(26) PEAK VERTICAL GROUND ACCELERATION PREDICTION USING JMA-87 TYPE ACCELEROMETER DATA

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INTRODUCTION: Peak ground motion is commonly used to scale response spectra or generated artificial acceleration for use in earthquake resistant design. Many attenuation laws for horizontal ground motion were developed in terms of magnitude, distance and ground condition. The transient vertical earthquake loads have been viewed as relatively unimportant since structures are designed to withstand for gravitational loads. Horizontal earthquake loads, although just as transient, are often viewed as the largest horizontal loads that a structure will ever have to bear. Effect of vertical ground motion to the structures will increase significantly by the fact that many records showed high value. 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 using new type accelerometer are proposed.

DATA: Time histories accelerations used for this study were recorded by the new JMA-87 type accelerometer from August 1, 1988 to December 31, 1993. All of the records can be considered as free field since the accelerometers are placed on the small foundation that are detached from the structure. Records with horizontal peak ground acceleration less than 1.0 gal and focal depth larger than 200 km are excluded. The resulting data consists of 2,166 three-component peak ground acceleration generated from 387 earthquakes. Data obtained show few strong motion at close distance and for better prediciton, strong motion at close distance are still required. Distribution of magnitude-slant distance shows positive correlation (≈0.57) between magnitude and distance. This correlation is typical for strong motion data set and 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.
Equation (1) can be expressed in matrix form as:

$$\begin{Bmatrix} \log y_1 \\ \log y_2 \\ \vdots \\ \log y_n \end{Bmatrix} = \left[\begin{array}{ccccc|ccc} 1 & M_1 & R_1 & \log R_1 & h_1 & S_{1,1} & \cdots & S_{N-1,1} \\ 1 & M_2 & R_2 & \log R_2 & h_2 & S_{1,2} & \cdots & S_{N-1,2} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & M_n & R_n & \log R_n & h_n & S_{1,n} & \cdots & S_{N-1,n} \end{array}\right] \begin{Bmatrix} b_0 \\ \vdots \\ b_4 \\ \hline c_1 \\ \vdots \\ c_{N-1} \end{Bmatrix} + \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{Bmatrix} \qquad (2)$$

where n is the number of records, N is the number of recording stations and ε_i is associated residual. If the j-th record is recorded in the last station, then $S_{i,j}$ is taken as -1.0 for i=1 to N-1. This configuration of the dummy variable, $S_{i,j}$, results in a zero mean for the station coefficients.
The coefficient of the N-th station is

$$c_N = -\sum_{i=1}^{N} c_i \qquad (3)$$

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

RESULTS: By constraining the geometric spreading to the spherical model (b_3 = −1), the resulting equation for horizontal motion is :

$$\log y_h = 0.206 + 0.477M - 0.00144R - \log R + 0.00311h + c_i^h + 0.276P \quad (4)$$

while for vertical motion :

$$\log y_v = -0.182 + 0.475M - 0.00162R - \log R + 0.00351h + c_i^v + 0.264P \quad (5)$$

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

Figure (1) shows recorded PGA in vertical direction adjusted to M=5.5 and depth=40 km at Tokyo station. Also shown the mean of predicted value, the mean±1σ. From this figure it can be seen that predicted equation fit relatively well with recorded acceleration. Using the mean station coefficient (c=0) and focal depth=10 km, the result obtained from equations (4) and (5) is compared with the attenuation proposed by Kawashima [4] and Ambraseys [5] and presented in Figure (2). While making comparison with Ambraseys, the JMA magnitude is converted to the surface-wave magnitude using relation [6]:

$$M_S = 1.27M_J - 1.82 \quad (6)$$

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 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 (4) and (5) which invidually predict peak horizontal and peak 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:

$$\log(y_v / y_h) = -0.388 - 0.002M - 0.00018R + 0.0004h + c_i^{r'} \quad (7)$$

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, which is smaller than 2/3.

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

$$\log(y_v / y_h) = -0.184 - 0.0004M - 0.00002R - 0.085\log R + 0.00046h + c_i^r + 0.14P \quad (8)$$

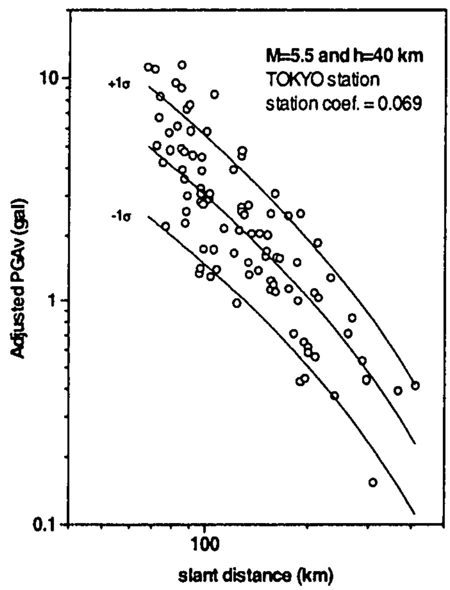

Figure 1. Predicted PGAv and recorded

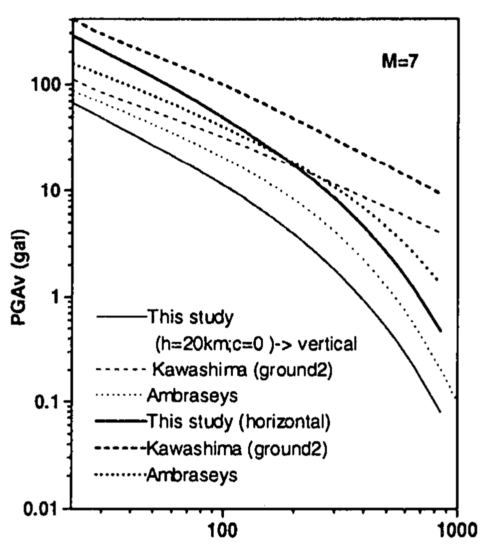

Figure 2. Comparison of predicted PGA

and can be written as:

$$\log(y_v / y_h) = -0.184 - 0.085\log R + c_i^r + 0.14P \quad (9)$$

Equation (9) shows that the ratio is dependent on distance, even the distance term is relatively small. However, this coefficient passed 99% confidence level, shows that this term is significant. This attenuation law looks reasonable indicating that at closer distance the expected ratio become larger. Figure (3) shows the expected ratio from equation (7) and (9) for Tokyo station. In addition, direct averaging at each station was also performed. While figure (4) shows the expected ratio from equation (7), direct averaging and minimum, maximum recorded ratio at each statiom. It is clearly shown that there is large discrepancy between predicted and recorded. However, results by direct averaging look very close to that of equation (7). 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 (7) without weighting are 0.47; 0.44; 0.4; 0.36 for rock, hard soil, medium soil and soft soil, respectively.

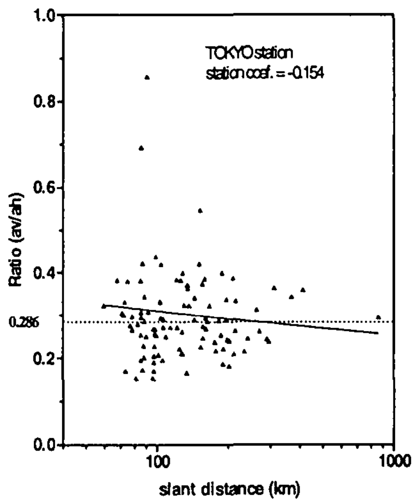

Figure 3. Predicted ratio and recorded

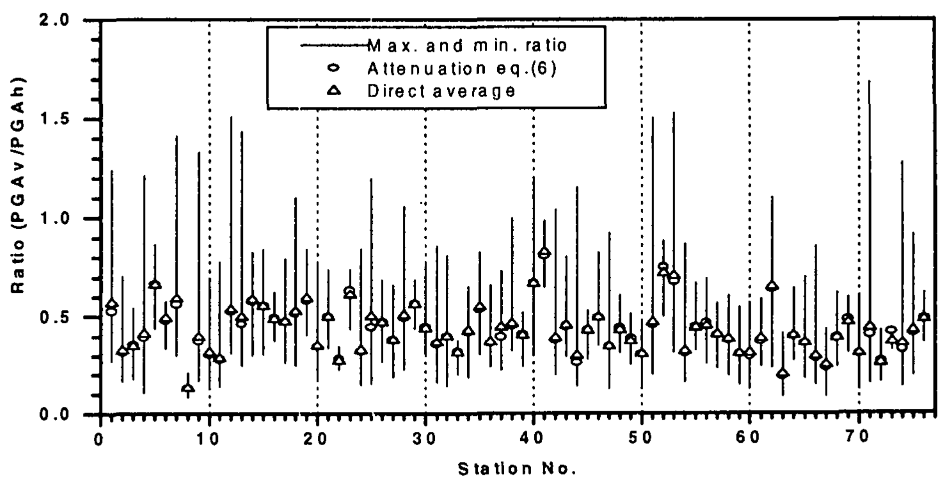

Figure 4. Predicted ratio from eq.(7), direct averaging and recorded max./min.

EFFECT OF FOCAL DEPTH: In accordance with previous study [2], it is also interesting to examine the effect of focal depth to the predicton of vertical ground acceleration. We grouped the records into several depth interval (Table 1) and performed regression analysis separately. Resulting coefficients are are given in Table 2. As observed by previous study [2] for horizontal motion, it also can be seen for vertical motion that depth term, b_4, for the groups with depths less than 90 km relatively larger than those with depths greater than 90 km. However, when we multiply to the correspond depth, opposite trend are obtained. Negative b_4 coefficient for group D also observed here as for horizontal motion [2]. The reason may be insufficiency of data for deeper events. Predicted PGA in vertical direction versus slant distance for each group of focal depth and M=6.0 is presented in figure (5). While plotting, focal depth is taking as mid-point of the group range. This figure clearly shows that higher predicted value is observed for deeper events. Except for group E, the shape of attenuation curve with respect to distance are similar. For group E, the attenuation rate with respect to distance is found to be smaller.

Table 1. Grouping of records to different depth range

Group	Focal depth range	No.of events	No. of records	No. of stations
A	0.1 - 30	111	553	72
B	30 - 60	135	775	69
C	60 - 90	93	509	53
D	90 - 120	31	229	42
E	120 - 200	18	100	39

Table 2. Resulting coefficients for different groups

Group	b_0	b_1	b_2	b_4
A	-0.318	0.500	-0.00197	0.00628
B	-0.177	0.474	-0.00230	0.00642
C	-0.678	0.571	-0.00185	0.00495
D	-0.422	0.605	-0.00134	-0.00126
E	-1.176	0.625	-0.00024	0.00159

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. Expected vertical ground acceleration will give higher value for deeper events at the same distance. The ratio (V/H) generally increases as the distance is closer and the ground condition is stiffer.

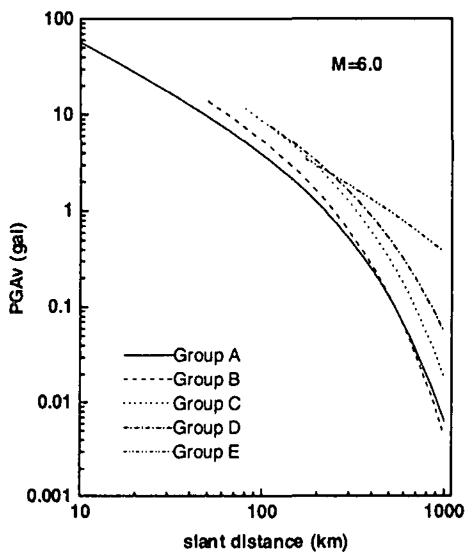

Figure 5. Predicted PGA_v from different depth range

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