VERTICAL GROUND MOTION PREDICTION EQUATIONS FOR PGA AND PSA IN ALBORZ-AZERBAIJAN, IRAN

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ABSTRACT

Before the current great earthquakes, the lateral loads were considered as a main reason of structural damages. So, the vertical component of earthquake was ignored in designing of most structures. The recent studies have shown that vertical component of ground motion can be an effective parameter in damage of the structures. Ground Motion Prediction Equations (GMPEs) are an essential parameter in seismic hazard analysis to obtain the spectrum which the most of them are developed for Horizontal component. In this study, we will develop a GMPE for vertical component in Alborz-Azerbaijan, Iran. It should be noted that the vertical GMPEs for spectral amplitudes have not been published in an international peer-reviewed journal for any region of Iran.

In order to determine regression coefficients, we used 294 three-component records of 53 earthquakes with magnitude ranging from Mw 4.1 to Mw 7.3. Records with epicentral distances more than 300 km are omitted from the database. The coefficients for the prediction of vertical peak ground acceleration and 5% damped spectral acceleration are calculated. Eventually, the proposed model is compared with available models and it can be understood that the proposed models are in agreement with other available GMPEs proposed for Iran, Europe and Middle East and worldwide.

INTRODUCTION

Lateral loads were considered as a main reason of structural damage before the current great earthquake same as Northridge (1994), Kobe (1995), Chi-chi (1999) and/or Bam (2003) and in designing of most structures, the vertical component was ignored. The studies showed that the vertical component can have significant effect on damage of the structures and it was proved by some authors. Saadeghvaziri and Foutch (1991) explained that the variation of axial load in base because of vertical excitation can cause of instability. Moreover, Yu et al. (1997) mentioned that 21% increasing in axial load and 7% variation in moment can be produced. Also, Shakib and Fuladgar (2003) discussed that consideration of vertical component in base isolated structures can increase the axial load in columns up to 3 times. It seems necessary to consider both horizontal and vertical components for dynamic spectral analysis, although, the horizontal response spectrum is only available in the most of building code, same as Iranian code of practice for seismic restraint design of buildings.

Current studies show the importance of vertical component of motion, but, some codes either neglect the vertical component effect or recommend using the constant ratio 2/3 proposed by Newmark and Hall (1973).

GMPEs have a key role for seismic hazard evaluation to obtain site-specific spectrum at a desired site. GMPEs may be obtained by using two approaches; physical and mathematical models. The necessary data to develop GMPEs is magnitude, source-to-site distance, site class and peak ground characteristics. Although, various Models have been developed for Horizontal component of GMPEs in Iran based on physical and mathematical approaches (Sinaiean, 2006; Ghodrati Amiri et al., 2009; Ghasemi et al., 2009; Soghrat et al., 2012; Zafarani and Soghrat, 2012), there are no reliable GMPEs for vertical component for Alborz-Azerbaijan or even for the whole Iranian plateau with local data. There are two approaches to obtain the vertical component of response spectrum. The first approach is a direct development by applying GMPEs for vertical component and using probabilistic seismic hazard analysis. Second method is to employ vertical to horizontal spectral ratio (VHSR) for scaling the horizontal spectrum (Ambraseys and Douglas, 2003; Bozorgnia and Campbell, 2004; Bommer et al., 2011; Gülerce and Abrahamson, 2011).

In this study, first, we collect the recorded data and events in the Alborz-Azerbaijan region. Then, we process the database and select the interest records and events. Among the proposed functional form of GMPEs, it is tried to select the best available model to derive the regression coefficients in the GMPEs. After evaluating the accuracy of the results, we compare our results to other studies.

DATABASE AND RECORD PROCESSING

Iranian plateau has experienced great and destructive earthquakes. Iran has been divided into five tectonic regions as Azerbaijan-Alborz, Kopeh Dagh, Zagros, Makran and central–east Iran (Mirzaei et al. 1998). The data has been recorded on the Iranian Strong Motion Network (ISMN) of the Building and Housing Research Center (BHRC). This network consists of more than 3,000 stations including more than 10,000 three-component accelerograms in various active seismic regions of Iran.

For eliminating any uncertainties in this research, only those records are considered which their average S-wave velocity to a depth of 30 m (Vs30) is known in their stations. Four site groups has been classified base VS30, which are: I- (Vs30>750); II-(375<Vs30<750); III-(175<Vs30<375); IV- (Vs30<175).

We used 294 acceleration time histories of the 53 Iranian earthquakes, whose range of moment magnitude (Mw) is 4.1–7.3. Figure 1 shows the locations of epicentres.

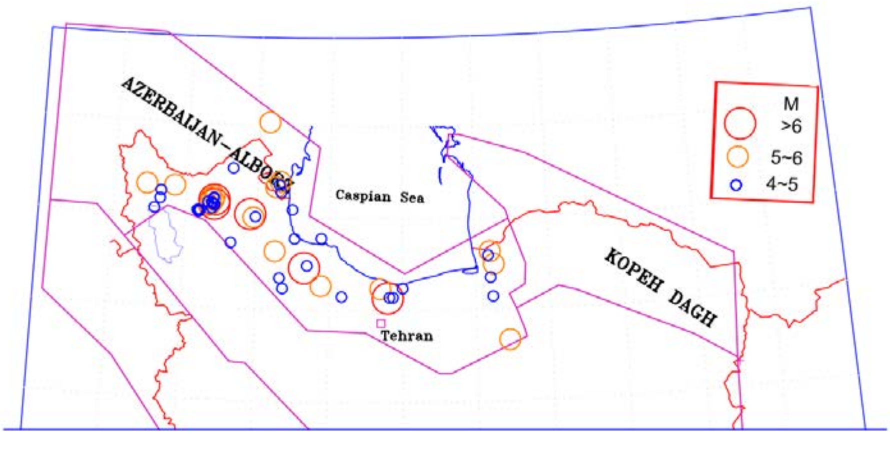

Figure 1. The distribution earthquake epicenters in studied region

Moreover, the distribution of magnitude-distance is plotted in Figure 2. As may be observed from the figure, the database has insufficient data at magnitudes more than 6.5 and distances over 200km. The only available distance measure for all earthquakes studied in this study is epicentral distance and so we use this measure in analyzing.

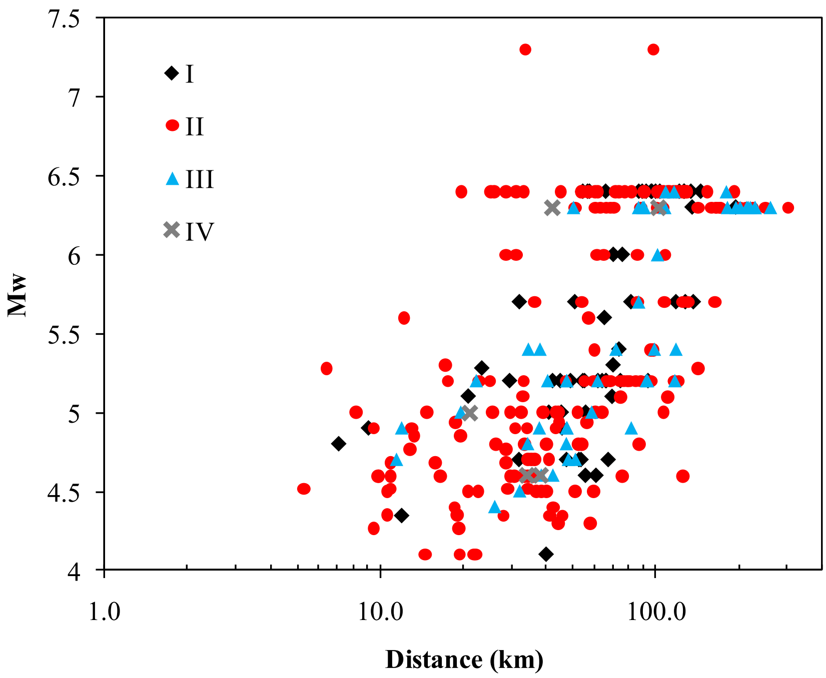

Figure 2. Distribution of moment magnitude, distance versus site classification

To reduce uncertainties, the records with the following features are omitted from dataset: data from instruments that triggered during the S-wave train; stations with no information on site conditions; data with poor quality and the events that recorded by only one station.

The uncorrected (unprocessed) acceleration time series were corrected by multi-resolution wavelet analysis (Ansari et al. 2010) to remove undesirable noise from the recorded signals, which has all abilities of the conventional band-pass filtering methods (e.g. Akkar and Bommer, 2006).

FUNCTIONAL FORMS AND REGRESSION RESULTS

The form of a ground motion model should be a function of magnitude, distance, site class and other available information same as style of faulting. Several functional forms for meaningful and reliable estimations have been examined. Finally, the selected functional form is (Akkar and Bommer 2007, 2010):

$$Log_{10}(Y) = b_1 + b_2 Mw + b_3 Mw^2 + (b_4 + b_5 Mw)\log_{10}\sqrt{R^2 + b_6{}^2} + \sum_{i=1}^{4}\delta_i S_i \qquad (1)$$

where Y is the response variable (PGA and PSA in cm/sec2); Mw, the moment magnitude; and R, epicentral distance. $b1$, $b2$, $b3$, $b4$, $b5$ and $b6$ are the regression coefficients. $S1$, $S2$, $S3$ and $S4$ are the coefficients for site classes I, II, III and IV, respectively. In case of Si just the corresponding δ_i is 1, and $\delta_{j\neq i}$=0. As it is described in the previous section, the style of faulting is not considered in this study due to lack of data which is a usual assumption (Ghasemi et al. 2009; Soghrat et al., 2012; Zafarani and Soghrat, 2012; Ghodrati Amiri et al., 2014).

In this study, the regression of the dataset is done consistent with the maximum likelihood method. In this regard, two major troubles should be observed: the problem of weighting observations from different events, and to avoid the earthquakes with a large number of recordings from excessively affecting the regression coefficients of model. To effectively modify the mentioned troubles, as well as selecting the earthquakes that have at least two records for modeling, the random effects model proposed by Brillinger and Preisler (1984, 1985) is also implemented. This model divides the error term into inter-event and intra-event terms. The more stable algorithm of Abrahamson and Youngs (1992) for maximizing the likelihood function in the random effect model is used in this research. The final coefficients for the median ground motion (i.e. vertical GMPEs) and corresponding standard deviations are given in Table 1. It should be noted that after some trials with different values of b6, it was fixed to be 12.8 km for all periods as a period-independent parameter.

Table 1. Coefficients for the developed vertical GMPEs

T	**b_1**	**b_2**	**b_3**	**b_4**	**b_5**	**b_6**	**S_1**	**S_2**	**S_3**	**S_4**	**σ_r**	**σ_e**
0	1.00	-0.30	0.09	-0.07	-0.21	12.8	1.08	1.08	1.09	0.74	0.28	0.08
0.5	-2.51	1.06	-0.03	-0.43	-0.09	12.8	0.06	0.21	0.16	0.06	0.29	0.11
1	-3.97	1.70	-0.10	-1.46	0.11	12.8	-0.33	-0.19	-0.18	-0.27	0.30	0.09
2	-2.57	0.64	0.02	-1.23	0.07	12.8	-0.05	0.12	0.17	0.19	0.31	0.12
3	-0.19	-0.73	0.15	-0.80	0.01	12.8	0.55	0.69	0.75	0.81	0.28	0.10

The inter-event and intra-event residuals for the proposed model are shown in Figure 3. As may be obvious from the figures, it can be said that the inter-event residuals do not show any noticeable trend with respect to the magnitude. Also, as it is clear from the figures, the intra-event residuals are unbiased with respect to the magnitude and distance parameters. The figures and the obtained standard deviations for proposed model show the data and functional form are appropriate in this study.

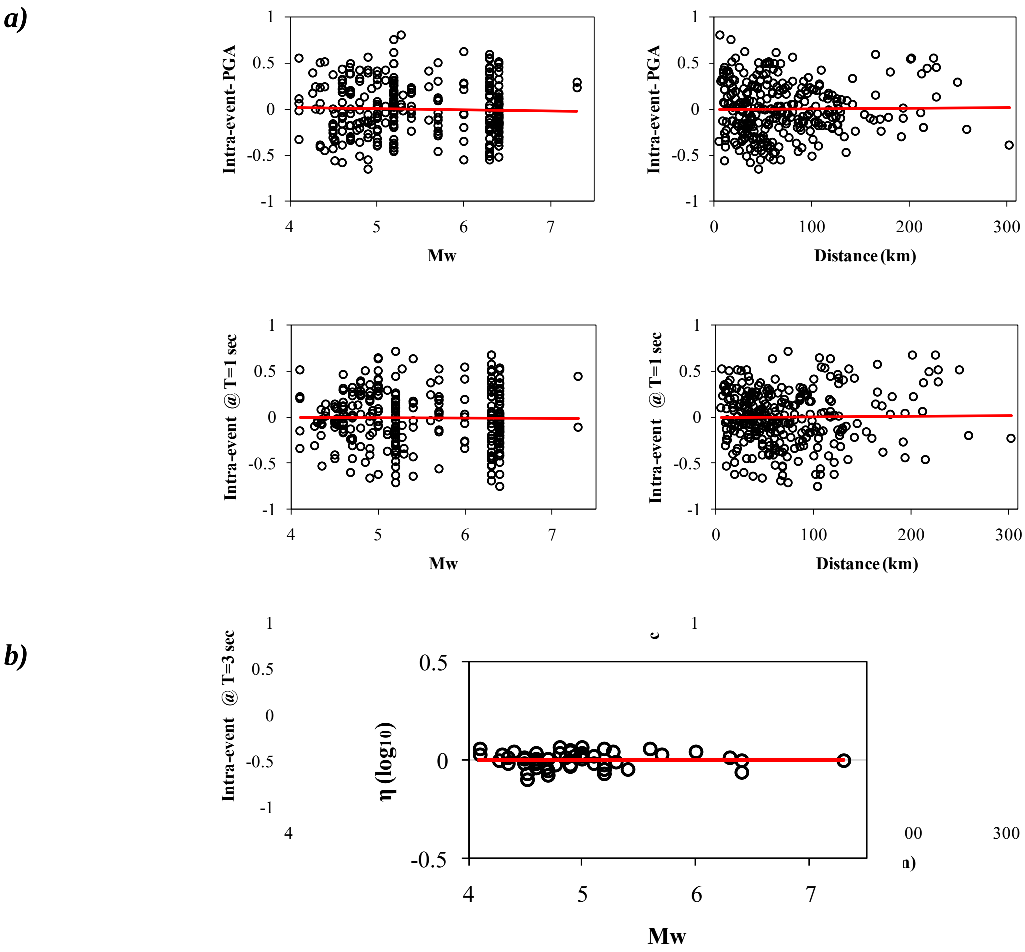

Figure 3. The error terms for Vertical GMPEs (*a*) Intraevent residuals as a function of distance and magnitude and (*b*) Interevent residuals as a function of magnitude.

COMPARISONS WITH LOCAL AND GLOBAL PREDICTIVE MODELS

A comparison of median predicted of vertical components based on the proposed ground-motion model with those from some other available GMPEs in the literature is shown in Figure 4. Table 2 shows characteristics of available GMPEs for comparison.

Table 2. Characteristics of selected GMPEs for comparison

Study	Abbreviation	Region	Mw range	R^*	R range	range of Period (sec)
Nowroozi (2005)	N05	Iran	3-7.4	R_{epi}	2-250	0
Bindi et al. (2010)	Bea10	Italy	4-6.9	R_{jb}	0-100	0-2
Bindi et al. (2011)	Bea11	Italy	4-6.9	R_{jb}	0-200	0-2
Campbell and Bozorgnia (2003)	CB03	Worldwide	4.7-7.7	r_{seis}	0-60	0-4

The proposed model for the PGA and PSA with site class of II and Mw=6 are represented in Figure 4. In addition, the available models in Table 2 are also drawn for an earthquake of Mw=6 at PGA and three periods of 0.5, 1 and 3 sec.

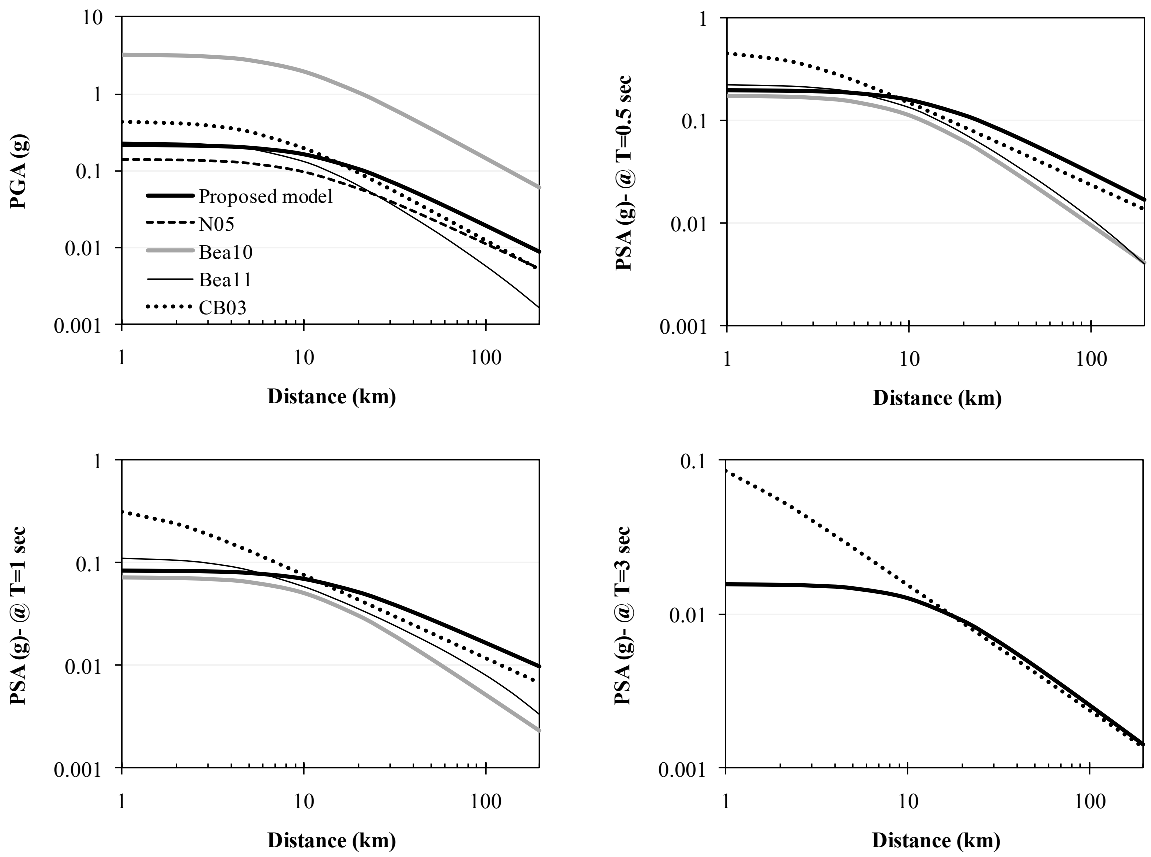

Figure 4. Comparison of the proposed model with other available models in Mw=6, SC=II, reverse faulting for vertical component. N05; (Nowroozi 2005), Bea10; (Bindi et al., 2010), Bea11; (Bindi et al., 2011) and CB03; (Campbell and Bozorgnia, 2003).

There are no spectral GMPEs For vertical component in Iran. Only, Nowroozi (2005) proposed vertical GMPEs for PGA. It seems in this study, for the first time, we developed vertical GMPEs as spectral amplitude for Iran. As may be observed from the Figure 4 for distances less than 10 km, there is a similarity between proposed model and Bindi et al. (2010, 2011), but for distances more than 10 km, the provided model of the present study is similar to Campbell and Bozorgnia (2003).

Minor differences in predictions of models can be assigned to the different definitions of soil categories and distance parameter. Also, the data amounts that these models have been developed, functional form of the equations, considering the style of faulting can be effective in the differences.

DISCUSSION AND CONCLUSIONS

In this study, we used 294 records of 53 events with moment magnitude greater than 4 and distances less than 300 km. we do not distinguish the style of faulting in proposed models. Site classification has been done based on Iranian Code of Practice for Seismic Resistant design of Building. Empirical GMPEs to obtain of elastic response spectral accelerations have been derived for use in seismic hazard assessments for Alborz-Azerbaijan region.

It seems that vertical GMPEs as spectral amplitude is developed for the first time in Iran. The standard deviations of the proposed models showed better results and lower values than most of available models for Iran. The intra and inter-event errors are stable and there is no dependency to distance and magnitude in different period.

We can observe the similarity between proposed models and GMPEs which developed for Iran, Europe and Middle East and Worldwide. Comparison of the proposed model with other available models, shows that the similarity between our model and Bindi et al. (2010, 2011) and Campbell and Bozorgnia (2003). Finally, the GMPEs derived in this study could be considered within a logic-tree formulation for seismic hazard assessments in the studied region or similar one.

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