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# Modelling the morphodynamics in the vicinity of a submerged detached breakwater

Mariana F. Oliveira<sup>@ 1</sup>, Filipa S.B.F. Oliveira<sup>2</sup>, António Trigo-Teixeira<sup>3</sup>

<sup>@</sup> Corresponding author: mariana.d.oliveira@tecnico.ulisboa.pt
<sup>1</sup> Instituto Superior Técnico, Universidade de Lisboa.
<sup>2</sup> Laboratório Nacional de Engenharia Civil. foliveira@lnec.pt
<sup>3</sup> CERIS, Instituto Superior Técnico, Universidade de Lisboa. trigo.teixeira@tecnico.ulisboa.pt

ABSTRACT: The importance that coastal zones assume in Portugal implies a necessity for adequate responses to erosion-associated risks. One example is the coastal stretch located between the Mondego and Lis rivers' inlets, which has been a frequent target of coastal protection measures, such as the construction of groins and seawalls. A possible alternative measure is a submerged detached breakwater, which can provide beach protection and enhance local surfing conditions. Thus, in this study the morphodynamics as a result of the wave - breakwater - bottom interaction in the active zone located in the vicinity of the structure was analyzed using two numerical models: a two dimensional, depth-averaged (2DH), Delft3D, and a one-line (coastline), LITLINE. The models were applied considering typical hydrodynamic forcing conditions (mean and most frequent waves) and morpho-sedimentologic conditions of the site. The sensitivity of the breakwater's parameters to the beach morphological response was analysed using Delft3D. The coastline evolution was compared with LITLINE's prediction. Delft3D is able to reproduce the dominant circulation patterns in the structure's vicinity, and between the structure and the coastline, which influence its evolution. On the contrary, the LITLINE's model simplifications do not enable a representation of the physical phenomena which dominate the breakwater's vicinity.

Keywords: Numerical modelling, Delft3D, Submerged breakwaters, Coastal processes, Erosion, Figueira da Foz.

RESUMO: A importância das zonas costeiras em Portugal implica melhorar a gestão costeira para mitigar os riscos associados à erosão. Um exemplo é o trecho costeiro localizado entre as embocaduras dos rios Mondego e Lis, que tem sido alvo de diversas medidas de proteção costeira, como a construção de esporões e defesas aderentes. Uma possível medida alternativa é o quebra-mar destacado submerso, que permite a proteção da costa e a melhoria das condições para a prática do surf. Assim, neste estudo analisou-se a morfodinâmica resultante da interação onda - quebra-mar - fundo arenoso na zona ativa da praia localizada na vizinhança deste tipo de estrutura através da aplicação de dois modelos numéricos: o sistema Delft3D na versão bidimensional no plano horizontal e o modelo de linha de costa LITLINE. Os modelos foram aplicados para condições típicas de agitação marítima (onda média e mais frequente) e geomorfologia da zona em estudo. Com recurso ao Delft3D efetuou-se uma análise de sensibilidade aos parâmetros de dimensionamento do quebra-mar na resposta morfológica da praia. Os resultados da geometria



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em planta da praia, especificamente a linha de costa (LC), foram comparados com os do LITLINE. Verificou-se que o Delft3D reproduz os padrões de circulação dominantes na vizinhança da estrutura, e entre esta e a LC, e que os mesmos condicionam a evolução da LC. Pelo contrário, as simplificações admitidas pelo LITLINE não permitem representar os fenómenos físicos dominantes na vizinhança do quebra-mar.

Palavras-chave: Modelação Numérica, Delft3D, Quebra-mares submersos, Processos costeiros, Erosão, Figueira da Foz.

## **1. INTRODUCTION**

Portugal has a long coast with great historical and present importance. The main problem that the coastal zones have been facing in the last decades is the increasing number of conflicts between their development and the erosion phenomena.

The long-term erosion observed in large extensions of the Portuguese coast is due in part to a deficit in sediment supply caused by anthropogenic actions and aggravated by the climate change. Additionally, the Portuguese coast is one of the most energetic in Europe, with very high sediment transport, high seasonal variability and occurrence of energetic storms.

The recommended approach for the present and future of the coastal zone is that the human occupation in these areas and the activities that they support should respect and adapt to the present and future coastal dynamics (Santos *et al.*, 2017). There are three types of adaptation strategies that can be considered: protection, relocation and accommodation. The first strategy, protection, has been the lead approach to coastal risks. It consists in maintaining or advancing the coastline through artificial beach nourishment, construction of artificial dunes or of hard structures such as groynes, detached breakwaters and seawalls.

The conventional stabilization structures, such as groynes and seawalls, are the most common. This type of hard structures has led to a severe artificialization of coastal zones, resulting in significant changes in the coastal landscapes and in the environment. Therefore, this type of protection is becoming increasingly unpopular due to their unfavorable impact on beach amenity and aesthetic. In contrast, submerged structures are increasing in popularity due to their multi-functional design which provides the dual benefits of beach protection and enhancement of local surfing conditions, without any loss of beach amenity or negative aesthetic impact. An example of such a multi-functional design is the artificial surfing reef at the Gold Coast in Australia (Black and Mead, 2001). In Portugal, there are examples of conventional detached breakwaters in Aguda beach and Castelo de Neiva, nonetheless these breakwaters have their foundation in natural rock, which makes it difficult the modelling of their behaviour.

Contrary to emerged structures, fully submerged structures have only rarely been adopted for beach protection, and for this reason their efficacy remains largely unknown. The existing literature about submerged breakwaters (SBWs) is limited, mainly focused in empirical relations and field experiences. Ranasinghe and Turner (2006) presents a review of existent SBWs, showing that in the majority of the cases, erosion in their lee occurs. However, the study of Black and Andrews (2001) reveals that natural submerged reefs, which are similar to SBWs, are frequently associated with shoreline salients. Furthermore, shoreline erosion is almost never reported in the lee of emerged structures. This indicates that the scarce number of existing studies is inconsistent.

These considerations mean that, prior to the wider adoption of SBWs for beach protection, further investigation of the physical processes governing shoreline response to these structures is necessary. Improving the knowledge of the relevant physical processes can be done via simulation methods (numerical or experimental) and in situ monitorization (Ranasinghe and Turner, 2006; Turner *et al.*, 2001; Tomasicchio, 1996). The present study uses the first class of methods to study the morphodynamics around an eventual SBW located between the Mondego and Lis rivers' inlets (study zone) using two numerical models: a two dimensional, depth-averaged (2DH) model, the Delft3D (Deltares, 2011a,b); and a one-line (coastline) model, the LITLINE (DHI, 2016).

# 2. CASE STUDY

This study focuses in the coastal stretch located in the central-west part of Portugal, limited by the Mondego and Lis rivers' inlets, at north and south, respectively (Figure 1).

The coastal stretch is characterized by a continuous beach - dune system, approximately rectilinear, with an extension of 32 km and mean orientation 19.6°N (Oliveira and Brito, 2015), interrupted only by the rocky headland of Pedrogão. Furthermore, the nearshore bathymetric lines are uniform and parallel to the coastline. This physiographic unit includes the maritime frontages of the urban settlements of Gala-Cova, Costa de Lavos, Leirosa and Pedrogão. This coastal stretch has been strongly influenced by anthropic interventions of different types since the mid 20th century (Oliveira and Brito, 2015), in order to face sediment shortage. Due to the induced sediment capture by Figueira da Foz's harbor jetties, various coastline stabilization and population protection structures were built, leading to the massive construction of groynes and seawalls in the maritime frontages of the urban settlements. The study stretch is characterized by being permanently exposed to a multi-directional wave regime that leads to an intense longshore sediment transport whose resultant is predominantly south-oriented.

## **3. DATA AND METHODS**

#### 3.1 Hydrodynamic forcing conditions

Based on the statistical analysis of a validated hindcast wave parameters time series for the period 1952 - 2010, Oliveira (2016b) concluded that the wave climate in the study zone is highly energetic and has high seasonal variations. The author determined the values of the two sets, mean and median, of the following statistical wave parameters at the closure depth: significant height (H<sub>s</sub>), peak period (T<sub>p</sub>) and direction (Dir). They are: H<sub>s</sub>=2.15 m, T<sub>p</sub>=11.5 s and Dir=299.5°N (10° towards NW with respect to the shoreline normal), for the mean wave; and H<sub>s</sub>=1.25 m, T<sub>p</sub>=9 s and Dir=305°N, for the most frequent wave. Both sets were used in this numerical study. At the offshore numerical boundaries it was prescribed a stationary wave spectrum and a constant sea level, which was the mean sea level (MSL), 2 m above the zero of the nautical chart datum (CD).

#### 3.2 Topo-hydrography and sedimentology

The initial geomorphological conditions of the study zone were simplified by assuming representative bottom characteristics (sediments and beach profile) and alongshore uniformity, in order to limit the complexity of the computed coastal processes and facilitate the interpretation of the cause-effect morphological evolution. The initial representative cross-shore beach profile proposed by Oliveira (2016a) was based on the morpho-sedimentologic characterization of the zone performed by Oliveira and Brito (2015). This beach



Figure 1 - Location of the coastal stretch between the Mondego and Lis rivers inlets and aerial views of the main coastal protection structures and urban settlements. Adapted from http://portugalfotografiaaerea.blogspot.com (consulted in September 2018).

profile has three slopes, depending on the zone, as follows (Figure 2):

- frontal dune face 1:3.5 (located between 4 m above CD and the frontal dune crest 14 m above CD);
- beach face 1:25 (located between CD and 4 m above CD);
- submerged profile 1:77 (located between 12 m below CD and CD).



Figure 2 - Initial topo-hydrography: (a) profile with SBW and (b) 3D view of the numerical domain of Delft3D.

Since the Delft3D model does not account for the effect of the geospatial variability of the sediment grain size on the morphodynamics around the SBW, the median sediment diameter ( $D_{50}$ ) was considered the one at the approximate depth of implementation of the SBW, that is  $D_{50}$ =0.30 mm.

#### **3.3 Methods**

Herein the setup of the two process-based numerical models, Delft3D and LITLINE is described. Both models were calibrated according to Oliveira *et al.* (2018) so that the longshore sediment transport for the mean wave would attain 1 800 000 m<sup>3</sup>/year, which fits within the reference values known for the Portuguese central-west coast (Vicente and Pereira, 1986). The main calibration parameters were: the wave-related transport factor for suspended and bed-load sediments, defined equal to 0.1 for the Delft3D model; and the bottom roughness, defined equal to 0.00004 for the LITLINE model.

The Delft3D numerical domain includes two uniform cartesian grids: the FLOW and WAVE grids. The FLOW grid, used to solve the hydro-morphological evolution, covers an area of 2000x790 m<sup>2</sup> in the alongshore and cross-shore directions, respectively. The WAVE grid, used for the waves solver, covers an area of 4000x1100 m<sup>2</sup> in the alongshore and cross-shore directions, respectively. The WAVE grid overlays the FLOW grid to avoid boundary problems. The grids resolution is uniform:  $\Delta y = \Delta x = 5$  m, in the alongshore and cross-shore directions, respectively.

After several sensitivity tests, the SBW was defined as structure of rough bottom, in the FLOW module by including a non-erosive sediment layer and by differentiating the bottom roughness. To include a non-erosive SBW, an initial sediment layer of 0 m was formulated locally, while for the surrounding bathymetry the bottom is a sediment layer of 5 m (enabling morphological changes). The differences in bottom roughness between the sandy bottom and the SBW were accounted, based on previous studies recommendations (such as Deltares, 2011a and Vlijm, 2011), by using a spatial varying Chézy coefficient (C): for the SBW C=20 m<sup>1/2</sup>s<sup>-1</sup> and for the sandy bottom C=65 m<sup>1/2</sup>s<sup>-1</sup>. In the WAVE module, the SBW was defined as an obstacle, affecting the wave propagation.

The Delft3D-FLOW module was coupled to the SWAN wave module, in order to take into account the reciprocal effects between the hydrodynamics and morphology. The coupling time, for these modules to exchange information, was set to 10 minutes. In order to enable numerical simulations for longer time scales, the morphological acceleration factor (morfac) approach was used. By using a morfac of 30, the speed of the changes in the morphology was scaled up to a rate of 30 to have a significant impact on the next 10 minutes' period of hydrodynamic forcing. Such procedure should be realistic because the offshore forcing hydrodynamic conditions, wave and sea level, were considered stationary.

In regard to the boundary conditions, the lateral boundaries, north and south, were forced with flow and transport conditions of Neumann type and the west offshore boundary was forced with flow and transport conditions of open boundary.

The computational domain of the LITLINE model includes an initial straight coastline that was considered the MSL isoline, with an extension of 4000 m. The depth of the offshore limit of the active zone of the representative cross-shore beach profile (Figure 2(a)) when submitted to the local mean wave was defined equal to -3.35 m CD, corresponding to an active length of 310 m. Based on the representative simplified profile, the top of the dune was set at 14 m CD and the beach berm at 4 m CD, which resulted in an active height of 7.35 m. The considered spatial resolution was the same as for the Delft3D model,  $\Delta y = \Delta x = 5$  m, as well as the lateral boundaries, which were forced with Neumann boundary conditions.

The numerical tests made in order to investigate the morphological evolution in the vicinity of the SBW during 30 days using Delft3D model are summarized in Table 1. In Figure 3 the design parameters of the SBW are represented. During the testing process of the effect of the SBW design parameters (length, crest submergence level and distance to the shoreline) on the adjacent morphology, the SBW slopes remained constant. The test H1 considers an emerged breakwater, above MSL, for the purpose of comparing the Delft3D model outcome with LITLINE's, since the latter doesn't allow testing breakwaters below MSL.



Figure 3 - Schematic diagram showing key design parameters for a SBW: structure length  $(L_q)$ , distance from shoreline to structure  $(D_{LC})$ , crest width  $(L_{cq})$ , crest height  $(h_c)$  and depth to sea floor at structure (h).

Table 1.	Numerical	simulation	conditions.	Shadowed cell	ls indicate
	variation	ns with resp	ect to the re	eference case.	

Tests	Name	$L_q$	$L_{cq}$	$D_{LC}$	h	$h_c$	$H_s$	$T_p$	Dir
Tests		[m]	[m]	[m]	[m]	[m]	[m]	[s]	[°]
Reference	R	150	10	204	4	3.5	2.15	11.5	280
Most frequent wave	F	150	10	204	4	3.5	1.25	9	285.5
	H1	150	10	204	4	4.5	2.15	11.5	280
Crest height	H2	150	10	204	4	3.0	2.15	11.5	280
$h_c$	H3	150	10	204	4	2.5	2.15	11.5	280
	H4	150	10	204	4	2.0	2.15	11.5	280
Distance to	D1	150	10	320	5.5	3.5	2.15	11.5	280
shoreline	D2	150	10	400	6.5	3.5	2.15	11.5	280
$D_{LC}$	D3	150	10	500	7.8	3.5	2.15	11.5	280
Structure	L1	300	10	204	4	3.5	2.15	11.5	280
length	L2	400	10	204	4	3.5	2.15	11.5	280
$L_q$	L3	500	10	204	4	3.5	2.15	11.5	280

#### 4. RESULTS AND DISCUSSION

#### 4.1 Reference case

The Delft3D model's outcome in predicting the morphological evolution in the vicinity of the SBW during 30 days of local mean wave action is presented in Figure 4. The stationary wave boundary conditions produced:

- the formation of submerged oblique bars, quasirhythmic bottom features (rip-like). The development of these bars is typically associated to incident waves with angles smaller than 30° with respect to the shore normal, which is the case of the simulation conditions. The growth of these bedforms can be observed in nature, although their cause is unclear
  Giardino *et al.* (2010) points out that it could be related to natural instabilities or model inaccuracies;
- the advance of the beach face in the lee zone of the SBW due to the reduced wave energy and thereby the sediment transport capacity of the waves alongshore. The sheltering effect of the SBW enables tombolo formation (in this study it was considered that a tombolo was formed in the lee of the SBW when sediment accumulation exceeds CD, approximately the low water level);
- sediment accumulation in the lee of the SBW is asymmetrical. The maximum sediment accumulation values are also reached in this zone (>2.5 m). Close to the shoreline an asymmetry of the accumulation pattern also occurs, since the mean wave action overlays the formation of the submerged bars, being more significant south of the SBW;
- erosion is observed between the submerged bars formation, though it is not caused by the SBW.



Figure 4. Test case R: (a) numerical morphology after 30 days and (b) numerical morphological evolution during 30 days (results of Delft3D model).

The filling differences in the lee zone of the SBW are presented in Figure 5, confirming that the central profile (Figure 5(b)) is the one with the maximum sediment accumulation (2.98 m of seabed elevation). At the end of the 30 days, erosion is observed from the initial depth -7.84 m CD up to -2.70 m CD, meaning that the sand is carried from greater depths and deposited close to SBW (sea side), resulting in 0.80 m of seabed elevation.



Figure 5. Test case R: simulated profile evolution and corresponding  $H_s$  for (a) y=1950 m, (b) y=2000 m and (c) y=2050 m (results of Delft3D model).

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Figure 6. Test case R: (a) total transport (suspended and bed load) and (b) depth averaged velocity after 30 days (results of Delft3D model).

The cross-shore profiles 50 m south and north of the SBW (Figures 5(a) and 5(c) respectively) show less seabed elevation in the lee zone of the SBW and also erosion in the beach face due to development of submerged bars. In addition, south of the SBW the sediment accumulation in the lee zone is higher due to the obliquity of the incident waves. In the first 10 days the adaptation rate is higher, and then it starts to stabilize.

The significant wave height is also represented in Figure 5, showing that for the central profile, after 30 days the wave breaking occurs for  $H_c=2.3$  m at a water depth of 0.66 m.

The total transport (sum of both modes, suspension and bed load) is presented in Figure 6(a). It is clear that the longshore transport prevails with a direction from north to south in the active beach zone. The permanent action of the local mean wave during a one year period would generate a littoral drift of 956 000 m<sup>3</sup>/year (value calculated for y=2000 m). Thus it turn out that under such conditions the presence of the SBW reduces the value for the littoral drift in almost 50% (1 800 000 m<sup>3</sup>/year in the absence of SBW).

The 2DH circulation currents and induced sediment fluxes due to alongshore gradients in wave setup can be identified in Figure 6(b). The onshore flow over the SBW diverges in the lee of the structure resulting in an asymmetrical circulation pattern: the development of a seaward return flow around the north end of the SBW and a circulation cell in the lee of the structure which converges in the south end of the SBW (the longshore current is enhanced due to the superposition of the unidirectional longshore current, caused by oblique incident wave, on the nearshore circulation cell).

# 4.2 Influence of design parameters

# 4.2.1 Crest height (h\_)

Several tests were made in order to evaluate the effect of the crest height in the vicinity of the structure (Table 1), leading to the following conclusions:

- test case H1 (Figure 7(a)), which corresponds to an emerged breakwater, 0.5 m above MSL, has the highest seabed elevation in comparison with the other tests (>2.5 m). This was expected because the sheltering effect of the structure is higher. The accumulation patterns from test H1 and R are very similar;
- the model outcome produces bigger differences on the accumulation patterns when the breakwater is

submerged, as presented in Figures 7(b), 7(c) and 7(d), where the difference between crest height is 0.5 m;

 an increase of the submergence level (which means lower crest heights) results in a decrease of the seabed profile elevation in the lee of the breakwater. Despite that, erosion is observed around the tips of the structure, specifically for test cases H3 and H4 with submergence levels of 1.5 m and 2.0 m below MSL, respectively. This local erosion is associated with the 2DH circulation patterns, *i.e.*, the seaward return flow around the tips of the structure;

• the cross-shore central profile presented in Figure 8 illustrates that the maximum seabed elevation for test case H1 is 3.5 m, H2 is 2 m, H3 is 1.18 m and H4 is 0.93 m.



Figure 7. Numerical morphological evolution during 30 days for test cases (a) H1, (b) H2, (c) H3 and (d) H4 (results of Delft3D model).



Figure 8. Test cases R, H1, H2, H3 and H4: simulated profile evolution after 30 days for y=2000 m (results of Delft3D model).

#### 4.2.2 Distance to the shoreline $(D_{1,c})$

The effect of the distance from the SBW to the shoreline was also evaluated (Table 1) producing the following outcome:

• tombolo formation is observed for test case D1 (Figure 9(a)), just like test R, although the sediment accumulation pattern is different. In test case D1, where the SBW is 320 m from the shoreline, the sediment accumulation extends far from the ends of the SBW, nevertheless this accumulation is more evident in the south end of the structure. In addition, the maximum accumulation values are observed in the lee of the SBW for test D1 (>2 m). This outcome is counterintuitive, because it would be expected that for longer distances to the shoreline

the sediment accumulation should decrease. This phenomenon can be explained by the stationary wave conditions, as in nature the incident waves direction varies as well as the wave energy which would lead to different accumulation patterns;

- the extension of the accumulation zone near the shoreline reduces with the increase of distance from de SBW to the shoreline;
- for test cases D2 and D3 (Figures 9(b) and 9(c), respectively) the model outcome predicts that for longer distances from the SBW to the shoreline the influence of the structure in the surroundings decreases, as well as the sheltering effect (less sediments are deposited and retained in the lee zone of the SBW). The asymmetrical accumulation pattern is also present in both tests;
- the effects of increasing the distance from the SBW to the shoreline are also presented in the cross-shore profile in Figure 10. The advance of the beach face in the lee side of the SBW reached the maximum values of 3.39 m, 2.85 m and 1.92 m of seabed elevation at the end of the 30 days for test cases D1, D2 and D3 respectively.

#### 4.2.3 Structure length (Lq)

The last tested design parameter was the SBW length (Table 1). The model predicted increase of the induced sediment accumulation in the lee of the SBW with the structure length increase (Figures 11(a), 11(b) and 11(c)), beginning to function like a T-shaped groyne. The sediment accumulation starts to advance towards north, specially in test L3, blocking the sediment flux passage to south. The blocking effect also induces erosion south of the SBW, more significant in tests L2 and L3.



Figure 9. Numerical morphological evolution during 30 days for test cases (a) D1, (b) D2 and (c) D3 (results of Delft3D model).



Figure 10. Test cases R, D1, D2 and D3: simulated profile evolution after 30 days for y=2000 m (results of Delft3D model).

The central cross-shore profile is presented in Figure 12. For all three tests the maximum level of sediment accumulation is reached, with maximum seabed elevation of 1.3 m. Close to the SBW in the sea side, the sediment accumulation is also higher than the reference case, test R.

#### 4.3 Most frequent wave effect

Besides the tests to the effect of the design parameters, the morphological evolution in the vicinity of the SBW was also tested for a less erosive wave, like the most frequent wave (Table 1). In comparison to the test case R, in which the local mean wave was tested, the model produced the following differences:

- the formation of submerged bars was attenuated (Figure 13);
- the sheltering effect of the SBW is reduced in the lee zone, since the most frequent wave has less transport capacity. In test case R there was the combination of two effects: the erosive wave effect (erosion of the beach face and transport to the offshore) and the SBW induced effects on the shoreline. In this case, test F, there is only the sheltering effect induced by the SBW presence, which isn't enough for a tombolo formation. The maximum seabed elevation reached the value of 1.2 m in the lee of the SBW;
- erosion south to SBW is observed and the beach active zone is reduced.



Figure 11. Numerical morphological evolution during 30 days for test cases (a) L1, (b) L2 and (c) L3 (results of Delft3D model).



Figure 12. Test cases R, L1, L2 and L3: simulated profile evolution after 30 days for y=2000 m (results of Delft3D model).



Figure 13. Test case F: (a) numerical morphology after 30 days and (b) numerical morphological evolution during 30 days (results of Delft3D model).

The most frequent wave is less erosive, thereby the permanent action of this forcing wave during one year drives a littoral drift of 17 800 m3/year for the study stretch, which is in agreement with previous knowledge since the mean wave has a higher transport capacity than the wave with the most frequent spectral wave parameters.

# 4.4 Comparison between Delft3D and LITLINE models

The LITLINE model outcome in predicting the MSL isoline evolution in the vicinity of the SBW is presented in Figure 14. Due to the oblique wave attack, the MSL isoline evolution is asymmetrical, advancing at north and retreating at south of the structure. After 30 days, salient formation is predicted, registering a maximum advance of 18 m in the lee of the SBW, and a maximum retreat of 35 m at south (y=1936 m).



Figure 14. Simulated shoreline evolution in the vicinity of an emerged detached breakwater subjected to a stationary wave (mean wave): initial shoreline, after 10, 20 and 30 days (results of LITLINE model).

The comparison of the outcome of the models is presented in Figure 15. This comparison has been made for an emerged detached breakwater (test H1) in order to evaluate the importance of coastal processes as well as the models' performance. The MSL isoline predicted by Delft3D model remains practically constant after 30 days, as opposed to the LITLINE model, which predicts a significant advancement and retreat, respectively north and south of the SBW.

The results show the differences in the modelling capacities of both models. The LITLINE model is simpler, and usually used in medium spatial scale applications (order of kilometers), and at medium-long term time scale applications (order of years to decades), both conditions in which was already applied to the study zone (Oliveira, 2016b). At the cost of coastal processes simplification, this model presents considerably reduced computational costs, and thus it is usually applied to much larger time and spacial scales than the complex Delft3D model. However, when used to predict the impact of

a SBW in the surroundings, it is unable to account for some morphological alterations. The shelter effect of the breakwater induces large variability in sediment fluxes and hence in the cross-shore beach profile in the lee of the structure, *i.e.*, the governing morphodynamic processes are predominantly 2DH. This means that the application of the LITLINE model is unfit and the Delft3D model is more capable of simulating the coastline alterations induced by the presence of this type of structure. This is because it allows the reproduction of circulation patterns that occur in the vicinity of the structure and between the structure and the coastline.

Delft3D is a more complete process-based model, which solves wave propagation, depthaveraged circulations currents, sediment transport in the longshore and crossshore components, and the induced morphological alterations. This allows for a better representation of nature, though at high computational cost and only applicable to limited spatial and time scales.



Figure 15. Bottom morphology in the vicinity of an emerged detached breakwater subject to a stationary wave (mean wave): (a) initial, (b) after 10 days, (c) after 20 days and (d) after 30 days. The color scale [m CD] refers to the Delft3D model results and black line (2 m above CD) to the LITLINE model results.

## **5. CONCLUSIONS**

The process-based morphodynamic numerical model Delft3D was applied for the case of morphological evolution of an alongshore uniform bathymetry and uniform grain size submitted to a stationary oblique wave spectrum in the presence of a detached breakwater during 30 days.

Considering the simulations with the numerical Delft3D model, it is observed that the mean wave action produced accumulation of sediments in the lee of the structure due to the reduction of wave energy (test case R). The model also reproduces the asymmetry in the sediment accumulation pattern, which is due to the oblique incident wave. As for the longshore transport, a reduction is registered, dropping to about 50% of the known value for the same wave conditions in the study zone. The circulation pattern around the structure is asymmetric and composed by two cells which are induced by the divergence of the currents generated in the SBW towards the coast.

The analysis of the SBW crest height variation shows that, as the submergence level increases, the seabed elevation in the lee of the structure decreases. Increasing the distance to the coastline reduces both the influence of the SBW on its surroundings and the capacity to retain sediments in its lee. Regarding the SBW length, the model results show that its increase results in an increase of the sediment deposition in the lee of the SBW, tending to the formation of a T-shaped groyne.

The test with a less erosive wave, like the most frequent wave, has been done (test case F). The SBW induced effects on the shoreline were attenuated in comparison to the mean wave action results, dropping to 5% of the reference case (test case R). One concludes from these results that the SBW would be more efficient in protect highly energetic coasts, like the Portuguese coast.

Lastly, a comparison between the Delft3D and LITLINE models has been done for a comparable test case. The comparison of the two models made clear that the simplifications assumed by LITLINE do not allow for the model to correctly reproduce the structure's effect on the coastline's local evolution. The Delft3D model captures the circulation patterns that occur in the structure's vicinity, and between itself and the coastline, which influences the coastline's evolution. Because of this, Delft3D is better fit to simulate the alterations induced in the coastline by the presence of this type of structure.

In the future, calibrating the Delft3D model with field data and performing tests with physical models for the same Delft3D testing conditions is recommended, in order to further validate the numerical model.

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