PREDICTION OF NEAR-SOURCE GROUND MOTIONS FOR GREAT EARTHQUAKES FROM SUPERPOSED EVOLUTIONARY PROCESS MODELS

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SUMMARY

A prediction model of near-source ground motions for great earthquakes is proposed on the basis of the statistical prediction model of nonstationary earthquake motions. The evolutionary power spectrum for great earthquakes is estimated from the synthesis of that for small-magnitude earthquakes(M=5.0). The number N_C of superposition of evolutionary power spectra of small earthquakes is obtained in the form of a linear relation between the logarithmic value of N_C and seismic moment M_0 based on 48 selected accelerograms from 8 Japanese earthquakes. A fault model for prediction of near-source ground motions is proposed.

INTRODUCTION

It is a basic subject in earthquake engineering to predict ground motion intensities at a specific site for given earthquake magnitude, distance, and local soil conditions. Statistical prediction models for peak acceleration, velocity, response spectra(Ref.1), and further, the prediction model for nonstationary earthquake motions(Ref.2) have been proposed on the basis of strong motion data. Fig.1 shows the scattergram of magnitude and epicentral distance for strong motion data recorded in Japan, which have been used for above prediction models. No data for large magnitude and short distance (near-source region), very important for engineering purposes, have been obtained. Therefore, the prediction models based on these data cannot be extended directly to this region. One of the problems in use of these prediction models for near-source regions is that the ground motions at near-source sites are affected strongly by the physical fault parameters such as a rupture direction of fault, source-to-site distance, and area of fault, etc. The second problem is that the earthquake magnitude does not represent the 'size' of earthquake clearly as compared with the case of small earthquakes.

In this view of the problem this study aims to extend the prediction model of nonstationary earthquake motions(Ref.2) into the model that can be used for estimation of near-source ground motions for great earthquakes. The present study is a generalization of the study by Goto, Sugito, Kameda, and Okumura(Ref.3).

EARTHQUAKE MOTION PREDICTION MODEL FOR GIVEN MAGNITUDE, DISTANCE, AND LOCAL SOIL CONDITIONS(EMP-I MODEL) (Ref.2)

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A statistical prediction model of nonstationary earthquake motions for given magnitude, distance, and local soil conditions (EMP-I model) has been proposed on the basis of 91 major Japanese accelerograms, baseline and instrument corrected (Ref.4). These 91 accelerograms as shown in Fig.1 have been selected under the condition that the magnitude and distance of the data are in the 'far-field region I' and the peak acceleration exceeds 30 gals. This model is developed into the EMP-II model which can estimate near-source ground motions in the next chapter. The outline of the EMP-I model is as follows.

Earthquake acceleration with nonstationary frequency content can be represented by

$$x(t) = \sum_{k=1}^{m} \sqrt{2G_x(t,\omega_k)\Delta\omega} \cdot \cos(\omega_k + \varphi_k) \tag{1}$$

in which $G_x(t, 2\pi f)$=evolutionary spectrum (Ref.5) for time t and angular frequency f, φ_k=independent random phaze angles distributed over $0\text{-}2\pi$, m=number of superposed harmonic components. The upper and lower boundary frequencies f_u, f_l are fixed as $f_u=10.03\ Hz$, $f_l=0.13\ Hz$, and also m and $\Delta\omega$ are fixed as $m=166$ and $\Delta\omega=0.06\ Hz$. The following time-varying function as shown in Fig.2 is adopted for the model of $G_x(t, 2\pi f)$.

$$\sqrt{G_x(t,\omega)} = \sqrt{G_x(t,2\pi f)} =$$

$$= \begin{cases} 0 & ; t \leq t_s \\ \alpha_m(f)\{(t-t_s(f))/t_p(f)\} \cdot \exp\{1-(t-t_s(f))/t_p(f)\} & ; t_s < t \end{cases} \tag{2}$$

in which $t_s(f), t_p(f)$= starting time and duration parameter, respectively, and $\alpha_m(f)$=intensity parameter which represents the peak value of $G_x(t, 2\pi f)$. These parameters have been determined relative to recorded accelerograms. The following regression equations have been used to establish the prediction model.

$$\log\hat{\alpha}_m(f) = B_0(f) + B_1(f) \cdot M - B_2(f) \cdot \log(\Delta+30) \tag{3}$$

$$\log\hat{t}_p(f) = P_0(f) + P_1(f) \cdot M + P_2(f) \cdot \log(\Delta+30) \tag{4}$$

$$\hat{t}'_s(f) = t_s(f) - t_m = S_0(f) + S_1(f) \cdot \Delta \tag{5}$$

where M=magnitude, Δ=epicentral distance in km and t_m= average of $t_s(f)$ along the frequency axis. The prediction model has been classified into 3 levels as for the quality of the soil data for specific sites. The site parameter S_n obtained from a certain integral of SPT blow-count (N-value) profiles has been defined to consider the effect of soil-softness of a site on the scatter of 'power' which is measured from the intensity parameter $\alpha_m(f)$. And also the transfer function obtained from the multi-refrection theory for shear waves has been incorporated to consider the effect of frequency characteristics for a site on the intensity parameter $\alpha_m(f)$.

Herein, developing the EMP-I model the earthquake motion prediction model which can estimate near-source ground motions for great earthquakes is proposed. Instead of the earthquake magnitude, the physical fault parameters, such as seismic moment M_0, rupture velocity v_r, propagation velocity v_{pr} of earthquake motions, fault length and width L, W, and rupture pattern are incorporated in the EMP-II model.

Number of Superposition N_G Scaled for Seismic Moment M_0

The number of superposition N_G of evolutionary spectra is defined. A great earthquake fault is treated as a set of small faults. N_G represents the number of small events on a specific great fault. The magnification factor $c(f)$ defined by Eq.(6) has been obtained for 48 accelerograms from 8 earthquakes listed in Table 1.

$$c(f)=\int_0^{t_0}\sqrt{G_x(t,2\pi f)}\,dt\Big/\int_0^{t_0}\sqrt{G_x^*(t,2\pi f)}\,dt \tag{6}$$

in which G_x= simulated evolutionary spectrum for recorded accelerogram, G_x^*= evolutionary spectrum given from EMP-I model which corresponds to the earthquake level of M=5.0 and the 'same distance' as the specific recorded accelerogram, and t_0= duration of the data. The number of superposition N_G, which represents the average of the magnification factor $c(f)$ along the logarithmic frequency axis, can be defined as

$$N_G=\int_{\log f_1}^{\log f_2} c(f)\,d(\log f)\;/(\log f_2-\;\log f_1) \tag{7}$$

in which the lower and upper boundary frequencies, f_1, f_2 are fixed as f_1=0.55 Hz, f_2=2.59 Hz. The parameter N_G is regarded as the number of superposition of evolutionary spectra which corresponds to the earthquake level of M=5.0 and the 'same distance' as the recorded data in the EMP-I model. The parameter N_G has been scaled for the seismic moment M_0, and the following regresion equation has been obtained.

$$\overline{N}_G= 1.28\times10^{-7}\times M_0^{0.296} \tag{8}$$

Fig.3 shows the relation between the number of superposition N_G and the seismic moment M_0. The evolutionary power spectra G_{x_0} for great earthquakes can be superposed from the number N_G of evolutionary spectra $G_{x_{ij}}$ for each small event. The arrival time lag $t_{a_{ij}}$ of earthquake motions for each small event, given by Eq.(9), can be incorporated for the superposition of evolutionary spectra.

$$t_{a_{ij}} = d_{ij}\;/\;v_r\;+\;(\Delta_{ij}\;-\;\Delta_s)\;/\;v_{pr} \tag{9}$$

The parameters appeared in Eq.(9) are defined in Fig.5. Details of the procedure for simulation of ground motions are explained in the following section.

Fault Model

A simple fault model as shown in Fig.5 is established to consider the effect of fault parameters on ground motion intensities and duration in near-source regions. The procedure to obtain near-source ground motions for great earthquakes is as follows.

1) The number of superposition N_C is obtained for given seismic moment M_0 by Eq.(8).

2) Distribute small earthquake events on the given fault under the condition that the coefficient of the number of small events in two directions of a fault width and length is identical to the coefficient W/L.

3) The arrival time lag $t_{a_{ij}}$ of the motion from each small event are calculated for a given rupture pattern, a rupture velocity, and a propagation velocity of motions from a fault to a specific site.

4) Calculate the evolutionary power spectra $G_{x_{ij}}$ for each small event, and superpose them considering the arrival time lag of each event. The superposed evolutionary spectrum G_{x_0} is given as

$$\sqrt{G_{x_0}(t,2\pi f)} = \sum_{i=1}^{N_i}\sum_{j=1}^{N_j}\sqrt{G_{x_{ij}}(t,2\pi f)} \tag{10}$$

where N_i, N_j=number of small events in two directions of a fault width and length. An example for superposed evolutionary spectra is shown in Fig.4.

5) Generate the ground motions by Eq.(1) after modifying G_{x_0} as for local soil conditions using the same manner in the EMP-I model.

Simulated Earthquake Motions for 1968 Tokachi-oki Earthquake

Fig.6 shows the recorded and simulated earthquake motions at Hachinohe site for 1968 Tokachi-oki Earthquake (M_0=2.8×10^{28} dyn cm). The number N_C is obtained as N_C=35 from Eq.(8). Therefore, the number N_i, N_j of small events in two directions of a fault width and length are fixed as N_i= 5, N_j= 7(W=100 km, L=140 km). In Fig.6 statistical uncertainties for the model parameters are not considered for the simulated earthquake motions. It is observed that the response spectra for the simulated motions agree well with that for recorded motions for a region of natural period T_0>1.0 sec. The duration for recorded motions is longer than that for simulated motions. One reason may be that the actual fault rupture does not proceed smoothly.

Estimation of Ground Motions in Near-Source Region

Peak ground motions in near-source regions, very important information in earthquake engineering, are estimated by the EMP-II model. Fig.7 shows the near-source attenuation of peak acceleration and total power of acceleration for two tipes of faults, relatively great and intermediate. The abscissa represents the distance Δ_c between the center of fault and the site. Physical parameters of these hypothetical faults correspond to the 1968 Tokachi-oki Earthquake(M=7.9) and 1978 Miyagiken-oki Earthquake (M=7.4), respectively. It can be observed that the peak acceleration does not depend on Δ_c in the region of $\Delta_c \leqq 60 \sim 70$ km for the fault F1 and $\Delta_c \leqq 30 \sim 40$ km for the fault F2. This attenuation characteristics are observed more clearly in case of total power of acceleration. These boundary values are nearly identical to the half fault length. The dashed lines in Fig.7 represent the statistical regression lines for peak acceleration for a normal soil site proposed by Kameda, Sugito, and Goto (Ref.10).

SUMMARY AND CONCLUTIONS

Majour conclusions derived from this study may be summarized as follows.

1. The prediction model of earthquake motions for given magnitude, distance, and local soil conditions (EMP-I model) has been briefly reviewed.

2. The number N_C of superposition of evolutionary spectra, which represents the number of small earthquake events (magnitude level; M=5.0), has been defined. The number N_C has been scaled for the seismic moment M_0 using 48 selected accelerograms recorded from 8 Japanese earthquakes.

3. The prediction model of near-source ground motions for great earthquakes (EMP-II model) has been proposed. The EMP-II model generates ground motions for given seismic moment M_0, fault width W, fault length L, rupture pattern, rupture velocity v_r, and propagation velocity v_r of earthquake motions.

4. The attenuation characteristics of peak acceleration and total power of acceleration in near-source regions have been estimated using the simulated ground motions generated by the EMP-II model.

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Table 1 Fault Parameters for Major Japanese Earthquakes(Refs.6,7,8,9).

earthquake (date)	magnitude M	fault area $S(km^2)$	dislocation $D(m)$	stress drop $\Delta\sigma(bar)$	seismic moment $M_0(dyn\cdot cm)$	rupture velocity $v_r(km/sec)$	dip angle of fault $\phi(°)$
1968 Tokachi-Oki (May 16,1968)	7.9	150x100	4.1	37	$2.8x10^{28}$	—	20
Saitama, Center (July 1, 1968)	6.1	10x6	0.92	99	$1.9x10^{25}$	3.4	30
Ehime, West Coast (aug 6, 1968)	6.6	40x18	1.0	—	$2.0x10^{26}$	3.0	72
Akita, South-East (Oct.16, 1970)	6.2	14x8	0.65	19	$2.2x10^{25}$	2.3	46
Nemuro Penn.,Off-Shore (June 17, 1973)	7.4	100x60	1.6	35	$6.7x10^{27}$	—	27
1978 Izu-Oshima Kinkai (Jan.14, 1978)	7.0	17x10	1.83	65	$1.1x10^{26}$	2.8	85
Miyagi, Off-Shore (Feb.20, 1978)	6.7	20x10	0.6	70	$8.0x10^{25}$	—	85
1978 Miyagiken-Oki (June 12, 1978)	7.4	80x30	1.8	70	$3.1x10^{27}$	3.5	20

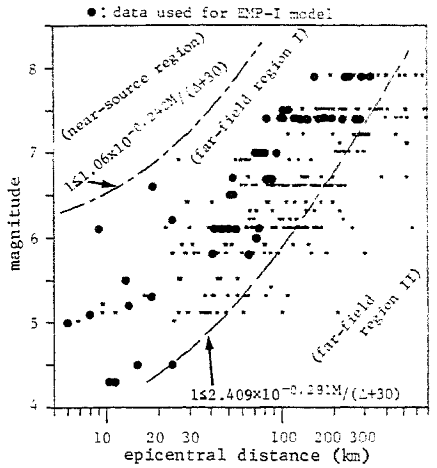

Fig.1 Scattergram of Magnitude and Distance of Strong Motion Data Recorded in Japan.

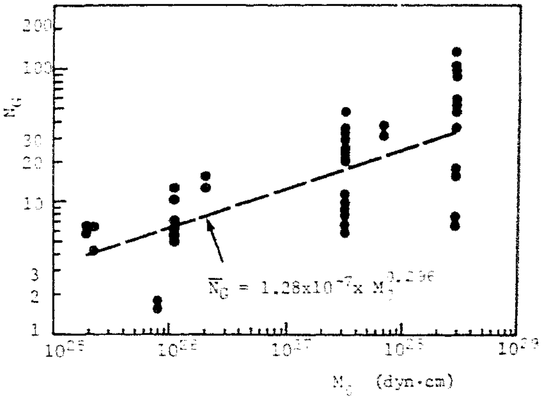

Fig.3 Relation between Number of Superposition N_G and Seismic Moment M_0.

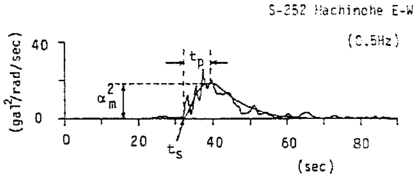

Fig.2 Recorded and Simulated Evolutionary Spectra(Ref.2).

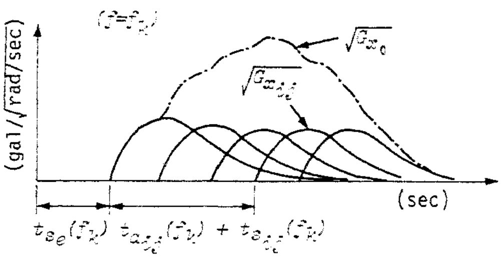

Fig.4 Superposed Evolutionary Spectra.

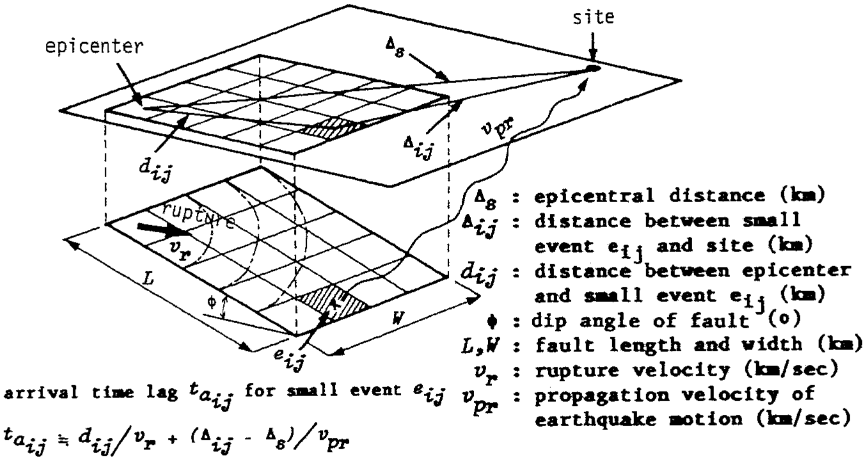

Fig.5 Fault Modeling with Multiple Fault Ruptures.

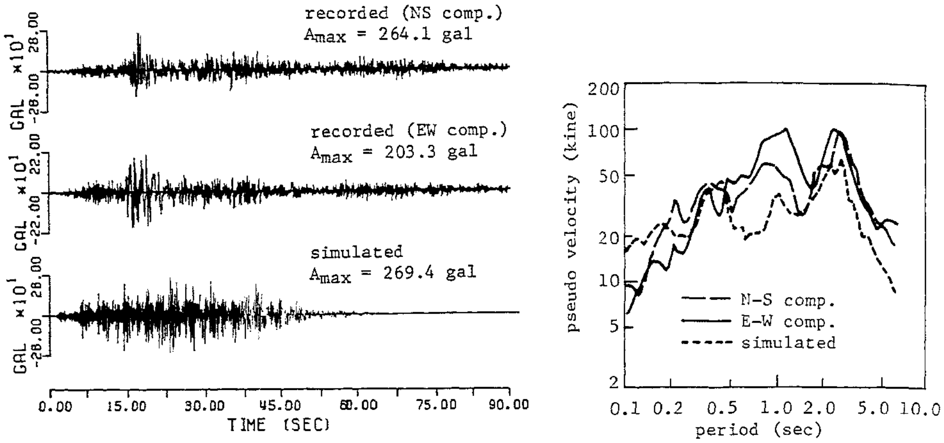

Fig.6 Recorded and Simulated Ground Motions and Response Spectra (Hachinohe Site, 1968 Tokachi-oki Earthq., M_0=2.8x10^{28} dyn·cm, L=140, W=100 km).

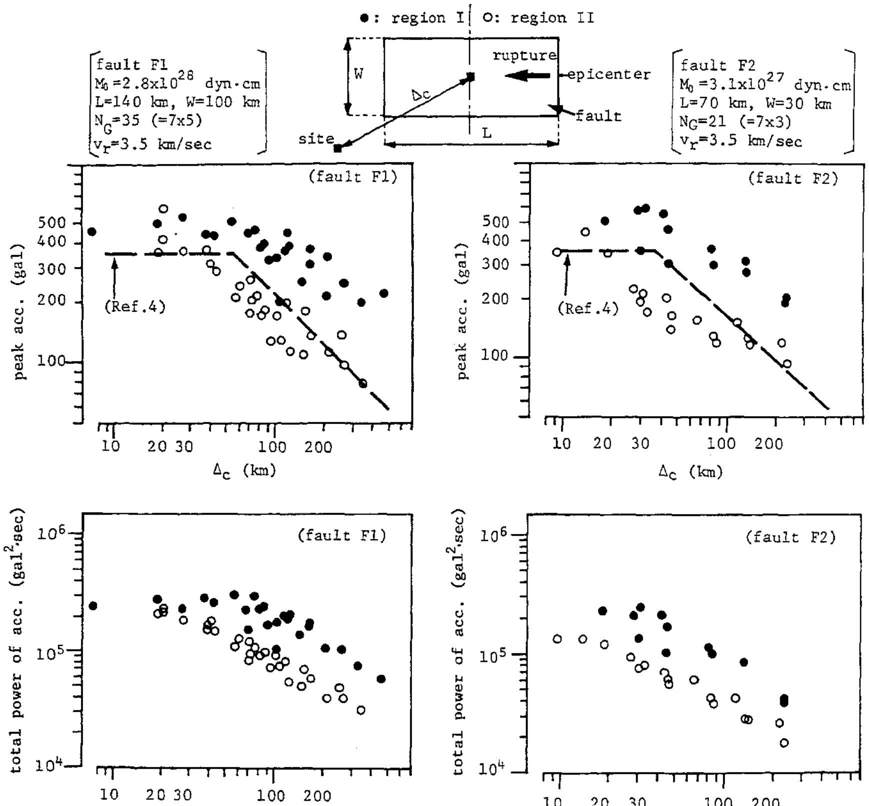

Fig.7 Near-Source Attenuation of Simulated Peak Acceleration and Total Power of Acceleration (EMP-II model).