Wave Simulation with Different Type of Coast Protection Structure – A Comparative Approach

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Abstract: - Coastal zones, and more precisely, the shoreline is constantly changing due to the action of waves, tides and human impact. The anthropic pressure on the coastal zone is growing more and more and implies the intense development of human activities as close as possible to the shoreline. This has led to the implementation of coastal protection measures, the hydro-technical structures, to prevent further damage to the shoreline, the coastal erosion. This is an important problem facing coastal zones around the world and requiring the implementation of coastal protection systems to prevent further damage to the shore. Coastal erosion occurs as an effect on sediment transport, modifying shore morphology. The sediments in the coastal zone are the moving element of seashore being moved by the action of the waves and currents on the transverse and longitudinal direction to the shoreline. In this paper we will present the changes that occurs on the waves after the impact with a protection structure or more and the changes that occurs in the shoreline.

Key-Words: - coastal zone, waves, coastal protection, elliptic mild-slope equation, shoreline, erosion

1 Introduction

To prevent and reduce coastal erosion and sediment transport, coastal protection systems are used which consist largely in the construction of structures to protect the shoreline. However, these types of construction pose particular problems of resistance and are especially determined by the action of waves caused by storms of special intensity.

There are various types of coastal protection work depending on the appearance of the elements and the type of materials used, shape and layout in the plan, etc. In order to find the most suitable system for the study area it is necessary to have a general scheme of the protection works involving the detailed knowledge of the morphological processes in the respective area, the exchange of alluviums with the adjacent areas, the agitation regime. It also needs to study the impact that these protection systems can have on adjacent areas.

For all of these, land data is required that is often insufficient. Thus various software are used to describe the best phenomena that appear with the minimum of necessary data. The results obtained should be staggered so that they can be improved by monitoring the behavior and effects of these works.

The dynamic and mobile element of the seashore is the beach that can be defined as a strip of sediment oriented along the coastal zone and descending on a smooth slope to the sea. From a morphological point of view, it has the role of taking over and dissipating the incident energy of the waves through the actions of deferring, infiltration and alluvial transport. Depending on the waves, levels and currents, the beach has the ability to adapt its shape to protect the coastal area.

Another important role of the beach is to describe the evolutionary morphological processes, both in terms of erosion and accumulations that develop by the variation of its width, the upper elevation and the underwater slope. These elements are monitored periodically, on the same profiles obtaining the quantitative parameter required to define the evolution of shore morphology.[4]

The climatic characteristics of Romanian coastal zone are specific to the temperate-continental zone due to the geographic position and the terrain configuration.

In the seaside area, annual wind speed averages are relatively high (between 4.2 and 6.95 m/s) with north and north-west directions.

An important effect of strong winds are the sea storms, whose edges exceed 10 m/s. The duration of the storms in the NEs reaches an average of 107

hours, of which about 47 hours with speeds at an apogee of over 28 m/s. [1]
Wind-blowing waves are those with speeds greater than 3 m/s, with a duration of about 82% per year. The predominant direction on the Romanian shore is in the North, and the weakest is the winds in the South East direction.
There are generated two types of waves: waves of hula and wind waves generated local.
The average height of the offshore waves increase from North (0.85m) to South (0.95 m) along the shoreline.[5]
The wind and wave directions vary widely depending on the seasons. The quietest period is recorded in the summer months between April and October, and the agitated period is in the winter months between November and March. The maximum height of the waves is recorded in the Southern area during the winter season.

2 Different type of Coast Protection Structure

Coastal protection systems can be divided into four categories:

- Shore consolidation works;
- Transversal protection works (groynes, dykes);
- Longitudinal work in the sea;
- Artificial nourishment.

Shore consolidation works are made on the beach with the main purpose of resisting 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 it hinders the natural aspect of the beaches and the tourist use.[4]
Transversal works, more precisely the groynes 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. Their effectiveness stream with suspended alluviums and the physical possibility of intersecting them.
Longitudinal works interferes with the eave propagation by intercepting the incident energy flow. Part of this energy is distributed widely, a portion is dissipated in the mass of the building, and the rest of the energy is transmitted through/over the dikes.[4]
These works can be of several kinds:

- Dikes with different shapes T, Γ or Y, related to the shore;
- Longitudinal structures parallel to the shore, located on the shore, at low depths; (Figure 1)
- Longitudinal structures built on sea but at depths of 3 to 4 m. [4]

Figure 1 – Detached Breaakwaters – Longitudinal structures

Breakwaters are designed to take over the wave energy so that the area behind them is a calm water, especially for ports. And these types of structures will change the beach profile. Over time, sand accumulates in the area and another area will suffer an erosion process.
Sometimes the detached breakwaters provide shelter for the beach landing of small fishing boats or for water for swimming.
All these types of structures cause morphological shore changes. In the following a part of types of coastal protection will be studied with their effects on waves.

3 MIKE by DHI Software

The water modelling software, a flexible and efficient engineering tool, MIKE by DHI is a computer program that covers all aspects of water and environment, from different source.
The 2D package of MIKE, MIKE 21 is used for modelling coasts and seas and cover all physical and environmental aspects of marine modelling. This modelling program use a modern technology with flexible mesh methods and efficient numerical solutions.
MIKE 21 PMS (Parabolic Mild-Slope Model) is a linear refraction-diffraction model based on a parabolic approximation to the elliptic mild slope equation. In this model we take in account the different effects of refraction and shoaling because the depth varying and diffraction along the perpendicular to the predominant wave direction. Also in coastal zones appears wave breaking and bottom friction and it is important to taking in account the energy dissipation.
The area of study is coastal areas where are present structures like groynes and detached breakwaters.

This model is based on parabolic approximation to the elliptic mild-slope equation for description of refraction, diffraction and reflection of linear time harmonic water waves on a gently sloping bottom.[3]
The elliptic mild-slope equation can be written as:

$$\Delta \cdot (CC_g \Delta\phi) + (k^2 CC_g + i\omega W)\phi = 0 \qquad (1)$$

where:
Δ is two-dimensional gradient operator,
$C(x,y)$ is phase speed,
$C_g(x,y)$ is group velocity,
$\phi(x,y)$ is mean free surface velocity potential.
More exactly the procedure can be summarized as follows[3]:
a. Starting from the offshore boundary *x=0*, calculate the complex function ϕ_n for each component, assuming no wave dissipation at the next row, $x+\Delta x$. More correctly, we calculate A_n given by equation:

$$\phi = A(x,y)e^{ik_0 x}, \qquad (2)$$

in which the rapid variation of ϕ with x has been factored out. *A(x,y)* is a slowly varying complex variable.
b. Using the principle of linear superposition, the contribution of all the wave components to the total energy is summed, and the total energy and mean period can be found at $x+\Delta x$.
c. The dissipation term is now included by adjusting A for each wave component, *n*, using:

$$A_{new} = \frac{\left(1 + \dfrac{\Delta x W}{4C_g}\right)}{\left(1 - \dfrac{\Delta x W}{4C_g}\right)} A_{old}\,, \qquad (3)$$

where the wave dissipation function, *W*, is calculated on the basis of the total energy, *E*, and the energy averaged mean frequency, f_m.

4 Cases of study

We use for our study a beach with a constant slope of 1:50 (Figure 3).
For all of cases we use as input parameters the wave conditions at the offshore boundary, the period for 4 seconds, the means root mean square wave height equal with 0.64 m and the mean direction 166 degrees (figure 2).[2]

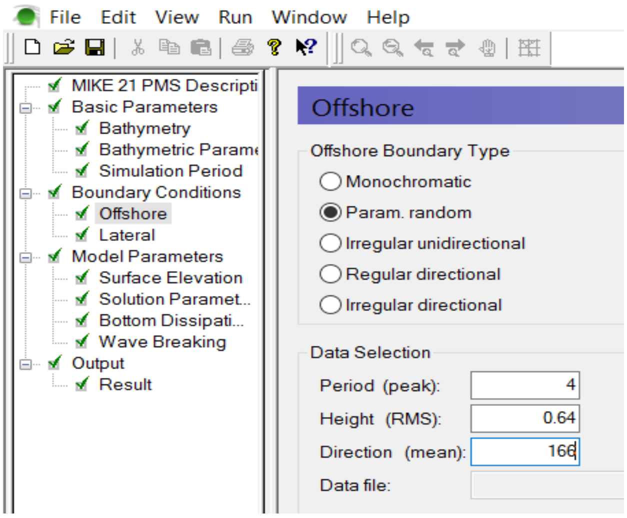

Figure 2 – Boundary Conditions in MIKE 21 PMS

Our purpose of the study was to simulate the evolution of waves due to different type of protection structures and the evolution of shoreline with different type of accumulation ”tombolo” or ”salient”.
The outputs of this model are two parameters of waves: the root mean square wave height and the mean wave direction.

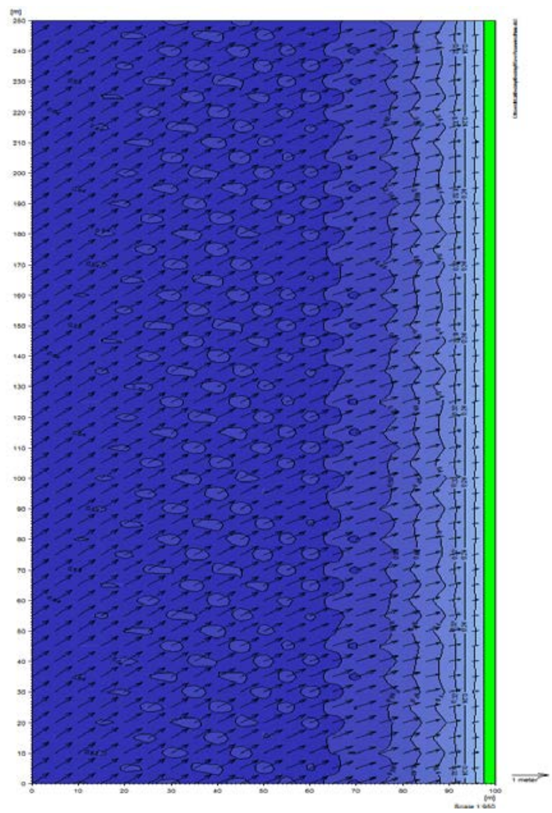
Figure 3 – Bathymetry of beach studied

Cases with different structures are presented below:

a. A short breakwaters structure with 200 m long and 40 m wide, and the distance from the shoreline is 280m.

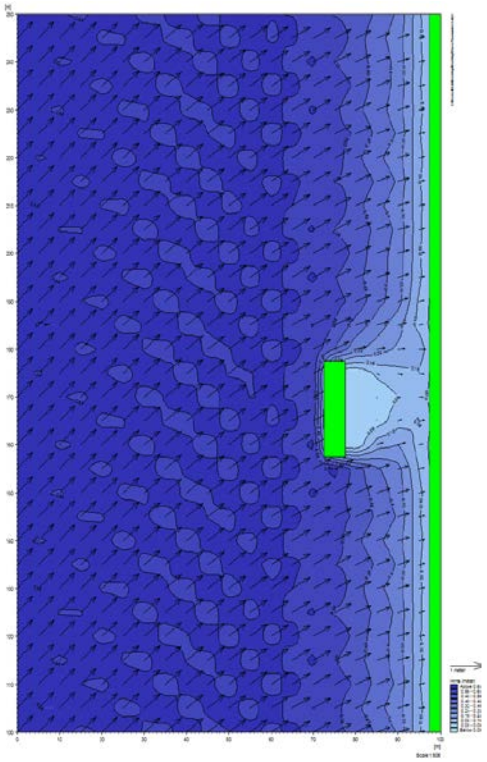

Figure 4 - A single detached breakwaters structure of 200 m length

b. A detached breakwaters structure with 400 m long and 40 m wide, and the distance from the shoreline is 280m.

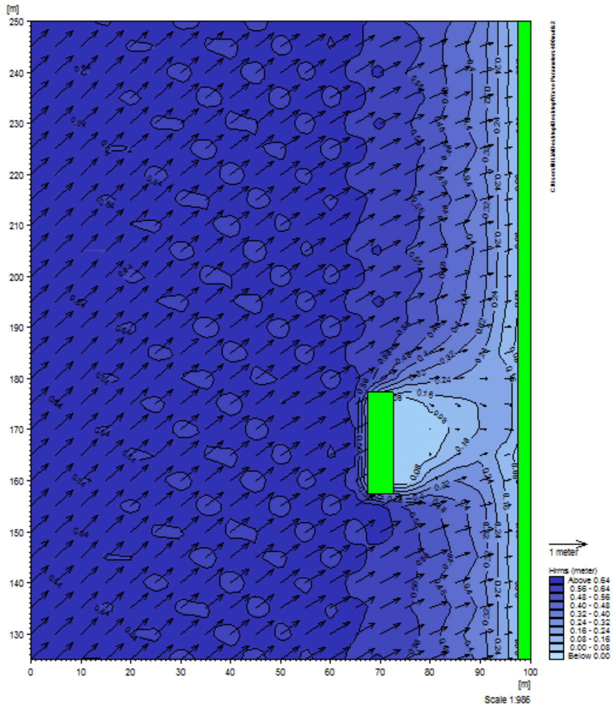

Figure 5 - A single detached breakwaters structure of 400 m length

c. A detached breakwaters with 400 m long and 40 m wide, and the distance from the shoreline is 120m.

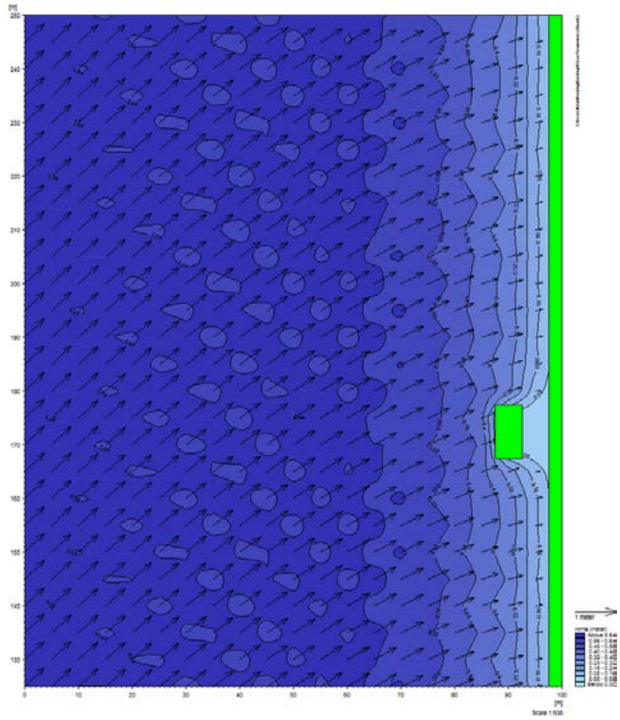

Figure 6 - A single detached breakwaters structure with distance from the shoreline 120m

d. Two detached breakwaters structures with 200 m long and 40 m wide, and the distance from the shoreline is 630m.

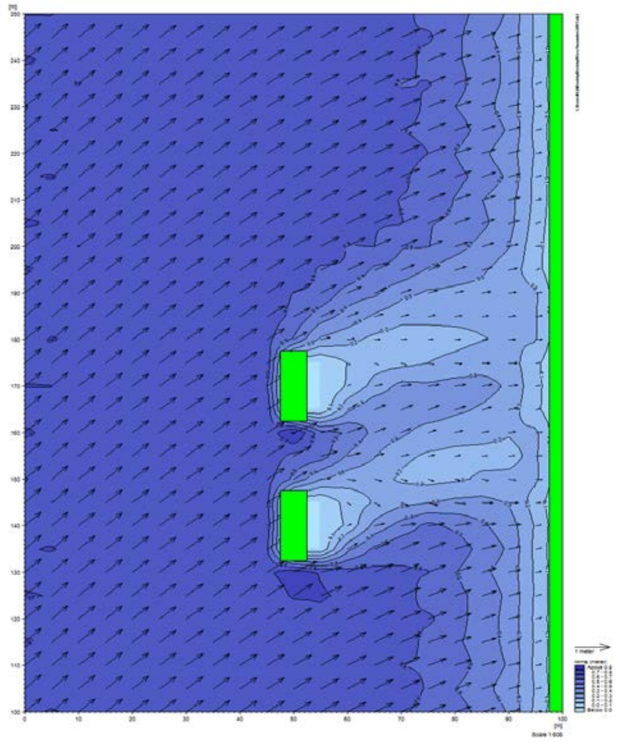

Figure 7 - Two detached breakwaters structures of 200 m length

e. A groynes structure of 160 m length connected to the shore.

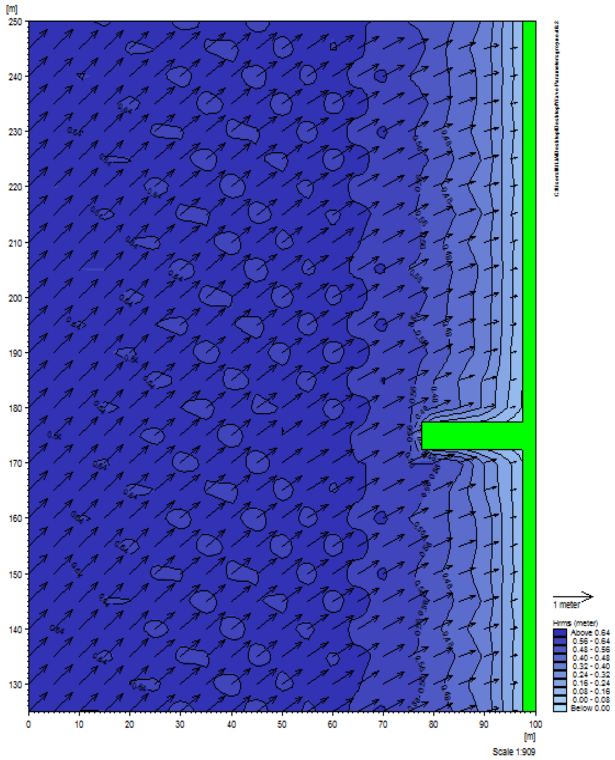

Figure 8 - A groynes structure of 160 m length

Of the five cases, we can observe that behind the detached breakwaters structures the waves no longer have significant heights and a deposit of sediment will be development; depending on the distance of the shore, there will be accumulations of ”tombolo” (figure 6) and ”salient” type and the sand for this accumulation will be trapped from the adjacent beaches and that both the upstream and downstream beach will suffer from erosion.

The wave heights are changed at the time of a collision with a detached breakwater and how the phenomenon of diffraction appears as a result of this phenomenon.

In the case with the long detached breakwaters at a greater distance from the shore generates significant accumulations, being beneficial to shore. A relatively long breakwater cause a greater reduction of longshore current than a short breakwater.

For segmented systems (Figure 7) a net seaward return flow of water can occur through the gaps, promoting offshore loss of sediment.

For example, in Mamaia Bay, Constanta a segmented system of detached breakwaters which have a greater distance from the shore generates a ”salient” accumulation being necessary for the protection of coastal zone, as we seen in figure 9, and a ”tombolo” accumulation in figure 10, when the distance is smaller. The hydrodynamic conditions in Mamaia Bay are the same with our cases.

Figure 9 – Mamaia Bay, detached breakwaters, ”salient” accumulation
[Google Earth]

Figure 10 – Mamaia Bay, detached breakwaters, ”tombolo” accumulation
[Google Earth]

The groynes are inferior to the detached breakwaters in terms of wave energy absorption, as we can see in figure 8 and 11.

Figure 11 – Mamaia Bay, groynes structure
[Google Earth]

All of this aspects are summarized in the next table, table 1.

Table 1 – Comparison between different structures

Cases	Protection Measure	Wave Energy	Protection	
			Coast/ Shore	Slope
a	One Detached Breakwaters L = 200m D = 280m	M	M	N
b	One Detached Breakwaters L = 400m D = 280m	G	M	N
c	One Detached Breakwaters L = 200m D = 120m	G	M	N
d	Two Detached Breakwaters L = 200m D = 280m	G	G	N
e	One groynes structure L=160m D = 0m	N	M	N

Legend:
L is the length of structures,
D is the distance from the structures to the shore,
M is from a moderate protection,
G is from a good protection,
N is from neutral protection

5 Conclusion

Before choosing protection measures, coastal engineers assess the strategies for the entire shoreline in order to choose the most appropriate of the four strategic options for each area/sector, namely: option without intervention, option to maintain shoreline, option controlled take-off and shoreline advancement.

In this way, they have at their disposal a wide range of engineering solutions and techniques to implement strategic options in the place where the intervention is proposed. Much of the modern hydro technical works combine ”light” and ”heavy” works so that the desired objectives are met, but after placing the hydraulic structures the attractiveness and natural aesthetic areas is lost.

Of the examples above, we noticed that the detached breakwaters structures shelter partly from the waves. A complete shelter cannot be possible because the phenomenon of diffraction. The longer the detached breakwater, the better the shelter.

The wave heights are determined by their distance from the breakwaters ends. In our example the beach planform is modified because the wave height affects the pattern of diffracted wave crests.

Wave diffraction control the shoreline response to detached breakwaters and the resulting shoreline alignment is generally parallel to the diffracted wave crests.

In all cases with detached breakwaters structures except the *c* case, the waves directions was modified at breaker zone between detached breakwater and the beach. The results in decreasing the wave energy and its direction modified the coastal currents was generated which formed ”salient” accumulation and protected the coastal zone.

A ”tombolo” accumulation is formed when the distance between detached breakwaters structures and shoreline is smaller.

The groynes structures dissipate the wave force which attacks the beach at normal direction. This structures have no significant effect on wave energy dissipation for approximate normally incident wave. The long-shore sediment transport and currents influence their effect.

A condition of no longshore transport is that the initial shoreline should be parallel with the incident breaking wave crests, and the wave diffracted into the shelter zone of breakwater which will transport sediment from the edges of this region into the shadow zone. And this process will continue until the shoreline will be parallel to the diffracted wave crests.

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.

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