Journal of Engineering Science *Vol. XXX, no. 2 (2023), pp. 135 - 143*
Fascicle *Architecture, Civil and Environmental Engineering* *ISSN 2587-3474*
Topic *Civil Engineering and Management* *eISSN 2587-3482*

https://doi.org/10.52326/jes.utm.2023.30(2).12
UDC 625.7:624.138.26:69.059

INTERVENTION SOLUTIONS ON LANDSLIDES IN ROAD AREAS. CASE STUDY

Diana-Nicoleta Dima[1], ORCID: 0000-0002-2217-4330,
Răzvan Chirilă[2], ORCID: 0000-0001-8490-3300,
Gelu-Răzvan Gimiga[1], ORCID: 0000-0002-6798-1793

[1]*Gheorghe Asachi Technical University of Iasi-Romania, Department of Transportation Infrastructure and Fundations, Blvd. Mangeron, No. 1, 700050, Iasi, Romania*
[2] *GeotehnIS Concept S.R.L., Iasi, Romania*
*Corresponding author: Diana-Nicoleta Dima, *diana-nicoleta.dima@academic.tuiasi.ro*

Received: 03. 22. 2023
Accepted: 04. 28. 2023

Abstract. In our country, there is a large variety of foundation soils, some of them having inferior characteristics to those necessary for the proper support of a communication path. This raises some of the most common problems in the field of road infrastructures, namely the sliding of slopes in the area related to road construction. This phenomenon appears more and more frequently, especially after some periods with accentuated atmospheric instability, sometimes leading to the partial inability to use the affected infrastructure sector. In some cases, the development of this phenomenon can lead to the traffic blockage and the isolation of the communities in the area, to the destruction of a well-defined road sector and even to the loss of human lives. In order to maintain the quality requirements imposed by the law and to limit the risk of reaching the limit state of normal operation, respectively of compromising the structure, the administrators and the staff who are directly involved in the maintenance and the expertise of the affected area, achieve direct examination works or investigation by means of specific observation and measurement. In the current practice, these works are part of the technical expertise of the affected area, being made by a specialized team, led by an authorized technical expert in the field.

Keywords: *consolidation solutions with drilled piles, investigations, landslide, monitoring, road sector.*

Rezumat. În țara noastră sunt prezente o gamă largă de pământuri de fundare, unele dintre ele prezentând caracteristici inferioare celor necesare susținerii corespunzătoare a unei căi de comunicații. Acest lucru ridică unele dintre cele mai frecvente probleme din domeniul infrastructurilor rutiere, respectiv a alunecării versanților din arealul aferent execuției drumurilor. Aceste fenomene apar din ce în ce mai frecvent, mai ales în urma unor perioade cu instabilitate atmosferică accentuată, conducând uneori la incapacitatea parțială de utilizare a sectorului de infrastructură afectat. În unele cazuri, dezvoltarea fenomenului poate conduce la blocarea circulației și izolarea comunităților din zonă, până la distrugerea unui sector de drum bine definit și chiar la pierderi de vieți omenești. În scopul menținerii cerințelor de calitate

impuse prin lege și a limitării riscului de atingere a stării limită de exploatare normală, respectiv de compromitere a structurii, administratorii, împreună cu personalul implicat direct în întreținerea sau expertizarea zonei afectate, realizează lucrări de examinare directă sau investigare prin mijloace de observare și măsurare specifică. În practica curentă, aceste lucrări fac parte din expertizarea tehnică a zonei afectate, fiind realizate de către o echipă specializată, condusă de un Expert tehnic autorizat în domeniu.

Cuvinte cheie: *sector de drum, alunecare de teren, investigații, monitorizare, soluții de consolidare cu piloți forați.*

1. Introduction

Landslides causes traffic disruptions have been one of the threats to the normal operation of regional roads [1-4] and are erosive actions of the soil that can lead to the displacement of a large volume of soil, changes in the slope of the land and even significant changes in the relief. They are caused by triggering factors such as torrential rains, water leaks, earthquakes or human interventions on the relief, due to lower characteristic parameters of the soils. Landslides can trigger suddenly, being dangerous to people, properties and communication routes, causing property damage or even loss of human lives [5-9]. The prevention and management of landslides requires continuous planning and monitoring, as well as rapid physical interventions to stabilize the area, through the construction of various support structures or through technical interventions on the foundation soils.

In this article, the authors focus on determining the causes of soil instability phenomena for a local road sector in the Moldova region and the solutions for consolidating, developing and monitoring the behaviour of the consolidated area during operation. The meteorological phenomena that have taken place in recent years have strongly affected the investigated road sector through rainwater runoff, which engaged soil particles in the immediate vicinity, resulting in a landslide with a length of 40 m.

2. Current situation on site. Characteristics of the analyzed area. Causes of the degradations

Due to the occurrence of a strong landslide, the road administrator ordered a specialist study for emergency intervention in the disaster area.

Along the analyzed route, a slope was identified with stability issues (Figure 1), unevenness, and potholes caused by the lack of drainage and maintenance systems, as well as erosion forms on the sloping areas, given that the road embankment was supported by a structure made of gabions. The area belongs to the high-risk area for soil collapse or landslide, with a high probability of primary landslide occurrence.

Intense weather conditions have heavily impacted the road sector, causing a 40 meters length landslide along the road embankment. Successive break steps were observed that threaten the overall stability of the road.

In the partially forested upstream slope, saturation areas were formed due to precipitation which softened to the point of flow. The flowing material and water from the slope are uncontrolledly discharged onto the road. Upstream zones of counter-slope have also been identified, which have favored the flooding of precipitation.

At the base of the excavation slope there is no walled ditch for collecting the waters, and the existing bridge is silted and does not have a drop chamber for collecting upstream and trench water.


a) b)


c) d)


e) f)

Figure 1. The analyzed landslide.

The road surface is inadequate because it presents counterslope and discharge areas due to excessive water. The road's viability is affected, so that road and pedestrian traffic cannot take place under normal conditions.

During dry periods, the existing road structure generates a lot of dust, and during rainy periods mud is formed and the road becomes impassable. Precipitation waters flow down and the road does not have a rainwater collection system to ensure controlled drainage of these waters. The road shoulder is made of earth and is structurally degraded.

2.1. Geologic, geomorphologic and hydrological characteristics

The analyzed sector is located in the Central Moldovan Hills, with elevations up to 200 m, wide valleys with lakes and slopes with numerous landslides. A small part of the sector belongs to the orogenic region and the rest to the platform region.

In the investigated geotechnical area, the Cetățuia River is the collector of the entire hydrographic network in the site area.

2.2. Seismic Characteristics

In terms of seismic activity (Figure 2), our country's territory is divided into macrozones with seismic intensities of 6, 7, 8, and 9 degrees. The analyzed area fits into grade 7.1 on the Medvedev, Sponhauer, Karnik (MSK) scale [10] and is located in the southwestern extremity of the Russian-Moldovan Platform that shows positive movements of 5 mm per year.

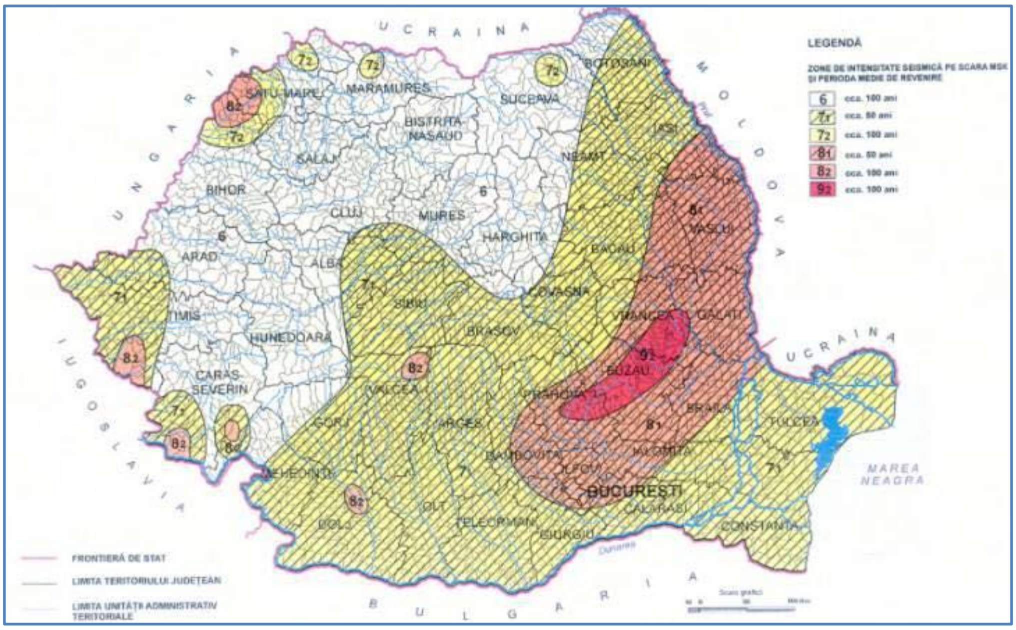

Figure 2. Seismic zoning. Macrozoning of the territory of Romania [10].

For earthquakes with an average recurrence interval of 225 years (IMR = 225 years), with a 20% probability of exceedance in 50-year (Figure 3), the seismic coefficient value, named ag in Romanian standard, is 0.25 g, and the control period (corner), name Tc in Romanian standard, is 0.70 s (Figure 4) [11].

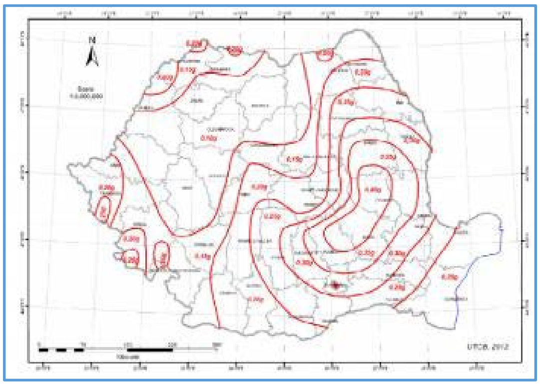

Figure 3. Zoning of peak ground acceleration values for design ag with IMR = 225 years and 20% probability of exceedance in 50 years according to [11].

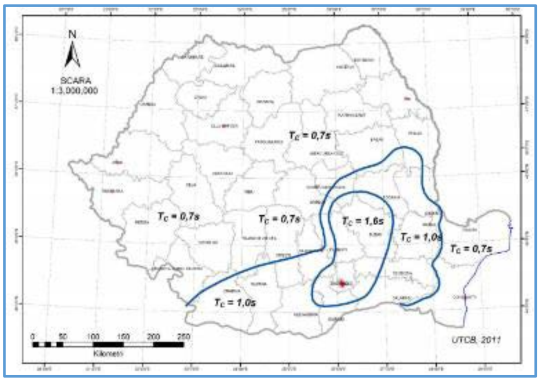

Figure 4. Zoning of the Romanian territory in terms of the control period (corner), named TC (control periods) in Romanian standard of the response spectrum [11].

The analyzed sector is located in the temperate-continental climate zone with Baltic influences. Annual precipitation is 500-700 mm with lower values in January, February, and March and higher values (600-700) in June and July. The area is characterized by average annual temperatures of 9-10°C, with the minimum air temperature dropping to -20 °C in winter months and reaching +39°C in summer months. According to [12], the maximum depth of frost in the studied area is 80-90 cm (Figure 5). The reference wind pressure is 0.70 kPa [13], and the snow load on the ground is 2.50 kN/m^2, as stated in [14].

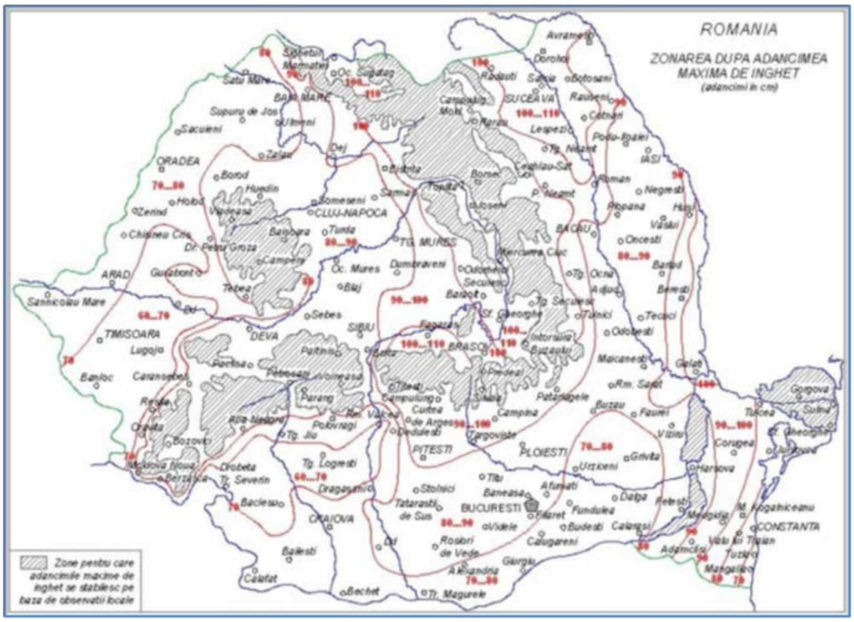

Figure 5. Maximum depths of frost. Zoning of the territory of Romania according to [12].

3. Geotechnical conditions. Methods, equipment and apparatus

The foundation ground was geotechnically investigated in the landslide area by performing a dynamic cone penetration test with a depth of 14.0 m (Figure 7) and two drillings: one in the road body at a depth of 15.0 m and the other downstream -2.70 m below the road elevation at a depth of 8.0 m.

The geotechnical drillings were carried out with a semi-mechanized drill, with disturbed and undisturbed samples taken. The drill diameter is 100 mm.

The system used for drilling (Figure 6) consists of:

- percussion hammer with internal combustion engine on gasoline
- hydraulic extractor - pulling power of 10 tons
- drill bits with diameters between 36 - 100 mm and lengths between 1.0 and 2.0 m
- connecting rods with lengths between 1.0 and 2.0 m
- utility vehicle used for mobilization on site, equipment transport, and maintenance on site
- wooden boxes for transporting samples to the laboratory
- stands and pipes for collecting undisturbed samples
- electric generator and concrete/asphalt corer - to cross any concrete/asphalt platforms.

The samples were collected manually, in plastic bags for moisture preservation, transported in soil sample boxes, and stored in an excicator in the laboratory to maintain the initial site conditions.

In order to complete the geotechnical information and determine derived geotechnical indices, a dynamic cone penetration test was performed using a Heavy Dynamic Penetrometer (DPH) cone, the results are briefly presented in Figure 6.

To determine the best intervention solutions, the following aspects were taken into account:

Figure 6. Heavy Dynamic Cone Penetrometer Equipment [15-17].

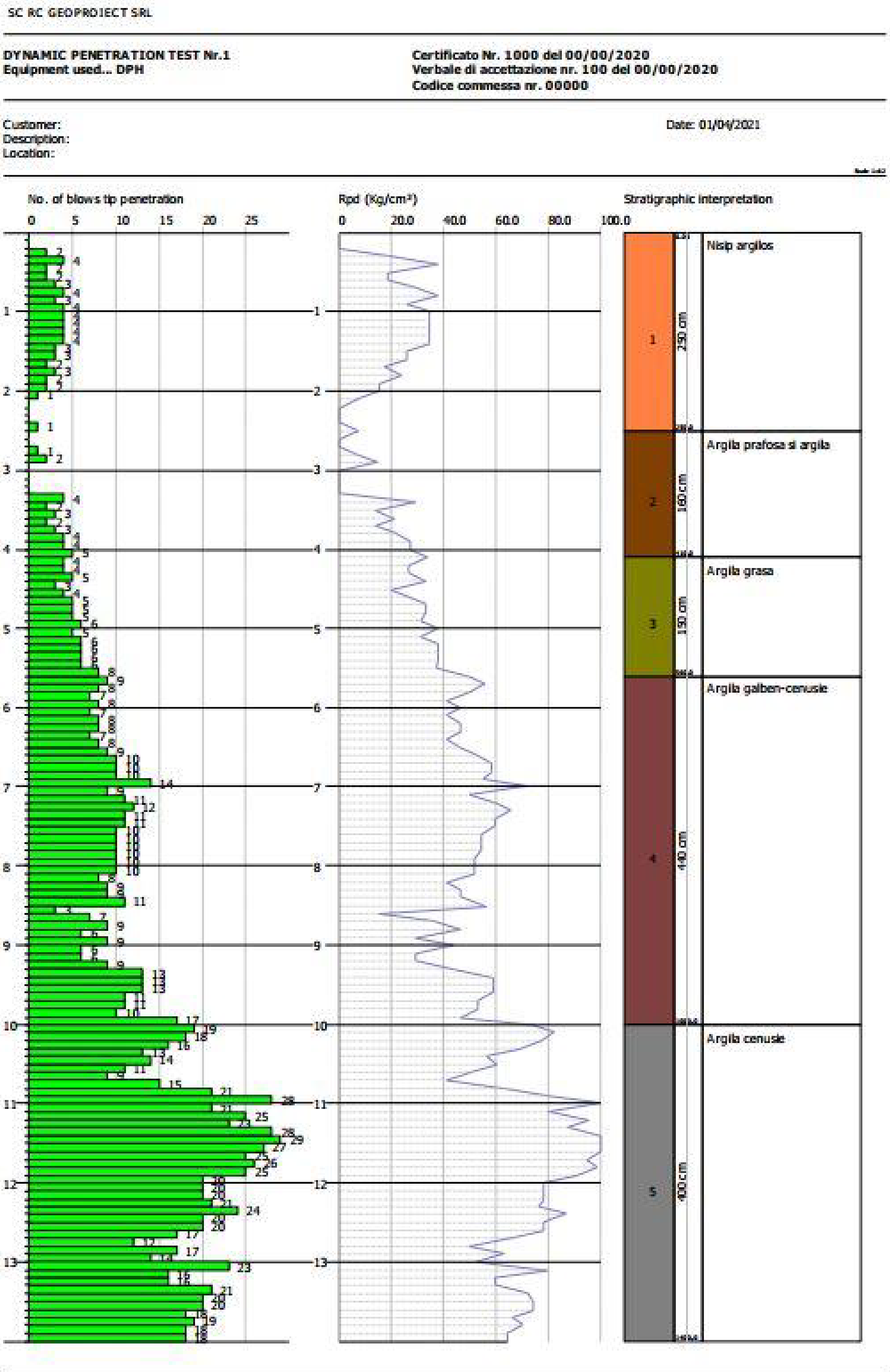

Figure 7. Dynamic penetration test graph.

- a sliding phenomenon occurred on the site
- the main elements of a landslide are visible (ebulment, landslide body, rupture steps and crown)
- under the action of disruptive factors, there is a risk that the phenomenon will develop upstream and affect the communal road sector in its entirety.

Thus, it was necessary to carry out a stability analysis with the help of calculation programs (Fellenius and Bishop method), through methods that admit the limit equilibrium conditions, in which to highlight the potential sliding planes (Figure 8), respectively the risk of advancing the sliding to the body of the road.

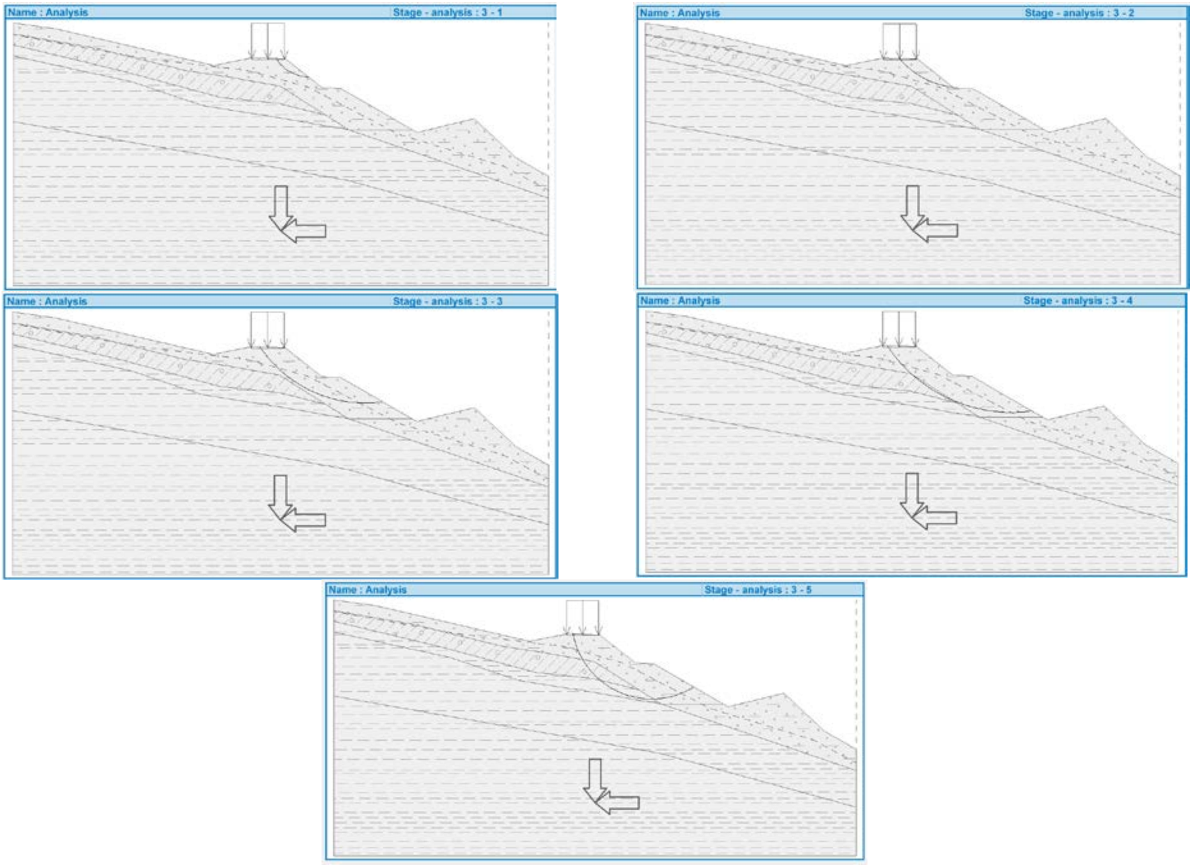

Figure 8. Potential sliding surfaces.

3. Conclusions and recommendations

The following conclusions can be drawn from the analysis of the stratification of the land revealed by geotechnical drilling and from the results of the stability analyses:

- In natural conditions (static loads), the road embankment does not have guaranteed stability. Potential sliding surfaces have been identified that highlight the active nature of the landslide with small periods of relative stabilization (phenomenon given by the natural balance of internal forces following a new configuration of the land).
- In seismic conditions (dynamic loads) it can be observed that the safety factors are sub-unit for the sliding surfaces that intersect only the first layers.
- Therefore, under the action of disturbing factors, slide planes can form in depth up to the contact with the resistance layer (approximately - 4.50 m compared to the existing road elevation).
- Considering the stratification of the land and the microrelief conditions, it can be estimated that the sliding surfaces will develop successively - rotationally, both upstream -

horizontally, and in depth - vertically, until the contact with the resistance layer. This will lead to the total damage of the road sector covered by the present study.

- The time factor gives the landslide an active alternative character - partially stable, but with the possibility of reactivation, with slide planes that started from shallow depths, with deep development.
- The main recommendations aim to eliminate all possibilities of water infiltration into the land and its wetting with a negative effect on the construction, respectively:
- The arrangement of a reinforcement structure made of drilled piles with a minimum diameter of 600 mm, at a minimum depth of 14.0 m. The piles will be spatially positioned, at a distance in the plan, calculated so that the earth does not flow between the piles.
- The arrangement of a horizontal drainage system under the bottom of the ditch to collect the water from seepage. The depth of the drain will be at least 2.00 m. It will have a minimum length of 40 m.
- Restoration of the water discharge bridge. It is recommended that the bridge foundation rests on the reinforcement structure in the downstream area.
- Development of the torrential valley on the upstream and downstream area for a minimum of 25-30 m. An initial systematization of the land both downstream and upstream is recommended, then protection with gabion mattresses/geocells filled with concrete.
- Restoring the road body and ensuring the designed width.
- Ensuring adequate storm water collection and drainage systems to avoid their infiltration into the road system, which can have a negative effect on the appearance of subsidence and cracks in the road body. They can be trapezoidal ditches, triangular ditches, rectangular ditches, etc.
- Unclogging and maintenance of existing ditches - on the extended area along the road, activity aimed at reducing the risk of destructive phenomena.
- Vegetation of the entire slope with perennial plants and trees with deep roots, in order to eliminate the risk of surface slides and erosion due to rainwater falling directly on the surface of the slope.
- Placement of a reinforced ditch on the drainage area, with the aim of eliminating the risk of soil flow in the area of the ditches. Behind the support structure, a drainage system will be created that can have a common body with the horizontal drain, with the aim of taking over the infiltration waters that come to the surface on the slope of the embankment.
- Ensuring the safety of traffic through the provision of indicators and metal protective parapets.
- Geotechnical monitoring with at least 2 boreholes equipped with inclinometer and tracking program of movements that may occur inside the slope and the consolidation structure. The inclinometers will be placed in the reinforcement piles.

By rehabilitating and modernizing the investigated sectors, the aim is to increase the load-bearing capacity of the road system, increase traffic safety, increase the viability of the streets according to the current and prospective traffic.

This work is part of a large research program in the field of slope instability, wanting to raise an alarm signal regarding the need to complete the work within the term considered in the design stage, with the aim of minimizing the damage caused by the impact of environmental factors and execution delay on the viability of the work. The program is

developed by the Faculty of Construction and Installations of the "Gheorghe Asachi" Technical University in Iasi.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Liu, Q.; Zhang, B.; Tang, A. Landslide risk of regional roads: Consider the road mileage of expected losses. *Transportation Research Part D: Transport and Environment* 2023, 120, 103771.
2. Pantelidis, L. A critical review of highway slope instability risk assessment systems. *Bulletin of Engineering Geology and the Environament* 2011, 70, pp. 395-400.
3. Argyroudis, S.A.; Mitoulis, S.A.; Winter, M.G.; Kaynia, A.M. Fragility of transport assets exposed to multiple hazards: State-of-the-art review toward infrastructural resiliance. *Reliability Engineering&System safety* 2019, 191, 106567.
4. Saleh, M.; Hashemian, L. Addressing Climate Change Resiliance in Pavements: Major Vulnerability Issues and Adaptation Measures. *Sustainability* 2022, 14(4), doi.org/10.3390/su14042410.
5. Nappo, N.; Mavrouli, O.; Nex, F.; van Westen, C.; Gambillara, R.; Michetti, A.M. Use of UAV-based photogrammetry products for semi-automatic detection and classification of asphalt road damage in landslide-affected areas. *Engineering Geology* 2021, 294, 106363.
6. Bordoni, M.; Persichillo, M.G.; Meisina, C.; Crema, S.; Cavalli, M.; Bartelletti, C.; Galanti, Y.; Barsanti, M.; Giannecchini, R.; Avanzi, G.A. Estimation of the susceptibility of a road network to shallow landslides with the integration of the sediment connectivity. *NHESS* 2018, 18, 1735-1758.
7. Mavrouli, O.; Corominas, J.; Ibarbia, I.; Alonso, N.; Jugo, I.; Ruiz, J.; Luzuriaga, S.; Navarr, J.A. Integrated risk assessment due to slope instabilities in the roadway network of Gipuzkoa. Basque Country. *NHESS* 2019, 19, 399-419.
8. Postance, B.; Hillier, J.; Dijkstra, T.; Dixon, N. Extending natural hazard impacts: an assessment of landslide disruptions on a national road transportation network. *Environ. Res. Lett.* 2017, 12, doi: 10.1088/1748-9326/aa5555.
9. van Westen, C.J.; van Asch, T.W.J.; Soeters, R. Landslide hazard and risk zonation - why is it still so difficult?. *Bull. Eng. Geol. Environ.* 2006, 65 (2), 167-184.
10. SR 11100/1-93 – Seismic zoning. Macrozoning of the territory of Romania
11. Normative P100-1/2013 – Normative for the anti-seismic design of social-cultural, agro-zootechnical and industrial housing constructions
12. STAS 6054-77 – Foundation land. Maximum frost depths. Zoning of the territory of the Socialist Republic of Romania
13. CR 1-1-4/2012 – Design code. Assessment of wind action on buildings
14. CR 1-1-3/2012 - Design code. Evaluation of the action of snow on constructions
15. cptools.ro. Available online: https://cptools.ro/project/set-prelevare-probe-geotehnice/ (accessed on 01/06/2023)
16. stitz-gmbh.de. Available online: https://www.stitz-gmbh.de/en_window_sampling.html (accessed on 01/06/2023)
17. directindustry.com. Available online: https://www.directindustry.com/prod/von-oertzen-gmbh/product-107869-1730862.html (accessed on 01/06/2023)

Citation: Dima, D.-N.; Chirilă, R.; Gimiga, G.-R. Intervention solutions on landslides in road areas. Case study. *Journal of Engineering Science* 2023, 30 (2), pp. 135-143. https://doi.org/10.52326/jes.utm.2023.30(2).12.

Submission of manuscripts: jes@meridian.utm.md