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EMPIRICAL ANALYSIS OF PEAK HORIZONTAL VELOCITY FOR THE HYOGO-KEN NANBU, JAPAN EARTHQUAKE OF JANUARY 17, 1995

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ABSTRACT

The empirical analysis of peak horizontal velocity is performed for the records from the 1995 Hyogo-ken Nanbu (Kobe), Japan earthquake (M_w 6.9). The following observations can be made: (1) the attenuation of peak horizontal velocity is consistent not only with the empirical relationship derived from Japanese data, but also with that derived from North American data; (2) the site effect on peak horizontal velocity is not negligible and is consistent with that expected from the previous studies; (3) the peak horizontal velocity on stiff site seems to be saturated at 50 to 70 cm/s; and (4) the source directivity effect on the records is not significant.

KEYWORDS

Strong motion; peak horizontal velocity; near-field; attenuation; site effect; source directivity effect; average shear-wave velocity; the 1995 Hyogo-ken Nanbu earthquake

INTRODUCTION

Evaluation of ground motion intensity in near-field is important for seismic design of critical structures such as a nuclear power plant. Although some of near-field motions were obtained in California and other regions, very few near-field data have been available from Japanese earthquakes. This is because that most of large Japanese earthquakes have their epicenters in the ocean. The limitation of the available data has made the evaluation of near-field motion for Japanese earthquakes difficult.

The 1995 Hyogo-ken Nanbu (Kobe), Japan earthquake (M_w 6.9) occurred just beneath the City of Kobe which is a highly developed modern city. By the earthquake, about 6,000 were killed, 200,000 dwellings were collapsed or heavily damaged, and the monetary loss reached 100 billion dollars. The earthquake also produced a number of strong motion records including records in the near field. This dataset provides a unique opportunity to examine the near-field ground motion intensity for a Japanese earthquake.

The attenuation of peak acceleration and velocity during the earthquake has been preliminarily studied by Irikura and Fukushima (1995). They indicate that the observed peaks agree well with those predicted by the existing attenuation relationships. Although gross features of the attenuation characteristics have been discussed in their study, the further analysis should be conducted to have a better understanding of the ground motion characteristics in the earthquake. Recent studies suggest that peak ground velocity is more appropriate measure for ground motion severity than peak ground acceleration or other single severity measures (i.e. Ando *et al.*, 1990). In this paper, attention is paid to the characteristics of peak horizontal velocity, and the dependence of peak horizontal velocity on distance, site conditions and azimuth is examined using the records from the Hyogo–ken Nanbu earthquake.

STRONG–MOTION DATA

The strong–motion data used in this study are 79 ground–level records. Because of the importance of peak ground velocity as a ground motion severity measure, the peak horizontal velocities are collected and analyzed. When the digitized data of the records are available, the digitized data are processed to obtain the peak velocities. For the other cases, the peak velocity values are taken from the reports published by individual institutions. The larger value of two horizontal components is used for the analysis.

Source–to–site distance is defined as the closest distance to the seismogenic rupture zone. Locations of the seismogenic rupture zone of the earthquake is determined based on the fault model by Sekiguchi *et al.*(1995). The earthquake is a shallow interplate earthquake with right lateral faulting. The rupture starting from the Akashi Straits propagated about 30 km to the north–east and about 15 km to the south–west. The source process of the earthquake seems to be similar to those of strike–slip earthquakes in California. Locations of the rupture and the recording sites are shown in Fig. 1. The peak velocities and the source distances of the data range 1.3 to 140 cm/s and 1 to 180 km, respectively.

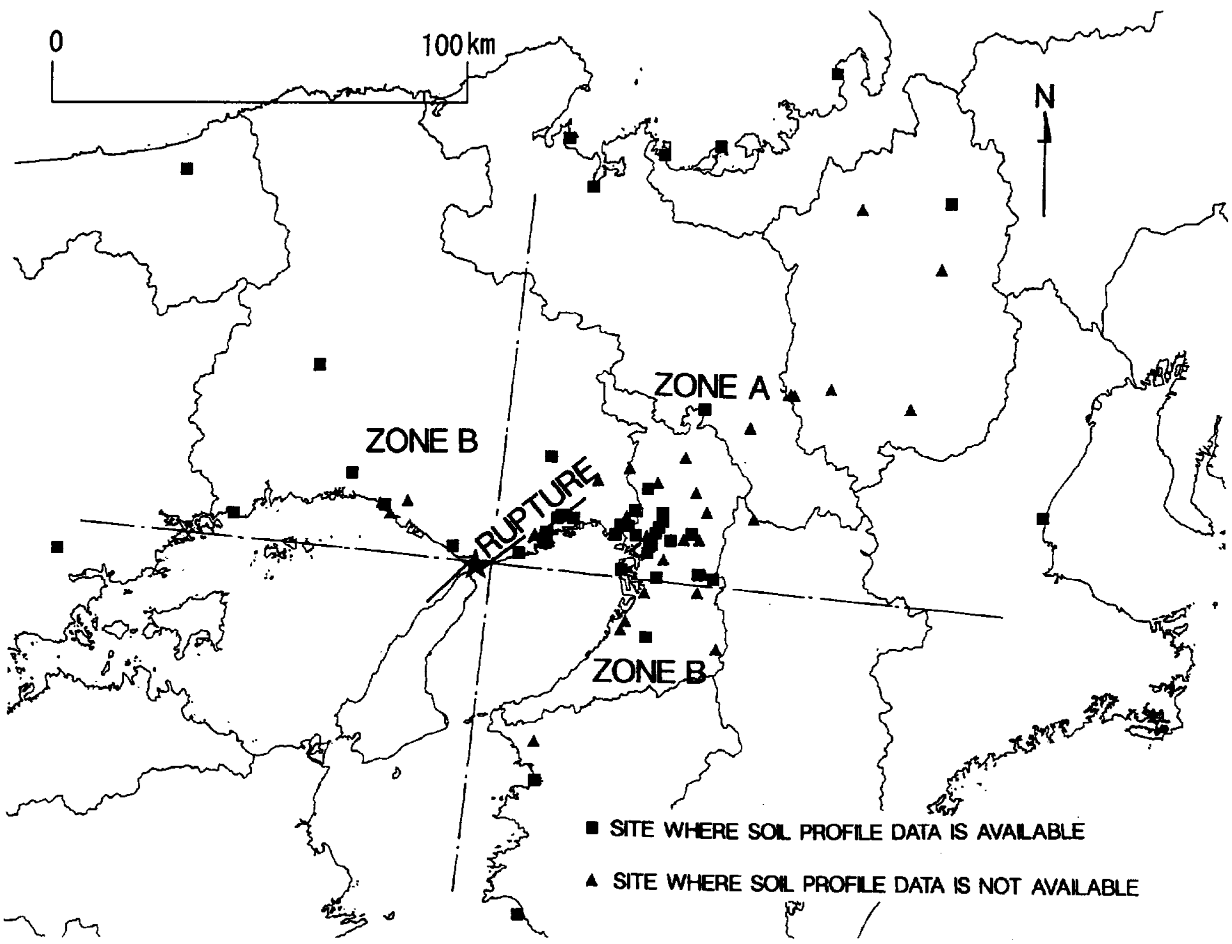


Fig. 1. Locations of fault rupture and recoding sites.

ATTENUATION OF PEAK HORIZONTAL VELOCITY

The attenuation of peak ground velocity is shown in Figs. 2. At very close distances, the peak velocities range 60 to 140 cm/s, indicating that the peak horizontal velocity can be over 100 cm/s in the epicentral area of a large shallow earthquake. The peak velocities attenuate with distance; the values are around 50 cm/s at distance of 10 km and 1.5 to 15 cm/s at distance of 100 km. The scatter of the data seems to be larger at longer distance.

The solid line in the figure show the empirical relationship for stiff site by Midorikawa (1993), which is derived from Japanese data. The dashed and dotted lines are the relationships for soil and rock by Boore and Joyner (1982), respectively. The relationships by Boore and Joyner (1982) is derived from North American data. The data from the earthquake are consistent with both of the empirical relationships derived from Japanese data and from North American data.

In the figures, two site classification schemes are used to examine the site effects; one is soil or rock category used by Joyner and Boore (1981), and another is stiff, intermediate or soft site category adopted in the seismic design method for building in Japan (IAEE, 1988). The peak velocities on rock or stiff site tend to be smaller than those on soil or soft site, suggesting the site effect on peak horizontal velocity. The regression analysis of the data indicates that the ratio of the peak velocity for soil to that for rock is 1.5 and that the ratios of the peak velocities for intermediate and soft sites to that for stiff site are 1.4 and 1.8, respectively. These values are consistent with the results of the previous studies (i.e. Boore and Joyner, 1982; Kawashima *et al.*, 1986; Midorikawa *et al.*, 1994).

As mentioned above, the site effects on peak horizontal velocity is not negligible. To evaluate the site effect, the average shear–wave velocity of ground to a depth of 30 m is used as a site parameter. This is because the average shear–wave velocity strongly correlates with the site amplification factor at intermediate periods (i.e. Joyner and Fumal, 1984; Borcherdt *et al.*, 1991; Midorikawa *et al.*, 1994). The site amplification factor is estimated using the following empirical equation proposed by Midorikawa *et al.*(1994):

$$\log R = -0.66 \log V + 1.83 \tag{1}$$

where R is the amplification factor with respect to the stiff site where the average velocity is approximately 600 m/s, and V is the time–weighted average shear–wave velocity to a depth of 30 m in m/s. The average shear–wave velocity is computed for 44 recording sites where the soil profile data is available. The shear–wave velocity of ground has been measured at 18 sites, while the velocity at the other sites is estimated from the boring data with use of the empirical relation of shear–wave velocity in terms of SPT N–value, depth and soil material proposed by Ohta and Goto (1978).

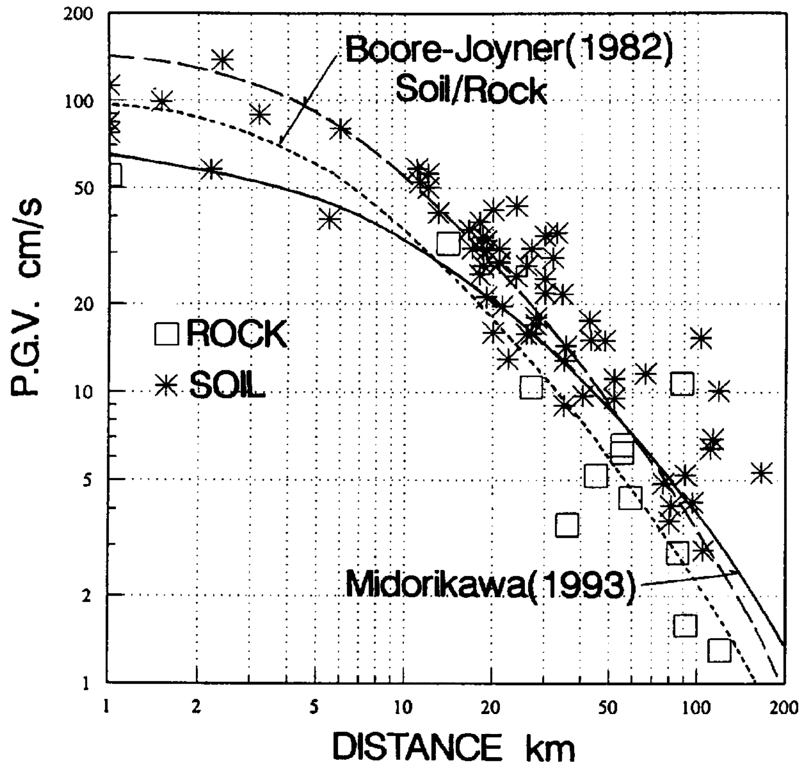
To eliminate the site effect, the corrected stiff–site peak horizontal velocity, PHV_s, is calculated by dividing the observed peak horizontal velocity, PHV, by the amplification factor, R:

$$PHV_s = PHV / R \tag{2}$$

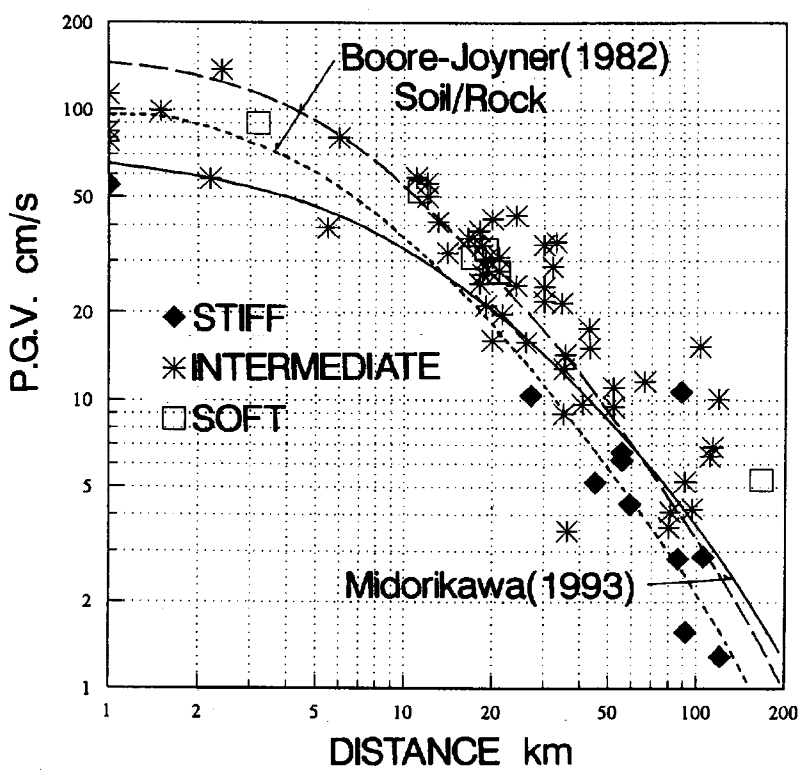
Figure 3 shows the attenuation of the corrected stiff–site peak velocity. At very close distances, the corrected peak velocities seem to be saturated at 50 to 70 cm/s. The corrected peak velocities attenuate with distance, but they still show some scatter. To identify the potential effect of azimuth on peak horizontal velocity, the data observed at zone A and at zone B are indicated by different symbols in the figure. The zone A is located on the rupture toward direction, and the zone B is on the perpendicular direction of the rupture, as shown in Fig. 1. No significant difference is observed between the data at both zones. This suggests that the source directivity effect on the records is not significant.

DISCUSSIONS AND SUMMARY

The empirical analysis of peak horizontal velocity is performed for the records from the Hyogo–ken



(a) soil and rock site classification



(b) stiff, intermediate and soft soil classification.

Figs. 2. Attenuation of peak horizontal velocity.

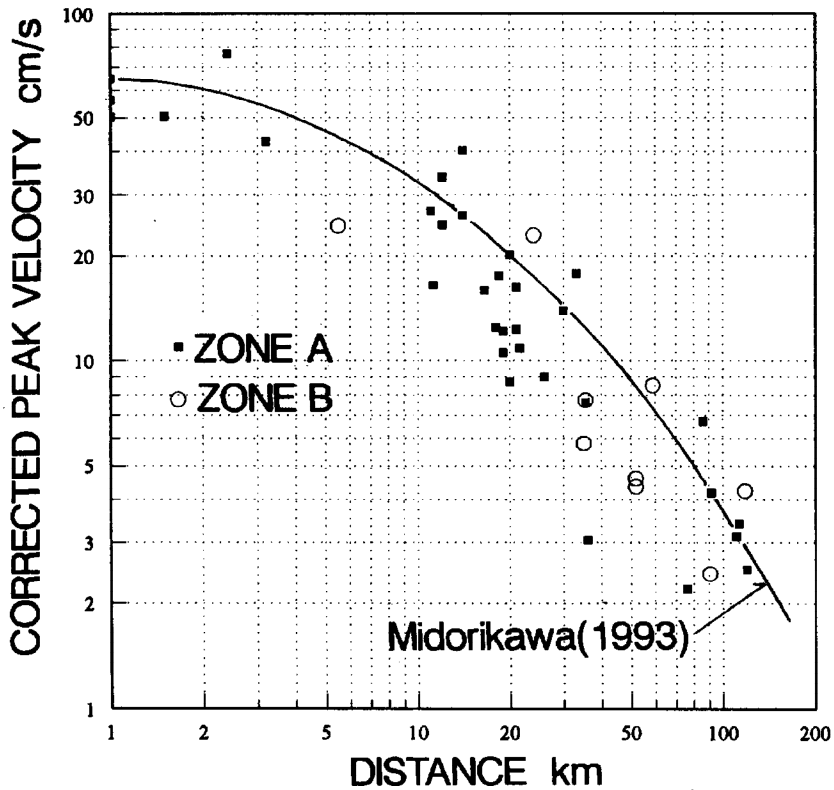


Fig. 3. Attenuation of corrected stiff–site peak horizontal velocity.

Nanbu earthquake. The following observations can be made: (1) the attenuation of peak horizontal velocity is consistent not only with the empirical relationship derived from Japanese data, but also with that derived from North American data; (2) the site effect on peak horizontal velocity is not negligible and is consistent with that expected from the previous studies; (3) the peak horizontal velocity on stiff site seems to be saturated at 50 to 70 cm/s; and (4) the source directivity effect on the records is not significant.

No significant source directivity effect observed would be because the rupture propagated bilaterally with some irregularity. For earthquakes with unilateral faulting, however, the source directivity effect could not be negligible and may be one of key parameters in strong–motion prediction, as has been discussed by the previous studies (i.e. Campbell, 1984; Midorikawa, 1991). Regarding the scatter in the attenuation of the corrected peak velocity in which the site effect should be eliminated, the possible reasons may be the non–uniform slip distribution on the rupture, the propagation path effect, and the site effect by the deeper underground structure.

The consistency in the attenuation with the previous studies would be because the rupture process of the earthquake may be average one for interplate earthquakes with the same size. It may be interesting to compare with the observations during the 1994 Northridge, California earthquake (M_w 6.7). The observed peak horizontal velocities in near–field are 130 cm/s at a stiff to intermediate soil site (Sylmar) and 50 cm/s at a stiff soil or rock site (Kagel Canyon). These values are also consistent with the observations in near–field during the Hyogo–ken Nanbu earthquake. As the number of the near–field records are limited in each seismic region, these facts may encourage the analysis of near–field records from worldwide earthquakes for empirical strong–motion prediction.

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