LANDSLIDE MAPPING TO ANALYSE EARTHQUAKE ENVIRONMENTAL EFFECTS (EEE) IN CARMONA, SPAIN – RELATION TO THE 1504 EVENT?

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Abstract (Landslide mapping to analyse earthquake environmental effects in Carmona, Spain – relation to the 1504 event?): The 1504 Carmona earthquake (intensity IX EMS) claimed the loss of human life and caused a number of Earthquake Environmental Effects. On the basis of historical data reported by George Bonsor (1918) this study is intended to estimate coseismic slope performance. The aim is to combine field investigations, geotechnical parameters and computerized models to generate digital probabilistic seismic landslide hazard maps on a local scale. GIS-based simulations of mass movements driven by hydrodynamical and gravitational processes are performed by means of the factor of safety, which is calculated for dry and fully water saturated conditions. Following Newmark’s sliding block model these approaches are extended to assess the potential of earthquake-triggered slope movements. Assuming a Peak Ground Acceleration of 0.3 g, representing the 1504 event, the most affected areas show a failure probability of 33.5%.

Key words: 1504 Carmona Earthquake, Seismic Landslide Hazard Assessment, South Spain

INTRODUCTION

In 1918 the archaeologist George Bonsor was the first scientist who published the effects of a strong earthquake near Carmona (South Spain) in 1504 (Bonsor, 1918). Based on the ESI-2007 Intensity Scale, Silva et al. (2009) attract notice again on this event in order to update Bonsor’s data. They focus on ground cracks, liquefaction, anomalous waves, flooding in rivers, temporary turbidity changes in wells and, especially, on mass movements, since landslides and rock falls belong to the most relevant phenomena of all EEE being observed in Carmona. This study provides different approaches to calculate the site scaled slope instability in terms of the 1504 earthquake (IX EMS) as a potential triggering factor for a number of observed landslides. Each of the methods combines geotechnical results and slope angles derived from a Digital Elevation Model (DEM). Figure 1 points out the sequential steps leading to the hazard-mapping procedure of the study. All simulations have been performed under dry and fully water saturated conditions.

LANDSLIDES IN CARMONA

Within the southern margin of the Guadalquivir river valley Carmona is founded on a small NE-SW trending ridge (Los Alcores). It consists of Miocene blue marls and grey clays coming from the southeast located Betic Cordillera front.
This substratum is covered by a Late Neogene calcarenite unit, which outcrops in a steep cliff, surrounding large parts of the city. Both units can be subjected to massive landslides. In order to distinguish seismically triggered slope movements from others driven by hydrodynamical and gravitational processes, all landslide phenomena are classified according to type of movement, material and size of the displaced mass. Furthermore, all possible causes including geological, morphological, physical and human influences are determined as an important aim.

All important investigation sites are indicated in figure 2 showing the studied area around Carmona. The map also includes joint diagrams from...
calcarenite strata and the location of observed rock falls, topples and slides as well as earth slides in the unit of blue marls and grey clays. Typical examples of these types are illustrated in Figure 3.

Landslides in Carmona are related to a number of preparative and triggering factors. Observed rock falls and topples in calcarenite strata can be mainly subjected to SSE- and ENE-striking tension cracks (fig. 2) and relatively low shearing parameters ($c' = 17$ MPa; $\phi' = 41^\circ$). Laboratory results of analysed loose material samples indicate effective cohesions between 13.04 and 20.16 kPa and angles of internal friction between 17.35 and 26.23°. This data and the high contents of clay minerals (35 – 66 %) are supposed to be essential for the occurrence of massive earth slides on steep slopes along the courses of streams.

Apart from these invariant parameters, both, water saturated soils caused by intensive rainfalls and earthquake shaking can be seen to be the most relevant causal factors for landslides in Carmona. Therefore, these triggering factors are considered in the following simulations.

**SIMULATION OF SLOPE STABILITY**

First slope stability has been simulated by means of the factor of safety, which is calculated by the ratio of the sum of the resisting forces that act to inhibit a slope failure to the sum of the driving forces that tend to cause a failure. The application of a Geographical Information System (ArcGIS 9.3) allowed a differentiated calculation for every grid cell (2 x 2 m), where input parameters vary due to different slope angles.

Based on the factor of safety the site-specific critical acceleration was calculated in a second step. According to Newmark’s sliding block analogy (Newmark, 1965) the critical acceleration is defined as the minimum horizontal seismic acceleration that is necessary to overcome the shear resistance of a friction block, resting on an inclined plane. That means, the higher the degree of slope stability, the higher the critical acceleration, which is needed to cause a failure.

To estimate the cumulative slope displacement during an earthquake, Wilson & Keefer (1983) developed a double integration approach based on numerically cumbersome calculations performed by Newmark (1965). Thereby, those sections of an earthquake accelerogram that exceed the critical acceleration of a slope are integrated two times to obtain the velocity and the cumulative displacement of the sliding block. Considering also the PGA of the Carmona earthquake (0.3 g) it was possible to determine the Newmark Displacement.

Newmark displacement rates are not directly correlated to the potential of earthquake-triggered landslides. For this reason, Jibson et al. (2000) developed a probabilistic empirical model, which allows the estimation of the probability of a failure for every grid cell (Eq. 1):

$$P_f = 0.335 + \left[1 - \exp\left(-0.048N^{1.565}\right)\right]$$  \[1\]

They have calibrated these parameters with data from Southern California and anticipate that the mapping procedure is applicable in any areas susceptible to seismic slope failure. Therefore the model was used to compile digital probabilistic landslide hazard maps for dry and fully water saturated conditions in the study area (fig. 4).
The most affected areas show a failure probability of 33.5%. They are generally related to the same slopes indicating a higher potential of landslides under non-seismic conditions, however, they are extended.

CONCLUSION

The performed assessment of earthquake-triggered landslides provides useful information to estimate potential damages during future earthquakes. In this sense, the designation of vulnerable areas can be used to predict interruptions of access roads, gas and water pipes or electrical lines in case of another strong earthquake in Carmona when landslides of large volumes will be triggered with high probability.

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