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Long-term numerical simulation for stability within the river mouth; case study: Rosetta promontory, Egypt

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Abstract: Estuaries are very sensitive and vulnerable to any interventions in coastal dynamics. Almost major of these inlets experience coastal problems such as severe erosion and accretion. Rosetta promontory, Egypt is an example of such environment. It suffers from coastline erosion and sedimentation inside the inlet. The shoaling of the inlet leads to hindering the navigation process of fishing boats, negative impacts to estuarine and salt marsh habitat and decreases the efficiency of the cross section to transferring the flood flow to the sea.
This paper aims to reach a new condition of stability of Rosetta Promontory by using coastal measures. The main idea is to control the sediment movement within the promontory mouth which causes shoaling inside the inlet. These coastal measures include boundary jetties to eliminate the coastal dynamic in the entrance as well as additional flow to enhance the circulation condition of the promontory.
This target is achieved by using a hydrodynamic model, Coastal Modeling System (CMS) to predict the coastal structure effect. Extensive field data collection is used to build and calibrate the model. About 6 scenarios were tested for 5 years to reach a suitable solution that mitigates the coastal problems at the inlet with minimal environmental effect. These scenarios include east jetty of 360m length only, a combination between the eastern jetty of 360 m and the west one with two different lengths 500 m and 800 m. The other three scenarios are the same as the above with addition flow discharge from the river mouth of 47 m3/s. The results show that using eastern jetty of length 360 m and western jetty of 800 m with periodically sediment dredging from the river mouth will help stabilizing the Rosetta promontory.

***Keywords**:* Rosetta promontory, erosion, sedimentation, inlet stability

1 INTRODUCTION

Estuaries are unique water systems; they are considered an interface between fresh river water and saline coastal water (Horrevoets, Savenije, Schuurman, & Graas, 2004). It provides a link between the coastal ocean and back-barrier bay, exchanging water, sediment, nutrients, and other materials between them (FitzGerald, 1996 ; Vila-Concejo, Ferreira, Morris, Matias, & Dias, 2004). In addition, they have a considerable effect on adjacent shorelines that interrupt by influencing the sediment budget (Stive and Wang, 2003).They are also situated in densely populated areas,(Van Leussen & Dronkers, 1988) .
Various estuaries may be influence by sea level rise, wave action, tides (Restrepo, et. al., 2002; Syvitski et al., 2009), and anthropogenic factors. The human influence including direct impacts affecting river discharge and sediment load such as water diversion, deforestation, dams construction and water diversion for irrigation alter the morphology of deltaic systems (Hood, 2010). A sufficient knowledge of the estuarine system's functioning, both for natural (physical and biological) and human interventions is essentially to solve estuary problems.
Estuary problems were addressed in many cases, and solutions were discussed, (Zhang, et.al., 2008; Kraus, et. al., 2008). In many situations engineering structures are required to stabilize the shoreline,

shoals and inlets, reduce sedimentation, prevent or reduce erosion, increase the channel depth and to allow larger vessels entering the harbor basin (Van Rijn, 2005).
Rosetta estuary is located on the eastern side of Abu- Quir Bay at about 60 km to the east of Alexandria city, Egypt as shown in “Fig. 1”. The promontory suffers from the extensive erosion due to damming the water of the Nile River by control structures. Moreover, Rosetta mouth considered as a sink for the eroded sediments transported from Abu Quir Bay and Rosetta (Ahmed, 2006). These sediments accumulate inside the inlet and results in a great problems for navigation process , the living of habitat in this area, threaten the nearby areas with inundation in flood conditions, and reduce the capacity of the waterway. Although protection works (two revetments of 3.50 km long and a total of 14 groins east and west of the promontory) were constructed to mitigate the erosion problem at Rosetta inlet, the problem is migrated to the neighbor locations. Many attempts to solve the sedimentation problem were performed. Although continuous dredging works were implemented, it failed to solve the problem (El Sayed et al., 2007). Delft3D software package of Deltares was used by (Ahmed, 2006) to study how to minimize the sedimentation problem inside the Rosetta Estuary. In the previous studies two jetties were proposed to mitigate the sedimentation problem and the results showed that this solution has hardly any impact on sedimentation problem due to sediment bypass through the eastern jetty and the frequent dredging operation is still necessary. A frequent dredging is also carried out to overcome the siltation problem inside the estuary (Ahmed, 2006;El Sayed, et. al., 2007).

This paper aims to stabilize the Rosetta promontory by using control structures to eliminate the sedimentation problem in the outlet and decrease the erosion problem in front of the revetments. The assessment will be implemented numerically using the Coastal Modeling System (CMS).

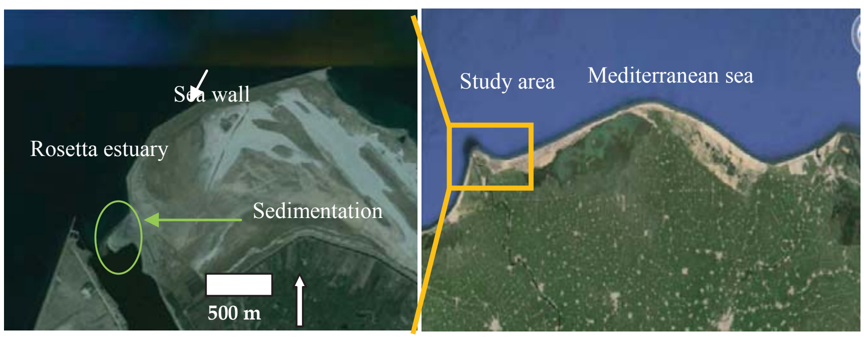

Figure 1. Location of the study area (Rosetta promontory at the terminal of Rosetta branch, Google earth (2005).

2 MATERIAL AND METHOD

2.1 Field data collection

The field data (bathymetric, wave, tide, Rosetta branch discharges) were obtained from the Coastal Research Institute, Hydraulic Research Institute, and Coastal Protection Authority. The bathymetric survey (about 50 profiles which are perpendicular to the coastline) utilized in this study was conducted in October 2005. The bathymetric survey of May 2006 was used to calibrate the numerical model. The wave data are the averaged wave climate of five years between 1986 and 1990. The wave directions are from WNW, NNW, N, and W with a small portion of waves arrived from the NNE and NE especially in March and April (El Sayed et al., 2007). Figure 2 shows the wave rose of the study area. The Nile delta coast is a typical micro tidal semi-diurnal tidal regime with a tidal range of 30 cm (Douglas L. Inman, 1984). The available tide data represented in water levels at Rosetta promontory covered the period from October 2005 to October 2006. The sediment grain sizes(d_{50}) at the nearshore zone of the area of interest are between 0.16 mm and 0.24 mm, (Ahmed, 2004) . In order to transform the wave from offshore station at depth 18 m to the model boundary at 11m depth, the maximum entropy code (by CMS developers) was applied for the directional spectrum to be ready as input in the model.

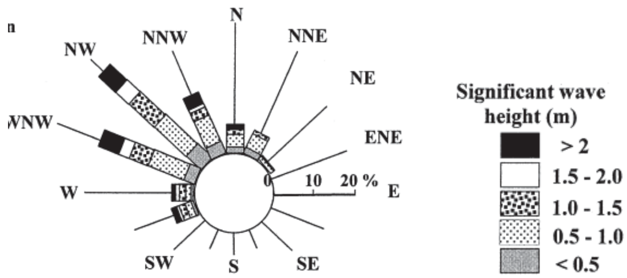

Figure 2. Average wave direction-height distribution at Rosetta coast, (Frihy & Dewidar, 2003)

2.2 Numerical modeling using the Coastal Modeling System (CMS)

The nearshore, off shore, the inlet, Rosetta branch, and adjacent beaches were surveyed between 2005 and 2006 by Coastal Research Institute. The CMS grid was constructed based on the above mentioned bathymetric data. A variable sized rectangular-cell grid system, with a spatial resolution ranging from 20*20 m in the vicinity of the inlet, and the nearshore zone, navigation channel to 70×120 m near the ocean boundary was generated with a number of ocean cells=24613. Having the fine grid spacing at and around the estuary enabled capturing the sediment transport and morphologic change processes where they mainly occurred. Larger the offshore grid spacing, the speeder the computational process is. A CMS-Wave was also generated that had the same dimensions as flow. To simulate for long term (five years), the flow field, CMS-Flow was driven by the measured tide along the open boundaries from October 2005 to May 2006. After examining 5 years (1986-1990) records, wave during 1986 was judged to be representative and used in the modeling effort. The half-plane model of CMS-Wave was selected for this study. Figure 3a, shows the model domain, the CMS grid bathymetry based on the available bathymetric data in October 2005. The target of this paper can be achieved by controlling the flow and the sediment transport from the eastern and western side of the promontory. Six scenarios were tested using Coastal Modeling System(CMS). The first scenario has an eastern jetty of 360m long, the second and third scenarios are a combination between the eastern jetty of 360 m and the western one with two different lengths (500 m, 800 m) respectively. The other three scenarios are the same as the above with addition flow discharge from the river mouth of 47 m3/s.

2.3 Model calibration

Input data for the wave, and flow modules were prescribed and the model was executed to predict the bottom evolution after six months starting from October 2005. Several profiles were considered at western and eastern sides of the inlets as shown in the "Fig. 3b" to perform sensitivity analysis and model calibration. The important parameter used in calibration; hydrodynamic time step, Manning coefficient, different transport formulas, scaling factor for bed load and suspended load, total adaptation length, and also the effect of smoothing the bathymetric contour.

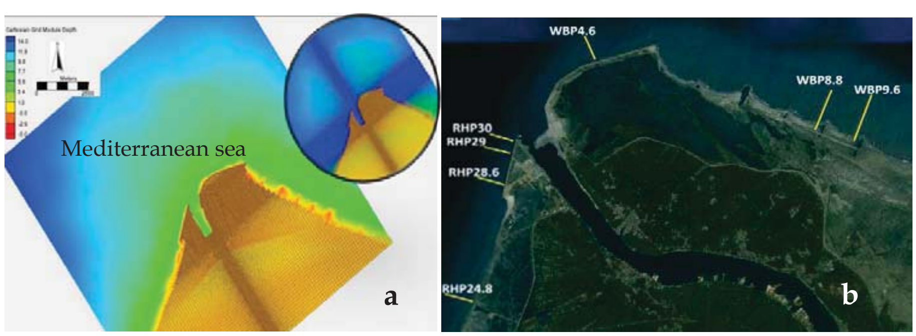

Figure 3. a) The model domain of Rosetta estuary, depths (positive) are relative to mean sea level, and the flow grid of the study area, b) location of the selected profiles along eastern and western sides of Rosetta inlet used in calibration and sensitivity analysis.

The correlation coefficient according to bed change and bed depth were calculated at all profiles. The results show that a good agreement with the measurements can be picked up as shown in (table 1) with 0.025 of Manning coefficient, 0.20 mm of d50, 450 sec time step, scaling factor of 2.0 and adaptation length of 10 m.

Table 1. The correlation coefficients of all profiles due to bed depth and bed change.

Section name	R (bed depth)	R(bed change)
RHP30	0.99139	0.769665
RHP29	0.99493	0.69535
RHP24.8	0.98825	0.814417
WBP4.6	0.97812	0.590895
WBP8.8	0.98689	0.558552
WBP9.6	0.97101	0.615809

3 RESULTS AND DISCUSSION

This work is a trial to reach a new stability condition for the Rosetta promontory as an example for the river mouths worldwide. "Figure 4" shows model results of morphological changes of Rosetta Promontory after five years. The results show that the behavior of eastern jetty alone is better than the other scenarios for the first 250m from the outlet as it increases the depth and width of the inlet comparing to the case of no structure. The accumulated sediments in this case are due to bypassing the sediment to the entrance after filling the upstream area of the eastern jetty. Not only the bypassing sediments constitute all sediments inside the inlet, but also the sedimentation generated due to the formation of strong eddy vortex at the opening resulted from the wave breaking inside the inlet as shown in "fig 5d". This vortex results in eroding in the left portion of the open and convey it in the back of the inlet as shown in "fig 5b".

For the rest cross sections, the eastern jetty of 360 m with the western one of 800 m length with normal flow gives better results than the other. In this case, the accumulated sediments are transmitted towards the outlet due to the existence of the western jetty that shifted the breaking of the waves outside the inlet creating calm conditions behind the jetty as shown in "fig 5e". These conditions reduced the wave induced current inside the inlet which constitute a weak eddy vortex.

In general, all the above solutions will required periodically dredging but the eastern jetty of 360 m length with the western one of 800 m length required the least volume as shown in table 2. The dredged material from inlet will be conveyed to the critical spots of erosion along the revetment to prevent exposing the foundation of seawall. Moreover, the accumulated sediments behind the jetty will be bypassed to these critical points.

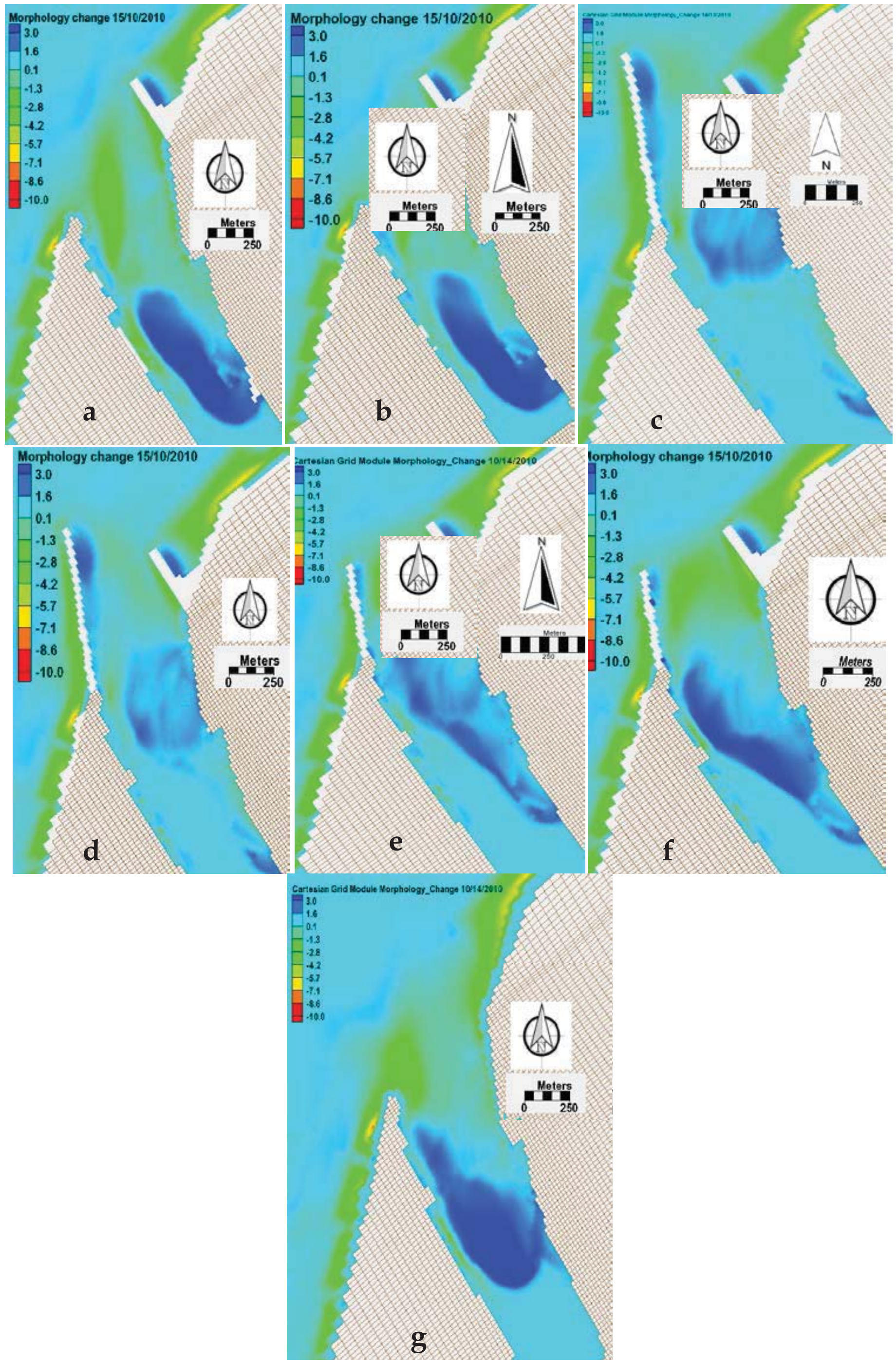

Figure 4. Model results of morphological changes of Rosetta Promontory after five years: a) eastern jetty only of length 360 m, Q=47 m^3/s, b) eastern jetty only of length 360 m, normal flow, c) eastern jetty of length 360 m with western one of 800m length , Q=47m^3/s, d) eastern jetty of length 360 m with western one of 800m length , normal flow, e) eastern jetty of length 360 m with western one of 500m length , Q=47m^3/s, f) eastern jetty of length 360 m with western one of 500m length, normal flow, g) case of no structure, normal flow.

Table 2. The calculated dredging quantities for different scenarios(normal flow).

Case	Volume change(+) m3	Volume change(-) m3	Net volume (m3)
1.No action	348943	18292	330650
2. Eastern jetty of length 360 m	168873	79489	89383
3.Eastern jetty of 360 m length with western jetty of length 500 m	187876	6873	181002
3.Eastern jetty of 360 m length with western jetty of length 800 m	88150	12928	75222

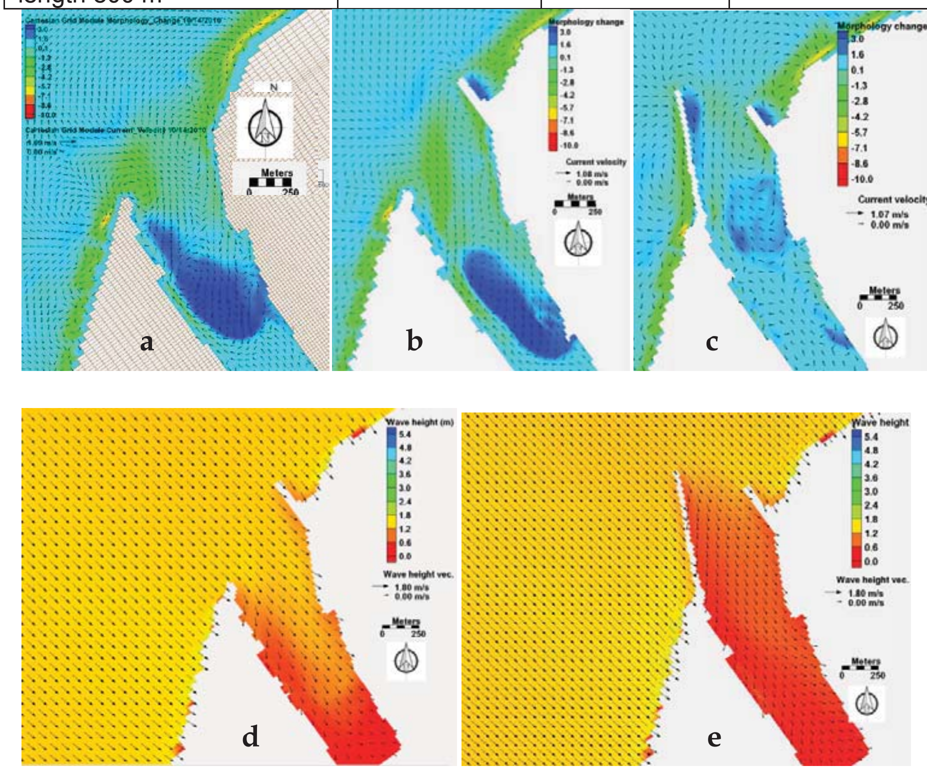

Figure 5. Resulted velocity vectors due to wave diffraction of the prevailing wave direction at: a) no structure case, b) eastern jetty of depth 360m , c) eastern jetty of length 360 m with western one of length 800 m, d) Wave heights distribution and wave height vectors at the inlet for eastern jetty , e) Wave heights distribution and wave height vectors for eastern jetty of length 360m combine with western jetty of 800m length.

4 CONCLUSION AND RECOMMENDATION

Rosetta promontory suffers from many coastal problems as erosion problem along the coastline and siltation problem inside the inlet. The shoaling of the inlet leads to hindering the navigation process of fishing boats, negative impacts to estuarine and salt marsh habitat and decreases the efficiency of the cross section to transfer the flow during emergencies to the sea. About six alternative scenarios are proposed to solve these problems. The main idea of these scenarios is to reach a new condition of stability for the Rosetta Promontory by using coastal measures. These coastal structures is used to control the coastal hydrodynamics and sediment movement within the estuary. They include modifying the inlet cross section by using boundary jetties to eliminate the coastal dynamic in the entrance. CMS two dimension numerical model is used to check the effectiveness of these scenarios. All scenarios were simulated for five years, it was found that the eastern jetty of 360 m length gives better results in some areas in front of the inlet rather than other scenarios, while the scenario which combine the eastern jetty(360m), and western one(800m) gives better results for the rest of inlet cross section. The results identify that combined eastern jetty of length 360 m with western one of 800 m will help in stabilizing the Rosetta promontory but it requires periodically sediment dredging. This dredging material can be pumped in the critical areas in front of the eastern and western revetment to eliminate the scour under its toe.

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