Optimizing romanian maritime coastline using mathematical model Litpack

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Abstract. There are many methods and tools to study shoreline change in coastal engineering. LITPACK is a numerical model included in MIKE software developed by DHI (Danish Hydraulic Institute). With this mathematical model we can simulate coastline evolution and profile along beach. Research and methodology: the paper contents location of the study area, the current status of Midia-Mangalia shoreline, protection objectives, the changes of shoreline after having protected constructions. In this paper are presented numerical and graphycal results obtained with this model for studying the romanian maritime coastline in area MIDIA-MANGALIA: non-cohesive sediment transport, long-shore current and littoral drift, coastline evolution, cross-shore profile evolution, the development of the coastline position in time.

1. Introduction

Romanian coastal zone is the area around the coastline of Romania, located in the western part of the Black Sea coast with 244 km in length and representing 7.65% of the length of the border. Littoral zone is divided into two main sectors: north and south part. The northern area stretches from the Gulf Musura to Cape Midia and poses no severe human impact as is found in the southern area, from the Cape Midia to Mangalia because this area has changed significantly coastal dynamics.

In southern unit the rate of erosion was intensified following this numerous dams built since 1980, which led to fluctuations in shoreline position, because these structures led to the formation of deposit accumulations, unnoticed in previous periods. There were projects of nourishment beach in Mamaia, but were effective only for short periods of time. Erosion has come to reach levels over 2 m/year in northern and central area, while in the south, between Vama Veche – 2 Mai erosion rates reach values of approximately 3 – 4 m/year, due to the effect of the southern breakwater from Mangalia harbour.

After development of erosion were required to implement rehabilitation projects being represented shoreline coastal protection structures:

- Seawalls, revetment;
- Transversal structures (groynes, breakwaters);
- Longitudinal structures;
- Nourishment project.

Next, we present the effect of coastal protection works, and more precisely the influence of the groynes for sediment cells located between Cape Midia and Mangalia.
2. Materials and methods

Groynes, defined as transversal structures, have the main goal to modify the sediment transport along the beach which requires priming of deposits on the upstream side and the erosion on their downstream side. The effectiveness of the groynes take into account the existence of a longitudinal current charged with silt in suspension and the possibility of their physical intersect.

An important function of the groynes is to maintain the sediments in the upstream area of the structure, so the coastline behind the accumulation of sand is protected (figure 1). More specifically, the protection depends on the stability of this accumulation of sand in extreme conditions. Therefore, groynes must cover the entire beach so that is not an area unprotected during storms or high waves. This means that structures must be built in the coastal area at the foot of cliffs/sand dunes and their height at the end of landward mustn’t be lower than the other end. The height of groynes may be lower if the structures are located along the seawalls, dependind on the requirements for sanding bypass.

Figure 1. Beach profile with groynes [8].

The next step is the simulation of a situation with two types of groynes resulting the impact on the shoreline of the two structures. Groynes are described by two different structures, one longer and one shorter which influencing coastal erosion differently. It is important to keep in mind the spacing between the two groynes from a field of groynes.

As input data are specified two parameters related to the geometry of groynes:
- The relative length of the groynes depending of the wave height;
- The spacing between two groynes depending on their length.

The simulation was done on a shore facing 90° exposed to waves predominate from N-E, resulting an accumulation of sand to the east. Also present increasing of the littoral transport to the west, which means the coast is eroded.

The simulation was performed using MIKE by DHI (Danish Hydraulic Institute), Water and Environment- Litpack. We use the part of Mike, Littoral Processes FM module, an integrated modelling system that simulates non-cohesive transport in points along quasi-uniform coastlines. This module contains four calculation modules, and may be use individually or in combination:
- Transport in point,
- Littoral drift,
- Littoral drift table generation,
- Coastline evolution.
The calculations of sediment transport in the Littoral Processes FM module is Quasi Three-Dimensional Sediment Transport model (STPQ3D) and calculates instantaneous and time-averaged hydrodynamics and sediment transport in two direction, horizontal, in a point. The model is based on the solution of the force balance across the water column

$$\tau = \rho \nu_t \left( \frac{\partial \bar{U}}{\partial z} \right)$$

where: $\tau$ - shear stress; $\rho$ - density of fluid; $\nu_t$ - total instantaneous eddy viscosity; $\bar{U}$ - flow velocity; $z$ - coordinate toward from sea bed to surface in depth direction. The time averaged flow velocity $\bar{U}$ is found by integration.

Coastline evolution calculation is based on continuity equation for sediment volumes, equation (2).

$$\frac{\partial y_{act}(x)}{\partial t} = -\frac{1}{h_{act}(x)} \frac{\partial Q(x)}{\partial x} + \frac{Q_{sou}(x)}{h_{act}(x) \Delta x}$$

which means

$y_{act}(x)$ - the distance from the baseline to the coastline
$t$ - the time
$h_{act}(x)$ - height of the active cross-shore profile
$Q(x)$ - longshore transport of sediment expressed in volumes
$x$ - longshore position
$Q_{sou}(x)$ - source/sink term expressed in volume
$\Delta x$ - longshore discretization

The height of the active cross-shore profile ($h_{act}(x)$) and the source/sink term ($Q_{sou}(x)$) are calculated based on the data of user, while the longshore transport rate $Q(x)$ is determined from tables relating the transport rate to the hydrodynamic conditions at breaking. $\Delta x$ is another term specified by user, the internal timestep $\Delta t$ is determined from stability criteria. The result, more exactly the coastline evolution in time is determined by solving the above equation.

The structures in coastal zone cause changes of the wave angle and height at breaking, leading to altered transport rates. Because not all natural effects are included in the model, the proper evaluation of the outputs requires a good understanding of the mechanansms behind the physical processes as well as the modelling.

3. Litpack applications

Using the LITPACK software, LITDRIFT was obtained the evolution of an unprotected shoreline with the littoral drift and the result. The case presented is characteristic of beaches from Mamaia, where the average diameter of sediment is $D_{50}=0.2$ mm. The shore is oriented $90^\circ$ exposed to the prevailing direction of the waves N-E, oriented $60^\circ$, with the height of 2 m, period 4.8 seconds. It can be seen that there is a small erosion rate since the evolution of the shoreline was made over a period of 30 days. Over a longer period there will be a significant erosion rate. To prevent this problem, are required shoreline protection projects which involve the construction of groynes depending on the characteristics of coastal zone.

The first change will be the placement of a single groyne of 200 m.

It can be observed that the accumulation of sand was stopped in the top of the structure but grows easily along the upstream of the coastline and tending to be parallel with the original shoreline. At the present stage of development, this type of short groyne protects a larger area than area protected by a long groyne. This is because the most long groynes captures sand near the structures, as shown in figure 2, which presents the evolution of the coastline with a long groyne (the length of groyne is the
same with the width of the surf zone, 400 m) and a short groyne (200 m). Shoreline response is given by an accumulation of sand on the downstream side.

![Beach profile](image)

**Figure 2.** The shoreline protected by a short groyne of 200 m (blue line) and a long groyne of 400 m (black line) [8].

In both cases discussed the erosion problem is solved only in the upstream side of the groynes, which means that the presence of these types of structures has resulted in a drastic response unlike evenly distributed erosion than persisted prior to surgery. So it is necessary to make some changes in this area.

The previously discussions can be seen in figure 3 which present some chronological images captured by Google Earth from Romania, Constanta, Eforie Sud. On March 31, 2016 there was an accumulation of sand in East area for E1 groyne, and erosion from west in case of E2 groyne, but over six months significant changes occur:

- For E1, the accumulation occurs on West and coast erodes on East;
- For E2, the accumulation significantly increases on West and increases the rate of erosion on East.

These changes related to the dynamics of the coastal zone, and the most important parameter is the direction given by the waves.

From these images we can see that the gap between the two structures change significantly, so using software LITPACK we present further changes to shoreline protected by several groynes.

As noted earlier, one long or short groyne causing erosion downstream (figure 2 and figure 3). So, the next graphs shows the evolution of shoreline with 3 groynes of different sizes and different distances to each other, forming the so called fields of groynes. By simulation (figure 3 and 4) shows the evolution of shoreline (figure 4, figure 5, figure 6, figure 7):
Three long groynes (400m) with distance spacing 600 m, for example 1.5 times greater than the length of groynes;
Three short groynes (200m) with distance spacing 600 m;
Three short groynes (200m) with distance spacing 1200 m;
Three long groynes (400m) with distance spacing 1200 m, for example 3 times greater than the length of groynes;

Figure 4. Littoral drift in case of 3 groynes of 400 m with spacing 600m.

Figure 5. Littoral drift in case of 3 groynes of 400 m with spacing 1200m.
It has been observed that for a groyne, both the waves and the length of groynes determines the length of the section that can be protected. However, the distance between them and the relation between the distance and their length are important parameters for fields groynes because we need a large time to fill a field of groynes with sand. The only development of shore that occurs between two groynes is an initial curvature of shoreline with no littoral transport. The erosion in downstream of groynes fields is identical with the erosion from one groyne; however the process takes place only in the first part of the simulation described. Later, when the bypass begins, the rate of erosion tends to decrease in case with one groyne against the case with a field of groynes when the rate of erosion tends to increase. That means, in the long term, a field of groynes will accelerate the erosion than one groyne. Figure 8 (with green line – case of 3 groynes, blue line – case of 1 groyne, yellow line – case of 2 groynes).
Figure 8. The littoral transport when shoreline is protected obly by groynes.

4. Conclusions
The coastal area and more specifically, the shoreline is constantly changing due to the action of waves, tides and human impact. The changing of shoreline depends on many factors and events which can happen at small time intervals, a few seconds to a few centuries. The shoreline was especially influenced by human impact over the years, by placing "hard works" for protection against erosion and flooding [12]. In some cases, the "hard works" were made without studying the upcoming effects on adjacent areas.

In terms of coastal protection, the main function of groynes fields is to retain a sufficient amount of sediment to resist in extreme conditions during littoral transport and therefore maintain a proper protection of the beach area. Specifically, this is achieved by changing the orientation of shoreline in each gap from two groynes, to become aligned with the direction of the prevailing waves and thus reduce sediment transport along the shoreline.

Moreover the results obtained with Mike by DHI software, LITPACK module, we observed that a field of groynes will erode larger area of coastal zone than a single groyne. It is also important the geometry of groynes which significantly change the littoral transport rate. So when choosing a type of structure like groynes should be considered the spacing between groynes according to all important parameters of the waves (amplitude, period and direction).

Besides these issues, a solution accepted by the engineers [13] is to nourish the area discussed before placing the structure to prevent major budget amendment of coast.
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