EFFECT OF BREAKWATERS ON WAVE ENERGY DISSIPATION
(CASE STUDY: RAS EL-BAR BEACH, EGYPT)

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ABSTRACT

The northern Egyptian coasts are subjected to many changes in shoreline balance due to waves and coastal currents. To protect and develop these coasts, many types of coastal protection structures have been used. This research demonstrates the effect of different systems of coastal protection structures on wave energy dissipation. By using the CGWAVE numerical model, the effect of each one and interaction between these structures on wave height could be studied. This model was used to simulate the wave propagation along Ras EL-Bar beach with different coastal structures such as groins, detached breakwaters, seawalls, shore-connected breakwaters and submerged breakwaters. By applying the numerical wave modeling on natural bed bathymetric at this area, the results show that, the effects of every system alone and interaction between these systems on wave energy by applying numerical wave modeling to the natural bed bathymetric of this area, the results show the effects of each system alone and the interaction between these systems in terms of dissipation of wave energy. The results of this model could be used as a guide in designing similar works in the future.

Keywords: Waves, Breakwater, Groins, Energy Dissipation, Coastal, Ras EL-Bar.

1. INTRODUCTION

Waves and currents attack the coastal beaches along the northern coast of Egypt. The erosion takes place in several regions and accretion occurs in some other places along the coastal areas. Many areas subjected to aggressive wave current interaction condition after construction of the High Aswan Dam along the Nile River. Damietta branch estuary is focused on this study. The sea side resort of Ras EL-Bar has been built by the sediment carried by the Damietta branch, but it was subjected to erosion after construction of the High Aswan Dam.

In many previous research works, the effect of coastal protection systems has been investigated through experimental and numerical simulation models. The performance effect and efficiency of each type has been investigated. In this research, the effect of different types of breakwaters on wave energy dissipation was investigated through a numerical simulation. The considered systems are groins, detached breakwaters, seawalls, submerged breakwaters and shore-connected breakwaters. The effects of interface between these systems were discussed and evaluated, related to the purpose of construction.

2. LITERATURE REVIEW

Berkhoff (1972) derived a two-dimensional differential equation which describes the phenomenon of combined refraction-diffraction of simple harmonic waves, applying Airy wave theory and assuming conservation of the wave energy flux. Berkhoff et al. (1982) applied the numerical methods by using
three models indicated as the refraction model, the parabolic refraction-diffraction model and the full refraction diffraction model to study short wave propagation in the horizontal plane.

Li and Anatasiou (1992) used the multigrid method to solve very efficiently the form of the mild slope equation for water wave propagation over large areas in the presence of current, taking into account the combined effects of shoaling, refraction, diffraction and wave breaking.

Zhao et al. (2001) developed a technique for including the effects of dissipation due to wave breaking in two-dimensional elliptic models based on the mild-slope wave equation. Bellotti and Broccini (2001) briefly analyzed some characteristics of waves in very shallow water near the shoreline as higher-order boussinesq-type equations. Bender and Dean (2003) studied wave transformation by bathymetric changes and resulting shoreline impact, using three case studies. Junj and Suh (2008) derived an analytical solution to extend mild slope equation for long wave propagation over an axi-symmetric pit where the water depth decreases.

3. PROBLEM DEFINITION

The sea side resort of Ras EL-Bar has been built by the sediment carried by the Nile River Damietta branch. Over the last century, the reduction of the flooding by the Nile has reduced the supply of the sediments and the uncompensated excessive power of the sea has caused large-scale erosion of the promontory which has been reduced by 2.0 km. The 200m long jetty was built at the extremity of the promontory in an attempt to control erosion.

Erosion continued west of the jetty and 400 m long seawall was added in 1965. Both of these structures were subjected to erosion and their bases were recently protected by rip-rap and dolos. Erosion still occurred to the west and three groins were built in 1972 (Mobarek, 1972), the first at the end of the seawall. The beach continued to recede and in 1980, a 350 m long rip-rap shore protection was installed between groins land. Erosion is still occurring along the beaches to the west. Delft (1987) studies recommended the construction of eight detached breakwaters and the nourishment process was added to accelerate the accretion process composing the salient.

![Fig. 1: Ras El-Bar Bay, 2010 (Satellite Image)](image)

Fig. 1 shows a satellite image of Ras El-Bar Bay in the year 2010.

Shore Protection Authority, (S.P.A) recorded numerous dangers of seawall along the area between the jetty and the groin system. In 2004, S.P.A completed the submerged detached breakwater
construction in the specified area as shown in Fig. (2). A new system was proposed and performed between the left and middle groin. The new system composed of submerged offshore breakwater.

In 2007 Sarhan designed two shore connected breakwaters to reduce the effect of wave energy inside the breaking zone, in Ras EL-Bar Bay.

4. FIELD DATA COLLECTION

The wave, current, tide, and beach slope are important parameters for the assessment of nautical and shore protection study.

4.1 Offshore Wave Data

A continuous record of the waves was obtained by using S4DW (Arab contractor Co., 2002). The directional wave spectrums were recorded every 20 minutes for four hours in water depth of 12 m.

The results are given in wave rose, Fig. (3), covering the period from august 1997 to may 1999.

From this figure, the following interpretations can be deduced.
- The predominant wave direction is confined in the sector between North West and north directions.
- The winter season is characterized by the high waves coming from the north.
- The maximum wave height reaches 4.25 m during January 1998 and 3.10 during February 1999.
- The peak wave period reaches 13 seconds and the average significant wave period ranges from 6 to 7 seconds.
4.2 Current Data

The current velocity data were grouped into systematic range as 1-10 cm/Sec, to 20-30 cm/sec. These results showed that monthly current rose for the available data during the period from August 1997 to May 1999, (Arab contractor Co., 2002), and the data show that:
- The maximum current velocity was 1.34 cm/sec during January 1998 and 0.70 cm/sec during 1999.
- The predominant long shore current direction was from west to east.

4.3 Water Level:

The water level is affected by the tidal level, the wind setup, wave setup and pressure effect. The following table (1) shows different values of water level.

<table>
<thead>
<tr>
<th>State</th>
<th>Level</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.H.W.L</td>
<td>1.18</td>
<td>Above Datum</td>
</tr>
<tr>
<td>M.H.W.L</td>
<td>0.71</td>
<td>Above Datum</td>
</tr>
<tr>
<td>M.W.L</td>
<td>0.61</td>
<td>Above Datum</td>
</tr>
<tr>
<td>M.L.W.L</td>
<td>0.58</td>
<td>Above Datum</td>
</tr>
<tr>
<td>L.L.W.L</td>
<td>0.00</td>
<td>Above Datum</td>
</tr>
</tbody>
</table>

(0.00) Table Datum = (- 0.39) Egyptian Datum.

4.4 Beach Slope

By using observation survey obtained from Ras El-Bar beach, the beach slope could be determined. The bathymetric data of the bed profile were observed in 2004 given as contour lines, the mean beach slope was determined near shore (0.80%).

4.5 Bed Profile Measurements:
This study depends on the monitoring of bed bathymetry of Ras EL-Bar beach along periods 1969, 1987, 2004, 2007, 2008 and 2010. The bed profile was recorded in 1969 to construct three groins perpendicular to the beach, Fig. (4) (Mobarek, 1972). Delft hydraulics (1987) measured the bed bathymetric in year1989 to construct a new system of the detached breakwaters, parallel to the shoreline, Fig. (5).

In 2004, bed bathymetry, Fig (6), was used for construction of semi-submerged detached breakwater as an extension of the detached breakwater which was constructed in 1990 along the beach of Ras El-Bar. The bathymetric changes and bed profiles between the second and third groins were collected by Sarhan (2007), Fig. (7). Monitoring of the same area during the years 2008, 2009 and 2010 were measured by the fourth author, Fig. (8).
Fig. 6: Bathymetric Survey along Ras EL-Bar Coastal Area, 2004

Fig. 7: Bathymetric Survey along Ras EL-Bar Coastal Area, 2007
Figs. (9) Through (13) give the bed profiles for years, 2004, 2007 and 2008 for sections under study which are used as input data for the numerical model.
5. NUMERICAL SEMULATION

The wave model, CGWAVE, (Demirbilek and Panchang, 1998) used in this research, was designed to simulate the wave propagation and wave height around coastal structures. The input data are bed profile, wave direction, wave period and wave height. The model simulates the combined effects of wave refraction-diffraction included in the basic mild-slope equation, it also includes the effects of bed friction on wave height, breaking and nonlinear amplitude dispersion.

The classical super element methods as well as a new parabolic approximation method developed recently are used to treat the open boundary conditions. An iterative procedure (conjugate gradient method) is introduced and modifications are used to solve the discredited equations, thus enabling the modeler to deal with large domain problems.

5.1 Governing Equation and Boundary Conditions

The solution of the two-dimensional elliptic mild-slope wave equation is a well-accepted method for modeling surface gravity waves in coastal areas. This equation may be written as:

\[ \nabla \cdot (CC_x^2 \nabla \phi) + \frac{C_x}{C} \sigma \cdot i \phi = 0 \]  \hspace{1cm} (1)

Where \( \phi (x, y) \) = complex surface elevation function, from which the wave height can be estimated; \( \sigma \) = wave frequency under consideration; \( C(x, y) \) = phase velocity = \( \sigma / k \); \( C_x(x, y) \) = group velocity = \( \partial \sigma / \partial k \); and \( k(x, y) \) = wave number (\( \approx 2\pi / L \)), related to the local depth \( d(x, y) \) through the dispersion relation.

\[ \sigma^2 = gk \text{tanh} (kd) \] \hspace{1cm} (2)

The mild-slope equation can be modified to include the effects of frictional dissipation and wave breaking as follows:

\[ \nabla \cdot (CC_x^2 \nabla \phi) + \left( \frac{C_x}{C} \sigma^2 + i \sigma \omega + iC_x \sigma \gamma \right) \phi = 0 \] \hspace{1cm} (3)
Where $\omega$ is a friction factor and $\gamma$ is a wave breaking parameter. The following form of the damping factor ($w$) in the wave model has been used:

$$w = \left( \frac{2n}{\kappa} \right) \frac{2f_r}{3} \frac{ak^2}{(2kd + \sinh 2kd) \sinh kd}$$  \hspace{1cm} (4)

Where $\alpha = H/2$ is the wave amplitude and $f_r$ is a friction coefficient to be provided by the user. The coefficient $f_r$ depends on the Reynolds number and the bottom roughness. Typically, values for $f_r$ are in the same range as for Manning’s coefficient ‘n’. For the wave breaking parameter $\gamma$, the following formulation has been used (Demirbilek and Panchang, 1998):

$$\gamma = \frac{2}{d} \left( 1 - \frac{\Gamma^2 d^2}{4a^2} \right)$$  \hspace{1cm} (5)

Where, $\chi$ and $\Gamma$ are empirical constants. Nonlinear wave may be simulated by using the nonlinear dispersion relation in place of Equation (2) was

$$\sigma^2 = gk \left[ 1 + (ka)^2 F_1 \tanh kd \right] \tanh \{kd + kaF_2\}$$  \hspace{1cm} (6)

Where:

$$F_1 = \frac{\cosh (4kd) - 2 \tanh^2 (kd)}{8 \sinh^4 (kd)}$$

$$F_2 = \left( \frac{kd}{\sinh (kd)} \right)$$

6. RESULTS AND DISCUSSION

Figs. (14) Through (17) show a sample of output of CGWAVE model for wave steepness ($\lambda=0.027$).
The interaction between the different multi-systems breakwaters were investigated through a numerical simulation and field data measurements. The effect of each breakwater on wave energy dissipation was studied taking into consideration the sequence of construction and the natural bathymetry along Ras EL-Bar coastal area since 1969 to 2010. The wave characteristics were classified into four cases as indicated in table (2). The bed profile data along Ras EL-Bar coastal area were surveyed before and after the construction of the coastal structure.

### Table 2: Different Cases of Wave Data

<table>
<thead>
<tr>
<th>Case</th>
<th>$H_o$ (m)</th>
<th>$T$ (sec)</th>
<th>$\lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case (1)</td>
<td>6.00</td>
<td>12.0</td>
<td>0.027</td>
</tr>
<tr>
<td>Case (2)</td>
<td>4.50</td>
<td>10.0</td>
<td>0.029</td>
</tr>
<tr>
<td>Case (3)</td>
<td>3.00</td>
<td>8.0</td>
<td>0.030</td>
</tr>
<tr>
<td>Case (4)</td>
<td>2.00</td>
<td>6.0</td>
<td>0.035</td>
</tr>
</tbody>
</table>

Four wave directions, -60°, -30°, N and +30° were considered during the study. The direction -30° was used and clarified in this paper. The area which was considered in this study is 340 m offshore which behind all systems of protection and effected by it.

### 6.1 Bed Profile along Ras EL-Bar beach

From the recorded bathymetric survey in 1969, 1989, 2004, 2007, 2008 and 2010the bed profiles were grouped according to the periods:
- From 1969 to 1972, before groin system construction.
- After the groin construction (1972)
- (1989) before the detached breakwater construction
- (2004) after the construction of submerged detached breakwater
- (2007) before the construction of Ras EL-Bar Bay
- (2008) and (2010) after construction of Ras EL-Bar Bay

The wave energy dissipation was calculated using the wave model for two cases, before and after the construction of each structure.
Ras EL-Bar Bay project could be considered as an example of a model to represent the interaction between different multi-systems of breakwater on wave energy dissipation. The total energy of waves ($E_T$) is given by (MuirWood, 1968):

$$E_T = \frac{1}{8} \gamma LH^2 \quad (7)$$

In which $\gamma$ is sea water specific weight, $L$ is water length and $H$ is wave height.

The relative wave energy dissipation could be represented by $R_L$:

$$R_L = \frac{(H_b^2 - H_a^2)}{H_b^2} \quad (8)$$

Which $H_b$ is wave height before the constructed breakwater and $H_a$ is wave height after breakwater construction. This relative energy dissipation is based on constant wave length before and after the construction of breakwaters.

The wave power, ($P$) is given by the following equation (Coastal Engineering Research Center, 2008):

$$P = \frac{1}{8} C_g \gamma H^2 \quad (9)$$

In which $C_g$ is group celerity of waves which is equal to $1/2C$ for deep water and equal to $C$ for shallow water, where $C$ is the single wave celerity.

Equation, (8) could be used to give relative loss in power keeping in mind that the group celerity of waves is the same.

It was found from the statistical analysis which gives the best determination coefficient ($R^2$) that the relationship between the relative energy dissipation ($R_L$) and the offshore distance ($X$) is an exponential equation

**6.2 Effect of Groin System**

From the results, it is concluded that the construction of the groin system has minimum effect on wave energy dissipation, Fig. (13), especially for normal or nearly normal incident wave direction to the shoreline. So, the long-shore current has the major effect.

**6.3 Effect of Seawall**

The wave force attacks the beach between groins, so that the construction of the seawall was necessary to protect the beach. Seawall dissipates wave energy according to its position and protects the shoreline from erosion. But the erosion takes place at the toe of the seawall as a side effect of breaking waves on the seawall. The bed profile between the groins changes to be steeper and encourage a higher wave to attack the seawall.

**6.4 Effect of Detached Breakwaters**

Detached breakwaters were having significant effects on wave energy dissipation which strike normally on the beach. The wave height behind the gap is higher than its value behind the breakwater. After constructing the detached breakwater in 1992 the relative wave energy dissipation reaches to 65% in the shadow zone behind the breakwater. Wave direction was modified at breaker zone between detached breakwater and the beach. The results in decreasing the wave energy and its direction modified the coastal currents was generated which formed salient, And protected the coastal area. Fig (18) shows the effects of detached breakwater on wave energy dissipation before (1989) and after detaching breakwaters.
6.5 Effects of Submerged Breakwater

By construction of submerged breakwater eastern the Bay the wave energy dissipation reaches to 30% behind it. The beach rear submerged breakwater protected by seawall so that it has no effects on the shoreline in this area. Fig (19) shows effects of submerged breakwater on wave energy dissipation.

6.6 Effect of Groins and Seawall

It is very important to use seawall with groins at this beach to dissipate the wave force which attacks the beach at normal direction, Fig. (15).

6.7 Effect of Groins, Seawall and Detached Breakwaters

Constructed of groins, seawall and detached breakwaters together have a significant effect on wave energy dissipation of waves attacking from any direction, Fig. (15).

6.8 Effect of Groins, Shore Connected Breakwaters and Detached Breakwaters

The effects of interaction between multi-system breakwaters which consist of groins, shore-connected breakwaters and detached breakwaters on wave energy dissipation are given in Figs (16, 17).

The wave energy dissipation reaches to 60%, this high value due to the interaction effects between detached breakwater and shore-connected breakwater. Figs (20, 21) show the wave energy dissipation in 2007 and 2008. Figs (22, 23) show that the wave energy dissipation increased after constructed Ras EL-Bar Bay. It increased from 55% in 2007 to 70% in 2008 relative to 2004.
Fig. 20: Relative Wave Energy Dissipation (RL) versus Offshore Distance (X) (Shore-connected Breakwater, 2007)

Fig. 21: Relative Wave Energy Dissipation (RL) versus Offshore Distance (X) (Shore-connected Breakwater, 2008)

Fig. 22: Relative Wave Energy Dissipation (RL) versus Offshore Distance (X) (Shore-connected Breakwater, $\lambda=0.027$)

Fig. 23: Relative Wave Energy Dissipation (RL) versus Offshore Distance (X) (Shore-connected Breakwater, $\lambda=0.035$)

Table (3) shows the formulae and $R^2$ for every type of breakwaters.
Table 3: Statistical Formulae and $R^2$ for Breakwaters under Study:

<table>
<thead>
<tr>
<th>Type of BW</th>
<th>$\lambda$</th>
<th>Equ.</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detached BW</td>
<td>0.027</td>
<td>$R_L=0.66e^{-0.04X}$</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>0.035</td>
<td>$R_L=0.67e^{-0.05X}$</td>
<td>0.63</td>
</tr>
<tr>
<td>Submerged BW</td>
<td>0.027</td>
<td>$R_L=0.44e^{-0.17X}$</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>0.035</td>
<td>$R_L=0.40e^{-0.09X}$</td>
<td>0.83</td>
</tr>
<tr>
<td>Shoreconnected BW</td>
<td>0.027</td>
<td>$R_L=0.65e^{-0.10X}$</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>0.035</td>
<td>$R_L=0.73e^{-0.05X}$</td>
<td>0.83</td>
</tr>
</tbody>
</table>

CONCLUSIONS

After modeling the wave field, it could be concluded that:
- Groins have no significant effect on wave energy dissipation for approximately normally incident wave. Their effect depends on long-shore sediment transport and currents.
- Seawall is very important to dissipate the wave energy, so it has main roles to keep the shoreline without any changes.
- Detached breakwaters have a significant effect on wave energy dissipation and development of salient along these beaches.
- In case of seawall existence, the submerged breakwater could be used to reduce the incident wave energy and consequently minimize the coast of construction.
- The shore connected breakwater could be used with another protection system in accelerating the rate of sediment deposition and shoreline development.
- For increasing value of wave steepness, relative wave energy dissipation increases.
- Detached breakwater and shoreconnected breakwater give higher value of relative wave energy dissipation.
- The relationship between the relative energy dissipation and offshore distance has been found to be an exponential relationship.
- From this research, the interaction between different types of shore protection system is clarified and alternatives will be valuable in deciding the most efficient systems according to the field and natural conditions.

REFERENCES:


**NOTATION & ABBREVIATIONS:**

**NOTATION:**

The following symbols are used in this paper

\n\begin{align*}
a &= \text{wave amplitude.} \\
C &= \text{phase velocity.} \\
C_g &= \text{group velocity.} \\
d &= \text{water depth.} \\
E_T &= \text{total wave energy dissipation.} \\
g &= \text{gravitational acceleration.} \\
H &= \text{wave height.} \\
H_a &= \text{wave height after construction.} \\
H_b &= \text{wave height before construction.} \\
f_r &= \text{friction coefficient.} \\
k &= \text{wave number.} \\
L &= \text{wave length.} \\
n &= \text{Manning coefficient.} \\
P &= \text{water power.} \\
R_L &= \text{relative wave energy dissipation.} \\
R^2 &= \text{determination coefficient.} \\
w &= \text{damping factor.}
\end{align*}
X = offshore distance (m).

Greek Letters:
Γ = empirical constant.
γ = breaking Index.
λ = wave steepness.
σ = wave frequency.
ϕ = surface elevation function.
χ = constant.
ω = friction factor.

ABBREVIATIONS:

BW = BreakWater.
L.L.W.L = Lowest Low Water Level.
M.H.W.L = Mean High Water Level.
M.L.W.L = Mean Low Water Level.
M. W.L = Mean Water Level.