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Geological-geotechnical characterization of a deep-seated landslide affecting a road-bridge in Alcoy (southeastern Spain)

Caractérisation géologique et géotechnique d'un glissement de terrain profond qui affect un pont routier à Alcoy (sudest de l'Espagne)

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ABSTRACT: Bridge construction on areas affected by landslides is a challenge, as deep foundations do not guarantee the success of the performed design. In such cases, it is important to identify the area affected by the instability and the depth of the sliding surface. In this case study, a 80 m reinforced concrete long bridge with three intermediate piers supported by a pile foundation 15 m depth is affected by the reactivation of a deep-seated rotational landslide. The level of damage of the bridge is so severe that some of the precast beams placed on supporting piers have been displaced out from its elastomeric bearing pads. All this damage alongside the active instability has ended in rendering the bridge unusable. The landslide affecting the bridge involves a layer of colluvial deposits overlaying marls with some intercalated calcareous layers. To understand the instability, a geological-geotechnical characterization was conducted by means of boreholes and laboratory tests. Moreover, electrical and seismic tomography was used to understand the distribution and characteristics of soil layers. Subsequently, structural and geotechnical monitoring was done. Finally, a structural analysis for damage assessment was conducted. The integration and analysis of all this information have proved to be effective for a comprehensive understanding of the deep-seat landslide, its kinematics, activity and conditioning factors.

RÉSUMÉ: La construction de ponts sur une zone avec de nombreux cas de glissements de terrain peut être un défi et une fondation profonde ne garantit pas le succès du projet proposé. Dans tels cas, il est primordial d'identifier non seulement la zone affectée par l'instabilité, mais également la profondeur de la surface de glissement. Dans ce cas d'étude, un pont de beton armé 80 m de longueur avec trois piliers intermédiaires reposant sur une fondation en pieu de 15 m de profondeur est affecté par la réactivation d'un glissement de terrain rotationnel profonde. Les pathologies sur le pont sont si grave que certaines des poutres préfabriquées placées sur les piliers ont été déplacées de ses coussinets élastomères. Tous ces dommages, parallèlement à l'instabilité active, ont fini par rendre le pont inutilisable. Le glissement de terrain qui affecte le pont implique une strate de colluvions qui se superposent aux marnes, avec quelques couches de calcaire intercalées. Afin de comprendre l'instabilité, une caractérisation géologique et géotechnique a été réalisée au moyen de sondages et d'essais de laboratoire. De plus, la tomographie électrique et sismique a été utilisée pour mieux comprendre la distribution et les caractéristiques des couches de sol. Subséquemment, une surveillance structurelle et géotechnique a été effectuée. L'intégration et l'analyse de toutes ces informations se sont révélées efficaces pour une compréhension globale du glissement profonde du terrain, de sa cinématique, de s'activité et de ses facteurs de conditionnement.

Keywords: Rotational landslide; slope instabilities; structural damage; bridge

1 INTRODUCTION

When a bridge is to be built in an area affected by existing landslides, deep foundations are usually used for trying to avoid the inherent challenges of these areas. However, the use of this type of foundation does not guarantee the success of the foundation as the piles can be no deep enough or do not have enough strength to stabilize the landslide by themselves. In such cases, it is of paramount importance to identify the area and depth affected by the landslide. An inventory of the tension cracks present in the soil can help to understand the boundaries of the landslide. Monitoring the changes in cracks, opening and length, or the identification of new cracks is required to establish the extent of an unstable area (Osasan & Afeni, 2010).

Complementary, other techniques can be used for the determination of the depth of the sliding surface. Inclinometer measurements are crucial to determine the depth of the slip surface of a landslide (Sass & Bell, 2008). The sliding surface can also be usually detected by seismic tomography due to the velocity contrast between the stable bedrock and the unstable mass (Jongmans et al., 2009; Méric et al., 2007). This surface can also be determined by electrical tomography because of the resistivity contrast between stable and unstable soils (Caris & Van Asch, 1991; Lapenna et al., 2005). Information provided by inclinometers is also essential to validate the geophysical measurements (Sass & Bell, 2008).

In this work, a methodological description of the work done as well as the geological characterization of a deep-seated landslide located in Alcoy (SE Spain) is presented.

2 STRUCTURAL TYPOLOGY OF THE ROAD-BRIDGE

The bridge affected by the reactivation of the landslide is 80 m long and presents a curved path. It has three intermediate piers supported by a cast-in-place pile foundation with six piles for every pier. The piles have a total length of 15.0 m and a diameter of 1.0 m. A reinforced concrete deck slab was built over the precast beams supported by the piers.

3 METHODOLOGY

Different methods have been used to determine the geological and geotechnical characteristics of the site as well as the bridge damage. These methods are briefly described in the following subsections.

3.1 Geological-geotechnical survey

Drillings, penetrations tests and inclinometers were used to obtain information about the subsurface structure. Two drillings were carried out up to a maximum depth of 40 m. Inclinometers were installed in each borehole using plastic inclination tubes. A geotechnical characterization of the samples collected in the borehole was made by classification and strength tests performed in the laboratory.

3.2 Crack mapping

Visual inspections of the slope and the nearby area were done, drawing a map with all tension cracks observed in the field, as well as those recognized from orthophotos.

3.3 Electrical and seismic tomography

Geophysical methods were used to determine the depth of the sliding surface, and more specifically P-wave seismic refraction tomography and Electrical resistivity tomography. Three profiles were conducted for each technique, one along the axis of the landslide and the other two profiles perpendicular to the previous one.

3.4 Damage survey

A detailed visual inspection of the structure has been developed. All damage (i.e. cracks, relative displacements, concrete spalling, etc.) affecting the beams, abutments, piers, deck and pavement of the bridge have been documented in detail.

4 RESULTS AND DISCUSSION

Two types of soil were distinguished in the geological-geotechnical survey. Firstly, a layer of colluvial deposits composed of clayey sands with an effective angle of internal friction of 36º and an effective cohesion of 22 kPa. Secondly, there is a layer of marls located beneath the Quaternary deposits. This layer is composed of medium plasticity clays with intercalated marly calcareous layers. The unconfined compressive strength of this clay is 396 kPa, the effective angle of internal friction is 35º and the effective cohesion is 27 kPa.

The spatial distribution of these layers is shown in Figure 1. It can be seen that the Quaternary deposits are located from the toe to the centre of the slope, whilst the marls are located from the centre to the top.

According to the information provided by the two inclinometers, the sliding surface is located at a depth of 23 m in the inclinometer 1 and of 7 m in the inclinometer 2. The location of the inclinometer is shown in Figure 1. The recorded displacements of the inclinometer 1 from November 2012 to February 2013 are depicted in Figure 2.

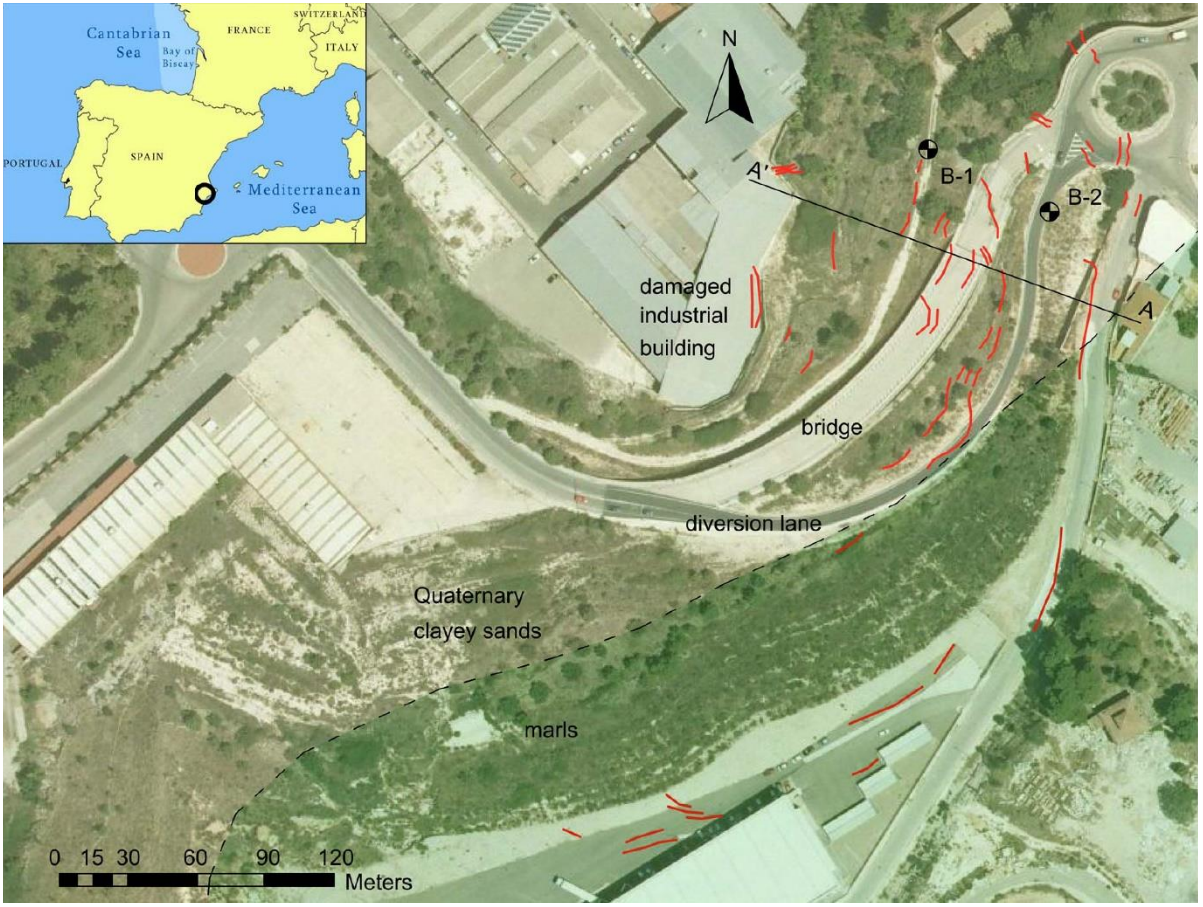

Figure 1. Geological and crack's distribution map of the study area and location of boreholes B-1 and B-2.

The tension cracks observed during the visual inspections of the slope and the nearby area are shown in Figure 1. A large number of tension cracks were detected near the north abutment of the bridge and between the bridge and the diversion line built after the damage caused by the landslide. Some cracks were also observed at the toe of the slope, by the damage industrial building, and at the top, on the edge of the access road to the industrial building located at the bottom of Figure 1.

Figure 3 shows a general view of the damaged industrial building located at the toe of the slope (bottom left of the figure) and the bridge (top right of the figure) from the left side of the slope.

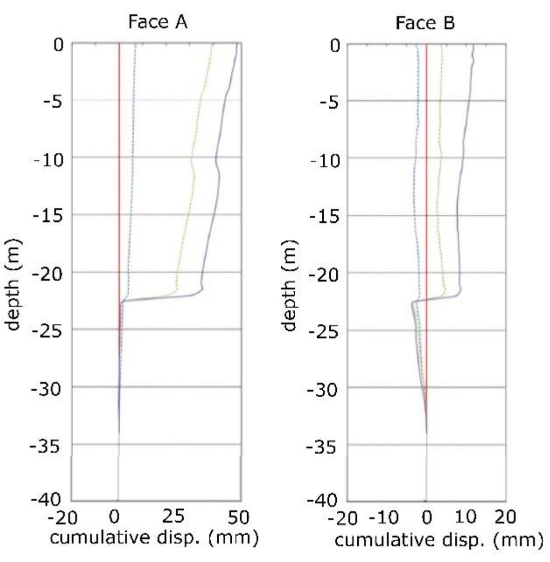

Figure 2. Profile of the Inclinometer 1.

Two tension cracks located near the north abutment on the soil surface below the bridge are shown in Figure 4. The landslide has affected the bridge in such an extent that some of the precast beams have been displaced out from its elastomeric bearing pads. The displacements of the outside precast beams have broken the seismic shear keys of the bridge, Figure 5. All this damage alongside the active instability has ended in rendering the bridge unusable.

Figure 3. General view of the slope.

Figure 4. Tension cracks on the soil surface below the bridge

Figure 5. Damaged precast beam. Note the state of the neoprene bearing pad.

The information provided by the geophysical investigation along with the information obtained from the inclinometers have allowed to define the failure surface of this deep-seated rotational landslide, which is shown in figure 6.

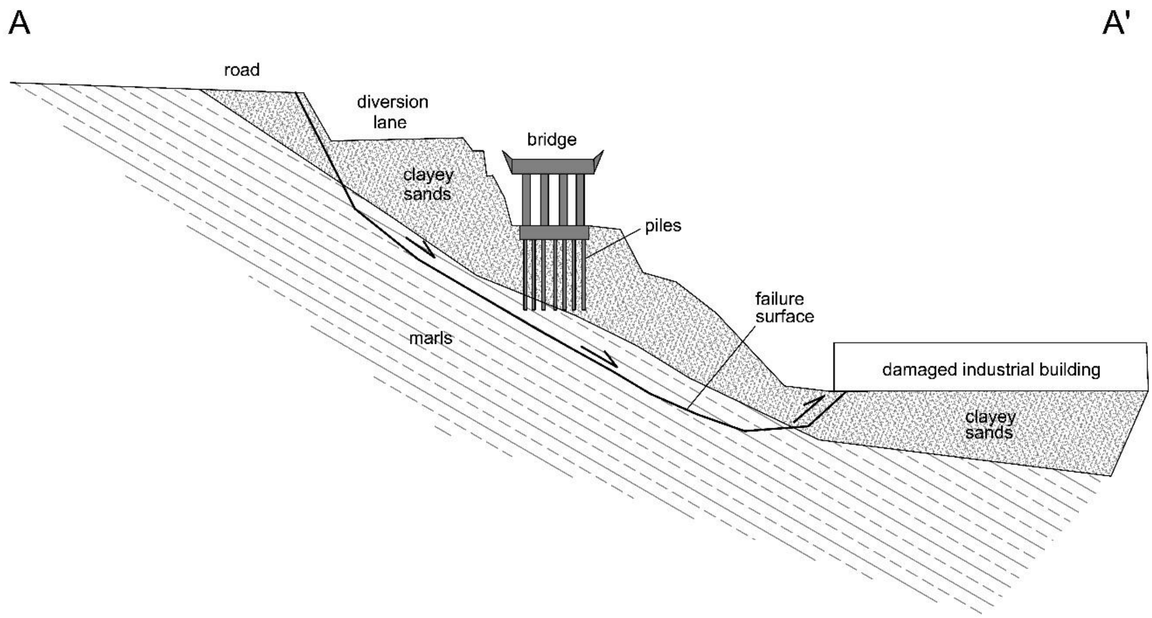

Figure 6. Cross section AA' with the estimated failure surface.

5 CONCLUSIONS

A deep-seated landslide can be successfully characterized by the integration of geological-geotechnical survey, crack mapping, geophysics tomography and structural damage. These techniques provide complementary information allowing a complete diagnosis of the geometry and mechanisms of the landslide. This comprehensive understanding of the phenomenon will ensure a successful design of future stabilizing activities.

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