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Eccomas Proceedia COMPDYN (2025) 5 04-5 09

ECCOMAS
Proceedia

COMPDYN 2025
10th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis (eds.)
Rhodes Island, Greece, 15-18 June 2025

ASSESSING THE IMPACT OF VERTICAL ACCELERATION ON SITE RESPONSE: A CASE STUDY FROM ISTANBUL USING THE KAHRAMANMARAS EARTHQUAKE DATA

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Abstract

The discovery of site and source conditions has a very large influence on the variation of building damage during earthquakes. Therefore, it is necessary to evaluate and analyze the effects of site and source conditions. One way is to perform a site response analysis to calculate the amplification or attenuation of the soil layers by using estimated acceleration records at the rock outcrop, shear wave velocity profiles, and shear modulus reductions and damping ratio curves as inputs for the encountered soil layers. Since the effects of horizontal acceleration are of great importance, in many cases the site response analysis is performed using only one of the horizontal acceleration recordings. However, the recent strong ground shaking of Kahramanmaraş in Turkey has shown that the vertical peak ground acceleration can be much higher than expected. Therefore, it is necessary to evaluate the effects of vertical acceleration on the site response. The main objective of the present work is to investigate the effects of vertical acceleration on site response in the Istanbul metropolitan area. In this case, a one- and two-dimensional equivalent linear analysis was performed with the DeepSoil and GeoStudio-Quake/W computer programs of the site response at a station of the Istanbul Rapid Response Network using the Kahramanmaraş earthquake records. The analyzed spectral accelerations are compared with the Turkish seismic design codes. The results show the importance of performing multi-dimensional site response analysis for important regions such as Istanbul during strong ground motion.

Keywords: Kahramanmaraş earthquake, Multi-dimensional site response analysis, Shear wave velocity, Vertical strong motion array, Effects of site conditions.

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doi: 10.7712/120125.1281 .26854

1 INTRODUCTION

As an earthquake region, Turkey has been exposed to strong ground movements in the past, such as the Kahramanmaras earthquake (Mw=7.7) on 06.02.2023 and an epicenter distance of 9 km. According to AFAD reports, the coordinates of the earthquake's epicenter were given as 37.288 N and 37.043 E. The recording stations in Kahramanmaraş registered a horizontal peak ground acceleration of 0.5 g. The earthquake shook Kahramanmaras and 10 other states in southeastern Turkey and caused considerable damage to buildings and infrastructure. The Kahramanmaraş earthquake was caused by a fault due to strike-slip motion [1]. These events and the damage they have caused show how important it is to check the site for earthquake safety before any construction work is carried out, especially in a metropolis like Istanbul. Scientists and researchers have proposed or developed many methods to determine or predict the individual factors of local site conditions in order to obtain a sufficient overview of the influence of these factors on wave propagation and ground surface shaking. Site response analysis (SRA) is an important task that can be used to predict the variation of ground surface motion during a strong ground motion. In this case, many of the fatalities and dire consequences of strong ground movements can be prevented. This procedure consists of three main steps, such as evaluating the soil properties and geotechnical parameters of the site of interest, selecting a suitable strong ground motion according to the conditions of the site of interest as input, and analyzing the soil structures with different methods according to the requirements of the project. There are three main categories for numerical analysis of soil behavior: one-, two- and three-dimensional. However, the conditions of the site and the importance of the project determine the appropriate method to achieve the optimal results [2].

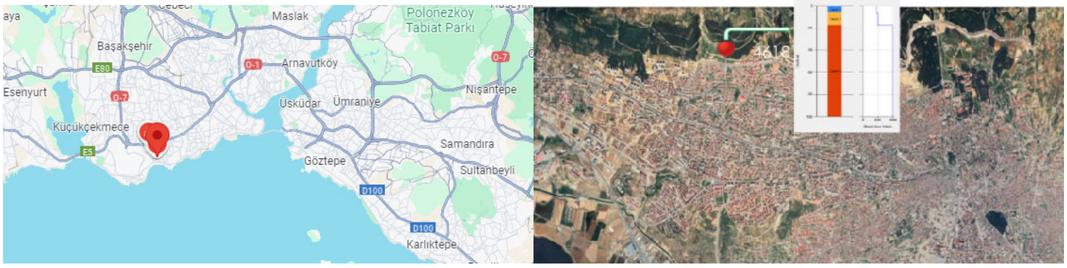
Nevertheless, the one-dimensional analysis of site response is the most common and saves costs and time. Some documents in the literature demonstrate the necessary and sufficient accuracy of the 1D method. In some cases, due to the importance of the desired area or structure or due to doubts about the results of the one-dimensional analysis or the verification of the correctness of the properties of the soil layers, multidimensional calculations are performed. Even though these types of analyzes require more time and money and this shows the inadequacies and shortcomings of the calculation, or the parameters used in the one-dimensional analysis. Depending on the mathematical background and different assumptions, there are different evaluation methods in SRA, such as linear, equivalent linear and non-linear. The equivalent linear tuning is much more flexible than the non-linear and more reliable than the linear [2].

In this research, one-dimensional (1D) and two-dimensional (2D) site response analyses are presented for one of the Istanbul Geotechnical Vertical Array stations named Ataköy (IGVA) using its soil and shear wave velocity profiles and Kahramanmaraş earthquake records in two horizontal (east-west and north-south) and vertical directions to evaluate the reliability of the region's information and compare the results with the available codes for the region. In addition, the 2D SRA results allow an assessment of the effects of the vertical direction of the earthquake waves on the amplification of the soil layers.

2 MATERIALS AND METHODS

The vertical array selected for this study is one of Istanbul's vertical arrays, named Ataköy in accordance with the region. The Ataköy vertical array is located in the south of the European side of the Istanbul metropolitan area (Figure1 (a)). The database for this borehole was obtained from four boreholes to record strong ground movements at different depths (25, 50, 70 and 140 meters), with a distance of 5 meters between each borehole. The database used to analyze the soil response includes shear wave velocity, soil stratification and classification.

These measurements were made using suspension PS velocity measurements and fluid-filled boreholes according to the method of OYO Corporation of Japan. In addition, Standard Penetration Test (SPT) and sampling were conducted at a depth of 140 meters in a borehole for detailed soil classification. The water table of the site was at a depth of about 15 meters and most of the soils of the site are fine-grained to about 100 meters below the ground surface. In addition, the average shear wave velocity in the upper 30 meters is about 280 m/s, which falls into Turkish Earthquake Code's ZC soil classification category.[3].



(a) (b)

Fig. 1. The location of Ataköy vertical array in Istanbul and station 4618 of MAM in Kahramanmaraş [1, 3].

The Kahramanmaraş earthquake was selected as input motion for this study because the time histories of acceleration in three different directions (north-south, east-west and vertical) during ground motion were recorded from the AFAD and Marmara Araştırma Merkezi (MAM) stations on the ground surface in the Kahramanmaras zone [1]. According to the researches investigations, station No.4618 has a V_{S30} of the soil profile near bedrock of about 715 m/s (Fig 1 (b)). In this case, the recorded data from this station can be used as the bedrock input for conducting site response analysis [4].

Regarding the third step of site response analysis, two types of analysis, including one-dimensional and two-dimensional, were conducted in this study to perform site response analysis as an equivalent linear method for predicting ground surface displacements during the strong ground motion of interest. The equivalent linear analysis used for 1D and 2D SRA was first proposed by Seed and Idriss. This method accounts for modulus reduction and hysteretic damping curves by implementing the shear modulus and damping of the soil iteratively up to a certain strain level for each soil layer. It is worth noting that the exclusivities of the soil remain constant during the analysis, but the shear modulus and damping ratio show a decreasing and increasing process, respectively. The results obtained with this method are sufficient for relatively stiff soil profiles and strain levels below 0.1% [5].

To perform 1D SRA, a well-known computer program called DEEPSOIL V6.1 is used, which can generate different results such as spectral acceleration, stress-strain curves, etc. at any depth of the soil profile by using only one direction of horizontal time history accelerations according to the user's requirements. The soil profile varies only in the vertical direction and the model is simulated uniformly to infinity in the horizontal direction [6].

The next step of this investigation is to perform a 2D equivalent SRA with the computer program GEOSTUDIO\ QUAKE V2023, where the horizontal and vertical direction can be used at the same time. In 2D modeling, the soil profiles can vary in vertical and east west horizontal directions. For this study, the vertical array is modeled as a rectangle with a width of 25 meters and a height of about 140 meters. For both modeling, damping ratio is considered as 5% [7].

According to the Turkish Earthquake Code (TEC) and the Seismic Hazard Map of Turkey in the AFAD system (TDTH.AFAD), there are four categories for the design earthquake level used for structural and geotechnical design, including DD1, DD2, DD3 and DD4. In this study,DD2 and DD3 were selected for a comparison between the results obtained and the proposed design ranges for the Ataköy region. DD2, i.e. an earthquake with a return period of 475 years, which corresponds to an exceedance probability of 10 in 50 years, and DD3, which refers to an earthquake with a return period of 72 years, which corresponds to an exceedance probability of 50 in 50 years. According to TDTH.AFAD, the proposed PGA for the DD2 scenario in the Ataköy region is 0.495g and for the DD3 scenario is 0.194g. The recorded acceleration time histories of the Kahramanmaras earthquake are scaled to these PGAs to obtain an appropriate input motion for the Ataköy region, which is then used as the input motion for the site response analysis. The appropriate spectral acceleration for this station is calculated as shown in Fig. 2 [8,9].

3 RESULTS

The comparison between the spectral accelerations based on the 1D analysis of the site response in different directions Fig. 2 shows the large difference especially in the short period (0-1 sec) with respect to the DD2 and DD3 spectrums. These results also show that the north-south direction is the predominant direction in this earthquake records. However, comparison of the results with the AFAD design spectrum shows that the results from the north-south direction are closer to the design spectral acceleration than the results from the east-west direction, especially for the values for the medium to long period (1-4 sec), which exceed the design diagram. As regards, the results of 1D-SRA are closer to the DD3 design spectra than to DD2. This indicates that 1D-SRA for the Ataköy region is more suitable for short-term designs.

Fig .2 shows the results of the 2D analysis of the site response using different directions of input motion. As shown, the spectral accelerations for both DD2 and DD3 categories differ slightly in the short period, but in the rest of the graph, both results overlap. From this graph, it can be seen that using vertical data in the multidimensional site response analysis does not affect the results as much as one of the horizontal directions of input motion.

As can be seen in Fig.2, the spectral acceleration obtained from the 2D analysis of the site response using the two different types of input directions shows less variation compared to the 1D results. In addition, according to this figure, the 2D results are higher than the 1D spectral accelerations, especially for the short and medium periods. However, the 2D results are closer to the AFAD design spectral acceleration, especially at long periods.

The comparison between the acceleration time histories in the 2D location analysis, in which the vertical direction was not used, and the vertical directions also shows the insignificant difference. In general, the results of the 2D SRA which uses both directions of input motion are closer to the DD2 and DD3 design spectra, suggesting that this type of site response analysis is better than the 1D SRA for the Ataköy region.

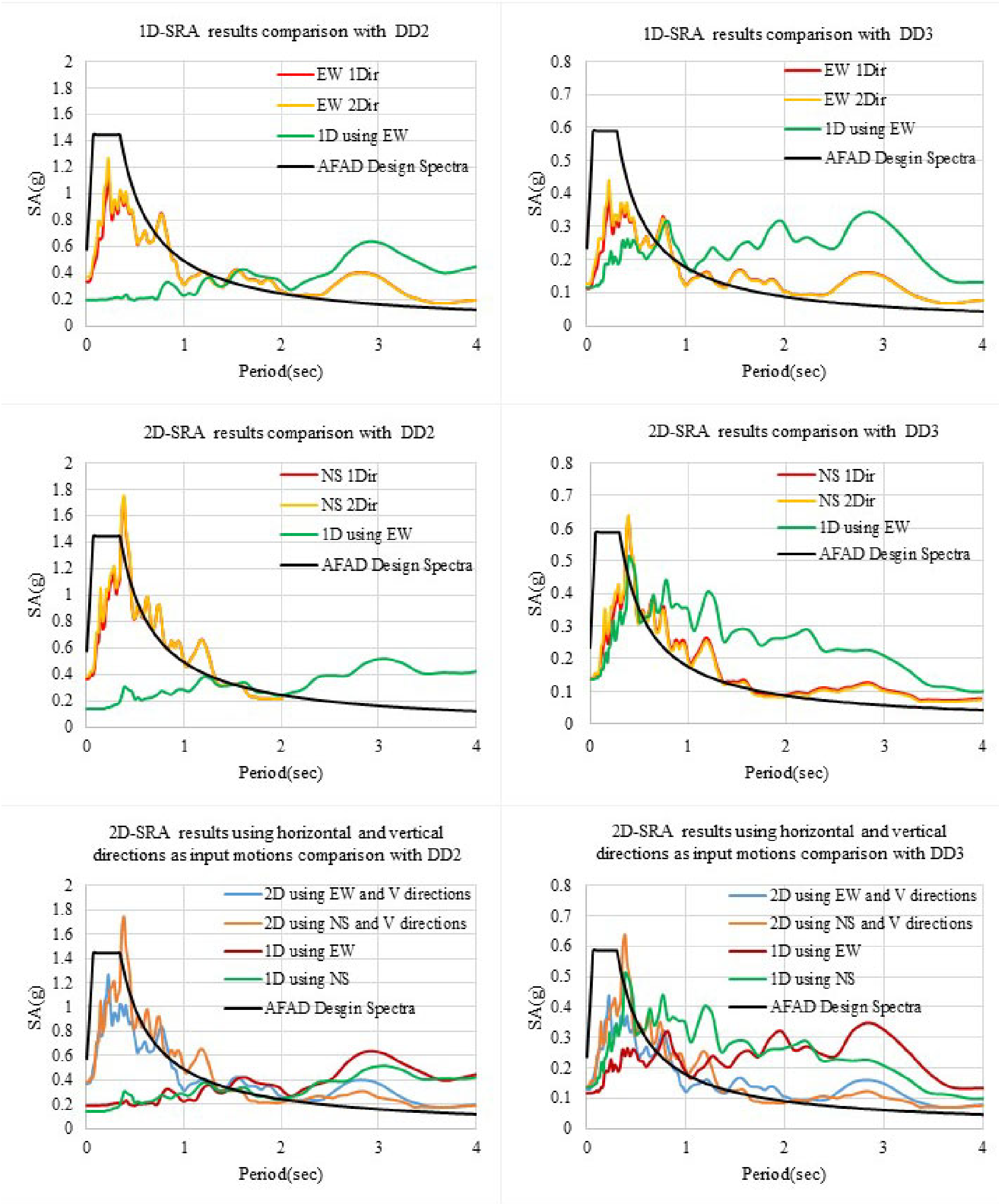


Fig. 2. Comparison between 1D and 2D-SRA using EW-NS and V directions with AFAD design SA

(**CONCLUSION**

Due to the importance of the city of Istanbul, this study attempted to model the Kahramanmaras earthquake on a vertical array of this city. One-dimensional and two-dimensional analyzes of the response of the location of the Ataköy vertical array station in Istanbul were calculated and compared with the spectral accelerations of the Turkish Seismic Code and AFAD with respect to the design ground shakings with 72 and 475 years return periods. The results obtained emphasize the efficiency and accuracy of the 2D analysis in terms of high agreement with the accelerations of the Turkish Seismic Code. In addition, the efficiency of the Turkish Seismic Code for the strong motions of interest was demonstrated based on the results. In addition, this study evaluated the influence of the vertical component of the input motion on the amplifications of the soil layers and for selected earthquake records and showed that the effects of the vertical component are negligible.

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