Debris flows in the Ukraine: some results of field and experimental studies

V. V. YABLONSKIY†, A. S. TISHCHENKO, A. V. DEZIRON & E. G. BOEVA
Ukrainian Regional Hydrometeorological Research Institute, Kiev, USSR

Abstract Debris flows in the Carpathians, the Crimean Mountains and in the ravine-gorge regions of the Ukraine are formed under the effect of sets of slowly- and rapidly-varying natural and anthropogenic factors. Dynamic values of the main characteristics of debris flows: velocity of the flow, maximum discharge, density and volume can be computed by means of a simplified model of the debris flow hydrograph schematized by a triangle. A formula for computing the mean cross-sectional velocity of a debris flow is presented. To provide debris flow monitoring and automation of their forecasting, noncontact remote methods safe for the observer should be used for measuring debris flow characteristics and indicators of debris basin state.

INTRODUCTION

The combination of natural conditions in the Carpathians, the Crimean Mountains, and ravine-gorge regions along the Dnieper and Dniester Rivers is favourable for the formation of debris flows.

Various natural processes affecting debris flow initiation fall mainly into two groups of processes: slowly varying and rapidly varying ones. According to the results of our investigations, debris flow velocity depends on hydraulic radius, longitudinal slope and density of the flow. The results are presented of the generalization of debris flow characteristics depending on the mechanism of their formation and on the porosity of soils forming them. The means of application of noncontact remote methods and measurement of debris flow dynamic characteristics are given and some results are presented of the investigations on the application of these measuring methods in an effort to create a debris flow monitoring system and to develop calculation and forecasting methods.

NATURAL AND ANTHROPOGENIC FACTORS OF DEBRIS FLOW FORMATION

The set of slowly varying debris flow formation processes comprises mainly

†We regret to announce the death of Dr Yablonskiy in February 1992.

lithological and geomorphological processes. Debris flows in the Carpathians and the Crimean Mountains occur in flysch zones, especially in places where different structures (anticlinal and synclinal) are in contact, where fractures are observed and where conditions for crushing, destruction and weathering of rocks are most favourable (Yablonskiy, 1972).

Mesozoic-Palaeogenic flysch rocks in the Carpathians and Taurian (Triassic-Jura) flysch rocks in Crimea form a mass of weathered rocks in the form of peculiar debris flow source areas mainly of two types: landslides in which friable watered sandy-clayey products of flysch weathering prevail, and talus-eluvial deposits in which sandy-gravelly material predominates (Semenikhina, 1985). The availability of sandstone interlayers in flysch promotes the formation of large-size sandstone rocks in debris flow source areas of the both types. The density of the debris forming rock is 2650-2700 kg m^{-3}. The mechanical composition of soils of debris flow source areas is very diverse as illustrated by Fig. 1. Also here is shown the composition of debris flows which participated in anthropogenic debris flow in one of the gullies in the vicinity of Kiev in March 1961. Soils forming debris flows are characterized by a very different porosity, comprising about 28% in large-fragmental alluvial soils and 45-47% in landslide soils. When debris flow originates, the soil is completely wetted therefore if soil density in a dry friable state is from 1400-1500 to 1800-1900 kg m^{-3} then it increases at the complete filling of the pores to 2000-2200 kg m^{-3}.

In view of the increased humidity of the air and soil, and of the frequent floods during which fine earth is carried away, soils forming debris flows in the Carpathians feature a low content of dusty clay particles which undoubtedly

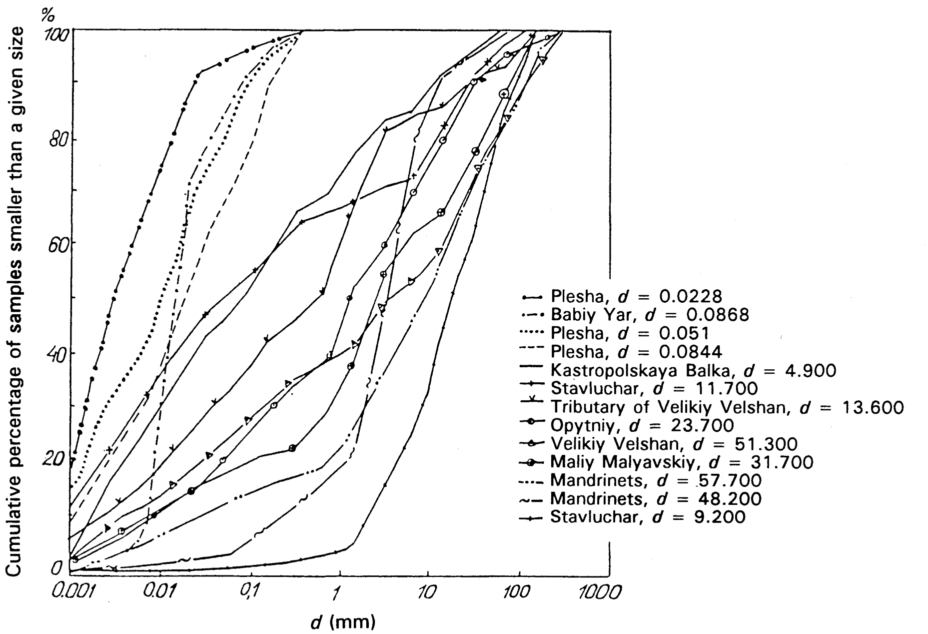

Fig. 1 Size of material forming debris flows in the Carpathians and Crimea.

Table 1 Mean values of limit shear stress (N m^{-2}) for soils with different moisture contents.

Suspension moisture content (%)	30-40	40-45	50	55	60	65
Limit shear stress (N m^{-2})	100	80	50	40	30	5

affects the flow conditions of debris mixtures. Only a few debris flows such as Plesha Brook have in their composition an increased content of clays which results in viscous-plastic flow. Stability of source areas is determined by the value of limit shear stress which varies for Carpathian and Crimean soils forming debris flow depending upon the moisture content within the range presented in Table 1 (determined by KaxNIGMI using an original technique).

Carpathian and Crimean debris flows are not huge; usually several tens of thousands of cubic metres of soil are involved. The greatest Carpathian debris flow in the Kanusyak mountain torrent was initiated as a result of the shearing of 70 000 m^3 of soil from a source area 230 m long. An anthropogenic debris flow was formed in a gullied region in the vicinity of Kiev on 13 March 1961 from soils washed into the upper part of the gully. About 600 000 m^3 of sandy-clayey soil with a high moisture content was involved in this debris flow. Debris flows of anthropogenic origin took place also in rock spoil banks of open cuts in Krivoy Rog.

Hydrometeorological conditions of debris flow formation are determined mainly by precipitation. As distinct from the line relating the sum of debris-forming precipitations to the duration obtained by Innes (1983), we have evolved relationships for two debris formation processes: for local precipitation over 35-40 mm per rainfall event and covering 20-30 km^2, and for frontal ones over 50-70 mm per rainfall event and covering several thousands of square kilometres (Yablonskiy, 1972, 1991).

The daily precipitation occurring once every hundred years in the Carpathians attains a maximum value of 200 mm (on the Gorgany ridge, a region of powerful debris flows). In the Crimea, precipitation events do not exceed 160 mm (Yablonskiy *et al.*, 1982). Debris flows of detritus-water prevail over most of the Carpathians and the Crimean. Only at Gorgany, on the Polonyna ridge and in the Rakhov mountain mass do shearing type debris flows form (according to Vinogradov's classification).

The anthropogenic impact on debris flow formation is associated with the excessive utilization of the forests protecting the soil cover, and with the formation of rocky spoil heaps in open cast mining of mineral resources which become the source areas for debris flow formation.

DYNAMIC CHARACTERISTICS OF DEBRIS FLOWS

A comprehensive analysis of the information on debris flow processes is used to estimate the dynamic characteristics of past debris flows. It comprises results of field inspections of beds and the measurements of longitudinal and transverse profiles up to the height of debris flow traces on the control part of the bed, the analysis of the hydrometeorological characteristics which caused the debris flow, the calculation of the flood forming the debris flow (Yablonskiy, 1974), the calculation of debris flow velocity, its maximum discharge, schematized hydrograph of the debris flow as well as the calculation of volumes of soil with pore water forming and involved in the debris flow, of the volume of the portion of flood water mass participating in the debris flow process and the total volume and density of a debris flow (Yablonskiy, 1979).

This simplified model is basically confirmed by the calculations of debris flow motion by means of strict mathematical models (Mironova & Yablonskiy, 1991). Using observations and experiments, resistance to debris flow motion was investigated and Yablonskiy (1988) obtained the following formula for the calculation of the mean cross-sectional velocity of a debris flow:

$$v_d = \frac{6.06 R^{0.667} \tan S^{0.25} (2.675 - \rho_d)}{(2.454 - 0.798 \rho_d)} \qquad (1)$$

where v_d is the mean cross-sectional velocity of the debris flow (m s^{-1}); ρ_d is debris flow density (kg m^{-3}); R is the hydraulic radius (m); tan S is tangent of the angle the bed slope makes with the horizon.

Numerous data on Carpathian and Crimean debris flows have enabled the adverse effect of debris flows on agriculture to be estimated by an index $n = Q_d/Q_w$. An analysis of the variation of the ratio between the maximum Q_d of a debris flow and the respective water discharge Q_w, $h = Q_d/Q_w$, for debris flows of different densities has revealed that the porosity of the soils forming debris flows has a great impact on the value of this ratio (Yablonskiy, 1991). The following formula is being used in the USSR in calculations of debris flow density ρ_d (Fleishman, 1978):

$$\rho_d = \rho_w + V_{se}/V_d(\rho_{se} - \rho_w) \qquad (2)$$

where ρ_w is density of water, V_{se} is volume of solid material (in compact structure), V_d is volume of debris flow. This corresponds to:

$$Q_d = Q_w/(1 - S_{se}) \qquad (3)$$

where Q_d is maximum discharge of the debris flow, Q_w is the maximum discharge of water, S_{se} is the share of solid material (in compact structure) involved in the debris flow, in respect to the volume of debris ($S_{se} = V_{se}/V_d$). However, since soils under natural conditions have a friable structure, S_{se} should be replaced by S_m, i.e. by the proportion of solid material in a friable structure. The latter is greater than S_{se}, therefore:

$$Q_d = Q_w/(1 - S_m) > Q_w/(1 - S_{se}) \qquad (4)$$

whence

$$Q_s/Q_w = 1/(1-S_m) \qquad (5)$$

According to data by Zolotarev *et al.* (1987), the loosening coefficient is equal on the average to 1.3 and the values of Q_d/Q_w should be increased correspondingly which is also confirmed by the calculations of characteristics of past debris flows (Fig. 2).

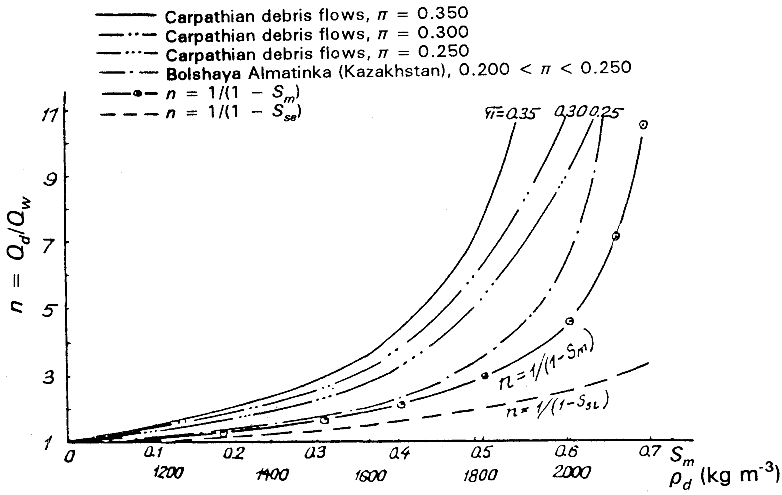

Fig. 2 Relationship between the ratio Q_d/Q_w and S_m or ρ_d. π is porosity (%).

NONCONTACT METHODS AND MEANS OF MEASURING THE DYNAMIC CHARACTERISTICS OF DEBRIS FLOWS

In the last few years, in an effort to create a debris flow monitoring system, to automate their forecasting and warning of debris flow hazard, the following debris flow characteristics have been measured: the height of debris flow surface level, the velocity of the debris mixture flow, the volumetric discharges of debris flows, debris mixture density, the strength of debris flow impact on an obstacle, etc. It is well known that the employment of measuring means which come into contact with the moving debris flow is inefficient, as such measuring means are destroyed by the flow. Specialists from the UkrNIGMI have tested a number of noncontact methods for measuring debris flow characteristics (Yablonskiy, 1990). These measuring means are installed in small channels representative of the debris flow region with the aim of determining when a debris flow will occur and to transmit data about it via a debris flow warning system. What is more, these hardware components jointly with technical means that provide for a sudden passage of water form an experimental system for studying debris flow motion under field conditions.

A debris flow measuring station comprises: debris flow measuring flume with trapezoidal cross section and strain-gauge mass meter which provides a continuous measurement of the mass of moving debris mixture; an acoustic ultrasonic level gauge, providing the measurement of the level of flow in debris flow measuring flume and thus a continuous monitoring of the volume of debris mixture in the flume; a remote Doppler radiowave meter to measure the velocity of the debris mixture flow. This set of instruments provides data to monitor the density of the debris mixture flow at different instants of time. The velocity meter has an independent power supply from a small storage battery and it can be successfully used separately from the set as a field instrument. The set, which is a part of a debris flow measuring station has already enabled the first results of experiments to be obtained: some regularities of the velocity of the flow front have been studied; data have been obtained on the relationship between the flow density in the leading part of the wave ("the snout of the bore" according to Takahashi (1978)) and in its "tail". At the moment, the above experimental study of debris flows under natural conditions is going on.

FUTURE WORK

We plan to extend the studies by the application of noncontact means for measuring the dynamic characteristics of debris flows as well as the automatic recording of all the characteristics being measured. Data on experimental debris flows make it possible to improve mathematical models of catastrophic processes so successfully developed in recent years.

Inasmuch as the set of measuring means which we have developed makes it possible to measure directly the physical parameters of natural flows, it is the basis for the development of special calibrating test beds in which instruments such as the seismic indicators of flow discharge can be tested (designed at KazNIGMI and NIIP).

We plan also to develop and to improve the models of debris flows by making them more sophisticated and bringing them closer to the natural processes. We consider it necessary to develop also studies into the measurement of the conditions of debris flow basins and source areas by means of noncontact methods using natural pulsed electromagnetic radiation of rocks.

We see our work in solving these problems as a contribution to the International Decade for Natural Disaster Reduction.

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