BEHAVIOR OF SHORE PROTECTION STRUCTURES AT ALEXANDRIA, EGYPT, DURING THE STORM OF DECEMBER 2010

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Abstract

Recently, December 2010, a severe storm hit Alexandria city, Egypt, and directly attacked its shoreline. Wind gusting to 65 kilometer per hour lasted for about two days creating a deep water wave of a height of 7.5 meter for the first time in the last 100 years. This paper documents the different types of shore protection structures and methods (sand nourishment, revetment, groins, sea walls, emerged and submerged breakwaters) used to protect Alexandria coastline at the area of study and their behavior during this storm.
This study concluded that the submerged breakwater used to protect Miami to Montaza beach, east of Alexandria, showed good efficiency concerning wave transmission and shore protection at storm times. It is recommended to apply the submerged offshore rubble mound breakwater and / or submerged offshore artificial reefs, to induce wave breaking and energy dissipation and to limit the wave heights to protect Alexandria coastline.

1. Introduction

Alexandria is the second largest city in Egypt, contains more than one third of the national industries and is considered as Egypt's principal seaside summer resort on the Mediterranean Sea. Alexandria's beaches are the main summer resort of the country and one of the most notable summer resorts in the Middle East for, in addition to its temperate winters, its beaches with white sands and magnificent scenery. Alexandria beaches stretch for 140 km along the Mediterranean Sea, from Abu Qir, in the east to Al-Alamein and Sidi Abdul Rahman, in the west. These attributes make Alexandria a favorite tourist spot; more than one million local summer visitors together with about 4.5 million residents enjoy the summer season at Alexandria every year (Frihy et al. , 1996). During summer of 2006, Alexandria received about 63 cruise ships containing 70,000 tourists and its hotels provided the equivalent of 47,000 visitor nights. During the same summer, Alexandria beaches received 3 million local visitors and 250,000 day trip visitors (Soliman & Reeve, 2007). A satellite image for Miami to Montaza beach west of Alexandria is shown in Figure 1.

Figure 1. A satellite image for Miami to Montaza beach west of Alexandrian, (Google Earth, 2011).

In the last few years, Alexandria coastline suffers from many erosion problems along its coastline which result from natural and human activities in the coastal zone. The beach width gradually decreased due to the action of the waves and currents. With the time, some beaches have disappeared totally and the wave action has attacked the toe of seawalls. Figure 2 shows example of erosion and flooding occurring at Alexandrian coastline during storm of winter 2006.

Figure 2. Erosion and flooding occurring at Alexandrian coastline.

Flooding problems appeared also in these eroded areas affecting the traffic flow. In winter 2003 to 2006, the shore line of Mandara beach at Alexandria, Egypt, had suffered serious flooding and erosion problems. The sand beach was vanished with wave scouring underneath the road seawall. Waves and sea sand jumped over the broken seawall to the Cornish road as can be shown in Figure 3.

Figure 3. Example of flooding at the Alexandrian coastline.

Recently, December 2010, a storm attacked Alexandria city and its beaches. The storm winds generated deep wave height of 7.5 meter for the first time in the last 100 years. As a result of this surge storms, water and sand overtopped the seawall and destroyed many parts of it. Figure 4 shows one example of this serious problem.

Figure 4. Wave attacks Alexandria coastline during the storm of winter 2010.

Due to the continuity of coming wave and speedy winds, the sea level has been raised for about one meter causing a serious flooding problem as shown in Figure 5.

Figure 5. Wave flooding due the sea level rise at Alexandria coastline, 2010.

Factors distributing to the erosion problems at Alexandria coastline can be summarized as follows:

- Incident waves, storm events, and sea level rise.
- Instability of Egyptian north delta coast due to lack of Nile River sedimentation and decreasing water flow into the sea.
- Loss of a considerable part of the sand beach due to extending the shore road towards the sea.
- Elimination of sources of organic sediments as result of water pollution
- Noticeable rise of temperature, sequent increase of wave height, and longer time of seasonable storms as features of climate changes.

Conventional beach protection structures such as groins and revetments are becoming increasingly unpopular, principally due to their adverse impact on beach amenity and aesthetic considerations. In contrast, submerged structures are widely perceived to be capable of providing the necessary beach protection without a loss of beach amenity or negative aesthetic impact (Ranasinghe & Turner, 2006).

The submerged breakwaters have only recently been adopted for beach protection. Black and Andrews (2001) mention that there are relatively few reported investigations of shoreline response to submerged structures.

During the past 20 years, alternative solutions were adopted for shore protections of Alexandria city. There was no clear strategic plan for the protection of Alexandria coastline and for that each zone of Alexandria shoreline has been protected by different type of structure. In the following section, summary of theses shore protection structures is presented and illustrated.

2. Alexandria Shore Protection Structures:

In this study, fifteen kilometer of Alexandria coastline extended from Chatby beach in the west to Montaza beach in the east is selected. This area is divided into ten zones according to the type of shore protection structure used as follows**:**

- **ZONE 1**
  The first zone at Chatby area has been protected by a high sea vertical wall since this area is 3-5 meter above sea water level. Small sand beach is in the lea ward of that wall as shown in Figure 6.

Figure 6: The vertical sea wall with the sandy beach at Chatby beach.

- **ZONE 2**
  The second zone extended after Chatby to Cleopatra beaches for almost 3500 meters. This area has been strengthened by strong revetment. 20 to 30 meter width of 10 ton concrete cubic blocks have been installed for a height up to 5 meter as shown in Figure 7.

Figure 7: Shore protection by concrete cubic blocks at Sporting beach.

- **ZONE 3**
  This zone is located at Cleopatra beach which is protected by offshore detached narrow and low crest breakwater.

- **ZONE 4**
  The fourth zone is Mostafa Kamel with almost 1500 meters length. This area consists of three marine clubs built offshore and have been protected by a combination of low and high crest rouble mound breakwaters and revetment.

- **ZONE 5**
  Zone 5 is the beautiful historical Stanly bay which has depended through the years on sand nourishment.

- **ZONE 6**
  Groins have been selected for the protection of Gleem area as can be shown in Figure 8.

Figure 8: A satellite image for groins for Geleem Area, (Google Earth, 2009).

- **ZONE 7**
  The private beach and the boat marina at San Stefano area have been surrounded with strongly armored quite elevated breakwaters.

- **ZONE 8**
  Next to San Stefano area, revetment has been adopted to Loran and Mahroosa areas. Figure 9 present this solution. As can see from Figures 7and 9, the revetment protected the shore line against further erosion but the beach profile was completely reinforced.

Figure 9: Reinforcement of beach profile by concrete revetment at Loran.

- **ZONE 9**
  Sidi Besher area is an almost 3000 meter long beautiful beach which has no artificial protection yet. There is a natural submerged reef offshore this area. Figure 10 shows the beautiful sandy beach of Sidi Besher area.

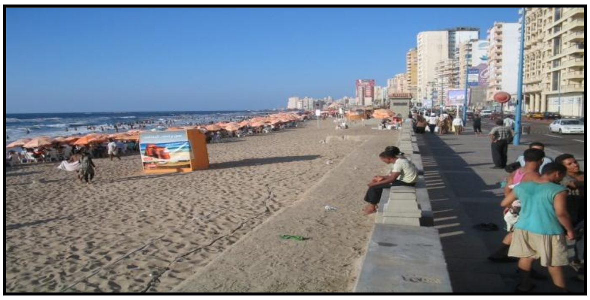

Figure 10: View of Sidi Besher beach shows beautiful sandy beach with high visitor density in summer.

- **ZONE 10**
  The zone is 3500 meters long from Miami to Montaza beach. This area has suffered severe erosion in 2003 storm. With time, the beach width decreased and vanished in some locations. The waves attacked the road itself after washing all the sand as can be notice from Figure 11.

Figure 11: Damage at Mandra beach during winter 2003.

In order to stabilize the eroded beach, a long, wide crest, and deep submerged breakwater has been constructed. The breakwater system consists of one main parallel breakwater and two overlapping parts as shown in Figure 12.

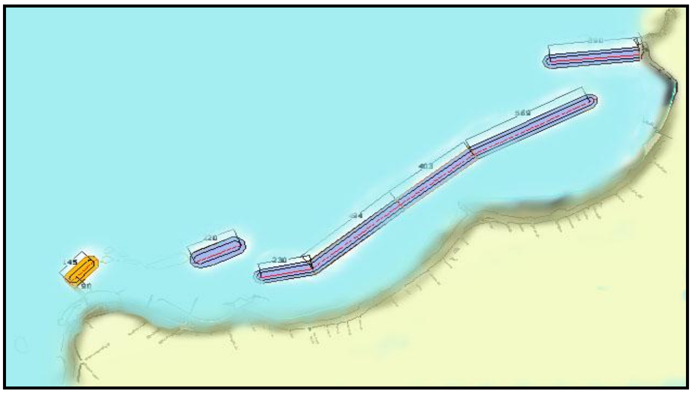

Figure 12: Layout of submerged breakwater applied at Miamy-Montaza area.

Total length of the breakwater segments is almost 3000 meter, 150 to 350 meter offshore, and 2.5 to 8.5 meter depth. Width of the breakwater crest ranges from 36 to 46 meters which is equal to the incident wave length. The construction of the breakwater started 2006 and was completed in the beginning of 2009 except for a 100 meter long end part. The part across Beir Masood area has not been completed yet due to lack of finance.

The submerged breakwater was attacked by 7.0 meter deep wave height in December 27th, 2006. Figure 13 shows the good efficiency of the breakwater in storm-condition. The shore line and sea-wall remained safe along the breakwater with noticeable good quality of water in the leeside in summer.

More details of the coastal structures which had been used to protect Alexandria coastline can be found at El-Sharnouby & Soliman (2010). In the following section, the efficiency of the different types of shore protection structures, used in the study area during the December 2010 storm, is discussed.

Figure 13: Efficiency of the submerged breakwater at 7.0 meter depth in storm time.

3. Behavior of Shore Protection Structures During December 2010 Storm:

The performance of these different types of shore protection structures, which has been shown in the previous section, at storm of winter 2010 is as follows:

Sea vertical wall:

The vertical sea wall in Chatby area (Zone 1) completely prevented the waves from attacking the road, but caused severe erosion at the front of the structure. The narrow beach disappeared and erosion reached the foundation of the sea wall.

Concrete blocks revetment:

Along the shore line, between Chatby and Cleopatra (Zone 2), the several rows of concrete blocks were effective as a line of defense against wave attack .Only wave splash could pass over the revetment to the road. However, beach profile was completely reinforced and sand beach vanished without any comeback any time of the year. Due to wave flooding over the revetment several times during storms, many of the blocks, with steel hanging bars, cracked.

Detached breakwater:

The narrow low crest detached breakwater used to protect Cleopatra beach (Zone 3) was a complete failure as presented in Figure 14. Most of the breakwater disappeared and what left is good only for sea birds to rest on. Waves crossed the breakwater easily, and the relatively short distance between the breakwater and shore line did not do any good for energy absorption.

Figure 14: Failure of the detached breakwater at Cleopatra beach.

Low and high crest ruble mound breakwater:

The three marine clubs at Mostafa Kamel area (Zone 4) suffered water flooding over the breakwaters and through the openings. The different types of shore protection structures acted negatively against each other. A comprehensive rehabilitation program was adopted for this area to establish only one joined protection structure.

Sand nourishment:

Sand nourishment was particularly good enough at Stanly beach (Zone 5). Offshore this area a marine bridge supported on piles was instructed. The pile foundations at sea level and the base layer at sea bed level played a good role in dissipating wave energy.

Groins:

Gleem area (Zone 6) suffered severe wave attack during the storm. Groins added no good to protect beach and on shore buildings against wave action. Even, the very little accumulated sand within years has been disappeared during the storm. Figure 15 shows the low efficiency of the groins when waves attacked Gleem area during the storm of winter 2010.

Figure 15. Waves attacked Gleem area during the storm of winter 2010.

Elevated strongly armored rouble mound breakwater:

As it might be expected, the quite high level heavy armor stones group of breakwaters 200 meter long each could protect the shore line at the private sector of San Stefano (Zone 7). Unfortunately, the negative side effect of the perpendicular and parallel breakwaters was quite pronounced at the shadow area of the breakwaters. Loran and Mahroosa areas (Zone 8) nearby San Stefano experienced the worst storm effect in Alexandria. In spite of the concrete revetment, the concentration of wave energy caused a considerable destruction. Waves took off side walk concrete slabs out of the side walk after jumping over the revetment. Shore road was flooded with water and small aggregates and concrete fences were destroyed and through away. Figure 16 shows the damages of the concrete slabs and fences.

Figure 16: Damages of the side walk and concrete fences at Loran area.

Sand nourishment at Sidi Besher beach:

The natural submerged reef offshore at Sidi Besher beach (Zone 9) could not help this time neither the sand nourishment. Waves covered the whole beach, attacked and destroyed fences and wood houses, and crossed over to the street as explained in Figure 17.

Figure 17: Damages of Sidi Besher beach due to waves attacks during 2010 storm.

Submerged breakwater:

Two years after the construction of the submerged breakwater at zone 10, the beach width behind it varied from 50 to 150 meter compared to 0.0 to 20.0 meters before installation without any nourishment. Figure 18 present a comparison between the beach width after and before the construction of the submerged breakwater.

Figure 18: Comparison between the beach width after and before the construction of the submerged breakwater at Mandra beach (El-Sharnouby & Soliman, 2010)

Details about the submerged breakwater design procedures in attached with a monitoring program which has been applied for the last two years to measure the performance of the submerged breakwater can be found at El-Sharnouby & Soliman (2010). The submerged breakwater showed tremendous efficiency concerning wave transmission and shore protection at storm times.
During this storm, the breakwater showed the same trend. Approaching high waves were broken over the submerged breakwater with transmission efficiency more than 75% as can be seen from Figure 19. The adequate water area behind the breakwater contributed well in dissipating the transmitted energy.

Figure 19: Waves breaking over the submerged breakwater at Mandara beach during the storm of winter 2010.

The wide sand beach took care of any left sweeping water. Figure 20 shows the good effect of submerged breakwater in the protection of Miami beach during the storm of winter 2010.

Figure 20: Effect of submerged breakwater in the protection of Miami beach during the storm of winter 2010.

The sea shore remained untouched in most locations along Miami-Montaza zone. Only few spots suffered gentle movement of water and sand to the street without any sort of destruction. After the storm, the breakwater itself was examined and no loss of his stone layers was recorded. The sand beach did not lose that much and regained its beach lines within weeks. The good performance of the submerged breakwater may be due to the followings:

- Minimum value of the freeboard (f), and maximum value of breakwater crest width (B=incident wave length) regardless of incident wave height, height of the structure, and water depth.
- Continuity of the 3000 meters long submerged breakwater without direct openings.
- Breakwater and site layout.
- Attenuation of transmitted wave over an adequate water area.
- The accretion of wide sand beach.
- Method of construction (end land method)
- Strong breakwater foot.

4. Conclusion:

During the last few years, significant erosion occurs along most of Alexandria's beaches as a result of sediment starvation, coastal processes and sea level rise. In winter of 2003 to 2006, many surge storms struck the Alexandrian coastline, water and sand overtopped the seawall and destroyed many parts of it. In December 2010 Alexandria was hit by the strongest storm ever recorded in recent history. These kinds of storms are expected to increase in the coming years, due to phenomena of sea level rise.

Along its long shoreline, various shore protection structures and methods were tested during the storm of December 2010. Sea vertical wall protected the shore road, but erosion took place at the front of the structure down to the sea wall foundation. Detached narrow and low crest breakwater was a complete failure with adverse results. Elevated ruble mound breakwater was effective, but had a quite severe negative impact on areas at its shadow. Concrete revetment acted fine, but the sand beach sand completely disappeared and many blocks cracked after the flooding. Sand nourishment temporally protected against flooding, but did not do much good during the storm. Without any impact on beach amenity and aesthetics, the long, wide, and

deep submerged breakwater could amazingly protect the shore line from destructive waves. The efficiency of the submerged breakwater was by far better than theoretically predicted concerning both transmission and erosion**.**
Other alternative which can be used is the submerged artificial reefs. More recently, submerged artificial reefs applications have varied widely, including: aquaculture production; coastal protection (Seaman and Jensen, 2000); and habitat protection (Baine, 2001). Artificial reef materials must last a minimum of 30 years to provide ecological services economically, and also be non-toxic to the marine environment (Grove et al., 1991).

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