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Evaluation of the site effects of the Ankara basin, Turkey

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ABSTRACT

Recent major earthquakes have explicitly demonstrated that near-surface local site conditions that can generate significant amplifications and spatial variations of earthquake ground motion play a major role in the level of ground shaking and in gathering information on soft soil response. It is therefore highly desirable to develop methods to identify and characterize regions that are prone to this type of site amplification. To determine the subsurface sediment characteristics over a wide area, measurement and analyses of microtremor have been widely employed. Considered to be a relatively easy and economically attractive method for collecting relevant information especially in urbanized areas, microtremor involves utilization of ambient seismic noise to evaluate the local site effects reliably which is one of the vital aspects of seismic hazard assessment. This paper aims to investigate the site response of the sediment characteristics in Ankara, the capital of Turkey through conducting short-period noise recordings of microtremor measurements. A total of 352 microtremor measurements have been performed in the project site within the Plio-Pleistocene fluvial and Quaternary alluvial and terrace sediments in the western part of the Ankara basin. The spectral ratio between the horizontal and vertical components (H/V) of the microtremor measurements at the ground surface has been used to estimate the fundamental periods and amplification factors of the site. The microtremor study was also correlated and complemented by in-situ seismic measurements of dynamic properties, geologic information, and some geotechnical boring information in the project area for evaluating site conditions in an account to estimate site effects. The results of this study identified three main factors that influence site response, namely, the age of the local geological formation, the depth of the soil thickness and soil characteristics in the younger sediments, and non-uniform subsurface configurations. In particular, the H/V results showed that the variation of the fundamental period map agreed well with the maximum value of the amplification as well as with the local site conditions of seismic sediment characteristics that provided reliable estimates of site response of soft soil deposits. Finally, these results were used in zonation studies for reliably determining the local site characteristics.

1. Introduction

The effect of local site conditions is directly related to significant damage and loss of lives. During the past decades, the effect of local soil conditions is known to have caused serious damage during several earthquakes. Some well known examples include the earthquake in Michoacan, Mexico in 1985 (Kobayashi et al., 1986), Loma Prieta, California, USA in 1989 (Hough et al., 1990), Kocaeli and Düzce, Turkey in 1999 (Rathje et al., 2003), Chi-Chi, Taiwan in 1999 (Rathje et al., 2005) and Wenchuan, China in 2008 (Wen et al., 2010). While there are several other potential factors contributing to damage, the amplification of ground motion due to local site conditions (such as topographical conditions, ground motion resonance and amplification, etc.) plays an important role in increasing seismic damage. These observations, as well as numerous others, indicate that quantification of site effects is a necessary component of a comprehensive assessment of seismic hazard (Rodriquez-Marek et al., 2001).

Ankara is not considered safe in terms of earthquake hazards despite its relatively long distance to major fault systems (i.e., approximately 75–100 km). An analogy may be made for the damage that occurred, for example, through the Kocaeli earthquake (1999) that was located more than 90 km away from the earthquake source in Gölcük-İzmit but caused significant damage around the Avcılar area due to site effects. Hence, the impact of local site conditions subsequent to the significant influence of strong ground motions on site amplification carries an important weight in earthquake geotechnics. In terms of understanding the mechanism of site amplification, a so-called “long-distance effect” problem that is related to the local site conditions of the project site creates a site amplification concept that is not yet well understood. Due to these reasons, even though Ankara may be considered to be situated distant to the major fault systems, the influence of the unconsolidated sediments under

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earthquake triggered motions needs to be investigated. In addition, areas of high seismicity, such as the Marmara region in Turkey present opportunities for determining amplification and resonant frequencies through analyses of strong motion data. The frequency of high magnitude events and the vast array of seismic instruments in operation may provide abundant data for obtaining these site factors. However, in Central Anatolia such as the Ankara region, seismic activity is less frequent and stations are widely spaced or literally absent (Koçkar, 2006). Installing a temporary network to record the weak-motion events for a reliable estimation of site conditions may be much more expensive and may require considerable amount of time in such a region. Recording ambient noise, in contrast, is easy, fast and economical to estimate the local site conditions, which might be one of the most reasonable solutions. For these reasons, the use of microtremors in estimating local site effects has become increasingly popular over the years. Amongst the empirical methods of microtremors in estimating the local site effects, the use of ambient short-period noise measurements to obtain ground motion response by the H/V method has proved to be successful in several studies. The H/V method, referred to as the Nakamura technique (Nakamura, 1989), was first introduced by Nogoshi and Igarashi (1971) as based on the initial studies of Kanai and Tanaka (1961). This method has proven to be a reliable method in some cases that produced satisfactory results (Atakan, 2009; Bard, 1999; Duval et al., 1995; Lebrun et al., 2001; Lermo and Chavez-Garcia, 1993). It was proposed in order to satisfy the source and path effect problem particularly in highly urbanized cities which is thought to be the main source of error in the spectral ratio methods, and thus is believed to provide reliable estimates of local amplification. Hence, it appears that the H/V techniques are useful in seismic zonation in such cases, but a thorough understanding of subsurface heterogeneities of the sediment characteristics at the project site is essential for a reliable interpretation of the data (Chatelain et al., 2008; Koçkar, 2006; Lacave et al., 1999; Lachet et al., 1996; Mucciarelli, 1998).

Since the majority of the overlying soils of Ankara constitute Plio-Pleistocene fluvial, and particularly Quaternary deposits that are formed in and near fault-bounded depressions of the Ankara basin and mark an active tectonic uplift in the Ankara region, microtremor measurement studies in order to predict earthquake response seem to constitute a high priority for the city of Ankara. The city has been growing towards the potential settlement areas consisting of these basin fill type of sediments where numerous buildings and infrastructures have already been built upon. Since the Ankara region has experienced destructive earthquakes in the past from the surrounding large-scale Fault Systems and Fault Zones that might have affected the soil conditions of these unconsolidated sediments, it is seismically active and serious damages might occur during future earthquakes. Due to the basin fill nature of these sediments which cover a large area in the Ankara basin, it is necessary to assess the local site effects associated with ground motion amplification and resonance.

This paper presents regional information regarding the site response of the sediment characteristics and assesses local site effects within the Ankara basin. Evaluation of the site conditions within the Ankara basin started with an assessment of the local geologic formations and mapping of surface geology based on available sources of information. The data from the geologic map was correlated with data from short-period noise recordings of microtremor measurements and the detailed site investigation study performed. Specifically, the spectral ratio between the horizontal and vertical components (H/V) of the microtremor measurements at the ground surface has been used to estimate the fundamental periods and the amplification factors of the site. These results appeared to complement and correlate well with the in-situ seismic refraction measurements, geologic information, and some geotechnical boring information used to characterize the depositional setting of the geologic units for reliably determining the local site character. The conducted data and relationships were used to develop seismic zonation maps of Ankara that can be used to evaluate the local site effects along with discussing the consequences of the site response of soft soil deposits. Since the models chosen to be included in the information analysis are suitable to be used with regional spatially-distributed data, a hazard model for each of the hazard components listed above was developed and implemented in a GIS environment.

2. Theory and methodology of the research

The application of short-period microtremors to estimate site effects has been investigated for many years by Kanai and Tanaka (1961), Kobayashi et al. (1986), Lachet et al. (1996), and Bard (2004). They assumed that the microtremor horizontal motions at short-periods consisted mainly of shear waves, and that the spectra of the horizontal motions reflected the transfer function of the ground at site. They also made it possible to estimate dominant period and amplification level of soft sediments by measuring directly the resonant frequency of soil. This approach, with some variants, has been used to characterize site effects in a wide variety of seismic environments (e.g., Chávez-García, 2007; Duval et al., 2001; Lermo and Chavez-Garcia, 1993). The microtremor methods used to determine the site response can be categorized into two main groups, the analytical (theoretical) and the empirical methods, which enables an adequate determination. However, empirical methods are somehow more effective in the sense that they are based on calculating the frequency spectrum directly from the recorded ground motion by using a single three-component seismograph. They provide a very interesting approach to site effect evaluation by virtue of the simplicity of the analysis, rapidity of field operations at various site conditions requiring only several minutes of short-period noise recording at each station and low cost noise measurements. After the H/V empirical method was introduced (Nakamura, 1989), the use of ambient noise measurements to obtain ground motion response has been successfully used in several studies. This technique is particularly capable of depicting the predominant frequency and provides satisfactory estimates of the site response of soft deposits (Lachet and Bard, 1994; Lebrun et al., 2001; Mucciarelli, 1998). Hence, it has been applied increasingly in various countries and in areas of moderate seismicity.

The H/V technique is based on the spectral ratio of horizontal to that of the vertical recording of ambient noise at a single site (Nakamura, 1989). The method was intended to achieve the amplification of the S-waves due to soft sediments by microtremor measurements. It is claimed that the spectral ratio of the horizontal to vertical components of the recorded ambient noise is equivalent to the ratio of the S-waves from an earthquake recorded on the surface of the sediments to that of the sediment–bedrock interface at the bottom of the sediment layer (Atakan, 2009).

Regarding this technique, the H/V spectral ratio [$S_{H/V}(\omega)$] was obtained by dividing the resultant spectra of the horizontal components of the sediment site [$H_{NS}(\omega)$ and $H_{EW}(\omega)$] by the spectrum of the vertical component [$V_S(\omega)$] of the sediment site [note that (ω) is the angular frequency]:

$$S_{H/V}(\omega) = \frac{H_S(\omega)}{V_S(\omega)} = \frac{\sqrt{(H_{NS}(\omega)^2 + H_{EW}(\omega)^2)}}{V_S(\omega)} \quad (1)$$

The various sets of experimental data confirmed that H/V spectral ratios are much more stable than the raw noise spectra (Duval et al., 1995; Fah et al., 1997; Lachet et al., 1996; Lermo and Chavez-Garcia, 1993). In addition, on soft soil sites, they usually exhibit a clear peak that is well correlated with the fundamental resonant frequency. However, the meaning and the amplitude of the peak is still a topic of discussion in the H/V technique. It should be noted that the nature of the ambient noise is not only restricted to the surficial sources which do not have the pervasive energy to excite the entire sedimentary