Fundamentality of methods for optimizing the protection of the road transport system in mountainous conditions, as a dynamic system

L I Kortiev¹, A L Kortiev¹, S D Vaneev¹, O V Olisøva¹, R P Kulumbegov²,*
¹North Caucasian Institute of Mining and Metallurgy (State Technological University), Vladikavkaz, North Ossetia – Alania
²South Ossetian State University, Tskhinvali, South Ossetia

*e-mail: kulumbegov_2@mail.ru lbtranskama@mail.ru

Abstract. The life cycle of a road in mountainous conditions, as a complex dynamic system, is fundamentally different from the plain. The comparison issues in terms of work technology and road safety are completely incompatible. In the same system, the methods for optimizing safety problems are incompatible, as the road transport system on the plain is almost in a static position, and it turns into a complex dynamic system in mountainous conditions, from the impact on it of slope phenomena such as mudslides, landslides talus and avalanche-glacial (ice) are referred to in the literature this time as surface or exogenous processes. The qualitative indicators of these mutually influencing factors are under investigation. Faced with a multitude of terminological varieties, in order of discussion, it would be correct to call them “Slope phenomena”. Depending on the location of the centers of development of slope phenomena and their impact on the road to the axis of the road, they transform the road transport system into a complex dynamic system from a static state. Slope phenomena on mountain roads are a big problem and the optimal safety solution from each type of impact on the road is of current importance, as generally the optimal safety is ensured in a complex dynamic system in mountain conditions.

1. The problem formulation
The road laying on the plain as a creation of a technical system, is accompanied by a one-sided human impact on the environment with certain negatively acting components. With the road commissioning, the second half of the system appears - moving vehicles. Both joint subsystems form a technical system, which we consider in a static state.

In mountainous conditions, the negative impact is more aggravated by drilling and blasting operations, the impact of soil masses crumbling on the inner and outer slopes. The overall picture of the negative impacts during construction is shown in Figure 1 [1].

The multifactorial impact on the environment (E) from the mountain road is not limited to the figure shown.

As usual, the centers of slope phenomena are widespread on the mountain slopes [2], and with the activation of the processes of collapse, road and environmental safety (RES) deteriorates.

The processes of mudflow collapse - mudslide, landslide - talus and avalanche - glacial (ice) phenomena on the road are the reverse processes of the impact of environmental conditions on the road,
resulting from the road construction on the slopes. However, a more detailed analysis of the issue confirms that slope phenomena affect not only the road and the technical structures built on it, but also the environment itself, sometimes causing significant harm to it with a decrease in traffic safety.

![Figure 1. Classification of the negative impact on the environment of road construction technological processes in mountainous conditions](image)

In such a multifactorial interaction of the technical system and the environment, the irreversible destruction processes occur, both of the road and of the slopes. In such a state, the mutual influence of the technical system and the natural environment in the active phase of the impact on the road and the irreversible deformations and destruction received on the road should be considered as a dynamic system.

A schematic representation of the impact of the natural environment (slope phenomena) on the road and the environment itself is shown in Figure 2.

At the same time, two components should be distinguished. The first includes the road and vehicles moving along it, as a technical system in a simplified sense, or a "road transport complex", and the second includes dangerous slope phenomena manifested in the "natural" environment. In this state, the object passes from a simple one into a complex dynamic system with two constituent parts “natural” and “road”.

The interaction of these two components of a complex dynamic system begins with laying a road in a mining environment and organizing traffic on it.

The road and vehicles negatively affect the environment [3-6], causing irreversible changes in it. A road on mountain slopes with sloping phenomena, when interacting factors appear, from a static state to a dynamic state, since the balance of the cut soil masses on the slopes is disturbed, as a result of which the processes of their collapse onto the road, road structures and vehicles occur, reducing RES.
The destructive processes of slope phenomena on the road are not limited to the impact on road structures and constructures, but also spread down the slope, increasing the environmental hazard of the environment on the territory adjacent to the road.

![Figure 2. Scheme of the quantitative impact of slope phenomena on a mountain road](image)

2. Research methods
The analytical method was used in the available scientific and technical literature and the monitoring method was comparative when examining destroyed sections of roads and protective structures.

3. The essence of the study
A lot of studies by domestic and foreign scientists are devoted to emergency and environmental safety as a result of the construction of highways, however, the reverse impact of environmental protection on the road and the creation of dangerous road conditions in mountainous conditions is poorly covered in the scientific and technical literature.

The environment of the mountain areas is mainly represented by the indented slopes, on which there are often potentially dangerous ground-snow massifs [7-9], which can lose balance from natural and man-made influences. The cause of natural influences can be atmospheric and climatic conditions, a large steepness of the slope, blasting operations, earthquakes, noise from the opposite slope, etc.

The anthropogenic impacts on slopes and outer slopes include: the slopes cutting when making excavations, noise impacts (shots from guns, machine guns, etc.), vibration impacts (impacts from heavy vehicles).

It is advisable to group slope phenomena in the study according to signs and reasons of origin. For example, mudflows - landslide [10] slope phenomena occur when moisture penetrates into the ground masses from rain and surface waters. Landslides and talus are caused by periodic warming and cooling of the daily and seasonal cycle. Snow-glacial (ice) [11] collapses are of a summer-winter nature (the collapse of the Kolka glacier occurred in warm summer). The dynamics of the processes of development
and collapse of the road and the environment during the year is shown in Figure 3. This final diagram was developed for the first time by the authors of this study.

During the dynamic state transition, soil-snow masses from a slope or slope fall onto the road, creating dangerous conditions for moving vehicles and destroying the road structure, protective structures and vegetation layer fall on the outer slope of the road, which contributes to the creation of another chain of dangerous conditions for the movement of vehicles ...

**Figure 3.** Graphs of the development of slope phenomena and their impact on the road and environment throughout the year depending on their location at absolute heights.

1 - landslides; 2 - mudflows; 3 - talus; 4 - landslides-rockfalls; 5 - avalanches; 6 - ice; 7 – rivererosion

Destruction of road elements leads to a narrowing of the overall dimensions of the carriageway, and elements of protective structures - to their fall on the carriageway, which in both cases reduces RES [12-13]. The collapsed soil and snow masses are dumped on the lower slope, continuing the degradation of areas there, and a negative impact on vegetation, fauna and ichthyofauna.

Roads on a slope, in addition to upper-slope and side-slope collapses, are also the subject to impacts from phenomena located along the slope below the axis of the road. The reasons for activation, collapsing effects and their further development are not identical to the upslope and slope phenomena and, accordingly, their impact on the road should be considered separately.

In general, the interacting factors of the road and the environment in mountainous conditions are diverse, but poorly studied, so it is necessary to eliminate this gap in transport science. The whole complex representation of reasons, negatively affecting each other, roads and the environment are shown in the table.

Landscape and slope phenomena have an impact on the performance of road construction, which to some extent affects the development of the road transport network.
Table 1. Of mutual influence of the road, vehicle and natural environment

| Road                                      | Vehicles                                      | Relief and natural conditions |
|-------------------------------------------|-----------------------------------------------|-------------------------------|
| 1. Occupation of areas                    | 1. Combustion of fuels and lubricants         | 1. Slopes                    |
| 2. Degradation of areas                   | 2. Wear of the road surface                  | 2. Radii on curves           |
| 3. Division of the biosphere              | 3. Tyre wear                                  | 3. Mudflows                  |
| 4. Changing hydraulic systems             | 4. Making noise                               | 4. Landslides                |
| 5. Complicated animal contact             |                                               | 5. Landfalls                 |
|                                           |                                               | 6. Talus                     |
|                                           |                                               | 7. Avalanches                |
|                                           |                                               | 8. Glaciers, ice             |

The terrain relief plays an important role in choosing the direction of the road [14], which predetermines the construction of a road with large slopes, and this in turn requires the construction of deep excavations and high embankments, which increases the losses caused by the environment. Long-term monitoring studies on the Transkam, Georgian Military and other mountain roads of the Caucasus have shown that the expertise of road safety projects is insufficient, which entails an increase in accidents. In order to reduce accidents in a complex dynamic system considered in this study, the authors of this article have developed and patented optimal protective structures, which in general for such a complex dynamic system is optimization. The optimization methods are tested in parallel experimentally, which confirms the fundamental nature of research methods. For clarity, individual slope phenomena are grouped into mudslides-landslides [15-17], landslides and avalanches-glaciers [18-20], shown in the figures 4-6.

Figure 4. Mudflow - landslide collapses on mountain roads:
   a) mudflows; b) landslide
Figure 5. Landfall - talus phenomena: a) landslides, b) talus

Figure 6. Avalanche - glacial (ice) collapse a) avalanches; b) glacial and icy

Conclusions
1. A complex technical system - a road in mountainous conditions can be affected by slope phenomena, as well as lower slope and avalanches from the opposite slope, which change this system into a dynamic state.
2. More than ten influencing factors were identified and highlighted. The qualitative and quantitative impact on a complex dynamic system continues to be investigated.
3. Scientific and technical support of projects in complex dynamic systems is not enough, which requires a revision of the approach of design and expert organizations to the issue.

The reported study was funded by RFBR and MES RSO according to the research project №19-511-07001
References

[1] Kortiev L. I. Mountain roads and territories protection from slope phenomena: Monograph / North Caucasus Mining and Metallurgical Institute (State Technological University). Publishing house "Terek", 2016. - 215 p.
[2] Treskinsky S. A. Mountain roads. Moscow: Transport, 1974.367 p.
[3] Trofimenko Yu. V., Evgeniev IE Ecology: Transport construction and environment. M.: "Academy", 2006. 400 p.
[4] Ornatskiy N. P. Automobile roads and nature protection. Moscow: Transport, 1982.176 p.
[5] Pavlova E. I. Transport ecology. Moscow: Transport, 2000.245 p.
[6] Federal target program "Reducing risks and mitigating the consequences of natural and man-made emergencies in the Russian Federation until 2010", M., 2004.
[7] Tushinsky G. K. Protection of highways from avalanches. Moscow: Avtotransizdat, 1960.152 p.
[8] Fleig V. Attention, avalanches! Moscow: Foreign Literature, 1960.223 p.
[9] Kortiev A. L. Safety of road traffic on mountain roads with avalanche collapses. Vladikavkaz, Terek Publishing House 2016. 171 p.
[10] Khositashvili GG, Tkach VN Mechanism of landslides in central Moldova (on the example of the Bykovets support site). Issues of forecasting landslide and erosion processes // Transactions of VSEGINGEO. Issue 119.M., 1978.
[11] Utkin BV Fight against ice / In the book: Winter maintenance of highways. M.: Transport, 1983. P. 135-148.
[12] Zolotar I. A. et al. Improving the reliability of highways. Moscow: Transport, 1977.182 p.
[13] Evgeniev I. E., Karimov B. B. Automobile roads in the environment. Moscow: Transdornauka, 1997.286 p.
[14] Kudryavtsev M. N., Kaganovich V. E. Exploration and design of highways. Moscow: Transport, 1980.296 p.
[15] Areshidze G. M. Landslides of the Georgian SSR. Tbilisi: Metsniereba, 1980.153 p.
[16] Dobrov E. M. Ensuring the stability of slopes and slopes in road construction. Moscow: Transport, 1975.216 p.
[17] Drannikov A.M., Sterltses G.V. Landslides on highways. Moscow: Transport, 1974.157 p.
[18] Lackinger, B.: Der Lawinenabgang am 12 März 1988 in Biberwier aus der Sicht des Gerichtssachverständigen. Jahrbuch des Österr.Kuratoriums für alpine Sicherheit im Bergland. S. 203-234.
[19] Karl Geabl, Bernhard Lackinjer. Lawinenhandbuch. Tirol, 1996, 247 p.
[20] Berger MG On the need to carry out work to prevent catastrophic pulsations of the Kolka glacier (to the 5th anniversary of the disaster on the Kolka glacier and in the Genaldon gorge) // Proceedings of the VI International conference "Innovative technologies for sustainable development of mountainous areas." Vladikavkaz, May 28–30, 2007. Vladikavkaz: SKGMI (STU), 2007. P. 184–194.