LAND SLIDES AND ROCK FALLS

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Contents

Summary

Rockfalls and landslides are genetically and spatially connected to each other. The basic distinction between them is that, moving rocks in a rockfall loose their contact with a slope while landslides never do that. For initiation of rock falls key favorable factors are significant altitude drop, high energy of relief, great steepness of slopes and valley lines. Landslide processes depend on thickness and composition of covering deposits and on the dynamics of their wetness. Development of landslides and all other gravitational processes, including stone falls, are conditioned by the relationship of a slope steepness with a thickness and composition of a weathering crust and other cover formations on the slope. The stability of slopes having a homogeneous geological structure is determined by strength and density of rocks, the slope height and its geometric form and, in particular, by the steepness. The landslide movement begins as a result of a break in the slope equilibrium and goes on until it reaches a new state of equilibrium. Classification of landslides is based on the types of mountain rock motions, those are—failures, overturns, sliding, extrusion and streams. There is continuous transition from sliding to fragmental avalanche as the motion accelerates. This is being caused by a reduction in the cohesion or an increase of the water content, and the steepness of the slope. The problem in preventing landslides is maintain the slope stability, i.e. not to allow material to slide down a still motionless slope or to stop the displacement of sliding land masses. Predicting landslide processes is of great importance. It depends on the size of area over which a prediction is made: for a limited part of the slope where one has to determine a degree of its stability and conditions of its breaking, a local forecast is made, or for a vast territory on which one has to isolate sites of which the slopes are dangerously unstable, and where factors which further deteriorate stability of the slopes, have the most intensive effect (a regional forecast). To determine the stability coefficient of slopes and its variations one can use different methods to calculate the coefficient, along with experimental methods of measuring stresses, as

well as physical modeling, historic-geologic methods and analog methods.

1. Slopes and slope processes

Mountain territories possess slopes of different steepness and length. Their stability is unequal and frequently cause slope problems doing great harm when developing a territory. There are two different types of slope: natural sloped areas of a land surface, and those artificially created. Average steepness of a slope or scarp is determined by an angle of inclination to the horizon of a line connecting its brow and foot along direction of the largest gradient. Complicated slopes or scarps consist of several sloped areas having different forms and steepnesses divided by either a line of sharp change of a gradient, or by horizontal sections (terraces or steps on the slopes, berms on scarps), or even by sections overturned inside a slope.

A slope is a part of the land surface, having a common inclination in the same direction, which, despite local irregularities, provides a general common direction of the water runoff and displacement of the rock mass toward its foot. Natural boundaries of a slope are lines of its sharp inclination change: in the upper part, these are a brow of plateau, terraces of a slightly sloped plain, and watershed; in the lower part the boundaries are a narrow valley line, terraces, and inclined plain. Slopes can have very different profiles; they can be rectilinear, concave, convex, concave-convex (upper part of the slope is convex, while the lower is concave), or conversely, convex-concave, winding, and step.

The slope development proceeds under influence of oppositely directed processes. Some of them tend to increase a height or steepness of slopes (tectonics, erosion, abrasion, artificial undercutting), and other processes tend to make slopes more gentle (gravitation processes, surface wash-off). Each slope has its own age, i.e. the time period running since the moment when the processes making it more steep stop their influence upon the slope. Age of a slope can be determined rather accurately if an alluvial terrace of known age and undeformed by last landslides adjoins its foot. Different parts of an ancient slope can have different ages, and, on the other hand, relict areas of different age can exist on a modern slope.

The slope processes are a displacement of mountain rocks down a slope which are not rare, forced not only by the gravity but also by the action of water running down the slope (surface wash-off, deluvium processes). The driving force of the gravity processes is the weight of the mountain rock masses moving down together waters within them. It is not uncommon that these movements are enhanced by seismic shocks or hydrodynamic pressure of water running through mountain rocks.

The following gravity processes are complicated: 1) defluction, or surface creep - predominantly a zigzag displacement of particles along the slope surface being the result of displacements arising under the effect of thermal expansion and compression, freezing and melting, swelling and shrinkage, activity of roots and moving animals with shifts caused by the gravitation; 2) decerption - dislocation of predominantly loose dry products of weathering under a joint effect of the gravity and forces caused by thermal expansion and contraction; 3) solifluction - dislocation of water-saturated loose deposits under a joint effect of the gravitation and processes connected with freezing and melting.

Causes and mechanism of landfalls and crumbling are similar, they vary only in scales of the phenomena. Landfalls are avalanches of large blocks and even massifs, while crumbling is a downfall of relatively small fragments of mountain rocks. Sometimes such dislocations start as one type, and finish as the other one.

Development of landslides and all the other gravity processes, in particular of rock falls, is determined by a relationship between the slope steepness and thickness and composition of the crust of weathering and other covering forms on the slope. Therefore, all of them are unified genetic series, so one can follow conditions of their appearance or transition of one to another depending on the slope steepness, its composition and thickness of the covering forms on the slopes.

2. Rock stresses and deformations on slopes

The slide processes are first determined by the gravitational field. Due to the gravity the mountain rocks composing the Earth crust undergo stresses motivated by a weight of the above laying mountain rocks. Besides stresses caused by the gravity, the other stresses can exist being the result of tectonic forces as well as thermal (caused by differences of thermal expansion), physic-chemical (caused by the volume variations under variations of humidity, chemical transformations, crystallization, etc.), hydrodynamic, residual, etc. However, these additional stresses do not always exist and everywhere, while those caused by the gravity are universal and unavoidable.

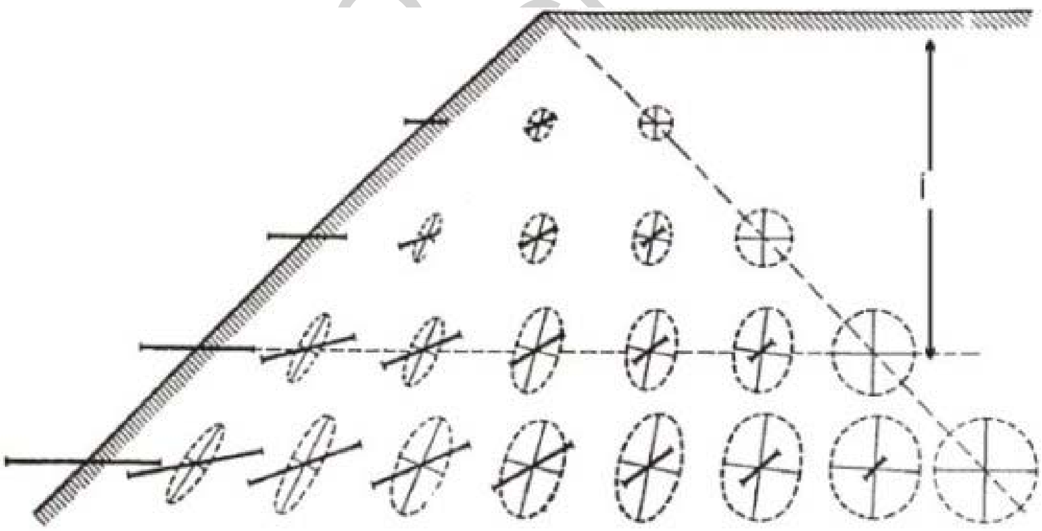

Figure 1. A scheme of stressed state in the side slope with its steepness of 45° spreading down over infinite distance under a coefficient of the lateral (side) thrust equal to unit. By E. P. Emeljanova.
Relative scale for tangential stresses is thrice larger than that for the main ones

Slope deposits are in a complicated stressed state which is illustrated by the ellipses of stresses. Figure 1 demonstrates a magnitude and direction of maximal tangential stresses (to make the draft more clear, from the pair of conjugate maximal tangential stresses only “active” stresses, i.e. stresses with direction coinciding with direction of potential (possible) slide displacement, are shown in the figure). Total stresses are shown in the side slope, their magnitude grows as its height over the level considered increases.

As one approaches from a plateau to a slope surface, the stressed state of mountain rocks changes as the following: first, ellipses of stresses become more and more stretched and their inclination progressively increases; second, the value of normal stresses decreases: the maximal stress does this slower, but the minimal one - very quickly; third, due to increase of the difference between the basic stresses the value of maximal tangential stresses quickly increase: in the very high slope the maximal tangential stresses reach the largest value on its surface; fourth, the direction of the maximal tangential stresses describes almost round-cylindrical surfaces that is favorable for both formation of sliding surfaces, and for developing a plastic flow; fifth, at the slope base near its foot a large axis of the ellipse of stresses progressively approaches to the horizontal position, and, in this case, the ellipse elongation also increases. Because of that, horizontal stresses near the foot are larger than the vertical ones that is favorable to bulging of the rocks.

At each horizontal level, the maximal tangential stresses reach the largest magnitude on the vertical line passing through the slope middle. Flattening of the slope decreases the concentration of the stresses in its foot, but along the depth influence of the flattening upon distribution of additional stresses in the base is damped. This dependence explains the long-known very important regularity: the more gentle is a slope, the deeper is subsidence of the sliding surface of a landslide when its general stability is disturbed.

Ruptures in the rock continuity (uncemented crevices, loose superposition of one rock onto another) cause also a rupture of continuity of the field of stresses, i.e. sharp changes of the stress magnitude and direction. It seems that each part of the slope separated from the others by ruptures of the continuity behaves as independent construction while adjacent parts serve for this as only a load or a base. Correspondingly, the stresses from that part of the slope composed by solid rocks are not transferred into a thickness of loose covering materials or rocks being slid along the slope and subjacent to it; this part of the slope serves for the loose rocks as only a base, and stresses in them are determined by their own weight. When the rocks are weathered from the surface, the stresses from the slope as a whole are not transferred into a part of the crust of weathering, which is separated by crevices parallel to the slope, while they are partly transferred into a zone with the crevices which are perpendicular to the inclined slope.

This rather complicated pattern of the stress distribution in slopes being caused by the gravity effect is still more complicated under influences of other factors causing own stresses. The tectonic stresses can be very important among them. Additional stresses can also arise under the effect of physico-chemical changes associated with variations of temperature and humidity. These stresses are maximal near the earth surface and quickly attenuate with the depth.

Dimensions and form of a body change under effect of stresses, i.e. it is deformed by tension, compression, shift, bending, and torsion. Deformations are divided into elastic and plastic. Elastic deformations are completely reversible, i.e. they disappear with removal of respective stress. They are rather small and proceed almost instantly. However, many materials, and the clay rock among them, have elastic aftereffect, i.e. elastic deformations continue to grow for some time after the load is applied, and they do not immediately disappear after it is removed.

The plastic deformations are irreversible. They reach significant value and run slower than the elastic ones do. That is why they are a function of not only the stress values, but also of a time of their action. These deformations running for a long time under the constant stress are called the creep.

A difference exists between the rock deformations running within the significant volume and a destruction going on along individual surfaces of a shear or a break-off. Deformations within a volume are almost entirely determined by average characteristics of mechanical properties of the rock. Destruction along a surface is confined to the largest defects of the structure, i.e. to the weakest sections. Because of that, an average resistance to shear along the sliding surface is always smaller than an average resistance to the rock shift within that part of its volume inside which the sliding surface has arisen, and the rock strength very much depends on its volume undergone to the destruction.

When examining the stability of slopes the resistance to a shear is usually expressed as a function of a pressure normal to the shear site, and, thus, trying to take into account the influence of the rock density and humidity variations upon the rock strengths when values of the normal stresses affecting them change. In such a case it is taken that the influence of the pressure on the resistance to shear follows the Coulomb empirical formula:

$$\tau = c + \sigma \mathrm{tg}\varphi.$$

So, the resistance to the shear τ is expressed in terms of indices of adhesion c (in kg/cm^2 or t/m^2), strength σ and angle of slope of internal friction φ, or a coefficient of friction $\mathrm{tg}\varphi$.

Use of the Coulomb law assumes a complete transmission of the pressure to the skeleton of the rock. But, in both the nature and a laboratory we almost always deal with an incomplete consolidation (or a swell), and, hence, with a redundant porous pressure (positive or negative). This circumstance is taken into account when the Coulomb law is expressed in the form:

$$\tau = c + (\sigma - u)\mathrm{tg}\varphi,$$

where u is a pressure with water filling the rock pores; $(\sigma - u)$ is the pressure to which the rock is subjugated.

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Biographical Sketch

Vladimir Mikhailovich Kotlyakov (born in 1931) is a member of the Russian Academy of Sciences (elected in 1991). He is Director of the Institute of Geography, Russian Academy of Sciences. With particular interest in glaciology and physical geography in polar and mountain regions, he directed the twenty-year project resulting in the World Atlas of Snow and Ice Resources (published in 1997).

V.M. Kotlyakov has participated in many expeditions. He worked and wintered in the Arctic, the Antarctic, and at the slope of the highest summit in Europe, the Elbrus, and he headed the high mountain glaciological expeditions to the Pamirs.

The main theoretical results of V.M. Kotlyakov`s works consist in elucidation of laws of snow and ice accumulation of the Antarctic ice sheet as well as ice sheets in general (1961), the snow cover of the Earth and its fluctuations within time and space (1968), the tasks and abilities of space glaciology (1973), the application of isotope and geochemical methods to the study of the environment and its evolution (1982), the study of the past for four glacial-interglacial cycles (1985 and further on). During the last years, V.M. Kotlyakov dealt with the global changes of the environment, geographical aspects of global and regional ecological problems, the problems of interaction between nature and society.

V.M. Kotlyakov is the honorary president of the Russian Geographical Society and President of the Glaciological Association. In 1987-91, V.M. Kotlyakov was elected the President of the International Commission of Snow and Ice, and in 1987–93, he was the member of the Special, and later Scientific, ICSU Committee of the International Geosphere-Biosphere Program, in 1988–96, the vice-president of the International Geographical Union. Now he is a member of the Earth Council.

V.M. Kotlyakov is elected a member of the Academia Europaea and the Academies of Sciences of France and Georgia, a honorary member of the American, Mexican, Italian, Georgian, and Estonian Geographical Societies.