Numerical simulation of shoreline change at Marabela resort along the Mediterranean sea

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This paper attempts to predict the shoreline change due to the detached breakwaters in Marabella village, at the northern coast of Egypt. Many simulation of shoreline change were carried out using different quantities of sand bypassing. The quantities required to restore the eroded beach are found to be about 40000 m^3 per year. The study takes into account the variation in the transmission coefficients with time. The numerical model GENESIS for shoreline change is used in this study. The model is best suited to situations where a systematic long-term change of shoreline position exists.

أعــدت هــذه الدراسة باستخدام نموذج عددي يحاكي تغير خط الشاطئ بالطبيعة وتم تطبيقه على منشأة تتكون من أربعة حواجز أمواج متقطعة موجودة في قرية مارابيلا السياحية والتي تقع غرب الإسكندرية وذلك باستخدام طرق المعالجة الحالية (تغذية خط الشــاطى بالــرمال) , وقــد وجد ان الكمية اللازمة لوقف تقدم النحرتساوى حوالى 40.000 (أربعون الف) متر مكعب / عام أخذا فى الاعتبار التغير فى معامل نفاذية الحواجز مع الزمن .

Keywords: Longshore sand transport, Numerical model, Shoreline change model, Shore protection, Detached breakwaters

1. Introduction

Formation of the sand-spit begins soon after constructing the breakwater. For most detached breakwaters approximately 50% of the sand volume is deposited in the first year with a steady state usually being reached after 5 to 10 years, Herbich [1]. The main factor controlling the behavior of detached breakwaters are; distance offshore, length, orientation angle, gap width and transmission characteristic of the breakwaters. The other factors related to the waves include, mean height, period and predominant direction (Harries and Herbich [2] Dally and Pope [3] Komar [4]).

The objective of this work is to predict the change in the shoreline due to the existence of the detached breakwaters at Marabella village. Also, the work attempts to propose a remedy to minimize the accretion and erosion problems. The solution depends on using sand bypassing with different amounts from the accreted area in the upstream of the breakwaters to the eroded area in the down stream of the breakwaters.

This study uses GENESIS model which is based on the one-line theory. This means that the beach profile moves parallel to itself, and therefore, any point on the profile is sufficient to specify the profile. One contour line can be used to describe change in the beach plan shape (Hanson and Kraus [5-7].

The equation governing shoreline change is based on conservation of sand and is given by;

$$\frac{\partial y}{\partial t} - \frac{1}{(D_B + D_C)}\left[\frac{\partial Q}{\partial X} + q\right] = 0\,. \tag{1}$$

Where:

y is the shoreline position,
t is the time,
D_B is the average berm height,
D_C is the depth of closure,
Q is the long shore sand transport rate,
X is the distance alongshore, and
q is the sand transport rate per unit width of the beach.

The empirical formula for the long shore sand transport rate used in GENESIS is;

$$Q = (H^2 C_g)_b \left[a_1 \sin 2\theta_{bs} - a_2 \cos\theta_{bs} \frac{\partial H}{\partial X}\right]_b . \tag{2}$$

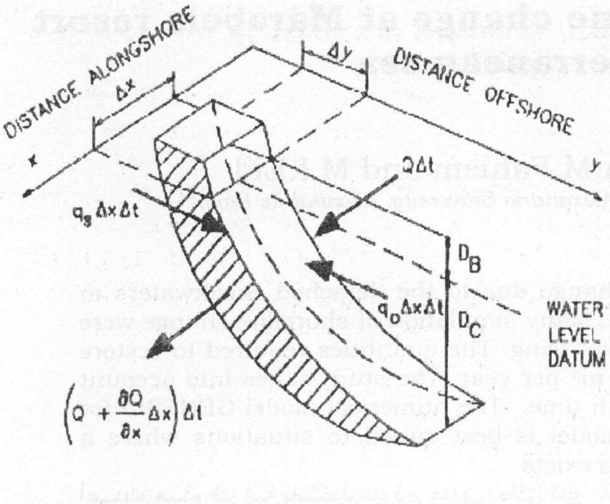

Fig. 1. Conservation of sand [7].

Where;

H_b is the breaking wave height,
C_g is the wave group velocity given by linear wave theory,
b is the subscript denoting wave breaking condition, and
θ_{bs} is the angle of breaking wave crest to the local shoreline.

The nondimensional parameters a_1 and a_2 are given by;

$$a_1 = \frac{K_1}{16(\rho_s/\rho - 1)(1-p)(1.416)^{5/2}}, \quad (3\text{-a})$$

and

$$a_2 = \frac{K_1}{8(\rho_s/\rho - 1)(1-p)\tan\beta(1.416)^{7/2}}. \quad (3\text{-b})$$

Where:

K_1, K_2 are the empirical coefficients (calibration parameters),
ρ_s is the density of sand,
ρ is the density of water,
P is the porosity of sand on the bottom, and
$\tan\beta$ average bottom slope from the shoreline to the depth of active long shore sand transport.

The diffraction coefficient due to a gap between two sources of diffraction, such as adjacent tips of two detached breakwaters, is given by;

$$K_D = K_{DL} K_{DR}. \quad (4)$$

In which K_{DL} and K_{DR} diffraction coefficients corresponding to the diffraction source on the left and right sides of the gap. The model uses an approximate diffraction model for random directional waves (Goda et al. [8]) , as described by Kraus [9, 10]) .

2. Marabella village

Marabella tourist village is located at the western coast of Egypt, 65 km to the west of Alexandria. The village has straight sandy beach with length 800 m. This beach is exposed to waves and currents. To create calm water for swimming and sporting, four detached breakwaters were constructed in 1993 aligned parallel to the beach. The breakwaters make an angle of 26^0 to the north.

The breakwaters consist of two layers of Dolos as armor layers, and rock core. The average elevation of the crest above the mean sea level, is one meter. The length of each segment of the three western breakwaters is 100m, and that of the eastern segment is 75m. The gap width is 50m, and the distance to the original shoreline is 95m. Salient were formed behind each segment, and serious erosion took place in the down drift area at the eastern side. The eroded area is located in front of The Suez Canal village and extends about 500m along shore. Since 1996, the salients are removed yearly by mechanical bypassing and placed at the down drift. The shoreline recession reached the buildings in the Suez Canal village, and waves began to damage them.

Scour was observed at the toes of most breakwaters, which in turn caused settlement along the breakwaters. The settlement occurred at different places and some of the Dolos units became under the water surface, especially at the tips of breakwaters. The settlement ranges from high value in the tips to low value at different distances from the tips for all the breakwaters. The settlement is increasing with time. This increases the amount of wave transmission.

Local wave data describing the Marabella beach was not available. The average seasonal wave data, is used to extract the annual wave climate, El-Serafy [11]. The wave rose shows that the waves come predominantly from the quadrant W-NW-N and exceed 0.9m for about 20% of the time. It also shows that the study area is subjected to a season of strong wave from January to March followed by three moderate seasons from April to December. Table 1 shows the direction, elevation, and period, of each wave data set, as percentage of the total time [12].

Fig. 2 shows the original shoreline position. The western breakwater was built; during the period from 19/10/1990 to 7/11/1990 .The second, third and fourth breakwaters were built, between 1/5/1991 and 1/10/1991, 3/10/1991 and 1/11/1991, 18/5/1993 and 11/8/1993, respectively, fig. 3.

Table 1
Characteristics of effective wave propagation

Direction	Mean height H, meter	Mean period T, sec	% of wave occurrence
NE	$H < 0.9$	< 5	5.7
	$0.9 < H < 1.5$	$5 - 7$	1.5
	$1.5 < H < 2.4$	$6 - 9$	0.7
N	$H < 0.9$	< 5	11.1
	$0.9 < H < 1.5$	$5 - 7$	2.1
	$1.5 < H < 2.4$	$6 - 9$	1
NW	$H < 0.9$	< 5	21.5
	$0.9 < H < 1.5$	$5 - 7$	7.68
	$1.5 < H < 2.4$	$6 - 9$	3.33
W	$H < 0.9$	< 5	9.2
	$0.9 < H < 1.5$	$5 - 7$	4.3
	$1.5 < H < 2.4$	$6 - 9$	3.2
28,7 % of the waves blow in offshore direction.			$\Sigma = 71.3$

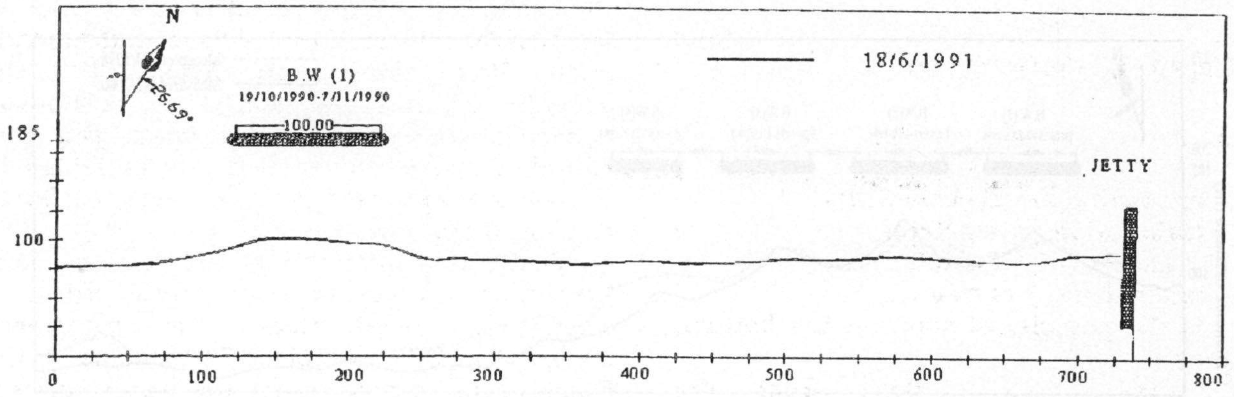

Fig. 2. Shoreline after the first stage, 18/6/1991 [12].

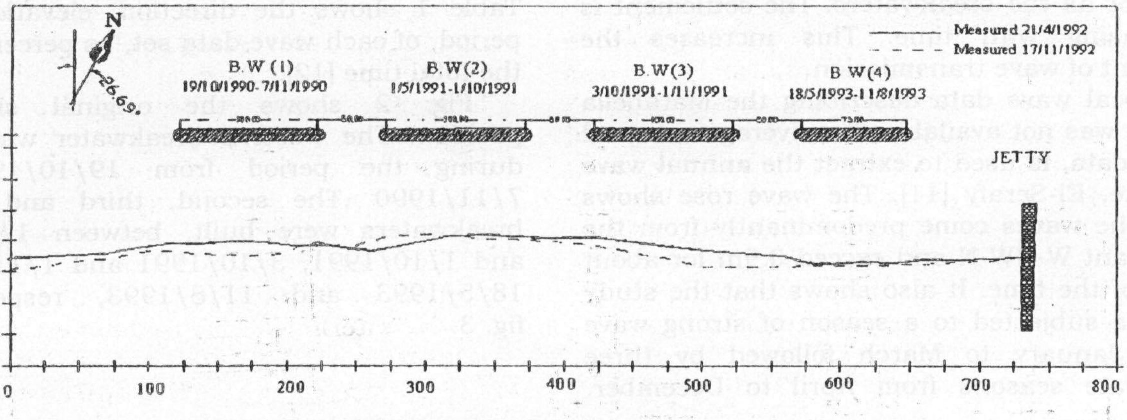

Fig. 3. Shoreline after completing the 4 breakwaters [12].

The Jetty, to the east of Marabella, was constructed at the beginning of the project 1991. The Jetty trapped the sand and prevented its movement to the Suez Canal village area. It was removed in 1995.

All of the available shoreline measurements did not cover the region to the east of the jetty. In recent years, mechanical bypassing is used for restoring the sever erosion problem. It started by the end of spring, 1997, to transport the sand from the accretion area behind the detached breakwaters to the erosion area. This is still being done every year by the beginning of the summer.

A shoreline survey was carried out on 20/4/1998. To calibrate the model, a new survey was carried out on 8/5/2000, fig. 4. The new surveyed points were selected at 10 m spacing along the general trend of the shoreline.

3. Model calibration procedure

The depth of closure D_c is taken 6 m, the time step Δt used in the calibration is 2 hours. The mean grain size of the sampled soil is 0.32 mm. This is the average of three samples. The long shore cell spacing was 10 m and 130 cells total. The two-shore line surveys used to calibrate the model are those of 1991 and 1992. The first of them was carried out just after the construction of the west breakwater. The second shoreline survey was carried out after the construction of the fourth breakwater. The final values of the long shore sand transport calibration coefficients are K_1= 0.4, K_2= 0.22. The final transmission coefficients for the detached breakwater, K_T, are 0.5, 0.2, 0.2 and 0.55, respectively from left.

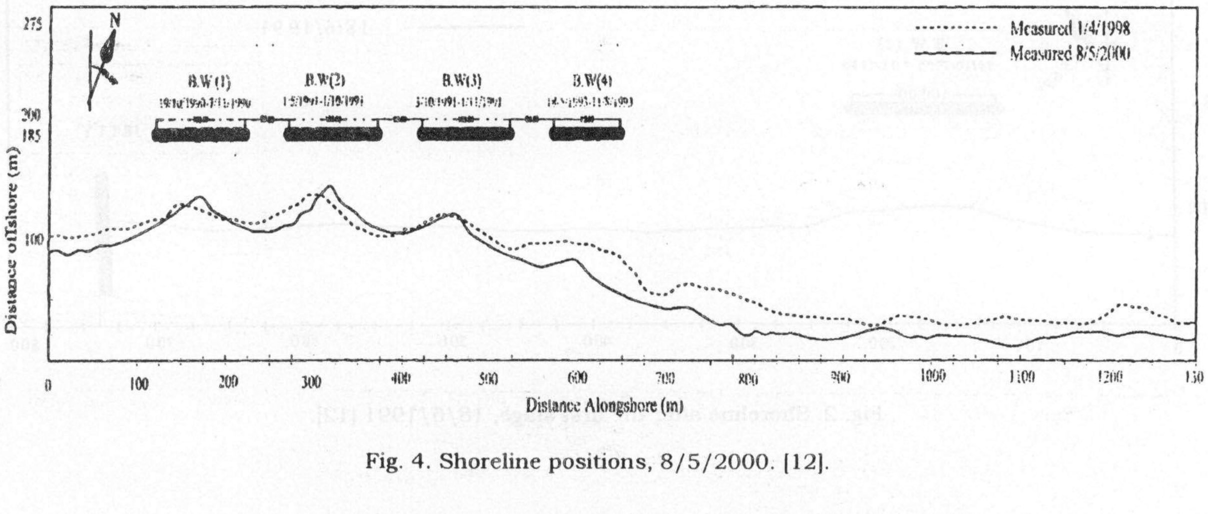

Fig. 4. Shoreline positions, 8/5/2000. [12].

One of the limitations of the model is that, it considers contour lines parallel to the shore line .To over come this limitation it was necessary to rotate the wave direction by 8 degrees to the east and reduce the wave height by 0.7. This leads to a close agreement between the measured and predicted shoreline. Those correction take care for the reflection, shoaling and dissipation effect. (Hanson et al. [5]). Fig. 5 shows that the predicted shoreline position agrees well with the one measured on 8/5/2000.

4. Model prediction

By varying the wave height and direction within a physically reasonable range, a series of shoreline change prediction is made within which the actual change is expected to lie. Variation of input parameters is also a part of the sensitivity analysis to be performed to obtain some idea of the model dependence on the parameters. It was found that GENESIS is insensitive to small changes in the parameters. Depending on the visual observations of the breakwaters and their deteriorations and settlement with time it is obvious that the transmission coefficients increase with time. This is taken into account in the prediction. If maintenance of the breakwaters is carried out in the future, another values must be considered.

Five alternative simulations are considered in this paper. The first two of them neglect sand bypassing, while the other three take it into account. In, case A, the transmission coefficients for the breakwaters are kept constant with values of 0.5,0.2,0.2 and 0.55, respectively. While, in case B, the previous values of the transmission coefficients are increased by 0.05 per year. Fig. 6 shows the results for cases A and B.

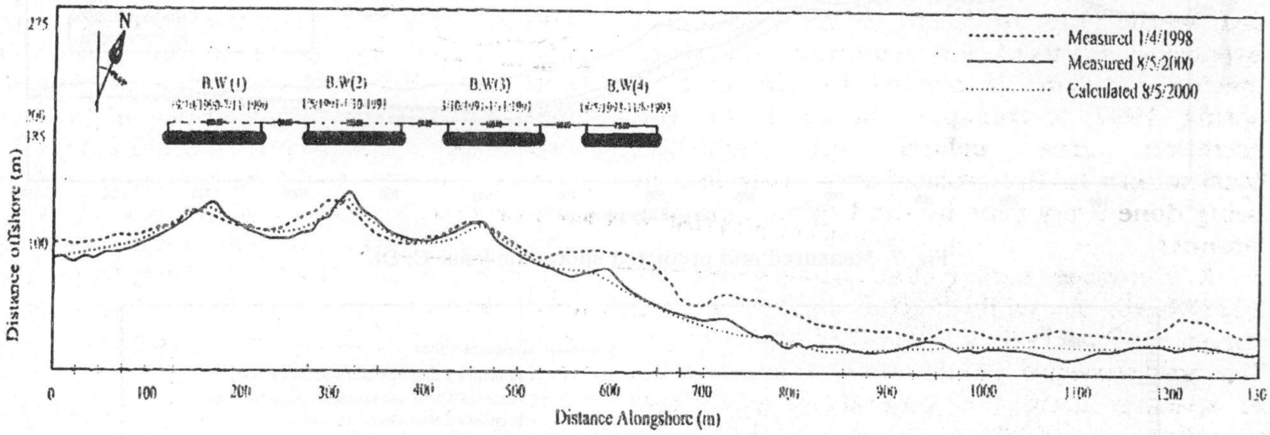

Fig. 5. Results of model calibration.

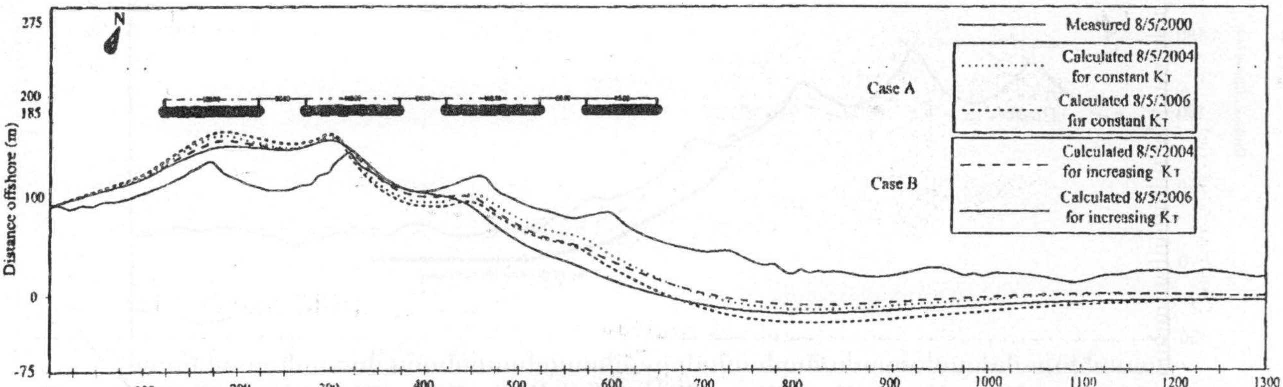

Fig. 6. Measured and predicted shore line (case A, B).

Case C handles current treatment method; sand bypassing with 26,000-m³/ year from the accretion area to the eroded area. The transmission coefficients are kept constant with the values given in case A. Case D shows the effect of sand bypassing, 26,000 m³/ year with increasing transmission coefficients as given in case B. Fig. 7 shows the results for cases C and D.

To find the minimum amount of sand bypassing needed to prevent any increase in the eroded area, many runs were carried out with different amounts of sand. It was found that using 40,000 m³/ year give reasonable results. Fig. 8,case E shows the outcome of this case for different bypassing times (April, December) and different simulation times (2 years, 4 years). Fig. 8 shows the most suitable locations for feeding and extracting sand.

5. Results

It was found that the expected increase in the transmission coefficient due to settlement of the breakwaters could not help stopping the accretion in the Marabela village and the erosion in the down drift, Suez canal village, parts of the beach. This is shown in cases A and B. Using sand by passing, 26,000 m³/year with and without increasing the

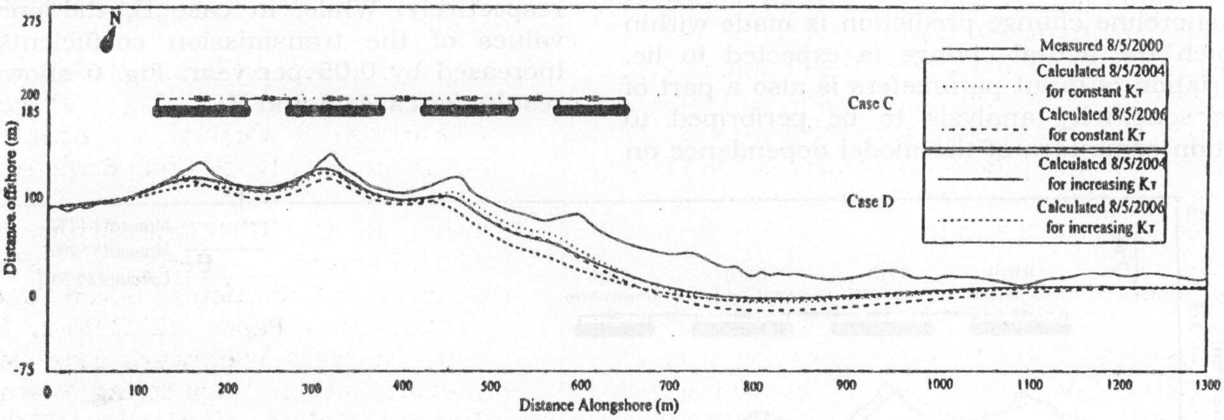

Fig. 7. Measured and predicted shore line (case C, D).

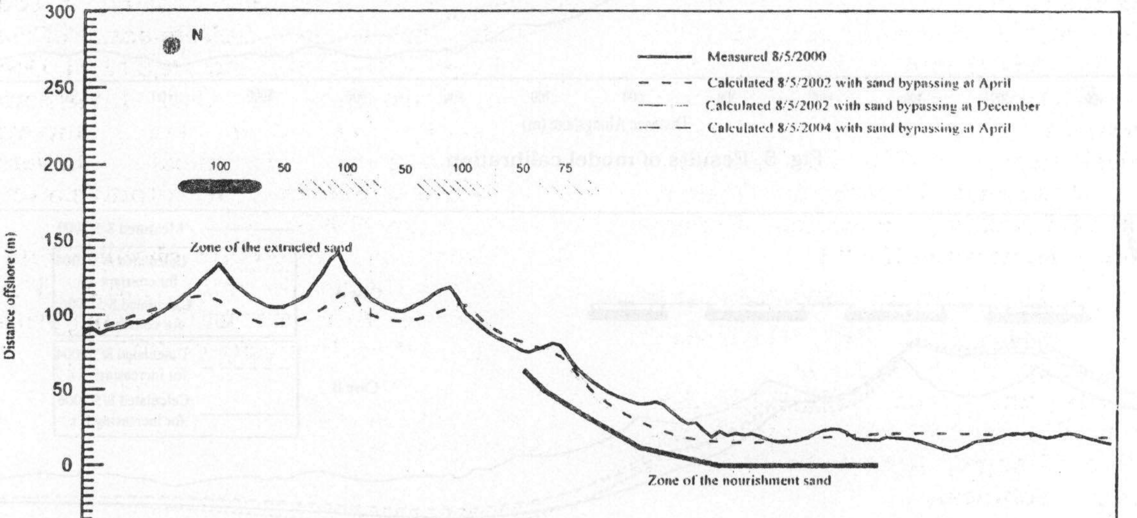

Fig. 8. Shoreline position calculated with sand bypassing (from accretion area to erosion area) with rate 40000m³ per year.

transmission coefficient did not help to prevent the erosion in front of the Suiz canal village. However, this helped in reducing the accretion in the area facing the breakwaters.

Finally, using 40,000 m^3/year for sand bypassing stopped the accretion in the Suez canal village beach and at the same time caused a recess in the shore line at the Marabela village.

5. Conclusions

From the previous predictions, it was found that increasing the transmission coefficients accompanied by sand bypassing with 26,000 m^3/year does not give satisfactory solution to the erosion and accretion problems. It leads to partial reduction in the rate of accretion facing the breakwaters. Increasing the sand bypassing to 40,000 m^3/year, in the model, caused the shoreline to recess in front of the breakwaters. At the same time, the shoreline started to advance slowly in the Suez canal village.

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