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UNAVOIDABLE PRECURSOR OF THE LANDSLIDE CATASTROPHES

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The catastrophic landslides can occur on slopes that may be considered as mechanical system at the unstable equilibrium state. The term "equilibrium" implies such state of a system, when two (and may be more) forces applied at rock massif balance each other. Such equilibrium could exist at certain values of elasticity and density of the geomechanical systems. For landslides these two main forces are the gravity force and the cohesive elastic or friction force between the landslide body and underlying rocks. Equilibrium conditions can be violated if the cohesive forces will decrease relative to the gravity force due to changing of the system elastoplastic parameters values. Therefore such equilibrium is unstable. In that case the phenomena that will cause the slope failure start developing. The larger difference between gravity force and cohesive one is the faster slope failure process should be.

The goal of our study is the analysis of geomechanical events, which should accompany landslide at its evolution towards the unstable equilibrium i.e. up to the catastrophic threshold when rapid failure occurs. There is a possibility to find the prognostic phenomena indicating such approach to the unstable equilibrium state and by that to predict time and scale of the catastrophic landslide. It can be done with a help of the general theorem formulated at first in different alternatives (Dubrovskiy, 1988, 1989; Dubrovskiy & Dieterich, 1990; Dubrovskiy & Sergeev, 2001, 2004), concerning the unstable equilibrium state systems:

If the system has the state of the unstable equilibrium at some set of the critical parameters describing it and this set separates areas of the parameters values relevant to a stable state and unstable state of the system then in stable parameters area external load would cause eigen oscillation of the system with frequencies, which will tend to zero if the system approaches unstable equilibrium at the finite critical wavelengths.

According to this theorem any catastrophe should be preceeded by slow oscillation of some parameters describing the state of a system. Frequency of these eigen wave motions tends to zero as approaching an instability threshold. Hereafter we will discuss the processes that take place along the landslide sliding surface prior to its complete formation.

It is possible to give some examples of preliminary behaviour before catastrophe threshold for the systems similar in principle to the landslide system: alternating vertical and horizontal tectonic motions before orogeny (Dubrovskiy, 1988), slow movements of the daylight surface, registered prior to earthquakes by the geodetic methods at a former Garm's polygon (Tadjikistan) of the Institute of Physics of the Earth, the onset of the slip instability along faults (Dubrovskiy & Dieterich, 1990, Li *et alii*, 1990), simulating processes of earthquake, rock burst and fracture development which are preceeded by the waves propagating along faults – trapped waves (Li *et alii*, 1990), slow wave motions before earthquakes in the Caucasus, Turkey, the Balkans surrounding the Black Sea where seiche oscillations have been registered (Nesterov, 1996).

All these examples are characterised by the presence of the unstable equilibrium state at certain values of parameters typical of a system. Genesis of such equilibrium is the same, as for landslide processes, namely equality of tectonic (gravitation – in the landslide case) forces and cohesive forces of rock formation. The processes of the fracture's activation (or of the formation of new rupture) and consequent movement along it at a catastrophic stage take place both in case of earthquakes, and in case of landslides. Therefore it is useful to note within the framework of this analogy some of the observed phenomena preceding such a catastrophic event as an earthquake.

Observable phenomenon of the low seismicity splash and its disappearance directly before relatively strong earthquake can be explained by the frequency decreasing of the waves while approaching of the geophysical parameters values of the future earthquake source to the critical values relevant to a catastrophic threshold. Since seismological equipment can register those oscillations only, which frequency fall within registration range, consequent low frequency oscillations could be missed by seismic network, but can be recorded by broadband instruments. Besides, in the system with dissipation it is possible actual silent directly before the earthquake when any disturbance attenuates, but more and more slowly as approaching a catastrophic threshold (Dubrovskiy & Sergeev, 2001; 2004). In any case these two stages (at first oscillatory and then aperiodic) of the prognostic precursor should present always, as they are essential parts of the earthquake source evolution towards the instability threshold.

Moreover, the considered wave deformation process preceding catastrophe, can initiate other precursor that have different physical nature: increasing of the radon abundance and changing of the water level in boreholes as the consequence of the crust permeability increasing at its periodic deformations, or the electrical and electromagnetic phenomena in atmosphere and ionosphere (Hayakawa, 1999) which can appear due to functioning of the electrohydrodynamic and electroelastic mechanism of the electric field generation and, hence, of the electromagnetic radiation (Dubrovskiy & Rusakov, 1989). The same can be exemplified by the above mentioned registration of the seiche oscillations in Black Sea (Nesterov, 1996), which directly correspond to the slow waves motion. Seiche oscillations are generated due to resonance phenomenon when the changing frequency of the pre-earthquake slow waves fall within the seiches frequency range. We can also note that the same effect of the seismoacoustic background noise frequency decrease is observed before the rock bursts in mines and during laboratory experiments of fault formation. Thus, random perturbations will grow as the system will develop from its initial state to a new one, due to energy transfer at a catastrophic stage of the process.

The similarity of the principal processes of the evolution of landslide sliding surface and of any other systems that could achieve an unstable equilibrium state, and thus can develop catastrophically gives us the possibility to make the following conclusion about possible precursor of the landslide catastrophes:

1) While the slope approach to a catastrophic threshold eigen oscillations of the system consisting of landslide sliding surface and surrounding rock (soil) mass become more and more low-frequency at finite sizes of the landslide. It should lead to the shifting of the seismoacoustic emission spectrum to the low-frequency range. Such shift can be unavoidably detected by the broadband seismic equipment.
2) For the systems without dissipative processes the frequency decrease of the eigen oscillations up to zero is followed immediately by the slope failure as a consequence of instability. Equipment with the limited frequency range will record (while approaching an instability threshold), at first, the eigen oscillations splash when their frequency fall within the equipment frequency range. Later on the frequency should decrease and, finally, "seismic silent" should be recorded when frequency goes out of recordable range.
3) In the system with dissipation the scenario of the systems' evolution to the catastrophic threshold turns out to be slightly different. The decrease of the perturbation frequency (and, thus, shift of the seismoacoustic background spectrum) should be observed as well. Then oscillatory perturbations will be by aperiodically, exponentially attenuation of perturbations. The decrement of the aperiodic attenuation should decrease during the evolution process, i.e. aperiodic perturbations become more and more "long-lived". It means that any perturbations, slow attenuating, promote the more faster transition of the slope system in a new state. Time of the aperiodic perturbations existence corresponds to the "seismic silent". This silent time span is real in contrast to the non-dissipating systems. The latter can include silent phase as well, which can be explained by the above finite frequency range of measuring equipment. When the attenuation decrement of the aperiodic perturbations becomes zero i.e. when aperiodic perturbations cease to attenuate, there catastrophe occurs. Hence, in case of systems with dissipation, it is possible to find two prognostic stages: the frequencies decrease of the observable wave disturbances at first, followed by the decrease of the attenuation decrement of the aperiodic perturbations.
4) The second prognostic stage can be short in time if the dissipation is small enough and the frequency decrease of the oscillatory perturbations up to very small values is followed almost immediately (without real silent) by the catastrophic slope failure as for non-dissipative systems.
5) The suggested approach to analytical study of any kind of catastrophes is based essentially on the solution of a stationary problem of the possibility and conditions of the unstable equilibrium state in the system in question. The solution of such stationary problem defines the important parameters of a system on which its evolutionary behaviour depends in stable area near to instability threshold (catastrophe). From the analytical point of view it is important that stationary problem's solution is much easier than the that of the dynamic one. It is important, that at that it is not necessary to know exactly the relevant differential equations and detailed describing of the system behaviour as a whole. The proposed theory (Dubrovskiy, 1988; 1989; Dubrovskiy & Dieterich, 1990; Dubrovskiy & Sergeev, 2001; 2004) is general and can be used not only for treatment of the man-caused and natural catastrophes, but also for any systems described by partial derivatives equations or ordinary differential equations. The generality of the presented theory of catastrophes is at a level of conservation laws.
6) No systematic study of the seismoacoustic background before landslide catastrophes has been carried out up to now. From this point of view the suggested approach to the catastrophe landslides prediction is completely new. It would be expedient to organise observations of the microseismic background spectrum and its behaviour in time in some landslide-prone area. Basing on the suggested catastrophes theory we can predict the spectrum shift to the low frequency range before catastrophic landslide. The intensity and rate of shifting should indicate how close the catastrophic events is and how large it could be. Such monitoring system requires installation of the necessary seismic equipment near the suspected place. The number and parameters of such equipment and installation places should be clarified at the site.

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