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ATTENUATION OF VERTICAL GROUND ACCELERATION USING JMA-87 TYPE SEISMOMETER DATA

University of Tokyo Student M. Laurensius Dicky
University of Tokyo Member Fumio Yamazaki, Gilbert L. Molas, Tsuneo Katayama

INTRODUCTION: Peak ground motion is commonly used to scale response spectra or ground motion time histories for use in earthquake resistant design. Many attenuation laws for horizontal ground motion were developed in terms of magnitude, distance and ground condition. However, relatively few studies have been made for attenuation of vertical ground motions. In this paper, prediction of horizontal, vertical peak acceleration and ratio of vertical to horizontal acceleration in Japan are proposed.

DATA: Time histories accelerations used for this study were recorded by the new JMA-87 type accelerometer from August 1, 1998 to December 31, 1993. Records with horizontal peak ground acceleration less than 1.0 gal and focal depth larger than 200 km are excluded. Using the above criteria 2,166 three-component peak ground acceleration from 387 earthquakes were obtained. Data obtained show few strong motion at close distance. Distribution of magnitude-slant distance shows positive correlation between magnitude and distance (0.57). This correlation is caused by the fact that seismic waves produced by large magnitude earthquake tend to propagate farther than those by small earthquakes.

ATTENUATION MODEL: In this study, the attenuation model proposed by Joyner and Boore [1] is used because there is physical meaning in that model. Since the effect of local ground condition is also important, station coefficients were used [2], instead of using soil type coefficients. The basic form of attenuation model is expressed as

$$\log y = b_0 + b_1 M + b_2 R + b_3 \log R + b_4 h + \sum_{i=1}^{N} c_i S_i \qquad (1)$$

where y is the peak ground acceleration, M is the JMA magnitude, R (km) is slant distance, h (km) is the depth, c_i is the station coefficient and $S_i=1$ for recorded station-i, $S_i=0$ otherwise.

In order to avoiding systematic errors if ordinary multilinear regression is used [3], the two stage regression is used. The normal equation obtained is singular, therefore, iterative regression analysis was performed [2].

RESULTS : The resulting equation for horizontal motion is :

$$\log y_h = 0.206 + 0.477M - 0.00144R - \log R + 0.00311h + c_i^h + 0.276P \qquad (2)$$

while for vertical motion :

$$\log y_v = -0.182 + 0.475M - 0.00162R - \log R + 0.00351h + c_i^v + 0.264P \qquad (3)$$

where P is 0 for 50-percentile values and 1 for 84-percentiles.

Figure (1) shows the attenuation of PGA in the vertical direction adjusted for magnitude, depth and site effect. Using the mean station coefficient (c=0) and focal depth=10 km, the result obtained from equation (3) is compared with the attenuation proposed by Kawashima [4]. It shows that the former one gives the lower expected values. Vertical acceleration is generally expressed as a fraction of horizontal motion. The value of two-thirds which is most often used as the maximum effective ratio seems conservative when averaging over all strong ground motions records. However, some records have a ratio greater than 2/3. The recent 6.6 magnitude Northridge earthquake shows this phenomenon. Considering the facts above, it is also our interest to predict the expected ratio of peak vertical to horizontal acceleration. The ratio can be examined in two ways. First by combining equations (2) and (3) which invidually predict peak horizontal and peak

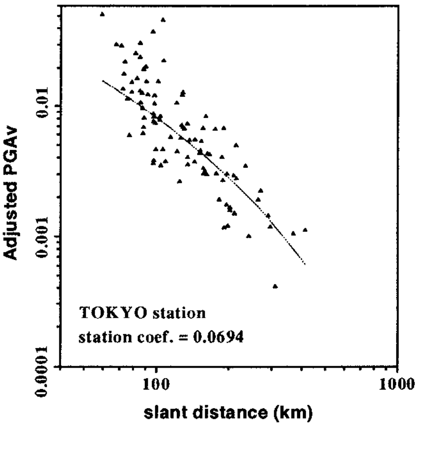

Figure 1. Attenuation curve of PGAv

vertical acceleration and the other is to perform a regression directly on the ratio of vertical to horizontal acceleration. Using the first approach the resulting equation is:

$$\log(y_v / y_h) = -0.388 - 0.002M - 0.00018R + 0.0004h + c_i^r \quad (4)$$

which is almost independent on the magnitude, depth and distance. The average of this ratio without taking weighting due to the different number of data for each station is 0.43.

Applying the second way by not constraining the geometric spreading to the spherical model, the resulting equation is :

$$\log(y_v / y_h) = -0.184 - 0.0004M - 0.00002R - 0.085\log R + 0.00046h + c_i^r + 0.14P \quad (5)$$

and can be written as:

$$\log(y_v / y_h) = -.0184 - 0.085\log R + c_i^r + 0.14P \quad (6)$$

Equation (6) clearly shows that the ratio is dependent on distance. This attenuation law looks reasonable indicating that at closer distance the expected ratio become larger. Figure (3) shows the expected ratio from equation (4) and (6) for Tokyo station. In addition, direct averaging at each station was also performed. Figure (4) shows that the results look very close to that of equation (4). It is expected that the ratio (V/H) will be larger for stiffer ground condition. Using ground condition classification given by Earthquake Design Spesifications of Highway and Bridges (ERDHSB), the averages of equation (4) without weighting are 0.47; 0.44; 0.4; 0.36 for rock, hard soil, medium soil and soft soil, respectively.

CONCLUDING REMARKS: Attenuation law for horizontal, vertical acceleration and the ratio of vertical to horizontal acceleration in Japan are proposed. The ratio obtained by using the attenuation of horizontal and vertical acceleration is almost independent of magnitude, distance and depth. This ratio is close to the ratio obtained by direct averaging at each station. Generally those ratios are lying between the attenuation law of V/H which is dependent only upon slant distance with the closest and farthest slant distance. The ratio (V/H) generally increases as the distance is closer and the ground condition is stiffer.

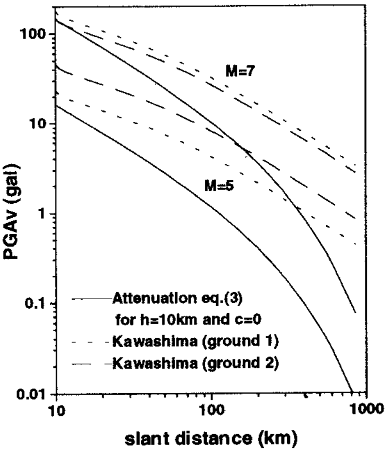

Figure 2. Comparison of PGAv attenuation curve

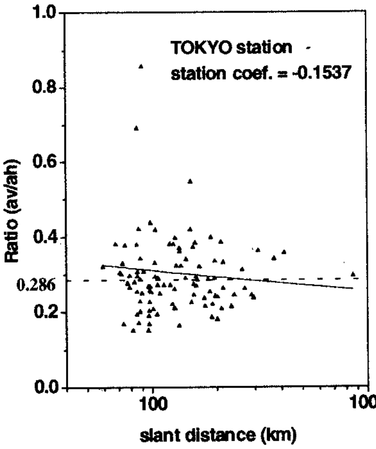

Figure 3. Attenuation curve of V/H

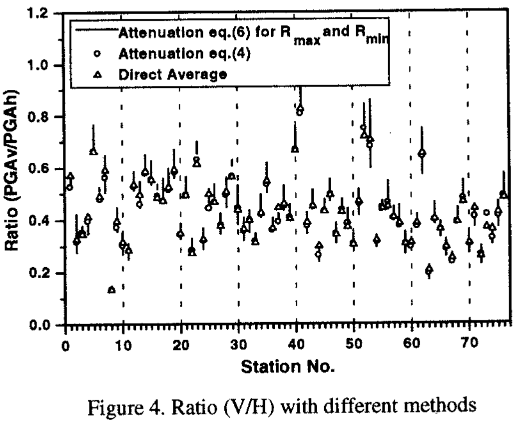

Figure 4. Ratio (V/H) with different methods

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