PRELIMINARY RESULTS OF STATIC AND DYNAMIC RECONSTRUCTION OF GÜEVÉJAR LANDSLIDE (GRANADA, SPAIN) DURING 1755 LISBON AND 1884 ANDALUSIAN EARTHQUAKES

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Abstract: *In this work, we present preliminary results of a reconstruction of the Güevéjar landslide (Granada, south Spain) during the 1755 Lisbon and 1884 Andalusian earthquakes. We perform a back-analysis of the landslide to estimate the static safety factor and the critical acceleration previous to both earthquakes and for the present-day situation. We obtain a critical intensity of V which matches the minimum intensity grade required to trigger coherent landslides. We conclude that the Güevéjar landslide is stable at present-day conditions but its reactivation is expected in case of an earthquake with a similar intensity to that during the 1884 Andalusian earthquake (I=VI-VII) or larger.*

Key words*: earthquake, Güevéjar, landslide, newmark*

INTRODUCTION

Earthquake-triggered landslides can be analyzed to estimate some characteristic of paleo-earthquakes which triggered them. Such paleoseismic landslide studies thus can help to reconstruct the seismic shaking history of a site or a region (Jibson, 1996).

The Güevéjar landslide is located near the Güevéjar and Nívar villages about 10 km to the north of Granada in the northern edge of the Granada Basin (south Spain). This great rotational landslide was caused by the 1755 Lisbon earthquake with epicentral intensity of XI-XII and magnitude 8.5 (Martínez Solares and López Arroyo, 2004) and was reactivated later by the 1884 Andalusian (or Arenas del Rey) earthquake with epicentral intensity of X and magnitud 6.5-7.0 (Muñoz and Udías, 1981). In both events, the Güevéjar village was destroyed but it was reconstructed in 1887 at its actual location outside the landslide area.

In this work, we show preliminary results of a reconstruction of the Güevéjar landslide during the 1755 and 1884 earthquakes. We based the analysis on previous works (Sanz, 1992, Jiménez Pintor, 2006; Jiménez Pintor and Azor, 2006) and field data to perform a back-analysis of Güevéjar landslide to estimate the static safety factor and the critical acceleration for both earthquakes and for the present-day situation.

GEOLOGY

The sedimentary materials outcropping in the study area belong to the continental infilling of the Granada Basin, one of the Neogene-Quaternary intramontane depressions located in the central part of the Betic Cordillera. The lithologies identified in the landslide area are from bottom to top: a) lignite-bearing marls (upper Turolian); b) clays, silts and conglomerates (Pliocene); c) marls and oncolitic limestones (Pleistocene); d) travertines (Pleistocene). The materials affected by the rupture surface are the lignite-bearing marls and the clays, silts and conglomerates.

A detailed geological map of the Güevéjar landslide can be found in Jiménez Pintor and Azor (2006). We used this map and field data to perform our slope model fitting the thickness and distribution of the sediments, the location of the water table and the main scarps of the 1755 and 1884 landslides.

METHODOLOGY

The back-analysis of the landslide is made with the 2D slope stability analysis software Slide (Rocscience Inc., 2003). This program calculates safety factors for circular and non-circular slope failure surfaces based on a number of widely used limit equilibrium techniques.

We firstly derived a slope profile from a 10 m x 10 m pixel-size digital elevation model at Güevéjar landslide location. This slope profile represents the maximum path of the landslide and we used previous works data obtained from similar landslide materials to set their strength parameters (Azañón et al., 2006). In our slope model, we have obtained the safety factor after each earthquake setting a non-circular slope failure surface and estimating a equivalent peak ground acceleration (PGA) using different Intensity-PGA relationships for the Mediterranean zone. Then, we removed the seismic acceleration to obtain the static safety factor previous to the each earthquake. The minimum seismic acceleration to overcome shear resistance and initiate the displacement of the landslide is calculated by:

$$a_c = (SF - 1)g \sin(\alpha) \qquad [1]$$

where a_c is the critical acceleration (in gravity units, 1g = 9.81 m/s^2), g is the gravity acceleration, SF is the static safety factor and α is the thrust angle. For rotational movement, Newmark (1965) showed that the thrust angle is the angle between the vertical and a line segment connecting the center of gravity of the landslide mass and the center of the slip circle.

THE 1755 GÜEVÉJAR LANDSLIDE

Pre-1755 topography (Fig. 1) was reconstructed using a GIS. We subtracted the contour lines of the actual landslide area and interpolated the previous topography. The 1755 Lisbon earthquake was felt in Güevéjar with a intensity of VI. We estimated a equivalent peak ground acceleration (PGA) of 0.06-0.10g. The safety factor obtained based on Morgenstern-Price limit equilibrium method is close to one (SF=0.98). This value is agree with the observation that the 1755 landslide did not have much displacement. Removing the seismic acceleration, we obtained a static safety factor previous to the earthquake of 1.26. The thrust angle obtained is 12º and the critical acceleration is 0.05g which is equivalent to a critical intensity of V which is one intensity grade lower that caused by 1755 Lisbon earthquake. This critical intensity value is in agreement with the minimum intensity (I=V) required to trigger coherent landslides as reported in historical earthquakes (Keefer, 1984; Keefer, 2003).

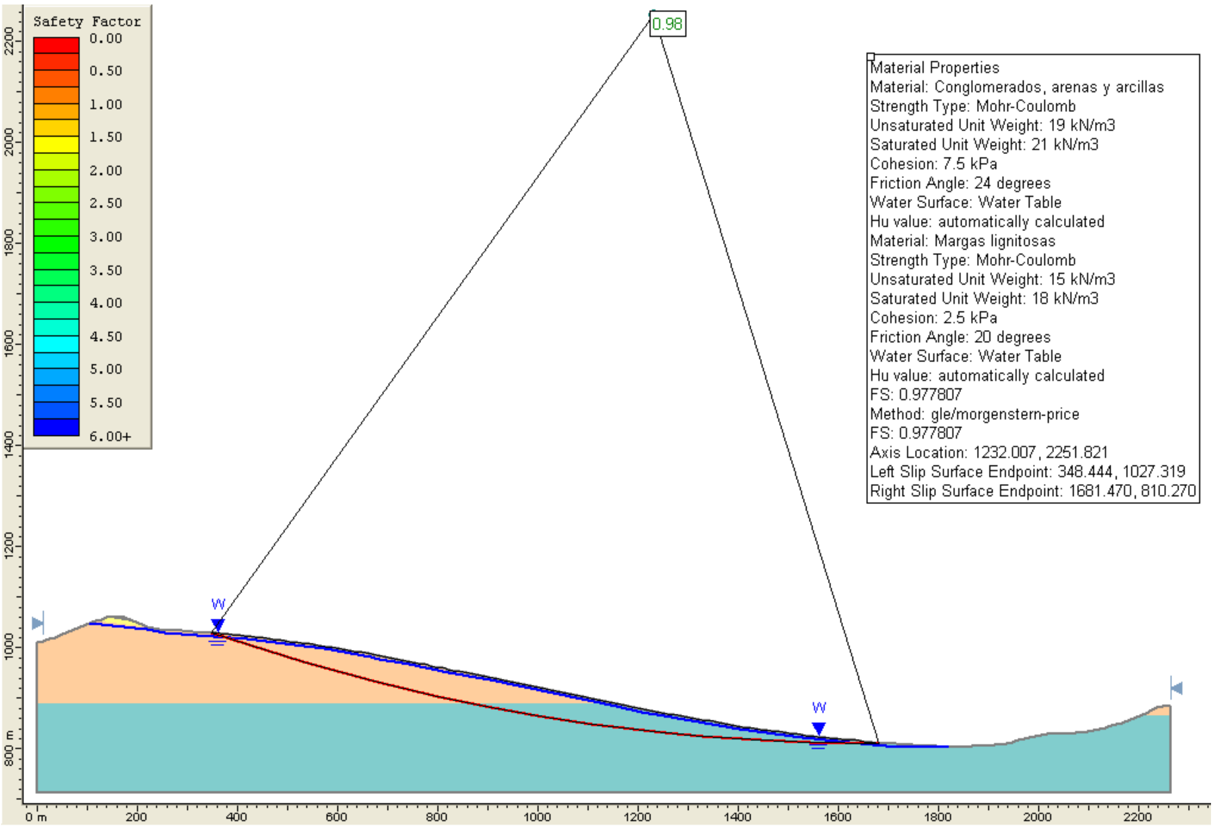

Fig. 1: Idealized cross-section of the 1755 landslide in saturated conditions. Soil properties are shown for each designated layer in the computer model. Obtained safety factor are also shown.

THE 1884 GÜEVÉJAR LANDSLIDE

We have considered that the pre-1884 topography (Fig. 2) is similar to the pre-1755 topography at the scale of the model and the results will not be affected too much. The 1884 Andalusian earthquake was felt in Güevéjar with a intensity of VII (Muñoz and Udías, 1981). In this case, estimated PGA values are 0.11-0.18g. The safety factor obtained using the Morgenstern-Price method is lower than the previous case (SF=0.89). This value is coherent with the fact that the 1884 landslide mass had more displacement. Removing the seismic acceleration, we obtained a static safety factor previous to the earthquake of 1.40. The thrust angle obtained is 14º and the critical acceleration is 0.10g which is equivalent to a critical intensity of VI which is one intensity grade lower than caused by 1884 Andalusian earthquake.

THE PRESENT-DAY GÜEVÉJAR LANDSLIDE

We have used the present-day topography (Fig. 3) and the 1884 slope surface rupture. The static safety factor obtained is stable (SF=1.91). Therefore, the landslide is estable in both dry and saturated conditions. However, ocurrence of small secondary landslides in the toe of the landslide seems possible, however these are not further analyzed in this work.

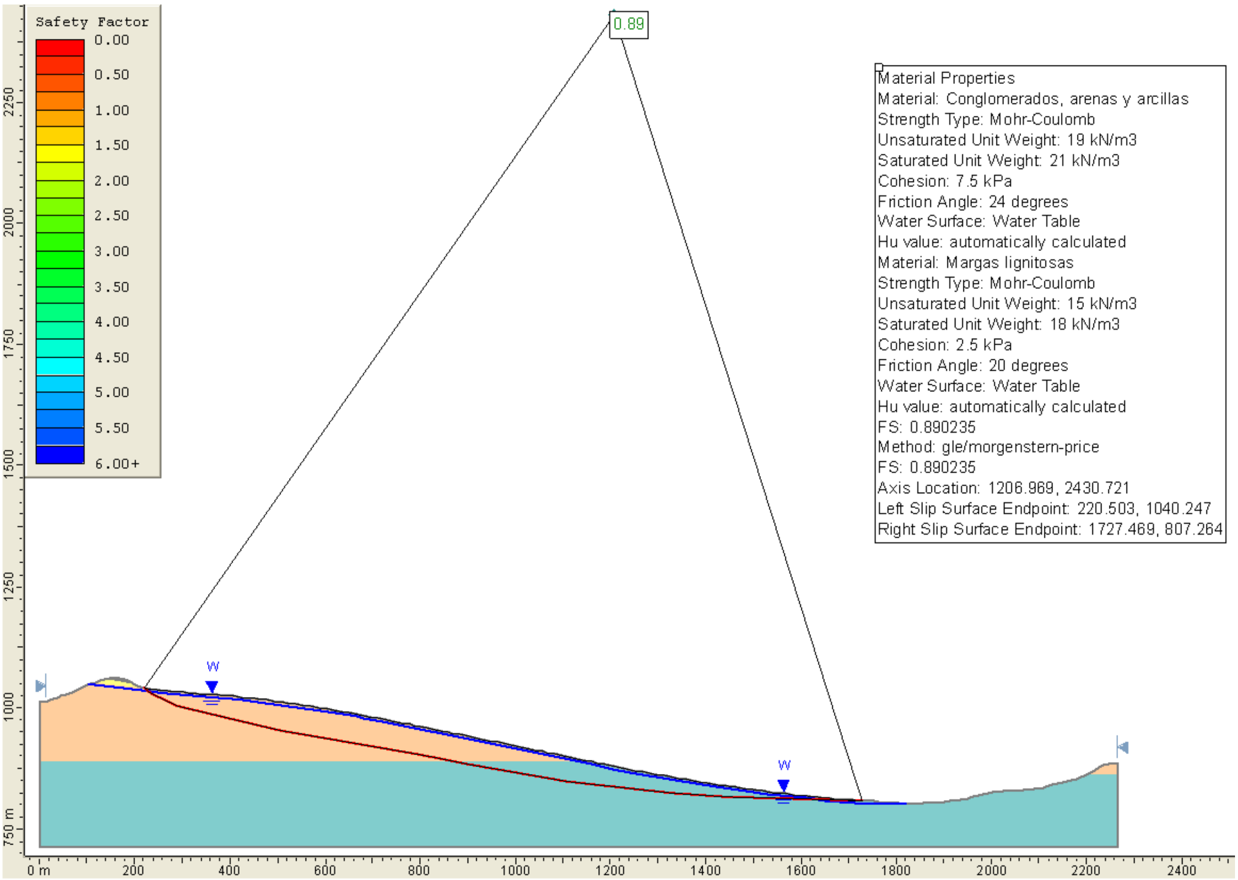

Fig. 2: Idealized cross-section of the 1884 landslide in saturated conditions. Soil properties are shown for each designated layer in the computer model. Obtained safety factor are also shown.

The thrust angle obtained is 8º and the critical acceleration is 0.13g which is equivalent to a critical intensity of VI-VII which is similar to the intensity grade caused by 1884 Andalusian earthquake.

CONCLUSIONS

We have developed a preliminary reconstruction of the Güevéjar landslide during the 1755 Lisbon and 1884 Andalusian earthquakes. Future investigations with a more accurate landslide model based on real geotechnical data and fitting the failure surface with geophysical and borehole data will give further insight into the failure mechanisms.

Taking into account the preliminar nature of the results, we can conclude the Güevéjar landslide is stable at present-day conditions even though we consider a complete saturation of the slope. The reactivation of Güevéjar landslide is only expected in case of an earthquake with a similar intensity to that during the 1884 Andalusian earthquake (I=VI-VII) or larger.

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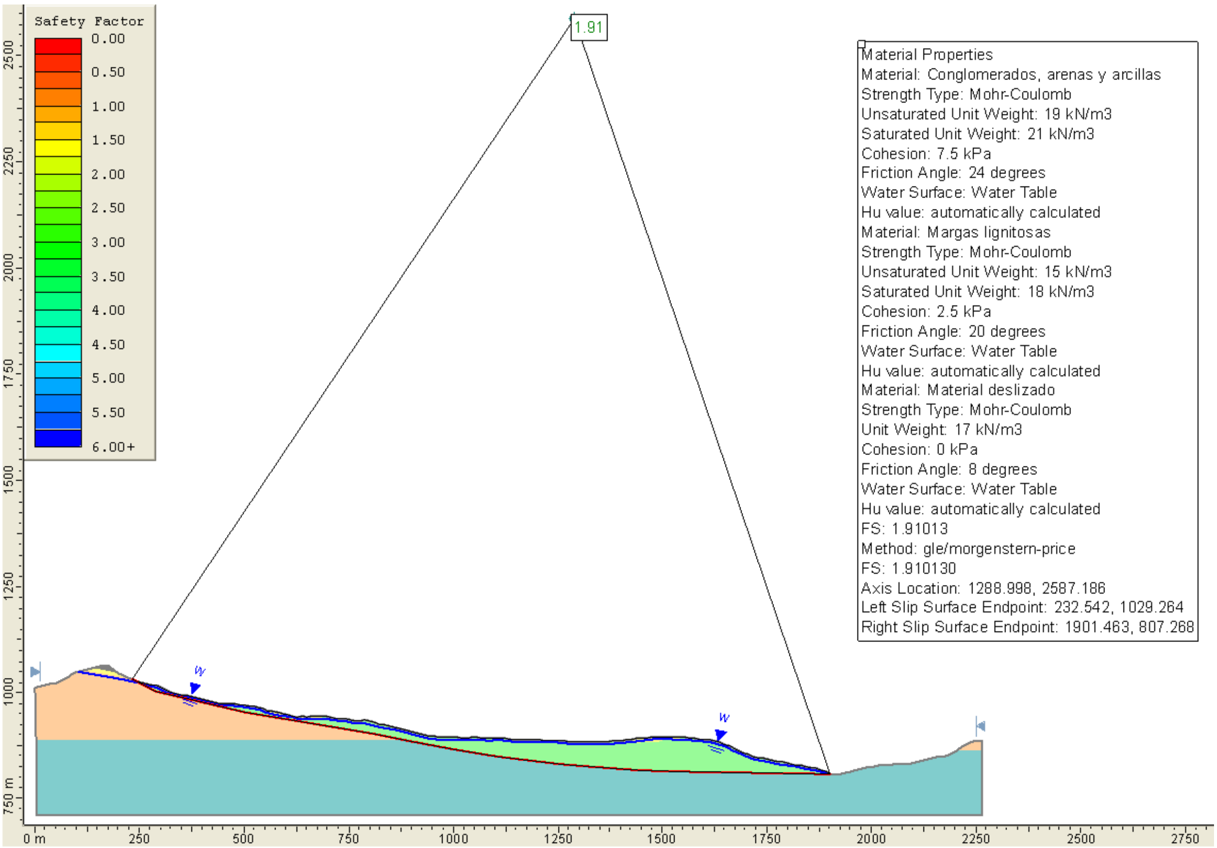

Fig. 3: Idealized cross-section of the present-day landslide in saturated conditions. Soil properties are shown for each designated layer in the computer model. Obtained static safety factor are also shown.