Eurasian Journal of Civil Engineering and Architecture

Volume 2 Issue 2

Nonlinear and Equivalent Linear Site Response Analysis for the Bodrum Region

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ABSTRACT

The change in the intensity and the frequency content of the motion due to the propagation of seismic waves in soil deposits has a direct impact on the response of structures during earthquake events. In most cases, One dimensional (1D) site response analysis is performed to assess the effect of soil conditions under ground shaking. Frequency domain equivalent linear and time domain nonlinear analyses are the most common approaches for performing 1D seismic site response analysis. The Aegean region and the surrounding area are considered to be one of the most seismically active regions of the world. Recently, the magnitude 6.7 earthquake hit Turkey's western coast and was felt in the resort towns of Bodrum and Datça in Muğla province. A good knowledge on the site effects of the original site in Bodrum is of primarily importance from the engineering point of view. In this study, one-dimensional ground response analyses for a specific site in Bodrum city was performed with using a nonlinear and equivalent linear site response approaches. In order to estimate the ground response of the original site, DEEPSOIL software which is a one-dimensional site response analysis program was used. In addition, the results of the two different approaches were compared. Results of the two original sites under two different earthquake motions are given in terms of peak ground accelerations (PGA) and spectral accelerations. These site effects should be considered when specifying ground shaking levels for seismic designs to prevent earthquake damage.

Keywords: Site response, equivalent linear analysis, nonlinear analysis, Deepsoil, earthquake.

INTRODUCTION

Earthquakes in the last century have shown that the role of site effects in the distribution and magnitude of the damages plays a significant role in seismic behavior (Hashash et al. 2010). Destructive seismic events in the last years such as the 1989 Loma Prieta Earthquake, the 1994 Northridge Earthquake, the 1995 Kobe Earthquake, the 1999 Kocaeli Earthquake, the 1999 Chi-Chi Earthquake, the 2011 Van Earthquake, the 2014 Gokceada Earthquake and the 2017 Bodrum Earthquake have shown the significance of the seismic site response. The change in the intensity and the frequency content of the motion due to the propagation of seismic waves in soil deposits and the existence of topographic features, commonly referred to as site effects, have a direct impact on the response of structures (Hashash et al. 2010).

One-dimensional site response analysis is widely used to quantify the effect of soil deposits on propagated ground motions in research and practice. These methods can be divided into two main categories: (1) frequency domain analysis (including linear and equivalent linear methods) and (2) time domain analysis (including linear and nonlinear analysis) (Hashash et al.2010; Edincliler and Calikoglu 2016). These analyses are used to estimate ground surface motions for the development of design response spectra, dynamic stresses, strains, and displacements with in the soil profile and liquefaction hazard analyses (Hashash et al. 2015). The analysis involves the propagation of the earthquake motions from the bedrock through the overlying soil layers.

In this study, two original sites in Bodrum city under the 2017 Bodrum/Kos Earthquake and the 2014 Gökçeada Earthquake were studied. The epicenter of Bodrum/Kos and Gökçeada Earthquake and the surroundings effected by the seismic event are shown in Figure 1. An equivalent linear method (ELA) in frequency domain and a nonlinear method (NA) in time domain were performed by the use of DEEPSOIL software. The liquefaction analysis was also performed to determine the liquefiaction potential of the selected site.

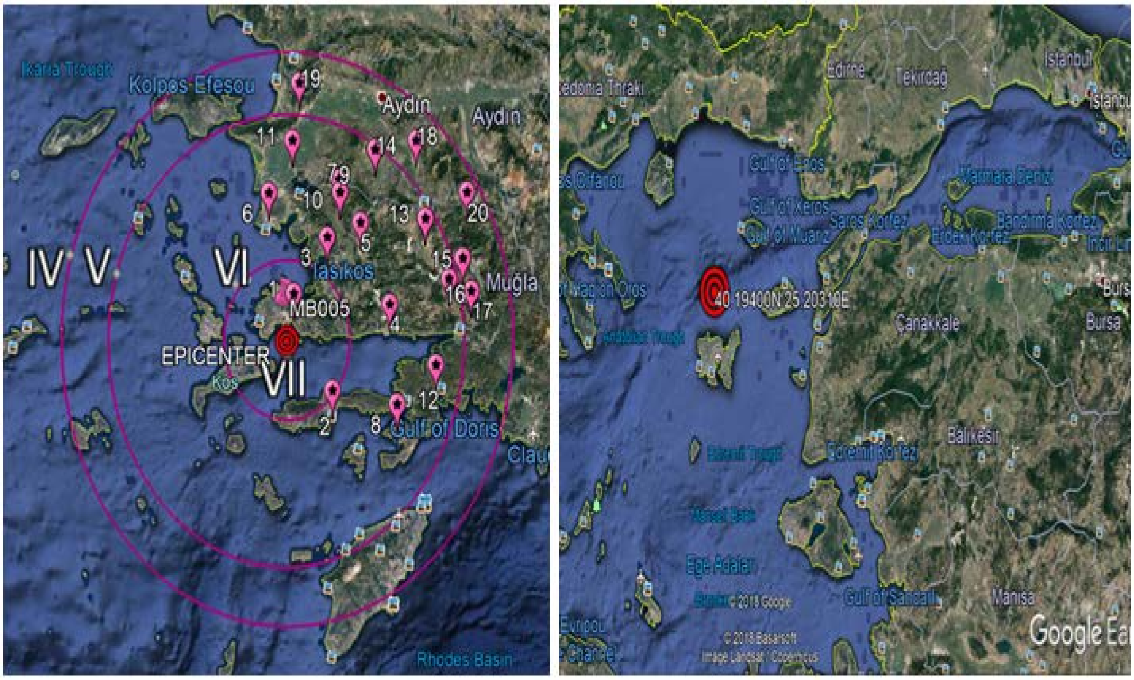

Figure 1. The epicenter of Bodrum/Kos (left) and Gökçeada Earthquake (right).

MATERIAL AND METHODS

Soil Profile

The two boreholes having a depth of 25.95 m. were selected from the Milas-Bodrum region. The location of the boreholes are given in Figure 2. The soil profiles are consisted of mainly silty sand, clay and silty clay deposits. The available soil data comprises of Standard Penetration Test (SPT)-N values at various depths and the soil properties such as density, grain size distribution, and shear strength parameters. Figure 3 and Figure 4 show the Standard Penetration Test (SPT)-N values and the calculated shear wave velocities (Marto et al. 2013) with depth for the two boreholes, SK1 and SK2.

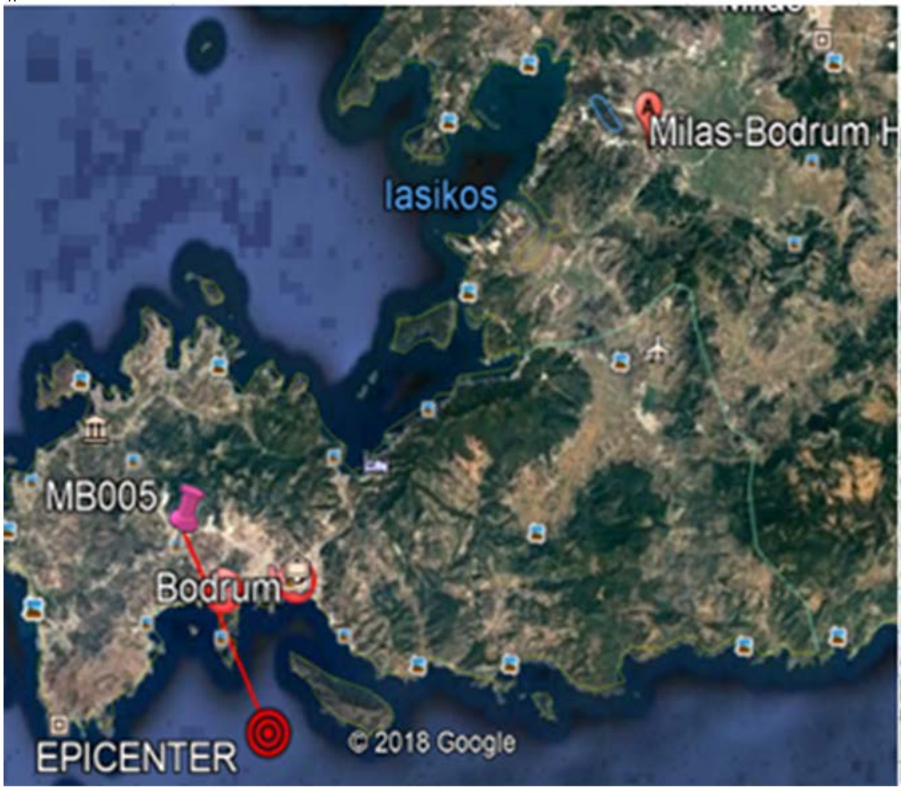

Figure 2. Selected locations from the Milas-Bodrum region.

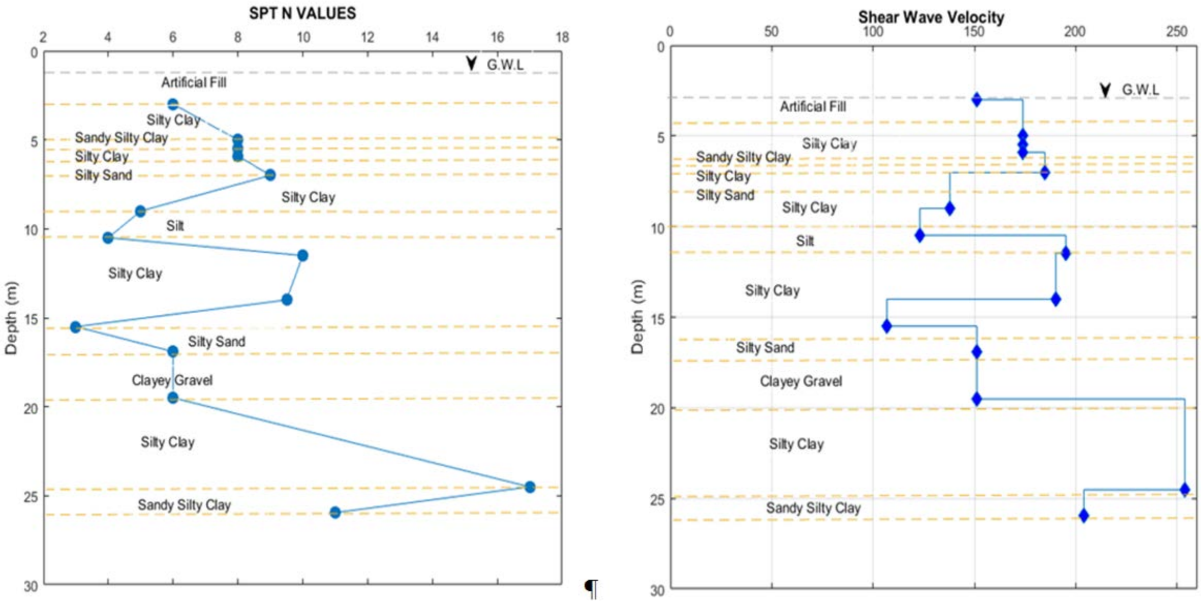

Figure 3. Shear wave velocity and SPT-N values for the SK1 borehole.

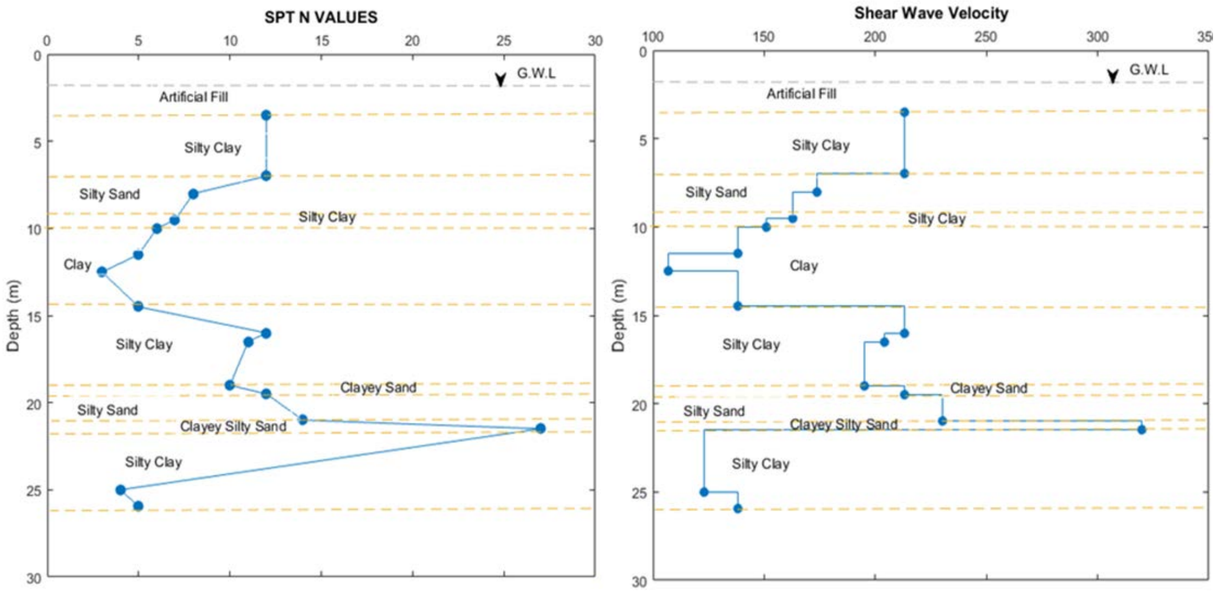

Figure 4. Shear wave velocity and SPT-N values for the SK2 borehole.

Earthquake Information

The Bodrum Earthquake occurred on July 21, 2017, local time 01:31 (20 July 2017 at 22:31 (GMT)) in the border region of Kos Island and Gökova Gulf. Kandilli Observatory and Earthquake Research Institute (KOERI)) determined the magnitude of that severe earthquke as M_L=6.2 (M_w=6.6), and the depth of the earthquake as 5km (KOERI, 2017). Also epicentral coordinates and epicentral depth were determined by AFAD Seismological Network as 36.92830 N, 27.44930E. (AFAD, 2017). The earthquake was felt in the south west of the Aegean Region, particularly in the province of Muğla and its towns.

The Gökçeada earthquake with M_L=6.5 occurred in the Northern Aegean on 24 May 2014 12:25 local time (UTC +3) approximately 30 km North West of Gökçeada (Imbros) Island resulting in strong ground motion in the region. The focal depth of the earthquake is 23 km and considered as shallow. The earthquake has been felt in Marmara and Aegean regions of Turkey, primarily in Çanakkale, Balıkesir, Edirne and Istanbul (KOERI ,2014). The epicentral coordinates were determined as 36.75230 N, 36.03700E (AFAD, 2014).

In order to compare the seismic response of the selected site, DEEPSOIL which is a one-dimensional site response analysis program was used. In this study, equivalent linear analysis (ELA) and nonlinear analysis (NA) were performed. Information of the earthquakes is given in Table 1.

Table 1. Information about the Bodrum/Kos and Gökçeada Earthquakes.

Name of Earthquake	Station Name	Date of Earthquake	Magnitude (M_L)	PGA (g)
Bodrum/Kos Island	Bodrum	July 21, 2017	6.2	0.16
Gökçeada(Northern Aegean Sea)	Gökçeada	May 24, 2014	6.5	0.18

Liquefaction Analysis

Number of methods are available for liquefaction analysis. The most common type of analysis to determine the liquefaction potential is to use the standard penetration test (SPT) data (Seed et al. 1985). The liquefaction analysis proposed by Seed and Idriss (1971) is often termed the simplified procedure. This is the most commonly used method to evaluate the liquefaction potential of a site (Day 2012). The simplified method compares the resistance of a soil layer against liquefaction (Cyclic Resistance Ratio, CRR) to the seismic demand on a soil layer (Cyclic Stress Ratio, CSR) to estimate the factor of safety (FS) of a given soil layer against liquefaction (FS_L=CRR/CSR). If the factor of safety induced by the earthquake is greater than 1, it is likely that liquefaction will occur during the earthquake. Factor of safety calculations were performed considering the real PGA values of the Bodrum and Gökçeada earthquake motions. Figure 5 gives variation of FS_L with depth for two locations under the two destructive earthquakes. FS>1 represents the unliquefied soil layers.

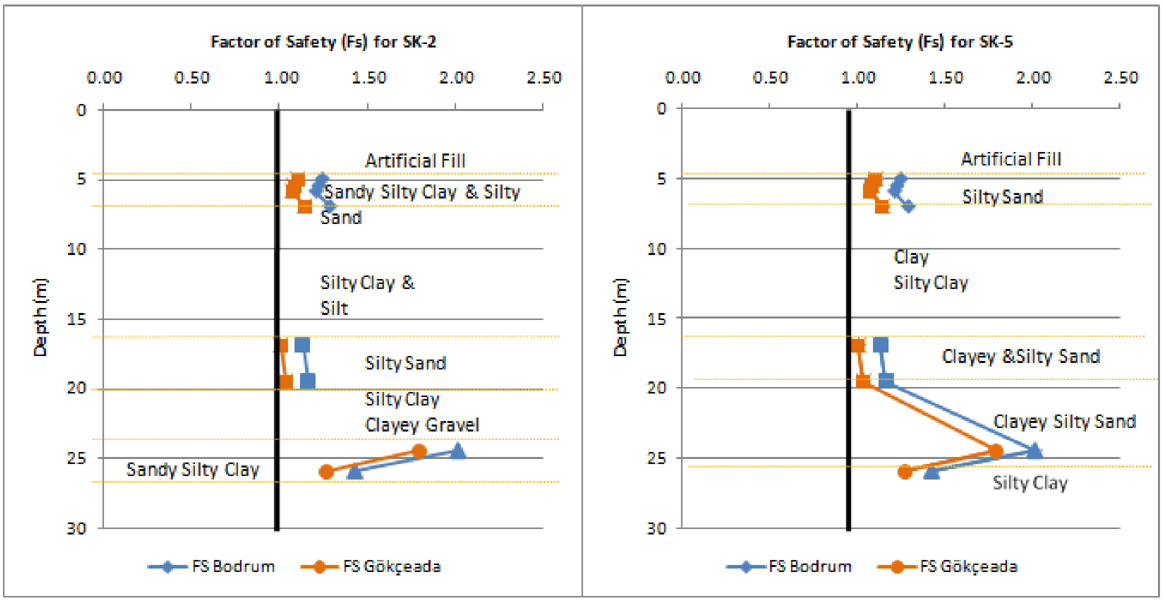

Figure 5. Variation of FS_L with depth for the two boreholes under the Bodrum/Kos and Gökçeada earthquakes.

RESULTS AND DISCUSSION

Under the selected earthquake motions, the general soil profile responses are evaluated by means of Peak Ground Acceleration (PGA) profile and acceleration response spectra with 5 %

damping. The ELA and NA were performed to obtain the PGA values versus depth under Bodrum/Kos and Gökçada Earthquakes. Comparisons of the results were done by considering the responses of ground surface to input motions.

Results under Bodrum Earthquake

Variations of PGA with depth and ground response spectra for the two boreholes are given in Figure 6 and Figure 7. Figures show the results of ELA site response analysis under the Bodrum/Kos Earthquake. Figure 8 and Figure 9 represent the NL site response analysis. Figure 6 shows that there is a decrease of 56% and of 33% in PGA values for the boreholes SK1 and SK2, respectively. In addition, maximum spectral acceleration (SA) value for bedrock is 0.70 g having a period of 0.15 sec. (Figure 7). On the other hand, maximum SA values for SK2 and SK5 boreholes were obtained as 1.19g and 0.64g, respectively with the period of 0.15 sec. It means that there is an increase of 70% for SK2 and a decrease of 9% for SK5 from bedrock to ground surface.

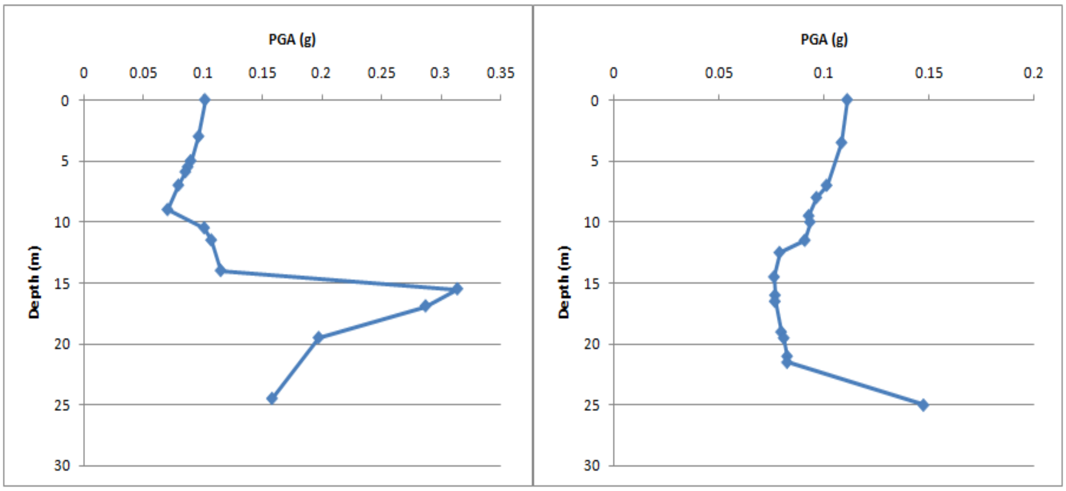

Figure 6. PGA values with depth for SK1 (left) and SK2(right) under Bodrum Earthquake (ELA).

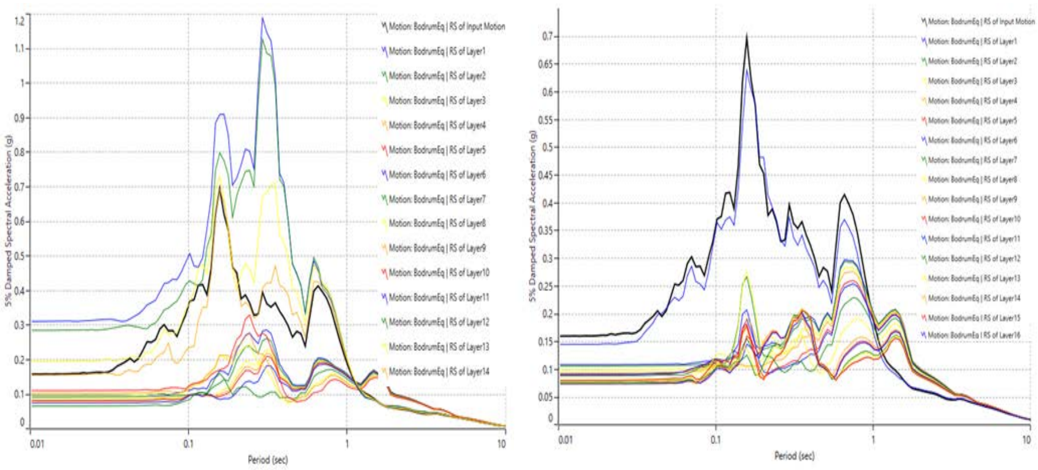

Figure 7. Ground response spectra for SK2 (left) and SK5 (right) under Bodrum Earthquake (ELA).

As seen in Figure 8, a decrease of 192% and 294% in PGA values for the boreholes SK2 and SK5 were obtained respectively. In addition to these, maximum spectral acceleration (SA) value for bedrock is 0.70g having a period of 0.15sec (Figure 9). On the other hand, maximum SA values for SK2 and SK5 boreholes were obtained as 1.08g and 0.80g, respectively. It means that there is an increase of 54% for SK1 and 14% for SK2 from bedrock to ground surface.

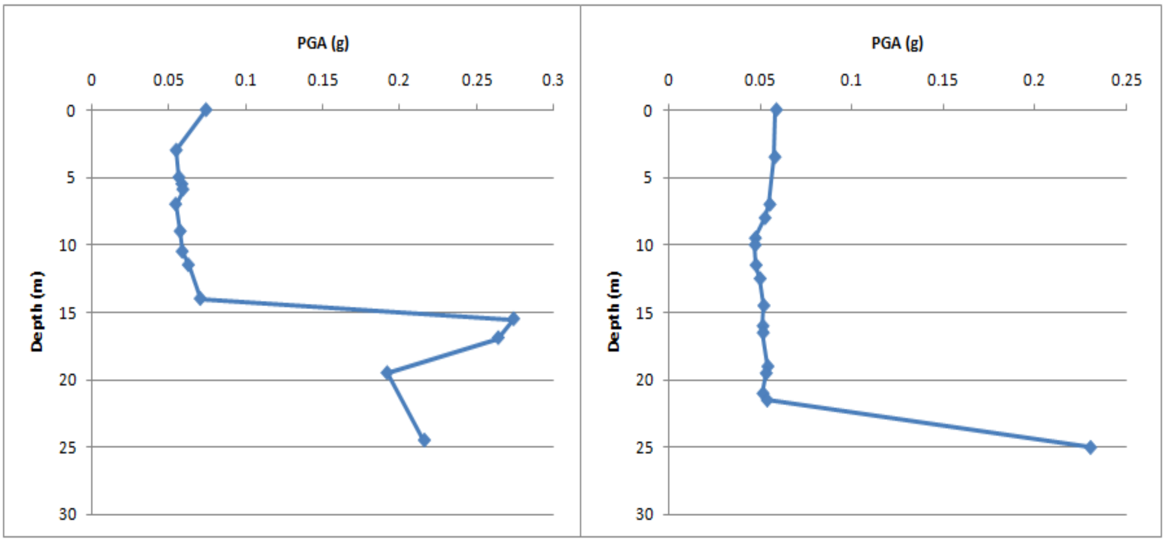

Figure 8. PGA values with depth for SK1(left) and SK2(right) under Bodrum Earthquake (NA).

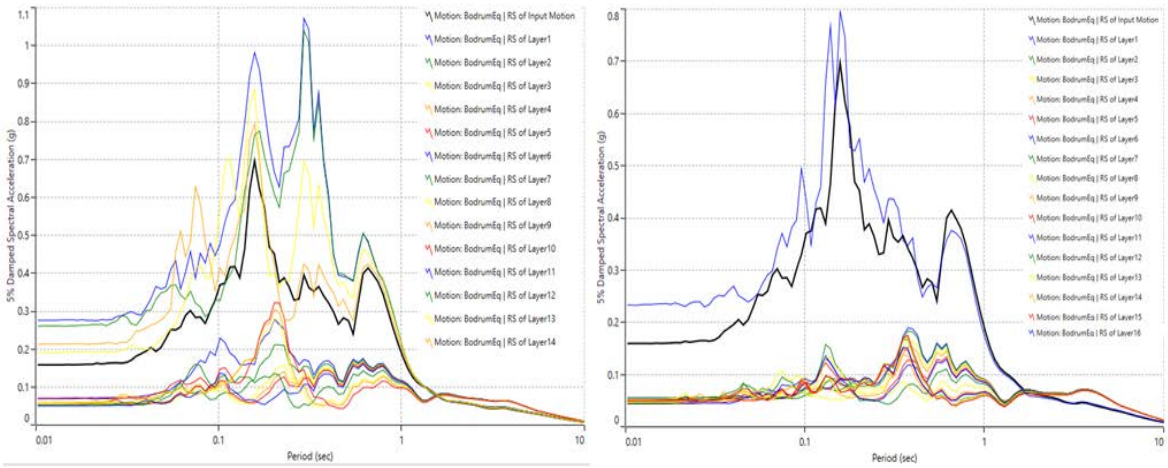

Figure 9. Ground Response Spectra for SK1 (left) and SK2 (right) under Bodrum Earthquake (NA).

Results under Gökçeada Earthquake

The results of EQL under the Gökçeada Earthquake are given in Figure 10 and Figure 11, and also Figure 12 and Figure 13 represent the results of nonlinear site response analysis.

Figure 10, shows that there is a decrease of 69% and 68% in PGA values for the boreholes SK2 and SK5 respectively. In addition to these, maximum spectral acceleration (SA) value for bedrock is 0.70g and 0.61g respectively, having a period of 0.15 sec. shown in Figure 11. On the other hand, maximum SA values for SK1 and SK2 borehole logs were obtained as 1.57g and 0.64g, respectively. It means that there is an increase of 120%for SK2 and 6% for SK5 from bedrock to ground surface.

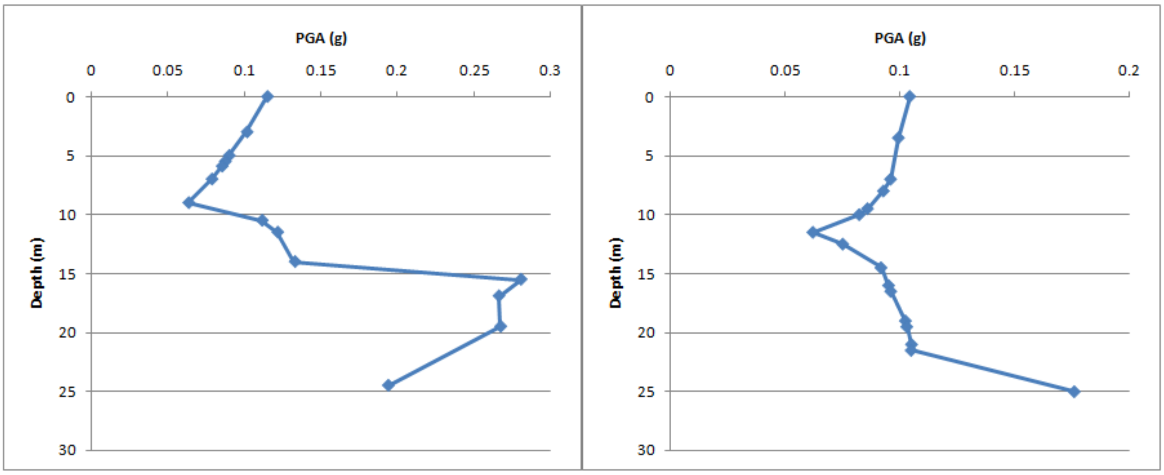

Figure 10. PGA values with depth for SK2 (left) and SK5(right) under Gökçeada Earthquake (ELA).

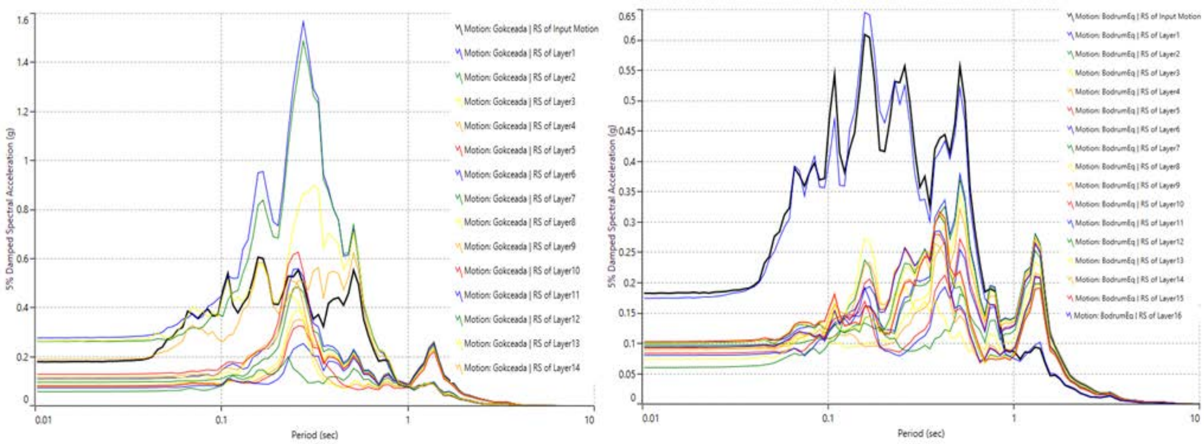

Figure 11. Ground response spectra for SK1 (left) and SK2 (right) under Gökçeada Earthquake (ELA).

According to Figure 12, a decrease of 122% and 305% in PGA values for the boreholes SK2 and SK5 were obtained respectively. In addition to these, maximum spectral acceleration (SA) value for bedrock is 0.70g having a period of 0.15sec. shown in Figure 13. On the other hand, maximum SA values for SK2 and SK5 borehole logs were obtained as 1.22g and 1.09g, respectively. It means that there is an increase of 74% for SK2 and 56% for SK5 from bedrock to ground surface.

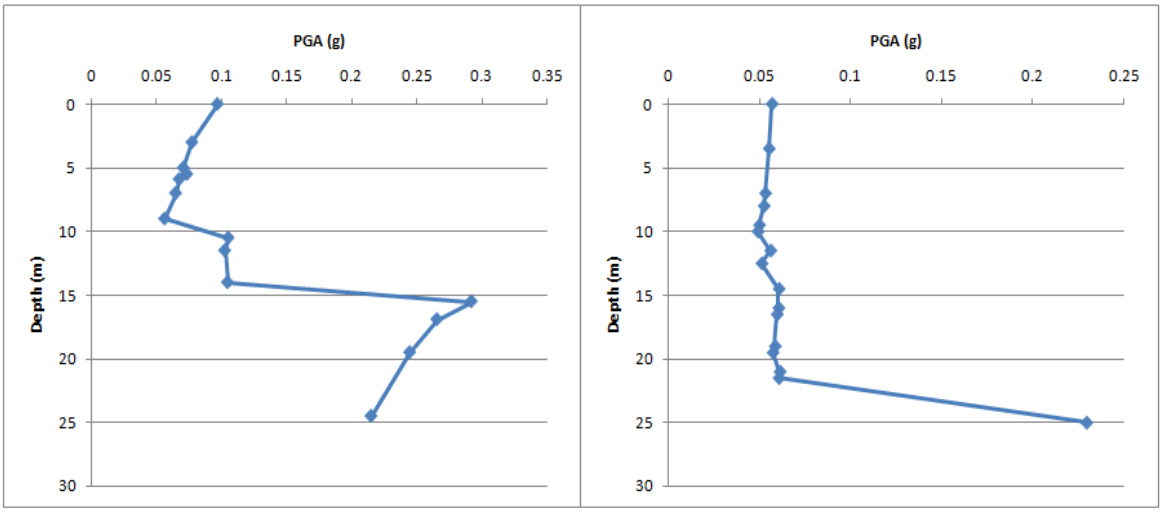

Figure 12. PGA values with depth for SK2 (left) and SK5 (right) under Gökçeada Earthquake (NA).

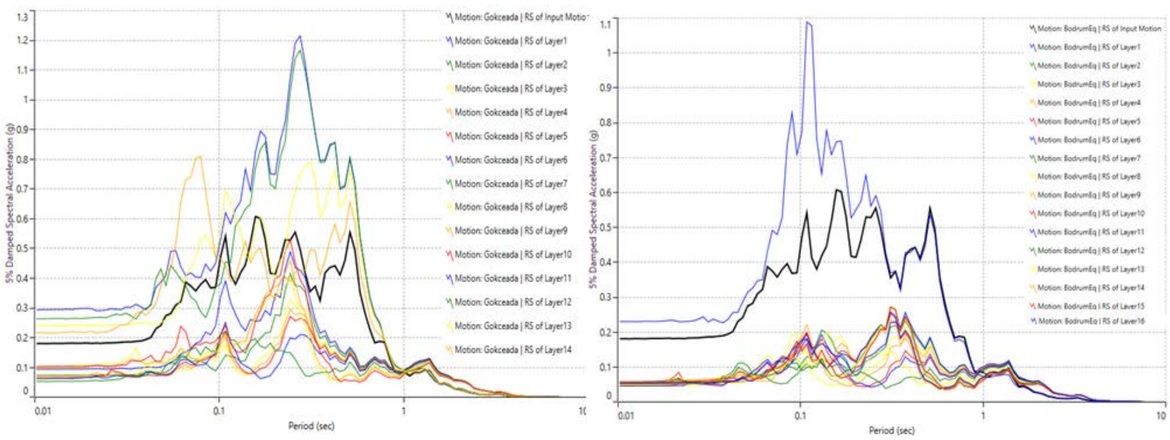

Figure 13. Ground Response Spectra for SK1 (left) and SK2 (right) under Gökçeada Earthquake (NA).

CONCLUSIONS

The results of one-dimensional ELQ and NLA site response analysis are compared for two boreholes belong to Bodrum Region under the Bodrum/Kos and Gökçeada Earthquakes. Results of site response analysis are given below:

Under the Bodrum/Kos Earthquake for the ELA, a decrease of 56% and of 33% in PGA values for the boreholes SK1 and SK2 respectively were obtained. Moreover, maximum SA values for SK1 and SK2 borehole logs were obtained as 1.19g and 0.64g, respectively. The period values were obtained as 0.15 sec. For the NA, a decrease of 192% and 294% in PGA values for the boreholes SK2 and SK5 were obtained respectively.

Under the Gökçeada Earthquake for the ELA, a decrease of 69% and 68% in PGA values for the boreholes SK1 and SK2 respectively. Moreover, maximum SA value the borehole was found as 0.70 g, having a period of 0.15sec. For the NA, a decrease of 122% and 305% in PGA values for the boreholes SK1 and SK2 were obtained, respectively.

As a conclusion, it is revealed that the Nonlinear Analysis (NA) leads to lower PGA levels compared to the Equivalent Linear Analysis (ELA). The differences increase with increasing input acceleration levels.

ACKNOWLEDGMENT

The authors would like to thank “Ege Temel Sondajcılık Sanayi ve Ticaret Ltd. Şti.” for their support.

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