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INTENSITY AND DURATIONAL CHARACTERISTICS OF SEISMOGRAMS RECORDED DURING THE FEBRUARY 6, 2023, M7.8 TÜRKİYE KAHRAMANMARAŞ PAZARCIK EARTHQUAKE

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ABSTRACT

The seismograms recorded at a total of 71 strong ground motion stations located within 100 km of the fault rupture were used to investigate the intensity and durational variability observed during the February 6, 2023, M7.8 Türkiye-Kahramanmaraş-Pazarcık earthquake. More specifically, the recorded intensity levels were compared with the ones predicted by the three ground motion models of the 2014 NGA WEST-2 Ground Motion Prediction Equations (GMPEs) and by the Turkish earthquake design code (TEC, 2018). Moreover, the significant duration (D) and equivalent number of uniform stress cycles (N), estimated by using these accelerograms, were compared with the ones predicted by Tafreshi and Bora (2023) and Cetin et al. (2021) models, respectively. To facilitate the comparisons, residuals were estimated and presented with reference to the i) station codes, ii) distance and angular orientation of the SGMS relative to the fault, iii) site class, and iv) recorded intensity levels.

Keywords: *Duration, Intensity, GMPEs, Turkish Earthquake code, Kahramanmaraş earthquake, Pazarcık earthquake.*

1. INTRODUCTION

On February 6, 2023, two earthquakes, with moment magnitudes M7.8 and M7.6, occurred in southeastern Türkiye on the East Anatolian Fault Zone (EAFZ), at local times of 04:17 and 13:24, respectively. The epicenter of the first event, which has a focal depth of 8.6 km, is in Kahramanmaraş-Pazarcık. Kahramanmaraş-Pazarcık earthquake initiated approximately 20 km southeast of the main strand of the EAFZ along a splay fault (Narlı fault), which is oriented in the northeast-southwest direction (Melgar et al., 2023; Okuwaki et al., 2023, Petersen et al., 2023). The first objective of the manuscript is to comparatively assess the recorded spectral acceleration intensity levels with the ones i) predicted by three ground motion models from the 2014 NGA WEST-2 Ground Motion Prediction Equations (GMPEs): Abrahamson, Silva and Kamai (2014), (ASK); Campbell and Bozorgnia (2014), (CB); and Chiou & Youngs (2014), (CY); and ii) recommended by the Turkish earthquake design code (2019), (TEC) for return periods of 475 (DD2) and 2475 (DD1) years.

The second objective is to comparatively assess the variability in the duration of the seismograms recorded during the Kahramanmaraş-Pazarcık M7.8 event. For this purpose, two durational parameters, namely, significant durations (D5-95 and D5-75), and the equivalent number of stress cycles (N) are to be assessed.

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2. STRONG GROUND MOTION DATA

To start with, the seismograms from strong ground motion stations (SGMS) within 100 km of the rupture plane ($R_{rup} \leq 100$ km) were accessed from Turkish Disaster and Emergency Management Authority (AFAD) web portal, accessible at https://tadas.afad.gov.tr. The stations with seismograms that did not meet the data validity criteria were excluded. As a result, a total of 71 stations were included in the final database. 51 out of 71 stations have measured shear wave velocity (V_s) profiles to estimate the representative value for the upper 30 meters (i.e.: V_{s30}). The estimated V_{s30} values vary in a range of 210 m/s to 1380 m/s. The available V_s profiles are accessible at https://tadas.afad.gov.tr. For SGMS, where site specific shear wave velocity Vs profiles are not available, V_{s30} values are estimated based on local geological and geotechnical data, considering available topographical, morphological and water saturation information (Okay, 2022).

3. COMPARATIVE ASSESSMENT OF INTENSITY AND DURATION PARAMETERS DURING THE FEBRUARY 6, 2023, M7.8 TÜRKİYE KAHRAMANMARAŞ PAZARCIK EARTHQUAKE

In this section, the seismic intensity predictions by 2014 NGA WEST-2 Ground Motion Prediction Equations (GMPEs) by ASK, CB, and CY models are compared with the recorded PGA values. Similarly, the TEC basis intensities are comparatively presented. Moreover, the significant duration ($D_{5\text{-}95}$, $D_{5\text{-}75}$), and equivalent number of uniform stress cycle, N values were separately estimated for the seismograms recorded at the 71 strong ground motion stations. These duration parameters will be compared with the predictions by Tafreshi and Bora (2023) and Cetin et al. (2021). For both the Intensity and the duration parameters, the inter-event residuals are estimated for each ground motion station. These residuals are shown against Joyner-Boore distance (R_{jb}), V_{s30}, recorded PGA values, and the azimuth angle (θ), which is selected to represent rupture directivity and/or velocity effects. Consistent with Somerville et al. (1997) it should be noted that due to fault rupture planes reaching the ground surface, R_{rup} and R_{jb} values are the same.

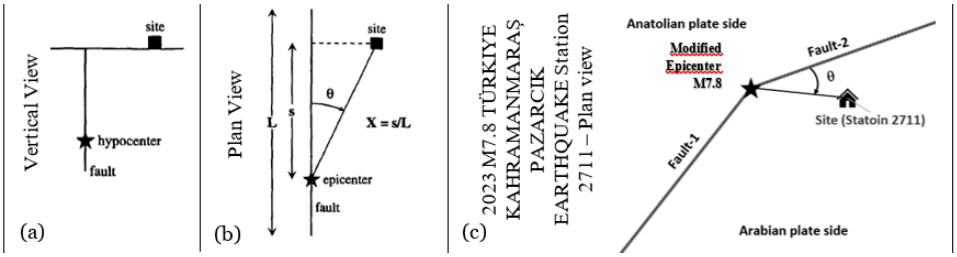

Figure 1. Rupture directivity parameters for a strike-slip fault (after Somerville et al., 1997)

3.1. Variability in PGA and Duration Residuals with Geographical Locations

In this section, the estimated residuals geographically grouped into city bins and presented in Table 1.

Table 1. A summary of mean ± σ residuals estimated for each city bin

Name	ASK	CB	CY	$D_{5\text{-}95}$	$D_{5\text{-}75}$	N
Şanlıurfa	-0.25 ± 0.44	-0.24 ± 0.42	-0.31 ± 0.44	0.49 ± 0.06	0.45 ± 0.11	-0.04 ± 0.54
Kahramanmaraş	-0.08 ± 0.39	-0.03 ± 0.39	-0.15 ± 0.39	0.36 ± 0.04	0.01 ± 0.05	-0.13 ± 0.33
Elazığ	-0.02 ± 0.50	0.00 ± 0.50	-0.15 ± 0.51	-0.26 ± 0.39	-0.52 ± 0.42	-0.69 ± 0.95
Malatya	0.70 ± 0.10	0.71 ± 0.19	0.66 ± 0.08	0.40 ± 0.38	0.55 ± 0.46	0.25 ± 0.72
Hatay	0.42 ± 0.62	0.48 ± 0.63	0.29 ± 0.62	-0.39 ± 0.51	-0.66 ± 0.84	-0.43 ± 0.58
Osmaniye	0.21 ± 0.96	0.23 ± 0.94	0.16 ± 0.95	0.49 ± 0.10	0.42 ± 0.15	-0.02 ± 0.37
Gaziantep	0.21 ± 0.31	0.27 ± 0.29	0.10 ± 0.29	0.22 ± 0.32	0.07 ± 0.32	-0.35 ± 0.44
Diyarbakır	0.07 ± 0.04	0.14 ± 0.05	-0.01 ± 0.01	0.31 ± 0.05	0.33 ± 0.14	0.32 ± 0.31
OVERALL	0.03 ± 0.31	0.13 ± 0.32	-0.04 ± 0.34	0.32 ± 0.01	-0.16 ± 0.22	-0.37 ± 0.78

Interpretation of Table 1 reveals in general that Şanlıurfa, Adana and Kahramanmaraş cities were shaken by PGA levels less intense than the levels predicted by GMPEs. In the overall, among others, CY model provided the least unbiased predictions, producing the lowest overall mean residual. The highest positive residual value is estimated for SGMS # 3135 in Hatay, where the most structural damage was concentrated. Moreover, cities of Hatay and Malatya were subjected to significant duration levels shorter than those predicted by the Tafreshi and Bora (2023) predictive model. In contrast, Kahramanmaraş, Adana, Osmaniye, Diyarbakır, and Elazığ cities experience slightly higher significant durations than the ones predicted.

Table 1 suggests that the stations located on the Arabian plate side of the fault rupture are shaken by longer durations than the ones on the Anatolian side. From equivalent number of uniform stress cycle, N-perspective, Kahramanmaraş and Diyarbakır show positive N residuals, indicating underpredicted N values. And the stations located on the Arabian plate side of the rupture were concluded to be subjected to a smaller number of stress cycles, when compared to ones situated on the Anatolian plate side. The highest positive N residual value is estimated for SGMS # 2703 in Gaziantep, a city that also endured significant damage.

3.2. Variability in PGA And Duration Residuals with V_{s30}

In this section, Table 2 presents a summary of the statistics of the residuals estimated for each V_{s30} bin. Residuals are grouped consistent with Turkish earthquake code-based soil site classifications scheme: ZB, ZC and ZD. It should be noted that TEC soil site classification scheme is identical with the one of NEHRP, and groups soil sites with 180 ≤ Vs30 < 360 , 360 ≤ Vs30< 760 , and 760 ≤ Vs30 < 1500 m/s with site class symbols of ZD, ZC and ZB, respectively. Interpretation of Table 2 reveals that the PGA and duration parameters were not significantly affected by site conditions. The scatter (i.e.: standard deviation) in residuals is observed to be higher in sites ZC for the PGA, ZC and ZB for duration parameter.

Table 2. A summary of mean ± σ residuals estimated separately for site class ZB, ZC and ZD. V_{s30} (m/s)

Predictive Model		$180 \le V_{s30} < 360$ ZD	$360 \le V_{s30} < 760$ ZC	$760 \le V_{s30} < 1500$ ZB
ASK		-0.24 ± 0.42	-0.31 ± 0.44	0.49 ± 0.06
CB		-0.03 ± 0.39	-0.15 ± 0.39	0.36 ± 0.04
CY		0.00 ± 0.50	-0.15 ± 0.51	-0.26 ± 0.39
Tafreshi and Bora (2023)	D_{5-95}	0.71 ± 0.19	0.66 ± 0.08	0.40 ± 0.38
	D_{5-75}	0.48 ± 0.63	0.29 ± 0.62	-0.39 ± 0.51
Cetin et al. (2021)		0.13 ± 0.32	-0.04 ± 0.34	0.32 ± 0.01

3.3. Variability in PGA And Duration Residuals with *Azimuth Angle, θ*

Figure 2 illustrates the dependency of the inter-event residuals on azimuth angle θ. An overall trend is evident across all GMPEs considered, wherein the residuals increase with decreasing θ angles. As the θ angle increases, the scatter in residuals also decreases. the weak trend of PGA residuals increasing with decreasing θ is preliminarily attributed to rupture shear effects (speculated as super shear) as opposed to the directivity ones. However, this conclusion is premature and deserves further in-depth assessments, which is not within the scope of our preliminary reconnaissance evaluations.

The D_{5-95} and D_{5-75} residuals increase as θ angle value increases. One can notice that at an azimuth angle of around 5°, residuals change sign. For the azimuth angles less than 5°, residuals are concluded to be negative, hence durations from recordings were overpredicted. Conversely, beyond 5°, the residuals are positive, indicating an underpredicted significant duration values. This observation confirms the effects of directivity and/or rupture propagation velocity effects on the duration of the seismic shaking during the Kocaeli-Pazarcık event. An overall weaker trend is evident across N residuals, wherein the residuals for SGMSs located in the Arabian plate side increase with decreasing θ angles. In contrast, SGMSs located in the Anatolian plate side decrease with decreasing θ angles, with a relatively weaker trend.

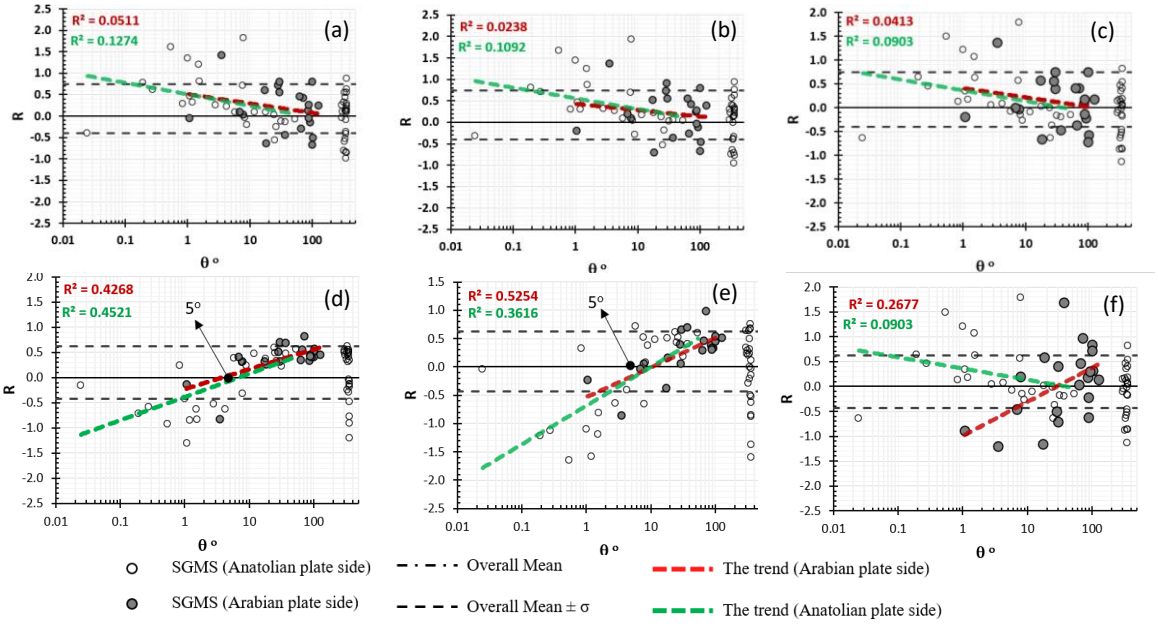

Figure 2. Inter-event PGA residuals for (a) ASK, (b) CB, and (c) CY, GMPEs and Inter-event duration residuals (d) $D_{5\text{-}95}$, (e) $D_{5\text{-}75}$, (f) and N, and their distribution with respect θ.

3.4. Variability in PGA And Duration Residuals with Distance to the Rupture Plane

In Figure 3, PGA and duration residuals are presented against R_{jb} (or R_{rup}).

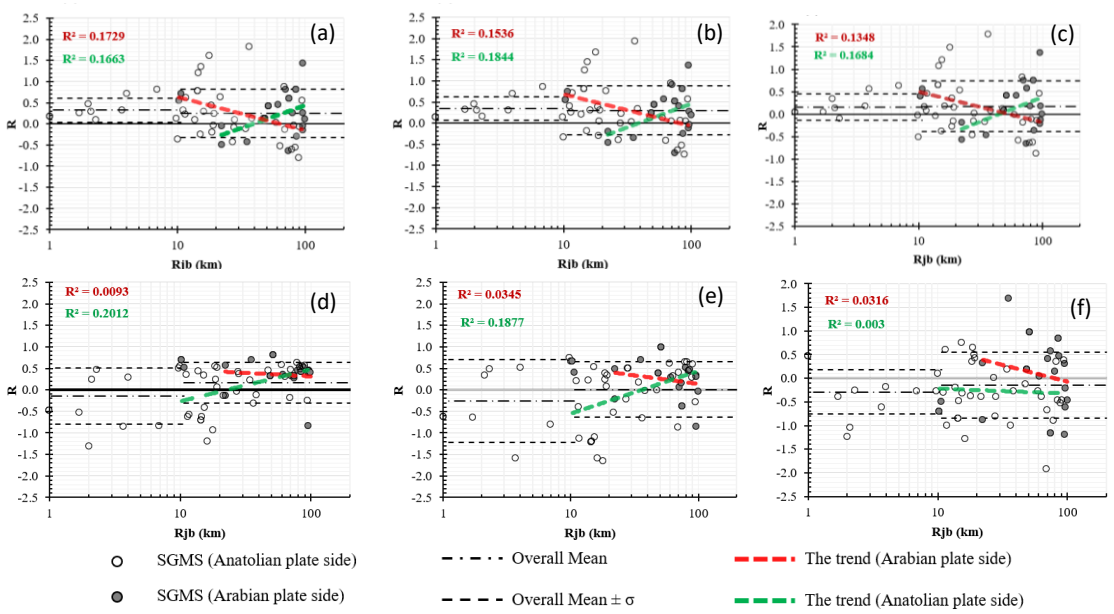

Figure 3. Inter-event PGA residuals for (a) ASK, (b) CB, and (c) CY, GMPEs and Inter-event duration residuals (d) $D_{5\text{-}95}$, (e) $D_{5\text{-}75}$, (f) and N, and their distribution with respect R_{jb} distances.

As revealed by Figure 3, in the overall, PGA residuals are observed to slightly increase with increasing R_{rup}, more pronounced for the residuals estimated by CY-GMPE. The trend lines suggest that residuals increase with R_{rup} for the stations located on the Arabian side. Conversely, it decreases for the stations located on the Anatolian plate side. The differences in estimated residual trends address the importance of path effects on the recorded PGA intensity levels.

Moreover, the overall, duration residuals are observed to increase slightly with increasing R_{rup}, more pronounced for the significant duration parameters. For significant duration residuals, the trends suggest that residuals decrease with R_{jb} for the stations located on the Arabian side. Conversely, it increases for the stations located on the Anatolian plate side. Hence for the stations on the Arabian plate side, significant duration decreases with increasing R_{jb}. From number of equivalent uniform stress cycle of view, N residuals show a decreasing trend with R_{jb}, more pronounced for the ones on the Arabian plate side. The differences in estimated residual trends exhibited by the recording from stations on the Arabian or Anatolian sides address the importance of path effects on the duration parameters.

3.5. Variability in PGA And Duration Residuals with PGA

Figure 4 presents the estimated residuals varying with the recorded PGA levels. On the same figure the linear and nonlinear trends are shown separately for the stations located on the Anatolian and Arabian plate sides of the rupture. Valid for all four GMPE models, residuals increase with increasing recorded PGA levels. In simpler terms, the employed three GMPEs overpredicted lower PGA levels and underpredicted the higher ones. The duration residuals decrease with increasing recorded PGA levels with a weaker trend for N values. In the overall, the duration of the shaking and its intensity levels are observed to inversely correlated. The residuals for the stations on the Anatolian plate side exhibited a more correlated residual trend with the recorded PGA intensity levels.

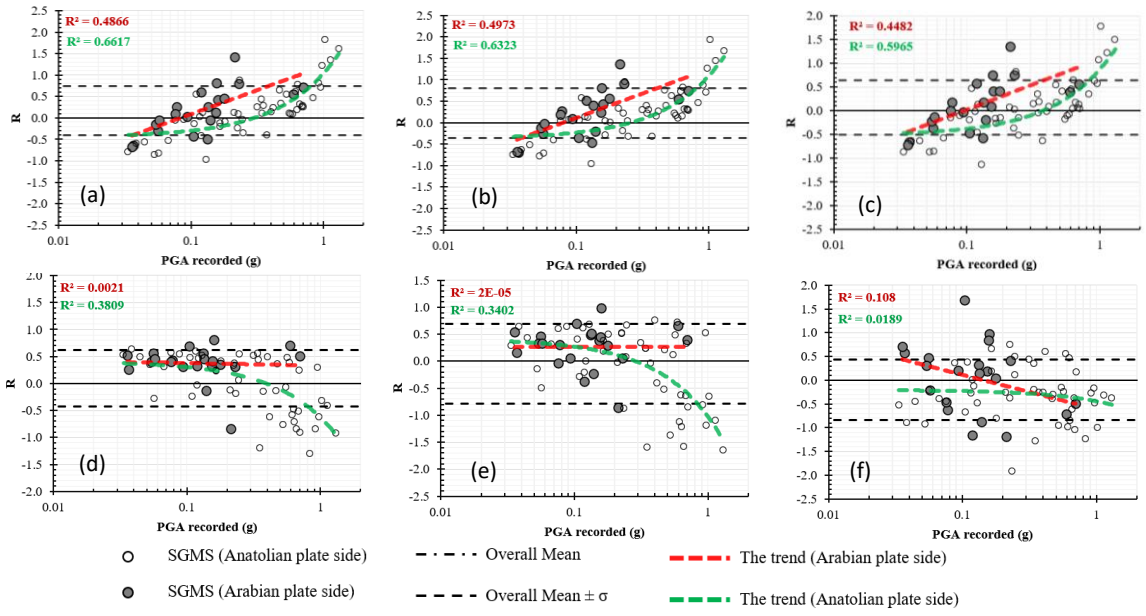

Figure 4. Inter-event PGA residuals for (a) ASK, (b) CB, and (c) CY, GMPEs and Inter-event duration residuals (d) $D_{5\text{-}95}$, (e) $D_{5\text{-}75}$, (f) and N, and their distribution with respect PGA.

3.6. Comparisons of the Recorded vs. PGA and SA Levels Recommended By Turkish Earthquake Code

Consistent with the Turkish Earthquake Design Code (TEC), the PGA and S_A values were assessed for the design scenarios of DD-1 and DD-2, which correspond to the return periods of 2475 and 475 years, respectively. These values are compared with the recorded seismic demand levels at SGMS sites. The results, as presented in Figure 5 reveal that the Turkish earthquake code DD-1 and DD-2 PGA levels were exceeded at 5 and 22, out of 71 stations, respectively. The stations where the seismic PGA demand was exceeded, are class ZC or softer sites. PGA levels for the DD-1 seismic scenario were exceeded at SGMS # 3135, 3125, 3129, 3126, and 3141, which are all located in the city of Hatay. On the basis of the residual trends provided in Figure 5, structures with spectral periods of 0.7 s and longer, were subjected to approximately 20 to 30 % higher seismic demands than the ones defined by TEC for the DD-2 design basis scenario. This conclusion is also in conformance with the concentrated structural damage in residential buildings with number of stories higher than 5 to 7 (Çetin et al., 2023a; Çetin and Ilgaç, 2023).

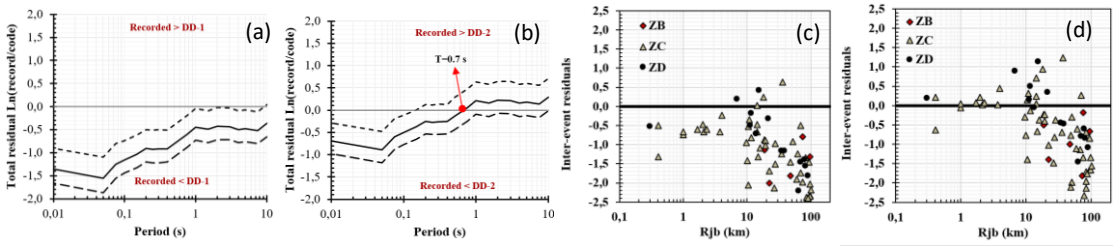

Figure 5. Inter-event residuals estimated for (a) S_A -TEC DD-1, (b) S_A -TEC DD-2, (c) PGA - TEC DD-1 and (b) PGA -TEC DD-2 seismic scenario levels. The dashed lines in each plot show mean ± σ limits.

4. SUMMARY AND CONCLUSIONS

This manuscript presents the findings of preliminary evaluations during the February 6, 2023, Türkiye-Kahramanmaraş-Pazarcık earthquake (M7.8), which aim to comparatively assess the recorded intensity levels with the ones i) predicted by three ground motion models from the 2014 NGA WEST-2 Ground Motion Prediction Equations (GMPEs): Abrahamson & Silva & Kamai (ASK), Campbell & Bozorgnia (CB), and Chiou & Youngs (CY), and ii) recommended by the Turkish earthquake design code (TEC) for return periods of 475 and 2475 years. And the durational parameters, more specifically, the significant duration and equivalent number of uniform stress cycles estimated from accelerograms recorded with the ones predicted by Tafreshi and Bora (2023) and Cetin et al. (2021), respectively.

For the intensity parameters, The overall mean $\pm$ σ residuals for the stations located on the Anatolian and Arabian plate sides of the fault rupture plane are estimated as 0.04 ± 0.63 and 0.16 ± 0.54, respectively. Hence, stations located on the Arabian plate side of the rupture demonstrate more pronounced underpredicted inter-event residuals when compared to those situated on the Anatolian plate side. The highest positive residual value is estimated for SGMS # 3135, in Hatay, where the most structural damage was concentrated. The PGA residuals increase with R_{jb} for the stations located on the Arabian side. Conversely, residuals decrease for the stations located on the Anatolian plate side. In the overall PGA residuals are observed to increase slightly with increasing rupture distances. The scatter (i.e.: standard deviation) in residuals is observed to be the highest for site class ZC. Valid for all three GMPE models, the PGA residuals increase with increasing recorded PGA levels. The dependency of the inter-event residuals on azimuth angle, θ was also assessed and the residuals increase with lower θ angles, and as the θangle increases, the residual PGAs decrease, and the scatter is reduced.

The PGA values were assessed for the TEC seismic scenarios of DD-1 and DD-2. DD-1 and DD-2 PGA levels were exceeded at 5 and 22 out of 71 stations, respectively. The stations where the seismic PGA demand was exceeded are all site class ZC or softer sites. PGA levels for the DD-1 seismic scenario were exceeded at stations 3135, 3125, 3129, 3126, and 3141, which are in all located in the city of Hatay. The extensive structural damage levels witnessed in these cities can be partially attributed to high levels of seismic intensities exceeding the ones defined by TEC DD-2.

Additionally, the structures with spectral periods of 0.7 seconds and longer were subjected to approximately 20 to 30 % higher seismic demands than the ones defined by TEC for the DD-2 design basis scenario. This conclusion is also in conformance with the concentrated structural damage in higher than 5 to 7 story residential buildings (Çetin et al., 2023a; Çetin and Ilgaç, 2023).

For Duration parameters, the overall mean $\pm$ σ residuals for the stations located on the Anatolian and Arabian plate sides of the fault rupture plane were estimated as -0.02 ± 0.54 and 0.37 ± 0.33, respectively. These significantly different mean residual values suggests that the stations located on the Arabian plate side of the fault rupture were shaken by longer durations than the ones on the Anatolian side. Duration residuals are observed to increase slightly with increasing R_{rup}. The scatter (i.e.: standard deviation) in residuals is observed to be higher in SGMS sites classified as ZC as compared to site classes ZB and ZD. Finally, a relatively stronger dependency of the inter-event duration residuals on azimuth angle θ is estimated. As azimuth angle θ increases, the significant duration residuals increase.

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