Journal of Engineering Science *Vol. XXIX, no. 1 (2022), pp. 112 - 120*
Fascicle *Architecture, Civil and Environmental Engineering* *ISSN 2587-3474*
Topic *Civil Engineering and Management* *eISSN 2587-3482*

https://doi.org/10.52326/jes.utm.2022.29(1).10
CZU 625.7:551.435(478)

LANDSLIDE PROTECTION OF ROADWAY NETWORK DURING THE CONSTRUCTION AND RECONSTRUCTION

Vladimir Polcanov, ORCID: 0000-0001-8389-2128,
Alina Polcanova, ORCID: 0000-0001-5826-8278,
Alexandru Cîrlan*, ORCID: 0000-0003-4009-2790

Technical University of Moldova, 168 Stefan cel Mare Blvd., Chisinau, Republic of Moldova
*Corresponding author: Alexandru Cîrlan, *alexandru.cirlan@cms.utm.md*

Received: 12. 17.2021
Accepted: 01. 28. 2022

Abstract. The article discusses an example of construction and operation of a high embankment of the road, which was constructed in the central part of Moldova. A detailed historic reference about the behavior of the embankment over 40 years of its operation is given. The reasons for the repeated deformations of the embankment have been identified. The analysis of the effectiveness of the undertaken landslide prevention works has been performed. In order to increase the effectiveness of landslide protection, the authors propose a procedure for multifactorial analysis of the interaction of complex natural systems and various engineering structures, which will allow designers to reasonably predict and make accurate design decisions in diverse geological settings.

Keywords: *effectiveness, embankment, highway, landslide deformations, landslide prevention works, rheology.*

Rezumat. Articolul discută un exemplu de construcție și exploatare a unui terasament înalt al drumului, care a fost construit în partea centrală a Moldovei. Se oferă o referință istorică detaliată despre comportamentul terasamentului pe parcursul a 40 de ani de funcționare. Au fost identificate motivele deformărilor repetate ale terasamentului. A fost efectuată analiza eficienței lucrărilor de prevenire a alunecărilor de teren întreprinse. Pentru a crește eficacitatea protecției alunecărilor de teren, autorii propun o procedură de analiză multifactorială a interacțiunii sistemelor naturale complexe și a diferitelor structuri inginerești, care să permită proiectanților să prezică în mod rezonabil și să ia decizii de proiectare precise în diverse setări geologice.

Cuvinte cheie: *eficacitate, terasament, autostradă, deformări alunecări de teren, lucrări de prevenire a alunecării, reologie.*

Introduction

The plans for the reconstruction of existing highways and construction of new highways, outlined by the Government of the Republic of Moldova, presume the encouragement of additional investments into the road industry. The effectiveness of their use will be largely determined by the consideration of all hazardous geological processes that can have a negative impact on the road. Among the main of them are landslide developments [1 - 3].

Analysis of archive materials of IPDA ("*INSTITUTUL DE PROIECTĂRI DRUMURI AUTO*") and "*Intexnauca*" showed that during the construction and operation of the roads in Moldova, cases of the instability of roadside slopes, slopes of engineering structures, destruction of road topping, catchwater, retaining and enclosing structures have been observed on numerous occasions. This is due to the need to construct deep excavations and high embankments in tough terrain in Moldova.

At present time, about 170 landslides have been recorded on the motorways and railways of the republic. Despite the relatively small number of such locations, they occupy a significant area and often cover neighboring slopes. Most of the surveyed landslides are in an active development stage.

Due to the lack of accurate cost data, there is a significant range of values in the assessment of total damage. Roughly speaking, highways of the republic alone might cost 40 million US dollars.

The aforementioned point confirms the justifiability of recognizing the need to solve the landslide problem as one of the most important economic problems.

Justification for conducting the study

Upon choosing an object, setting the main goal and objectives of the study, a preliminary analysis of the landslides development on the highways and railways of Moldova was conducted. The results of the undertaken analysis are presented in [2].

Based on a detailed inspection of 80 locations, which are subject to landslide deformations, it was established that the anthropogenic factor was the cause of the landslide development in 25% of cases. Improper management of construction works, insufficient land development for construction, lack of effective anti-landslide protection, and low quality of performed work caused some of the landslides. An example is the case of partial destruction of the railroad section in the southern Moldova, between the towns of Cahul and Giurgiulesti in 2014. A kick-start of landslide processes in this area required an attraction of additional investments of more than $20 million.

The foregoing implies the need for paying closer attention to ensuring the safety of construction and operation of highways.

In this situation, look-ahead research, which is oriented to exclude the influence of the anthropogenic factor on the development of the landslide process, should be recognized as mandatory.

The quality of predevelopment research, which is the basis for the further feasibility study of an investment and construction project, is determined, inter alia, by the objectivity of the performed engineering and geological surveys [4]. Unfortunately, until now in the republic there are no regulatory documents in the field of design and construction, which take into account the diversity and specific regional features of the landslides evolvement. The studies conducted by the authors confirm that during the preparation of programs for engineering surveys, insufficient attention is paid to such fundamental issues as reducing the cost of surveys, cost-effectiveness analysis of works, acceleration of surveying, increasing the degree of their reliability.

Main objective of studies

The construction and reconstruction of highways planned for the near future will require the solution to problems related to ensuring the stability of natural slopes and slopes of engineering structures. Evidence shows that to ensure their long-term stability it will be necessary to develop a complex of landslide prevention works, which should take into account the rheological nature of deformation development [1, 2, 5].

Economic efficiency and economic expediency of the landslide control project will depend on how competently it will be developed. The cost of protective measures will undoubtedly have an impact on the total cost of road construction (reconstruction).

We chose to research a section of the Chisinau-Giurgiulesti highway, bypassing the town of Ialoveni. The main objective of the planned studies was to identify the reasons for recurrent deformations of the embankment and the effectiveness of the prescribed landslide prevention works.

Study techniques

The speed of detecting deformations of landslide massifs, recorded in the dynamics of their development, is universal information that allows revealing many aspects of the landslide process. In most cases, it is very difficult to obtain this information; therefore, experts can estimate the speed and amplitude of landslide processes only on the basis of visual observations. During these studies we used:

- Geodesic observational techniques with the use of modern electronic devices that allow obtaining sufficiently accurate observation results on the basis of a network of marks;
- Field geotechnical survey of natural slopes and road embankment slopes;
- Laboratory studies of the soils from the deformation location for determination of steady strength and rheological parameters: lightweight strength, viscosity grade, bond, cohesive properties and more;
- Graphic, analytical, and mechanical-mathematical simulations.

Survey results. Discussion

Following the main goal of the survey, the authors analyzed the extensive material which was obtained during the study of tech-work projects and detailed designs of landslide prevention works that were carried out on the considered section of the road [6 - 10].

Experts began to research the location in 1972. The program of surveys, which were carried out at that time, had a provision for the revealing the special aspects of geotechnical and hydrogeological conditions, as well as the physic-mechanical properties of soils for designing of the needed deformation prevention works [7].

Embankment construction works and the setup of strengthening and drainage structures were carried out from 1977 to 1980.

Unfortunately, deviations from the design decisions were observed during the construction phase: the embankment filling was performed with disturbances of process conditions. Confirmation of this fact comes from unacceptable fluctuations in the moisture-density of soils; the slopes were not strengthened, there were no trench drains, etc.

The road was in operation until August of 1984. It is worthwhile noting that during this period there were no regular observations over the condition of the embankment; for this reason, the beginning of the process of slowly developing creep deformations in the mass of the embankment was not recorded.

On the 27th and 28th of August, 1984, the highway services established the existence of cracks in the concrete slabs of the right lane and displacement of the metal marginal bars. Serious movements occurred on September 4, 1984, when deformations of the lower part of the right slope began. The breakage wall was located below the berm; its height was 0.1 - 0.5m; deformed slope's width was 10 – 12m; its length - about 100,0m. Ground displacement (to the right) was up to 1.5m. The assumed thickness of the rocks, which were involved in the landslide dislocation, was estimated at 20 m; the volume of soil was estimated at 350-600 thousand m^3.

During the period of September 5 - 19 experts observed how the stage of the steady-condition creep develops into a progressing one. During the night of September 20, 1984, the embankment collapsed. The landslide was 140m wide; its length was 130m; the height of the breakage wall was 9.0m.

The landslide body had a block structure; the blocks were separated by deep (up to 6 meters) transversal cracks. The sliding tongue had a form of protrusion rampart up to 3.0m high. The surface outside the protrusion rampart was covered with a dense network of cracks.

In 1985, experts worked out a complex of works for restoration of the embankment [8], which included:

- dismantling the embankment (in the deformed area) to a depth of 9 meters;
- restoration of the embankment with slopes 1:2 and 1:3;
- setup of a tail slope;
- setup of a system of small sheet piles;
- setup of three-rowed retaining construction made of driven piles;
- setup of drainage and run-off systems.

The project was implemented in part.

In 1985 the road section was put into operation. However, as long ago as in August 1986 (after the earthquake), cracks with a width of up to 10 cm and a length of up to 25 meters were found on the slope and the shoulder of the road. The cracks periphery corresponded with the boundary of the right side of the landslide that had occurred earlier.

Arranged instrumental observations revealed the development of slow deformations of the embankment. The power of the tail slope was increased in order to stabilize them.

After the completion of works, the deformations of the embankments stopped. However, three years later, in the summer of 1994, the previously formed cracks opening and the formation of a significant deflection of the earthwork surface occurred. The next complex of landslide prevention works was issued in 1995 [9]. Unfortunately, planned works were not fully carried out this time either. As a consequence of this, the process of deformation development resumed.

Cracks with an opening width of up to 1.0 cm were formed for the space of 130 meters on the road surface, along its centerline and to the left of it by 0.5 - 1.0 m. On the right side, a pattern of a possible landslide was formed. It could be traced along the cracks with an opening width of 10 - 15 cm and a newly formed ledge, which had a height of 40 cm.

The right driving lane has descended vertically by 20 - 60 cm for the space of approximately 100.0 m. Horizontal displacements appeared, resulting in the deformation of the water gutters and their partial destruction.

Therefore, a complex of anti-landslide measures, including a one- and two-row structure made of Gambia piles, failed to guarantee the operation of the embankment and failed to prevent the development of deformations.

A new project was developed in 2009 [10]. Its development was preceded by detailed studies of the environmental conditions, field and laboratory trials, and numerous calculations. The causes and factors of the instability of the embankment were identified based on them.

The following was taken into account during the development of a new complex of measures:

- The embankment was constructed on an inclined surface of primary rocks. The incline of the natural slope along the centerline of the road is on average 4º; in the direction of dip line – 9 - 13º;
- The surveyed part of the embankment is located at the junction of two geomorphological elements: the floodplain of the brook (with a slight incline) and the slope of mean steepness;
- The embankment base on the slope is composed of Sarmatian clay, which is subject to creep deformations under conditions of the creep threshold decrease, which happens with an increase of moisture and a disruption of lightweight strength (as a result of the creep process itself);
- The embankment slope lies on a thick mass of water-saturated floodplain deposits, which are in an incomplete stage of consolidation.
- Lithological composition of soils, which form the embankment, is heterogeneous;
- A change in the moisture conditions during periods of maximum precipitation and snow melting leads to a decrease of the ground strength in the particular sections of the embankment, both along strike and at depth;
- Unassured drainage promotes surface-water infiltration into the mass of the embankment and, consequently, causes a reduction of the strength of rocks.
- Erosion advancement on the slopes and at the base of the embankment leads to a decrease in local stability;
- Side slopes in some sites do not meet the requirements for long-term stability;
- The waterlogged upper layers of the embankment are exposed to the dynamic influence of automotive transport, which reduces the strength and stress-related characteristics of the soils of the capping layer.

The fundamental reason for the occurrence of landslide processes was the development of volumetric rheological deformations in the body of the embankment.

The following additional works were performed in accordance with the revised mechanism for the development of landslide deformations:

- Capping layer soil cut and fill to a depth of 3.0 - 5.0 m;
- Works concerning assurance of impermeability and frost resistance of soils, which compose the road border and located immediately below road topping;
- Works concerning assurance of water disposal and surface water controls;
- Works concerning groundwater flow control (setup of groundwater cutoff);
- Change of slope gradients;
- Reinforcement of ramps through sowing grass, by planting vegetation with an advanced root system, which slows down the advancing of erosional-landslide processes.

The project was executed in 2010 (Figures 1 - 4).

Figure 1. Restoration work at a site of embankment bypassing the town of Ialoveni.
Source: Bogza S. from "Simbo-proiect S.R.L." 2009.10.06.

Figure 2. Arrangement of bored piles in the right slope of the embankment.
Source: Bogza S. from "Simbo-proiect S.R.L." 2009.10.06.

Figure 3. Section of embankment in December of 2019.
Source: Rascovoi A. from Technical University of Moldova.

Figure 4. Section of embankment in December of 2019.
Source: Rascovoi A. from Technical University of Moldova.

In December of 2019, the authors of this work carried out a visual inspection of the embankment section and performed works. It showed that there are no significant deformations in the mass of the embankment. However, in some spots, in the surfacing, there are longitudinal and transverse cracks opening up to 2 cm wide (Figure 5, 6). The origin of the cracks can be explained by the unfinished consolidation of the newly filled soils and, presumably, by the insufficient rigidness of the road material.

Figure 5. Longitudinal cracks in the road surface. December 2019.
Source: Rascovoi A. from Technical University of Moldova.

Figure 6. Transversal cracks in the road surface. December 2019.
Source: Rascovoi A. from Technical University of Moldova.

Conclusions and suggestions

An analysis of the condition of a high embankment, which was constructed on the bypass of Ialoveni town in tough terrain, showed that the stability of its slopes cannot be ensured without the application of a set of measures based on identifying the mechanism of the evolvement of landslide deformations.

Ensuring the stability of embankments is not always possible, it requires significant efforts and material expenses.

In order to increase the effectiveness of landslide protection, the authors propose to create a procedure for multifactorial analysis of the interaction of complex natural systems and various engineering structures, which will allow designers to reasonably predict and make accurate design decisions in diverse geological settings.

Development of practical recommendations will facilitate, among other things, the appropriate selection of optimal alternative for the road renovation for the 9th Pan-European corridor with reference to the maintenance of ecological equilibrium in the most vulnerable part of the central Codri. In the long term, this will ensure the stability of the subgrade on the examined road with the use of minimal financial and material resources and maintaining a high degree of reliability of key decisions. Multi-purpose use of survey results will allow to improve environmental protection and to ensure the protection of not only linear infrastructure but also valuable commercial lands.

Acknowledgments. The authors would like to express sincere gratitude to the management and staff of IPDA ("INSTITUTUL DE PROIECTĂRI DRUMURI AUTO"), "Intexnauca S.A." and "Simbo-proiect S.R.L." for the opportunity to use archival materials during the work on this article.

References

1. Polcanov V.N. *Roli reologicheskih processov v razvitii opolznej na territorii Moldovy* [The role of rheological processes in the development of landslides on the territory of Moldova]. Chisinau: UTM: Tehnica – UTM, 2013.
2. Polcanov V.N., Polcanova A.V. Opyt izuchenija inzhenerno-geologicheskih uslovij ustojchivosti sklonov i otkosov iskusstvennyh sooruzhenij [The experience of studying geologico-enginering stability conditions of natural slopes and slopes of engineering structures]. – Chisinau: UTM: Tehnica – UTM, 2017.
3. Cîrlan A. *Studiul proprietăților reologice ale solurilor pentru evaluarea stării de tensiune-deformație a terenurilor de fundații* [Investigation of the rheological properties of soils for the assessment the base stress-strain state]: Ph.D. Thesis [online]. Chisinau (Republic of Moldova): Technical University of Moldova, 2019. [accesat 13.07.2021]. Disponibil: http://www.cnaa.md/files/theses/2019/54491/alexandru_cirlan_thesis.pdf
4. Bondarik G.I. *Inzhenerno-geologicheskie izyskanija* [Engineering and geological resarch]. – Moscow: ID KDU, 2008.
5. Bukatchuk P.D., Blyuk I.V., Pokatilov V.P. *Geologicheskaja karta MSSR. M-b 1:200000 (Objasnitelinaja zapiska)* [Geological map of the MSSR. Sc. 1:200000 (Explanatory note)]. – Chisinau, 1988.
6. Polcanov V., Funieru N. *Despre proiectarea și edificarea construcțiilor rutiere pe teren accidentat pe teritoriul Moldovei* [About designing and building road construction on rough terrain on the territory of Moldova] In: Inginerie civilă şi educație. 2019. pp. 97-100.
7. *Tehno-rabochij proekt rekonstrukcii avtomobilinoj dorogi Kishinev-Bolgrad v rajone s. Jaloveny (obiekt №767) [The technical-working project for reconstruction of Chisinau-Bolgrad highway in the area of Ialoveni (object No. 767)].* Archive of IPDA. – Chisinau, 1973.
8. *Otchet ob inzhenerno-geologicheskih izyskanijah dlja meroprijatij po vosstanovleniju nasypi na avtomobilinoj doroge Kishinev-Bolgrad na uchastke obhoda p.g.t. Kutuzovo (obiekt №1222)* [Report of engineering-geological surveys for measures to restore the embankment on the Chisinau-Bolgrad highway at the bypass section of the urban-type settlement. Kutuzovo *(object No. 1222*]. Archive of IPDA. – Chisinau, 1985.
9. *Otchet ob inzhenerno-geologicheskih izyskanijah dlja protivo-opolznevyh meroprijatij na avtomobilinoj doroge Kishinev-Chimishlija-Vulkjeneshti-Dzhjurdzhjuleshti-granica s Rumyniej na uchastke obhoda p.g.t. Jaloveni (obiekt №3170)* [Report on engineering-geological surveys for anti-landslide measures on the highway Chisinau-Cimislia-Vulcanesti-Giurgiulesti-border with Romania at the bypass section of the urban-type settlement. Ialoveni (object *No.* 3170).]. Archive of IPDA. – Chisinau, 1995.
10. *Otchet ob inzhenerno-geologicheskih izyskanijah na obiekte "Reabilitacija avtomobilinoj dorogi R3 Kishinjeu-Hyncheshti, uchastok obhoda gJaloven'"* [Report on engineering and geological surveys at the object "Rehabilitation of the R3 Chisinau-Hincesti road, bypass section of Ialoveni"]. Archive of UNIVERSCONS" S.R.L. – Chisinau, 2009.