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Near-surface geophysical methods for investigating the Buyukcekmece landslide in Istanbul, Turkey

Esref Yalcinkaya [a,*], Hakan Alp [a], Oguz Ozel [a], Ethem Gorgun [a], Salvatore Martino [b], Luca Lenti [c], Celine Bourdeau [c], Pascal Bigarre [d], Stella Coccia [d]

[a] Istanbul University, Engineering Faculty, Geophysical Engineering, 34320 Avcilar, Istanbul, Turkey
[b] Department of Earth Sciences and Research Center for the Geological Risks (CERI), University of Rome “Sapienza”, Italy
[c] French Institute of Sciences and Technology for Transport, Development and Network (IFSTTAR-Paris), France
[d] INERIS Ecole des Mines des Nancy Campus ARTEM CS 14234, F-54042 Nancy Cedex, France

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ABSTRACT

In this study, near-surface geophysical techniques are used to investigate the physical characteristics of the Buyukcekmece landslide (Istanbul, Turkey). The Buyukcekmece landslide has continuous activity at a low velocity and is classified as a complex mechanism. It includes rototranslational parts, several secondary scarps, several landslide terraces, and evidence of two earth flows. It mainly develops in the clayey layers of the Danismen Formation. According to our findings, P-wave velocities ranging from 300 m/s to 2400 m/s do not provide notable discrimination between sliding mass and stable soil. They show variations in blocks reflecting a complex structure. We obtained the S-wave velocity structure of the landslide up to 80 m by combining the analysis of MASW and ReMi. It is clear that S-wave velocities are lower in the landslide compared to those of the stable area. Identical S-wave velocities for the entire area at depths higher than 60 m may point out the maximum thickness of the landslide mass. Resonance frequencies obtained from the H/V analysis of the landslide area are generally higher than those of the stable area. The depths computed by using an empirical relationship between the resonance frequency and the soil thickness point out the failure surfaces from 10 to 50 m moving downslope from the landslide crown area. The resistivity values within the landslide are generally lower than 30 Ω m, i.e., a typical value for remolded clayey debris. The geophysical results reflect an overview of the geological model, but the complexity of the landslide makes it difficult to map the landslide structure in detail.

1. Introduction

The Marmara region of Turkey is preparing for the expected Istanbul or Marmara earthquake (Fig. 1). A number of studies performed after the devastating 1999 Izmit (M7.4) and Duzce (M7.2) earthquakes characterize the Marmara fault, which is part of the North Anatolian Fault (NAF) extending under the Marmara Sea, as a seismic gap with a high potential for producing a large earthquake ($M > 7$) (Parsons et al., 2000; Hubert-Ferrari et al., 2000; King et al., 2001; Barka et al., 2002; Parsons, 2004; Pondard et al., 2007). A previous study by Utkucu et al. (2009) describes the Marmara region, which contains an imminent seismic hazard. In the region, many studies have been performed related not only to the understanding of the seismic hazard but also to the mitigation of seismic risk. The project of MARSite (new directions in seismic hazard assessment through focused earth observation in the Marmara Supersite, http://marsite.eu) is one such study financed by European Union-FP7. It consists of 11 work packages that have a wide study range from geodetic monitoring to early warning. The 6th work package of the MARSite project, which constitutes the base of this study, focuses on the earthquake-induced landslide hazard in the Marmara region.

Earthquake-triggered landslides have an increasingly disastrous impact in seismic regions due to the fast growth of urbanization and infrastructure. Just considering disasters from the last fifteen years, among which are the 1999 Chi-Chi earthquake, the 2008 Wenchuan earthquake, and the 2011 Tohoku earthquake, these events generated tens of thousands of co-seismic landslides. The landslides resulted in a high death toll and considerable damage by affecting the regional landscape, including its main hydrological features. The recordings of the last seven years have demonstrated that >50% of the total losses due to landslides worldwide are attributed to co-seismic slope failures (Petley, 2010). Moreover, as reported by Bird and Bommer (2004), the greatest damage caused by earthquakes is often related to landslides.

In addition to the high level of seismic risk, landslides in Turkey constitute the second highest source of life and economic losses induced by natural hazards. In fact, the 1999 Izmit earthquake (M7.4) caused numerous landslides in the northern Marmara Sea, especially along the western

* Corresponding author.
E-mail address: eyalcin@istanbul.edu.tr (E. Yalcinkaya).

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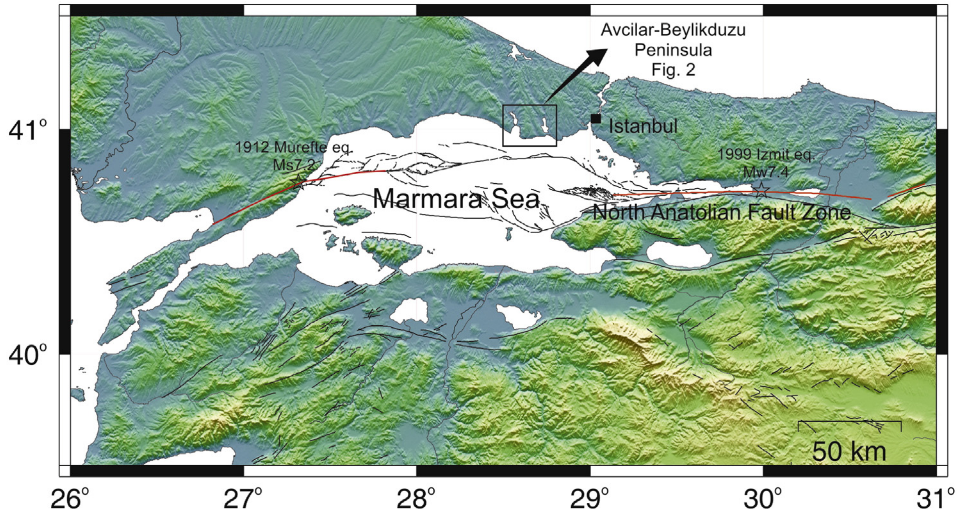

Fig. 1. North Anatolian Fault Zone (NAF) extending in to the Marmara Region of Turkey (black lines) and the surface ruptures of the last two earthquakes that occurred on the NAF (red lines). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

shores of Istanbul. In the Marmara Region, the risk of earthquake-triggered landslides is steadily increasing due to the growing “urban pressure” in landslide prone areas. In particular, the Avcilar-Beylikduzu Peninsula, situated between Kucukcekmece and Buyukcekmece Lakes west of Istanbul (Fig. 2), is an active landslide area, especially when considering high seismic landslide risk because of extensive construction and a rapid increase in population. In the Marmara region where a disastrous earthquake is expected, earthquake-triggered landslides, their characterization and monitoring and also early warnings are key issues in terms of public safety and disaster prevention.

In the last decade, near-surface geophysical techniques have been widely used to characterize landslides (e.g., Meric et al., 2007; Jongmans et al., 2009). The applications based on the moving mass of a landslide have different physical properties in terms of the surrounding rock or stable soil due to deformations, fractures, water content, and porosity. There are two main targets of geophysical investigations: the first is the location of the vertical and lateral boundaries of the landslide, that is, the failure surface, and the second is the mapping of the internal structure of the landslide (Jongmans and Garambois, 2007). A boundary or contrast in the properties of sub-surface layers can be readily available from geophysical methods. However, this boundary may not always be sufficiently strong to be explored by geophysical methods, or the resolution of the applied techniques may not be adequate for determining the location of the potential slip surface. According to McCann and Forster (1990), the success of any geophysical technique depends on four main controlling factors: the existence of a geophysical

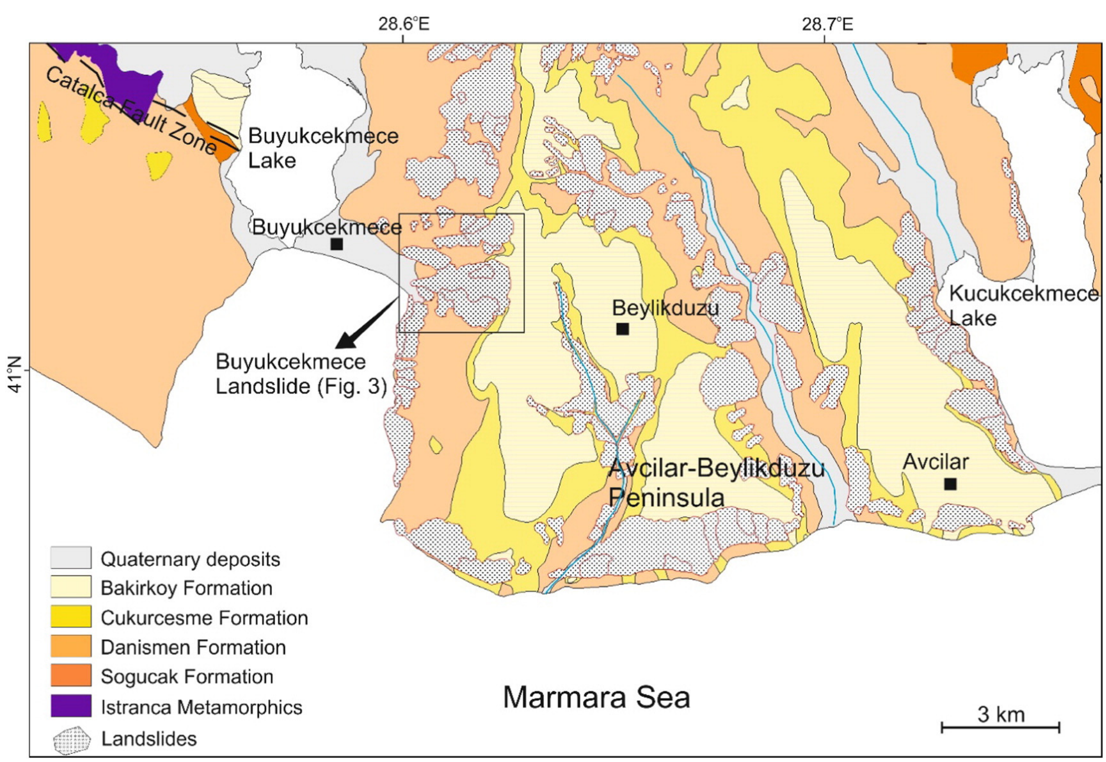

Fig. 2. Landslide map and simplified geology of the Avcilar-Beylikduzu Peninsula.
(Modified from Duman et al. (2004), Ozgul et al. (2005) and Ergintav et al. (2011).)