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S-WAVE ATTENUATION AND SPECTRAL DECAY PARAMETER FOR THE AVAJ REGION, IRAN*

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Abstract – The strong ground motions recorded during the 2002 Avaj earthquake have been used to estimate S wave attenuation, Q_β, and spectral decay parameter, κ, for the Avaj region. Q_β for shear wave is estimated as a function of frequency in the range of 0.6- 18 Hz. The results show that Q_β increases with frequency in the form of $Q_\beta=62.7\ f^{0.9}$. Our estimates are within the estimated range for different parts of the world for Q_o and n. The spectral decay parameter, κ, has been estimated from the high frequency of the spectra. The dependence of κ on the epicenteral distance for the Avaj region is also found.

Keywords – S-wave, attenuation, spectral decay, strong motion

1. INTRODUCTION

A reliable assessment of seismic risk in a region requires knowledge and understanding of both the seismicity and the attenuation of strong ground motion. It is well known that some of the larger uncertainties in earthquake hazard analysis are caused by uncertainties in seismic wave attenuation. The decrease of amplitude with increasing distance from the source is referred to as attenuation. It is mainly due to the geometry of propagation of seismic waves and partly due to the anelastic properties of the material through which they travel.

As a wave is propagated through real materials, wave amplitudes attenuate as a result of the different processes responsible for energy dissipation. This can be summarized as scattering by heterogeneities and intrinsic absorption. The attenuation characteristics of different regions in the world have been investigated by different researchers [1-4]. To estimate the expected ground motion in a region it is necessary to estimate S wave attenuation, Q_S, and spectral decay parameter kappa, κ, for the study area. In the present study these parameters have been estimated for the Avaj region based on the strong ground motion data which was recorded by the Building and Housing Research Center (BHRC) network, Iran.

2. DATA

On June 22, 2002, a strong earthquake with an estimated magnitude of M_W 6.5 (reported by HRV) occurred near Avaj (250 km west of Tehran) in NW Iran at 2:58:27.2 (GMT) (7: 28: 00 local time). Over 226 people were killed and more than 1300 people injured. The earthquake was felt in Tehran and 373 villages around Ghazvin, Hamedan, Zanjan, and Arak cities were affected (Fig. 1).

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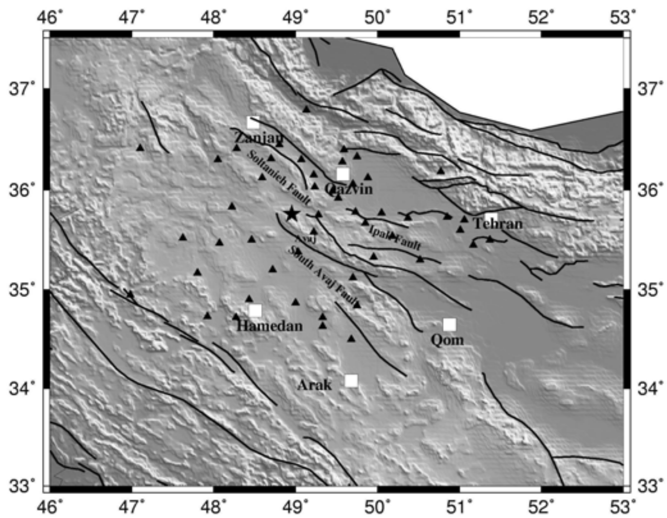

Fig. 1. Location of strong ground motion stations and epicenter of Avaj earthquake

The strong ground motion records have been obtained at 56 stations. All the instruments are of SSA-2 type with a threshold of 10 gals. The recorded ground motions are digital and of relatively short duration. Therefore they comprise direct arrival. The original digitized accelerograms have been processed following a standard procedure. Maximum acceleration of 429 cm/sec^2 and 455 cm/sec^2 for the two horizontal components and 292 cm/sec^2 for the vertical component was recorded at the Avaj station.

3. METHOD

Generally Q_β is related to frequency as $Q_\beta = Q_o f^n$, where Q_o and n are constants. The observed spectral amplitudes at hypocenteral distance, R, from the source is described as [5-8]:

$$A(f, R) = S(f).\ B(f, R) \tag{1}$$

Where, B (f, R) is the attenuation function that describes the decay trend of the observation with distance. S (f) is a scaler which depends on the size of the earthquake. A homogeneous attenuation model is adopted to parameterise B (f, R):

$$B(f, R) = R^{-n}\ e^{(-\pi f R/\beta Q_\beta)} \tag{2}$$

where f is the frequency and β is the velocity of S waves which have been taken as 3.22 km/sec[4]. The geometrical spreading function is represented as R^{-n}. Substituting Eq. (2) to Eq. (1) gives:

$$\log A(f, R) - n\log R = \log S(f) - \pi \log(e) \frac{f}{\beta Q_\beta} R \tag{3}$$

The attenuation functions, B (f, R), were obtained by fitting the spectral amplitude decay of the records in the frequency band of 0.6 and 16 Hz. At a distance of less than 100 km a spherical geometry, i.e. 1/R is considered. We have considered a geometrical spreading function of $1/R^2$ for a distance greater than 100 km due to head wave propagation [4, 9]. The Q_β are obtained from the slope of this linear equation, i.e. {log A (f, R) nlogR} versus R. Then, Q_β is calculated for each designated center frequency as $Q_\beta = \pi \log(e) \frac{f}{b\beta}$. To estimate Q_β, we carefully considered the S wave train. The analysis is confined to SH-waves because these are minimally affected by crustal heterogeneity [10].

The signal duration of the S wave motion is calculated using the Hermann relation [11] as:

$$T_d = T_S + 0.05R$$

Where T_S is source duration, which is related to corner frequency, f_c, [12] as:

$$T_S = 1/f_c$$

To estimate the spectral decay parameter, κ, we used the method proposed by Anderson and Hough [13]. They show that at high frequencies, the spectrum of S wave acceleration is characterized by a trend of the exponential decay of $e^{-\pi\kappa f}$. To obtain the spectral decay parameter, linear least square fits to the spectra were obtained. Values of slopes were then converted to the spectral decay parameter.

4. RESULTS

For an appropriate selection of the SH-wave components of the recorded data, the radial (L) and transverse (T) components of the recorded acceleration are suitably rotated so that corresponding estimates along and perpendicular to the azimuth direction are obtained. The rotated transverse components provide the acceleration data of the SH-waves recorded at each station. The SH-wave accelerograms are shown in Fig. 2 for some of these records at Avaj, Abegarm, Bahar, Danesfahan, Garmab, Khodabandeh, Nahavand, Razan, Shirinsu and Soltanieh stations. The Fourier spectrum of the SH- wave for these stations is shown in Fig. 3. Average Q_β values for the five centre frequencies (1.5, 3.0, 6.0, 12.0 and 18.0 Hz) have been estimated at 23 stations. Table 1 gives the estimated Q_β for these centeral frequencies at recording stations. While Fig. 4 shows the estimated Q_β for the five centre frequencies selected. Figure 5 shows the relation between Q_β and the frequency which was obtained by regression analysis. The frequency dependence of Q_β for this region based on the recorded data is estimated as:

$$Q_\beta = 63\ f^{0.99}$$

The value of spectral decay parameter, κ, which was estimated for 56 stations, is tabulated in Table 2. Figure 6 shows examples of Fourier spectra of acceleration for the horizontal component and best fit to the high frequency part at selected stations for the estimation of κ.

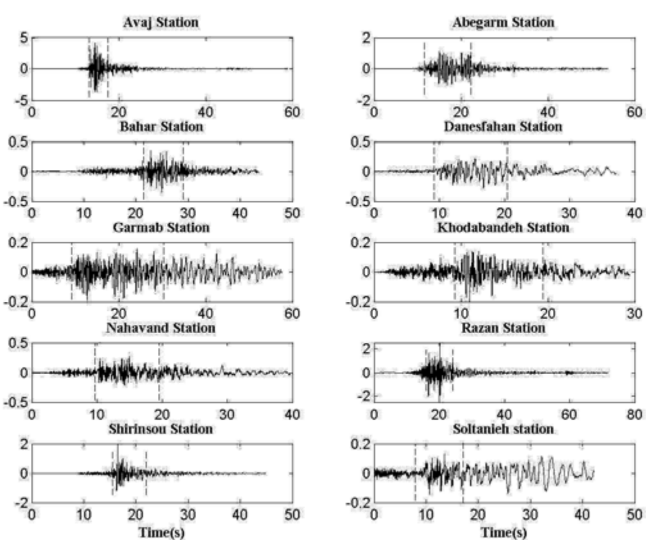

Fig. 2. Example of the SH-wave which was used in the analysis for 10 stations

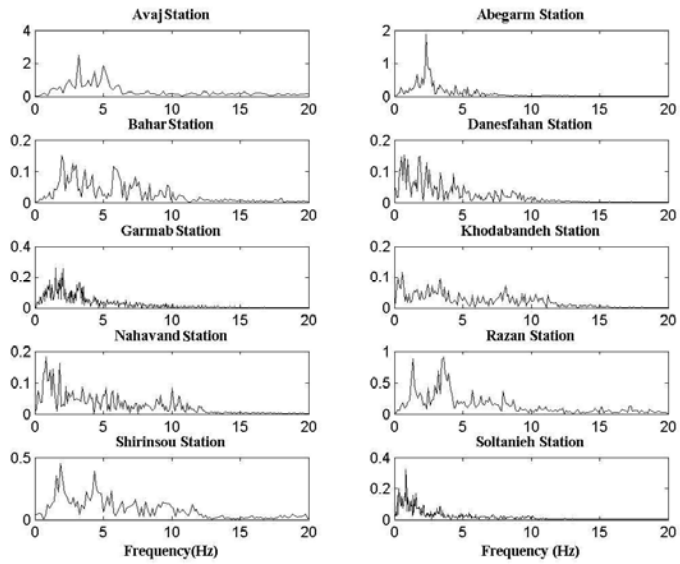

Fig. 3. Fourier amplitude spectrum of SH- wave at 10 stations

Table 1. Average Q_β values for the five centre frequencies

Frequency (Hz)	Q_β
1.5	104.63
3.0	141.76
6.0	284.06
12	688.84
18	826.17

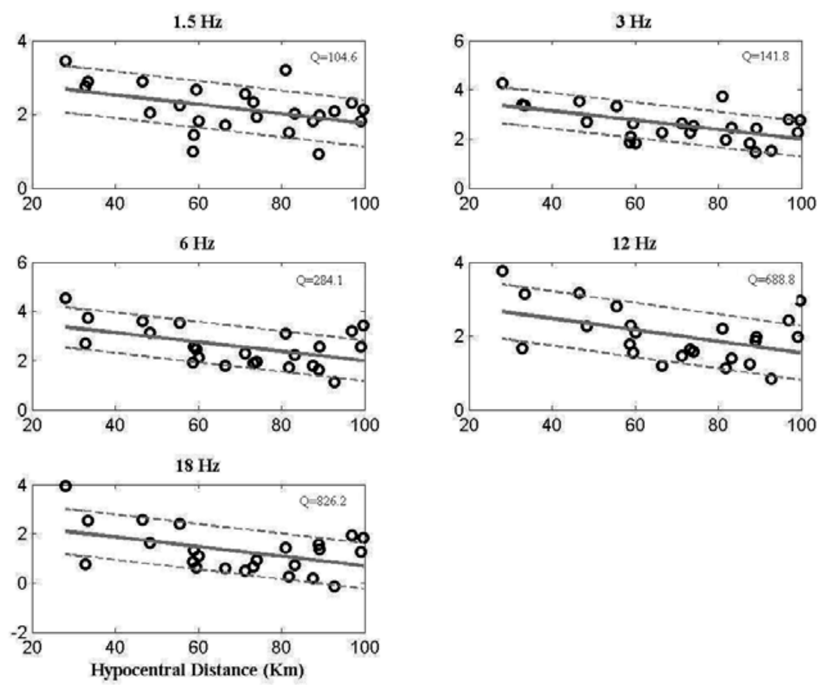

Fig. 4. The estimated values of the quality factor, Q_β, for five frequencies selected

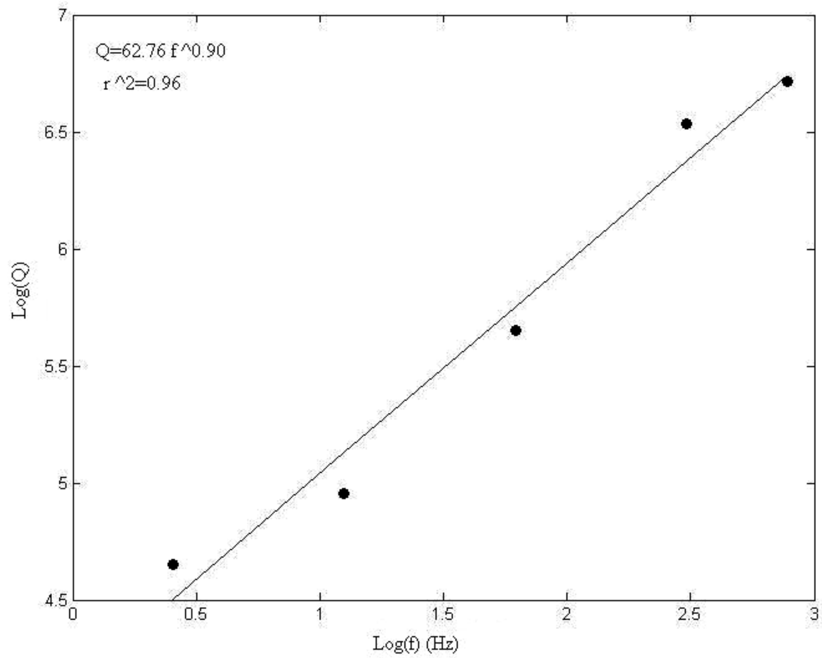

Fig. 5. The attenuation of S-wave for Avaj region

Table 2. Estimated κ for two horizontal components and its average value

STATION	Spectral decay parameter		
	L	T	Ave
ABEGARM	0.098	0.112	0.105
AVAJ	0.059	0.056	0.058
RAZAN	0.046	0.056	0.051
SHIRINSO	0.061	0.053	0.057
DARSCHIN	0.075	0.077	0.076
KABODARAHANG	0.056	0.050	0.053
KHODABANDEH	0.065	0.072	0.068
ZIYAABAD	0.072	0.093	0.082
ABHAR	0.088	0.084	0.086
NAHAVAND	0.083	0.068	0.075
GARMAB	0.079	0.076	0.078
SAEINQALEH	0.096	0.096	0.096
DANESFAHAN	0.097	0.092	0.095
DEHJALAL	0.079	0.092	0.086
GHOHORD	0.090	0.106	0.098
TAKESTAN	0.081	0.076	0.078
ROSTAMABAD	0.082	0.084	0.083
SOLTANIYEH	0.100	0.095	0.097
NIKOYEH	0.029	0.034	0.032
GHAHAVAND	0.052	0.053	0.052
NOBARAN	0.080	0.095	0.088
BAHAR	0.055	0.052	0.054
KAHAK	0.078	0.074	0.076
KHARAGHAN	0.098	0.110	0.104
BACKKANDI	0.080	0.052	0.066
ZARINABAD	0.111	0.098	0.104

Table 2. (Continued)

BOEINZAHRA	0.081	0.092	0.086
AGHABABA	0.089	0.074	0.082
HALAB	0.132	0.126	0.129
HAMEDAN-ABBASABAD	0.038	0.040	0.039
HAMEDAN	0.067	0.064	0.065
KOMIJAN	0.069	0.065	0.067
HAJIB	0.073	0.075	0.074
GHORVEH	0.066	0.061	0.063
ZANJAN	0.123	0.122	0.123
JOFTAN	0.066	0.084	0.075
KHOSROABAD	0.089	0.101	0.095
ESFANDAN	0.055	0.058	0.056
KOHNUSH	0.072	0.076	0.074
GILVAN	0.067	0.088	0.077
ESHTEHARD	0.132	0.141	0.136
AJIN	0.103	0.093	0.098
FARMAHIN	0.104	0.103	0.103
MAMONIEH	0.097	0.093	0.095
MARDABAD	0.121	0.141	0.131
TALEGHAN	0.127	0.113	0.120
TAKAB	0.146	0.166	0.156
VAHIDIYEH	0.121	0.128	0.125
GARMDAREH	0.108	0.113	0.111
KAVANEH	0.098	0.106	0.102
VAHNABAD	0.133	0.134	0.133
QOM	0.203	0.197	0.200
KAHRIZAK	0.162	0.166	0.164
TEHRAN1	0.150	0.105	0.127
TEHRAN2	0.111	0.122	0.117
TEHRAN3	0.153	0.159	0.156

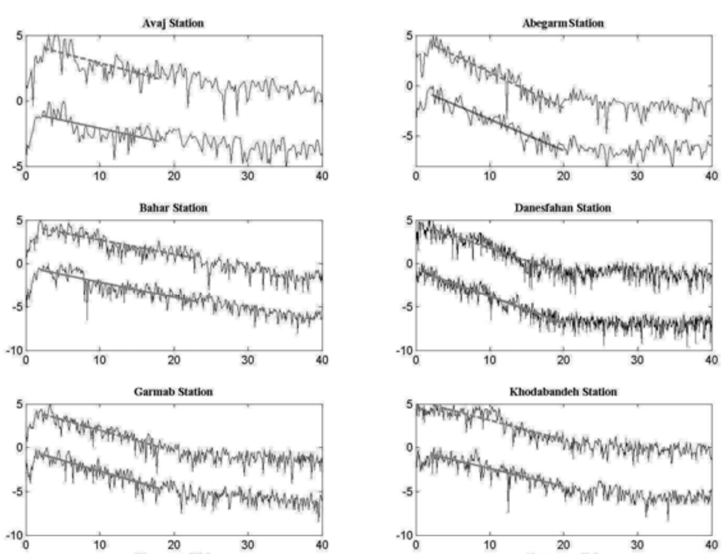

Fig. 6. Fourier spectra of acceleration horizontal components and best fit to the high frequency parts

5. DISCUSSION

We have analyzed S wave attenuation and spectral decay parameter using recorded strong motion data during the 2002 Avaj earthquake. Average Q_β values have been estimated for the five central frequencies of 1.5, 3.0, 6.0, 12.0 and 18.0 Hz. This is based on the frequency contents of the recorded strong ground motion at 23 stations. The frequency content is observed on the records up to 20 Hz (Fig. 3). Therefore, we considered these central frequencies for estimating Q_β. It was found that for the frequency band of 0.6 Hz to 18 Hz the frequency dependence of Q_β can be estimated as $Q_\beta= 61f^{0.99}$. This implies high attenuation of the S wave at the studied frequency and distances.

A number of observations have been made for the study of Q_β for different regions of the world (Fig. 7). The Q_β is estimated for Grahwal Himalaya as $Q_\beta= 90f^{1.06}$ [3]. This estimation for the Friuli region of Italy is $Q_\beta= 80f^{1.1}$ [14]. The estimated Q_β for the southern Kanto region, Japis, is given as $Q_\beta= 83.3f^{0.73}$ [15]. Q_β for the back- arc region of Hellenic is estimated as $Q_\beta= 55f^{0.91}$ [4]. Our estimates are within the estimated range for different parts of the world for Q_o and n values (Fig. 7). A strong correlation between n and the level of tectonic activity of the region has been observed by several investigators [16-18]. The estimated n in the relation for Q_β for the Avaj region shows that the region is active. The occurrence of several large earthquakes, such as the 1962 Buin-Zahra (M_W 7.2) and the 1990 Rudbar earthquake (M_W 7.3) in the east and north of Avaj, indicates the activity of this region [19, 20].

Several factors could affect the observed scatter, which is shown in Fig. 4. For instance, the observed scatter for the Avaj station, which is located at a hypocenteral distance of 20 km, could be inferred due to the source effect, especially at lower frequencies. While the scatter in the far stations, with respect to the focus of the earthquake, could be due to site effect, nevertheless the observed data fall well in the $\pm\sigma$ (Fig. 4) range which means that there is no spurious recorded value. In addition, the observed spectral amplitudes show an increasing trend beyond 90 km which might be due to the presence of refracted waves from Moho.

The spectral decay parameter, κ, has been estimated based on the method proposed by Anderson and Hough [13] at 56 stations. Linear least square fits were applied to the spectra to estimate the spectral decay parameter. The values of the slopes were converted to the spectral decay parameter, κ, and subsequently plotted against the epicenteral distance (Fig. 8).There is a considerable amount of scatter in the individual measurements of κ. This comes from variability in the high- frequency spectrum as radiated at source or highly variable attenuation in the source region. The interception of κ, i. e. at zero distance, is controlled by attenuation near the surface, while an increase of κ with distance is an effect of lateral propagation. This is important for the simulation of strong ground motion for engineering applications based on stochastic models.

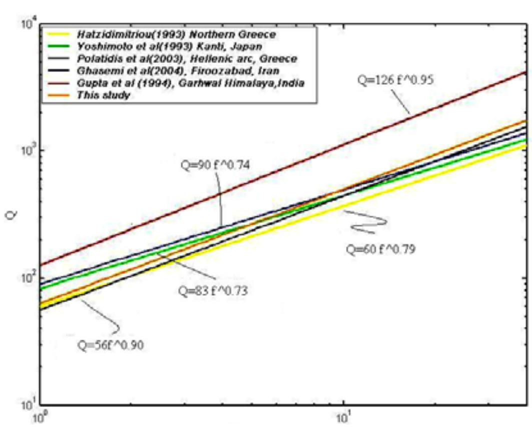

Fig. 7. Comparison of attenuation of S-wave for different regions

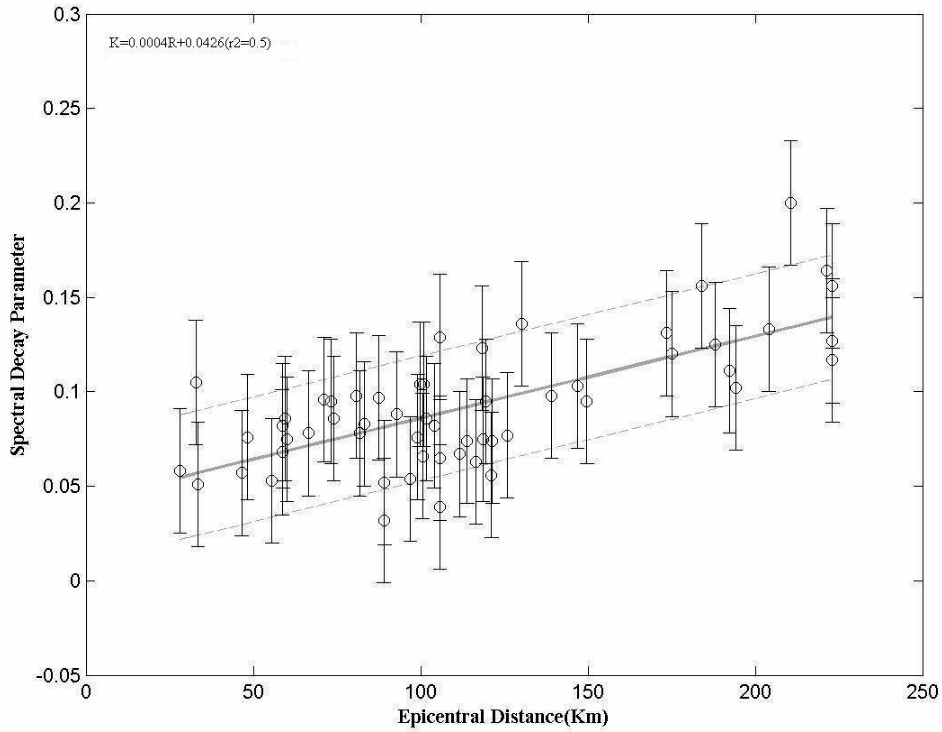

Fig. 8. Dependence of spectral decay parameter on epicenteral distance

6. CONCLUSIONS

On the basis of the analysis of the recorded strong ground motion at 56 stations for the 2002 Avaj earthquake, the following conclusions have emerged for the S-wave attenuation and spectral decay parameter: Q_β for shear wave is estimated as a function of frequency in the range of 0.6- 18 Hz. The results show that the Q_β increases with frequency in the form of $Q_\beta=63\ f^{0.9}$.The spectral decay parameter, κ, has been estimated from the high frequency. The dependence of κ on the epicenteral distance is also found.

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