RESEARCH ON THE BEHAVIOUR OF SHORE DEFENCES TO HYDRODYNAMIC EROSION

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Abstract

Shore defences located in beds formed in weakly cohesive rocks are affected by the phenomenon of hydrodynamic erosion in a differentiated way. Research carried out over a period of about 20 years on a section of the Moldova River highlighted the behaviour of "heavy - concrete slabs" and "light – geo-bags" bank defences. The climate changes of the last period of time, which influenced the hydrological regime of the river, determined a rapid degradation of the shore protection made of concrete slabs. The replacement of the shore defence made of concrete slabs with a structure made of geo-bags filled with ballast influenced the behaviour of the shore to hydrodynamic erosion. At the same time, the shore protection made with geo-bags filled with ballast stabilized with cement allowed a better cooperation with the foundation ground consisting of weakly cohesive rocks. The defence made of geo-bags has a larger area and perimeter at the same cross-section of the river. This situation causes the reduction of the velocities and the frictional effort at the wall, respectively the reduction of the erosion effort.

Key words: geo-bags, river beds, type of degradation, unstable banks

The riparian zone of the watercourses is intensively populated or occupied with social and economic objectives. The protection of the population and the objectives of interest from the destructive actions of water is achieved by regularizing the riverbeds and protecting the banks. These works modify the river bed in transverse and longitudinal profile, but disturb the aquatic and riparian ecosystems. A factor for changing the riverbed morphology is represented by hydrodynamic erosion (Luca M. *et al*, 2012). This phenomenon acts extremely aggressively on coastal defences. The choice of defence solutions must respect the technical and economic requirements, as well as the ecological ones.

A detailed analysis of morphological changes in riverbeds is presented by Ichim I. *et al* (1989) on various fields of research, namely hydrological, hydraulic, geotechnical, etc. A documentary study carried out by Avram M. (2020) highlighted the presence of an important number of articles published in the last 10 - 20 years and which deal with riverbed erosion under morphological aspects, the differential determination of roughness on the perimeter of the bed, the type of bed degradation and its rehabilitation methods, the characteristics regarding the transport of alluvium, the behaviour of coastal defence constructions and others.

The use of adequate bibliographic material allowed the authors to obtain a representative volume of data on the phenomenon of river bed erosion both in cross section and in longitudinal profile (Dapporto S. *et al*, 2003, Neuhold C. *et al*, 2009, Rinaldi M., 2003, Thorne C., 1982, Wang W. *et al*, 2014).

The phenomenon of erosion of the bed and implicitly the degradation of hydrotechnical and civil constructions located in it is a complex problem of international study, and the treatment also reaches the governmental level (US Army, 1993, Government of India, 2012).

Recent climate changes have modified a number of natural and anthropogenic risk factors that intervene in the functioning of coastal defences (Luca M. *et al*, 2012). This situation has also determined a change in the concepts of creating bank defences on rivers in contact with human communities or economic objectives (Avram, 2020, Luca M and Luca Al. L., 2012).

The study of the phenomenon of hydrodynamic erosion of shore defences is carried out by direct methods (topographical measurements in the field) and by simulating the phenomena of erosion - sedimentation using physical and numerical models. Among the frequently used hydraulic-mathematical models can be listed: Maik 21, Hec-Ras, Mohid and others

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(Avram M., 2020, Bohorqueza P., Anceyb C., 2015, Creţu Gh., Badaluţă C., 2006). Most of the simulation models have a disadvantage due to the relativity of the data and the presentation of a single erosion depth on the simulated river section. The research carried out in this field shows the importance of the phenomenon in various economic, social and environmental protection fields.

MATERIAL AND METHOD

The researches were carried out on the lower course of the Moldova River (*figure 1*), in a large area near the town of Soci, Miroslovesti commune, Iaşi county. The Moldova River is part of the hydrographic basin of the Siret River. The BH surface of the Moldova River is 4326 km^2, and the length is 205 km. The longitudinal profile of the river is balanced and has an average slope of 1% (Atlas of Water Cadastre in Romania).

The foundation of the river is made up of weakly cohesive rocks, a fact that favours bed erosion on the watered perimeter (Luca M., 2006, Luca M., 2012, Luca M. *et al*, 2019). The river bed in the research area consists of alternating layers of ballast, dusty sand and clayey sand (Luca M., 2006).

Figure 1 **Geo-physical characteristics in the research area of the Moldova River (The geographical Atlas of Romania, 1985)**

The research was carried out on a regularized river section with a length of 380 m and equipped with a bank defence made of geo-bags. The bed in the research area presents two arms separated by an island (*figure 2*). The arrangement of the river section was imposed by the presence of three pipes with large diameters (800 – 1000 mm), which cross the river bed transversely.

The research methodology was differentiated by fields of study: hydrological, hydraulic, technological, resistance and stability of coastal defence works, analysis of structural and functional states of constructions. The hydrological data (average and maximum flows) are determined in the research site and correlated with those taken from the Pildești Hydrometric Station on the Moldova River located downstream of the research area.

Figure 2 **General downstream view of the Moldova River bed with the two arms and the separation island (Luca M., 2006)**

The structural state of the coastal defence was analyzed from its commissioning (year 2015) until 2023, by performing systematic analyzes at time intervals and after floods. The researched coastal defence was divided into study sectors with lengths of 50 - 60 m.

On each analysis sector, data were taken on the state of the defence work regarding the following: type of degradations, number of degradations, geometric characteristics of the degradations, the evolution of the degradations over time, the influence on the stability of the work, the possibility of remediation.

The technical data were supplemented with photo reliefs by sector and type of degradation. All technical data were stored in "databases" and processed on the study areas.

RESULTS AND DISCUSSIONS

In the research area on the Moldova River, a hydrotechnical construction is located with the function of undercutting three intake pipes for the transport of drinking water. The pipelines are part of the Regional Water Supply System of Iasi County. The first pipe has a diameter of 800 mm and the next two 1000 mm. The last two pipelines were executed in the years 1969 – 1971, when the river bed was regularized and a shore defence with concrete slabs was created (Luca M., 2012). The shore defence protected the shore in good condition until 2004 (*figure 3*).

Between 2005 and 2012, a series of high-flow floods occurred on the Moldova River (Romanescu G., Stoleru C., 2008; Luca M., 2012), which partially degraded the hydrotechnical construction of the undercrossing (Luca M., 2006; Luca M., 2012). At the same time, the hydrodynamic erosion determined the lowering of the bottom of the bed and the total uncovering of the first adduction pipe and partially of the second pipe. Degradation of the stability of the first supply pipe led to its total failure.

Figure 3 **The structural state of the left bank defence on the Moldova River in 2005 (Luca M., 2006)**

The phenomenon of hydrodynamic erosion, intensified by a series of natural factors (the high frequency of floods with high flows in the last 50 years), but also anthropogenic ones (limitation of maintenance works, intensive exploitation of ballast at the upstream limit of the sub-crossing area), determined the partial degradation (*figure 4*) and then the total degradation of the shore defence in the period 2005 - 2012 (*figure 5*).

Figure 4 **The structural state of the shore defence made of concrete slabs in 2008 (Luca M., 2012)**

The technical expertise carried out in 2012 highlighted the state of degradation of the undercrossing construction, as well as the shore defence and indicated its rehabilitation (Luca M., 2012). The rehabilitation project was carried out in 2012 and applied in 2015 (Luca M., Luca Al. L., 2012).

Taking into account the extremely aggressive action of the phenomenon of hydrodynamic erosion, the foundation of the bed consisting of weakly cohesive rocks and the location of the undercrossing in a natural site, a shore protection made of elastic constructive elements was designed, which is adaptable to the conditions of the site. In this case, the shore defence was designed from elastic structures like geo-bags over a length of 520 m.

Figure 5 **The total degradation of the defences on the left bank of the Moldova River, year 2012 (Luca M., 2012)**

Shore defences made of geo-bags are used in many countries (Government of India, 2012), especially where local materials (ballast) can be used. Geo-bags are used to protect the banks of rivers or lakes, at the slopes of embankments (Găzdaru A. *et al*, 1999).

The analyzed geo-bags are made with bags made of polyester fabric and filled with ballast. Geo-bags have a rectangular shape with a length of 1.50 m, a width of 0.80 m and a height of 30...40 cm. Geo-bags used in coastal defence are of two types, where the differentiation is given by their position in the site:

- type I is represented by geo-bags filled with ballast, and in shore defence they occupy the position of contact with the shore;
- type II is represented by geo-bags filled with ballast and cement addition, and in the shore defence it occupies the water contact position.

The geometric dimensions of the shore defence were determined by dimensioning calculations and verification of the groupings of forces existing in the site in accordance with the norms in force (Luca, 2012, GE 027-97) (*figure 6*). The shore defence made of geo-bags adapts very well to unstable foundations and achieves favourable conditions for the aquatic ecosystem.

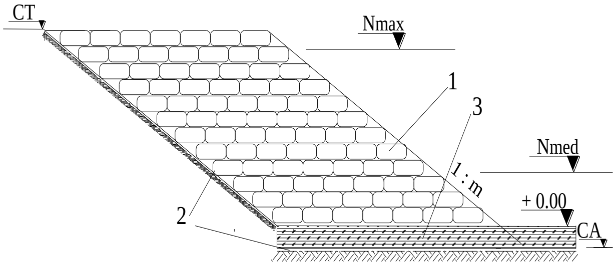

Figure 6 **The structure of shore defence with geo-bags: 1 – geo-textile bags, 2 - geogrid, 3 - fascia mattress (Luca et Luca, 2012).**

Shore defence was carried out in battlements placed in the area of each shore. The installation conditions were difficult, being determined by the presence of water originating from infiltration from outside the cofferdam. Geo-bag protection on the Moldova River was carried out in 2015 by using ballast as a filling material. The ballast was taken from the location area (*figure 7*).

Figure 7 **Execution stage of the shore defense with geo-bags on the Moldova river (photo Luca M., 2015)**

Starting in 2016, a systematic monitoring of the behaviour of the shore defence made of geo-bags was carried out, immediately after its entry into operation. The monitoring was carried out in several research directions. A direction of research was the behaviour of the coastal defence structure to hydrodynamic action. Data on the behaviour of these structures to the multiple actions of water are relatively scarce in the specialized literature.

The analysis carried out in the field between 2016 and 2023 and the data processing indicated the following results:

- the shore defence behaved differently along the length and height of the shore, generally during the seven years of operation; no important structural degradation generated by the water and especially the flood of 2016 can be highlighted (*figure 8*);

Figure 8 **General view of the left bank defense after the 2016 flood (photo author, 2016)**

Figure 9 **General view of the left bank defence after the 2018 flood (photo Luca M., 2015)**

- a series of geo-bags placed in contact with water showed degradation in the form of tearing of the material; the tears are in the direction of flow and have lengths of 4-10 cm with widths of 2-5 cm through which part of the material was expelled (*figure 10*); the number and size of material breaks is greater for geo-bags located towards the base of the shore defence; the number of material breaks is random on the research sectors, being influenced by the quality of the material filling the geo-bags, as a result of the absence or decrease of the amount of cement;

Figure 10 **Degradation of geo-bags through cracks and tearing of material 2018 (photo author, 2020)**

- the flood of 2018 caused significant damage to a series of geo-bags placed in contact with the water, by tearing the fabric in small lengths, but with an intense process of expelling the material from the inside (*figure 11*); the Moldova River transports coarse alluvium by creeping during floods, a situation that produces such degradations:

The hydrodynamic erosion of the water, as well as the action of the floaters, manifested itself extremely aggressively through the floods that spread on the Moldova River in 2016 (Q_{max} = 444 m^3/s) and 2018 ($Q_{max} \approx 1200$ m^3/s).

The analysis carried out in the field after the transit of the floods did not highlight the movement of geo-bags on the vertical and horizontal shore defence.

Figure 11 **Degradation of geo-bags in contact with water in the flood of 2018 (photo author, 2018)**

The shore defence made of geo-bags has been degraded at the top by anthropogenic actions. Some activities such as fishing (*figure 11*) and grazing by herds of sheep and goats have contributed to the degradation by tearing and breaking of the geo-bags (*figure 12, figure 13*).

Figure 12 **Degradation of the geo-bags located at the top of the coastal defence by anthropogenic actions (photo author, 2022)**

A good performance presents the shore defense from geo-bags to ensure the environmental requirements demanded by the aquatic and riparian environment. The mounting structure of geo-bags allows the deposition of alluvial material following floods or level variations, an aspect that favors the growth of aquatic and riparian vegetation (*figure 14*).

Figure 13 **Degradation of the geo-bags located at the top of the coastal defence by the movement of sheep flocks (photo author, 2020)**

Figure 14 **Coastal defence area with the presence of vegetation and alluvium deposits (photo author, 2019)**

The elastic shore protection modifies the hydraulic regime in the flow section through the presence of macro-roughnesses determined by the shape and method of mounting the geo-bags. The geo-bags bank protection compared to the one with concrete slabs has the following particularities: a dappled wetted perimeter, a much greater roughness and an accentuated fragmentation of the current in the bank area. All this leads to a decrease in the velocity and implicitly in the tangential effort at the wall, so that the hydrodynamic erosion force is substantially reduced (Luca M. *et al*, 2012).

The research carried out in the field highlights the need to apply annual maintenance works to restore the integrity of geo-bags degraded by natural and human action. Also, after the passage of a high-flow flood, a check of the structural condition must be carried out to highlight degradations.

CONCLUSIONS

The research carried out on the bank defence carried out on the Moldova river highlighted a differentiated behaviour of geo-bags in the hydrodynamic action depending on the location (river bed / bank), their arrangement in the horizontal plane and the structure of the filling (ballast with / without addition of cement).

Geo-bags located below the average water level show degradations resulting from the action of submerged materials, which produced cracks and breaks limited in size to the geo-textile material.

Geo-bags located in the area of water level variation show degradations in the form of longitudinal breaks limited to the length of the fabric, where the filling material was partially washed away, a situation that determined the change in the geometric shape.

Geo-bags located in the area of high levels are degraded the most by human actions in the riparian zone, but also by the movement of animals.

Compliance with the filling recipes and the way of placement in the shore defence structure are basic conditions in ensuring the resistance over time of geo-bags.

The elastic shore protection works made of geo-bags are modelled very well in the erodible riverbeds, effectively taking over the subsidence and displacements in a three-dimensional plane and contribute to the protection of the aquatic environment.

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