Appendix B
Illustration of Newmark-Hall Approach to Developing Design Response Spectra

B-1. Introduction

Newmark and Hall (1982) describe their approach for developing design response spectra using peak ground motion parameters (peak ground acceleration (PGA), peak ground velocity (PGV), and peak ground displacement (PGD)) multiplied by the appropriate spectral amplification factors. For ease of reference, summarized herein are the amplification factors developed by Newmark and Hall (1978, 1982) and the use of these factors to develop elastic response spectra. As illustrated by Newmark and Hall (1982), in general, it can be shown that the response of a simple damped oscillator to a dynamic motion of its base can be represented graphically in a simple fashion by a logarithmic plot as shown in Figure B-1.

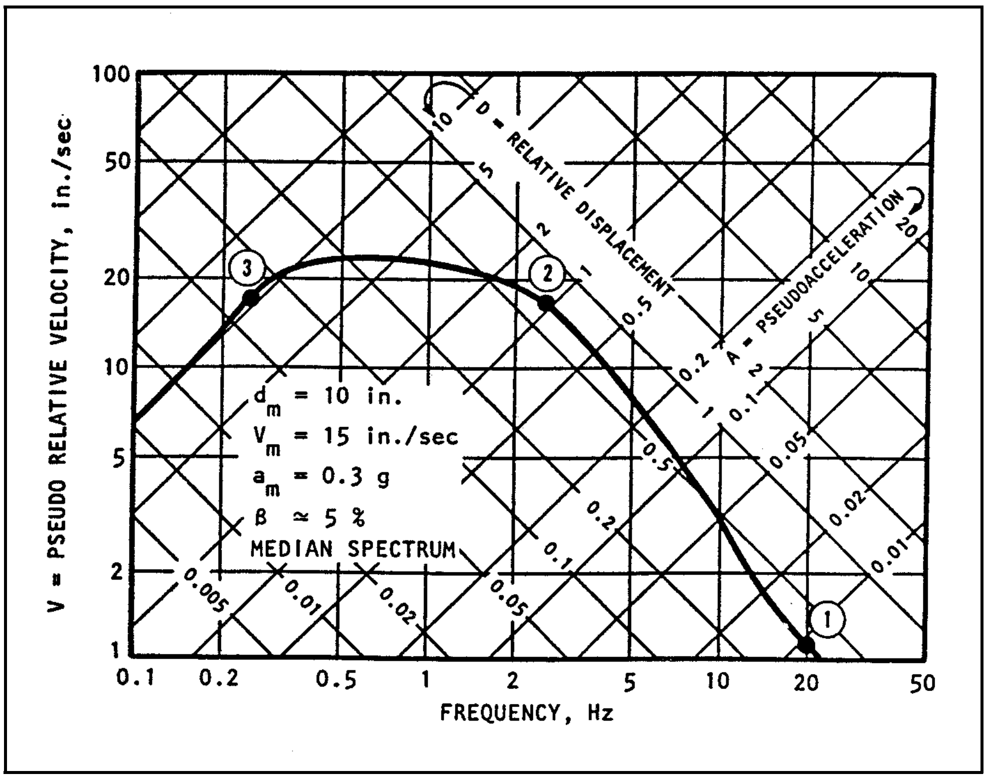

Figure B-1. Typical response spectrum for earthquake motions (Newmark and Hall 1982)

In this figure, the plot uses four logarithmic scales to show the following three response quantities:

D = maximum relative displacement between the mass of the oscillator and its base

V = maximum pseudo-relative velocity = ωD

A = maximum pseudo-acceleration of the mass of the oscillator = $\omega^2 D$

B-2. Response Curve

In these relations, ω is the circular natural frequency of the oscillator, or $\omega = 2\pi f$ where f is frequency in cycles per second (cps) or Hertz (Hz). The peak ground motions for the earthquake motion for which the oscillator response in Figure B-1 is drawn in approximate form are PGD = 10 in., PGV = 15 in. per sec, and PGA = 0.3 g, where g is the acceleration of gravity. The response curve shown is a smooth curve rather than the actual jagged curve that one normally obtains from a calculation for an earthquake accelerogram, and is given for a damping ratio β of about 5 percent of critical. The symbols 1, 2, and 3 on the curve denote the response of different oscillators, No. 1 having a frequency of 20 Hz, No. 2 of 2.5 Hz, and No. 3 of 0.25 Hz. The advantage of using the tripartite logarithmic plot, with frequency also plotted logarithmically, is that one curve can be drawn to represent the three quantities D, V, and A. The tripartite logarithmic representation is possible only for quantities such as D, V, and A that are simply related by powers of ω. As noted by Hudson (1979), for earthquake-like excitations, it can be shown that the pseudo-relative velocity can be assumed equivalent to the maximum relative velocity and the pseudo-acceleration equivalent to the maximum acceleration over most of the usual frequency and damping range, with the acceleration equivalence being more accurate than the velocity equivalence.

B-3. Elastic Design Spectrum

A simplified spectrum is shown in Figure B-2, plotted on a logarithmic tripartite graph; note that the various regions of the spectrum are smoothed to straight line portions. On the same graph are shown dotted lines that are drawn at the level of the maximum (peak) ground motion values, and the figure therefore indicates the amplifications of maximum (peak) ground motions for the various parts of the spectrum. It should be noted that the Newmark-Hall approach illustrated in Figure B-2 requires that the values of peak

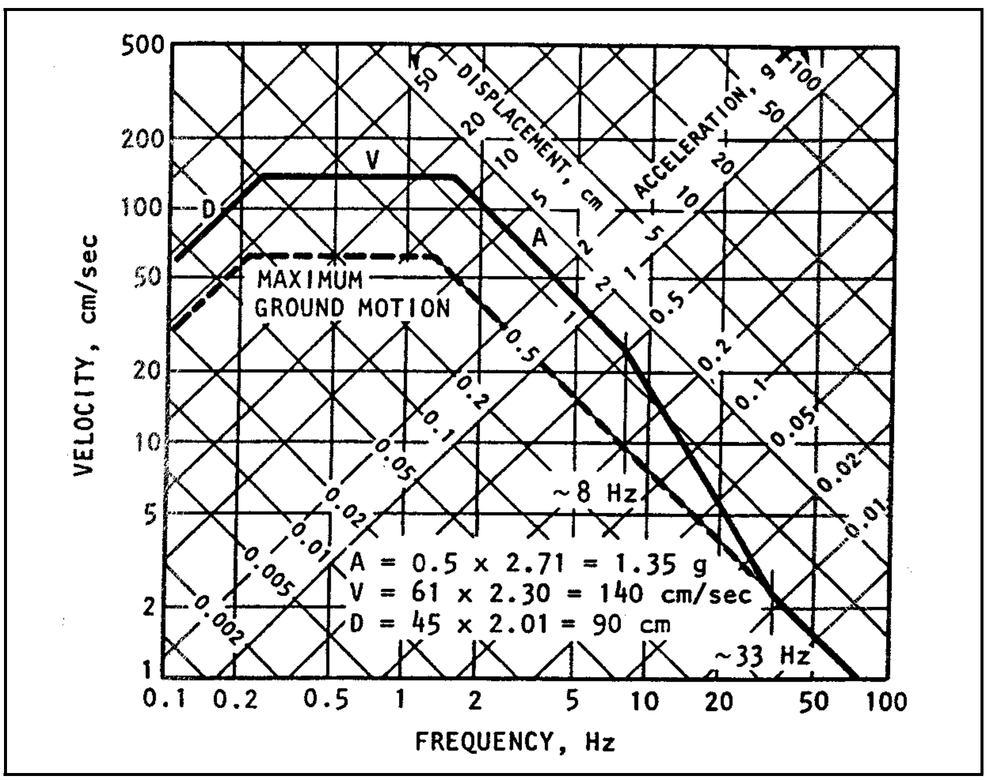

Figure B-2. Elastic design spectrum horizontal motion (0.5 g maximum acceleration, 5 percent damping, one sigma cumulative probability) (Newmark and Hall 1982)

ground motion parameters (PGA, PGV, and PGD) be estimated before the response spectrum can be constructed. Using appropriate ground motion data and relationships, these values can be estimated at the site given the earthquake magnitude, source-to-site distance, and local soil conditions. However, lacking other information, Newmark and Hall (1982) recommend that for competent soil conditions a V/A ratio of 122 cm/sec/g be used, and for rock a V/A ratio of about 91 cm/sec/g be used. Also, to ensure that the spectrum represents an adequate band (frequency) width to accommodate a possible range of earthquakes, Newmark and Hall (1982) recommend that AD/V^2 be taken equal to about 6.0 (in the above *A*, *V*, and *D* are PGA, PGV, and PGD, respectively). Using these *V/A* and AD/V^2 values, the corresponding *D/A* values of 90 cm/g and 51 cm/g are computed for competent soil conditions and rock, respectively. The smooth elastic design spectrum shown in Figure B-2 is an 84th-percentile spectrum developed for a site located on competent soil conditions with an estimated PGA value of 0.5 g. In this example, a *V/A* value of 122 cm/sec/g and a *D/A* value of 90 cm/g are used. Using these values the PGV and PGD values corresponding to PGA = 0.5 g are 61 cm/sec and 45 cm. Newmark and Hall (1978) provided values of amplification factors for the different parts of the spectrum; these spectrum amplification factors are shown in Table B-1 for various damping ratios and for two levels of probability (50th and 84th percentiles) considering the distribution to be lognormal. Using the 84th-percentile spectrum amplification factors of 2.71, 2.30, and 2.01 associated with the acceleration, velocity, and displacement regions of the spectrum for 5 percent damping (Table B-1), the following response spectrum bounds are computed:

$$A = 0.5 \times 2.71 = 1.35 \text{ g}$$

$$V = 61 \times 2.30 = 140 \text{ cm/sec}$$

$$D = 45 \times 2.01 = 90 \text{ cm}$$

The resulting elastic response spectrum is shown in Figure B-2. As noted in this figure, Newmark and Hall (1982) connect the amplified acceleration *A* at 8 Hz to the PGA at 33 Hz to complete the high-frequency portion of the spectrum. However, Newmark and Hall (1982) do not specify at what frequency the amplified displacement *D* should be connected to the PGD line.

Table B-1
Spectrum Amplification Factors for Horizontal Elastic Response (Newmark and Hall 1982)

Damping % Critical	One Sigma (84.1%)			Median (50%)		
	A	V	D	A	V	D
0.5	5.10	3.84	3.04	3.68	2.59	2.01
1	4.38	3.38	2.73	3.21	2.31	1.82
2	3.66	2.92	2.42	2.74	2.03	1.63
3	3.24	2.64	2.24	2.46	1.86	1.52
5	2.71	2.30	2.01	2.12	1.65	1.39
7	2.36	2.08	1.85	1.89	1.51	1.29
10	1.99	1.84	1.69	1.64	1.37	1.20
20	1.26	1.37	1.38	1.17	1.08	1.01