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DETERMINATION OF SPECTRAL AMPLIFICATION FACTORS BY A SIMULATION BASED METHOD FOR SOUTH COAST SOILS OF ISTANBUL

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Abstract

The city of Istanbul was seismically instrumented by a dense Rapid Response Network (IRRN) and Geotechnical Downhole Arrays (IGDA) after the 1999 M_w=7.6 Izmit Earthquake. Especially, the south coast soils of Istanbul European Side composed of Cenozoic aged younger formations are expected to be affected by a probable earthquake more, compared to the other parts of the city. Along a 10 km long route, response spectral amplification factors are calculated depending on a simulation-based method. The method includes 1-D site response analyses of 1000 shear wave velocity (V_s) profiles produced by Monte Carlo simulation, and the assignment of a best-fit V_s profile due to the least squared error between recorded ground motions and the modelled ones. The best-fit V_s profile is chosen due to the recorded motions of near field earthquakes R_{jb}<100 km with M<4.8. The optimized V_s profile is used for modelling the response spectral accelerations by scaled bedrock motions of downhole arrays due to expected bedrock PGA rates of 10% probability of exceedance in 50 years defined in Turkish Earthquake Building Code (TEBC, 2018). A scaling procedure for bedrock PGAs is applied to model nonlinear response spectral amplification factors. The south coast soil layers of Istanbul exceed the design spectrum for a return period of T=475 years (10% probability of exceedance in 50 years) especially at Zeytinburnu district. The proposed method can be applied to any instrumented seismically active regions to reveal the response spectral performance.

Keywords: Spectral Amplification Factor, Equivalent-Linear Analysis, 1-D Site Response, PGA scaling, Downhole Array

1 INTRODUCTION

The probabilistic risk assessments in Marmara region points out devastating effects especially on the south coasts of the city due to poor building inventory and site conditions [1, 2]. A detailed reliable assessment related to revealing the site effects of younger Cenozoic aged weak and loose soil formations of south coasts of the city, would be possible by modelling the site response rather than using V_{s30} based site amplification factors. The main concern of this study is to assess V_{s30} based site amplification factors defined in Turkish Earthquake Building code (TEBC, 2018) [3], after modelling the S-wave velocity profiles of the sites by an optimization procedure based on the low amplitude bedrock motions of Istanbul Geotechnical Downhole Arrays (IGDA) and propose location-based site coefficients.

To model the site effects properly and to mitigate the seismic risk, many geotechnical downhole arrays were established lately all over the world (i.e., WLA in the United States, KNET and KiK-net in Japan, IGDA in Istanbul). The studies on downhole arrays focused on S-wave velocity modelling including waveform deconvolution methods [4, 5], cross-correlation technique [6] and a procedure of depth correction and impedance normalization [7]. Kurtulus (2011) [8] proposed a simulation-based optimization procedure for S-wave velocity modelling based on the comparison of response spectral ratios of recorded and modelled ground motions. Besides, site effects were discussed for downhole arrays considering both Fourier spectral and response spectral acceleration ratios [9, 10, 11, 12]. The study aimed to model S-wave velocity distribution (V_s) by using both detailed in-situ tests (i.e., SPT, REMI, PS logging etc.) and applying Monte Carlo simulation-based optimization procedure by carrying out the response analysis of 1000 soil profiles, afterwards assigning the best matching V_s profile due to the least squared error between low amplitude recorded and modelled surface response accelerations of Istanbul Rapid Response Network (IRRN). Following, the site effects were obtained for the specified seismic stations by the scaled bedrock motions of IGDA to the location-based expected probable earthquake levels (10% probability of exceedance in 50 years for T=475 years) defined in TEBC (2018).

2 GROUND MOTION DATA AND SITE CONDITIONS

The study area in the south coast of Istanbul European side is densely instrumented by the stations of IRRN and IGDA (Figure 1). The earthquakes studied occurred in Marmara Sea mostly and the closest epicentral distance to the downhole stations of ATK and ZYT is measured as 19.7 km and 21.9 km respectively for 16.11.2015 M_L4.2 earthquake.

Figure 1. The distribution of studied earthquakes (4.0≤M≤4.7) in Marmara Region (left figure), and the study area covering the selected IRRN and IGDA stations (right).

These earthquakes were selected due to the availability of ground motions recorded by both IGDA and IRRN (Table 1). The listed events imply low amplitude bedrock motions recorded by 140 m deep Ataköy (ATK) and 288 m deep Zeytinburnu (ZYT) downhole arrays.

Table 1. List of events recorded by both IRRN and IGDA.

Eq. no.	Date	Lat. °	Lon. °	Depth (km)	M_L
1	27/11/2013	40.85	27.92	9.6	4.7
2	04/08/2014	40.602	29.165	10.7	4.0
3	28/10/2015	40.820	27.765	12.7	4.5
4	16/11/2015	40.826	28.759	7.7	4.2

The study area is mainly composed of Cenozoic aged sand and clay interlayered altered limestone units (i.e., Bakırköy formation) on top and sand interlayered clay units (i.e., Gürpınar formation) on bottom over Trakya and Ceylan bedrock formations. The site conditions for each seismic station were obtained by Microzonation studies (i.e., drilling, ReMi, PS logging etc.) held by OYO for Istanbul Metropolitan Municipality (IMM) [13] and accordingly a mean observed s-wave velocity profile was assigned to each station.

3 VELOCITY MODEL OPTIMIZATION AND NONLINEAR SITE RESPONSE

A log-normal distribution was applied by a coefficient of variation of 0.2 for V_s and thickness of the soil layers, and 0.1 for the V_s of the bedrock to generate 1000 random soil profiles based on the mean observed s-wave velocity models. The simulated velocity models by Monte Carlo method were analyzed by 1-D wave propagation theory implemented in SHAKE (i.e., applies equivalent linear soil model) [14] to obtain the best matching velocity model due to the least squared error between the response spectral acceleratiom ratios of the recorded and the modelled ones (Figure 2).

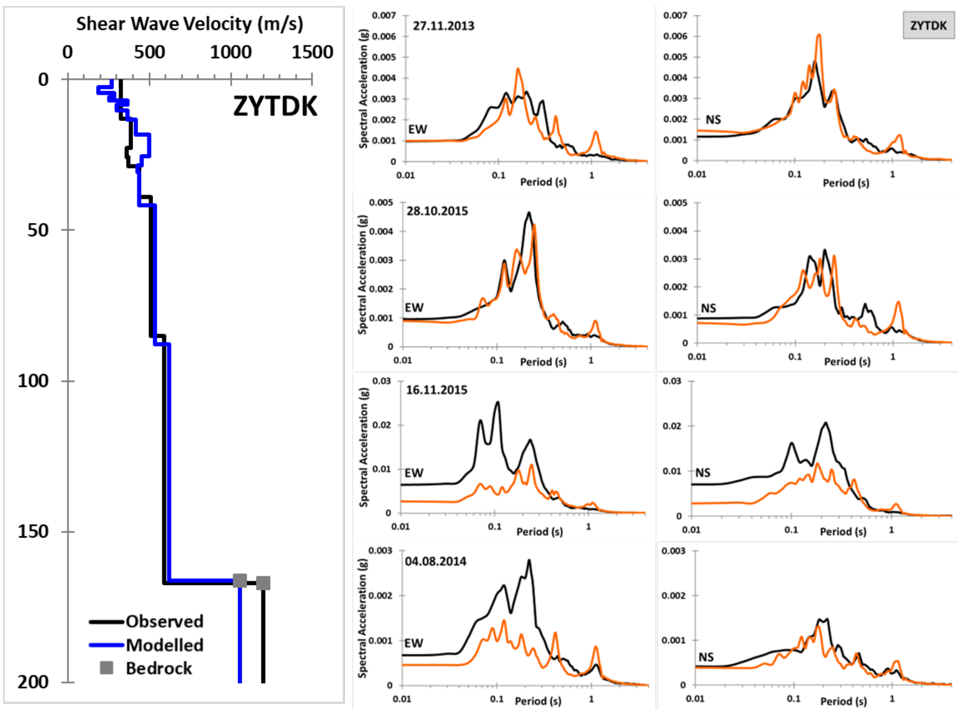

Figure 2. Observed and modelled s-wave velocity profiles (left figure) and spectral accelerations (right figure) for ZYTDK station.

The overall procedure can be regarded as an approximation to velocity model optimization. For the optimized model for ZYTDK station in Zeytinburnu district, the V_s variation for top

30 m was estimated lower than the observed one, whereas the rest is quite similar. The modelled response spectral accelerations match well with the observed ones, especially for lower amplitude earthquakes. After optimization procedure for all stations the V_{s30}-based site class of the stations due to TEBC (2018) did not change, mostly observed as class-D. The low amplitude bedrock motions of ZYT and ATK downhole arrays listed in Table 1, were scaled to the expected probable coordinate-based PGA levels defined in TEBC (2018) for 10% probability of exceedance in 50 years for a return period of 475 years for the site response analysis of mean modelled s-wave velocity models. The mean and mean±std curves for response spectral accelerations on surface exceeded the design spectrum especially at Zeytinburnu district, accordingly spectral amplification factors as well (Figure 3). To be representative of the district, the results for ZYTDK station are presented only in this paper.

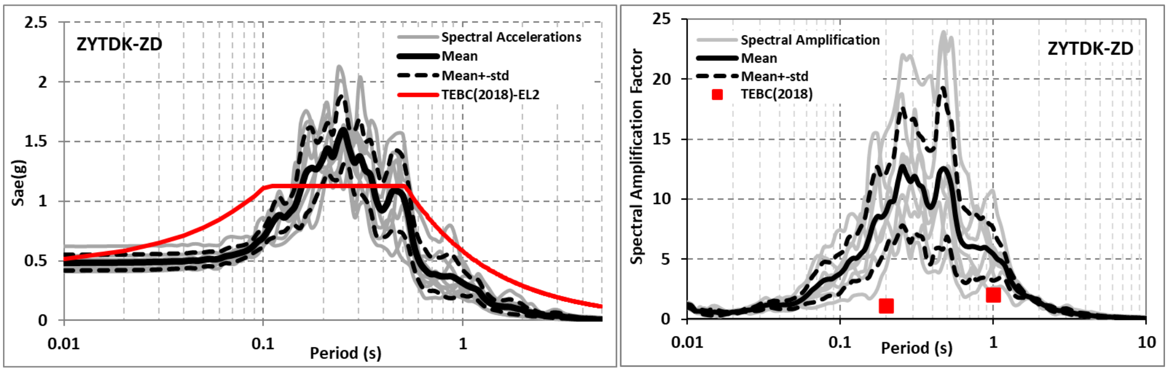

Figure 3. Spectral accelerations and spectral amplification factors for ZYTDK station by scaled bedrock motions.

4 CONCLUSIONS

This paper presents the assessment of local site coefficients for the young soil deposits of the south coast of Istanbul European side by the scaled recorded bedrock motions of IGDA. The study is comprised of an optimization procedure for S-wave velocity models for seismic stations by the recorded low amplitude bedrock motions, then estimation of site response by scaling the bedrock motions to the location-based PGA levels defined in TEBC (2018). The procedure enables to validate the local site coefficients defined in the current seismic regulation of Turkey and propose new ones instead. Moreover, it can be applied to any seismically instrumented sites where site investigations are available as well.

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