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Assessment of liquefaction and lateral spreading on the shore of Lake Sapanca during the Kocaeli (Turkey) earthquake

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Abstract

The 1999 Kocaeli earthquake of Turkey (M_w=7.4) caused great destruction to buildings, bridges and other facilities, and a death tall of about 20,000. During this earthquake, severe damages due to soil liquefaction and associated ground deformations also occurred widespread in the eastern Marmara Region of Turkey. Soil liquefaction was commonly observed along the shorelines. One of these typical sites is Sapanca town founded on the shore of Lake Sapanca. This study was undertaken as quantitative measurement of ground deformations induced by liquefaction along the southern shore of Lake Sapanca. The permanent lateral ground deformation was measured through the aerial photogrammetry technique at several locations both along the shoreline and in the town. In situ soil profiles and material properties at Sapanca area were obtained based on the data from 55 borings and standard penetration tests (SPT), and laboratory tests, respectively. The data and the empirical methods recommended by an NCEER workshop were employed to evaluate the liquefaction resistance of the soils. In addition, simple shaking tests on a limited number of samples were also performed. The permanent ground displacements were estimated from the existing empirical models, sliding block method and residual visco-elastic finite element methods. Then these estimations were compared with the observed ground displacements. The assessments suggested that liquefaction at Sapanca have occurred within Quaternary alluvial fan deposits at depths 1 and 14 m, and the major regions of liquefaction and associated ground deformations were located along the shore and creeks. The evaluations also indicated that for sites with no sand boils but with ground displacement greater than 1 m, thickness of the non-liquefiable layer was large. It is also noted that no liquefaction-induced ground surface disruption is expected at the site when the thickness of the liquefiable and non-liquefiable layers vary between 0.5 and 1.5 m, and 3.5 and 5.5 m, respectively. Except one model, all the empirical models employed in the study over-predicted the observed lateral ground displacements, while sliding block method and residual visco-elastic finite element methods yielded reasonably good results if the known properties of liquefied soils are used.

Keywords: Kocaeli earthquake; Lake Sapanca; Lateral spreading; Liquefaction; Residual visco-elastic finite element method; Standard penetration test

1. Introduction

Liquefaction-induced permanent lateral ground deformation, which is called lateral spreading, is a potential source of major damage to structures and lifelines

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during earthquakes, and became to be known after the 1964 Niigata earthquake. Turkey is one of the most seismically active countries in the world and most of the damaging earthquakes that occurred in Turkey are of in-land type. These earthquakes mostly result in permanent ground deformations due to both faulting and liquefaction. The Kocaeli earthquake of 17 August 1999 with a magnitude (M_w) of 7.4 induced permanent ground deformations due to both liquefaction and faulting, and resulted in heavy damage to structures and buried lifelines. Liquefaction and associated ground deformations were observed in a very large area along the southern shore of the Gulf of İzmit and city of Yalova, and town of Sapanca and city of Adapazarı in the western and eastern parts of the earthquake stricken region, respectively (Fig. 1). However, most detailed investigations on liquefaction phenomena were concentrated in the city of Adapazarı (e.g., Bray et al., 2001; Erken, 2001; Yasuda et al., 2001). The only investigation besides the authors' group (Aydan et al., 2004) on the liquefaction-induced ground deformations at the southern shore of Lake Sapanca was carried out by Cetin et al. (2002) at a hotel area (Sapanca Vakıf Hotel), which is located 1 km northwest of Sapanca town, and covers an area of approximately 0.33 km^2. These investigators analyzed the ground settlements and lateral deformations measured at the surface in the hotel area and compared the observed and calculated deformations. However, in addition to this local site, the southern shore of Lake Sapanca on which Sapanca town is founded was largely affected by liquefaction and liquefaction-induced ground deformations.

This study was undertaken by the authors for the quantitative measurement of permanent ground deformations induced by liquefaction in a large area. It aims to assess liquefaction and lateral spreading along the southern coast of Lake Sapanca and in Sapanca town, and to test the performance of existing empirical relationships suggested for the prediction of lateral spreading as well as of sliding block method and residual visco-elastic finite element methods. It is considered that the results of this study will be of great significance to investigate the relation between the damage to buildings and resulting strain fields in association with geological and geotechnical conditions of the ground. The liquefaction-induced ground displacements on the southern shore of the lake and within the town were measured through the aerial photogrammetry technique developed by Hamada et al. (1986) using both pre- and post-earthquake photographs (Aksu et al., 2002; Atak et al., 2004). 14 geotechnical boreholes, in this study, were drilled at or very near to locations of lateral spreading and sand boils on the shore of the lake and in the town. In addition, the ground conditions were also investigated by collecting existing geotechnical borehole data. By considering in situ geotechnical data and results of laboratory tests, a series of analyses on liquefaction susceptibility of the study site were carried out and permanent lateral ground deformations were also estimated employing existing empirical prediction relationships and sliding block method (Aydan and Ulusay, 2002) and residual visco-elastic finite element methods proposed by Aydan (1994, 1997). Then these estimations were compared with the observed ground deformations.

2. Ground displacements and liquefaction damages

Because the grounds at Sapanca, particularly on the shoreline of Lake Sapanca are composed of saturated loose fluvial deposits, this region was highly affected by liquefaction during the 1999 Kocaeli earthquake. Extensive damage caused by liquefaction-induced ground deformations was observed on the southern shore where the incidents of sand volcanoes and sand blows were clearly visible at various localities (Fig. 2a). The general trend of the eruption fissures was systematically parallel to the shore with an orientation of N50–75°W. The liquefaction observed in the vicinity of Sapanca Vakıf Hotel was spectacular and the hotel building sank and moved towards the lake due to liquefaction-induced lateral spreading (Fig. 2b, c). In addition, some holiday complexes, restaurants, parks and roads on the same shoreline were also moved towards the lake due to these ground deformations (Fig. 2d), and several settled and/or inclined buildings could be observed. For instance, the Vakıf Hotel seen in Fig. 2c subsided and inclined towards the lakeside and its first floor was submerged. This building consists of two-ridges of annex and old mansions, and a roofed passage between the both mansions fell down during or after the earthquake. Except the above-mentioned damage, any damage could not be observed in the superstructure of this building.

Permanent displacements both in horizontal and vertical directions were measured from ground fissures and separated shifted walls at some locations on the shoreline (Fig. 2e). Horizontal displacement due to lateral spreading occurred in the hotel area towards the lake was 352 cm. The hotel sank about 0.3 m into the ground. A swimming pool, 25 m long, is located in front of the hotel building and sank into the lake (Fig. 2c). Displacements were also measured at a neighboring holiday complex as 305 and 56 cm. It is also noted