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Hydrodynamic modeling of outlet stability case study Rosetta promontory in Nile delta

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Abstract

The hydrodynamic features of Rosetta promontory are simulated numerically to minimize the outlet siltation problems. Many coastal structures (i.e. revetments, groins) are used to solve the erosion of the shoreline and siltation in the outlet. However, the shoreline along the promontory is still unstable and these structures did not achieve the expected results to reduce the problem where the erosion problem is shifted down drift. In this research three potential solutions were investigated. The first solution is to apply a soft approach in term of re-establishment of natural hydrologic conditions such as providing additional water discharge processes through diverting Burullus drains to the end of the estuary to achieve the nature and stable condition for the promontory. The second proposed solution is to reach the equilibrium cross section of the outlet by dividing the Rosetta outlet into two parts by constructing two 500 m separated jetties. The third solution is to control the sedimentation in the outlet by constructing 450 m length jetty attached to the eastern bank of the estuary. Numerical Coastal Modeling System (CMS) was used after tuning the model parameters to check the feasibility of the different proposed solutions on the stability of outlet channel. The study shows that an additional discharge of 47 m^3/s in the first scenario results in a stable outlet cross section suitable for navigation purposes but with limited effect on the erosion problem.

Keywords: Numerical modeling; Siltation; Shoreline erosion; Nile delta; Soft approaches

1. Introduction

The Nile delta of Egypt is one of the earliest deltaic systems in the world (El Banna and Frihy, 2009). It was formed by sedimentary processes between the upper Miocene and present (Nelsen, 1976; Stanley and Warne, 1993) and built up by the alluvium brought by the old former seven active branches of the Nile. Those branches have been silted up and replaced at present by Damietta and Rosetta Branches.

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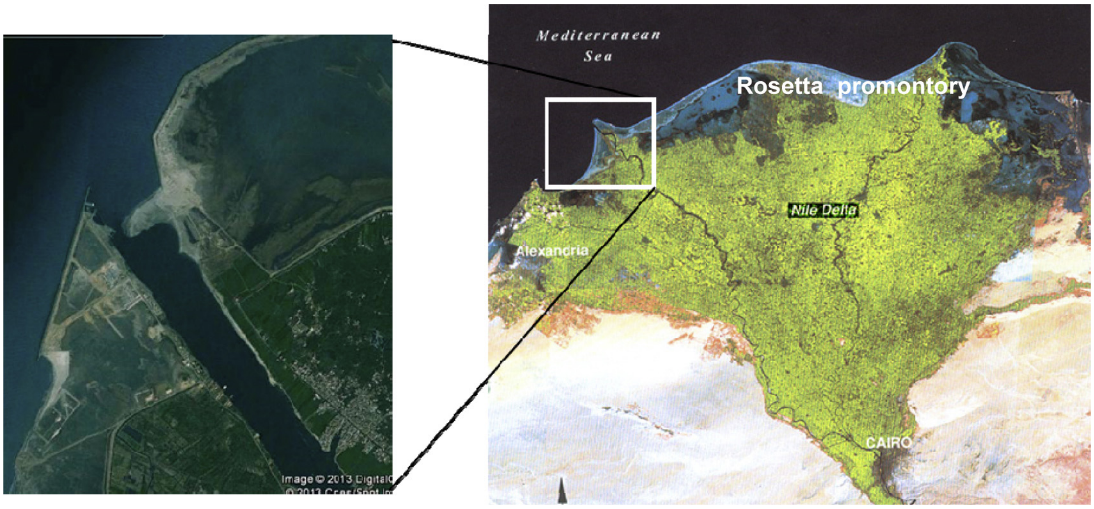

Fig. 1. Location of the study area (Rosetta promontory at the terminal of Rosetta Branch), Google earth 2006.

Rosetta Branch and promontory are 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. Since 1900, the water flow and sediments carried out by Rosetta Branch to the sea have been reduced due to the construction of Aswan High Dam and the control works along the River Nile (El Sayed et al., 2007). As a result, the erosion of the shoreline increased drastically and the sedimentation accumulated inside the outlet as shown in Fig. 1. The sedimentation problem of Rosetta promontory is a result of the coastal currents induced by waves that carry the bed material loads to the promontory. The low discharges released to the sea after construction of High Aswan Dam (HAD), are not capable of pushing the bed material load away from the promontory (Frihy, 1996). As a result, the sediment deposits in the promontory. Siltation problem in the promontory which creates a lot of problems such as hindering the navigation process of fishing boats (Ahmed, 2004a,b and Fanos et al., 1995), adverse impacts to estuarine and salt marsh habitats, and decreasing the efficiency of cross sections of the outlet channel to release the emergency discharges to the sea (Mahmoud et al., 2006). Some researchers derived different relationships between the equilibrium cross-sectional area, and spring tidal prism based on measurement data of outlets in different parts of the world, however this relationships also vary with different geological background (Stive et al., 2012).

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.

The aim of this study is to reach the equilibrium condition within the promontory by reaching the nature stable cross section of the outlet or creating a new equilibrium cross-section taking into consideration the integral solution for the whole area from Abu Quir Bay to Brullus Lake. These solutions were investigated using the numerical Coastal Modeling System (CMS) in terms of reestablishment of natural hydrologic conditions such as providing a discharge processes through the estuary to return to the natural and equilibrium conditions for the study area. Also some control structures are proposed to reduce sedimentation within the promontory or to reach the equilibrium cross section of the outlet.

2. Methodology

2.1. Field data collection and analysis

The field data (bathymetric, wave, tide, Rosetta Branch discharges) was obtained from the Coastal Research Institute, Hydraulic Research Institute, and Coastal Protection Authority. The bathymetric survey (about 50 profiles which are

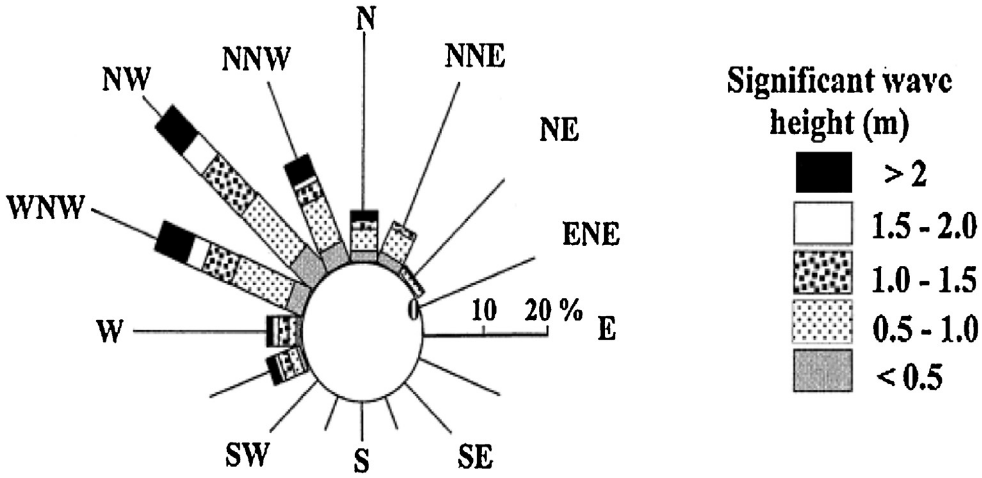

Fig. 2. Average wave direction–height distribution at Rosetta area (Frihy and Dewidar, 2003).

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 of actual measurements 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). Fig. 2 shows the average wave height–direction distribution. The Nile delta coast is a typical microtidal semi-diurnal tidal regime with a tidal range of 30 cm (Douglas and 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 near shore zone of the area of interest are between 0.16 mm and 0.24 mm. In order to transform the wave from offshore station at depth 18 m to the model boundary at 11 m depth, the maximum entropy code (by CMS developers) was applied for the directional spectrum to be ready as input in the model.

2.2. Numerical modeling using CMS model

2.2.1. The model description

The CMS is a process-based suite of models that integrate hydrodynamics, sediment transport, and morphological changes through the coupling of two modules, CMS-Flow and CMS-Wave, and they are coupled through steering module. It is conducted to calculate combined circulation (current and water surface elevation), waves, and morphological changes at outlets and nearby areas through the Surface-water Modeling System (SMS) interface. The CMS was developed specifically for modeling outlet processes and morphology changes.

CMS-Flow solves depth-integrated continuity and momentum equations using a finite-volume method (Reed et al., 2011). CMS-Flow provides the water level and current velocity to CMS-Wave. CMS-Wave is a spectral wave transformation model and solves the steady-state wave-action balance equation on a non-uniform Cartesian Grid. The wave model computes wave refraction, shoaling, reflection, diffraction, and breaking. The radiation stress induced by breaking is computed and imposed to CMS-Flow for the calculation of wave-induced long shore current, which are necessary for calculating sediment transport under combined waves and currents. There are three sediment transport models available in CMS; a sediment mass balance model, an equilibrium advection diffusion model, and a non-equilibrium advection-diffusion model. Non equilibrium transport model is used in this study.

2.2.2. Model setup

Two simultaneous computational grids were used: one for the CMS-Flow model and one for the CMS-Wave model. Both grids covered the Rosetta outlet system including the navigation channel, the branch of the river and adjacent beaches. The grids extended seaward of depth of closure beyond which no considerable sediment movement. The CMS-Flow grid as shown in Fig. 2, left panel it extends to 7 km offshore and 10 km to the right, and 8 km to the left of the outlet. The grid has a varying grid dimension ranging from 20 m inside Rosetta outlet to 130 m offshore. Having the fine

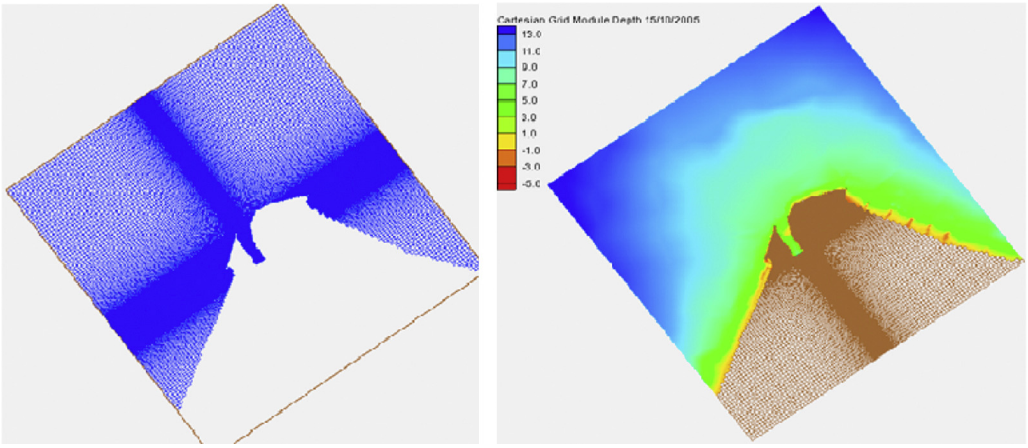

Fig. 3. CMS-Flow grid (left panel), and he model domain of Rosetta estuary (right panel). Depths are relative to mean sea level, positive depth under water.

grid spacing at and around the estuary enabled a good simulation of sediment transport and morphological processes in the concerned area. The larger offshore grid dimension speed up the computational process. The computational grid of CMS-Wave has the same dimensions as in the flow. To simulate the flow field, CMS-Flow was driven by the measured tide along the open boundaries from October 2005 to May 2006. After examining five years wave records (1986–1990), it was found that 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 (Fig. 3), right panel shows the CMS grid bathymetry based on the available bathymetric data in October 2005.

2.2.3. 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 outlet as shown in Fig. 4 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.

The correlation coefficient according to bed change was calculated at all profiles and gives a range (0.6–0.81). The results show that a good agreement with the measurements can be obtained as shown in Fig. 5 with 0.025 of Manning coefficient, 0.20 mm of D_{50}, 450 s time step, scaling factor of 2.0 and adaptation length of 10 m.

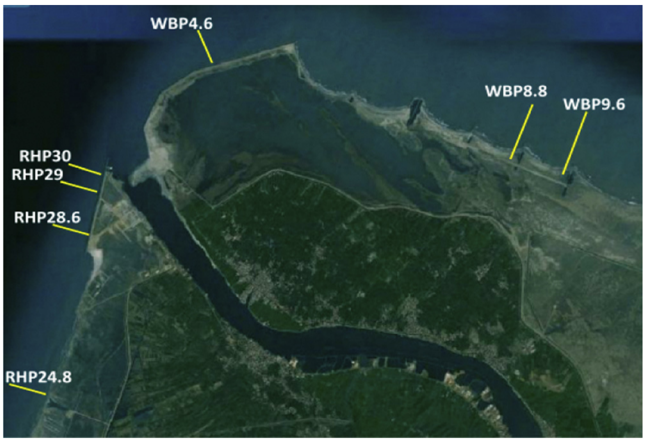

Fig. 4. Location of the selected profiles along eastern and western sides of Rosetta outlet used in calibration and sensitivity analysis.

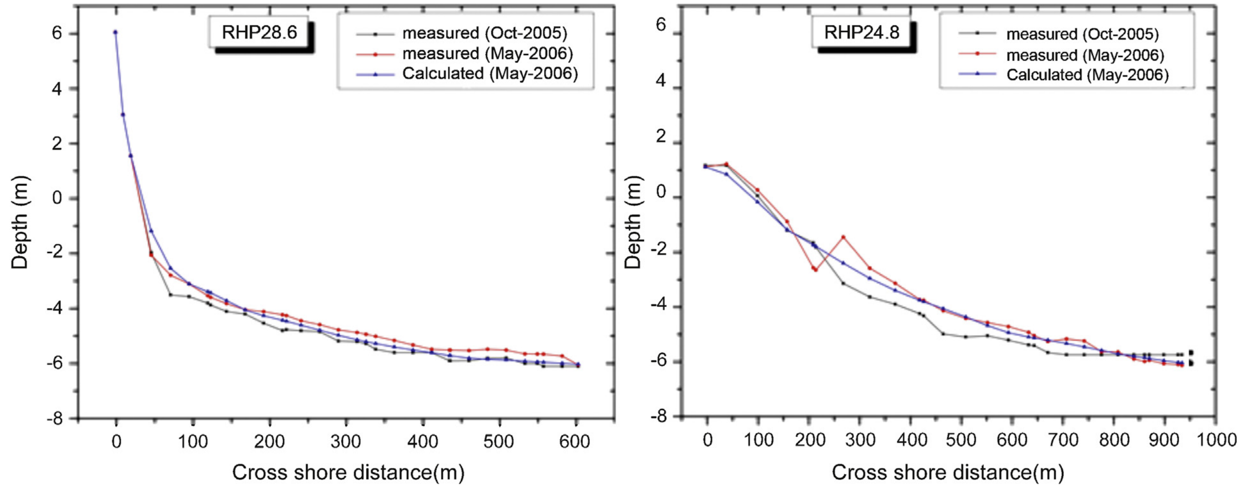

Fig. 5. Comparison between the computed beach profile and measured one for CMS calibration.

3. Analysis and results

Three scenarios were performed to eliminate the sedimentation problem within the Rosetta estuary as well as the erosion problem of the promontory. The first scenario is to increase the water discharge to the outlet through Moheet drain by using the excess water from the drains which discharge directly to Burullus Lake. El-Adawy et al. (2013) recommended diverting some drains that discharge into the Burullus Lake to enhance its ecological situation. The second scenario is to construct two separated jetties inside the outlet with and without the proposed excess discharge in the first scenario to reach the stability condition of the outlet by decreasing the cross section of the outlet. The third scenario is to construct an eastern jetty to control the sedimentation problem of the estuary. These proposed alternatives are shown in (Fig. 6a and b). Fig. 6c shows the different cross sections utilized to compare morphology of bed profile for different scenarios.

CMS model is used to simulate the three scenarios. Fig. 7 shows the effect of the first scenario, increase the discharge flow from the Rosetta Branch from 19 to 73 m^3/s on the bed morphology after six months. The results show that with increase the flow a channel in the western side of the Rosetta outlet start to be created as a result of increase the flow to reach an equilibrium cross section. The channel depth increases with increasing the flow while the channel width is partially constant. The channel width ranges from 100 m at the entrance and increase to 325 m just behind the spit. The channel depth range from 3 to 5 m below the mean sea level. The discharge of 47 m^3/s can be considered as the optimum discharge in view of the water availability, channel dimension for navigation, and stability of the promontory structures.

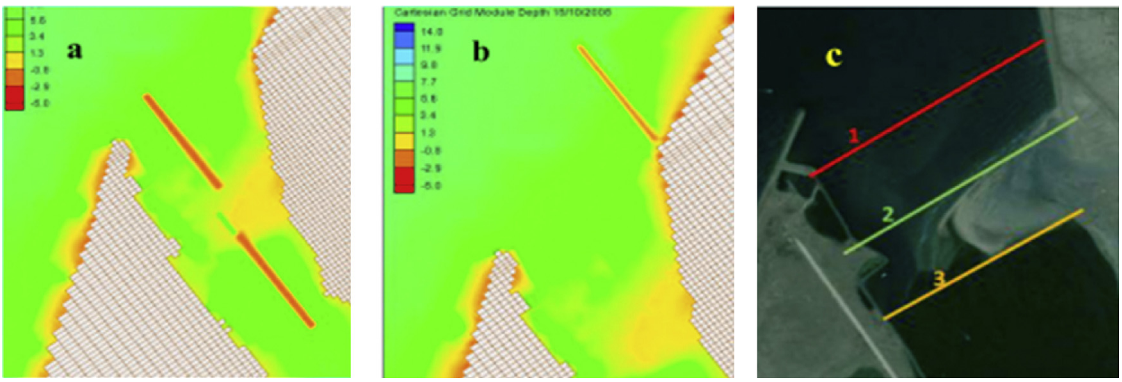

Fig. 6. (a) Second scenario (two jetties), (b) third scenario (jetty at tip of eastern revetment), (c) cross section through the outlet used in the comparative study.

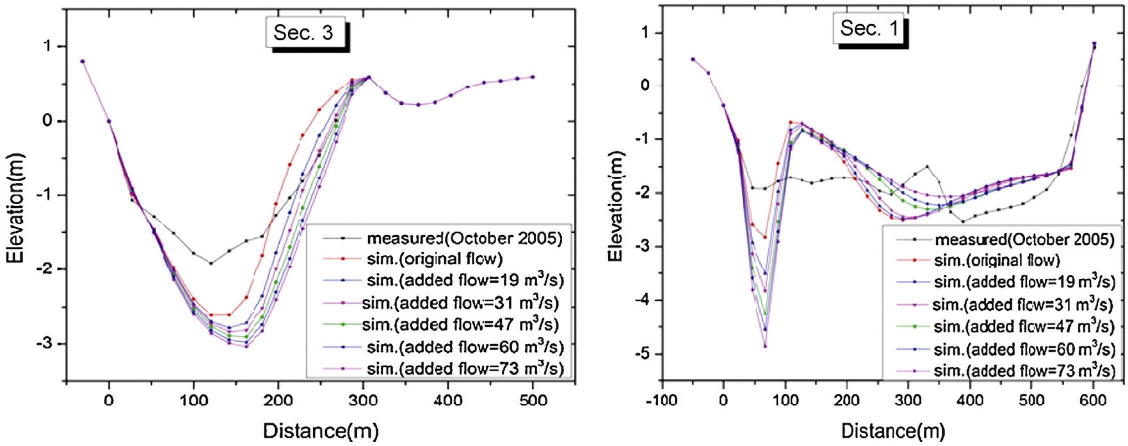

Fig. 7. Effect of different flow discharges on the cross sections of waterway.

The second scenario consists of constructing two separated jetties of 500 m length at the center of the outlet separated by about 200 m. Fig. 8 shows the effect of the proposed jetties on the stability of waterway cross section in case of no change in flow and in case of 47 m^3/s discharge. The results showed the increase of navigation channel width in the western side of the outlet with a huge sedimentation in the eastern side of the outlet. The western channel depth increases with increasing the flow while, the sedimentation in the eastern channel did not affected by increasing the flow. The results showed that the jetty with 47 m^3/s flow causes sedimentation in front of the eastern and western revetment of the promontory (Fig. 9). On the other hand, the new cross section of the outlet is not enough to discharge the expected water during floods which may be cause a flooding problem to the nearest cities.

In the third scenario, a jetty of 450 m length was proposed to be constructed at the eastern side of the outlet to stop the current induced sediment inside the outlet where the nodal point of the sediment transport located just east of the outlet. In Fig. 10, a comparison between the jetties presented in the second scenario and the eastern jetty of this scenario was performed. It is shown that the eastern jetty succeeds to stabilize the outlet to its original condition but this condition is not suitable for the navigation. On the other hand, the sediment starts to accumulate east of the jetty and increases the local erosion inside the estuary at western side (Fig. 11).

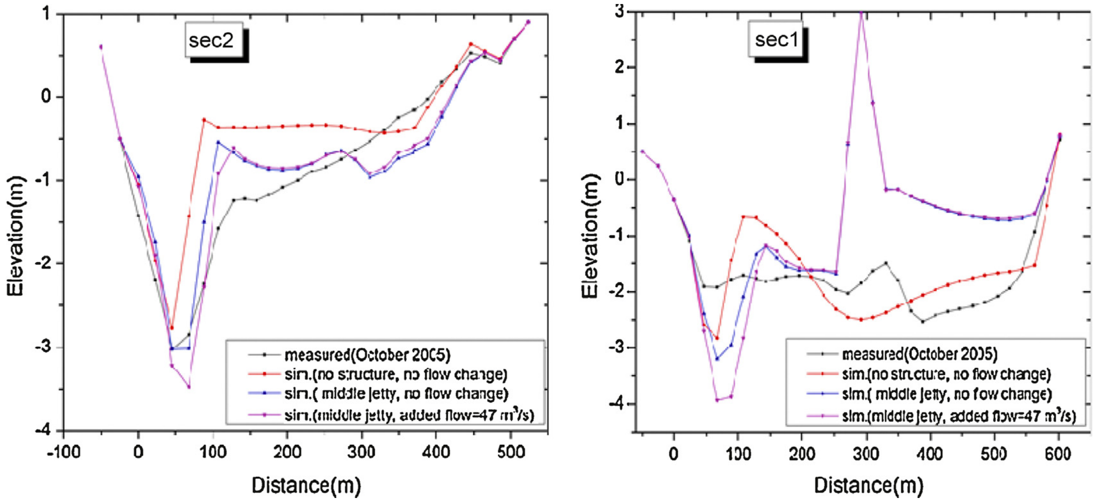

Fig. 8. Effect of construct jetties at the center of the outlet.

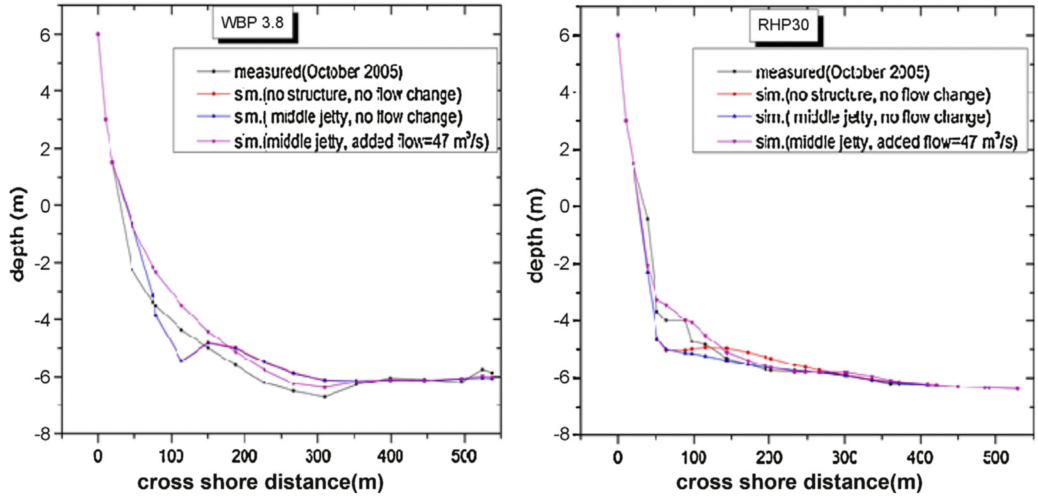

Fig. 9. Effect of the second scenario on the eastern and western revetments.

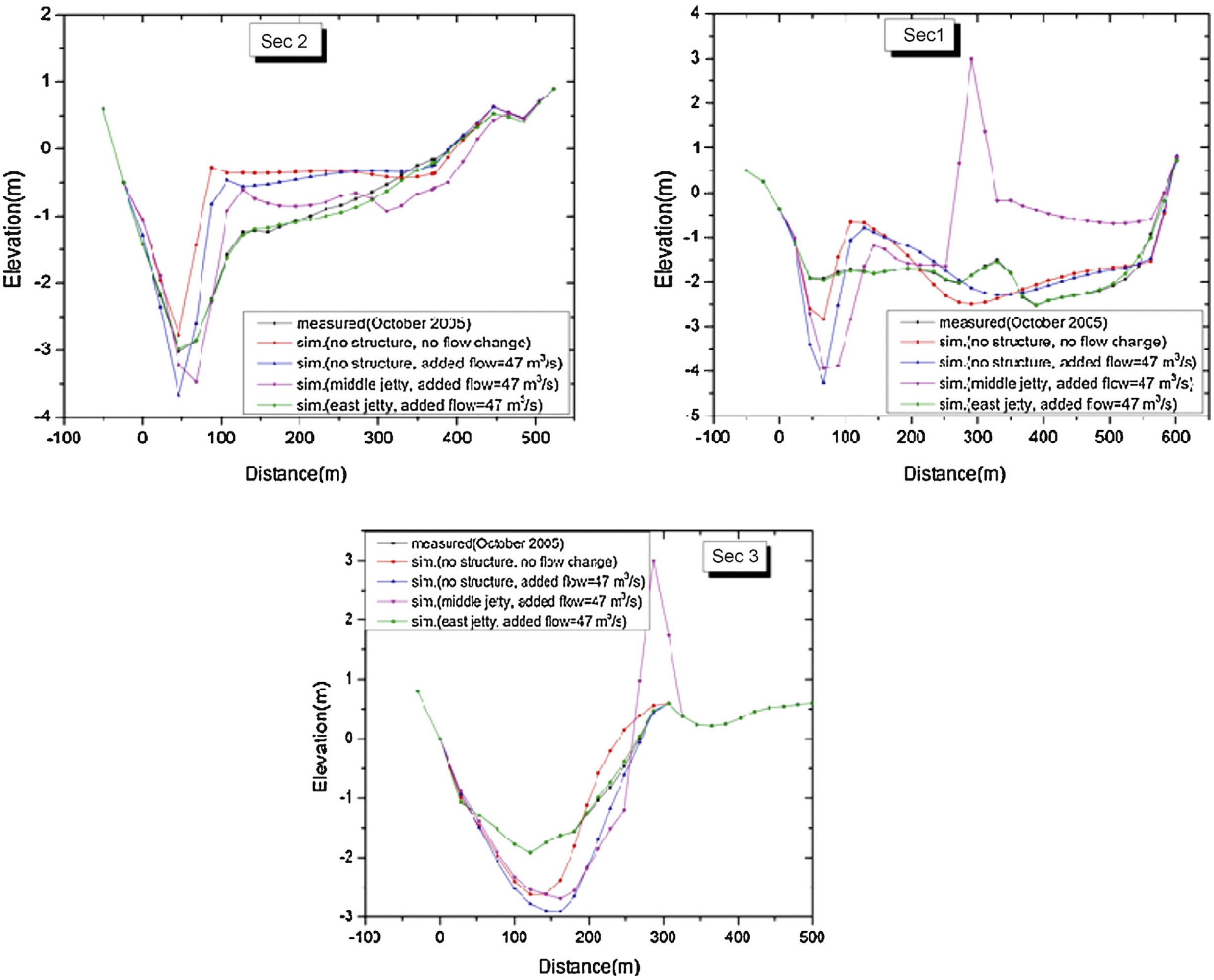

Fig. 10. Comparison between the effect of the center outlet jetties and the eastern jetty on the waterway cross section stability.

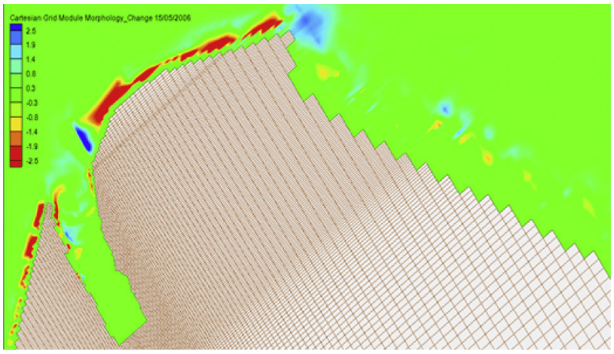

Fig. 11. Morphological changes with the eastern jetty.

4. Conclusions

Rosetta promontory has been facing critical coastal problems. The main reason of these problems is the reduction of water and sediment discharge to the outlet which causes severe erosion of the shoreline as well as siltation problem inside the Rosetta Branch. Three scenarios are proposed to solve these problems. The main idea of these scenarios is to improve the stability of the outlet cross section. This can be reached by increasing the discharge through the outlet, decreasing the cross section by center outlet jetty, and/or eliminate the sediment supply by constructing jetty in the nodal point of the sediment transport which is located just east of the entrance. CMS two-dimension numerical model is used to check the effectiveness of these three scenarios. The available bed morphology of Oct. 2005 and May 2006 with one-year data of wave and tide is used to construct and calibrate the model. It was found that increasing the flow to 47 m^3/s without any hard structure (1st scenario) will create 100 m wide channel west of outlet suitable for navigation with a save depth for the stabilization of coastal structures. But it has a limited effect on the erosion problem in front of the eastern and western revetment. The second scenario, two separated jetties of 500 m length at the center of the outlet, will cause a dramatically accretion on the eastern part of the outlet which squeezes the cross section of the outlet and increase the flood vulnerability for the nearest cities. The third scenario, eastern bank jetty of 450 m length, will stabilize the outlet cross section to its initial condition which might restrict navigation. It is found that the first scenario has the best option to control the sedimentation problem of the outlet but with limited effect on the erosion problem. It is recommended to test more scenarios to reach the integrated solution for the area.

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