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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 swellduringits propagation from the open sea to the coast in order to understand and predict the relatedhydrodynamicphenomena, a study of the energyspectrum of the swellalong 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 swellduringitsbreaking on the coast.
The purpose of thisoperationis to highlight the phenomenon of coastalerosioncaused 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 usedrespectively 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 coastwerechosen for the visualization of the test cases.

KEY WORDS: *Wave propagation, surfing, STWAVE model, SMS, coastal zone.*

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I. INTRODUCTION

The swellis one of the dominant forcing of the ocean. It characterizes the response of water to a disturbance of its surface by winds, ittravels over manykilometers by deepbottom, ismodified at the approach of the coastunder the influence of severalfactors (includingbathymetric variation, presence of structure, ...) beforecoming to ground on the beaches. The modification of the characteristics of the swell at the approach of the coastis at the origin of the concentration or the dissipation of itsenergyaccording to the type of phenomenonor the bathymetrypresent. It seemsthereforeinescapable for the prediction of coastalhydrodynamicphenomena to highlight and dissect the factorsthat are likely to cause erosion and silting of areas of shiptraffic.

Indeed, in the coastal area of Pointe-Noire, the variousworksthat have allowed the establishment of coastal and port facilities and to find the appropriatedepth for the propermovement of ships, are the cause of the modification of the characteristics of the swell in general and itsenergy in particular, which has givenrise to the phenomenon of erosion in some places and an uncontrollablesediment flow.

The studyconducted 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 hydrodynamicphenomenainduced by the swell, includingsilting of the accesschannel 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.

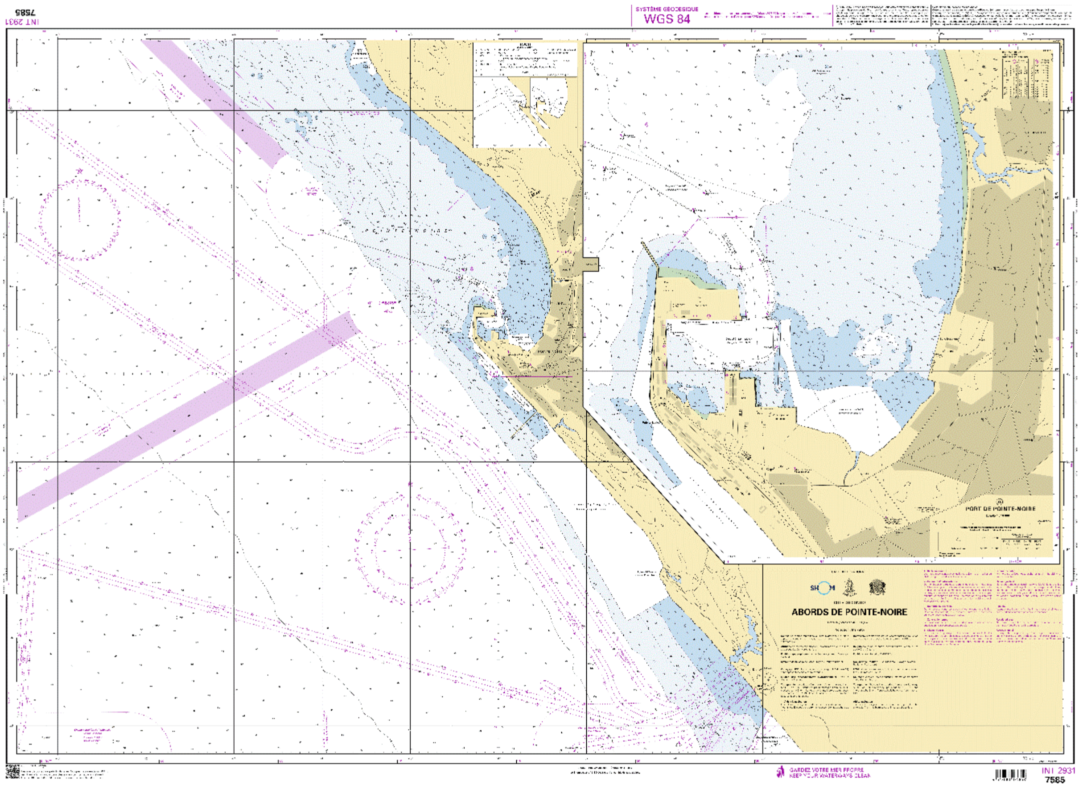

Figure 1: Presentation of the maritime map of Pointe-Noire.

II. MATERIALS AND METHODS

II.1 Oceanographic conditions

II.1.1 Geographic location

The coastal zone thatis the subject of thisstudyis a 170 km long coastlinethatincludes the Autonomous Port of Pointe-Noire, itislocated in the southeast of the Gulf of Guinea at 4°67 South and 11°97 East, sheltered by a natural drop-off, quitecommon in the area, of the coastlineoriented on average at 320°-140°, in front of a fairlywell-developed continental shelf of about fortykilometerswide 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 averageannual flow into the estuary of 45,000 m3/s **PITON B. and al (1979)**, islocated 150 km south-southeast of Pointe-Noire at 6°03 South and 12°22 East ; at the latitude of thisestuary, a canyon cutsdeeplyinto the entire continental shelf and runs up the estuary to 30 km inland. A second river, the Kouilou, with an averageannual flow of about 900 m3/s, flows into the sea about 40 km north-northwest of Pointe-Noire.

It is in the coastal area between Cape San Juan at 1°N, at the border between Equatorial Guinea and Gabon, and the Bay of Tigers, that the South Equatorial surface currentoriginates, pushed by a ratherweaksectorwind. Except at the exit of the Congo estuarywhere the high speeds.

Figure 2 : Geographic location of Pointe-Noire.

II.1.2Climatics conditions

The Pointe-Noire regionislocated in the southern part of the Congo, fromwhichitderivesitsgeneralclimaticfeatures. The main features of the climate of southern Congo have been described in severalworks 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 MascareneIslands, with a predominantlysouthern influence. The semi-permanent Egyptian-Lybian and South African anticyclones alsoplay a very important role in thisclimate.

The work of **Samba G. and al (2011)**, where long series of climatic data wereanalyzed, subdivide the Congo intotwoclimatic types : the equatorialclimate in the north and the humid tropical climate in the south. The Pointe-Noire regionbelongs to the humid tropical climate. This climateispredominantlyinfluenced by intertropical low pressure fromOctober 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 ischaracterized by an alternation of twoseasons: arainy and hot seasonthatextendsfromNovember to April characterized by a very high rainfall and a dry seasonfrom June to Septemberduringwhich the water balance isprobablydeficient**IPCC, (2007)**. The months of May and Octoberprovide a transition period for the entry and exit of the dry season.

II.1.3 Waves

The coast of Pointe-Noire generallyreceiveswaves of the Atlantic swellfromsouthsouthwest to southwest. Waveheights range from 1.0 m to about 2.0 m. However, waveshigherthan 2.0 m are rare. The periodspectrumis 7 to 15 s. During 5 days per year, the significantwaveheight in the immediatevicinity of Pointe-Noire wouldbebetween 2.8 m and 3.3 m **INROS LACKNER AG, (2004)**.

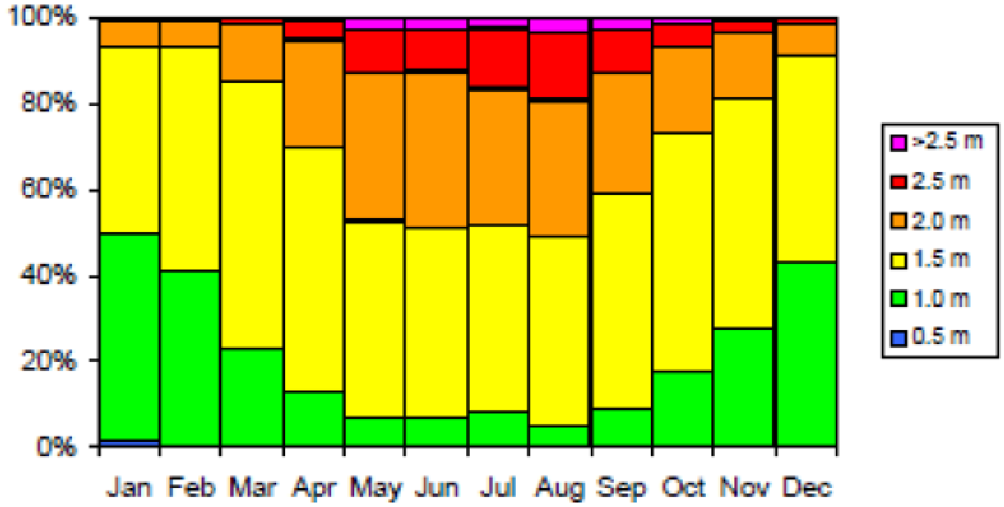

Figure 3 : Waveheight distribution on the coast of Pointe-Noire.

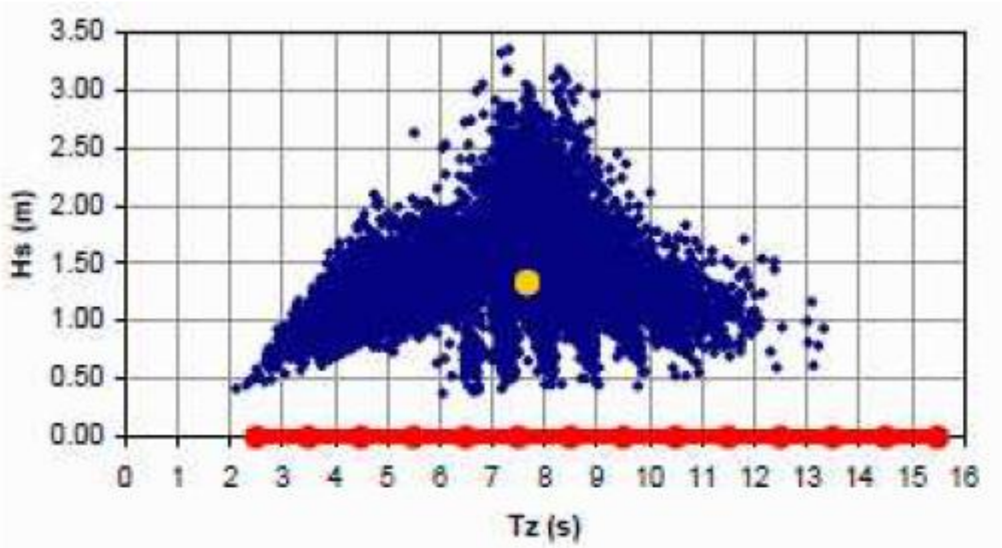

Figure 4: Distribution of waveheights and theirperiods

II.1.4 Current

Off Pointe-Noire, the generalcurrentisdirected to NW-NW. Near the coast, due to the preponderant action of the sales, the currentis variable and irregular. The generalcurrents 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 outerbreakwater, the generalcurrents are reinforced by the swellcurrentsoriginatingalong the structure. In the bay, the current speeds are low, lessthan 0.2 m/s in 95% of cases **INROS LACKNER AG, (2004)**.

Tidal currents are oftenonlynoticeablenear the coast, but are generallyweak. Offshore currents are mainlygenerated 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 wavesapproaching the coastalong the shoreline. The waveparametersobtainedfromthisoperation are analyzed for hydrodynamicphenomenarelated to wave propagation. To simulate the wave propagation from the open sea to the coastalregion, 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 wasused. This model is capable of simulatingwind-generatedwavegrowth, decomposition and transformation in offshore and coastalregions. STWAVE is a new generation spectral windwave model based on an unstructuredmesh. It solves

the spectral angularenergy conservation equation of the wave by the finitedifferencemethod and takesintoaccountvariousphenomenasuch as refraction, diffraction, shoaling, nonlinearwave-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 entirecoastline of Pointe-Noire, SMS 13.1.21 providesadequatebathymetry, and propagation quantitiessuch as waveperiod, direction, speed, amplitude.

II.2.1 Equation governing the model

STWAVE simulateswaverefraction and shoaling induced by depth variation, depth and slopedrivenbreaking, winddrivenwavegrowth, wave-wave interaction and white-capping thatredistribute and dissipateenergy in a growingwavefield.
The governingequations are similar for the half-plane and full-plane modes. The governingequations for the half-plane mode are discussed first sincethis option includes the interaction of waveswithcurrents by considering a reference frame movingwith the current. The waveparameters in this frame are denoted by the subscript r as "relative" to the current and the parameters in the non-movingreference frame are denoted by the subscript a for "absolute".
The wave dispersion relationshipisgiven in the movingreference frame as follows**Jonssonand 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 wavenumber ;
h: water depth.
In the absolutereference frame, the dispersion equationis 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 wavenumberiscalculated by substitutingequation (1) intoequation (2) and an iterative solution is made for k.
The wavenumber and wavelength are related by the relation $\lambda = \frac{2\pi}{k}$in bothreference frames.
The solutions for refraction and shoaling alsorequirewavecelerities, C and group celerities, 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 isdefined as follow

$$\mu = \tan^{-1}\left(\frac{c_{gr} \sin\alpha + U \sin\delta}{c_{gr} \cos\alpha + U \cos\delta}\right) \tag{7}$$

The distinction betweenwave orthogonal (direction perpendicular to the wavecrest) and wave radius (direction of energy propagation) is important in describing the interaction betweenwaves and currents. Withoutcurrents, as in full plane mode, the waveradii and waveorthogonals are the samewithcurrents, the waveenergy moves along the waveradiiwhile the wave direction isdefined by the waveorthogonals. A schematic of the definition of wave and currentvectorsisprovided in Figure 5.

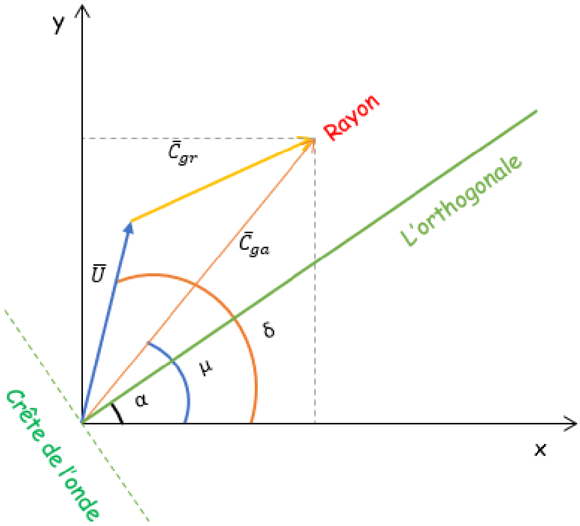

Figure 5 : Definition sketch of wave and currentvectors, after Smith and al (2001).

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

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

Whenwave-current interactions are excluded, the orthogonal wave direction for stable conditions isgiven 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 governingequation for the steady state conservation of the spectral wave action along a wave ray takingintoaccount the wave-current interaction is**Jonsson, (1990)**,

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

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

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

E:waveenergydensitydivided by ρ_ω and g where ρ_ω is the density of the water,
S:energy source and sinkterms.

III. RESULTS AND DISCISSIONS

The presentation of the resultswillbe as follows :

III.1 Meshing of the study area and bathymetry

The accuracy of all numericalmodelsdependsmainly on the accuracy of the bathymetry data. In thispaper for the wave simulation the bathymetrywasgeneratedfrom the generaloceanbathymetricmap (GEBCO_08 grid). This is a global terrain model for the ocean and land at 30 arc second intervals. The GEBCO_08 grid data representelevations in meters, withnegative values for bathymetricdepths and positive values for topographicheights. The bathymetry of the area of ourstudyisobtained by the GEBCO_08 grid and then the processing of the domainmesh and the simulation wereperformed by STWAVE under the SMS 13.1.21 interface.

The SMS interface has allowedunder the MeshGrid module the delimitation of the bathymetry of the area concerned by thisstudy and the meshcoveringthis surface. **Figure 6**, represents the completemesh of the domain, with (x, y) coordinates and z the depth of water.

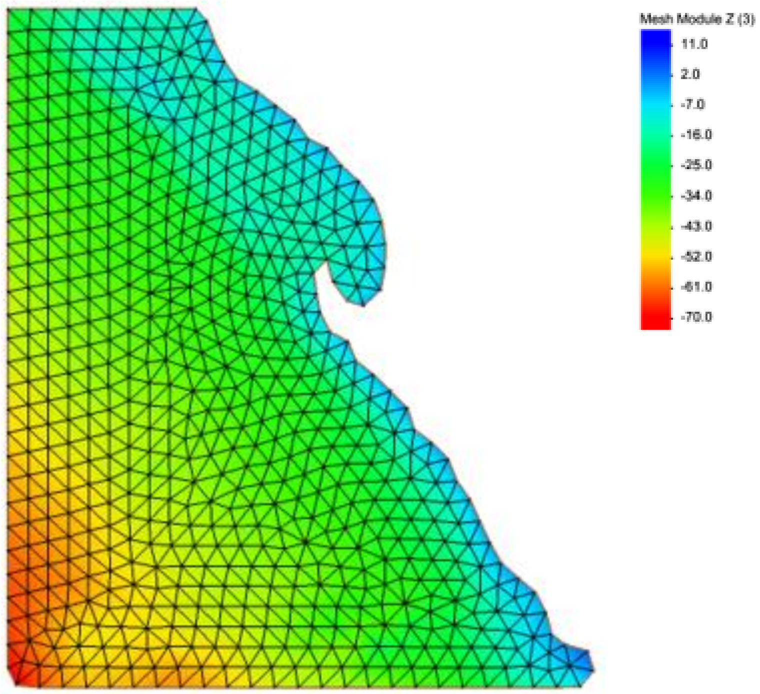

Figure 6: Grid of the study area and presentation of the bathymetry.

III.2 Wavebreaking in the study area

The wavebreakingcriterionapplied 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-basedzero-moment waveheight ;

λ: the wavelength;

k:the wavenumber.

hiscriterionispowerfulbecauseitincludesbothdepth- and slope-limitedbreaking impacts. At the entrance to a coastline, wherewaves are enhanced by wave-current interaction, wavebreakingisenhanced by increasingwaveslope. Laboratoryexperiments by **Smith and al (1997)** on irregularwavebreaking on ebbcurrentsshowedthat a breakingrelationship in the form of the **Miche (1951)**criterionwas simple, robust and accurate, seealso**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

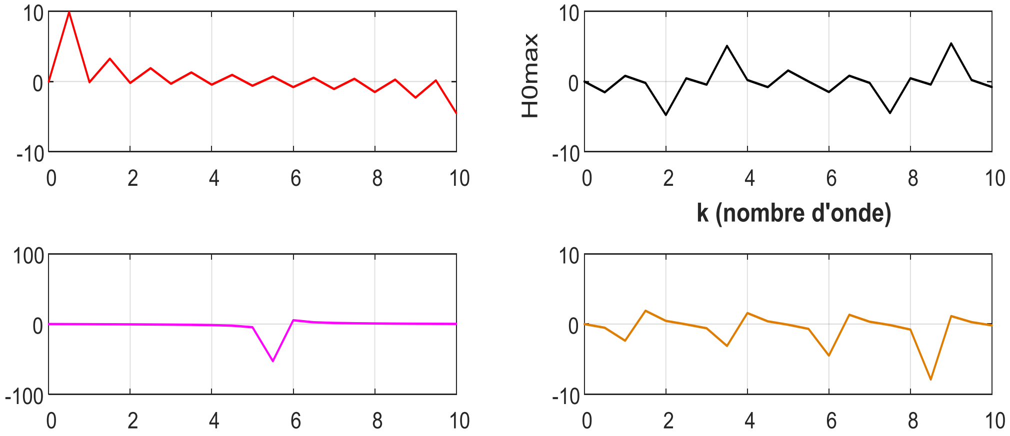

Figure 7: Maximum limit of the zero-momentum wave height H0max as a function of the wave number k. The different points are located near the surf zone.

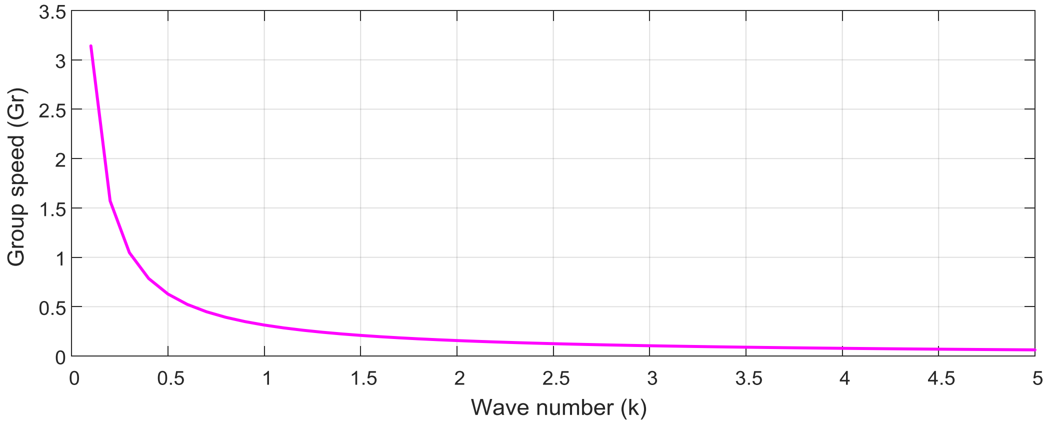

Figure 8: Group velocity of the swell as it approaches the coast

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.

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