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THE LUNAR TIDE IN THE GULF OF SUEZ AS A CANAL SHAPED BASIN

BY

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ABSTRACT

The Hydrodynamical numerical methods were used to study the tidal motion in the Gulf of Suez as a channel shaped with variable depths. Its width was assumed uniform in one case and variable in the other. The rotation of the earth was ignored in the calculations while friction was taken into consideration. The results obtained for the semi-diurnal lunar tide in the two cases were compared with real observations at different locations along the gulf. The results are more satisfactory in the second case which reveals that the width affects the motion in shallow water bodies.

When the mean water depth over each cross-sectional area was replaced by the largest value existing in each section, better results were obtained. This implies that the tidal motion in shallow basins as the Gulf of Suez is very sensitive to the distribution of the water depths. Thus, more accurate results could be obtained if finer grid resolution could be used. Generally, the tidal patterns indicate the presence of a stationary wave with a nodal line in the vicinity of Ras Gharib.

INTRODUCTION

The Gulf of Suez (Fig.1) is about 250 km long and 22 km wide on the average. Its bottom is nearly flat with a depth of 55-75 m. At its entrance, its bottom is falling abruptly to depths of more than 500m. The Tor Bank lies in the fairway of the gulf with depths of about 20-35 m. (Morcos, 1970). Its northern part is characterized by a steeper western side, while its southern part has two equally steeps sides.

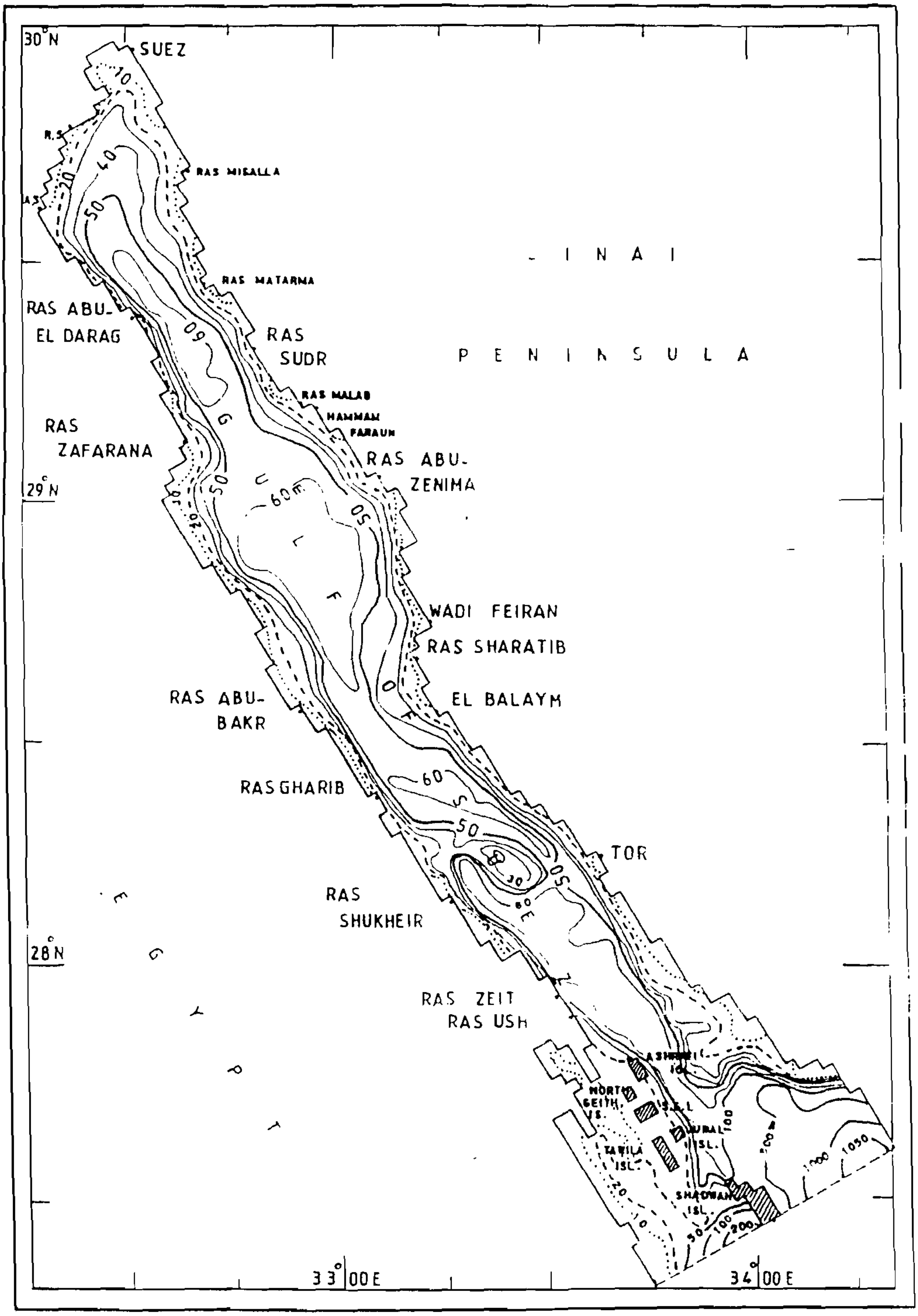


Figure 1: Gule of Suez Map.

The sea level in the gulf shows wide varieties from north to south. The principal lunar M2-tide is the most important tidal constituent in the gulf except at the nodal line where the diurnal tidal component dominates.

The tides in the gulf have been examined by few investigators through the harmonic analysis of the sea water level observed for short periods at 5 stations along its length. There is only one tide-gauge at Suez which is still working till now. Defant (1926) applied the hydrodynamical theory of tides to the Red Sea and both Gulfs of Suez and Aqaba. He divided the Gulf into twelve sections, by which the water elevation as well as the tidal currents of the components (M2+S2) have been estimated. The results obtained have been compared with the observations, which are satisfactory in general (Table 1). According to Defant (1926), the small amplitude values obtained in the northern part of the gulf may be due to the negligence of the friction influence in his calculations which may play a certain role in such shallow water body.

Grace (1930) showed also that the agreement between observation and theory is still not very good because transverse motions and friction which were not taken into account in these studies are more disturbing there.

In the present study, a one dimensional numerical model was applied to investigate the semi-diurnal lunar tide in the gulf, which was assumed as a long narrow canal with a constant width and variable depth. Its shape was then taken as a basin with variable width and depth (Fig.2) to estimate the influence of width on its tidal motion. Friction has been taken into consideration as a linear function with friction coefficient of $4\text{-}7 * 10^{-5}\ sec^{-1}$. Transverse motion and the rotation of the earth were not involved in the computations.

The Model

I - The Canal with a uniform width

The vertically integrated hydrodynamical differential equations for a simple one dimensional canal are given as:

$$\delta u/\delta t = -g\, \delta \zeta / \delta x - Ru + X \qquad \text{..........(1)}$$

$$\delta \zeta / \delta t = -\, \delta (uH)/\delta x \qquad \text{..........(2)}$$

where :

x,y : cartesian co-ordinate along the northwest and northeast directions after the rotation of the x-axis, in the north, 30° to the west

t : time.

Table (1): Observed and calculated values of amplitudes and phase angles.

Values / Location	Observed values			Calculated Values												
				Previous Works						Present Works						
				Defant (1926)* M2+S2		Soliman (1979) as long Canal		Soliman (1979)** Two dimensional		A Canal with uniform width		A Canal with varible depth & width		A Canal with uniform width & largest depth	
	A	ϕ	ϕ	A	ϕ	A	ϕ	A	ϕ	A	ϕ	A	ϕ	A	ϕ
	(cm)	at Aden	at Greenw.	(cm)	o	(cm)	o	(cm)	o	(Cm)	o	(Cm)	o	(Cm)	o
Suez	56.1	342	290 (278)	61 (70)	296	56	260	41	292	29.8	275	34	270	49	280
Zafrana	42.4	345	289 (280)	50 (55.1)	296	41.1	255	28	287	24	268	28	263	41.5	274
Ras Gharib	18.2	340	288 (274)	12 (25.2)	292	13.6	247	8	274	10.8	209	12.5	216	24.1	247
Tor	7.8	271	216 (203)	9 (9.7)	126	11.5	154	3.3	200	13.8	162	14.5	163	19.8	204
Ashrafi	13.4	184	131 (116)	23 (17.4)	126	18.7	129	14.8	130	22	133	23.1	130	22.5	163
Shadwan	25.1	185	130 (117)	29 (27.4)	122	22.6	106	20.5	127	25.4	125	25.4	125	25.4	155

* Amplitudes between ( ) correspond to observations of M2 + S2

** The Gulf of Suez itself was a one dimensional basin of 8 grid - points along its length and one grid point in width.

u,v : depth mean current components in the new co-ordination.
ζ : free surface water elevation.
H : total water depth.
R : linear friction coefficient at the bottom.
g : gravity acceleration.
X : tidal producing force in the new x-direction.

Initial and boundary conditions

v = 0.0 at both banks (eastern and western banks).
$U_n = 0.0$ at the northern end of the gulf. .... (3)

At the open boundary, the sea level was given by the following periodic relationship:

$\zeta = A \cos(\sigma t + \phi)$ .... (4)

where:

A : the amplitude of M2-tidal component at the entrance,
σ : the frequency of the co-oscillating motion.
ϕ : phase angle.

The initial state of the free surface was suggested to take a sinusoidal shape by the following formula:

$\zeta = 25.0 * \cos \pi \{(I-1)/60\}$ .... (5)
and
u = 0.0 every-where.

where I : grid number

Difference scheme

A finite difference scheme (Fig.2) with a forward difference in time (Δt in seconds) and central difference in space (Δx in cm) has been applied to evaluate ζ (i) and u(i) at time t + Δ t from the known values at time t.

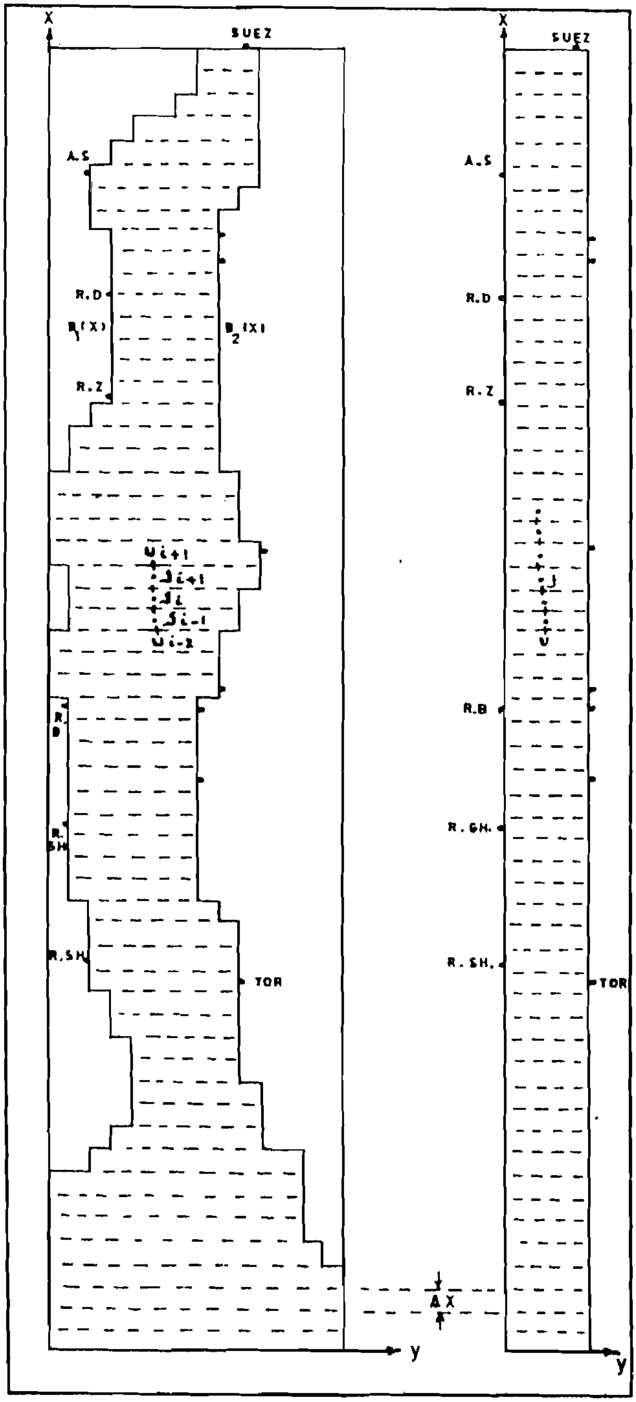


Figure 2: The different shapes and the grid system used.
a- A canal shaped basin with constant width.
b- A Canal shaped basin with variable width.

Stability conditions

For stability, Courant-Friedrichs-Lewy criteria is given as :

$$\Delta t = \Delta x / (2\, g\, H_{max.})^{1/2} \qquad \ldots\ldots\ldots\ldots \quad (6)$$

Assuming $\Delta x = 5.56$ km and $\Delta y = 4.88$ km, hence and according to the above relation, t has been taken as 120 lunar seconds.

N.B. Fig (2)

Grid system

The variables were chosen with ζ -points at the middle of the grid and u-points at the upper side.

Difference scheme

A simple difference scheme was prepared to calculate ζ-and u-values at time t + Δt from the known values obtained at time t with forward differences for time and central differences for space derivatives.

II - The canal with a variable width:

If B_1 (x) and B_2 (x) represent the banks of the gulf (Fig,2), then by integrating equation (2) w.r.t. y , it follows:

$$\int_{B_1(x)}^{B_2(x)} [\delta\{u(x,t)*H(x,y)\}/\delta x]dy + \{B_2(x) - B_1(x)\}\ \delta\ \zeta/\delta t = 0 \ \ldots\ldots (7)$$

since

$$\delta/\delta x \int_{B_1(x)}^{B_2(x)} \{u(x,t)*H(x,y)\}dy) = [\ \delta B_2/\delta x.\ H(x,B_2(x)) - \delta B_1/\delta x$$

$$*H(x,B_1(x)]* \int_{B_1(x)}^{B_2(x)} [\delta(u(x,t)$$

$$*H(x,y))/\delta x]\ dy \ \ldots\ldots\ldots\ldots \quad (8)$$

where :

$$H(x,B_2(x)) = H(x,B_1(x)) = 0$$

and if :

$$S(x)=\int_{B_1(x)}^{B_2(x)} H(x,y)\,dy = H(x) * B(x)$$

where:

$$B(x) = B_2(x) - B_1(x),$$

therefor:

$$\delta\zeta/\delta t = -1/B(x) * \delta/\delta x\,(Su) \qquad \ldots\ldots\ldots\ldots \quad (9)$$

where:

$B(x)$: the width of the gulf,
$H(x)$: the average depth of the gulf over its width.
$S(X)$: the cross- sectional area of the gulf.

RESULTS AND DISCUSSION

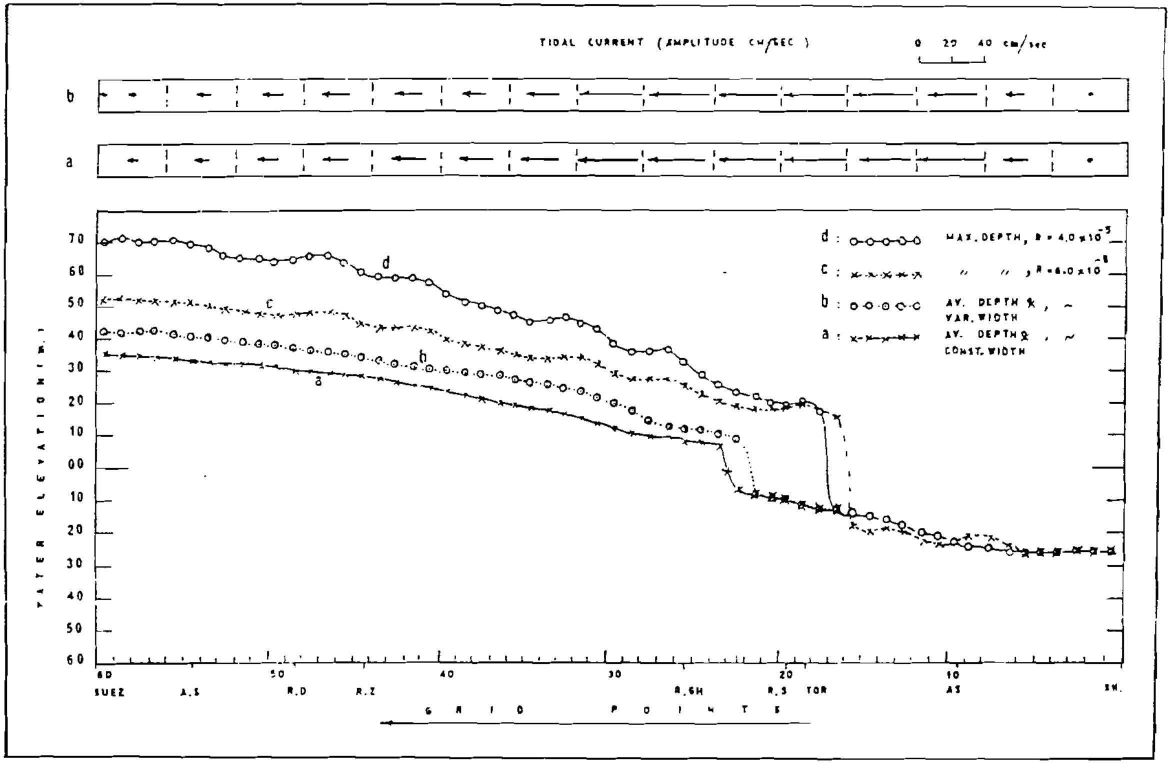
Any closed basin acquires its tidal motion under the action of the external attracting forces. If these basins are allowed to move freely with the open seas as in the case of bays and gulfs, they will show wave patterns which are different in character if compared with the independent motion existing in that basins.

Since the Suez Gulf is opened at its entrance to the Red Sea, its tidal motion will be driven by the astronomical forces as well as by the penetrating waves that enter the gulf from the sea. To estimate the influence of the independent tidal motion in the gulf, it is assumed to be closed at its entrance with a rigid boundary. On applying the one-dimensional model (equations 1-2) on the gulf which is considered as a narrow canal with a uniform width of about 4.8 km and variable depth, the results obtained showed that the independent tidal ranges are very small which indicate that the tidal motion in the gulf is mainly of co-oscillating type.

If the gulf is allowed to move freely with the Red Sea, the boundary condition at its entrance is described by a periodical motion given by equation (4).

Different frictional coefficient values ($5\text{-}7 * 10^{-5}$ sec^{-1}) have been tested to get the proper elevation values. Stability conditions mostly reached after three tidal cycles .

Figure 3a-d: Tidal amplitude (lower) and currents (upper) at the grid points along the gulf for different depth and width conditions and different friction co-efficient.



To investigate the influence of width on the tides of the gulf, its width has been taken into consideration as previously described in case II for the canal with variable depths. This could be achieved by introducing equation (9) in the model instead of equation (2).

Generally, the tidal ranges obtained through the above two mentioned cases revealed that the tidal ranges at Suez are relatively smaller than the observations but more or less in agreement with the theoretical results obtained by Defant (1926), although friction has been taken into account in the present study. The results also indicate that friction damps only the growing of the waves as given by Soliman et al. (1993).

To improve the results, the model in case I with uniform width has been carried out again but taking the largest depths observed in each cross-section to represent the depths of the gulf.

Fig.3 (lower) presents the amplitudes of the M2-tidal motion along the gulf for the three proposed cases. It is worthy to mention that the amplitudes in the deep southern part are nearly unchanged neither by changing the boundaries nor by changing the frictional coefficient. Whilst the shallow northern part is very sensitive to any changes in both conditions. This reveals that the shallowness of the water as well as the variation in width in the northern part of the gulf have prime influences on its tidal motion. The results obtained are in good agreement with observations (Table 1).

Generally speaking, the disagreement between observations and the theoretical results obtained in the Gulf of Suez by Grace (1930) and Defant (1926) could be now explained on the basis of the present results. Hence, it is concluded that the slight variation of the depths in the shallow areas may have significant influences on the results.

Fig. 3 (upper), presents the tidal currents along the gulf for the proposed cases. The pattern indicates the presence of a stationary wave with vanishing speeds at the northern and southern boundaries, while they gradually increase towards the nodal line which exists in the southern part. High speed values of the order of 24.0 cm/sec were observed in the region of Ras Gharib in the first and second cases, while values of more than 50.0 cm/sec were obtained in the vicinity of Tor bank in the third case.

Hence, width affects to a certain extent the tidal motion in the gulf. In addition, the depth distribution has appreciable influence on the calculated amplitudes particularly in the shallow areas, and hence using finer grid resolution could give more comparative results.

CONCLUSIONS

1- The tidal motion in the Gulf of Suez is mainly of co-oscillating type . A nodal line is located in its southern part.

2- Friction damps only the growing of the waves in the shallow regions, while it has insignificant influence in the deep areas.

3- The shallowness of the water as well as the variation in width in the northern part of the gulf have strong influences on its tidal motion.

4- The tidal current pattern indicates the presence of a stationary wave in the gulf with nearly vanishing speeds at its northern and southern boundaries.

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