Soil Dynamics and Earthquake Engineering 105 (2018) 160–170

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Site amplification and resonance frequency in the urban environment

S. Ümit Dikmen*, Gülüm Tanırcan

Bogazici University, Kandilli Observatory and Earthquake Research Institute, Department of Earthquake Engineering, Cengelkoy, 34684, Istanbul, Turkey

ARTICLE INFO

Keywords:
Site amplification
Resonance frequency
Downhole arrays
Outcrop
Earthquakes
Built environment

ABSTRACT

The effects of the built environment on site amplification and resonance frequency are studied utilizing 34 earthquake recordings made at three seismic downhole arrays (ATK, FTH and ZYT) and two outcrop stations at Istanbul. The earthquake data set included minor to moderate earthquakes having hypocenters at various distances and azimuths with respect to the arrays. The buildings considered in the study are at distances less than 110 m from the arrays and have different dynamic characteristics. The results indicate the impact of the buildings on the site amplification and resonance frequency. At ATK and ZYT arrays, the buildings have a lowering effect on the site amplification, while at FTH array a shift in the resonance frequency is observed. Results from ATK and FTH sites also support previous findings that even in case of similarity between the shear wave velocity profiles amplification levels can differ significantly.

1. Introduction

Site amplification and the fundamental frequency of vibration, f_o are important parameters in the seismic characterization of sites for design and analysis purposes. Though, the site amplification is mainly affected by the shear wave profile between the surface and the engineering bedrock at the site, other factors such as the topography, basin structure, built environment can have significant impact on the amplification ratio [13,15,16]. Studies published in the recent years indicate that the built environment within the near distance of the measurement points affects surface response, subsequently the surface amplification (e.g. [14,12]).

Various techniques and methods, both analytical and empirical, have been proposed in the past for the estimation of the site amplification and f_o. Amongst them the average shear wave velocity of the top 30 m section of a deposit (V_{s30}), has been proposed as a single proxy for the characterization of sites. The idea was practical and did not require much sophistication for its determination. Hence, owing to its ease in application most codes have also adopted it for site characterization [3,10,34]. However, though its wide spread use, the method has opponents as well as proponents. Hence, numerous valuable studies have been conducted and published on the use of V_{s30} (e.g. [5,35,23,7]). As analytical techniques, 1D both frequency and time domain approaches, with their associated computer programs, have proven to be practical tools as well.

On the other hand, the use of data collected from the downhole arrays, especially when the arrays are in reasonably close distances clustered to form a network, have proven to be a useful approach for studying site amplification as well as the resonance frequency at site. Kokusho & Sato [18], Kokusho [19] utilizing the data obtained from KiK-net proposed that the ratio between the shear wave velocity at the base level of a downhole (V_{sb}) and an average shear wave velocity of the equivalent soil profile, $\overline{V_s}$ show strong correlation with the site amplification. They also stated that such a correlation does not exist when V_{s30} was used. Heloise et al. [15,16], also using the KiK-net data, proposed that if a vertical array is available f_o can also be calculated through the spectral ratio of surface to downhole recordings.

The primary objective of this study is to estimate the site amplification ratios and the f_o and at the downhole array sites through different techniques, explore the differences between them in consideration with their surrounding urban environment. The surface and base downhole data obtained from 34 earthquakes were used to estimate f_o and amplification ratios of sites. SSR (surface to outcrop and surface to base), HVSR as well as Response Spectral Ratio (RSR) site response estimates are compared. Comparison between the spectra reveals that sites with similar shear wave velocity profiles might have drastically different amplification levels. Furthermore, ground motion data at downhole sites are influenced by vibration of adjacent massive

---

Abbreviations: ATK, Ataköy Downhole Array; BSR, Borehole Spectral Ratio; FTH, Fatih Downhole Array; HVRS, Horizontal to Vertical Spectral Ratio; IMM, Istanbul Metropolitan Municipality; IRRS, Istanbul Rapid Response System; KOERI, Kandilli Observatory and Earthquake Research Institute; NEHRP, National Earthquake Hazard Reduction Program; OSR, Outcrop Spectral Ratio; RSR, Response Sprectral Ratio; SRSS, square root of the sum of the squares; SSR, Standart Spectral Ratio; TUBITAK, Scientific and Technological Research Council of Turkey; ZYT, Zeytinburnu Downhole Array

* Corresponding author.

E-mail address: umit.dikmen@boun.edu.tr (S.Ü. Dikmen).

https://doi.org/10.1016/j.soildyn.2017.12.010
Received 26 April 2017; Received in revised form 11 August 2017; Accepted 3 December 2017
0267-7261/

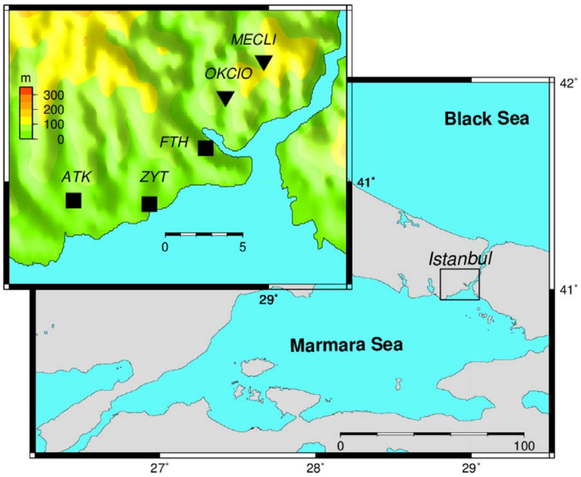

Fig. 1. Locations of the KOERI recording stations used in the study. (color coding indicates the land elevations).

structures. Information gained through these analyses is a step forward to further investigation on how the energy radiated from structures back to soil changes its behavior.

2. Recording stations

Three seismic downhole arrays and two surface stations, operated by Bogazici University Kandilli Observatory and Earthquake Research Institute (KOERI), situated in reasonably close distance used in the study (Fig. 1, Table 1).

2.1. Downhole arrays

2.1.1. Ataköy Downhole Array (ATK)

Ataköy Downhole Array was deployed in 2005 as part of a joint research project of KOERI together with German Research Center for Geosciences (GFZ). Also, Istanbul Metropolitan Municipality (IMM) financially supported the project. The ATK array has instrumentation at the ground surface and at 25, 50, 70 and 140 m depths. The site is on a seemingly flat area (less than 3% grade) about 15.0 m above the sea level.

The array is about 45 m away from a 16 story (46 m high) building (Fig. 2). The building is a reinforced concrete structure constructed by tunnel formwork technology. The fundamental modal frequencies of vibration of the building are 1.01 (1st NS), 1.26 (1st torsional), 1.35 (1st EW), 3.84 (NS), 4.15 (2nd torsional) and 5.04 Hz (2nd EW) for the first six modes, as determined by the field measurements [27–29]. The frequencies are obtained from the transfer functions calculated using ground and top floor Fourier Spectra.

2.1.2. Fatih Downhole Array (FTH)

Fatih Downhole Array (FTH) array was deployed in 2010 through a research project funded by the Scientific and Technological Research Council of Turkey (TUBITAK) and KOERI. The array has instrumentation at 23, 60 and 136 m depths in three downholes as well as one on the ground surface. The land elevation at the array is about 68.0 m above the sea level.

Table 1
Distances between the recording stations (km).

Station ID	ATK	FTH	ZYT	MECLI	OKCIO
ATK		9.3	5.0	15.3	12.0
FTH	9.3		5.1	6.8	3.6
ZYT	5.0	5.1		11.9	8.6
MECLI	15.3	6.8	11.9		3.4
OKCIO	12.0	3.6	8.6	3.4	

Fig. 2. Aerial view of the ATK array and the 16 story residential building nearby. (courtesy of ibb.gov.tr).

Fig. 3. Aerial view of the Fatih Mosque Complex and location FTH array. (courtesy of ibb.gov.tr).

FTH Array is located within the Fatih Mosque Complex in the Historic Peninsula of Istanbul. The distance between the center of the mosque and the downhole array is about 110 m (Fig. 3). The mosque is instrumented and real time monitored by KOERI. Beyen [4] studied the response of the mosque during 1999 Marmara Earthquake and reported the predominant frequencies as 2.5, 3.5, 4.3 and 5.3 Hz in NW-SE direction and 2.6, 3.2, 4.5 and 5.0 Hz in NE-SW direction.

Further to that study, in this work, base to dome amplification functions are calculated by using the data from seven different earthquakes (Earthquake # 6, 7, 8, 11, 16, 20, 21 in Table 3) recorded by three sensors, two at the dome periphery and one at the ground level, (Fig. 4). The dome periphery sensors are aligned with the outer walls of the mosque, approximately NW-SE and NE-SW directions. The amplification functions of both sensors, TF-1 and TF-2, combined by square root of the sum of the squares (SRSS) yield 2.8, 3.6 and 5.6 Hz as the first three fundamental frequencies. Difference between the predominant frequencies calculations can be attributed to the strengthening actions performed during restoration of the structure which was completed in 2013 [8].

2.1.3. Zeytinburnu Downhole Array (ZYT)

The Zeytinburnu Downhole Array is located within premises of the Zeytinburnu Municipality's complex (Fig. 5). The financial support for the array was provided through a research project funded by TUBITAK and BU. The array was deployed in 2010 and has three downholes with 30, 57 and 288 m depths. The building of the Zeytinburnu Municipality, located on the east side of the array, is a two story high historical load bearing brick masonry building (Fig. 5). On the west side of the array there is a five story, including a half basement floor, school building with a reinforced concrete frame type structure. The buildings are approximately 50 m apart. The fundamental frequencies of the buildings, based on earlier studies on similar buildings, have been estimated empirically as 3.5–4.5 Hz for the municipality building and 1.5–2.5 Hz for the school building. Unfortunately, no technical data about the