Physical and numerical study of "breaker types" over an artificial reef

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ABSTRACT

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Portugal is one of many countries in the world to suffer from coastal erosion. Conventional ways of protecting a coastline appear to entail some disadvantages. An innovative and interesting way of protecting a local coastal zone by means of multi-functional artificial reefs avoids some of them. A multi-functional artificial reef is a submerged breakwater which protects the local coastline and may also enhance the surfing possibilities and the environmental value of the local area. The structure has several positive side-effects: first, it provides an unimpaired visual amenity; second, it offers tourist and economic benefits by improving the surfing. A physical and numerical study has been undertaken to investigate the influence of the length and submergence of the reef. Preliminary conclusions on the length of the reef suggest that it should be 0.5 times the wave length at the start of the reef, and regarding the submergence they indicate that a value smaller than the offshore wave height is necessary to get a surfable wave for a reef slope of 1:10.

ADDITIONAL INDEX WORDS: *Multifunctional artificial reefs, Surfability, Coastal protection.*

INTRODUCTION

The economic importance of coastal zones has been growing in the past few decades, for a variety of reasons which include an increase in the population and related economic activities established near the coastlines. All this development has led to growing numbers of visitors wanting to enjoy a sandy beach on their holidays and practise outdoor sports such as surfing, sailing, fishing, etc. Unfortunately, many coastal zones are now suffering from erosion, and the aspects and characteristics that make the coasts so attractive could be among the causes of their gradual destruction. In Portugal there are several examples of coastline erosion and degradation. One of these places is the Leirosa agglomeration, located to the south of Figueira da Foz, midway along the Portuguese West Atlantic coast. A frontal dune that runs from the groyne of Leirosa almost as far as the mouth of the Estremal stream, an extension of about 2 km, is partly destroyed. This has caused a retreat of the coastline and has put at risk (LOPES *et al.*, 2003):

- the agglomeration of Leirosa, whose situation is not yet critical, but it has to be kept an eye on;
- the offshore sewage outfall of Leirosa, which runs south parallel to the coast, and is connected to the outfall from the Celbi and Soporcel cellulose pulp and paper companies;
- the integrity of an aeration and load chamber of the submarine outfall pipeline located about 1 km to the south of Leirosa.

A stretch of the dune in front of the aeration chamber of the submarine outfall pipe was partly strengthened in 2005, using bags of geotextile filled with sand for a length of about 120 m (ANTUNES DO CARMO et al., 2006; SCHRECK REIS et al., 2008). This was done after storms in February 2001 which particularly

affected this zone and which will lead to a gradual and dangerous weakening in the coming years. Although the vulnerability of this zone has been partly remedied by the construction of a groyne, the continuity of the dune system was broken by the installation of the submarine outfall pipe (see Figure 1).

Leirosa

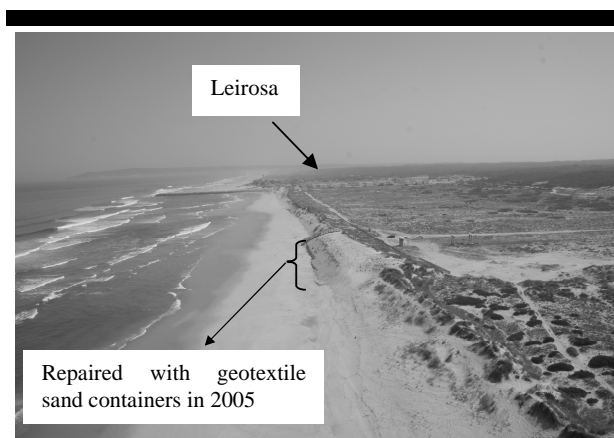Repaired with geotextile sand containers in 2005

Figure 1 View from the air with Leirosa at the top, aeration and load chamber of the outfall in the middle and the part of the dune in front of the aeration chamber that was partly repaired (Antunes do Carmo, January 2006).

Heavy protection structures are neither allowed nor planned in the POOC (legal development plan for the coast), and so a multi-functional artificial reef (MFAR) is under study as an alternative measure to protect this very sensitive coastal dune system

A MFAR is a relatively new approach to protecting a coast; it is a submerged breakwater that has several purposes. In addition to protecting the local coastline and improving the surfing possibilities, a MFAR can enhance the environmental value of the area where it is built. The advantages of a MFAR are that the visual impact is low and that with a proper design the down drift erosion can be minimal.

Regarding the functionality of a MFAR, much research has been carried out on surfability, i.e. the possibility to surf a wave (for example MEAD and BLACK, 2001 and HENRIQUEZ, 2004). However, no research has yet been done on the influence of the submergence and length of the reef slope on the breaker type, even though this is important for the design of the reef regarding the surfability aspect. The term 'breaker type' refers to the form of a depth-limited wave at breaking and influences other breaking-wave properties. Although there are several classifications of the breaker type, it is generally accepted that waves break by spilling, plunging, collapsing, and surging (GALVIN, 1968, 1972). According to BATTJES (1974) different types of wave breaking are categorized according to the offshore or inshore Iribarren number. The value of the (offshore/inshore) Iribarren number is determined by the bottom slope, the wave height (offshore/inshore) and the offshore wave length. However, Henriquez (2004) notes that the submergence of a submerged reef also has an influence on the breaker type. The length of the slope of the reef could also have an influence on the breaker type. In fact, when the reef has a fixed height and if the same wave conditions are used, deeper submergence automatically means a breaking point nearer the crest of the reef, which means a greater length of the slope experienced by the wave.

This paper presents the laboratory study, in a wave flume, together with numerical modelling, of the influence of the submergence and the length of the reef. The results will be presented and discussed.

PHYSICAL MODEL DESCRIPTION

The 2D flume used in this study is 73.0 m long, 3.0 m wide and 2.0 m deep. The model was operated according to Froude's similarity law; the geometrical scale was 1:10. In order to avoid re-reflections from the wave paddle, the wave absorption system of the flume should be active during the tests. Figure 2 and Table 1 show the geometry that was tested and the values for the several parameters.
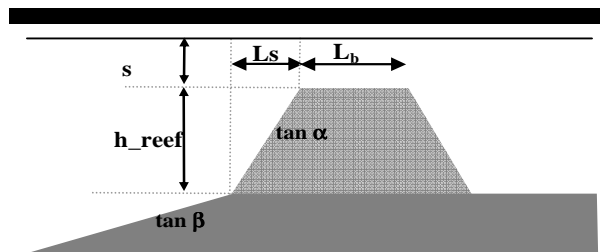

Figure 2. Geometry used in physical experiments.

Table 1. Parameter values of the geometry.

H_reef (m)	Tan α	Tan β	L_s (m)	L_b (m)
0.19	1:10	1:50	1.90	7.5

Height and slope values of the reef are based on the preliminary design rules presented in TEN VOORDE et al., 2008. A characteristic mean value of the Portuguese west coast beaches is assumed for the beach slope, and the width of the reef is taken to be once the wave length at the wave maker.

Fifty-one tests were run: 17 combinations of varying wave heights and varying submergences were tested. Each wave height was tested with three different periods. In order to guarantee that breaking occurred, a depth less than $0.8*H_b$ was assumed to be necessary (KAMINSKY and KRAUS, 1993), where the height of the wave at breaking H_b was chosen to be at minimum $1.0*H_0$. For most wave heights a submergence of $0.8*Hb$ was tested and one 0.04 m smaller. However, in order to test if waves with submergences deeper than $0.8*Hb$ will also break, some wave heights were tested with submergences of $0.8*Hb$ plus 0.04 m or plus $2*0.04$ m. See Table 2 for the test conditions.

Table 2. Test conditions (H = wave height, s = submergence, h = water depth, T = period).

H (m)	s (m)	h (m)	T (s)
0.10	0.08	0.75	
	0.12	0.79	
0.15	0.08	0.75	
	0.12	0.79	
	0.16	0.83	
	0.20	0.87	
0.20	0.12	0.79	2.52
	0.16	0.83	2.84
	0.20	0.87	3.16
	0.24	0.91	
0.25	0.16	0.83	
	0.20	0.87	
	0.24	0.91	
0.30	0.20	0.87	
	0.24	0.91	
0.35	0.24	0.91	

RESULTS

The results clearly show that the greater the submergence, the more the wave breaks towards the reef. Wave heights of 0.10, 0.15 and 0.20 m give good results for breaking waves on the reef. Wave heights of 0.25, 0.30 and 0.35 m break at the beginning or before the reef. There is not much difference for the three periods of 2.52, 2.84 and 3.16 s.

Regarding the submergence, the conclusion is different for every wave height. For the design wave height for surfing on the Portuguese coast, which is defined as 1.5 m, it can be said that the best breaker type for surfing is found for a submergence of 0.16 m. However, the wave shape is expected to be more plunging and better for surfing for a higher reef. Figures 3 to 5 show the results of the breaker type for a single input value of 0.15 m wave height and a period of 2.84 s (which is equal to 1.5 m and 9 s in prototype). The title of each figure gives the measured wave height and period at a distance of 5.1 m from the wave maker. The wave height in all the figures is smaller than the input value of 0.15 m. That is because some of the energy is lost. The wave period in Figures 3 to 5 is close to 2.84 s.
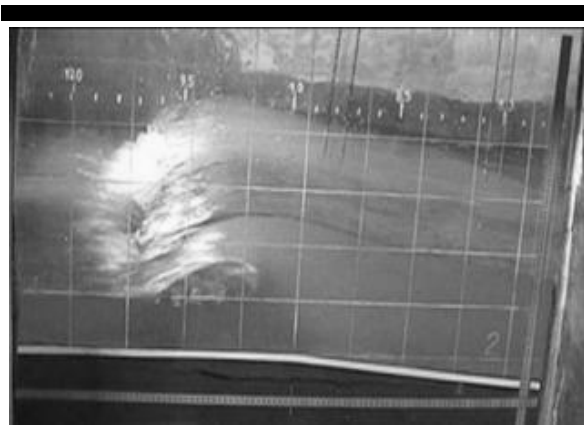
Figure 3. Breaker type for: s = 0.12 m, H = 0.14 m and T = 2.88 s.

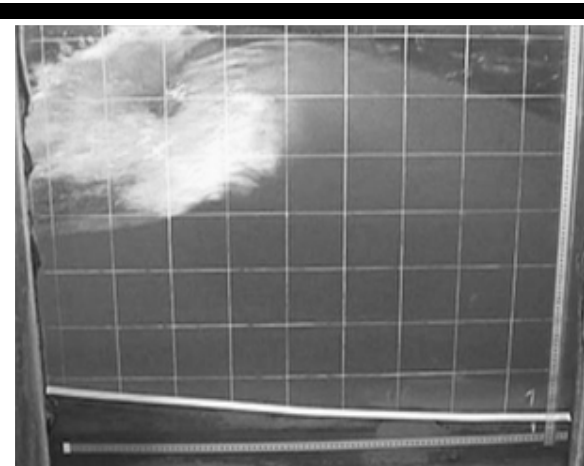Figure 4. Breaker type for: s = 0.16 m, H = 0.13 m and T = 2.84 s.

Figure 5. Breaker type for: s = 0.20 m, H = 0.14 m and T = 2.84 s.

NUMERICAL MODEL DESCRIPTION

In order to get more insight into the influence of both the height of the reef and the submergence of the breaker type, numerical simulations were performed for the design wave condition for the Portuguese west coast, H = 1.5 m and T = 9 s. The simulations considered prototype values and used the COBRAS model. By taking the volume-average of RANS equations, Lin and Liu (1998) presented a two-dimensional numerical model, nicknamed COBRAS, to describe the flow inside and outside coastal structures, including permeable layers. Hsu et al. (2002) extended the preliminary model by including a set of volume-averaged k-ε turbulence balance equations. The movement of the free surface is tracked by the Volume of Fluid (VOF) method. In the VA-RANS equations, the interfacial forces between the fluids and solids were modelled by the extended Forchheimer relationship, in which both linear and nonlinear drag forces are included. COBRAS-UC is a new version of the model developed at the University of Cantabria in order to overcome some of the initial limitations, and especially to convert it into a tool for practical application. Most of the modifications in the new version COBRAS-UC were founded on the extensive validation work carried out for low-crested structures (Garcia et al., 2004) and wave breaking on permeable slopes (Lara et al., 2006), which used the model. The improvements cover: the wave generation process; code updating and refactoring; optimization and improvement of the main subroutines; improvement of input and output data definition, and the development of a graphical user interface and output data processing programs, Losada et al. (2007). In the present study, this model was used to calculate the mean wave overtopping discharge for an emerged breakwater, which is basically a combination of an impermeable concrete vertical wall with a two-layer permeable rock slope in front of it.

Reef height

The height of the reef is directly related to the length of the reef. The length of the reef has to be investigated in order to guarantee that it is enough to achieve the desired breaker type. Two heights were tested first: h = 1.9 m, and h = 3.9 m. The submergence was set 1.5 m and the slope of the reef has been chosen 1:10. The reef geometry and the wave conditions are shown in Figure 6 and Table 3. See Figures 7 and 8 for the shape of the wave for these two cases.
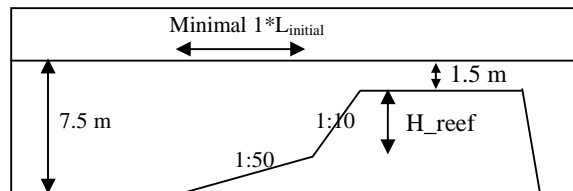

Figure 6. Reef geometry.

Table 3. Parameter values of the geometry.

H_reef (m)	Slope reef	s (m)	H (m)	T (m)
0.19	1:10	1.5	1.5	9
0.39				

Figure 7. Breaker type for a 1.90 m reef height.
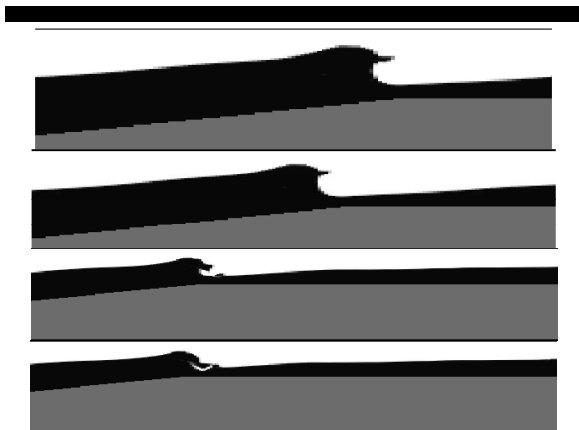
Figure 8. Breaker type for a 3.90 m reef height.

Figure 9. Breaker type for a 3.20 m reef height.

Figure 10. Reef geometry.

Table 4. Parameter values of the geometry.

s (m)	H_reef (m)	Slope	H (m)	T (m)
0.08				
0.12	3.2	1:10	1.5	9
0.20				

Figure 7 shows a breaker type similar to that for the same case in the physical experiments (Figure 4), even though the latter seems a bit more plunging. Figures 7 and 8 show that a 1.9 m wave height forms a spilling wave and a 3.9 m wave height forms a plunging wave. For surfing a plunging wave is preferred. A third simulation was therefore conducted to see if a plunging wave is obtained with a smaller height of 3.2 m. The results of the breaker type are shown in Figure 9.

Figure 9 shows that a plunging wave is still formed with a 3.2 m high reef, which is necessary for surfing. 3.2 m was thus chosen as the best reef height for the wave conditions used. A height of 3.2 m means a reef length of 32 m; 32 m was about half of the wave length at the start of the reef (59 m). A preliminary conclusion was drawn that $0.5*L_{begin\_reef}$ is assumed to be the smallest value that is necessary to form a surfable wave.

Submergence reef

The submergence of the reef is the second parameter that was investigated with numerical simulations. The geometry and the wave conditions are shown in Figure 10 and Table 4. The results of the breaker shape are shown in Figures 11, 12 and 13.
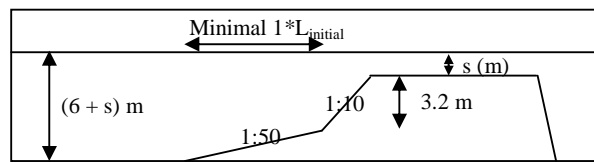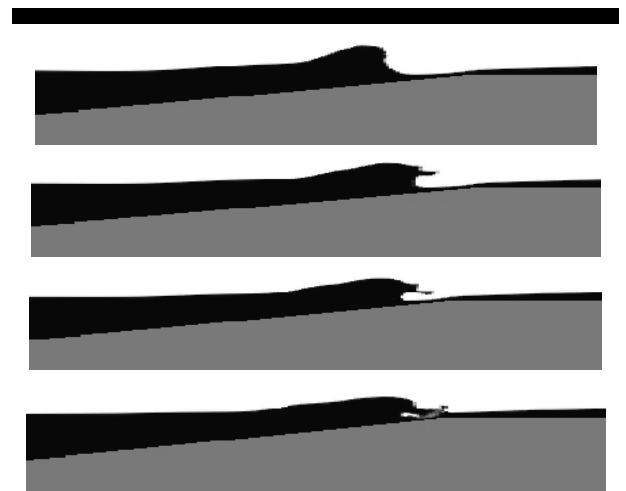

Figure 11. Breaker type for a submergence of 0.8 m.

Figure 12. Breaker type for a submergence of 1.2 m.

Figure 13. Breaker type for a submergence of 2.0 m.

From Figure 9 (the breaker type for a submergence of 1.5 m) and from Figures 11, 12 and 13 it can be concluded that with submergences of 0.8, 1.2 and 1.5 m the wave is surfable. With a submergence of 2.0 m the breaking wave is probably not good for surfing. The same conclusion was drawn in the physical experiments even though the reef was not as high.

CONCLUSIONS

Multi-functional artificial reefs (MFARs) are submerged breakwaters that serve several purposes. As well as protecting the local coastline, they enhance surfing possibilities and/or increase the environmental value of the area where they are situated. MFARs have new promising aspects, too: first, they provide an unimpaired visual amenity, and second, they can offer tourist and economic benefits by improving the surfing conditions. Physical and numerical studies were carried out to investigate the influence of the length and the submergence of the reef.

Preliminary conclusions are that: (1) the length of the reef should be 0.5 times the wave length at the start of the reef, and (2)

regarding the submergence, a value smaller than the offshore wave height is necessary to get a surfable wave for a reef slope of 1:10.

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