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Contribution to the modeling of wave propagation in the coastal and harbor area of Pointe-Noire

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ASTRACT
In order to study the behavior of the swell during its propagation from the open sea to the coast in order to understand and predict the related hydrodynamic phenomena, a study of the energy spectrum of the swell along the axis of the coast in particular in the areas protected by the dike and the areas not protected by the dike in order to identify the areas of high concentration of energy of the swell during its breaking on the coast.
The purpose of this operation is to highlight the phenomenon of coastal erosion caused by the breaking of the swell in the area not protected by the dike. To do this, the STWAVE (Steady-state spectral WAVE model) under the SMS 13.1.21 (Surface-water-Modeling-system) interface and Matlab have been used respectively to simulate the bathymetry of the study area, the break-up criterion in STWAVE and the group velocity at the approach of the coast. Some points on the coast were chosen for the visualization of the test cases.
***KEY WORDS**: Wave propagation, surfing, STWAVE model, SMS, coastal zone.*

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I. INTRODUCTION

The swell is one of the dominant forcing of the ocean. It characterizes the response of water to a disturbance of its surface by winds, it travels over many kilometers by deep bottom, is modified at the approach of the coast under the influence of several factors (including bathymetric variation, presence of structure, ...) before coming to ground on the beaches. The modification of the characteristics of the swell at the approach of the coast is at the origin of the concentration or the dissipation of its energy according to the type of phenomenon or the bathymetry present. It seems therefore inescapable for the prediction of coastal hydrodynamic phenomena to highlight and dissect the factors that are likely to cause erosion and silting of areas of ship traffic.

Indeed, in the coastal area of Pointe-Noire, the various works that have allowed the establishment of coastal and port facilities and to find the appropriate depth for the proper movement of ships, are the cause of the modification of the characteristics of the swell in general and its energy in particular, which has given rise to the phenomenon of erosion in some places and an uncontrollable sediment flow.

The study conducted in this article aims to establish a numerical model of wave propagation from the open sea to the coast of Pointe-Noire to understand the hydrodynamic phenomena induced by the swell, including silting of the access channel of the Port of Pointe-Noire on the one hand and erosion in Loango Bay on the other hand of the coast of Pointe-Noire.

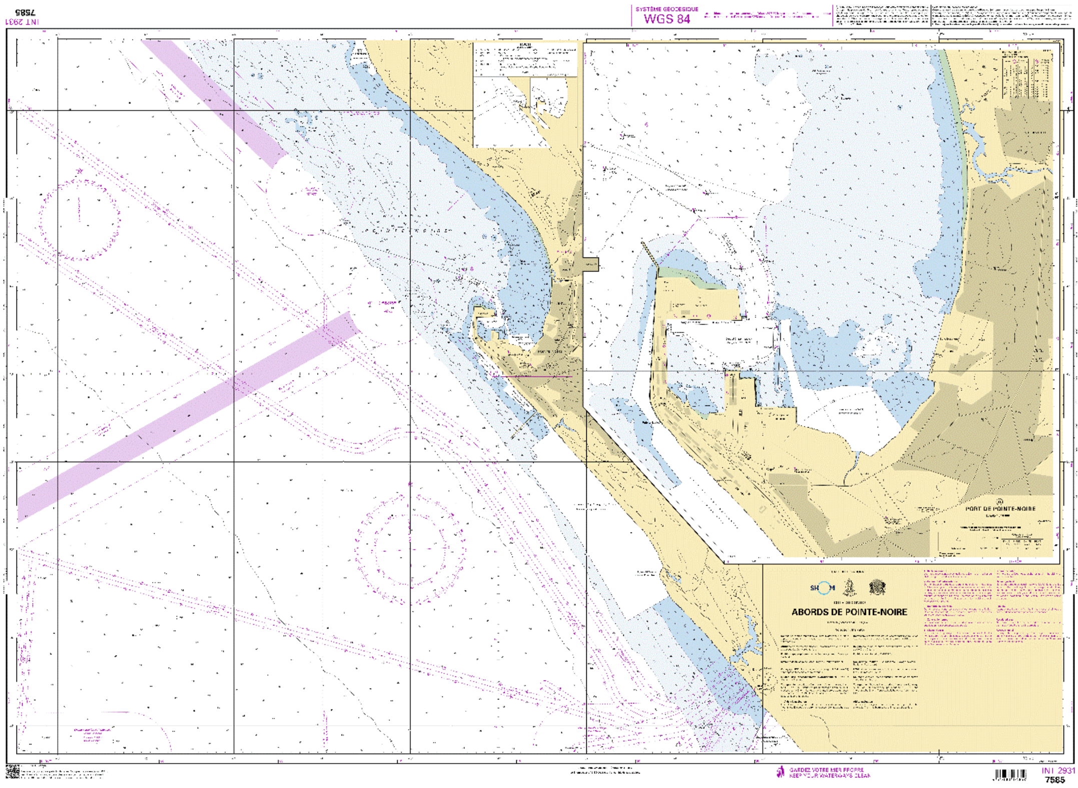

Figure 1: Presentation of the maritime map of Pointe-Noire.

II. MATERIALS AND METHODS

II.1 Oceanographic conditions

II.1.1 Geographic location

The coastal zone that is the subject of this study is a 170 km long coastline that includes the Autonomous Port of Pointe-Noire, it is located in the southeast of the Gulf of Guinea at 4°67 South and 11°97 East, sheltered by a natural drop-off, quite common in the area, of the coastline oriented on average at 320°-140°, in front of a fairly well-developed continental shelf of about forty kilometers wide up to the isobath 100 meters (Fig. 2). The Congo River estuary, the second largest river in the world in terms of flow, with an average annual flow into the estuary of 45,000 m3/s PITON B. and al (1979), is located 150 km south-southeast of Pointe-Noire at 6°03 South and 12°22 East; at the latitude of this estuary, a canyon cuts deeply into the entire continental shelf and runs up the estuary to 30 km inland. A second river, the Kouilou, with an average annual flow of about 900 m3/s, flows into the sea about 40 km north-northwest of Pointe-Noire.Except at the exit of the Congo estuary where the high speeds.

Figure 2: Geographic location of Pointe-Noire.

II.1.2Climatics conditions

The Pointe-Noire region is located in the southern part of the Congo, from which it derives its general climatic features. The main features of the climate of southern Congo have been described in several works by Leroux M. (1975) and Samba-Kimbata M. J. (1978). As in all of Central Africa, the Congo in general and southern Congo in particular are dependent on three permanent anticyclones located to the northwest over the Azores and Canary Islands, to the southwest over the island of St. Helena and to the southeast over the Mascarene Islands, with a predominantly southern influence. The semi-permanent Egyptian-Lybian and South African anticyclones also play a very important role in this climate.

The work of Samba G. and al (2011), where long series of climatic data were analyzed, subdivide the Congo into two climatic types: the equatorial climate in the north and the humid tropical climate in the south. The Pointe-Noire region belongs to the humid tropical climate. This climate is predominantly influenced by intertropical low pressure from October to May and southern subtropical high pressure from June to September. The cloud cover is all the more important and quasi-permanent as the activity of the intertropical convergence zone (ITCZ) is inverse. It directly influences the insulation and solar radiation.

It is characterized by an alternation of two seasons: a rainy and hot season that extends from November to April characterized by a very high rainfall and a dry season from June to September during which the water balance is probably deficient IPCC, (2007). The months of May and October provide a transition period for the entry and exit of the dry season.

II.1.3 Waves

The coast of Pointe-Noire generally receives waves of the Atlantic swell from south southwest to southwest. Wave heights range from 1.0 m to about 2.0 m. However, waves higher than 2.0 m are rare. The period spectrum is 7 to 15 s. During 5 days per year, the significant wave height in the immediate vicinity of Pointe-Noire would be between 2.8 m and 3.3 m INROS LACKNER AG, (2004).

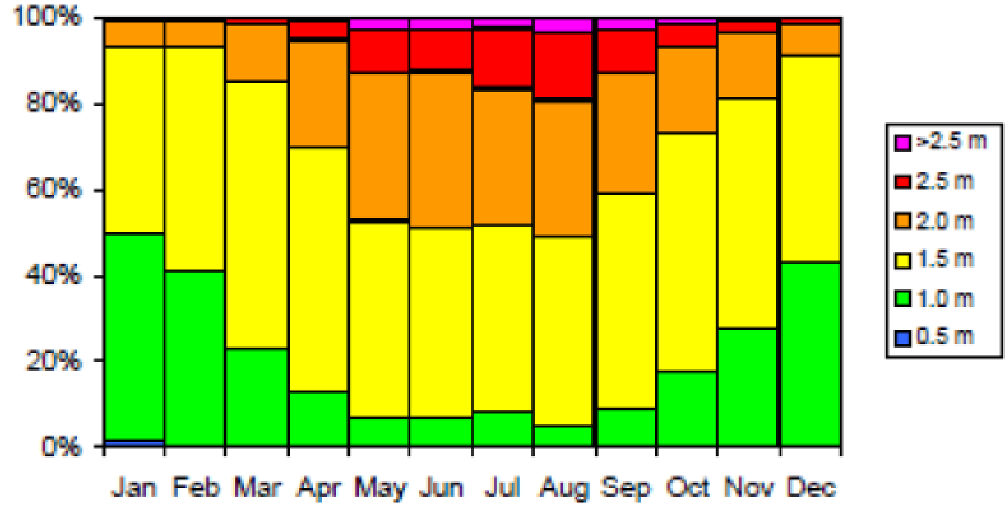

Figure 3 : Waveheight distribution on the coast of Pointe-Noire.

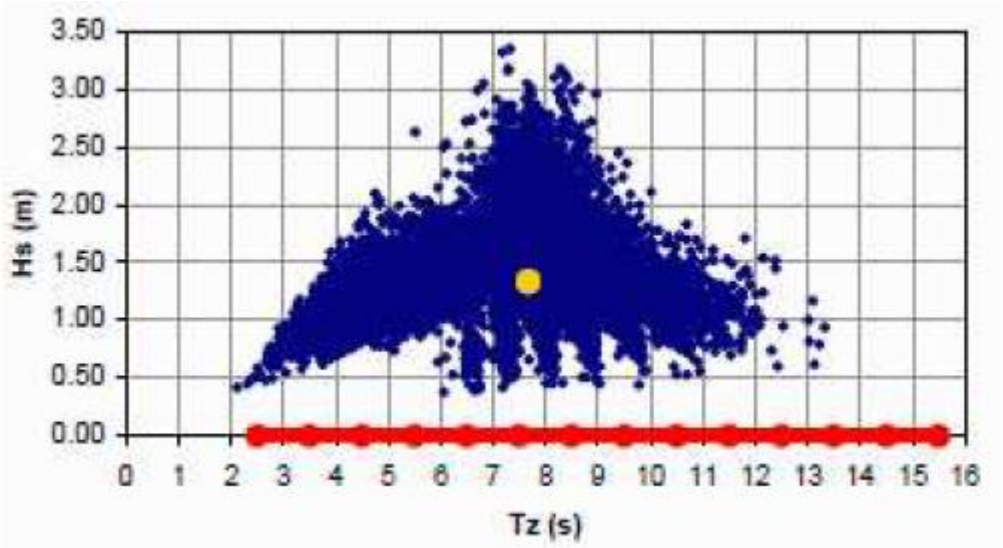

Figure 4: Distribution of waveheights and theirperiods

II.1.4 Current

Off Pointe-Noire, the general current is directed to NW-NW. Near the coast, due to the preponderant action of the sales, the current is variable and irregular. The general currents in front of the port are weak, in the order of 0.15 to 0.25 m/s. Speeds of 0.5 m/s are rare. 85% of the currents are northward. At the outer breakwater, the general currents are reinforced by the swell currents originating along the structure. In the bay, the current speeds are low, less than 0.2 m/s in 95% of cases INROS LACKNER AG, (2004).

Tidal currents are often only noticeable near the coast, but are generally weak. Offshore currents are mainly generated by the wind.

II.1.5 Wind

The predominantwind direction isfrom the SSW with an average speed of 7/8 knots.

II.2 Numerical modeling

Numerical simulations are carried out in order to study the characteristics of the waves approaching the coast along the shoreline. The wave parameters obtained from this operation are analyzed for hydrodynamic phenomena related to wave propagation. To simulate the wave propagation from the open sea to the coastal region, the Steady-state spectral WAVE model (STWAVE), SMITH and al (2001) under the SMS 13.1.21 (Surface-water-Modeling-System) interface on the CMS-WAVE module was used. This model is capable of simulating wind-generated wave growth, decomposition and transformation in offshore and coastal regions. STWAVE is a new generation spectral wind wave model based on an unstructured mesh. It solves the spectral angular energy conservation equation of the wave by the finite difference method and takes into account various phenomena such as refraction, diffraction, shoaling, nonlinear wave-wave interaction as well as energy dissipation due to breaking and friction with the bottom.

In order to study the transformation of waves on the entire coastline of Pointe-Noire, SMS 13.1.21 provides adequate bathymetry, and propagation quantities such as wave period, direction, speed, amplitude.

II.2.1 Equation governing the model

STWAVE simulates wave refraction and shoaling induced by depth variation, depth and slope driven breaking, wind driven wave growth, wave-wave interaction and white-capping that redistribute and dissipate energy in a growing wave field.

The governing equations are similar for the half-plane and full-plane modes. The governing equations for the half-plane mode are discussed first since this option includes the interaction of waves with currents by considering a reference frame moving with the current. The wave parameters in this frame are denoted by the subscript r as "relative" to the current and the parameters in the non-moving reference frame are denoted by the subscript a for "absolute".

The wave dispersion relationship is given in the moving reference frame as follows **Jonsson and al (1990)**:

$$\omega_r^2 = gk\tanh(kd) \tag{1}$$

Where:

ω : is the pulsation of the wave;

g: is the acceleration of gravity;

k: is the wave number;

h: water depth.

In the absolute reference frame, the dispersion equation is as follows:

$$\omega_a = \omega_r + kU_c\cos(\delta - \alpha) \tag{2}$$

U_c: speed of the current.

δ : is the reference direction with respect to the x-axis.

α: is direction orthogonal to the wave direction.

The wavenumber is calculated by substituting equation (1) into equation (2) and an iterative solution is made for k. The wavenumber and wavelength are related by the relation $\lambda = \frac{2\pi}{k}$in both reference frames.

The solutions for refraction and shoaling also require wave celerity's, C and group celerity's, C_g, in the current reference frame,

$$c_r = \frac{\omega_r}{k} \tag{3}$$

$$c_{gr} = 0.5c_r\left(1 + \frac{2kd}{\sinh(2kd)}\right) \tag{4}$$

The direction of the relative celerity of the group is α, the orthogonal direction of the wave, see Figure 5. In the absolutereference frame,

$$C_a = C_r + U\cos(\delta - \alpha) \tag{5}$$

$$\left(C_{ga}\right)_i = \left(C_{gr}\right)_i + (U)_i \tag{6}$$

Where i is the tensor notation for the x and y components. The direction of the wave radius is defined as follows:

(7)

$$\mu = \tan^{-1}\left(\frac{c_{gr}\sin\alpha + U\sin\delta}{c_{gr}\cos\alpha + U\cos\delta}\right)$$

The distinction between wave orthogonal (direction perpendicular to the wave crest) and wave radius (direction of energy propagation) is important in describing the interaction between waves and currents. Without currents, as in full plane mode, the wave radii and wave orthogonal are the same with currents, the wave energy moves along the wave radii while the wave direction is defined by the wave orthogonal. A schematic of the definition of wave and current vectors is provided in Figure 5.

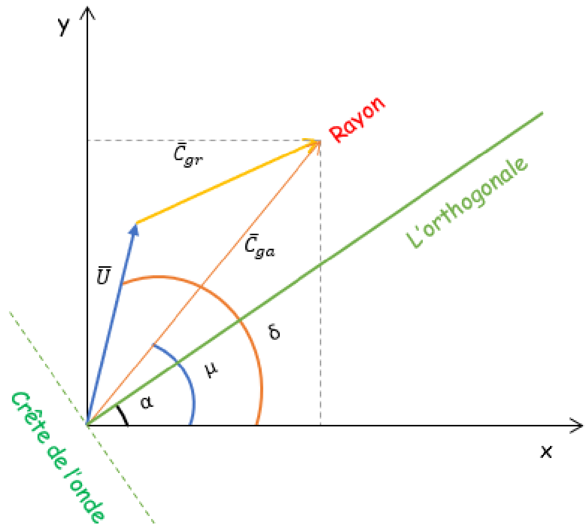

Figure 5: Definition sketch of wave and currentvectors, after Smith and al (2001).

The orthogonal direction of the wave for equilibrium conditions in the presence of currents is given by **Mei (1989)** and by **Jonsson (1990)**:

$$C_{ga}\frac{D\alpha}{Dr} = -\frac{C_r k}{\sin(2kd)}\frac{Dd}{Dn_0} - \frac{k_i}{k}\frac{DU_{ci}}{Dn_0} \tag{8}$$

When wave-current interactions are excluded, the orthogonal wave direction for stable conditions is given by :

$$C_g\frac{D\alpha}{Dr} = -\frac{Ck}{\sin(2kd)}\frac{Dd}{Dn_0} \tag{9}$$

D: total derivative,

R: coordinate in the direction of the wave ray,

n_0 : coordinate normal to the orthogonal wave.

The governing equation for the steady state conservation of the spectral wave action along a wave ray taking into account the wave-current interaction is **Jonsson, (1990)**,

$$\left(C_{ga}\right)_i\frac{\partial}{\partial x_i}\frac{C_a C_{ga}\cos(\mu-\alpha)\,E(\omega_a,\alpha)}{\omega_r} = \sum\frac{S}{\omega_r} \tag{10}$$

With a similar version for no wave-current interaction (full plane mode or zero current in half plane mode),

$$\left(C_{ga}\right)_i\frac{\partial}{\partial x_i}\frac{CC_g\cos(\alpha)\,E(\omega,\alpha)}{\omega} = \sum\frac{S}{\omega} \tag{11}$$

E: wave energy density divided by ρ_ω and g where ρ_ω is the density of the water, S: energy source and sink terms

III. RESULTS AND DISCISSIONS

The presentation of the results willbe as follows :

III.1 Meshing of the study area and bathymetry

The accuracy of all numerical models depends mainly on the accuracy of the bathymetry data. In this paper for the wave simulation the bathymetry was generated from the general ocean bathymetric map (GEBCO_08 grid). This is a global terrain model for the ocean and land at 30 arc second intervals. The GEBCO_08 grid data represent elevations in meters, with negative values for bathymetric depths and positive values for topographic heights. The bathymetry of the area of our study is obtained by the GEBCO_08 grid and then the processing of the domain mesh and the simulation were performed by STWAVE under the SMS 13.1.21 interface.

The SMS interface has allowed under the Mesh Grid module the delimitation of the bathymetry of the area concerned by this study and the mesh covering this surface. **Figure 6**, represents the complete mesh of the domain, with (x, y) coordinates and z the depth of water.

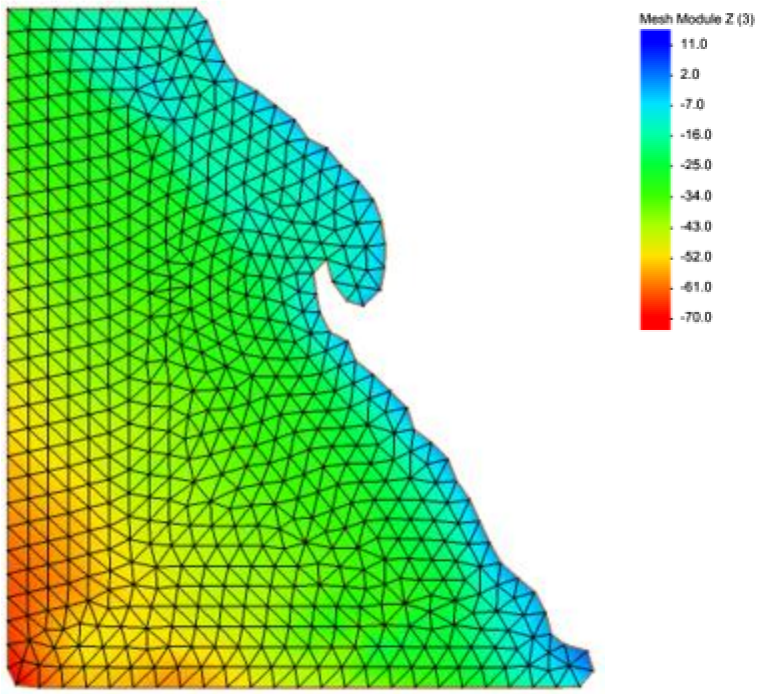

Figure 6: Grid of the study area and presentation of the bathymetry.

III.2 Wavebreaking in the study area

The wave breaking criterion applied in STWAVE is a function of wavelength and water depth:

$$H_{m0,\ max} = 0.1\lambda \tanh(kd) \tag{12}$$

Where:

$H_{m0,max}$: the maximum energy-based zero-moment wave height;

λ: the wavelength;

k: the wave number.

his criterion is powerful because it includes both depth- and slope-limited breaking impacts. At the entrance to a coastline, where waves are enhanced by wave-current interaction, wave breaking is enhanced by increasing wave slope. Laboratory experiments by **Smith and al (1997)** on irregular wave breaking on ebb currents showed that a breaking relationship in the form of the **Miche (1951)** criterion was simple, robust and accurate, see also **Betty and al (1997)**, **Battjes (1982)** and Battjes and **Janssen (1978)**.

X	Y	Z
11.80208333	-4.706249999	-3
11.80625	-4.710416666	-4
11.81041607	-4.714583332	-6
11.82708333	-4.727083332	-5

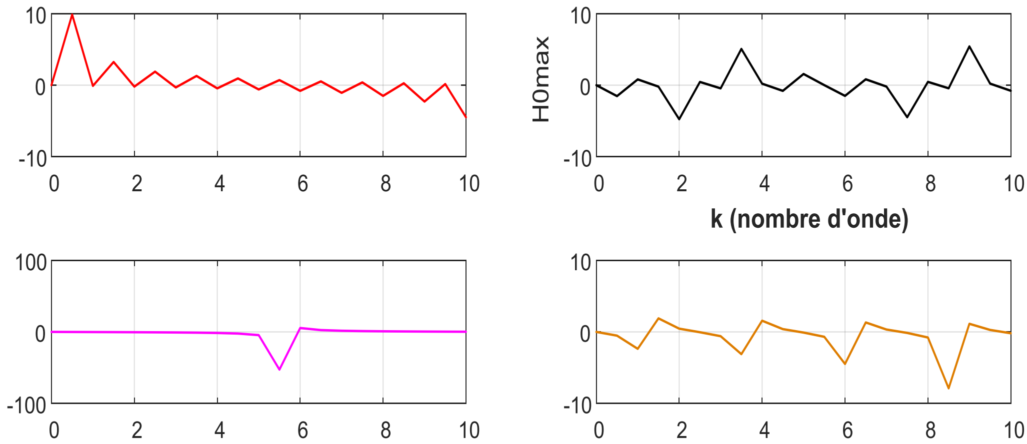

Figure 7: Maximum limit of the zero-momentum wave height H0max as a function of the wave number k. The different points are located near the surf zone.

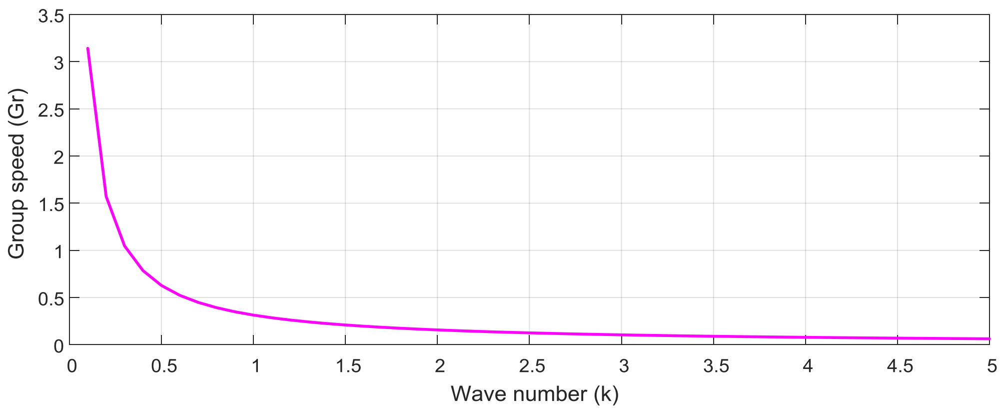

Figure 8: Group velocity of the swell as it approaches the coast

IV. CONCLUSION

The test cases presented in this article are intended to study the direct impact of wave breaking on the protected and unprotected areas by the dike in order to understand the phenomena related to wave-structure interaction on the one hand and the phenomenon of coastal erosion in the unprotected area, especially at the level of Loango Bay on the other hand. Thus, simulations of the group velocity of the swell on some points approaching the coast have been made to simulate the problem of agitation near the coast of Pointe-Noire. This work, which allowed the use of the Steady-state spectral WAVE model (STWAVE) under the SMS 13.1.21 interface (Surface-water-Modeling-system), will lead to a detailed study of hydrodynamic phenomena, especially coastal erosion and excessive silting of the access channel of the Autonomous Port of Pointe-Noire from the said model.

BIBIOGRAPHICALS REFERENCES

[1]. PITON B., POINTEAU JH., WAUTHY B., ESPOSITO P., MONTEL Y. : Données hydro climatique à Pointe-Noire (Congo) de 1953 à 1977 (+1978 ET 1979). Off. Rech. Sci. Tech. OUTRE-MER, Docum. SCI. CENTRE POINTE-NOIRE ; COG ; DA. 1979 ; N° 53 ; pp 1-60. H. T. 20 ; ABS. ENG ; BIBL. 11 REF.

[2]. INROSLACKNER AG, (2004) : Dossier d'appel d'offres-Travaux de dragage pour l'accès nautique au port. Section V. Spécifications Techniques.

[3]. SMITH J.M., SHERLOCK A.R, RESIO D.T. (2001) STWAVE : steady-state spectral Wave model : user'smanual for STWAVE Version 3.0 Supplemental Report ERDC/CHL-SR-01-1. US ArmyEngineerResearch and development Center, Vicksburg, MS.

[4]. Jonson, I. G. 1990 Wave-current interactions. The sea. Chapter 3, vol 9, Part A, B. LeMehaute and D.M. Hanes, ed., New York : John Wiley and Sons, Inc.

[5]. Battjes, J.A. 1982. A case study of waveheight variations due to currents in a tidal entrance. Coast. Engrg. 6: 47-57.

[6]. Battjes, J.A. and J.P.F.M. Janssen. 1978. Energy loss and set-up due to breaking of randomwaves. Proc. 16th Coast. Engrg. Conf. ASCE. 569-587.

[7]. Miche, M. 1951. Le pouvoir reflechissant des ouvrages maritimes exposes a l'action de la houle. Annals des Ponts et Chaussess. 121e Annee: 285-319 (translated by Lincoln and Chevron, University of California, Berkeley, WaveResearchLaboratory, Series 3, Issue 363, June 1954).

[8]. Smith, J.M. 2001. Modeling nearshore transformation with STWAVE. ERDC/CHL CHETN I-64. Vicksburg, MS: U.S. ArmyEngineerResearch and Development Center. http://chl.erdc.usace.army.mil/chetn.

[9]. Leroux M. (1975) : Climatologie dynamique de l'Afrique. Travaux et document de géographie tropicale, n°19 CEGET, CNRS, pp 88-112.

[10]. Samba-Kimbata M. J., (1978) : Le climat du bas Congo. Thèse de 3ème cycle, Université Bourgogne, Dijon 280p.

[11]. Samba G. and Nganga D., (2011) :Rainfallvariability in Congo-Brazzaville 1932-2007. Int J. Climatol. Published online in Wiley online library 20.

[12]. IPCC, (2007) : IPCC FourthAssessment Report : climate change 2007 (AR4). Geneva, Switzerland.