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Evaluation of site amplification and site period using different methods for an earthquake-prone settlement in Western Turkey

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Abstract

Seismic micro hazard zonation for urban areas is the first step towards a seismic risk analysis and mitigation strategy. Essential here is to obtain a proper understanding of the local subsurface conditions and to evaluate ground shaking effects. In this study, present and future settlement areas of Yenisehir, which is located in the earthquake-prone Marmara Region of Turkey, were evaluated with respect to site amplification and site period. Borings in conjunction with in-situ penetration tests, seismic velocity measurements, resistivity surveys and microtremor studies were performed, and available data from previous investigations were complied to determine the variation of the soil profile as well as the characteristics of the soil layers within the study site. In addition, new empirical correlations between shear wave velocity (V_s) and number of blows from standard penetration test (SPT-N) were also developed to be used for the estimation of amplification factors. Site amplification was assessed using empirical methods based on estimated values of V_s, 1-D site response numerical modeling program and microtremor measurements. Among the three methods employed, the numerical technique and microtremor method yielded considerably higher amplification factors when compared to those obtained from the empirical method. This situation is considered as a limitation of the empirical methods. The survey of site response suggests ground amplification. The microzonation map based on soil site amplification suggests amplification factors between 1.6 and 5 in the present settlement, while the areas at the north and south of the settlement generally amplify the motion 5 to 9 times. The site periods obtained from microtremor studies vary from 0.51 to 0.8 s throughout the settlement. In addition, the comparison between fundamental site periods and fundamental building periods, which were measured in a few buildings and estimated from an empirical expression, indicate that prime attention should be paid to resonance phenomena, particularly for the northern part of the settlement where high-rise buildings are still in construction.

Keywords: Microzonation; Microtremor measurement; Numerical modeling; Predominant site period; Shear wave velocity; Site amplification; Yenisehir (Bursa)

1. Introduction

It is well known and widely accepted that the effects of surface geology on seismic motion exist and can be large. The earthquake damage is generally larger over soft sediments than on firm bedrock outcrops. This is particularly important because most of urban settlements have occurred along river valleys over such young and soft surface deposits. Ground-shaking site effect caused by an earthquake can vary significantly within a small distance. This is because at sites having soft soil and/or

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topographic and basement undulations, seismic energy gets trapped, leading to amplification of vibration to man-made structures. Man-made structures with resonance frequency matching that of the site have the maximum likelihood of getting damaged. Therefore, information about the site response is an integral part of the construction of seismically-safe structures and urban planning. One of the well known examples of such effects is Mexico City. In Mexico City, there exist very soft clay deposits underneath the downtown area of the city. These led to very large amplifications which caused loss of life and structural damages during the distant Gurrero Michoacan earthquake of 1985 (Kramer, 1996).

Turkey is one of the most seismically active countries in the World. In particular, the August 17, 1999 Kocaeli earthquake, which resulted in more than 20,000 fatalities and extensive structural damage, was a major disaster for the most industrial and urbanized region of Turkey called Marmara Region. Therefore, this earthquake focused the attention on densely urbanized and industrialized settlements. In addition to extensive liquefaction and associated ground failures, and submarine landslides at different parts of the earthquake region, site amplification and related damages were also reported. The most typical amplification during this earthquake was experience at Avcilar district of Istanbul (Tezcan et al., 2002; Ergin et al., 2004).

On the other hand, a large earthquake, which is expected to occur in the Marmara Sea within the next 30 years (Parsons et al., 2000), also pose a threat particularly to the settlements located in the Marmara Region. In addition to Istanbul and Kocaeli provinces, Bursa is also one of the three most industrialized and populated cities of the Marmara Region. There are 17 towns officially belonging to Bursa. One of them is Yenisehir which is found 50 km east of Bursa (Fig. 1). Increase in its population resulted in urbanization and construction of new buildings. The 1999 Kocaeli earthquake was also felt in Yenisehir, but did not cause serious structural damage in this settlement. After this devastating earthquake, prime consideration began to be paid to geological and geotechnical investigations by municipalities particularly by those in the affected region including the municipality of Yenisehir.

The first geotechnical study in Yenisehir was performed by Doyuran et al. (2000) for the evaluation of the foundation conditions of the present and future settlement areas of the town. The study involved drilling at 17 locations, standard penetration testing (SPT), trial pitting and laboratory testing. Doyuran et al. (2000) established a microzonation map of the town based on the earthquake risks and geotechnical characteristics of the foundation material and identified two zones in terms of suitability of settlement. However, ground-shaking site effects such as site amplification and fundamental site periods were not included in this previous study.

In this most recent study, site amplifications and fundamental site periods in the settlement area of Yenisehir and its close vicinity were investigated using Grade-2 and Grade-3 methods recommended by the Technical Committee for Earthquake Geotechnical Engineering (TCEGE, 1999). For the purpose, available geotechnical data from Yenisehir were compiled, geotechnical studies involving borings with SPT tests and groundwater level measurements, and laboratory testing. In addition, the data of seismic and resistivity surveys and microtremor measurements (MTM) collected by the General Directorate of Disaster Affairs (GDAA) (Dikmen et al., 2004) for this study were also evaluated. The soil amplification was assessed using three methods, such as shear wave velocity-based empirical relationships, 1-D site response program SHAKE and microtremor data. Site periods obtained by SHAKE modeling were presented and compared with those obtained from microtremor study. Finally, an attempt was made to establish microzonation maps derived from amplification factors and site periods for Yenisehir town.

2. Description of the site

The town of Yenisehir is situated within an elliptical basin called the Yenisehir Plain (Fig. 2). This basin is separated from Iznik Plain and Inegol Plain by ridges at the north and south, respectively. The Kocasu stream, flowing from southwest to northeast (Fig. 2), is the main stream of the basin. Yenisehir is founded on a flat area mainly consisting of alluvial deposits (Fig. 3a). However, towards the south and the north, where urbanization has not extended yet, elevations gradually increase. The average slope of the site is generally less than 5°. It reaches to 10° in the north, while is between 10° and 30° along the ridges formed by metamorphic rocks in the south.

The population of Yenisehir is 26,000. Increase in its population resulted in urbanization. Therefore, new buildings particularly high-rise buildings are under construction in the northern part of the settlement (Fig. 3b). The present and future settlement areas of Yenisehir cover about 18 km^2. An organized industrial district on gentle slopes at the southern part of the settlement is being planned. In addition, a civil airport located 4 km west of the town was opened to domestic flights one year ago (Fig. 2).