INNOVATIVE METHODS FOR USING NATURAL AND TECHNOLOGICAL CONSEQUENCES FROM DEBRIS FLOWS

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Abstract

There are numerous engineering and management methods to protect various settlements, industrial facilities and economic infrastructure, as well as people and animals, from large-scale debris flows. Debris flow protection structures are mainly constructed from reinforced concrete, metal, and local soil (protective dams). Structures containing components made from recycled waste materials, such as used metal drilling pipes, car tyres and reinforced concrete railway sleepers, have also proven to be effective. Natural formations, such as depressions and ravines, are often incorporated into the design of engineering measures for debris flow protection. Large boulders, which are products of glacial activity or rockfalls, are a common feature of mountainous regions and are often incorporated into the design of such structures. Towards the end of the last century, a group of Russian authors proposed using large boulders in the construction of debris flow protection structures. These boulders were anchored to the riverbed and to each other using a complex cable-and-anchor system. However, the effectiveness of this engineering concept was undermined by the weak anchoring system used. In the present study, the authors proposed an improved method for securing and fixing boulders in debris flow protection systems: metal piles made from pipes or standard metal profiles should be used. These piles are passed through vertical through-holes drilled along axes passing through the centre of gravity of each boulder, and are embedded into the riverbed to the required depth. Risk analysis of the potential consequences of debris flows has shown that using large natural boulders as the main elements in debris flow protection structures, in combination with a reliable anchoring system, significantly increases the reliability of these structures at relatively minimal cost. At the same time, the sustainable protective structures preserve the geoecological landscape attractiveness of mountainous areas.

Keywords: debris flow, construction, petrostructure, risk, riverbed, pile, building, catastrophe

I. Introduction

Debris flows are widespread in mountainous regions and, in some cases, in elevated plains. In inhabited areas, debris flow events often result in human casualties and considerable material damage. Cities and settlements, railways and highways, power and communication lines, oil pipelines, canals, agricultural lands, and recreational areas are frequently affected by debris flows. Various methods of protection against debris flows have been explored in the works of S.M. Fleishman [1], M.S. Gagoshidze [2], I.I. Kherkheulidze [3], A.N. Oliferov [4], Zh.B.Bainatov [5], S.G. Rustamov et al. [6], F.K. Kochergin [7], A.F. Barinov [8], V.F. Petrov [9], B.S. Stepanov and R.K. Yafiazova [10], F.G. Gabibov et al. [11].

When selecting protective measures against debris flows, it's important to note that a standardized approach is not appropriate. Each specific case requires an individual and tailored solution.

According to N.A. Alekseev [12], a comprehensive system of debris flow protection measures includes organizational and economic, agrotechnical, forest reclamation and hydraulic engineering measures. The first three are aimed at preventing the occurrence of debris flows at their source, while hydraulic engineering measures are intended to combat already-formed Debris flows. It should be emphasized that each of these measures is equally important, and their implementation should begin either simultaneously or with minimal delay, and continue until fully completed.

Common debris flow protection structures are typically constructed from reinforced concrete, metal, or local soil (such as protective dikes). Structures incorporating recycled materials (e.g., used metal drilling pipes, tires, and reinforced concrete railroad ties) have also proven to be quite effective.

Natural formations such as depressions and ravines are often utilized in the design of debris flow control engineering measures. Local soil materials are employed in the construction of anti-debris flow dikes.

II. Use of local petrostructures for the design of debris flow protection structures

An analysis of numerous debris flow protection structures has demonstrated the potential for developing new designs based on the use of local natural georesources in the form of widespread petrostructures. In a debris control system functioning as a permeable barrier with an extensive planform layout along a debris-prone channel - developed by specialists from Aeroproject (Russia) - locally available boulders are actively utilized. These are large, rounded rock fragments ranging in size from 0.5 to 9.0 meters.

In this permeable barrier [13], individual boulders (1) (Fig. 1), located on the bed (2) of the debris flow channel, are randomly interconnected by flexible cables (3), and connected to anchors (4) fixed along the banks and the channel bed (2). The cables (3) are further connected to the anchors (4) via additional vertical cables (5).

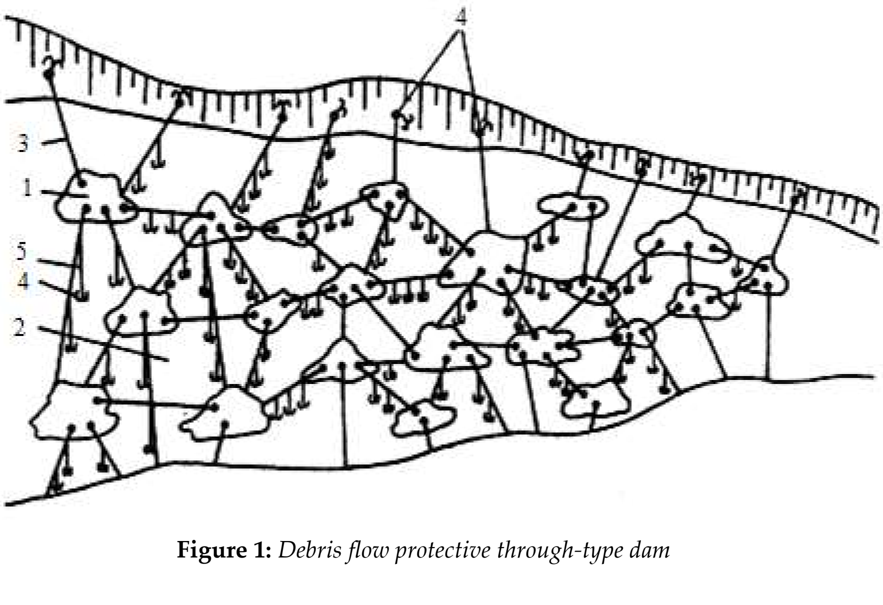

Figure 1: *Debris flow protective through-type dam*

This through-type debris flow protection dam functions as follows. When a debris flow encounters the barrier - a spatial lattice formed by interconnected boulders (1) and randomly secured cables (3 and 5) with anchors (4) - it is delayed and loses momentum.

No evidence has been found regarding the practical implementation of this structure. Despite the conceptual appeal of this engineering solution, it presents significant drawbacks. Securely attaching cables directly to the boulders is technically challenging and poses a risk of connection failure. Moreover, the construction of such a structure in practice would require numerous anchoring elements, substantially increasing construction costs.

III. Development of innovative debris flow protection structures using local petrostructures to significantly reduce stability loss risk

The authors have developed new designs for through-type debris flow protective dams utilizing large, locally sourced boulders.

In the first variant of the proposed design [14], boreholes are drilled to a calculated depth at randomly selected locations within the debris flow channel (1) (Fig. 2). Into these boreholes, pile-posts (2) are installed. As pile-posts (2), repurposed drilling pipes that have reached the end of their service life (typically around 5.5 meters when cut in half), decommissioned railway rails, or standard steel profiles such as I-beams and pipes may be used.

Once the pile-posts (2) are in place along the debris flow channel (1), through-holes are drilled along the central axis of selected large boulders (3). The diameter of these holes is slightly larger than the diameter (or maximum cross-sectional width) of the pile-posts (2). Using a crane, each boulder (3) is lifted and placed onto a pile-post (2) through the pre-drilled hole. The boulders (3) are then fixed in place on the pile-posts (2) using bolts (for pipes) or other fasteners (4).

This through-type debris flow protection dam functions as follows. When a debris flow occurs, it encounters a barrier consisting of randomly positioned, securely fixed large boulders (3), anchored to designated locations in the channel bed using pile-posts (2) and fasteners (4). The flow is partially obstructed and loses momentum. A portion of the solid material within the debris flow is deposited within the dam's structure, while the remaining, weakened flow continues downstream either to the next protective structure or deposits its solid load within the alluvial fan zone.

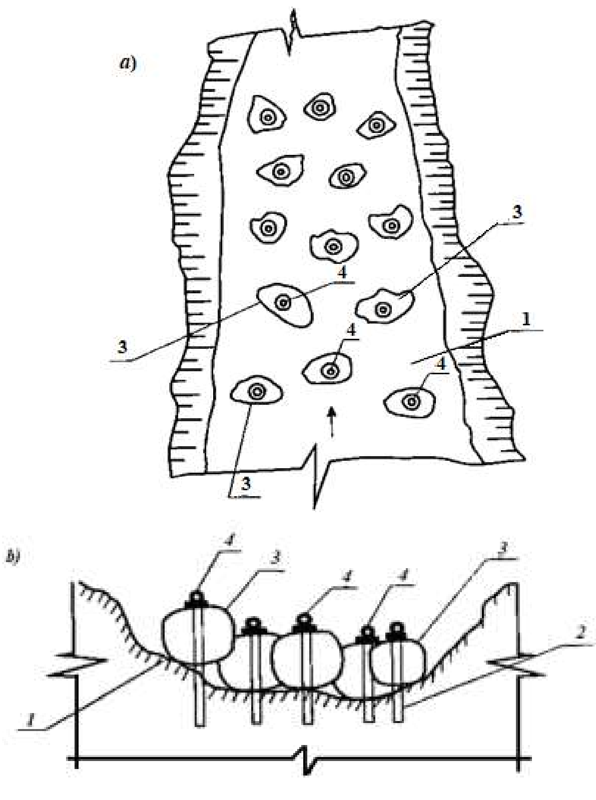

Figure 2: *Debris flow protection dam constructed from individual boulders mounted on pile-posts: a) plan view; b) front view*

In the second variant [15] of the proposed debris flow protection structure (Fig. 3), boreholes are drilled in a staggered (checkerboard) pattern at designated locations along the debris flow channel (1) to a specified calculated depth. Pile-posts (2) are then installed into these boreholes -

typically made from repurposed drilling pipes that have been cut in half after reaching the end of their service life. The depth of the boreholes for the pile-posts (2) is calculated to exceed the expected scouring depth.

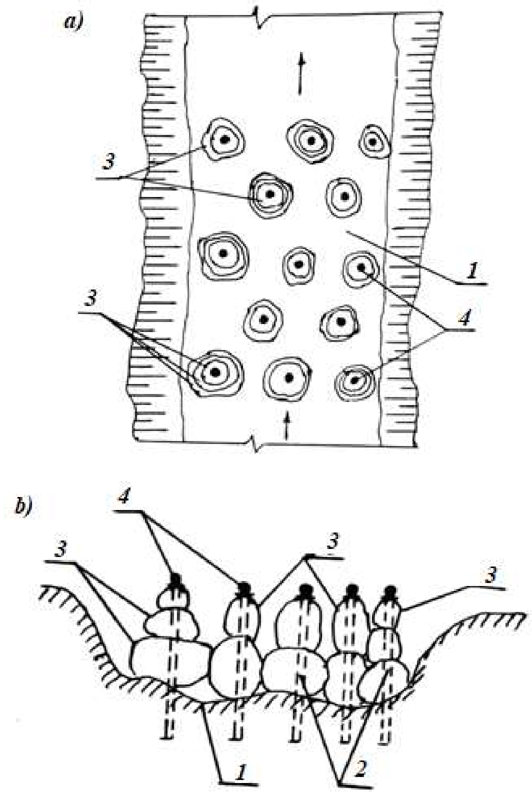

Figure 3: *Debris flow protection dam constructed from multiple boulders mounted on pile-posts: a) plan view; b) front view*

After the pile-posts (2) are installed into the boreholes, liquid concrete is poured into the holes. Once the concrete has cured and gained sufficient strength, the pile-posts (2) are ready for further assembly of the debris flow protection structure.

Next, through-holes are drilled (or bored) in selected large boulders (3) of various sizes, along axes passing through the center of gravity of each boulder. The diameter of each hole slightly exceeds the diameter of the pile-posts (2). Using a crane, each boulder (3) is lifted and mounted onto the pile-post (2) via the pre-drilled hole.

The boulders (3) are mounted on the pile-posts (2) in the following sequence: first, the largest boulder (3) selected for a given pile-post (2) is mounted; then, a smaller boulder (3) is placed above the larger one on the same post. In cases where three boulders (3) of different sizes are mounted on a single pile-post (2), the sequence is as follows: first the largest, then the medium-sized, and finally the smallest boulder (3).

The boulders (3) are secured at the top of the pile-posts (2) using fasteners (4), such as washers and spherical nuts threaded onto the tops of the pile-posts (2).

The debris flow protection structure operates as follows: when a debris flow occurs, the flow moving along the channel encounters a barrier formed by stacks of large boulders (3) mounted on pile-posts (2). This barrier slows the flow and causes it to lose a significant portion of its energy. A portion of the solid material carried by the debris flow is deposited within the structure, while the remainder of the weakened flow continues downstream - either toward the next protective structure or to deposit its solid content within the alluvial fan zone.

The technical and economic efficiency of the proposed new designs lies in the increased reliability and stability of the debris flow protection structure, as well as in the reduced construction costs. This cost-effectiveness is achieved through the use of a simpler method for securing large boulders to the debris flow channel.

IV. Conclusions

1. Natural landforms such as depressions and ravines are utilized in the design of engineering measures for debris flow protection. Local soil and geomaterials are used in the construction of anti-debris flow dams.
2. Analysis of numerous existing debris flow protection structures has demonstrated the potential for developing new designs based on the use of local natural geo-resources, particularly widely distributed petrostructures in the form of large boulders (rounded rock fragments ranging from 0.5 to 9.0 meters in size).
3. A through-type debris flow dam design was previously developed in Russia. Despite its conceptual appeal, the design presents significant drawbacks, as securely attaching cables directly to boulders is technically challenging and introduces a risk of connection failure. Additionally, the practical implementation of this design requires numerous anchoring elements, substantially increasing construction costs.
4. The authors have developed new debris flow protection structures using natural petrostructures (large boulders). In these designs, the boulders are reinforced within the debris flow channel using pile-posts embedded into the riverbed. The boulders are mounted from above onto the pile-posts through axial through-holes drilled along the center of gravity of each boulder. This approach ensures the structural stability and reliability of the protective system under the impact of debris flows.

CONFLICT OF INTEREST.
Authors declare that they do not have any conflict of interest.

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