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PROJECT

European Landslide Hazard Maps: Fostering European Harmonization of Slope Movement Hazard Assessment at various spatial scales

(Coordinator: CERG, Strasbourg)

Centro Europeu de Riscos Urbanos
Lisboa - Portugal

WP1: Report on proposed methods for earthquake triggered landslide assessment suitable to apply at regional scale

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Introduction

(Work done in 2017)

For the development of earthquake triggered landslide susceptibility assessment and mapping methods applicable at regional scale of analysis, as in many other fields, requires availability of proper base data and information. However, in the case of mainland Portugal, the information and data which could serve for this purpose is extremely limited in the various aspects related with the topic, which is due to a combination of unfavorable factors: 1) large earthquakes with landslide triggering capacity are relatively rare events, widely spaced in time and include the 1344, 1531 and 1909 earthquakes generated in the Lower Tagus River Valley, and distant events, the 1755 and 1969 earthquakes, in the SW offshore of Portugal (Cabral, 1995); 2) Most of these events occurred before the existence of seismic data acquisition equipment installed in the country, and in consequence the analysis of their effects is mostly limited to the analysis of historical descriptions with all the associated shortcomings and lack of instrumental data.

In fact, as pointed out in the report of activities of the 2016 year of the project, the available database on seismically triggered landslides in mainland Portugal is extremely limited, with only 28 occurrences reported by analysis of historical descriptions (Vaz, 2010; Vaz and Zêzere, 2016), and one case by a large landslide back analysis (Marques, 2001, 2005). This implies severe limitations for this type of studies carried at regional or county scale of analysis, which include:

1) Impossibility of carrying statistically based seismic landslide susceptibility assessment and mapping, due to the lack of usable landslides inventories;

2) Impossibility of carrying out proper validation of susceptibility models which could be applied.

The scarcity of database also applies for the knowledge on the major seismogenic areas which affect the country and also on the availability of strong motion records of large earthquakes.

In this context, the only viable options for earthquake triggered landslide susceptibility assessment and mapping, are physically based approaches. However, these approaches rely heavily on the quality of the input data, namely soil strength parameters (cohesion and friction angle) and potentially unstable soil thickness. In what concerns soil strength parameters, the availability of base data is also limited, with back analysis of past landslides being the more credible approach to the problem. For potentially unstable soil thickness field measurements and site investigation borehole data may be a primary source of information.

Methods for earthquake triggered landslides susceptibility assessment

Due to the very limited base data available for this type of studies in mainland Portugal and the regional scope of the susceptibility mapping to produce, the applicable methods are physically based and include the infinite slope or rigid block limit equilibrium analysis methods using pseudostatic coefficients or the rigid block displacement method proposed by Newmark

(1965), following previous studies carried out at regional scale (e.g. Jibson et al., 2000) with possible inclusion of recent advances on the topic (e.g. Jibson, 2011).

The region selected to test the application of these methods corresponds to the Lisbon County (total area 84.4 km^2), based on two main aspects: Lisbon was severely destroyed by the 1755 earthquake and is also the capital of the country, making it an important study area for historical and present day reasons; in the work team there is a large amount of raw date in various stages of processing, fundamental for this type of studies.

Most of the work done in 2017 was based on the collection of information which was previously collected and produced by the research team, and also the processing steps required to enable the application of the proposed methods in the Lisbon County area, and included the following aspects:

- Preparation of the topographical information available (1:1,000 topographical maps) and production of a DTM which was object of systematic corrections to remove the effects of constructions.

- Preparation of the geological/lithological base map, to include also an extensive survey of landfill and excavation mapping based on aerial photographs interpretation of different dates (1947, 1958, 1967, 1977-78, 1987, 2004) complemented by the information contained in more than 6000 site investigation boreholes, which provided the indication that at least 31% of the county area is covered by landfills (Fig. 1).

- Updating of a mainly rainfall triggered landslides inventory made by interpretation of aerial photographs and field surveys, which contains 642 landslides, mainly of the shallow translational type (Fig. 2);

- Use of landslides back analysis to constrain geotechnical properties of the different geological units;

- Use of the more than 6,000 borehole Standard Penetration Tests (SPT) database in combination with the landfill mapping to estimate the thickness of the potentially unstable upper soil (Fig. 3);

- Analysis of rainfall data to establish rainfall scenarios for susceptibility modeling;

- Construction of a land use map to enable the estimation of effective rainfall infiltration for hydrological modelling;

- Application of a susceptibility model based on the infinite slope stability method with the formulation proposed by Sharma (2002) with the water table position estimated using the high rainfall scenarios coupled with the hydrological model of SHALSTAB (Montgomery and Dietrich, 1994) (Fig. 4).

The results of the model for high rainfall scenarios of 1 day, 7 days and 15 days, were validated with the landslide inventory using ROC curves, and produced an area under the curve of 0.836 for the 1 day rainfall model (Fig. 5), and 0.820 and 0.816 for the 7 and 15 days scenarios.

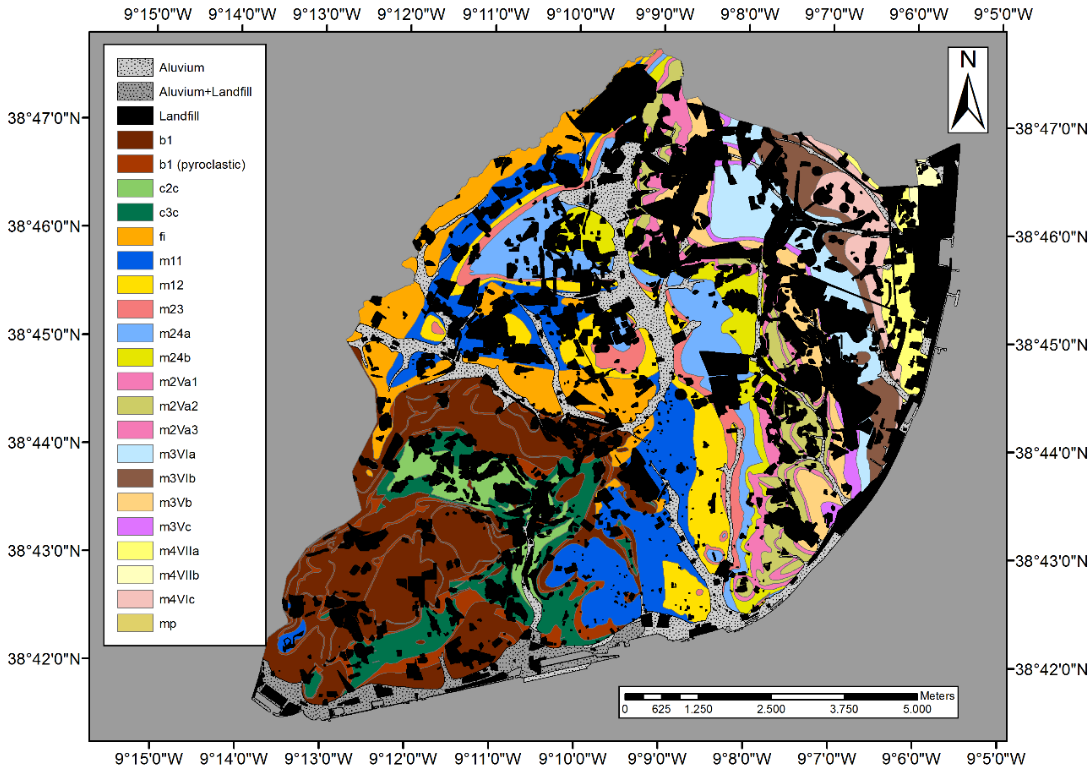

Fig. 1 – 1:10,000 geological base map (Almeida, 1986) with the inventory of landfills produced by aerial photo interpretation and borehole data (black, 31% of the Lisbon county area).

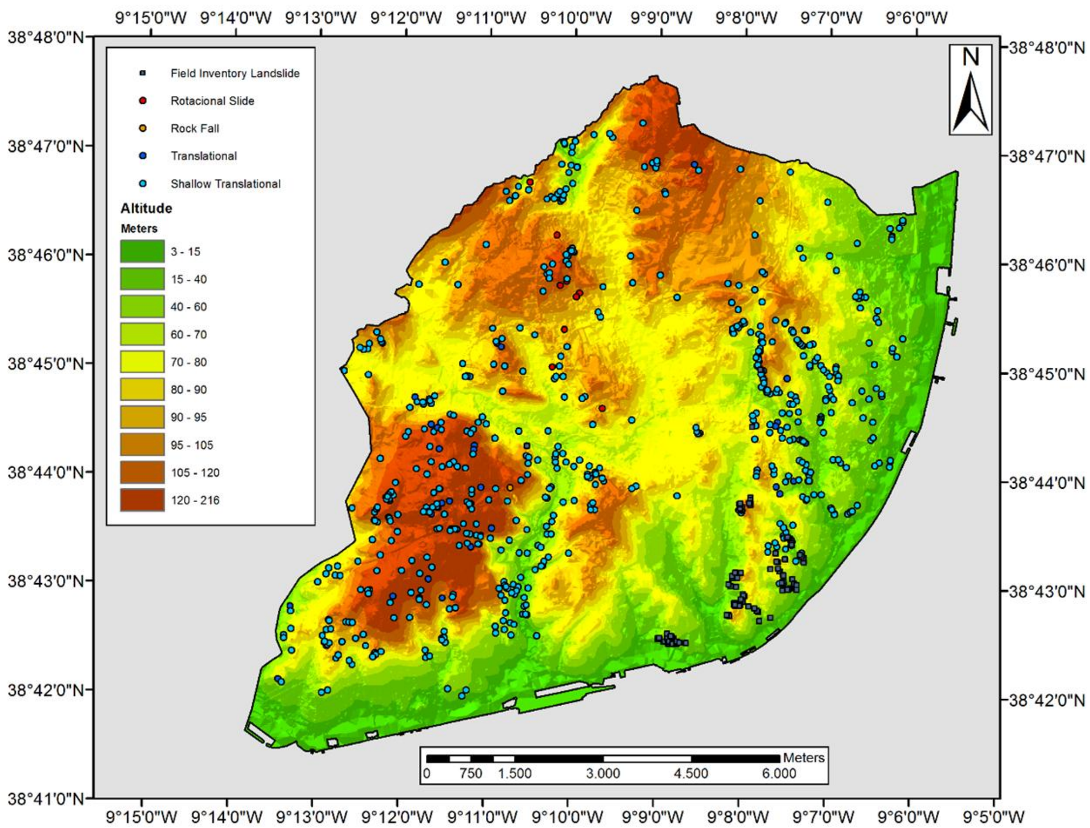

Fig. 2 – Aerial photo and field based landslide inventory (642 landslides) over DTM.

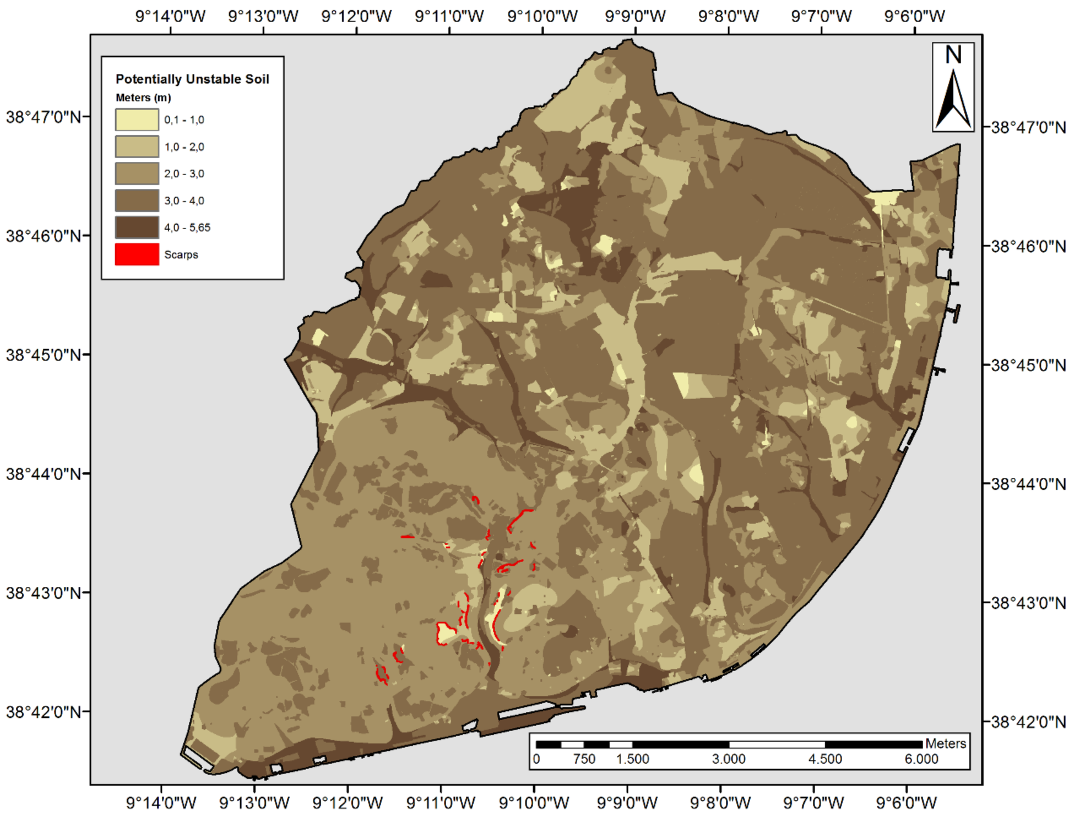

Fig. 3 - Potentially unstable soil thickness estimated by interpretation of 6,000 site investigation borehole data and landfill and excavation mapping.

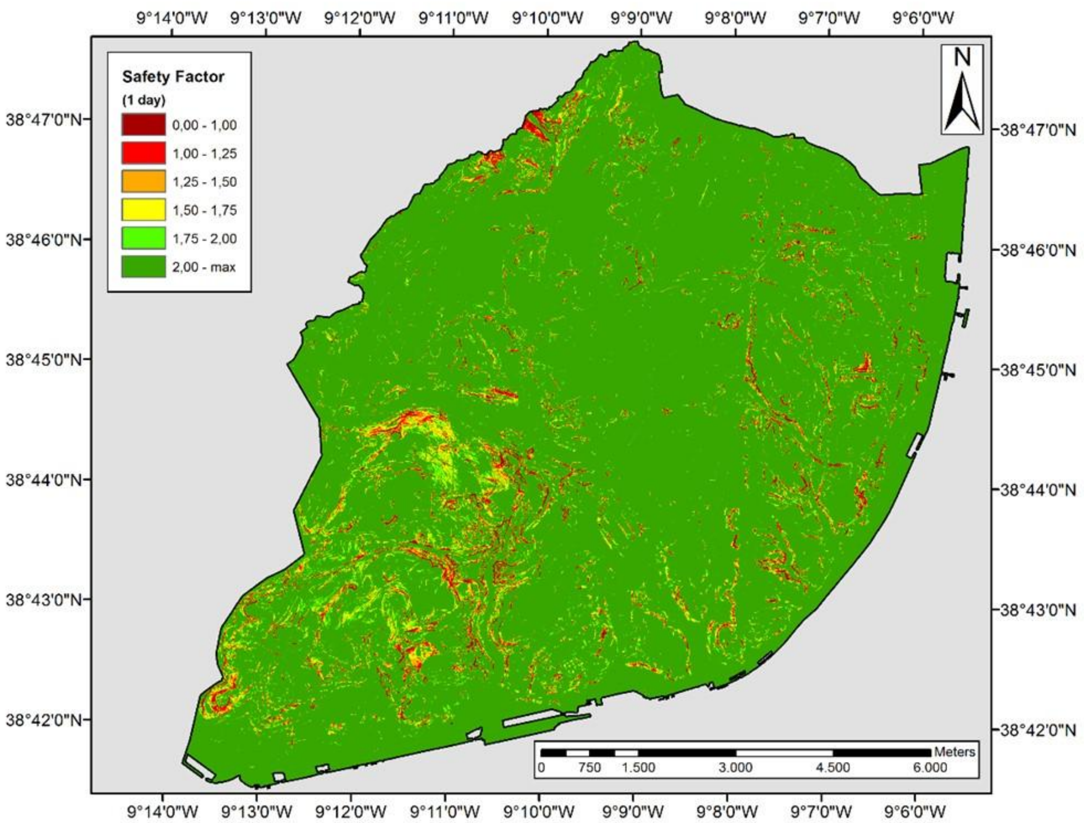

Fig. 4 – Safety factor map for the 1 day rainfall scenario.

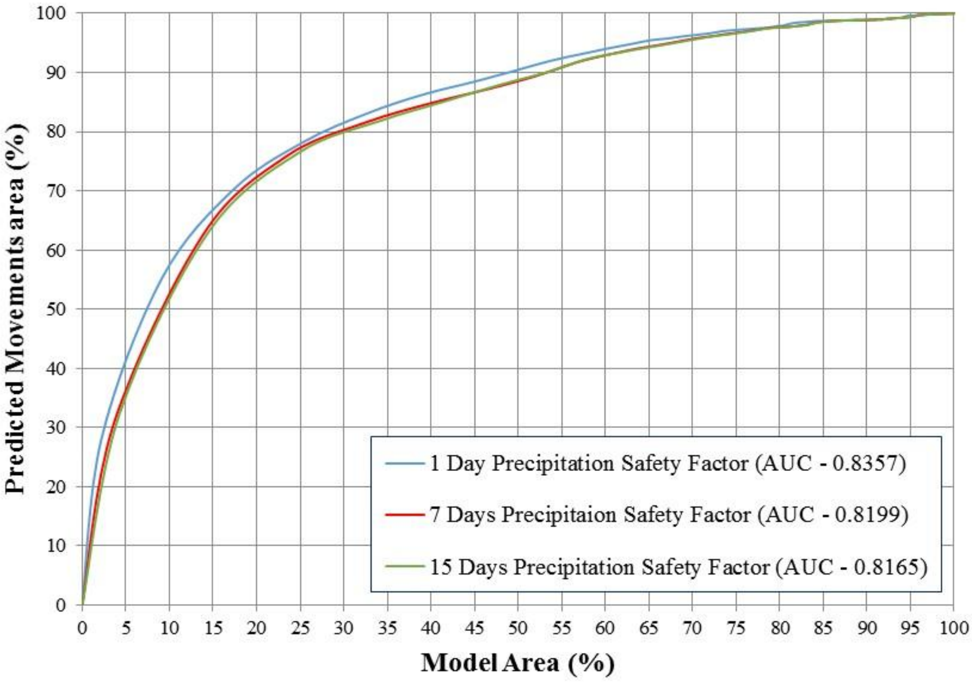

Fig. 5 - Prediction curves of the safety factor models for physically based rainfall triggered landslides of Lisbon County for 1, 7 and 15 days high rainfall scenarios.

In addition it was found that the model results predict the location of zones in the hills of the old city, where there is damage in buildings caused by excessive slope deformation, and also the occurrence of one landslide in 2010 and a retaining wall failure in 2017 which caused a several million euro damage.

The results obtained, which correspond to prediction rate, indicate that the base information used is consistent has an adequate level of reliability to enable the application of the seismic landslide susceptibility modeling.

This work is part of a paper in conclusion to submit to an international journal.

Work in course:

With the object of completing an earthquake triggered landslide susceptibility assessment and mapping for the Lisbon County, using the base information already treated and verified and considering the severe limitations of other relevant base data, mainly of strong earthquake and site effect records, the work in course includes:

- Preparation of a map of maximum acceleration for the county area considering the values recommended by the national version of the Eurocodes adapted to the soil conditions in the study area.

- Analysis of the only available record of a major earthquake which affected mainland Portugal, the 1969 earthquake, to conclude on the feasibility of the application of the Newmark (1965) method using an approach close to the one applied by Jibson (2000).

- Application of the model possible with the available information, i.e. infinite slope with pseudostatic coefficients or the Newmark rigid block.

- Comparison and validation of results with the rainfall triggered landslides inventory.

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