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RELATIONSHIP BETWEEN VERTICAL AND HORIZONTAL RESPONSE SPECTRA FOR THE NORTHRIDGE EARTHQUAKE

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ABSTRACT

Relationship between vertical and horizontal response spectra of the free-field ground motions recorded during the 1994 Northridge earthquake is examined. Based on the attenuation models for vertical and horizontal response spectral ordinates, distance-dependent relationships between vertical and horizontal response spectra are presented. An approximate procedure to derive vertical acceleration response spectra from the spectra of horizontal motion, based on shifting the horizontal spectra to shorter periods and reducing them by a set of distance-dependent reduction factors, appears promising for practical engineering applications.

KEYWORDS

Vertical ground motion; vertical response spectra; Northridge; Loma Prieta; near-source.

INTRODUCTION

Behavior of response spectra of free-field vertical motion has been studied by Bozorgnia and Niazi (1993) for the 1989 Loma Prieta, California, earthquake and by Niazi and Bozorgnia (1992) for several other earthquakes recorded over SMART-1 array in Taiwan. The main characteristics of the ratio of the vertical-to-horizontal (V/H) response spectra are:

- V/H spectral ratio is a function of period, distance to the fault, and earthquake magnitude. The ratio is largest at short periods in the near-field region.

- At short periods, the commonly used ratio of 2/3 grossly underestimates the V/H spectral ratio, especially in the near-field region. At long periods, V/H spectral ratio falls below 2/3.

Recently Bozorgnia *et al.* (1995) developed attenuation models for vertical and horizontal response spectra of the 1994 Northridge earthquake. The Northridge earthquake distance-dependent spectra are used here to examine the relationship between spectra of vertical and horizontal ground motions. A simple approximate procedure is examined for practical engineering applications to generate the vertical acceleration response spectra from the horizontal spectra. The procedure is based on shifting the acceleration

response spectra of horizontal motion to shorter periods and reducing them by a set of distance-dependent reduction factors.

ATTENUATION OF VERTICAL AND HORIZONTAL SPECTRA

Attenuation relationships for vertical and horizontal response spectra of the 1994 Northridge earthquake have been recently developed by Bozorgnia *et al.* (1995). The database used in the development of the attenuation models consisted of 123 response spectra of the free-field motions recorded at 41 alluvial sites during the Northridge earthquake. The peak vertical ground acceleration at the recording stations in the database was as high as 0.85 g (at Rinaldi Receiving Station). Five percent damped vertical and horizontal spectral ordinates were analyzed at 21 periods ranging from 0.05 to 3.0 seconds. For the data considered, it was found that an attenuation relationship of the form given in equation (1) was a suitable model.

$$\ln (PSA) = a + d \ln (R + c) + \varepsilon (0, \sigma^2) \qquad (1)$$

In this equation, PSA is pseudo-spectral acceleration (g); R is the closest distance to the surface projection of the fault rupture plane (km); 'a' , 'c', and 'd' are regression parameters to be computed; and ε is a random error with a zero mean and variance of σ^2. For the horizontal motion, the arithmetic mean of the spectral ordinates of the two horizontal components was used. The dimensions of the fault rupture plane for the Northridge earthquake were taken from Wald and Heaton (1994). Other details of the development of the attenuation relations and the spectral database can be found in Bozorgnia *et al.* (1995).

Distance-dependent response spectra, resulted from the spectral attenuation relationships at various periods, are shown in Figure 1. Figure 1(a) shows 5% damped median response spectra of vertical ground motion at alluvial sites for distances R=5, 10, 20, and 40 km from the surface projection of rupture plane. Figure 1(b) shows distance-dependent response spectra for horizontal ground motion. A comparison of Figures 1(a) and 1(b) shows that the peaks of vertical acceleration response spectra are at shorter periods than those for the horizontal motion. This is an indication of the fact that vertical ground motion is richer in high frequency than horizontal motion. Also, in the near-field region, vertical spectral ordinates at short periods are comparable to, or larger than, those of horizontal spectra.

RELATIONSHIP BETWEEN VERTICAL AND HORIZONTAL SPECTRA

One way of presenting the relationship between vertical and horizontal spectra is vertical-to-horizontal (V/H) response spectral ratio. Figure 2 shows the V/H spectral ratio for the 1994 Northridge earthquake for different values of distance 'R'. The commonly assumed ratio of 2/3 is also marked in the figure. It is clear that the V/H spectral ratio is a function of distance and spectral period. In the near-field region, the ratio is higher in the short period range of the spectra, and the V/H spectral ratio is much larger than the 2/3 ratio. The V/H spectral ratio presented in Figure 2 can be used to derive vertical response spectra from the horizontal spectra.

In previous studies by Bozorgnia and Niazi (1993), and Niazi and Bozorgnia (1992) characteristics of the V/H spectral ratio were examined for the 1989 Loma Prieta, California, earthquake, and twelve other earthquakes recorded on SMART-1 array in Taiwan. A comparison of the V/H spectral ratio for the Northridge, Loma Prieta, and other earthquakes recorded on SMART-1 array, reveals that the main characteristics of the V/H spectral ratio for these earthquakes are qualitatively similar.

As Figure 1 shows, the peak of horizontal acceleration response spectra is at a longer period than that for

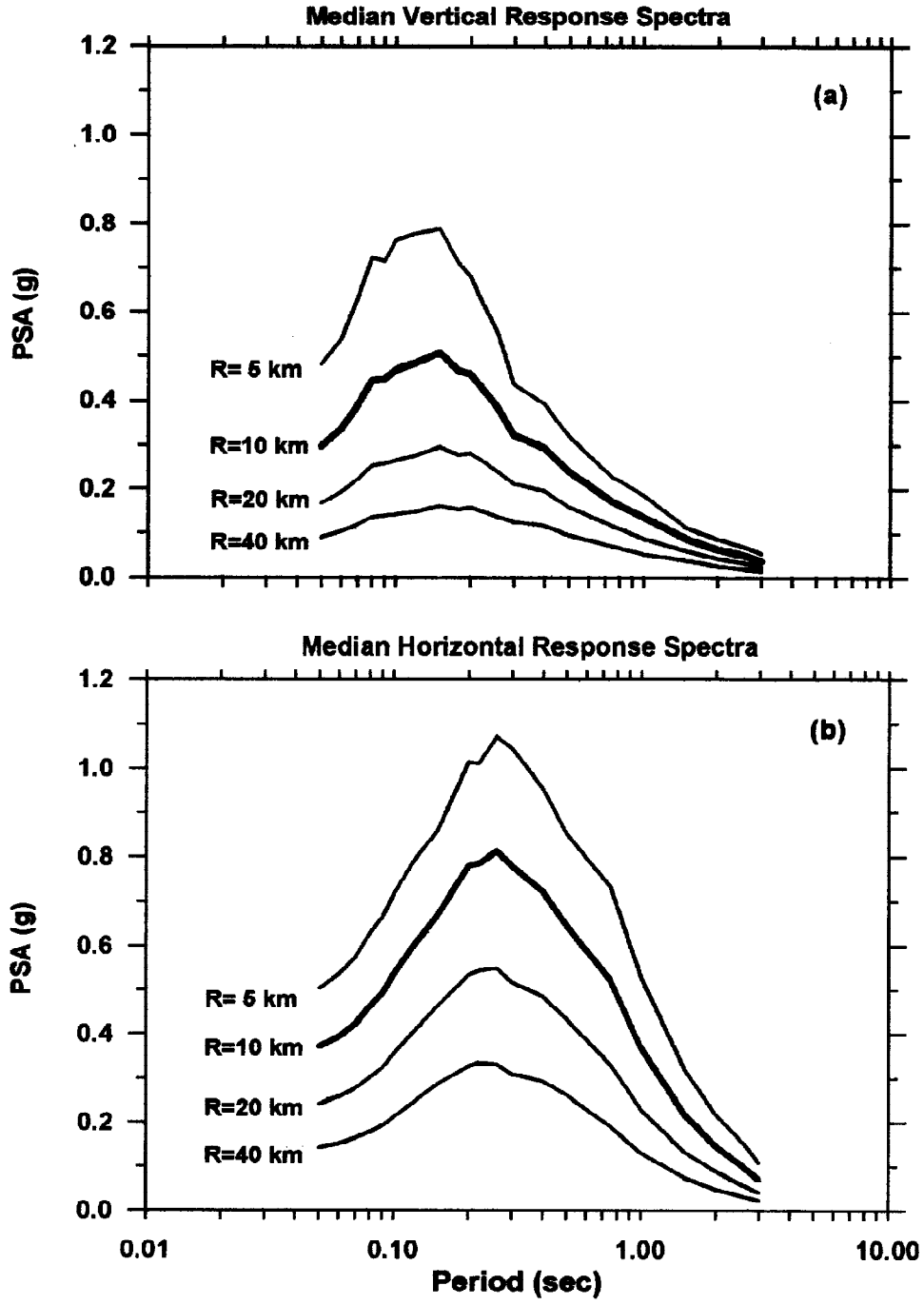

Figure 1. Distance-dependent response spectra for the Northridge earthquake for 5% damping at distances R=5, 10, 20, and 40 km from the surface projection of fault plane.

vertical component. Also, the peak of the spectral acceleration for horizontal motion is larger than that for the vertical component. This suggests that it may be possible to approximate vertical acceleration response spectra by shifting the horizontal spectra to shorter periods and reducing them. A similar procedure has been suggested by Watabe, *et al.* (1990). In the present study, however, un-scaled *distance-dependent* vertical and horizontal response spectra are directly used. Consequently, the reduction factor to be applied to the shifted horizontal spectra can be easily estimated as a function of the site-to-source distance. The amount of the period shift is also generally a function of distance; however, in showing the potential for practical applications of the procedure, a constant period shift is used here for simplicity. For the Northridge earthquake data, the following approximate procedure is proposed to derive the acceleration response spectra of the vertical component from those of horizontal motion: (1) Shift the acceleration response spectra of the horizontal motion to shorter periods by a period shift factor of about 2.0 ; and (2) apply the following set of distance-dependent reduction factors to the shifted horizontal acceleration spectra: 0.75, 0.65, 0.57, and 0.52 for distances R=5, 10, 20, and 40 km, respectively. These reduction factors are the ratios of the vertical spectral accelerations at a period of 0.15 sec (corresponding approximately to the peak of vertical spectra) to the horizontal spectral ordinates at a period of 0.3 sec. The shifted and reduced horizontal spectra and the original vertical spectra are plotted in Figure 3. This figure shows that for the Northridge earthquake data, such an approximation is promising for practical engineering applications, especially around the spectral peaks in the near-source region, where the vertical component is pronounced.

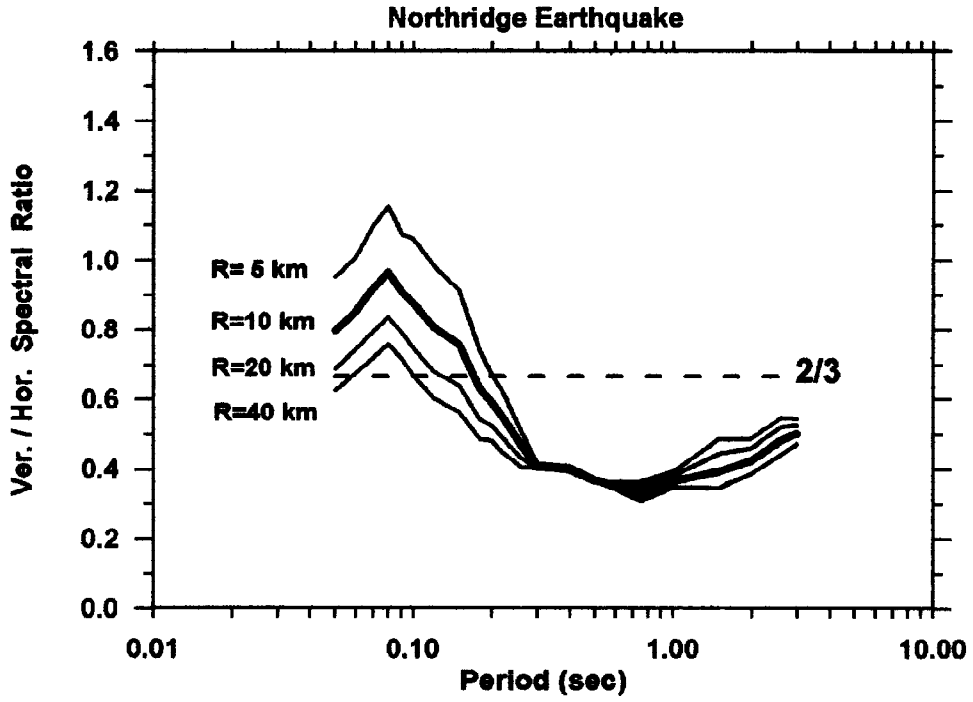

Figure 2. Vertical to horizontal spectral ratio for the Northridge earthquake, at distances 5, 10, 20, and 40 km from surface projection of fault plane.

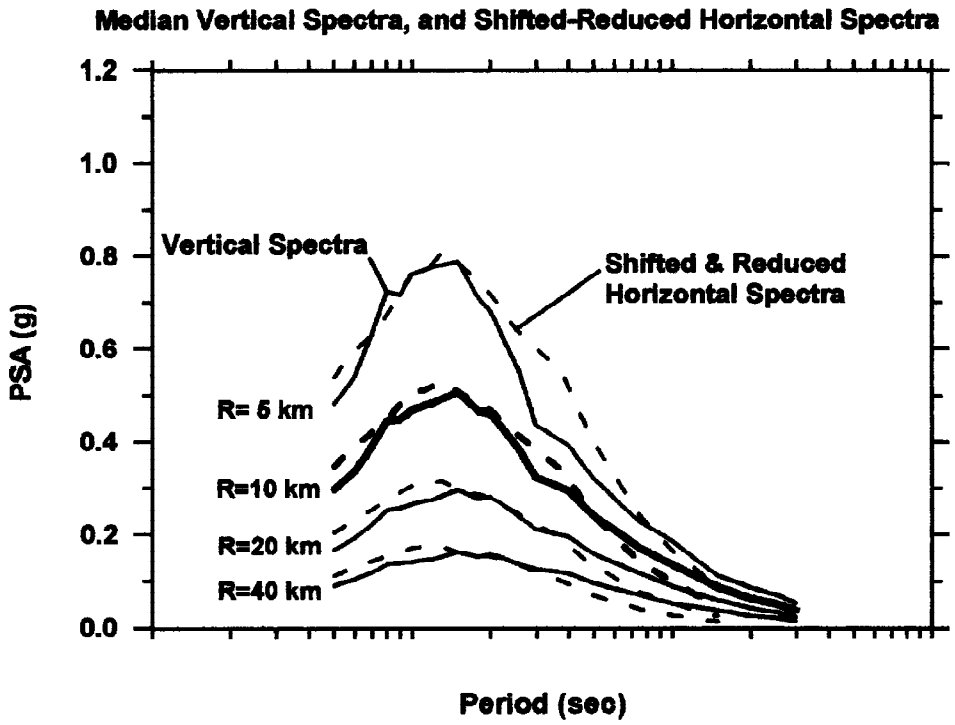

Figure 3. Northridge earthquake distance-dependent vertical response spectra, and shifted and reduced horizontal spectra.

CONCLUSIONS

Relationship between acceleration response spectra of vertical and horizontal components was examined for the 1994 Northridge earthquake. Based on the attenuation models for vertical and horizontal spectral ordinates, distance-dependent relationships between vertical and horizontal spectra were presented. Consistent with the data recorded in several other earthquakes, vertical-to-horizontal spectral ratio for the Northridge earthquake was a function of period and site-to-source distance and exceeded value of 2/3 at short periods in the near-field region. An approximate procedure to generate distance-dependent vertical acceleration response spectra from those of horizontal motion was examined. The procedure, which consists of shifting the horizontal spectra to shorter periods and reducing them by a set of distance-dependent reduction factors, appears promising for practical applications.

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