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ESTIMATION OF NEAR-FIELD GROUND MOTION USING EMPIRICAL GREEN'S FUNCTION

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SUMMARY

A synthetic method for heterogeneous faulting model is proposed to estimate near-field ground motion using empirical Green's function. The accelerogram at a distance larger than fault length can be simulated well using the synthetic method for the ω^{-2} method with uniform slip velocity distribution and incorporating randomness in rupture propagation on the fault plane. However,the near-field accelerogram at a distance closer than fault length is is required to consider the fault heterogeneities such as spatial variation of slip velocity and rupture propagation.

1. INTRODUCTION

Recently, numerous studies have shown that the faulting processes of large earthquakes are heterogeneous using inversion technique of observed seismograms and high frequency strong motions are induced by irregularities of faulting motion. Therefore, ground motion at closer distance might be strongly influenced by spatial and temporal variation of slip and/or stress drop on the fault plane.

In this paper we develop the empirical Green's function method for synthesizing near-field ground motion from heterogeneous fault model. As an example, the irregular faulting process of the 1980 IZU-HANTO-TOHO-OKI earthquake has been studied using different inversion procedures of different data sets. We compare the synthetic accelerograms for the uniform slip model and for the heterogeneous models derived from different inversion results with the observed one.

2. Method

The gross aspects of the source rupture process are predicted based on the scaling law of the source spectra. To date numerous authors have showed that the ω-2 spectral scaling model successfully explain acceleration spectra. The constraints from the ω^{-2} spectral scaling are as follows:

$$\tilde{U}_0/\tilde{u}_0=M_o/m_o=N^3 \quad \text{and} \quad \tilde{A}_0/\tilde{a}_0=(M_o/m_o)^{1/3}=N \qquad (1)$$

where $\tilde{U}_0$ and $\tilde{u}_0$ are the flat level of displacement spectrum at low frequencies, $\tilde{A}_0$ and $\tilde{a}_0$, the flat level of acceleration spectrum at high frequencies, and M_o and m_o are the seismic moments for large and small event,respectively.

The synthetic method for the ω^{-2} model is given by Irikura (1986) and Irikura and Aki (1988), summing small event records to satisfy the above constraints. In this paper I develop a synthetic model for heterogeneous fault model, in which the source parameters such as slip velocity, rise time and rupture velocity vary spatially on the fault plane.

Let the moment ratio between the large event to be simulated and a small event used as empirical Green's function be N^3. Then the fault area of the large event is divided into N x N subfaults shown schematically in Fig. 1. The synthetic seismogram U(t) for the large event is given using the small event record u(t) as

$$U(t)=\sum_{i=1}^{N}\sum_{j=1}^{N}(r/r_{ij})F_{ij}(t)*u(t) \qquad (2)$$

$$F_{ij}(t)= a_{ij}\delta(t-t_{ij}) + (b_{ij}/n'_{ij})\sum_{k=1}^{(N-1)n'_{ij}}\delta[t-t_{ij}-(k-1)\tau_{ij}/(N-1)n'_{ij}] \qquad (3)$$

where τ_{ij} is rise time, a_{ij} corresponds to relative slip velocity and integration of $F_{ij}(t)$ with respect to time corresponds to relative slip displacement at each element. The shape of $F_{ij}(t)$ is shown in Fig. 2. n'_{ij} is appropriate integer number to shift the fictitious periodicity $\tau_{ij}/(N-1)$ into a high frequency out of the frequency range of interest (Irikura,1983).

In order to meet the constraints (1), the following conditions for the given parameters are required: $\langle \int F_{ij}dt \rangle = N$ and $\langle a_{ij} \rangle = 1$, where $\langle\ \rangle$ means average.

3. Synthesis for the 1980 IZU-HANTO-TOHO-OKI earthquake

The Synthesis Using Uniform Slip Velocity Model The epicenters of the mainshock and the aftershocks and the observation stations (JIZ and KWN) used for analysis are shown in Fig. 3. The displacement spectra of the M 6.7 mainshock and the M 4.6 aftershock follow the ω^{-2} model as shown in Fig. 4.

The fault length and width of the mainshock are assumed to be 15km and 7.5km from the aftershock distribution (Imoto et al.,1982). The mainshock and the aftershocks were recorded by the strong motion velocitymeter at JIZ, about 25km away from the mainshock epicenter and by the strong motion accelerometer at KWN, about 10km away from the epicenter.

The synthetic velocity seismogram for JIZ and the acceleration seismogram for KWN, using the method for the uniform slip velocity model are compared to the observed ones in Fig. 5 and 6. The waveform envelope, the maximum amplitude and the spectral amplitude level of the synthetic velocity at JIZ agree well with those of the observed one. On the other hand, the waveform envelope and the maximum amplitude of the synthetic acceleration at KWN do not agree with those of the observed one, although the spectral amplitude levels of the synthetic agree well with those of the observed.

This synthetic method is made to satisfy the spectral scaling relation for the ω^{-2} model. Therefore, the synthetic spectrum naturally agrees with the observed one, as long as both the large and the small event have spectral contents expected from the ω^{-2} model. The synthetic waveform at a near distance is strongly influenced by spatial variation of slip and/or stress drop on the fault plane. This may be a reason that the synthetic waveform at KWN does not agree with the observed one, while the synthetic one at JIZ agrees relatively well with the observed one.

The Synthesis Using Heterogeneous Faulting Model The faulting process of the 1980 IZU-HANTO-TOHO-OKI earthquake has been studied using different inversion method of different data sets.

Employing a waveform inversion method for strong motion displacement seismograms recorded at JMA (Japan Meteorological Agency) stations at near distance, Takeo(1988) deduced the slip distribution and the nature of rupture propagation on the fault plane as shown in Fig. 7. From the inversion of the velocity seismograms at near distance, Fukuyama and Irikura (1988) determined the local stress drop and rupture time at each subfault as shown in Fig. 8. The Takeo's model from long period seismograms shows larger fault area and slower rupture propagation than the Fukuyama and Irikura's model from shorter period seismograms. After this, we call the model obtained by Takeo 'Model A', that by Fukuyama and Irikura 'Model B'. Another heterogeneous faulting model is obtained by Iwata and Irikura (1988). They recover the distribution of the maximum slip velocity on the fault plane with a back-projection using near-field accelerograms as shown in Fig. 9. This model is called 'Model C'.

Both the theoretical calculation by Takeo(1988) and the empirical synthesis by Fukuyama and Irikura (1988) are not available for accelerograms dominated by higher frequency motions than 1Hz. Then I use Equation (2) to synthesize near-field accelerograms. The synthetic accelerograms at KWN for the above heterogeneous models are compared to the observed one in Fig. 10. The synthetic waveform for Model A seems to be elongated compared to the observed. However, the spectral amplitude levels of the synthetic accelerogram agree with those of the observed one, because the synthesis is properly made to satisfy the constraint (1). On the other hand, the waveform envelope as well as the spectral amplitudes of the synthetic one for Model B agree well with those of the observed one. The synthetic accelerogram at KWN for Model C also agrees well with the observed one in waveform envelope and spectral level.

Models B and C seem to be different in detail, but have a common feature that high slip velocity is concentrated at the north part of the fault plane. On the other hand, in Model A high slip areas are extended to the south part and assumed to be equivalent to high slip velocity areas in the synthesis, because rise time is taken to be constant over the fault. This may be a reason that the synthetic waveforms for Model B and C have a similar shape and are different from the synthetic waveform for Model A. Thus, I conclude that the spatial and temporal variation of slip velocity or local stress drop plays an important role in obtaining the synthetic accelerogram by this method.

4. Conclusions

From the synthesis of near-field ground motion from the mainshock of the 1980 IZU-HANTO-TOHO-OKI earthquake, I obtained the two important results. 1. At a distance larger than the fault length, the synthetic accelerograms using the simulation method for the model agree well on waveform and spectral shape with the observed one even if a uniform slip velocity distribution on the fault plane is assumed. 2. At closer distance, the heterogeneity of slip velocity or stress drop on the fault plane is needed to know, to obtain a good agreement between the synthetic waveform and the observed one.

Acknowledgment

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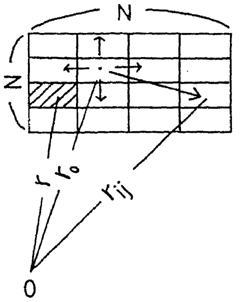

Fig. 1

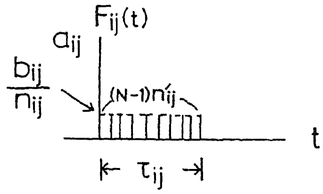

Fig. 2

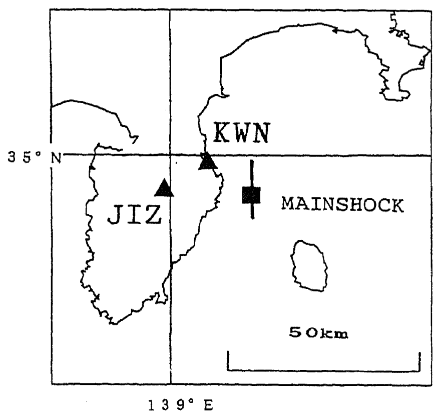

Fig. 3

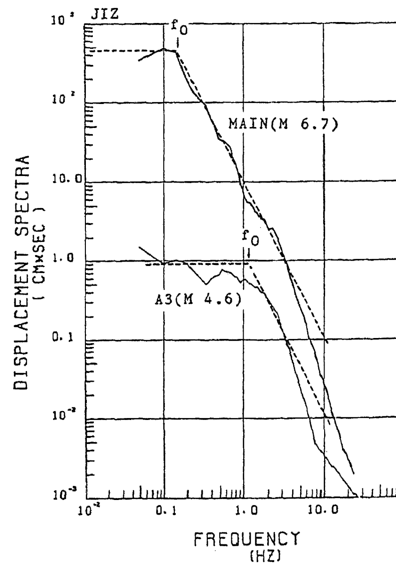

Fig. 4

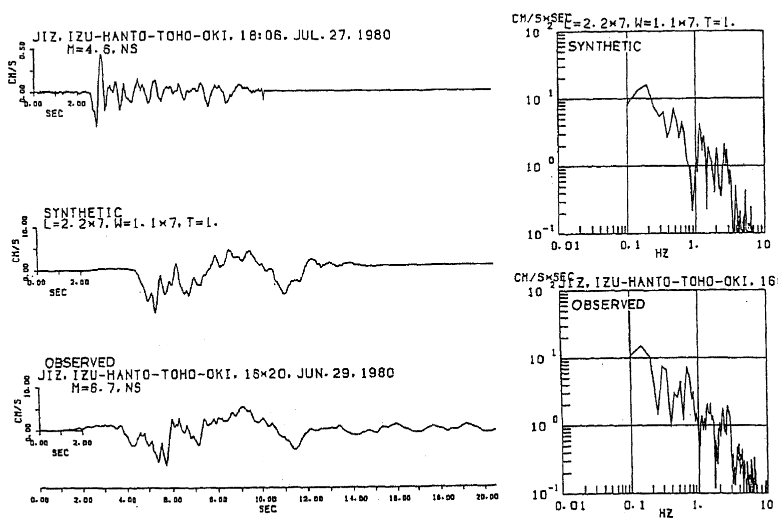

Fig. 5 Comparison of the synthetic velocity seismogram with the observed one at JIZ. The synthesis is made using the uniform slip velocity model.

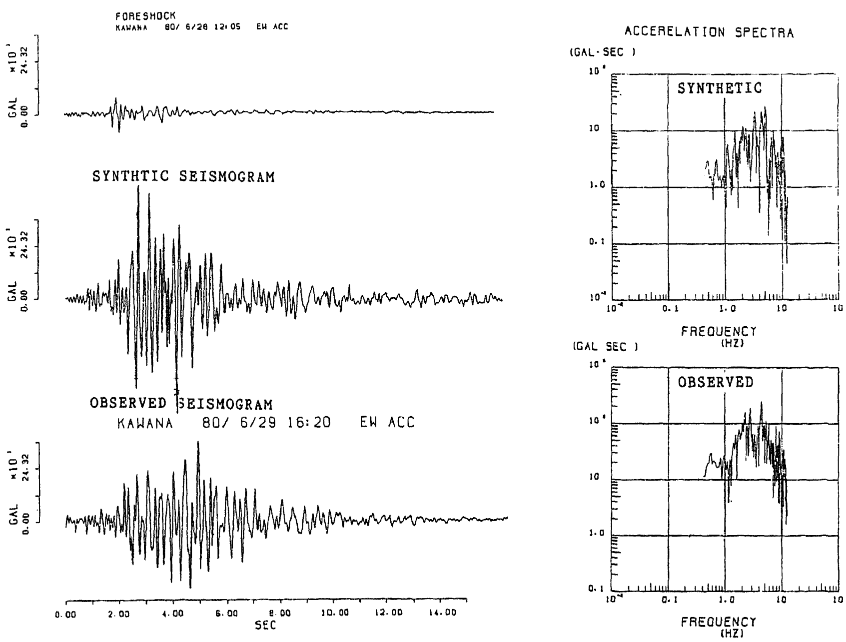

Fig. 6 Comparison of the synthetic accelerogram with the observed one at KWN. The synthesis is made using the uniform slip velocity model.

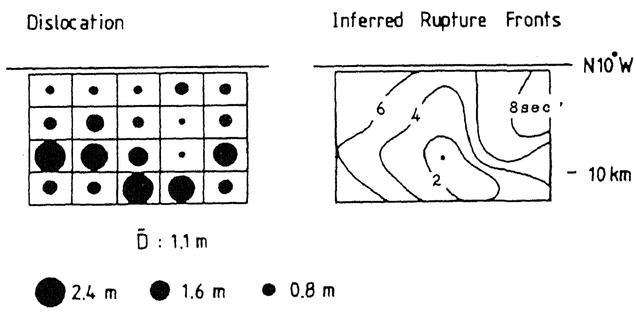

Fig. 7 Model A: Rupture propagation and slip distribution on the fault plane of the 1988 IZU-HANTO-TOHO-OKI earthquake by Takeo (1988).

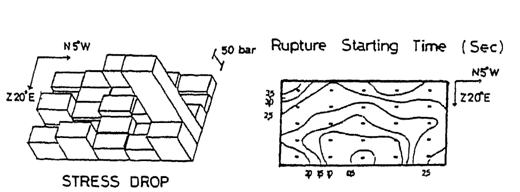

Fig. 8 Model B: Rupture propagation and stress drop distribution by Fukuyama and Irikura (1988).

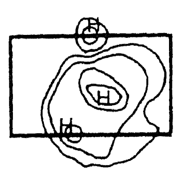

Fig. 9 Model C: Maximum slip velocity distribution by Iwata and Irikura (1988).

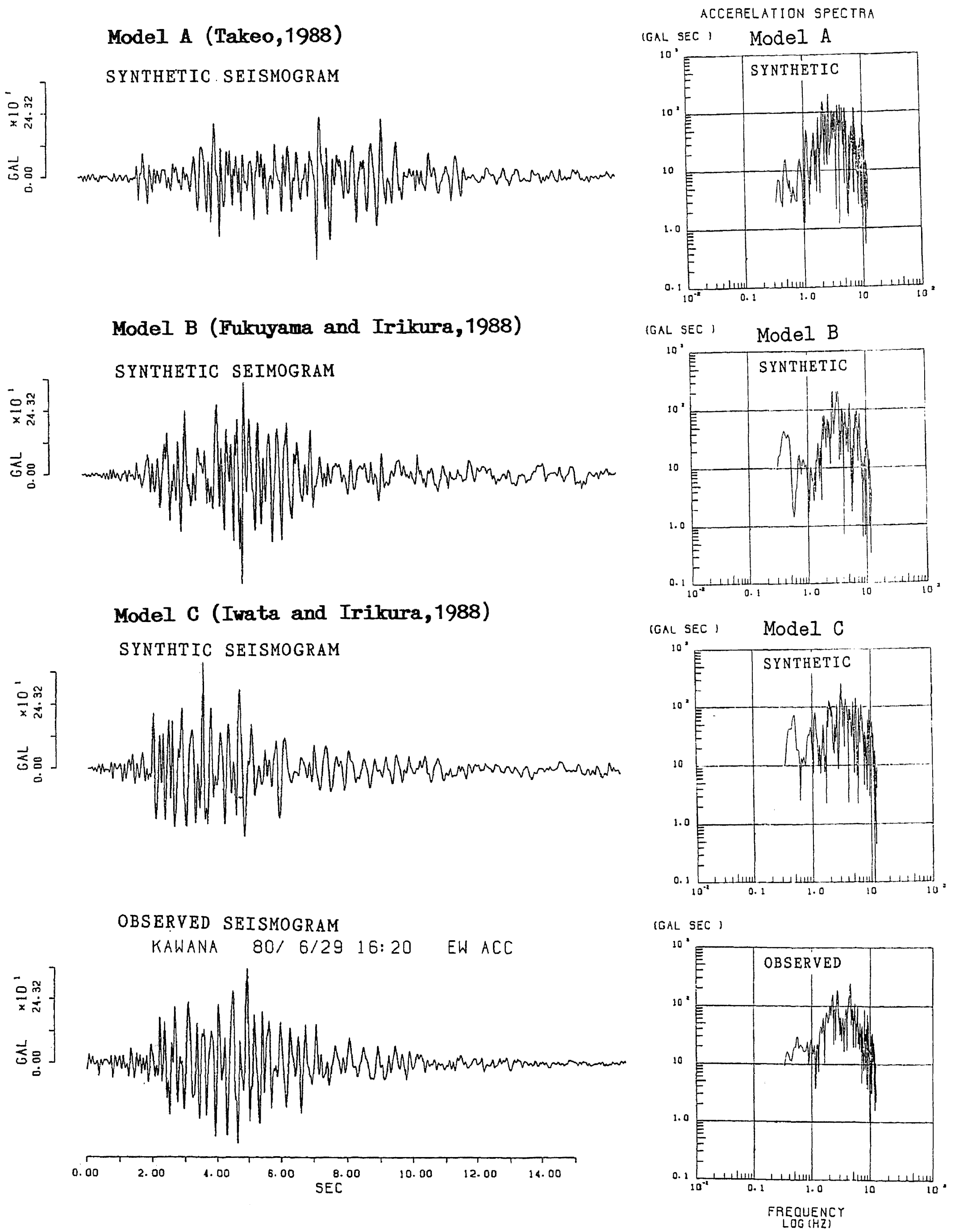

Fig.10 Comparison of the synthetic accelerograms for the heterogeneous faulting models (Model A, B, and C) with the observed one at KWN. The synthesis is made using Equation (2).