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Shoreline Changes Due to Construction of Alexandria Submerged Breakwater, Egypt

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ABSTRACT:

This paper presents the shoreline changes due to the construction of a submerged breakwater. A case study of a submerged breakwater, which was constructed at Alexandria coastal area, Egypt, to stabilize the eroded beach of Miamy - Asafra - Mandara -Montaza areas in years 2006 to 2008, is presented. The breakwater system consists of one main parallel part and two overlapping parts 150 to 300 meters offshore. The total length of the breakwaters is 2520 m with water depth ranging from 2.5 to 8.5 m at the location of the structure. A bathymetry surveying has been conducted in years 2006, 2008, 2009 and 2010. These data are presented and analyzed to introduce the shoreline response due to the construction of the submerged breakwater using the Digital Shoreline Analysis System (DSAS). The analysis of the collected data shows shoreline accretion along most areas of Miamy beach, western part of Asafra beach, eastern part of Mandara beach and Montaza beach with range from 0.4 to 8.7 meter per year. In contrast, areas of shoreline erosion exist at eastern part of Asafra beach and western part of Mandara beach with range from -0.8 to -20.8 meter per year. A beach width varied from 25 to 50 m compared to 0.0 to 25 m before the submerged breakwater installation has been established in most areas of the protected beach.

Keywords: Submerged Breakwater, Coastal Management, Shoreline Changes, Alexandria Coastline, Coastal Erosion

1 INTRODUCTION

Serve coastal erosion is taking place along the Nile Delta in Egypt; the erosion is caused by an imbalance of sediment budgets, mainly as a result of the construction of the high Aswan Dam (Fanos, 1995). Alexandria city which is located in north Egypt (Figure 1), suffers from many erosion problems along its coastline resulting from natural and human activities in the coastal zone.

Figure 1. Map of the Alexandria city, Egypt.

Significant erosion occurs along most of Alexandria's beaches as a result of sediment starvation, coastal processes and sea level rise. The beach widths have gradually decreased due to the action of the waves and currents. With time, some beaches have totally disappeared and the wave action has attacked the toe of seawalls (Soliman and Reeve, 2007). Flooding problems have also appeared in these eroded areas affecting the traffic flow. In December 2003, the shoreline of Mandara beach (Alexandria city, Egypt) had suffered serious erosion. The sand beach had disappeared is some areas, with waves scouring and undermining the road and seawall. Waves and sand also overtopped the broken seawall onto the Cornice road.

There are many factors that have contributed to that severe Alexandria coastline erosion, including:

- Incident waves, storm events, and the phenomena of Sea Level Rise (SLR) (Frihy, 2003).
- Instability of northern delta coast due to the lack of Nile river sedimentation (Frihy et al. , 2010).
- Loss of a considerable part of the sand beach due to the enlargement of the Cornice road toward the sea (El-Sharnouby and Soliman, 2011).

Several types of coastal structures had been used to protect Alexandria coastline during the last twenty years. There was no certain strategic plan for the protection of Alexandria coastline and for that each zone of Alexandria shoreline has been protected using different types of structures. These different types of shore protection structures and methods are sand nourishment, revetment, groins, sea walls, emerged and submerged breakwaters. More details of these types and their positive and negative effects can be found in (El-Sharnouby and Soliman, 2010 and 2011) .

Conventional beach protection structures, such as groins, revetments and emerged breakwaters, are becoming increasingly unpopular, principally due to their adverse impact on beach amenity and aesthetic considerations. In contrast, submerged structures are widely perceived as capable of providing the necessary beach protection without a loss of beach amenity or negative aesthetic impact (El-Sharnouby *et al.*, 2011). On the basis of the field observations, Lamberti *et al.*, (2005) mentioned that submerged breakwater work effectively under different environmental conditions, providing the opportunity to protect beaches in the context of Integrated Coastal Management. Submerged Breakwaters present several advantages with respect to conventional structures, not only concerning the visual impact (which, from the "beach-user's" point of view is very important), but also in that they allow more wave overtopping, enhance the water renovation rates in the sheltered area, and produce higher sediment transport rates. As a result, there is increasing community pressure on coastal management authorities and government agencies to consider submerged structures for beach protection. The increasing popularity of submerged structures is also due to a growing recognition that their bathymetry can be optimised to enhance local surfing conditions (Ranasinghe *et al*., 2006).

In this paper, Summary of field observations of shoreline response to submerged structures reported in the published literature are presented in section 2. Then, details of Alexandria submerged breakwater are shown in section 3. Section 4 presents the field data and wave analysis used in the design of Alexandria submerged breakwater. Discussion of the collected data and the analysis of the results of these investigations on the development of a predictive capability for shoreline response to submerged structures are illustrated in section 5. Finally, conclusion of the obtained results is identified in section 6.

2 LITERATURE REVIEW OF SUBMERGED BREAKWATERS

The most important objectives of submerged breakwater construction are as follows (Burcharth and Lamberti, 2004):

- Protection of land and infrastructure by prevention or reduction of coastal erosion.
- Improvement of recreational conditions.
- Minimizing impacts on cultural and natural heritage of the coastline.
- Minimizing and / or mitigating impacts of submerged breakwater on species, habitats and ecosystems.
- Enhancing natural living resources for food and recreation.

The review of the available published literature of submerged breakwaters is presented with the aim of investigating the environmental and structural parameters governing shoreline response to submerged structures, gleaned from the results of field, laboratory and numerical studies undertaken to date. Submerged structures constructed to date range from single, shore-parallel breakwaters to large, multi-functional surfing reefs with complex design configurations. Ranasinghe and Turner (2006) presented the main features of the engineering projects involving ten submerged structures reported to date as summarized in Table 1. Alexandria submerged breakwater with three other sites has been added to their table, raising the number to fourteen submerged structures. It is of particular note that, of the fourteen submerged structures, net erosion was reported at seven of the sites. For convenience, the investigations described here are sub-divided into those associated with shore-parallel structures, multi-functional structures, and natural reefs, and are introduced in the chronological order of publication date.

Table 1. Features of the sites and the submerged coastal structures reported in the published literature. (B =length of structure, S =distance from undisturbed shoreline to structure, W=crest width, h =water depth at structure, h_c=water depth at crest of the structure, tanβ =bed slope in the vicinity of the structure), (Adopted from Ranasinghe and Turner, 2006).

Location	Reference	Structure type	Shoreline response	Nourish.	Long shore transport rate (m^3/year)	B (m)	S (m)	W (m)	h (m)	h_c (m)	tan β
Delaware Bay, USA	Douglass and Weggel, 1987	Single breakwater +2 end groins	Erosion	Y	Negligible	300	75	Not reported	1	at MLW	Not reported
Keino-Matsubara Beach, Japan	Deguchi and Sawaragi, 1986	Single breakwater	Erosion	Y	Not reported	80	85	20	4	2m below MLW	0.1 near shore and 0.03 offshore
Niigata, Japan	Funakoshi *et al.*, 1994	Single breakwater +2 groins	Erosion	N	Exists, but not quantified	540	400	20	8.5	1.5 m below MLW	0.02
Lido di Ostia, Italy (#1)	Tomassicchio, 1996	Single breakwater	Erosion	Y	50,000	3000	100	15	4	1.5 m below MSL	0.05
Lido di Ostia, Italy (#2)	Tomassicchio, 1996	Single breakwater	Accretion	N	50,000	700	50	15	3-4	0.5 m below MSL	0.1
Lido di Dante, Italy	Lamberti and Mancinelli , 1996	Single breakwater	Accretion	Y	Negligible	770	150	12	3	0.5 m below MSL	0.02
Marche, Italy	Lamberti and Mancinelli , 1996	Multiple segmented breakwaters	Erosion	N	Negligible	Not reported	100-200	10-12	3	0.5 m below MSL	Not Reported
Palm Beach, FL, USA	Dean *et al.*, 1997	Single breakwater	Erosion	N	100,000	1260	70	4.6	3	0.7 m below MLLW	0.04
Vero Beach, FL, USA	Stauble *et al.*, 2000	Segmented breakwater	Erosion	N	30,000	915	85	4.6	2.1-2.7	0.25-0.35 m below MLLW	0.03
Gold Coast, Australia	Jackson *et al.*, 2002	Multi-function surf reef	Accretion	Y	500,000	350	100-600	2	2-10	1.0 m below MLW	0.02
Mount Reef, Maunganui, New Zealand	Black and Mead, 2009	Multi-function surf reef	Not reported	N	Not reported	80	-	90	3-3.5	0.5 m Below CD	0.02
Pratte's Reef, El Segundo, CA,USA	Jackson and Corbett, 2007	Multi-function surf reef	Not reported	N	Not reported	56	30-40	3-12	1.8 m (MLLW)	-	0.05
Boscombe Reef, UK	Mead *et al.*, 2010	Multi-function surf reef	Accretion	N	Not reported	80	280	100	3-5	0.5 m Above CD	0.05
Alexandria Egypt	El-Sharnouby & Soliman, 2010	Segmented breakwater	Accretion	N	Not reported	2555	150-300	36-46	2.5-8.5	0.5 m below MLW	0.025

3 ALEXANDRIA SUBMERGED BREAKWATER

The 2520 meters rubble mound submerged breakwater in Alexandria is considered one of the longest, deepest, and widest submerged breakwaters all over the world (Allsop *et al.*, 2009). A submerged breakwater system was installed to protect the seashore of Miamy - Asafra - Mandara -Montaza areas in Alexandria, Egypt in years 2006 to 2008. The submerged breakwater consists of three segments with two overlaps as shown in Figure 2.

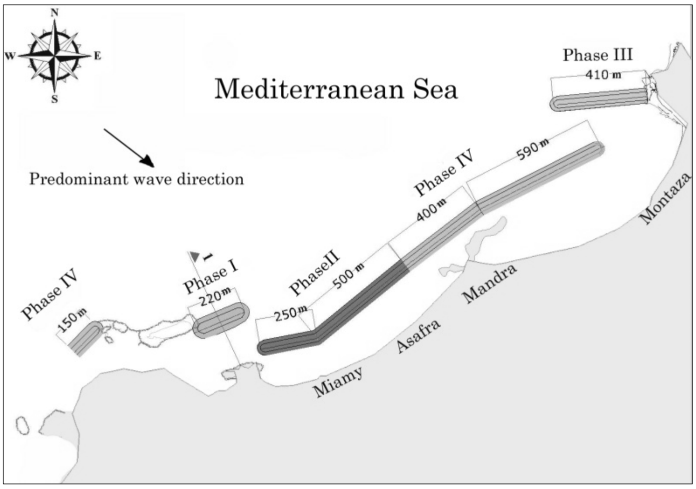

Figure 2. Plan of the submerged breakwater system for Miamy, Asafra, Mandara and Montaza areas.

Design characteristics of submerged breakwater include:

- Crest width (W) and base width (W_w).
- Water depth (h) and water depth at the crest of the structure (h_c).
- Incident wave height (H) and incident wave length (L_w).
- Length of the breakwater (B) and offshore distance (S).

The submerged breakwater characteristics are shown in Figure 3.

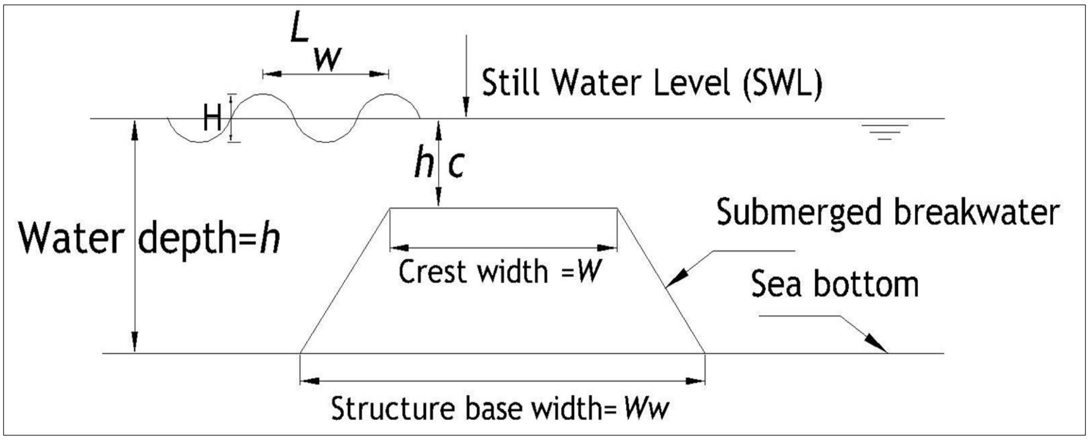

Figure 3. Submerged breakwater characteristics

El-Sharnouby et al. (2007) gave details of the design procedures, environmental analysis, predicted wave and shoreline response of Alexandria submerged breakwater. The findings of El-Sharnouby et al. (2007) can be summarized as follows:

1. Flushing time of water mass in the breakwater lee ranges from 4 to 6 days in calm weather conditions.
2. The current velocities behind the submerged breakwater are about 5 times of those in case of emergent breakwater and from 50% to 100% of current velocities in open sea.
3. The submerged breakwater provides transmission coefficient ranging from 0.28 to 0.36 in storm conditions.
4. The shoreline is well protected from wave attack providing a width of beach sand not less than 30 meters.
5. Wave height is about 0.50 meter or less in the leeside of the submerged breakwater for at least 90% of the year days.

6. Continuous submerged breakwater provides better shoreline stability with a 60% decrease of the total eroded volume.
7. Accretion will take place within 12 months after installation.

The depth of water at the breakwater varies from 2.5 to 8.5 meters. Five cross sections at different locations are considered for design according to the depth and wave height. Outer slope is 1:2 and inner slope varies from 1:3 to 1:5 in order to alleviate turbulence in the lee side. For water depths between 3 and 5 meters, the breakwater is armoured with two layers of 3 ton tetra-pods blocks on the seaward side while one layer of 5 ton concrete cubes is adequate as the armour layer in the lee side. For depths between 5 and 8.5 meters, 5 ton tetra-pods blocks and two layers of stone concrete cubes are used. Details of the submerged breakwater cross section at water depths from 3 to 5 meters are shown in Figure 4.

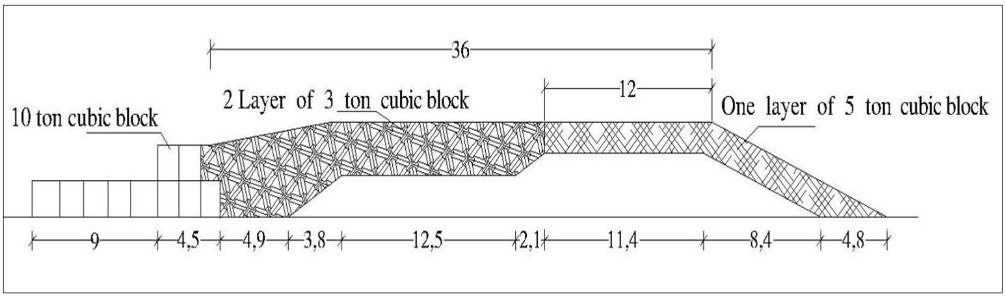

Figure 4. Cross section 1-1 of submerged breakwater at depth 3 to 5 m.

Filters of greater stone size are used at both sides to protect the breakwater body made from fine natural stones (10-300 Kg). The width of the breakwater crest is 36 meters at water depths between 3 to 5 meters and 46 meters at water depths between 5 and 8.5 meters. The width at the base of the structure is between 66 and 92 meters. The freeboard is kept constant for all cross sections with a 0.5 meter value related to Chart Datum.

The construction of Alexandria submerged breakwater was divided into four stages (Miamy, Asafra, Mandara and Montaza) as shown in Figure 2. The breakwater construction was completed in 2006, 2007, 2008 and June 2008 respectively. The Arab Contractors Company, one of Egyptian leading company, was responsible for the construction of the submerged breakwater with a total cost of about GBP 40 Million.

4 FIELD DATA AND WAVE ANALYSIS:

In this section, the filed data and wave analysis used in the design of the submerged breakwater are presented. The tide range values on Alexandria coastline have been measured for one year as shown in table 2 (El-Sharnouby *et al.,* 2007).

Table 2. Values of Alexandria coastline tide range for one year (MHWS is Mean High Water Spring, MSL is Mean Sea Level, MLWS is Mean Low Water Spring and LAT is Lowest Astronomical Tide).

Astronomical tide at the project site			
MHWS	MSL	MLWS	LAT = CD
0.50 meter	0.20 meter	0.0 meter	0.0 meter

The Extreme Water Levels (EWL) due to tide range and surge effect are shown in table 3 (El-Sharnouby et al., 2007).

Table 3. Extreme Water Levels (EWL) due to tide range and surge effect (El-Sharnouby et al., 2007).

Return period	1 year	50 years	100 years
m CD	0.76	1.06	1.11

The value of sea level rise which has been used is 1.2 millimeter / year (Elmohsen, 2004). The project design life is of fifty years and the expected sea level rise is 0.06 m. The design water levels according to tide range, extreme water level and sea level rise are summarized in table 4.

Table 4. The design water levels according to tide range, extreme water level and sea level rise.

Event	Operational	1 Year	50 Years	100 Years
EWL [m CD]	0.50	0.76	1.06	1.11
SLR [m]	0	0.06	0.06	0.06
DWL [m CD]	0.50	0.82	1.12	1.17

Table 5 presents the values of significant wave height, peak wave period and wave direction in water depths 14, 10 and 6 m for 1, 50 and 100 years return period (El-Sharnouby *et al.,* 2007).

Table 5. Values of significant wave height, peak wave period and wave direction in water depths 14, 10 and 6 m for 1, 50 and 100 years return period.

RP (yr)	Wave Results								
	-14 CD			-10 CD			-6 CD		
	H_s	T_p	Dir.	H_s	T_p	Dir.	H_s	T_p	Dir.
	m.	sec.	deg.	m.	sec.	deg.	M	sec.	deg.
1	1.4	4.6	255	1.2	4.6	261	1.1	4.6	267
1	3.6	10.3	282	3.2	10.3	286	3.0	10.3	289
1	6.0	11.1	299	5.0	11.1	300	3.6	11.1	300
1	4.6	10.3	321	4.4	10.3	317	3.5	10.3	315
50	6.2	12.6	282	4.6	12.6	287	3.6	12.6	289
50	6.5	14.6	299	5.5	14.6	299	4.0	14.6	299
50	6.2	13.2	321	5.4	13.2	318	4.0	13.2	316
100	2.6	6.2	255	2.4	6.2	262	2.1	6.2	269
100	6.7	14.0	289	5.4	14.0	288	4.0	14.0	290
100	7.0	16.1	298	5.9	16.1	299	4.4	16.1	299
100	6.9	15.0	321	5.7	15.0	318	4.4	15.0	316
100	5.6	13.0	331	5.3	13.0	326	4.0	13.0	328
100	5.1	12.5	352	4.6	12.5	338	3.9	12.5	338

El-Sharnouby *et al.,* (2007) calculated the wave heights after the construction of the submerged breakwater using Delft-3D numerical model. Transmission coefficients values (K_t) were calculated using the empirical formulae of Ghalayini *et al*., (2003); Friebel *et al*., (2000) and Seabrook and Hall, (1998). Values of K_t were found to range from 0.31 to 0.6 for 1, 50 and 100 years return period and the values of wave heights behind the breakwater during the summer session (May to October) will not exceed 0.55 meter.

5 FIELD OBSERVATIONS AND SHORELINE ANALYSIS:

The submerged breakwater system showed more efficiency during storm times than was anticipated by all means of transmission analysis which has been conducted in the design phase. The water mass between the submerged breakwater and the beach circulates well with very gentle and light waves even under storm conditions. In December 27th, 2010, the submerged breakwater segment of 220 meters long, in 8.5 meters water depth and with 46 meters crest width (Figure 3) was hit by the highest wave recorded on Alexandria coastline in the last 50 years (7.0 meter wave height in deep water). The approaching high waves were broken over the submerged breakwater with good transmission efficiency as can be seen from Figure 6. The adequate water area behind the breakwater contributed well in dissipating the transmitted energy. The shoreline and sea-wall remained safe along the 220 meters breakwater segment during all storms with noticeable good quality of water on the leeside in summer time.

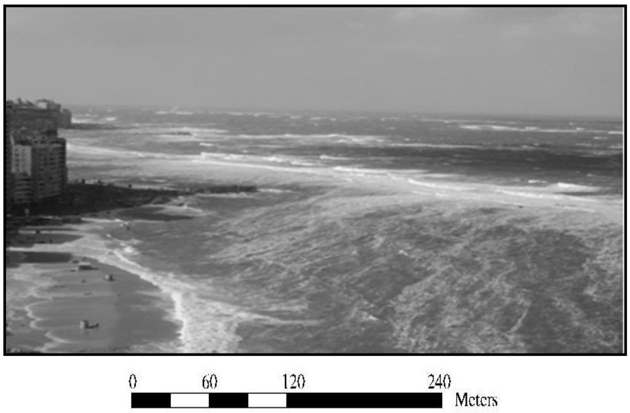

Figure 6. Waves breaking over the submerged breakwater during the storm of winter 2010.

The performance of the submerged breakwater system after its complete construction has been measured throughout 48 months of monitoring of the shoreline, sand beach and sea wall stability. Bathymetric surveying had been done in 2006 before the construction of the submerged breakwater. Three other bathymetry surveys have been undertaken after the construction of the three breakwater segments in years 2008, 2009 and 2010. The covered area is 3.5 km long and 1.7 km width which include about twenty three thousand points with grid spacing 10 m in both directions. The coordinates have been connected according to Universal Transverse Mercator (UTM) system. All vertical coordinates have been corrected and measured from Cart Datum level (CD). In order to study the shore accretion / erosion progress, the Digital Shoreline Analysis System (DSAS) is used as a reliable statistical approach for the rate of coastline change (Thieler *et al.*, 2009). The DSAS is an application added to the ArcView which is Geographical Informational System (GIS) software. It has been developed to calculate shoreline rates of change from a series of shoreline positions. The data used by the DSAS are the digitized shorelines for four bathymetry surveys of years 2006, 2008, 2009 and 2010. Twenty night transects covered the study area has been used as shown in Figure 7.

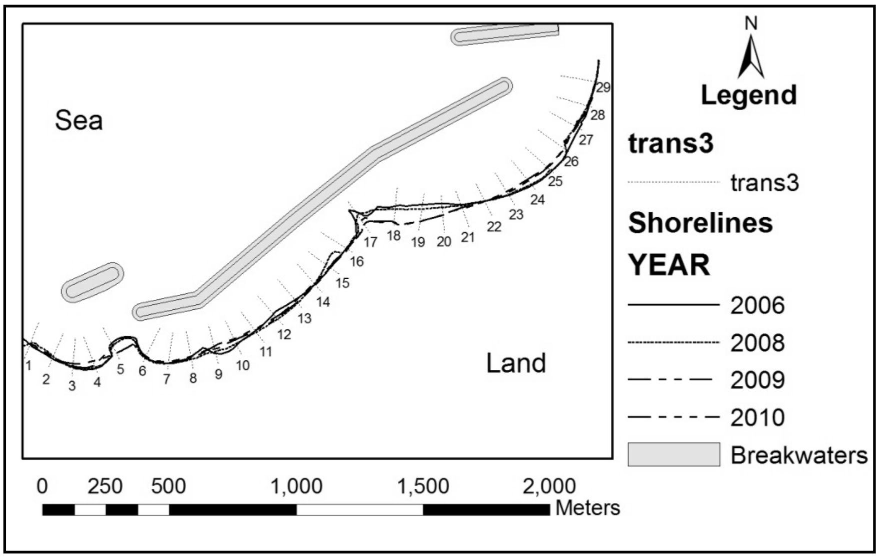

Figure 7. The implemented shorelines and transects at the study area.

The rates of shoreline change are calculated using the linear regression rate method. In conjunction with the linear regression rate, the standard error of the estimate (LSE) is calculated. It assesses the accuracy of the best-fit regression line in predicting the position of a shoreline for a given point in time.

LSE is defined as:

$$LSE = \sqrt{\frac{\sum(y-y')^2}{n-2}}$$

where: y = known distance from baseline for a shoreline data point,

y' = predicted value based on the equation of the best-fit regression line,
n-2 = number of degrees of freedom

Values of shoreline change rates at the area of study and the standard errors of the estimate are presented in table 6.

Table 6. Values of shoreline change rates and their standard errors using four shoreline positions.

Transect	Mean shoreline change rate (m/yr)		Standard error
	Accretion	Erosion	
1		1.3	6
2	2.2		3
3	3.0		7
4	6.7		10
5		7.5	17
6	1.0		3
7	1.6		3
8	0.1		6
9	7.0		6
10	7.8		6
11	2.0		6
12		4.9	10
13		2.5	8
14		0.0	4
15		0.8	12
16		1.4	3
17		18.0	12
18		20.8	17
19		20.4	14
20		13.9	7
21		4.8	4
22		0.0	1
23	4.9		4
24	8.4		7
25	7.4		6
26	5.7		2
27	4.7		4
28	0.4		3
29	0.0		1

As a result of the analysis, shoreline accretion occurs along most areas of Miamy beach and the western part of Asafra beach (ranges from 1.6 to 7.8 m/yr) and at the eastern part of Mandara beach and Montaza beach (ranges from 0.4 to 8.4 m/yr). In contrast, areas of shoreline erosion exist at eastern part of Asafra beach (ranges from -0.8 to -4.9 m/yr) and at western part of Mandara beach (ranges from -4.8 to -20.8 m/yr). Figure 8 (left side) shows an example of the shoreline accretion at transects 25 to 29. The beach width has been increased up to 33 meters in February 2010 compared to November 2006. Figure 8 (right side) shows an example of the shoreline erosion at transects 15 to 20 where the beach width has been decreased in a range from (3 to 80) meters.

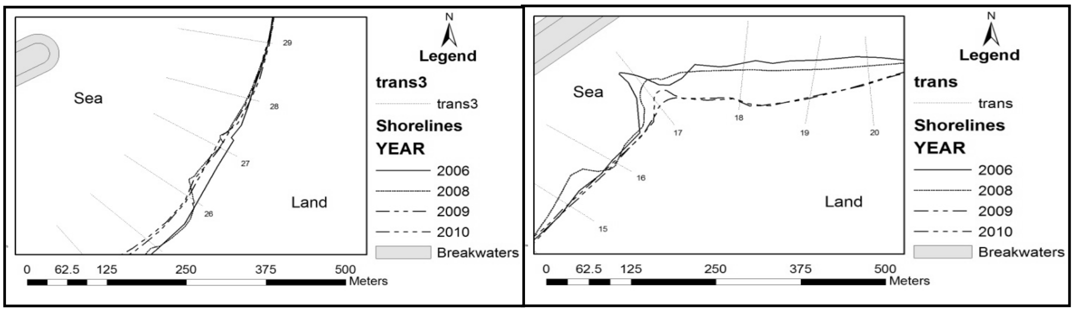

Figure 8. Shoreline progress at transects 25 to 29 (left) and at transect 15 to 20 (right).

Figure 9 shows a photos comparison between the beach width before and after the construction of the submerged breakwater at Montaza beach. The figure clearly shows that the beach width increases along the shoreline protected by the submerged breakwater. Natural sedimentation has formed a beach with a 25 meter average width on the leeside of the breakwater. The accumulated beach has shown a stable line for the last two years. It is assumed that the accretion of the beach crest, which is noticed in some areas, has occurred due to cross shore profile changes with onshore movement of sand. This process occurs naturally under smaller wave conditions. More detailed surveying work is needed to examine whether bed profiles have steepened or there has been further erosion offshore.

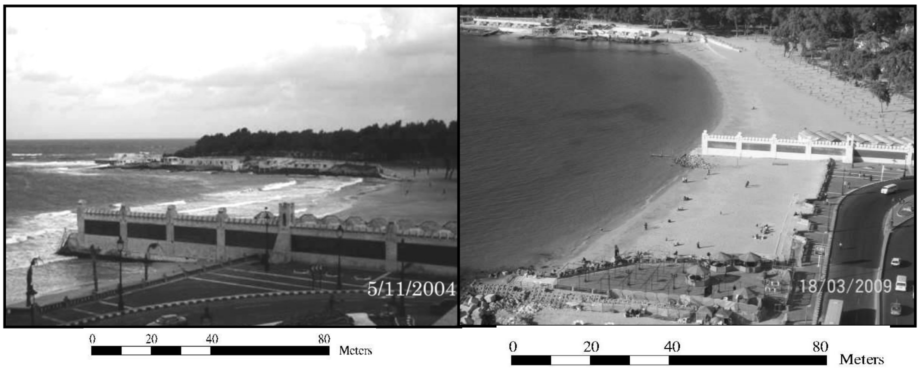

Figure 9. Comparison between the beach width before and after the construction of the submerged breakwater at Montaza beach, Alexandria, Egypt.

6 CONCLUSIONS

During last few years, Alexandria coastline has faced many flooding problems. In winters of 2003 to 2006, many surge storms struck the Alexandrian coastline. The impacts of Sea Level Rise will be felt through both an increase in mean sea level and through an increase in the frequency of extreme sea-level events such as storm surges (Church et al., 2008). The option of raising the level of the defences is not feasible due to both reductions in amenity and cost ineffectiveness, as existing infrastructure would have to be sacrificed to accommodate larger defences. This leads to the proposed deployment of a submerged offshore rubble mound breakwater to induce wave breaking and energy dissipation, in order to limit the wave heights reaching the beach (El-Sharnouby and Soliman, 2010; El-Sharnouby et al., 2007; Soliman and Reeve, 2009).

Alexandria submerged breakwater was installed to protect the sea shore of Miamy - Asafra -Mandara - Montaza areas in Alexandria, Egypt in years 2006 to 2008. A digital shoreline analysis software was used to calculate the annual rate of coastline changes at 29 cross-shore transects prior to years 2006 - 2010. An additional beach with a 25 meters average width on the leeside of the breakwater has been established in most areas and the accumulated beach has shown a stable line for the last two years. The water mass between the submerged breakwater and the beach circulates well with very gentle and light waves even under storm conditions. The good performance of Alexandria submerged breakwater is due to the minimum value of freeboard (0.5 meter) and the maximum value of breakwater crest ($W=L_w$) (regardless of construction height or incident wave height), continuity of the breakwater, site and breakwater layout, appropriate offshore distance (150-300 meter), and method of construction. The review of fourteen submerged breakwaters (single, shore-parallel breakwaters, and multi-functional surfing reefs with complex design configurations), which is presented table 1, shows that shoreline erosion was reported at seven of the sites. Furthermore, the key environmental and structural parameters governing the mode (i.e. erosion or accretion) and the magnitude (i.e. size of salient) of shoreline response to submerged structures are yet to be accurately identified. Submerged coastal structures offer the potential for low aesthetic impact incorporating multifunction design, but until the response of the adjacent shoreline to submerged structures is better resolved; their proper use is likely to depend mainly on engineering judgment and understanding of their behaviour, making use of case history and field data as well as theoretical analysis. Attenuation remains the key aspect for success of submerged breakwaters.

NOTATION

B	Length of the breakwater
h	Water depth
h_c	Water depth at the crest of the structure
H	Incident wave height
H_t	Transmitted wave height
K_t	Transmission Coefficient = H_t/H

L_w Incident wave length
S Offshore distance
W Crest width

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