a reasonable agreement between the modeled and measured current velocities. The renewal of the water within the port is important to ensure the quality of the sea water.

Introduction

The Red Sea is a long, narrow body of water, roughly NNW-SSE oriented, about 1930km long and 270km wide on average between latitudes 12°N and 28°N. Although the Red Sea is considered a well-behaved sea for testing the tidal theories (Pugh, 1987), a complete explanation of Red Sea tides is not yet agreed; probably because they are a combination of an independent oscillation of the waters within the Red Sea and a forced oscillation induced by the Gulf of Aden tides and perhaps, other factors as well. The local oscillatory tide is of small amplitude and semi-diurnal period which results in high water at one end of the sea when it is low water at the other end. The period of the tidal oscillation is approximately 12.8 h for a depth of 500 m and length of

1600 km. The average spring tidal range is about 0.5 m at either end of the Red Sea. South of the Strait of Bab Al-Mandab the time of high water changes by several hours, and the spring tidal range increases to about 1.0 m (Morcos, 1970).

The range decreases towards the central part of the Red Sea with a nodal point at about 20°N. There is also a nodal area just north of Bab-Al-Mandab, south of which the influences of the Gulf of Aden tides become dominant. In addition to the semi-diurnal tide there is also a subsidiary oscillation of small amplitude which has a diurnal period. In most places it is masked by the larger semi-diurnal oscillation but it does become apparent at times in the central area. Associated with changes in tidal levels is the horizontal movement of water (tidal currents). In general tidal currents in the Red Sea are weak, at least in the open sea, but in restricted areas they may be as high as about $0.3 m.s^{-1}$ (Albarakati, 2009b). These high velocities may be of tidal origin but topographic influences and the effect of local or diurnal wind variations are the major factors.

Jeddah Port is the largest port on Red Sea. It lies on the eastern coast of the Red Sea at about 21° 27.5`N and 39° 10`E (Fig. 1). It is the main port in Saudi Arabia. The renewal of the water within the port area is one of the major problems to ensure the water quality. Although tidal range is relatively small, about 0.3m (Morcos, 1970) in the central part of the Red Sea but its influence increases in the shallow areas (Albarakati, 2009a).

Therefore, the aim of this study is to investigate the water circulation in Jeddah Port using a two dimensional tidal model. The model was applied during neap and spring tide. The reduced gravity method is essential to be used in a water column where there is a vertical change in the density. The thermocline layer is taken to separate between the upper and lower layers (Albarakati, 2009b).

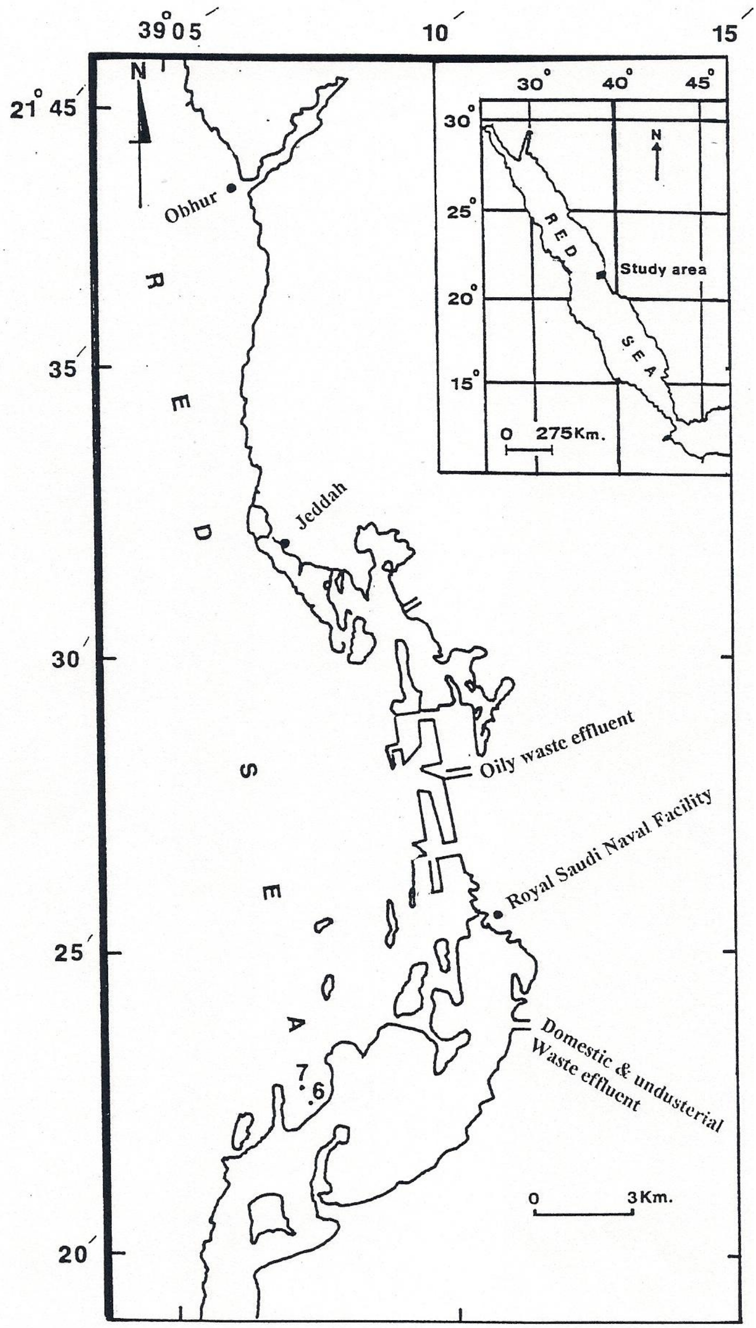

Fig. 1. A map of the study area.

Model Description

A hydrodynamic model is used mainly to solve the basic equations which govern the flow. These equations are the continuity equation and equation of motion:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\frac{\partial \eta}{\partial x}+\frac{k\,u\,\sqrt{(u^2+v^2)}}{D+\eta}-\Omega\,v=0$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial \eta}{\partial y}+\frac{k\,v\,\sqrt{(u^2+v^2)}}{D+\eta}-\Omega\,u=0$$

$$\frac{\partial z}{\partial t}+\frac{\partial}{\partial x}\{u(\eta+D)\}+\frac{1}{\Delta x}\frac{\partial}{\partial y}\{v(\eta+D)\Delta x\}=0$$

Where,

u and v : depth-mean velocity along x and y axes ($\mathrm{m.s^{-1}}$).
Δx : spacing between lines of longitude (m).
η : elevation of the surface water above mean sea level (m).
D : depth of the bed below the ordnance datum (m).
t : time (s).
k : friction coefficient = 0.0025
Ω : Coriolis parameter = 2 ω $sin\phi$.
ω : is the tidal frequency.
ϕ : latitude.

The method of reduced gravity (Arango and Reid, 1991; and Stewart, 2004) was used:

$$g' = \frac{\rho_2-\rho_1}{\rho_1}g$$

Where, ρ_1 is the surface density, ρ_2 is the density of lower layer and g is gravity.

Model Bathymetry and Initial Conditions

The model bathymetry was obtained from the admiralty chart, by bilinear interpolation of the depth data into the model grid.

The tidal motion is suggested to start from rest; $u=v=0$ at $t=$ 0t-0. At open boundary the tidal amplitude and phase were given. The model was used for spring and neap tidal cycle. Coriolis force is neglected because the study area is relatively small (about 11.4km). The grid size of the model is Δx= Δy=150m.

Results and Discussion

Neap and spring tidal circulation as obtained from the model are presented in Fig. 2 to Fig. 5. Yellow areas are the land and green color indicates the shallow areas (less than 1m). The tidal circulation during the neap tide (Ebb) is dominated by the western flow (Fig. 2), with a velocity range of 0.32-0.54m.s^{-1}. The high values of the current velocities are shown at the shallow area.

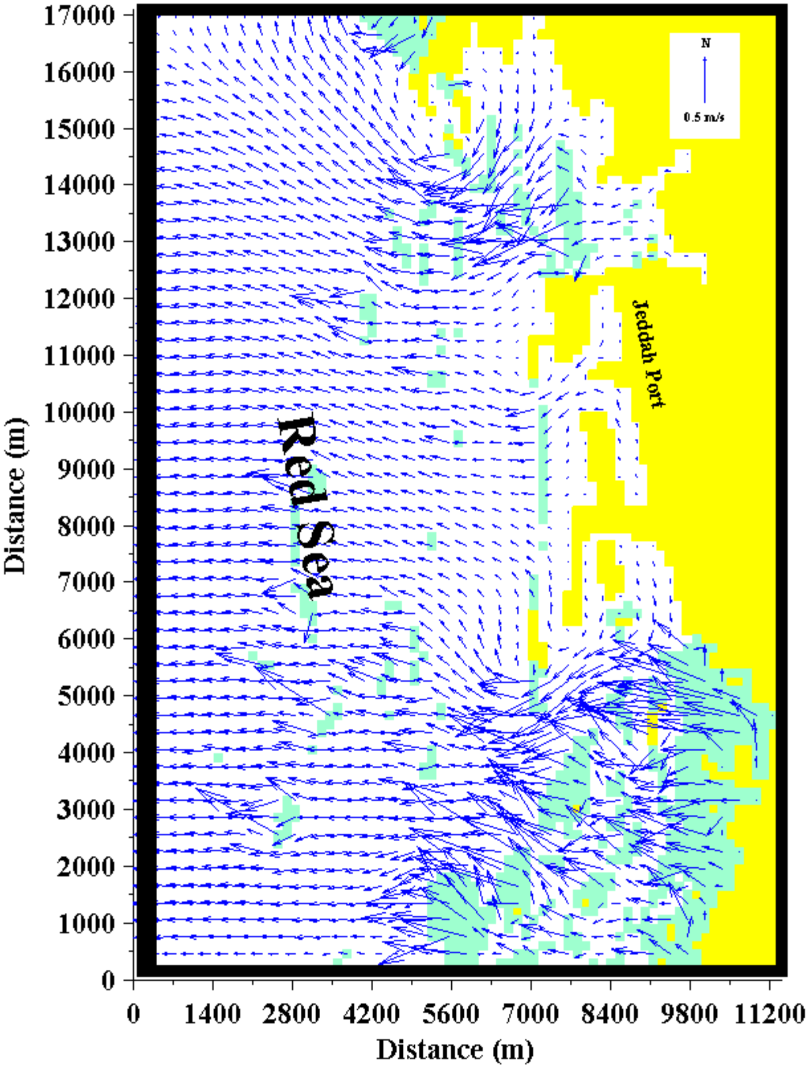

Fig. 2. Water circulation during neap tide (Ebb).

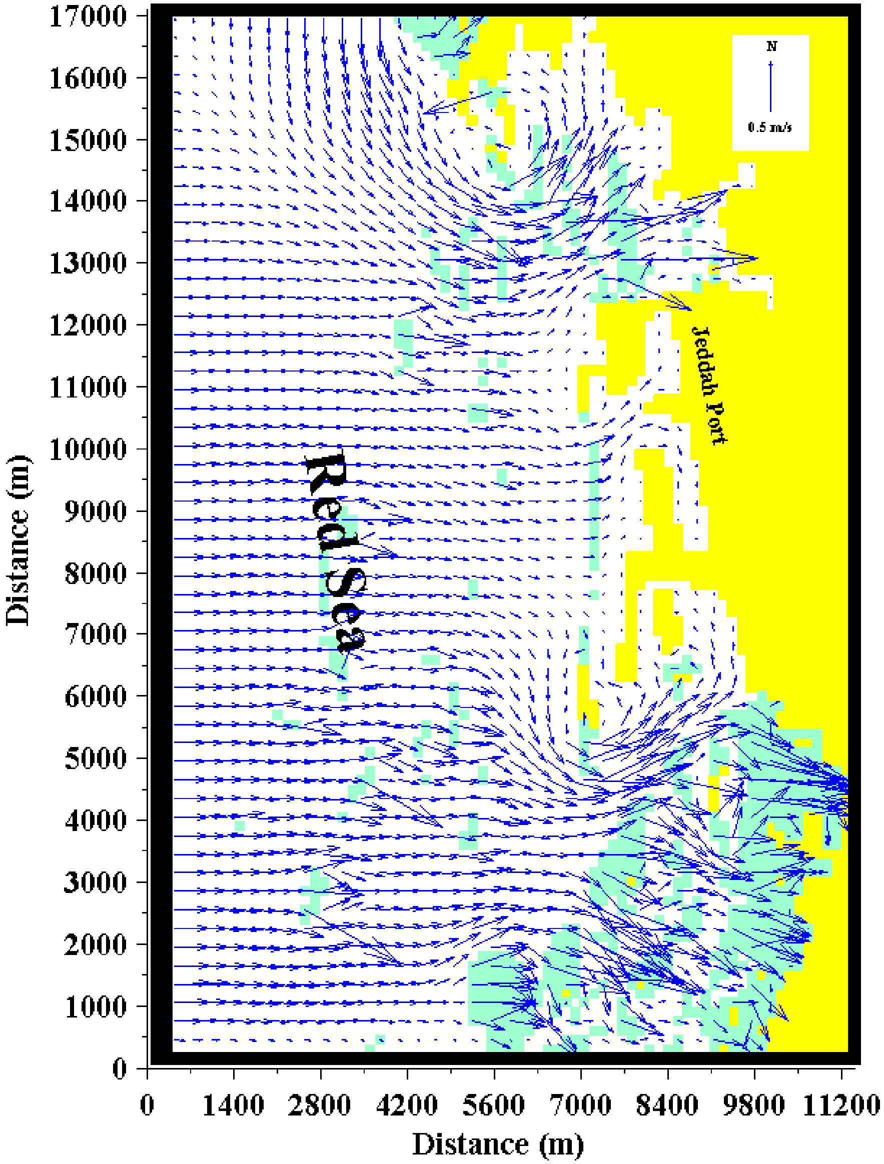

Fig. 3. Water circulation during neap tide (Flood).

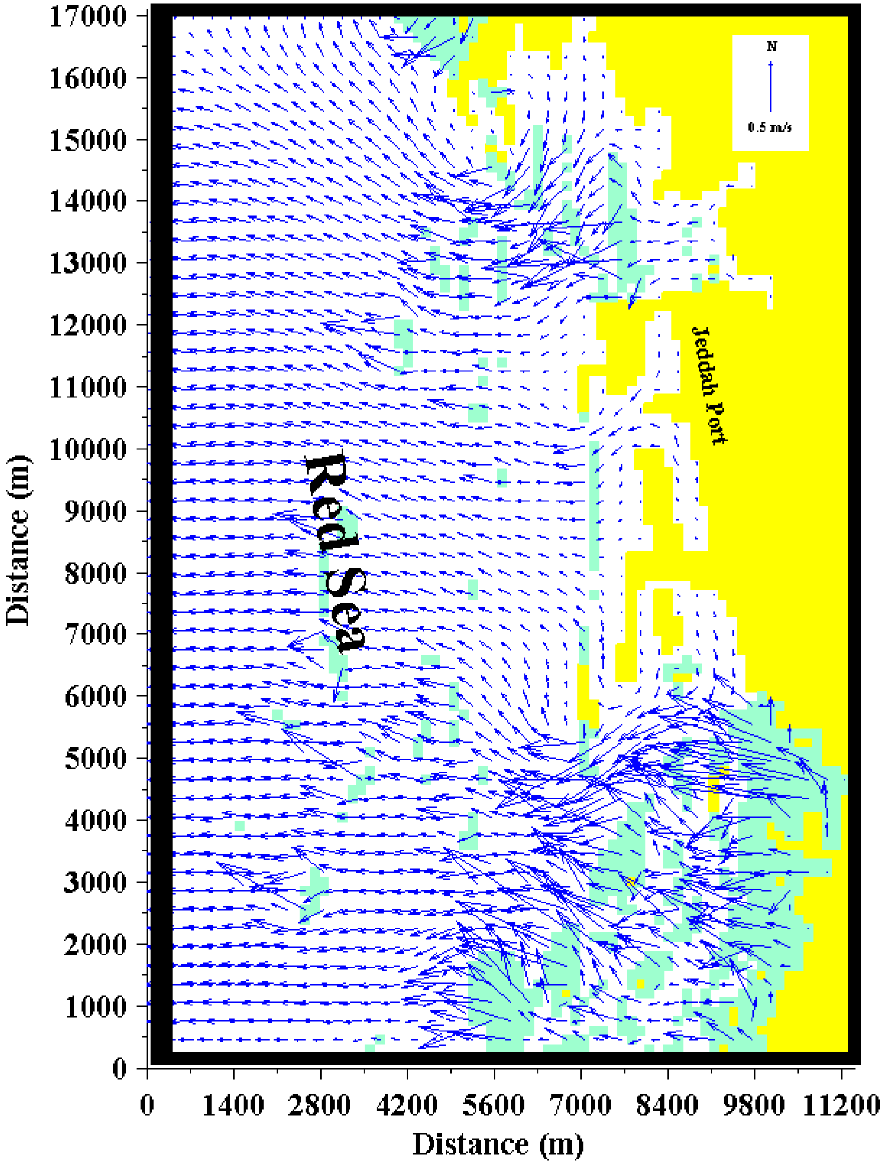

Fig. 4. Water circulation during spring tide (Ebb).

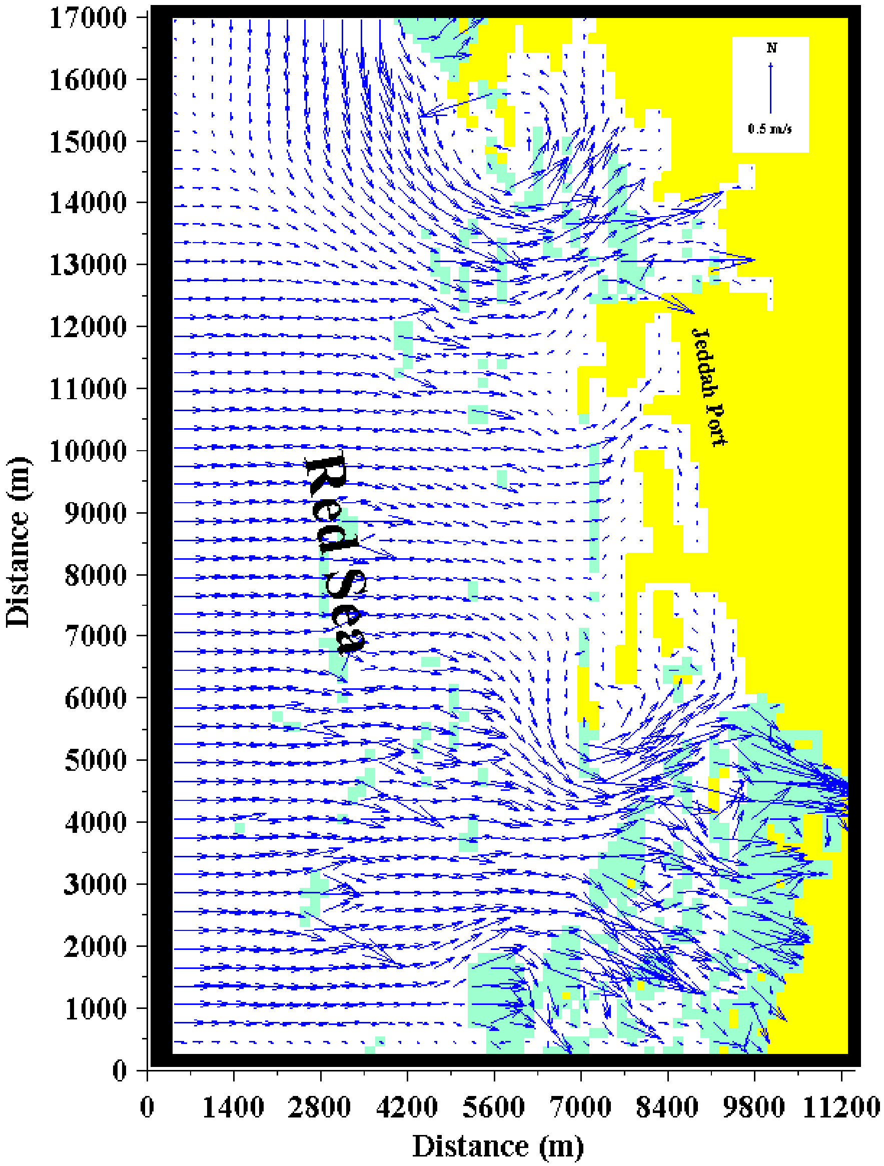

Fig. 5. Water circulation during spring tide (Flood).

The computed current velocities were compared with the observed velocities to validate the model results. Valeport current meter was used to measure the current velocities during spring tide in April, 2007. The location of the current meter station is (21° 25.32`N, 39° 09.85`E).

Figure 6 shows the comparison between the current magnitudes and Fig. 7 shows the comparison between modeled and observed current directions. The comparison showed reasonable matching between the model results and the observed current velocities and directions considering that only tidal force is applied in the model to govern the motion.

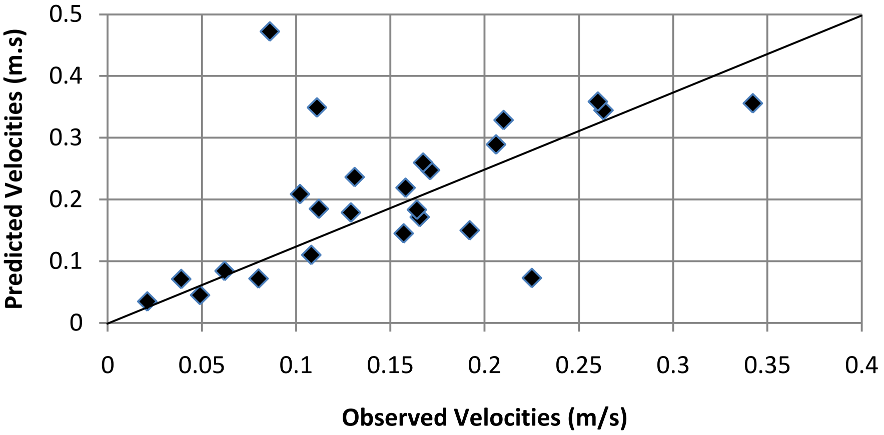

Fig. 6. Comparison between observed and predicted current velocities.

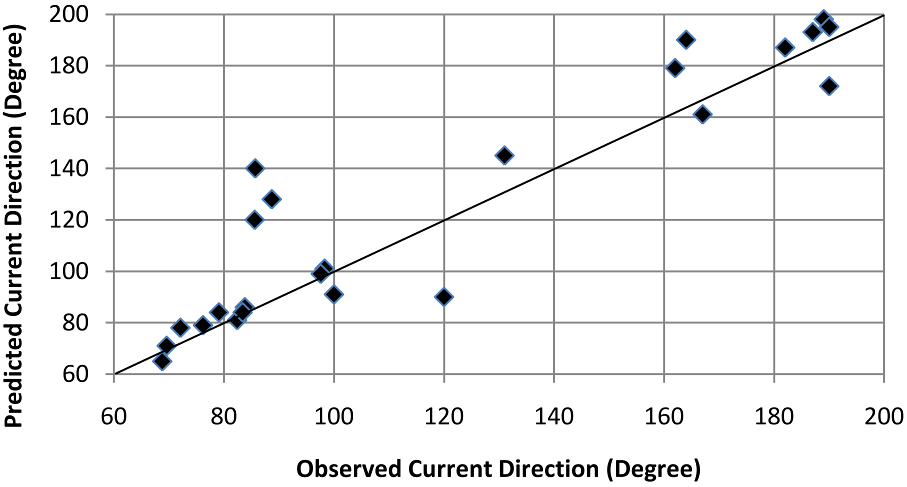

Fig. 7. Comparison between observed and predicted current directions.

Conclusion

According to the model results, the water circulation in Jeddah Port exhibits strong ebb to flood variability, reversing from west to east movement during neap and spring respectively. There are no much differences in the water circulation during the spring and neap tide. Although the tidal range in Jeddah area is small, the predicted tidal current velocities are important for ensuring the renewal of the sea water within the port area.

The current velocities are larger in the shallow areas (<1m depth) where the natural channels are surrounded by the coral reefs (about 0.5m.s^{-1}). This causes the tidal force to be modified (Zimmerman, 1981). On average the current velocity is about 0.3m.s^{-1}.

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نموذج رياضي لتوقع حركة التيارات المدية أمام ميناء جدة الإسلامي، البحر الأحمر

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المستخلص. يقع ميناء جدة الإسلامي في الساحل الشرقي للبحر الأحمر، وهو من أكبر موانئ المملكة العربية السعودية، تم تطبيق نموذج رياضي لتوقع حركة التيارات المدية وهو نموذج ثنائي الأبعاد، وقد أظهرت المقارنة توافقًا مقبولاً بين نتائج النموذج الرياضي مع قياسات التيارات البحرية المقاسة، ومن أهمية هذه الدراسة التأكد من تجدد المياه داخل ميناء جدة الإسلامي.