

Landslide25_14

Landslide mitigation measures along the banks of Carpathian rivers

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SUMMARY

The main objective of this study is to investigate the geological structure and hydrological conditions at the investigation site, specifically the riverbank of the Bystrytsia-Nadvirnianska River, and to provide baseline geological and hydrogeological data, including engineering recommendations, for the development of a working design for riverbank stabilization and reinforcement. The main goal of the bank protection measures is to prevent adverse exogenous processes that pose risks to the local population and infrastructure.

A comprehensive set of field hydrological investigations was conducted at the investigation site, including a reconnaissance survey of the riverbed and floodplain sections of the Bystrytsia Nadvirnianska River; flow velocity measurements; depth profiling along the eroded segment of the riverbank; and sampling of river water.

The suite of fieldwork, laboratory soil analyses, and the subsequent data processing were carried out in accordance with national standards and regulations governing the proper execution of engineering and geological investigations.

This study presents a series of riverbank stabilization measures for the Bystrytsia Nadvirnianska River. The results obtained contribute to the understanding of the geological structure of the region and are recommended for use in future bank protection projects.

Introduction

Bank protection is a critical process involving a set of measures aimed at strengthening riverbanks to prevent excessive impact and erosion caused by water flows. One of the major threats to riverbanks is flooding, which is particularly relevant in our region. The Pre-Carpathian area is classified as a zone with a high risk of heavy rainfall and potential catastrophic floods. Flood events on Carpathian rivers occur approximately 4–5 times per year. Given these conditions, riverbanks require professional and systematic reinforcement. If a bank begins to subside or erode, it can lead to adverse consequences such as slope collapse and overgrowth of the riverbank (Demchishin, 2004).

Landslides in the Nadvirna district are closely linked to riverbank erosion and require systemic mitigation strategies. Their primary causes include geological and hydrogeological conditions. Rivers such as the Prut, Bystrytsia Nadvirnianska, Strymba, and Rybnysia flow through clay-rich flysch sediments, which are highly susceptible to landslides—especially under conditions of water saturation and active river erosion. Intense rainfall and floods undermine river slopes, triggering collapses and downward soil movement. Anthropogenic factors also contribute significantly: river channel straightening, deterioration of bank protection structures, and the construction of roads and pipelines further destabilize riverbanks.

Landslides damage critical infrastructure such as roads, bridges, residential buildings, and utility networks (including gas and electricity). There is also a heightened risk of flooding caused by blocked channels and damaged dams, threatening agricultural lands and private property.

Landslides in the Nadvirna region are not isolated or random events—they result from a complex interplay of riverbank undercutting, frequent soil saturation, and human activity. They pose serious risks to public safety and infrastructure. Addressing this growing threat requires comprehensive engineering and administrative measures, including riverbank reinforcement, early monitoring systems, and regulatory land-use planning.

Method and/or Theory

Significant development of lateral erosion of the riverbanks has been observed at the study site, particularly along the right bank. Active bank erosion occurs on the concave bends of the river due to centrifugal flows, which transport clastic material away by lateral currents (Gabinet, Kulchytsky, & Matkovsky, 1976; Voitovyeh et al., 2021).

By comparing a scaled satellite image with a 1:1000 topographic map from previous years, it was established that in the absence of bank protection, over a two-year period the riverbank line shifted by 44 meters towards civil structures due to lateral river erosion.

The rate of bank erosion caused by lateral erosion was 22 meters per year (Goptarova et al., 2024).

Results

The calculation of the riverbed scour depth for the Bystrytsia Nadvirnianska River is performed by comparing the maximum flow velocity of floodwaters with the critical (non-scour) velocity for soils susceptible to erosion (engineering-geological element No. 2) (Petrochenko & Petrochenko, 2011).

In the presence of geological constraints, the scour depth for cohesionless soils is determined using the following formula:

$$h_p = d_c (V_m / V_{np})^6, \quad (1)$$

where, $d_c = 0,086 \text{ m}$ the average diameter of soil particles (gravel with boulder content, EGE No. 2) (Fig. 1) subject to erosion at the riverbed; V_m - maximum flow velocity; V_{np} - allowable (non-scour) flow velocity.

The maximum flow velocity is derived from the formula that expresses the relationship between the maximum diameter of bedload particles and the near-bed velocity of the flood flow:

$$d_m = V_m^2 / 25 \quad (2)$$

According to field measurements, the maximum boulder size within the study section of the Bystrytsia Nadvirnianska riverbed reaches up to 0.95 m. Therefore, the corresponding maximum near-bed flow velocity is: $V_m = 4.75 \text{ m/s}$.

The allowable (non-scour) velocity for Engineering-Geological Element No. 2 (EGE No. 2) (Tabl. 1), determined through interpretation of tabulated data, is: $V_{np} = 2,74 \text{ m/s}$.

According to the calculations, the scour depth of the riverbed composed of coarse clastic soils (with an average particle diameter of 8.6 cm) is as follows:

$$h_p = d_c (V_m / V_{np})^6 \quad (3),$$

where $h_p = 0,086 * (4,75 / 2,74)^6 = 2,30 \text{ m}$.

It should also be assumed that certain sections of the riverbed may be composed of either coarser or finer clastic material. Accordingly, the average particle diameter will vary, leading to fluctuations in the estimated scour depth within the range of: $2.30 \pm 0.50 \text{ m}$. (DSTU ISO 15175, 2005), (State Committee of Ukraine for Urban Planning and Architecture, 1997).

At a near-bed flow velocity of $V_m = 4,75 \text{ m/s}$, partial erosion of certain sections of the bedrock surface composed of weathered argillites is possible. In the study area, the bedrock layers are represented by alternating argillites and sandstones; the sandstones are considered non-erodible.

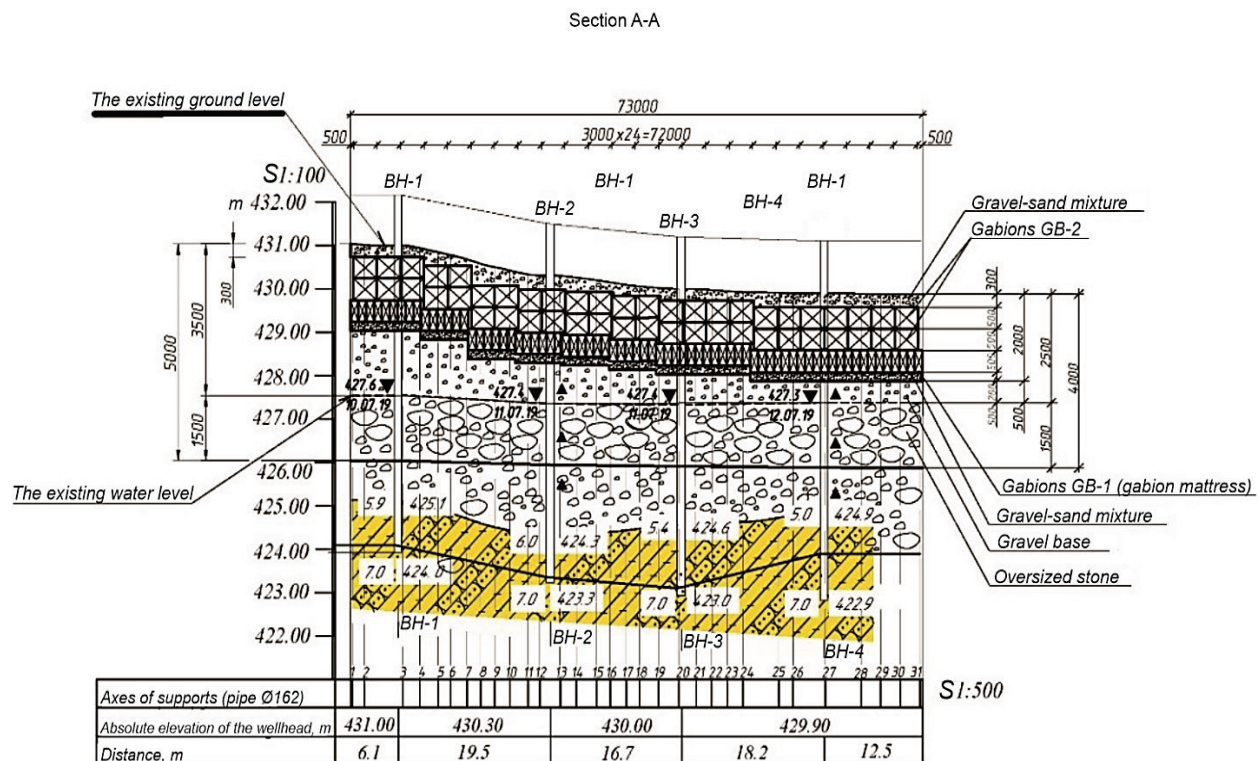


Figure 1 Scour Depth Calculation Scheme for the Bystrytsia Nadvirnianska Riverbed (BH 1-4 – Mining well number (borehole))

Conclusions

The investigated site is affected by several adverse physical and geological phenomena and processes, including: active lateral erosion, particularly along the right riverbank; partial general scouring of the riverbed; groundwater-induced flooding and periodic partial inundation during peak flow events. Based on these conditions, the site is classified as having Category III complexity of engineering-geological conditions (Zuzuk et al., 2021).

The natural base for the foundations (frame structures) of bank protection facilities may consist of non-erodible and slightly erodible soils corresponding to engineering-geological element (EGE) No. 3 (Ministry of Regional Development of Ukraine (2018)). The recommended embedment depth is as follows: up to 0.8 m in sandstone and up to 1.5 m in argillite.

One potential solution involves restoring the old bank protection line by utilizing the exposed existing pipe frame. An advantage of this approach lies in the fact that the riverbed in front of the damaged structure has already been scoured down to the underlying non-erodible or slightly erodible bedrock. Therefore, it would be reasonable to backfill the space on both sides of the pipes using materials with the above-mentioned properties, which would reduce the need for excavating new deep trenches.

Morphodynamic changes indicate a continuing trend of river channel migration toward existing infrastructure, particularly in the direction of the nearby garage cooperative, posing a potential threat to engineered structures, agricultural lands, and residential areas.

Another promising solution involves straightening the river channel by cutting a connecting canal to the riverbed used in the 1950s and equipping it with adequate flow capacity.

In the absence of riverbank protection measures, further active advancement of the erosion front, bank degradation, and deepening of the river channel are anticipated. These processes significantly increase the risk of landslides, infrastructure damage, and flooding of adjacent areas during peak flow events.

To stabilize the situation, a comprehensive set of riverbank protection measures should be implemented, tailored to the geological conditions of the site and the actual hydrodynamic characteristics of the flow. This includes dense riverbank backfilling, fluvial process modeling, and the establishment of a systematic monitoring program for bank stability.

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