Directivity Pulse Effect on the Response Spectrum of Near-Fault Ground Motion

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1. Introduction

Near-Fault Ground Motion (NFGM) is an earthquake ground motion with a strong amplitude velocity pulse in the ground motion time history. This velocity pulse is generated by the directivity effect of the earthquake fault mechanism. Although these pulse type ground motions are observed only within 10 to 20 km from the fault, the hazard cannot be ignored. Therefore, the pulse effect on the response spectrum for the seismic design should be considered for important structures such as nuclear power plants. In this research, the simple approach to estimate the response spectrum considering the velocity pulse effect is developed.

2. Decomposition of Near-Fault Ground Motion

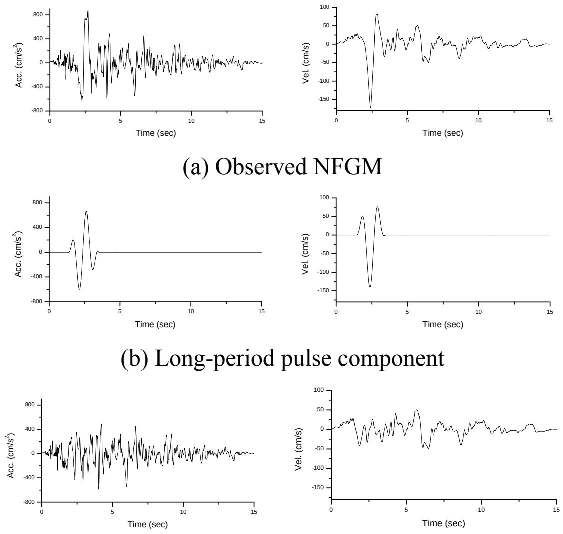
NFGM time history is divided in two components. One is the coherent long-period component induced by directivity effect, and the other is the incoherent high-frequency component generated by an abrupt stopping of cracks blocked by barriers. The long-period component is represented by a velocity pulse mathematical model, and the high-frequency component is determined by subtracting the long-period component from the observed NFGM. In this research, the velocity pulse mathematical model developed by Mavroeidis and Papageorgiou [1] is used, as expressed in Eq. (1). In this model, the pulse envelop is assumed to be an elevated cosine function, with the range as expressed in Eq. (2).

$$v(t) = A\frac{1}{2}\left[1+\cos\left(\frac{2\pi f_p}{\gamma}(t-t_0)\right)\right]\cos\left[2\pi f_p(t-t_0)+\nu\right] \quad (1)$$

$$t_0 - \frac{\gamma}{2\pi f_p} \le t \le t_0 + \frac{\gamma}{2\pi f_p} \quad (2)$$

where the vibration cycle within the pulse range is expressed as oscillatory character γ, the phase angle as ν, and the appearance time of the center of pulse range as t_0.

Fig. 1 (a) shows the time history of NFGM observed at Rinaldi Receiving Station for the 1994 Northridge earthquake. Pulse period T_P is found from the maximum value of the pseudo-velocity response spectrum at 1.0 second. Other parameters are determined as A = 94cm/sec, γ = 2.7, φ = 200˚, and t_0 = 4.77 seconds. Figs. 1 (b) and (c) show the decomposed time histories of each component.



(a) Observed NFGM

(b) Long-period pulse component

(c) High-frequency component

Fig. 1. Time histories of NFGM, with the long-period pulse component and high-frequency component recorded at the Rinaldi Receiving Station, 1994 Northridge earthquake

3. Combination of the Response Spectrum for Near-Fault Ground Motion

The response of single degree of freedom (SDF) systems, especially with a natural period around the velocity pulse period range, is greatly influenced by the pulse component rather than by the high-frequency component. This response causes the response spectrum of NFGM to increase with a high and sharp shape. When normalized with respect to the velocity pulse period and its amplitude, which is represented by peak ground velocity (PGV), the response spectrum of a similar form may be obtained [2, 3]. For quantitative estimation of the pulse effect in the response spectrum, 29 ground motion time histories from 15 earthquakes were used in this research. Basically, NFGM data collected by Mavroeidis & Papageorgiou [1] was used, while excluding the Whittier Narrow earthquake data which was related to the interface P wave and some ChiChi earthquake data in the fault parallel components related to the fling step effect. Fig. 2 is normalized pseudo-velocity response spectra with respect to the pulse period and PGV. These spectra show almost identical forms in the long-period range around and beyond the pulse period. In the short-period range, some differences exist between each ground motion, which is due to the influence of the high-frequency component.

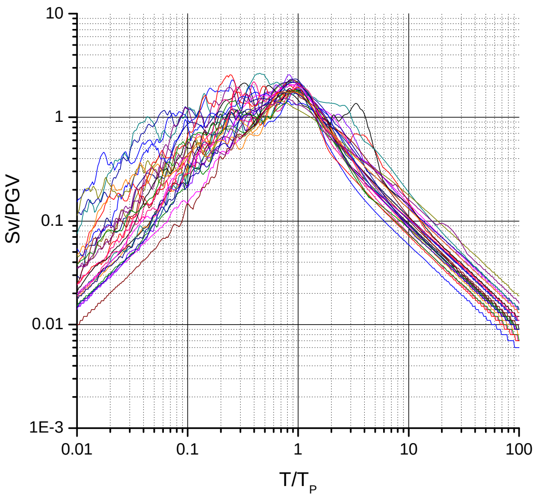


Fig. 2. Pseudo-velocity response spectra of NFGM normalized with respect to the pulse period and PGV

Predominant periods of the high-frequency and long-period pulse components in NFGM are well separated. In this condition, the square root of sum of square (SRSS) method may be one of the simplified approaches for the estimation of the response excited by two different ground motions simultaneously. When compared to the observed NFGM response spectrum, the SRSS combination response spectrum is similar but slightly lower in the range shorter than the pulse period and higher in the range at or longer than the pulse period. The overestimation in the range longer than the pulse period is because the pulse mathematical model has more clear pulse characteristics than the observed ground motion, and the portion of the long-period pulse component is enough to estimate the combination value without the high-frequency component. Therefore, the combination coefficient C is introduced to correct the difference between the spectrum from the observed NFGM and the combined spectrum. This coefficient has a different tendency in each period relative to the pulse periods. Accordingly, C is assumed to be a function of the period normalized with respect to the pulse period. Its value is taken as a mean value calculated using acceleration spectra of each component according to the decomposition procedure from observed NFGM data. Finally, the SRSS combination of NFGM is expressed in Eq. (3).

$$SA_{NFGM}\left(\frac{T}{T_P}\right)=\left\{C\left(\frac{T}{T_P}\right)\right\}\times\sqrt{\left\{SA_{Pulse}\left(\frac{T}{T_P}\right)\right\}^2+\left\{SA_{HF}\left(\frac{T}{T_P}\right)\right\}^2} \quad (3)$$

Fig. 3 shows the example of the combination method for the case of the Northridge earthquake ground motion obtained at the Rinaldi Receiving Station as shown in Fig. 1. The responses of the high-frequency and long-period components are shown by the dashed line and the dotted line, respectively. The estimated response spectrum using this combination method is shown by the solid line. This figure also includes the response spectrum of the observed NFGM. The estimated response spectrum corresponds well to the response spectrum from the observed NFGM.

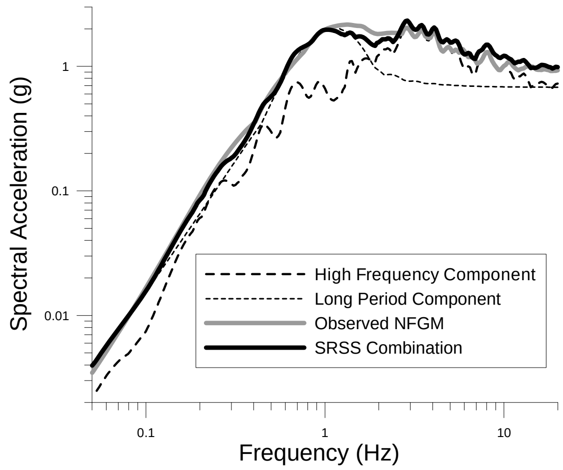


Fig. 3. Elastic pseudo-acceleration response spectra of the long-period component and of the high-frequency component observed at the Rinaldi Receiving Station during the Northridge earthquake, and the SRSS combination of the two components

4. Conclusion

The combination method of the response spectrum for near-fault ground motion is developed. This is based on the SRSS method, and the combination coefficient is calculated as a function of the normalized period. This approach is simply applicable to the estimation of the velocity pulse effect on the response spectrum.

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