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Numerical Modeling of Waves and Currents by Using a Hydro-Sedimentary Model

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Abstract**—**Over recent years much progress has been achieved in the fields of numerical modeling shoreline processes: waves, currents, waves and current. However, there are still some problems in the existing models to link the on the first, the hydrodynamics of waves and currents and secondly, the sediment transport processes and due to the variability in time, space and interaction and the simultaneous action of wave-current near the shore. This paper is the establishment of a numerical modeling to forecast the sediment transport from development scenarios of harbor structure. It is established on the basis of a numerical simulation of a water-sediment model via a 2D model using a set of codes calculation MIKE 21-DHI software. This is to examine the effect of the sediment transport drivers following the dominant incident wave in the direction to pass input harbor work under different variants planning studies to find the technical and economic limitations to the sediment transport and protection of the harbor structure optimum solution.

Keywords**—**Swell, current, radiation, stress, mesh, MIKE21, sediment.

I. Introduction

PORT structures can be set up by the natural construction of one or several dikes or jetties. A wrong calculation in the design of port structures can lead to problems of penetration of long waves followed by formation of currents in the basin. As a result, large amounts of sediments may be transported silt up accumulated for the harbor basin. This process results from the sediment movement inshore areas, in fact, considerable amounts of sand and non-cohesive suspended sediment are transported by the action of waves and currents. When the waves reach the coast and break on the beach, they generate coastal currents that interact with the wave's incident to transport sediment [1]. Waves are essential movements of sediments in the nearshore, during the breaking, the wave energy from is dispelled and transformed mainly turbulence that puts moving sediments which are transported by currents it produces and/or those due to tides and winds; [2], [4]. Several authors agree on the importance of the activity of interactions between sediment and water which activate in swash zone and it is the place for exchange and sediment transportation [5], [6]. Therefore, it is important to forecast the development of sediment movement including the detecting and localization of areas of erosion and deposition at or near the shores of coastal structures arrangements and harbor basin. It is quite clear that certain coastal change is linked to anthropogenic action, such as conducting of the existing engineering structures without taking into account the marine system and interactions with the different the factors listed above.

This study is developing forecasts the sediment movement from planning scenarios harbor basin on the Algerian coasts. It is based on a set of numerical simulations with a hydro-sedimentary model in a bi-dimensional model using computer codes MIKE 21-DHI Software. It's consisting of four modules including two perfectly complementary modules concerning hydrodynamics and the study area of shoaling: MIKE 21-SW and MIKE 21-PMS, a module that provides information on the current patterns with MIKE 21-HD, and can be integrated into a module which calculates non-cohesive suspended sediment transport with MIKE 21-ST.

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II. Model Description

A. Model of Wave Agitation

Prediction models waves are generally based on the equation for energy where the energy density from the wave $E(\sigma, \theta)$, the function pulsation, and the wave direction varies slowly with space (x, y) and the temporal variable.

In the presence of the current, it is more pertinent to simulate the density of wave action $N(\sigma, \theta)$ instead of the energy density of the wave. Density of wave action is defined by [7]:

$$N(\omega, \theta, x, y, t) = \frac{E(\omega, \theta, x, y, t)}{\sigma} \tag{1}$$

The relative frequency of the wave is equal to:

$$\sigma = \sqrt{gk \tanh(kd)} = \omega - kU \tag{2}$$

Under steady conditions, i.e. when the current and wave parameters are invariant over time (relative to the time scale of the wave period), the equation for the conservation of the wave is expressed by:

$$\frac{\partial}{\partial x}(c_x N) + \frac{\partial}{\partial y}(c_y N) + \frac{\partial}{\partial \theta}(c_\theta N) = \frac{S}{\sigma} \tag{3}$$

c_x, c_y, c_θ are areas component of group velocity direction; the term S is the "spring" function varies. It represents the combined effect of the generation and dissipation of wave action; N is the density wave action.

MIKE-PMS 21 is a linear model of refraction and diffraction based upon a parabolic approximation of the elliptic equation of propagation on a gradual slope from the shore [8], it is called Parabolic Mild Slope Equation:

$$\nabla.(CC_g \nabla \phi) + \frac{C_g}{C}\omega^2 \phi = 0 \tag{4}$$

The greatness of group velocity, Cg, is expressed by:

$$C_g = \frac{\partial \sigma}{\partial k} = \frac{1}{2}\left(1 + \frac{2kd}{\sinh(2kd)}\right)\frac{\sigma}{k} \tag{5}$$

$\omega^2 = g\,k\,\mathrm{th}(kd)$ is the dispersion relationship. Equation (4) can be solved directly by the finite element method [9]. Such a model is particularly intended to study the problems of agitation harbor when the effects of diffraction and wave reflection can be significant. However, in coastal engineering, it is desirable to use a parabolic model [10].

B. Sediment Transport Model

The proposed model relies on the formulation of the Sediment Transport Program, based on a two-dimensional approach to computing horizontal (2DH) in which the sediment transport rate is calculated in the direction of the mean current with a resulting transverse component of bottom slope.

The average vertical profiles are calculated by integrating the stress of turbulent friction:

$$\bar{\tau}(z) = \rho \nu_t \left|\frac{\partial \bar{U}}{\partial z}\right| \tag{6}$$

The flow of q_b transport is calculated according to the number without associated with shear velocity in the bottom dimension [11].

The total rate of transport of non-cohesive sediments q_t is calculated by adding rate of sediment transport q_s suspension load and bed load q_b:

$$\langle q_t \rangle = \langle q_s \rangle + \langle q_b \rangle \tag{7}$$

Each rate is calculated separately. Brackets indicate that such rates are averaged during the period of the wave. The transport rate q_b is calculated according to the dimensionless number Φ by relating shearing stress in the bottom:

$$\Phi = \frac{U'^2_f}{(s-1)gD} \tag{8}$$

where s: is the relative density of the sediment, g: acceleration of gravity, D: diameter of the grain size. U'_f: is instantaneous velocity shearing associated with the skin friction. The rate of transport of the sediment suspended q_s instantaneous is calculated by:

$$\vec{q}_s = \int_0^d \vec{u}'(z,t)c(z,t)dz \tag{9}$$

where t: is the time; d: depth of water; c: volume concentration of suspended sediment; u: velocity of the combined flow of currents and waves.

The instantaneous concentration of the sediment suspended is obtained solving the following diffusion equation [12], [13]:

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial z}(\varepsilon_a \frac{\partial c}{\partial z}) + w_s \frac{\partial c}{\partial z} \tag{10}$$

C. Study of Harbour Facility

The project is extending of the shelter in Khemisti fishing harbor, it is located 30 km from the province of Tipaza, and it has in recent years very active in the fisheries sector. In order to meet concerns of the region an extension study the shelter Khemisti fishing in the fishing harbor was initiated.

The design is protected by two jetties, a main north-east for a distance of 195 m and the west side of 120 m with a password input side facing west. All along the coastline of Khemisti is developing a shoreline of elongated shape almost 2.10 km in length, which runs from the mouth of two smaller wadis (Fig. 1).

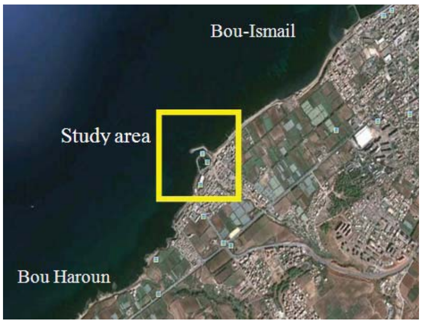


Fig. 1 Geographical location port Khemisti: Scale 1/25000

For comparing the results of the studies of the reduced model, we have used the code calculations MIKE 21 to study various alternatives for the implementation instead jetties of the harbor work.

In order to analyze the evolution of the field of radiation stresses and sediment flow, the study area has been divided into to eight profiles in longitudinal and three in transversal (Fig. 2).

Analysis of the bathymetric chart reveals an irregular morphology in the Navy between the coastline and the depth contour -4 m. Minimum altitudes, average, maximum, values correspond to: 0.00m, -22.50m, -45.00 m.

It should be noted that according to the survey results with the lance, the presence of a rocky area which extends from the shoreline to or -4 m isobath in the West and Central part of the site whereas in West party the latter reaches -10 m isobath.

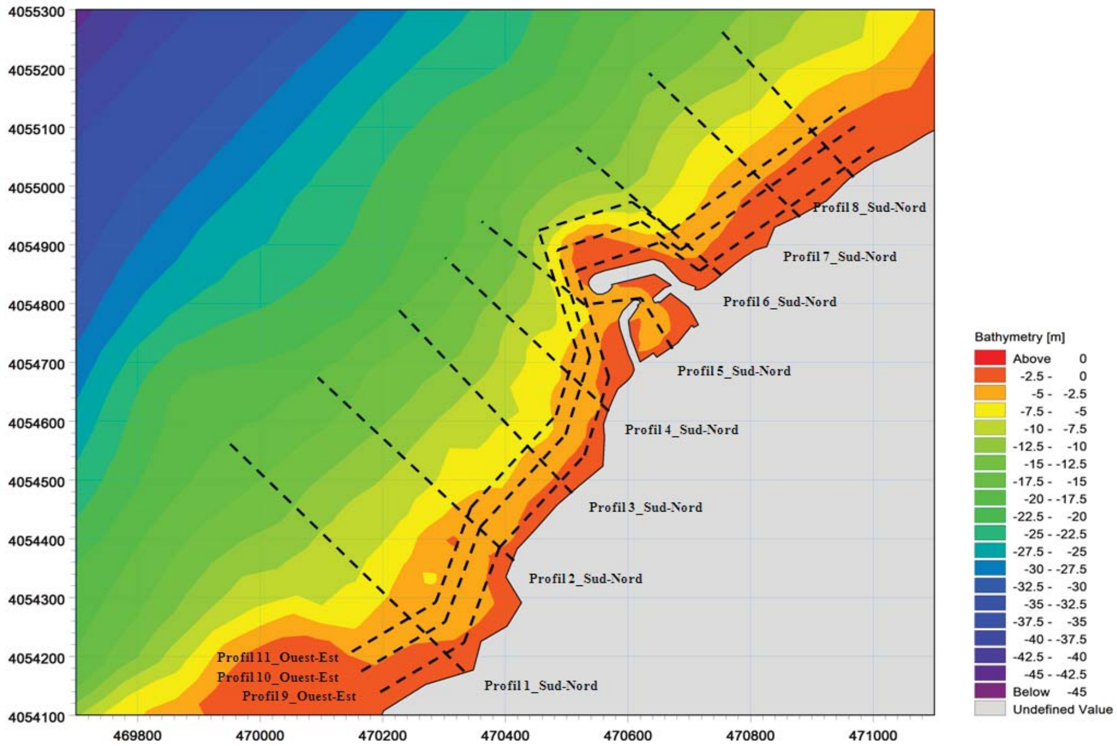


Fig. 2 Bathymetric map of the study zone with the positioning of the profiles

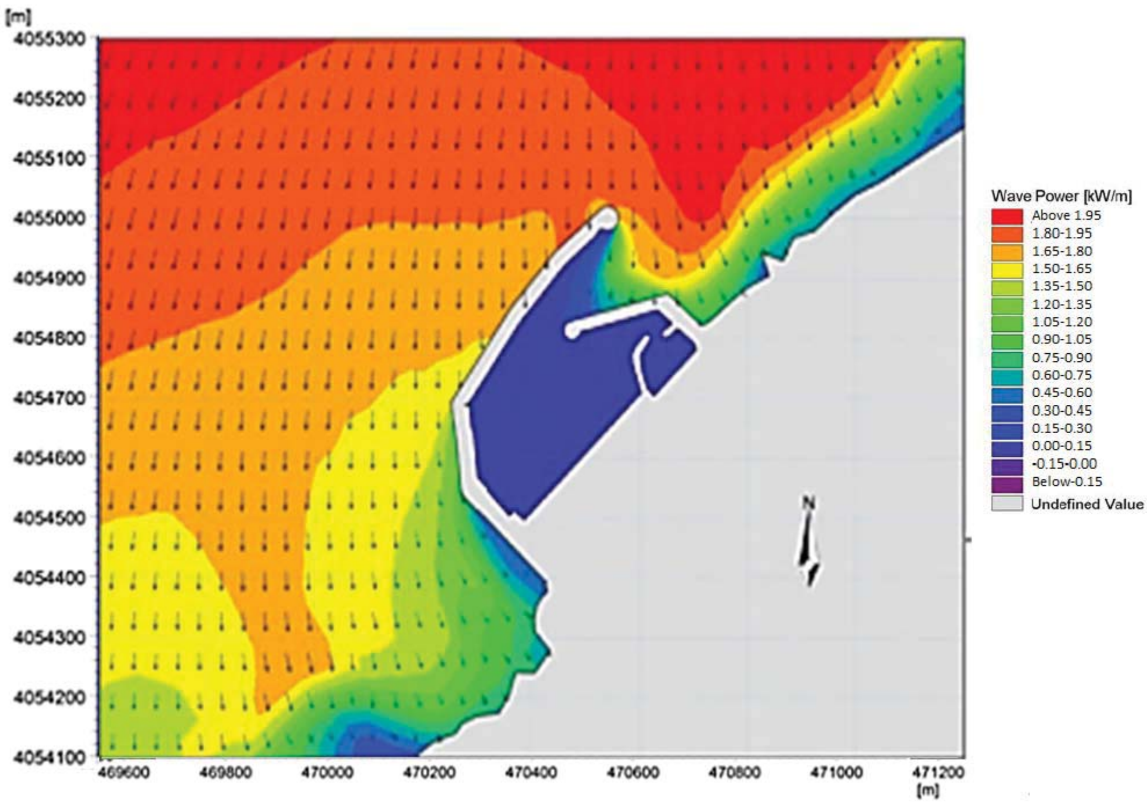
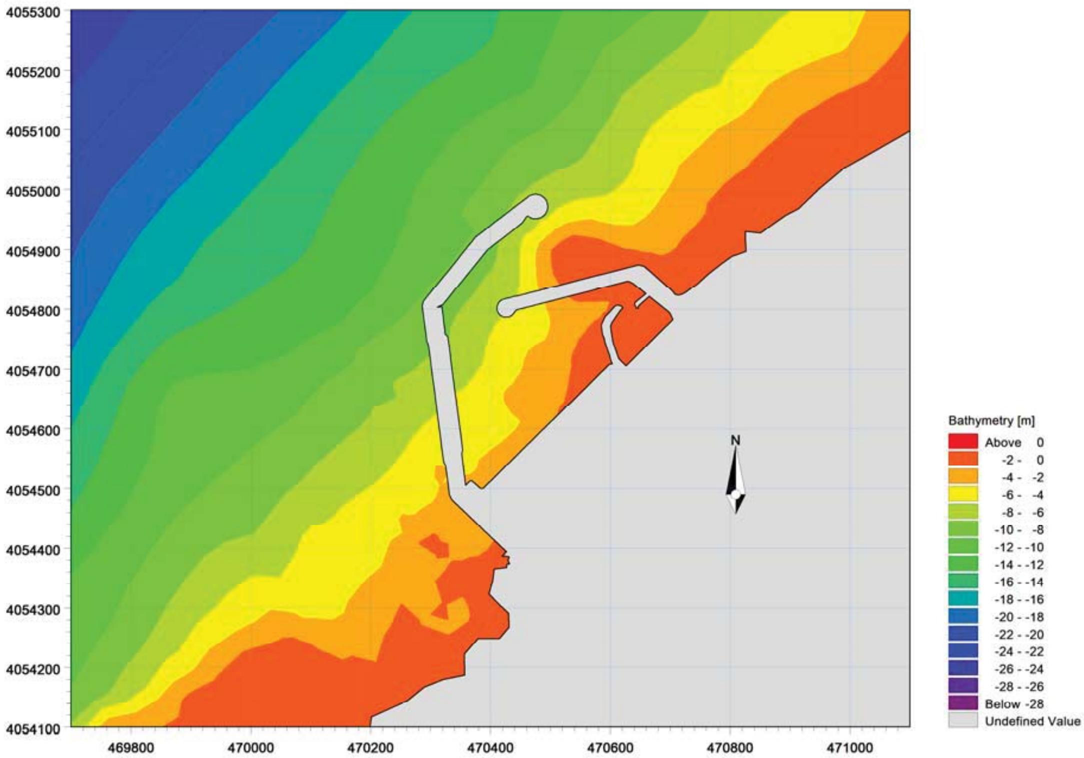


Fig. 3 Characteristic of offshore wave (MWD=30°; H_S =2.56 m; T_P=8 s)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N
Bathymetry [m]
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-4 - -2
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-8 - -6
-10 - -8
-12 - -10
-14 - -12
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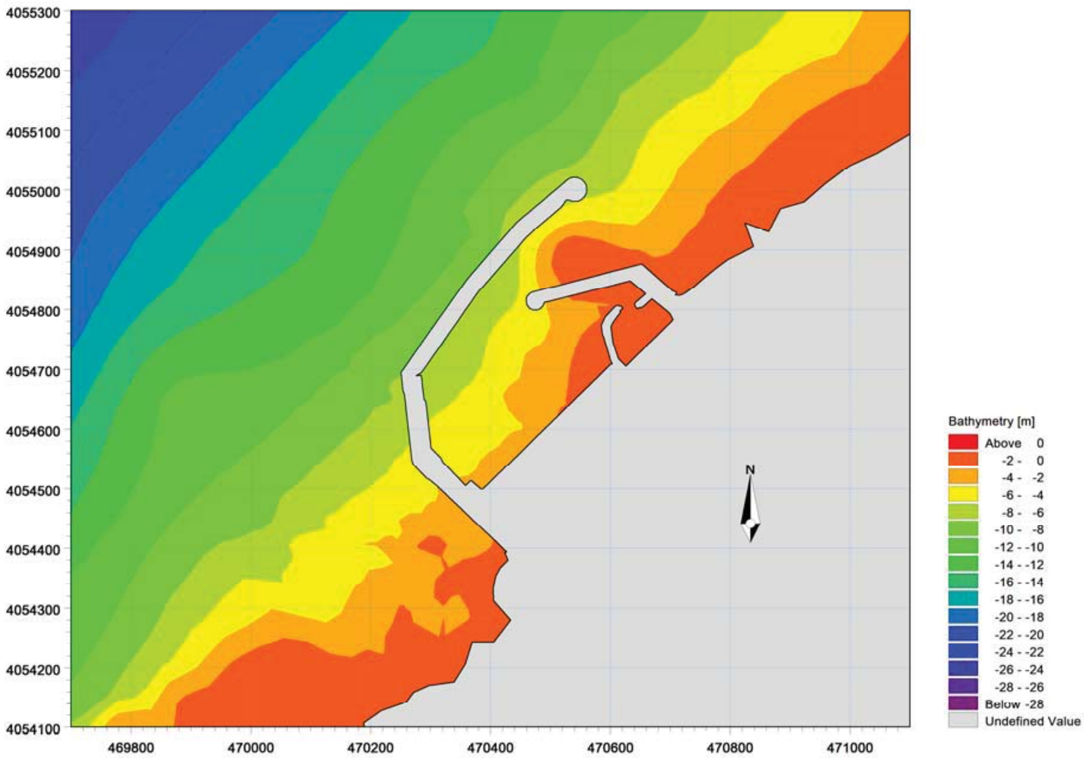
Below -28
Undefined Value

(a)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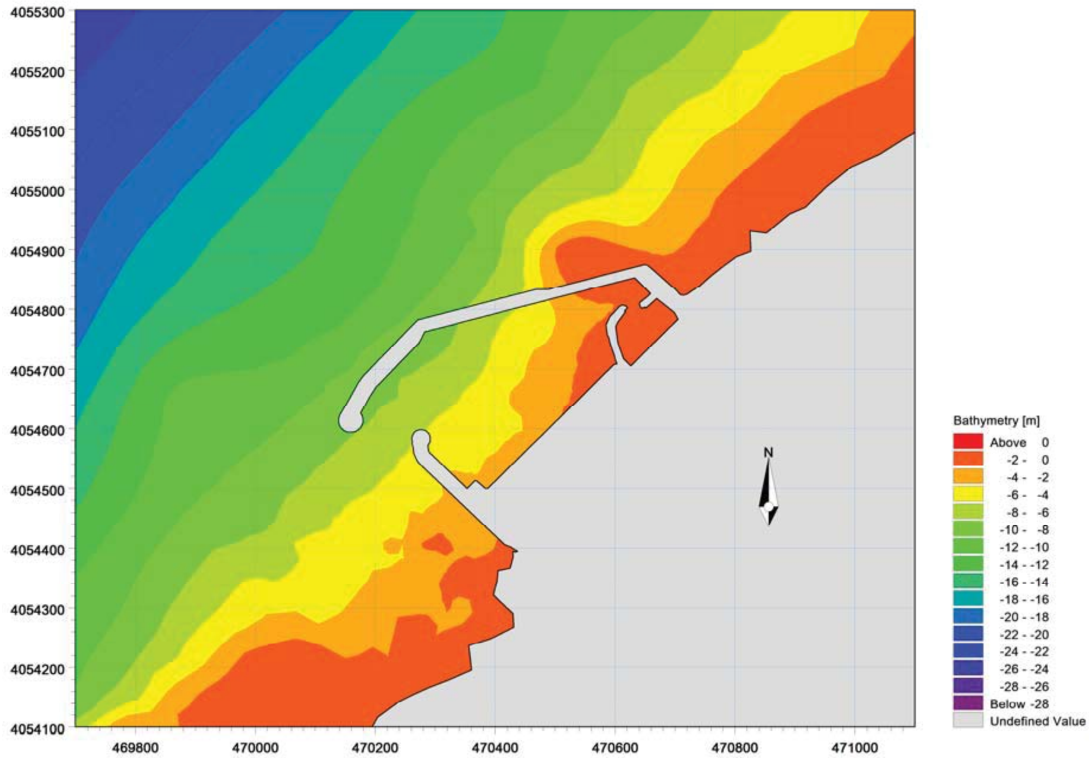


(c)

Fig. 4 Diagram of the various harbor development alternatives: (a) Alternative 1, (b) Alternative 2, (c) Alternative 3

D. Validation Testing

For generating the simulation, we have adopted four (04) classes of the most frequent and most important waves, their effect is predominant. These waves result from ship observations from 1963 to 1970 by the United States Naval Weather Command.

To verify the reliability of numerical computing codes MIKE-21, a comparative study was made based tests carried out. The wave flume is 40 m long, 0.6 m wide with a depth of 1.10 m. It is fitted with a random generator waves. Generation waves obtained by using a computer associated with a recording tape in nature and wave converted into trains of waves JONSWAP type. Each test is performed with a wave progressively increasing increments.

A bearing of the wave is characterized by significant wave height pair (H_s) and wave period (T_p). The recommended duration for each test is 15 minutes model which corresponds to a 93 sec storm nature, duration of the endurance series is 2 hours in the model corresponding to a period of 12 hours storm at the site. The distribution shows that pelites all samples has low concentrations this fraction; these levels vary between 0 and 7%. This low percentage indicates that the sediments from the Area are in perpetual reworking. In the study area, the median grain diameter (D_{50}) is between 149 to 255 µm.

TABLE I
RECAPITULATIVE OF THE INCIDENT WAVES CHARACTERISTICS SIMULATED

Direction	Period T (s)	Height H_S (m)
MWD 30°	6,0	1,1
	8,0	2,56
	10,0	5,0
	13,5	8,1
MWD 270°	6,0	1,19
	8,0	2,7
	10,0	5,5
	9,7	11,9
MWD 310°	6,0	1,10
	8,0	2,60
	10,0	4,50
	12,6	7,20
MWD 360°	6,0	1,00
	8,0	2,70
	10,0	4,90
	13,6	8,00

The wave propagation is reflected in the approach to the shore by a modification of these characteristics ie decreased wave height and deviation of the angle of incidence results from the phenomenon of refraction. Numerical modeling was used to examine the initial condition of the site and highlight the hydrodynamic factors that are behind sand encroachment of the existing harbor development (Fig. 3).

A comparative study between the results of tests on a reduced Wave Flume model and that resulting from numerical simulation by MIKE21-SW code for refraction are relatively comparable. Rightly, the maximum relative error between the values obtained in both tests does not exceed eight percent confirming the reliability and consistency of calculation results obtained refractive simulation.

The set of values of comparative parameters is shown in Tables II and III.

TABLE II
COMPARATIVE OVERVIEW MEANINGFUL HEIGHT BETWEEN THE REDUCED AND THE NUMERICAL MODEL BASED ON THE DEPTH OF WATER

Direction of waves	Period (s)	Reduced Model		
		H_s d=-5m	H_s d=-10m	H_s d=-15m
N 30°	10.0	3.85	4.85	5.00
N 45°	10.0	3.00	3.82	3.80
N 360°	10.0	3.33	4.30	4.25
N 320°	10.0	3.11	4.02	3.96
Direction of waves	Period (s)	Numerical model		
		H_s d=-5m	H_s d=-10m	H_s d=-15m
N 30°	10,0	3,83	4,90	4,87
N 45°	10,0	3,29	3,97	*4,00*
N 360°	10,0	3,48	3,66	*3,60*
N 320°	10,0	3,88	3,78	*3,44*

TABLE III
COMPARATIVE VALUES OF FACTORS REFRACTION K_r FOR PERIOD T = 10 S

Direction of waves	Numerical model		
	K_r d= -5m	K_r d= -10m	K_r d= -15m
N 30°	0.60	0,70	0,65
N 45°	0.61	0,77	0,77
N 360°	0.67	0,88	0,87
N 320°	0.75	0,97	0,95
Direction of waves	Reduced Model		
	K_r d= -5m	K_r d= -10m	K_r d= -15m
N 30°	0.61	0.72	0.67
N 45°	0.66	0.80	0.81
N 360°	0.63	0.78	0.75
N 320°	0.83	0.91	0.93

III. RESULTS AND DISCUSSION

Following the review of the site according to the four directions of the incident waves offshore by emphasizing the evolution of hydrodynamic factors caused by sediment transport.

It is apparent that the wave direction 30 ° N are the most favorable for the formation of longshore currents thus providing a driving force for sediment transport in the direction of the overlooking incident waves in the direction from west to east over the pass to the harbor entrance.

To search for a mechanism to fight against the sand encroachment of the harbor basin phenomenon, it is paramount to act directly on the direction of longshore currents generated by the incident swell following the direction mentioned above. For this, we propose to examine three structural variants aimed at mitigating the effect of the effect of the maximum alongshore currents on the pass and the harbor basin (Fig. 4).

Characteristics of Alternative 1 (a): Main jetty: 690 m, secondary jetty: 275 m, main jetty, orientation: 218° and direction secondary jetty: 75 °

Characteristics of Alternative 2 (b): Main jetty: 774 m, secondary jetty: 224 m, main jetty, orientation: 218° and direction secondary jetty: 75°

Characteristics of Alternative 3(c): Main jetty: 620 m, secondary jetty: 255 m, main jetty, orientation: 75° and direction secondary jetty: 134°

The code MIKE- ST, can determine the sediment flux based on sedimentological data from the site and allows provides an optimal solution for the construction of the alternatives studied.

Relying on the hydrodynamic and sedimentological data from the study site, three alternatives were suggested to extend the existing port jetties constituting the basin of the new port.

It is evident that longshore currents represent the ability to put moving non-cohesive sediment particles on the wave actions.

It is appropriately noted that for wave most unfavorable is direction 30°N of waves; the alternative two has relatively less affected by the sediment flux of its location at the pass and the harbor basin.

The evolution of sedimentary flow is northeast with an average specific rate equal to 1378.50 m^2/year. According to the profiles of sediment flux depending on the cumulative distance of the West Coast to the East (Localization at profile N°. 9, 10 and 11), we have estimated the max, average, min, flux sediment respectively. The following sediment discharge maximal equal 7077.10 m^2 /year that show significant sediment flux in the vicinity offshore.

To other directions of waves enumerated above, the sediments flux induced by longshore currents produces no effect on the harbor (Fig. 5).

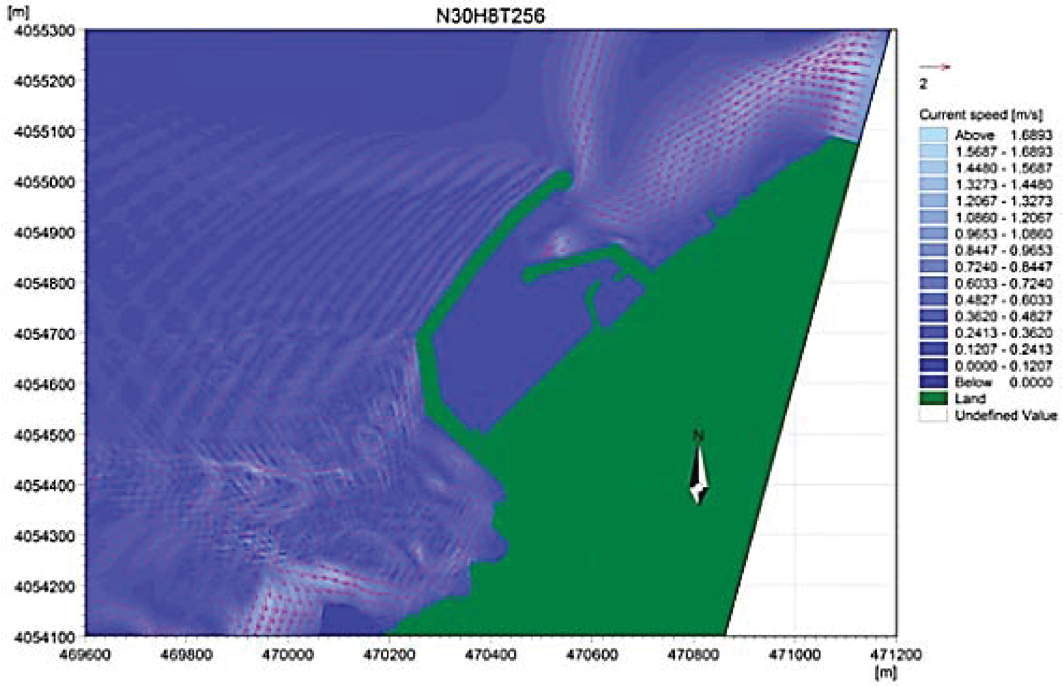
For direction 30 ° N, the flow occurring at the exit of the channel of the harbor is to be constituted as serious hinders to the transit shoreline functioning of the port.

In view of mitigating the impact of the coastal streams North-Est direction towards at the entry of the pass, place of concentration of radiation stresses favoring transportation and deposition of the sediments.

We considered it useful to provide a breakwater 258 m in length at the entrance to the entrance channel of the harbor basin in carrying modifications on different jetties as follows: 665 m for the main jetty, 182 m with the length of the pass entrance harbor basin is 120 m. It should be noted that the orientations the jetties keep the same values alternative 2 above-mentioned (Fig. 6).

IV. CONCLUSION

As from numerical simulation, is obvious that the computer code MIKE21-HD, to determine the flow velocities from the field tensor of radiation. The MIKE-ST code, to determine the sediment flux according to sedimentological data based on a hydro-sedimentary model. The review of the study of the evolution of the sediment flux as from calculation of the wave direction and refraction off for determining the velocity field of marine currents possible to identify the optimum solution planning a harbor structure in a comparatively short time.



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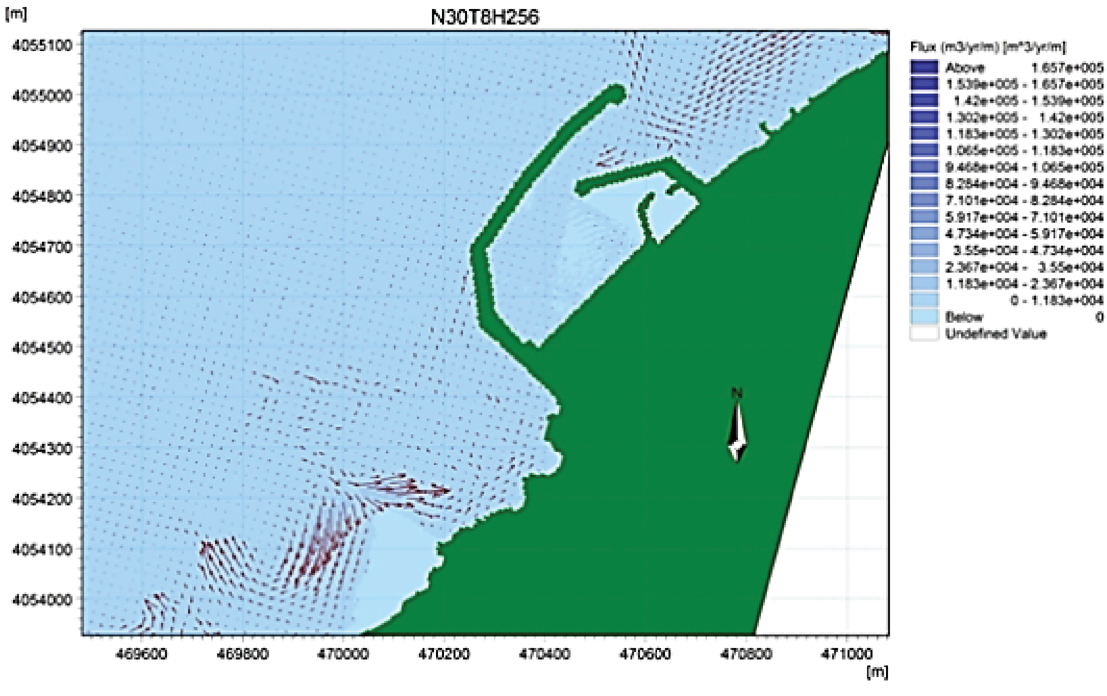
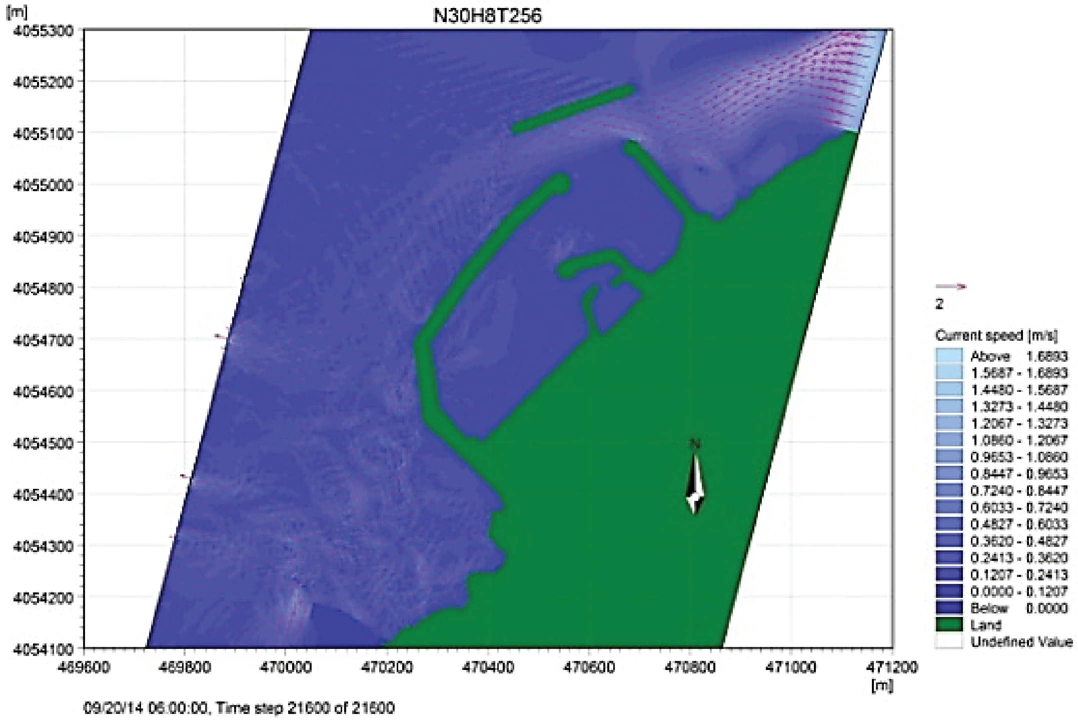


(b)

Fig. 5 Simulation results for wave agitation for alternative 2; MWD: 30°N, H_s: 2.56m, T_p=8s: a) Field velocities products of current Waves; b) Evolution of the flow of sediment transport



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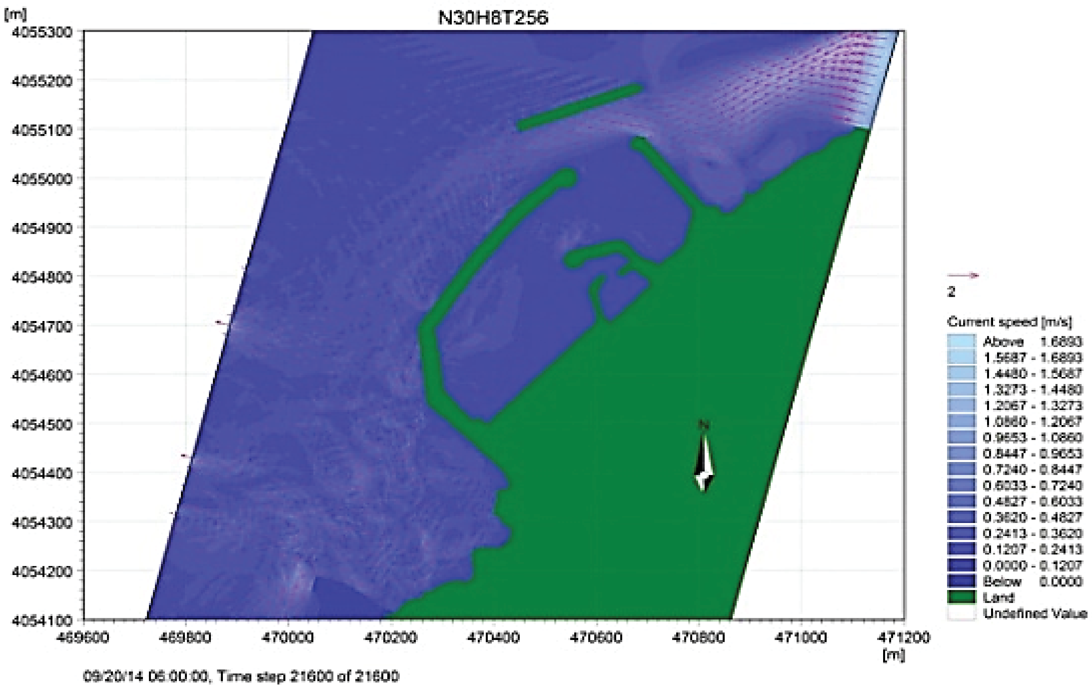

(b)

Fig. 6 Simulation results for wave agitation for alternative 2 with a breakwater; MWD: 30°N, H_s: 2.56m, T_p=8s; Field velocities products of current waves; b) Evolution of the flow of sediment transport

The optimal variant chosen is based on minimizing the formation of low radiation stresses responsible for the transport of non-cohesive sediments from a current-induced shoaling and refraction formation. However, the results from the computer code must always be supported by reduced model reduced model because of the complexity of sedimentary and hydrodynamic phenomena in shallow water.

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