Proposed Artificial Surfing Reef for Macumba Beach, Rio de Janeiro - Brazil

L.G.M. de Aguiar, L.A.F. de Oliveira Filho, and E. Valentini

Ocean Engineering Department – Federal University of Rio de Janeiro – Brazil
lgmaguiar@peno.coppe.ufrj.br

ABSTRACT

This paper presents a numerical model study to (1) investigate the geometric form of Artificial Surfing Reef (ASR) necessary to promote a high level wave breaking for surfing at Macumba beach, on the west zone of the Rio de Janeiro city, Brazil; and (2) evaluate the wave energy variation near to the shoreline faced the refraction, diffraction and dissipation by breaking of the wave, caused by the ASR. The study was conducted considering natural conditions of Macumba beach, such as: bathymetry, wave and tide. Starting from one basic Delta-type ASR form, several other geometric forms were tested in order to find the best configuration. All these geometries were evaluated through parameters related with surfability as: lane length, wave height amplification, breaking type, peel angle, wave height decay and wave wall conditions. Coastal reaction due the ASR installation was also evaluated.

INTRODUCTION

Rio de Janeiro, on the southeast of Brazil, is a city with natural vocation to surf practice: beautiful beaches, excellent weather conditions (warm and sunny) during all the year, good frequency of incoming swells and people that enjoy outdoor sports. Thus, surfing is one of the favorite sports in the city. On the other hand, the typical sand bottom of Rio de Janeiro’s shelf does not promote a suitable breaking for surf when the wave height is higher than 1.5 m, reducing the number of appropriate places for surfing in the city and neighborhoods, causing a crowd and limiting the evolution of the local professional surfers. A measure of the quality of the waves is given by their reputation as great surfers in bad waves, but poor ones in good waves as those occurring in WCT’s contests. However, the small tide range in Rio de Janeiro city, less than 1 m, allows the promotion of perfect wave breaking for surf, through the building of an Artificial Surfing Reef (ASR). Added to the very favorable weather conditions, Rio de Janeiro could become one of the best places in the world to undertake surfing, attracting surfers and tourists in general. This was the aim of the study presented in this paper.

DESIGN CRITERIA

Thinking as civil and coastal engineers we tried to create a set of procedures convenient for ASR projects. In this paper, we developed some procedures based on formal wave mechanics theory and surfing practice focusing ASR performance, using the REFDIF numerical model. Structural and construction techniques are out of the scope of this paper. Wave breaking is the most important phenomenon for surfing. Breaking process was earlier discussed, in qualitative and quantitative ways, by many authors, among then WIEGEL (1964), GALVIN (1968), BATTJES (1974); WALKER (1974, 1997); PEREGRINE (1983); MEAD and BLACK (1999); MEAD (2003); BLENKINSOPP (2003). However, taking into account the point of view of surfing practice, there are still few references in literature. In this way a set of design criteria for artificial surfing reef was developed, based on the available theory and adding personal surfing experience of the main authors. The proposed criteria involve the following parameters:

Wave surfability

Wave surfability condition was parameterized by means *Modified Iribarren Number*, given by the equation below where *m*' is the ASR bottom slope relative to the wave direction approach, H_b and L_b are, respectively, the wave breaking height and length.

$$\xi_b = m' \sqrt{\frac{L_b}{H_b}} \quad (1)$$

According to Battjes (1974) the wave breaking classification is the following: spelling breaking for $\xi_b < 0.4$; plunging breaking for $0.4 < \xi_b < 2.0$; collapsing for $\xi_b > 2.0$. It is necessary to avoid collapsing wave breaking, so it is necessary to promote spelling or plunging breaking at the ASR; so, the idea is to look for values of the modified Irribaren number at the proposed ASR between 0.4, and 2.0.

Wave Amplification Factor

One of the main functions of an ASR is to amplify wave height. In this way a wave amplification factor (*A*) was defined, in terms of the ratio of the resulting wave breaking height at the ASR and the approaching one, according to the following relation:

$$A = \frac{H_{b-\max-ASR} - H_{in}}{H_{in}} \quad (2)$$

Where $H_{b\text{-max-ASR}}$ is the maximum wave breaking height at the ASR, H_{in} is the approaching wave height.

Surfing Lane

One important element for surfers is the extension of the surfing lane, which is defined as the extension that the athlete can ride surfing the wave. In terms of an "artificial" surfing point, it is desirable that the surfing lanes could attend several surfers performance. That means: to promote lanes with different degrees of difficulty, attracting athletes of all levels of ability.

Surfer Performance

Surfer performance is a subjective matter. The point here is how to parameterize surfer's performance in terms of the objectives of an engineering work as an ASR project. WALKER (1974) presented a classification for surfer's performance in tree levels: beginners, intermediate and advanced, based on the velocity that the surfer could reach as a function of the wave peel angle. More recently, HUTT *et al.* (2001) presented another (also subjective) classification for surfer's performance divided into 10 levels also associated to the peel angle as shown in Table 1.

Table 1: Surfer performance classification, according to Hutt et al, 2001.

Level	Description	Peel Angel (°)
1	Beginners. Just drop the wave.	90
2	Learner surfers able to ride laterally along the crest.	70
3	Surfers who can generate velocity pumping on the wave's face.	60
4	Surfers learning to execute standard surfing maneuvers.	55
5	Surfers able to execute standard maneuvers on a single wave.	50
6	Surfers able to execute standard maneuvers consecutively.	40
7	Top amateur surfers able to execute advanced maneuvers.	29
8	Professional surfers.	27
9	Top 44 professional surfers.	Not Available
10	Surfers in the future.	Not Available

As a conclusion on this topic: wave peel angle on the lane is an important parameter in the design of an ASR, and it must be defined according to the degree of difficulty desired for the projected surfing point. At the present study it was established that the lane's difficulty must start on level 5.

Peel Angle

Peel angle is defined as the angle between the wave crest and wave breaking line, as shown in Figure 1. The velocity that surfers can develop is inversely dependent on the peel angle value. According to the degree of difficulty proposed to ASR, and based on the values expressed in Table 1 the designer can establish the peel angle range for the project.

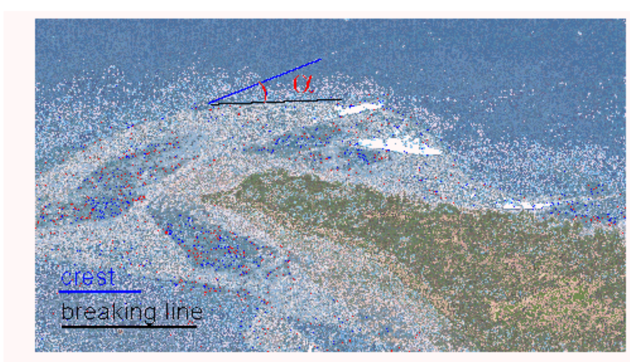

Figure 1: Scheme of peel angle.

Wave Decay

To improve the wave height amplification on an ASR is necessary but is not sufficient. It is also necessary to inhibit the wave decay along the lane. That means: it is necessary to amplify the wave height on the reef but it is also necessary to keep the wave height along the lane. This situation is illustrated in Figure 2 where it is shown very big wave amplification on the sea board of an ASR but a very big decay of the wave height along the lane. The picture on the right at the same figure illustrates this situation in nature.

Figure 2: Wave decay along the lane. Left: Wave height special distribution where one can see a strong amplification at the sea board of the reef followed by an also strong decay along the lanes. Right: An example of this situation in nature.

Taking into account the above exposed, it is introduced the wave decay parameter given by equation 3 where H_b is the wave height at the breaking point and *i* and *i-1* are consecutive positions along the lane.

$$\delta = \frac{H_{bi} - H_{bi-1}}{H_{bi-1}} \quad (3)$$

Wave Wall

The wave wall is the segment along the wave crest near the breaking point. In Figure 3 as an example, it is presented a plan view of the wave wall related to bottom contours and the lanes. Wave wall is an important element for surfers as they use this space to develop their performance. Ideally the wave wall must be high and steep (so surfers can develop velocity), and these characteristics must present small decay with the wave propagation. As a consequence, to keep these characteristics along the lane, it is necessary to guarantee small variation on bottom contours. Figure 4 shows two cases as examples of favorable and unfavorable walls.

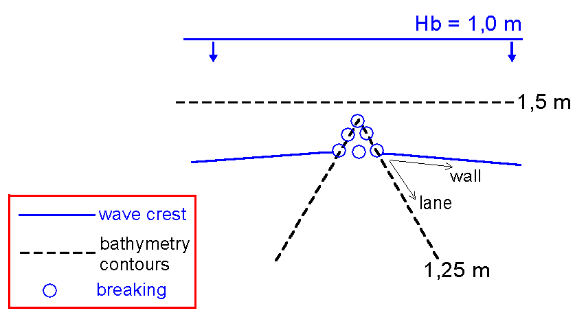

Figure 3: Example of wave wall plan view.

Figure 4: On the left: An example of an unfavorable wall (Recreio beach, Rio de Janeiro). On the right: An example of a favorable wall (Macumba beach, Rio de Janeiro). Photos by www.ricosurf.com.br.

Surf Lane

Surf lane is defined as the length along with it is possible to surf. One lane can have more than one section, and each section is characterized by its own qualities. For example, one site can have a lane composed by one fast section with plugging breaking and another section with low velocities and spilling breaking. As the degree of difficulty for surfing depends on the wave velocity, for designers it means that it is possible to choose (thinking about the project demand) how many sections the site lane will have and how difficulty they will be. Obviously, the best choice is to create a lane as big as possible. But, on the other hand, surf lane length is related also to ASR's size (or volume) which is related to construction costs. This is a matter that involves economic and social aspects that are out of discussion in this paper but, certainly, must be analyzed during the development of an ASR project.

Coastal Reaction

It is well known that shoreline configuration depends on the wave energy distribution along the coast, and wave propagation is strictly related to bottom features in intermediate or shallow waters. The installation of an ASR nearshore promotes the creation of a shadow zone landward the structure. This means that in this zone the incident wave energy is lower than under natural conditions. Since in the vicinity the wave energy density remains the same, there will be a convergence in the shadow zone promoting sedimentation. The procedure adopted here was earlier suggested by MOCKE *et al.* (2003). Figure 5 shows a plan view of the elements involved, where:

- L_p is the total length along the coast affected by the presence of an ASR;
- L_c is the central length that corresponds to the segment where waves use to break before the ASR installation;
- L_w and L_e are adjacent segments where breaking height is reduced;
- Δd is the distance between natural and ASR's breaking line;
- ΔH_{bw} and ΔH_{be} are the wave height breaking variation at ASR both sides.

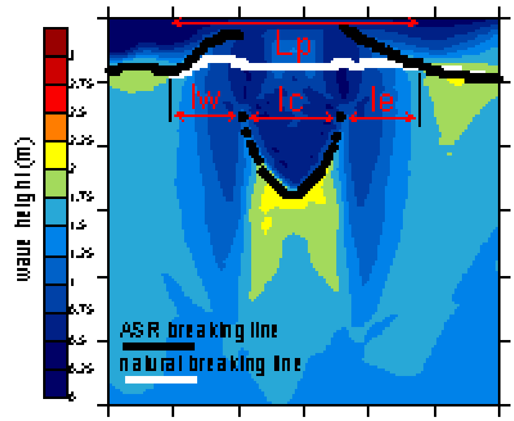

Figure 5: Plan view of the wave height distribution, according to the chromatic scale on the left, and the elements involved on coast reaction due the presence of an ASR.

TESTED ASR'S SHAPES

This study started by testing the geometry of the classical delta banc. As shown in Figure 6 it was located according to natural bathymetric contours and reef characteristics, like internal angle θ, lateral slopes *m*, and wave direction, were tested to evaluate its efficiency.

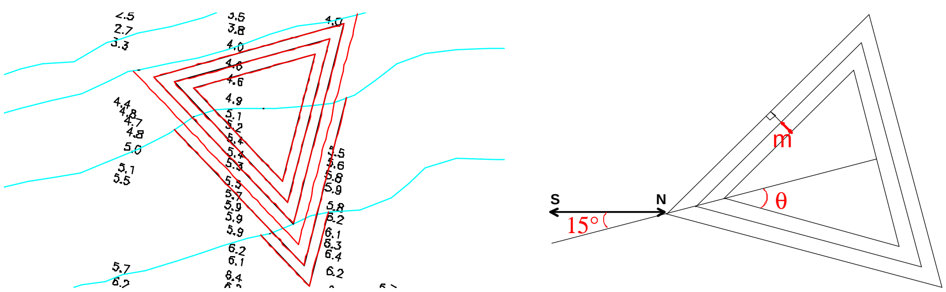

Figure 6 Basic Delta ASR. On the left: plan view of the delta shape ASR with details of depth contours and natural bathymetry. On the right: Sketch showing variables in test: internal angle θ, lateral slope *m*, wave attack angle.

The results showed that: wave amplification factor (*A*) and wave decay along the lanes (δ) enlarge as bottom slope diminishes; Irribaren number (ξ) enlarges with bottom slope (see Figure); and the peel angle (α) is bigger at the beginning of the lane than at its end (see Figure 8). This result means that the wave is slower at the takeoff area and become getting faster along the lane, and it is just the opposite of the desired situation.

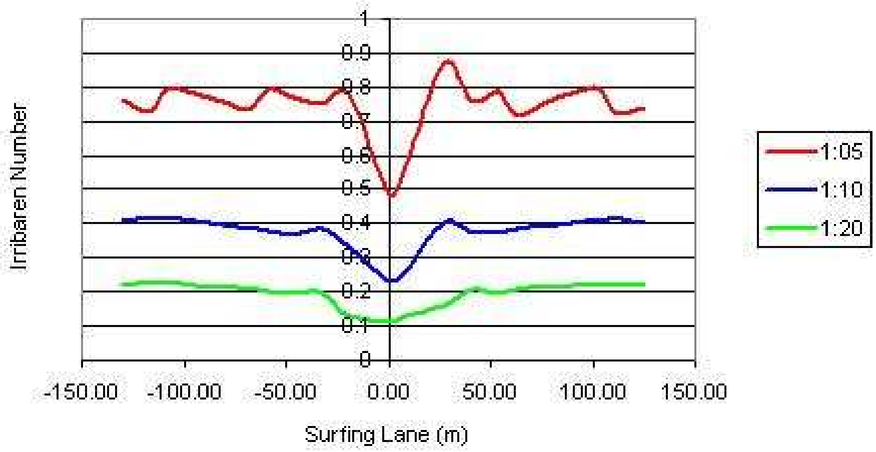

Figure 7: Basic Delta ASR. Irribaren Number along the lanes varying with bottom slope (negative values correspond to right lane).

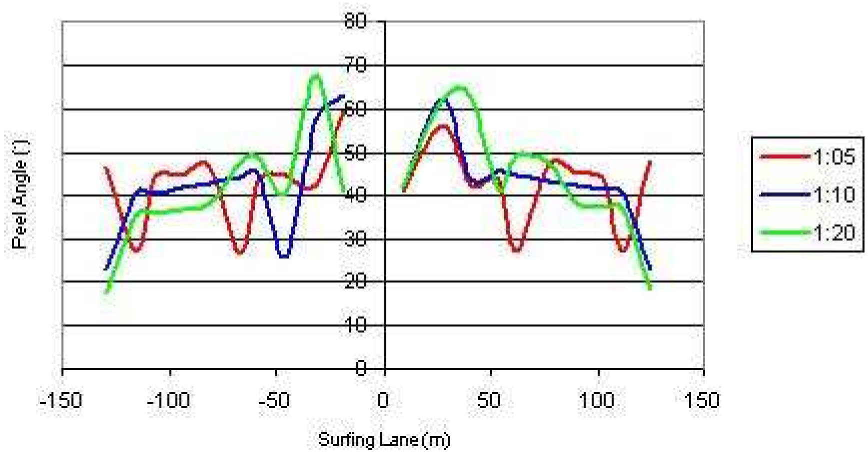

Figure 8: Basic Delta ASR. Peel angle along the lanes varying with bottom slope (negative values correspond to right lane).

Trying to correct the problems observed at the delta shape ASR, its geometry was modified looking forward better results. The new shape was created based on natural bed features existing in Banzai Pipeline, Hawaii. The main characteristics of this ASR, nick-named as Pipe, are presented in Table 2 and in Figure 9. The model results revealed very fast plunging wave breaking, which is good for advanced surfers. But, on the negative side, lane length is small due to strong wave decay. For the purposes expected in the project of an ASR, this is not a particularly good result as the main idea is to create a point with several degrees of difficulty.

Table 2: Main characteristics of Pipe ASR.

Item	Value
Internal reef angle	60^{o}
Internal platform angle	15^{o}
Reef slope	1:20
Platform slope	1:5
Irribaren Number	~1
Peel angle	39^{o}
Wave amplification factor	99%
Wave decay on the lane	9,5%

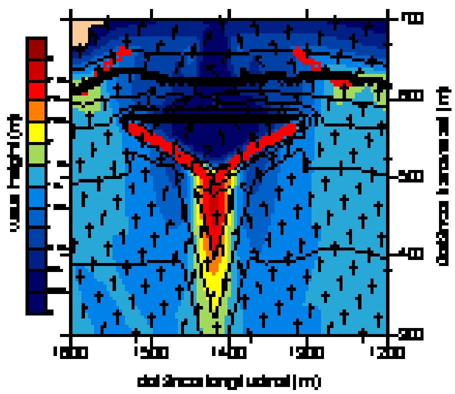

Figure 9: Pipe ASR. On the left: Geometry inspired in Pipeline natural bottom feature. On the right: Wave height distribution.

Analyzing these results it is possible to conclude the following:

- The reef must have different orientations related to wave approach direction, making possible the development of a lane with more than one section, and each section with different degree of difficulty.
- The degree of difficulty depends on the wave velocity and breaking type. The ideal situation is to have one plunging and faster section at the beginning of the lane, and lower sections in sequence, until reach spilling breaking at the end.
- The above objectives are related, among other factors, to reef's internal angle (θ). So there was proposed a geometry based on the classical delta shape, here nick-named as "triple-diamond", in which, where from the main point to the landward end there are three different internal angles (θ_1, θ_2 and θ_3) as shown in Figure 10 Reef lateral slopes were also tested.

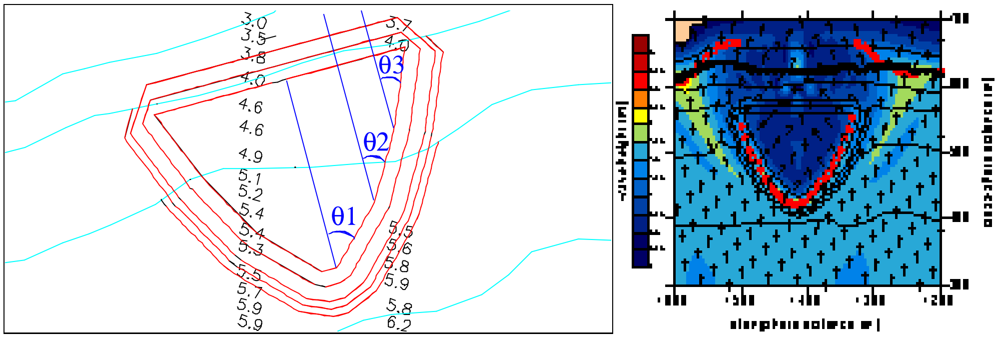

Figure 10: Triple Diamond ASR. On the left: Reef geometry. On the right: Wave height distribution.

As expected, the designed lane presented three different sections with increasing peel angle and decreasing difficult level. However, there still are three problems: the Irribaren number, besides the decrease pattern along the lane, is lower then the desired one; wave decay is still high; and the degree of surfer performance starts on level 6 and the desired starting level is 5 (according to Table 1). This problem was solved adding a platform seaward the reef, which promotes a bigger wave focalization, consequently bigger Irribaren numbers, and, to minimize the volume of the reef, it was designed one "empty" shape, keeping the slopes at the sea side and presenting an abrupt slope at the inner side.

All these results allowed the design of a new ASR geometry, nick-named the "Boomerang" which is shown in Figure 11. It is a core-empty reef, sectioned in different internal angles and side slopes. This shape is able to develop a fast plunging takeoff and two lanes (left and right) totalizing 276m. Each lane has three sections with decreasing degree of difficulty, from level 7 to 5 (according to Table 1). The main results are shown in Table 3, and the wave peel angle and Irribaren number distributions along the lanes are plotted in Figure 12 and Figure 13 respectively.

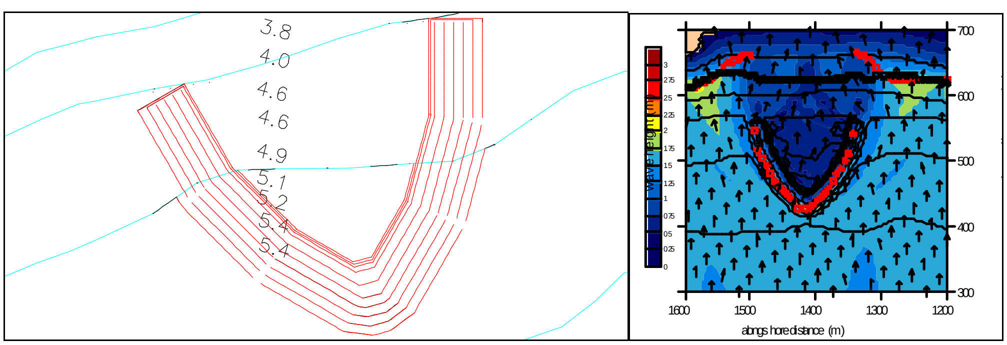

Figure 11: Boomerang ASR. On the left: Reef geometry. On the right: Wave height distribution.

Table 3: Main results for "boomerang" ASR. In the table: H_b is wave breaking height, ξ is the Irribaren number, α (°) is the peel angle, SL is surfer level, δ (%) is the wave decay along the lane, *L* (m) is lane sections length.

Lane	H_b (m)	ξ	α (°)	SL	δ (%)	*L* (m)
Section 1	1.85	0.80	38°	7	0 %	56
Section 2	1.69	0.71	45°	6	- 2%	38
Section 3	1.45	0.59	53°	5	- 9 %	44

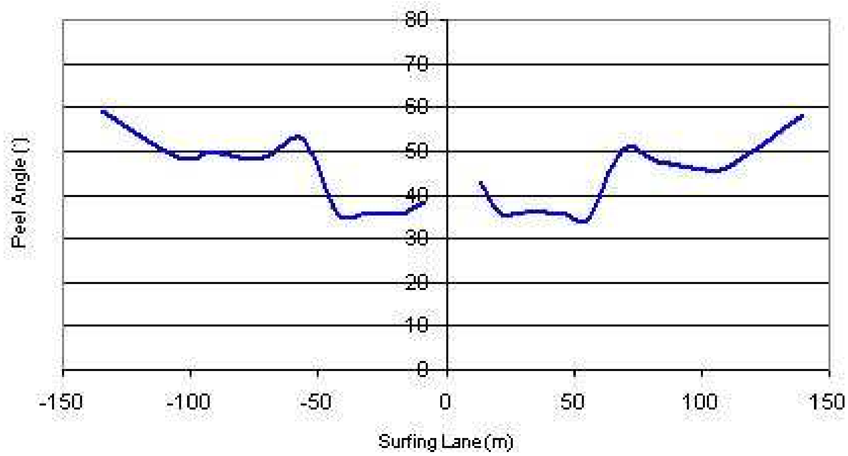

Figure 12: "Boomerang" ASR. Peel angle distribution along the lanes. Negative values correspond to right lane.

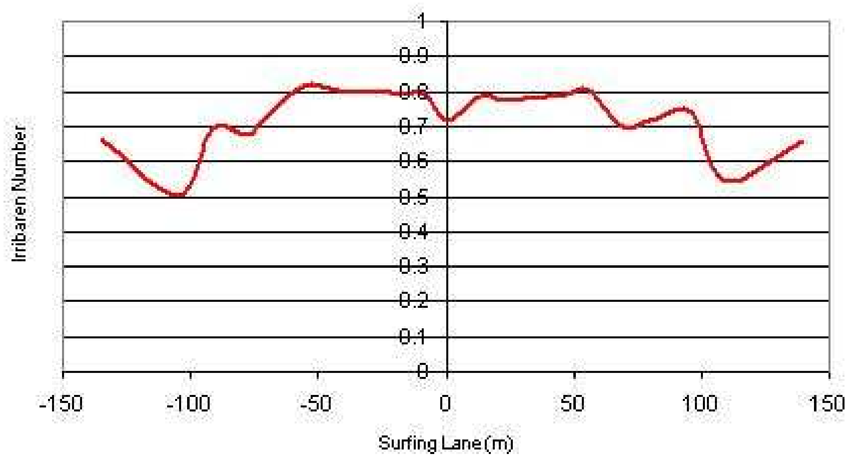

Figure 13: "Boomerang" ASR. Irribaren number distribution along the lanes.

Negative values correspond to right lane.

CONCLUSIONS

The primary objective of this study is to define the geometric form of an ASR, in order to promote a high level wave breaking for surfing, defined by surfability parameters calculated with the output results of the numerical model REFDIF. The idealized wave should have a long surfing lane breaking with peel angles varying between 27° and 50°, with low wave height decay and plunging type breaking. It was also quantified the wave energy reduction caused by the dissipation in the ASR, through coastal reaction parameters. The "Boomerang" ASR showed the best performance in terms of surfability and coastal reaction. In order to improve surfability, platforms were introduced seaward of the ASR. In the "Boomerang Platform 1" ASR, the wave decay along the surfing lane was reduced 30% in comparison with the "Boomerang" ASR. In order to get better accuracy, it is recommended to test the same geometries presented in this paper with a non-linear wave propagation model also considering the case of random wave incidence.

REFERENCES

BATTJES, J.A., 1974. "Surf Similarity", *Proceedings of the 14th Coastal Engineering Conference (Vol 1)*. Copenhagen, Denmark, American Society of Civil Engineers, New York, pp 466-480.

BLENKINSOPP, C., 2003. "The Effect of Micro-Scale Bathymetric Steps on Wave Breaking and Implications for Artificial Surfing Reef Construction". *Proceedings of the 3rd International Surfing Reef Symposium*. New Zeeland.

GALVIN. C. J., 1968. "Breaker-Type Classification on the Laboratory Beaches". *Journal of Geophysical research*, Vol. 73. No 12, June, 1968.

HUTT, J. A., K. P. BLACK; and S. T. MEAD, 2001. Classification of surf breaks in relation to surfing skill. In Black, K. O (ed.), Natural and artificial reefs for surfing and coastal protection, *Journal of Coastal Research*, Special Issue No. 29, pp.66-81.

MEAD, S. T., 2003. "Keynotes Address: Surfing Science". *Proceedings of the 3rd International Surfing Reef Symposium*. New Zeeland.

MEAD, S.T., and K.P. BLACK., 1999. "Configuration of Large-Scale Reef Components at a World-Class Surfing Break: Bingin Reef, Bali, Indonesia". *Coasts and Ports'99 Conference Proceedings. Vol. 2, 438-443.*

MOCKE, G., F. SMIT, F. and SHIROMAL, F. (2003). "Coastal Protection and Amenity Value of an Artificial Surf Reef for Dubai", Proceedings of the 3rd International Surfing Reef Symposium, Raglan, New Zeland, p180-195.

OLIVEIRA Fº, L A F., 2003. "O Conceito de Surfabilidade e Aspectos Fundamentais para o Projeto de um Fundo Artificial". Civil Eng. *Monograph*. Polytechnic Scholl – Federal University of Rio de Janeiro. Supervisor: E. Valentini. (*in Portuguese*).

OLIVEIRA Fº, L A F & E VALENTINI, 2003. "Critérios mínimos para projeto de fundo artificial para surfe" – XV Simpósio Brasileiro de Recursos Hídricos – ABRH – Curitiba, PR. (*in Portuguese*).

PEREGRINE, D. H., 1983. "Breaking Waves on Beaches". *Ann. Rev. Fluid Mech.*, 15, 149-178.

WALKER, J.R., 1974. "Recreational Surf Parameters", *Look Laboratory Report TR-30*. Department of Ocean Engineering, University of Hawaii, Honolulu, HI, 245 pp.

WALKER, J.R., 1997. "Surf reef Fundamentals", *Proceedings of the 1st International Surfing Reef Symposium*. University of Sidney, Australia, 21 pp.