ESC2016-13, 2016
35th General Assembly of the European Seismological Commission

35th General Assembly of the
European Seismological Commission
4-10 September 2016
Trieste

Dynamic geological-geophysical models of unstable slopes in seismic areas – analysis enhanced by 3D stereo visualisation

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This paper presents a series of new integrated 3D models of landslide sites that were investigated in very distinctive seismotectonic and climatic contexts: (1) along the Hockai Fault Zone in Belgium, (2) in the seismic region of Vrancea, Romania, (3) near the Rogun Dam construction site in Tajikistan. All those sites (as many others that we studied in the past) have in common that they are deep-seated failures located in more or less seismically active areas. Thus, the Hockai Fault zone hosting the first sites produced the largest ever recorded earthquake in NW Europe (M=6-6.5, 1692); Vrancea is marked by the highest M>7 earthquake activity in Europe (however, hypocentres are typically very deep, > 100 km), and the Rogun Dam construction site is located near the southern border of the Tien Shan (in the NW of the Pamir) that is one of most seismically active areas of the World. In such areas, slope stability analyses have to take into account the possible (or even very likely) contributions to ground failure.

Our investigations methods had to be adapted to capture the deep structure as well as the physico-mechanical characteristics influencing the dynamic behavior of the landslide body. Field surveys included electrical resistivity tomography (ERT) profiles, seismic refraction profiles analysed in terms of seismic P-wave tomography (ST) and with respect to surface waves (SW), ambient noise measurements to determine the soil resonance frequencies through H/V analysis (HV), complemented by geological and geomorphic mapping. The H/V method is one of the most recently developed method that was initially only applied to map soil resonances in a relatively flat urban context. Now, this method is more and more used in the frame of landslide investigations or on any site marked by topographic relief. However, some attention has to be paid in order to distinguish between topographic and geological site resonance frequencies – only the latter may be used to define the depth of soft soils.

Results of data interpretation were compiled in 3D geological-geophysical models (using GOCAD) supported by HR remote sensing data of the ground surface. For the Rogun site, geophysical results could be compared with borehole data that were integrated in the 3D model. Data and results were not only analysed in parallel or successively; to ensure full integration of all inputs-outputs, some data fusion and geostatistical techniques were applied to establish closer links between them. Inside the 3D models, material boundaries were defined in terms of surfaces and volumes. Those were used as inputs for 2D, 2.5D and 3D numerical dynamic models (presented in a companion paper). 2-2.5D numerical models were completed with the UDEC and 3D modelling with the Flac3D (Itasca) software. Material properties were defined on the basis of ground samples and using seismic data (P-wave tomography and surface wave analysis). For sites in the areas (1) and (2), a full back-analysis was carried out to assess the possibility of a seismic triggering of the landslide. For the Rogun site (3), we simulated a series of possible future earthquake scenarios affecting the slopes. For one slope downstream from the future dam structure (construction started in 2017), very large displacements were modeled. According to those models, an earthquake shaking with PGA exceeding 0.35 g would trigger total failure of the slope with (partial) dam formation on the river.

Interpretation of the complex inputs and outputs was enhanced by 3D stereo visualization using a headset system allowing for full immersion in a virtual environment.