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ATTENUATION OF PEAK ACCELERATION TAKING INTO ACCOUNT MULTIPLE FAULT RUPTURE MECHANISMS

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SUMMARY

Estimates of peak acceleration calculated from existing attenuation laws become unrealistic near the earthquake source because the epicentral distance is not an adequate parameter by which to express the distance between the source region and the site. A simplified analytical procedure with which to estimate the attenuation of peak ground motion was developed that takes into account the fault extent. Peak acceleration near the fault region is expressed as a function of the fault parameters and the relative collocation between the fault and the observation site.

The peak accelerations of the 1983 Nihonkai-Chubu Earthquake were simulated, those at bed rock level were estimated, then the damping effect of the path traveled and the amplification factor of the surface ground were introduced. The contours of our estimated peak accelerations are in good agreement with the recorded peak accelerations for this earthquake.

INTRODUCTION

A multi-variable regression analysis that included the magnitude of the earthquake, the epicentral distance and the site condition was made in order to investigate the attenuation of peak accelerations. Many regression equations have been proposed (Refs.1,2), but a regression curve is affected by the characteristics of the data base used. Although the numbers of records of observed earthquakes are increasing, consistent data that show homogeneous distribution of the epicentral distance and magnitude are rare, especially over a short distance and for a large magnitude. We here present a simplified analytical method with which to predict peak accelerations near the source region where the effect of the fault extent can not be ignored.

To account for the extent of the fault, a large event must be synthesized from small events that occur in part of the fault plane. A method for this first was proposed by Harzell (Ref.3) in a somewhat simple formula. There have been many attempts to improve his method (Refs.4,5). We have used Irikura's revised model (Ref.6). It is based on the idea that slips that occur on the fault plane during a large event can be replaced by the spatial distribution of slips that take place during small events. Therefore, high frequency components can be generated sufficiently.

The equation of superposition is transformed into a frequency domain to obtain the power spectrum of the large event. The expectation of peak ground motion thus can be evaluated in terms of three spectral moments.

As a wave propagates through soil, its amplitude attenuates because of inertial friction. This friction effect is expressed by the dimensionless quantity Q, which, in general, depends on the frequency. Many equations have been proposed to express the frequency dependence of the Q-value for Japan (Refs.7,8). Iwata and Irikura (Ref.9) obtained the Q-value of the shear wave from the 1983 Nihonkai-Chubu Earthquake by using an inversion method.

The effect of the site itself also is important when predicting surface ground motion. Having assumed seismic bed rock for which the shear wave velocity is about 3km/sec, we needed the amplification factor between the deep bed rock and the ground surface. Midorikawa et al.(Ref.10) defined the relation between geological conditions and the amplification factor for the value of peak acceleration of deep seismic bed rock. We have taken into account the damping effect of the propagation path and the amplification effect of the surface ground in order to obtain a realistic predicted acceleration.

METHOD FOR PREDICTING PEAK ACCELERATION

A fault mode of the Haskell type has been assumed. The model is described by a rectangular fault with five factors: the fault length, L; the fault width, W; the rise time, τ ; the final offset of dislocation, D; and the rupture velocity, V_r . Assuming that small events are caused by the dislocation of small areas along the fault, we can synthesize a large event by superposing these small events and taking into account the time delay caused by rupture propagation. Fig.1 shows the fault mode. The fault plane is divided into n elements, each of which corresponds to the area of a small event.

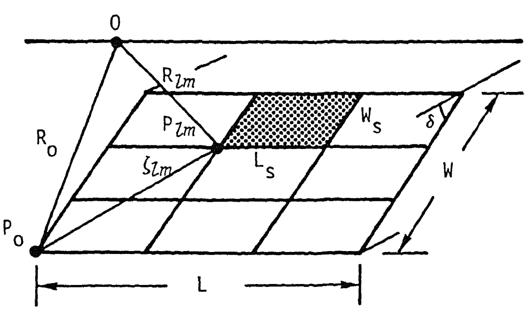

Fig.1 Fault Model

In Irikura's revised model (Ref.6), the motion of a large event, $g_L(t)$, at observation point O is expressed by the motion of a small event, $g_S(t)$, as

$$g_L(t) = \sum_{l=1}^{N_L N_D} \sum_{m=1}^{N_W} g_{slm}(t - t_{lm}) \tag{1}$$

in which N_L ,N_W and N_D are the number of subdivisions that correspond to the fault length, fault width and dislocation. We assume the relation $N_L = N_W = N_D = n = \sqrt[3]{M_{oL}/M_{oS}}$, in which Mo_L and Mo_S are the seismic moments for the large and small events. t_{lm} is the time delay related to the wave propagation.

Earthquake motion produced by a small event and its Fourier transform can be written

$$g_S(t) = \frac{R_{\theta\phi}}{4\pi\rho v_s^3} \cdot \frac{S(t)}{R_{lm}} \tag{2}$$

$$G_S(f) = \frac{R_{\theta\phi}}{4\pi\rho v_s^3} \cdot \frac{S(f)}{R_{lm}} \tag{3}$$

in which $R_{\theta\phi}$ is the radiation pattern, ρ the density of the medium, S(t) the source time function and S(f) the source spectrum. Multiplying the Fourier transform of Eq.(1) by the conjugate of G(f), we can express the power spectrum of the earthquake motion of a large event as

$$P_L(f) = \frac{2}{T}\left(\frac{R_{\theta\phi}}{4\pi\rho v_s^3}\right)^2 S(f)S^*(f)\left(\sum_{l=1}^{n^2}\sum_{m=1}^{n} e^{-i2\pi f t_{lm}}/R_{lm}\right)\left(\sum_{l=1}^{n^2}\sum_{m=1}^{n} e^{i2\pi f t_{lm}}/R_{lm}\right) \tag{4}$$

in which T is the duration of the stationary part of the ground motion and * indicates the conjugate complex.

Once the power spectrum of a large event is given, the expectation of the peak ground motion, A_{max}, can be established from Kiureghian's formula (Ref.11)

$$A_{max} = p\sqrt{\lambda_0}, \qquad p = f(T, \nu_e, \lambda_0, \lambda_1, \lambda_2) \tag{5}$$

in which p is the peak coefficient and λ_i (i=0,1,2)the spectrum moment of zero and of the first and second order, and ν_e the reduced ratio of the zero-crossing.

Eq.(4) is easily extended to multiple fault rupture mechanisms. If a fault is composed of two fault planes and the time delay of rupture propagation from one fault to another is assumed to be t_0, the power spectrum of the multiple faults is

$$P_L(f) = \frac{2}{T}\left(\frac{R_{\theta\phi}}{4\pi\rho v_s^3}\right)^2 (S_1(f)S_1^*(f)XX^* + S_1(f)S_2^*(f)XY^* + S_2(f)S_1^*(f)YX^* + S_2(f)S_2^*(f)YY^*) \tag{6}$$

in which

$$X = \sum_{l=1}^{n^2}\sum_{m=1}^{n} e^{-i2\pi f t_{lm}}/R_{lm}, \qquad Y = \sum_{l=1}^{n^2}\sum_{m=1}^{n} e^{i2\pi f(t_{lm}+t_0)}/R_{lm} \tag{7}$$

The expectation of peak acceleration is obtained as in Eq.(5)

Attenuation of the peak acceleration is affected strongly by the rupture process and the direction of the observation site. For a single fault plane we can calculate the expectation of peak accelerations using Eqs.(4) and (5). The values of each parameter; the starting point of rupture, dip angle and direction of the observation point, are given in Fig.2(a). The attenuations for magnitudes 6, 7 and 8 are shown in Fig.2(b) (dip angle δ = 90°). In each section of the figure, the peak acceleration is at the upper bound. When the observation point is on the fault line (θ = 90°), the peak acceleration has a constant value for the distance that coincides with the length of the fault.

Values for observed peak accelerations during the Nihonkai-Chubu Earthquake and the contours of the estimated peak accelerations at base rock level that were obtained by our proposed method are shown in Fig.3. This earthquake involved two fault planes, and the magnitude of the earthquake was 7.7. We assumed that the seismic moment of the southern fault plane was 3.6×10^{27} dyne·cm and that of the northern one 2.2×10^{27} dyne·cm. Dip angles are 40° and 20°, and the depths of the fault planes are 2 and 3km. Although there is a fairly large discrepancy between the estimated and recorded values, this can be lessened by considering the damping effect of the propagation path and the amplification effect produced by the soft surface deposit.

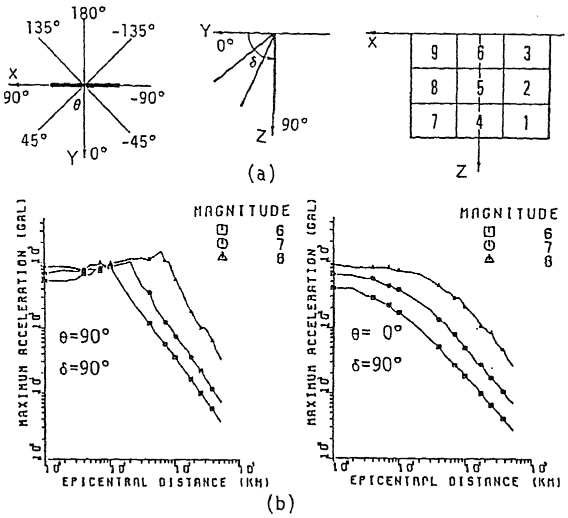

Fig.2 Classification of Parameters and Attenuation of Peak Acceleration for Magnitudes 6, 7 and 8. (Starting Point of the Rupture:1)

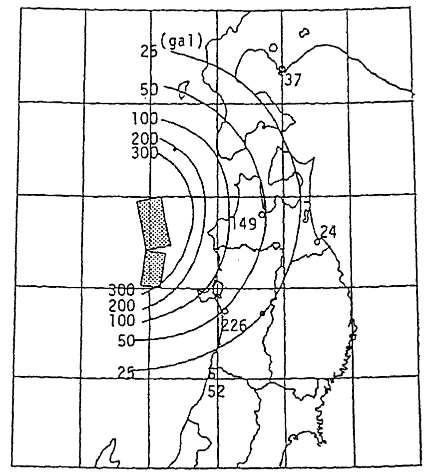

Fig.3 Contours of Peak Accelerations at the Bed Rock Level.

ADOPTION OF THE PATH AND SITE EFFECTS

PATH EFFECT In Eqs.(4) and (6), we consider only the radiation damping that is proportional to the reciprocal of the distance, 1/R. But, we must also take into account the damping by the inertial friction of the material, the Q-value, to come close to the actual phenomena.

From the spatial decay of the propagating wave, the exponentially decaying equation of G(f) can be defined as (Ref.12)

$$G'(f) = G(f)exp\left[\left\{-\frac{\pi f}{cQ}\right\} R_{lm}\right] \qquad (8)$$

in which G(f) is the Fourier transform of earthquake motion as in Eq.(3), c the wave propagation velocity, and Q the Q-value.

Iwata et al.(Ref.9) determined the Q-value from the records of the 1983 Nihonkai-Chubu Earthquake using a linear inversion method. Fig.4 shows the frequency dependent Q-value in the full logarithmic scale. Open circles indicate the Q-values obtained from the mainshock and largest aftershock data sets, and crosses the Q-values from the other aftershocks data set. We approximated these values with the straight line shown in the figure. The equation is expressed by

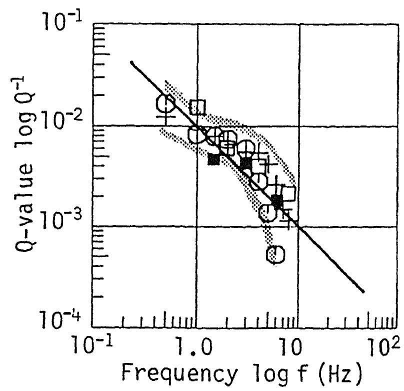

Fig.4 Frequency-dependent Q-values Determined by the Linear Inversion Method (Ref.9).

$$\log Q^{-1} = -\log f - 2 \qquad (9)$$

The effect of the inertial damping is incorporated by substituting Eq.(9) in Eq.(8) and multiplying the result by the G(f) of Eq.(3).

<u>SITE EFFECT</u> The amplification effect of the surface ground also is important for accurate prediction of the intensity of the surface ground motion.

Midorikawa (Ref.10) investigated the correlation between geological conditions and shear wave velocities and defined the amplification factor using geological conditions. These amplification factors, $\alpha_1 \sim \alpha_5$, are

$$\begin{array}{ll} \alpha_1 = 5.5 & \text{(QUATERNARY)} \\ \alpha_2 = 4.0 & \text{(QUATERNARY EXTRUSIVES)} \\ \alpha_3 = 5.0 & \text{(NEOGENE TO QUATERNARY)} \\ \alpha_4 = 3.5 & \text{(NEOGENE)} \\ \alpha_5 = 2.5 & \text{(PRE-NEOGENE)} \end{array} \qquad (10)$$

We can obtain the expectation of peak accelerations of ground surface, A_{max}^{surf} , by multiplying one factor of Eq.(10) by the maximum acceleration of the bed rock, A_{max} :

$$A_{max}^{surf} = \alpha_i \cdot A_{max} \qquad (i=1\sim5) \qquad (11)$$

The geological conditions in the Tohoku district are shown in Fig.5 (Ref.13). We assigned $\alpha_1 \sim \alpha_5$ to each site according to the amplification factor of Eq.(10).

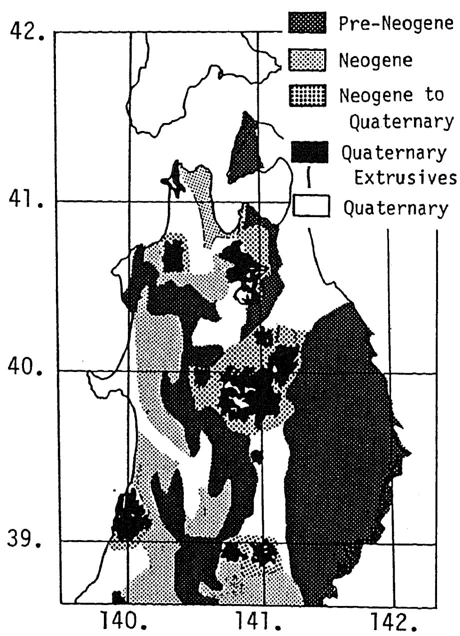

Fig.5 Geological Condition in the Tohoku District.

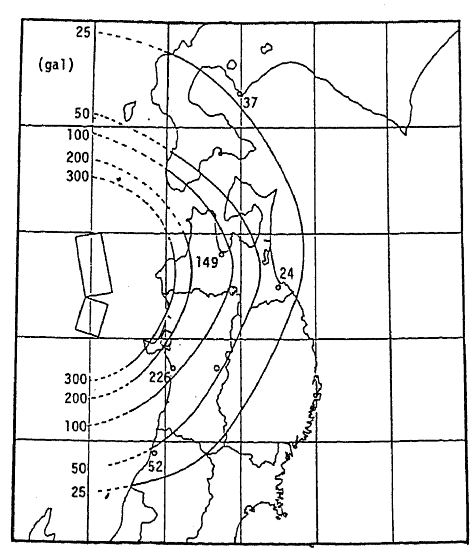

Fig.6 Contours of Peak Accelerations; Path and Site Effects accounted for.

RESULTS

Estimated values of peak accelerations in the 1983 Nihonkai-Chubu Earthquake, taking into account the damping of the traveling path and the amplification factor of the surface ground, are shown in Fig.6. The fault parameters are the same as in Fig.5. In comparison with Fig.5, the peak accelerations generally are larger, and the contour of the estimated peak acceleration expands into outer space. The estimated peak accelerations improved by the revised method are in good agreement with the recorded values.

CONCLUSION

We derived a new theoretical attenuation law that includes the effect of the fault extent. The estimated attenuation curves have upper bounds near the source region and the range is at most, the fault length. Our proposed method also can be used to estimate peak accelerations of an earthquake with multiple fault events such as in the Nihonkai-Chubu Earthquake. To obtain the peak accelerations, we had to consider the damping of the traveling path and the amplification of the site. The estimated values obtained with the improved method are in good agreement with the recorded values.

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