DEBRIS FLOWS AND ANTI-DEBRIS-FLOW MEASURES

Mirtskhoulava Ts.E., Natishvili O.G. and **Tevzadze V.I.**
Institute of Water Economy and Engineering Ecology, Georgian Academy of Sciences, Georgia

Keywords*:* debris flows, structural debris flow, nonstructural debris flow, debris-flow material, debris-flow mixture, debris-flow prediction, forest reclamation, agrotechnics, terraces, dam, barrage, debris-flow flume, grid-type structure

Contents

Summary

Material is presented on the etymology of the term “debris flow,” defined as a natural phenomenon of catastrophic character and of enormous destructive power; the common and distinctive features of this phenomenon are noted, and the geography of its distribution is given, as well as the scale of damage caused by it to the national economy.

Debris flows affect not only alpine regions but mid-montane and foothill areas as well, hence the priority attention accorded to the latter.

The two principal types of debris flow—structural and nonstructural—are described, with indication of their physico-mechanical, rheological, and dynamic characteristics, conditions of formation, and factors causing them. Calculation models of both types of debris flow are proposed, taking account of their anomalous (non-Newtonian) properties, which make it possible to determine the density, mean velocity and impact force of these flows. Concrete examples are provided of the destructive impact of debris flows on objects of various types, and of the methods of calculating and predicting their rise

and frequency of occurrence.

Organizational-economic, forest reclamation, and agrotechnical measures are discussed in terms of combating debris flows and mitigating their destructive impact.

Small-size hydraulic engineering structures are considered in the form of flow-directing dams and walls, separate blocks of differing spatial forms, continuous and grid-type, barrage-type drift-arresting structures of various types of building materials, and short- and long-term purpose-built terraces on slopes.

Gravity and arch-type dams are considered as medium- and large-size hydraulic engineering structures designed for anti-debris-flow protection. Rock filling, concrete, and reinforced concrete are recommended as building materials, and prefabricated construction is also an option.

The most advantageous sites for placement of these structures—small-, medium-, and large-size—are on catchment slopes, river banks, and in the flood plain. Concrete examples of the building and conditions of operation of these structures are presented, with an indication of the main characteristics and their sites (Almaty, Kazakhstan; Kobe, Japan, etc.).

Views are advanced regarding the prospects for the development of methods of anti-debris-flow protection, with the aim of mitigating the immediate threat of debris flows and applying modern systems of monitoring.

1. Etymology of the Term

Debris flow refers to catastrophic natural phenomena and channel processes of episodic action, characterized by sudden occurrence, relatively short-time action, and great destructive force, often causing human casualties.

The term *debris flow* is usually associated with a sudden mountain flow of short duration, with great density and considerable destructive force, transporting an enormous quantity of rock debris in the form of a mixture of clayey-colloidal particles, with stones and water. The quantity of these components differs.

These flows have different names in different languages: *sel* flow in Arabic, *debris flow* in English, *Wildbach* (“Wild mountain flow”) in German, *torrent* (“torrential flow”) in French, *dosekyuru* (“earth-and-stone flow”) in Japanese, *ghvartsopi* (“mad or rabid flow”) in Georgian, and so on. All these terms reflect the nature of the phenomenon with more or less adequacy.

Until recently the comparatively accurate term *mud-debris flow* was used in the specialist literature, but it has now fallen into disuse.

2. Types of Debris Flow

Because there are various proportions of the main components in debris flows, they can be subdivided into two principal types, structural and nonstructural (turbulent). These differ both qualitatively and quantitatively.

Structural debris flows consist of a mixture of finely divided clayey-colloidal particles, larger components (up to large-size rocks), and water. The solid components make up to 80% of the weight, including up to 10% of clayey-colloidal particles; in this type of flow there is not more than 20% of water. Owing to this ratio of components, structural debris-flow mixture forms a single concrete-like medium (prior to setting) that does not break up into component parts during its movement or after it has stopped. It gradually hardens, as it were, and comes to rest on slopes with a gradient other than zero. The surface of the flow has a convex form, while the front part moves in the shape of a wave. The density of the debris mixture ranges from 1700 kg m^{-3} to 2300 kg m^{-3}.

Nonstructural (turbulent) debris flows contain over 20% (by weight) of water and an insignificant (less than 5%) proportion of clayey-colloidal particles, owing to which these flows move in a turbulent manner. Depending on the pattern of frictional forces between the surfaces of the flow and the territory (usually a water bed) over which it flows, the flow is either saturated with suspended loads or deposits them on the bottom of the water channel. Unlike structural debris flows, nonstructural debris flows constitute a mechanical mixture of water and alluvia. As a result, when they reach segments of the river-bed with a small slope, or at a debris cone, they break up into component parts. The solid component remains at the river bottom, while the water component continues its movement. The density of a nonstructural debris flow ranges from 1300 kg m^{-3} to 1700 kg m^{-3}.

3. The Occurrence of Debris Flows

Debris flows occur exceptionally in mountain and foothill regions, where they constitute one of the varieties of river-bed process. They should also be viewed as a manifestation of an extreme erosional process, characteristic of mountain river courses with strongly deformable beds.

Debris flows, with all their negative consequences, are observable in the Alps, in the mountains of Yugoslavia and Bulgaria, on the Kola peninsula, in the Caucasus, in the mountains of Central Asia, in the Far East, in Sakhalin and Khamchatka peninsula, in the Japanese Alps, in the Himalayas, in the mountains of the eastern coast of North and South America, in New Zealand, and so on.

Depending on the geological aging of mountain masses, where debris flows are normally formed, both structural and nonstructural debris flows can be produced. Where clayey shales and related rocks predominate in the erosional hearth of the upper reaches of debris-flow-bearing streams, structural debris flows are observable, while in the absence of such rocks, nonstructural debris flows occur.

4. Formation of Debris Flows and Factors Causing Them

Debris flows are formed in the upper reaches of streams, and in the erosional hearths of mountain masses composed of friable rocks. They are facilitated by large diurnal and seasonal temperature changes.

The preparation of debris flow material in the erosional hearths of the upper reaches of streams is to a considerable extent facilitated by a definite combination of geological, geomorphological, and climatic conditions, as well as tectonic processes occurring in the regions of major mountain masses. The descent of debris flows is normally observable in the warm months of the year (June–September in the Northern Hemisphere), and is attended by either driving rains or intensive melting of snow and glaciers. In view of the latter, debris flows may form in sunny weather as well.

In zones of glaciers and permanent snow cover, especially in the summer period, morainal lakes appear, with their characteristic high values of albedo, up to 95%, often facilitated by orographic conditions. The rise of the level of these lakes leads to a rupture of snow and glacier deposits and the spillover of a large quantity of accumulated water. Debris flows them form, comprising the debris products of the breakdown of rocks and channel deposits accumulated on the bed.

Notwithstanding the type of debris flow in them, watercourses can be divided into three main sections: (a) the upper, (b) the transit zone, and (c) the debris cone. The interaction of the debris flow with the channel at these sections depends on the stream type and on the character of the arrangement of bed sediments.

When structural debris flow moves along the entire length of the channel, it is gradually depleted through the deposition of its tail part on the channel bottom—both at the upper section and in the transit zone. However, the largest quantity of the debris flow as a single conglomerate is deposited at the debris cone, occasionally reaching 10^6 m^3 or more.

When a nonstructural debris flow occurs in the upper section of the channel, intensive enrichment of the flow with channel deposits is observable, while beginning with the transit zone, the drift sediment transported by the stream is deposited, a process that is practically completed at the debris cone. Only an insignificant part of the solid runoff is subsequently brought to the recipient river (in transit) by flood waters in the shape of finely divided and clayey particles.

5. Computation of Debris Flows

The computation of debris flows mainly reduces to the determination of their physico-mechanical, rheological, and dynamic parameters, such as the density of debris flow mixture, the grain of solid particles in a clayey-colloidal suspension, viscosity, yield stress, velocity, and discharge of flow.

The density of debris flow mixture is determined by the dependence:

$$\rho_{mf} = \frac{1}{P_{wt}/\rho_{wt} + P_{rk}/\rho_{rk} + P_{mm}/\rho_{mm}} . \qquad (1)$$

Volume weight (specific weight) of debris flow

$$\gamma_{df} = \rho_{df} \cdot g \, .$$

The fall velocity of the solid particles in a clayey-colloidal suspension may—if necessary—be determined by the available experimental data. Empirical dependences are also available for the determination of the viscosity and the yield stress; both in turn depend on the weight concentrations of the solid components of the debris flow, the concentration of rock (stone) inclusions, and their mean diameter.

The mean velocity of the structural debris flow may be determined by the formula:

$$V_{av}^{st} = \frac{\gamma_{mf} \, i H k}{3\mu} , \qquad (2)$$

where

$$K = \left[(h/H)^2 \cdot (1{,}5 - 0{,}5 h/H) \right];$$

$$h = H - h_0 ;$$

$$h_0 = \tau_0 / \gamma_{mf} i ;$$

$$\tau_0 = 5 \cdot 10^4 d_{rk} \exp 23\left(P_{sl} - 0.8 P_{rk}^{0.1} \right) \; N \; m^{-2} ;$$

$$\mu = 10^6 d_{rk} \exp 35\left(P_{sl} - 0.8 P_{rk}^{0.11} \right) \; N \; \sec \; m^{-2} ;$$

The mean velocity of nonstructural debris flow may be determined by the relation

$$V_{av}^{nst} = \frac{6{,}5 H^{2/3} i^{0{,}25}}{\sqrt{\rho_{mf} \left(\rho_{rk} - 1 \right) / \left(\rho_{rk} - \rho_{mf} \right)}} . \qquad (3)$$

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Biographical Sketches

Tsotne Evgeievich Mirtskhoulava was born in 1920, in Poti, Republic of Georgia. He obtained the degree of Doctor of Technical Sciences from Moscow Institute of Water Economy Engineers in 1960. From 1961 to the present he has been a Professor at Georgian State Technical University, and from 1969 to the present he has been head of laboratory and director of the Institute of Water Management and Engineering Ecology. He is a member of the Georgian Academy of Sciences, and is known as a specialist in problems of the processes of water erosion, the reliability of hydro-installations, and ecosystems. He is the recipient of more than 10 honorary degrees, and spoke at UN conferences on erosion and flood control in New York (1973), Vienna (1980), and New Dehli (1983). He has spoken at many congresses and symposiums of the International Association for Hydraulic Research (IAHR), and from 1976–1980 was a member of the Council of IAHR.

From 1970–1980 he was a member of the editorial board of the IAHR journal *Hydraulic Research*, and since 1979 has been a member of the editorial board of *Land Reclamation and Water Economy*, Moscow. He is the author of 300 papers, including 50 published in English, and 23 monographs.

Otari Georgievich Natishvili was born in 1929 in Tbilisi, Republic of Georgia. He gained his Doctorate in Technical Sciences from the Institute VODGFO in Moscow in 1968, and since 1972 has been a Professor at Georgian State Agrarian University. From 1959–1970 he was head of laboratory at the Institute of Water Management and Engineering Ecology, and from 1970–1990 was Chair, Dean, Pro-Rector and Rector of the Georgian State Agrarian University. He is a member of the Georgian Academy of Sciences, and since 1990 has been Academician-Secretary of the Department of Agricultural Science Problems of the Georgian Academy of Sciences.

He is the author of 120 published papers, five monographs, and five textbooks.

Vakhtang Ismailovich Tevzadze was born in 1933 in Tbilisi, Republic of Georgia. He gained his Doctorate in Technical Sciences from St. Petersburg State Hydrological Institute in 1986. Since 1991 he has been a Professor at Georgian State Technical University and Georgian State Agrarian University, delivering a course of lectures in hydraulics and hydrology. Since 1993 he has been head of laboratory of

Natural Catastrophes and Vice-Director of the Institute of Water Management and Engineering Ecology. His research interests are in mountain rivers, particularly debris-flow streams, and in 1973 he went to Japan on a study tour to gain the experience of Japanese experts in combating debris flows. He is the author of 101 published papers, two monographs and a textbook.