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SPECTRAL ATTENUATION CHARACTERISTICS OF STRONG GROUND MOTIONS IN EAST-CENTRAL IRAN USING THEORETICAL DATA

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ABSTRACT

Ground-motion prediction equations are an essential element of PSHA. In seismic hazard analysis, attenuation calculations determine how quickly ground motions decrease as the distance from a seismic event increases. The estimation of ground motion for future earthquakes as a function of magnitude and distance is an important problem from earthquake engineering point of view. This article presents spectral equations for the estimation of horizontal strong ground motions caused by shallow crustal earthquakes with magnitude range of M_w 5.0 to 7.4 and distance to the surface projection of the fault less than 100 km for theoretical (simulated) records. The reason for development of ground motion in this region is that strong ground motion data are too sparse to allow ground motion relations to be derived directly from sufficient observed data. By considering the modeling parameters, we have used the stochastic finite fault modeling to generate a large suite of acceleration time histories for this region.

The attenuation characteristics of horizontal spectral accelerations of strong motion in near-field are studied in this paper and the attenuation relations for horizontal acceleration response spectrum in the period range of 0.1–5 s for rock classification in the East-Central Iran are established. These equations were derived by two-stage regression analysis, on a set of 1200 theoretical strong-motion records generated in this area.

The present results will be useful in estimating strong ground motion parameters and in the earthquake resistant design in the East-Central Iran region.

INTRODUCTION

A more critical part of seismic design of structures is development of design ground motions. Methods are commonly used to develop these ground motions include: seismic zoning maps, site specific deterministic analysis and site specific probabilistic seismic hazard analysis. All this methods requires strong ground attenuation relationships to estimates earthquake ground motions from parameters characterizing the earthquake source, the propagation path and geological condition.

The equations generally predict median values of ground-motion parameters as a function of explanatory variables such as magnitude, distance, site classification and style-of-faulting. The reliability of all ground-motion prediction equations are strongly influenced by the characteristics of the dataset used to calibrate them. The optimal condition to obtain stable regressions would be to have a large amount of data with a wide distribution of magnitudes, distances and source mechanisms (Douglas, 2003). Unfortunately, this is a very rare case; in fact prediction equations are usually limited to the typical magnitude range observed in the study region that, in general, allows to derive empirical relationships only for strong motion data (Ambraseys et al. 2005 a,b; Sabetta and Pugliese, 1987,1996; Tento et al. 1992; Campbell, 1985; Douglas, 2003) or weak motion data (Frisenda et al. 2005; Massa et al., 2007).

In such areas of high seismicity, sufficient ground-motion data are available to perform a statistical fitting procedure for the purpose of developing an attenuation relationship in a seismic hazard analysis. There are insufficient ground-motion data to provide a complete database for developing an empirical attenuation relationship in the East-Central Iran.

Stochastic finite-fault modeling techniques that can be used to develop regional ground-motion prediction equations for both point sources and large faults have been extended and validated (Beresnev and Atkinson, 1997a, 1998b, 2002; Motazedian and Atkinson, 2005). As a result of developments in stochastic modeling, it is now feasible to use a finite-fault model to improve ground-motion predictions for larger earthquakes in the study region. The use of a finite-fault model is particularly important in improving the reliability of estimates for large-magnitude events at close distances.

STUDY REGION

Devastating events have occurred in the East-Central Iran in the recent past, which is a warning about the possibility of such earthquakes in future also. The active tectonic environment in Iran is related to the convergence of the Eurasian and Arabian plates. Indentation of the Arabian plate into a composite system of collision-oblique transpressive fold-thrust mountain belts has resulted in the lateral escape of central Iran towards the Lut Block, without a through-going high slip rate strikeslip fault like the San Andreas or the North Anatolian. The Kuh Banan, Nayband, Gowk, Sabzevaran, Bam, Neh and Rafsanjan strikeslip faults are the main active faults of the East-Central Iran. Despite the active deformation features along these faults in the Kerman plateau, there is a lack of seismicity and active deformation in the low-lying Lut Desert. The right-lateral shear along the western margin of the Lut block is directly transmitted between the Nayband, Lakarkuh, Kuh Banan, Gowk, and Bam fault systems (Fig. 1).

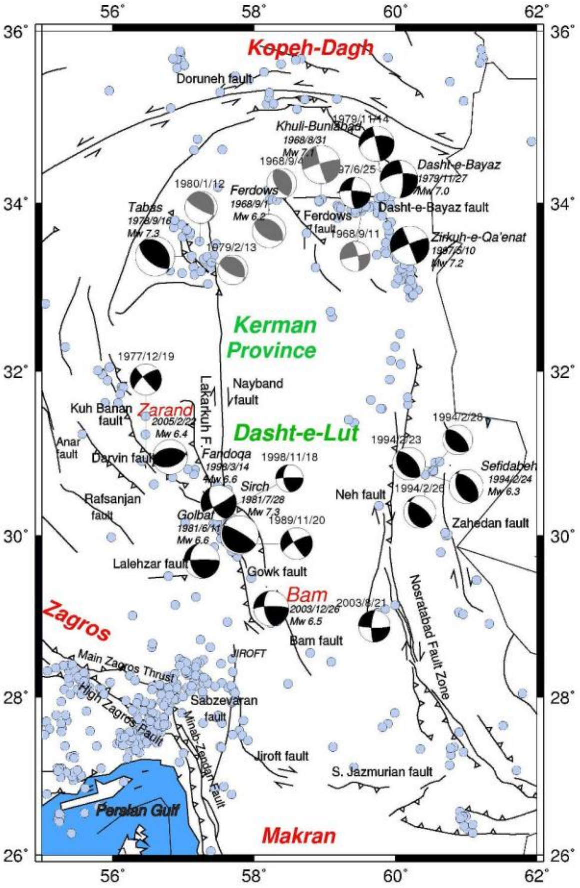

Fig. 1. Tectonic and seismicity of the East-Central Iran.

STRONG-MOTION DATA BASE

The strong ground motion data base considered in the present work consists of simulated earthquakes in the East-Central Iran. A total of 1200 strong-motion simulated accelerograms at distances less than 100 km are used to derive equations. Observed data in this region consist of 137 strong-motion accelerograms recorded at distances of up to 150 km from 24 earthquakes with moment magnitudes ranging from M_w 5.0 to 7.4.

The available observed dataset for this study is composed of 137 strong ground-motion data recorded since 1978 by regional strong motion seismology network operating in Iran, which has started its activities since 1973 in the organizational framework of the planning organization (Fig 1). to derive empirical ground motion models.

In Fig. 2, circles, the distribution of magnitude with distance of the 1200 simulated data and triangles, the distribution of magnitude with distance of the 137 observed data are shown. As shown in this figure, seismic data of the region (triangles) are insufficient for direct empirical regressions to obtain ground-motion relations and there is a shortage of ground motion data for large-magnitude earthquakes, and earthquakes at short distances. As stated by Douglas (2003) few earthquakes may be a limit in constraining the behavior of the ground motion equations. We use a stochastic finite-fault method, in which a large earthquake fault can be divided into smaller earthquake faults (subfaults). By applying stochastic Finite Fault Modeling, we can simulate the acceleration time series for large earthquakes at any distance (circles). In this approach, a stochastic model is first used to generate a set of generic artificial waveforms for different magnitudes and distances. Recorded data were used to determine key attenuation parameters, such as regional Q, duration behavior, geometric attenuation behavior and generic site amplification. Key attenuation parameters were applied in stochastic finite fault modeling.

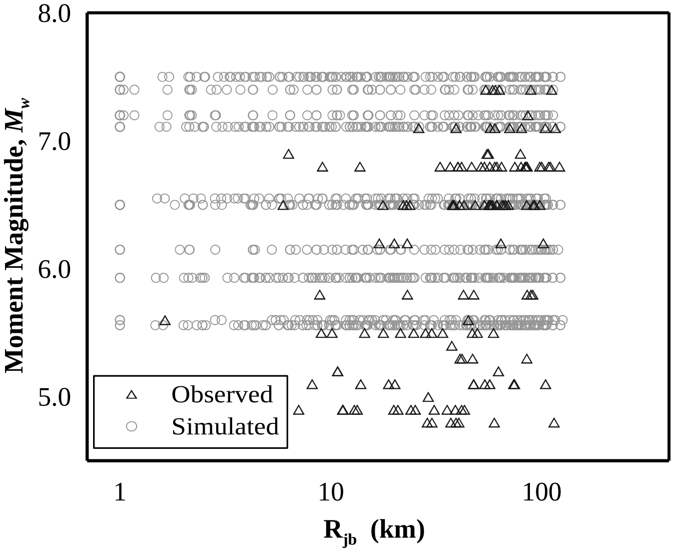

Fig. 2. Distribution of the observed and simulated data with respect to magnitude and distance.

Acceleration response spectra, PSA, were calculated for 14 periods ranging from 0.1 s to 5 s and standard damping of 5% was applied.

Ground-Motion Relations

The attenuation is typically considered a function of the magnitude of the event, the frequency being considered, and geological conditions between the event and the site. The equation we selected to represent the ground-motion relations for the average horizontal component of PGA and PSA is given by

$$LogY = a + b(M_w - 6) + c(M_w - 6)^2 + d({r_{jb}}^2 + h^2)^{1/2} + \varepsilon_r + \varepsilon_e \tag{1}$$

$$\varepsilon_e(i) = \sum_{1}^{k} \varepsilon_r(k)/n \tag{2}$$

$$\varepsilon_r(k) = y_{observed}(k) - y_{predicted}(k) \tag{3}$$

In first equation, Y is the average horizontal component, of PGA or 5% damped PSA in g (g =981 cm/sec^2); M is moment magnitude; r_{jb} is the closest distance to the surface projection of fault rupture in *km* (Boore et al., 1997); h=7.0 (average depth of ECI earthquakes); a, b, c and d are frequency-dependent parameters to be determined. Residuals for ith event and kth record are described by ε_e and ε_r, respectively, and n is number of records in each event.

The coefficients of the models have been determined using functional forms with an independent magnitude decay rate and applying the random effects model (Abrahamson and Youngs, 1992; Joyner and Boore, 1993) that allow the determination of the inter-event, inter-station and record-to-record components of variance. The goodness of fit between observed and predicted values has been evaluated using the maximum likelihood approach as in Spudich et al. (1999).

RESULTS

Analysis of the present dataset largely follows the method adopted by Joyner and Boore (1993). The coefficients in the Eq.1 for predicting ground motion were determined by using nonlinear regression analysis. Nonlinear regression is a method of finding a nonlinear model of the relationship between the dependent variable and a set of independent variables. Unlike traditional linear regression, which is restricted to estimating linear models, nonlinear regression can estimate models with arbitrary relationships between independent and dependent variables. This is accomplished using iterative estimation algorithms. This exercise was performed separately on PGA and PSA data at each oscillator period considered (total of 14 periods from 0.1 to 5.0 s).

The coefficients for estimating the maximum horizontal-component pseudo-acceleration response by Eq.1 are given in Table 1 for rock classification. Because of shortage in knowledge of site condition and site amplification, the site classification used in this study is very basic and only Rock.

Table 1. Coefficients and Statistical Parameters from the Regression Analysis of PGA and PSA

$LogY=a+b(M_w - 6)+c(M_w - 6)^2 + d({r_{jb}}^2 + h^2)^{1/2} + \sigma \quad h=7$					
Period	a	b	c	d	σ
PGA	2.615	0.310	-0.0455	-0.0126	0.33
0.1	2.830	0.295	-0.0682	-0.0225	0.35
0.2	2.936	0.259	-0.0666	-0.0154	0.32
0.3	2.855	0.308	-0.0777	-0.0182	0.36
0.4	2.757	0.369	-0.0913	-0.0216	0.34
0.5	2.662	0.406	-0.0985	-0.0144	0.33
0.6	2.598	0.439	-0.0107	-0.0154	0.37
0.7	2.497	0.448	-0.0109	-0.0141	0.29
0.8	2.451	0.4.80	-0.0113	-0.0132	0.35
0.9	2.374	0.514	-0.0108	-0.0134	0.34
1.0	2.303	0.523	-0.0961	-0.0129	0.32
2.0	1.859	0.619	-0.0861	-0.0215	0.34
3.0	1.580	0.665	-0.0664	-0.0196	0.36
4.0	1.344	0.690	-0.0535	-0.0227	0.33
5.0	1.185	0.709	-0.0511	-0.0218	0.37

For the model to be unbiased, the residuals should have zero mean and be uncorrelated with respect to the parameters in the regression model. Amplitude residuals are, on average, relatively small and do not appear to vary significantly with hypocentral distance and magnitude and regression models are unbiased with respect to these two parameters (Campbell and Bozorgnia, 2000, 2003).

The resulting ground-motion relations for selected response spectral ordinates are plotted in Figure 3. In this Figure, PGA, PSA at 0.2 and 1.0 s are shown versus r_{jb} for magnitude range of 5.0-7.5.

DISCUSSION

The work presented in this article provides an important framework for developing regional ground-motion relations and indicates that we cannot simply rely on ground-motion attenuation models from other regions for Iranian earthquake hazard and risk assessments. Attenuation parameters derived in these empirical studies are currently being used as key inputs for stochastic models to predict ground motions for larger-magnitude events. The attenuation behavior of small to moderate earthquakes over a wide range of distances can be

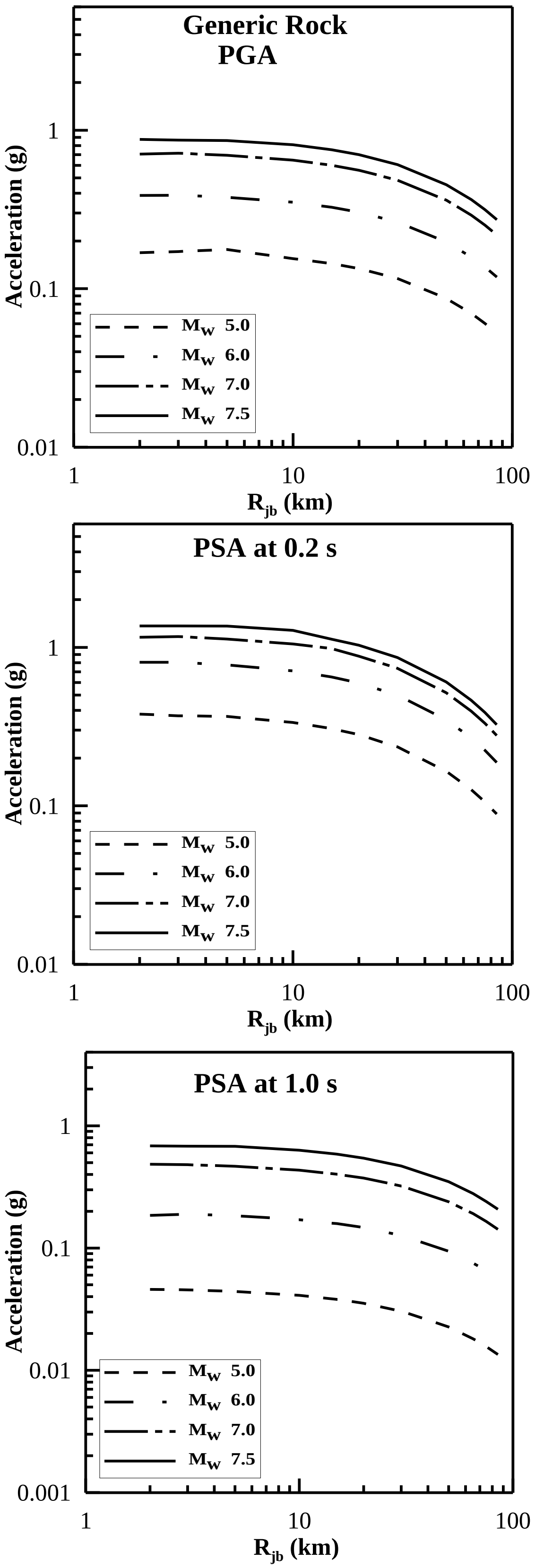

Fig. 3. Ground-motion relations for the rock site for PGA, PSA

obtained from real records, but they are insufficient to establish key attenuation parameters.

The stochastic method has been used to derive ground-motion relations for many different regions such as eastern North America (ENA) and California. The developed ground motion relations for East-Central Iran are validated using available seismographic data, and compared to ground motion relations for other regions. We compared our new ground-motion relations with some ground-motion relations that are widely used to estimate horizontal response spectra for seismological and engineering analyses in non-extensional regions of western North America (WNA) and other world regions. (Abrahamson and Silva, 2007; Boore et al., 1997; Ambraseys et al., 1996; Campbell and Bozorgnia, 2003, 2007; Zare et al., 1999; Ohno et al., 2001; Zhao et al., 2005). All of these relations represent a seismically active, shallow-crustal tectonic environment, consistent with our study.

The standard deviation of the residuals expresses the random variability of ground motions, which is an important parameter for earthquake hazard analysis. The standard deviation of residual is from 0.37 to 0.41 by considering observed data (Table 1).

As mentioned by Fukushima (2003), each different tectonic environment should be associated with one specific ground motion attenuation relationship. In fact, however, three categories of regional ground motion attenuation relationship are typically used in seismic hazard assessments [Abrahamson and Shedlock, 1997]:

(i) Shallow crustal earthquakes in active tectonic regions (e.g. western North America, but also Italy, Turkey, Algeria, and Greece).

(ii) Shallow crustal earthquakes in stable continental regions (characterised by high stress drops, high *Q* values, and therefore high-frequency ground-motions as experienced during the Saguenay, Canada, earthquake).

(iii) Subduction zone earthquakes (characterized by deep events).

The developed ground motion relations for the study region are compared with recent published attenuation relationships figure 4 compare the predicted median spectral acceleration from the selected ground-motion relations with that predicted from our ground motion relations for a site located at a distance of 10 km.

The values of the attenuation relationship developed in this study for PGA is similar to the Zhao et al. (2005) and Campbell and Bozorgnia (2003) relationships.

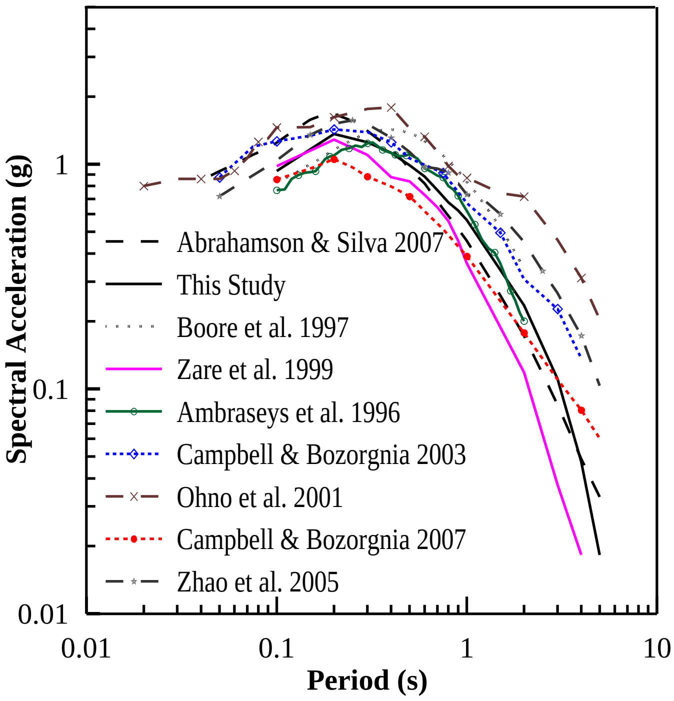

Fig. 4. Comparison of 5% damped acceleration response spectra predicted from eight widely used empirical ground-motion relations in seismology and engineering for generic rock. The comparison is for Mw 7.0 and a distance of 10 km.

CONCLUSIONS

The recommended attenuation relationships are considered to be appropriate for estimating horizontal component of peak ground acceleration and response spectra for 5% damping for rock site for the East-Central Iran. In this study, the first theoretical attenuation relationship developed for the study region based on simulated records by using stochastic finite fault model. The theoretical attenuation relationship for horizontal component of peak ground acceleration and spectral acceleration are applicable to earthquakes of M_W 5.0 to 7.4 at a distance of up to 100km.

REFERENCES

Abrahamson, N.A. and W.J. Silva [1997]. "*Empirical Response Spectral Attenuation Relations for Shallow Crustal Earthquakes",* Seismological Research Letters, Vol. 68, No. 1, 94-127.

Abrahamson, N.A. and K.M. Shedlock [1997]. "*Overview*", Seism. Res. Lett. 68,9-23.

Ambraseys, N.N., and A. Simpson [1996]. "*Prediction of vertical response spectra in Europe",* Earthq. Eng. Struct. Dynamics 25, 401-412.

Boore, D.M., W.B. Joyner, and T.E. Fumal [1997]. "*Equations for estimating horizontal response spectra and peak acceleration from western North American earthquakes"*: a summary of recent work, Seism. Res. Lett. 68, 128–153.

Campbell, K.W., and Y. Bozorgnia [2000]. "*Vertical ground motion: characteristics, relationship with horizontal component, and building-code implications",* Contract Number 1097-606, Final Report, Prepared for the California Strong-Motion Instrumentation Program, Sacramento, California

Campbell, K.W., and Y. Bozorgnia [2003]. "*Updated Near-Source Ground-Motion (Attenuation) Relations for the Horizontal and Vertical Components of Peak Ground Acceleration and Acceleration Response Spectra",* Bull. Seism. Soc. Am., 93 (1), 314-331.

Campbell, K.W., and Y.Bozorgnia [2008]. "*NGA ground motion model for the geometric mean horizontal component of PGA, PGV, PGD and 5% damped linear elastic response spectra for periods ranging from 0.01 to 10 s",* Earthquake Spectra 24, 139– 171.

Fukushima, Y. [2003]. "*Attenuation Relation for West Eurasia Determined with Recent Near-Fault Records from California, Japan and Turkey",* J. Earth. Eng., 7(4), 573-598.

Ohno, S., Takahashi, K. and M. Motosaka [2001]. "*Empirical estimation of Horizontal and Vertical Motions based on California Earthquake Records and its Application to Japan Inland Earthquakes",* Journal of Struct. Construct. Eng. (Transactions of AIJ), No. 544, 39-46 (in Japanese).

Zare, M, and H. Hamzehloo [2005]. "*Strong ground motion measurements during the 2003, Bam, Iran, earthquake",* Earthquake Spectra,Special issue 1, pp. S165- S 179