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Nonlinear Site Response Analysis for the Izmir Region: A Case Study

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ABSTRACT

Izmir city is mostly located on deep alluvial sediments capable of amplifying ground motions during an earthquake. Soil layers composed of sand with a high groundwater table are very common in these regions. The three areas of Karşıyaka, Mavişehir and Bornova in Izmir city are seen as particularly interesting due to the large amounts of alluvial fan, plain and delta deposits expected in these areas. Site effects should be considered when specifying ground shaking levels for seismic designs to prevent earthquake damages. One-dimensional site response analysis is widely used to quantify the effects of soil deposits on propagated ground motions in research and practice. In this study, one-dimensional ground response analyses for a specific site which is known as liquefiable site in Izmir were performed with using a nonlinear method based on effective stress modelling in time domain. In order to estimate the ground response of liquefiable site, DEEPSOIL software which is a one-dimensional site response analysis program was used. Results of the two original sites under two different earthquake motions are given in terms of peak ground accelerations (PGA) and spectral accelerations.

Keywords: Site response, liquefaction, DEEPSOIL, nonlinear analysis, earthquake.

INTRODUCTION

In the last decades, destructive earthquakes in Turkey, such as the 1999 Kocaeli earthquake, the 2011 Van earthquake, the 2014 Gokceada earthquake and the 2017 Bodrum earthquake have demonstrated the importance of local geologic conditions on the seismic site response. It is revealed that significant damage and loss of life depends on the effects of local site conditions.

The Gokceada earthquake occurred on a fault with a North-East and South-West strike, where the largest portion of the energy was released towards these directions. Therefore, the effect of the earthquake was felt substantially in Canakkale and Istanbul and their surroundings (Figure 1). The region is the continuation of the North Anatolian Fault Zone (NAFZ) in tectonic terms and is within a tectonic regime that produces such medium-sized earthquakes. The fault segments to the east of the ruptured area were broken by 1912 Sarkoy-Murefte (Mw=7.4) and the 1975 Saroz bay (Mw=6.3) earthquakes (KOERI, 2014).

Figure 1. Epicenter of the Gokceada earthquake (KOERI, 2014).

There are several earthquake resources that will affect the Bodrum peninsula. The most efficient one is Gokova graben in terms of the closeness to the Bodrum (Figure 2) (KOERI, 2017).

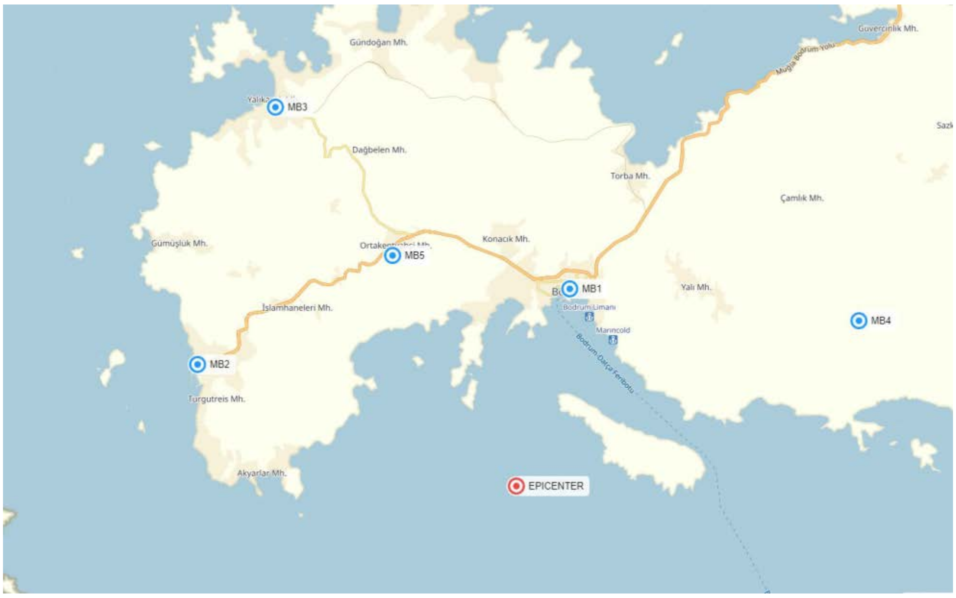

Figure 2. Epicenter of the Bodrum (Kos Island) earthquake (KOERI, 2017).

Site response analyses which involves the propagation of earthquake motions from the bedrock, through the overlying soil layers, to the ground surface are an important step in the seismic evaluation of many geotechnical structures. 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). One-dimensional site response analysis is widely used to quantify the effect of soil deposits on propagated ground motions in research and practice. The changes in the intensity and the frequency content of the motion due to the propagation of seismic waves in soil deposits have a direct response on structures during the earthquake events (Hashash et al. 2010). 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; Adampira et al. 2015; Edincliler and Calikoglu, 2016).

The main aim of this study is to estimate the ground response of liquefiable site which is located in Izmir city. This study performs a series of site response analyses under different earthquake motions as the 2014 Northern Aegean Sea (Gokceada) earthquake and the 2017 Bodrum Earthquake motions. In order to compare the seismic response of the liquefiable site, DEEPSOIL which is a one-dimensional site response analysis program was used. In this study, nonlinear analyses were performed.

MATERIALS AND METHODS

Izmir city has soil deposit on deep alluvial sediments capable of amplifying ground motions during an earthquake. Karsiyaka and Cigli regions are seen as particularly interesting due to the large amounts of alluvial fan, plain and delta deposits in these areas. Two borehole data from these regions were investigated under Gokceada and Bodrum earthquake motions. Information on the earthquakes is given in Table 1 and Figure 3).

Table 1. Basic information about input ground motion records.

Name of Earthquake	Date	Station Name	Magnitude	PGA (g)
Northern Aegean Sea	May 24, 2014	Gokceada	6.5	0.18
Bodrum (Kos island)	July 21, 2017	Bodrum	6.5	0.16

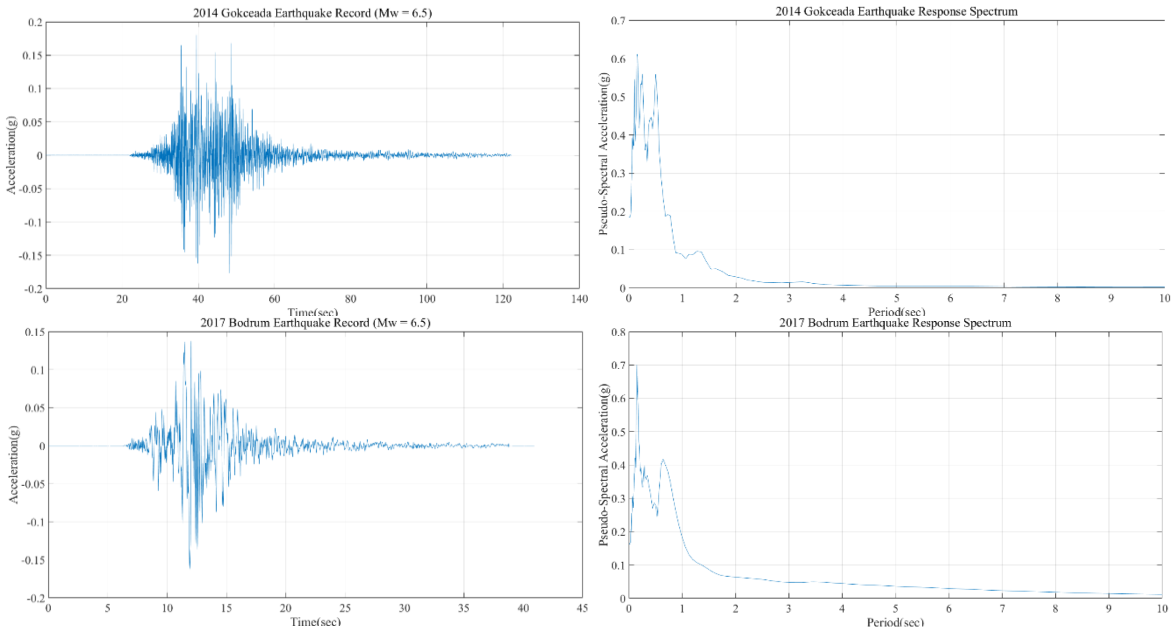

Figure 3. Acceleration time histories and response spectra of the Northern Aegean Sea and Bodrum earthquakes.

Soil Profile

Borehole logs having a depth of 20 m from Cigli and Karsiyaka districts were selected from well-known regions in Izmir that is seriously affected under the 2014 Gokceada and 2017 Bodrum earthquakes. Soil profile of the borehole for Cigli district is given in Figure 4. In this study, the simplified soil profile data was created. Soil profile of Cigli district is consisted of mainly silty sand and clayey silt deposits. Soil profiles were defined with ten layers. For the soil profiles, the surficial first layer is clayey silt for Cigli district and sandy clay for Karsiyaka district, respectively. Figure 4 and Figure 5 show the simplified shear wave velocity (V_{s30}) along the soil cross section.

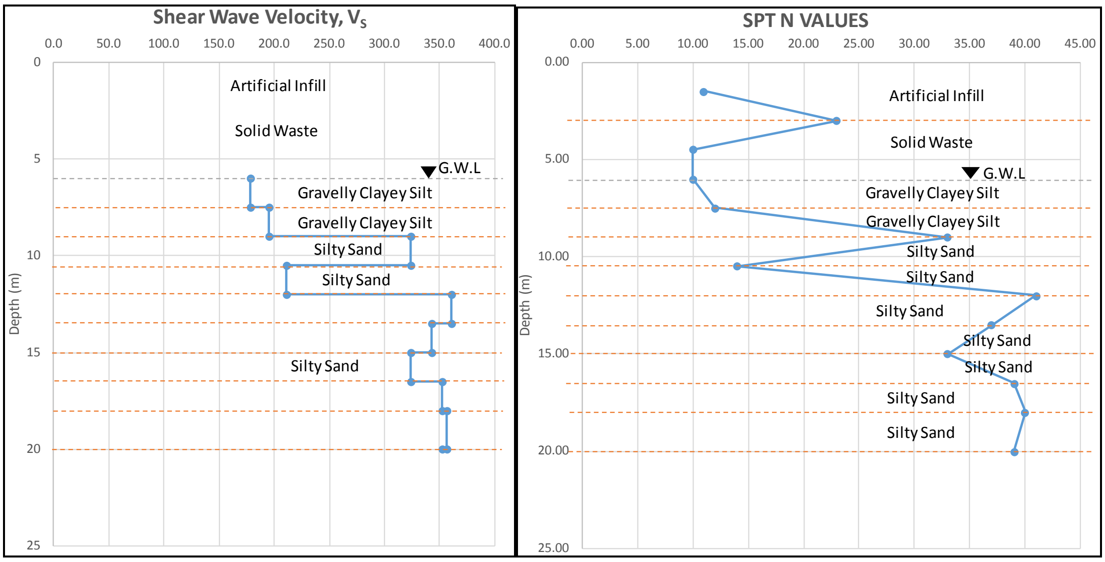

Figure 4. V_{s30} and SPT-N values for Cigli district.

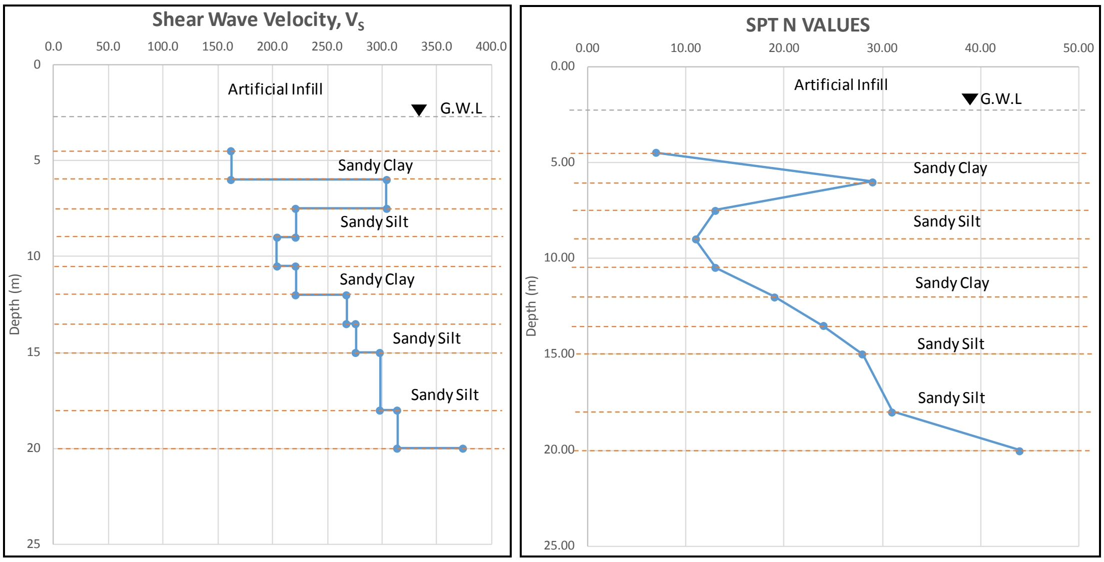

Figure 5. V_{s30} and SPT-N values for Karşıyaka district.

Liquefaction Analysis

The most common type of analysis to determine the liquefaction potential is to use the standard penetration test (SPT) (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). By using the standard penetration test, the cyclic resistance ratio (CRR) of the in situ soil is then determined. If the Cyclic Stress Ratio (CSR) induced by the earthquake is greater than the CRR determined from the standard penetration test, then it is likely that liquefaction will occur during the earthquake, and vice versa. In the present study, liquefaction analyses were performed for liquefiable soil layers in both borehole logs. Factor of safety calculations were performed considering the real PGA values of the considered earthquake motions. Figure 6 gives factor of safety against liquefaction with depth. FS>1 represents the unliquefied soil layers. However, if there occur any earthquake having higher PGA values than these earthquakes, liquefaction phenomenon will be inevitable.

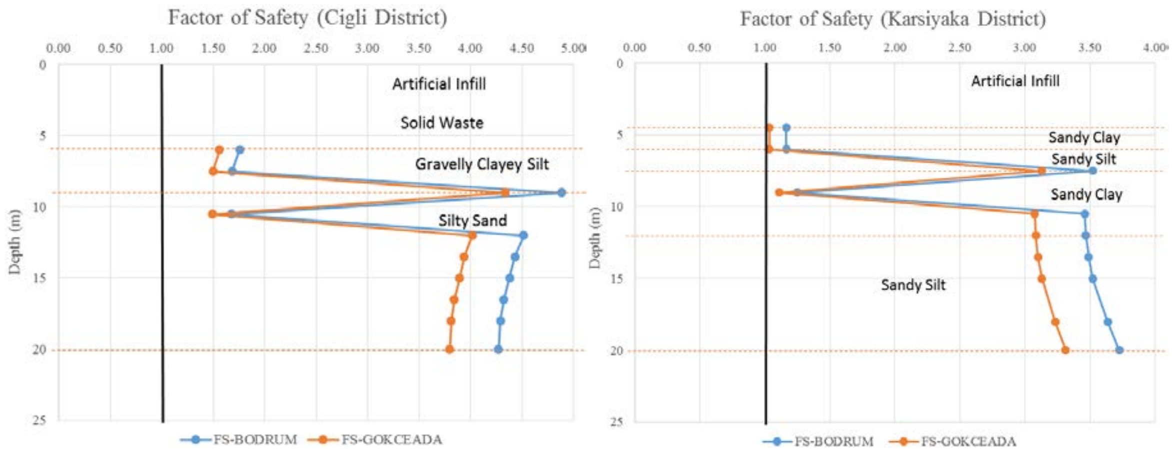

Figure 6. Variation of factor of safety against liquefaction with depth for the selected bore logs (Left: Cigli; Right: Karsiyaka).

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. Variation of PGA with depth and ground response spectra of sublayers of soil profiles (from the bedrock up to the surface) under the Gokceada and Bodrum earthquakes are given in the following parts. Comparisons of the results were done by considering the responses of ground surface to input motions.

Results under Gokceada earthquake

The PGA obtained in different soil layers and comparison of ground response spectra for Cigli and Karsiyaka borehole logs under the 2014 Gokceada earthquake are given in Figure 7 and Figure 8. As seen in Figure 7, on the ground surface, an increase of 82% and 59% in PGA values were obtained for Cigli and Karsiyaka district, respectively. When Cigli log compared to Karsiyaka log, an increase of 39% in PGA was obtained for Cigli district. In Figure 8, maximum spectral acceleration (SA) value for bedrock is 0.61g having a period of 0.15 sec. On the other hand, maximum SA values for Cigli and Karsiyaka borehole logs were obtained as 1.39g and 1.14g, respectively. The period was increased from 0.15 sec to 0.25sec for Cigli and 0.50sec for Karsiyaka districts. This corresponds to 67% and 233% increase in period values.

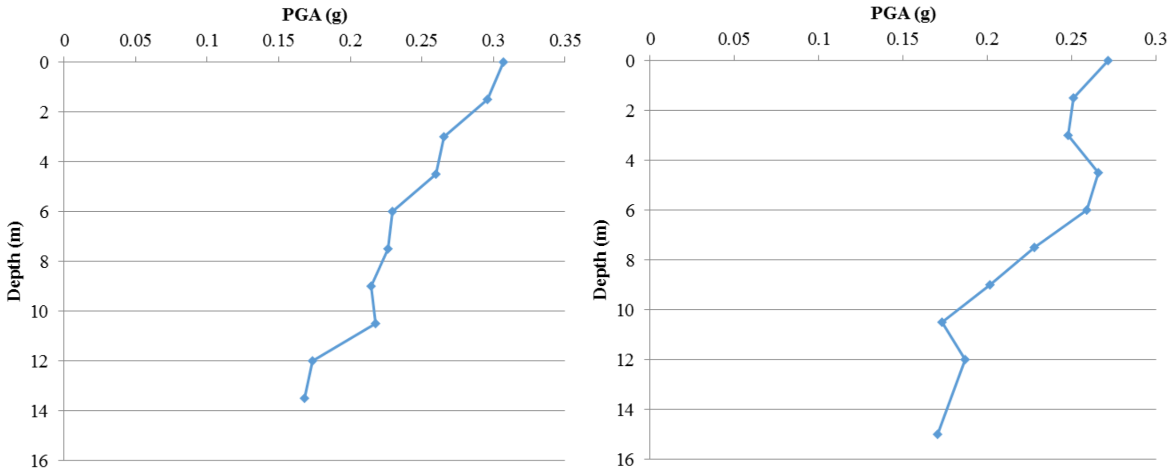

Figure 7. PGA values in the different depths for Cigli (left) and Karsiyaka (right) districts under Gokceada earthquake.

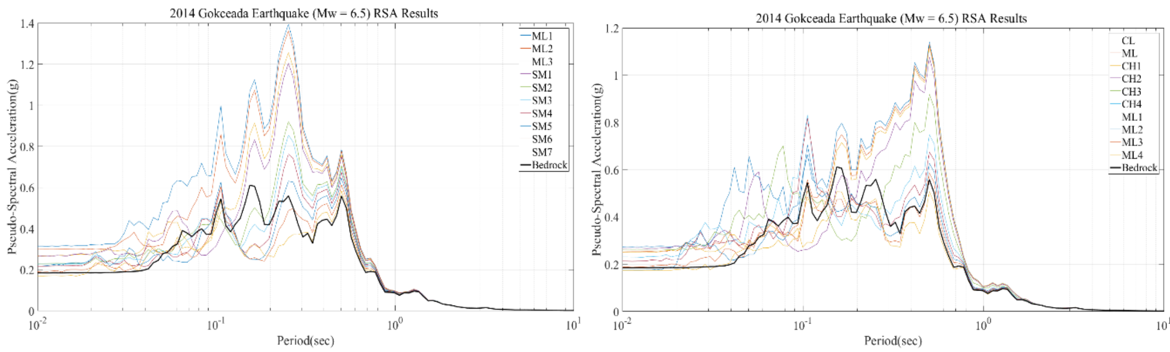

Figure 8. Comparison of ground response spectra under Gokceada earthquake (Cigli-left and Karsiyaka-right).

Results under Bodrum earthquake

In Figure 9 and Figure 10, the peak ground acceleration (PGA) obtained in different soil layers and comparison of ground response spectra of soil profile's sub-layers from the bedrock up to the surface for Cigli and Karsiyaka under Bodrum earthquake motion are given. In Figure 9, a 75% increase in PGA value for Cigli and 44% increase in PGA value for Karsiyaka were obtained. When Cigli compared to Karsiyaka, an increase of 70% in PGA was obtained for Cigli. In Figure 10, maximum SA value for bedrock is 0.70g having a period of 0.15 sec. On the other hand, maximum SA values for Cigli and Karsiyaka were obtained as 1.13g and 0.91g, respectively. That means a 61% increase in maximum SA value from bedrock to ground surface for Cigli. The period was increased from 0.15 sec to 0.16 sec for Cigli and increased from 0.15 sec to 0.29 sec for Karsiyaka. It makes a decrease of 7% and 93% increase in period values.

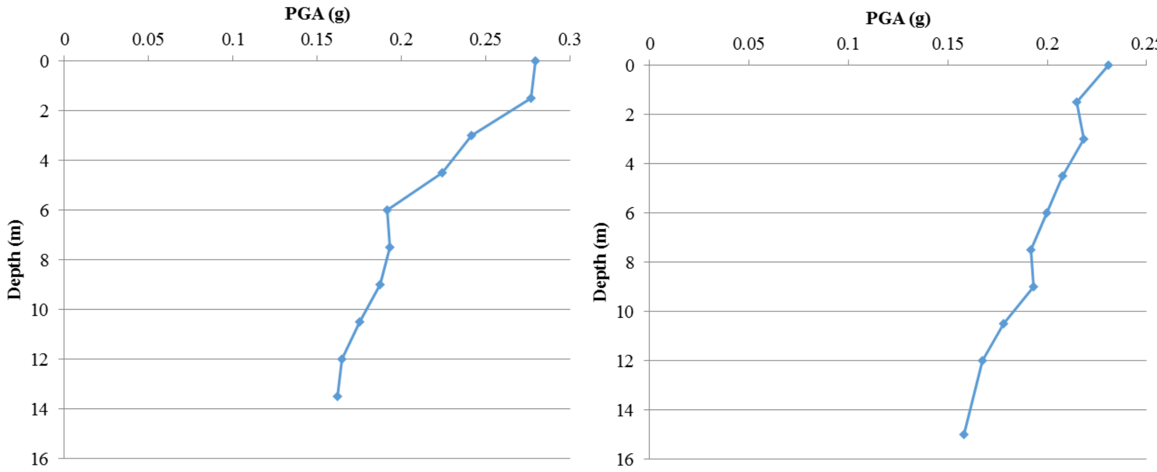

Figure 9. PGA values in the different depths for Cigli (left) and Karsiyaka (right) districts under Bodrum earthquake.

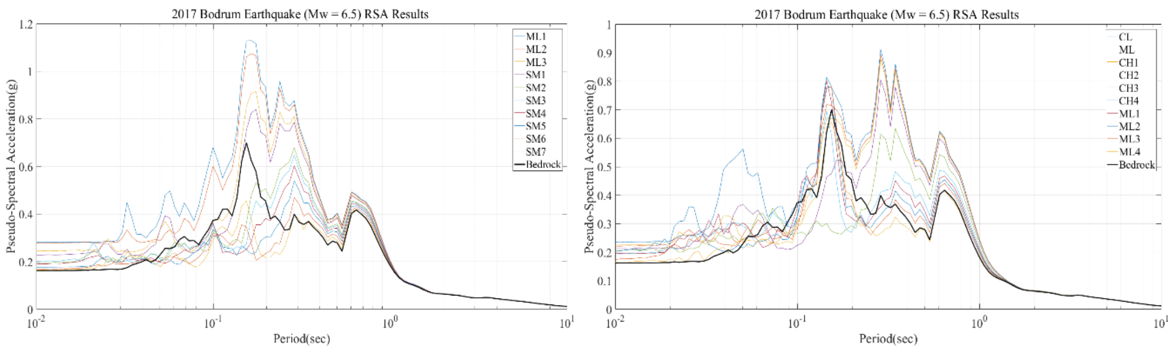

Figure 10. Comparison of ground response spectra under Bodrum earthquake (Cigli-left and Karsiyaka-right).

CONCLUSIONS

Site responses of two soil profiles from “Cigli District” and “Karsiyaka District” in Izmir city as a real liquefiable site under two earthquake motions are evaluated. Based on the main findings, the following conclusions can be drawn:

- Due to higher PGA value, Cigli and Karsiyaka were affected mostly under the Gokceada earthquake.
- Under the Gokceada earthquake, an increase of 82% and 59% in PGA values were obtained for Cigli and Karsiyaka, respectively. Furthermore, maximum SA values for Cigli and Karsiyaka are obtained as 1.39g and 1.14g, respectively. The period was increased from 0.15 sec to 0.25 sec for Cigli and 0.50 sec for Karsiyaka. This corresponds to 67% and 233% increase in period values.
- The first layer having a silt deposit in Cigli is highly affected under the selected earthquake motions when compared to Karsiyaka log.
- Site effects strongly affect the spectral accelerations at short periods.
- The peak spectral accelerations obtained for Cigli is higher than Karsiyaka district.

In summary, depending on the earthquake characteristics and soil profiles, considerable differences are found in the output parameters such as surface accelerations and response spectrum curves.

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