Technical Note

Spectral Attenuation of Strong Motions for Near Source Data in Iran

M. Zaré[1], S. Karimi-Paridari[2], and S. Sabzali[3]

1. Associate Professor, Seismology Research Center, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, I.R. Iran, email: mzare@iiees.ac.ir
2. PhD Candidate, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, I.R. Iran
3. MSc Graduate in Earthquake Engineering, International Institute of Earthquake Engineering and Seismology, Perdis Ruz Consulting Engineers, Tehran, I.R. Iran

ABSTRACT

In this paper the attenuation of Iranian strong motions is studied using Iranian strong motions database. This database comprises more than 6000 well recorded three-components data (analog and digital) for which the teleseismic source parameters were available, or calculated by the records. Here, the one-step regression method is used in order to develop the attenuation model. The spectral values of the recorded strong motions in Iran are used to derive the empirical attenuation laws for different response spectral ordinates at different site conditions. The empirical relationships are established for the spectral acceleration as the function of moment magnitude, hypocentral distances, and constant parameter representing the site conditions. The data set consists of 87 three component accelerograms, all recorded in 1975-2003. In this paper the attenuation coefficients are in general accordance with the previous attenuation coefficients established for Iran. However, the spectral values, obtained here, are greater in comparison with those gained by the previous studies (1999 and 2006). The difference might be due to selecting greater motions, recorded in the distances nearer to the seismic source.

Keywords:
Attenuation;
Spectral;
Iran;
Strong motion;
Site condition;
Acceleration;
Near source

1. Introduction

The Iranian strong motion records are obtained by a national network operated by *BHRC* (Building and Housing Research Center) [7] installed in different cities and villages in Iran since 1973. The network first was started by Kinemetrics *SMA*-1 analog instruments (1975-1989), and then developed by installation of *SSA*-2 digital instruments after the Manjil earthquake, 1990. By the end of May 2006, the number of the instrument was reported to be 1100 stations, in which more than 6300 three component accelerograms are obtained. The first complete catalog was presented in Bard et al [3].

This study is to investigate spectral attenuation law for Iran, using the response spectra of Iranian strong motion data in the form of different parameters. It is to establish the empirical relationships for the strong motions and to study the changes in different regions of the country, regarding attenuation law.

2. Attenuation Model

Establishing the attenuation relationships for a certain region may provide information applicable in other similar regions. Meanwhile, an attenuation relationship, as an empirical model fitted to the data of a specific area, may not be easily used in other regions with different tectonic and crustal specifications [1-2].

3. The Applied Approaches

To establish the attenuation relationships for Iran, the approach presented by Joyner and Boore [8] and Fukushma and Tanaka [8] was followed. A one-step regression is used to fit a model to multiple independent variables (magnitude, distance, site parameters,...). In the two-stage methods, the parameters controlling distance dependence and a set of amplitude factors, one for each earthquake, are determined in the first stage, by maximizing the likelihood of the set of observations. The parameters controlling magnitude dependence are then determined in the second stage by maximizing the likelihood of the set of amplitude factors [10].

In the one-step method, all parameters are obtained simultaneously by maximizing the likelihood of observations. This approach is used by Joyner and Boore [9] and Brillinger and Pristler [6], yielding the results similar to the two-step method for the spectral ordinates using the north-western American data [4].

4. Fundamental Form

The genuine form of the dependence is:

$$Log A = a.M + b.R - d.Log R + ci.Si + \sigma P \qquad (1)$$

where, A is the strong motion parameter, a is the magnitude coefficient, M is the magnitude, b is the distance coefficient showing inelastic attenuation, R is the distance, c is the site class coefficient, S is the site class, σ is 84 percent (P = 1) to be added to the mean (50 percent values; P = 0), d is the coefficient for *logR* introduced to allow a geometrical expansion which may be different from the body wave dependence. In this study the moment magnitude (*Mw*) is used for M and the hypocentral distance for X. The *ci.Si* expression is to show the site effects for 4 site classes that are already defined by Zaré et al [12]. In short, site classes are assigned to the sites of fundamental frequencies; over 15*Hz* for site class 1; 5-15*Hz* for site class 2; 2-5*Hz* for site class 3; below 2*Hz* for site class 4.

5. Ground Motion Parameters

The regressions were performed for various ground motion parameters for the spectral accelerations, *Sa*(*T*). The regression on *Sa*(*T*) was fulfilled for 7 different periods between 0.1 and 2*sec*. found for the damping of %5. The general form of the attenuation relationship for the spectral acceleration (*Sa*) is;

$$Log\, Sa(T) = a(T).M + b(T).R - Log R + ci(T).Si + \sigma(T).P \qquad (2)$$

In the present study another form of this relation is used based on better accordance with the input data. This formula is already used by Boore et al [5];

$$ln\, Sa(T) = b_1(T).Si + b_2(T)(M-6) + b_3(T)(M-6)^2 + b_5(T).Ln R + \sigma Sa(T).P \qquad (3)$$

b_2 and b_3 are assumed as constant coefficients; here, only b_1 and b_5 are calculated for different site types.

6. The Input Database

The database, used as the input for this study, consists of 87 three components accelerograms, see Table (1), recorded between 1975 and Dec. 2003 by National Iranian Strong Motion Network. The moment magnitude and hypocentral distance are estimated for these records directly by the strong motion records. The hypocentral distance is obtained by the *S-P* time difference, while the seismic moment is directly calculated by the level of acceleration spectra plateau and the corner frequency [11].

The spectral values of selected records are used to derive the empirical attenuation laws for different response spectral ordinates in different site conditions, see Table (1). The strong motions are selected based on their peak acceleration values (having the *PGA* of 0.05*g* on at least one component) and the good signal quality in the frequency band of 0.3*Hz* or lower. The empirical relationships are established for the spectral acceleration as the function of moment magnitude, hypocentral distances and constant parameter, representing the site conditions. The data are splited into two subsets corresponding to two geographical areas: 1. central Iran and Alborz region 2. Zagros region, according to the strong earthquakes recorded at 60*km* distances (1975-2003). The soil effects are considered in the regressions, mainly based on an assessment of site classes. The basis of these site classes is the fundamental frequencies obtained by *H/V* amplification functions. The results presented in this paper are the coefficients obtained for all data (89 records) selected including the data of Alborz-Central Iran and Zagros.

Table (1) contains the records obtained by *BHRC* code, column 2; station name, column 3; latitude and longitude of the station coordinates are in column 4 and 5, respectively; site classes, column 6; applied band-pass filter, column 7; peak acceleration values for the 1st horizontal component, vertical component and 2nd horizontal component are shown in columns 8, 9 and 10, respectively); earthquake date, column 11; *Mw* magnitude, column 12; focal mechanism (if any), column 13; hypocentral distance, column 14. The abbreviations '*Rv*', '*SS*' and '*R-SS*' in column 13 are for reverse, strike-slip, and the combined mechanisms of reverse and strike slip, respectively.

Site conditions are considered through the

Table 1. Strong motion records.

No	Record	Station	Lat.N	Long.E	Site	BP Filter (Hz)	HPGA1 (Gal)	VPGA (Gal)	HPGA2 (Gal)	Earthquake	Mw	FocMec	Hyp. Dist (km)
1	1054-01	Naghan	31.94N	50.74E	1	0.17-23.5	720	520	615	06/04/77	6.1	Rv	7
2	1082-01	Deyhuk	33.29N	57.50E	1	0.2-31	320	162	376	16/09/78	7.4	Rv	36
3	1083-01	Boshuyeh	33.86N	57.42E	1	0.27-17	98	87	94	16/09/78	7.4	Rv	64
4	1084-01	Tabas	33.60N	56.93E	1	0.1-40	1103	848	84	16/09/78	7.4	Rv	27
5	1139	Ghaen	33.72N	52.18E	1	0.1-39	197	119	134	27/11/79	7.1		44
6	1305	Kuhbanan	31.41N	56.29E	3	0.3-30	100	49	73	11/04/87	4.8		16
7	1300-01	Birjand	32.88N	59.21E	1	0.27-30	64	47	49	24/11/87	5.3		8
8	1353-01	Ghazvin	36.27N	50.01E	3	0.22-25	186	90	134	20/06/90	7.3	SS	76
9	1357-01	Lahijan	37.21N	50.33E	4	0.1-25	108	75	176	20/06/90	7.3	SS	96
10	1362-01	Abbar	36.92N	48.97E	1	0.1-25	526	548	503	20/06/90	7.3	SS	40
11	1364	Zanjan	36.66N	48.57E	1	0.1-25	125	51	60	20/06/90	7.3	SS	80
12	1500-03	Zanjiran	29.10N	52.56E	2	0.25-39	72	27	61	14/03/94	4.3		8
13	1500-04	Zanjiran	29.10N	52.56E	2	0.2-39	64	36	75	17/03/94	4.8		12
14	1494-03	Kavar	29.21N	52.67E	2	0.2-39	52	39	47	17/03/94	4.6		12
15	1500-05	Zanjiran	29.10N	52.56E	2	0.23-39	111	30	73	17/03/94	4.2		16
16	1492-04	Zarrat	29.21N	52.77E	4	0.1-39	53	22	51	18/03/94	4.4		21
17	1500-08	Zanjiran	29.10N	52.56E	2	0.1-39	28	26	51	19/03/94	4.4		11
18	1492-05	Zarrat	29.21N	52.77E	4	0.1-39	37	20	51	23/03/94	4.7		20
19	1492-06	Zarrat	29.21N	52.77E	4	0.1-39	213	60	244	30/03/94	5.2		24
20	1492-08	Zarrat	29.21N	52.77E	4	0.1-39	57	21	49	03/04/94	5.2		24
21	1502-04	Zanjiran	29.10N	52.56E	2	0.1-39	193	73	180	05/06/94	4.8		10
22	1502-05	Zanjiran	29.10N	52.56E	2	0.1-39	38	19	71	06/06/94	4.2		10
23	1492-15	Zarrat	29.21N	52.77E	4	0.1-39	111	36	84	18/06/94	5.1		21
24	1502-08	Zanjiran	29.10N	52.56E	2	0.1-39	94	51	93	20/06/94	5.1		8
25	1492-16	Zarrat	29.21N	52.77E	4	0.2-40	318	112	280	20/06/94	5.9	SS	32
26	1493-02	Firouzabad	28.80N	52.57E	3	0.25-40	272	115	295	20/06/94	5.9	SS	34
27	1502-09	Zanjiran	29.10N	52.56E	2	0.2-40	1100	990	1090	20/06/94	5.9	SS	16
28	1501-01	Zanjiran	29.10N	52.56E	2	0.1-39	84	37	109	23/06/94	3.7		12
29	1501-07	Zanjiran	29.10N	52.56E	2	0.23-39	135	59	136	24/06/94	4.5		8
30	1523-23	Jovakan	29.05N	52.56E	1	0.3-39	70	30	66	19/09/94	3.8		16
31	1528-01	Fin	27.65N	55.90E	3	0.3-39	54	33	32	28/10/94	4.2		4
32	1523-28	Jovakan	29.05N	52.56E	1	0.1-39	142	33	101	08/12/94	5		16
33	1519-04	Zarrat	29.21N	52.77E	4	0.1-39	65	23	54	15/12/94	4.7		20
34	1528-03	Fin	27.65N	55.90E	3	0.1-39	529	412	494	24/01/95	4.9		16
35	1528-22	Fin	27.65N	55.90E	3	0.1-39	53	27	42	24/01/95	4		16
36	1528-23	Fin	27.65N	55.90E	3	0.1-39	60	27	52	24/01/95	4		8
37	1528-26	Fin	27.65N	55.90E	3	0.1-39	179	83	143	24/01/95	4.5		16
38	1528-10	Fin	27.65N	55.90E	3	0.23-39	165	61	165	24/01/95	4.6		16
39	1528-12	Fin	27.65N	55.90E	3	0.23-39	84	51	84	24/01/95	4.1		6
40	1528-15	Fin	27.65N	55.90E	3	0.23-39	39	27	60	24/01/95	3.5		6
41	1528-17	Fin	27.65N	55.90E	3	0.23-39	54	21	35	24/01/95	3.9		14
42	1564-02	Khanzanu	29.70N	52.15E	1	0.1-39	52	24	56	23/10/95	4.9		8
43	1560-01	Lali	32.35N	49.09E	3	0.1-39	116	151	99	24/11/95	4.5		19
44	1560-04	Lali	32.35N	49.09E	3	0.1-39	78	81	105	27/11/95	5		18
45	1506-01	Hosseinieh	32.73N	48.25E	4	0.15-40	195	105	132	31/07/94	5.6	Rv	24
46	1549-04	Ammarloo	36.78N	49.76E	3	0.2-34	64	47	58	06/01/95	4		10
47	1547-01	Sefidrud	36.76N	49.38E	1	0.2-34	52	13	15	07/03/95	2.7		15
48	1620-01	Doab-Pol-	36.03N	53.02E	3	0.2-34	112	47	68	03/06/95	4		20
49	1626	Hassan-Keif	36.50N	51.40E	3	0.1-34	65	39	41	26/06/95	4.1		14
50	1620-01	Doab-Pol-Sefid	36.03N	53.02E	3	0.2-34	64	23	38	28/07/95	4.1		20
51	1571-10	Shabankar	29.47N	50.98E	4	0.3-40	57	37	80	24/01/96	4.7	SS	18
52	1571-26	Shabankareh	29.47N	50.98E	4	0.23-39	23	27	81	25/01/96	4		20
53	1571-33	Shabankareh	29.47N	50.98E	4	0.3-20	170	90	70	26/01/96	4.6		80
54	1659-02	Ashkhaneh	37.61N	56.92E	4	0.2-25	118	35	102	04/02/97	6.5	SS	50
55	1707-02	Barezoo Dam	37.60N	57.97E	1	0.15-20	44	25	60	04/02/97	6.5	SS	60
56	1693-01	Ardebil-Ostandari	38.25N	48.30E	4	0.1-40	85	58	72	28/02/97	6.1	SS	36
57	1695-00	Astara	38.40N	48.85E	4	0.1-40	54	18	40	28/02/97	6.1	SS	40
58	1701-01	Ardebil-Maskan	38.24N	48.29E	4	0.08-40	122	64	130	28/02/97	6.1	SS	35
59	1702-00	Germi	39.03N	48.08E	3	0.2-20	52	21	48	28/02/97	6.1	SS	36
60	1716-00	Hir	38.60N	48.50E	2	0.15-30	59	20	34	28/02/97	6.1	SS	96
61	1724-00	Namin	38.40N	48.48E	2	0.15-40	72	34	106	28/02/97	6.1	SS	56
62	1725-00	Sarein	38.22N	48.08E	1	0.2-40	42	27	55	28/02/97	6.1	SS	60
63	1833-02	Karigh	37.87N	48.05E	3	0.25-40	578	197	672	28/02/97	6.1	SS	26
64	1920-04	Karigh	37.87N	48.05E	3	0.2-30	68	19	53	21/03/97	4.6		30
65	1921-01	Sarein	38.22N	48.08E	1	0.2-40	38	63	42	21/03/97	4.6		12
66	1927-03	Nir	38.08N	47.97E	3	0.2-40	127	48	125	21/03/97	4.6		16

Table 1. Continued...

67	1753-00	Sangan	34.38N	60.26E	1	0.08-40	118	82	112	10/05/97	7.2	SS	80
68	2161-00	Kerman-Farmandari	30.27N	57.11E	4	0.3-20	31	22	58	18/11/98	5.3	SS	50
69	2176-01	Shahdad	30.39N	57.73E	1	0.2-20	52	38	48	18/11/98	5.3	SS	24
70	2373-01	Yekan	38.72N	48.42E	1	0.2-30	57	42	38	18/11/98	4.9		44
71	2322-00	Zanjireh	38.45N	45.35E	2	0.2-30	98	33	82	18/11/98	4.9		24
72	2369-01	Tasuj	38.30N	45.40E	4	0.3-40	59	27	56	18/11/98	4.9		28
73	2224-03	Derakht-eToot	35.75N	61.10E	1	0.15-40	138	145	245	05/12/99	5.1	Rv	14
74	2225-11	Salehabad	35.70N	61.10E	1	0.2-40	138	142	102	05/12/99	5.1	Rv	17
75	2286-05	Nargeszar	29.45N	51.90E	2	0.15-40	143	87	195	05/12/99	4.5		14
76	2355-03	Baladeh	29.28N	51.93E	2	0.25-40	78	44	75	05/12/99	4.5		44
77	2465-01	Chehel-Zarei	29.46N	50.85E	4	0.2-35	65	33	76	03/05/00	5.1	R-SS	35
78	2748-01	Abegarm	35.74N	49.28E	4	0.11-28	130	55	125	22/06/02	6.3	Rv	34
79	2749-01	Avaj	35.58N	49.22E	3	0.10-25	465	250	445	22/06/02	6.3	Rv	28
80	2754-01	Kabodar-Ahang	35.20N	48.73E	1	0.20-40	78	71	155	22/06/02	6.3	Rv	78
81	2756-01	Razan	35.39N	49.02E	4	0.18-40	182	132	200	22/06/02	6.3	Rv	55
82	2763	Abhar	36.15N	49.22E	4	0.18-20	32	27	73	22/06/02	6.3	Rv	55
83	2769	Darsachin	36.03N	49.23E	4	0.15-20	52	44	72	22/06/02	6.3	Rv	54
84	2778	Ghohrud	35.47N	48.07E	3	0.08-18	51	23	88	22/06/02	6.3	Rv	95
85	3162-1	Mohammad-abad-e Maskun	29.97N	57.88E	4	0.1-40	120.1	69.2	71	26/12/03	6.5	SS	48
86	3168-2	Bam	29.12N	58.38E	3	0.11-40	992	775	623	26/12/03	6.5	SS	12
87	3176-1	Abaragh	29.38N	57.97E	1	0.1-40	162.6	83.2	107.7	26/12/03	6.5	SS	56

categorization in four site classes based on the receiver function [12]. Site class 1 is defined as the sites with no significant amplification below 15*Hz*. It corresponds to the rock and stiff sediment sites with an average S-wave velocity higher than 700*m/sec* in the top 30 meters. Site class 2 is the sites of the fundamental peak exceeding 3 at the frequencies 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 of the sites for which *RF* shows the peaks between 2 and 5*Hz* and corresponds to the alluvial sites with *Vs*30 between 300 and 500*m/sec*. Finally site class 4 is defined as the sites for which *RF* indicates the peaks in frequencies below 2*Hz*, and it may be viewed as corresponding to thick soft alluvium. This ranking is based on the geotechnical measurements of 50 sites (compressional and shear wave velocity and microtremors) and the calculation of the receiver function for strong motions using three component accelerograms. This categorization is almost similarity to that of Boore et al [4] for the data of northwestern America. The average *Vs* for studying site classes obtained by Boore et al [4] are 180, 360, 750 and more than 750*m/sec*, whereas the ones applied in this research are 300, 500, 700 and the more than 700*m/sec*.

7. Results

The results of the regressions obtained for the horizontal components are presented in Table (2). The coefficients are presented for 7 different periods from 0.1*sec* (*PGA*) to 2 seconds.

The attenuation coefficients are used and tested giving a magnitude 7.0 and 10*km* hypocentral distances on the horizontal component in Figure (1)

Table 2. The coefficients calculated for spectral attenuation in the horizontal component.

$\ln Sa(T) = b_1(T).S_i + b_2(T)(M\text{-}6) + b_3(T)(M\text{-}6)^2 + b_5(T).\ln R + s_{Sa}(T).P$								
Iran	*Constant*		*Calculated*					
Period (sec)	*b2*	*b3*	*b1.1*	*b1.2*	*b1.3*	*b1.4*	*b5*	*sigma*
0.10	*0.753*	*-0.226*	0.037	0.304	-0.480	-0.186	-0.037	0.48
0.14	*0.707*	*-0.230*	0.279	0.337	0.015	0.210	-0.054	0.47
0.20	*0.711*	*-0.207*	0.459	0.349	0.257	0.373	-0.102	0.50
0.44	*0.852*	*-0.108*	-0.431	-1.023	-0.986	-0.736	-0.093	0.67
0.70	*0.962*	*-0.053*	-0.459	-0.833	-0.778	-0.231	-0.251	0.74
1.30	*1.073*	*-0.035*	-1.710	-2.537	-2.961	-1.884	-0.178	0.84
2.00	*1.085*	*-0.085*	-1.204	-2.268	-1.154	-1.265	-0.546	0.91

for different site classes.

The response spectra for a rock site (class-1) for horizontal component and different distances of 5, 10, 20 and 40 kilometers are assessed using the results presented in Table (2) for the magnitude Mw = 7.0, see Figure (2). These results show greater amplification of spectral values for the softer soil conditions. The amplification increase approaching towards the site class 4 from the site class 1.

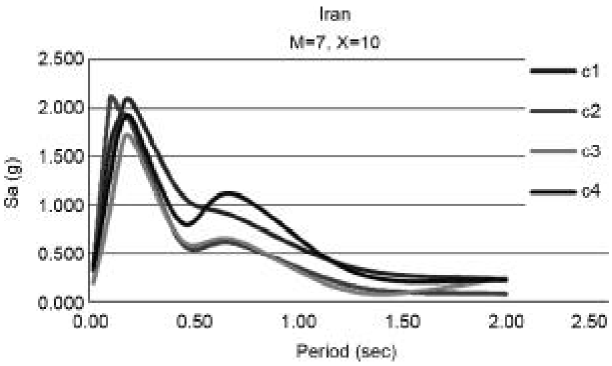

Figure 1. Spectral attenuation for horizontal component, magnitude 7.0, 10Km hypocentral distance in site classes 1, 2, 3 and 4.

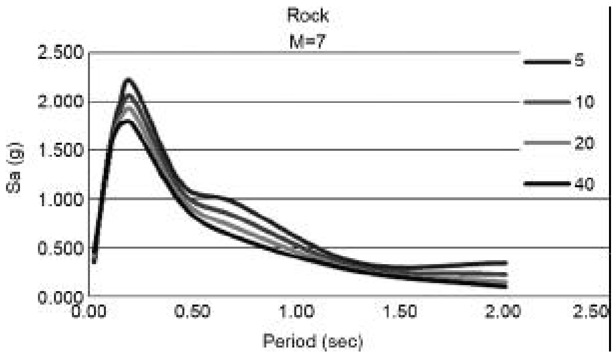

Figure 2. Spectral attenuation coefficient for horizontal component, magnitude 7.0, site classes 1 (Rock) and hypocentral distances of 5, 10, 20 and 40km.

8. Conclusion

The new attenuation coefficients are in general agreement with the previous attenuation coefficients obtained by the first author in his PhD dissertation. However the spectral values obtained in this study are higher in comparison with those gained in the previous studies (1999). The difference might be due to the selection of greater motions recorded at the distances nearer to the seismic sources. The near-fault strong motion record obtained in Bam earthquake, 26. December 2003, is included in the input data of the present study.

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