Bitlis Eren Üniversitesi Fen Bilimleri Dergisi
BİTLİS EREN UNIVERSITY JOURNAL OF SCIENCE
ISSN: 2147-3129/e-ISSN: 2147-3188
VOLUME: 12 NO: 4 PAGE: 1248-1260 YEAR: 2023
DOI:10.17798/bitlisfen.1376430

Evaluation of November 23, 2022, Duzce Earthquake data with Ground Motion Prediction Equations

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Keywords: GMPE, Gölyaka, Earthquake, Past-Earthquake Assessment, Attenuation Relationship.

Abstract
An earthquake with a magnitude of 5.9 Mw occurred in Düzce (Gölyaka) on November 23, 2022. A rupture occurred on the Karadere Segment, a section of the North Anatolian Fault zone. According to the investigations, an 8 km section that was not broken in the 1999 Gölcük Earthquake was broken by this earthquake and caused the earthquake. Station number 8105, one of the stations of the Disaster and Emergency Presidency, measured the maximum ground acceleration of the earthquake as 0.6 g. This value is above the peak ground acceleration (PGA) value taken from the hazard map of the region. This earthquake in the Marmara region attracts the attention of researchers both because it is close to the 1999 Gölcük Earthquake and because there is an earthquake expectation in Istanbul and its surroundings. Researchers create ground motion prediction equations to predict the effects of future earthquakes. This study, it is aimed to compare 5 ground motion equations developed for Türkiye. PGA data were collected and compared with the 5 ground motion prediction equation (GMPE, or attenuation relationship) employed from the stations taking measurements from the earthquake, and the compatibility of the earthquake with the 5 existing models was investigated. As a result of the study, it was determined that the GMPEs prepared using the data in the region where the earthquake occurred showed a higher fit among these GMPEs. In addition, it has been observed that low PGA values at stations farther from the epicenter of the earthquake fit better with the curves obtained from the GMPEs. The number of data sets in GMPEs and the study area increase the possibility of estimating earthquake parameters. The data set for AR4 GMPE used in the study and the fact that the region taken into consideration is the region where the earthquake occurred increased the data-model compatibility. It was concluded that existing GMPEs should be updated to predict future earthquakes and their effects better.

1. Introduction

Northwest Marmara is one of the first regions that come to mind when earthquakes are mentioned in Türkiye. Two major earthquakes that occurred in 1999 changed Türkiye's perspective on earthquakes [1]. On November 23, 2022, at 04.08 local time, an earthquake with a 5.9 Mw occurred in Düzce Gölyaka epicenter. According to Disaster and Emergency Management Presidency (DEMA) data, the depth of the earthquake was announced to be 6.8 km below the ground. The visual showing the epicenter of the earthquake is demonstrated in Figure 1 [2, 3].
Magnitude and depth information of different centers collecting earthquake-related information are presented in the table below (Table 1).

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Received: 15.10.2023, Accepted: 13.12.2023

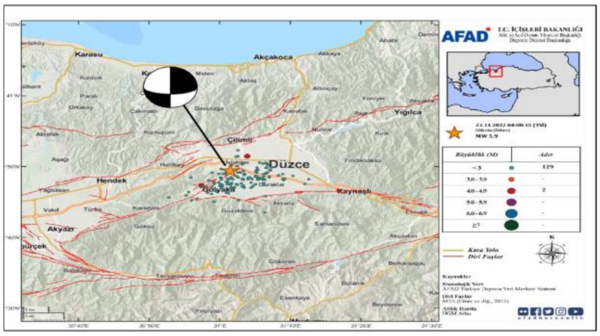

Figure 1. The epicenter of 5.9 M_w Gölyaka Earthquake [2, 3]

Table 1. Information for different centre [4].

Centre	Latitude	Longitude	Depth	Magnitude (M_w)
DEMA	40.823	31.025	6.81	5.9
KOERI	40.817	30.987	10.6	6.0
EMSC	40.820	30.990	11.0	6.1
USGS	40.836	30.983	10.0	6.1

DEMA: Disaster and Emergency Management Affairs

KOERI: Kandilli Observation Earthquake Research Institute

EMSC: European-Mediterranean Seismological Centre

USGS: United States Geological Survey

The earthquake occurred in the Karadere Segment [5], located on the North Anatolian Fault line, at the northeastern end of this segment. When the data obtained from the stations in the region were evaluated, the highest acceleration values were measured at station no. 8105. The acceleration measured by this station in the East-West direction is 0.60 g. The station is located in the center of Düzce. Turkey Earthquake Hazard Map [2 ,3] illustrates that the earthquake hazard of the region is clearly high. The map showing the earthquake hazard of the region is demonstrated in Figure 2. The PGA value from the Turkey Earthquake Hazard Map for the earthquake ground motion level at the point where the earthquake occurred is 0.593 g.

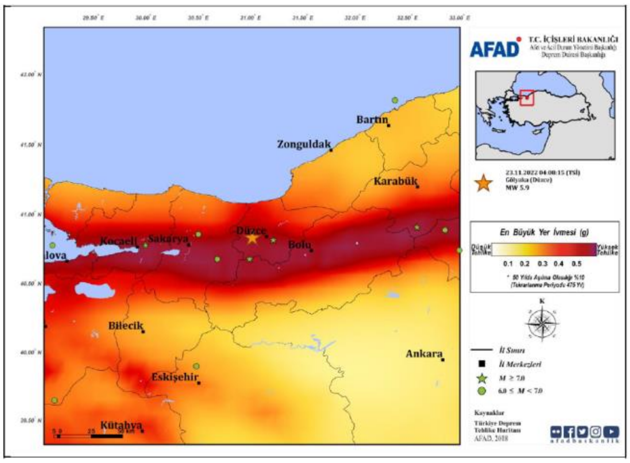

Figure 2. Seismicity of the study area [2, 3]

Post-earthquake studies are generally focused on evaluating earthquake-induced structural damage, examining earthquake records, evaluating ground properties, and comparing ground motion prediction equations [6-15]. In the literature, there is a study on the evaluation of ground motion prediction equations of the results of the 24 January 2020 Elazığ earthquake by Bayrak et al. [16]. In this study, microtremor measurements were taken in the field after the earthquake. With these measurements, shear wave velocity and damage index parameters were obtained by empirical relations. Ground motion prediction equations and earthquake acceleration values were scrutinized and the most compatible model was determined. Özalp et al. [17] conducted evaluations about the source fault. It was stated that no surface fracture was observed in the study, and structural damage occurred in buildings located in areas suitable for ground enlargement around the Karadere segment. It was stated that the earthquake occurred when an 8 km section, which was not broken during the 1999 Izmit earthquake broke. There are also reports containing field observations and evaluations regarding this earthquake [2-4]. Equations in the literature as GMPEs are utilized to estimate the earthquake parameters that earthquakes will create according to a certain magnitude and distance, starting from the epicenter of the earthquake [18]. These GMPEs vary depending on the fault where the earthquake occurred, the soil conditions of the region, and the measured magnitude of the earthquake. For this reason, GMPEs are equations that reflect a specific region. Obtaining local GMPEs is important to accurately reflect the study area. Additionally, new regional PGA attenuation equations for vertical ground motion and accompanying seismic micro-zoning maps for this purpose were developed by Bulajic [19]. Both seismicity and earthquake scenarios studies were performed for the region where the study was carried out [20, 21].

In this study, the GMPEs prepared by the researchers for Türkiye in general or a specific region were employed. The greatest ground acceleration values at the stations recorded in the Düzce (Gölyaka) earthquake, which were taken into account in the study, were investigated together with the GMPEs. The compatibility of these ground acceleration values with 5 different ground motion prediction equations was evaluated. The results are explained with their justifications.

The main purpose of this study is to obtain the shortcomings and differences of the currently used ground motion prediction equations by evaluating the post-earthquake measurement data together with the ground motion prediction equations. This study examines the behavior of different ground motion prediction equations on actual earthquake data.

2. Estimation of Ground Motions

Within the scope of the study, stations taking measurements for the Gölyaka-Düzce earthquake were evaluated. The figure below shows the distribution of stations taking measurements after the earthquake (Figure 3). When the records taken from these stations are evaluated, there is no information about ground properties at some stations. For this reason, stations with existing ground information were selected and taken into account in the study. Records were taken from a total of 68 stations with available ground information. Information about the records is shown in Table 2 below. Table 2 includes the station code, latitude, longitude, acceleration values measured in 3 directions, Rjb distance, shear wave velocities and soil classification according to the soil classification presented in the Turkish Building Earthquake Code [22].

Table 2. Information about the records.

NO	Code	Longitude	Latitude	PGA_NS (g)	PGA_EW (g)	PGA_UD (g)	R_{jb} (km)	V_{s30} m/s	Site Class.	Site Class.-2
1	8109	31.0144	40.7810	0.27	0.36	0.24	5.94	183	C	Soft Soil
2	8106	31.1124	40.7671	0.35	0.38	0.23	12.87	338	C	Soft Soil
3	8101	31.1489	40.8436	0.30	0.31	0.26	14.01	282	C	Soft Soil
4	8102	31.1644	40.8342	0.22	0.42	0.25	14.98	280	C	Soft Soil
5	8104	31.1804	40.8611	0.36	0.37	0.23	17.17	395	B	Soil
6	8105	31.1520	40.9028	0.59	0.60	0.22	17.45	914	A	Rock
7	8108	31.2300	40.8613	0.11	0.12	0.07	21.10	487	B	Soil
8	1407	31.0028	40.5818	0.14	0.10	0.07	29.35	273	C	Soft Soil
9	8110	31.1428	41.0900	0.11	0.16	0.07	34.29	407	B	Soil

10	5406	30.6225	40.6703	0.074	0.073	0.03	41.45	272	UNKNOWN	Soft Soil
11	1403	30.7898	40.3984	0.05	0.07	0.02	54.33	472	B	Soil
12	1411	31.6175	40.6846	0.10	0.14	0.05	55.78	229	C	Soft Soil
13	5401	30.3801	40.7371	0.011	0.012	0.01	58.50	412	UNKNOWN	Soil
14	5403	30.2700	40.6908	0.02	0.03	0.01	68.56	215	C	Soft Soil
15	5404	30.2932	40.5191	0.08	0.06	0.04	73.91	381	B	Soil
16	4129	30.1122	40.7175	0.026	0.032	0.01	81.14	203	C	Soft Soil
17	4110	30.1525	41.0691	0.0073	0.0071	0.00	81.75	308	UNKNOWN	Soft Soil
18	4120	30.0274	40.7676	0.00014	0.00011	0.00	87.67	214	C	Soft Soil
19	4103	30.0250	40.7858	0.0129	0.0101	0.00	87.75	1013	A	Rock
20	4122	30.0263	40.7483	0.0166	0.0141	0.01	87.93	303	C	Soft Soil
21	1410	32.0370	40.7711	0.0125	0.0129	0.01	88.93	338	C	Soft Soil
22	4117	30.0267	40.6699	0.0152	0.0132	0.01	89.13	282	C	Soft Soil
23	1409	32.0638	40.7174	0.0279	0.0276	0.02	91.83	362	B	Soil
24	1405	32.0760	40.9381	0.0123	0.0148	0.01	92.67	365	B	Soil
25	4104	29.9700	40.6804	0.0047	0.0046	0.00	93.62	770	B	Rock
26	4105	29.9694	40.6744	0.0278	0.0165	0.02	93.79	289	C	Soft Soil
27	4125	29.9172	40.7665	0.0063	0.0062	0.00	96.93	826	A	Rock
28	4126	29.9149	40.7625	0.0176	0.0150	0.01	97.16	188	C	Soft Soil
29	4127	29.9047	40.7609	0.0107	0.0109	0.01	98.02	215	C	Soft Soil
30	1402	32.2059	40.7925	0.0100	0.0098	0.00	102.98	445	B	Soil
31	4112	29.8400	40.7245	0.0158	0.0145	0.01	103.81	352	UNKNOWN	Soft Soil
32	0601	31.9170	40.1608	0.0150	0.0141	0.01	108.41	340	C	Soft Soil
33	1101	29.9774	40.1411	0.0043	0.0047	0.00	120.19	901	A	Rock
34	4111	29.5888	40.6844	0.0110	0.0116	0.01	125.36	300	UNKNOWN	Soft Soil
35	2602	30.4973	39.7893	0.0108	0.0070	0.01	126.39	328	C	Soft Soil
36	3410	29.6082	41.1719	0.0077	0.0095	0.01	128.62	587	B	Soil
37	7802	32.5322	40.9563	0.0089	0.0073	0.01	130.97	393	B	Soil
38	7712	29.5088	40.6929	0.0063	0.0074	0.00	131.94	280	C	Soft Soil
39	2606	30.4558	39.7487	0.00003	0.00002	0.00	131.92	348	C	Soft Soil
40	2607	30.1460	39.8175	0.0050	0.0064	0.00	137.74	265	C	Soft Soil
41	4130	29.3879	40.7545	0.0064	0.0082	0.00	141.51	484	B	Soil
42	7801	32.6237	41.2046	0.0095	0.0053	0.01	144.07	530	UNKNOWN	Soil
43	7711	29.3271	40.6594	0.0121	0.0098	0.01	147.60	199	C	Soft Soil
44	2608	31.1830	39.5197	0.0030	0.0021	0.00	147.44	480	B	Soil
45	3418	29.2755	40.8146	0.0036	0.0043	0.00	150.74	1182	A	Rock
46	7709	29.3060	40.5642	0.01685	0.01693	0.01	151.08	382	B	Soil
47	1631	29.2993	40.4941	0.0097	0.0101	0.00	153.40	410	B	Soil
48	7710	29.2668	40.5900	0.0079	0.0099	0.00	153.80	358	UNKNOWN	Soft Soil
49	7708	29.2473	40.6576	0.0124	0.0117	0.01	154.31	196	UNKNOWN	Soft Soil
50	1619	29.2907	40.4224	0.0184	0.0148	0.01	156.37	348	C	Soft Soil
51	1610	29.5088	40.0671	0.0201	0.0122	0.01	156.95	252	C	Soft Soil
52	1635	29.2587	40.4496	0.0045	0.0048	0.00	158.06	570	B	Soil
53	2609	30.6966	39.4463	0.0049	0.0033	0.00	158.25	407	B	Soil

54	1803	32.8834	40.8149	0.0055	0.0056	0.00	159.90	348	C	Soft Soil
55	3405	29.1567	40.9111	0.00330	0.00329	0.00	160.96	1862	B	Rock
56	7707	29.0788	40.6381	0.0130	0.0081	0.00	168.68	312	C	Soft Soil
57	1630	29.1221	40.3630	0.0153	0.0090	0.00	172.00	301	C	Soft Soil
58	3407	29.0095	41.0582	0.0069	0.0033	0.00	174.87	595	B	Soil
59	3411	28.9761	41.0119	0.0051	0.0034	0.00	177.01	323	C	Soft Soil
60	1620	29.1296	40.1824	0.0051	0.0042	0.00	178.86	459	B	Soil
61	3413	28.9482	41.0943	0.0030	0.0025	0.00	180.56	452	B	Soil
62	1627	29.0752	40.2257	0.0123	0.0141	0.00	181.14	249	C	Soft Soil
63	4307	30.0143	39.4053	0.0033	0.0035	0.00	182.80	438	B	Soil
64	1622	29.0527	40.1960	0.0056	0.0045	0.00	184.20	448	B	Soil
65	1618	28.9282	40.3510	0.0032	0.0041	0.00	188.04	314	C	Soft Soil
66	1621	28.9756	40.2269	0.0049	0.0046	0.00	188.91	396	B	Soil
67	7706	28.8266	40.5131	0.0065	0.0095	0.00	191.93	277	C	Soft Soil
68	3415	28.7585	41.0273	0.0096	0.0125	0.01	195.34	283	C	Soft Soil

In this study, apart from the code [22] soil classification, another classification has been made in Figure 2, which will be Rock, Soil and Soft Soil as presented in Table 1, to make a common soil classification among the GMPEs. Again, in this triple classification, shear wave velocities were taken into account. For rock soil, Vs≥760 m/s, for soil, 360≤Vs≤760 m/s, for soft soil, Vs≤360 m/s. Ground properties are divided in Table 3.

Table 3. Ground properties for records

Soil Type	Number of Records
Rock	7
Soil	24
Soft Soil	37
Total	68

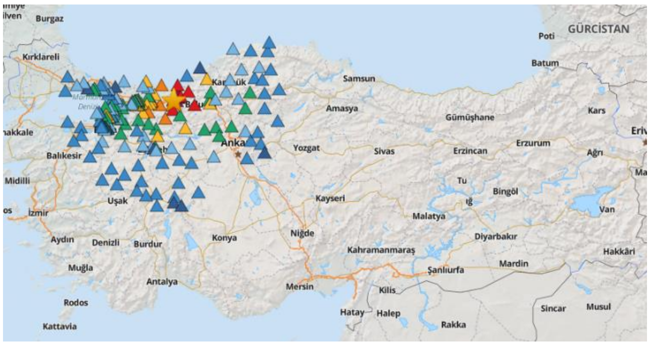

Figure 3. Distribution of stations

68 records to be used in the study were obtained from stations belonging to different soil classes. The distribution of earthquake records according to soil classes is presented in Table 3 above.

The highest acceleration values during the earthquake were measured at station no. 8105. An acceleration value of 0.60 g was obtained in the East-West direction. Acceleration time graphs for the 3 directions of the acceleration record are demonstrated in Figure 4. The PGA value for the location of station 8105 on the earthquake hazard map is 0.472 g. It appears that this value has been exceeded. This exceedance is also seen in the comparison of the spectra.

Ss and S1 values for the earthquake ground motion level, which has a 10% probability of being exceeded in 50 years as determined in the Turkish Building Earthquake Code [22], that is, a recurrence period of 475 years, were taken from the hazard map and the design spectrum for the DD-2 ground motion level was obtained. Since it is known that station no. 8105 is in the ZB soil class, the values obtained for the spectra were obtained for the ZB soil class. The response spectra of the East-West and North-South components for station 8105 are also presented in Figure 5. When looking at the comparison of these two spectra, the data of the station that measured the highest acceleration value during the earthquake shows that the regulation conditions were exceeded. It is seen that overshoot occurs especially in periods up to 0.5 s. This situation is expected to occur in low-rise buildings that suffer structural damage [17]. The data obtained from the Turkey Earthquake Hazard Map of station number 8105 is in Table 4.

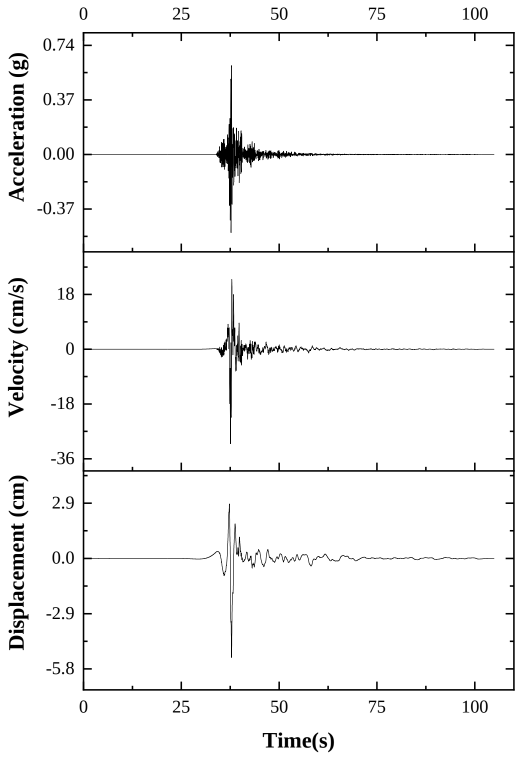

Figure 4. 8105 Stations Time Histories

3. Ground Motion Prediction Equations(GMPEs)

If accurate earthquake data is used, ground motion prediction equations can reflect the earthquake demand that may occur in a particular region. Attenuation relations are generally prepared for a specific region or city. They estimate earthquake parameters using magnitude and distance values as earthquake input. In general, the magnitude of the earthquake, the distance of the fault to the study area and the ground properties are the basic parameters of the GMPEs. These parameters may vary depending on the details of the study and the characteristics of the fault close to the study area. The most well-known GMPEs in the world are the GMPEs found in the NGA-West2 [24] project, which was prepared using the largest data set. Even though they are compatible with many regions of the world, the data sets are also regional in these equations. In Türkiye, there are ground motion prediction equations created regionally or for the entire country. The most well-known of these are the equations prepared by Özbey et al. [25], Kalkan&Gülkan [26, 27], Akkar et al. [28, 29]. For example, the ground motion prediction equations prepared by Özbey et al. are GMPEs prepared for North-West Marmara. In this attenuation relationship, 1999 Gölcük earthquake data were employed. The fault taken into consideration is the North Anatolian Fault. Within the scope of this study, 5 ground motion prediction equations prepared for the country and regionally were evaluated. Below, the equations of the decay relations and the explanation of the parameters are given respectively. Attenuation relations are named "AR" in this study, as well as the names of the authors.

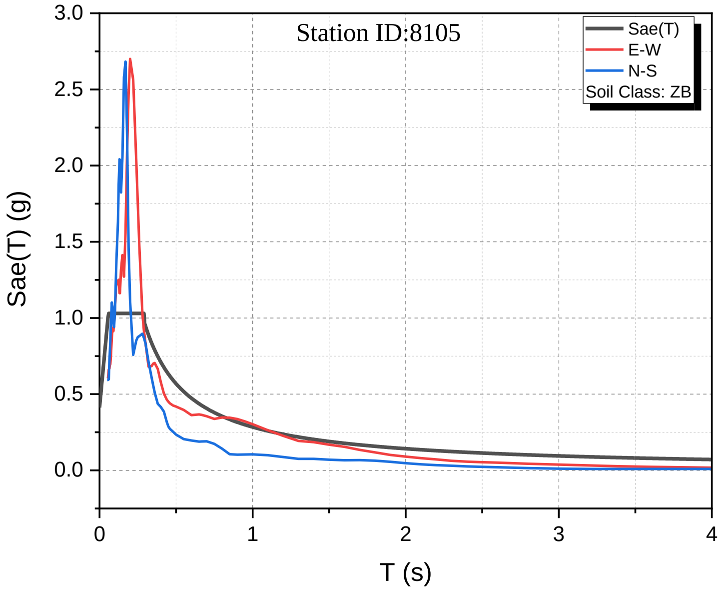

Figure 5. Comparison of Response and Design Spectra

Table 4. Parameter obtained from hazard map [23]

Latitude, Longitude	40.90278-31.15198
Station ID	8105 DEMA
Soil Class	ZB
S_s (Short period map spectral acceleration coefficient)	1.145
S_1 (Map spectral acceleration coefficient for a period of 1.0 seconds)	0.316
PGA (Peak ground acceleration (g))	0.472
PGV (Peak Ground Velocity (g))	29.291
F_s (Local ground impact coefficient for the short-period region)	0.900
F_1 (Local ground impact coefficient for a period of 1.0 seconds)	0.800
S_{DS} (Short-period design spectral acceleration coefficient)	1.030
S_{D1} (Design spectral acceleration coefficient for a period of 1.0 seconds)	0.253

3.1. AR1 (Özbey et al., 2004)

In the article titled an empirical GMPEs for Northwestern Türkiye ground motion using a random effects approach [25], researchers developed an GMPEs for Northwest Marmara. Analyzes were carried out using 195 different ground motion records of 17 earthquakes in the GMPEs prepared using Kocaeli and Düzce Earthquake data (Equation 1).

$$\log(Y_{ij}) = a + b(M_i - 6) + c(M_i - 6)^2 + d\log\sqrt{R_{ij}^2 + h^2} + eG_1 + fG_2 \quad (1)$$

G1 and G2 coefficients in the equation; It takes the values G1=0 and G2=0 for local soil classes A and B, G1=1 and G2=0 for local soil class C, and G1=0 and G2=1 for soil class D. The regression coefficients of the study are in Table 5. The soil classifications defined in the study are presented in Table 6. 4 different soil classes are grouped according to shear wave velocities.

3.2. AR2 (Kalkan and Gülkan, 2004)

In their study titled Site-Dependent Spectra Derived from Ground Motion Records in Türkiye [27], Kalkan and Gülkan developed this model by using 112 strong ground motion records of 57 earthquakes that occurred between 1976 and 2003. The ground motion prediction equation in the study is located below (Equation 2).

$$\ln Y = b_1 + b_2(M-6) + b_3(M-6)^2 + b_5 \ln r + b_v \ln(V_S/V_A)$$
$$r = \left(r_{cl}^2 + h^2\right)^{\frac{1}{2}} \quad (2)$$

The regression coefficients used in the study are presented in Table 7. We divided soil groups for recording stations in Türkiye into three categories: rock (with average Vs=700 m/sec), soil (Vs=400 m/sec), and soft soil (Vs=200 m/sec).

3.3. AR3 (Akkar and Çağnan, 2010)

In the study titled A Local Ground-Motion Predictive Model for Türkiye, and Its Comparison with Other Regional and Global Ground-Motion Models [28], a model for Türkiye in general was obtained. The results were compared with other GMPEs for Türkiye and equations valid worldwide. Italian and Türkiye data sets were utilized. The resulting equation is given below (Equation 3). The constant c1 is the reference magnitude.

$M \leq c_1$

$$\ln(Y) = a_1 + a_2(M - c_1) + a_4(8.5 - M)^2 + [a_5 + a_6(M - c_1)]\ln\sqrt{R_{jb}^2 + a_7^2} + a_8F_N + a_9F_R$$

$M \geq c_1$

$$\ln(Y) = a_1 + a_3(M - c_1) + a_4(8.5 - M)^2\ [a_5 + a_6(M - c_1)]\ln\sqrt{R_{jb}^2 + a_7^2} + a_8F_N + a_9F_R \quad (3)$$

The regression coefficients in the study are presented in Table 8.

3.4. AR4 (Ulutaş et al., 2010)

An GMPE based on Turkish strong motion data and iso-acceleration map of Türkiye [30]. The curve that

Ulutaş et al. used the 5.8 Mw earthquake data set and obtained with this data set is given in Figure 8.

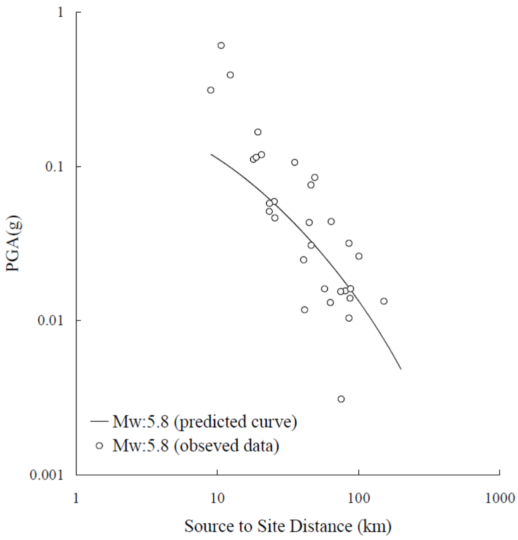

Figure 6. Proposed new GMPE plotted along with the 5.8 M_w data set for the study [25]

The ground motion prediction equation created in the study is given in Equation 4.

$$\log(PGV) = -2.12833 + 1.21448M - 0.08137M^2 - (2.46942 - 0.22349M)log\sqrt{R_{jb}^2 + 6.41443^2} + 0.20354S_S + 0.08484S_A - 0.05856F_N + 0.01305F_R \quad (4)$$

The regression coefficients in the study are in Table 9. In this study, therefore, three site conditions, namely rock, soil and soft soil sites, were considered.

3.5. AR5 (Akkar and Bommer, 2010)

Akkar and Bommer [29] developed the following Equation 5 for the Mediterranean, Europe and Middle East regions. It is stated that it is suitable for use in Türkiye.

$$\log(PSA) = b_1 + b_2M + b_3M^2 + (b_4 + b_5M)log\sqrt{R_{jb}^2 + b_6^2} + b_7S_S + b_8S_A + b_9F_N + b_{10}F_R + \epsilon\sigma \quad (5)$$

where SS and SA take the value of 1 for soft (Vs30 < 360 m/s) and stiff soil sites, otherwise zero, rock sites being defined as having Vs30 > 750 m/s.

Table 5. Regression coefficients [25]

Period(s)	a	b	c	d	h	e	f	$\sigma_{log(Y)}$
PGA	3.287	0.503	-0.079	-1.1177	14.82	0.141	0.331	0.260

Table 6. Definition of site classes in the attenuation models [25]

Site Class	Shear wave velocity
A	>750 m/s
B	360-750 m/s
C	180-360 m/s
D	<180 m/s

Table 7. Regression coefficients [27]

Period(s)	b_1	b_2	b_3	b_5	b_V	V_A	h(km)	σ_{lnY}
PGA	0.393	0.576	-0.107	-0.899	-0.200	1112	6.91	0.612

Table 8. Regression coefficients [23]

T(s)	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	σ*	τ*	σ_{Tot}*
PGA_{GM}	8.924	-0.513	-0.695	-0.185	-1.255	0.181	7.336	-0.021	0.018	0.652	0.516	0.832

Table 9. Coefficient of Regression

Period(s)	b1	b2	b3	b5	b_V	V_A	h	$\sigma_{ln(Y)}$
0(PGA)	-0.682	0.253	0.036	-0.562	-0.297	1381	4.48	0.562

5. Results

By using GMPEs and Gölyaka earthquake data in the previous part of the study, the harmony between GMPEs and real earthquake data was investigated in this section. Attention was paid to the limitations of GMPEs and the classification of ground properties.

Site conditions in the database reported from institutions are updated at different times based on new information and are constituted of three groups as rock,

soil, and soft soil thus GMPEs in this study employed different soil class assessments.
Figure 7-Figure 11 show that as the distance increases, a higher agreement is generally observed between GMPEs and earthquake data. As the distance gets closer, it is seen that the earthquake data remain above the data related to the GMPEs, that is, they take on higher values.

In the GMPEs that take into account different soil classes, it is seen that the lowest harmony between the curves and the data is in the graphs of rock soil. This is due to the low number of station data with rock soil characteristics.

In some GMPEs, soil classification is not considered. In this study, the AR3 attenuation relationship was prepared for rock soils. Therefore, the data used here are the data of all earthquake records. The reason why earthquake data is concentrated in some parts of the curves is that the PGA value corresponding to that region is obtained from more than one station.
It was determined that the highest harmony between curves and data between GMPEs for this study was observed in AR4. The GMPEs shows a certain harmony when the standard deviation is taken into consideration.

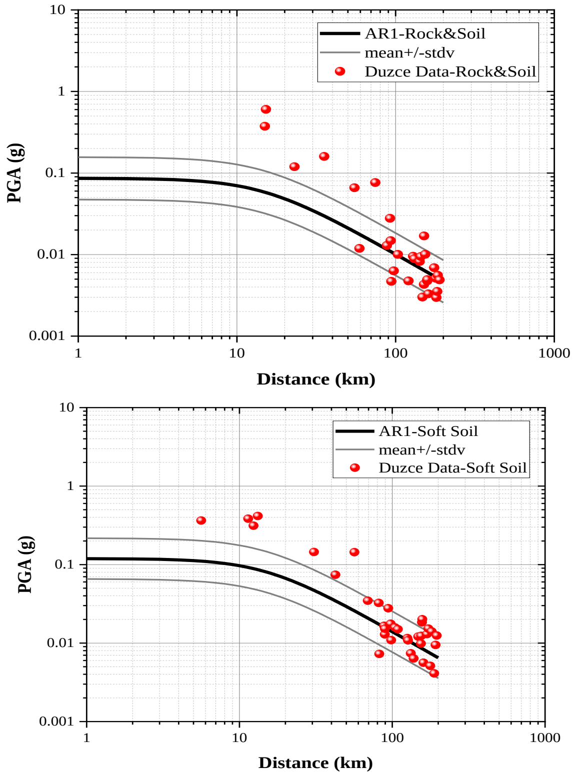

Figure 7. Comparison of AR1 and Gölyaka Earthquake's Data

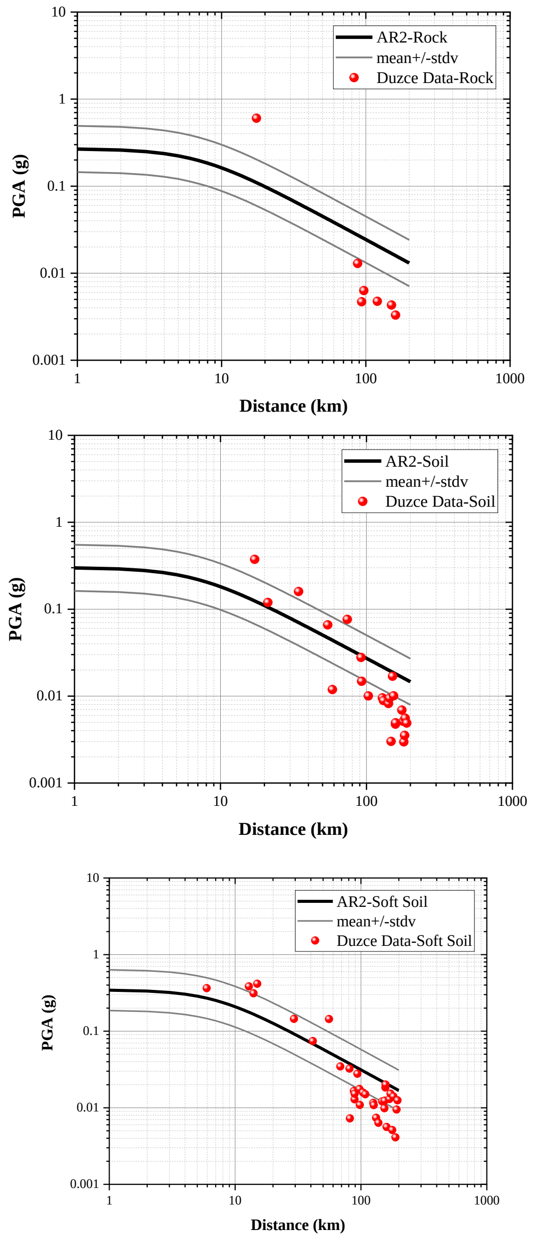

Figure 8. Comparison of AR2 and Gölyaka Earthquake's Data

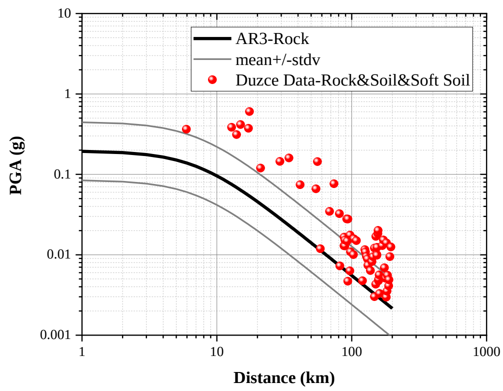

Figure 9. Comparison of AR3 and Gölyaka Earthquake's Data

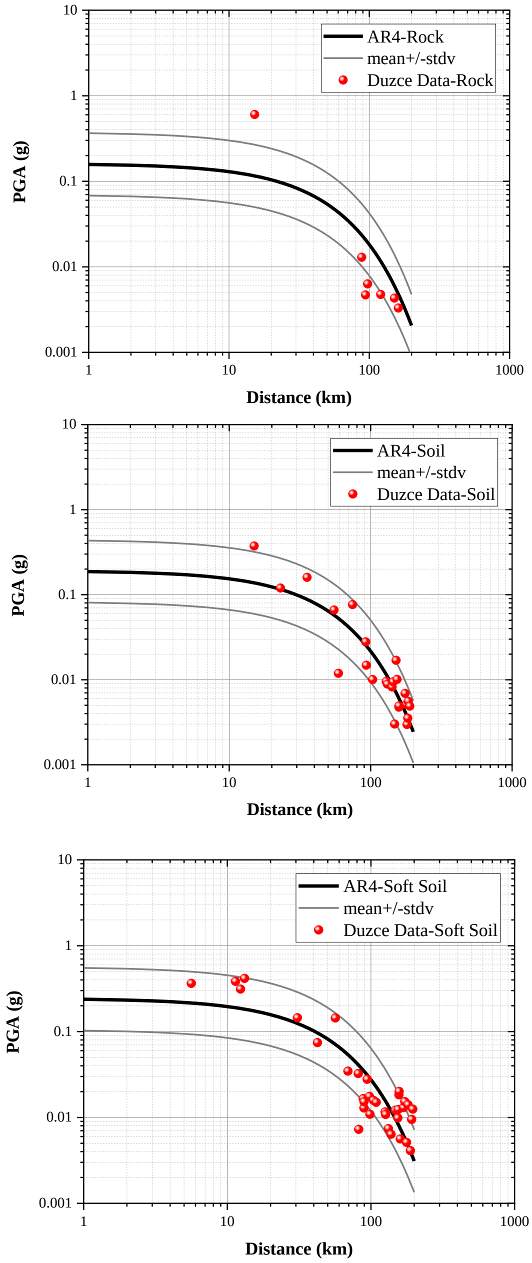

Figure 10. Comparison of AR4 and Gölyaka Earthquake's Data

In general, the compatibility of the 5 GMPEs with real earthquake data increases as the distance increases. It cannot be said that it predicts the PGA values measured more closely very well. It can be said that this is due to the small number of data by the decay relations. In addition, examining this harmony after earthquakes guide detailing the parameters in subsequent GMPEs The most important data that feeds the attenuation relations; are the measurement stations. The fact that these stations provide accurate information and are numerous increases the accuracy of the prepared prediction equations. The increasing station network in recent years will increase the accuracy of the GMPEs obtained in new studies.

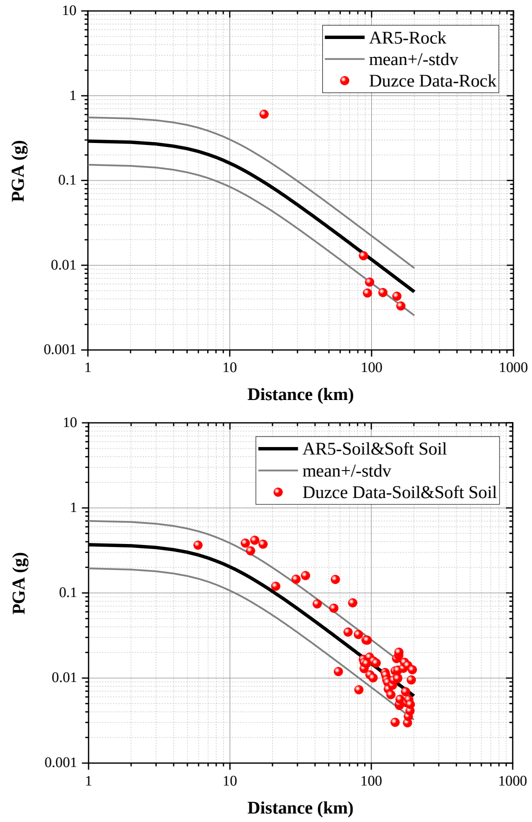

Figure 11. Comparison of AR5 and Gölyaka Earthquake's Data

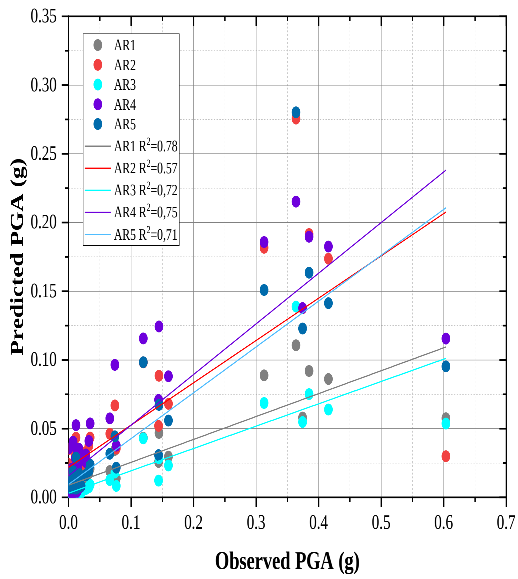

Figure 12. Correlation between Predicted PGA and Observed PGA

When the Observed and Predicted PGA values are compared (Fig.12), it is seen that the GMPEs except AR2 show similar compliance, even though the fits in the curves of the attenuation relationships seem very different. With R2 correlations, it is seen that 4 equations have values above 0.70. Although the AR1 curve alone does not seem to have a very high fit, the highest fit between the predicted and predicted PGA's belongs to this GMPEs. However, high R2 values do not fully reflect high fit. It is seen that as the correlation approaches the y=x line, closer values can be estimated. When we look at the curve drawn for the AR4 equation, we see the best fit between predicted and observed in the y=x curve. Looking at Figure 10 and Figure 12, the highest agreement is found in AR4, the data set uses a wide range of data and was developed by considering the region where the Gölyaka earthquake occurred. Ulutaş's work focuses on the Marmara region.

6. Conclusions

Within the scope of the study, data on the 5.9 Mw earthquake that occurred on November 23, 2022, were investigated. Acceleration values obtained from the stations were evaluated with 5 different GMPEs developed for Türkiye. According to the results obtained from 5 different GMPEs the fits of the models were evaluated and interpreted. The results obtained within the scope of the study are given below.

• According to the results obtained in the study, 5 different GMPEs were evaluated. All the GMPEs are compatible with certain earthquake magnitudes. In general, the curves of the GMPEs remain below the real values by a standard deviation.

• As the distance increases, the actual earthquake data and the values predicted by GMPEs converge in regions where PGA values are low.

• The GMPEs called AR4 shows the highest fit in the study. The reason for this is that the data set utilized to obtain the GMPEs is large in number. Another reason is that the aim is to develop the GMPEs for the Marmara region. The fact that the Gölyaka earthquake remains within the region where the GMPEs is focused is effective in the high degree of harmony.

• The most important issue in obtaining GMPEs is the data set and the ground properties of the region. These need to be well-detailed and effective with the right approach. For this reason, existing GMPEs need to be improved and updated with new earthquake data to better reflect possible earthquakes.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

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