Design of rockfall protection structures

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Abstract. The article analyses the rockfall phenomena that disrupt the continuity and safety of railway traffic in mountainous areas. The reasons causing rockfall phenomena are given. Recommendations are given for the choice of rockfall-proof structures design to ensure safe operation of facilities against rockfall processes depending on a number of initial parameters.

1 Introduction

Railway transport infrastructure is a technological complex comprising railway transport subsystems, subsystem components and elements of railway transport infrastructure subsystems that ensure the functioning of this complex. A number of factors influence the smooth operation of this complex, one of which is considered to be the climatic factor of the external environment. The climatic factor of external environment includes temperature, air humidity, air or gas pressure (altitude above sea level), solar radiation, rain, wind, dust (including snow), temperature changes, salt spray, frost, hydrostatic water pressure, action of mold fungi, air content of corrosive agentsIn Uzbekistan, as a result of the ongoing transport policy, large-scale reforms have been implemented in all sectors of the economy, in particular, the transport and communications infrastructure, namely railways and motorways with an increasing volume of passenger and freight traffic, is being developed. The main areas of scientific and technical development of construction production are reflected in the Strategy for the Development of the Transport System of the Republic of Uzbekistan for the Period to 2035 (according to Decree of the President of the Republic of Uzbekistan of 01.02.2019. No. UP-5647 "On measures to radically improve the state management system in the field of transport"; Presidential Decree No. PP-4160 of 05.02.2019 "On additional measures to improve the ranking of the Republic of Uzbekistan in the annual report of the World Bank and the International Finance Corporation "Doing Business"). [1].

Over the years of independence, Uzbekistan has been active in the construction of new highways across the country. The Navoi - Uchkuduk railway is continued to Nukus via SultonUvaistag and the sands of the Kyzylkum desert. A direct line from Karshi to Termez via Tashguzar, Baysun and Kumkurgan, 223 km long, was commissioned in 2007. The exit to the Fergana Valley through Uzbekistan is the 123-km Angren-Pap railway line, with a long and complex tunnel crossing under the Kamchik Pass [2-4].

When designing and constructing railways in mountainous terrain, large volumes of excavation and rock works are carried out and dangerous geological processes are activated.

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One of the most common physical and mechanical processes that disrupt the continuity and safety of rail and road transport in mountainous areas is rock-fall phenomena.

On the basis of many years of research on the movement of rock debris in landslides, theoretical and experimental studies, scientists and engineers have developed the basic provisions of the theory and methodology for special calculations of landslide and protective structures [3,5,6]. This marked the beginning of the widespread use of catch walls, trenches, shelves and embankments to protect the track on rockfall sections. In recent times, rational types of rockfall protection structures have been developed and successfully applied in practice.

2 Methods

The combination of factors and relative role of one or another exogenous factor in relief formation depend on climate. In this regard, the distribution of relief forms on the Earth, created mainly with the participation of exogenous processes, is subject to the law of geographic zonality. In mountainous countries vertical morphological zoning, or zonation, is evident due to differences in climate due to the altitude above sea level.

Complexes of elementary forms that are similar in appearance and origin are called genetic landform types.

Folded mountains are uplifts of the earth's surface occurring in the moving zones of the earth's crust, most often at the edges of lithospheric plates. Ridge mountains result from the formation of hills, grabens and the movement of parts of the earth's crust along faults. The folded mountains are the result of crustal areas that have been mountaineering, transformed into denudational plains and re-glaciated in the past. Volcanic mountains are formed by volcanic eruptions.

Summarising the arid topography outlined above, it is possible to classify:
- in terms of planetary landforms, the study areas belong to continental landforms;
- by relief megaform - the Alai mountain system;
- by macroform - the spurs of the Zarafshan range;
- by meso-form - mountain range, large accumulative forms such as barchan chains;
- by microform - uplands and hollows, barchans, barchan ridges;
- by nanoforms - fine erosion furrows, ripple marks on the surface of aeolian forms.

At the present time, when transport volumes are constantly increasing and traffic speeds are rising, protection of railways and roads against rockfall and landslide phenomena is of particular importance. Rockfall and landslide phenomena can cause destruction of roadway elements, accidents of road and railway transport, formation of large debris, creating traffic interruptions. The volume of rock that has fallen is used to assess rock falls. Based on the volume, landslides are divided into: very small (less than 5 m^3), small (5-50 m^3), medium (50-1000 m^3) and large (over 1000 m^3). Occasionally in natural conditions gigantic landslides are observed, resulting in the collapse of millions of cubic meters of rocks [3,5].

3 Results and discussion

The causes of rockfalls can be divided into natural-historical or passive causes, which only create favourable conditions for the occurrence of rockfalls, and active causes, which directly cause rockfalls (Table 1). The active causes that initiate landslides include dynamic impacts from traffic and seismic impacts. Seismic effects are divided into seismodynamic, seismogravitational and seismotectonic. All types of seismic impacts, from the weakest (2-4 points) to catastrophic (9 or more points), can cause landslides, the greater the intensity of earthquakes [3, 7, 8].

Table 1. Causes of rockfall phenomena.

The character	**Signs**	**Activationconditions**
Geologicalstructure		Lithology - the presence of rocks that, because of their mineralogical composition, structure and cementation conditions, are easily subject to disintegration - weathering.
		Stratigraphy - the alternation of strata of different strengths and resistance to weathering and suffusion.
		Tectonics - presence of fault surfaces, planes, separations, folds, steep dip angles of strata (particularly towards the track), etc.
Passive	Terrainconditions	Significant differences in elevation, steep slopes, cliffs, ridges, overhanging rocks, etc.
	Climatic characteristics of the area	Sharp diurnal fluctuations in temperature, intense precipitation and strong and frequent winds.
Active	Activitiesofatmosphericag ents	The weathering and disintegration of rocks.
	Groundwateractivities	Wetting along bedding planes and along fractures in rocks, reducing frictional forces, suffosion, hydrodynamic pressure, etc.
	Surfacewateractivities	Wetting of rocks, scouring, erosion and similar phenomena that disturb the stability of slopes.
Active	Seismicshocks	Breaks in rock continuity. Fracture of rock massifs.
	Humanactivities	Slope undercutting during excavation, rock disturbance during blasting, shocks from train traffic, deficiencies in current maintenance of the roadbed (e.g. poor condition of drainage structures), etc.

Rockfalls are particularly dangerous. In this regard, it is necessary to improve the structures and methods of construction of protective structures, mechanization of the processes of their erection and improvement of the quality of the performed works. Experience in the construction and operation of rockfallprotection structures shows that these structures can serve for a long time and fulfil their purpose only when the construction works are carried out at a high technical level with the fullest consideration of all factors affecting them.

The experience of rock excavation construction and operation in Uzbekistan and abroad shows that rock-fall phenomena are practically unavoidable to some extent in most cases. At the same time, collapses of relatively small volumes of rock and single debris fall out are predominant.

Since preventive mining work associated with systematic observation of the condition of slopes and their timely removal from unstable elements cannot completely eliminate the danger of random rockfalls and falling single rock debris, special anti-fall structures have to be erected when building new roads or operating existing ones in mountainous terrain [9-13].

HPPs are a formidable manifestation of natural forces. They cause the destruction of structures and loss of life. It is dangerous to build in areas prone to regular landslides. In some cases they pose a serious threat to industrial facilities, roads and entire settlements.

The first step in combating them is to carry out a geotechnical survey of the area at risk. Geologists find out the geological history and structure of the area, the composition of the rocks and the nature of their fracturing. Particularly important is the identification of their wetting and watering regime, freezing and thawing. Only with all these data is it possible to judge the degree of danger of an HPPs hazard.

Only small EPs are dealt with in practice. When a major EP is threatened, urgent evacuation of the population and assets from the entire threatened area is undertaken. In hazardous locations, measures can be taken to relocate parts of roads, power lines and facilities to a safe location, as well as active measures to construct engineering structures, such as guide walls designed to change the direction of the movement of rockfall.

Surveillance and forecasting systems are organized on the basis of hydro meteorological service institutions and are based on thorough engineering-geological and engineering-hydrological studies. Active measures to prevent landslides, rockslides, slides and rockfalls involve the construction of engineering and hydro technical structures.

If small overhanging portions of the massifs are in danger of collapse, the threat of collapse can be prevented by gradual collapse of the rocks in separate pieces. If small overhanging portions of the massifs are in danger of collapse, the threat of collapse can be prevented by gradually separating the rocks. Artificial collapse is achieved by driving metal wedges into cracks or by small explosions.

In some cases, this route can be dangerous. For example, if a landslide threatens homes or a power plant. In that case, a different route must be taken: fortifying the overhanging mountain massifs. This is achieved in different ways. In some cases, cement mortar is injected into the cracks in the rock to bind and monolith the detached parts of the massif. In other cases, iron bars are put in place to hold the individual parts of the rock together and prevent them from falling. Sometimes reinforced concrete retaining walls are used to protect roads and structures against small rock falls, just as in landslides. Where there is a serious risk of collapse, roads are tunnelled.

When there is a threat of very large landslides, it becomes necessary to organise special observations of the condition of threatening slopes. Landslide control is demanding and costly and, unfortunately, does not always have a good effect.

In each individual case, rockfall control measures must be planned in such a way that a certain protective measure is opposed to each active cause and cause of movement. Therefore, the rockfall classification for an area should be based on those characteristics that are leading in the selection of protective measures. The gradations of all the indicators studied should also be chosen, which relate to talus.

In modern construction practice, the following protective measures are used against landslides:

1) The removal of the part of the debris located above the railway slope; used when the debris is highly mobile, when the structure is of particular importance, taking into account the technical feasibility.

2) Create a buttress at the bottom of the scree by artificially moving some of the scree material there if the scree is undercut at the bottom of the slope.

3) The surface of the debris, the most unstable boulders are removed and regularly re-harvested when the total mass of the debris is sedentary.

4) Dewatering the foot of the scree (water interception), carried out primarily where there are streams or springs flowing into the scree.

5) Creation of catch walls, berms, retaining walls. The method is mainly suitable for catching individual rolling stones.

6) Construction of protective canopies over roads or derivation channels. Possible on relatively steep slopes to protect against individual rolling debris.

7) The construction of stone galleries or tunnels is necessary to pass rockfalls over the road when it is not possible to delay the slow slippage of a massif of considerable thickness.

A rockfall protection system is a key element in the design of new and maintenance of existing road, railway and other mountainous sections. The availability of these systems has a direct bearing on the safe operation of existing infrastructure [14, 15]. Changing climate, anthropogenic influences and seismic processes in the Earth's interior can have dangerous consequences in the form of falling rock and earth masses (Fig. 1).

Fig. 1. Consequences of uncontrolled rock falls: a) Rockfalls make it difficult to travel in the mountainous areas of British Columbia, Canada; b) Destructive earthquake rockfall, New Zealand; c) Clear Creek Canyon, Colorado, USA; d) A rockfall in Thailand.

The following classifications of rockfall prevention structures are prescribed by current regulations: Retaining structures designed to prevent shifts, collapses, landslides and ground falls when it is impossible or economically inexpedient to change the topography of the slope (slope) [14, 16].

These include:

- buttresses are individual supports cut into stable soil layers to support individual rock masses;

- shingles - massive structures to support unstable slopes;

- cladding walls - to protect soils from weathering and crumbling. These include protective coatings of shotcrete, sprayed concrete and aerocrete (foamed cement-sand mortar);

- anchoring - as a stand-alone retaining structure in the form of anchoring individual rock blocks to a solid mass on rock slopes (slopes).

- retaining structures and devices (walls, gabions, nets, shafts, trenches, berms) provided to protect facilities from the effects of rockfalls, landslides, falling single rock debris, where it is not possible or economically feasible to construct retaining structures or prevent rockfalls by removing unstable massifs.

- anti-collapse galleries.

The latter were until recently considered as a necessary and only technical solution aimed at the protection of landslide sections of railway tracks, roads, pedestrian routes. Indeed, galleries made of precast, monolithic reinforced concrete and piecework materials are used worldwide as a reliable engineering structure (Fig.2).

The following features can be attributed to the technical solution described above:

-wide range of applications (calculated impact energy 200-3000 kJ),

- the possibility of a shock-absorbing backfill, which can soften the effect of the impact.

At the same time, anti-fall galleries have a number of disadvantages:

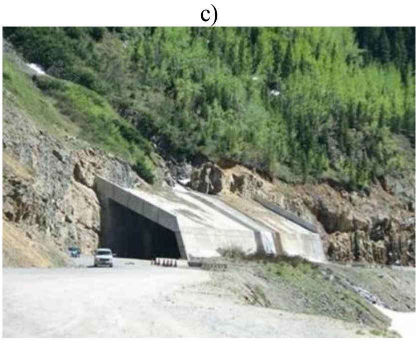
- falling debris with an impact energy of 5000-8000 kJ destroys the reinforced concrete structures of the galleries;
- huge labour costs when erecting capital structures on slopes;
- due to labour costs high construction costs;

-capital construction entails interfering with the existing ecological situation on the slope.

a)

b)

c)



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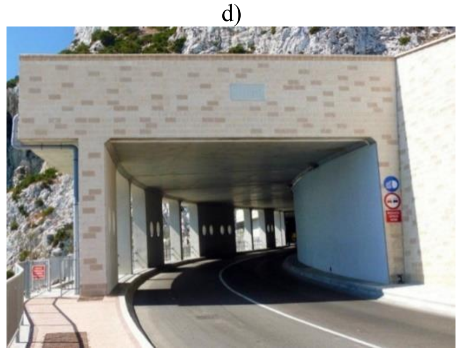

Fig. 2. Anti-fall galleries around the world: a) Gallery on the Krugobaikalskaya railway, Russia; b) Gallery on the Krugobaikalskaya railway, Russia; c) Anti-slip gallery, USA; d) DudleyWard Tunnel, Gibraltar.

Recent developments in rockfall protection with flexible catching systems (flexible rockfall barriers) (Fig. 3), make it possible to provide cost-effective protection even in areas where it was previously considered impossible or too costly. This solution has a wide range of applications, making it an alternative to traditional slope protection systems.

Fig. 3. Flexible anti-campaign barriers.

The barriers can absorb impact energies of up to 8000kJ, which is comparable to a 20 metric tonne block falling at over 100km/h. The absorption performance of the barriers has been obtained by in-situ testing under the most stringent vertical drop conditions, in accordance with the European Norm ETAG 027 and the Swiss Norms for type testing of anti-crash barriers [5, 14].

In addition to the advantages of using flexible site protection solutions described above, the following can be added

- less work, high speed of structure installation;
- lightness;
- cost-effective - the individual elements of the system are perfectly matched to each other, thus minimising the amount of consumables;
- environmentally friendly - unlike solid structures, flexible barriers do not disturb the landscape.

4 Conclusion

1. Analysis of the occurrence of hazardous mining exogenous processes (HPPs) on railways has been carried out.
2. Protection technologies and measures to prevent railway collapses from mining HPPs are given.
3. The development of areas with difficult topography often requires the consideration of unfavorable natural influences, which include rockfall.
4. In order to ensure the safe operation of facilities against rockfall hazards, it is necessary to install rockfall protection structures, which are of different designs depending on a number of initial parameters.
5. Modern rockfall barriers must not only contain the energy from the rockfall process, but also be technologically advanced, economical, durable and have minimal environmental impact during installation.

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