RESEARCH ON THE DEGRADATION OF PIPELINES POSITIONED IN THE UNDERCROSSING OF RIVERS

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ABSTRACT: *The intensification of the phenomenon of hydrodynamic erosion of riverbeds, determined by the passage of rapid floods, affects the stability of constructions and installations positioned in the flow section. The paper presents an analysis of the behavior of the Poiana Uzului - Bacau adduction pipeline on the undercrossing section of the Tazlaul Sarat river. The June 2016 flood on the Tazlaul Sarat River, with a flow rate of 342 m3/s, morphologically changed the flow section where the 800 mm diameter cast iron adduction pipe is located in the underpass. The flood changed the route of the minor bed towards the right bank, a situation in which the adduction pipe was exposed. The suspension of the pipeline, made of cast iron tubes plugged into a length of about 30 m, introduced a risk of rupture of the adduction. The combination of natural and anthropogenic factors determined the degradation of the pipeline.*

Keywords: *adduction pipe; bed morphology; damage; flood; hydrodynamic erosion;*

1. Introduction

The climate changes of the last period of time produced changes in the hydrological regime of the hydrographic basins in eastern Romania. The main changes are represented by a new distribution of precipitation during the calendar year, but also by a concentration of water volume for short periods of time [Apostol L., 2004, Avram M., 2020]. This situation led to the occurrence of torrential rains, which determined the formation of rapid floods at short intervals in the hydrographic basin of the Siret River [Avram M., 2020, Romanescu G. and Stoleru C., 2013, Avram M. et al, 2018]. The floods determined the formation and maintenance of an erosion force, which morphologically modified the river bed in transverse plane and longitudinal profile.

Flash floods are also treated worldwide regarding their formation parameters, high frequency of occurrence and, in particular, maximum transported flows. At the same time, the disasters produced, the protection solutions adopted, as well as the simulations carried out to determine the flooded surfaces are presented [Avram M., 2020, Neuhold C. et al, 2009, Dapporto S. et al, 2003, Hooke J.M., Yorke L., 2010, Rinaldi M., 2003].

Constructions and installations located in the riverbed are strongly affected by the destructive action of floods. The erosion force determines the partial and total degradation of the bed regularization works, bank defence works, bridge piers and water intakes [Luca M., 2017].

A special case is represented by fluid transport pipelines that cross river beds. The morphological change can cause the elevation of the bed perimeter to drop, in which case the pipe sections are uncovered.

They can be partially and totally degraded, until they are taken out of service [Luca et al, 2017].

The paper presents the results of a research carried out in the undercrossing area of the Tazlaul Sarat River by the adduction pipeline that transports drinking water from Poiana Uzului [Darmanesti Treatment Plant] to the consumers on the route and finally to the city of Bacău.

2. Research material and method

The researched material consists of the pipeline section that undercuts the bed of the Tazlaul Sarat River in the Moinesti area. The pipe section is made of cast iron, has a diameter of 800 mm and is part of the drinking water supply pipe that supplies the city of Bacau, but also other localities in Bacau County. The research material also included a sector of the bed of the Tazlaul Sarat River, as well as the riparian area where the adduction pipeline is located (Fig. 1).

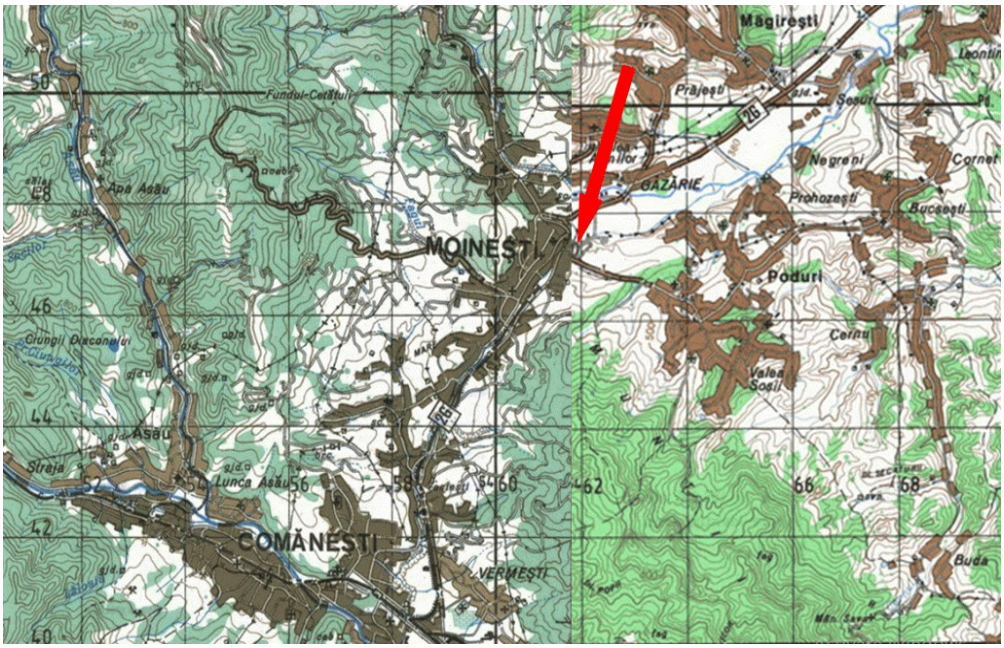

Fig. 1. Location of the research sector in the area of Moinesti city, Bacău County
(scale 1:100000, Geographical Atlas of Romania, 1985)

The Tazlaul Sarat River is a right tributary of the Tazlau River and has the cadastral code XII-69-33-10 [The Water Cadastre Atlas of Romania, 1992]. The hydrographic basin of the Tazlăul Sărat river is asymmetrical with an area of 211 km2 and an average altitude of 430 m. The length of the river is about 42 km, and the slope is 1.17%. The Tazlăul Sărat River upstream of the Hydrometric Station [HS] Lucaceati has a length of 26 km, a catchment area of 95 km2 and an average slope of 36.9‰ [Ujvari I., 1972].

The Tazlaul Sarat River receives the most tributaries from the right side. They contribute with important flows, being reduced by the outflows from the Gosman-Geamana peak. The hydrological and climatic data used in the research were taken from the Lucacesti Hydrometric Station and from the technical reports of the Siret Basin Administration [WAB Siret, 2018]. The data related to the state of degradation of the site, as well as the works to restore the bed and secure the supply pipeline, were taken from technical expertise [Luca M., 2017].

The research was carried out in several stages:

- Analysis of the natural and anthropo-genic risk factors in the location area, with the identification of those that caused the degradation of the environment surrounding the pipeline. Acquisition of topographical, hydrological, geotechnical and behaviour data of undercrossing structures.

- Analysis of the parameters of the June 2016 flood in the location of the pipeline on the Tazlaul Sarat River and their influence on the morphology of the bed and the riparian area.

- Analysis of the structural and functional state parameters of the supply pipe.

3. Results and Discussions

The natural environment and the constructions located in it are affected by a series of risk factors, which cause the appearance of destructive phenomena. Riverbeds are continuously under the influence of natural risk factors [floods, high speeds, maximum flows, erosion, sedimentation], which morphologically modify the flow section [Avram M., Luca M., 2017, Ichim et al, 1989]. The bed of the Tazlaul Sarat River on the research sector is an edifying example due to its morphological state in continuous change. The weakly cohesive rock foundation allowed the development of a wide bed, in which the actual minor bed has a meandering route and is easily modified by floods [Luca M., 2017, Luca M., Avram M., 2017].

Also, anthropogenic risk factors contribute to

the degradation of the riverbed and affect the operational safety of the constructions located in it. Among the anthropogenic risk factors present on the research section were identified: the absence of riverbed regularization works, the degradation of bank protection works, the non-application of minor riverbed maintenance works and others [Avram M., Luca M., 2017]. An extremely destructive anthropogenic risk of riverbeds is the inadequate extraction of ballast [Luca M., 2017].

The summer months [June in particular] are characterized in the hydrographic basin of the Trotus River by an abundant rainfall regime, a situation in which the conditions are created for the formation of high-risk floods [Avram M., 2020, Manolache A.V., 2018, Avram M ., Luca M., 2017]. Tazlaul Sarat River is characterized by the presence of floods with high flows, considering the position of its hydrographic basin in the piedmont area heavily fed with torrential rains [Luca M., Avram M., 2017, Tarnovan A., et al, 2021]. Annual amounts of precipitation increase with altitude, from 682 l/m2 in Moinesti, up to 1039 l/m^2 in Bolatau in Zemes Commune [Apostol L., 2004, Avram M., Luca M., 2017]. Consequently, torrential rains occur in the months of May and June, which cause the formation of flood waves on the Tazlaul Sarat River.

At the beginning of June of 2016, a torrential rain occurred in 12 hours that accumulated 61.10 l/m^2. The volume of precipitation increased in 24 hours to 80.20 l/m2. The rain continued for two more days, in which case the total volume was 85.90 l/m2 [Table 1]. A large part of the rains in the Tazlaul Sarat River basin have a torrential character in the last 40 years, especially in the warm season. This aspect is reflected in the water runoff regime on the slopes and in torrential water courses, streams and implicitly in the bed of the Tazlăul Sărat River. Also, floods have a high frequency and present important maximum flows, with calculation probabilities higher than those used in the design of the regularization works of the riverbeds.

Torrential precipitation from June 2-3, 2016 generated a flood wave that destructively affected the middle and lower course of the Tazlaul Sarat River. The flood on the Tazlaul Sarat River started on 02.06.2016, at 10:00 a.m., with a height of 69 cm and a flow rate of 6.70 m3/s, values measured at S.H. Lucacesti. The peak of the flood was recorded at S. H. Lucacesti on 06/02/2016 at 16:30, where the maximum height was 360 cm, and the maximum flow reached 342 m3/s [Table 2]. The flow increased about 50 times in a time interval of about six hours. The probability of exceeding the maximum flow rate was 3% in the control section [Fig. 2]. The flood spread of 2.73 m exceeded the banks on some of the middle and lower reaches of the Tazlaul Sarat River [Luca M., Avram M., 2017, WAB Siret, 2016].

Table 1. Precipitation (P) measured at H.S. Lucaceşti in June 2016
[W.A.B. Siret, 2016]

Day	02.06	02.06	03.06	03.06	03.06	03.06	04.06	Total
Time slot	06.00-18.00	18.00-24.00	24.00-06.00	06.00-12.00	12.00-18.00	18.00-24.00	24.00-6.00	
P (*l*/m^2)	61.10	-	19.10	3.00	0.60	-	2,10	85,90

The Tazlaul Sarat River has a peculiarity due to the presence of a large number of tributaries on the right side [torrents, streams] and which are fed from the drains on the slopes. From here an abundant supply of the river is obtained even from the upper course. The flood of June 2016 produced flooding of the riparian area with significant damage to the natural, economic and social environment along a large length of the middle and lower reaches of the Tazlaul Sarat River. For example, on the section of the river that crosses the localities of Zemes commune, significant degradation of the bed and the riparian zone occurred [Luca M., and Avram M., 2017, WAB Siret, 2016]. The bank defences were completely degraded, and a series of pipelines located in the bank [longitudinal to the river bed] were uncovered and partially degraded. Also, the destruction of the coastal defence caused the partial erosion of the roads in the riparian area, as well as the **bridges**.

The maximum flow of the flood produced important changes in the morphology of the bed of the Tazlaul Sarat river on the section located to the east of the city of Moinesti and on the border withthe outskirts of the Commune of Poduri,

Table 2. Parameters of the flood on the Tazlaul Sarat River from 02.06-04.06.2016 at S.H. Lucacesti (W.B.A. Siret, 2016)

H_{max} (cm)	Q_m (m^3/s)	p (%)	$Q_{max\ 1\%}$ (m^3/s)	$Q_{max\ 2\%}$ (m^3/s)	$Q_{max\ 5\%}$ (m^3/s)	$Q_{max\ 10\%}$ (m^3/s)	P. tot l/m^2	Obs.
360	342	≈ 3	545	425	290	200	85,9	+ 60 cm CP
Q_m – measured flow; p – probability of occurrence; CP – danger rating.								

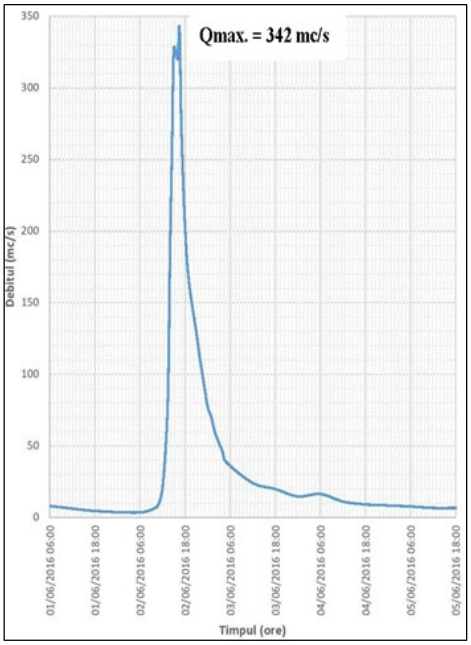

Fig. 2. The flood hydrograph recorded at the Lucacesti HS (W.B.A. Siret, 2016)

Fig 3. The reprofiled bed of the Tazlaul Sarat River in the research area (Luca M., 2017)

Bacau County [Fig. 3]. The river bed moved horizontally and created new flow paths. One of the routes moved towards the right bank, which it eroded over a length of about 300 m [W.B.A. Siret, 2016]. In the eroded area there is a supply pipe that transports drinking water. This pipeline supplies a number of localities in Bacău county and mainly the city of Bacau. From the data presented by W.B.A., Siret [2016] identified 350 m of eroded bank in the pipeline location area [Fig. 4].

Pipelines for the transport of fluids used to cross riverbeds can be positioned transversely to the axis of the current, or obliquely at a certain angle. Depending on the material from which the pipes with large diameters are made, undercrossing can be done in some situations as follows:

- the steel pipes undercross the river bed by means of a down-siphon type installation, with massive anchorages on both banks;

- pipes with large diameters made of plugged tubes [cast iron, reinforced concrete, composites with epoxy resins and others] undercrossing the river bed through a long linear pipe that descends and rises progressively below the bottom of the bed at the installation level; the degree of curvature is dictated by the angle that the socket joint allows.

The undercrossing construction is structured on two major components [Luca et al, 2017]:

- the undercrossing installation that contains the customized pipe section for crossing the bed, the anchorages and massifs on the two banks and equipment for monitoring the water flow parameters;

- the construction of shore defences for protection against water erosion of the underpass facility; the bank defence is made from a constructive structure adapted to the geotechnical conditions of the site and to the forecast of the erosion depths of the river bed.

Fig. 4. The state of the bed of the Tazlaul Sarat River in the research area after the flood:
1 – old bed; 2 – new bed created during the flood; 3 – the undercrossing area;
4 –adduction pipe (Google earth image 2017)

The objective considered in the research is a section of the adduction pipeline that transports drinking water from the Darmanesti Treatment Station to the city of Bacau. The pipeline is 64 km long and is made of PREMO [pre-compressed reinforced concrete] tubes with a diameter of 1000 mm. The section in the undercrossing of the Tazlaul Sarat River is made of pressure cast iron tubes with an internal diameter of 800 mm. The installation of the undercrossing pipe is according to the second variant presented previously. The analysis carried out in the field did not reveal the presence of an anchoring massif in the eroded shore, as well as protective constructions against the hydrodynamic action of water [protection elements, fixing constructions, support constructions (Fig. 5) [Luca M, 2017]. It is possible that some of these components were made, but over time they were completely abandoned.

The adduction pipeline from Poiana Uzului to the city of Bacau has a rich history of damage during operation. The absence of adequate protection measures, some unforeseen since the design, as well as an exploitation management with some less in-depth problems, determined the occurrence of multiple failures over time. Many damages are represented by failures of the material from which the pipe is made due to the action of the transient flow of water. Also, a series of actions of the embedding environment [settlement and subsidence in the supporting soil layer] caused deflations, cracks at the joints and implicitly water losses.

Much of the damage is in areas of the site that can be checked, controlled and repaired in the

Fig. 5. The state of degradation of the adduction pipe site in the area of the bank right of the Tazlaul Sarat River from the outskirts of the Moinesti city (Luca M., 2017)

short term. Damage in the undercrossing area is more difficult to control and requires special equipment. In the last period of time, the adduction pipeline had a series of rehabilitation and modernization works to limit the number of damages.

The failure of pipes made of plugged tubes and positioned in the undercrossing of water courses involves a series of difficult operational problems. If the bed in which the pipeline is located is formed in a poorly cohesive sedimentary rock, the negative problems that must be monitored for a normal operation of the undercrossing structure are amplified [Luca M. et al, 2017]. In the investigated case, a series of natural and anthropogenic risk factors acted together, which determined the degradation of the underpass construction?

The erosion effort given by the water speed is exerted on the perimeter surface of the bed. Its maximum value is recorded in the zone of maximum depths, respectively at the bottom of the bed. In general, at the waterline where the water height is higher, the maximum erosion depths occur and develop. In the case of under-crossing pipes, their uncovering begins in the zone of maximum depths. In the investigated case on the Tazlaul Sarat River, the exposure of the adduction pipe took place near the bank, continued in the bank and in the riparian area [Fig. 6].

The research carried out in the field revealed the extent of the erosion of the right bank in the area where the adduction pipeline is located. The erosion of the bank advanced in the riparian zone and caused the pipeline to be uncovered and subsequently suspended by washing away the rock support layer [Fig. 5 and Fig. 6.a].

The result of the erosion of the bank led to the suspension of the adduction pipeline for a length of about 15-20 m. The erosion of the right bank was accelerated, in particular, by the movement of the bed towards the right bank, a situation in which a new flow arm was created. The loss of bank stability was favoured by flood parameters [high velocity, high water height] and geotechnical characteristics of the bed [alluvial ballast layers, dusty sands and gravel intercalations]. The right bank reached heights of 3.50 – 4.50 m compared to the bottom of the new bed (Fig. 6). The erosion continued under the lower generator of the adduction pipe, right in the joint area represented by a plug, a situation that can generate an accident (Fig. 6.b).

The advance of the bed into the bank was also determined by the curvature of the new arm created by the flood, where the concave part was positioned in the undercrossing entry area of the adduction pipe. The infiltration of water along the pipeline placed in the bank favoured the expansion of the phenomenon of erosion in the riparian zone.

Fig. 6. Bank erosion on the Tazlaul Sarat River in June 2016, with the advance on the bank and the suspension of the adduction pipeline in the Moinesti area: a – downstream view; b – upstream view (Luca, 2017)

The importance of the adduction pipeline in the regional water supply system of Bacau County required the immediate taking of measures to ensure the stability of the pipeline and its safe operation. For this, a series of works were designed and executed to bring the riverbed back on a route that would protect the undercrossing area of the adduction pipeline.

In the period 2016 - 2017, rehabilitation works were carried out on the construction of the undercrossing of the river for the adduction pipeline. The work carried out focused on fixing the pipeline to the shore by means of a structure made up of mattresses and gabion boxes filled with river stone [Fig. 7].

of gabions filled with river rock.

The gabion structure advances in the river bed in the form of an unsinkable dike to direct the water current towards the axis of the original bed (Fig. 8).

The main riverbed was restoration, shaped and sized to accommodate the flood flows. The new bed is 300 m long and is at a safe distance from the protected bank where the adduction pipe is located. From the analysis of the Google Earth image taken in 2016, the movement of the riverbed towards the right bank is highlighted. The image taken in 2023 shows the protection works of the right bank in the area where the adduction pipeline is located. Also, the stability of

Fig. 7. Protection works on the adduction pipeline located in the shore area of the Tazlaul Sarat river: a – fixing the pipeline to the shore with gabions filled with stone (1 – the location conditions of the pipeline); b – fixing the pipeline in the river bed in the shore area (Luca, 2017)

Work was also carried out to fix the pipeline near the bank, where the location area was eroded, as well as in the bed [Fig. 8]. These works were made of gabion mattresses filled with stone. Considering the category of importance of the hydraulic installation located in the undercrossing and the negative conditions in the site (highly erodible river bed) (Fig. 7.a), a series of additional works had to be added to ensure the protection and stability of the adduction pipe.

The bank protection work was extended to different lengths upstream, downstream and in the bed of the pipeline site (Fig. 8). The protection work on the entrance area of the pipeline in the undercrossing was made of retaining walls made

the river bed and the way the water current is removed from the protected bank are highlighted [Fig. 8].

The research carried out highlighted a series of difficult exploitation problems that occur in the pipelines located in the sub-crossing of the river beds formed by weakly cohesive rocks. These problems are also due to climate changes in recent times.

The studies and research carried out in a hydrographic basin with frequent floods with high flows highlighted the need to improve the current legislation regarding the administrative status of the minor riverbed and the riparian zone. In certain situations, the methods of cooperation

Fig. 8. View of the location area of the works carried out in the bed of the Tazlaul Sarat River at the eastern limit of the Moinesti city: 1 – protection of the bank with the location of the pipeline; 2 – the new bed of the river (sc. 1:100000 image Google earth 2023)

between the minor river bed and the riparian zone and the constructions located in this perimeter must be defined concretely.

4. Conclusions

1. Pipelines for water transport that undercrossing the river bed formed in weakly cohesive rocks must present special foundation works and protection against the combined actions given by natural and anthropogenic factors in the location area.

2. In the period 2000 - 2018, a series of floods occurred in the Tazlaul Sarat river basin with high frequency and high flow rates, which morphologically changed the bed and degraded the regularization and bank defence works, as well as the constructions located in the riparian area.

3. The flood produced in June 2016 on the/s Tazlaul Sarat river with a flow rate of 342 m3 [probability of overflow 3%] morphologically changed the river bed in the area of Moinesti city, a situation in which it degraded the stability of the adduction pipe that supplies drinking water the city of Bacau.

4. The phenomenon of degradation of the pipe made of cast iron pipes Dn 800 mm plugged showed a peculiarity due to the position of the affected pipe section, namely its positioning in the shore area and with the entrance to the riverside area.

5. Degradation of the pipeline was favoured by the high-flow flood, but especially by the absence or destruction of protection works of the undercrossing construction in the shore area. The degradation of the pipeline was also favored by the absence of the bank defence works required for the undercrossing constructions.

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