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Review

Analysis of the Mamaia Bay shoreline Retreat with Hard and Soft Protection Works

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ABSTRACT

Integrated Coastal Zone Management is a complex concept that involves various economic, social and environmental factors. There are often conflicting approaches to these factors. Furthermore, when it is decided to implement structural works in the coastal area, it must be taken into account the particularity of the area, the way in which it is developed and the type of work to be done. The Gulf of Mamaia in the Romanian Black Sea coast is the target of structural changes through the implementation of an extensive coastal rehabilitation program. The works made are of "hard" type and aim to change the shore line configuration. From this perspective, the target of the present paper is to make an analysis between the type of work that is being carried out and another kind of "soft" work aiming especially to favor the ecological reconstruction of the area and the approach of an environmentally friendly concept. Thus, we propose to analyze the two types of works with a view to apply the Bruun rule in order to mitigate the effect of the increase of the sea level and to prevent the shoreline retreat.

1. Introduction

Maintaining the shoreline is an element of great interest for the coastal communities. As we analyzed in the paper called "Approach to the analysis and evaluation of the strategic intervention options in the Romanian coastal zone taking into account economic, social and environmental factors" there are a multitude of social, economic and environmental activities that take place in the Romanian coastal area requiring a strategic approach [1]. From this perspective, in the present paper, we are discussing some strategic options for the human intervention in the Romanian coastal zone. Engineering works to protect coasts from erosion must be closely linked to the human activities that take place in the coastal areas, even though we are talking about tourism, transport, urbanization or industrial activities [2]. We will choose the optimal approach to analyze and evaluate these

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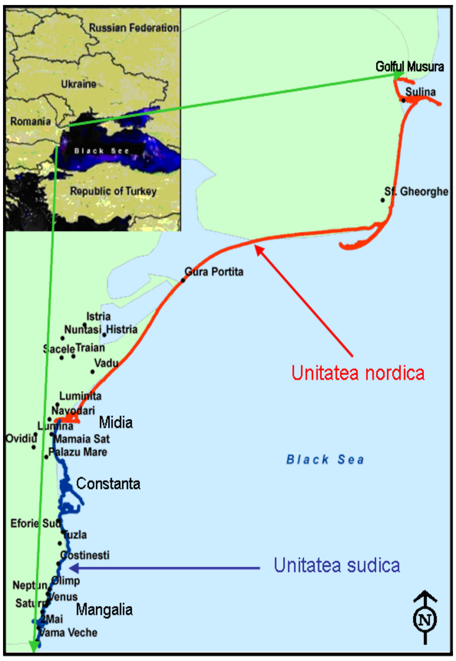
options by addressing economic, social and environmental factors. This multifactorial approach must take into account a careful analysis of the stakeholders in the coastal areas, bearing in mind that each area has its peculiarities and needs to be treated separately. Furthermore, when developing the approach to analyze and evaluate strategic options, we will take also into account the sectoral plans made in the coastal area as well as the local, regional and national development plans [3].

Romanian Black Sea coastline stretches over a length of 244 km (between the Musura arm and Vama Veche) representing 6% of the total length of the Black Sea shoreline. This includes also 128 km oftransitional waters and 116 km of marine coastal water.

Romanian coast shows has about. 80% low altitude shores - beaches and approx. 20% higher shore – cliffs. The the northern sector is representing 68% and the southern sector 32%[4].



Northern Unit

Southern Unit

Figure 1. Map of Romanian coast area and its location in the Black Sea basin (Source Halcrow 2011)

Mamaia Bay is situated in the upper part of the southern Romanian seaside. The area is bordered by the Danube Delta biosphere reserve, which is a protected area, while in the west is the Siutghiol Lake.

Mamaia Bay is a strongly anthropized area, adjacent to the city of Navodari to the North and the city of Constanta to the south. In the north we find Petromidia refinery and Midia Navodari port, and the entire area represents also an important touristical destination. (Fig 2)

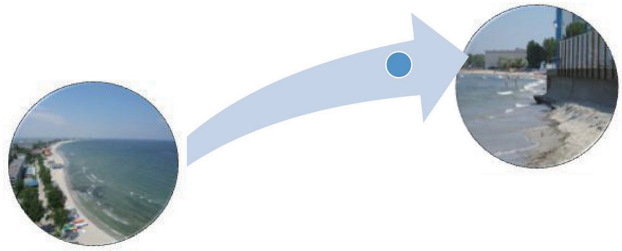


Figure 2. Mamaia bay arial view and beach buildings. In this area it is teriogenic sand which originates mainly from the Danube river deposits coming through the 3 branches (Chilia, Sulina and Sfantu Gheorghe), while the secondary source of sand formation is from shell fragments. [5] (Fig 3)

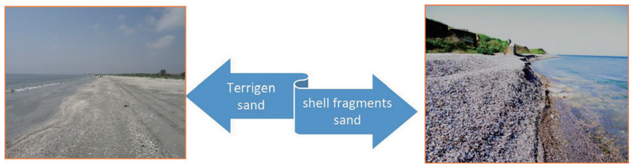


Figure 3. Sand of Mamaia Bay

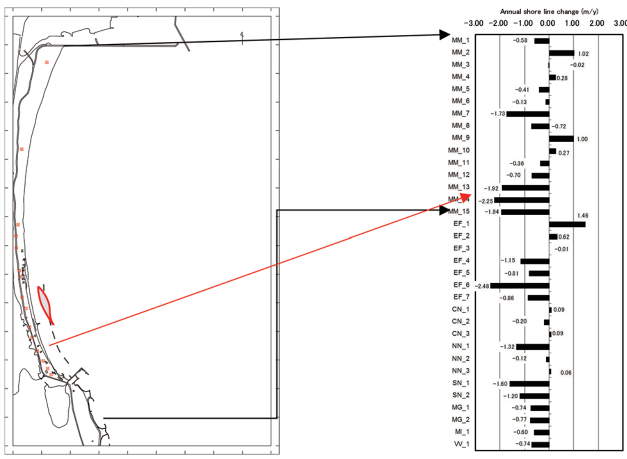


Figure 4. Sediment loss in Mamaia Bay (Source Halcrow, 2011), in the left side the map of Mamaia Bay is illustrated, while in the right side the annual shoreline change in m/y.

Moreover, sediments in this area are carried by the waves offshore, registering a strong erosion that can reach over 2 meters / year, requiring a certain amount of years to have coastal protection measures (nourishment or placement of hard structures such dams or other protected structures). [6], Fig 4. The black arrows in this figure indicate the Mamaia area, denoted as MM, while the red arrow the location with the maximum sediment loss, which corresponds to MM14 (-2,35 m/y).

According to the JICA 2007 report, tides have very low height in the Black Sea, the maximum amplitude arriving just to 0.05 m. From this perspective, the Black Sea is considered a medium micromareic environment and any

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increase in the sea level is due to waves and wind. Thus, the Black Sea level variations at the regional level will depend on the balance of the amount of water entering and leaving the basin. Stanev, and Perova in 2002, led to large-scale changes in the annual sea and decade and may reach up to 20-30 cm.

The quantity of water balance changes depends on several factors as for example:

1) precipitation and evaporation at the sea surface;

2) water entering and leaving the two Straits (Kerch and Bosphorus);

3) river input (the biggest influence coming from the rivers Danube, Dniester and Dnieper).

Furthermore, the changes in sea level depend on the seasonal variations. Since 1840, the average level in the Black Sea has continuously increased between 2.8 and 3.1 mm/year [Dan s. and others, 2009]. Short-term variations occur due to changes in sea level atmospheric pressure, wind speed and direction. Although the frequency of the storm waves is less than in the Oceans, they bring important changes, inducing 7-8 times greater values than other variations of sea level. This can reach an increase of up to 1.3 m above the average level. [Mungovi g. and others, 2000]

Along the coastal zone, particularly in the realm of the lakes and enclosed seas, as the Black Sea is, may occur also seiche waves. They are formed usually due to sudden changes of the strong wind direction or to changes in atmospheric pressure. The difference between the storm waves and seiches is related to their spreading mode, seiches moving from top to bottom and wind waves moving forward. Seiches may take from a few minutes to around 13 hours having amplitudes of up to 2 m. [Patrick n., 1999]. They are reflected by sudden sea level rises of up to 1.5 m followed by slight decreases. On the Romanian Coast such phenomena can be met especially in the northern region.

Romanian seaside wind speed is relatively high with average values between 4.8 and 6.95 m/s with a maximum from the direction N, N-V. [Report of the coastal zone, 2011 Appendix B] The highest values of the wind are recorded during the cold season (winter) from December until February, in opposition with the hot season (July-September) when their intensity decreases. This is also the explanation for the eroding beaches in winter and recovering in April-June when weaker wind is noticed. Patrick (1998) showed that 55% of the storm duration and frequency are from the North. Along the coastline, the phenomenon of coastal breeze may be encountered. This occurs as a result of temperature differences between the sea and the dry land, being more sharp between the months of May and September, when the temperature at the level of the land is higher. The high wind speeds and the waves have also a significant effect on the transport of sediments.

The European Commission of the Danube made the first wave regime observations in 1866. At that time the state of agitation of the sea was determined to in relationship with a scale of 3 degrees, and from 1943 it was passed to a scale of 10 degrees. [Bumblebee c., 1965] Subsequently, specialists made wave height and the regularity analysis, energy potential and their forecasts. [Rahm e., 2009]. Wind waves (locally produced) are prevalent in the Black Sea although swell (distant generated waves) can be also noticed. The average value of the significant wave height increases from the North (0.85 m) to the South (0, 95m). [Report of the coastal zone, 2011- Appendix B]. In general, wind direction and wave is variable whereas changes occur seasonally in the most severe winter conditions. However, Royal, 2004, observed that over 90% of the waves propagate from the North, lowering the height once it approaches the shore.

The Romanian coastal zone is extremely exposed to erosion, which can reach tens of meters. Projects for the rehabilitation of the coastal zone have been focused on the withdrawal of the shoreline, particularly in the North, where of fine sand sediments are formed, being transported by the waves during the storm. However, some of these sediments transported tend to be recovered because of constructive waves. In the southern sector, there is a net loss of sediments which can diminish the beaches.

The currents present in the Black Sea are determined by the atmospheric circulation, wind and water flow, the bathimetry of the coastal areas and hydro-technical constructions (coastal and port structures). Along the coastal zone of the Black Sea there is a current parallel with the shoreline that stretches approximately 20-40 km offshore. This has speeds between 5-10 cm/s being oriented in the direction N-S. There are also present 2 turbions in the West of the Black Sea and a circular current surrounds. These currents were formed due to the shape of the Black Sea basin. The mouth of the Danube through its three branches influences the formation of weak currents, at great depths, in the opposite direction to those of the surface.

The Romanian coastal zone is characterized by mild winters (with temperatures generally above 0 ° C) and hot summers (average temperature of 21-22 ° C). These variations, under the influence of the coastal processes, foster the formation of dunes and Aeolian sediment transport. Humidity in the coastal region is much higher than in other regions, while this has a negative effect on wind transport. Coastal breezes generate temperature differences between the sea and the land. As a result of the analysis of some data sets, in the Report of the coastal zone (2011) prepared by the administration of the Romanian Dobrogea Waters Basin rainfall levels are between 283-531 mm/m2/year. However, rainfall acts negatively on the dunes and seashore which can lead to landslides and collapses. This fact can be observed particularly in the winter, when torrential rains coincide with storms causing strong erosions. In addition to these processes, the amount and distribution of the rainfall influences flow and subsequently make changes to the shore.

The Danube is the main source of sediments, which is transported with the help of waves and currents. Most sediment is transported via the Chilia arm. Panin, 1998, Giosan and al, 1997, showed that with the construction of the dams at Sulina it was blocked the transport of sediments along the coast from the North. So this means that the sediments coming from Ukraine were stoped. The influence of the Danube is decreasing far before Constanța, the sediments in the southern part being derived from other sources, as for example from the reshuffling of existing deposits along the shore line, namely bars/coastal barriers,etc. [Kuroki, 2006]. Although the southern part is characterized by caves, they do not bring a significant contribution due to soft and loess beaches with fine sand that can be easily moved. The layer of limestone base is resistant to the action of the waves what hampers the sedimentary transport. Kuroki, 2006, showed that over 98% of sediments are of calcareous origin. Net losses of sediment are hard to predict, but there are areas where sedimentary transport is active, for example, areas that have built structures for protection. At the same time, sediments originating from the Danube and sediments resulting from the shore erosion have a finer film grain which makes them easy to be tranported. Sedimentary transport rates vary with time due to the seasonal changes of the wind and waves direction and intensity. Unlike the Northern part, where fewer structures built, in the southern part they altere the sediment movements, generating sedimentary cells. Moreover, the pier next to the port of Midia stopped the transportation of sediments to the South. Summarizing, coastal structures built by humans reduced sediment transport along the shore. Finally, another sedimentary deficit comes from the extraction of the sedimentary material on beaches, although the Romanian law forbids this practice. Another practice described in Ungureanu and Stănică, 2000, includes the elimination of bivalve shells from the southern part for improving the quality of the beaches with tourism destination.

2 Different Types of Coast Protection Structure in Mamaia Bay

To protect the zone in the Mamaia Bay, more than a half of the beach benefits of "hard systems protection", consisting in 5 immerse breakwaters and 2 jetties. The breakwaters are designed to take the energy of the waves so that the area behind them becomes calm water. They are built especially for the harbors. On the other hand, by placing these types of structures in the beach area, they will change the profile of the beach behind them. For example, if the sand accumulates in a parallel area, another area will undergo an erosion process. Furthermore, sometimes detached breakwaters are meant to provide shelter for swimming water or for landing on the beach of small fishing boats.

Coastal protection systems can be divided into four categories:

1) Shore consolidation works;

2)Transversal protection works (groins, dykes);

3) Longitudinal works in the sea;

4) Artificial nourishment.

Shore consolidation works are made on the beach with the main purpose of resisting to the direct wave action. It is important that they do not lead to erosion in their foundation area or in the front beach. These types of works are not often used as they hinder the natural aspect of the beaches and the tourist use. Transversal works, more precisely the groins have the main purpose of stopping the transport of sediments along the beach, which implies the development of upstream accumulations and erosion on their downstream side. Longitudinal works interfere with the wave propagation by intercepting the incident energy flow. Part of this energy is distributed widely, a portion it is dissipated in the mass of the building and the rest of the energy is transmitted through/over the dikes.

These works can be of several kinds, as for example:

1) Dikes with different shapes T, Γ or Y, related to the shore;

2) Longitudinal structures parallel to the shore, located on the shore, at low depths; (Figure 5)

3) Longitudinal structures built on sea, but at depths of 3 to 4 m.

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Figure 5. Detached Breakwaters – Longitudinal structures

Breakwaters are designed to take over the wave energy so that the area behind them is calm water, especially for ports. These types of structures will change the beach profile. Over time, sand accumulates in the area and as a consequence another area will suffer an erosion process.

3. Methodologies

In our study, we perform a simulation of the morphological evolution behind several detached breakwaters that are exposed to the significant wave action from two directions. The zone of study is the southern part of Mamaia Bay, Constanţa, where we find several types of "hard protection systems".

For the simulation we use Mike 21 PMS – Parabolic Mild Slope Wave Module software produced by DHI Water and Environment. According to the manual of MIKE 21 PMS, the module uses a linear refraction diffraction pattern based on a parabolic approximation to the mild slope elliptical equation, which is solved using a Crank-Nicholson finite difference scheme. It is analyzed the effect of refraction and shock due to variation in depth, diffraction along the perpendicular to the predominant wave direction and energy dissipation due to bottom rubbing and wave breakage. The model will also consider the analysis and effect of frequency and directional spread using linear overlapping. The output data are integral waveforms (eg. root height, the peak wavelength, and the average wavelength). Mike 21 PMS is used for waves disturbance projects in open coastal areas and for the calculation of interaction between wave fields and coastal structures (eg grooves, detached dikes) when negligible backward dispersion (reflection in the received waves) and the diffraction is predominantly perpendicular to the main direction of the waves.

The aim of this study was to model through a simulation the morphological evolution behind several detached breakwaters exposed to the wave action.As input data, we specified first the bathymetry map, figure 6, which contains depths of water for the model area. [9]

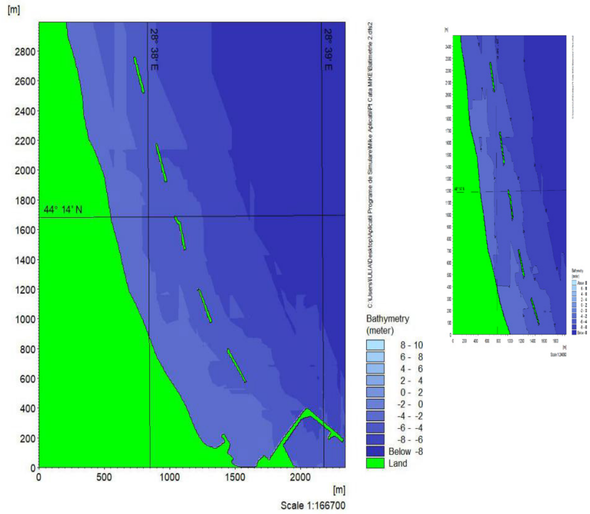

Figure 6. Bathymetry map of the Southern part of Mamaia Bay

A grid spacing of 10 m is chosen in the x- and y-directions. This gives a resolution of 10 grid points per wave length at a water depth of 1 m. The conditions of the two boundaries that are perpendicular to the shoreline (in our case north/south) are unknown beforehand for the wave conditions, so we choose symmetrical conditions (depth contours parallel to the y-axis).

The bottom friction is specified by the constant Nikuradse roughness parameter with 1.5 mm, and the parameters in the Battjes & Janssen (1978) wave breaking formulation are specified as: $\alpha = 1.0$, $\gamma_1 = 1.0$, $\gamma_2 = 0.8$ (which are the default wave breaking option and values).

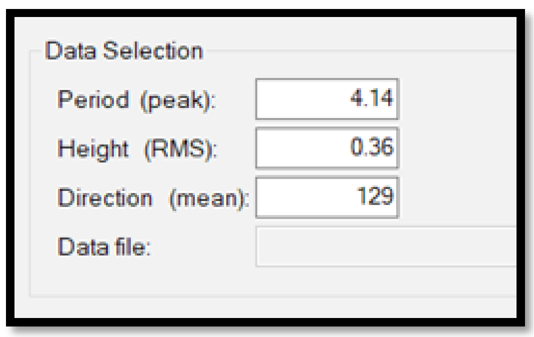

Figure 7. Input Data in MIKE 21 PMS

The wave conditions at the offshore boundary are specified as the root mean square wave height $H_{RMS} = 0.36$ m, peak wave period Tp = 4.14 s, as we can see in Figure 7, with different wave crests. For the zone of study, there were considered incoming waves having the directions of 129^o and 90^o.

3.1 Beach Morphodynamic Models

Diagnosis/prediction of the beach response to the wave forcing and sea level changes have been carried out. The basic principle considers that, when the sea level and/or the wave forcing change, the beach profile is forced to change to a new profile. Beach erosion/retreat models can be differentiated into 'static' models and 'dynamic' / 'bottom-up' models

In the static models, beach erosion/retreat is assessed through the solving of one or of a system of equations. In these models, hydrodynamic and sediment dynamic processes are not (fully) considered. Therefore, most of the static models are used to predict effects of long-term sea level rise (ASLR) on the cross-shore beach profile, consequently these models are 1-D models. Here, we will considered 3 of such models, i.e. the models Bruun (1962, 1988), Edelman (1972) and Dean (1991) [10]

3.2 Dinamic and Bottom-up Models

The basic 'ingredient' of the dynamic beach morphodynamic models is the coupling of

1)hydrodynamic and

2)sediment transport models

The results of the coupled models are then used to determine the morphological changes using e.g. some form of the sediment continuity equation.

The Bruun model assumptions are:

1)The active cross-shore beach profile attains an 'equilibrium' profile

2)Under ASLR, the equilibrium profile migrates onshore, causing erosion in the sub-aerial and deposition in the sub-marine beach

3)Deposition occurs between the (new) shoreline and the closure depth and

4)Seabed elevation increase due to deposition equals sea level rise

The governing expression is:

$$s = \frac{l \cdot a}{h_c + B_h} \qquad (1)$$

where s represents the coastal retreat; l the distance to the closure depth; hc is closure depth; α the sea level rise; and Bh indicates berm elevation.

It has to be noted however that there is no control by sediment size or wave characteristics, except for the most energetic waves of the year that define the closure depth (figs. 8 and 9). Much has been written for and against the validity of assumptions of the Bruun model (e.g. Pilkey et al., 1993; Cooper & Pilkey, 2004; Zhang et al., 2004) [10].

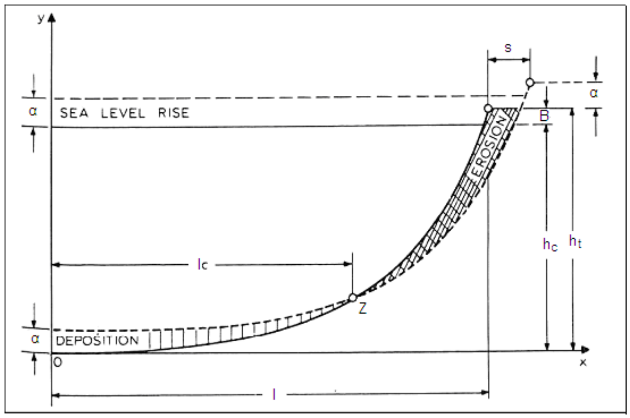

Figure 8. Scheme showing the parameters of the Bruun model. Key: S, coastal retreat; l, distance to the closure depth; hc the closure depth; α, sea level rise; Bh, berm elevation; ht, hc + B (after Slott, 2003). (Source https://slideplayer.com/slide/6269153/)

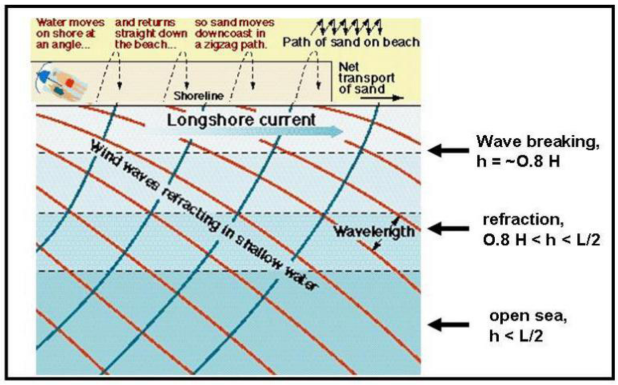

Figure 9. Coastal wave zones. Longshore transport in the coastal zone occurs mainly in the surf and swash (wave run up) zones (After SEPM, 1996). Key: h, water depth; H, wave height; L, wave length. (Source https://slideplayer.com/slide/6269153/)

4. Results and Discussion

The result of this model is the effect of shoaling, refraction, diffraction, bottom dissipation and wave breaking.

The model results are presented as contours of root mean square wave heights, H_{RMS} and wave direction vectors scaled by the wave height. The influence of the wave breaking close to the shore is evident, as well as the reduction of the heights behind the breakwater due to wave diffraction.

From these two cases, we can see that the detached breakwaters have a significant effect on wave energy dissipation, which can form salient, or tombolo accumulation, depending the distance between structure and shoreline.

In the first case, if there was a single structure parallel

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to the coast, this was not very efficient when the waves with 129^0 direction are fairly oblique to the shoreline (figure 10), as the effective length of the structure perpendicular to the wave direction is relatively small is this case (figure 12). The single breakwaters cannot be recommended because of the sand filet accumulation coast, which is very short [11].

More so, than it can be seen in the South of the study area in Figure 10 the wave heights are relatively high (with red color) because a breakwater or other coastal structure does not protect the next adjacent zone.

Segmented systems of breakwater schemes with relatively short gaps can also be used as a combined shoreline and coastal protection measure for all types of coasts, because for the formation of pocket beaches the gaps do not depend very much on the wave direction when the gaps are small. This type of protection can be found in the Southern Unit, especially in Eforie, Venus, and Saturn etc. [12]

For the case of Mamaia, even if the gaps between breakwaters are relatively short, the distance from the shore is higher than in the other cases and forms instead of the pocket beaches "salient" accumulation, figure 11. The location of the dikes in a particular system has the role of protecting the beach from strong waves, but at the same time, it captures algae and floating debris in the sea. The location of the breakwaters system can create an advantage or disadvantage in the beach area, requiring a thorough study of the waves and current dynamics in the area concerned.

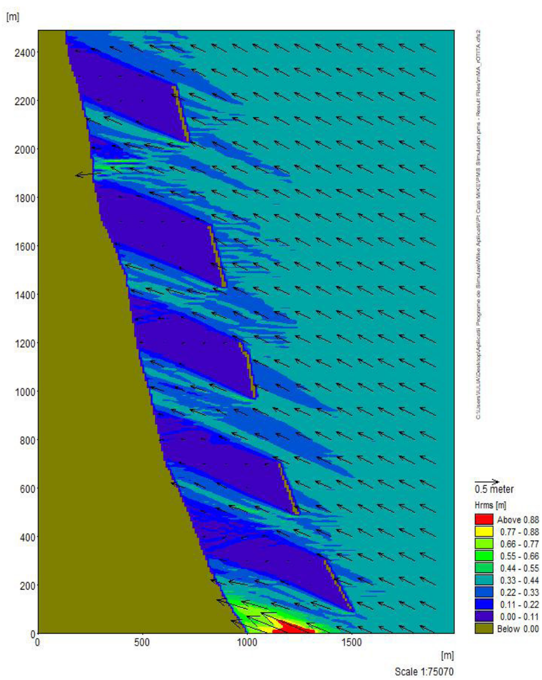

Figure 10. Mamaia Bay with 129^0 incoming waves

Figure 11. Salient accumulation in Mamaia Bay

It is known that sheltered areas are found behind the breakwaters, as has been shown in the above-mentioned modeling, while the areas where erosion is manifested are the areas in front of the dyke and the beach areas not protected by the breakwaters. [13]

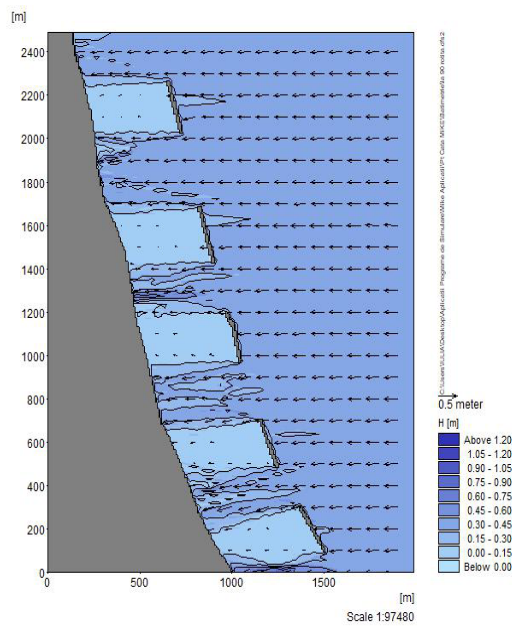

Figure 12. Wave height - Mamaia Bay with perpendicular incoming waves

As mentioned earlier, the special accumulation describing the study area as a result of the dykes is a function of the distance between the dykes and the coast, referring to the direction of the wave-breakwaters interaction and the angle that the breakwater makes with the coast line. This angle is particularly important because it is a component part of the formation of the bulk type, see figure 13. Depending on the angle at which the breakwaters were built, it influences and determines a new wave direction that will also attract the direction where the sediments will accumulate over time.

The phenomena of refraction and diffraction can be observed in next figures, 14 and 15.

Measurement of diffraction waves is of particular importance. Both natural and human structures influence the diffraction characteristics to some extent and have an effect on height distribution in height in a port or sheltered place. Knowing the diffraction process is important in planning installations that provide protection against incident waves. [14] The location of these installations and their design are essential to reduce shear and resonance phenomena, and in this case, it is necessary to know the effects of diffraction from where. Similarly, the prediction of the wave height is influenced by the diffraction caused by hydrographic changes.

The phenomenon by which energy is transferred laterally along wave surges is called water wave diffraction. This phenomenon controls the shore response to detached breakwaters. Water wave diffraction is particularly noticeable if a wave field is interrupted by a dike or a small island. If this phenomenon does not exist, behind the natural or artificial barrier located in the sea there would be a region of perfect calmness. The line separating the two regions would produce a discontinuity. However, through the wave diffraction phenomenon, the area behind the dikes is disturbed by the area in front of them. [15]

From this research, the waves regime alteration due to the protection system is clarified and alternatives will be valuable in decided the most efficient systems according to the natural conditions.

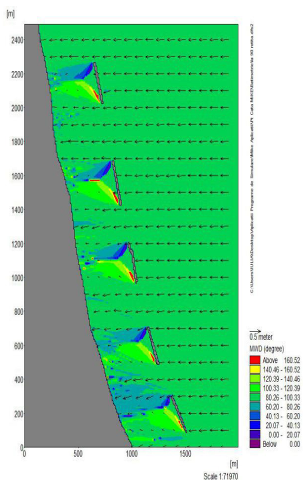

Figure 13. Direction of waves - Mamaia Bay with perpendicular incoming waves

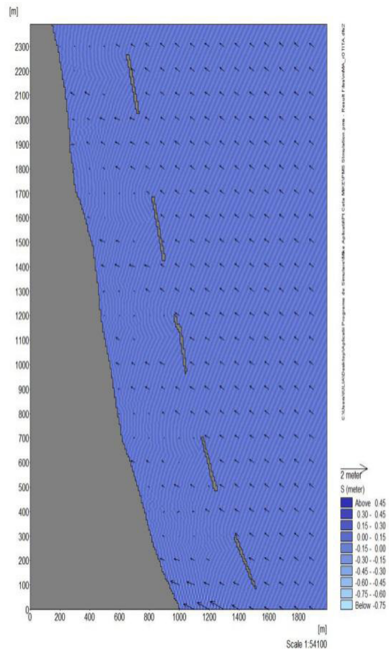

Figure 14. Refraction and diffraction of the Mamaia Bay with 129 ^{0} incoming waves

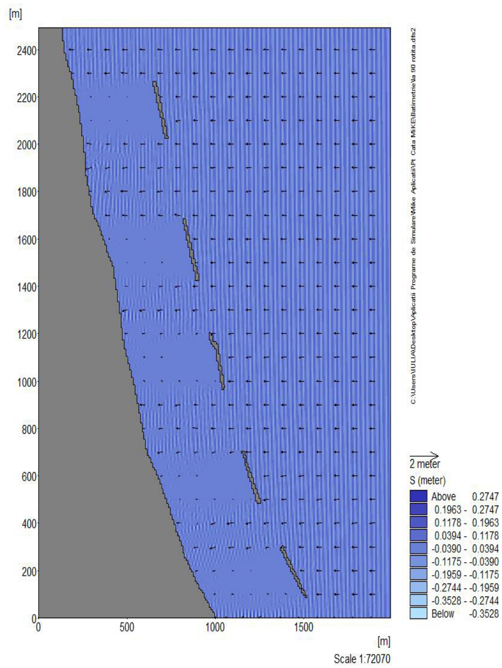

Figure 15. Refraction and diffraction of the Mamaia Bay with 129^0 incoming waves

In the figure below (fig.16) can be seen the existing capacities on the beach of Mamaia South

Artificial nourishment:	L=1,2 km;
Rehabilitation of submerge dikes:	L= 0,5 km;
Jetties	L= 0,2 km;
New submerge dikes:	L= 0,51 km.

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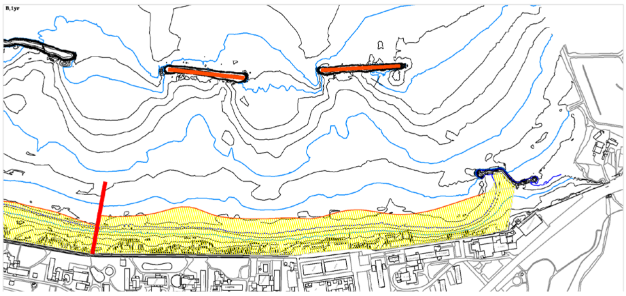

Figure 16. Existing capacities on the beach of Mamaia South (Source Halcrow 2011). That red color represents hydro constructions to be rehabilitated, because their current state no longer allows a protective effectiveness of shoreline

In the next table (Table 1) we applied the Bruun rule in the Gulf of Mamaia, taking into account two scenarios, one optimistic (sea level increase of 3 mm / year) and one pessimistic (increase of the sea level of 10 mm / year) . [16]

Table 1. Estimates of shoreline retreat in Mamaia Bay

Sedimentary cell	Sectors	Estimates of shoreline retreat and the annual equivalent level (m / year) using the Bruun rule (2020-2050)	
		Increasing sea level by 3.3mm/ year	Increasing sea level by 10mm/ year
Mamaia Bay	Mamaia North Mamaia Center Mamaia South	-7,5m (0.25m/an)	-22,6m (0.75m/an)

Sea level rise expectation, flooding and wave effect on flooding is shown below

1)A 0.3m rise in sea level to 2050

2)A further 0.7m in the following 50 years

3)Include an allowance for local and/or regional land subsidence

Flooding: storm surge

1)Storm surge is an increased water level over predicted tide height during storms

2)Storm surge is included in the determination of the ARI water levels

Wave effects on flooding

1)Wave run-up: rush of water up the beach

2)Wave setup: locally raised water level from wave breaking

At this point, it has to be also highlighted that behind the detached dike, the waves decrease in height and there will be a significant sediment accumulation depending on the distance between the breakwaters and the shoreline. The two types of accumulation can be of the “salient” type, when the distance is larger and the “tombolo” type, when the distance is smaller. The sand captured in this area will be from the adjacent beaches, which implies erosion upstream and downstream. These types of accumulations are influenced by the position of the dykes, the height and direction of the waves. This phenomenon can be seenin the case of Mamaia Bay, where there are several detached cracks and the hydrodynamic conditions coincide with those described above [17]. It can be seen how the wave heights are changed at the time of a collision with a detached breakwater and how the phenomenon of diffraction appears because of this phenomenon. A condition of no longshore transport is that the initial shoreline should be parallel with the incident breaking wave crests. Thus,the waves will be diffracted into the shelter zone of the breakwater, which will transport sediment from the edges of this region into the shadow zone. In addition, this process will continue until the shoreline will be parallel to the diffracted wave crests. [18]

5. Conclusion

Mamaia Bay is a well known and very important location in the western side of the Black Sea, being one of the most important touristic areas in Romania, On the other hand, since the western side of the Black Sea is its most energetic part, this coastal environment is subjected to high erosion risks. This affects especially the touristic areas, as Mamaia is, where strong beach retreats can be noticed. From this perspective, the target of the present paper was is to make an analysis between the type of work that is being carried out and another kind of “soft” work aiming especially to favor the ecological reconstruction of the area and the approach of an environmentally friendly concept. An extended analysis of the environmental conditions affecting the target area has been first performed. Further on simulations with the Mike 21 PMS – Parabolic Mild Slope Wave Module software have been performed.

Following the results of the present work we can state that, in order to be able to provide effective mitigation measures for the protection of Mamaia Bay, t a thorough study of the area is required. This should be done before choosing the most appropriate of the coastal protection options, which are: non-intervention option, coastline option, stop-controlled option and shoreline progression. After selecting the right option, there are various engineering solutions and techniques to implement the required project. Most types of solutions are based on "heavy" and "light" works that lead to loss of attractiveness and natural aesthetics. From the models presented in the previous sections it follows that the construction of the breakwaters is dependent on the characteristics of the waves and of the shores. These structures cannot fully accommodate the area as the diffraction phenomenon occurs, but the longer the breakwater is, the better the area might be considered.

Furthermore, by applying the Bruun rule, and taking into account coastal protection measures, effective programs can be initiated to protect the socio-economic objectives. Decision makers and public authorities should plan coastal development based on environmental factors, hydro-meteorological conditions and sea-level rise. The accuracy of the data and its detailed analysis is essential in such a process.

Finally, it has to be highlighted that the results of the present work are in line with those comming from several previous studies, as for example those discussed in [19-25].

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