EGYPTIAN JOURNAL OF AQUATIC RESEARCH 1687-4285
VOL. 32 NO. 1, 2006: 48-60.

SIMULATION OF WAVE PROPAGATION IN THE EASTERN HARBOR OF ALEXANDRIA, EGYPT

A.M. ABDELLAH

Assistant Professor of Physical Oceanography
Oceanography Department, Faculty of Science, Alexandria University, Alexandria, Egypt
Corresponding author: A.M. AbdAllah, Oceanography Department, Faculty of Science, Alexandria University, Alexandria, Egypt, e-mail: drabd77@yahoo.com

Keywords: Modeling, Wave Propagation, Wave Run Up, Overtopping, Eastern Harbor.

ABSTRACT

The present study is conducted in investigate the patterns of wave propagation and transformation in the Eastern Harbor, and to predict the wave heights inside it using CGWAVE model and also to estimate wave run up and overtopping at its surrounding seawall using ACES software package. The investigation showed that, during NW storm relatively rough wave conditions (wave heights of about 2 m) were predicted in the eastern and northeastern parts of the harbor. During NNE storm the rough conditions were predicted to affect most parts of the Eastern Harbor. Estimations of wave run up and overtopping at the seawall in the area off the coastline to the east of El-Mansheya using ACES software Package gave a run up value of 3.23 m with an overtopping rate of about 100 liters/s-m. The model results show good agreement with observations. The incident wave height (1.75 m) used in these calculations is that predicted by CGWAVE at depth contour of 2.5 m during NNE storm wave with Hs_0 of 3.4 m and Ts of 9.0s

1. INTRODUCTION

The Eastern Harbor (Fig. 1a) is a semi-enclosed embayment covering an area of about 2.8 km^2. The coastline of the harbor has a length of about 3800 m and it has been reinforced by concrete blocks. During the sever winter storms this concrete seawall is not capable in preventing wave overtopping at some locations along its coast. Wave overtopping on the Eastern Harbor can block the Corniche highway bordering it and causes damages. On the east, the harbor is bordered by a land projection, El-Silsila and to the northwest by a large causeway. The northern side of the harbor is protected by an artificial breakwater dividing the bay into two outlets: El-Boughaz and El-Silsila outlets, the first one has a width of about 300 m with a water depth of 9-12 m, while the second outlet is shallower and narrower with depth of about 3.5 m and a length of 140 m. The Eastern Harbor is shallow in most places, averaging about 5 m in depth, the deepest area (12 m) is found near El-Boughaz outlet (Fig. 1b). Generally, the bottom slopes down gradually toward El-Boughaz opening to the Mediterranean, where the depths increase to 50 m at about 8 km offshore. The harbor, generally, has rocky beaches except at its south-western coast where a narrow sandy beach (300x700 m) is found.

Wave climate plays a very important role in all coastal projects. However, in most cases, little wave data are available for engineering construction and planning. Field observation and physical modeling of waves are extremely difficult, costly, and time-consuming. Buoys are far away from the site, and remote-sensing instruments do not systematically provide wave data at the desired resolution in the near shore region. Since no data-recording instrument can anticipate future sea states, the desired sea-state information may be obtained and plans evaluated with reliable mathematical modeling techniques.

The aim of the present work is to investigate the patterns of wave propagation and transformation in the Eastern Harbor, and to predict wave height inside it using CGWAVE model-the coastal surface water wave model of the mild slope wave equation (Demirbilek and Panchang, 1998), and to estimate wave run up and overtopping at its surrounding seawall using ACES software package (Leenkencht *et al.*, 1992).

Generally the wind system over the Egyptian Mediterranean coast is related to the atmospheric pressure distribution over the Eastern Mediterranean with a prevailing N-NW wind, except that in cold period(November–March). During this period, the wind direction is more variable and storms occasionally occur persisting for one to several days (Hamed, 1983). Based on the analysis of wind data at Alexandria during the period from 1997 to 1999, Shaltout (2003) showed that about 60% of time wind was blowing from N-NW sector, with maximum wind speed of about 26 knots from NW direction and 24 knots from NNE sector.

The waves along the Egyptian Mediterranean coast are mainly generated by the prevailing NW winds and cyclonic storms which travel from west to east in the Mediterranean Sea. Both of these wind systems generate waves which predominantly approach the coast from the NW quadrant (Inman *et al*., 1976). The wave climate in the deep water off Alexandria is relatively well known and has been determined by Teisson and Bouchard (1987) and Shaltout (2003). According to Teisson and Bouchard (1987), the statistically significant wave height for the statistical return period of 1 year and 100 years are about 4.0 m and 8.0 m, respectively. Hind casting of the wind induced wave in deep water off Alexandria by Shaltout (2003) during 1997-1999 showed that:

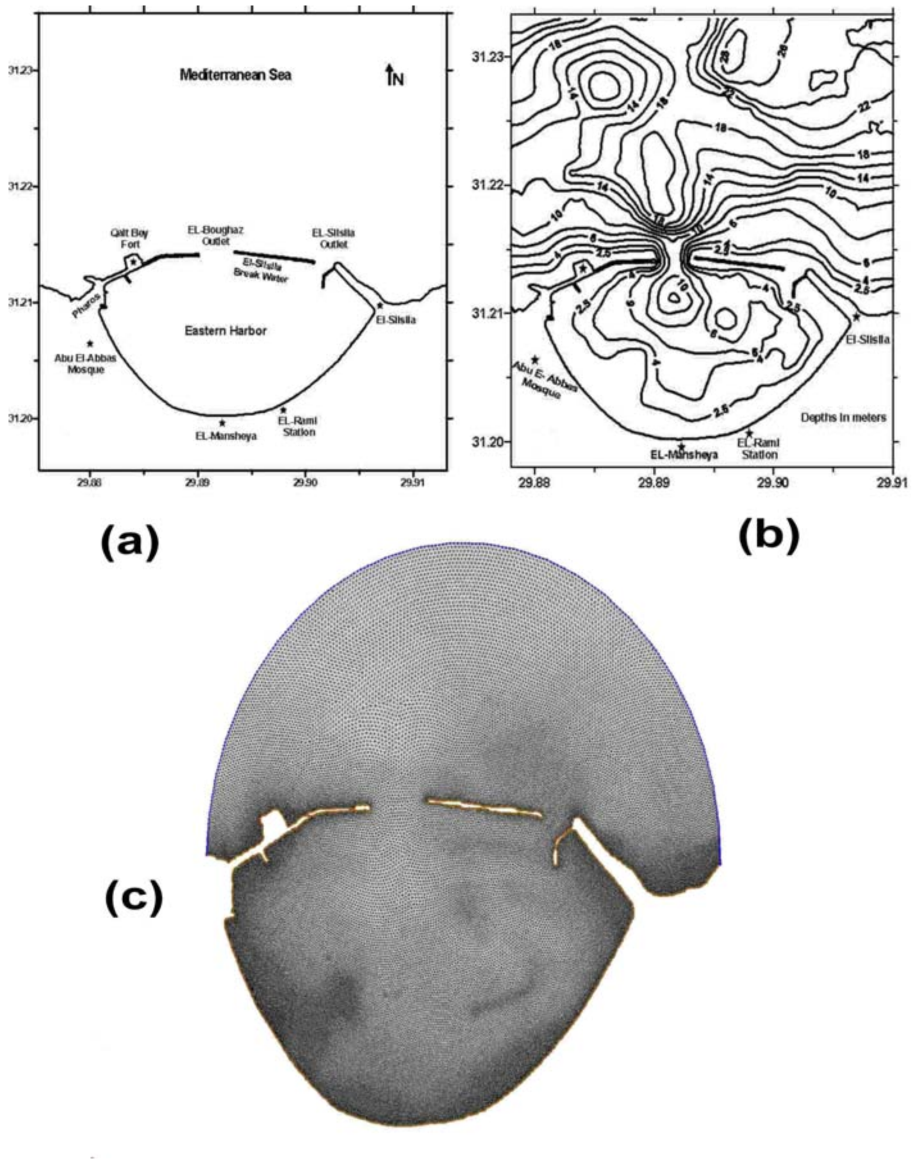
a- about 65% of waves approaching Alexandria coast come from the WNW-N sector, of which waves from NW direction constitutes 28%; a small percentage (≈ 10%) of waves from NNE-E directions was also indicated;

b- About 85% of waves have deep water significant wave height (Hs_o) less than or equal to 0.6 m. However, the seasonal energy average is dominated by relatively infrequent but energetic waves with Hs_o of more than 1.5 m. The maximum value of Hs_o calculated during the whole period (1997-1999) was 4.5 m from NW direction and with significant wave period (Ts) 7.0 s. Energetic waves approaching the coast from NNE-E directions were also indicated with maximum Hs_o of about 3.5 m and Ts of 9.0 s coming from NNE direction;

c- 55% of waves have significant wave period (Ts) ranging between 4.0 s and 9.0 s, while 10% of them have a longer period s of more than 9.0 s.

2. MATERIAL AND METHODS

The CGWAVE model was used to simulate the wave propagation into the Eastern Harbor and its surrounding coastal waters. The data used in these simulations are the bathymetric data of the investigated area, which are obtained from the Admiralty Chart of Alexandria Harbor (number 243, 1959) since the new chart carried out by NIOF is still not available. In the present work two simulations were done for two cases frequently encountered during winter storms: case I-deep water waves coming from NW direction with significant wave height of 4.5 m and wave period of 7.0 s; case II- deep water waves coming from NNE direction with Significant wave height of 3.4 m and wave period of 9.0 s.


Mediterranean Sea
N
Qait Bey Fort
EL-Boughaz Outlet
EL-Silsila Outlet
El-Silsila Break Water
Pharos
Eastern Harbor
El-Silsila
Abu El-Abbas Mosque
EL-Mansheya
EL-Raml Station
31.23
31.22
31.21
31.20
29.88
29.89
29.90
29.91
Depths in meters
(a)
(b)
(c)

Wave breaking, friction and reflection at land boundaries were taken into consideration. Breaking coefficient was taken to be equal 0.15 with peak wave height percentage of 0.64. Bottom friction coefficient assigned a value of 0.085. The reflection coefficient assigned a value of 0.25 at those parts of the Eastern Harbor where sandy beaches are found (in the area between Abu El-Abbas Mosque and El-Mansheya), while the rest of the vertical sea wall surrounding the harbor and the detached breakwater assigned a value 0.9. Figure 1.c shows the computational mesh. It covers an area of about 6 km^{2,} and comprises 42505 nodes defining 83235 triangular elements. The outer boundary of the model domain is bounded by a semi-circle with a radius of about 1.5 km.

2.1. CGWAVE Model

CGWAVE is a general-purpose wave prediction model for simulating the propagation and transformation of ocean waves in coastal regions and harbors, and appropriate for modeling the most significant physical processes in channels, inlets and harbors, open coastal regions, around islands and structures. The model simulates wave refraction, diffraction, reflection (by coastlines, structures, and the bathymetry), nonlinear dispersion, and dissipation due to friction and breaking for a wide spectrum of input wave frequencies and directions (Demirbilek and Panchang, 1998). CGWAVE is based on frequency domain solution of the Berkoff (1976) or the mild-slope equation (MSE), which represents the depth-integrated equations for the conservation of mass and momentum for waves propagating in water of variable depth. The model is operational in Surface-water Modeling System (SMS) for generating model's finite element mesh and analysis and visualization of model results.

2.2. Basic Equations

The CGWAVE model is based on the solution of the two-dimensional elliptic mild-slope wave equation (Berkhoff, 1976). This equation may be written as:

$$\nabla.(CC_g \nabla \hat{\eta}) + \frac{C_g}{C} \sigma^2 \hat{\eta} = 0 \qquad (1)$$

Where:

$\hat{\eta}$ (x,y) = complex surface elevation function, from which the wave height can be estimated

σ = wave frequency under consideration (in radians/second)

C(x,y) = phase velocity = σ/**k**

C_g (x,y = group velocity = $\delta\sigma / \delta k = nC$

with

$$n = \frac{1}{2}(1 + \frac{2kd}{\sinh 2kd}) \qquad (2)$$

k(x,y) = wave number = 2π/L, related to the local depth d(x,y) through the linear dispersion relation:

σ^2 = gk tanh (kd) (3)

L= wave length

Equation 1 simulates wave refraction, diffraction, and reflection (i.e. the general wave scattering problem) in coastal domains of arbitrary shape.

2.3. Wave Run Up and Overtopping

Wave run up is defined as the vertical height above still-water level to which a wave will rise on structure (if assumed infinite height). Overtopping is the flow rate of water over the top of the finite height structure as a result of wave run up (Leenkencht et al, 1992).The volume of water that flows over the structure can impact backside flooding. Onshore wind can increase overtopping rate at the structure, the effect is dependant upon wind velocity, direction and structure characteristics. In the present work wave run up and overtopping was estimated using ACES Software Package (Leenkencht et al, 1992). The Automated Coastal Engineering System (ACES) is an integrated collection of coastal engineering design and analysis software. ACES provide a comprehensive environment for applying a broad spectrum of coastal engineering technologies. Of these technologies wave run up and overtopping on impermeable structures model will be used. The following parameters will be used as input for this model:

Slope type: smooth; wave type: monochromatic; Breaking criteria = 0.78,

Incident wave height = 1.75 m; Wave period = 9.0s; cotan of near-shore slope =100;

cotan of structure slope (vertical seawall) = 0.0; Water depth at structure= 2.5 m;

Seawall height above still water level = 1.5 m; onshore wind velocity = 24 knots (wind speed frequently encountered during winter storms).

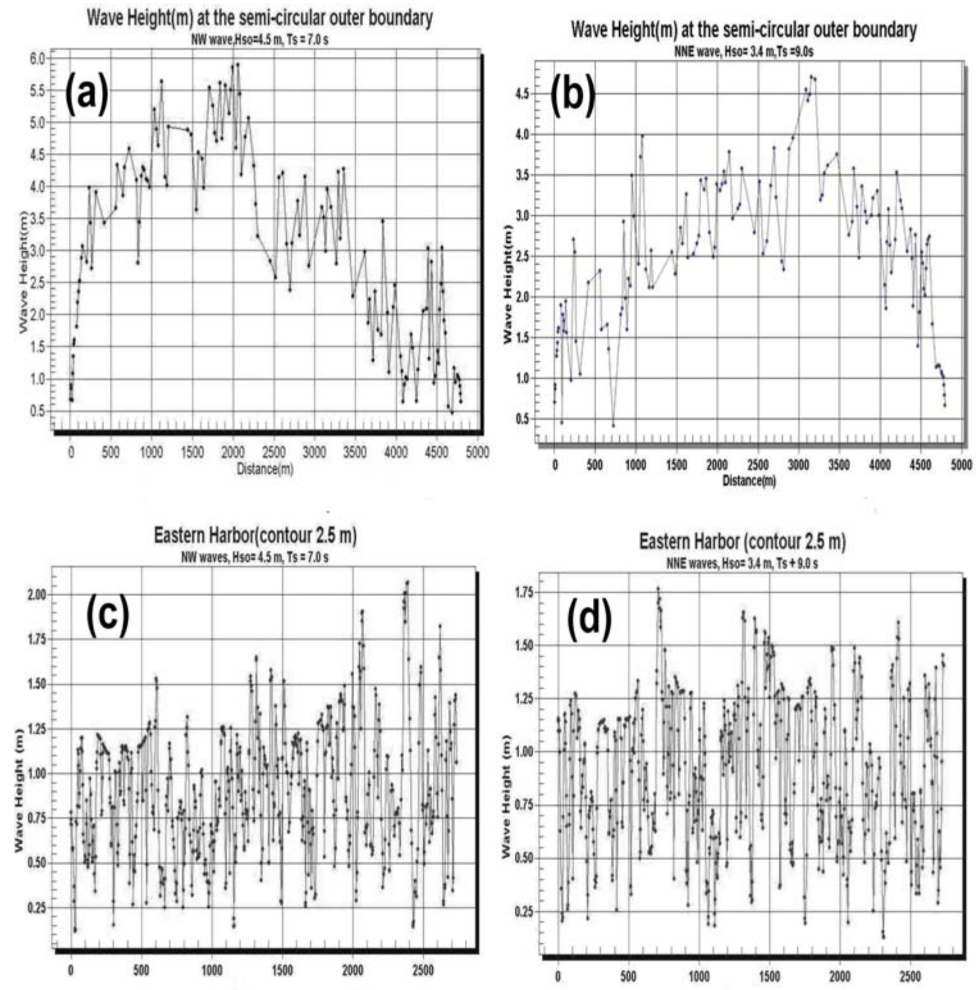
3. RESULTS AND DISCUSSION

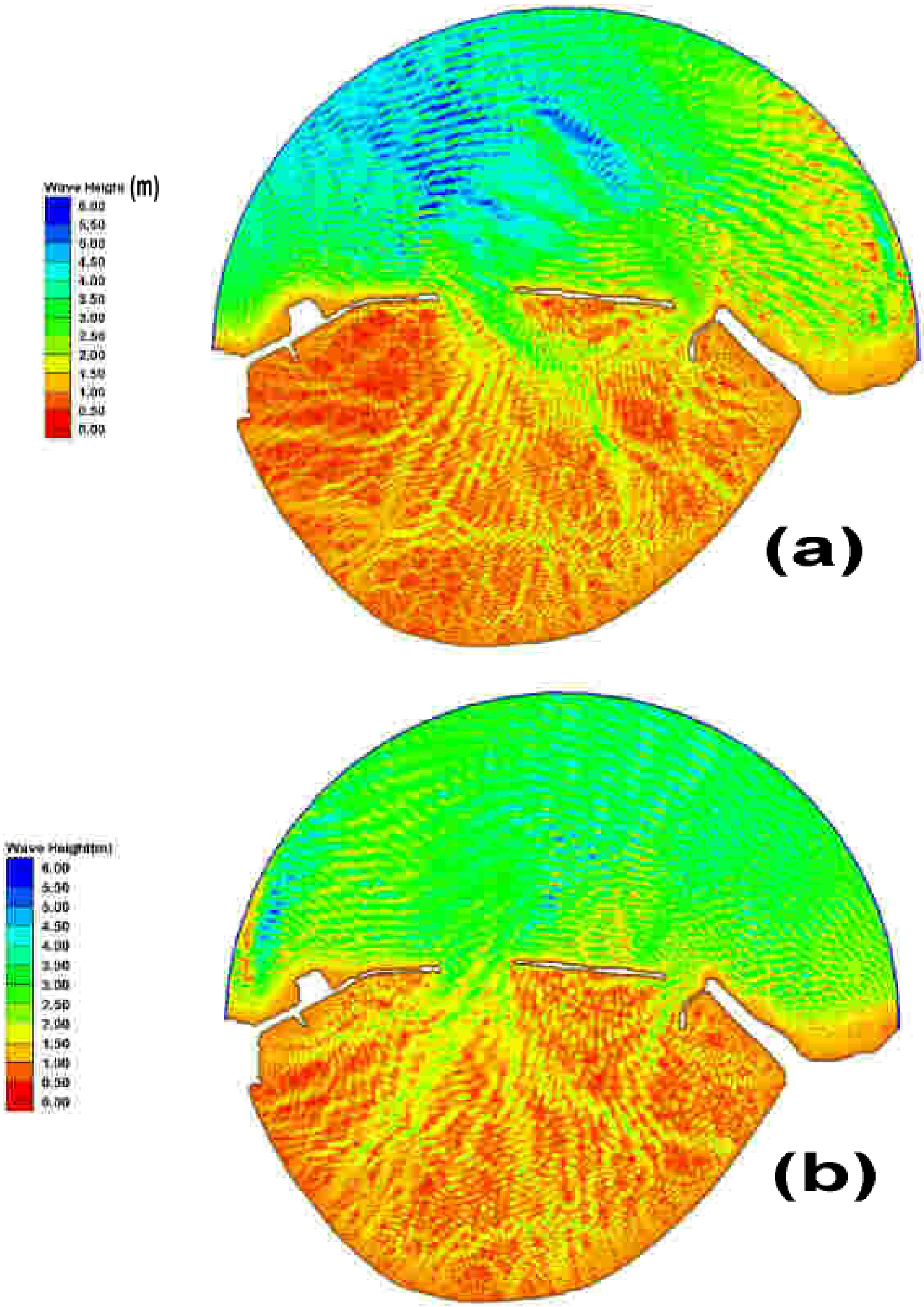
3.1. Wave Propagation

Simulations of wave propagation in the Eastern Harbor using CGWAVE model during NW storm (Case I) showed that: outside the harbor, waves with maximum wave height of about 6.0 m were estimated along the semi-circular outer boundary of the computational domain in the NW-N sector (Fig. 2a). This increase in wave height over the deepwater value is mainly due to the effect of wave shoaling and refraction outside the computational domain. The wave height inside the Eastern Harbor, except in the area near El-Boughaz and El-Silsila outlets, are generally lower than 3.0 m (Fig. 3a). This significant attenuation of wave height is attributed to the sheltering effect of El-Silsila detached breakwater and the land projection at EL-Silsila and Qait Bay Fort. During NW storm (case I), relatively rough wave conditions were predicted in the eastern and northeastern parts of the harbor (Fig. 3a). The maximum predicted wave height is about 2.0 m, it occurred along the bottom contour 2.5 m in the area off the coastline between El-Ramel Station and El-Silsila(Fig. 2c)

During NNE storm (case II), the maximum estimated wave height (4.8 m) outside the Eastern Harbor was found mainly in the N-NE sector (Fig. 2b). Inside the harbor the wave heights are generally, lower than 3.0 m and the rough conditions were predicted to affect most parts of the Eastern Harbor (Fig. 3b). The maximum wave height predicted (about 2.0 m) was found along the bottom contour 2.5 m in the area off the coastline between Abu-El-Abbas mosque and El-Mansheya (Fig. 2d).

The visual observation of waves inside the Eastern Harbor conducted by the author during the winter storms of 2005 indicated the development of waves with heights of about 2.0 m off the sea wall at the eastern parts of the harbor and the occurrence of wave overtopping at several locations between Abu El-Abbas Mosque and El-Silssila. The estimates of wave heights obtained from the model are in good agreement with the visual observations in the investigated area. The significant variations of wave heights along the bottom contour 2.5 m as indicated from Figs 2c, 2d is mainly due to the irregular bottom topography of the Eastern Harbor which causes waves to be refracted in a complex way and produce regions convergence and divergence of wave energy, and also due to the wave diffraction and reflection at the seawall surrounding the harbor.


Wave Height(m) at the semi-circular outer boundary
NW wave,Hso=4.5 m, Ts = 7.0 s
(a)
Wave Height(m)
Distance(m)
Wave Height(m) at the semi-circular outer boundary
NNE wave, Hso= 3.4 m,Ts =9.0s
(b)
Wave Height(m)
Distance(m)
Eastern Harbor(contour 2.5 m)
NW waves, Hso= 4.5 m, Ts = 7.0 s
(c)
Wave Height (m)
Eastern Harbor (contour 2.5 m)
NNE waves, Hso= 3.4 m, Ts + 9.0 s
(d)
Wave Height (m)

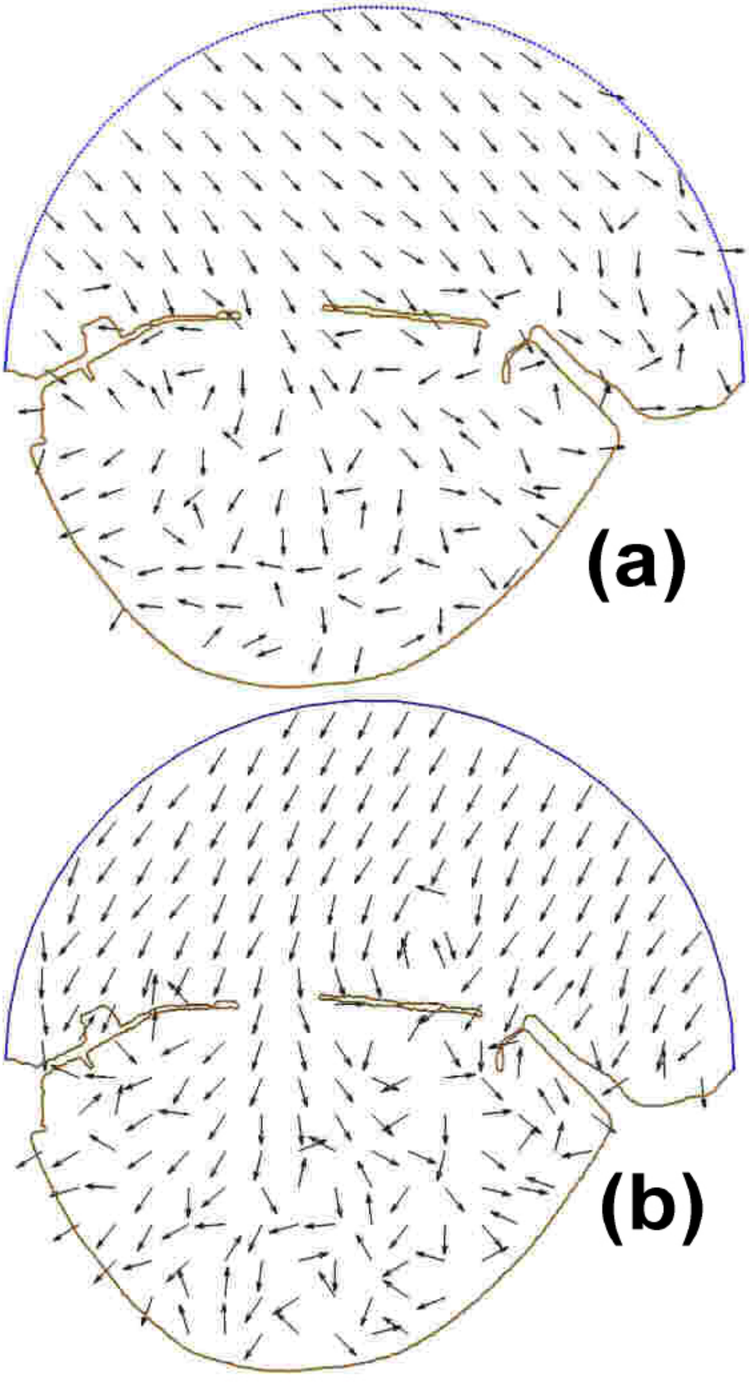

Wave Height (m)
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
(a)
Wave Height(m)
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
(b)

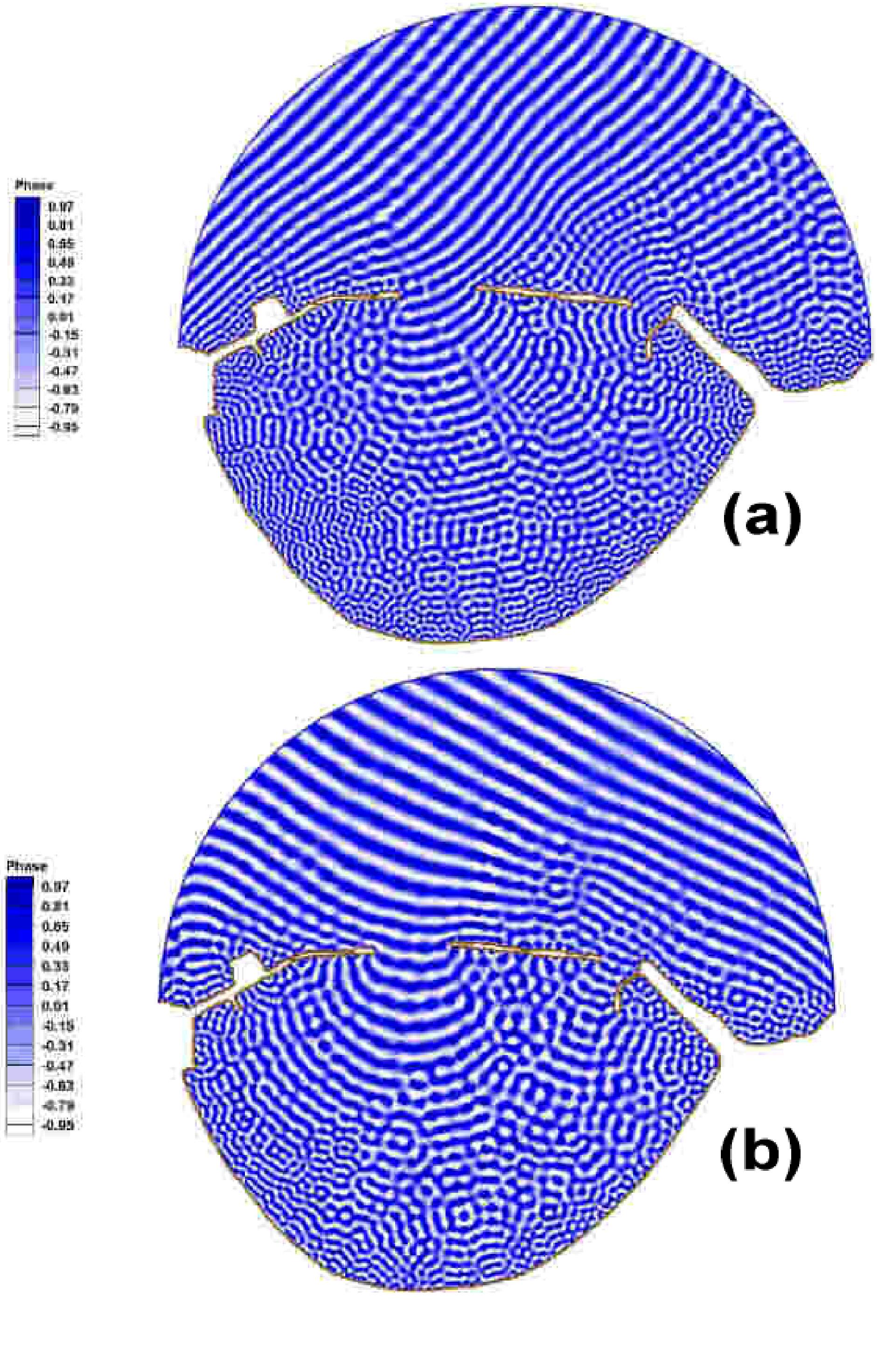
Outside the harbor, the propagation of waves is controlled mainly by wave refraction (Figs. 4, 5). The phase diagrams (Figs. 5) show bending of the phase lines due to the refraction across the bathymetry. Inside the harbor wave refraction and diffraction are the main controlling factors (Figs. 4, 5). Figure 5 shows breaks in the phase lines inside the harbor that indicate multidirectional wave crossing. Waves can penetrate into the Eastern Harbor due to refraction and diffraction around El-Silsila breakwater causing an inconvenient wave condition during storms. The mitigation action of El-Silsila Breakwater on the wave climate inside the Eastern Harbor affects its morphology. The French Nautical instruction manual (1981) indicates that the Eastern Harbor of Alexandria is no longer frequented, being partly filled by high inner sand banks due to the dikes and the detached breakwater built to protect it. These sand banks are found in the area between Abu El-Abbas Mosque and El-Mansheya and it is expected to increase its extent with time seaward as a tompolo.

3.2. Estimation Of Wave Run Up And Overtopping

The Eastern Harbor is surrounded by a seawall to protect its coast and bordering sea road (El-Cournish) from high waves frequently encountered during the winter season. This seawall increases in height from about 1.0m above sea level in the area near Abu El-Abbas Mosque to above 4.0 m, near El-Silsila area. During cold period (November-March), high waves penetrating into the harbor through El-Boughaz and El-Silsila outlets may cause damage to marinas located in its north-western part and wave overtopping at different locations in the area between Abu El-Abbas Mosque and El-Silsila.

Estimation of wave run up and overtopping using ACES software package (Leenkencht et al, 1992) indicated that the wave run up to be equal 3.23 m with an overtopping rate of about 100 liter/s-m .This estimate can increase with increasing the incident wave height and decreasing the height of the seawall. The incident wave height (1.75 m) used in these calculations is that predicted by CGWAVE model for case II (deep water wave approaching the coast from NNE direction, $\theta_o = 245^O$) with $Hs_o = 3.5$ m and Ts = 9.0 s at 2.5 m depth contour off the coast line to the east of El-Mansheya. In this region wave overtopping usually occurs during rough wave conditions inside the harbor. Case II was chosen for wave run up and overtopping calculations because storms coming from N-NE sector have significant impacts on the western part of the harbor than storms coming from NW-N sector. In this part of the harbor marinas are located and the seawall height surrounding that part of the harbor is too low(1.0-2.0 m) to prevent wave overtopping during such storms that significantly impact El-Cournish highway, coastal restaurant and clubs constructed along its south-western beaches.


(a)
(b)


Phase
0.97
0.81
0.65
0.49
0.33
0.17
0.01
-0.15
-0.31
-0.47
-0.63
-0.79
-0.95
(a)
Phase
0.97
0.81
0.65
0.49
0.33
0.17
0.01
-0.15
-0.31
-0.47
-0.63
-0.79
-0.95
(b)

4. CONCLUSIONS

Simulations of wave propagation in the Eastern Harbor using CGWAVE model for case I (deep water waves coming from NW direction with significant wave height of 4.5 m and wave period of 7.0 s) and case II (deep water waves coming from NNE direction with Significant wave height of 3.4 m and wave period of 9.0 s) indicated that, the wave heights inside the harbor are generally lower than 3.0 m. For case I, the maximum wave height predicted (about 2.0 m) along the bottom contour 2.5 m occurred in the area off the coastline between El-Ramel Station and El-Silsila, while for case II it occurred in the area between Abu-El-Abbas mosque and El-Mansheya. These estimates of wave heights show a good agreement with the visual observations in the investigated area. Generally, outside the harbor the propagation of waves is controlled mainly by wave refraction while inside the harbor wave refraction and diffraction are the main controlling factors.

Estimations of wave run up and overtopping at the seawall in the area off the coastline to the east of El-Mansheya using ACES software Package gave a run up value of 3.23 m with an overtopping rate of about 100 liters/s-m. The incident wave height (1.75 m) used in these calculations is that predicted by CGWAVE model for case II at depth contour of 2.5 m.

REFRENCES

Berkhoff, J.C.W.: 1976, Mathematical models for simple harmonic linear water waves – wave diffraction and refraction. Delft Hydraulics Laboratory Publication.

Demirbilek, Z., and Vijay Panchang: 1998, CGWAVE: A coastal surface water wave model of the mild slope equation. Technical Report, CHL.-98, 120.

Hamed, A.A.: 1983, Atmospheric circulation over the southeastern part of the Mediterranean Sea in relation with weather condition and wind waves along the Egyptian coast. Ph.D. Thesis, Alexandria University, Faculty of Science, Alexandria, Egypt.

Inman, D. L., David g. Aubrrey and Steven S. Pawka: 1976, Application of near shore processes to the Nile Delta, Proceedings of seminar on Nile Delta Sedimentology, Academy of Scientific Research and Technology, Alexandria, Egypt 25-29 October, 1975, 205-237.

Leenkencht, D.,A. Szuwalsk and A. Sherlock: 1992, Automated Coastal Engineering System (ACES).Technical Reference, CERRC, Corps of Engineers, 210.

Service Hydrographique et Océanographique de la Marine.1981. Instructions nautiques: Afrique - Côte Nord, entre la Mer Egée et le canal de Suez. Série D, vol. 6.

Shaltout, M.E.: 2003, A study on water waves in the Mediterranean Sea along the Egyptian coast, M.Sc. Thesis, University of Alexandria, Alexandria, Egypt.

Teisson, C. and Bouchard, J-P.: 1987, Étude de faisabilité pour la centrale thermique de Sidi Krir (Égypte). Phase I. EDF-LNH Reports, HE-42/87.10 and HE-43/87.21.

List of Figures