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ENGINEERING-GEOLOGICAL FEATURES OF ROCKS CAUSING LANDSLIDE HAZARDS ON SECTIONS OF MOUNTAIN ROADS

АВТОМОБИЛЬ ЖОЛДАРЫНЫҢ ТАУЛЫ УЧАСКЕЛЕРІНДЕ КӨШКІН ҚАУПІН ТУДЫРАТЫН ТАУ ЖЫНЫСТАРЫНЫҢ ИНЖЕНЕРЛІК-ГЕОЛОГИЯЛЫҚ ЕРЕКШЕЛІКТЕРІ

ИНЖЕНЕРНО-ГЕОЛОГИЧЕСКИЕ ОСОБЕННОСТИ ГОРНЫХ ПОРОД, ВЫЗЫВАЮЩИЕ ОПОЛЗНЕВЫЕ ОПАСНОСТИ НА ГОРНЫХ УЧАСТКАХ АВТОМОБИЛЬНЫХ ДОРОГ

Abstract. *In the mountainous regions of Kazakhstan there are problems associated with landslides of soil masses from mountain slopes. The reserch of processes such as landslides and their impact on infrastructure, especially road networks, continues to be a pressing issue in mountainous regions. In various countries of the world, including Kazakhstan, the USA, Italy, Japan, Switzerland and others, landslides are one of the pressing problems. The article examines the research on problem associated with landslide processes in the mountainous regions of Kazakhstan and foreign. Also analyzes the emergence of defects on road surfaces and in the embankment structure, particularly where roads pass through mountain slopes the "Zharkent-Koktal-Arasan" road section as an example Kazakhstan. This problem is relevant, since landslides pose a threat to the safety of people and vehicles, and also provide a reliable start to the destruction of the road situation. The fact that landslides are serious phenomena, issues related to the impact of landslides on roads remain poorly studied in the road soil of Kazakhstan, which requires the need to conduct research in this area.*

Special attention is given to defects such as the swelling of road surfaces, which can be explained by the movement of landslide masses that push the earth upward. This phenomenon is linked to the presence of thick layers of poorly lithified loose sedimentary deposits that have accumulated due to tectonic processes. The findings of this study will help better understand the mechanisms of landslide processes and their impact on the stability of road infrastructure. This will contribute to the development of measures to prevent and minimize the damage caused by landslides, thereby increasing the safety of road traffic in Kazakhstan's mountainous regions.

Keywords: *landslides, road, mountain slopes, crack, soil.*

Аңдатпа. *Қазақстанның таулы аймақтарында тау беткейлерінен топырақ массаларының көшкінімен байланысты проблемалар бар. Көшкін сияқты процестерді және олардың инфрақұрылымға, әсіресе жол желісіне әсерін зерттеу таулы аймақтарда өзекті мәселе болып қалуда. Әлемнің әртүрлі елдерінде, соның ішінде Қазақстанда, АҚШ-та, Италияда, Жапонияда, Швейцарияда және т.б. көшкіндер өзекті мәселелердің бірі болып табылады. Мақалада Қазақстанның таулы аймақтарындағы және шетелдердегі көшкін* *процестеріне байланысты проблемаларды зерттеу қарастырылған. Сондай-ақ, Қазақстандағы Жаркент-Көктал-Арасан жол учаскесін мысалға ала отырып, әсіресе жолдар тау беткейлері арқылы өтетін жерлерде жол жабындары мен жағалау құрылыстарындағы ақаулардың пайда болуы талданады. Бұл мәселе өзекті, өйткені көшкіндер адамдар мен көліктердің қауіпсіздігіне қауіп төндіреді, сонымен қатар жол ортасын бұзудың сенімді бастапқы нүктесі болып табылады. Көшкін – күрделі құбылыс болғандықтан, Қазақстанның жол топырақтарында көшкіндердің жолдарға әсерімен байланысты мәселелер әлі де аз зерттелген, бұл осы саладағы зерттеулерді қажет етеді. Жол жабындарының ісінуі сияқты ақауға ерекше назар аударылады, мұны жерді жоғары қарай итермелейтін көшкін массаларының қозғалысымен түсіндіруге болады. Бұл құбылыс тектоникалық процестер нәтижесінде жинақталған әлсіз тасталған борпылдақ шөгінділердің қалың қабаттарының болуымен байланысты. Бұл зерттеудің нәтижелері көшкін процестерінің механизмдерін және олардың жол инфрақұрылымының тұрақтылығына әсерін жақсы түсінуге көмектеседі. Бұл көшкіндердің залалының алдын алу және барынша азайту бойынша шараларды әзірлеуге, сол арқылы Қазақстанның таулы аймақтарында жол қозғалысы қауіпсіздігін арттыруға ықпал етеді.*

Түйін сөздер: *көшкін, тас жол, тау беткейлері, жарықтар, топырақ.*

Аннотация. *В горных регионах Казахстана существуют проблемы, связанные с оползнями грунтовых масс со склонов гор. Исследование таких процессов, как оползни и их влияние на инфраструктуру, особенно дорожную сеть, продолжает оставаться актуальной проблемой в горных регионах. В различных странах мира, включая Казахстан, США, Италию, Японию, Швейцарию и другие, оползни являются одной из актуальных проблем. В статье рассматриваются исследования проблем, связанных с оползневыми процессами в горных регионах Казахстана и за рубежом. Также анализируется возникновение дефектов на дорожных покрытиях и в конструкции насыпи, особенно там, где дороги проходят через горные склоны на примере участка дороги «Жаркент-Коктал-Арасан» в Казахстане. Данная проблема является актуальной, так как оползни представляют угрозу безопасности людей и транспортных средств, а также являются надежным началом разрушения дорожной обстановки. Поскольку оползни являются серьезными явлениями, вопросы, связанные с воздействием оползней на автомобильные дороги, остаются малоизученными в дорожных грунтах Казахстана, что обуславливает необходимость проведения исследований в этой области. Особое внимание уделено такому дефекту, как вспучивание дорожных покрытий, которое можно объяснить перемещением оползневых масс, выталкивающих землю вверх. Это явление связано с наличием мощных слоев слаболитифицированных рыхлых осадочных отложений, накопившихся в результате тектонических процессов. Результаты данного исследования помогут лучше понять механизмы оползневых процессов и их влияние на устойчивость дорожной инфраструктуры. Это будет способствовать разработке мер по предупреждению и минимизации ущерба от оползней, тем самым повысив безопасность дорожного движения в горных районах Казахстана.*

Ключевые слова: *оползни, автомобильная дорога, горные склоны, трещина, грунт.*

Introduction. In the mountainous regions of Kazakhstan there are problems associated with landslides of soil masses from mountain slopes. Landslides are a dangerous geological phenomenon that can cause significant damage to road infrastructure, especially in mountainous areas. The impact of landslides on roads varies depending on geological conditions, climatic factors and human activity. The problem of landslides is relevant for many countries, where mountain roads and transport networks are subject to destruction as a result of these processes.

Research conducted in different countries shows the impact of landslides on transport routes and measures taken to protect them. In Kazakhstan, landslides are one of the main threats to roads. Kucherov and Zharikov (2019) studied the geological conditions of this region, finding that the main causes of landslides are both natural factors, such as intense precipitation, and anthropogenic impacts, including road construction and deforestation. In their study, they drew attention to the importance of geotechnical surveys to prevent destruction. Salyk and Madiyev (2017), in turn, analyzed defects in road surfaces that arise as a result of landslides and proposed methods for slope strengthening and soil stabilization. In the United States, the problem of landslides is especially relevant for regions such as California, Oregon, and Washington, where intense rainfall and earthquakes can cause abrupt changes in soil conditions. Montgomery and Dietrich (1994) proposed a physically based model for predicting landslides based on the study of the water regime, soils, and tectonic movements. Wosowski and Allasia (2017) studied in more detail the impact of climate change and tectonic processes on landslides, highlighting that changes in precipitation intensity and earthquake frequency significantly increase the probability of landslides in some regions of the United States.

Italy, with its mountainous regions, also experiences regular landslides, especially in the Alps and the Apennines. Gori and Guerriero (2016) studied the influence of geological and tectonic factors on landslide development in their study. They found that most landslides in Italy are caused by rocky slopes and earthquakes that are common in the country. Malaggini and D'Amico (2015) developed methods for monitoring and mapping landslides, taking into account their impact on road infrastructure. They proposed a protection system that includes slope stabilization using geogrids and improved drainage systems. In Japan, landslides are a serious threat, especially in areas prone to earthquakes and intense rainfall, such as the Japanese Alps and the islands of Kyushu and Honshu. Tatsuoka and Shiono (2015) show in their research how seismic activity affects slope instability, causing landslides. They also suggest using remote sensing technologies to more accurately predict these phenomena. Fujimoto and Ueda (2019) studied the geological conditions that contribute to landslides, including complex tectonic movements that create areas with high seismic activity. These studies highlight the need for regular geotechnical inspections and the adaptation of road infrastructure to changing conditions. In Switzerland, with its Alpine roads, landslides are a constant threat to the transport network. Rickenmann and Zimmermann (2016) investigated debris flows and their impact on road infrastructure in the Alps, emphasizing that these flows often cause road failures and require not only rehabilitation but also preventive measures. They proposed a forecasting and monitoring system that allows for the rapid identification of hazardous areas and the adoption of measures to prevent catastrophic consequences. The work of Grutzner and Bieri (2014) also touched upon the impact of climate change on landslide intensity, arguing that rising temperatures and more frequent precipitation accelerate slope failure processes. In China, especially on the Tibetan Plateau, landslides have a serious impact on road infrastructure. Li and Wang (2018) investigated landslide risk assessment methods in areas with difficult geological conditions and proposed approaches to minimize damage. An important part of their work was the development of a soil monitoring system that allows predicting landslide occurrence with a high degree of accuracy. Zhang and Liu (2017) add that intense seismic processes in these areas also contribute to landslides, which requires the adoption of sustainable technologies for road construction.

India, with its mountainous regions such as the Himalayas and the Western Ghats, also faces the problem of landslides. Saha and Kumar (2020) analyze the impact of landslides on the road network in the Himalayas and propose new methods for slope stabilization. Their work considers not only geological and climatic factors, but also anthropogenic ones such as deforestation and disturbance of the natural landscape. Reddy and Natarjan (2016) emphasize that effective landslide management requires the integration of geotechnical surveys and improved monitoring of weather conditions.

In Brazil, landslides are also a problem on mountain roads, especially in the Serra-Geral region. Silva and Monteiro (2015) investigated geological conditions that favor landslide occurrence, such as weak rock consolidation and high rainfall. Costa and Ribeiro (2019) proposed road protection systems, including slope stabilization with geogrids and improved drainage systems.

Materials and research methods. In regions like Kazakhstan, Japan, and Switzerland, local geological conditions – such as soil composition, moisture content, and slope angle – are key determinants of landslide risk. For instance, Denisov (1956) discusses the characteristics of clay rocks in hydraulic engineering, and their role in slope failure in specific terrains. Mustafaev et al. (2011) add depth to this by detailing hazardous geological processes in Southeast Kazakhstan, including those caused by landslides, which often destabilize roads and embankments.

Additionally, Bondarik et al. (2007) emphasize the importance of engineering geodynamics in managing the dynamic interactions between landslides and constructed infrastructures. Understanding these interactions helps in developing better engineering solutions for road stabilization and safety.

Effective landslide management involves preventive measures like soil stabilization, drainage systems, and geotechnical monitoring. Works by Tsai et al. (1984) and Rzhanitsyn (1986) discuss methodologies for stabilizing soils and protecting infrastructures in challenging geological conditions. Khomyakov (2013) highlights the stabilization of gravelly soils in urban underground constructions in Almaty, which is relevant to cities facing similar geotechnical challenges.

Moreover, Sagybekova et al. (2019) explore coarse-grained soil testing for construction applications, providing insight into how soil testing and stabilization methods can mitigate the impact of landslides in both mountainous and urban environments.

Such phenomena are also observed on the Zharkent-Koktal-Arasan highway. Geographically, this road is confined to the Dzungarian Alatau, the southern spur of the Dolantau ridge , and the southern-facing slope. The slope slopes and exposure are the dominant factors in the formation of the landslide slope (Fig. 1, Fig. 2).

Figure 1. Landslide area (top view)
Note – compiled by the author (Sagybekova, 2024)

The geological structure of the site includes effusive formations of the Carboniferous period of different ages. These are undifferentiated Lower Carboniferous tuff deposits of medium composition, as well as tuffs and tuff lavas of the Upper and Middle Carboniferous age, represented by rocks of medium and acidic compositions. The deposits are highly dislocated and weathered, (C 2-3, m, n). In the southeast, at 300, 400 метрахthey are overlain by loosely detrital Neogene and Paleogene deposits.

On the landslide section of this road, the landslide body is represented by coarse-grained boulder-gravel – sand formations of the Upper Quaternary and modern age (Q_{III-IV}) of deluvial-proluvial genesis.

The movement of a landslide is evolutionary in nature (slow sliding) as a result of the constant introduction of debris into the upper part of the landslide body, which, when “loaded”, presses on the lower block and moves it onto the road.

The swelling of the road surface can be partly explained by the fact that the body of the landslide, resting on the beam of the bedrock near the "tongue" of the landslide, squeezes it upward. This also partially occurs due to the action of water near the road surface, which also freezes and thaws.

Next to the road there are rows of wells-collectors, which are clogged with debris. This explains the movement of the landslide upwards and towards the Borokhudzir River. In the upper part, north-east of the landslide body, cracks of the second order of separation began to form (Fig. 2).

Figure 2. II-nd rupture crackorder in the landslide area
Note – compiled by the author (Sagybekova, 2024)

Results and their discussion. The main sliding crack has been formed for a long time (5-10 years) and is gradually increasing. The magnitude of the evolutionary shift according to the survey data does not exceed 0.6 1,1 мper year, but is constantly increasing. The granulometric composition of the landslide soils is shown in Table 1, the soils belong to the 3rd complexity category (according to mechanical development).

Table 1. Granulometric composition of landslide deposits on the Borokhudzir River

Locations	Blocks 100 1000 мм % or more	Crushed stone 10-100 мм, %	Wood chips 1-10 мм, %	Sand 0.1-10 мм, %	Aleurite, pilite <-0.1 mm, %
Upper ledge of the landslide	15	30	25	18	12
Middle part of the landslide	12	32	30	16	10
The lower part ("tongue") of the landslide	10	35	35	8	12
Note – compiled by the author (Sagybekova, 2024)					

Previously conducted studies of the geological structure of the region where the Zharkent-Koktal-Arasan highway passes show that the studied slope is characterized by the predominant development of various metamorphic, sedimentary and magmatic formations of the pre-Paleozoic and Paleozoic eras. Mesozoic rocks represent large intermountain depressions. Cenozoic deposits are developed mainly in internal and intermountain depressions, erosion valleys and on mountain slopes. They are represented by crystalline schists, quartzites, and less often gneisses with interlayers of marble and amphiboles. Contrasting tectonic movements caused the formation of mountain ranges and intermountain depressions, in which powerful strata of weakly lithified loose-clastic formations accumulated.

Cobblestones taken from the floodplain of the Borokhudzir River for the purpose of using them as rubble stone revealed the following values: water absorption – 42-56%, softening coefficient – 0.56-0.70, loss of strength after 25 freezing cycles – 42-56%, temporary compressive strength of water-saturated samples – 21-55 MPa.

The rocks on the slopes of the Dzungarian Alatau mountains, where the studied section of the Zharkent-Koktal-Arasan road passes, are characterized by the following properties: for granites of medium- and fine-grained structure, the ultimate compressive strength of dry rock reaches 150-174 MPa; in a water-saturated state – 146-171 MPa, after 10 freezing cycles – 139-169 MPa; softening coefficient – 0.94; frost resistance – 0.07-0.16; water absorption – 0.18-0.32%. The given indicators characterize the rocks of all groups of Paleozoic formations as very strong (Table 2).

Table 2. Physical and mechanical properties of rocks of the metamorphic group of formations of the pre-Paleozoic and Paleozoic

Indicators	Porphyrites, quartz porphyrites and diorite porphyries	Effusives and pyroclasts, carbonate – siliceous shales	Carbonate-carbonate, carbonaceous-clayey shales
Particle density	2.90-3.01 2.96 (31)	2.73-2.75 2.74 (14)	2.71-3.11 2.89 (9)
Density, t/ ^{m3}	2.65-2.91 2.82 (31)	2.66-2.81 2.72 (14)	2.04-3.40 2.76 (9)
Porosity, %	2.4-8.6 5.5 (31)	0.7-0.75 0.7 (14)	0.7-13.8 3.7 (9)
Strength limits, 10^{-1} MPa: – compression – for stretching	2010-2899 2640 (31) 120-183 169 (27)	1180-2610 1890 (17) 150-291 221 (11)	526-3230 1860 (6) 181-266 232 (6)
Angle of internal friction, degrees	30-49 37 (24)	39-50 45 (17)	30-37 32 (6)
Adhesion, MPa	28.5-51.0 38.2 (24)	16.0-38.2 27.2 (17)	5.5-34.0 0.6 (6)
Modulus of elasticity, MPa	0.5-0.9 0.6 (38)	0.5-0.9 0.8 (17)	0.5-1.2 0.6 (6)
Poisson's ratio	0.19-0.25 0.22 (38)	0.18-0.30 0.24 (17)	0.24-0.35 0.28 (6)
Note – compiled by the author (Sagybekova, 2024)			

The complex of Quaternary alluvial-proluvial deposits is developed at the foot of the Dzungarian Alatau mountains, on the landslide slope of the Dolantau ridge and is represented by block-crushed rock material with sandy-clay filler. Coarse-grained material is usually poorly rounded and prone to sliding. The deposit surfaces are covered by layered loams with a thickness of 5-10 м. The physical and mechanical properties of loamy rocks analyzed in the KazADI laboratory are given in Table 3.

Table 3. Physical and mechanical properties of loamy soils of the complex of Quaternary alluvial-proluvial deposits

Indicators	$a_r Q_I$	$a_p Q_{II-III}$		$a_p Q_{III-IV}$	
	Sandy loam	Sandy loam	Loam	Sandy loam	Loam
Particle density, t/ m^3	2.67-2.76 2.68 (12)	2.65-2.90 2.72 (27)	2.60-2.82 2.73 (99)	2.68-2.87 2.72 (5)	2.74-2.77 2.75 (5)
Density, t/ m^3	1.28-1.53 1.45 (12)	1.37-1.74 1.51 (27)	1.29-1.84 1.51 (99)	-	1.44-1.64 1.50 (5)
Skeletal density, t/ m^3	1.26-1.52 1.44 (12)	1.33-1.67 1.47 (27)	1.09-1.77 1.43 (99)	1.14-1.81 1.45 (5)	1.35-1.46 1.40 (5)
Porosity, %	44-52 47 (12)	38-50 45 (24)	35-59 47 (99)	-	47-51 49 (5)
Moisture content at yield point, %	-	20-24 22 (16)	22-38 26 (99)	18-41 29 (5)	26-29 27 (5)
Plasticity index, %	-	3-7 26 (9)	6-17 10 (99)	0.8-7.0 4 (5)	10-12 23 (5)
Angle of internal friction, degrees: – at natural humidity – with soaking in water	- -	25-27 26 (9) -	7-48 25 (52) 7-25 18 (56)	8-31 23 (5) -	- -
Adhesion, 10^5 , MPa: – at natural humidity – with soaking in water	- -	- -	0.04-1.60 0.94 (50) 0.04-0.75 0.30 (54)	0.08-1.35 0.38 (5) -	- -
Note – compiled by the author (Sagybekova, 2024)					

Elimination of one of the main causes of landslides, changes in the stress state of clay rocks, can be achieved by leveling the slopes. On gentle slopes or embankments there will be no pressure drop, which means there will be no clay flow. This creates the need to move earth masses in order to unload the upper part of the slope by cutting and to load the foot of the slope. If it is impossible to cut the upper part of the slope, it is necessary to load the foot of the slope; for this purpose, an earthen bench is poured in the place of possible uplift of the foundation.

The specified measures can be correctly designed only with verification calculations of the slope stability coefficient n . First of all, it is necessary to calculate n of the slope before the construction of the road, and then check the value of n after filling the embankment or driving the excavation.

To calculate the coefficient of stability of a slope composed of heterogeneous soil layers, it is recommended to use the Maslov- Behrer horizontal force method . This method allows one to graphically or analytically determine the active soil pressure within a selected block as on a retaining wall with a vertical rear edge and with a sliding surface inclined to the horizon. The friction of the face is not taken into account.

The calculation is made according to the following formulas:

$$H = P\ tg\ \alpha\ , \qquad (1)$$

where H is the pressure on an imaginary wall in the absence of friction and adhesion in the soil;

P – weight of the calculation block;

α – the slope of the sliding surface to the horizon (the sign of the angle function α determined in accordance with trigonometric rules).

$$R = P\ tg\ (\alpha - \varphi_p) \qquad (2)$$

where R *is* the unquenched part of the pressure (active pressure); φ_p – angle of shear resistance at stress p.

Thus, knowing the value of the angle of internal friction φ, the adhesion c from laboratory tests and the stress p , the value of the angle of resistance to shear is calculated. Then the part of the total pressure on the imaginary wall that is perceived by friction and adhesion in the soil is calculated T:

$$T = H - R = P\ [\ tg\ \alpha - tg\ (\alpha - \varphi_p)]. \qquad (3)$$

Conclusion.

The combined knowledge from these references offers a solid foundation for understanding landslide hazards and their management in various countries. By integrating geotechnical engineering practices and landslide risk assessments, it's possible to mitigate the impacts on road infrastructure and urban development, especially in seismically active or geologically unstable regions.n the mountainous regions of Kazakhstan there are problems associated with landslides of soil masses from mountain slopes. Such phenomena are also observed on the Zharkent-Koktal-Arasan highway. Geographically, this road is confined to the Dzungarian Alatau, the southern spur of the Dolantau ridge , and the southern-facing slope.

Thus, the calculation by the method of a circular cylindrical surface is reduced to finding (by selection) the most dangerous sliding surface. In practice, the calculation is carried out by a circular cylindrical surface (the method of K. Terzaghi).

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