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Landslide susceptibility assessment in Northern Epirus using a deterministic approach

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Introduction

Epirus is a region having a high density of active landslides and numerous areas prone to slope instabilities due to its particular geology and large annual precipitation. In such conditions, blasting operations performed in the context of seismic surveys have to be planned in such a way that there is no risk of triggering ground instabilities or generating significant ground deformations. Herein, we present a summary of a methodology for landslide susceptibility assessment developed and applied in the context of the seismic survey operations in the Ioannina hydrocarbon exploration block. The project took place under the supervision of Repsol and Energean Oil & Gas Joint Venture, which have been awarded the specific block.

The study area covers an extensive part of Northern Epirus (Fig. 1), which is dominated by carbonate and clastic sedimentary rocks. Of particular importance are the outcrops of the flysch of the Ionian Zone, as well as the outcrops of Posidonia shales and Miocene marls, which all are characterized by low strengths. The study was implemented in three stages: a) preliminary desktop analysis, b) field survey, data collection and sampling and c) evaluation of ground failure hazard using a deterministic approach.

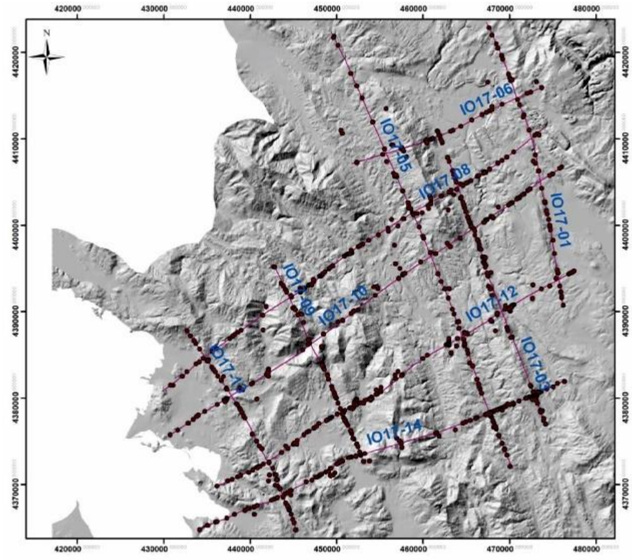

Figure 1: Extent of seismic lines. Circles represent points of data collection and sampling.

Methodology

Considering the large extent of the seismic lines (400km total length), a GIS-based preliminary screening procedure was first applied in order to identify areas of low landslide susceptibility and exclude them from subsequent detailed analysis. This consisted of calculating the topographic/bedding plane intersection angles (Meentemeyer & Moody 2000) within 200m from the seismic lines, combined with geological map data and examination of satellite photos for land use and infrastructure, in order to assign a risk classification score. The preliminary screening allowed for an optimized fieldwork planning given a specific timeframe and resources.

Based on the screening stage, a field survey took place in which more than 700 points along the seismic lines were accessed in order to produce the geotechnical input necessary for the landslide susceptibility computations. Field work included dip measurements for bedding planes and two major joint sets (if present), characterization of discontinuity condition (weathering, coating), joint roughness coefficient (JCR) assignment, rock mass characterization using GSI and Schmidt hammer tests for the estimation of the unconfined compression strength. In a limited number of locations, rock samples were collected for further strength testing in the lab.

The landslide susceptibility computations were done using a multimodal deterministic approach (Fell et al. 2008), in which three slope stability indicators were computed at each point of a 15m x 15m grid by making simplifying idealizations regarding slope geometry and assuming ground uniformity. The indicators were: a) the static factor of safety *FS*, b) the critical seismic acceleration a_c, and c) the permanent displacement $d_{perm,eq}$ caused by a reference earthquake event. Similarly to the work of Grant et al. (2016), the following modes of failure were considered: i) rotational sliding, ii) planar sliding along bedding planes, and iii) wedge failure along two discontinuities (one being the bedding planes). Equivalent Mohr-Coulomb rock mass strength parameters (cohesion, friction) were estimated based on the GSI classification (Hoek et al. 2002). For structureless rock masses (e.g. Miocene marls), strength parameters were estimated based on the available technical literature. For rotational failures, mathematical expressions were used which were derived from the charts of Michalowski (2002) and Loukidis et al. (2003) for the FS and a_c calculation, respectively. The final FS and a_c values were set to be the minimum among the examined failure modes. Having established a_c at each grid point, $d_{perm,eq}$ was calculated using formulas based on Newmark sliding block considerations (e.g. Jibson 2007). Three scenarios of groundwater regime were examined, namely pore water coefficient values 0, 0.2 and 0.4. Fig. 2 presents a sample of the outcome of deterministic approach computations for a seismic line segment.

Finally, the landslide susceptibility mapping was followed by detailed design of the blasting operations (shothole locations, depth and weight of explosive charges) in collaboration with Repsol S.A. personnel. The operations planning was made by taking into account, along with the seismic refraction resolution requirements, computations of the permanent displacement $d_{perm,blast}$ caused by blasting, applying the necessary degree of conservatism.

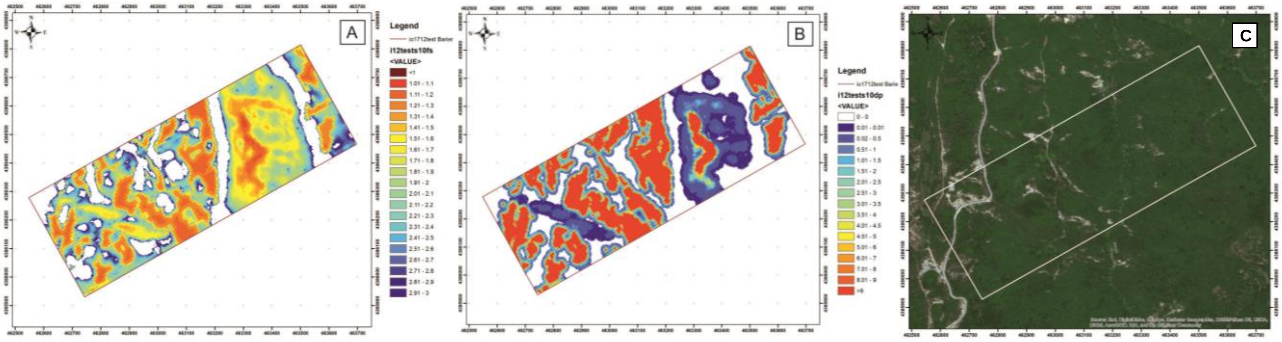

Figure 2: Example results: Maps of a) static FS, b) $d_{perm,eq}$ (in cm) and c) satellite image of a sector along line I7012.

Results

According to the analysis, 45% of the areas were identified as low risk, 34% as moderate risk and 21% as high risk. Line IO1701 (Fig. 1) exhibited the lowest susceptibility, while Line IO1705 was the line of highest susceptibility, with substantial number of natural landslides located in small distance from the line corridor. Generally, the seismic line segments that cross the western slope of Kassidiaris Mountain are located in an area of significant active landslide events, e.g. Aetopetra, Lavdani landslides. All quantitative slope stability indexes point out to the fact that sectors dominated by flysch and Miocene marls present the highest susceptibility for ground failures. The results of the study were incorporated in the blasting operations planning, targeting in preventing development of permanent displacements that would trigger landslide events under any real circumstances by canceling shotholes in high risk locations or reducing the explosive charges.

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