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Existing constructive solutions for flood protection

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Abstract: Structural solutions for mudflow protection are technical and engineering solutions developed to protect structures from the negative consequences of mudflows, which mainly consist of a complex of measures implemented during the design, construction, and operation of structures. These solutions include special construction and technological methods to ensure infrastructure safety and minimize damage caused by mudflows. This article provides an analysis of existing methods for protecting bridge structures from mudflows. For the effective practical application of technical and technological measures to prevent the negative consequences of this mudflow threat, their adaptation to local conditions, along with world best practices in protecting against mudflow danger, a comparative analysis of local methods is of current importance.

Keywords: Mudflow, debris flow protective structures, bridges, constructive solution, technological measure

1. Introduction

A mudflow is a dynamic mass consisting of a multiphase medium with high kinetic energy, consisting of sand, gravel, rock fragments, clay, and other rocks, and this geodynamic phenomenon can cause serious damage to engineering infrastructure in mountainous and foothill areas. A number of engineering and technical solutions, i.e., structural protective measures, are used to prevent rocky mudflows, control their direction, or reduce the negative impact of their consequences.

2. Research methodology

Specially designed and constructed barrier basins in the flow direction retain stones and mud from the mudflow, allowing multi-phase purified water flow. As a result, the kinetic energy of the flow and the risk of soil erosion are reduced, and the elements of engineering and civil buildings and structures located within the radius of flow propagation are protected from the direct impact of mudflows. Solid components accumulated in the reservoirs can be safely removed, which mitigates the force of the hydraulic shock and increases the stability of hydraulic structures in the direction of the flow (Fig. 1).

Fig. 1. Special reservoirs built in the direction of mudflow

Barrier basins are engineering protective structures that allow the removal of solid-phase components (stones, sand, clay, and other particles) from the mudflow, and there are a number of factors limiting the late practical application of this design solution.

To ensure the functional continuity of these structures, there is a need for the utilization of solid components based on periodic mechanized technologies, which is characterized by the complexity of the operational process and the high level of operating costs. Limited resources (land resources) create technical and economic difficulties in implementing such systems, especially in densely urbanized or complex topographically structured areas (mountainous and foothill). Also, barrier basins are effective only in areas where extreme hydrological conditions and high-intensity mudflows are observed, they cannot fully utilize their functional capabilities during normal rainfall, and their productivity drops to almost zero. In general, despite the high technological significance of barrier basins in mudflow management, due to the intensive labor intensity of operational maintenance and territorial limitations, they are not used as a suitable (universal) solution for all conditions.

Elastic grating barriers made of high-alloy steel wires are one of the design engineering solutions that dissipate the dynamic loads of mudflows with high kinetic energy, intercept solid particles of large fractions, and absorb the impact. These systems are typically integrated with shock-absorbing support elements, elastoplastic grip mechanisms, and deformable binding elements, designed for segmental suction of the flow shock impulse (Fig. 2).

Fig. 2. Special wire mesh built in the direction of the mudflow

Despite a number of structural advantages, a high degree of local deformation and elastoplastic fatigue, as well as micro cracks in the crystal lattice of the metal, formed as a result of impulse impacts of the mudflow, leads to the degradation of the mechanical properties of the structure. As a result, it becomes necessary to regularly recalibrate or

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replace elements that have undergone a certain degree of deformation. The structure has high sensitivity to asymmetrical external loads, and as a result of the uneven mass distribution of particles of large fractions in the flow, the deformation process occurs asymmetrically. This leads to an unconventional and uneven distribution of internal stresses in structural elements, the emergence of local stress zones, and an increase in the probability of fatigue of the material. This situation increases the risk of steel wire barriers breaking.

Despite the fact that elastic grille barriers have a high degree of dynamic stability as a modern, energy-absorbing, deformable engineering solution, their susceptibility to mechanical fatigue, complexity of maintenance, high capital costs do not allow them to be used as a rational structural solution that protects against mudflow hazards.

Multi-stage energy dissipation systems, arranged in stages parallel to the flow direction, are hydraulic shock absorbers aimed at dissipating the kinetic component of the mudflow, reducing transit loads, and separating solid-phase components (gravel, stones, rock fragments, and clay) by creating local sedimentation zones. This not only reduces erosion processes, but also ensures the safety of structures located in the lower part (Fig. 3).

Fig. 3. Special multi-stage dams built in the direction of mudflow

Nevertheless, this multi-stage dam system leads to a significant increase in the overall hydraulic inertia and the coefficient of hydraulic resistance in the flow direction. This situation is accompanied by an artificial increase in transitions between laminar-turbulent regimes in the flow. Continuous accumulation of solid-phase mass in the flow leads to a disruption of sedimentation equilibrium over time and local stabilization of the sedimentary layer. Also, in the process of stepwise dissipation of energy, secondary hydrodynamic caverns are formed as a result of pulsed flow attenuation between the steps. In these areas, zones of local vortex flow and cavernous erosion centers appear, which negatively affect the stability of the soil layer at the base of the structure. As a result, the stability of the structure's foundation is at risk, the operational throughput potential decreases, and the maintenance interval is reduced.

Fig. 4. Special multi-stage dams built in the direction of mudflow

Engineering structures designed to direct mudflows in safe directions are hydraulic structures designed in accordance with the natural relief and hydrological conditions and serving to prevent mudflows, manage them, and protect socio-infrastructure facilities from direct impact. These structures, as a rule, minimize the techno genic and environmental damage caused by mudflows and increase the level of regional security by diverting the flow in alternative directions with safe energy distribution (Fig. 4).

Such structures include mudflow direction walls, dams, drainage canals, and buffer basins. They perform the function of reducing the kinetic energy of the mudflow, retaining solid fractions, and controlling the direction of water to safe areas. The design and placement of these structures are carried out depending on the relief, hydrological conditions, characteristics of mudflows, and the location of objects requiring protection. These systems also have a number of functional and structural limitations in their practical application, and the complexity of design and the dependence of their application on the terrain are considered the main shortcomings. In this case, systems designed to change the flow direction require a high level of hydro morphological analysis, digital terrain modeling, and simulation flow analysis. In complex geo topographic conditions, these systems lose their adaptability, and the risk of diverting mudflows remains. That is, in the event of a large volume of mudflow, secondary danger zones may arise in areas considered safe.

In the event of extreme precipitation or geodynamic activity (landslides, earthquakes), these structures may not be able to withstand the external load at the level specified in the project, which leads to violation of the structural integrity of the system, failure of local elements, and the occurrence of hydraulic failures. As a result, the functional efficiency of the structure decreases, and in emergency situations, the possibility of flow control is partially or completely lost. Therefore, when designing such structures, multi-variant hydraulic modeling should be carried out, taking into account extreme mudflow scenarios.

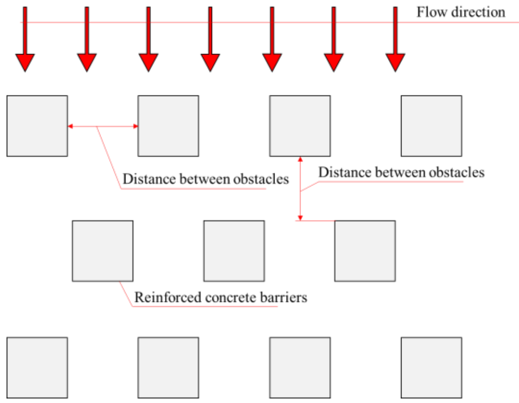

Fig. 5. Protective structure blocking mudflow

Figure 5 shows a structural barrier built to reduce the risk of mudflow to structures, which is placed at different angles or perpendicular to the flow direction. The main task of this structure is to reduce the negative impact of mudflow hazard on engineering structures and facilities by directing mudflow flows to a safe area.

In this case, it is recommended that the distance between barriers be from 0.5m to 2.0m in accordance with the local conditions of the designed territory (flow velocity, water level, and hydraulic pressure), and the distance between barriers - from 1.0m to 3.0m, and the dimensions of the barriers - from 0.5x0.5m to 1.5x1.5m. A correctly chosen size and slope can reduce mudflow energy from 40% to 70%.

This engineering structure is usually reinforced with reinforced concrete or natural stones and is considered a reliable structural solution that can withstand the hydraulic pressure of a mudflow. This barrier, having the shape of a rectangular column, receives the impact of the mudflow and directs it in a lateral direction. As a result, the current strength dissipates, and its kinetic energy decreases. Such structures are usually designed in mountainous and lowland areas with a high probability of mudflows. Also, for the effective operation of these types of protective structures, their condition must be constantly monitored. Through systematic visual observation and technical inspections, cracks or material degradation are detected, and timely preventive repair work is recommended.

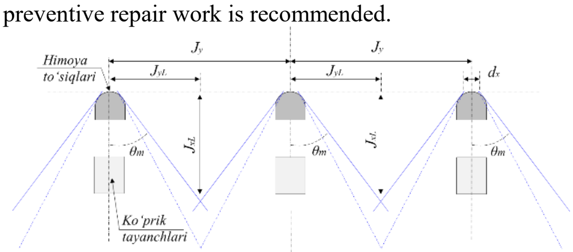

Fig. 6. Protective structure blocking mudflow

The engineering solution presented in this figure is a system of protective barriers aimed at reducing the hydrodynamic impact of mudflows on the supports of bridge structures. Protective barriers are installed in the front part of supporting bodies in the direction of the flow and serve to reduce the speed and impact force of the mudflow. They are usually built in the form of reinforced concrete, gabion, masonry mesh, or solid granite blocks.

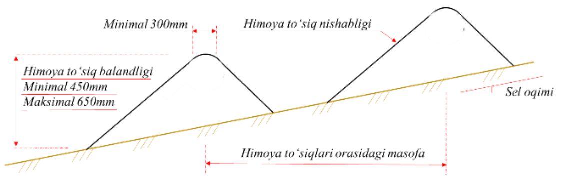

Fig. 7. Protective structure blocking mudflow

A protective dam is a temporary or permanent structure used to reduce erosion processes associated with mudflows, rainwater, or streams, and to regulate mudflows. These structures are designed for areas where there is no constant flow, but during rains or mudflows, strong water flows occur. That is, these protective dams slow down light or moderate mudflows that occur after rain in mountainous or sloping areas, gradually directing them downstream. Several such dams are constructed sequentially in a chain pattern. These protective dams are an effective, inexpensive, and convenient engineering solution for protecting against small and medium-level mudflows. It slows down the mudflow, prevents erosion and soil erosion, and safely directs the flow downstream.

3. Conclusion

Mudflows, in particular, rocky mudflows, are high-energy flows arising under the influence of hydro meteorological and geodynamic factors, containing a large amount of water, gravel, stones, and hard rocks, which pose a serious danger in mountainous and foothill areas. Such flows have a negative impact not only on infrastructure facilities, but also on the environment, socio-economic activity, and the safety of human life. That is why the application of complex engineering and man-made solutions for the prevention and management of rocky mudflows is of great importance. Therefore, the above-mentioned solutions used to reduce mudflow risk are selected as a complementary combined system depending on the characteristics and natural conditions of the territory.

Moreover, for such structures to fulfill their functional purpose, a thorough analysis of the geological and hydrological conditions of the area, the correct selection of building materials, and a thorough design process are necessary. Regular monitoring and maintenance of the condition of protective dams ensure their long-term effectiveness. That is, existing engineering solutions for reducing mudflow risks should be constantly modernized and improved through the introduction of modern scientific approaches, digital modeling technologies, and environmentally friendly innovative methods.

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