GEOFIZIKA VOL. 9 1992

Short communication
UDC 550.340.12

Anelastic-attenuation coefficient γ and the correction of A_0 values of Richter magnitude formula for Albania

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Received 17 June 1992, in final form 19 October 1992.

Using some graphical and analytical methods recommended mostly by American authors, a value of γ = 0.007052 km^{-1} is determined for 1 Hz Lg surface waves of near earthquakes of Albania. Starting from this value of γ, a reevaluation of the corrections for the A_0 factor in the Richter's magnitude formula for Albania is also carried out.

For epicentral distances 80–700 km the difference in magnitude determination between the values obtained using tabulated Richter factor and corrected values is 0.1–0.4.

Koeficijent γ neelastičke atenuacije u Albaniji i korekcije iznosa A_0 u Richterovom izrazu za račun magnitude

Koristeći neke grafičke i analitičke postupke koje preporučuju uglavnom američki autori, određen je iznos γ = 0.007052 km^{-1} za Lg površinske valove bliskih potresa u Albaniji s frekvencijom 1 Hz. Prihvativši tu vrijednost za γ izračunane su korekcije za koeficijent A_0 u Richterovom izrazu za određivanje magnitude.

Za epicentralne udaljenosti 80–700 km razlika magnituda određenih koristeći tabulirane Richterove faktore i korigirane vrijednosti iznosi 0.1–0.4 jedinica magnitude.

1. Introduction

The magnitude scale proposed by Richter (1935) is expressed by the formula $M_L = \log A(\Delta) - \log A_0(\Delta)$ where A is the maximum trace amplitude at distance Δ and $A_0(\Delta)$ are some tabulated values which reduce the amplitudes observed at various distances to the expected amplitudes at the standard distance of 100 km. Because the values of A_0 are determined for California, since that time many authors have proposed formulas for the linear relation between the logarithm of maximum amplitude and hypocentral distance for determination of local magnitude.

There are two difficulties that emerge when using Richter's formula. First, Richter's original magnitude scale was designed to measure local earthquakes in the Southern California area recorded on the Wood-Anderson torsion seismometer; secondly, even if the above instrument can be used directly it is not correct to use the same A_0 factors which depend on the attenuation features of a given zone.

According to the recommendation from the World Data Center A (Willmore, 1979), in routine practice of the Albanian Seismological Network (ASN) we have used a magnitude scale derived by converting the record traces of our DD-1 short period seismographs into values compatible with Wood-Anderson instrument. We have used the values of A_0 factor tabulated by Richter for California.

Our aim in this work is to find the mean anelastic-attenuation coefficient γ for the Albanian territory and thereby to obtain new values for A_0 and to improve the accuracy of magnitude determination. The use of new correction factors for A_0 and the derivation of some new formulas for magnitude determination for the ASN is the object of another study.

2. Description of method

Coda waves compose the latter part of a local or regional earthquake seismogram. Aki (1969) first studied the coda waves of local earthquakes and found that attenuation could be determined using these waves. The quality factor Q, and anelastic-attenuation coefficient γ are the most commonly used parameters for description of the attenuation of seismic waves. These parameters are dependent on frequency and vary from place to place (e.g. Aki, 1982). For each type, the attenuation is the sum of the loss factors from intrinsic anelasticity and scattering (Kennett, 1983).

There is a recent and growing interest in the study of coda waves for the evaluation of the quality factor. Methods for study of effects on single and multiple scattering on coda waves have been developed by Aki and Chouet (1975), Dainty (1981) and Gao et al. (1983) among others. Based on one method given by Herrmann (1980) the value of the quality factor Q for coda waves has been estimated for Northern Albania (Muço, 1985). The low value of Q for this region ($\sim$150) shows the influence of thick sediments deposited there.

The phase Lg is prominent on regional short-period seismogram. This is a short-period surface wave characterized by sharp onsets and large amplitudes which was firstly identified by Press and Ewing (1952) and which propagates through the silicic crust of continents. In stable continental regions, it is observed at distances as great as 4000 km (Press and Ewing, 1952). The Lg phase is the most distinct phase in the records of short-period seismographs of ASN for earthquakes in and near-by Albania. Although the latter part of coda is not coherent across arrays of seismological stations which indicates that at least part of it is produced by scattering processes (Mitchell and Hwang, 1987), the Lg waves are widely used for local magnitude determination (Baker, 1967; Baker, 1970; Nuttli, 1973; Bakun and Lindh, 1977; Herrmann and Nuttli, 1982; Herrmann and Kijko, 1983; Huangcheng et al., 1987).

The attenuation parameters Q and γ can be determined using known techniques (Aki and Chouet, 1975; Sato, 1977; Gregersen, 1982; Rogers et al., 1987; Carpenter, 1987). In our case, because the ASN uses only analog recording and because our purpose is limited to the determination of only the anelastic-attenuation coefficient, we used some other simple techniques (Nuttli, 1973; Bollinger, 1979; Nuttli, 1980).

For a uniform point source of elastic waves in a spherical earth model and for the Airy phase, the amplitude of dispersed surface waves measured in the time domain is given by Nuttli (1973):

$$A = \mathrm{K}\, D^{-1/3}\, (\sin D)^{-1/2}\, \mathrm{e}^{-\gamma \mathrm{D}} \tag{1}$$

where A – amplitude in arbitrary units, D – epicentral distance in degrees, γ – anelastic-attenuation coefficient (km^{-1}) and K – an arbitrary proportionality coefficient. This formula is plausible for amplitudes of Lg phase with frequencies of about 1 Hz. Calculating different master curves of A versus D for different values of γ to the above formula, we could compare them with observations of A and D, and by fitting the master curves to the data we could select an approximate value of γ. Nuttli (1980) has also proposed another graphical technique for γ estimation, writing equation (1) in the form:

$$A^{*} = 56.306\, A\, (\sin D)^{1/2}\, D^{1/3} \sim \mathrm{e}^{-\gamma \mathrm{D}} \tag{2}$$

The number 56.306 is a normalization factor which at distance 10 km, makes the left part of equation (2) equal to unity. Using equation (2) (A in micrometers, D in degrees), for different values of γ, one can construct a family of straight lines which can also be compared with observations obtained by the same procedure for a real data set.

Observational studies (Nuttli, 1973; Dwyer et al., 1983) and numerical ones (Herrmann and Kijko, 1983; Rogers et al., 1987) suggest that peak short period vertical ground motion at regional distances is produced by the Lg wave with peak amplitudes behaving according to:

$$A = A'\, D^{-5/6}\, \mathrm{e}^{-\gamma \mathrm{D}} \tag{3}$$

where D is epicentral distance (in km) and A' is the source term. Equation (3) is also derived from equation (1) (Dwyer et al., 1983). To make it appropriate for a least squares application, we can take the log of both sides:

$$Y = X - \gamma D \tag{4}$$

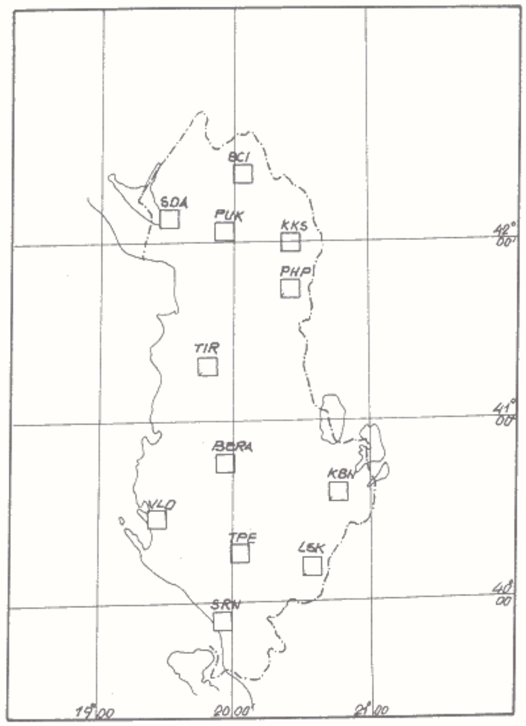

Figure 1. The Albanian Seismological Network (ASN).

where

$$Y = \ln (A\, D^{5/6}) \quad \text{and} \quad X = \ln A' \tag{5}$$

Minimizing the function:

$$F = \sum_{i=1}^{M} \sum_{j=1}^{N} \left[Y_{ij} - (X - \gamma D_{ij}) \right]^2 \tag{6}$$

where M is the number of earthquakes and N(j) is the number of amplitude values for each seismological station, we can obtain a more accurate, analytical value of coefficient γ.

As was explained in the introduction, our primary goal in this study is to estimate corrections for A_o factor in Richter's magnitude formula. Following a study of Ebel (1982), we can write the correction factor A_o as:

$$\log A_o = \log (A_{cal}/A_z) = \log\{\exp[(\gamma_{cal} - \gamma_z)D]\} \tag{7}$$

where γ_{cal} and A_{cal} are respectively anelastic-attenuation coefficient and amplitude for South California region, and γ_z, A_z are the same quantities for any different zone. Determining the correction factors for A_o, the formula for local magnitude takes the form:

$$M_L = \log A - \log A_o - \delta(\log A_o) \qquad (8)$$

where the A_0 values are those tabulated by Richter but they are corrected now by a factor which takes into consideration the difference of the anelastic-attenuation coefficient between the two zones (in our case: California and Albania).

3. Data analysis and results

Following the techniques described above, 250 earthquakes occurring from 1982 up to 1987 in and near-by Albania, were examined. A care was taken to have a good azimuthal and distance coverage. The magnitudes were in the range 2.0–5.0 and epicentral distances from 10 to 700 km. The hypocentral parameters were taken from either Monthly Seismological Bulletin of ASN or from the Bulletin of the International Seismological Center (ISC). The amplitude and frequency estimations for selected earthquakes were carried out in seismograms of 12 stations of the ASN (Fig. 1). Amplitudes were read for three maximal values of each seismogram and a mean value was determined. All the amplitude and frequency estimations were carried out on vertical 1 Hz short-period component of DD-1 type (Fig. 2). The predominant frequency was estimated by counting the number of zero crossings of the seismic trace within the 10 s interval and dividing it by two times the window length.

Because the master curves are constructed for one fixed magnitude, to compare them to the real data, a normalization or equalization procedure for one fixed magnitude is indispensable. It is quite clear that an earthquake with a small magnitude but very near to a seismological station could give an amplitude

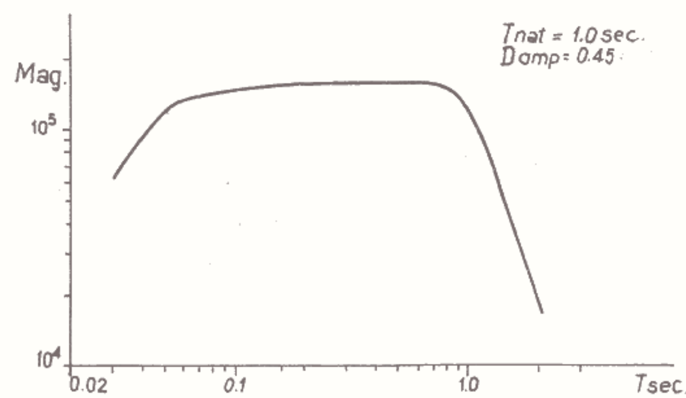

Figure 2. The response curve of vertical component of the DD-1 seismograph.

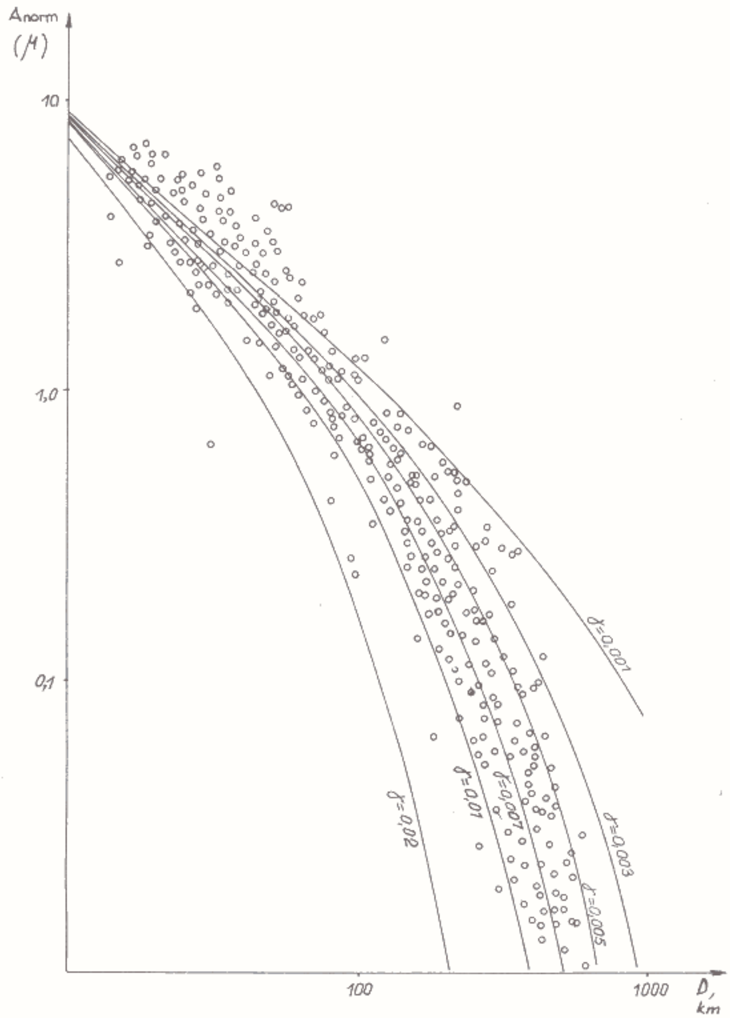

Figure 3. The comparison of master curves calculated from eq.(1) with data set of normalized observed amplitudes.

larger than an earthquake with a greater magnitude at a farther distance. Following the procedure recommended by Bollinger (1979) for equalization of the data, we picked M = 3.5 as the base magnitude and recalculated all the amplitude data. These equalized data are compared to the master curves of equations (1) and (2) (Figs. 3 and 4). Because the frequency of our data varies from 0.85 to 1.6 Hz, this comparison is made also for all *A/T* values (Nuttli, 1973; Bollinger, 1979) (Fig. 5). An approximate value of γ = 0.007 km^{-1} is obtained from these comparisons. The best fit is obtained for distances 100–700 km and there is

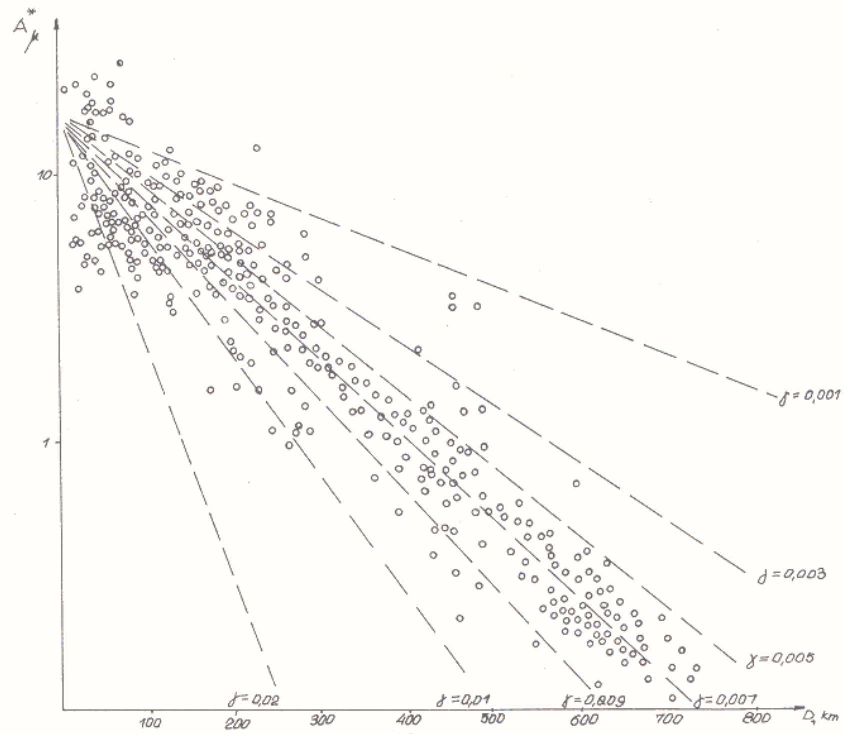

Figure 4. The comparison of straight theoretical lines calculated from eq.(2) with data set of normalized observed amplitudes.

considerable scatter for shorter distances, probably due to heterogeneities of station settings. These geological characteristics tend to be homogenized for distances more than 100 km.

The application of the least squares method described above with about 1600 data, gave us the values: $\gamma = 0.007052 \pm 3 \times 10^{-5}$ km^{-1}, and $X = 4.4229 \pm 0.021$ [see equation (6)], with a correlation coefficient equal to 0.86. We have accepted this value of γ as representative for the Albanian territory. Using this value in formula (7) and also the one of $\gamma = 0.0054$ km^{-1} for California (Ebel, 1982), we obtained the correction values for A_o factor in the local magnitude formula of Richter:

$$\delta(\log A_o) = -0.0016\, D \log e = -0.0006949\, D \qquad (9)$$

where D is epicentral distance in km. As seen from Table 1, for distances of about 80 km these correction values are about 0.1 and increase up to 0.4 for distances over 500 km.

Figure 5. The comparison of master theoretical curves with data set of normalized A/T.

Table 1. The values of $\delta(\log A_0)$ for different distances according to the new value of γ.

D, km	50	100	150	200	250	300	350	400	450	500	550	600
$-\delta(\log A_0)$	0.03	0.07	0.10	0.14	0.17	0.21	0.24	0.28	0.31	0.35	0.38	0.42

Distance, km	$-\delta(\log A_0)$
$D < 80$	0
$230 > D > 80$	0.1
$360 > D > 230$	0.2
$500 > D > 360$	0.3
$D > 500$	0.4

4. Conclusions

1. Theoretical curves and normalized straight lines expressing the dependence of amplitude on distance were obtained from the amplitudes of near earthquake records of the ASN.
2. The value of the anelastic-attenuation coefficient for Lg waves near 1 Hz for Albanian territory was determined as $\gamma = 0.007\ km^{-1}$.
3. Using this value of the anelastic-attenuation coefficient, the correction values of the A_0 factor in Richter's formula for local magnitude were calculated.

Acknowledgements – We would like to express our thanks to E. Sulstarova for his remarks on this article and to A. Mushi for his drawings.

Some improvements were made during the stay of one of authors (B.M.), in the Earthquake Research Institute, Tokyo, Japan and he would like to express his gratitude to all the staff of this Institute for the generous provision of all the facilities. He also thanks very much R. Geller from University of Tokyo for the corrections in English.

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