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LARGE ANCIENT LANDSLIDES OF ARMENIA FORMED DURING STRONG EARTHQUAKES, AND THEIR MANIFESTATION IN THE RELIEF

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Summary: *The territory of the Republic of Armenia is located within the Mediterranean-transasian seismic belt and at the present stage of its development is characterized by high seismicity. This circumstance provokes the formation of landslides. At the same time, large landslides-blocks and landslides-flows up to 5-8 km long, up to 1-2 km wide and up to 100-170 m or more can form during strong earthquakes. On the slopes, such landslides associated with strong earthquakes of the past are distinguished by a characteristic relief, a relatively small amount of vertical displacement (100-200m, rarely up to 300m). At the same time, the amplitude of their horizontal movement in places reaches 0.5-1 km. This is due to the excessive horizontal acceleration obtained by a landslide during an earthquake. The report will consider examples of such landslides and their distinctive features.*

Key Words: *Earthquakes, landslides, vertical displacement, horizontal acceleration.*

Introduction. The territory of Armenia, together with the entire Armenian Highlands, is located within the Mediterranean–Trans-Asian seismic belt and at the present stage of its development is characterized by high seismicity. Strong earthquakes cause the shaking of the slopes of mountain structures and their loose-block thickness, as well as rocks. At the same time, the stability of rocks is lost, existing landslides are activated and new landslides appear. For example, during the 1988 Spitak earthquake, 19 new landslides appeared in the northern part of Armenia alone and many old landslides intensified [1]. There is information about the descent of large landslides during the Vayots Dzor (735), Dvin (893.), Garni (1679.), Tsakhkadzor (1827.), Zangezur (1931 and 1968) and other earthquakes [2]. Earthquakes of magnitude from 8 to 9 are possible on the territory of Armenia. Naturally, such high seismic activity could have contributed to the formation of large landslides in the past. The latter, indeed, exist on the territory of Armenia and are distinguished by their characteristic features.

Methods. Large ancient landslides of seismogenic origin in Armenia were identified by us back in the late seventies of the twentieth century during field studies in the Aghstev river basin. In the course of the research, topographic maps of the scale of 1:25,000 and 1:100,000 and aerial photographs of the scale of 1:25,000 were analyzed and areas resembling landslide bodies were identified according to the characteristic relief. After that, these areas were examined in the field and their belonging to landslides was clarified. The accuracy of the results of the cameral interpretation of topographic maps and aerial photographs was almost 100%.

Results and discussion. Our research has shown that all the areas previously identified by us as supposed seismogenic landslides really differ from other landslides in their features. First of all, they are large landslides-blocks and landslides-streams with a bumpy surface with swampy depressions, shallow suffusion lakes, separate well-preserved blocks of bedrock that seem to "float” in crushed-loamy formations (the product of fragmentation and grinding of bedrock during earthquakes and landslide movements). The thickness of the rocks disturbed by landslide deformations in the basin of the Aghstev river (drilling data) ranges from several tens of meters to 100-170 m or more (Hovk - 110-160m, Achajur - 170m). The linear dimensions of seismogenic landslides are also impressive: the length is up to 6 km or more (the village of Hovk is 5-5.5 km, the village of Martuni is 6.5-7 km), the width is 1-2 km or more [3, 4]. Interestingly, large landslides-streams have a significant amplitude of horizontal displacement (up to 0.5-1.0 km) and in their “tongue” part the riverbeds are strongly deflected in the opposite direction (see Fig. 1).

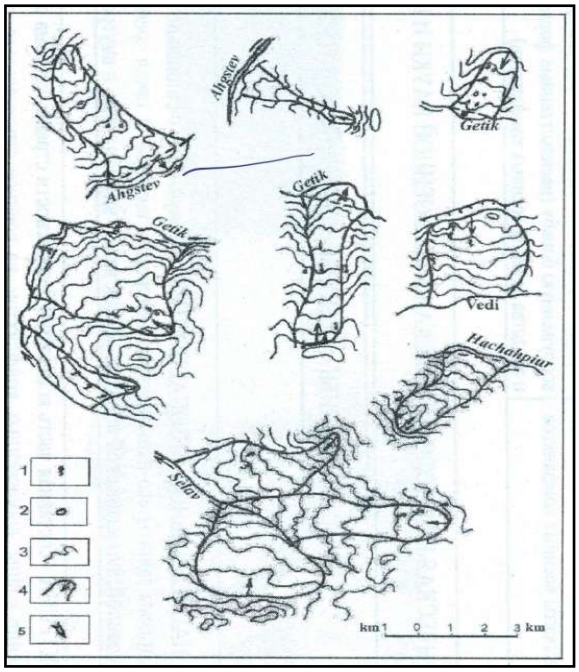

Fig. 1. Characteristic seismogenic landslides:
1 – springs, 2 – lakes, 3 - horizontals,
4 - contours of landslides, 5 – direction
of landslide displacement.

These large ancient (presumably Pliocene-Lower Quaternary age) landslide bodies are called by us tectonic-seismogravitational formations (or seismogenic landslides). One of these landslides (Hovk), due to its complex structure, was attributed to the olistostromes (*accumulation, or piling up,* of landslides) [5]. A large amount of horizontal displacement of the landslide body is characteristic of those of their varieties, in the formation of which a large role belongs to strong earthquakes [6]. It is strong earthquakes that give landslides excessive horizontal acceleration [7]. And the vertical displacements are relatively small.

A cluster of large seismogenic landslides is present in the zone of the Vayots Dzor active fault. These landslides cause significant damage to the villages of Ugedzor, Artavan, Saravan. A landslide formed on the slope of Amulsar Mountain is very active here. The only highway connecting Yerevan with the Syunik region is constantly being destroyed due to its progress.

There are also seismogenic landslides in the zone of the Garni seismically active fault (the villages of Vokhchaberd, Garni, Atsavan, Gehadir). At the same time, all these landslides are quite active, which is manifested by the destruction of buildings, deformations of the highway, etc. The most studied of the seismogenic landslides of the republic is the Hovk landslide-stream (length 5-5.5km, width 1.5-2 km), located on the southeastern slope of the Ijevan ridge (see Fig. 2).

It covers an area of with Hovk and its “tongue” part reaches the floodplain of the Aghstev river. In the northern part of the village, two active landslides of the second order stand out on the body of this large landslide: the northern (1.6 km long) and southern (1.9-2 km long) streams, both about 150-200m wide. In the upper part of the main landslide, another active landslide of the second order with a length of about 1 km and moving almost due south is isolated. The Hovk landslide-stream was first investigated by G.D.Sahakyan and K.A.Gulakyan back in 1958. In the future, many Armenian specialists took part in the study of this landslide. Since 1978. this landslide was investigated by employees of the Dilijan expedition of the IGS of the National Academy of Sciences of the Republic of Armenia and specialists from other organizations cooperating with them (the author took an active part in the work of this expedition).

Based on many years of research, the overall picture of the Hovk landslide-flow is presented as follows [8]. The landslide began to form back in the Upper Pliocene-Lower Quaternary, when differentiated movements of blocks of the Earth's crust intensified in the Lesser Caucasus. At this time, the collapse of the raised blocks and the formation of a giant collapse occurred. At the second stage, in the middle-Upper Quaternary, a giant sliding landslide formed on the body of an ancient stabilized landslide-collapse. In the Holocene (the third stage), a current landslide formed, which is still active at the present time. Small active landslides with numerous stretching cracks are currently forming on the body of this active landslide (the fourth stage) (see Fig. 3).

The total thickness of the displaced masses in Hovk is 110-160m (drilling data). In the upper part they are represented by fatty and carbonated sandy loams, loams and clays with inclusions of crushed stone and limestone blocks. The upper landslide mass is characterized by dustiness, increased $CaCO_3$ content (up to 32-44%), the number of soil plasticity is 12-26. This thickness has shifted along fatty and plastic clays of low density, lying at depths of 40-50m. Young landslide formations are underlain by limestone blocks that have shifted along the surface of dacitic porphyrites modified to a clay state [4].

a)   b)

c) 

Fig. 2. Hovk landslide [1]: a) - a general view of the landslide site,
b) - the active part of the landslide on the territory of the village of the same name,
c) - a karst funnel contributing to the concentration and infiltration
of precipitation moistening the landslide.

Fig. 3. A young active landslide formed on the body of an ancient landslide
(photo by V. Boynagryan). It periodically blocks the highway and
enters the flood-plain of the Aghstev river.

A typical ancient seismogenic landslide stream is the Martuni landslide on the left slope of the Getik River valley (right tributary of the Aghstev river). Its length is 6.5-7 km, width - 1.3-1.5 km. The head of the landslide is located at an altitude of 2600 m, the edge of the “tongue” of the landslide is at an altitude of 1700 m (the height difference is 900 m). The landslide deflected the riverbed 1 km to the right). Viscous and fatty clays, loams, sandy loams and gravel-crushed soils shifted here on the surface of hydrothermally altered porphyrites. Not only earthquakes played a significant role in the formation of this seismogenic landslide stream, but also numerous springs coming out at the foot of the slopes, as well as heavily moistened clay soils of the zone of faults passing here.

Currently, only the “tongue” part of the landslide is active. This activation of the ancient stabilized landslide is associated with the erosion of the ”tongue" of the landslide by the waters of the Getik River, as well as

with water leaks from water pipes, the construction on the landslide of various structures. The “slide mirror” of the landslide passes at a depth of 19 to 38 m.

On the left bank of the Getik River, near the village of Dprabak, there is a large (length about 4 km, width up to 3.5 km) seismogenic landslide-block. The surface of the landslide has a bumpy-hilly, sometimes stepped relief. Numerous wetlands and small lakes stand out on it. The displacement here involves a thickness of quaternary formations with a thickness of 21-73 m, represented by moist, viscous, lumpy, greasy, dusty clays (less often loams and sandy loams) of light to dark brown and yellowish-gray color with inclusions of gravel, crushed stone and fragments of volcanic rocks (stone material is 25-40%). This stratum creeps along the surface of slightly altered, weathered porphyrites, tuff-breccia and quartz porphyrites. This landslide block is characterized by active displacement with speeds from 16 to 28 cm per year.

On the right bank of the Getik River there is a well-known Aigut landslide-a stream that is very clearly distinguished on topographic maps and aerial photographs, as well as on the terrain by the bumpy relief of the surface, the presence of suffusion depressions and small lakes on the body of the landslide. The body of the landslide with the NW and SE is limited by faults. Here clays, loams and crushed-gravel strata with fragments and blocks of porphyrites crawl along the surface of hydrothermally altered porphyrites of dark gray and black color. The power of the displaced mass is 25-51.6m. The landslide is quite active, periodically blocks the highway and goes to the riverbed.

Another active seismogenic landslide is located within the village of Vokhchaberd. Here, a block measuring 2.5 x 1.3 km^2 and with an average thickness of 70-80m fell off the steep slope of the Vokhchaberd ridge and shifted along the fault line of an overfault nature. In this area, Paleogene deposits are thrown up on Neogene ones. The southeastern wing of the fault is raised. The amplitude of the vertical displacement of the block, according to our measurements, is approximately 200-225m with a significant (up to 1 km) horizontal removal of the landslide body. This ratio of horizontal and vertical components confirms the seismogenic nature of the formation of this landslide [6]. The landslide has a stepped profile, the steepness of the landslide slope is 20-250; the Vokhchaberd and Hrazdan formations, as well as a whitish rock mass are crawling. The landslide is currently quite active. Near the village of Vokhchaberd, the roadbed is constantly deformed, there is an intensive destruction of residential and utility buildings. The activity of the landslide increased after the 1988 Spitak earthquake.

Conclusion. Ancient stabilized seismogenic landslides need to be identified and mapped, as they can represent a certain danger in the event of a violation of their equilibrium state in the case of engineering works. In the forested areas of northern Armenia, during field research, the author repeatedly encountered large deformations of the relief, resembling landslides-streams and landslides-blocks that changed the appearance of the terrain with the deviation of riverbeds in the opposite direction. The breakdown wall is not always clearly visible, but it can still be distinguished. Their external signs are not always clearly manifested, therefore, in order to identify them, it is necessary to use, along with field work, a preliminary analysis of aerial photographs and high-resolution satellite images. To identify and map large ancient seismogenic landslides, it is necessary to use a wide range of modern surveys in the visible, thermal infrared, radio wave, and other spectral zones. Good results in identifying traces of ancient seismogenic landslides can be obtained using radar technologies. At the stage of preliminary studies of the terrain, unmanned aerial vehicles can be used.

References

1. Landslides of Armenia. // Yerevan: ASOGIK, 2009, 308s.
2. Boynagryan V.R. Geomorphology of the Armenian Highlands. // Yerevan: ASOGIK, 2016, 650 p.
3. Boynagryan V.R. Landslide (block) violations of the slopes of the Aghstev river basin (Armenian SSR) and some issues of their study // News of the Academy of Sciences of the Armenian SSR. Earth Sciences, XI (1), 1988, pp. 30-37.
4. Boynagryan V.R. Slopes and slope processes of the Armenian Highlands. // Yerevan: Publishing House of YSU, 2007, 279 p.
5. Aslanyan A.T. Large olistostromes of Pliopleistocene age in the valley of the Aghstev river (ArmSSR) // Izvestiya AN ArmSSR. Earth Sciences, 1, 1979, pp. 24-32.
6. Tazieff H. Interpretation des glissements de terrain accompagnant legrand séisme du Chili. // Bull. Soc. Belge de Geologie, 69 (3), 1960.
7. Emelyanova E.P. Basic patterns of landslide processes. // M.: Nedra, 1972, 310 p.
8. Sahakyan G.D. The stages of development of the Vurgun landslide massif (the basin of the Aghstev river of the Armenian SSR). // Izvestia of the Academy of Sciences of the Armenian SSR, Earth sciences, 1, 1989, pp. 62-66.