A GROUND MOTION PREDICTION EQUATION FOR CAV IN ZAGROS

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ABSTRACT

A study on estimation of a ground motion prediction equation for three versions of Cumulative Absolute Velocity (CAV) is conducted using 320 three-component strong motion records from 49 earthquakes with moment magnitude between 5.0 and 6.1. Earthquakes are occurred in Zagros and hypocentral distance ranges from 10 to 193 km. Three well-known definitions of CAV are calculated for each record. The versions of CAV are: 1- CAV obtained by integration of absolute acceleration over whole duration (CAV_{Total}), 2- CAV determined from sum of integrations of absolute acceleration over one second intervals with PGA greater than 0.025g (CAV_{STD}), and 3- CAV calculated by integration of absolute acceleration over portions with PGA greater than 0.005 (CAV_5). Calculation of CAV_{Total} and CAV_5 from all of records passing a primarily quality control leads to nonzero values. However, nonzero CAV_{STD} values are obtained from only 156 records with maximum hypocentral distance of 119 km. For the regression analysis we used two models; one a simple model with only magnitude and geometrical spreading terms, and in the other model we added the magnitude second power term and a term related to anelastic attenuation. The results show that the CAV_{Total} regression by the simplest model is the best model fit. Standard deviations of the attenuation coefficients as well as analysis of residuals demonstrate that CAV_{Total} is the most predictable version of CAV. On the other hand predictability of CAV_5 is less than others.

INTRODUCTION

PGA, PGV and response spectral ordinates are well-known ground motion parameters which are widely used for earthquake attenuation and seismic hazard studies. These parameters only describe the amplitude of ground shaking caused by an earthquake. Apart from amplitude, duration is also important for distinguishing between destructive and non-destructive impact of an earthquake. Cumulative Absolute Velocity (CAV), as a ground motion parameter, contains both of duration and amplitude effects of a strong motion record.

As well as the role of CAV in elimination of non-damaging earthquakes from results of probabilistic seismic hazard analysis (Klugel 2009), it is also able to predict the intensity of an earthquake and has been shown to have a significant correlation with damage to structures. Fahjan et al., (2011) discussed applications of CAV to urban early warning systems and Sadeghi-Bagherabadi et al., (2013) utilized attenuation relation of a special version of CAV in earthquake rapid magnitude determination for rapid response purposes. Reed and Kassawara (1990) selected CAV as a damage parameter for determining exceedance of the operating basis earthquake after the occurrence of a seismic event at a nuclear power planet.

Zagros is one the main seismotectonic zones of Iranian plateau and its seismisity is dominated by a large number of earthquakes with magnitude less than 7.0. Depth of earthquakes in Zagros are between 10 and 15 km and rarely exceeds 20 km. Many population are inhabited in rural and urban areas of this region, and Zagros hosted a number of important infrastructures such as dams and power plants as well. In current paper we try to select a proper model and estimate the coefficients of a ground motion prediction equation for the three versions of CAV.

CUMULATIVE ABSLUTE VELOSITY

CAV is first introduced by EPRI in 1988 by integration of an absolute acceleration time series over whole of the record, denoted herein as $\mathrm{CAV}_{\mathrm{Total}}$ (Equation 1).

$$CAV_{Total} = \int_0^{t\max} |a(t)| dt \tag{1}$$

EPRI (1991) introduced a standardized definition of CAV to serve as a threshold for shutting the nuclear power plants down in case of disastrous earthquakes. Equation 2 shows the standardized version of CAV:

$$CAV_{STD} = \sum_{i=1}^{N} H\left((PGA_i - 0.025) \int_{i-1}^{i} |a(t)| dt \right) \tag{2}$$

where N is number of the 1 second time intervals, PGA_i, is the value of peak ground acceleration (g) in time interval i and $H(x)$ is the Heaviside step function presented in Equation 3:

$$H(x) = \begin{cases} 0 \rightarrow x < 0 \\ 1 \rightarrow x \geq 1 \end{cases} \tag{3}$$

Lastly, Kramer and Mitchel (2005) proposed a new version of CAV called CAV_5 and demonstrated that it has a closer relationship to pore-pressure generation in comparison to PGA and Arias Intensity. As a result, they suggested the use of CAV_5 as a measure for soil liquefaction. CAV_5 could be determined from Equation 4:

$$CAV_5 = \int_0^{\infty} \langle x \rangle |a(t)| dt \tag{4}$$

The $\langle x \rangle$ function is shown in Equation 5:

$$\langle x \rangle = \begin{cases} 0 \rightarrow |a(t)| < 0.005g \\ 1 \rightarrow |a(t)| \geq 0.005g \end{cases} \tag{5}$$

We have extracted above mentioned types of CAV from our data base and the geometric mean of two horizontal components are used for regression.

DATA

We have collected a data base containing 320 three-component strong motion records registered by Iran Strong Motion Network (IMSN) in Zagros (Figure 1). Moment magnitudes of the earthquakes are between 5.0 and 6.1 and hypocentral distances range from 10 to 193 km (Figure 2). Events covering a period from 1994 to 2012.

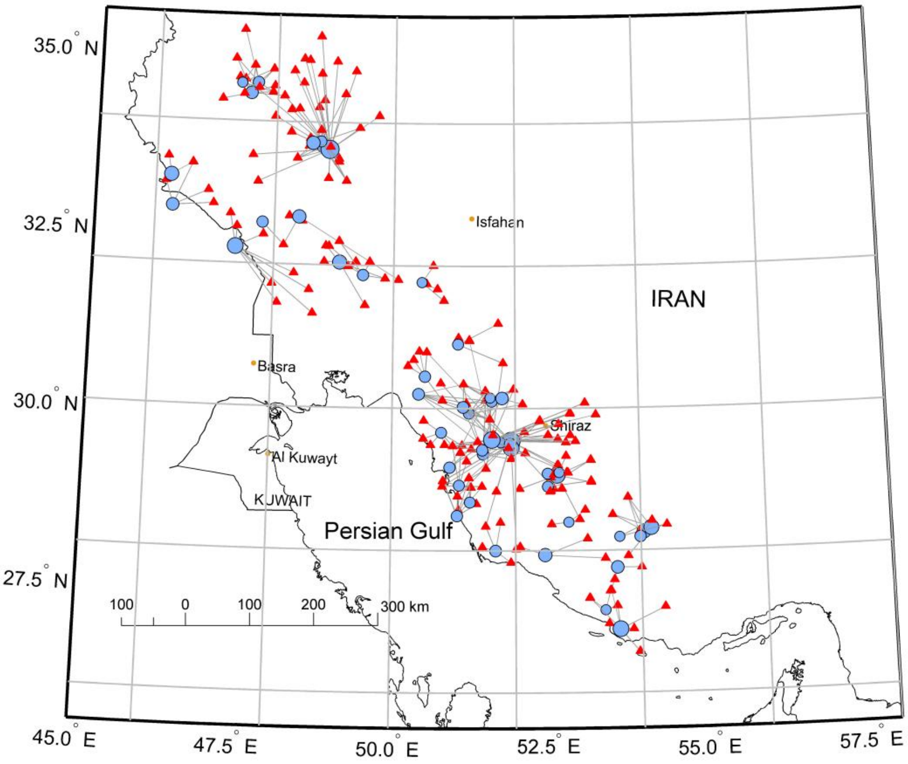

Figure 1. Earthquakes (circles) and stations (triangles) used in the study

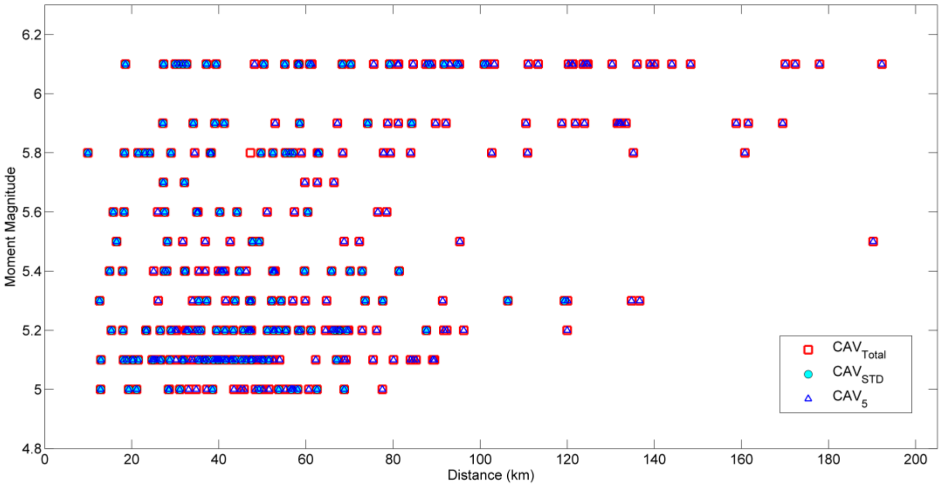

Figure 2. Distribution of moment magnitude and distance of the three versions of CAV

By calculation of the three CAV types, 320 number of CAV_{Total} and CAV_5 in addition to 156 CAV_{STD} are obtained. The maximum hypocentral distance in CAV_{STD} data set is 119 km (Figure 2). In other words, strong motions stations beyond 119 km did not record any wave-form with PGA greater than 0.025 g. However, many other parameters such as magnitude and surface geology should be incorporated in defining a threshold condition for non-zero CAV_{STD}.

MODEL SELECTION AND REGRESSION ANALYSIS

We began with the simplest model with moment magnitude and hypocentral distance as independent variables. The model only contains a constant and one magnitude dependent term and a term describing geometrical spreading (Equation 5).

$$\log(CAV) = a + b(M) + d\log(R) \tag{6}$$

We estimated the unknown coefficients of Equation 6 using weighted least squares method (WLS) and added two terms to the model. One of the terms is related to anelastic attenuation and the other is in order to avoid the magnitude saturation. The resulting model with five unknown coefficients are presented in Equation 7:

$$\log(CAV) = a + b(M) + c(M-m)^2 + d\log(R) + e(R) \tag{7}$$

Where e is coefficient of anelastic attenuation and m is mean value of the existing magnitudes in the data base. The m is used to reduce the correlation between the magnitude first and second power terms (see Kutner et al., 2005) The unknown coefficients of the Equation 7 and their standard deviations are also estimated by WLS (Table 1).

Table 1. Correlation coefficients, estimated coefficients, standard deviations and P-value of the models

CAV version		CAV_{Total}							
Model		Equation 6			Equation 7				
RMS(Residuals)		0.066			0.066				
R^2		0.71			0.7				
Weight		0.468-0.145 *log*(*R*)			0.464-0.142 *log*(*R*)				
Coefficients		*a*	*b*	*d*	*a*	*b*	*c*	*d*	*e*
Coefficient value		0.632	0.105	-0.455	0.742	0.098	-0.007	-0.517	-0.0005
STD		0.052	0.010	0.016	0.091	0.012	0.035	0.044	0.0003
P-value		0.000	0.000	0.000	0.000	0.000	0.826	0.000	0.110
Correlation coefficient			*M*			*M*	$(M-m)^2$	*Log(R)*	
	$(M-m)^2$					-0.46			
	Log(R)		-0.41			0.10	-0.01		
	R					0.22	-0.05	-0.93	
CAV version		CAV_{STD}							
RMS(Residuals)		0.157			0.155				
R^2		0.48			0.46				
Weight		0.653-0.191 *log*(*R*)			0.601-0.159 *log*(*R*)				
Coefficients		*a*	*b*	*d*	*a*	*b*	*c*	*d*	*e*
Coefficient value		0.681	0.185	-0.667	1.003	0.161	0.068	-0.871	-0.003
STD		0.210	0.036	0.064	0.369	0.048	0.133	0.215	0.002
P-value		0.000	0.000	0.000	0.007	0.000	0.606	0.000	0.203
Correlation coefficient			*M*			*M*	$(M-m)^2$	*Log(R)*	
	$(M-m)^2$					-0.65			
	Log(R)		-0.13			0.10	-0.05		
	R					-0.12	0.03	-0.96	
CAV version		CAV_5							
RMS(Residuals)		0.187			0.187				
R^2		0.36			0.37				
Weight		0.472-0.046 *log*(*R*)			0.475-0.049 *log*(*R*)				
Coefficients		*a*	*b*	*d*	*a*	*b*	*c*	*d*	*e*
Coefficient value		0.464	0.216	-0.616	0.275	0.227	-0.020	-0.512	-0.0008
STD		0.149	0.029	0.047	0.260	0.036	0.102	0.127	.0009
P-value		0.002	0.000	0.000	0.291	0.000	0.845	0.000	0.374
Correlation coefficient			*M*			*M*	$(M-m)^2$	*Log(R)*	
	$(M-m)^2$					-0.50			
	Log(R)		-0.41			0.11	-0.01		
	R					-0.22	-0.04	-0.93	

We calculated the correlation coefficients between all the explanatory variables of equations 6 and 7. The regression results clearly indicate that R and $log(R)$ are significantly correlated together (Table 1). The high correlation and the P-value for variables $(M\text{-}m)^2$ and R show that they are insignificant variables. Considering the estimated unknown coefficients, their standard deviation and correlation coefficients, as well as P-values, we decided to use the Equation 6 as a model. The final results of regression based on WLS for the three types of CAV are presented in table 1.

CONCLUSIONS

Given the coefficients and weights presented in table 1, we have calculated CAV values and have compared them with distribution of observed CAVs (Figure 3).

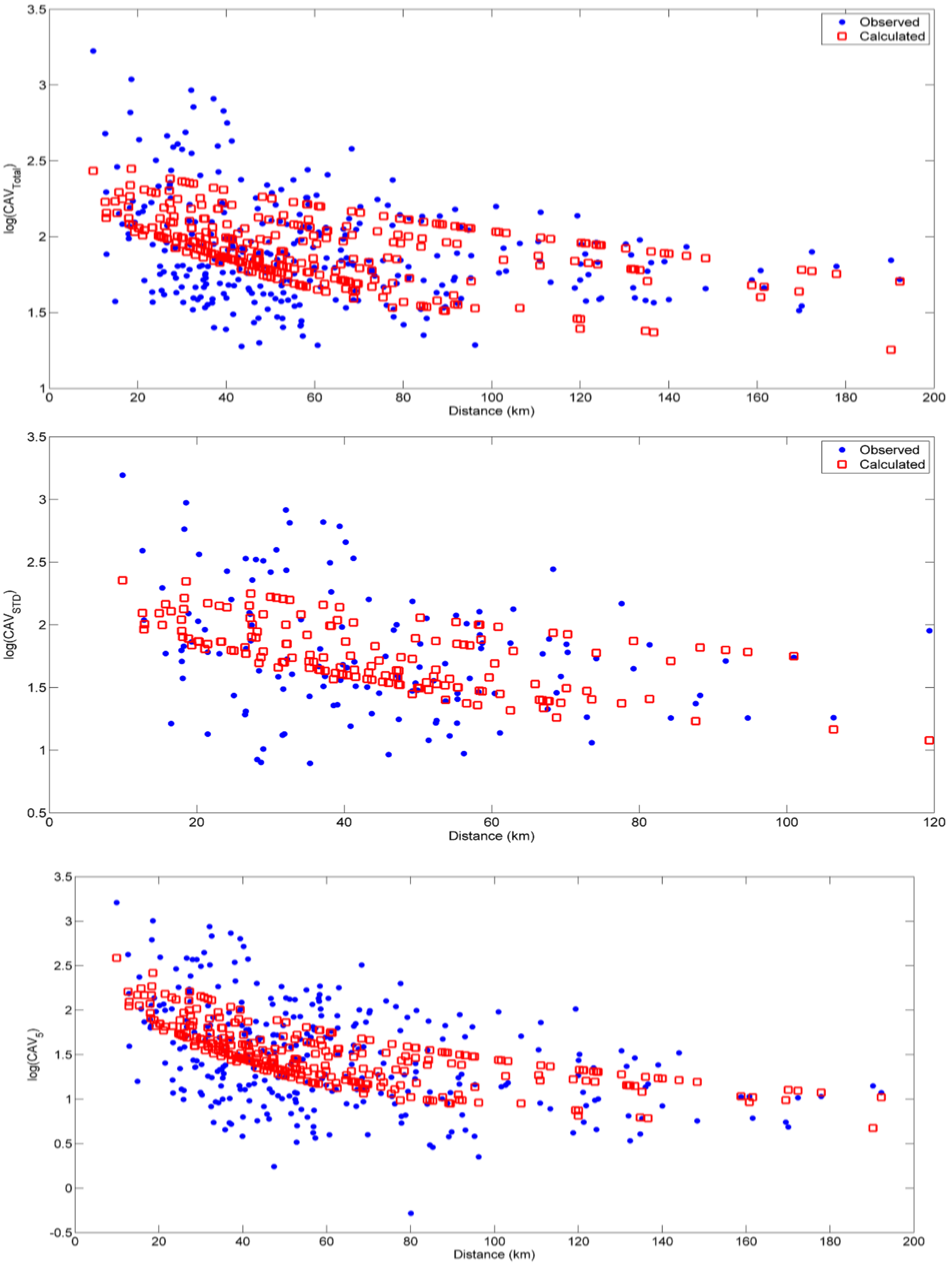

Figure 3. Calculated and observed CAV values versus distance

We also calculated residuals by subtracting logarithm of observed from logarithm of estimated values (Figure 4). Plotted residuals versus hypocentral distance indicates that they have an acceptable symmetry around baseline. CAV_{Total} has the highest R^2 and the lowest residual, and standard deviation of its fitting model is smaller than the others. It could be deduced, therefore, that CAV_{Total} is the most predictable version of CAV. On the other hand as could be seen in Figure 4 and Table 1, residuals of CAV_5 are greater than CAV_{Total} and CAV_{STD} and it indicates that CAV_5 is less predictable than other types of CAV. The longest hypocentral distance for CAV_{STD} data set is about 120 km, hence it is most unlikely that a nuclear power plant 120 km away from a seismic source in Zagros confront the exceedance of CAV_{STD} shutting down threshold.

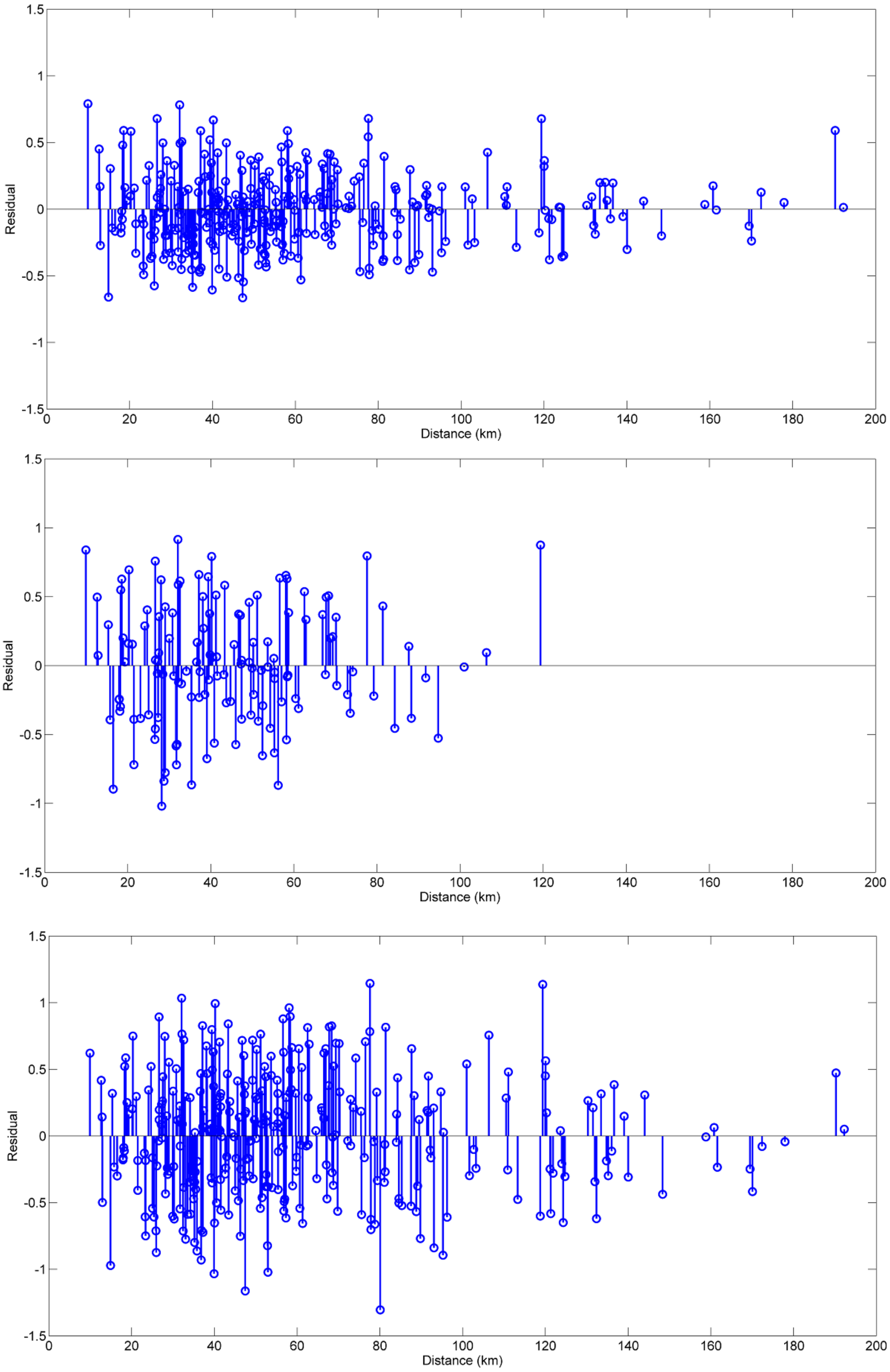

Figure 4. Residual versus hypocentral distance for CAV_{Total} (top), CAV_{STD} (middle), CAV_5 (bottom)

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