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Study of Dissipating of Wave Energy in the Breakers Zone of the Gulf of Guinea: Case of Autonomous Port of Cotonou in Benin Coastal Zone

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Abstract

Rapid population growth and major trends of world economy growth have led to significant energy needs in our country. Benin, Gulf of Guinea country, although with a significant coastal network powered by potential energy from breaking waves, has experienced a deficit and a critical energy instability, marked by recurrent power cuts and disruption of the national economy. To ensure the integration of this source of renewable energy in the Benin energy mix and sustainably reduce the energy deficit in progress, this work has aimed to study the dissipation of wave energy at the bathymetric breaking in the breakers zone of Cotonou coast. Sea conditions and the statistics parameters of the breaking waves under perturbation effect of the seabed were evaluated to predict the beginning of the breaking. The modeling is based on the Navier-Stokes equation in which the viscosity and the interactions between the molecules of the oceanic fluid are neglected. The nonlinear wave dispersion relation is also used. The results obtained for this purpose showed that water particles have an almost parabolic motion during their fall; their velocity is higher than those of the early breaking. In this area, the waves dissipate about 80% of their energy: it generates turbulence which leads to a strong setting in motion of sediments.

Keywords

Wave, Breaker Zone, Wave Power, Energy Dissipation, Seabed

1. Introduction

Waves are oscillations of the sea surface, generated by the wind energy and maintained by gravity [1]. The profile of a wave can change under the effect of an external disturbance (wind, seabed…). It may encounter some movements, such as shoaling, breaking, refraction, diffraction, reflection… [2]. Waves carry a significant amount of energy which derives from the force of wind upon the seas around the globe and that is dispersed by the bathymetric breaking on coasts: they are renewable energy sources. Waves' breaking is a key aspect of the dynamics of sea states, particularly in the coastal dynamics. The dissipative processes, including the breaking, constitute one of the important terms of the energy balance sheet to the wave field and require appropriate definition in calculating the sea conditions. However, breaking is still poorly understood and poorly defined.

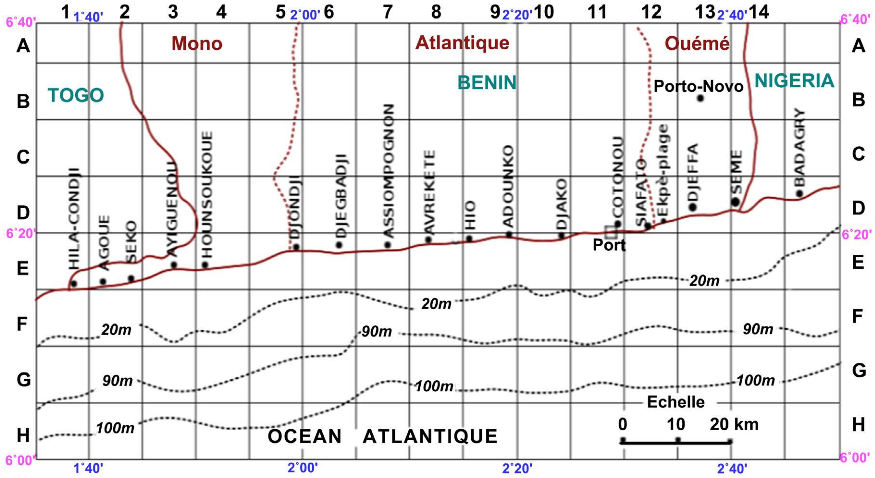
Benin is a coastal state of the Gulf of Guinea. As such, it has access to the ocean which is at the core of perpetual wave motions [3]. Despite the important population growth, Benin has been experiencing, for nearly two decades, a significant and recurring energy crisis characterized by long periods of power cut owing to a significant energy deficit. To this end, it turns out to be essential to explore its energy sources. Marine dynamic is a source yet not well-researched and undeveloped in Benin. Oceans are rich in energy flows that can be exploited [4]. Characterization of the breakers zone has been done on Benin coast based on data of MCA Benin, Navier-Stokes equation, and dispersion relation of nonlinear waves. An analysis of the energy dispersion rate of wave energy carried out in this area shows that it represents the dissipation zone par excellence for breaking waves. The study of variation of the group velocity in the area reveals that water particles enrolled at the breaking accelerate and drop with a velocity higher than that of the early breaking. Finally, the horizontal length of the breakers zone and the fall period of enrolled particles are measured on the study site and a study has been carried out on their variation.

2. Material and Methods

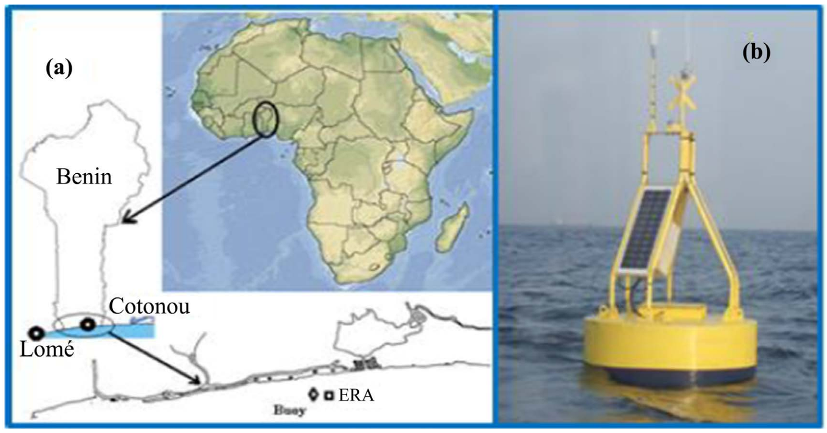
2.1. Study Site and Data Used

The bathymetric map (**Figure 1(A)** below) obtained at the CBRST (Benin Centre for Scientific and Technical Research) shows the evolution of the local water depth in the coastal area of Benin and predicts the average slope and macroscopic variability of the seabed. This map shows that the seabed in the coastal area is almost flat and sloping. It is a gently sloping seabed $p = \tan\beta$ as $0.001 < \tan\beta \le 0.1 \Rightarrow \tan\beta \approx \beta$. The slope in the shoaling zone corresponds to the following on average $\beta_m \approx \frac{100}{2000} = 0.05$ [5].

Benin is a country of the Gulf of Guinea located between the parallel 6˚15' and 12˚30' north latitude the one hand and meridians 1˚ and 3˚40' east longitude on the other hand (**Figure 1(B-a)**) [6]. It has gotten a coastal area that is 125 km from Hillacondji in the west, to Krake in the east. Benin coast is more or less linear



(A)



(B)

Figure 1. (A) Bathymetric map of Benin; (B) Sketch of study area (Benin, Gulf of Guinea). (a) Location of ERA and (b) oceanographic buoy.

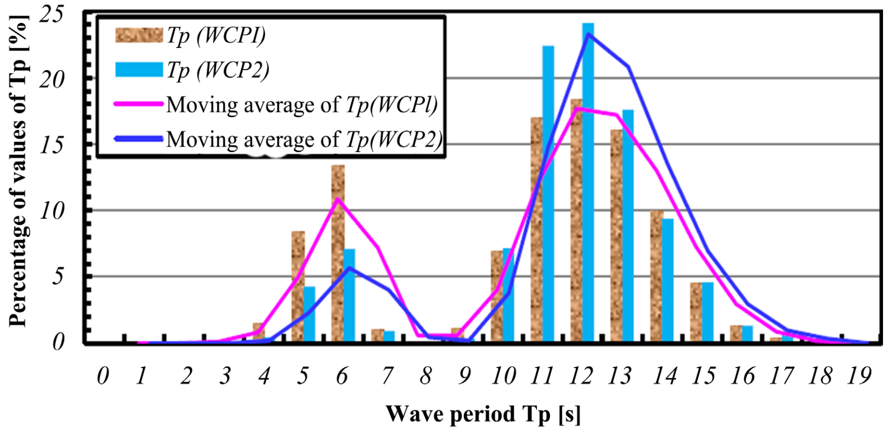
and cut off in two places, namely, the Bouche du Roy and the channel mouth of Cotonou. Its coastal zone is between latitude 6˚15' and 6˚23' north [7].

Waves parameters, significant wave height (H_s) and peak period (T_p) are recorded every 30 min. The buoy data (**Figure 1(B-b)**) are used for ERA data validation and cover the period from December 2015 to October 2016 (See HOUNGUE *et al.*, 2018, for more descriptions).

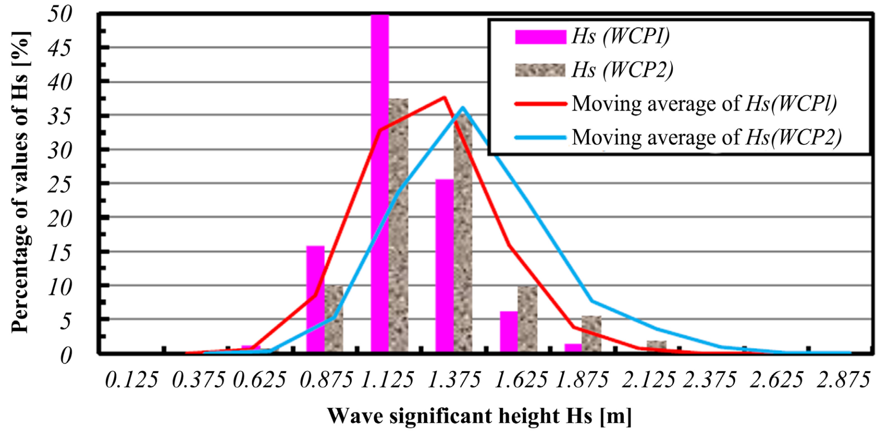
The gravity on the coast of Benin is approximately $g = 9.80\ \text{N/kg}$ and the density of sea water is $\rho = 1025\ \text{kg/m}^3$ [8].

As part of the expansion of the port of Cotonou, the Millennium Challenge Account-Benin (MCA-Benin) performed a series of measures in terms of wave power. These measures are performed with two stations of wave recorder buoy called WCP1 and WCP2 whose geographical coordinates are respectively (N 6˚20.118'; E 2˚27.255') and (N 6˚20.373'; E 2˚26.140') [9].

Data analysis yielded the following diagrams which respectively reflect the period T (**Figure 2(A)**), the peak to valley height H (**Figure 2(B)**) and direction (**Figure 3**) of propagation of swells off the Benin coast [10].



(A)



(B)

Figure 2. (A) Period of swells in the coastal zone of Benin; (B) Height of swells in the coastal zone of Benin.

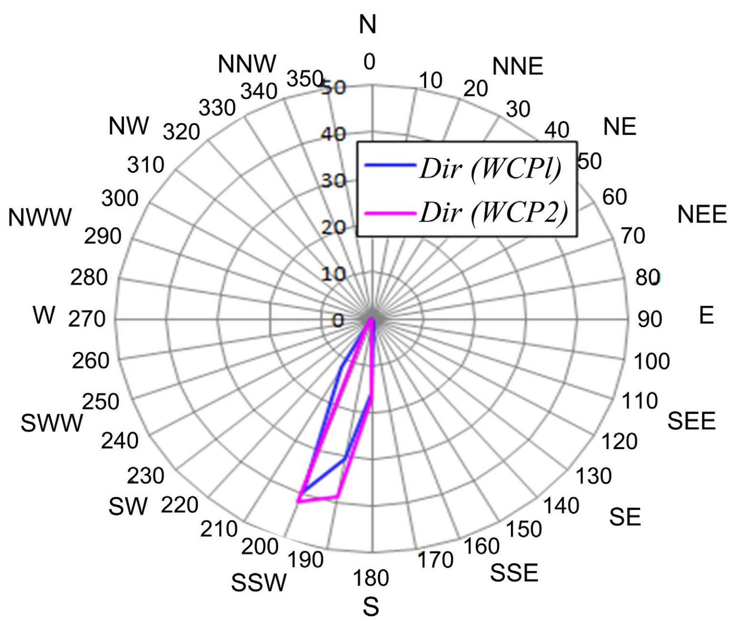


Figure 3. Propagation direction of swells in Benin coastal zone.

From the analysis of these curves, it appears that the swells in the Gulf of Guinea in Cotonou have:

- ✓ A height which varies between 0.4 m and 2 m (0.4 m ≤ H_o ≤ 2 m) with a common average value of about 1.1 m ($H_{om} \approx 1.1$ m);
- ✓ A period of peak that ranges between 8 s and 18 s (8 s ≤ T ≤ 18 s) and whose average value is about 12 s ($T_m \approx 12$ s);
- ✓ A propagation direction that lies between the south (S) and southwest (SW) with a strong dominance of the direction from the south to the southwest (SSW).

As for the sea breeze or short swells generated by local winds, they have a period that varies between 3 s and 7 s.

2.2. Swell Velocity at Breaking Point

When swells become nonlinear under the effect of shoaling (lifting of swell), refraction, reflection, diffraction… it is induced by the disturbing effect of the seabed, the wave dispersion relation proposed by Dalrymple *et al.*, to improve angularity [11] [12].

$$\omega^2 = gk\tanh(kh) \tag{1}$$

with $h = d + \frac{H}{2}$

Group velocity $C_g = \frac{\partial \omega}{\partial k}$ and phase velocity $C_\varphi = \frac{\omega}{k}$ have been inferred from that relation of nonlinear dispersion [13].

Bathymetric breaking occurs in shallow waters where $\tanh(kh) \approx kh$; thus we have.

$$C_g = C_\varphi = \sqrt{g\left(d + \frac{H}{2}\right)} \tag{2}$$

Using the results obtained with the theory of Boussinesq and the breaking standard of Kaminsky and Krauss (1993) [14], the local depth of water d_b, the height of wave H_b and the wavelength L_b at the breaking point [15] and where H_o and $L_o = \frac{gT^2}{2\pi}$ represent the off height and wavelength.

$$\begin{cases} d_b = \dfrac{H_o^{0.908} L_o^{0.092}}{1.33(\tan\beta)^{0.216}} \\ H_b = 0.903 H_o \left(\dfrac{L_o}{H_o}\right)^{0.227} (\tan\beta)^{0.054} \\ L_b = \dfrac{0.613 T^2 H_o^{0.454} L_o^{-0.459}}{\pi(\tan\beta)^{0.108}} \end{cases}$$

$$\Rightarrow \mu_b = \frac{d_b}{L_o} = \frac{H_o^{0.908} L_o^{-0.918}}{1,33(\tan\beta)^{0.216}} \tag{3}$$

Thus at the breaking point, we have:

$$C_{g_b} = C_{\varphi_b} = \sqrt{g\left(d_b + \frac{H_b}{2}\right)} \tag{4}$$

2.3. Modeling of Breaking in the Breakers Zone

The breakers zone is the area where swells break for the first time. In this area, the vertical rise of the free surface behaves like a wave of expansion during the breaking. When the maximum height obtained begins to drop at the end of shoaling, water particles located on the surface follow the break and drop sharply.

2.3.1. Position, Velocity and Trajectory of the Water Particles Affected

The forces of pressure and gravity and that of Coriolis caused by viscosity make it possible to establish the Navier-Stokes equation below [10].

$$\frac{\partial \boldsymbol{u}}{\partial t} + (\boldsymbol{u}\cdot\nabla)\boldsymbol{u} = -\frac{1}{\rho}\nabla p + \boldsymbol{g} + \frac{\mu}{\rho}\Delta \boldsymbol{u} \tag{5}$$

So, the acceleration $\boldsymbol{a}$ of dropping particles is:

$$\boldsymbol{a} = \frac{\mathrm{d}\boldsymbol{u}}{\mathrm{d}t} = \frac{\partial \boldsymbol{u}}{\partial t} + (\boldsymbol{u}\cdot\nabla)\boldsymbol{u} = \frac{1}{\rho}\nabla p + \boldsymbol{g} - \frac{\mu}{\rho}\Delta \boldsymbol{u} \tag{6}$$

At the surface, the pressure is nearly constant and equal to the atmospheric pressure ($p = p_{atm} = Cste \Rightarrow \nabla p \to \boldsymbol{0}$). As the viscosity μ is negligible compared to the density ρ of the ocean ($\mu \ll \rho \Rightarrow \frac{\mu}{\rho} \to 0$), we obtain the following [15]:

$$\boldsymbol{a} = \boldsymbol{g} \tag{7}$$

By approximating the direction of swell spread to a straight line, the wave's position $\boldsymbol{r}$ and its velocity $\boldsymbol{v}$ are specified on the mark $(O, \boldsymbol{i}, \boldsymbol{k})$ such as the origin O (**Figure 4**), taken at the free surface of a calm ocean, coincides with the start of the breakers zone (as shown in the figure below).

At the breaking point, the height of the wave is H_b and its group velocity C_{g_b}. Therefore, the early breaking begins at a position $\boldsymbol{r}_o$ with a velocity $\boldsymbol{u}_1$ as.

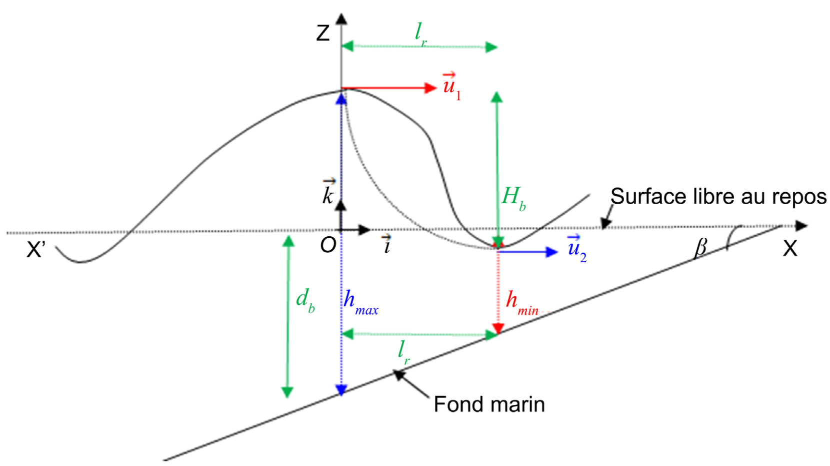


Figure 4. Wave in the breakers zone.

$$\boldsymbol{r}_o \begin{cases} x_o = 0 \\ z_o > 0 \end{cases} \text{ and } \boldsymbol{u}_1 \begin{cases} u_{1x} = C_{g_b} \\ u_{1z} = 0 \end{cases} \tag{8}$$

The position and velocity are respectively given by:

$$\boldsymbol{r}(x,z) = -\frac{1}{2}\boldsymbol{a}t^2 + \boldsymbol{u}_1 t + \boldsymbol{r}_o$$

$$\Rightarrow \boldsymbol{r}(x,z) \begin{cases} x(t) = C_{g_b} t \\ z(t) = \eta(t) = -\frac{1}{2}gt^2 + z_o \end{cases} \tag{9}$$

$$\boldsymbol{u} = \frac{\mathrm{d}\boldsymbol{r}}{\mathrm{d}t} \Rightarrow \boldsymbol{u}(x,z) \begin{cases} u_x = C_{g_b} \\ u_z = -gt \end{cases} \tag{10}$$

Thus, the path equation of the water particles located at the surface during the breaking in the breakers zone is:

$$\eta(x) = z = -\frac{1}{2d_b + H_b}x^2 + \frac{H_b}{2} \text{ with } 0 \le x \le l_r \tag{11}$$

2.3.2. Fall time t_c, Length of Breakers Zone l_r, and Local Depth of Water d_c at the Sloping Point

If at the end of the breakers zone the particles renew contact with the ocean at a point $\boldsymbol{r}_C$ with a velocity $\boldsymbol{u}_c$ and a horizontal component $\boldsymbol{u}_2$, then we get the following:

$$\boldsymbol{r}_C \begin{cases} x_C = l_r \\ z_C \le 0 \end{cases} \text{ and } \boldsymbol{u}_c \begin{cases} u_{Cx} = u_2 = C_{g_b} \\ u_{Cz} = -gt_C \end{cases} \text{ with } H_b = z_C - z_o \tag{12}$$

At the end of a time t_C, the particle slopes on the free surface at rest and twist it towards the depth at a position $\boldsymbol{r}_c(l_r, z_c)$; thus we obtain:

$$\boldsymbol{r}_c(l_r, z_c) \begin{cases} l_r = C_{g_b} t_C \\ z_c = -\frac{1}{2}gt_C^2 + z_o \end{cases} \Rightarrow \begin{cases} l_r = \sqrt{H_b(2d_b + H_b)} \\ t_C = \sqrt{\frac{2H_b}{g}} \end{cases} \tag{13}$$

The local depth of water d_c at the sloping point is as:

$$d_c = d_b - l_r \tan\beta = d_b - \sqrt{H_b(2d_b + H_b)} \tan\beta \tag{14}$$

2.3.3. Variation in Group Velocity and Wave Energy in the Breakers Zone

From the previous results, we have:

$$C_g = u = \sqrt{C_{g_b}^2 + g^2t^2} = C_{g_b}\sqrt{1 + \frac{g^2t^2}{C_{g_b}^2}} \text{ if } 0 \le t \le t_C \tag{15}$$

Let $\delta_v = \frac{C_g}{C_{g_b}}$ be the coefficient of variations of the group velocity in the zone

$$\delta_v = \frac{C_g}{C_{g_b}} = \sqrt{1 + \frac{2gt^2}{2d_b + H_b}} \text{ with } 0 \le t \le \sqrt{\frac{2H_b}{g}} \tag{16}$$

If C_{gc} is the velocity of particles at the sloping point, then the ratio $\delta_{vc}=\frac{C_{gc}}{C_{g_b}}$ expressing the variations in velocity between the end and the beginning of the breakers zones is given by:

$$\delta_{vc}=\frac{C_{gc}}{C_{g_b}}=\sqrt{1+\frac{2gt_c^2}{2d_b+H_b}} \text{ with } t_c=\sqrt{\frac{2H_b}{g}}$$

$$\Rightarrow \delta_{vc}=\frac{C_{gc}}{C_{g_b}}=\sqrt{1+\frac{4}{1+\frac{2d_b}{H_b}}} \tag{17}$$

2.3.4. Energy Dissipation Rate in the Breakers Zone

The total energy carried by a swell is given by:

$$E=\frac{1}{8}\rho g H^2 \tag{18}$$

when the breaking ends (in Surf and Swash zones) where $d\le d_b$, the height of wave drops if the local depth of water d falls; according to Bonneton P. 2002, this is expressed by the relation below:

$$H(d)=H_b\left[\sigma\left(\frac{d}{d_b}\right)^{-\frac{1}{2}}+(1-\sigma)\left(\frac{d}{d_b}\right)^{\frac{1}{4}}\right]^{-1} \tag{19}$$

with $\sigma=\frac{2H_b}{T\tan\beta\sqrt{g\left(d_b+\frac{H_b}{2}\right)}}$

H_b and d_b are respectively the height of swell and the local depth of water at the bathymetric breaking point. Thus, we obtain the following at the first dropping point of enrolled water particles:

$$H_c=H_b\left[\sigma\left(\frac{d_c}{d_b}\right)^{-\frac{1}{2}}+(1-\sigma)\left(\frac{d_c}{d_b}\right)^{\frac{1}{4}}\right]^{-1} \tag{20}$$

with $\sigma=\frac{2H_b\sqrt{2}}{T\tan\beta\sqrt{g(2d_b+H_b)}}$

Let $\tau_d=\frac{E_{wb}-E_{wc}}{E_{wb}}$ be the dissipated energy rate in the breakers zone during the breaking where E_{wb} and E_{wc} represent respectively the total energy at the beginning and at the end of the breakers zone.

$$\Rightarrow \tau_d=1-\left(\frac{H_c}{H_b}\right)^2$$

$$\Rightarrow \tau_d=1-\left[\sigma\left(1-\frac{l_r\tan\beta}{d_b}\right)^{-1/2}+(1-\sigma)\left(1-\frac{l_r\tan\beta}{d_b}\right)^{1/4}\right]^{-2} \tag{21}$$

3. Results and Discussion

3.1. Presentation of the Results

Graphs of **Figure 5** show the variations in horizontal length l_r of the breakers zone and the fall time t_c of water particles according to the off height and wave period in the breakers zone at Cotonou. In terms of the graph in **Figure 6**, it reveals the influence of the slope of the seabed on the latter.

The curves in **Figure 7** and **Figure 8** below represent the variations in ratio δ_{vc} according to the height and period of waves on the one hand and the slope of the seabed on the other hand.

The graph below (**Figure 9**) expresses variations in ratio of the wave energy dissipation in the breakers zone for $\beta \approx 0.05\ \text{rad}$. As for the graph in **Figure 10**, it highlights the influence of the slope of seabed on the dissipation on the energy.

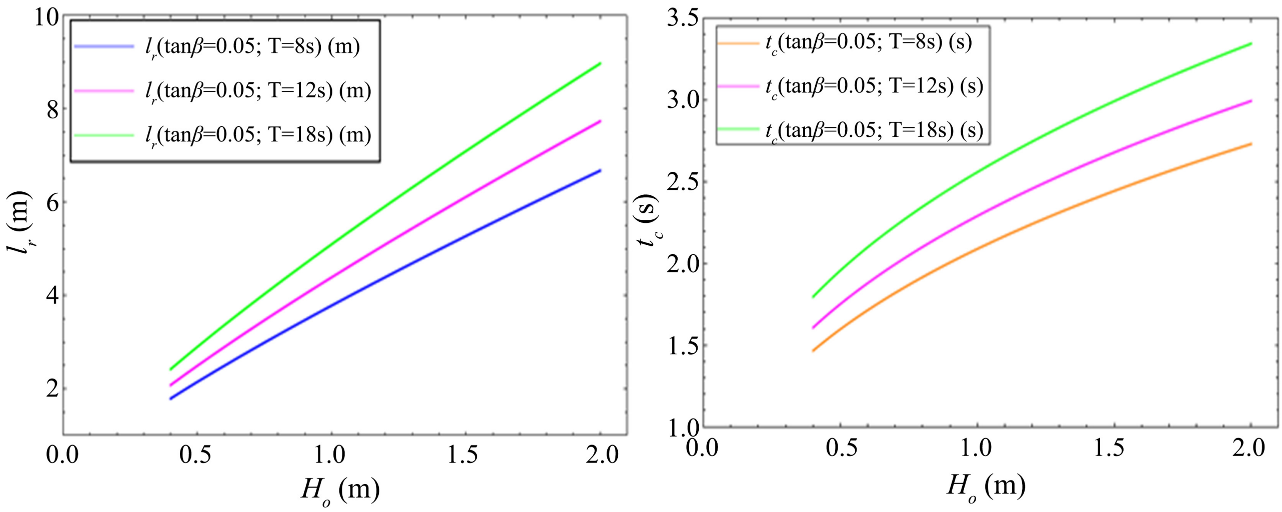


Figure 5. Variations in horizontal length l_r of breakers zone and water particles fall time t_c.

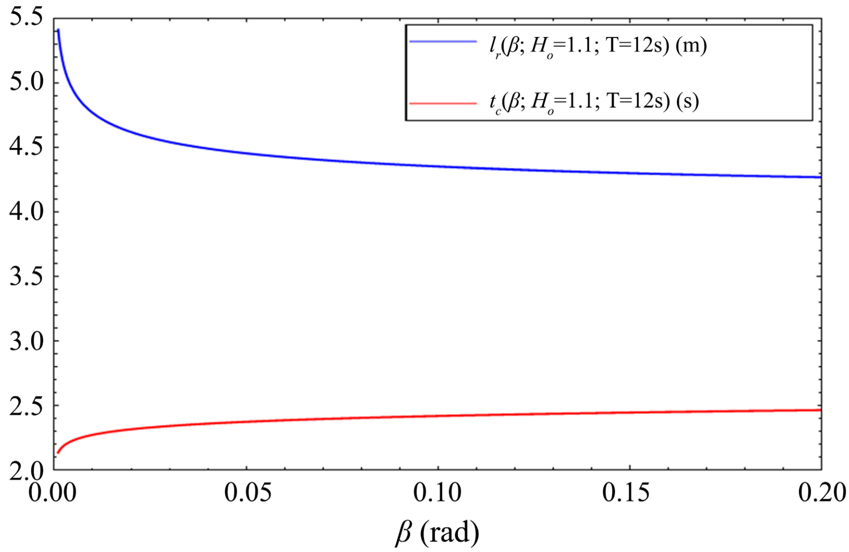


Figure 6. Influence of the seabed slope on the length l_r the time t_c.

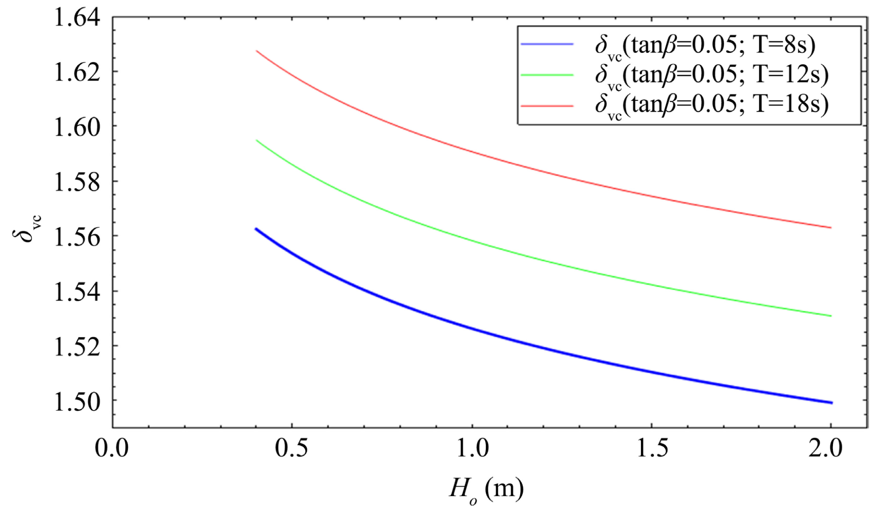


Figure 7. Coefficient δ_{vc} of variations in velocity of enrolled particles.

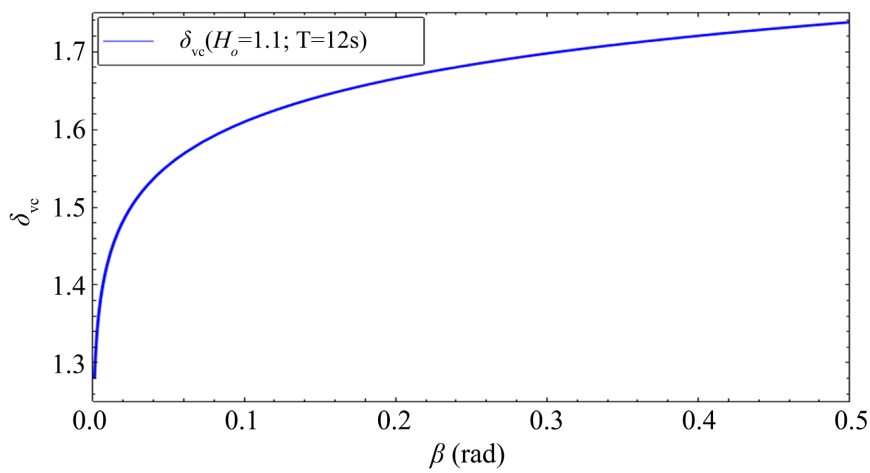


Figure 8. Influence of the slope of the seabed on δ_{vc}.

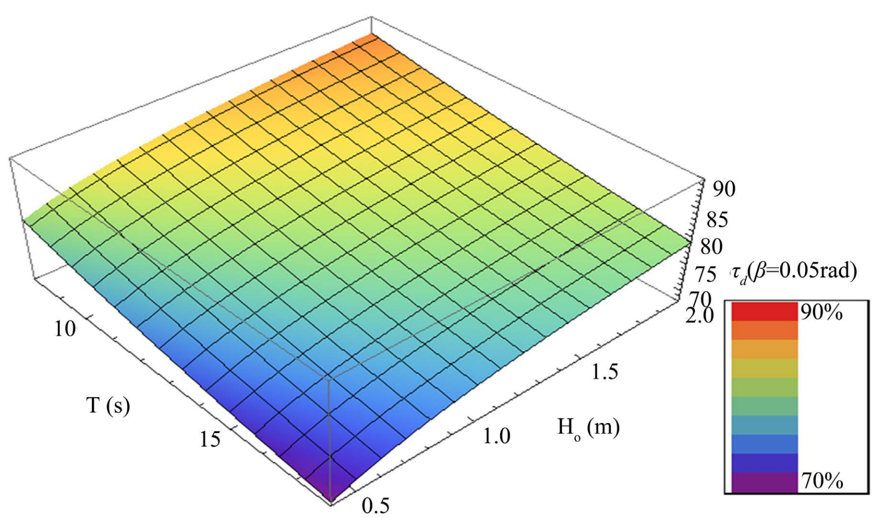


Figure 9. Variation in energy dissipation rate according to the off height and wave period.

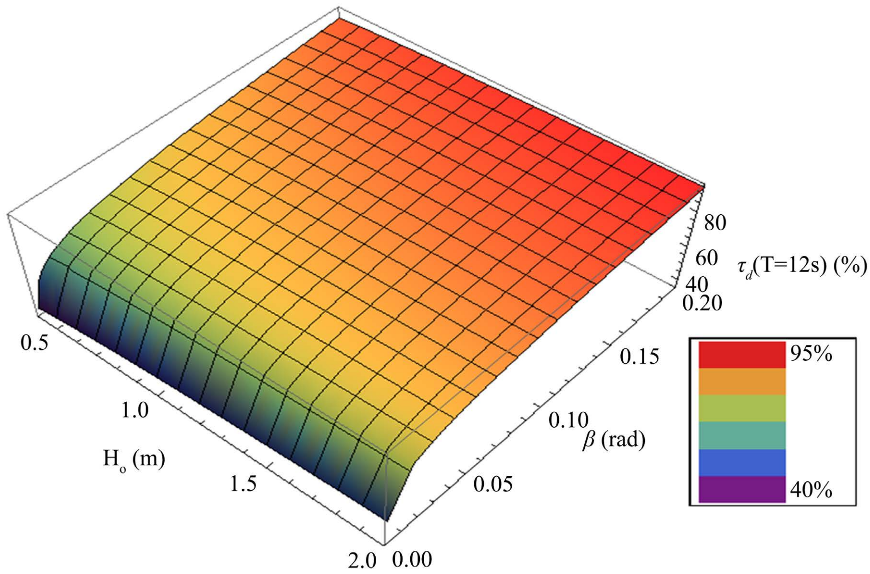


Figure 10. Influence of the slope of the seabed on energy dissipation in breakers zone.

3.2. Analysis and Discussion of Findings

The curves of **Figure 5** which present the variations of length horizontally from the breakers zone and the sloping duration of enlisted water particles, show that these two quantities increase according to the off height and wave period when the average slope of the seabed is $\tan\beta \approx 0.05$. On the site, when the period fluctuates between 8 s and 18 s and then the height is between 0.4 m and 2 m:

- The horizontal length l_r of the breakers zone varies between 2 m and 7 m approximately ($2\text{ m} \le l_r \le 7\text{ m}$).
- The fall duration of the water particles fluctuates between 1.5 s and 3.5 *s* approximately ($2\text{ s} \le t_c \le 2.5\text{ s}$).
- Variations of the curves in **Figure 6** show that l_r drops when the slope of the seabed rises whereas t_c falls. When the slope β of the seabed to the horizontal varies between 0.001 rad and 0.2 rad with $H_o = 1.1\text{ m}$ and $T = 12\text{ s}$:

● The length l_r varies between 5.5 m and 4.3 m approximately ($4.3\text{ m} \le l_r \le 5.5\text{ m}$).

● The fall time t_c corresponds to figures between 2 s and 2.5 s approximately ($2\text{ s} \le t_c \le 2.5\text{ s}$).

Variations in the coefficient δ_{vc} (**Figure 7**) which reflects the ratio of water particles velocity at the end and beginning of the breakers zone reveal that:

- $\delta_{vc} > 1 \quad \forall T, H_o$ and β: therefore the velocity acquired by the water particles at the end of the breakers zone is always higher than their velocity at the beginning of this zone; the velocity of the particles increases in the breakers zone.
- δ_{vc} is a monotonic function of the wave period T but a descending function of their off height H_o: the longer the period is (the smaller the height of swell is), the more important the velocity of water particles is in the breakers zone.

The evolution of the curve of Figure 8 related to the influence of the slope of the seabed on δ_{vc} states that this coefficient is a monotonic function of the slope of the seabed. But this growth tends a limit when $\tan\beta \to 1 \Rightarrow 0 \le \beta \le \frac{\pi}{4}$.

The graph of Figure 9 shows the variations in dissipation rate τ_d of the swell energy according to their off height and period in the breakers zone on the coast of Benin. Its evolution reveals that:

- The dissipation rate increases with the off height of the swells; it is therefore a monotonic function of the wave height.
- The rate decreases as the frequency of these waves increases: it is a decreasing function of the period.
- Each breaking wave loses between 70% and 90% of their energy in the breakers zone in Cotonou with an average slope $\tan\beta \approx 0.05$ when the period fluctuates between 8 s and 18 s and the height between 0.4 m and 2 m.
- Breaking is the major source of dissipation of wave energy on the study site.

As for the diagram of Figure 10 which shows the influence of the slope of the seabed on the dissipation rate τ_d of the wave energy, one can read that:

- The dissipation of the breaking waves energy in the breakers zone increases with the slope of the seabed.
- On the study site, when $T = 12\text{ s}$ and $0.4\text{ m} \le H_o \le 2\text{ m}$, the rate of dissipation varies between 40% and 95% as the slope of the seabed to the horizontal varies between 0.001 rad and 0.2 rad.

4. Conclusions

Dissipation of breaking wave energy is a shaft of renewable energy. It appears from this study that the breaking waves in the breakers zone at the coast of Benin lose about 80% of their total energy. This generates turbulence on this site, and leads to a strong set in motion of non-cohesive sediments: it heightens coastal erosion that one can observe on this coast. This dissipation increases with the off height of waves but decreases with their period; it is a monotonic function of the slope of the seabed. In addition, results show that the horizontal length l_r of the breakers zone is an increasing function of the period and the wave height can vary between 2 m and 7 m. As for the fall time of the water particles in this zone, it fluctuates between 1.5 s and 3.5 s. Similarly, the velocity of the water particles increases in this zone depending on the period of the swells and the slope of the seabed but constitutes a decreasing function of their off height H_o.

In Benin context characterized by a large energy deficit, the development of this sea renewable energy would be a good perspective to address the crisis and improve the modern conveniences of the country in terms of energy.

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Conflicts of Interest

Authors have declared that no competing interests exist.

We (Author and Co-Authors) confirm that neither the manuscript nor any part of its contents is currently under review or published in any other journal. All authors (Author and Co-Authors) have approved the manuscript and are in agreement with its submission to JMP.

References

[1] Bonneton, P. (2001) *Comptes Rendus de l'Académie des Sciences - Series IIB - Mechanics*, **329**, 27-33. https://doi.org/10.1016/S1620-7742(00)01278-2

[2] Ardakani, A. and Bridges, J. (2010) Shallow Water Sloshing in Rotating Vessels Undergoing Prescribed Rigid-Body Motion in Two Dimensions. Department of Mathematics, University of Surrey, Guildford, 1-48.

[3] Kounouhewa, B.B., Tokpohozin, N.B., Houekpoheha, A.M., Awanou, C.N. and Chabi-Orou, B.J. (2014) *Journal de la Recherche Scientifique de l'Université de Lomé, Serie E*, **16**, 527-536.

[4] Bonneton, P. (2003) *Revue Française de Génie Civil*, **7**, 1061-1076. https://doi.org/10.1080/12795119.2003.9692534

[5] Houekpoheha, A.M., Kounouhewa, B.B., Hounsou, J.T., Tokpohozin, N.B. and Awanou, C.N. (2015) *Revue des Energies Renouvelables*, **18**, 89-103.

[6] Houekpoheha, A.M., Kounouhewa, B.B., Tokpohozin, N.B. and Awanou, C.N. (2014) *Revue des Energies Renouvelables*, **17**, 489-495.

[7] Abbasov, I.B. (2012) *Applied Mathematics*, **3**, 135-141. https://doi.org/10.4236/am.2012.32021

[8] Houékpohéha, M.A., Kounouhéwa, B.B., Hounsou, J.T., Tokpohozin, B.N., Hounguèvou, J.V. and Awanou, C.N. (2015) *International Journal of Renewable Energy Development*, **4**, 64-71. https://doi.org/10.14710/ijred.4.1.64-71

[9] Hervé Houngué, G., Kounouhewa, B.B., Almar, R., Sohou, Z., Lefebvre, J.-P., Houépkonhéha, M. and Tokpohozin, B. (2018) *Journal of Coastal Research*, **81**, 130-137. https://doi.org/10.2112/SI81-017.1 http://www.JCRonline.org

[10] Kounouhewa, B.B., Houekpoheha, A.M., Tokpohozin, N.B., Awanou, C.N. and Chabi-Orou, B.J. (2014) Simulation of swell energy power in Autonomous Port of Cotonou. *Journal de la Recherche Scientifique de l'Université de Lomé, Serie E*, **16**, 183-193.

[11] Bougis J. (2004) Modèle d'approche de la houle par une méthode de refraction - Diffraction en coordonnées curvilignes. *Revue Paralia, VIIIème Journées Nationales Génie Civil-Génie Côtier*, Compiègne, 7-9 September 2004, 55-64. https://doi.org/10.5150/jngcgc.2004.007-B

[12] Babanin A.V. (2009) *Acta Physica Slovaca*, **59**, 305-535.

[13] Senechal, N. (2003) Etude de la propagation des vagues au-dessus d'une bathymétrie complexe en zone de surf. Thesis, No. 2759, Bordeaux I University, Bordeaux, 1-288.

[14] Sabatier, F. (2001) Fonctionnement et Dynamiques morpho-sédimentaires du littoral du Delta du Rhone. Doctoral Thesis, Thesis No. 0/1/A/I/X/3/0/1/0/3, AIX-Marseille II University (School of the Faculty of Science and Technology of Saint Jerome), Marseille.

[15] Tokpohozin, N.B., Kounouhéwa, B., Avossevou, G.Y.H., Houékpohéha, M.A. and Awanou, C.N. (2015) *Acta Oceanologica Sinica*, **34**, 137-142. https://doi.org/10.1007/s13131-015-0610-2

Abbreviations and Acronyms

ρ : Density of sea water (kg/m^3);
μ : Fluid dynamic viscosity (sea water);
$\boldsymbol{r}$: Vector position of a point located on the free surface;
η : Vertical elevation of the water level relative to the reference (m);
β : Inclination of the seabed relative to the horizontal (rad);
g: Gravity acceleration (m/s^2);
H: Wave crest-to-trough height (m);
H_0 : Offshore wave height peak to trough (m);
H_b : Wave crest-to-trough height at breaking point (m);
H_c : Peak-to-trough height of the swell in the breaker zone (m);
L: Wave length of the swell (m);
L_0 : Wavelength of the offshore swell (m);
L_b : Wavelength of the swell at the breaking point (m);
L_c : Wavelength of the swell in the breaker zone (m);
l_r : Horizontal length of the breaker zone (m);
$T = \frac{2\pi}{\omega}$: Swell period (s);
d: Surface-seabed distance near in coastal areas (m);
d_b : Local water depth at the breaking point (m);
d_c : Local water depth in the breaker zone (m);
C_g : Wave group speed (m/s);
C_φ : wave phase speed (m/s);
C_{gb} : Swell group speed at breaking point (m/s);
$C_{\varphi b}$: Swell phase speed at breaking point (m/s);
C_{gc} : Swell group speed in the breaker zone (m/s);
E: Total wave energy (J/m);
E_{wb} : Total energy at the start of the breakers zone (J/m);
E_{wc} : Total energy at the end of the breaker zone (J/m);
t_c : Duration of fall of water particles in the breakers zone (s);
$\tau_d = \frac{E_{wb} - E_{wc}}{E_{wb}}$: Rate of energy dissipated in the breakers zone;
$\delta_v = \frac{C_g}{C_{g_b}}$: Coefficient of variations of group speed in the breaker zone;
$\delta_{vc} = \frac{C_{gc}}{C_{g_b}}$: Rate of the speeds of the water particles enlisted at the end and at the start of the breakers zone.