MAGNITUDE SCALING OF THE FORWARD RUPTURE DIRECTIVITY PULSE IN NEAR-FAULT GROUND MOTIONS

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INVESTIGATIONS UNDERTAKEN

We assembled a complete set of near fault ground motion records, including records from the recent Turkey and Taiwan earthquakes. We measured the period of the near-fault rupture directivity pulse on the fault normal component of recordings that experienced forward rupture directivity effects. Using these data, we developed preliminary equations relating the period of the near fault pulse to earthquake magnitude. Based on these preliminary time domain models, we developed preliminary magnitude scaling models for the near-fault response spectrum by incorporating a narrow band peak into a conventional model.

RESULTS

Relationships between Pulse Period and Magnitude

Equations relating the period and amplitude of the fault-normal forward rupture directivity velocity pulse to earthquake magnitude and distance were developed by Somerville (1998), Somerville et al. (2000) and Alavi and Krawinkler (2000). The recordings used were mostly within 10 km of the fault, and the period was assumed to be independent of the distance from the fault. We have updated the relationship between velocity pulse period and magnitude using data from the 1999 Chi-Chi, Taiwan and Kocaeli, Turkey earthquakes. Separate relationships were developed for near fault recordings on rock and soil sites. These relationships use the period T_{Dir} of the largest cycle of the fault normal velocity waveform recorded at stations near the fault that experience forward rupture directivity. These empirical relationships are defined only for full forward rupture directivity conditions, and are not defined for the full range of angles and rupture distances that are included in the Somerville et al. (1997) response spectral model for rupture directivity effects.

The data for rock are consistent with a self-similar scaling relationship in which the period of the pulse T_{Dir} increases in proportion to the fault length. This is consistent with the self-similar nature of the source scaling relations found by Somerville et al. (1999). The relationship derived from the data listed in Table 1 and shown at the top of Figure 1 is:

$$\log10\ T_{Dir} = -3.17 + 0.5\ M_w$$

The relationship for soil is allowed to depart from self-similarity, in order to accommodate non-linear effects (Rodriguez-Marek, 2000). The effect of the soil layer is generally to increase both the peak velocity and the period of the input rock motion. The amount of the increase depends on the level of the input ground motion, and the thickness and physical properties of the soil layer. The relationship derived from the data listed in Table 2 and shown at the bottom of Figure 1 is:

$$\mathrm{Log}10\ T_{Dir} = -2.02 + 0.346\ M_w$$

These linear relationships for rock and soil intersect at $M_w = 7.4$. It is expected that the relationship for soil is actually curved, and merges with the rock relationship for magnitudes larger than 7.4, rather than having lower values of T_{Dir} than for rock at magnitudes larger than 7.4.

Narrow Band Rupture Directivity Model

We have derived preliminary response spectral models that include the magnitude dependence of the period of the rupture directivity pulse, derived from the relations between pulse period and magnitude given above. These response spectral models are for the horizontal fault normal component under maximum rupture directivity conditions (X cos theta = 1 in Somerville et al., 1997). To generate the spectrum, a conventional acceleration response spectrum, which is assumed to represent the fault parallel component, is scaled by a cosine-shaped function centered at a period equal to 0.75 times the value of T_{Dir} of the velocity pulse for a given magnitude M_w from the equation given above. The peak amplitude of the scaling function is 2 (with a standard error of 0.4 natural log units), and the width is about a factor of 1.5 on either side of T_{Dir}. The average horizontal component is obtained by using a scaling function with a peak amplitude of the square root of 2.

In Figure 2, we compare the response spectra for rock and soil predicted by this model with the standard model of Abrahamson and Silva (1997), which does not explicitly include directivity effects, and the broadband model of Somerville et al. (1997), whose directivity effects are based on the monotonic increase of ground motion amplitudes with magnitude at all response spectral periods. The new models produce larger response spectra in the period range of about 0.5 to 2 seconds for earthquakes smaller than M_w 7.5, and smaller response spectra at all periods for earthquakes larger than M_w 7.5, compared with the Somerville et al. (1997) model.

References

Abrahamson. N.A. and W.J. Silva, 1997. Empirical response spectral attenuation relations for shallow crustal earthquakes. Seismological Research Letters, 68: 94-127.

Alavi, B. and H. Krawinkler, 2000. Design considerations for near-fault ground motions. Proceedings of the U.S. – Japan Workshop on the Effects of Near-Fault Earthquake Shaking, San Francisco, March 20-21.

Rodriguez-Marek, A., 2000. Near fault seismic site response. Ph.D. Thesis, Civil Engineering, University of California, Berkeley, 451 pp.

Somerville, P.G., H. Krawinkler and B. Alavi, 2000. Development of improved ground motion representation and design procedures for near-fault ground motions. Final Report to CSMIP Data Utilization Program, Contract No. 1097-601.

Somerville, P.G., N.F. Smith, R.W. Graves, and N.A. Abrahamson (1997). Modification of empirical strong ground motion attenuation relations to include the amplitude and duration effects of rupture directivity. Seismological Research Letters, 68: 199-222.

NON-TECHNICAL SUMMARY

Current ground motion models all assume increasing spectral amplitude at all periods with increasing magnitude. However, near fault recordings from recent earthquakes confirm that the near-fault fault-normal forward rupture directivity velocity pulse is a narrow band pulse whose period increases with magnitude. This magnitude dependence of the period of the near fault pulse is expected from theory, because the period of the pulse is related to source parameters such as the rise time (duration of slip at a point on the fault) and the fault dimensions, which generally increase with magnitude. This magnitude dependence of the pulse period causes the response spectrum to have a peak whose period increases with magnitude, such that the near-fault ground motions from smaller earthquakes may exceed those of larger earthquakes at intermediate periods (around 1 second). The objectives of this paper are to develop equations relating the period of the fault-normal component of the forward rupture directivity velocity pulse to the earthquake magnitude, and develop a model for the acceleration response spectra of near-fault fault-normal ground motions that includes the magnitude dependence of period of the response spectral peak.

REPORTS PUBLISHED

Paul G. Somerville (2001). Magnitude scaling of the near fault rupture directivity pulse Proceedings of the International Workshop on the Quantitative Prediction of Strong-Motion and the Physics of Earthquake Sources, October 23-25, 2000, Tsukuba, Japan.

Table 1. Period of the Forward Rupture Directivity Pulse Recorded on Rock

Earthquake	Magnitude (Mw)	Recording Station	Closest Distance (km)	Peak Velocity (cm/sec)	Period of Vel. Pulse (sec)
Kocaeli	7.4	Gebze	18.2	37.68	4.7
Landers	7.3	Lucerne	1.1	136.04	5.0
Loma Prieta	7.0	Los Gatos Pres. Center	3.5	103.91	2.8
		Lexington Dam	6.3	118.23	2.4
Kobe	6.9	JMA	0.6	104.29	1.55
		Kobe Univ.	1.0	49.08	1.6
Northridge	6.7	Jensen Generator	6.4	31.76	1.2
		Rinaldi	7.1	175.0	1.28
		LA Dam	6.8	79.73	1.24
		Pacoima Dam Abut.	7.8	107.90	0.9
San Fernando	6.6	Pacoima Dam Abut.	3.5	114.53	1.44
Morgan Hill	6.2	Anderson Dam	3.5	26.71	0.79
		Coyote Lake Dam	0.5	66.13	0.92
		Gilroy #6	11.8	36.40	1.1
Parkfield	6.1	Temblor	4.4	13.0	0.6

Table 2. Period of the Forward Rupture Directivity Pulse Recorded on Soil

Earthquake	Magnitude (Mw)	Recording Station	Closest Distance (km)	Peak Velocity (cm/sec)	Period of Vel. Pulse (sec)
Chi-chi	7.6	Tsaotun	5.9	116.0	4.3
Kocaeli	7.4	Yarimca	5.0	96.0	4.7
Loma Prieta	7.0	Gilroy #3	14.4	49.3	1.5
Kobe	6.9	Takatori	2.0	175.0	1.65
		Port Is downhole base	2.5	84.3	2.25
Northridge	6.7	Olive View Hospital	6.4	122.2	2.24
		Sylmar Converter	6.2	131.1	2.6
		Sylmar Converter E	6.1	116.3	2.6
		Newhall Fire Station	7.1	118.2	2.2
		Newhall Pico Cyn	7.2	108.9	2.1
		Jensen Filtration Plant	6.2	101.1	1.4
Erzincan	6.7	Erzincan	2.0	120.2	2.5