THE ENERGY CONTENT OF THE STRONG GROUND MOTIONS IN IRAN

Mehdi ZARE[1]

SUMMARY

The energy content is investigated for the first time for the strong motions in Iran. The parameters such as A_{rms} and energy of acceleration are calculated for a data set of 468 three component accelerograms, all recorded during the last 24 years in Iran. During the observation period (1975-1997), the data correspond to stronger earthquakes in central Iran and Alborz region, meanwhile in Zagros belt the seismic activity relates to moderate magnitudes ranges (M4-6). The seismic activity rate was higher in Zagros than the other areas; therefore the quantity of the data in Zagros region is about twice the rate of the rest of the country. The empirical relationships are established based on the energy of acceleration and a_{rms} , and a difference is obvious between the results of study on Zagros data and on the data coming from the rest of the country (mainly Alborz and Central Iran). This difference may correspond to different seismic activity rates or attenuation. The effects of the site conditions on the energy variations are looked for, but no important dependence is found in this regard.

INTRODUCTION

The strong motion network in Iran has provided a significant amount of records from various regions of the country for the last 24 years. This network was equipped first with Kinemetrics SMA-1 analog instruments (1975) which have been gradually replaced and densified with SSA-2 digital instruments after the Manjil earthquake of 1990, Mw7.4, in NW Iran. The number of installed instruments in this network was reported to be about 1000 stations by the end of 1997. The stations have been mainly chosen within the cities or villages for an easy maintenance. A listing of these data is published by BHRC, the organism that maintains this network presently in Iran (BHRC 1993).

The scope of this study is to investigate the energy content of Iranian data, and to derive empirical relationships for the energy-related parameters: root mean square acceleration; a_{rms} and the "energy of acceleration"; e_a, proportional to Arias Intensity. The data-set used in this study, already presented in Bard et al (1998), Zaré et al (1999a), consists of 468 three component records. The source parameters come from the teleseismic records for 190 events (279 recordings) (Bard et al 1998), while moment magnitudes and hypocentral distances were derived from the strong motion data themselves for 185 events (189 records) (Zaré et al 1999a).

INUT DATA

Some differences in seismicity rates are obvious at least between the two regions of Iran: Zagros in SW and west, and Alborz-Central Iran, in the center, north and east. The Zagros thrust fault zone is the main

geologic frontier between the Zagros and the rest of the country (mainly; Central Iran). The time of the event, the hypocentral distance to source and the exact timing on the digital records (if accessible) were the criteria to attribute each record to the seismic events in these zones. In the Zagros area the middle range magnitudes (M4-6) are more frequent (Figure-1). In Alborz-Central Iran zone, the earthquakes are less frequent with higher magnitudes than Zagros. The surface faulting is rare in the Zagros region according to the existence of the

[1] *Seismology Research Center, International Institute of Earthquake Eng and Seismology, Email: mzare@dena.iiees.ac.ir*

incompetent layers in the crust. The crust in the central-Iran and Alborz region is geologically older and more deformed. The Tabas earthquakes of (1978, Mw7.4, Central-Iran) and Manjil earthquake (1990, Mw7.3, Alborz belt) are examples of such destructive events. Most of the focal mechanisms in Iran (in Zagros and in other regions) are compressional and strike slip (Bard et al 1998) in relation with the local plate tectonics context.

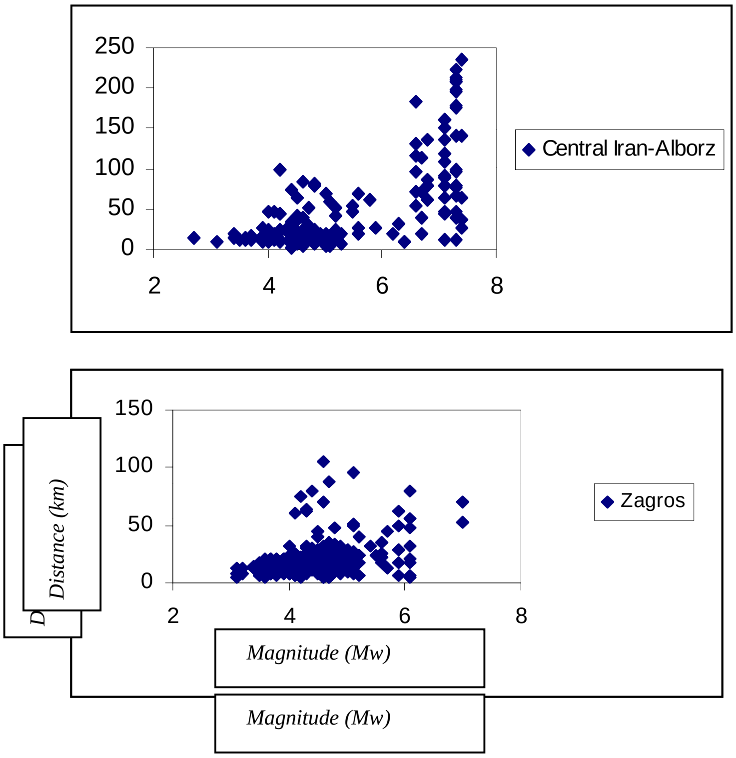


Figure 1: The quantity of the Iranian data used in this study in Central Iran, Alborz (up) and Zagros (down). The hypocentral distance is used.

The accelerometric data-base of Iran (Bard et al 1998) is not homogeneous; most of the data are recorded in Zagros. Since the most destructive earthquakes have shocked the Alborz and Central-Iran region, the most distant records (up to 230km) are obtained in these two regions but the records from the Zagros regions recorded mostly from the events by the distances of less than 100km (Figure-1).

The site conditions for the Iranian strong motions have already studied (Zaré et al 1999b). Site class 1 is defined as sites that do not exhibit any significant amplification below 15 Hz. It corresponds to rock and stiff sediment sites with an average S-wave velocity over the top 30 meters in excess of 700m/sec. Site class 2 determined as sites for which the receiver function (RF) exhibits a fundamental peak exceeding 3 at a frequency located between 5 and 15 Hz. It was shown to correspond to stiff sediments and/or soft rocks with Vs_{30} between 500 and 700 m/sec. Site class 3 is representative for the sites for which RF shows the peaks between 2 and 5Hz and corresponds to the alluvial sites with Vs_{30} between 300 and 500 m/sec. Finally site class 4 is defined as sites for which RF indicates the peaks in frequencies below 2Hz, and it

may be viewed as corresponding to thick soft alluvium. This ranking was the result of the geotechnical measurements on 24 sites (compressional and shear wave velocity and microtremors) and the calculation of the receiver function for the strong motions using the three component accelerograms.

METHODOLOGY

The definition of cumulative duration" (Bullen and Bolt 1985), which is based on the concept of the cumulative energy obtained by integrating the squared accelerations is considered in this paper. In this concept, duration is the time interval required to accumulate a predefined fraction of total energy (95% for Husid et al (1969); 90% for Trifunac and Brady (1975)). Trifunac and Brady (1975) take the part between of 5% and 95% of total energy.

The Fourier amplitude spectra $A(\omega)$ of an acceleration time-history, $a(t)$, is the modulus value of the Fourier transform of $a(t)$ (Vanmark and Lai 1980);

$$A(\omega) = \left| \int_{-\infty}^{+\infty} a(t) e^{-i\omega t} d(t) \right| = \left| \int_{0}^{t_0} a(t) e^{-i\omega t} d(t) \right|$$

ω is the angular frequency in rad/sec, $i = \sqrt{-1}$ and t_0 is the length of the accelerogram (sec). To explain how the total energy of the strong motion is distributed over frequency, one may use the squared Fourier amplitude spectrum, $A^2(\omega)$. The integral of $A^2(\omega)$ over the frequencies is a representative for the total strong motion "energy", related to the Arias intensity, I_0 [Arias (1970)]. This parameter shows the total energy per unit mass for the entire acceleration record for all single degree of freedom oscillators;

$$I_0 = \frac{\pi}{2g} \int_0^{t_0} a^2(t) dt$$

In this article a formulation near to such definition is followed as:

$$e_a = \int_0^{t_0} a^2(t) dt = \int_{-\infty}^{+\infty} a^2(t) dt = \frac{1}{2\pi} \int_{-\infty}^{+\infty} A^2(\omega) d\omega = \frac{1}{\pi} \int_0^{\infty} A^2(\omega) d\omega.$$

Such quality is named as the "energy of acceleration" (e_a):

$$e_a = \int_0^{t_0} a^2(t) dt$$

a_{rms} is the square root of the average of the squared ordinates for a given duration, t_2-t_1, (Udwadia and Trifunac 1974):

$$a_{rms} = \left(\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a^2(t) dt \right)^{1/2}$$

$$a_{rms} = \sqrt{\frac{\sum e_a}{t_2 - t_1}}$$

RESULTS

The values of a_{rms} and e_a are calculated for 468 three component records (processed already in Zaré 1999), and the attenuation of these parameters studied.

Attenuation of a_{rms} and e_a

The empirical attenuation relationships for a_{rms} and the energy of acceleration (e_a) are similarly obtained, applying a two-step regression, using the magnitude, distance and the site factors as the dependent variables. The method to establish such relationships for Iran was followed essentially after Joyner and Boore (1981) and Fukushma and Tanaka (1990). This method is used to fit a model to multiple independent variables (magnitude, distance, site,…). Hence, using this method, it is possible to do the regression for the dependence to magnitude and the dependence to distance, as well as the dependence to other terms, separately. In this method the parameters controlling distance and site effects dependence and a set of the amplitude factors, one for each event, must be determined in the first step, by maximizing the likelihood of the set of the observation. The determination of the parameters controlling the magnitude dependence is then performed in a second step, by maximizing the likelihood of the set of the amplitude factors (Boore et al 1993). The applied formula is:

$$\log A = a \cdot M_w + b \cdot X - d.\log X + c_i \cdot S_i + \sigma \cdot P \qquad (1)$$

where A is the strong motion parameter, a is the coefficient for moment magnitude; M_w, b is the coefficient related to anelastic attenuation; c_i is a constant which represent the 4 site classes (Zaré et al 1999a); S_i. The d coefficient for the logX is to investigate the geometrical expansion with distance. This coefficient is fixed to 1 and 0.5 corresponding to pure body and surface waves, respectively. The coefficients of the regression using the relationship (1) are presented in tables 1 and 2 for a_{rms} and e_a, respectively.

Table-1: The coefficient for the attenuation of a_{rms}, applying equation (1), with d=1

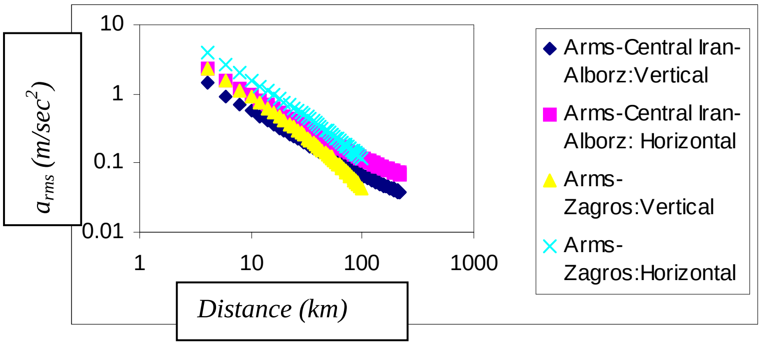
Region/comp.	a	b	c1	c2	c3	C4	Sigma
Alborz-C. Iran-(Vert.)	**0.367**	**0.0008**	**-1.836**	**-1.821**	**-1.819**	**-1.785**	**0.328**
Alborz-C. Iran-(Hori.)	**0.383**	**0.0010**	**-1.713**	**-1.610**	**-1.677**	**-1.727**	**0.350**
Zagros–(Vert. Comp.)	**0.438**	**-0.0036**	**-2.077**	**-2.116**	**-2.022**	**-1.997**	**0.352**
Zagros–(Hori. Comp.)	**0.458**	**-0.0015**	**-1.992**	**-1.962**	**-1.971**	**-2.034**	**0.341**
Iran data- (Vert.)	**0.324**	**0.0010**	**-1.553**	**-1.420**	**-1.642**	**-1.514**	**0.350**
Iran data- (Hori.)	**0.317**	**0.0011**	**-1.350**	**-1.081**	**-1.333**	**-1.244**	**0.401**

Table-2: The coefficient for the attenuation of e_a, applying equation (1), with d=1

Region/comp.	a	b	c1	c2	c3	c4	Sigma
Alborz-C. Iran-(Vert.)	**0.848**	**-0.0040**	**-4.509**	**-4.501**	**-4.480**	**-4.359**	**0.572**
Alborz-C. Iran-(Hori.)	**0.881**	**-0.0037**	**-4.353**	**-4.176**	**-4.236**	**-3.286**	**0.582**
Zagros–(Vert. Comp.)	**0.953**	**-0.0159**	**-4.777**	**-4.808**	**-4.643**	**-4.556**	**0.617**
Zagros–(Hori. Comp.)	**0.982**	**-0.0113**	**-4.655**	**-4.543**	**-4.488**	**-4.635**	**0.586**
Iran data- (Vert.)	**0.802**	**-0.0036**	**-4.134**	**-4.093**	**-4.370**	**-4.069**	**0.591**
Iran data- (Hori.)	**0.815**	**-0.0035**	**-3.963**	**-3.678**	**-3.986**	**-3.725**	**0.628**

As it is evident from the c1 to c4 coefficients in tables-1 and 2, the site effects were not very important in these regressions. The attenuation of the estimated values using (1) with the coefficients of table-1, estimated for the magnitude Mw=7 for different distances and on the rock sites in figures 2 and 3, for a_{rms} and e_a, in Alborz-Central Iran, Zagros and entire of the data-base, respectively. The results show that taking d=1 (body waves attenuation) induce greater estimations for the near-source distances (less than 20km). Using d=0.5 (surface waves attenuation), the greater values obtain at distances more than 60km, for the Alborz-Central Iran and entire of the data-base). According to the lesser data for the greater distances and a

conservative approach for the near field distance, it is suggested to use the coefficients with d=1 for e_a and a_{rms} . However special studies are recommended for the near-field of the great magnitude events, using a deterministic approach on the records obtained in similar conditions.



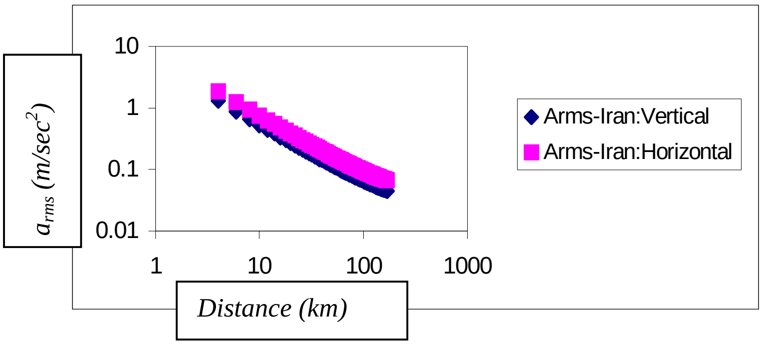


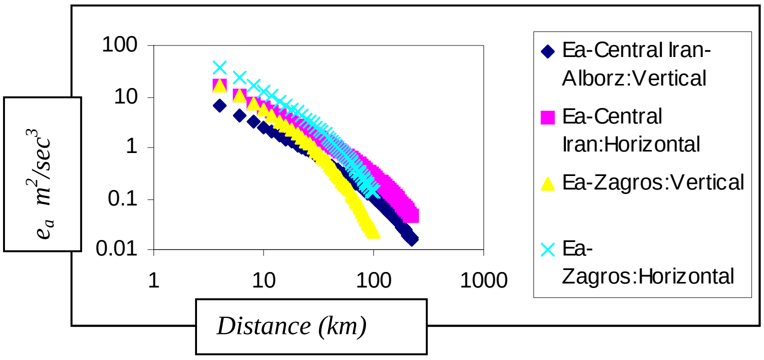
Figure 2: The attenuation of a_{rms} for a magnitude M_w= 7 in Central Iran, Alborz and Zagros (up) and Iran (entire of the data-base) (down) using equation (1) and the coefficient of table 1. The hypocentral distance is used.

CONCLUSION

This article presented investigations on the energy contenton the Iranian strong motion data. All results are detailed in Zaré 1999. The conclusions and the propositions for the further studies may be summarized as follows;

The content of energy of the strong motions is different in Zagros area and the rest of the country. This difference comes partially from the difference in the seismicity rates in Zagros belt, or other reasons.

The attenuation of a_{rms} and e_a show some differences in the estimations in the near and far source distances. The limits for the application of such relationship must be considered in the future: the attenuation coefficients for the Zagros area give proper results in the distances less than 50km, and for the Alborz-Central Iran region in the distances less than 200km. The entire of the data-base might be used in distances up to 170km. The magnitude limits are the Mw3.0 to Mw7.4 for Alborz-Central Iran and M_w3.0 to M_w7.0 for Zagros region.



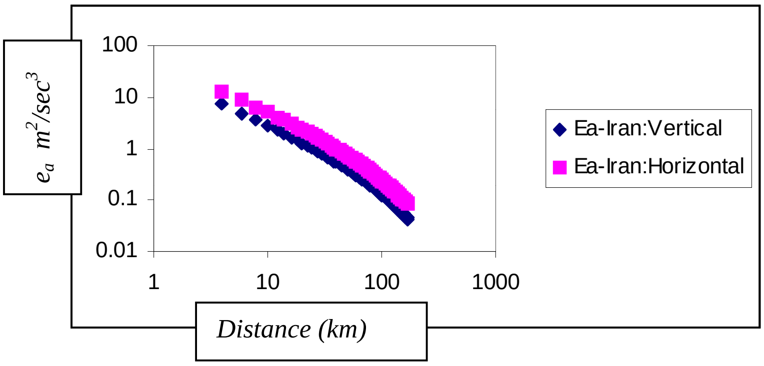


Figure 3: The attenuation of e_a for a magnitude M_w= 7 in Central Iran, Alborz and Zagros (up) and Iran (entire of the data-base) (down) using equation (1) and the coefficient of table 2. The hypocentral distance is used.

ACKNOWLEDGMENTS

The contributions of Drs Pierre-Yves Bard and Mohsen Ghafory-Ashtiany to this study and their useful comments are greatly acknowledged. The BHRC (Building and Housing Research Center, Tehran) who have released the raw strong motion records is greatly thanked. A financial support in France was provided by a French scholarship (Ministère Français des Affaires Etrangères) is duly acknowledged. The financial support in Iran was provided by IIEES (International Institute of Earthquake Engineering and Seismology), which is thanked.

REFERENCES:

Arias A. (1970), A Measure of Earthquake Intensity, in Seismic Design of Nuclear Power Plants, R.J. Hansen Editor, M.I.T. press.

Bard P.-Y., M. Zaré and M. Ghafory-Ashtiany. (1998), The Iranian Accelerometric Data Bank, A Revision and Data Correction, Journal of Seismology and Earthquake Engineering, Vol.1, No.1, pp1-22.

Boore D. M., W.B. Joyner and T.E. Fumal. (1993), Estimation of Response Spectra and Peak Accelerations from Western North American Earthquakes: An Interim Report, U. S. Geol. Survey, Open-file report: 93-509. 72.p.

Building and Housing Research Center. (1993), A Collection of the Accelerogram Network of the Islamic Republic of Iran, Pub. No#179, 173p.

Bullen K. E. and B. A. Bolt. (1985), An Introduction to the Theory of Seismology, Cambridge Univ. Press, 4th Edi., 499 p.

Husid R., H.Median and J. Rios. (1969), Analysis de terremotos Norteamericanos y Japonsesses, Revista del IDIEM 8, Chile.

Joyner W.B. and D. M. Boore. (1981), Peak Horizontal Acceleration and Velocity from Strong Motion Records from the 1979 Imperial Valley, California, Earthquake, Bul. of Seismological Soc. of America, Vol.71, No.6, pp.2011-2038.

Trifunac M.D. and A.G. Brady. (1975), A Study on the Duration of the Strong Earthquake Ground Motions, Bull. Seismol. Soc. of America, Vol.65, No.3, pp.581-626.

Udwadia F.E. and M.D.Trifunac. (1974), Characterization of the Response Spectra through the Statistics of Oscillator Response, Bull. Seismol Soc. of America, Vol.64, No.1, pp.205-219.

Zaré M., P-Y. Bard, M.Ghafory-Ashtinany. (1999a), Moment Magnitude for the Strong Motion Accelerograms in Iran, submitted to the Journal of Pure and Applied Geophysics, 22 pages.

Zaré M., P-Y. Bard, M.Ghafory-Ashtinany. (1999b), Site Characterizations for the Iranian Strong Motion network, Journal of Soil Dynamics and Earthquake Engineering, Vol.18, no.2, pp.101-123.

Zaré M. (1999), Contribution à l’étude des mouvements forts en Iran; du catalogue aux lois d’atténuations, PhD thesis, Université Joseph-Fourier, Grenoble, France, 237pages.