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VII.5 Anelastic attenuation from intraplate earthquake recordings

The previous report in this series contained a brief discussion of different models proposed for the anelastic attenuation (Q) in southern Norway, and the effects of these models when used in the calculation of source displacement spectra for earthquakes recorded at distances up to 500 km.

Recently, a different approach to this problem has been taken by Dahle et al (1989), who have collected and analyzed 87 earthquake records from 56 earthquakes occurring in predominantly intraplate areas (North America, Europe, China, Australia). The magnitudes of these events are in the range from M_s 3 to 8, the epicentral distances are from less than 10 to more than 1000 km, and the magnitude/distance correlation is 0.32. Depending on the type of regression analysis used, such correlation may introduce biases in the estimated regression coefficients.

The main purpose of the Dahle et al (1989) analysis was to establish models for strong ground motion (peak ground acceleration and pseudo-relative velocity) as a function of magnitude and distance, as follows:

$$\ln A = c_1 + c_2 M + c_3 \ln R + c_4 R \qquad (1)$$

where A is the ground motion amplitude, M is magnitude, and R is epicentral distance. A step-wise approach to the regression was taken, resulting in 'average intraplate' relations for PGA (peak ground acceleration) and PSV (pseudo-relative velocity), the latter for a number of frequencies from 0.25 to 40 Hz. For more details on the results here, we refer to Dahle et al (1989).

In the present context, the most interesting of the parameters estimated is the anelastic coefficient c_4 in equation (1), when A is Fourier amplitude (of acceleration). Assuming that a frequency dependent anelastic attenuation is causing the decay of these Fourier amplitudes, the c_4 term may then be written as

$$c_4 = -\frac{\pi f}{v \cdot Q(f)} \tag{2}$$

where f is frequency in Hz, and v is wave velocity (here taken as 3.5 km/s). This relation has been used at times (cf. Nuttli and Herrmann, 1984) to constrain the c_4 parameter using independent information on anelastic attenuation.

In the present case, however, we estimate c_4 (independently of the magnitude regression) and compute Q(f) subsequently using equation (2). In order to avoid the above-mentioned bias effects in the distance coefficients because of the (albeit weak in the present case) magnitude-distance correlation (Fukushima et al, 1989), we perform a two-step multilinear regression analysis (Joyner and Boore, 1981). In that case, the estimation of the distance coefficients is decoupled from the magnitude dependence by introducing dummy variables, and equation (1) is then rewritten as follows:

$$\ln A = \sum_{i=1}^{N} a_i E_i + c_3 \ln R + c_4 R \tag{3}$$

where

$$E_i = \begin{cases} 1 & \text{for earthquake } j \\ 0 & \text{otherwise} \end{cases}$$

N is the number of dependent variables (spectral points) in the magnitude-distance space, while there are L different earthquakes indexed j = 1,L.

The present analysis adopts a geometrical spreading model according to Herrmann and Kijko (1983), where the spreading function is defined as a combination of spherical and cylindrical as follows:

$$G(r,r_o) = \begin{cases} R^{-1} & \text{for } R \le R_o \\ (R_o \cdot R)^{-1/2} & \text{for } R > R_o \end{cases}$$

Herrmann and Kijko (1983) selected R_o = 100 km as a likely value in this model, partly based on a knowledge of at which distance the wave train changes from predominantly S waves (with spherical spreading) to predominantly Lg waves (with cylindrical spreading).

The distance dependent term c_4 is then determined by linear regression in the first step, along with the coefficients a_j, and the second step is performed by linear regression of the equation:

$$a = c_1 + c_2M \quad (4)$$

In following this method of analysis, a dependence of c_4 with frequency is found as shown in Fig. VII.5.1, resulting in, by using equation (2), Q(f) values as shown in Fig. VII.5.2. The functional appearance of the Q(f) values indicated in this case that a simple polynomial approximation of the following type could be used

$$Q(f) = A + Bf + Cf^2 \ldots. \quad (5)$$

resulting in the following relation:

$$Q(f) = 539 + 152f + 1.43f^2 \quad (6)$$

This relation is shown in Fig. VII.5.2 (lin-log scale) as well as in Fig. VII.5.3 (log-log scale) where also two other relations (for southern Fennoscandia) are shown, namely, Sereno et al 1988):

$$Q(f) = 560 \cdot f^{0.26} \quad (7)$$

and Kvamme and Havskov (1989):

$$Q(f) = 120 \cdot f^{1.1} \quad (8)$$

It is seen from Fig. VII.5.3 that the new relation (Q3) is reasonably close to Kvamme and Havskov (Q2) for high frequencies and reasonably close to Sereno et al (Q1) for low frequencies.

To illustrate the effects in terms of amplitude decay from the anelastic attenuation model derived here, we have plotted the function e^{C_4R} (C_4R equals Q^{-1} times number of wavelengths) in a log-linear scale in Fig. VII.5.4, for three different frequencies (0.25, 2.0 and 20 Hz). In addition, the amplitude decay effects of spherical and geometrical spreading are shown together with the Herrmann and Kijko (1983) model for R_o = 50, 100 and 200 km. In the latter case, spreading is spherical up to distance R_o, and cylindrical from there on. The figure clearly shows how the spreading effects dominate the anelastic effects even up to quite large distances, and it is therefore important to consider and to be aware of, in any case when anelastic attenuation is studied, how the results could be affected by the assumption with respect to geometrical spreading.

In the present case, we find that the results obtained for the c_4 coefficient depend on this model in the sense that the choice of a smaller R_o will increase the absolute value of c_4, and decrease Q, while a higher R_o will have the opposite effect. These effects of R_o on Q are, however, stronger for low frequencies than for higher frequencies. This means, in terms of Q models of the more conventional type $Q(f) = Q_o f^{\eta}$, that changes in R_o affect first of all Q_o. In turn, Q_o determines the seismic moment, which means that R_o essentially trades off with moment. For a closer discussion of the source moment for the earthquake discussed in the previous report in this series (8 August 1988), we refer to Hansen et al (1989).

In terms of the other Q relations shown in Fig. VII.5.3 (equations 7 and 8), it should be noted (T.J. Sereno, jr., personal comm.) that the larger epicentral distances (200 - 1400 km) used in the Sereno et al analysis essentially remove the effect of R_o on Q(f), which in that case is primarily determined by the way in which the spectral slopes change with distance. Kvamme and Havskov, on the other side, and in particular Dahle et al, use data with smaller epicentral distances, leading to a greater dependence of Q(f) on the model used for geometrical spreading.

It would therefore now be valuable to improve our knowledge and understanding of the geometrical spreading and the way in which it depends on wave type, source depth and crustal structure.

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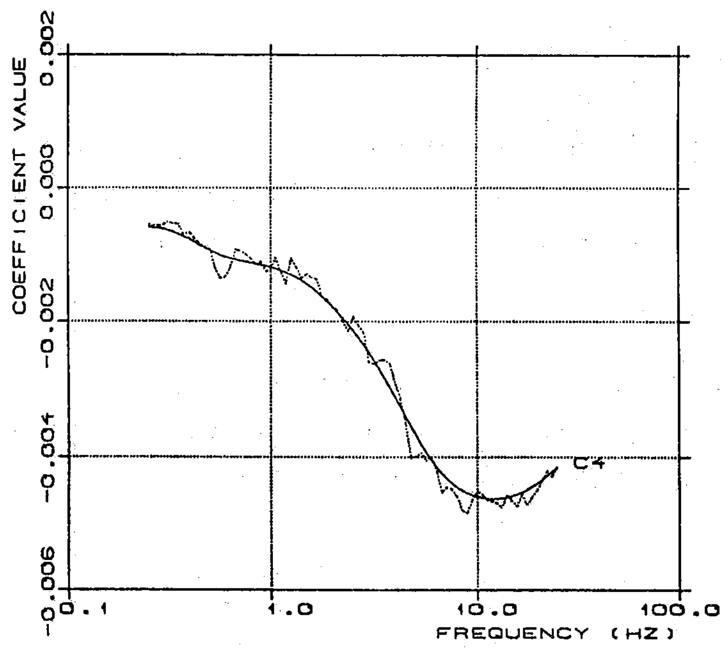

Fig. VII.5.1. Regression coefficient c_4 in equation (1) vs. frequency as derived from Fourier amplitude spectral estimates. The smooth line is a smoothed version of the computed values.

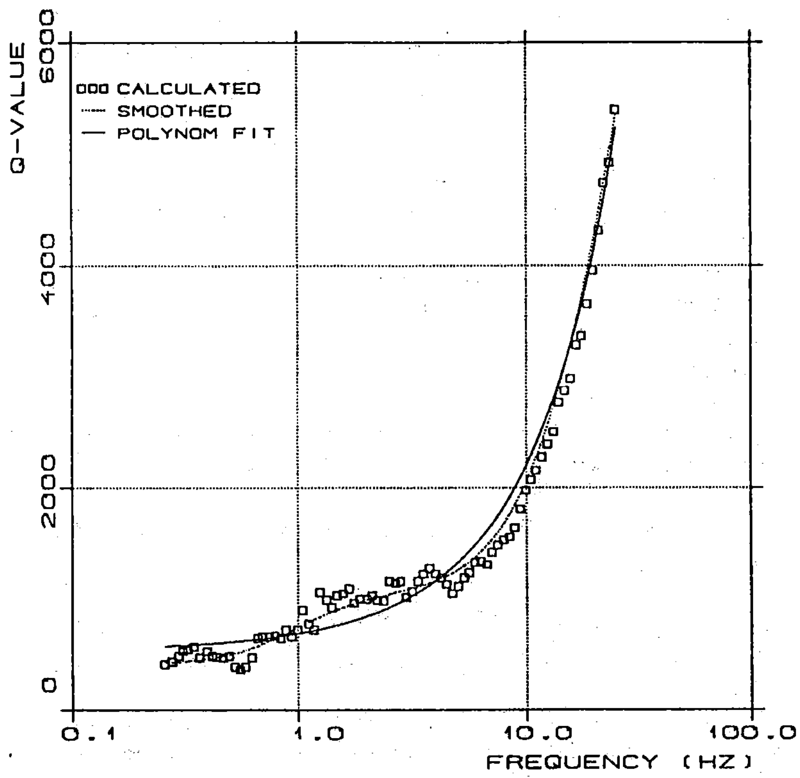

Fig. VII.5.2. Quality factor Q as a function of frequency, as derived from the c_4 coefficients in Fig. VII.5.3 using equation (2). Squares indicate calculated values, the dotted line is a smoothed version, and the fully drawn line is a polynomial fit given by equation (3).

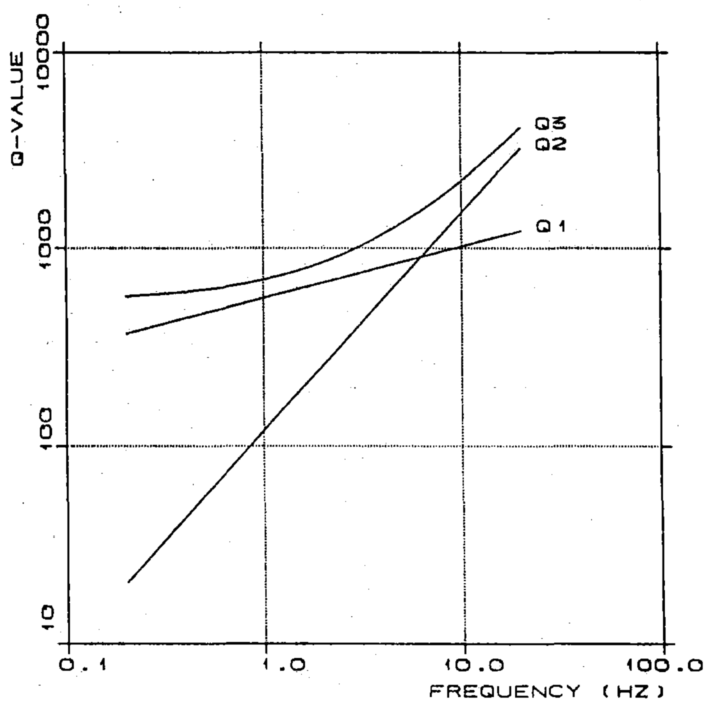

Fig. VII.5.3. Three different relations for anelastic attenuation: (1) $Q = 560f^{0.26}$ (Sereno et al, 1988); (2) $Q = 120\ f^{1.1}$ (Kvamme and Havskov, 1989); (3) $Q = 539 + 152f + 1.43f^2$ (Dahle et al, 1989).

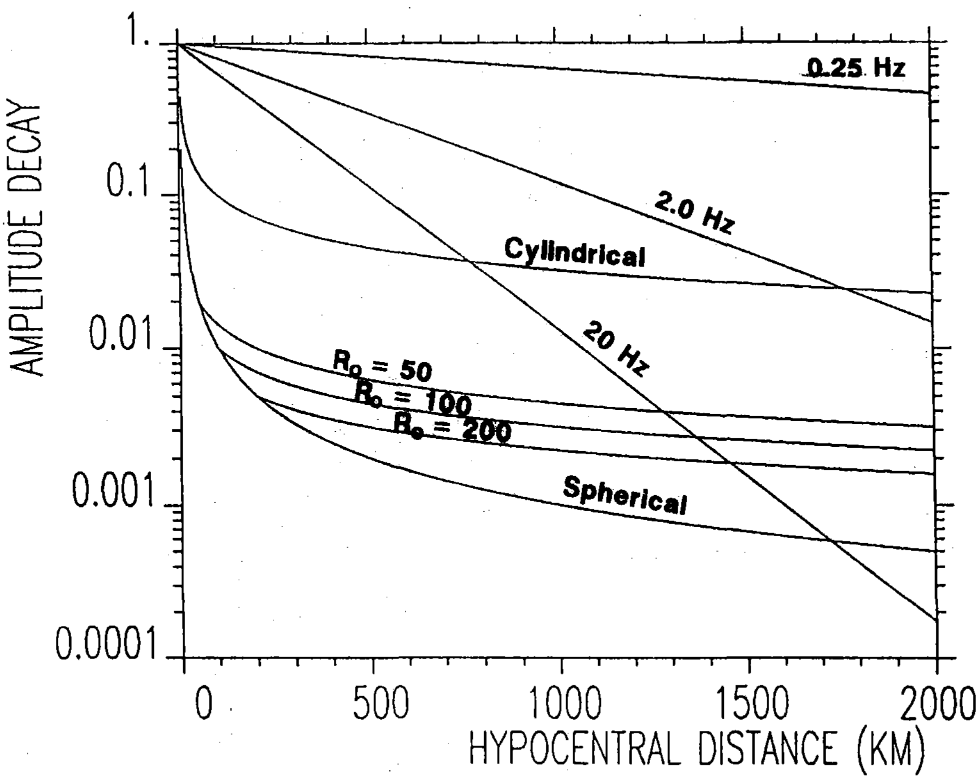

Fig. VII.5.4. Anelasticity and geometrical spreading decay of Fourier spectral acceleration (unit-size at 1 km distance) with increasing hypocentral distance. The anelastic term is shown for 3 frequencies (0.25, 2.0 and 20 Hz) according to the results of this study. Geometrical spreading functions for the limiting cases purely spherical or purely cylindrical are shown, together with the Herrmann and Kijko (1983) model with R_o = 50, 100 and 150 km. A, B and C are the coefficients in the degree 3 polynomial fit to Q(f) as given by equation (3).