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PEAK ACCELERATION ATTENUATION BY ELIMINATING THE ILL-EFFECT OF THE CORRELATION BETWEEN MAGNITUDE AND EPICENTRAL DISTANCE

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SUMMARY

A new regression method was developed to derive peak acceleration attenuation. This method uses attenuation rate βi and reliability ψi, which are obtained through regression analysis of multiple records in a single event. The total attenuation rate, β, is the weighted mean of the β_i's and the ψ_i's. The value $\beta = 2.32$, which is significantly greater than the value proposed by most recent studies, was obtained. Using Principal Component Analysis and the data of a recent strong shake, the regression result was verified. It was concluded that the new regression method is more accurate than the traditional method. Moreover, it was shown that the new regression equation is not affected by the strong correlation between magnitude and epicentral distance.

INTRODUCTION

Generally, there is a tendency to an uneven distribution of data when multiple records of earthquakes are used, that is, small earthquakes occur within a small distance of the epicenter, while large earthquakes occur at larger distances. This problem always appears in seismic observation, even in the attenuation equations used in Japan (see Ref. 1) the records of large earthquakes at short distances are not included in the data set. Since there is a strong correlation between magnitude and epicentral distance, it is difficult to evaluate the contribution to peak acceleration from magnitude and epicentral distance alone. Therefore, the characteristics of peak acceleration attenuation are not clear in most of the recent attenuation rate studies, where the range of peak acceleration attenuation rate β, from 0.8 to 1.8, is too wide to be considered accurate.

As more data from strong motions is accumulated, the true characteristics of this phenomenon may become more evident. However, a good attenuation cannot be obtained just by increasing the data. The standards of judgment for each type of data should be clarified, and it must be considered how we can eliminate the ill-effect of the correlation present in the data set.

ESTIMATION OF ATTENUATION RATE

Data Set of Peak Acceleration Figure 1 represents the magnitude distribution of 27 events recorded in the Kanto Region of Japan from 1971 to 1985. These provided 227 peak acceleration data points for this study. For each event, only one horizontal acceleration component was used at any observation station, which was recorded near the ground surface, and had a maximum peak value at that station.

As seen in Figure 1, the correlation coefficient between magnitude and epicentral distance has the high value of 0.84. Therefore, when performing the regression analysis, magnitude and epicentral distance cannot be used as two independent parameters.

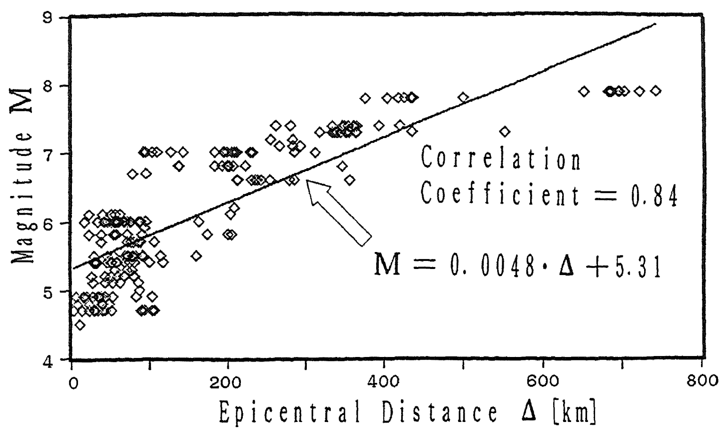

Figure 1. Magnitude Distribution of the 27 Events which Provided 227 Peak Acceleration Data Points for This Study (Kanto Region of Japan, 1971~1985)

<u>The Attenuation Rate of a Single Event</u> In order to study the characteristics of peak acceleration attenuation without the effect of the correlation between magnitude and epicentral distance, we assumed regression equation (1). Since we are working on a single event, the magnitude is the same for all the records, therefore it cannot be used in this analysis. If the effect of the ground condition is omitted, the rule of attenuation becomes a simple equation in which the values of peak acceleration are inversely proportional to epicentral distance.

$$\log \bar{A} = -\beta_i \cdot \log(\Delta + 10) + \delta_i \qquad (1)$$

where i is the earthquake number; $\bar{A}$ is the estimation of peak acceleration; βi is the attenuation rate, and the δ_i is a constant for earthquake i.

Figure 2 shows two different cases of equation (1). After comparing these situations, two factors are considered important:

① The number of available records. This number can be considered in terms of the degree of freedom.

② The value of the correlation coefficient between peak acceleration and epicentral distance, which is higher the closer the data points are to the regression line.

To take into account factors for the 27 events, we defined a new parameter ψ_i, reliability, for each β_i:

$$\psi i = N_i \cdot Ri^2 \qquad (2)$$

where N_i is the degree of freedom of regression, and R_i is the correlation coefficient between peak acceleration and epicentral distance for event i. If reliability ψ_a is greater than ψ_b, for example, that might mean β_a has more records than β_b, or β_a's regression line fits the data distribution better than that of β_b, or both as in Figure 2. In any case, we can say that β_a is more reliable than β_b.

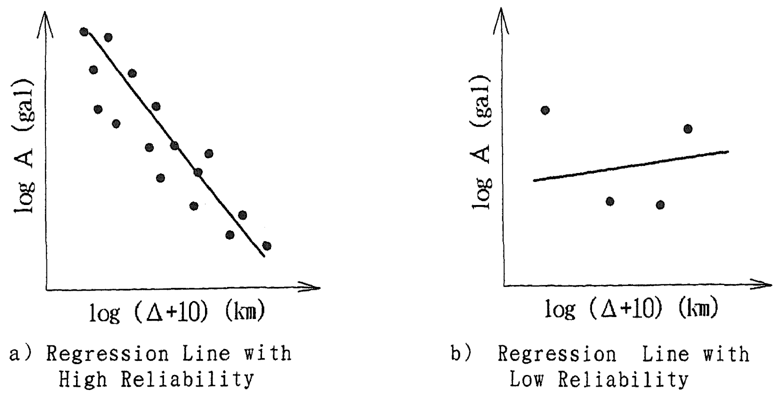

Figure 2. Two Different Cases of Equation (1).

The attenuation rate β_i of the 27 earthquakes scattered from -6 to +9 is shown in Figure 3. This range is too wide if the physical meaning of the negative values which were amplified by the large distance is considered. Therefore, there are some β_i's which for some reason did not attenuate at all, thus should be excluded from the analysis of the ultimate regression. Taking the new parameter reliability ψ_i(defined by expression(2)) into consideration, as shown in Figure 3, a rule of attenuation appears: β_i's are only scattered for ψ_i less than 1, for ψ_i greater than 1 the β_i's converge in a narrow range; for ψ_i greater than 3, β_i's converge between 2 and 3.

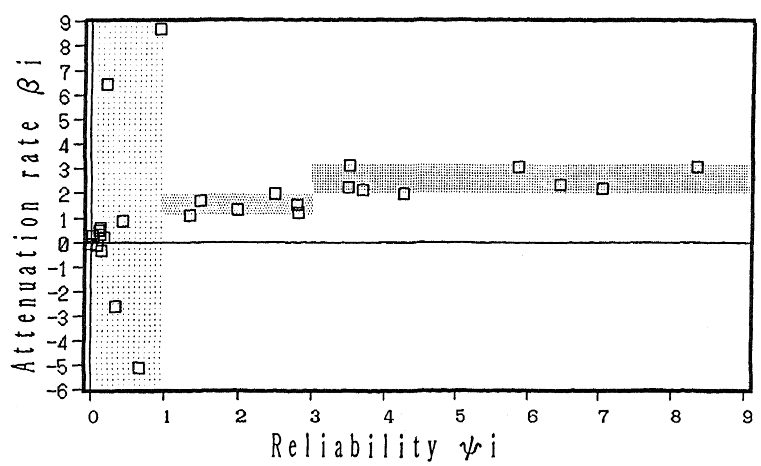

Figure 3. Attenuation Rate Distribution of the 27 Events Against the New Parameter Reliability ψ_i.

Checking the parameters of the 27 earthquakes, it is clear that for those with $\psi_i \geqq 1$ the β_i's will converge; the same boundary can classify the type of earthquakes. The events with ψ_i greater than 1 coincide with the earthquakes having a shallow focus - we will refer to them as group U. We will refer to the earthquakes with ψi smaller than 1 as group B. The latter include the following five types of earthquakes:

1. Events with focus depth greater than 388 km.
2. Events with small magnitude and focus of about 100 km.

3. Events whose focuses are so far from the stations that the difference between epicentral distances has no meaning.
4. Events recorded by three stations only.
5. Events with an abnormal record (Figure. 4).

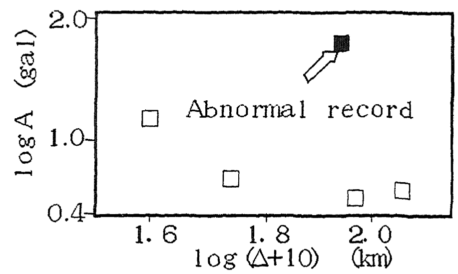

Figure 4. Event with Abnormal Record

To derive an attenuation relation, we must take into consideration the different types of attenuation. ψ_i is an effective parameter to help us in judging the validity of the records of an event. In this study, we excluded group B from the ultimate regression.

IMPROVEMENT OF REGRESSION METHOD

The result of the multiple regression is given by equation (3), using the data set of group U. The same data set, was also used with equation (5).

$$\log \bar{A} = 0.428 \cdot M - 1.76 \cdot \log(\Delta + 10) + 0.069 \cdot T + 2.09 \quad (3)$$

$$R = 0.778$$

$$\beta = \frac{\Sigma \psi_i \cdot \beta_i}{\Sigma \psi_i} \quad (4)$$

$$\log \bar{A} = 0.509 \cdot M - 2.32 \cdot \log(\Delta + 10) + 0.039 \cdot T + 2.33 \quad (5)$$

$$R = 0.777$$

where $\bar{A}$, M and Δ are as explained before, and T is the predominant period of the site. The difference between equation (3) and equation (5) is that in the first one, multiple regression analysis was performed on the peak acceleration A with three terms (M, Δ and T) , and in the latter a particular value of β - the weighted mean of the β_i's and ψ_i's - was obtained and fixed by expression (4), and the multiple regression analysis was performed with two terms (M and T)

It is interesting to note that since in regression equation (5), the coefficients of magnitude M and epicentral distance Δ have larger absolute values than in regression equation (3), the increase in peak acceleration due to the increase in magnitude is more noticeable for equation (5) than for equation (3), and at the same time the attenuation of peak acceleration due to distance is much faster in equation (5) than in equation (3). In other words, regression (5) is more sensitive to magnitude and epicentral distance. The question is: why do both regression equations have almost the same correlation coefficients ?

Since T has a much smaller absolute value than the coefficients of M and Δ, in both equations, we simplified the question by omitting T, with little effect on the estimation. If we plot the data for log A, M and log Δ, we obtain a bar-type distribution as shown in Figure 5. Due to the strong correlation between M and Δ (log (Δ + 10)), many regression planes with the same correlation coefficient exist, although their attenuation rates are different. As can be understood from Figure 5, if there is a strong correlation between M and Δ, another special method technique should be used besides the minimum mean square method to obtain the best attenuation rate. The next question is which attenuation law is more reliable?

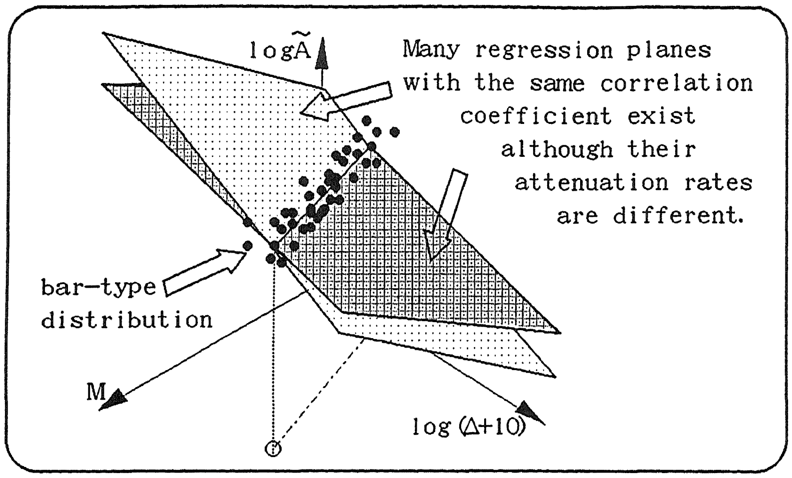

Figure 5. Due to the Strong Correlation between Magnitude and Epicentral Distance the Data Has a Bar-type Distribution.

Principal Component Analysis (PCA) may be effectively used to examine the differences between the reliabilities of equation (3) and equation (5). PCA was performed using five variables: log A, M, log(Δ+10), T, and log ($\bar{A}$/A), the last of which was added to represent the residuals between the observed and estimated peak accelerations. Figure 6 shows the first principal components for the two cases. The coefficients for M and Δ are both negative while the one for log $\bar{A}$ is positive, implying the undesirable but inevitable properties of the data set which is dominated by a small peak acceleration with large M and Δ. However, the coefficient for log($\bar{A}$/A) in equation (5) is very small compared with the one in equation (3), indicating that the errors associated with the estimation in equation (5) are not affected by the ill-effect of the correlation between M and Δ.

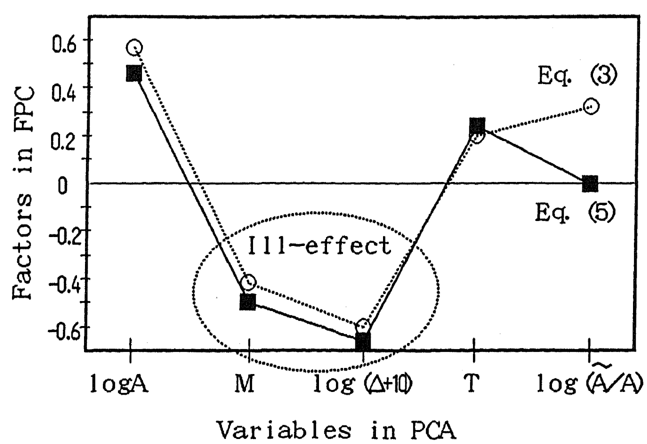

Figure 6 Implications of First Principal Components Obtained by the Principal Component Analysis.

Comparison of the Result with Recent Records Figure 7 plots the data for peak acceleration against epicentral distance for a strong shake occurred in December 1987. As shown, the attenuation rate of 2.81, has the same tendency as the attenuation rate of regression equation (5). The Miyagiken-Oki earthquake (1978, Japan) and the Nihonkai-chubu earthquake (1983, Japan), also show the same tendency.

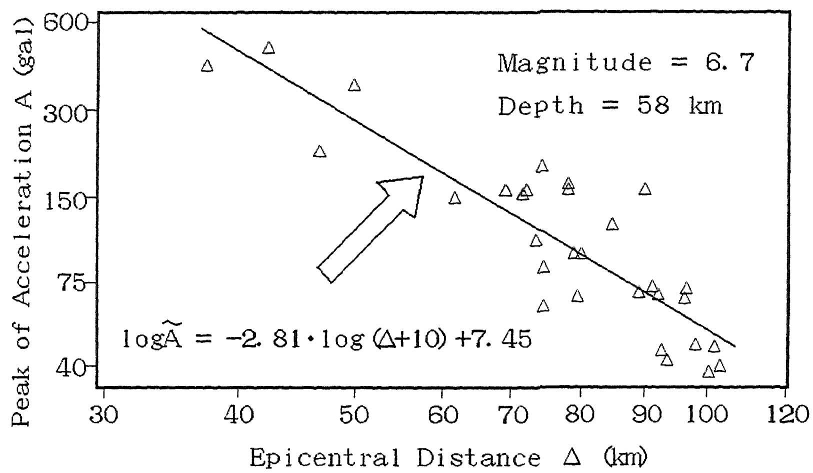

Figure 7 Peak Acceleration Against Epicentral Distance from Earthquake Off-Chiba Prefecture (December 17, 1987, Japan).

CONCLUSIONS

As we have shown, since there is a strong correlation between magnitude and epicentral distance, a particular attenuation rate is needed for regression analysis. From single event regression, the new parameter reliability ψi can be used as a basis for determining the attenuation type. Also, a proper attenuation rate is obtained from the weighted mean of ψi's.

Finally, by eliminating the ill-effect, the obtained value for the attenuation rate is higher than the values proposed by most recent attenuation rate studies.

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