ESTIMATION OF ACCELERATION CHARACTERISTICS OF STRONG EARTHQUAKE GROUND MOTIONS BY A SIMPLE METHOD OF SYNTHESIS

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SUMMARY

This paper presents a very simple method for simulating high-frequency ground motions resulting from a large earthquake. In this method the accelerograms of three fore- and aftershocks (M=4.9) of the 1980 Izu-Hanto-Toho-Oki earthquake are used to synthesize accelerations of the main shock (M=6.7), and the results are then compared quantitatively with the data from the main shock. It is shown that this simple method gives good estimates for the peak acceleration, duration, total power and response spectral intensity, as well as the response spectrum.

INTRODUCTION

The estimation and characterization of strong ground motions produced by large earthquakes are of primary engineering interest. One effective method is to synthesize the ground motion by using the observed seismograms from the small shocks as Green's functions.

Since the first work by Harzell [1], the synthesis method has been successfully developed and is giving good estimates for the range of frequencies lower than about 1 Hz [2]. For most structures, however, relatively high-frequency ground motions (1 Hz or higher) are more important, so recently much effort has been directed to developing a method applicable to acceleration ground motions [3].

In this paper, a very simple synthesis method for estimating high frequency ground motions is described. As a test application, the acceleration ground motions at the five strong-motion stations near the source region of the 1980 Izu-Hanto-Toho-Oki earthquake (M=6.7) were synthesized using accelerograms of three fore- and aftershocks (M=4.9). The synthesized ground motions were then compared quantitatively with the observed ones in terms of the four characteristic values, peak acceleration, duration, total power and response spectral intensity, and the spectrum itself to examine the reliability of the present method.

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METHOD

The present method of synthesis is a simple modification of Irikura-Muramatsu's work [4]. First we assume the following empirical similarity relations in the source parameters between two events which occur in the same source region but with different seismic moments, M_o and M_{oe}:

$$L/L_e = W/W_e = D/D_e = \tau/\tau_e = (M_o/M_{oe})^{1/3} = n \qquad (1)$$

where L and W are the length and the width of the fault, D the offset of dislocation and τ the rise time, and the subscript e indicates the parameters for a small event. The fault area of the large event is divided into $n\times n=n^2$ elements, and the small event is applied to each element as a point source. Under these conditions, we also assume the same focal mechanisum and the same transfer characteristics of the wave propagation. Furthermore, for both the large and small events a simple ramp function is assumed for the source. Then, the ground motion for the large event, a(t), may be approximated by the following weighted and phase-delayed summation over $a_e(t)$, the ground motion for the small event:

$$a(t) = \sum_{l}^{n} \sum_{m}^{n} (R_e/R_{lm}) \cdot a_e[t-(R_{lm}-R_o)/c-r_{lm}/v] \qquad (2)$$

in which v and c are the velocities of the rupture and wave propagation, respectively. The meanings of R_o, R_e, R_{lm} and r_{lm} are illustrated in Fig. 1. As seen in Fig. 2, the effect of synthesis by this method (B) is almost the same as that by Irikura-Muramatsu's (A) in the frequencies higher than about 1 Hz, except that the ghost peak (frequency= $1/\tau_e$) in (A) disappears in (B).

ACCELEROGRAMS

The 1980 Izu-Hanto-Toho-Oki earthquake (M=6.7) took place off the east coast of the Izu Peninsula, central Honshu, on June 29, 1980 and caused severe damage to some buildings in the coastal area. The epicenters of the main shock and three fore- and aftershocks and the locations of the strong-motion stations related to the present study are shown in Fig. 3. The epicentral distance for the main shock ranges from 11 km (KWN) to 43 km (TKD). The data for the magnitude and recorded peak accelerations for each event are listed in Table 1. The accelerograms of the main shock differ greatly from station to station, reflecting the effects of attenuation with distance, geological conditions at the site, etc., as seen in Fig. 7(a).

FAULT PARAMETERS

The fault parameters used in the synthesis are shown in Fig. 1. The rupture is assumed to initiate at the central lower end of the fault and to extend circularly. The scaling factor, n, and the strike direction of the fault were taken as unknowns in order to investigate their effect on the synthesized ground motions.

Three strong-motion stations (NBK, JON and TKD) were selected to estimate the optimal value of n, since the ground motions at these stations are insensitive to the fault strike. As a demonstrative example exhibiting the effect of the value of n, some of the synthesized accelerograms are illustrated in Fig. 4, where the strike direction of N5°W was tentatively assumed. Fig. 5 shows the variation of the three characteristic values of peak acceleration, total power and duration time for the synthesized accelerograms (average of two horizontal components) as a function of the value of n, expressed by a percent error relative to the values for the observed ones. Although the peak acceleration and total power vary greatly with respect to the n value, the errors remain less than 10-20 % for n=6-7. Hence, we adopted n=7 as the optimum.

The fault strike of the main shock was estimated in a similar way, taking the KWN station, closest to the epicenter, as a key station. As seen in Fig. 6, although the change in errors of the estimated values is not monotonic, the strike direction of N5°W gives the minimum error.

COMPARISON OF SYNTHESIZED AND OBSERVED ACCELEROGRAMS

Synthesized accelerograms at the five strong-motion stations for the main shock are shown in Fig. 7 (b and c). As was expected, the waveforms of the synthesized motions do not agree with the observed ones in detail, however, a good similarity is found in the gross features. The four characteristic values evaluated from the synthesized and observed accelerograms are compared in Fig. 8. The peak acceleration, duration, and total power have been matched within an error of about ±25 % (with a few exceptions) over the wide range of the observed values, while the spectral intensities fell below the observed ones, but the errors do not exceed about 35 %.

Figs. 9 and 10 show the comparison of the velocity response spectra (damping 5 % and 10 %) for the near-field stations KWN (Δ=11 km) and AJR (Δ=20 km), respectively. In Fig. 9, the average of the spectra from three small shocks is shown in (a), while the spectra for the foreshock of June 28 is shown in (b). The spectral shapes for the observed and synthesized accelerograms are quite similar, except a small discrepancy as seen on the spectra for 5 % damping. The great discrepancy in the EW component of AJR spectra may be explained by some ground effects.

ESTIMATION OF STRONG GROUND MOTIONS AT A DAMAGED SITE

A school building (SRC) at Futo in Ito City suffered exceptionally severe damage [5]. The site was a temporary strong-motion observation station (FTO), but unfortunately no record of the main shock was obtained. It was expected that the main shock motions at this site might be estimated with considerable accuracy by synthesizing the accelerations using the foreshock record of June 28, which gave the best estimates for the KWN station about 5 km north of FTO.

The synthesized accelerations and integrated velocities are extremely large as shown in Fig. 11. However, considering the fact that many fissures opened on the playground of the school during the main shock, non-linear properties of the soils must be taken into account. Fig. 12 shows the result of a non-linear analysis by the equivalent linearized method (SHAKE) using the data listed in Table 2. As a result, even though the peak values were reduced to about 80 % of the former, the peak accelerations and velocities attain values of 700-900 gal and 30-40 kine, respectively (Fig. 12).

The response spectra for these accelerograms are shown in Fig. 13 together with those for observed records at KWN, where the buildings were only slightly damaged. The destructive features, such as response amplitudes two to three times larger than those at KWN and a comparatively flat shape over a wide range of periods, may account for the damage to the school building during the main shock.

CONCLUDING REMARKS

The present method of synthesis is that developed by Irikura and Muramatsu modified to make it applicable to high-frequency ground motions. The results of application to strong-motion accelerograms of a moderately large earthquake show the usefulness of this method in estimating the acceleration characteristics of strong ground motion in spite of the crudeness of the method. The number of divisions of the main fault area, n^2(n=6-7) estimated by the error analysis agree well with that obtained from the Fourier spectral ratio of the strong-motion velocity records ($n \doteqdot 6$), and the estimated strike direction of the fault is consistent with fault plane solution for the main shock (N2°W or N9°W).

REFERENCES

[1] Harzell, S. H., 1979, Earthquake aftershocks as Green's functions, Geophys. Res. Lett., Vol. 5, pp. 2-4.

[2] Kanamori, H., 1979, A semi-empirical approach to prediction of long-period ground motions from great earthquakes, B.S.S.A., Vol. 69, pp. 1645-1670.

Irikura, K. and I. Muramatsu, 1981, A method of synthesis of strong motions using small motions from fore-shocks or after-shocks (in Japanese), Programme and Abstracts, Seis. Soc. Japan, No. 1, pp. 109-111.

Mikumo, T. and I. Muramatsu, 1981, Long-period ground displacements and velocities estimated for future possible earthquakes (in Japanese), Annuals of Disas. Prev. Res. Inst., No. 24B-1, pp. 85-104.

[3] Hadley, D. M. and D. V. Helmberger, 1980, Simulation of strong ground motions, B.S.S.A., Vol. 70, pp. 617-630.

Iida, M. and M. Hakuno, 1982, Estimation of acceleration due to large earthquake from observed records of small earthquake and analysis of source process and site condition, Proc. 6th Japan Earthq. Engg. Symp., pp. 81-88.

Irikura, K., 1983, Semi-empirical estimation of strong ground motions during large earthquakes, Bull. Disas. Prev. Res. Inst., Vol. 33, pp. 63-104.

[4] Irikura, K. and I. Muramatsu, loc. cit.

[5] Sonoda, Y. and Y. Osawa, 1980, On the damage of buildings caused by the Izu-Hanto-Toho-Oki earthquake of 1980 (in Japanese with English abstract), Bull. Earthq. Res. Inst., Vol. 55, pp. 1123-1132.

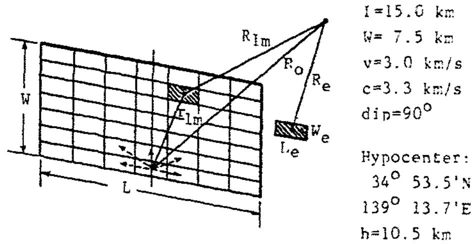

Fig. 1. Fault model of the 1980 Izu-Hanto-Toho-Oki earthquake.

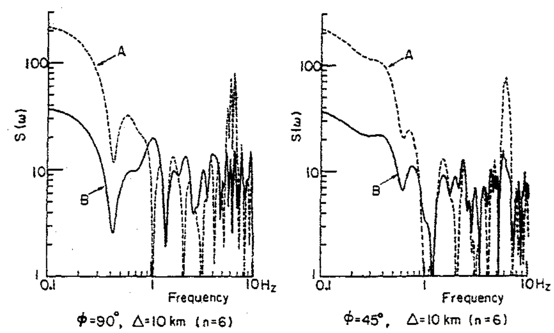

Fig. 2.

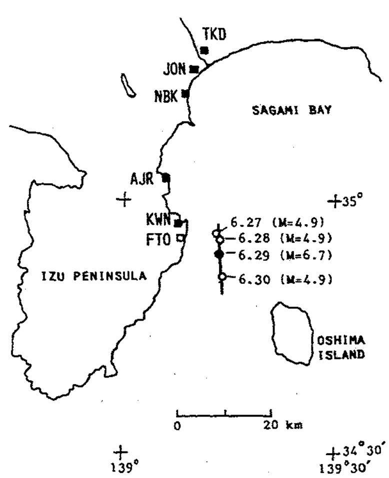

Fig. 3. Epicenters of earthquakes and strong-motion accelerograph stations.

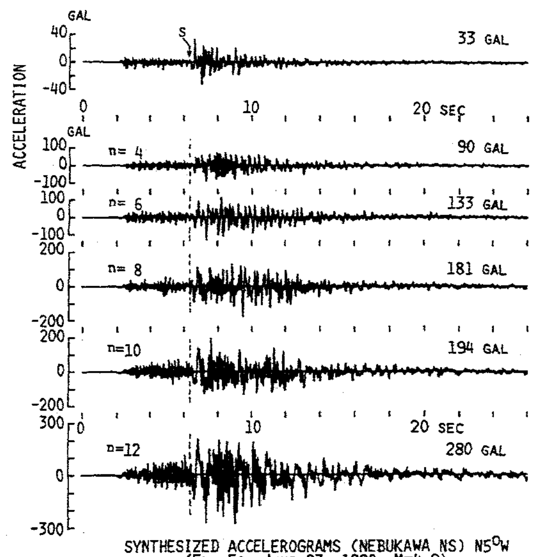

Fig. 4. Examples of synthesized accelerograms illustrating effect of n. Top trace is the recorded accelerogram for the foreshock of June 27.

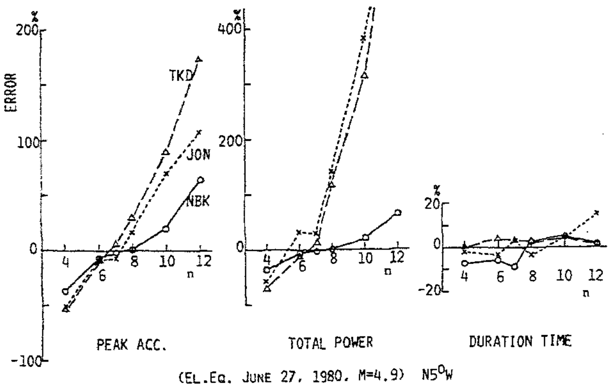

Fig. 5. Deviation error of the characteristic values between the synthesized and observed accelerograms versus n.

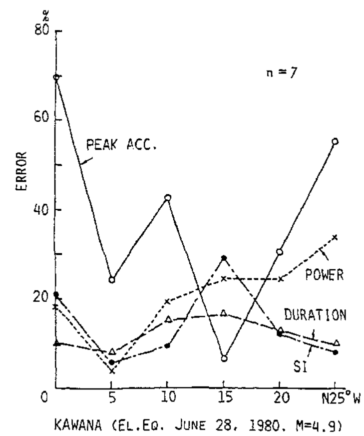

Fig. 6. Deviation error versus the strike direction of fault.

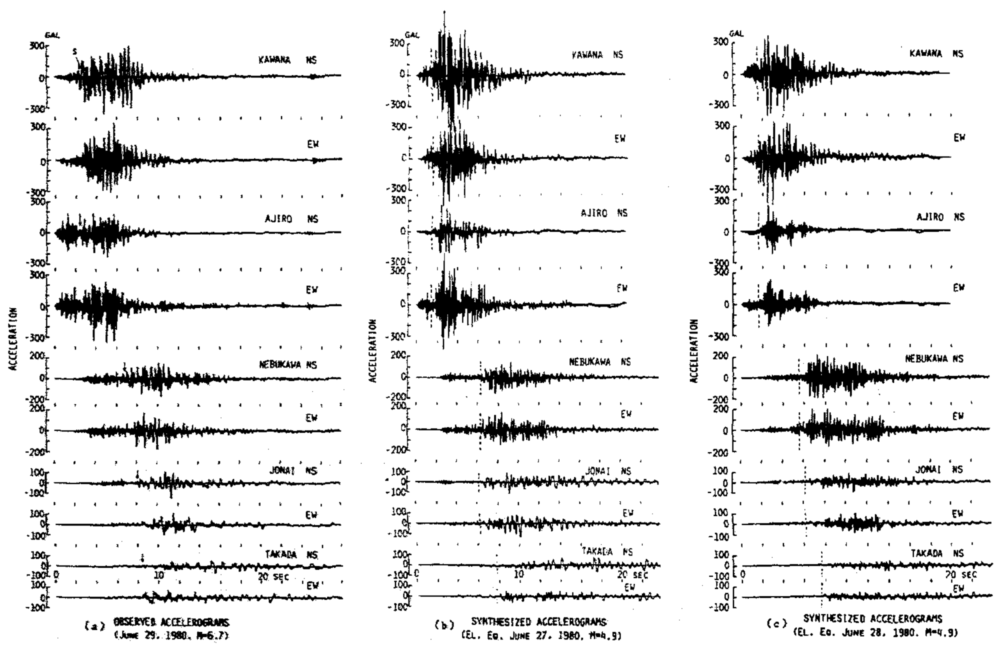

Fig. 7. Observed (a) and synthesized (b; Eq. of June 27, c; Eq. of June 28) accelerograms for the main shock at the five strong-motion stations.

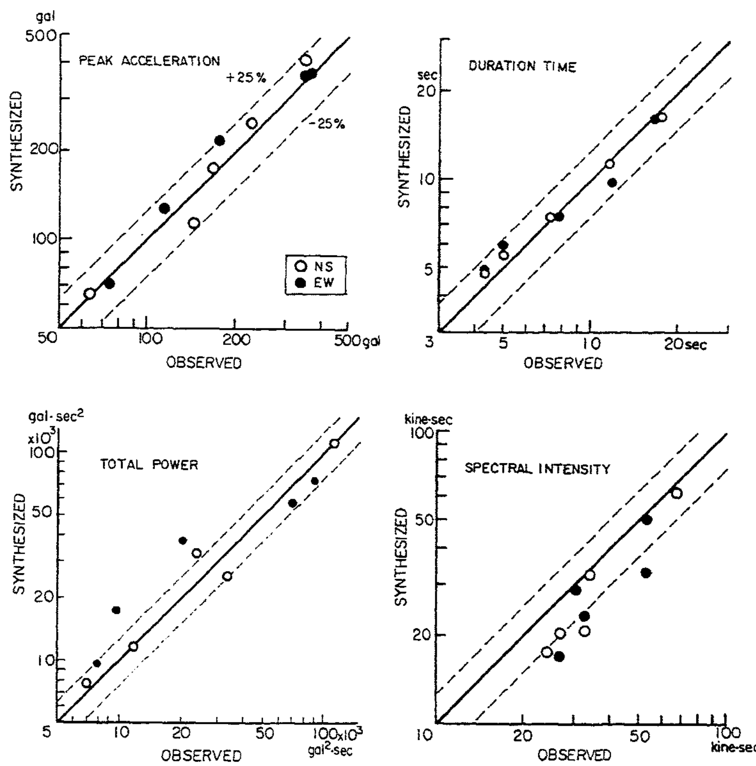

Fig. 8. Comparison of characteristic values for the synthesized and observed accelerograms, for each horizontal component at the five stations. The synthesized value is the average for the three accelerograms and the broken lines indicate the range of error within ±25 %.

Table 1. Peak ground accelerations at the five strong-motion stations.

Earthquake		Comp.	Peak Acceleration (gal)				
Date & Time	M		KWN	AJR	NBK	JON	TKD
June 27 (06h06m)	4.9	NS	137.6	79.9	33.4	17.9	14.2
		EW	104.9	100.7	38.9	20.9	11.7
June 28 (12h05m)	4.9	NS	74.2	59.0	50.4	18.4	10.6
		EW	87.5	63.4	37.6	16.3	10.8
June 29 (16h20m)	6.7	NS	350.3	226.2	168.0	143.6	63.7
		EW	363.1	350.4	174.9	113.9	75.1
June 30 (02h23m)	4.9	NS	32.8		28.8	21.1	10.6
		EW	36.0		30.8	22.4	16.0

Table 2. Underground structure at the site of the Futo(FTO) Elementary School.

Layer No.	H(m)	Geology	V_S(m/s)	ρ(gr/cm³)
1	4.0	Sandy Loam	150	1.7
2	3.0	Fine Sand	220	1.8
3	17.0	Loam	200	1.5
4	∞	Lapilli Tuff	1000	2.2

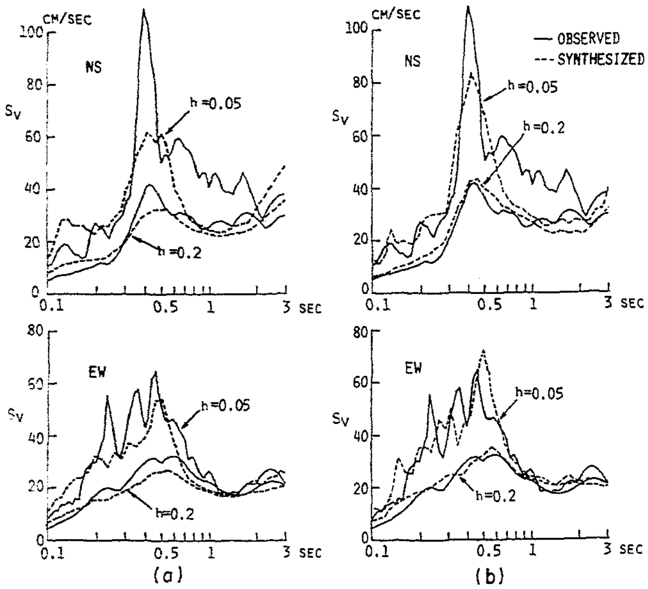

Fig. 9. Comparison of observed and synthesized response spectra at Kawana(KWN); (a) average for the three synthesized accelerograms, (b) for the foreshock of June 28.

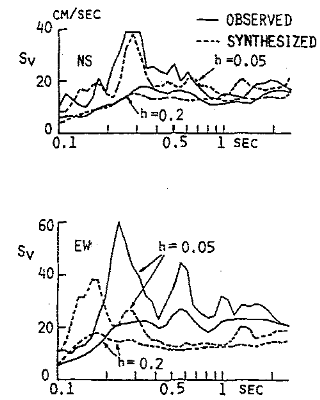

Fig. 10. Comparison of observed and synthesized (average for two accelerograms) response spectra at Ajiro(AJR).

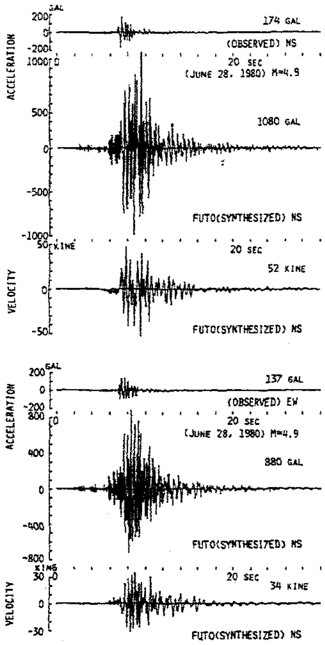

Fig. 11. Synthesized ground accelerations and integrated velocities at Futo.

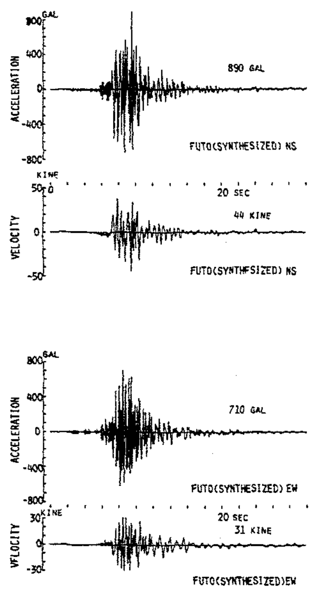

Fig. 12. Synthesized ground accelerations and integrated velocities at Futo considering the non-linear characteristics of the soil.

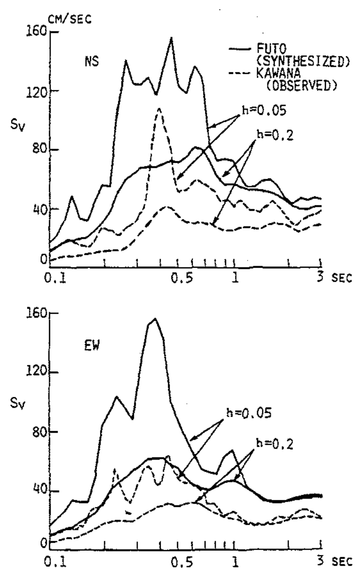

Fig. 13. Comparison of response spectra for the synthesized accelerograms at Futo and for the observed ones at Kawana.