

RESEARCHES ON BEHAVIOUR OF REGULATION WORKS LOCATED IN MORPHOLOGICALLY UNSTABLE RIVER BEDS

Paul Vivian Sion¹, Mihail Luca², Ilie Logigan³, Mihaela Avram¹

Keywords: bottom sill, geo-bags, geotextile, hydrodynamic erosion

Abstract. The paper deals with the behaviour of geotextile regulation works on the dynamic action of floods in erodable river beds. Geotextiles have become an important component in the structure of river bed regulation and shore protection works. The dynamic action of floods, through liquid and solid flows, influences the stability and the resistance in time of geotextile constructions. The studies and researches were carried out on a sector of Moldova River between Soci and Pildești localities, on the territory of Iași and Neamț counties. The researchers analysed the behaviour of geo-bagss made of polyester bags filled with local materials (generally sand and gravel) used for bottom sills, routing dikes and shore protection elements. The research results indicate a differentiated behaviour of geo-bagss according to their location (in water or on shore) and water action (dynamic or static). Water dynamic action has caused significant degradation of geo-bagss from bottom sills and routing dikes structures located in the river bed. Geo-bagss have low resistance to the alluvial material action (stone, trees) transported in the river bed during floods. The research highlighted the proper behaviour of geo-bagss during the river bed erosion phenomenon, when they moved and ensured the continuity of the bottom sills and their performance.

Introduction

River regulation works are part of the watercourses in ensuring the stability of hydrological and hydraulic parameters in a well-defined sector. The design of regulation and shore protection works in the river bed is done with hydrological parameters (flows, levels, protection levels, protected areas etc.) obtained through statistical processing of data collected over long time periods. Climatic changes produced over the last 30 years on Romanian territory have substantially altered a number of hydrological data, a situation requiring the re-evaluation of some design regulatory documents. The European tendency to naturalise river beds with large

¹ PhD stud. "Gheorghe Asachi" Technical University of Iasi, Romania, Doctoral School

² Ph.D.eng. Professor, „Gh. Asachi” Technical University of Iasi, mluca2004@yahoo.com (corresponding author)

³ Ph.D.eng. Lecturer, „Gh. Asachi” Technical University of Iasi

volumes of rigid regulation works and with negative environmental influences has led to changes in design concepts.

Climate change has influenced the way rainfall is distributed over a river basin. This change creates hydrological risk phenomena in the river basin and watercourses. The risk phenomenon influences the behaviour of shore protection and regulation works (Luca et al., 2018).

The naturalisation works of river beds have required the use of elastic structures, especially in river beds located in low cohesive rocks, made of plastics and biodegradable materials. Materials such as geotextiles have found applications in the structure of shore protection and river flow regulation works (Luca et al., 2016).

The purpose of the paper is to present the results of studies and researches on the behaviour of shore protection works which include geotextile and biodegradable materials, with applications on Moldova area rivers.

1. Study area and research method

The studies and researches took place on watercourses from Moldova area, which, in some sectors, have a river bed made of low cohesive rocks. Moldova River is included in this category, on its lower course. A series of researches have also been carried out on Siret River. In the first stage, river sectors with regulation and shore protection works were researched. The identified research sectors are located on Moldova River lower course, as follows:

- sector 1 is located around Soci locality, Miroslovești commune, Iași County;
- sector 2 is located downstream of Pildești locality, Neamț County.

The theoretical and experimental research was carried out on the following directions:

1. Research of constructive parameters of shore protection and regulation works on the study sectors.
2. Investigation of their behaviour in time during water action at medium and flood flows.
3. Studies and researches regarding the use of new solutions for shore regulation and protection works through modern materials adaptable to river beds with continuous morphological transformations.
4. Research on the behaviour of new structure types made with modern materials and technologies.

Moldova River has in the research area a route characteristic of the lower course, located in a low-slope area. The river flow direction is NW - SE. Moldova River has the following characteristics up to Tupilați hydrometric station (HS): length - 176.60 km, hydrographic basin surface - 3951 km², slope - 1.30‰,

medium altitude - 236 m, multi-annual average flow - $32.9 \text{ m}^3/\text{s}$, suspended solids flow - 43.2 Kg/s (Atlasul Apelor, 1992, Ujvari, 1971).

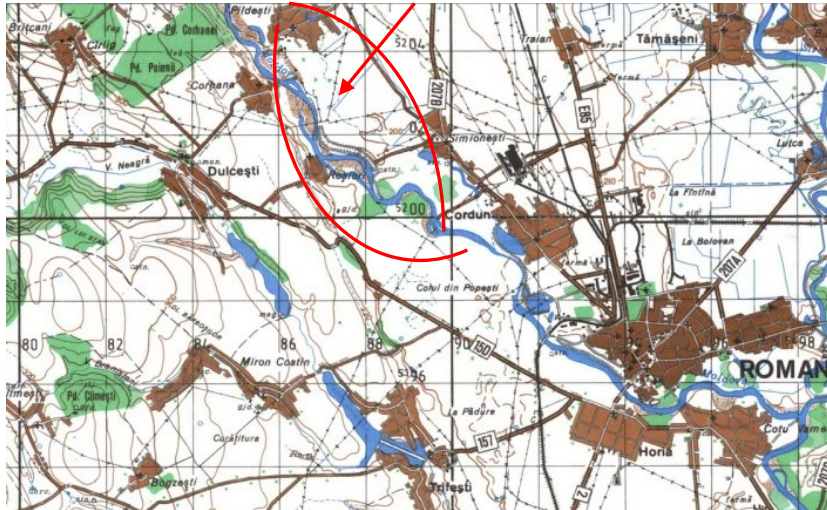


Figure 1: The location of research Sector II on the lower course of Moldova River

Hydrological data (average and maximum flows) taken from Tupilați Hydrometric Station, Neamț County, were used in the research.

The analysis of the structural and functional state of the existing field works was carried out through direct inspection, topographical measurements, degradation forms visualisation, geometric parameters measurement, photo and video recordings etc. Data taken from the field were compared to those in technical design documentation, or similar work done internally and externally.

In the study area located on Moldova River there are a number of gravel extractions, especially on the left bank, with an important yearly gravel production.

Data collected through documentation and field research have been processed using the statistical, hydrological, hydraulic, strength computation software suited for the case studies.

2. Results and discussion

The studies and researches were carried out on Moldova River sectors located on the lower course where flow regulation and shore protection works are located. The Moldova River bed in all three research sectors has the characteristic of a foundation made of low cohesive rocks (Luca, 2012).

The Moldova River characteristics analysis in the study area allows the highlight of the following data:

- the site area is specific to a river bed developed in a plane, with a NV-SV direction, where the minor river bed has a continuous tendency of meander formation following floods;
- the river bed width is variable depending on the presence of regulation works; the river bed width is relatively large compared to the depth; the width is 45 - 80 m in small waters and 300 - 1000 m at flood flows, except for calibrated river beds through regulation works;
- water depth ranges from 0.80 - 1.20 m at multiannual average flows (about 32.9 m³/s at Tupilați HS) up to 4.00 - 5.50 m at flood flows ($Q_{\max} = 800 - 1200 \text{ m}^3/\text{s}$);
- the solid flows transported have high values, being favoured by the large number of gravel extraction areas, and sand, gravel and boulders are the major part of these flows where a biological component (forestry) also appears;
- the river bed has alluvial deposits (alluvial and islands banks) that influence vertical erosion phenomena and especially shores (an active phenomenon in Soci area).

Significant morphological changes of the minor river bed and regulation structures were produced by flood flows over the last 30 years. From the analysis of the monthly average flow parameters on the three Moldova River research sectors, it results that the highest values are recorded in June - July (main peak) and less in the spring or autumn (Luca et al., 2012).

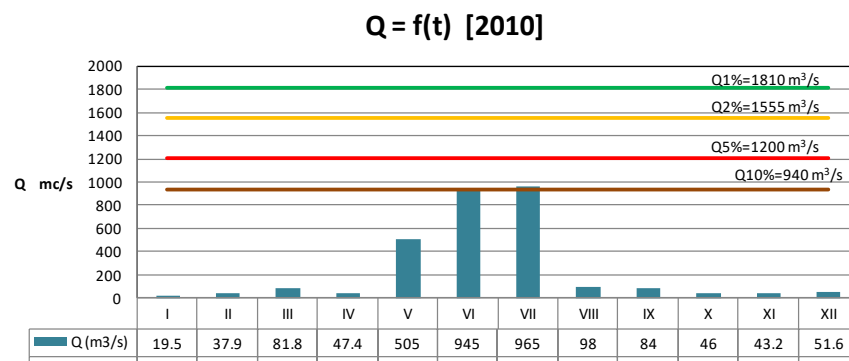


Figure 2: The monthly flow variations graph in 2010 on Moldova River at HS Tupilați

Maximum flows are the result of the spring-summer torrential rain distribution, especially in the May-July period, which is generally specific to Siret basin. A contribution to the maximum flow rate is given by the lower field

vegetation coverage upstream of the research area. Maximum flows were recorded in 1991, 2002, 2005 and 2008, 2010, 2016, which caused floods and major degradation to shore protection and regulation works.

Moldova River was crossed by a flood with $Q_{\max} = 1154 \text{ m}^3/\text{s}$ in 2005, and in 2010 two floods: first during summer with $Q_{\max} = 660 \text{ m}^3/\text{s}$; second in autumn with $Q_{\max} = 965 \text{ m}^3/\text{s}$. The maximum flow rate of $1402 \text{ m}^3/\text{s}$ was recorded in 1991. The minimum historical flow was recorded in 1987 ($0.85 \text{ m}^3/\text{s}$).

Case Study I - Behaviour of shore protection and regulation works on "Moldova River, Soci area" sector. Studies and fieldwork have shown the following results:

A. Characteristics of the river sector. River bed calibrated on a length of about 425 m and equipped with shore protection over a length of 500 m. In the study area the river has two arms with a length of 380-400 m, which are separated by an island. The left arm is more developed in cross section and carries about 70% of total flow (Luca, 2012, Luca et al., 2018).

B. Objectives located on the study sector: on this sector the undercrossing of Timișești – Iași water supply pipes are located. On a river length of about 80 m there are three pipes (two 1.00 m in diameter and one 0.80 m in diameter).

C. Regulation works present on the study sector:

- The river undercrossing by the water supply pipes and its safety in operation has required the river bed regulation (a meander cutting, the presence of two arms, flow sections calibration) and shore protection works on the left and right bank. The works were carried out between 1969 and 1971.

- The shore protection works were carried out in four constructive solutions (A1, A2, A3, A4) and contain a plain concrete slab measuring $50 \times 50 \times 10 \text{ cm}$, supported on a concrete beam, a stone prism as a foundation, and a fascine mattress in contact with the bedrock (Fig. 3) (Luca, 2012).

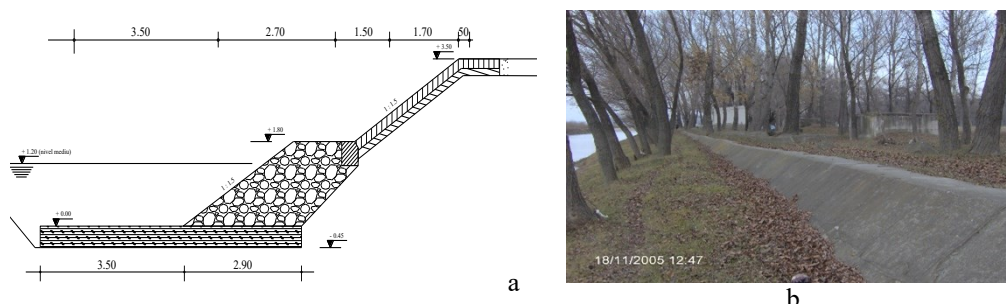


Figure 3: The Moldova River left shore protection: a - building scheme; b - view of shore protection in 2005 with emphasis on the silting area (Luca, 2012).

D. The behaviour of regulation works to destructive water action: shore protection works were executed in 1969 ... 1973, and their structural condition was degraded especially during 2004 - 2012. The main degradation factors were:

- Natural factors: Frequent and high flow floods showed the most intense river bed erosion action. Solid (mineral and biological) transport has contributed to the degradation of the structures.

- Anthropic factors: The upstream gravel extractions and at the limit of the water supply pipe location area contributed significantly to the solid transport intensification and implicitly to the hydrodynamic erosion phenomenon increase. The absence of maintenance and rehabilitation works of shore protections has helped accelerate the degradation phenomena up to their total destruction.

E. Stages of regulation works degradation:

- thalweg and shore erosion at high flow and speed variations, action favoured by the geotechnical structure of the river bed (alternating ballast layers, sand, loamy sand);

- the erosion and removal of the rock under the shore protection foundation, a situation which led to the displacement of the large stone prism and the washing of the material during floods;

- under pressures behind the concrete slabs, with the washing of the support layer, joints degradation, situations that caused cracks and fragmentation of the slabs with their expulsion from the embankment;

- the stone prism removal has resulted in the breaking of the concrete beams supporting the tiles; this situation led to the collapse of tiles and the direct water action on the shore (Fig. 4);



Figure 4: Degradation stages of Moldova River left shore protection: a - stone prism displacement, concrete slabs support beam breaking; b – slabs slipping on the embankment (2008).

- the shore protection was degraded in proportion of 5-10% in 2004, and in 2012 it reached 80%;
- the left bank shore protection was totally degraded in 2015 on a length of about 200 m, in which case the water was acting on the shore;
- the river bed erosion phenomenon uncovered the water supply pipes and led to their deterioration during 2010-2015.

F. Methods, technologies and materials for restoring the river bed stability and for securing the protected objectives:

- a series of technical expertise were carried out on the studied river sector, which highlighted the intense river bed erosion at the action of natural and anthropic factors; the research has indicated unsatisfactory behaviour of rigid shore protection structures to frequent water action in a river bed made of low cohesive rocks;
- designing and carrying out regulation and shore protection works to respond to site actions and conditions; among these are mentioned (Luca et al., 2016):
 - a - increasing the burial depth of water supply pipes in Moldova River bed;
 - b - building water routing (beak) and longitudinal slope stabilising structures (bottom sill);
 - c - building a shore protection made of geo-bags filled with ballast (geo-bags in contact with water have a cement supplement) placed on a fascine mattress and a geotextile fabric (Fig. 5) (Luca, 2012);
- restoration works for regulation structures were completed in 2015.

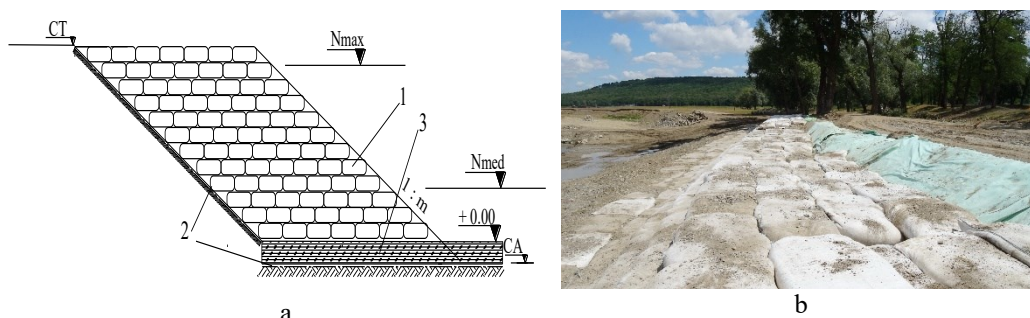


Figure 5: Embankment protection with geo-bags: a - building scheme, 1 - geo-bags, 2 - geotextile, 3 - fascine mattress; b - execution stage of shore protection with geo-bags (year 2015).

Case study II - Behaviour of regulation and shore protection works on „Moldova River, Pildești area” sector. Studies and fieldwork have shown the following results:

A. River sector characteristics. Moldova River natural bed is modelled to fulfil the function of ensuring the level and flow for Roman City water catchment. The natural Moldova River bed has a variable width of 350 - 400 m, with

numerous morphological changes in the cross section and longitudinal plane. The meandering tendency is strong, and on the research sector is on the right bank. In order to keep the minor river bed near the right bank where the water catchment structure is located, regulation and shore protection works were designed and executed. The depth of water varies between 1.45 and 1.85 m, with higher values after the bottom sill, at average flow rates.

B. Objectives located on the study sector: 66 wells drilled at depths of 7.50 – 14.0 m and seven reinforced concrete cofferdams are located in the riparian area of the left river bank. Total catchment average flow is 438 l/s (Aquaproiect, 2016).

C. Regulation works present on the study field: Regulation works on the catchment sector have been carried out since 1996. Their execution continued with interruptions during 2000 - 2006. The initial works are made of (Aquaproiect, 2016):

- regulation works: minor river bed near the left bank profiling, flow section calibration, flow routing through a dike, bottom sills 200 m apart etc.; the routing dike was made of large stone laid on fascine mattresses;

- shore protection works: reinforced concrete slabs located on the left embankment profiled with 1:1.5 slope; the tiles rest on a simple concrete beam.

Part of the river bed regulation works degraded during 1996 - 2006. After 2006, river bed structures and shore protections were rehabilitated using geo-bags (geotextile bags filled with local material, mainly ballast) placed on a fascine mattress. The 2016 flood partially and totally degraded a number of structures, especially regulation works. For the rehabilitation and completion these works (year 2017, routing dike, enclosure dike, bottom sill, shore protection), only geo-bags were used (Aquaproiect, 2016).

D. The behaviour of regulation works on the destructive water action: the regulation and shore protection works were executed sequentially in 1994 - 2017. Their structural condition was particularly degraded during 1997 - 2016. The main degradation factors were:

- Natural Factors: Frequent and high flow floods and solid material transport (stone and forest material).

- Anthropogenic factors: The upstream and downstream gravel extractions and the ones at the catchment structure edge, which has contributed to the solid transport intensification and the hydrodynamic river bed balance change. The absence of maintenance and rehabilitation works of the river bed and shore protection structures contributed to the constructions degradation phenomena acceleration.

E. Regulation works degradation stages:

- thalweg and shore erosion at high flow and speed variations due to floods; the erosion is favoured by the geotechnical structure of the bed;

- dikes and bottom sills rocks displacement due to the action of frequent floods in recent years; the result of this action is the migration of the minor bed to

the right bank, resulting in the non-assurance of the level and flow necessary for the catchment structure;

- routing dams, bottom sills, cross beams and the shore protection executed after 2006 from geo-bags were partially degraded by the action of flood water carrying solid material; the use of ballast as filler material made the rehabilitation process faster and at a lower price;

- field research carried out during 2014 - 2019 indicated a relatively good behaviour of geo-bags at water action, as follows:

- a - geo-bags behave relatively well to medium and high waters by absorbing horizontal and vertical displacements; floaters have degraded the geo-bags structure by breaking the fabric, emptying the material, removing from site etc.;

- b - the old river bed enclosure dike and the routing dike to the new river bed are the most affected by flood transit through the direct shock reception of the water loaded with alluvial material (Figure 6);



Fig. 6. Calibrated Moldova River bed bottom sills degradation stages: a - geo-bags displacement the from the bottom sills; b - downstream view of the bottom sill (year 2018).

- c - bottom sills are stable and ensure the level required by the water catchment operation;

- d - geo-bags, an elastic construction element, introduced in the regulation and shore protection, work effectively with erodable river beds.

F. Methods, technologies and materials for restoring the river bed stability and for securing the protected objectives:

- the stability of the minor river bed must be ensured in the right shore area where the groundwater catchment is located on the river sector;

- designing and carrying out regulation and shore protection works that respond to site actions and conditions, which use local materials and have a low price, given their repeated degradation.



Fig. 7. General view of the Moldova River left bank in the groundwater catchment area a - shore protection structure (the old protection made of the slabs and the new one made of geo-bags); b - degradation state of the routing dike from the calibrated river bed right bank view (year 2018).

The hydrological regime in the Siret River basin and in the Moldova basin, in the last period of time, is characterised by the high floods frequency. The floods generated in recent years on Siret and Moldova River and its tributaries have caused significant economic damage and human loss (Romanescu and Stoleru, 2013).

The high frequency of floods on Moldova River influenced the stability of the rigid regulation and shore protection works (concrete walls). The Moldova River site geotechnical and hydrological features favour the execution of light protection works, the geo-bags case, considering the use of the existing ballast in the site area. Elastic shore protections work efficiently with erodable river beds and do not have an impact on the surrounding environment (Luca et al., 2016.). The regulation and shore protection works on low cohesive rocks river beds must be calculated taking into account the morphological changes developed in the vertical and horizontal plane, as well as their evolution over time (Luca and Stoenescu, 2007, Mitoiu and Marin, 1999).

Conclusions

The presence of low cohesive rocks in Moldova River bed foundation leads to the stability loss of the rigid regulation and shore protection works as a result of the high frequency and important alluvial transport floods.

The research carried out on the Moldova River lower course in the area of some important economic objectives indicated a severe degradation of the shore protection works following the foundation and concrete slabs hydrodynamic erosion.

Studies and research have shown the possibility of using geo-bagss materials to carry out regulation works subject to frequent floods with significant solid transport.

The research carried out over two case studies revealed a variable behaviour of the geo-bags during water action depending on their location (in the river bed or on the shore), their structure and the filling quality.

Elastic shore protection structures work efficiently with erodable river beds, behave well in vertical and horizontal compressions and displacements, and do not have an impact on the surrounding environment.

References:

1. **Ichim I., Bătucă D., Rădoane M., Duma D.**, (1989), *Morfologia și dinamica albiilor de râuri*, Editura Tehnică București.
2. **Luca M., Stoenescu, I.**, (2007). *Current Issues Concerning Regularization Works Behavior under Disaster Conditions*. International Conference „Disaster and Pollution Monitoring – IC.DPM. 3”. 1-2 nov. Iași, 93-98 pp.
3. **Luca M.**, (2012), *Expertiză tehnică privind lucrări de reabilitare în zona de subtraversare râu Moldova a conductelor de aducțiune apă Timișești, sat Soci, jud. Iași*. SC Polias-Instal Iași.
4. **Luca M., Tamașanu F., Luca Al., L., Ilie G.**, (2016). *Research on the stability of the defence works to eroded river beds*. Ovidius University Annals, Series: Civil Engineering, Issue 18, Ovidius University Press, p. 33-41.
5. **Luca M., Avram Mihaela, Luca Al.L., Chirica Ștefania**, (2018). *Studies and researches on natural and antropic risk the Moldova's lower course*. PESD Vol. 12, no. 2, “Al. I. Cuza University of Iasi”, pp. 183-193.
6. **Ministerul Mediului**, (1992). *Atlasul cadastrului apelor din România*.
7. **Mitoiu C., Marin G.** (1999), *Regularizarea albiilor de râuri*, Ed. BREN Bucuresti.
8. **Romanescu G., Stoleriu C.** (2013). *Causes and Effects of the Catastrophic Flooding on the Siret River (Romania) in July-August 2008*. Natural Hazards, 69:1351-1367. <https://doi.org/10.1007/s11069-012-0525-6>
9. **S.C. Aquaproiect S.A. București** (2016) *Refacerea amenajării râului Moldova în zona sursei de alimentare cu apă a orașului Roman (frontul Pildești-Simionești)*, jud. Neamț.
10. **Ujvari I.**, (1972). *Geografia apelor României*. Edit. Științifică, București.
11. **Vamanu E., Olariu P.**, (2002). *Riscuri hidroclimatice în Spațiul hidrografic Siret în contextul modificărilor geografice*. Culegere de lucrări, Sesiunea științifică anuală INMH București.



© 2020 by the authors. Licensee UAIC, Iasi, Romania. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY-NC-ND) license (<https://creativecommons.org/licenses/by-nc-nd/4.0>).

