THE ASSESSMENT OF SEISMIC SITE EFFECTS DURING THE 24 JANUARY 2020 ELAZIG-SIVRICE MW: 6.8 EARTHQUAKE

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ÖZET

24 Ocak 2020 tarihinde yerel saat ile 20:55'te (17:55 GMT), Türkiye'nin en büyük ikinci fay hattı üzerinde yer alan Elazığ'ın Sivrice ilçesinde, USGS'ye göre 6.7 veya AFAD'a göre 6.8 büyüklüğünde şiddetli bir deprem meydana gelmiştir. Ne yazık ki deprem, can kaybı ve hasarla birlikte bölgede şiddetli bir yıkıma neden olmuştur. Bölgede meydana gelebilecek olası deprem hasarlarının en aza indirgenmesine yardımcı olmak ve gelecekteki depremler için sahaya özel sismik tasarım rehberi olması amacıyla, depremin sismik alan etkileri değerlendirilmiştir.

Bu çalışma kapsamında, 2020 Sivrice-Elazığ Depremi sismik alan etkilerinin değerlendirilmesi başlıca üç aşamada gerçekleştirilmiştir; (i) sismik zemin tepki analizleri, (ii) zemin sıvılaşması riskinin araştırılması ve (iii) sismik mikrobölgelendirme haritalarının oluşturulması. Çalışmaya başlamadan önce, ilk olarak jeoteknik ve jeofizik veriler edinilmiştir. İdeal zemin profilini oluşturabilmek için 210 adet sondaj kuyusunun verileri çalışmaya dahil edilmiştir. Daha sonra, toplam yedi deprem kayıt istasyonu (SGMS) tarafından kaydedilen Sivrice-Elazığ Depremi'nin kuvvetli yer hareketi sarsıntısı, sahaya özel sismik tepki analizi için gerekli olan kaya hareketini oluşturmak için yerel olarak ölçeklendirilmiş ve kalibre edilmiştir. Ek olarak, sismik zemin tepki analizlerini yapmak için Deepsoil programı kullanılırken, zemin sıvılaşması çalışmalarını yapmak için Cetin vd. (2000, 2004 ve 2018) methodu uygulanmıştır. Yukarıda bahsedilen analizlerden elde edilen sismik parametreler Elazığ-Merkez'in sismik mikrobölgelendirilmesinin oluşturulmasında kullanılmıştır. En büyük yer ivmesi (PGA), spektral ivme (Sa) ve zemin sıvılaşma riski haritaları geliştirilmiştir. Son olarak, bu çalışmanın bir sonucu olarak Elazığ-Merkez'in sismik tehlikesinin değerlendirilmesi için öneriler geliştirilmiştir. Bir uyarı: Literatürden toplanan jeoteknik verilerin analiz boyunca geçerli ve temsili olduğu varsayıldığı için, bu verilerdeki herhangi bir yanlışlık sonuçları değiştirebilir.

Anahtar Kelimeler: saha etkileri, Elazığ-Sivrice depremi, saha tepki analizleri, zemin sıvılaşması, sismik mikrobölgeleme.

ABSTRACT

On January 24, the Sivrice district of Elazig, was struck by a severe earthquake with a magnitude of 6.8 (AFAD). Tragically, the earthquake resulted in severe devastation,

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including structural damage and fatalities. In order to aid in the mitigation of potential earthquake damage that may occur in the region and to serve as a guide for site-specific seismic design for future earthquakes, the seismic site effects of the earthquake were assessed.

The assessments of seismic site effects during the 2020 Sivrice-Elazig earthquake were undertaken following mainly three stages; (i) the performance of seismic site response analyses, (ii) the investigation of soil liquefaction hazard, and (iii) the construction of seismic zonation maps. Geotechnical and geophysical data were acquired prior to initiating the study. A total number of 210 boreholes were included in the study and were used to create the idealized soil profile. The strong ground motion shaking of Elazig-Sivrice event, recorded by a total of seven strong ground motion stations (SGMS), was then calibrated and scaled locally in order to generate the rock motion needed in the site-specific seismic response analysis. Additionally, Deepsoil software was used to conduct the seismic site response analysis, whereas the Cetin et al. (2000, 2004, 2018) approach was adapted for the soil liquefaction study. Finally, the seismic parameters collected from the aforementioned analyses were used in the construction of the seismic zonation of Elazig-Center. This was accomplished by developing peak ground acceleration (PGA), spectral acceleration (Sa), and soil liquefaction hazard maps. Finally, recommendations for assessing seismic hazard for the Elazig-Center district were developed as part of this study's conclusion. As a word of caution, geotechnical data culled from the literature was assumed to be valid and representative throughout the analysis; therefore, any inaccuracies in the adopted geotechnical data can alter the results.

Keywords: site effects, Elazig-Sivrice earthquake, site response analyses, soil liquefaction, seismic zonation.

1. INTRODUCTION

On January 24 at 8:55 p.m. local time (17:55 GMT), a severe earthquake struck the Sivrice district of Elazig province, Turkey, located in the southwest of the Eastern Anatolia region. The earthquake had a magnitude of M_w=6.8 according to AFAD (The Ministry of Interior Disaster and Emergency Management Presidency) and M_w=6.7 according to the USGS (United States Geological Survey). The main shock recorded a peak ground acceleration (PGA) of 0.292 g.

The earthquake was felt in approximately 20 Turkish cities, as well as in Iraq, Palestine, Lebanon, and Syria. According to AFAD, the earthquake caused 41 fatalities (37 in Elazig and 4 in Malatya) and 1466 injuries. In Elazig, 50 structures were demolished, 308 severely damaged, and 150 moderately damaged. In Malatya, 155 structures were destroyed, and 1278 structures sustained significant damage. In Diyarbakir, eight structures were destroyed, and 16 others were significantly damaged.

To mitigate future earthquake damage and guide site-specific seismic design, the seismic site effects of the event were investigated in three stages: seismic site response analysis using Deepsoil software, soil liquefaction hazard evaluation, and the development of seismic site zonation maps. The investigation included data from 210 boreholes as reported in the Elazig (Central) Municipality Geological-Geotechnical Survey Report Based on Zoning

Plan (Akare Planlama, 2015). It is important to note that the geotechnical results from Akare Planlama were assumed to represent accurate soil and site conditions, and any deviation from this assumption may affect the findings.

2. SUB-SURFACE INVESTIGATION OF THE STUDY AREA

The subsurface investigation of the study area in Elazig Center is based on comprehensive data collected from a variety of geotechnical surveys. The study includes data from 210 boreholes, with a total drilling depth of 3050 meters. These boreholes, which range in depth from 5.00 to 30.0 meters, were strategically distributed across several geological formations. The Standard Penetration Test (SPT) was conducted across all boreholes, providing essential data for soil classification and geotechnical analysis. Additionally, pressuremeter tests were carried out at 50 levels across 10 boreholes. Geophysical in-situ tests, including vertical electrical drilling, microtremor, and seismic refraction studies, were also conducted to evaluate bedrock characteristics, underground velocity structures, and dynamic-elastic properties.

To complement the in-situ testing, a series of laboratory tests results were used in the study, those tests were performed according to TS-1900 standards; included Triaxial Compression Tests, Water Content Tests, Sieve Analyses, Atterberg Limits, Consolidation Tests, Point Loading, and Uniaxial Compression Tests. For the geophysical data used in this study, P and S wave velocities were measured across 170 profiles to determine the soil classes and dynamic-elastic properties. The wave velocity measurements, conducted with geophone intervals set at 4 meters and laying lengths of 95 meters, were processed using a 24-channel "Geometrics" seismograph.

Using the gathered data, idealized soil profiles were developed for each borehole as show in Figure 1. These profiles incorporated SPT logs and were critical for site-specific seismic site response analysis. The seismic refraction data was instrumental in assigning shear wave velocities to the boreholes, with most distances between boreholes and measurement points ranging from 100 to 400 meters.

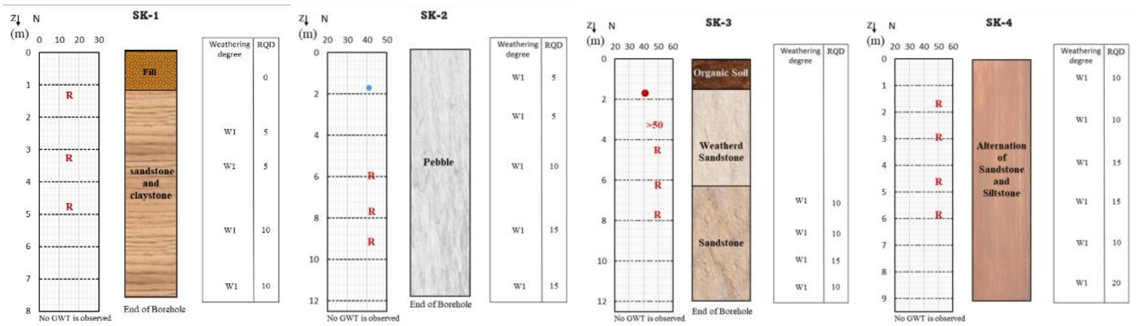


Figure 1. Some idealized soil profiles developed for the analyses

3. SITE RESPONSE ANALYSES

1-D equivalent linear site-specific seismic response analyses are conducted to understand the site effects of the 2020 Elazig-Sivrice earthquake. A total of 210 boreholes were utilized for these analyses. An idealized shear wave velocity profile is created by modifying existing profiles and tailoring them to achieve relatively deep and smooth profiles. The site response analysis is carried out using Deepsoil software in three stages: (i) deconvolving the original outcrop acceleration time history recorded at a strong ground motion station into bedrock motion, (ii) scaling this motion for each of the 210 boreholes, and (iii) performing an equivalent linear site response analysis. The resulting in-situ outcrop time histories, spectral acceleration plots, and PGA values for each borehole are presented.

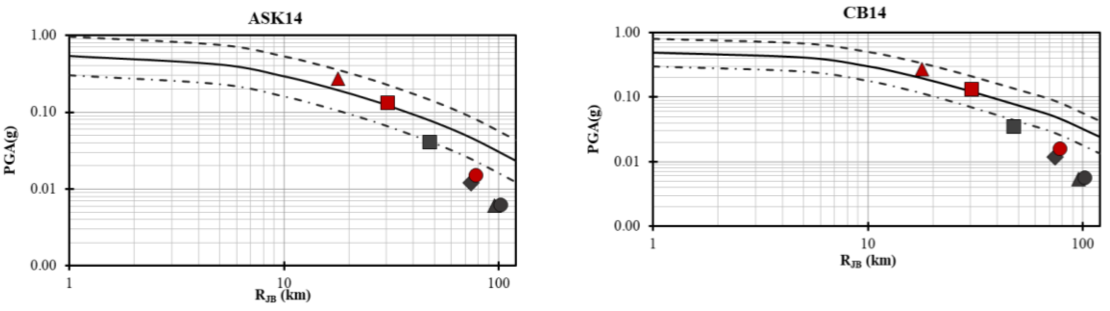
3.1. Preliminary Study

AFAD reported that the epicenter of the event was near Cevrimtas village in the Sivrice district, where the most significant PGA was recorded at 0.29 g. The earthquake was recorded by seven Strong Ground Motion Stations (SGMS) in Elazig, with only one, the Elazig center (2301), located within the study area. The NGA-West GMPE was used to evaluate whether this station could be used as-is or needed scaling. The geometric mean of the PGA for the stations was calculated, and relevant distance parameters, including Rupture distance (R_{RUP}) and Joyner-Boore distance (R_{JB}), were obtained from AFAD.

3.2. The Selection of Input Ground Motion

The geometric mean of the PGA was calculated for each of the seven stations, and distance parameters (R_{RUP}, R_{JB}, and Z_{TOR}) were used to calibrate the acceleration history record. The NGA-WEST2 models by Abrahamson, Silva, and Kaman (ASK14), Campbell and Bozorgnia (CB14), Chiou and Young (CY14), and Idriss (I14) were used for this calibration. The predicted PGA using these models was compared with the recorded PGAs to determine if further calibration was necessary. After predicting the PGA using the NGA-WEST2 GMPE's.The AFAD-recorded PGAs of each of the strong ground motion stations are scaled. The resulting R_{JB} vs. PGA charts for ASK14, CB14, CY14, and I14 are presented in Figure2.

As illustrated in Figure 2, the ground motion prediction equations by CB14 and I14 provide a good match with the recorded intensities within 40 km R_{jb} distances. As a result, no further calibration was needed.



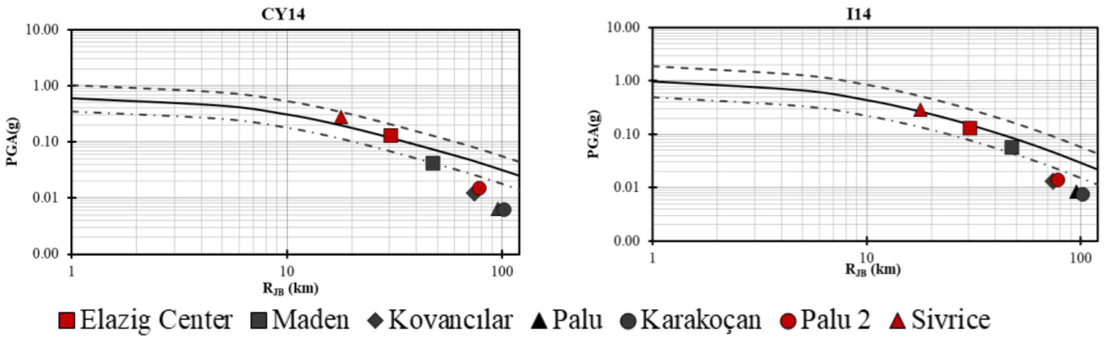


Figure 2. Comparison of the PGA values assessed by (a) ASK14, (b)CB14, (c)CY14 and (d)I14 at various distances to the PGA values observed at the SGM Stations for V_{S30} = 407

3.3. The Construction of the Idealized Shear Wave Velocity Profile

The shear wave velocity profile is a critical parameter in site response analyses. The Elazig-Center (2301) profile, with a depth of 32 meters and a shear wave velocity of 715 m/s, was used as the primary profile. Deeper profiles were identified through a literature review, and nearby profiles, such as Sivrice (2308) and Palu (2305), were incorporated to construct an idealized shear wave velocity profile extending to 145.5 meters, reaching to a shear wave velocity of 3377 m/s, where bedrock is assumed.

3.4 Performing Site Response Analysis

With an idealized shear wave velocity profile and representative soil profiles established, the equivalent linear site-specific seismic response analysis was conducted. The recorded outcrop time history at the Elazig Center (2301) was first deconvolved to bedrock motion, scaled for each borehole, and then deconvolved to obtain outcrop motion. The analysis results, including Acceleration Time History and spectral plots for selected boreholes, are presented. For demonstration purposes, the results obtained from some boreholes are represented in Figures 3 and Figure 4.

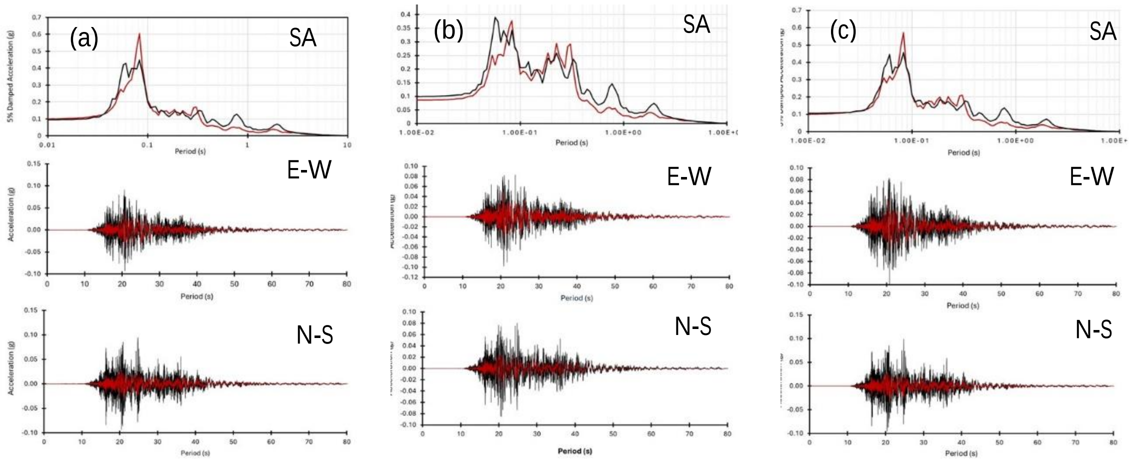


Figure 3. The Spectral, E-W component and N-S components plots of the acceleration time history of (a)SK-30, (b)SK-150 and (c)SK-210 boreholes.

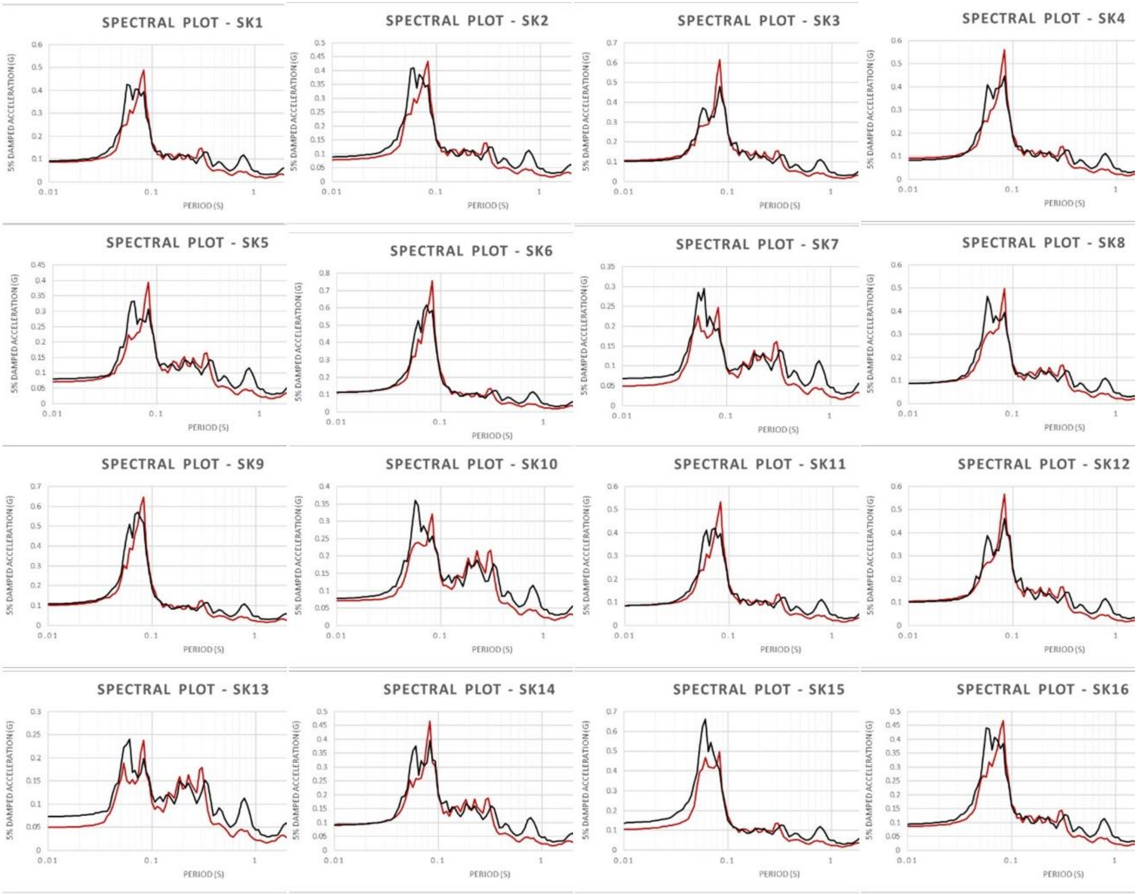


Figure 4. *Spectral Acceleration SA charts of SK-1 to SK-15 (5% Damped acceleration (g) vs. Period (s))*

4. ZONATION OF THE STUDY REGION

Seismic zonation models "also known as seismic hazard risk models," have been developed, in this section, utilizing raster computing methods, using the ArcGIS software tool, to provide information on locations of considerable ground motion danger during an earthquake in the center of Elazig. This section will include the seismic zonation maps prepared for the peak ground acceleration PGA, Spectral acceleration Sa at different periods.

4.1. Peak Ground Acceleration Maps

After conducting site-specific seismic response analyses, one of the most significant outputs one may get is the peak ground acceleration PGA.

To help envision how the PGA values are distributed over the study area and better understand the region's seismicity, seismic zonation maps are prepared using the ArcGIS software tool. Their main maps are prepared.

- Scatter discrete PGA and amplification maps where the real output values obtained from the site response analyses were plotted on the geological settings Elazig-Center.

- Zonation maps for the PGA values and PGA amplifications were generated using kriging interpolation and adopting the Exponential Semi-variogram model.

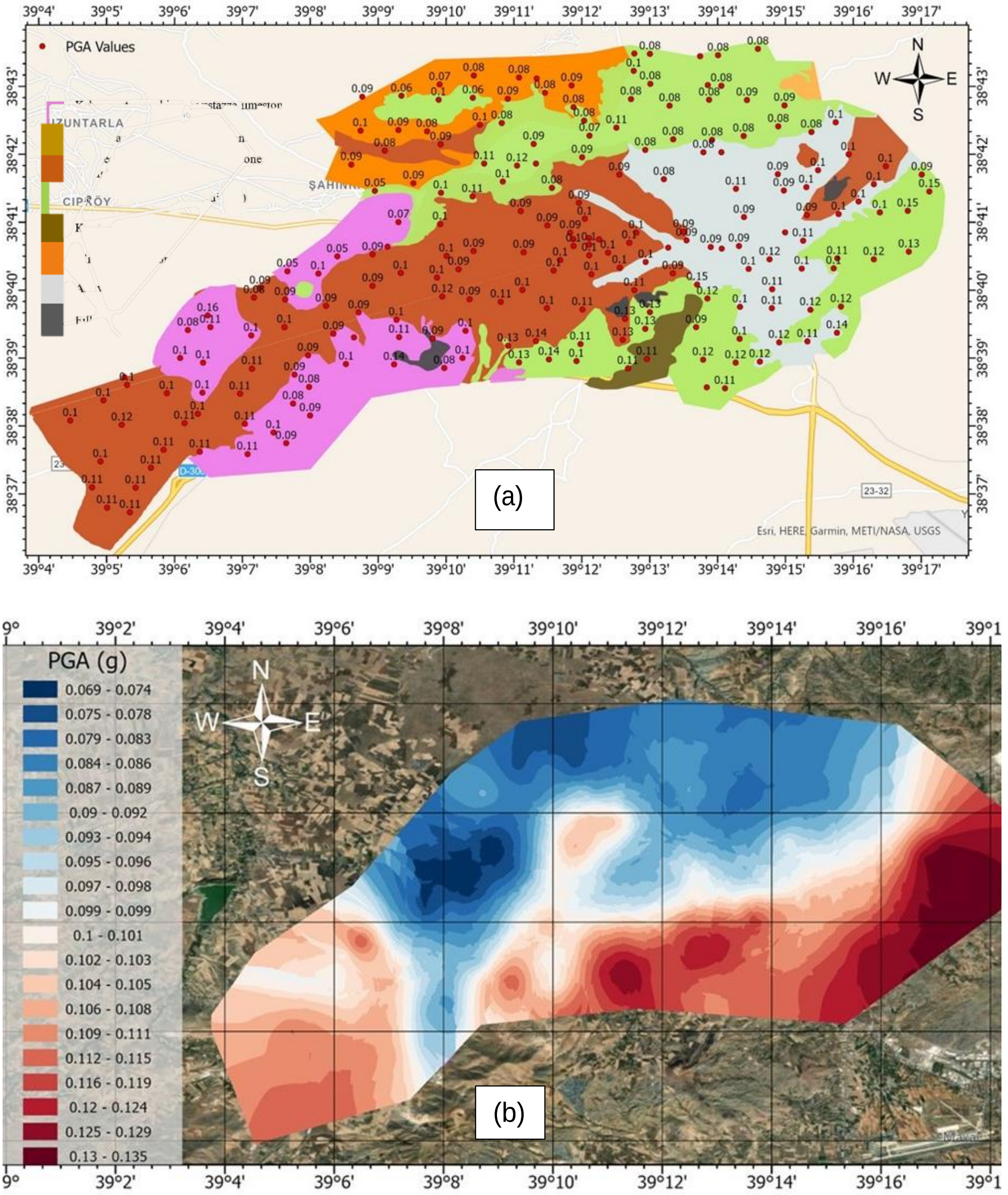
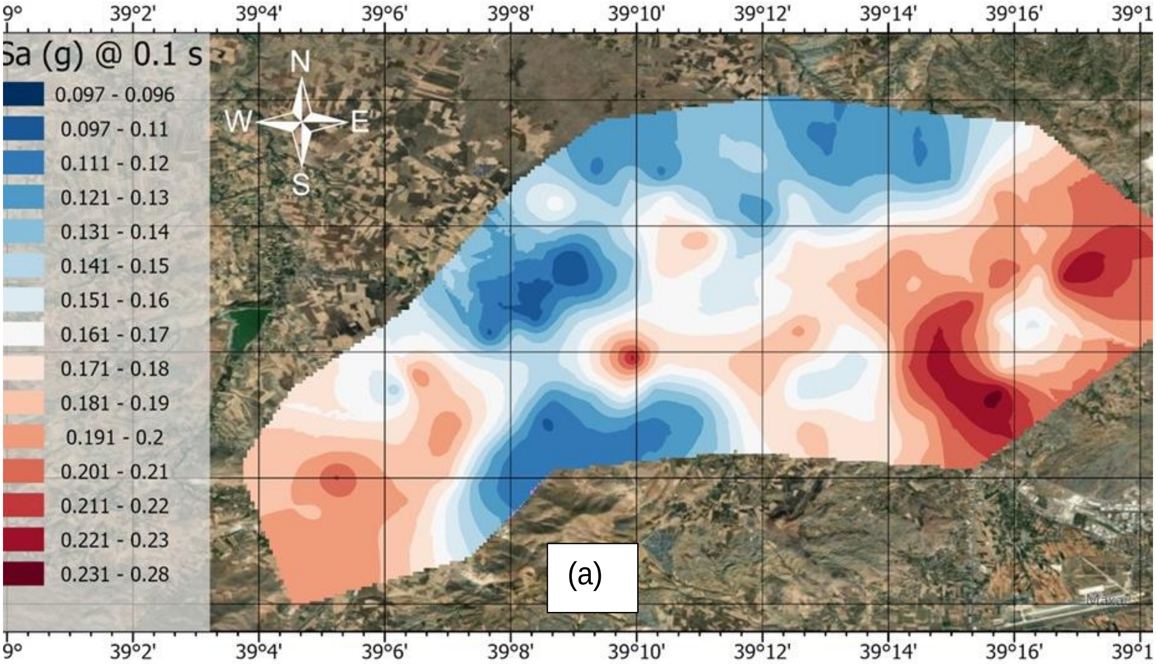


Figure 5. (a) *Discrete PGA values plotted on the geological Map of Elazig-Center (b) PGA (g) zonation map*

4.2. Spectral Acceleration Maps

A building's ability to withstand shaking at its foundation relies, of course, on the quality of the structure. However, It is crucial to keep in mind that the building's height is a major consideration. In other words, the frequency at which it naturally tends to vibrate is its fundamental period or natural frequency. When the natural frequency of the ground motion corresponds with the structure's natural frequency, buildings have a high likelihood of achieving (partial) resonance. Resonance increases the swing of the structure, and if the period of amplification is long enough, amplification of ground motion might result in damage or destruction.

As a result, determining the spectral acceleration or the seismic amplification at various frequencies or periods is critical. The Sa values are determined in previous sections, conducting site response analyses at various locations. To provide a big picture of the situation, Sa zonation maps are provided (for T=0.1 s, T=0.2 s, T=0.3 s), higher periods did not show high Sa values, so they were excluded, a more detailed study is conducted by Elsaid (2022). Figure 6 shows zonation maps drawn for spectral acceleration plots generated using kriging interpolation methodology.



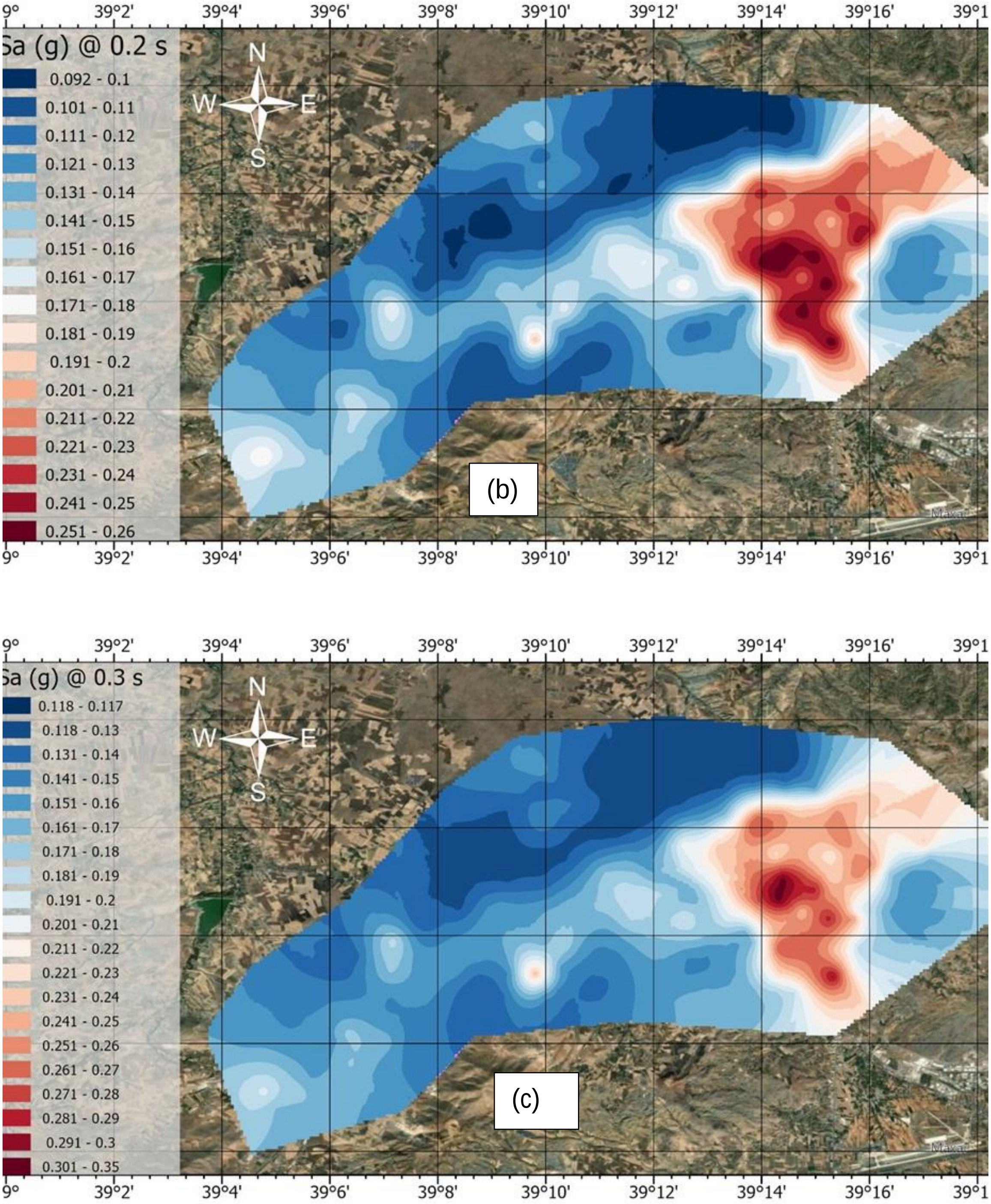


Figure 6. *Spectral acceleration Sa (g) zonation map of Elazig-Center at Period* (a)*T=0.1 s*, (b) *T=0.2 s*, (c) *T=0.3 s.*

5. DISCUSTION AND CONCLUSION

Seismic evaluations in this study focused on two primary aspects: site response analysis using the equivalent linear technique and the subsequent creation of zonation maps. The analyses revealed significant variability in Elazig-Center's seismic response, with Peak Ground Acceleration (PGA) values ranging from 0.0244 g at SK-62 to 0.175 g at SK-35. Excluding outliers, the highest average PGA values (0.136 g to 0.144 g) were observed in the east-south region, specifically between Sugözü and Çatal Çesme, an area largely non-residential. Another zone of elevated PGA (0.128 g to 0.135 g) was identified south of Elazig-Center, near Sürsürü and Olgunlar.

Zonation maps further subdivide Elazig-Center into three distinct areas: *Zone 1* in the southeast with the highest PGA values (0.30 g to 0.35 g), followed by intermediate values in the southwest and east (*Zone 2*), and the lowest values in the northern belt as illustrated in Figure 7. These findings highlight the varying seismic risks within Elazig-Center, providing essential data for future urban planning and mitigation efforts.

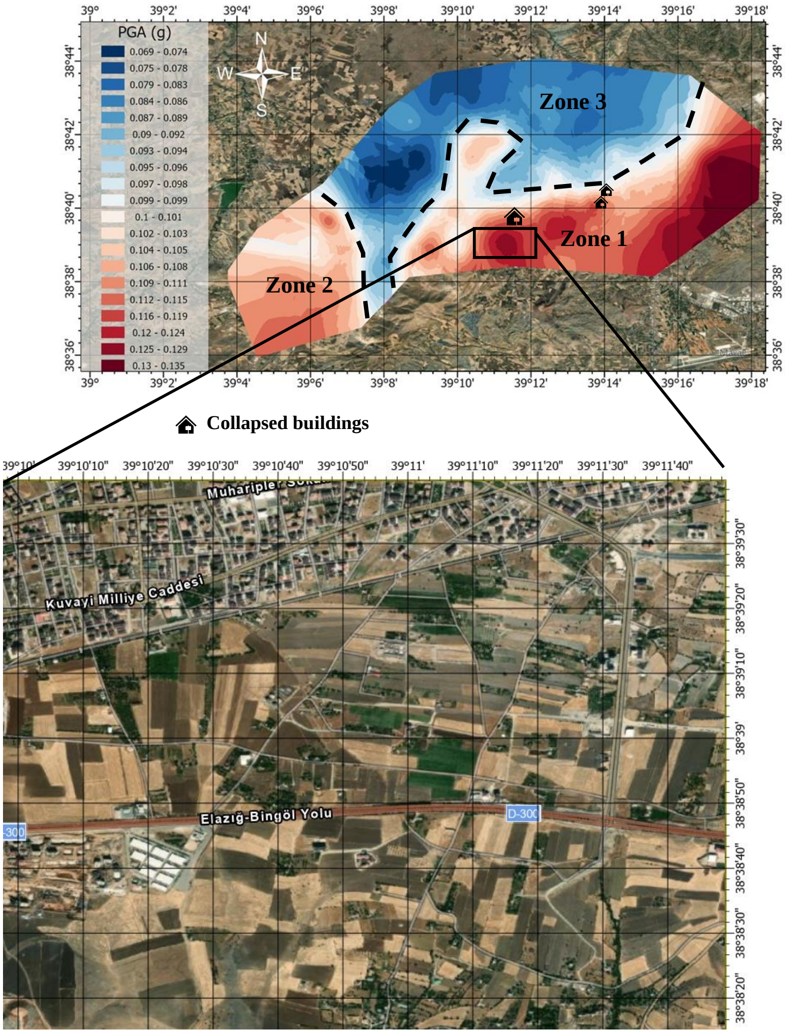


Figure 7. subdividing Elazig-Center into three zones according to PGA zonation maps.

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