LANDSLIDES TRIGGERED BY DISTANT EARTHQUAKES IN CENTRAL ASIA

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Summary: *Acquiring data on the triggers of slope failures, such as intensive snow falls, earthquakes and melting snow are essential to understand the mechanism of the failure and predict future natural hazards. Sudden landslides formed simultaneously in different areas triggered by deep foci Pamir-Hindu Kush earthquakes create great danger in the foothill areas of the Central Asian region. The role of distant deep-foci Pamir-Hindu Kush earthquakes as a "trigger" for formation and mechanism in dispersive soils under the influence of prolonged, low-frequency vibrations is examined. Microseismic measurements on 7 landslide sites (by Nakamura method) mainly on landslide sites with a depth of 17-30 m showed the dominant frequency characteristics 1.5-2.2Hz, which coincide with the dominant frequency of deep-focus Hindu Kush earthquakes at these distances from source. Numerical simulation used to assess and comprehend the flow behaviour and some flow-like landslides backcalculated with RAMMS: HillSlope simulation tools.*

Key words: *earthquake, landslide, numerical simulation.*

Central Asia is particularly sensitive to the effects of natural and man-made climate change: the degradation of glaciers, landslides, the dying of the Aral sea and desertification. The effects, whether gradual or catastrophic, on the fragile economies of Central Asia countries, including Uzbekistan, can lead to the collapse of the socio-economic systems and infrastructures of these countries.

The area of the Republic of Uzbekistan is 450 thousand square kilometers of which 20% of total land is mountainous. Of that landslide prone zone, from 15,000 to 17,000 square kilometers is subject to the landslide disaster risk with a population of 3 million. The landslide hazard area includes more than 500 villages, 152 recreation facilities, more than 200 sites of roads and canals and more than 22 mines and water resource facilities. In Uzbekistan, from 100 to 300 active landslides and avalanches occur every year [6].

Acquiring data on the triggers of slope failures, such as intensive snow falls, earthquakes and melting snow are essential to understand the mechanism of the failure and predict future natural hazards. It is time to take a different view at the problem of seismic safety of mountain areas. It is necessary to amend seismic hazard maps with the probability estimate of dangerous slope processes and take it into account at the identification and calculation of seismic risks. It is especially relevant to mountain river valleys with the existing and planned cascades of hydro-technical facilities.

In Uzbekistan, the influence of earthquakes in the formation of landslides has gained little attention, mostly because the studies focused on the role of rainfall and groundwater in the formation of new landslides. For the Central Asian region the largest center of seismic activity is the zone of Pamir-Hindu Kush deep-earthquakes[5]. Every year in this area occur about 200 earthquakes at depths of 180-250 km and 35-40% of it occurs in the spring. Some events are reaching M-7 and in the Central Asia territory, they produce ground motions such as 3-4 MSK units of intensity (Fig.1). Among the four known intercomtinental zones where earthquakes occur in intermediate focal depth (Burma, Romania, Spain and the Pamir-Hindu Kush), the latter is the most active and best covered by instrumental measurements and fairly well understood. Comparative analysis of time synchrony of Pamir-Hindu Kush earthquakes and formation of large landslides in the period from 1969 to 2018 showed that more than 200 cases of landslides formed in South Kyrghystan, Uzbekistan and Tajikistan [7,8].

Landscape sensitivity, in terms of the degree to which it can cope with these rates of change, should therefore be considered as a consequence of combined changes in the preparatory factors (e.g. precipitation events, antecedent groundwater conditions) and triggers (e.g seismic vibrations at this time). Relationships between rainfall patterns and slope instability are reported in the literature for a range of slope failure mechanisms and climates[2]. These studies demonstrate the importance of considering the likely impact of future climate change on slope instability. However, triggers and antecedent rainfall thresholds are highly site-, region-and material-specific and therefore it is not possible to use studies reported in the literature as a guide to future behaviour of other landslides in regions that experience different climates and triggers.

The mechanism of the effects of climate change to the growth in the number of landslides at the turn of the twenty-first century is connected with the increased frequency of turnover of wet and dry years, number of years, when the amount of precipitation in preceding period between November and February was more than 550-600mm. In March – April heavy rainfalls fall more often around 30-40 mm, for a few hours with an intensity of 8-15 mm / hour. Increased cases where the value of rainfall for two – three days was 90-110 mm. This large volume of precipitation was significant enough to saturate the soil or weathered rock, and the higher water table thus contributed much to soil (debris) flows and made steep slopes potential to fail after earthquake shaking.

Seismic effect of the impact was determined by the parameters of amplitude, dominant frequency and duration of vibrations [3]. The latter factors could be decisive for the stability of slopes in the wet spring season, but short-term impact with high frequency, even with very high acceleration may be not dangerous. Therefore, drop-out of abnormally large amount of precipitation or severe earthquake in this region may not cause landslide, and may form several landslides. Much depends on whether the slope has reached a critical state of stability.

For the main part seismically generated landslides usually do not differ in their morphology and internal processes from those generated under non-seismic conditions. However, they tend to be more widespread and sudden. Almost every type of landslide is possible, including highly disaggregated and fast-moving falls; more coherent and slower-moving slumps, block slides, and earth slides; and lateral spreads and flows that involve partly to completely liquefied material Features of combination of two external spatial factors (atmospheric) rainfall and earthquakes on the time and place of formation of the local slope of the landslide have a very complex relationship. Since the seasonal conditions of moisture saturation of slopes can increase its susceptibility to seismic vibrations for the orders.

For example, three groups of landslides were considered. The first – massive landslides in wet years with frequent earthquakes. The second – mass manifestation of landslides in wet years, but with the lack of strong earthquakes. The third one – activation of man-made major landslides at earthquakes vibrations.

This study shows the relationship between the timing of large landslides and formation of mud flows in the mountainous areas of Central Asia to the timing of long-duration, low-frequency distant Pamir-Hindu Kush earthquakes. Fifty-six cases of landslide liquefaction, extrusion, and mud flows at the time of earthquakes were found in which there are complex relationships between precipitation and earthquakes, in the time, place and mechanisms of the landslide development.

The main risk of landslides and mud flows caused by the Pamir-Hindu Kush earthquakes is in the suddenness of their formation, and it is very difficult to predict their place and time. As a result, it is suggested that agencies devote more attention and resources to early detection, warning, and loss prevention of landslide hazards associated with Pamir-Hindu Kush earthquakes [5].

Landslides are one of the most damaging collateral hazards associated with earthquakes. In fact, damage from triggered landslides and other ground failures has sometimes exceeded damage directly related to strong shaking and fault rupture. Seismically triggered landslides damage and destroy homes and other structures, block roads, sever pipelines and other utility lifelines, and block stream drainages. Predicting where and in what shaking conditions earthquakes are likely to trigger landslides is a key element in regional seismic hazard assessment.

Factors contributing to slope failure at a specific site are generally complex and difficult to assess with confidence; therefore, regional analysis of a large group of landslides triggered in a well-documented earthquakes is useful in estimating general conditions related to failure.

Landslides can occur during an earthquake where shaking reduces the strength of the slope. A preliminary comparative analysis of the synchronicity in time of deep foci Pamir – Hindu Kush earthquakes and the dates of formation of large landslides in the period from 1969 to 2017 showed that more than 100 cases of landslides formed in the south of Kyrgyzstan, Uzbekistan and Tajikistan. These earthquakes in the Central Asia territory induced low-frequency (1-5 Hz) prolonged (2-3 min) ground motions and in the spring time on the moist slopes causes processes of compaction, liquefaction and displacement of loess soils. Complex relationship of two spatial factors – precipitation and earthquake to origin time, place and mechanism of landslides, occurred in last years in Central Asia, are presented in examples. Seismically generated landslides usually do not differ in their morphology and internal processes from those generated under non-seismic conditions. However, they tend to be more widespread and sudden. Thus, even a small earthquake, although its consequences are not considered by building codes, can lead to adverse effects and have catastrophic consequences. A relatively modest Gissar earthquake of 1989 with the magnitude of M=5.5 triggered the liquefaction of loess soils resulting in landslides and a huge (3.5 km) debris-flow on a slope with the gradient of only 5-6^0 . This led to 274 human casualties [5].

The analysis of a specific site generally usually requires a probabilistic approach, but a deterministic check on the resulting decision is appropriate. Generally many tectonic faults and unidentified seismic sources contribute to the seismic hazard and risk at a site, and the integration of these through a probabilistic analysis provides the most insight.

These phenomena can lead to changing of earthquake hazard assessment results and constitutes a major portion of the seismic risk to the structures. Sometimes it required reconsideration of seismic zoning maps for providing seismic safety of constructions.

A complex of geophysical work was carried out to study the structure of the site, to identify waterlogged zones, and the propagation velocities of longitudinal and transverse waves were determined. Seismometric measurements were carried out with digital seismic station CMG-6TD, manufactured by Guralp. We determined the frequency of oscillations (F0), the ratio of the horizontal to vertical spectra (HVSP) and seismic liquefaction factor (Kg) in 7 landslide sections at 60 points.

Microseismic measurements on 7 landslide sites by Nakamura method [4] showed the dominant frequency characteristics 1.5-2.5Hz, which coincide with the dominant frequency characteristics of deep-focus Hindu Kush earthquakes (Table 1). The exception is the landslide Old Station, where the frequency characteristics do not match, because the thickness of the dislocating layer of this landslide is more than 100 m.

Table 1

Year	Date	M	T,sec	f,hz	Site	H ,m	Volume, m^3	f ,Hz
1995	16.05	5.9	130	1.3-2.4	Naugarzan	30	20 mln.	1.7
2011	21.03	5.8	120	1.5-2.5	Old station	100	120 mln.	1.1
2012	23.03	4.4	120	1.5-2.5	Altynbel	20-24	1.8 mln.	1.9
2013	04.04	5.4	150	1.5	Parkent	20-22	250 thous.	1.45
2016	17.01	5.0	130	1.3-2.5	Karagli	18-23	1.8 mln.	-
2017	17.04	5.1	120	1.8	Dovut	5-8	4.5 mln.	-
2018	24.03	5.1	95	2.1	Achiyak	17-22	86 thous.	2.2-2.5

The mechanism of displacement of landslides during earthquakes is characterized by almost simultaneous deformation of rocks throughout the landslide area. Liquefaction of soils occurs in thin layers inside the massif or the entire mass, with the simultaneous appearance of a large amount of water on the area of the landslide. At some sites, the first signs are temporary springs, cracks, and settling of the ground surface above cavities, i.e. there is first a vertical deformation, which disrupts the movement of groundwater. Then, there is subsurface erosion, the water issuing from springs becomes turbid, and within 5–10 days flows occur. Under the influence of low-frequency, long-term seismic vibrations, landslides such as block slides, liquefaction and mud flows are generated. For extrusion types of landslides, the beginning of their formation is always associated with a seismic impact. These are deep, long, large-scale landslides with bulging ridges in the floodplains of gullies and a graben-like wall of separation at the top of the slope. They are formed in old and ancient landslide hollows. All investigated in this paper landslides are characterized by a one-time simultaneous displacement, occurred at dominant frequency of earthquakes vibrations 1.5–2.5 Hz and duration nearly 180 s.

Modeling of flow-like landslides is one of the possible approaches that can be used to simulate landslide instability and flow development. Large landslides often assume a complex behaviour showing a continuum passage from sliding to flowing. Numerical simulations can be used to assess and comprehend the flow behaviour of flow-like landslides. These models can also predict landslide runout and runup to perform an hazard zonation.The landslide Khandiza in South Uzbekistan is located close to village Khandiza. The beginning of the landslide movement was recorded on March 31, 2017, when mudflow with volume of 1.8 million m^3 occurred. During 22 hours the mass of loess soil with a height of 3 to 5 m moved for a distance of 110 m. 257 persons living in the expected hazard zone (66 houses) were temporarily evacuated. Within the next 3 days (April 3) the landslide moved for a distance of 230 m, with heights up to 10m, destroying a school building. Within another 3 days (April 6) the landslide reached the river and covered half of it‘s bed. The landslide soil was partially washed away by the the main river and was moved by excavators in order to prevent the full blocking of the river bed. The overall runout of the mudflow within 18 days was 2200 m.

Khandiza 2017 mud flow events in Uzbekistan was back calculated with RAMMS: HillSlope simulation tools[1]. These results are based on the assumption that the entire landslide fails instantaneously and not progressively as a sequence of smaller landslides with barriers over a longer period of time, so predicted the trajectories, runout distances, but not the velocities of such processes (Fig.1).

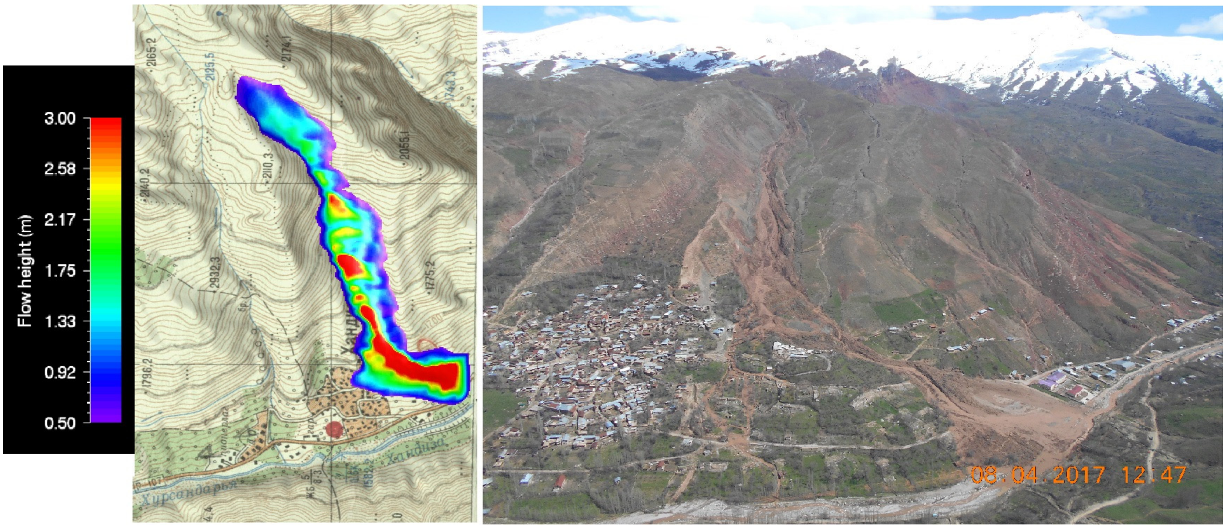

Fig. 1. Best-fit results of the mudflow event Khandiza, simulated with RAMMS: HillSlope.

Generally the runout prediction of simulation model for the Khandiza mud flow event show plausible result as compared to the observed deposition zones. These vital output parameters can be used to provide insight of the event and extent of run out zone of future potential flows. However, more case studies have to be conducted to develop a more comprehensive recommendation for modeling the runout of mud flows in natural terrain.

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