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Some features of near-field strong ground motions in the central part of Japan

Kazuyoshi Kudo, Minoru Sakaue & Zifa Wang
Earthquake Research Institute, University of Tokyo, Japan

ABSTRACT: Some interesting phenomena observed from the near–field strong motion records in the central part of Japan are firstly discussed in this paper. These include the comparison of vertical and horizontal motions, the radiation pattern and the effect of seismic sources. Comparison of the maxima of vertical and horizontal motions concludes that the two maxima have no significant difference, which contradicts to the general acknowledgement that the maximum value of horizontal motion is greater than that for vertical one. Study on radiation pattern demonstrates that it greatly affects the ground motions. On the other hand, statistical analyses verify that there is little difference between the data observed in the central part of Japan and that observed in California. Spectral ratio of velocity response spectra between rock site and soil site indicates that the averaged one coincides with the amplification by the overlaying soils from a one–dimensional wave theory.

1 INTRODUCTION

From the end of June, 1989, a swarm of earthquakes occurred near the coast of Ito city, Shizuoka Prefecture, Japan, which included three fairly large events, that is, M=4.9 on July 5, M=5.2 on July 7, and M=5.5 on July 9. Submarine eruptions also occurred on July 13. This swarm of earthquakes left us quite a number of strong motion records with some valuable data at the near fields (stations ITO and SOF; epicentral distances within 3km). This data set have enabled us to further investigate various effects of strong ground motions, such as the difference between the maxima of horizontal and vertical motions, the radiation pattern, and the period characters of P–wave and S–waves. Due to the difficulty of distinguishing the effect of directivity from that of radiation pattern, we do not discuss them separately in this paper, instead we only focus on the radiation pattern which includes the effect of directivity.

2 DIFFERENCE OF HORIZONTAL AND VERTICAL MOTIONS

It is generally acknowledged that vertical motion is smaller than the horizontal one (Fukushima and Tanaka, 1990). This idea has been adopted even in the design code for buildings in some countries like China. Recent observation in the United States has demonstrated that at the near field the vertical acceleration is sometimes greater than the horizontal one. This leads to a new subject to be studied in earthquake engineering, that is, what is the difference between the vertical and horizontal movements of strong motions, in which cases should we abandon the idea that vertical motions be smaller than horizontal ones.

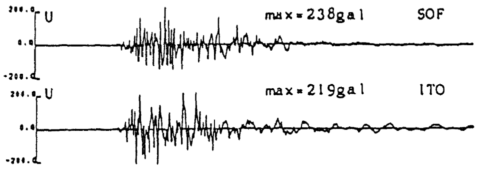
Up to present all these exceptional cases have been confined within near fields. Fortunately, we in Japan captured the motions at fairly near fields (station named as ITO and SOF) during the earthquake near Ito city (M=5.5). These records provided us a chance to study the problems described above. The recorded acceleration is shown in Fig. 1 for both stations. Comparing Fig.1–(a) with Fig.1–(b) we can see clearly that vertical motions consist predominant components at short periods. Maximum vertical acceleration at SOF is greater than that of horizontal ones. At ITO the two values are almost the same. Fourier spectral amplitude at SOF as shown in Fig. 2 delineates that there is a crossing point for the vertical and horizontal movements at about 8Hz. Over this point the vertical component becomes larger, while below this point it becomes smaller than the horizontal ones.

Figure 3 plots the maximum horizontal accelerations versus vertical ones at SOF (rock site) for various events. The dashed line means two times or half of the values at the corresponding point along the solid line. There seems no reason to believe that the maximum horizontal accelerations are larger than the vertical ones. This proved to be one of the characteristics of strong motions at near fields. Due to the fact that seismic sources are quite shallow, the inclined incidence probably becomes the most important factor in resulting in the above phenomena. What we should point out is that the maximum vertical accelerations not only happened before the arrival of S–waves but also after the arrival of S–waves.

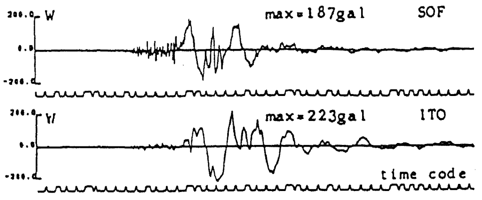
3 RADIATION PATTERN

It has long been verified that, at long periods or at far fields, the strong motions are highly dependent upon the shape of faults and the directivity of stations. On the other hand, Liu and Helmberger

(1985) pointed out that radiation pattern became ambiguous at short periods. Boatwright and Boore (1982) stated that strong motions were strongly related to the rupture direction and the directivity of stations. Therefore, it is quite important to clarify the fact whether the seismic motions at short peripds are related to radiation pattern.



a) Vertical motions



b) Horizontal motions

Figure 1. Accelerations recorded at stations ITO and SOF

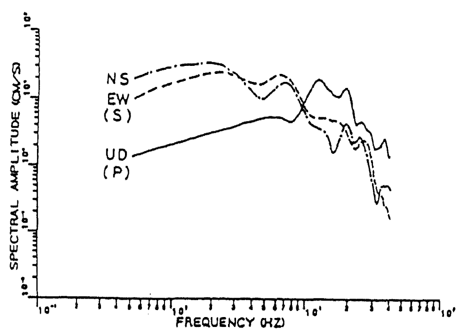


Figure 2. Spectra for S-waves and P-waves at SOF

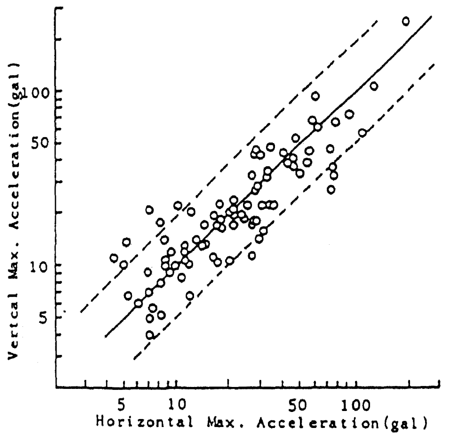


Figure 3. Maximum horizontal and vertical acceleration at SOF

In order to study this problem, we approximate the body wave at far fields as

$$\Psi^{SH}(T) - S(T) * M_0 * R^{SH_{\theta\varphi}} * D(T) * P^{SH}(T) * L^{SH}(T) \quad (1)$$

$$\Psi^{SV}(T) - S(T) * M_0 * R^{SV_{\theta\varphi}} * D(T) * P^{SV}(T) * L^{SV}(T) \quad (2)$$

where $\Psi(T)$ is the Fourier spectral amplitude, S(T) the source time function, M_0 the seismic moment, $R^{SH}{}_{\theta\psi}$ the radiation coefficient (so called radiation pattern), D(T) the directivity function, P(T) the path effect, and L(T) the local site amplification. If we assume that radial motion corresponds to SV–waves and transverse one implies the SH–waves, the ratio of Eq.(1) to Eq(2), which is expressed as following, should be period constant for the same station in swarm earthquakes.

$$Ratio = \frac{R^{SH_{\theta\varphi}}}{R^{SV_{\theta\varphi}}} * \frac{P^{SH}(T) * L^{SH}(T)}{P^{SV}(T) * L^{SV}(T)} \quad (3)$$

In other words, the last part at the right side should be period independent. In contrast to this concept, the spectral ratio of the transverse component to the radial one seems not to be period independent for almost all the stations. Figure 4 shows one of the results. The bold line is a smoothed result of the ratio. The dashed line is the theoretical ratio of Eq.(3). On the other hand, the difference of maximum horizontal accelerations between two stations changes abruptly for the three relatively large events mentioned above although the hypocenter of three events are almost at the same point. One other example which shows the effect of radiation pattern is the arrival of S-waves for different events at a same station. For example, at station YHN the arrivals of S-waves in two horizontal components are almost the same in the earthquake of July 7, whereas, they differ obviously in the earthquake of July 9. Quantitatively, we cannot say how much the radiation pattern has contributed to the above results at present, because we cannot distinguish the effect of directivity from that of radiation. What seems to be a fact is that these two factors affects the acceleration records very much.

4 STATISTICAL ANALYSES OF STRONG MOTIONS

In order to get a general image of the average strong motion in the Izu Peninsula and Ashigara Valley, we carried out a statistical analysis of the strong motions at rock sites there. Let us first look at Eq.(1) once again. Because we only consider rock here, L(T) approaches to unity. For the benefit of the analysis, D(T) and S(T) are included in M_0, which leads to a period dependent $M_0(T)$. P(T) is rewritten as a function of hypocentral distance R. Because we consider the velocity response spectrum here, Eq.(1) should be multipled by a factor which is a function of period and damping ratio. Again for convenience, radiation coefficient $R_{\theta\psi}$ is included into this factor expressed as $f_2(T)$ in Eq.(4), but the effect of radiation pattern should be weakened in the averaged strong motion records or in a regressional analysis. Therefore, Eq.(1) is rewritten for velocity response spectrum as

$$S_V(T) = \frac{M_0(T)\, e^{-f_1(T)R} f_2(T)}{R^n} \qquad (4)$$

where $f_1(T)$ is a function of quality factor, n=1 implies the S-waves at far fields while n=0.5 means surface waves at far fields. Rewriting $M_0(T)$ as a function of magnitude, and making a little modification of the expression for hypocentral distance R, various equations can be written for the logarithmic form of Eq.(4). Some typical equations are listed here.

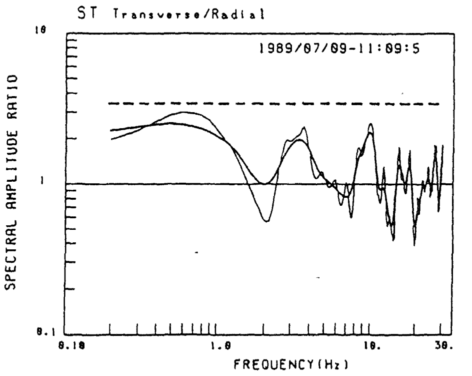


Figure 4 Spectral amplitude ratio at station STG

$$LogS_V(T) = a(T)M - (b(T)R + LogR) + c(T) \qquad (5)$$

(see Takemura et al., 1987)

$$LogS_V(T) = a(T)M - b(T)LogR - c(T) \qquad (6)$$

(see Midorikawa and Kobayashi, 1978)

$$LogS_V(T) = a(T)M + b(T)M^2 - LogR - c(T)R + d(T)$$

(See Joyner and Boore, 1982) (7)

where a(T), b(T), c(T) and d(T) are regression coefficients, M the magnitude. Due to the scarcity of strong motion data observed in Izu Peninsula and Ashigara Valley, data with magnitude over 4.0 on JMA scale are used in this analysis. In order to weaken the heavy weight caused by concentration of swarm earthquakes in the small magnitude range, a simple averaging is used for the response spectra before the regression analysis. The averaged magnitude-hypocentral distribution is shown in Fig. 5. These data are used in the regression analyses for the three equations in Eqs.(5)~(7). The regression analyses result in the coefficients at various periods. Resubstituting the derived coefficients into Eqs.(5)~(7) response spectra can be predicted for an assumed hypocentral distance and a magnitude. Calculated results demonstrate that Eqs.(5)~(7) do not bring about significant difference in the data range shown in Fig. 5. Whereas, at short distances or at distances outside the data range(that is, greater than 100km in this study), Eq.(5) and Eq.(7) result in smaller response spectra than that by Eq.(6) and the actually observed data. There are probably two reasons why this kind of results occurs. One is the scarcity of our observed data, the other is that quality factor or the linear term of R is strictly constrained by the data used in the analyses, which indicates that the application of the two equations outside the data range becomes much more difficult.

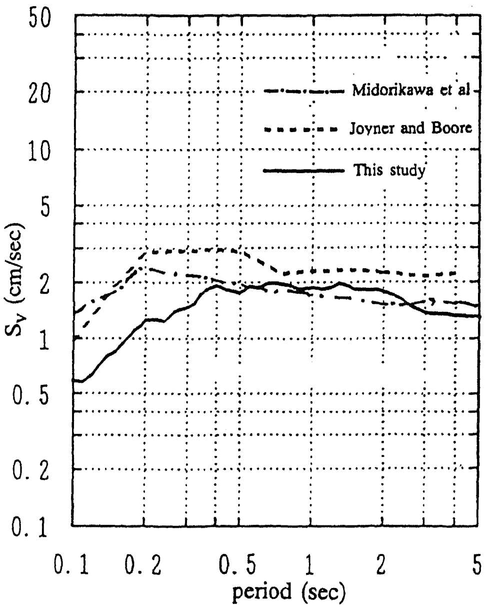


Figure 6 Amplification by the surface sediments at CNT

Figure 6 shows the predicted velocity response spectra for R = 50km and M = 6 by the data from various places. The solid line shows the result from the data in the Izu Peninsula and Ashigara Valley by Eq.(6) (No significant difference if other equations are used). The dashed line shows the result by Joyner and Boore(1982) from the data recorded in California. The pointed dash line show the result by Midorikawa and Kobayashi(1978) from the data mainly recorded in the northern part of Japan. What we should point out is that predictions by Midorikawa and Kobayashi(1978) is the so called input response spectra at rock sites. In this sense we could say that the result by Midorikawa and Kobayashi is little larger than that by our data and that by Joyner and Boore(1982) although results by Midorikawa and Kobayashi refer to the bi-directional response spectra, which generally result in larger response than the ordinary response spectra. Except the spectra in short period range there is little discrimination for the result in the longer period range (longer than 0.5 seconds). The smaller value in short period in this area of Japan has been considered one of the characters of the strong motions in this area, some authors even suggest that the JMA magnitude should be decreased 0.7 in predicting maximum accelerations (see, for example, Fukushima and Tanaka, 1990). Comparison of the data in the longer period with the data from other areas, there seems to be no necessity to compensate this kind of decrement.

5 AMPLIFICATION DUE TO SURFACE SEDIMENTS

One of the most important factors that affect strong motions has long been recognized as the amplification by surface sediments, that is, L(T) in Eq.(1). Of course, it has not been so developed to predict the amplification due to surface sediments at a specific site under varied cases of strong motion incidence. It is the purpose in this section to get an average view of the amplification due to surface sediments. In Ashigara Valley there is a station named CNT with the underground structure known quite in detail. The amplification by surface sediments is calculated by the one-dimensional wave propagation theory using the known soil profiles. This result is shown in Fig. 7 by a dashed line. On the other hand, the ratio of response spectra (no damping) on the surface of CNT to that by substituting the corresponding M and R into Eq.(6) is also calculated. The calculated average ratio is shown in Fig. 7 by a solid line. It is surprising that the two results coincide so well in the period range less than two seconds, because we have made no fitting of any parameters in the theoretical calculation. The difference in the range longer than two seconds has not been precisely studied. At present there seems two reasons related to this difference. One is the difference between response spectrum and Fourier spectrum. The other is the effect of surface waves, which is not considered in the one-dimensional calculation. Further verification of the above considerations should be carried out in the future.

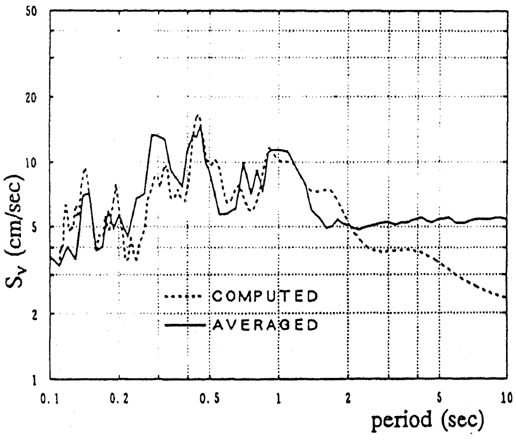


Figure 7 Comparison of predicted response spectra by the data from different areas

In addition, there are quite a few cases in which the response spectra deviate a lot from the averaged value, this probably leads to further engineering need to develop other computational models rather than the one-dimensional ones.

6 CONCLUDING REMARKS

We have discussed the distinguishing features of strong motion in Japan, especially the one in Izu Peninsula and Ashigara Valley. They include the predominant short period components in the vertical motions, the no difference of the maxima of horizontal and vertical motions, the strong effect of radiation patterns, the lack of short period component compared with those of other areas, and that the average amplification by surface sediments can be approximately expressed by the one-dimensional wave propagation theory. These have been the preliminary results on the analyses of the data observed in the Izu Peninsula and Ashigara Valley observation array. Further study on the conclusions made in this paper should be progressed in the future.

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