This paper has three main objectives which are to develop a simulator that can simulate and graphically represent the fall of rain in a swimming pool, developing a map editor with the ability to edit/view bathymetries and finally to make a systematic study on the influence of the introduction of an artificial reef on the beach of Macumba located in Brazil, Rio de Janeiro, to practice the surf.

1.1 – Wave breaking and surfability parameters

The breaking of waves on a beach has three areas of action:

- **Breaking zone** - is the portion of the beach profile characterized by the occurrence of the process of wave breaking;
- **Surf zone** - The region where the waves propagate after breaking, in the case of low slope beaches, the waves suffer the exponential decay in height to reach the beach line;
- **swash zone** - In this area, the coast line is not a fixed line, but it moves backward and forward.

Depending on the slope of the beach, the height and the length of the wave, the waves may burst in four different modes

- **spilling breaker** – Occurs in beaches of low slope, in which the wave bursts gradually sliding on the base.
- **plunging breaker** – It occurs on beaches with moderate or high slope. The wave exacerbates abruptly to move closer to the coast and violently breaking up and forming a tube.
- **surging breaker** - gradient occurs on beaches so high that the wave is not enough to burst properly, amounting on the side of the beach and interacts with the reflux of previous waves
- **collapsing breaker** - occurs at beaches of outstanding abruptness and is considered a type intermediate between the plunging breaker and surging breaker

In general surfing conditions depend on several factors:

- **Wave height** – The wave height has to be superior than 0.5m for the practice of surf;
- **Wave breaking type** – The appropriate type of wave breaking is plunging or surging;
- **Breaking angle and surfing speed** – The breaking angle is a very important parameter in surf and is directly related to surfing speed;
- **Surfing line** – The surfing line is the extension along a wave in which a surfer can ride a wave;
• Wave decay – In order to be appropriate for surf, a wave must have approximately the same height along the surfing line.

The Iribarren number, $\xi$, is used to classify the wave breaking where higher values mean higher breaking intensities. The breaking categories are given by:

- **Spilling breaker** – if $0.5 < \xi_b < 0.4$.
- **Plunging breaker** – if $0.5 < \xi_b < 3.3$ or $0.4 < \xi_b < 2.0$.
- **Surging breaker** – if $\xi_b > 3.3$ or $\xi_b > 2.0$.
- **Collapsing breaker** – is the hardest type to identify.

In the spilling breaker, the face of a wave is gently sloping and leads to a speed of surf lower compared to the most inclined of plunging breaker, it is better for the application of more advanced maneuvers. One of the main functions of a ASR (Artificial Surfing Reef) is to amplify the height of the incident waves. Thus, a factor of the wave amplification ($A$) is defined in terms of the ratio between the maximum height of the wave in the ASR and height of the wave closer to the ASR by the following formula:

$$A = \frac{H_{\text{max}} - H_{\text{in}}}{H_{\text{in}}} \quad (1.1)$$

Where $H_{\text{max}}$ is the maximum height of the wave over the ASR and $H_{\text{in}}$ is the maximum height of the incident wave.

One of the important elements for the surfers is the extension of the breaking line which is defined as the extent to which a surfer achieves when surfing a wave. The reef must be sized to induce breaking lines, as extensive as possible.

In terms of the development of an ideal ARS it is important that along the breaking lines occur sections with different degrees of difficulty, ie, different breaking types or breaking angles, to enable a greater number of practitioners to take advantage of the existence of ARS.

The breaking angle is related to the place of the breaking wave, which is determined by the depth and characteristics of the wave. Generally, the waves start to burst when the wave height is approximately 0.7 to 1 times the depth of the place of breaking. Thus, a wave of 1 m will burst in about 1 to 1.4 m high water. If the wave finds a variable depth along the crest of wave (natural or artificial reefs under an oblique angle on the crest of wave) the wave will break out from the point where the depth meets the conditions above, propagating throughout the oblique frame of the bottom.

2 Breaking angle

The amplification of the wave height of over ASR must be such that the decay of the wave along the breaking line should be minimized.

1.2 - Simulator of the fall of rain in a swimming pool

In order to model the volume of the fluid, the volume is divided into columns linked together assuming that the properties of the fluid within each column remain constant in the other columns. The flow between columns occurs through a series of virtual pipes that connect the columns adjacent to each other. The connections are made by their axes and their diagonals. This is represented in figure 3.

3 Column representation

As the mass of the fluid in a pipe length given by $l$ is $m = \rho cl$ and assuming a constant atmospheric pressure, this equation becomes:

$$a_{y \rightarrow i} = \frac{\rho g (h_y - h_i) + E_y - E_i}{pl} \quad (1.2)$$
Assuming a constant acceleration during the iteration period \( \Delta t \), the flux in the pipe, \( Q_{y \rightarrow kl} \), is given by:

\[
Q_{y \rightarrow kl}^{t+\Delta t} = Q_{y \rightarrow kl}^t + \Delta t \left( ca_{y \rightarrow kl} \right)
\]  

(1.3)

Thus obtaining the variation of volume per column:

\[
\Delta V_y = \Delta t \sum_{kl} \left[ \frac{Q_{y \rightarrow kl}^{t+\Delta t} + Q_{y \rightarrow kl}^t}{2} \right]
\]

(1.4)

The vertical position of the point \( z_{ij} \) is determined by the average of the height of the four columns around the grid point:

\[
z_{ij} = \frac{h_{i,j} + h_{i,j+1} + h_{i+1,j} + h_{i+1,j+1}}{4}
\]

(1.5)

The applied forces in each control point are reformulated as external pressure, \( E_{ij} \), which is applied to the adjacent columns to the control point:

\[
E_{ij} = -\frac{f_c}{4dx dy}
\]

(1.6)

\( f_c \) → força aplicada no ponto de controle

A force in the negative direction of the zz axis, will result in an increase in external pressure, so the negative signal in the expression. The points of control connect four columns and the external pressure will also be distributed to the four adjacent columns.

Figure 4 is the class diagram from which the program has been developed. The class interface serves to introduce the options for simulation, visualization of simulation and to the post-processing functions (recording of images and video). The class Form2 is a class which, as the name suggests, creates a Form. This Form serves as a container for the next class, SimuView that has the function of customizing the controls and the configuration of the OpenGL libraries and to allow the 3D representation of the simulation. The Calc class is the class where the calculations required for the determination of the evolution are done.

**1.3 – Map Editor**

This program is developed according to the structure of figure 6.

A class interface is the main class of the program. It is in this class that begins the process of developing 2D / 3D maps. Classes that are in the left column
(BuilderForm2D, Editor2Dform, OpenglEditor2D and EditorMapa2D) are the classes that enable the program to the development of a 2D map. The class BuilderForm2D is the class where the methods are transmitted to the rest of the program. The class Editor2Dform is a class that serves as a container to the class OpenglEditor2D. It is in this class that the graphical representation of simulation of the map is done. The class EditorMapa2D contains the functions that carry out changes to the map and graphic changes to the class OpenglEditor2D.

The following pictures show examples of generated maps and views of bathymetries.

10 Macumba beach, Rio de Janeiro, Brasil.

The beach of Macumba, in the area west of the city, is one of the most sought for surf because it presents fair conditions at the east side, where the waves have a progressive breaking type. To the west, the breaking wave is not conducive to the practice of surf, as it occurs very close to the beach. The field of calculation used by the model was discretized by a mesh of 501×441 points, with spacing of 2 m in both directions, which corresponds to an area of 1000×880 meters. Two bathymetries were used throughout this study, the natural bathymetric and another in which it was implemented an artificial reef. The maximum depth of the beach is 9.25 m.

The base simulation values are:
- Tide level 0;
- Wave period of 9 s;
- Wave direction 0º;
- Wave amplitude 1.5 m.

In following charts you can see the results for two different values of initial range: 1.0 and 1.5 m in the initial wave amplitude.

In figures 11 and 12 one can observe that for the natural bathymetric, the heights of wave amplitudes obtained are proportional to the amplitude of the incident waves. For bathymetric with the artificial reef the waves obtained are also proportional to the breaking induced by the reef. There is also a difference in wave height proportional to the difference of the incident wave amplitudes. In conclusion, the behavior of the model for these heights is almost linear.

Figure 11 and 12 show these results.
The results obtained in this section are related to the initial condition with amplitude of 1.5 m, a period of 9 s, direction of 0° and average level of tide of 0 m.

Figure 13 Error! Reference source not found. shows the breaking line associated to the area in the influence of the ASR.

Figure 14 shows the breaking angle along the breaking line.

Com esta configuração tem-se um ângulo ao longo da linha de rebentação que tem como valor médio 40° para o lado esquerdo do recife e de 42° para o lado direito do recife.

Figure 15 shows the amplitudes and the amplification factors along the breaking line. The amplification of the initial wave occurs only in a range that has as limits 50 m to the left and to the right of the center of the reef. Figure 16 represents the Iribarren number along the breaking line. The average value is 0.34 for both sides of the reef. This value corresponds to a progressive breaking type.
Of the initial conditions examined the conditions that result in better wave breaking conditions and to the practice of surf are:

- Tide level 0m;
- Period 12 s;
- Incident direction -22.5°;
- Wave amplitude 1.5 m.

For these conditions, the number of Iribarren has values close to 0.4 corresponding to a wave with progressive wave breaking. This breaking type is not ideal for the practice of surf, but for the tested values (typical values for the beach of Macumba), this is the closest to the ideal.

The dimensions of the reef allow us to obtain a breaking line with 70 m to the left of the center point of the reef and 80 m to the right of that point. The breaking angle along the lateral side of the reef is 40 ° to the face left and 42 ° to the right side.

This reef allows the amplification of the incident wave in the first 50 meters in distance in relation to the starting point of the wave interaction with the reef.

1.5 - Conclusion

In this paper a fluid simulator was presented. This simulator has been developed with the intention to develop an application capable of reproducing the behaviour of the interaction between fluids. This work has been done and presents results that can be considered, within the approximations made and the constraints required, functional. Future developments to be considered are the introduction of algorithms that introduce fewer approximations and have fewer restrictions (range speeds, interactions between fluids and objects and to represent accurately the wave breaking).

The map editor developed presents the basic features of changing bathymetries allowing the introduction of geometric shapes and a consistent view. Improvements to be implemented are the ability to introduce the same geometric shapes in a more dynamic way and the introduction of other forms.

It was shown the operation of the model REF / DIF, this model has been applied to a test case, the beach of Macumba, Brazil. The results of the model to different conditions of agitation are presented in addition to an analysis of the operation of the artificial reef for the practice of surf on the beach of Macumba.

The application of the REF / DIF model test case confirmed that the waves resulting from the interaction with the reef exhibit characteristics such as number of Iribarren less than 0.4, i.e. progressive breaking type, with an angle of about 40 ° and extension the breaking line for both sides of the centre of the reef in about 70m, with a maximum amplification that reaches 10%. Compared with the results for the beach without reef, the conclusion is that reef significantly improves the conditions for the practice of surf, even if the conditions are not the ideal.
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