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# Evaluation of site effect within the tectonic basin in the northern side of Ankara

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ABSTRACT

This study mainly concentrates on the determination of site effects for the Plio-Quaternary and especially alluvial soils of the Çubuk district and its close vicinity in Ankara, Turkey. In the study area, particularly in the vicinity of the asymmetric graben that has formed due to the tectonic activities along the NE–SW trending normal faults, a microtremor survey was implemented to identify the local site response under a possible seismic event. The results were compared and correlated by using passive and active surface wave measurements, engineering geological and geotechnical deep borehole logs along with information on local geology and geological tectonic setting. Regarding the microtremor results, larger fundamental periods were acquired than expected over the area and the effect of the tectonic deformation on the stiffness of the soils was also observed at either the H/V curves or the shear wave velocity profiles. The results have demonstrated that geotechnical information down to a depth of 30 m may not be compared with the H/V parameters. The H/V amplitudes were not always accompanied with the higher periods in the Quaternary sediments. This could be due to the basin and basin edge effects observed particularly at the center and boundary of the basin, respectively. Additionally, the microtremor survey showed that the spectral ratio amplitudes derived by the H/V ratio are debatable and are not a direct indicator of local soil behavior under a seismic excitation.



## 1. Introduction

The tendency of selecting small or large settlement areas such as provinces, district and towns in Turkey is mostly related with the proximity to water and fertile agricultural areas. Most of these areas in Turkey are under the control of faulting activity. The rapid growth of the population in Turkey has led to the construction of buildings and infrastructure in urban areas. The tendency of these areas to be developed in sedimentary valleys (basins) and rapid and unplanned urbanization has increased the vulnerability of the structures located at these areas to a potential earthquake, due to site effect from a geological point of view. Nearly all destructive earthquakes have occurred within the last two decades, namely, the 1999 Kocaeli event ($M_w$: 7.4) in Turkey, the 2008 Sichuan event (Mw: 7.9) in China, the 2010 Christchurch event ($M_w$: 7.1) in New Zealand and the 2011 Van event ($M_w$: 7.2) in Turkey have clearly showed that local soil conditions can have a remarkable influence on ground motion and on the damage pattern. The number of conducted studies in determining the effect of the local soil conditions on the ground motion and on the damage pattern has gradually increased (e.g., Bour et al., 1998; Rodriguez-Marek et al., 2001; Cara et al., 2008; Leyton et al., 2013) and gained importance since the results clearly show the relations between the pattern and site conditions. Therefore, to understand spatial variations of the ground motion, gathering elaborative information from soft soil is crucial.

Detailed evaluation of the different dynamic sediment characteristics over a wide area, where prominent site amplification occurs, can be obtained by using many methods. However, some of these methods (i.e., empirical, few experimental and especially the theoretical ones) are still economically and technically difficult to be carried out by utilizing a dense grid due to the requirement of a vast quantity of data. Utilizing many of them (SSR and HVSR) can be very troublesome in a technical manner for areas lacking weak or strong motion earthquake stations and long reoccurrence period of earthquakes. Due to these reasons, the microtremor survey has drawn great attention because it is a relatively easy and cost effective method. This experimental technique is based on recordings of ground motion or ambient noise in the field to estimate the basic characteristics of expected ground motion without requirements to know and determine subsurface geometry, physical and mechanical information about the lithological units underlying the target area as well as earthquake propagation models (Bour et al., 1998).

Although it has been preferred all around the world for the last two decades by many scientists in order to analyze site effects (i.e., Gueguen et al., 1998; Bodin et al., 2001; D'Amico et al., 2008; Koçkar and Akgün,

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2012), it has been conducted to determine and/or investigate bedrock geometry (Bodin et al., 2001; Di Giulio et al., 2008; Walling et al., 2009; Del Monaco et al., 2013), dynamic characteristic of the lithological units (Kudo et al., 2002; Fäh et al., 2003; Tokimatsu et al., 2004; Asten et al., 2004; Nunziata, 2007; Panzera et al., 2014); the zones prone to liquefaction hazard (Beroya et al., 2009), slope dynamic response (Del Gaudio et al., 2014) as well as soil–structure interaction (Gosar, 2007; Panzera et al., 2013).

In accordance with the scope of this work, geological and seismic site characterization of mainly the Upper Pliocene to Pleistocene fluvial clastics and Quaternary alluvial and terrace deposits (henceforth named as Plio-Quaternary sediments in its entirety) were performed at the Çubuk district and its close vicinity. A detailed microtremor survey was conducted by adopting a grid system to the Çubuk basin.

The majority of the microtremor records were taken from the Plio-Quaternary sites. The microtremor results processed by the H/V technique were checked by sensitivity analyses with a different quantity of samples. These were correlated with the other facts obtained from surface seismic surveys and geotechnical measurements along with several deep boreholes over the area. The seismic and geotechnical studies were performed by means of active and passive surface wave measurements obtained at 41 sites, several borings along with relevant geotechnical laboratory tests. By integration of these data, the relationships among the geologic units, subsurface geometry of the bedrock, variation of the fundamental periods and spectral ratio amplitudes and the shear wave velocity ($V_S$) data through considering both vertical and lateral variations were investigated to check the reliability of the results and also to explain the site response of the soil deposits for reliably determining the local site characteristics.

## 2. Study area

The study area covers the Çubuk district and its close vicinity, mainly the northern part of the Çubuk Plain which is situated approximately 40 km north of Ankara. The location of the study area is given in Fig. 1. The area covers nearly 120 km$^2$ between the northern part of the Çubuk basin and the Çubuk district. The investigation was conducted at a moderately populated area with mostly residential settling, an international civil airport and a considerable amount of small to large industrial buildings which has a major potential for increased urbanization in the near future. The area is developing towards the western and eastern parts of the district with relatively small industrial estate and building complex, villa, and apartment blocks as residences and vacation homes, etc. In a geological manner, the investigated part of the Çubuk Plain covers mostly Plio-Quaternary and especially late alluvium sediments and most of these mentioned building structures are also built on these deposits.

## 3. Geology and seismotectonics of the study area

### 3.1. Regional geology

The Çubuk Plain is a depression and it becomes narrow when it continues towards northeast. The center of the plain was affected excessively as a result of tectonic movements and subsided along the NE–SW trending normal faults (Fig. 2). As can be seen in Fig. 2, the faults present at the west and east of the basin caused to form an asymmetric graben structure in today's plain. This led to thick sedimentary deposits at the basin along the faults (Kupan, 1977; General Directorate of the State Hydraulic Works (DSİ), 1979; Erol, 1980; Koçyiğit and Türkmenoğlu, 1991; Eker, 2009; Eker et al., 2012). The deposits are both lacustrine and fluvial clastics and contain volcanic intercalations (Koçyiğit and Türkmenoğlu, 1991). The rock units cropping out in the region range from Triassic to Quaternary in age. The older rock units in the region are highly deformed pre-Upper Miocene basement rocks, Miocene deposits and Upper Miocene–Lower Pliocene rocks (Fig. 2). These older rocks are overlain uncomfortably by the Plio-Quaternary deposits in the generalized stratigraphic column (Akyürek et al., 1996; Erol et al., 1980).

### 3.2. Paleogeography of the region

The Upper Pliocene to Pleistocene sedimentary units are widely exposed and cover the major part of the study area (Fig. 2). The upper part of these units that shows continental origin possesses a highly heterogeneous structure, grain size distribution and color. Their thicknesses

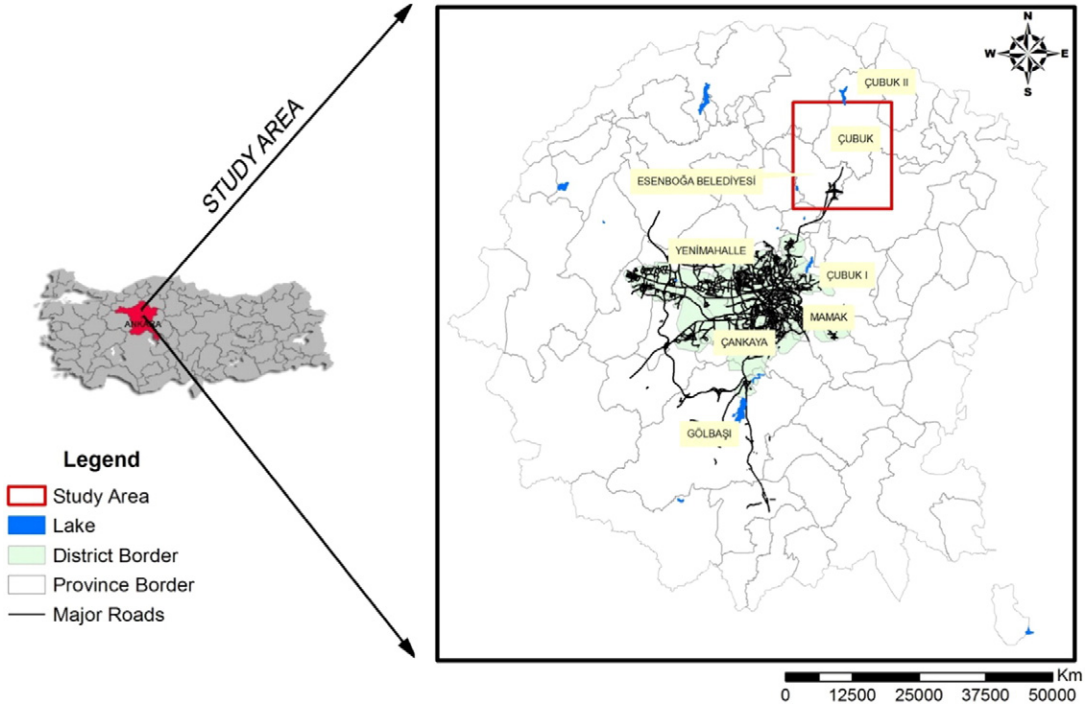


**Fig. 1.** Location map of the Çubuk district within the boundary of the Ankara Province.