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Investigation of Regional Differences in Strong Ground Motions for the Iranian Plateau

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Abstract**—**Regional variations in strong ground motions for the Iranian Plateau have been investigated by using a simple statistical method called Analysis of Variance (ANOVA). In this respect, a large database consisting of 1157 records occurring within the Iranian Plateau with moment magnitudes of greater than or equal to 5 and Joyner-Boore distances up to 200 km has been considered. Geometric averages of horizontal peak ground accelerations (PGA) as well as 5% damped linear elastic response spectral accelerations (SA) at periods of 0.2, 0.5, 1.0, and 2.0 sec are used as strong motion parameters. The initial database is divided into two different datasets, for Northern Iran (NI) and Central and Southern Iran (CSI). The comparison between strong ground motions of these two regions reveals that there is no evidence for significant differences; therefore, data from these two regions may be combined to estimate the unknown coefficients of attenuation relationships.

Keywords**—**ANOVA, attenuation relationships, Iranian Plateau, PGA, regional variation, SA, strong ground motion.

I. INTRODUCTION

THE first step to perform the seismic hazard assessment for a specific region is to have reliable ground motion models (GMMs) or ground motion prediction equations (GMPEs). In general, GMPEs have a functional form in which ground motion parameters such as PGA and 5% damped linear elastic response SA at different periods for a future earthquake can be obtained from the details of the considered earthquake in the desired site such as magnitude, fault mechanism, distance, and soil condition.

To determine the coefficients of GMPEs for a wider range of magnitudes and distances, a large database is needed. In essence, the robustness and the reliability of computed coefficients can be improved by using a larger database. However, combining records from regions with different tectonic settings and discrepant seismic characteristics can lead to an increase of the standard deviations of GMPEs, and consequently, decreasing the accuracy level of the seismic hazard assessment.

One way to find out whether or not two regions are seismically and tectonically similar is to directly compare seismic parameters (e.g., anelastic attenuation and stress drop) of those regions to investigate any variations. For instance, the data from Western North America (WNA) cannot be merged with the data from Eastern North America (ENA) due to their various seismic properties. WNA possesses a lower stress drop and a higher anelastic attenuation compared to ENA. This procedure can be done in regions where seismic parameters have been precisely determined. Although several research studies have been recently performed to estimate the quality factor of different parts of Iran [1], [2], further studies are still required to accurately quantify the stress drop parameter and site amplification factor (kappa). Another way to verify if two regions have similar tectonic regimes in order to be combined to create a larger database was proposed by Douglas [3], [4] utilizing a simple statistical technique known as ANOVA.

In the past, several GMPEs have been proposed and developed based on the Iranian strong motion records. Some of these models separate records of the Alborz region from records of the Zagros region [5], [6]. A few of proposed GMPEs for Iran consider an additional coefficient in the functional form to observe the difference of regional records [7].

Ghasemi et al. [8] have studied the possibility of the regional variations between Alborz and Zagros regions using 999 records from 1979 to 2007 based on the ANOVA technique. In the present study, we divided the database into two different larger regions: NI containing Alborz, and CSI including Zagros. The initial database has 1157 records which occurred during 1976 to 2013 in different locations of the Iranian Plateau. These records have moment magnitudes, **M**, of 5 to 7.4 and Joyner-Boore distances up to 200 km. The main objective of this study is to explore whether or not strong ground motions from NI and CSI regions have similar patterns in order to combine these data into one dataset, and consequently, to obtain robust and reliable GMPEs. In this respect, the ANOVA technique as well as patterns of the attenuation of strong motions with respect to the distance for different magnitudes have been utilized. The comparison has been done for geometric averages of horizontal PGAs as well as SAs at periods of 0.2, 0.5, 1.0, and 2.0 sec. It should be noted that the effect of the site class as well as the effect of the fault mechanism have been considered in this study.

II. STRONG MOTION DATABASE

Triaxial accelerograms from the Iran Strong Motion Network (ISMN) recorded by the Building and Housing Research Center (BHRC) during the period of 1979 to 2014 have been used in this study. Installed instruments consist of analog (SMA-1) and digital (SSA-2) instruments. Following [9] and [10], we corrected these accelerograms to remove the mean, the linear trend, and the noise. Local site conditions for recording stations have been determined following [11]. Eventually, 1157 records with R_{JB} of up to 200 km, moment magnitudes, **M**, of 5 to 7.4, and focal depths less than 35 km

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have been considered to further study. It should be noted that geometric averages of horizontal PGAs and SAs at periods of 0.2, 0.5, 1.0, and 2.0 sec are considered in this study.

The main database has been divided into a dataset for NI and another dataset for CSI based on the geographical locations of earthquakes and stations.

Each dataset is classified based on the local site condition [12]. Since the number of earthquakes recorded within very soft stations was very small, records from this category have been merged with the records from soft soil category. The statistics of each dataset with respect to the soil condition are tabulated in Table II.

Fig. 1 demonstrates the distribution of the data in the magnitude-distance space.

TABLE I
SUMMARY OF THE RECORDS USED FOR EACH REGION

Region	Number of Records	**M** Range	R_{JB} Range (km)
NI	426	5 - 7.4	2.61 - 199.28
CSI	731	5 - 7.3	0 - 195.92

TABLE II
DISTRIBUTION OF THE RECORDS WITH RESPECT TO THE SOIL CLASSIFICATION

Region	Soft	Stiff	Rock
NI	102	161	163
CSI	91	298	342

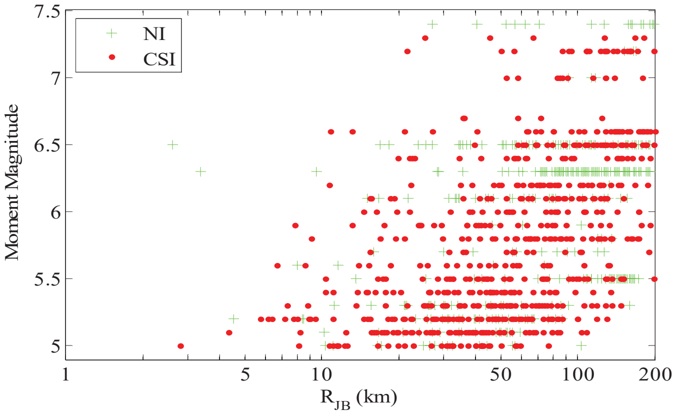

Fig. 1 Distribution of the data in the magnitude-distance space. “+” signs represent NI region and “o” signs denote CSI region

According to Fig. 1, the distribution of the data is balanced and suitable for distances more than 10 km; however, there is a lack of data once the distances are less than 10 km and magnitudes are more than 6.

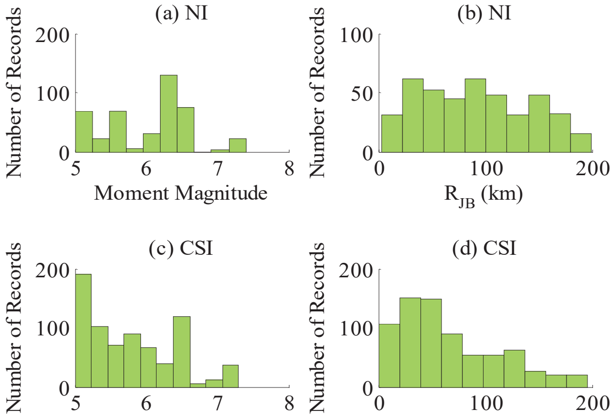

Fig. 2 Histograms displaying the frequency of the records for different distances and magnitudes

Fig. 2 shows the frequency histograms of the considered records at each dataset for different distances and magnitudes.

III. METHODOLOGY

According to [3] and [4], each dataset is divided into small bins of magnitude and distance intervals. Records inside a specific bin are treated as repeated data. Douglas in [3] and [4] used intervals of 0.25 M_S × 5 km units, while we use 0.5 **M** × 10 km due to the data sparsity at each bin for smaller intervals. Thus, we define 100 magnitude-distance bins in this study. Then, natural logarithms of ground motion parameters are estimated to avoid having any biases in the result. In addition, bins with at least three records are considered to perform one-way ANOVA. To perform ANOVA, the null hypothesis is defined as the means of transformed ground motion parameters for both regions at each bin are identical. Thus, this hypothesis is rejected if there is a significant difference between the means of ground motion parameters estimated for NI and CSI regions at each bin.

According to Table II, the majority of the data for both regions have been recorded on rock and stiff stations. Furthermore, hence, the number of records at each bin is small, the database cannot be split by the stations soil type. Therefore, following [13], to compensate for the effect of the local site condition, PGA and PSA values at stiff and soft stations have been scaled to the rock classification using the site model proposed by [14]. In addition, all ground motion parameters have been scaled to the strike slip mechanism utilizing coefficients obtained by [13] to remove the effect of the style of faulting.

IV. RESULTS

Before discussing the ANOVA technique in details, we compare the pattern of the attenuation of ground motion parameters with respect to the distance. Figs. 3 and 4 illustrate the distribution of the ground motion parameters with respect to the distance at different distance-magnitude intervals for PGA and SA at period of 2.0 sec.

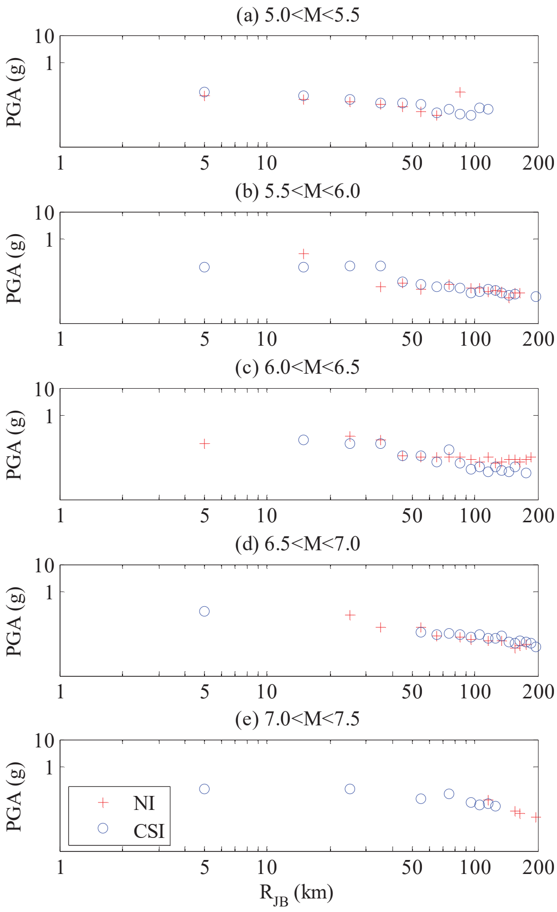

Fig. 3 Distribution of the ground motion parameters with respect to the distance at different distance-magnitude intervals for PGA. “+” signs represent NI region and “o” signs denote CSI region

There is a reasonable number of magnitude-distance bins particularly for magnitudes less than 7.0 to compare the pattern of the attenuation of PGAs and SAs (see Figs. 3 and 4). According to Figs. 3 and 4, the patterns of the attenuation of ground motion parameters for NI and CSI regions generally have similar trends. There is only one bin for the interval with 5.0 < **M** < 5.5 and 80 < R_{JB} < 90 in which the average ground motions for NI are more than CSI. For 5.5 < **M** < 6, there are only two bins centered at 15 and 35 km in which ground motion parameters are different. For 6.0 < **M** < 6.5, there is a good match for distances less than 100 km; however, ground motions from NI region are attenuated a little less than CSI for distances greater than 100 km. For 6.5 < **M** < 7.0, ground motions are correlated well, but for magnitudes greater than 7.0, we have insufficient data, especially for NI region, to assess the similarity of the ground motion parameters. It can be seen in Fig. 3 that only seven bins out of 41 bins which contain sufficient data from both regions show significant differences for PGA values. Similar patterns have been observed for SA at periods of 0.2, 0.5, and 1.0 on these two regions as well.

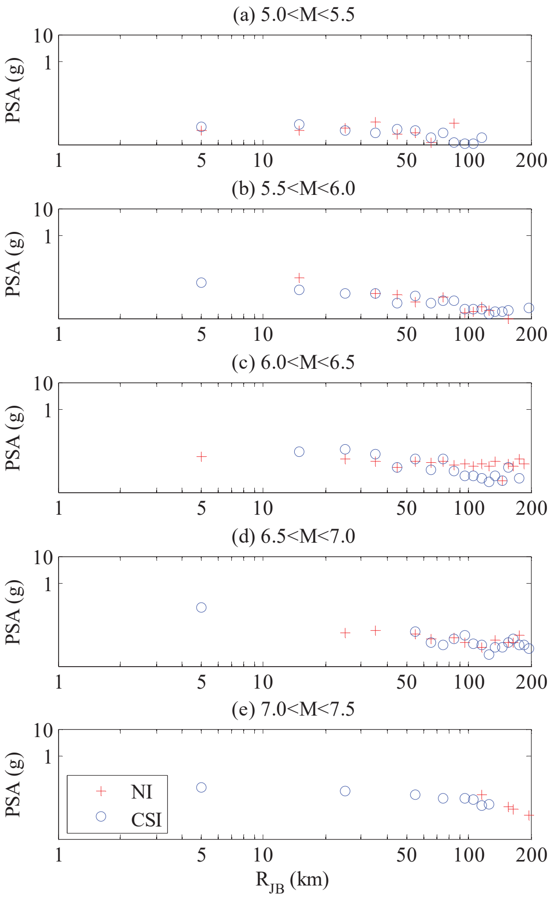

Fig. 4 Distribution of the ground motion parameters with respect to the distance at different distance-magnitude intervals for SA at 2.0 sec. “+” signs represent NI region and “o” signs denote CSI region

Now, using ANOVA, we statistically compare how similar the transformed values of PGAs and SAs at various periods are. Tables III and IV tabulate the values acquired from the ANOVA technique for two specific bins.

In accordance with the p-values obtained from the ANOVA technique, the null hypothesis is rejected at the 5% significance level for 5 out of 41 total intervals, 6 out of 41 total intervals, 8 out of 41 total intervals, 6 out of 41 total intervals, and 4 out of 41 total intervals for PGAs and SAs at periods of 0.2, 0.5, 1.0, and 2.0 sec, respectively. Totally, except 29 intervals out of 205 magnitude-distance intervals defined in the study, the null hypothesis cannot be rejected at the 5% significance level in the remaining intervals. As a conclusion, patterns of the attenuation of PGAs and SAs with distance at the different magnitude intervals from NI and CSI regions are very similar, and accordingly, data from these two regions could be combined into one set to reliably and robustly compute the coefficients of GMPEs.

TABLE III
ANOVA TABLE FOR PGA VALUES IN THE BIN WITH 5.0 <M< 5.5 AND 130 <R_{JB}<140

Source	SS	df	MS	F	p-value
Groups	0.076	1	0.076	0.06	0.812
Error	34.451	26	1.325		
Total	34.527	17			

Note: SS, df, and MS are abbreviation for the sum of squares, the degrees of freedom, and the mean of the sum of squares. The parameter F denotes the critical value acquired from F test.

TABLE IV
ANOVA TABLE FOR SA VALUES AT THE PERIOD OF 2.0 IN THE BIN WITH 6.0 <M< 6.5 AND 130 <R_{JB}<140

Source	SS	df	MS	F	p-value
Groups	3.750	1	3.750	5.39	0.0372
Error	9.047	13	0.696		
Total	12.797	14			

Note: SS, df, and MS are abbreviation for the sum of squares, the degrees of freedom, and the mean of the sum of squares. The parameter F denotes the critical value acquired from F test.

V. CONCLUSIONS

The ANOVA technique is an alternative method to investigate whether or not records from different regions can be combined into one database to estimate coefficients of GMMs or GMPEs. This issue is very critical, since having records from regions with discrepant tectonic and seismic characteristics can lead to increasing the standard devotions of GMPEs, whereas more robust and reliable GMPEs can be acquired through using a larger database. The Iranian Plateau is one of the areas that has a high potential of generating large and devastating earthquakes. In this study, we compared records from two different regions of the Iranian Plateau, NI and CSI (Central Southern Iran), to explore if we can combine data from these regions into one database to develop new GMPEs.

According to the selected datasets for these two regions, there are 41 bins in the magnitude-distance range of interest for earthquake engineering and seismologist in which we have an adequate number of records from both regions out of 100 created bins to compare the pattern of the attenuation of ground motion parameters with distance and to perform the ANOVA technique. Based on the presented analysis, there is little evidence for regional differences between recorded data from past earthquakes occurring in these regions. As a result, records from these regions may be combined into one database to develop new GMPEs.

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