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LANDSLIDE PROCESSES AS A GEOTECHNICAL FACTOR INFLUENCING THE EFFICIENCY OF CAPITAL INVESTMENTS

Alina Polcanova[1], Alexandru Cîrlan[2], Alexandru Râșcovoi[3], Vladimir Polcanov[4]

[1,2,3,4]*Technical University of Moldova, Chisinau, Republic of Moldova*

Abstract: In recent years, residential construction in the Republic of Moldova has been concentrated primarily within major urban agglomerations, primarily in Chișinău and its satellite towns, including Ialoveni, Codru, Grătiești, and Stăuceni. The shortage of undeveloped land parcels increasingly necessitates the utilization of slopes susceptible to landslides for construction purposes. Building on such geotechnical unstable terrains invariably requires additional capital investments in geological investigations, design, and stabilization works. This paper examines the nature, classification, and main causes of landslide processes, as well as their spatial distribution across the territory of Moldova. Particular attention is devoted to assessing the economic consequences of landslide risk for construction projects and to developing methods for integrating geotechnical data into investment planning. The study emphasizes the importance of preventive engineering measures and rational land-use strategies aimed at minimizing financial losses and enhancing the overall efficiency of capital investments in construction projects located within landslide-prone areas.

Keywords: *landslide slopes, residential construction, capital investments, investment efficiency.*

JEL code: *L74, O18, Q51, R42*

Introduction

The present research was conducted within the framework of the scientific project 020406, *“Models, Systems, and Technologies for Energy Efficiency, Decarbonization, and Digitalization of Processes in Energy, Industry, Construction, and Transport”*, carried out by the Department of Civil Engineering and Geodesy at the Technical University of Moldova.

Following a sharp increase in housing costs and an anticipated slowdown in the sales market, it is appropriate to assert that residential construction in Moldova has once again effectively “stalled.” This situation compels stakeholders in the construction sector to seek new approaches for organizing investment activities. A key aspect of this process is identifying ways to reduce construction costs.

In accordance with the stated research theme, the objective of this study was to identify methods to increase the efficiency of investment projects in the construction on potentially landslide-prone slopes.

This objective determined the need to solve the following tasks:

- Provide a brief description of landslides in Republic of Moldova;
- Examine the causes of potential landslide development associated with slope construction;
- Justify the possibility of reducing the construction costs of residential buildings.

The information base of the article consists of the authors’ own research findings, as well as data obtained from specialized literature relevant to the topic under investigation.

Research Results and Discussion

Already at the beginning of the last century, Terzaghi K., the founder of soil mechanics, noted that a landslide appears externally as a random phenomenon only because the observer failed to detect the precursory signs in time. This observation implies that, to ensure the safe operation of buildings and structures located within landslide-prone areas, it is essential to answer affirmatively the question regarding the potential development of landslides on the slope under construction.

The study revealed that landslides are a characteristic regional feature of the territory of the Republic of Moldova. Over several decades, they have been studied by researchers from the Academy

of Sciences of Moldova, as well as scientific and industrial organizations, including the Technical University (formerly the Chișinău Polytechnic Institute named after S. Lazo), the N. Dimo Institute of Soil Science, and others.

The works of Bilinkis G.M., Bukatchuk P.D., Goldshtein M.N., Zolotaryov G.S., Kazarnovsky V.D., Levadniuk A.T., Maslov N.N., Moniushko A.M., Orlov S.S., Polcanov V.N., Sirodoev G.N., Timofeeva T.A., Turovskaya A.Ya., Shadunts K.Sh., and others significantly contributed to the identification of landslide-prone areas, the study of the nature of landslide processes, the determination of their causes, and their classification [1-5].

According to the Geological Department, there are approximately 16,000 landslides in the republic. Their classification is based on data regarding the type of landslide displacement, the characteristics of the slip surface, depth of involvement, geological structure, and other parameters.

For practical purposes, the following types of landslides are distinguished [1, 2]:

- landslides – collapses;
- landslides – slides;
- landslides – slippages;
- landslides – extrusions;
- landslides – in subsiding soils;
- landslides – flows;
- landslides – mudflows;
- soil liquefaction and creep.

The main causes of landslide development include [3, 4]:

1. Relief characteristics – a hilly and undulating terrain with significant fragmentation;
2. Tectonic conditions – neotectonic movements occur unevenly and reach their maximum in Central Moldova. According to the neotectonic zoning map, this area currently experiences uplift at rates of up to 10mm/year;
3. Development of fluvial and gully erosion;
4. Lithological and structural soil features – landslide processes are associated with thick sequences of Neogene sand-clay sediments;
5. Physical and mechanical soil properties, including rheological properties;
6. Abnormal precipitation events;
7. Hydrogeological conditions – the characteristics and occurrence of groundwater reduce slope stability by 20–30%;
8. Anthropogenic factors – up to 80% of active landslides result from improper human activities.

The anthropogenic influence is linked to:

- ✓ extensive deforestation;
- ✓ plowing of slopes;
- ✓ improper execution of construction and installation works;
- ✓ overloading of the upper part of the landslide slope;
- ✓ significant undercutting of the slope;
- ✓ unregulated discharge of surface water.

One of the specific features of landslides in Republic of Moldova is their potential development on slopes with gradients exceeding 5-8°. Slopes of such gradient cover approximately 46% of the country’s territory. In other words, nearly half of Republic of Moldova is landslide-prone. Central Moldova is the most affected region: in the Călărași district, 77% of the territory is subject to landslides [5-7].

It has been established that landslides on Republic of Moldova slopes can develop under conditions of rheological deformation [8-10]. This circumstance indicates that the formula proposed by Orlov S.S. [11] for assessing landslide hazard on a slope may be insufficient.

An example of the impact of the landslides processes, developing under conditions of creep deformation on the housing stock is the case in Grătiești town. Residential buildings constructed on an old landslide slope underwent slow displacements (Fig. 1). Such displacements led to widespread

cracking in the load-bearing structures of the houses, as well as in boundary fences made of blocks (Figs. 2 and 3).



Figure 1. General view of the slope section in the Grătiești town, undergoing slow deformation

Photo by Alexandru Râșcovoi, September 2025



Figure 2. Crack in the load-bearing wall resulting from slow displacement of clayey soils

Photo by Alexandru Râșcovoi, September 2025



Figure 3. Vertical crack in the masonry fence

Photo by Alexandru Râșcovoi, September 2025

It should be emphasized that at the time of construction on this slope section, no visible deformations were detected. Their subsequent development is attributed to anthropogenic factors, manifested as additional loading on the slope and saturation of the foundation soils. Under these conditions, the acting shear stresses (τ) exceeded the so-called “creep threshold” (τ_{lim}), which contributed to an increased rate of deformation and the occurrence of localized soil movements under conditions of oversaturation ($\tau > \tau_{lim}$).

The width of crack openings can reach critical values (Fig. 4). Consequently, catastrophic slope movements are possible (Fig. 5).



Figure 4. Crack on the slope reaching critical dimensions

Photo by Alexandru Cîrlan, Cricova town, April 2025



Figure 5. General view of the slope failure scarp

Photo by Alexandru Cîrlan, Cricova town, April 2025

An illustrative example is the case of landslide-induced deformations and the subsequent damage to residential buildings, road infrastructure, and recreational areas in Codru town (Figs. 6 and 7). Construction in Codru, particularly in its eastern part, takes place on an ancient landslide slope. The slope is prone to creep deformations. Chaotic development without a comprehensive Landslide Protection Project (LPP) led to a change in the ratio of retaining and shear forces. The landslide *„was not long in coming”.*



Figure 6. Landslide scarp near a residential building

Photo by Alexandru Cîrlan, Codru town, December 2016



Figure 7. Loss of stability of an excavation slope

Photo by Alexandru Cîrlan, Codru, April 2025

The research results presented by the authors of this article are consistent with the results of studies conducted by Salbego G. et al. In particular, one study [12], based on a detailed analysis of a landslide in the Pre-Alpine region of Italy, established that the implementation of drainage structures prior to the onset of landslide movements would not only have increased the overall slope stability but also reduced by 30% the costs associated with mitigating the consequences of the landslide.

This circumstance confirms that preventive anti-deformation measures are not only effective but also economically advantageous. To assess their economic efficiency, it is necessary to thoroughly study the nature of landslides at each local site and to design a comprehensive Landslide

Protection Project (LPP) taking into account thes pecific geological and hydrogeological conditions, as well as the characteristics of the planned construction, including the master plan, number of floors of buildings, facilities, social and cultural infrastructure, etc.

In the work of Salbego G. et al., attention is also drawn to the need for the development of a landslide hazard map based on a comprehensive study of the regional conditions. In particular, it is noted that nearly 50% of the landslides that occurred during the heavy rainfall events of 2010 could have been predicted. This conclusion aligns with the concept proposed by the authors of the present study, who emphasize the importance of implementing well-planned construction practices based on maps of active and potential hazardous geological processes.

When developing landslide-prone slopes, it is essential for the developer (investor) to have a modern master plan of the territory [10]. The master plan should include zoning of the territory according to the degree of landslide hazard. Based on this zoning, the sequence of construction of buildings and structures, as well as the complex of anti-landslide measures, is determined. Naturally, any delay in the preparation of the master plan leads to increased time and financial costs during the implementation of the investment project.

One of the ways to reduce investment costs may be to provide the investor with plots fully equipped with the necessary engineering networks. In this case, the costs refer to site preparation, which can amount to 25–30% of the total investment.

An analysis of design and construction practices on hazardous sites in the Vatra and Codru towns, has shown that when slopes are developed by several investors, it becomes necessary to revise previously adopted design decisions and, consequently, to modify the estimated construction costs. Ultimately, this increases the market price per 1 m² of residential area. It should be noted that the cost of engineering and geological surveys on a hazardous slope and the design of anti-landslide measures alone can reach several million MDL.

Based on the study of landslides in Hong Kong, Wong H.N. [13] proposes the use of a landslide risk assessment methodology through the analysis of each individual infrastructure unit located on the slope, including the slope itself - its genesis, development conditions, and other factors. This approach makes it possible to evaluate in detail the potential consequences of a landslide for each specific object and to calculate the overall risk.

The author suggests applying Quantitative Risk Assessment (QRA), which provides measurable, quantitative results and reduces the uncertainty associated with risk evaluation. Although QRA does not guarantee absolute accuracy, it offers valuable quantitative data that can support decision-making in slope development.

Practical experience has shown that raising awareness of landslide-related risks among stakeholders and the public encourages a willingness to make balanced, compromise decisions when comparing risk levels and associated costs. Ultimately, this has facilitated the use of quantitative methods in landslide risk management. In the author’s opinion, the methodology proposed by Wong H.N. can also be effectively applied in the Republic of Moldova.

The importance of developing a landslide risk management strategy, including hazard zoning methods and the implementation of comprehensive engineering protection systems, is emphasized in the work of Cascini L. et al. [14]. The authors note that early hazard and risk zoning has a positive impact on urban development by reducing the associated risks of hazardous geological processes, particularly landslides.

In the study by Perera E.N.C. et al. [15], the results of a comprehensive geotechnical and economic analysis of the landslide impact in Aranyaka (Sri Lanka, May 17, 2016) are presented. The authors stress that the absence of preliminary geotechnical investigations, effective drainage systems, and engineering stabilization measures significantly increased both structural and economic losses. It is particularly noted that integrating slope stability analysis and geotechnical risk assessment into the stages of planning, design, and implementation of investment projects is a key factor in reducing subsequent rehabilitation costs and increasing the efficiency of capital investments in areas susceptible to landslide processes.

In the work of Kim H.G. et al. [16], the authors assess the economic damage caused by landslides and the effectiveness of protective measures. The average cost of damage per hectare for the period 1997–2014 amounted to USD 130,000/ha, with a minimum of USD 70,000/ha and a maximum of USD 372,000/ha, including recovery, adaptation, and management expenses. Vulnerable territories include residential areas covering 12,900 ha and transport infrastructure spanning 1,100 ha. Notably, the authors provide projections for the 2040s and 2090s, indicating that by the 2090s, future costs may increase 3-4 times, reaching approximately USD 300–410 million, particularly in residential and transport zones.

Unfortunately, in the Republic of Moldova, landslide monitoring is currently almost non-existent. This situation makes it difficult to present an up-to-date picture of landslide hazard zones; the existing maps are outdated, and the cost of the facilities located in these zones [4, 6, 10].

Typically, a Landslide Protection Project (LPP) includes the installation of drainage systems and retaining structures constructed from bored piles. The piles may be placed in several rows and tiers, with the mandatory installation of wall drainage [1, 2, 5].

This circumstance necessitates the implementation of modern methods for the organization and management of construction, as well as — equally important — the provision of operating conditions for the landslide protection structures, residential buildings, and associated facilities throughout all stages of their life cycle.

Conclusions and recommendations

1. An analysis of the development of landslide-prone slopes has been carried out. The necessity of additional funding for conducting engineering investigations and developing a Landslide Protection Project (LPP) has been substantiated.

2. Directions for reducing investor expenses in residential complex construction have been identified by involving public institutions in site preparation, design, and implementation of LPPs.

3. To increase the efficiency of investment projects, it is necessary to develop and implement a mechanism for reducing investment costs by reducing the cost of landslide protection measures and site preparation works.

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