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USE OF A NUMERICAL WAVE MODEL TO STUDY THE ENVIRONMENTAL IMPACT OF THE DEVELOPMENT OF A RESORT AT EL-AIN EL-SUKHNA

Mohamed Elzeir* & Amro El-Feki**

*Assistant Professor, Civil Engineering Department,
Faculty of Engineering, El-Minia University, Egypt
**Assistant Professor, Irrigation and Hydraulic Department,
El- Mansoura University, Egypt

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استخدام نموذج عددى للأمواج لدراسة تأثير مشاريع تنمية منتجع العين السخنة على البيئة

Mohamed Elzeir
Assistant Professor, Civil Engineering Department,
Faculty of Engineering,
El-Minia University, Egypt.

Amro El-Feki
Assistant Professor, Irrigation and Hydraulic Department,
El-Mansoura University, Egypt.
Current Address:
Faculty of Civil Engineering and Geosciences,
Technical University of Delft, Delft, the Netherlands.

خلاصة:

تقوم الحكومة المصرية حالياً بمشاريع تنمية على شواطئ العين السخنة الواقعة على خليج السويس، وذلك من خلال استثمارات رجال الأعمال. ورغم أن الاهتمام الأول لرجال الأعمال هو استيفاء احتياجات وطلبات المصطافين والمترددين على المنتجع فإنه يجب عليهم أن يأخذوا فى اعتبارهم التنمية البيئية المتوازنة.

موضوع دراسة البحث الحالى هو استقصاء الوضع الحالى للمنتجع من خلال المسح المبدئى لإحدى القرى السياحية بالمنتجع واستخدام التحليل العددى. ومن ثم سيقترح مشروع تنموى متكامل لضمان تنمية المنطقة تنمية متوازنة ومتوافقة مع البيئة.

وقد وضح جليا من نتائج المحاكاة العددية المستخدمة فى هذا البحث فوائد استخدام النماذج الرياضية البسيطة فى تقييم (حتى لو كان كيفيا وليس كميا) مشاريع تنمية وحماية الشواطئ.

ABSTRACT:

Egyptian government is developing the beaches of El-Ain El-Sukhna, on the Gulf of Suez through the investment of businessmen. The interest of the businessmen who want to satisfy the recreation-seekers usually should take into account environment sustainability. This research investigates the current situation depending on both preliminary survey of one of the sites in El-Ain El-Sukhna and numerical analysis technique. Then, a comprehensive development project is suggested to maintain environmental friendly sustainable development of the area.

Simulations show the usefulness of using simple numerical models to provide at least, in this study, qualitative assessment of beach protection and development.

INTRODUCTION:

Within the framework of privatization, the Egyptian government embarked on a development project in El-Ain El-Sukhna on the Gulf of Suez. The project is to sell the (virgin) beach, which is not yet used, to businessmen so that they construct what so-called "Tourist villages". The objectives of the project include providing recreational sites for Cairo residents, foreign tourists, as well as other recreation-seekers.

It is well known that the Red Sea is one of the richest natural environments in terms of biological habitats and water quality. Therefore, the new (tourism) activity should be carefully investigated and designed so that it introduces the least, if any, environmentally unfavorable impact. Although construction works started in the project area, the development

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is still far from complete. Hence, it is believed that it is not yet too late to address the issue of sustainably developing the area and taking the necessary precautionary (as opposed to curing) measures. We have been involved in a primary environment impact assessment for one of the tourist villages in El-Ain El-Sukhna. We will use the limited data available from that investigation to propose comprehensive monitoring program and design criteria for the beach.

EL-AIN EL-SUKHNA:

The beach of El-Ain El-Sukhna is on the west coast of the Gulf of Suez, 80 km south to Suez (Fig. 1).

The bed material is coarse consisting of gravel and pebbles up to a size of 25 cm (Fig. 2). Although bed structure is suitable for wildlife habitat existing there, it is not suitable for many recreational activities like swimming, strolling, jogging, diving, and surfing. The bottom topography was sampled over intervals of 10 meters normal to the shoreline with transects at distances ranging from 25 to 100 meters apart. The bed slope is mild and almost uniform. At 100 meters offshore, water depth is 4 meters. Fig. 3 shows the three dimensional bed topography and the corresponding contour map. This map is interpolated from the measured grid points.

Table 1: *average monthly meteorological data in the area of the Gulf of Suez*

Month	Wind speed (m/s)	Wind direction (degree)	Air temperature (°C)	Relative humidity (%)	Air pressure (mbar)	Water temperature (°C)
January	10.3	297	19.9	64.3	1013	20.4
February	7.2	292	20.3	62.7	1006	20.1
March	7.3	282	25.4	64.9	1009	21.0
April	2.9	282	29.0	63.6	1008	22.1.
May	6.9	297	31.1	61.5	1008	23.0
June	10.7	320	34.7	60.9	1003	23.9
July	11.2	312	25.4	62.72	1002	25.4
August	10.4	317	28.6	62.4	1000	25.7
September	12.6	317	26.7	64.6	1002	25.1
October	9.9	301	25.2	65.7	1006	24.7
November	12.7	2987	25.3	65.4	1008	24.5
December	6.3	284	20.4	66.8	1010	20.8

Wind prevailing in El-Ain El-Sukhna is that prevailing on the Gulf of Suez (Table 1) with some occasional storms during winter. Maximum wind speed is about 12.7 m/s. Wind is generally parallel to the shoreline (NNW). Hence, wind-induced waves are parallel to the coast, with average height of 0.50 to 1.60 meters (ENODC, personal communication). It should be noticed that this is the wave climate in the deep waters of the Gulf. As the waves experience shoaling, towards the shore, they are refracted. Very close to the beach, waves attack the beach almost perpendicular to it.

The investigated tourist village has a shoreline approximately 710 meters long (Fig. 4). North to the site, the shoreline is running almost in a straight line in north-south direction. The northern neighbor built a seawall aiming at protecting his artificial sandy beach. 210 meters from the north border of the site, a T-shaped artificial extension of the beach was too late to address the issue of tionary (as opposed to curing) pact assessment for one of the ted data available from that d design criteria for the beach.

he Gulf of Suez, 80 km south

les up to a size of 25 cm (Fig. ng there, it is not suitable for ng, diving, and surfing. The normal to the shoreline with bed slope is mild and almost 3 shows the three dimensional nap is interpolated from the

? *Gulf of Suez*

Air pressure (mbar)	Water temperature (°C)
1013	20.4
1006	20.1
1009	21.0
1008	22.1.
1008	23.0
1003	23.9
1002	25.4
1000	25.7
1002	25.1
1006	24.7
1008	24.5
1010	20.8

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constructed (Fig. 5). This extension will be called hereafter "artificial island". 240 meters further south, the shoreline goes deeper inland (towards east) forming bay-like water body.

The artificial island created in its onshore side a stagnant water body. Floating trash accumulate in the stagnant water on the onshore side of the artificial island disturbing the aesthetic scene and the sea users. Moreover, as the dominating wind is north to north-west, the southern part of the beach is more sandy than the northern part because of sand transported by wind from the surface of the artificial island. The change of the bed structure induced a change in the biological structure in the south part of the beach. Beach was strongly compacted and a layer of concrete was formed due to dumping construction wastes on the beach (Fig. 6).

Although wave climate is calm, the tourist village owner likes to attenuate approaching waves to suit recreational activities and to avoid erosion of nourishing sand. He proposed construction of breakwaters, which serve wave attenuation (or complete damping) and as a marina for boat mooring. Most of the already-constructed villages have first, artificial islands connected to the shore by a light (steel or wooden) bridge (Fig. 7); second, some hard structure (seawalls, or breakwaters) for both boat mooring and breaking attacking waves.

SHALLOW WATER WAVE MODEL:

The linearized shallow water wave theory, based on mass and momentum conservation laws, is given by:

$$\frac{\partial^2 \eta(x,y,t)}{\partial t^2} = \frac{\partial}{\partial x}\left(c^2(x,y) \frac{\partial \eta(x,y,t)}{\partial x} \right) + \frac{\partial}{\partial y}\left(c^2(x,y) \frac{\partial \eta(x,y,t)}{\partial y} \right) \in \Omega \quad \text{.........(1)}$$

where, $c(x,y)$ is the wave celerity, $\eta(x,y,t)$ is the surface elevation, and Ω is the domain of interest. The celerity in the model is a function in the spatial coordinates. So, the shoaling effect is incorporated by the variation in celerity that is computed as,

$$c(x,y) = \sqrt{gh(x,y)} \quad \text{..(2)}$$

where, $h(x,y)$ is the water depth at x,y location.

This model is adopted to study the wave pattern on the beach of the resort and show the impacts of the proposed solutions to the problems.

FINITE DIFFERENCE DISCRETIZATION OF THE WAVE MODEL:

Solving the wave equation (Eq. 1) over the domain of interest Ω requires a spatial discretization of the wave field. It is necessary to discretize the domain Ω into a number of cells where the variable of interest is defined in its nodal points (surface elevation). Fig. 8 illustrates domain discretization and boundary conditions. At each nodal point (x_i, y_j) at time t, where, $x_i = i\,\Delta x$, $y_j = j\,\Delta y$, $j = 0, 1, 2, \ldots JJ$, $i = 0, 1, 2, \ldots II$ and $t_k = k\,\Delta t$, $k = 0, 1, 2, \ldots KK$. Denote

$$\eta_{i,j,k} = \eta(x_i, y_j, t_k) \quad \text{..(3)}$$

The spatial derivative at time level k is approximated as,

$$\frac{\partial}{\partial x}\left(c^2(x,y)\frac{\partial\eta(x,y,t)}{\partial x}\right) \approx \frac{c^2_{i+1/2,j}\left[\dfrac{\eta_{i+1,j,k}-\eta_{i,j,k}}{\Delta x}\right] - c^2_{i-1/2,j}\left[\dfrac{\eta_{i,j,k}-\eta_{i-1,j,k}}{\Delta x}\right]}{\Delta x} \quad \text{..............} (4)$$

where, $\eta_{i,j,k}$ is the water surface elevation at node (i, j) and at time level k, Δx is domain discretization in x-direction and $c_{i+1/2,j}$ is the average celerity between adjacent nodes in x-direction.

Similarly, one could derive discrete equation in y-direction. An explicit finite difference scheme is performed for the time derivative in Eq. 1 as follows,

$$\frac{\partial^2\eta(x,y,t)}{\partial t^2} \approx \frac{\eta_{i,j,k+1} - 2\,\eta_{i,j,k} + \eta_{i,j,k-1}}{\Delta t^2} \quad \text{......................................} (5)$$

where, $\eta_{i,j,k+1}$ is the water surface elevation at node (i, j) and at time level k+1, $\eta_{i,j,k-1}$ is the water surface elevation at node (i, j) and at time level k-1 and $\eta_{i,j,k}$ is the water surface elevation at node (i, j) and at time level k and Δt is the time step in computation.

Further evaluation leads to the finite difference analog of the partial differential Equation 1 as,

$$\eta_{i,j,k-1} = A_{i,j}\,\eta_{i+1,j,k} + B_{i,j}\,\eta_{i,j-1,k} - C_{i,j}\,\eta_{i-1,j,k} + D_{i,j}\,\eta_{i,j+1,k} + (2 - E_{i,j})\,\eta_{i,j,k} - \eta_{i,j,k-1}$$

where,

$$A_{i,j} = \left(c_{i+1/2,j}\frac{\Delta t}{\Delta x}\right)^2, B_{i,j} = \left(c_{i,j+1/2}\frac{\Delta t}{\Delta y}\right)^2, \; C_{i,j} = \left(c_{i-1/2,j}\frac{\Delta t}{\Delta x}\right)^2, D_{i,j} = \left(c_{i,j-1/2}\frac{\Delta t}{\Delta y}\right)^2 \quad \text{.....} (6)$$

and $$E_{i,j} = A_{i,j} + B_{i,j} + C_{i,j} + D_{i,j}$$

The stability criterion of the numerical scheme is given by,

$$\Delta t \le \frac{\Delta x}{c} \quad \text{...} (7)$$

where, c is computed at the maximum depth to avoid numerical instability.
This scheme is convenient in that it uses the results from time level at k and k-1 levels to compute time level at $k-1$. Boundary conditions have to be applied at all domain boundaries as shown in Fig. 8.

COMPUTATIONAL ALGORITHM:

The computational procedure works as follows. A grid is superimposed over a schematized bathymetry map (Fig. 9). Each nodal point is assigned a water depth. Boundary conditions are applied to the four outer boundaries of the numerical domain. Two types of open boundary conditions are used, prescribed surface elevation at the open sea boundary parallel to the shore and no forcing is applied at the two open sea boundaries normal to the shore and a reflection boundary condition at the shore side. A sinusoidal wave is generated at the seaside with a specified wave height and a wave period. The waves are propagating normal to the shoreline. The wave domain perpendicular to the shore is extended twice its length (100 m) and the water depth is assumed linear so it reaches about 8 m. The reason for this is to give sufficient

$$\left[\frac{\eta_{i,j,k}-\eta_{i-1,j,k}}{\Delta x}\right] \quad \ldots\ldots\ldots\ldots (4)$$

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he partial differential Equation

$$2-E_{i,j})\eta_{i,j,k}-\eta_{i,j,k-1}$$

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distance for the wave to develop before entering the area of interest and therefore reducing the influence of boundary conditions from the sea side.

TESTING OF THE MODEL FOR SIMPLE CASE:

The model has been tested under simplified case where the beach line is flat without any construction protruding from the beach and a sinusoidal wave, with a wave height of 1 m, propagating normal to the beach. In Fig. 10, snapshots of the wave pattern in this case, which were taken at 4.5, 11.3, 17.0, 22.5 and 26 seconds respectively are displayed. It can be seen that a wave propagating normal to the beach from the open sea will experience shoaling of the bed. The bed shoaling causes the wavelength to reduce, and the wave height to increase. This is a typical shoaling effect. Hence, results are physically acceptable.

SIMULATING VARIOUS SENARIOS FOR BEACH PROTECTION AND DEVELPOMENT:

Three simulations were performed to study beach protection and development. The first simulation is performed to account for the current configuration of the island. The second is performed when a water passage is created by removing the web connecting the beach and the island. The third is performed when a breakwater is used to attenuate waves. The alignment of the breakwater forms a pool surrounded by the breakwater, the atrificial island and the shore. Results are presented in Fig.11 with left column showing the current situation. The figure shows the wave pattern when a wave is propagating towards the shoreline. It is clear that wave propagates past the island and water behind the island is not affected. Hence, the water behind the island is stagnant and the wave is damped. The island is behaving as a breakwater for the shore.

In the second simulation, the island is completely detached from the shore. Results are presented in Fig. 11 (middle column). It is clear that, the stagnant water spots that once appeared in Fig. 11 (left column) are disappeared in Fig. 11 (middle column). Some numerical oscillations can be observed at the upstream part of the island due to corner effects. However, these oscillations do not propagate in the domain of interest on the shore side. One can observe an interaction between the water from both sides. This of course is good from environmental point of view to provide healthy environment for the ecosystems on the seabed.

In the third simulation, the breakwater is schematized as a reflecting boundary parallel to the shoreline at a distance of 120 m from the shoreline. Results are presented in Fig. 11 (right column). It can be seen that the domain in the lee side of the breakwater is calm because the propagating wave is partly reflected and partly dissipated by the breakwater. So, it can be used to avoid the trash accumulation on the beach.

ANALYSIS OF THE ENVIRONMENTAL IMPACT ON THE DEVELOPMENT:

The artificial island intercepts water circulation. It has adverse consequence on the biological existence and builds up a stagnant water body where floating trash accumulates on the onshore side of the artificial island.

If the web connecting the artificial island to the shore is cut and replaced by a light bridge, circulation between north and south parts of the beach will be resumed. The circulation will prevent trash from accumulation and preserve a suitable biological habitat for the existing fauna. However, in choosing the width of the opening between the artificial island and the shore (which is equal to the bridge length), due attention must be paid to the phenomenon of narrow water bodies connecting two open seas (Elzeir and Hibino, 1999 and 2000). At the entrance of a narrow water body, fields propagating from the open seas are reflected; hence the narrow water body prevents exchange and transport between the open seas. Also, after removing the web, the artificial island will work as a detached (offshore) breakwater, with the possibility of sediment accretion in the onshore side of the artificial island (US Army Corps of Engineers, 1989 and Omran, 2000). Accretion must be studied in order not to re-close the passage between the artificial island and the shore.

Daniel (2001) divided methods of beach restoration into three categories; namely, hard structures (seawalls, bulkheads, groins, jetties, and breakwaters), soft stabilization (sand replenishment, and vegetation), and relocation of threatened buildings. Hard structures are suitable to protect onshore properties. However, they are not suitable to protect recreation beach against erosion (US Army Corps of Engineers, 1989). Hence, breakwater suggested by the owner and seawalls built by the neighbors are seriously detrimental to the recreation beach.

Although beach nourishment by sand borrowed from offshore sites or inland sites may have short-term impact on the existing biological habitat, its long term impact is favorable while that of hard structures is usually unfavorable (US Army Corps of Engineers, 1989, and Burlus et al, 2001).

Guild (1999) explained in detail how sand nourishment helps the beach to adjust so that it breaks attacking waves as far offshore as possible. In general, high steep waves move material offshore; and low mild waves of long period move material onshore (US Army Corps of Engineers, 1989). Hence, during storms where waves are steep, sand is transported offshore; while normal wave climate returns sand from offshore onto the beach.

An artificial reef far offshore can help attenuating waves in the deep sea before approaching the beach. The artificial reef can be designed so that it has positive impact on the biological environment. Munõz-Petez et al (2001) stated that no equilibrium beach profile is possible within a distance less than 30-100 meters from the edge of the reef.

PROPOSED STRATEGY:

As the beach has not been fully developed yet, there should be detailed survey of the beach bathymetry, and geometry, bed material, and biological structure.

Pilcher and Alsuhaibany (2000) investigated reefs in the Red Sea. From among their recommendations is that "*Egypt needs to implement integrated coastal area management plan and a review and upgrade of existing regulations to protect coral reefs that are coming under strong development pressure*"

A general beach development plan must be established. The plan includes guidelines regarding methods of beach protection and replenishment, and wave attenuation. Hard onshore or near-shore structures should be avoided. Sand replenishment is determined through monitoring rate of replenishment on the beaches of El-Ain El-Sukhna. Offshore artificial reef can be used to attenuate waves before coming closer to the shore. While rough

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sea may bother some recreation-seekers, extremely calm (still) seawater is not favorable. Therefore, artificial reef to attenuate waves is more preferable than breakwaters that completely damp waves.

A continuous monitoring must follow the implementation of the above-mentioned design. Monitoring stations should be located north and south to the developed area as well as within the developed area. Considering beach hydrodynamics, monitoring should include bathymetry, sand budget, wave climate, and water currents. Surveying the beach once a year for bathymetry and sand budget are sufficient. Continuous monitoring of wave climate and water currents at north and south stations (as inlets and outlets of the developed area) should be sufficient.

Sand nourishment should be accomplished at the beginning of winter, just before the storm season (Guild, 1999). Meanwhile, annual monitoring for bathymetry and sand budget should take place at the end of summer, after the main recreation season and before adding the new sand nourishment.

It is recommended that businessmen owning the resorts be involved in the suggested investigation. This way, public awareness recommended by Pilcher and Alsuhaibany (2000) is enhanced.

CONCLUSIONS:

Egyptian government is developing the beaches of El-Ain El-Sukhna, on the Gulf of Suez through the investment of businessmen. The interest of the businessmen who want to satisfy the recreation-seekers usually should take into account environment sustainability. This research investigates the current situation depending on preliminary survey of one of the sites in El-Ain El-Sukhna and numerical analysis of wave propagation. Then, a comprehensive development project is suggested to maintain environmental friendly sustainable development of the area. Simulations show the usefulness of using simple numerical models to provide at least, in this study, qualitative assessment of beach protection and development.

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NOTATIONS:

The following symbols are used in this paper:

c:	wave celerity
g:	gravitational acceleration
h:	water depth
i, j:	indices for nodal points
k:	index for time steps
t:	temporal coordinate
Δt:	size of time step
x, y:	spatial coordinates
$\Delta x, \Delta y$:	sizes of spatial steps
η:	surface elevation
Ω:	domain of interest
ENODC:	Egyptian National Oceanographic Data Center.
NNW:	North to Northwest

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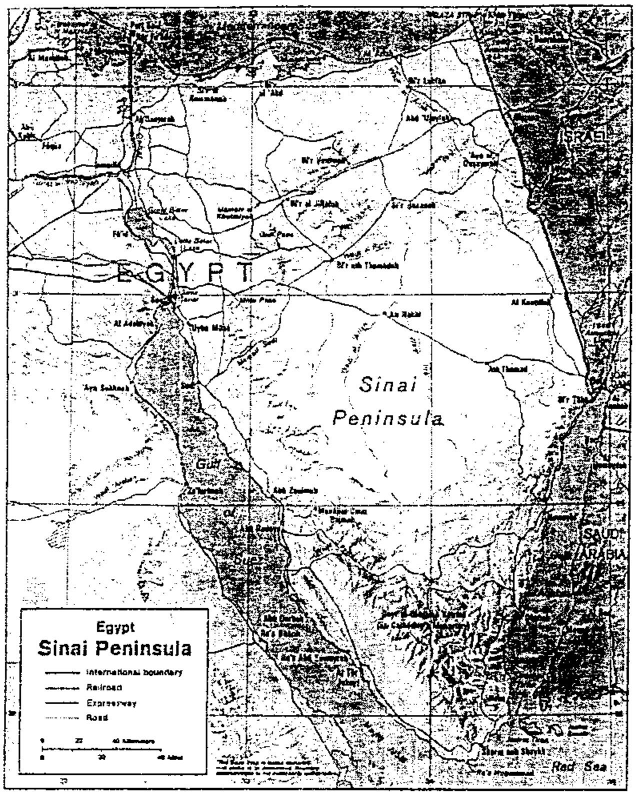

Figure 1. Location of El-Ain El-Sukhna near the Gulf of Suez on the Red Sea.

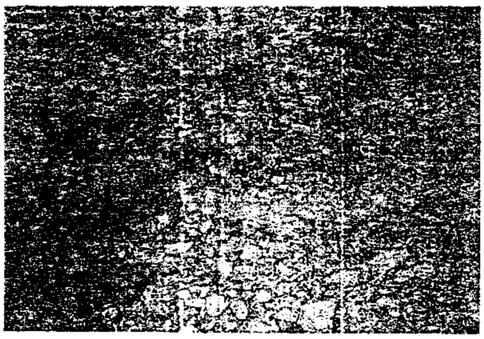

Figure 2. Native bed material at El-Ain El-Sukhna.

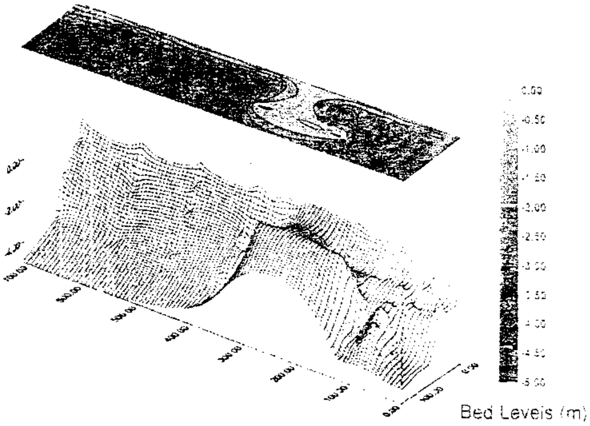

Figure 3. General layout and bathymetry of the tourist village.

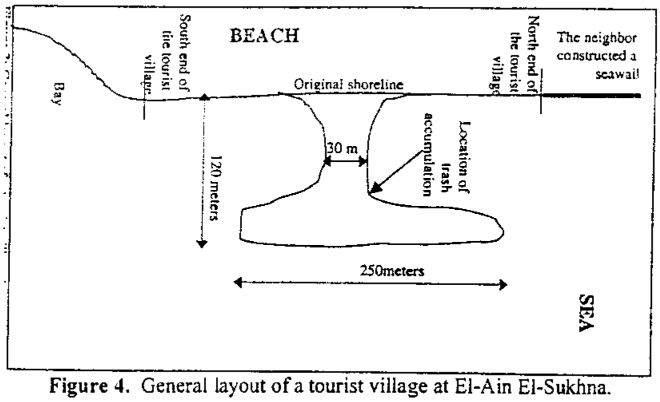

Figure 4. General layout of a tourist village at El-Ain El-Sukhna.

Figure 5. Artificial island constructed on the beach.

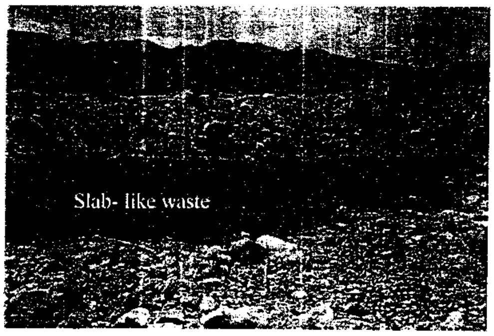

Figure 6. Construction waste dumped on the beach seriously compacted the soil

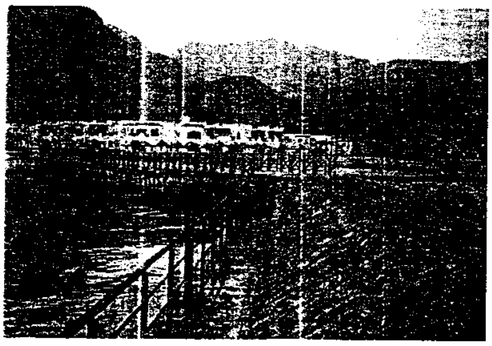

Figure 7. Artificial island connected to the beach by a light steel bridge

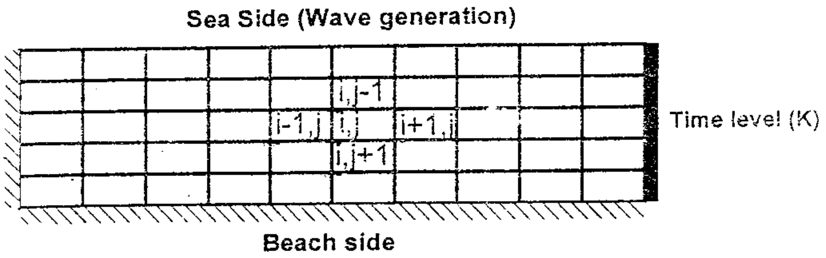

Figure 8. Domain discretization and boundary conditions.

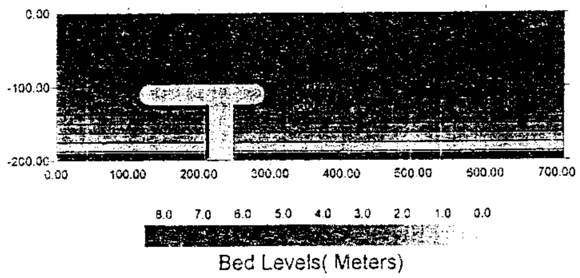

Figure 9. Schematized profile of the bottom topography and shore line for model implementation.

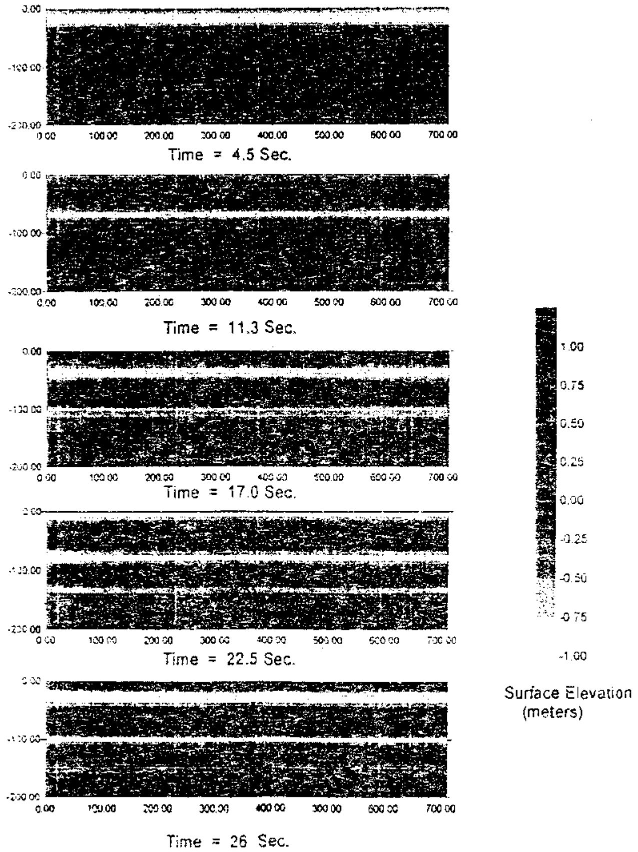

Figure 10. Results of simulating an idealized beach test case.

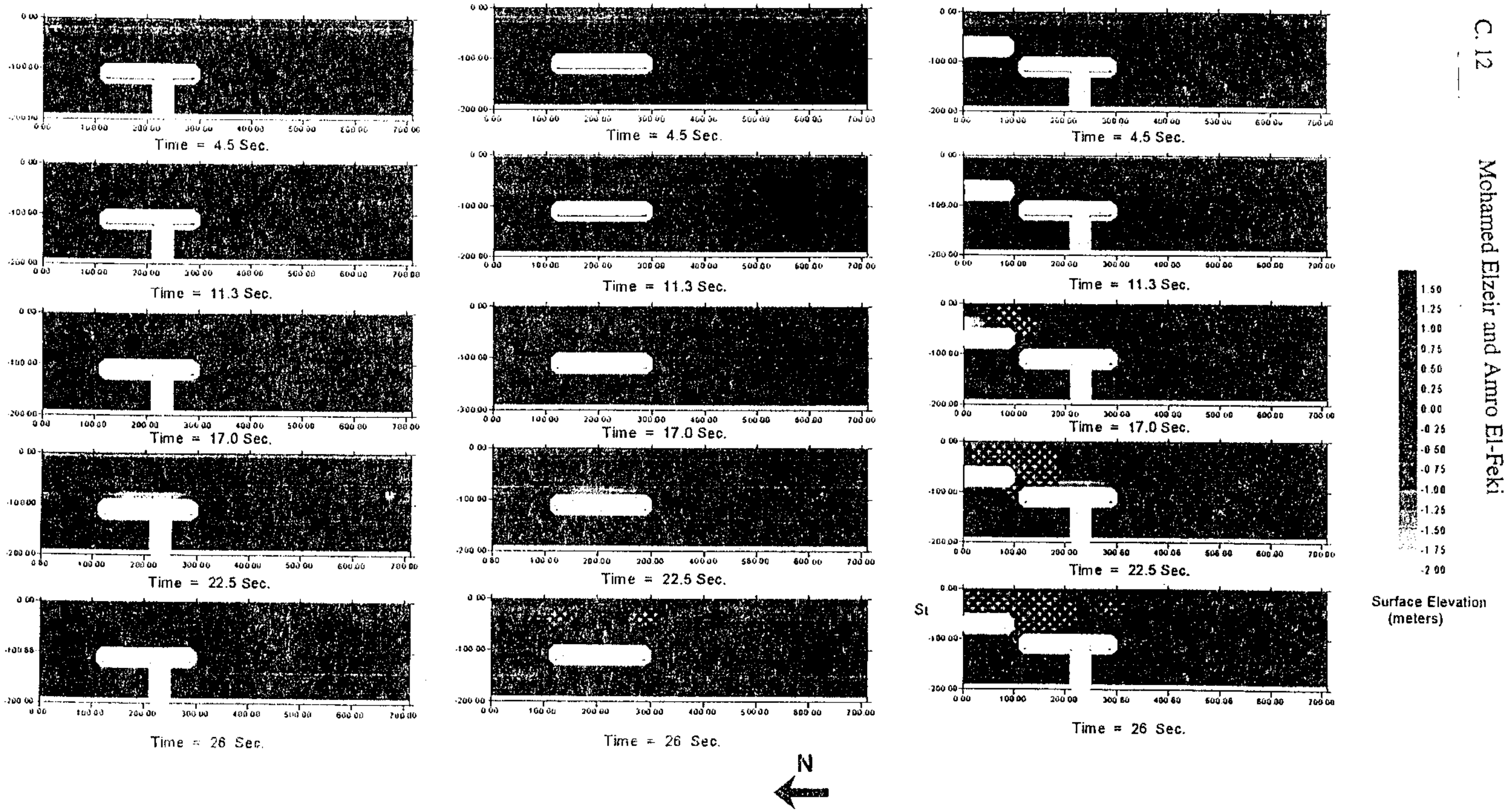

Figure 11. Numerical simulation of wave pattern of the current situation and the proposed solutions: Left column is the current situation, Middle column is the case of having a water passage across the artificial island, and right column is the case of a breakwater.