Breakwaters' impact on Egypt's north coast equilibrium

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ABSTRACT

This study was initiated to examine shoreline changes behind offshore breakwaters to evaluate the design of a detached breakwater system. Curves for different wave conditions were constructed using the numerical model "Genesis". The model was used with limited data sets and calibration parameters to give reasonably accurate results. A prototype was used at Marabella Beach, Egypt (Mediterranean Sea) for calibration, verification, and data gathering. The calibrated model was compared with shoreline changes to determine proper values for sediment transport parameters before being verified. Afterward, field observation data recording Marabella shoreline changes from July 2004 – July 2005 was chosen. Better results were found when the average deep water wave direction was shifted to the down drift side and the wave height was decreased. The model was verified during the period of February – May 2004 with the existence of a single detached breakwater. Using the limited application of the model at Marabella, "Genesis" clearly is reasonably effective for simulating the influence of waves and coastal structures like detached breakwaters on the Northern Coast of Egypt's sandy beaches. The constructed curves provide useful information for practical purposes.

1. INTRODUCTION

Erosion of many coastal regions takes place due to rising sea levels, reduced river sediment supply, storm waves and the disturbance of the along-shore sediment transport due to breakwaters, groins, and jetties. Erosion of parts of Egypt's Nile Delta is a side effect of the Aswan High Dam (AHD) which prevents river sediment flow to eroding shorelines. Presently, shore protection structures are being built along Egypt's north coast to protect against further erosion damage. An effective coastal defense structure for shoreline with sandy beaches is the detached breakwater system. This contains segments that neither obstruct long-shore currents nor impede sand transport. Instead, they diffract waves, affecting the currents' patterns and near-shore sediment transport components. Sand deposition results, due to diminished wave energy.

2. CALIBRATION, VERIFICATION, AND APPLICATION OF MODEL

The mathematical model "Genesis", "Generalized Model for Simulating Shoreline Change" which was developed by both Nicholas Kraus of the Waterways Experimental Station, US Army Corps of Engineers, and Hans Hanson of the Department of Water Resources Engineering, University of Lund, Sweden, was used. The model was calibrated and compared with the shoreline changes at Marabella beach on Egypt's north coast, just west of Alexandria, to determine the proper values for the sediment transport parameters. Then, the model was verified so that there could be a certain level of confidence in its results. When a high level of calibration and verification can be achieved, it may be possible to extend the application of the model beyond the limits of the data used in the calibrated and verified model. Field observation data was recorded for shoreline changes at Marabella from July 2004 to July 2005 due to the existence of three detached breakwater units. An objective fitting criterion was calculated as:

$$y_{diff} = \sum_{i=1}^{N} [\mathbf{y}_{\mathbf{meas}} - \mathbf{y}_{\mathbf{calc}}]\mathbf{i} \qquad \mathbf{(1)}$$

Where y_{meas} = Measured shoreline position(m); y_{calc} = Calculated shoreline position (m); y_{diff} = difference between measured and calculated shoreline position (m); H_o = Wave height; θ_o = Wave direction; L_B = Breakwater length; Y_B = Offshore distance; Y_b = Surf zone width; T = Wave period; Y_S = Salient amplitude; K_T : Wave transmission coefficient for single structure; $K_T = 0.0$ in case of impermeable breakwater; and $K_T = 0.4$ in case of permeable breakwater.

In addition to varying the calibration parameters, it was found that better results could be obtained if the average deep water wave direction was shifted ten (10) degrees to the east from the representative values given by the input wave data and the wave height decreased by twenty (20) percent. From figure (1), it is clear that the model produced three well-developed salients at the proper locations. Comparing measured and calculated shoreline shapes, the agreement is qualitatively good. The model was verified during the period between February 2004 and May 2004. The shoreline shape in February was considered an initial one. In May, the shape was predicted by the model and compared with the measured one.

3. SIMULATION PROCEDURE AND MODEL SETUP

Total number of grid points taken: 40 (grid spacing: 25m); Time step taken: 6 hours (corresponding grid spacing: 25m); Shoreline simulation began 1 February 2004 and ended 1 May 2004; Long-shore sand transport calibration coefficients: KI/K2=0.54/0.32 (respectively); Wave angle change amount: -10 degrees; Wave height/wave angle change factors from calibration: 0.8/1.0 (respectively); Depth of off-shore wave input: 20m; Wave file started: 1 January 2004; Effective sand grain size (diameter): 0.2mm; Average berm height: 1.0m; Closure depth: 4.0m; Number of detached breakwaters: 1; Breakwater length: 100.0m; Distance from x-axis to tips of detached breakwaters: 150m; Depth at detached breakwater tips: 3.0m; Transmission coefficients for detached breakwaters: 0.2. By plotting the data, it was found that two locations along the beach had moved very little over the simulation period. Consequently, the fixed ("pinned") beach boundary condition was used at the lateral points of the grid length.

The shoreline positions in February 2004 were measured with respect to an arbitrary straight baseline drawn parallel to the coastal trend. The shoreline positions in May 2004 were measured with respect to the same baseline. The wave data file contains the wave characteristics defining the wave time period, deep wave height and angle of the coast throughout the year. Before filling the deep wave angle values, they were transformed to fit the coordinate system of the model. Figure (2) shows that comparison between the measured and calculated shorelines after three months of simulation (May 2004 shoreline). It is clear that the model produced a well-developed salient at the proper location. Again, a qualitatively good agreement is verified between the measured and calculated shoreline positions (May 2004).

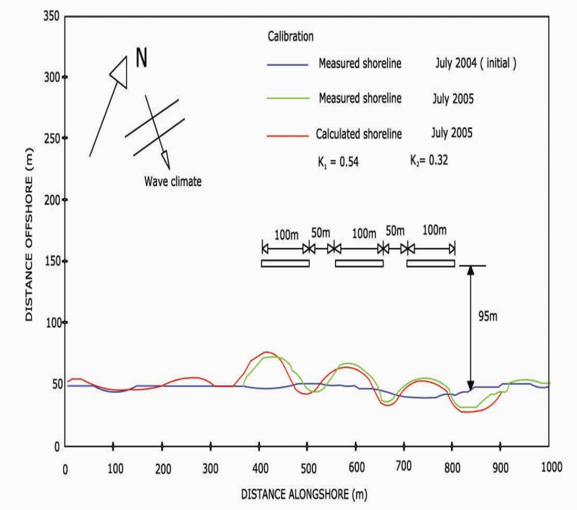

Figure 1. Result of model calibration for one year simulation

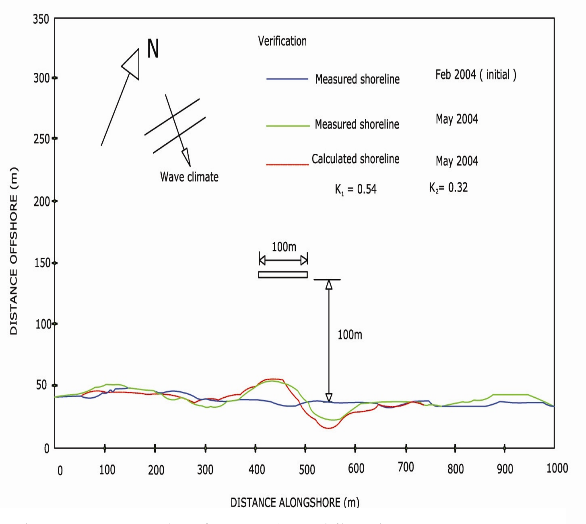

Figure 2. Result of model verification (3 months simulation)

4. DISCUSSION OF RESULTS AND ANALYSIS

The shoreline response to the building of offshore breakwater structures is mostly governed by resulting changes in the long-shore transport of materials in its vicinity, causing the shoreline to adjust to the new conditions and seek balanced configurations. The effect of wave height increments on shoreline changes behind offshore breakwaters was investigated for the chosen shoreline shape.

Figure (3) shows the shoreline changes due to the increase of wave height.

Clearly, the salient growth rate increases with the increase of deep water wave height as higher waves transport more sediment into the shadow zone created by the breakwater. Also, the affected neighboring shoreline length increases as the attacking wave height increases. Shoreline changes due to different incoming wave directions were also investigated for deep water wave directions to be 30, 45, and 60 degrees. Figure (4) represents the effect of increasing wave direction on shoreline changes. It is evident that the bulge in the shoreline always tends to align itself with the predominant wave direction, as expected. The salient's apex is shifted downward as the attacking wave direction increases. Some upstream erosion appears as a result of very oblique waves. Shoreline changes due to different values of the incident wave period were investigated, showing a variation of the wave time period from 4 to 6 to 8 seconds. Figure (5) shows the shoreline changes due to the variation of the wave period.

Evidently, the salient size decreases as the wave period increases since the longer waves provide more energy to the shadow zone. Obliquely arriving waves tend to restrict the salient size. Figure (6) demonstrates the effect of breakwater length changes on shoreline shape.

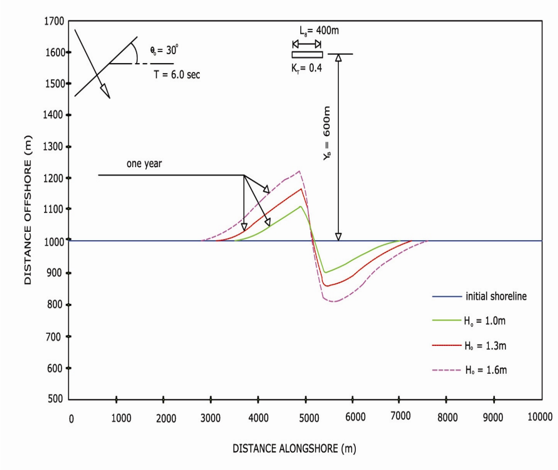

Figure 3. Effect of wave height

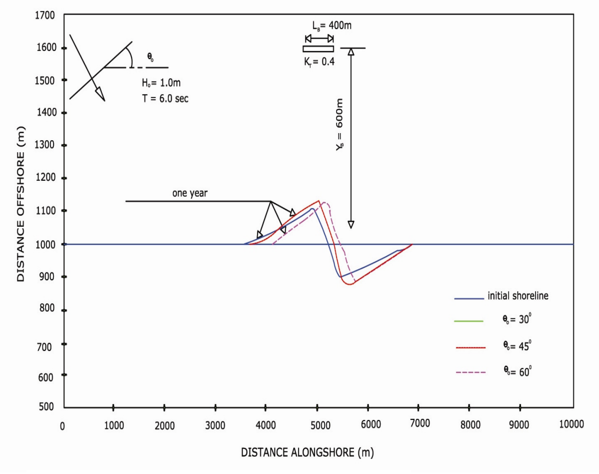

Figure 4. Effect of wave angle

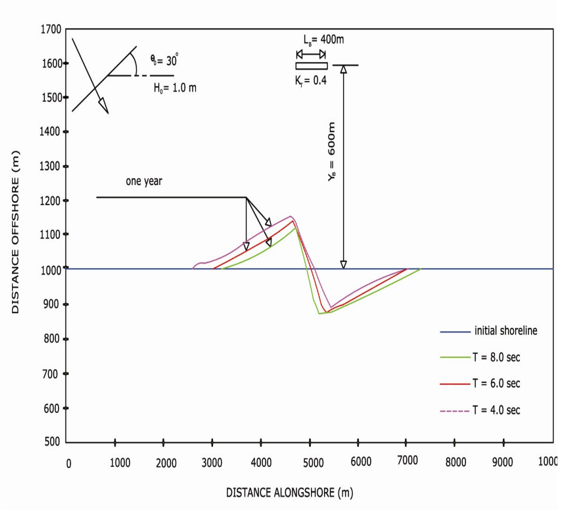

Figure 5. Effect of wave time period

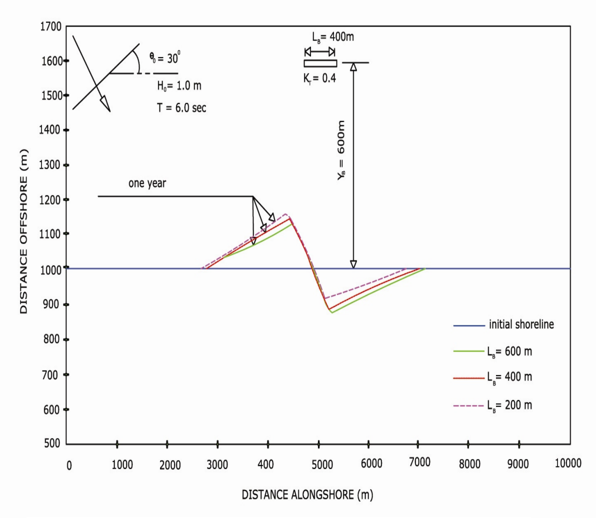

Figure 6. Effect of breakwater length

The figure shows that the salient size increases as the breakwater length increases because the wave height behind the breakwater decreases as the breakwater length increases. Thus, a calm area is created behind the breakwater, allowing an accumulation of sediments. Therefore, the shoreline advances toward the breakwater. Figure (7) shows the effect of the varying offshore distance on shoreline changes.

From the figure, it is noticeable that the salient size decreases as the offshore distance increases since the wave height behind the breakwater increases as the offshore distance increases. This increases the wave energy being transferred to the shadow zone, minimizing the salient size.

The effect of wave transmission at detached breakwaters on shoreline changes was investigated. Transmission coefficient varied from 0.2 to 0.4 to 0.6. Figure (8) illustrates shoreline changes due to different values of the wave transmission coefficient. As expected, the seaward extent of the induced salient decreases as wave transmission increases. Also, the salient broadens slightly with increased transmission. The effect of sand grain size variations on shoreline changes behind offshore breakwaters was investigated. Sizes varied from 0.1 to 0.3 to 0.5mm.

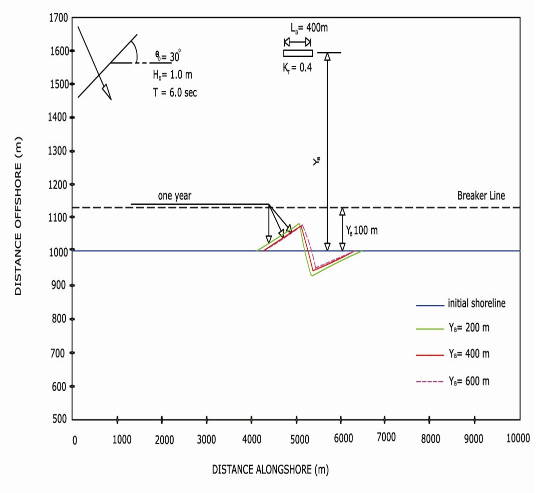

Figure 7. Effect of offshore distance

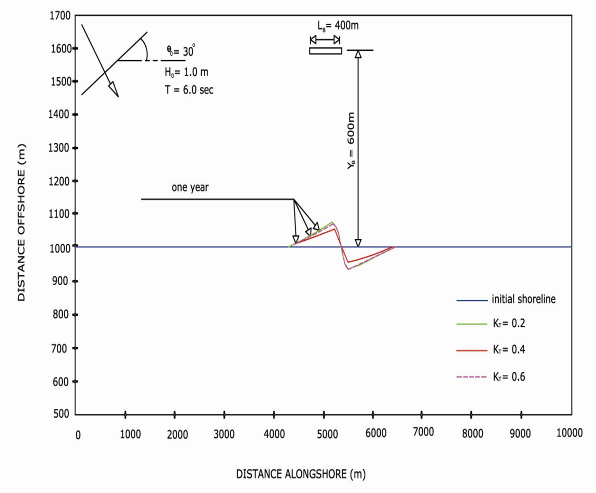

Figure 8. Effect of transmission coefficient

Obviously, a finer grained beach results in large salients and a coarser grained beach results in smaller shoreline changes. Sediment grain size affects the shape and growth of the salient by affecting the slope of the balanced beach profile. Thus, a fine sand material results in a gentler beach profile which promotes salient growth. Shoreline changes over long periods (l, 5, 10, and 15 years) were investigated. The longer the simulation period is, the greater the change in shape. The salient growth rate in the first year is large compared with the years afterward since the beach approaches equilibrium with time. Conclusively, wave height is the most influential factor on shoreline changes, and the shoreline aligns itself with the predominant wave direction. Breakwater transmission can play a major role in the shore's configuration, but the shape of the shore behind breakwaters reaches equilibrium after a long period.

5. CONSTRUCTION OF DESIGN CURVES

Design curves for the Egyptian wave climate were applied on a real shoreline segment to estimate present shoreline changes and predict any future changes due to the existence of offshore breakwaters. These curves provide useful information for selecting breakwater dimensions based on wave condition in the protected area. They can also be used for segmented structures. The designer obtains dimensions of the first segment and uses the same measurements for the remaining sections. The effect of the segments on the up-drift salient is the same as the up-drift segment. To indicate this effect, runs were performed for different conditions and configurations. Figure (9) shows one of these runs.

For gaps, the designer can take a value of 0.5 – 1.0 breakwater length. Figures (10-12) show the best fitting curves obtained for some examples of the design curves for the Egyptian wave climate, which were constructed for the following :
θ_0 = 15, 30°, 45°, 30° and 60° for K_T = 0.0 and 0.4, and for beach slopes 1:50, 1:100 and 1:200 for K_T = 0.0, 0.2, 0.4 and 0.6.

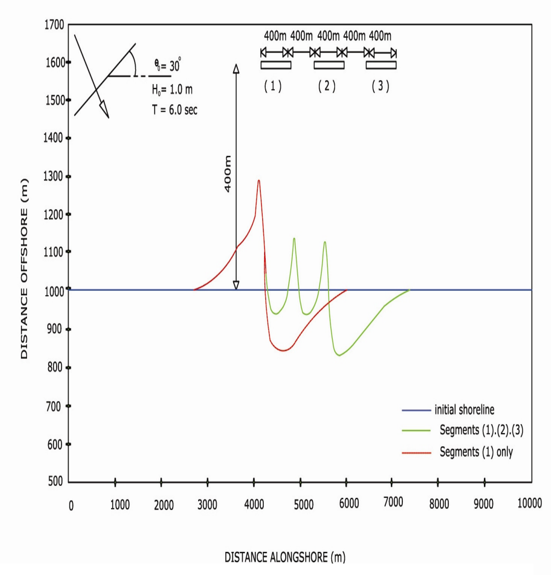

Figure 9. Comparison between segmented and single offshore breakwaters

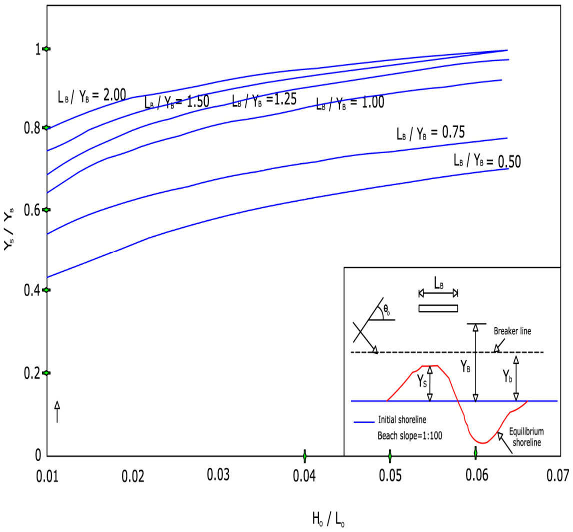

Figure 10. Curves for detached breakwaters outside surf zone (θ_0 = 15°, K_T = 0.0)

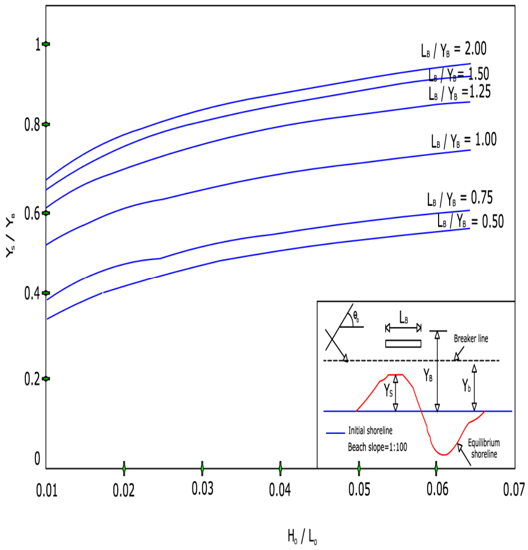

Figure 11. Curves for detached breakwaters outside surf zone (θ_0 = 60°, K_T = 0.4)

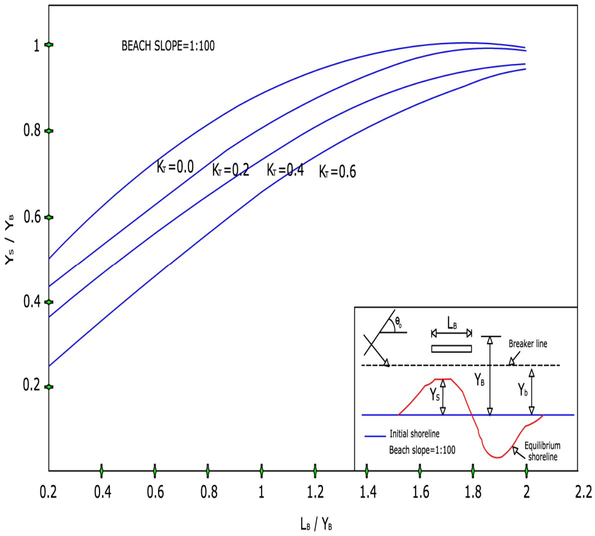

Figure 12. Curves for detached breakwaters outside surf zone

From these curves, one can conclude that the natural beach slope has a great effect on the selection of the position and the configuration of detached breakwaters. If the profile is gently sloping and the salient is the desired shoreline shape behind the breakwater, it is necessary to make the ratio less than 1.0 and/or increase the transmission of the breakwater. Such configuration prevents connection of shoreline to breakwater, flattening it uniformly along the shore. Applying the curves to the Egyptian wave climate, an actual segment of the shore (Marabella) was used to predict future shoreline changes due to existence of detached breakwater. Average position of breaking zone (surf) is approximately 150 m from original shoreline.

6. CONCLUSIONS

As a result of this study, having studied shoreline changes due to the construction of detached breakwaters through the use of the numerical model "Genesis," the following conclusions can be made:

- Design curves can also be used for single detached breakwater and segmented detached breakwater structures and can provide useful practical dimensions information.
- Salient growth rate is directly proportional to increased deep water wave heights as higher waves transport more sediment into the shadow zone, and breakwater transmission can play a major role in the shape and configuration of the shoreline.
- The shoreline changes due to the variation of wave time period; salient size and wave period are inversely proportional because longer waves provide more energy.
- Salient size and breakwater length are directly proportional because the wave height behind the breakwater decreases as breakwater length increases creating a calm area behind the breakwater where sediments can accumulate.
- Salient size and offshore distance are inversely proportional; i.e., salient size decreases as offshore distance increases and the salient growth rate in the first year is the largest.
- The seaward extent of the induced salient decreases as wave transmission increases and the salient broadens slightly with increased transmission.
- Finer grained beaches result in larger salients (the converse also being true).

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