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THE SYNTHESIS OF THE NEAR FIELD STRONG GROUND MOTION CONSIDERING RADIATION AND DIRECTIVITY

Soji YOSHIKAWA[1], *Akira KOWADA*[2], o *Yoshinori IWASAKI*[3] and *Masaru TAI*[3]

1) Professor Emeritus of Kyoto University, Kyoto, Japan
2) Structural and Architectural Div., The Kansai Electric Power Co.,Inc., Osaka, Japan
3) Geo-Research Institute, Osaka Soil Test Lab., Osaka, Japan

SUMMARY

The strong ground motions at several sites by the main shock of the Imperial Valley Earthquake(M_L=6.6)of October 15, 1979 were simulated using the after shock records as experimental green's function. The after shock is found strong effects of directivity as well as radiation. The results of the simulation are compared among the different assumptions of experimental green's functions on directivity and radiation correction. The simulations of the acceleration motions are found improved significantly by introducing the correction of the directivity for the sites where the relative site position to the fault are affected by moving source Doppler's effects.

1. *Introduction*

Recent advances of the synthesis of the strong ground motions are based upon not only the progress of the knowledge on the fault mechanism but also the availability of strong motion records at various locations. One of the most promising method is to use small earthquake motions as green function to synthesize large event developed by Irikura(1983).

Imperial Valley Earthquake of October 15, 1979 was the first case which provided the seismic records with which the validation of the applicability of the simulation method in nearfield can be discussed. The study of the arrayed records of the aftershock indicates clear radiation pattern as well as directivity effects. In this paper we show these characteristics of the aftershock ground motions and discuss the effects of radiation and directivity of the aftershock on the synthetic results.

2. Imperial Valley Earthquake

The main shock(M_L=6.6) of the Imperial Valley Earthquake was followed by an aftershock of magnitude of(M_L=5.0). Both earthquakes were considered to have the same mechanism of strike slip type faulting. The fault dimension was reported as the length of 30km and the width of 10km. The estimated seismic moments were 5.0×10^{25} *dyne×cm* for the main shock (Hartzell and Helmberger(1983)) and 4.25×10^{23} *dyne×cm* for the afterschok (Frankel(1984)). The aftershock records were studied by a few research groups. Liu and Helmberger(1985) showed that the variation of the pulse width of the velocity wave with the change of the azimuth angle of the recorded site to the epicenter and explained as a result of the double shock events which occurred progressively with a distance of about 0.5km.

Iwasaki(1988) analyzed the pulse width change with take-off angle and found that the pattern of these change correspond well to those which are expected theoretically from the rupture mode of bilaterally propagation with the offset initiation point from the center. These changes of pulse width are considered as the result of Doppler's effect of moving source on the fault surface. Liu and Helmberger(1985) indicated that the changes of the duration time of the main pulse width of the velocity motion with azimuth angle as shown in Fig.1. The directional amplitude variation of the aftershock for the typical sites are shown in the form of the directional variation of velocity response spectra in Fig.2. The directional variation of the response spectra was evaluated by calculating the response spectra for every 15 degrees of the azimuth angle. The length of the radius axis corresponds to the period and the radius of the plotted circles shows the velocity response amplitudes at normalized by the maximum value at the site. The direction at which the maximum response value appears corresponds well to the theoretically expected direction by strike slip fault mechanism in the period of 0.5 to 1.0sec. However, it becomes rather weak in the shorter range of the period due to increasing random characters. As discussed above, the aftershock records at each site contain are found to be affected by radiation as well as directional characteristics.

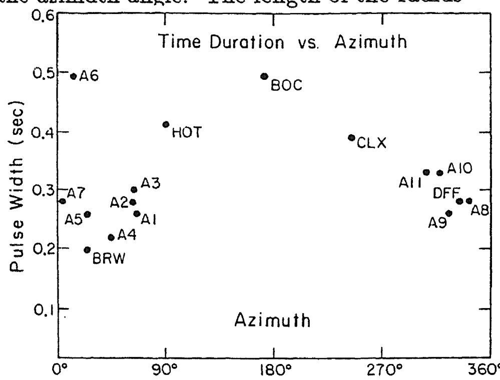


Fig.1 Time duration of the velocity pulse with versus station azimuth (after Liu and Helmberger(1985))

3.Synthesis of Mainshock

Based upon Irikura(1986), the mainshock strong ground motions are synthesized using the recorded aftershock motions as green's function. The basic seismic ratio number N is defined as the cubic of the moment ratio of the mainshock(M_o)to the smallshock(M_a)as follows:

$$N = \left[\frac{M_0}{Ma}\right]^{\frac{1}{3}} = \left[\frac{U_0}{U_a}\right]^{\frac{1}{3}} \tag{1}$$

where U_o and U_a are displacement spectral levels for main and aftershock.

Empirical relationship among the characteristic frequencies(f_o and f_a;corner frequency of main and aftershock) and moment ratio is found as the following equation:

$$\log\left[\frac{f_a}{f_0}\right] = \left[\frac{M_0}{M_a}\right]^{\frac{1}{3}} \tag{2}$$

Assuming the ω^2 law of the decay of the amplitude in the higher frequency range of the displacement source spectrum, the acceleration amplitude(A_0, A_a) may be expressed by the following expression:

$$\frac{A_0}{A_a} = \left[\frac{f_0}{f_a}\right]^2 \frac{U_0}{U_a} \tag{3}$$

The fault area is divided into $N\times N$ fault elements denoted as (i,j) element. The main event ground acceleration $a_o(t)$ for the main event is obtained by summing motion $a_{a(t)}$ from fault element(i,j) by the following equation:

$$A(t) = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\frac{r}{r_{ij}}\right]R_{ij}(\alpha)a(t-t_{d,ij})+\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{N-1}\left[\frac{r}{r_{ij}}\right]R_{ij}(\alpha)(\frac{1}{n'})a\left[t-t_{d,ij}-k\left\{\frac{\tau_d}{(N-1)n'}\right\}\right] \tag{4}$$

where $R_{ij}(\alpha)$: radiation pattern function, $t_{d,i,j}$:delay time, τ_d: rise time for aftershock

The seismic moment of the main shock(M=6.6) is reported as $M_0 = 5.0\times10^{25} dyne\times cm$ by Harzell and Helmberger(1982). The aftershock was given to have the seismic moment of $M_a = 4.25\text{x}10^{23}$ $dyne\times cm$ by Frankel(1984). The dimensional ratio between the main shock and the aftershock becomes as follows:

$$N = \left[\frac{M_0}{M_a}\right]^{\frac{1}{3}} = 120^{\frac{1}{3}} = 5 \tag{5}$$

The fault of the main shock was assumed to have 30km of the length and the width of 10km and was divided into5×5 fault elements with dimensions of $6km \times 2km$. Shear wave velocity was assumed as $3.3km/sec$ and the rupture velocity as $3.0km/sec$. The fault assumed to initiate the rupture at the south bottom corner of the fault and propagated northwards along the faults surface.

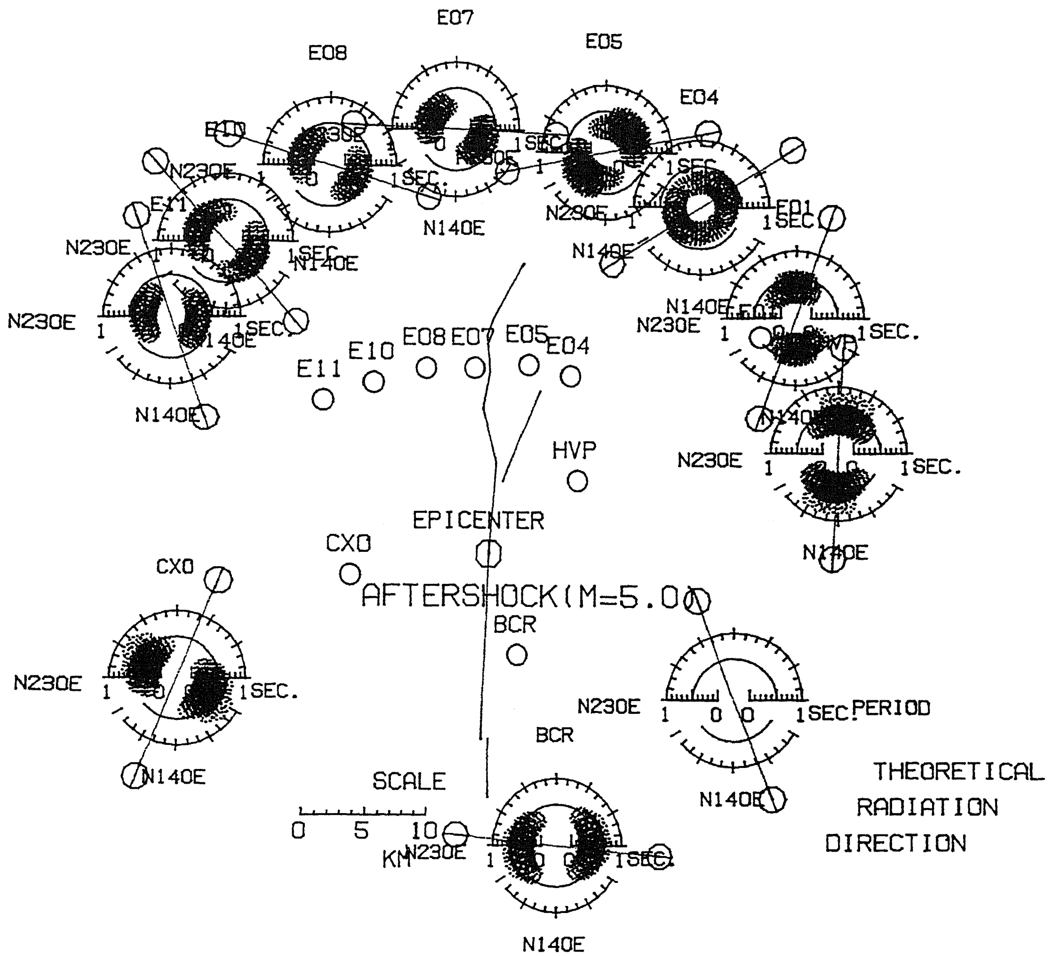
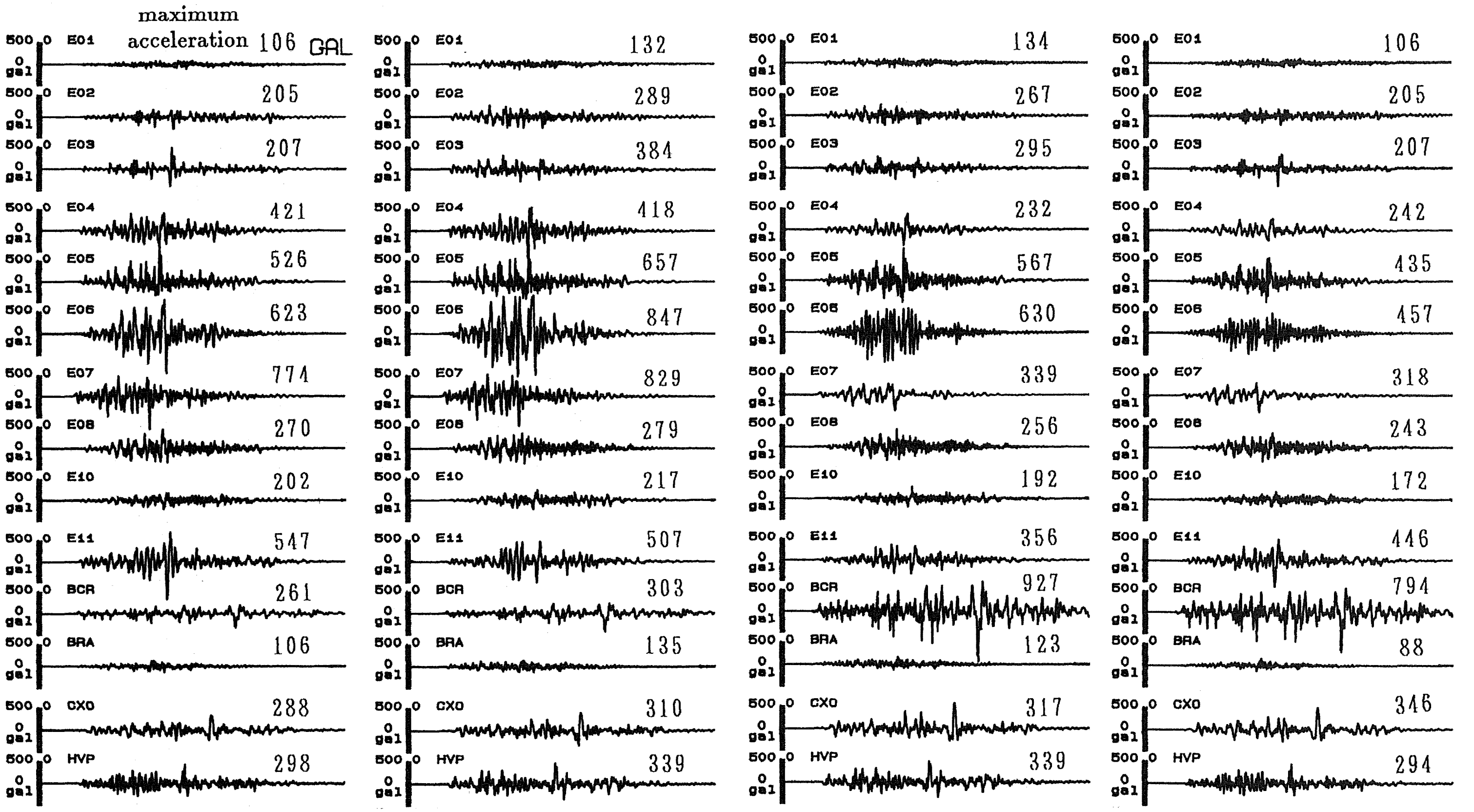


Fig.2 Predominent Direction of Response Velocity Spectra and theoretically expected radiational direction

4. Green's Function

Four different experimental green's functions were assumed based upon different modifications for the recorded aftershock motions for each site. The first is to use the same component of the ground motion of the aftershock to be synthesized at the site. The second is to correct radiation effect only. The third is to correct directivity effect and the fourth is to correct both radiation and directivity. The directivity effect due to the running source is expressed by the displacement spectrum $A(\alpha)$ as follows,

$$A(\alpha) = \frac{\sin\left[\dfrac{\omega L}{2c}\dfrac{c}{V_r} - \cos\alpha\right]}{\left[\dfrac{c}{v_r} - \cos\alpha\right]} \tag{6}$$



(1) simple summation (2) radiation corrected (3) directivity corrected (4) radiation and directivity corrected

Fig.3-1 Synthesized Acceleration

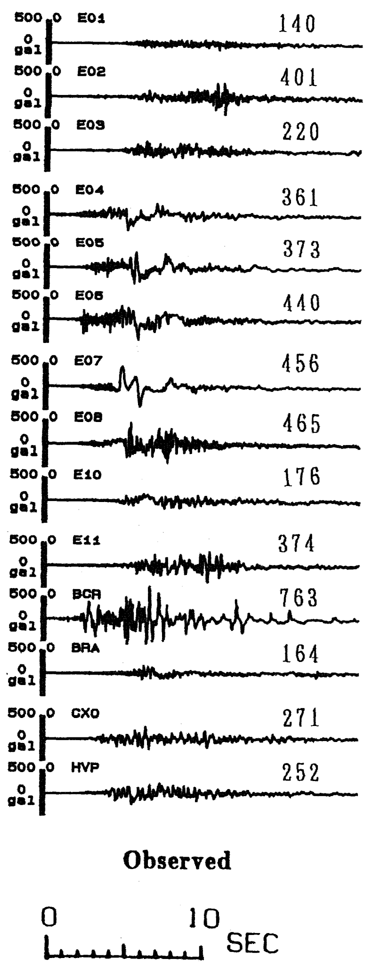


Fig.3-2 Observed Acceleration

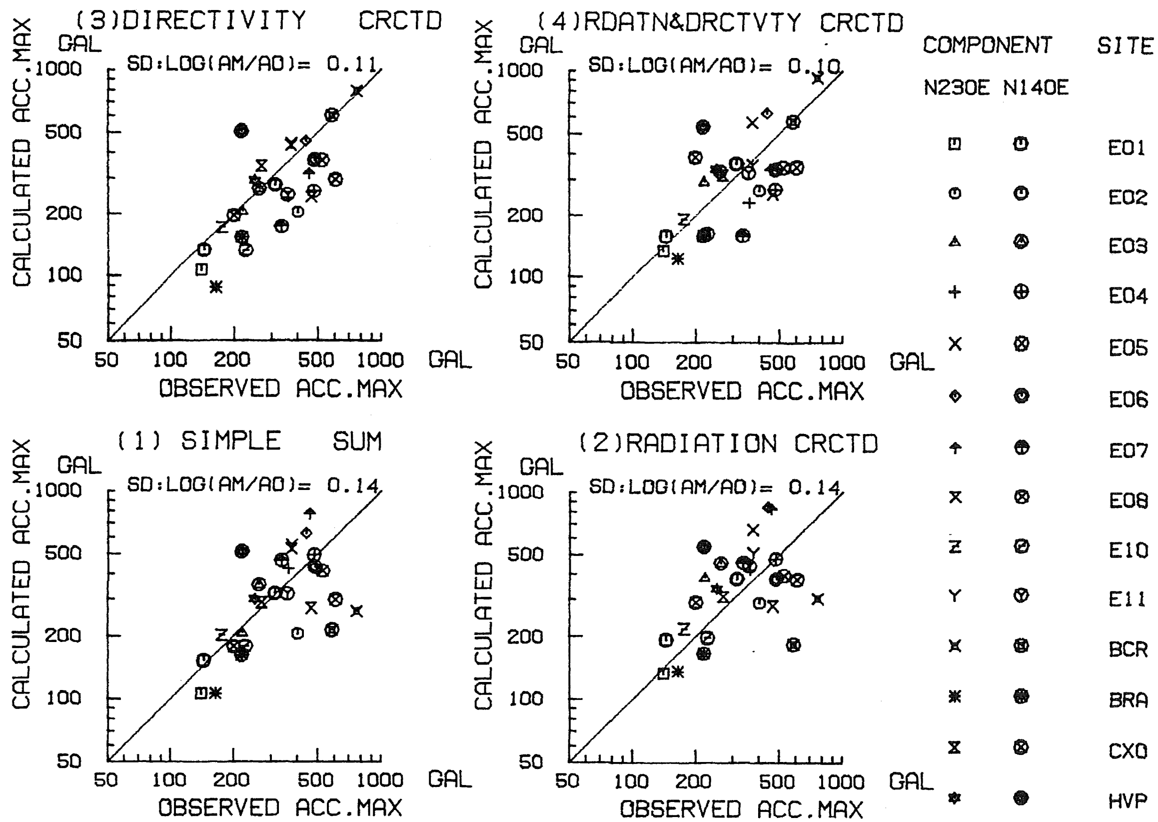


Fig.4 Observed and Synthesized Max. Acceleration

The directivity effects were removed through the numerical operation on the spectrum of the recorded motion.

5. The Results of Synthesis

Figs.3-1 and 3-2 show the comparison of the observed and synthetic results using aftershock records as green's function for the component of $N230°E$ at each site. Four different methods of synthesis were compared to calculate main shock acceleration motion by the Imperial Valley Earthquake of 1979.

These methods are (1) *Simple summation* of the aftershock as green's function for the same component at the sites, (2) *Radiation correction* is applied to obtain the green's function at each site and the radiation amplitude modification is also given when the green functions are to be summed, (3) *Directivity correction* is applied to obtain the green's function and these green's functions are summed up without radiation amplitude modification, and (4) *Radiation* and *directivity correction* were applied to obtain green's function and they are summed considering radiation. Fig.4 shows the comparison of the maximum acceleration amplitudes of observed and computed by the above methods. The standard deviations of the log of differences between the calculated and observed maximum accelerations are shown in Table-1.

Table-1 Standard Deviation of the Log of the Difference between Calculated and Observed

method	standard deviation
(1) simple summation	0.14
(2) radiation corrected	0.14
(3) directivity corrected	0.11
(4) radiation and directivity corrected	0.10

As shown in Table-1, the standard deviations of the difference between calculated and observed values are within rather small range of 0.10 to 0.14. However, it should be noted that for several sites such as BCR and E07 where the directivity effects are considered to prevail, directivity correction are found to improve simulation results significantly.

6. Conclusions

The synthesis of the mainshock of the Imperial Valley Earthquake using four kinds of green's function based upon the aftershock records showed the importance of the directivity of running source the aftershock records might be affected. If the recorded site of the small event is located within the affected take off angle, the synthesis of the main event which has the same faulting mechanism as the small event may cause significant errors in estimation of the acceleration history. Radiation pattern from the source is found to cause less effects than the directivity on the synthesized acceleration.

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