MODIFICATION OF THE TORO ET AL. (1997) ATTENUATION EQUATIONS FOR LARGE MAGNITUDES AND SHORT DISTANCES

by

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1. ATTENUATION EQUATIONS FOR ROCK

Ground motions for rock are calculated using the attenuation equations recently developed by EPRI (EPRI, 1993), as slightly revised and extended by Toro et al. (1997). These attenuation equations are of the form

$$\ln Y = C_1 + C_2(\boldsymbol{M}-6) + C_3(\boldsymbol{M}-6)^2 - C_4 \ln R_M - (C_5 - C_4)\max\left[\ln\left(\frac{R_M}{100}\right),\ 0\right] - C_6 R_M + \varepsilon_e + \varepsilon_a \tag{4-1}$$

$$R_M = \sqrt{R^2 + C_7^2} \tag{4-2}$$

with coefficients given by Table 2 of Toro et al. (1997). In the above equation, **M** is moment magnitude, R is horizontal distance, ε_e is epistemic uncertainty, and ε_a is aleatory uncertainty.

The EPRI attenuation equations include the effect of crustal structure and contain a thorough treatment of epistemic and aleatory uncertainty in source characteristics, path effects, and near-site anelastic attenuation (kappa). Aleatory uncertainty is treated as magnitude- and distance-dependent (see Toro et al., 1997 for details). Epistemic uncertainty (i.e., ε_e in Equation 4-1) is treated as magnitude-dependent and is modeled in the seismic-hazard calculations by using four separate attenuation equations and their associated weights. These four attenuation equations differ from the corresponding median attenuation equation in the values of coefficients C_1 and C_2 (see Table 2 of Toro et al., 1997). Figures 4-1 and 4-2 show these four alternative attenuation equations, as well as the median attenuation equation, for peak ground acceleration (PGA) and 1-Hz spectral acceleration (PSA) at 1 Hz.

Figures 4-1 and 4-2 also show the ground-motion amplitudes predicted by Herrmann (personal communication, 1997) for **M** 5. He uses the Atkinson-Boore (1997) source spectrum and models of geometric and anelastic attenuation based on the analysis of nearly 2200 vertical ground-motion records from small earthquakes in the New Madrid region (Samiezade-Yadz, et al., 1996). Herrmann's predictions for PGA are consistent with the EPRI attenuation equations. His predictions for 1 Hz are significantly lower, as a result of the Atkinson-Boore two-corner source spectrum, which predicts much lower amplitudes near 1 Hz. Figure 4-3 compares the EPRI (1993) and Atkinson-Boore (1997) predictions for 1 Hz spectral acceleration and multiple magnitudes, and shows that the difference between the two sets of predictions becomes larger at higher magnitudes. The issue of one-corner (or Brune) vs. two-corner spectra has not been settled. This study uses the Brune model for the sake of conservatism and consistency with recent practice.

The EPRI attenuation equations consider the effects of rupture size for small and moderate earthquakes, but not for large earthquakes with extended ruptures. For calculations involving the faults in the NMSZ faults and the East Prairie extension, especially for close distances, it is necessary to utilize attenuation equations that consider the potentially large dimension of the earthquake rupture. These attenuation equations must use closest distance to the rupture (or some similar measure) to characterize distance. They must also include the effects of elongated ruptures (i.e., only a portion of the energy release occurs near the site) and the effect of possible variations in source scaling (i.e., large earthquakes are postulated to have lower stress drop). These effects are usually denoted as magnitude-saturation or extended-source effects and are used in nearly all attenuation equations for California.

Two approaches are followed here to introduce extended-source effects. The first approach (which we denote as the Empirical Approach) uses a result by Atkinson and Silva (1997), who utilized the extensive strong-motion database from California. In order to fit the short-distance California data with a point-source model (like that used to derive the EPRI attenuation equations), Atkinson and Silva found that it was necessary to reduce the stress drop by a factor of two between magnitudes 5.5 and 7.5. This reduction does not imply a factor of two reduction in the actual stress drop; it simply implies that the combined effect of geometric effects and source scaling is equivalent to a factor of two reduction in stress drop. This effect may be represented by substituting Equation 4-2 above with the Equation

$$R_M = \sqrt{R^2 + C_7^2 [\exp(-1.25 + 0.227\boldsymbol{M})]^2} \qquad (4\text{-}3)$$

where R is the closest horizontal distance to the rupture.

The second approach (which we denote the Modeling Approach) uses extended-source ground-motion modeling to determine the shape of the amplitude vs. rupture-distance curve for large magnitudes. Thus, this approach considers only the geometric effects of extended ruptures. Details on this modeling approach are contained in Risk Engineering (1993). The resulting effect may be represented by substituting Equation 4-2 with the equation

$$R_M = R_f + 0.006 \exp(m_{bLg}) \qquad (4\text{-}4)$$

for attenuation equations in terms of m_{bLg} or

$$R_M = R_f + 0.089 \exp(0.6\boldsymbol{M}) \qquad (4\text{-}5)$$

for attenuation equations in terms of moment magnitude. In the above two equations, R_f is the shortest (slant) distance to the fault rupture.

The median ground-motion amplitudes predicted by the attenuation equations modified according to the Empirical and Modeling approached are shown in Figures 4-4 and 4-5, where they are compared to the amplitudes predicted by the model with no saturation. This study uses the following weights for the saturation approaches for the fault sources: Empirical, 0.4; Modeling, 0.4; and no saturation, 0.2. Calculations for the area sources use no saturation.

2. REFERENCES

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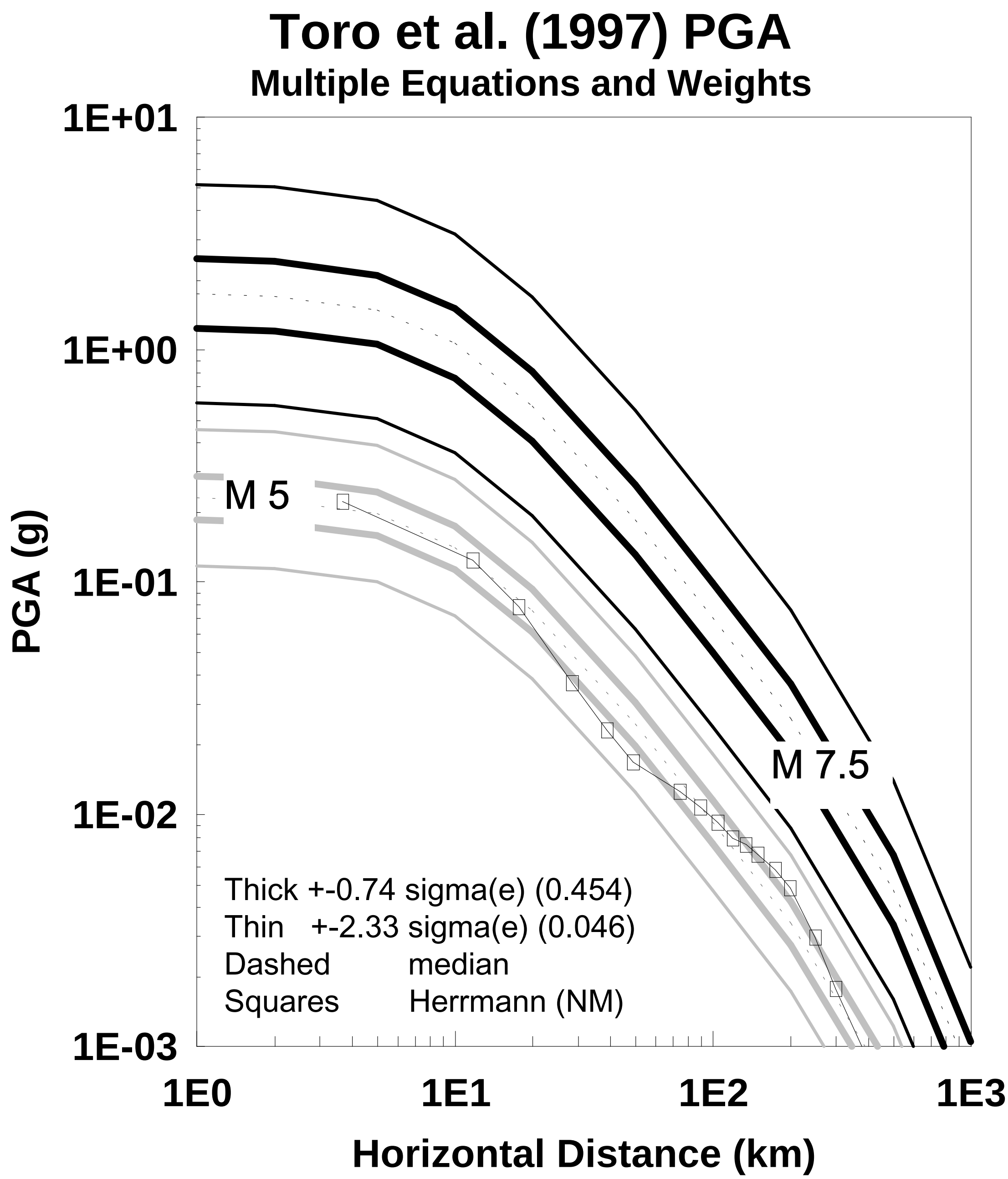

Figure 4-1. EPRI attenuation equations for PGA on rock (point-source assumption).

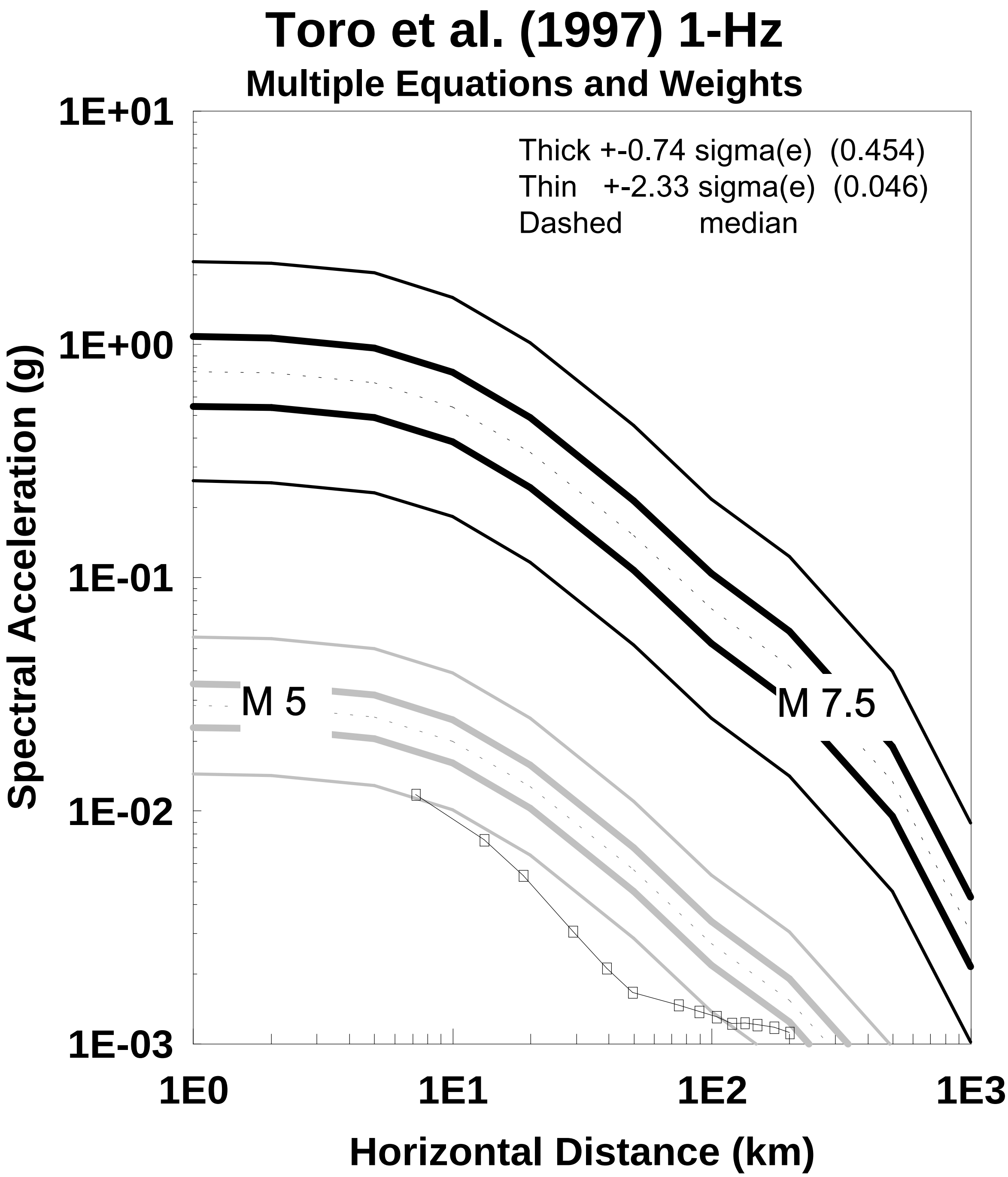

Figure 4-2. EPRI attenuation equations for 1-Hz spectral acceleration on rock (point-source assumption).

Figure 4-3. Comparison of EPRI (1993) and Boore-Atkinson (1997) attenuation equations for 1-Hz spectral acceleration. Source: Atkinson and Boore (1997).

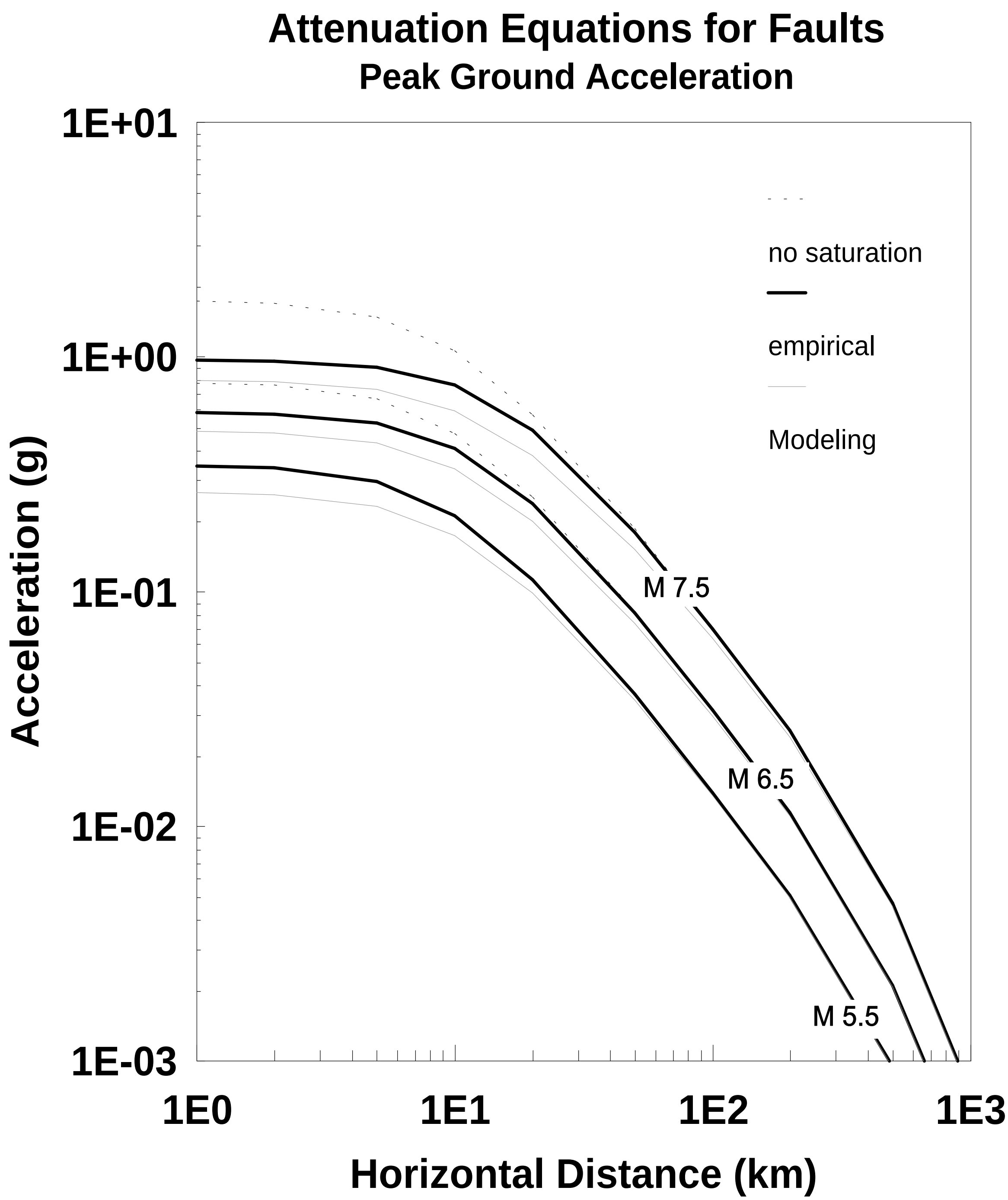

Figure 4-4. Median extended-source attenuation equations for PGA. Note: the no-saturation and empirical predictions for M 5.5 are identical.

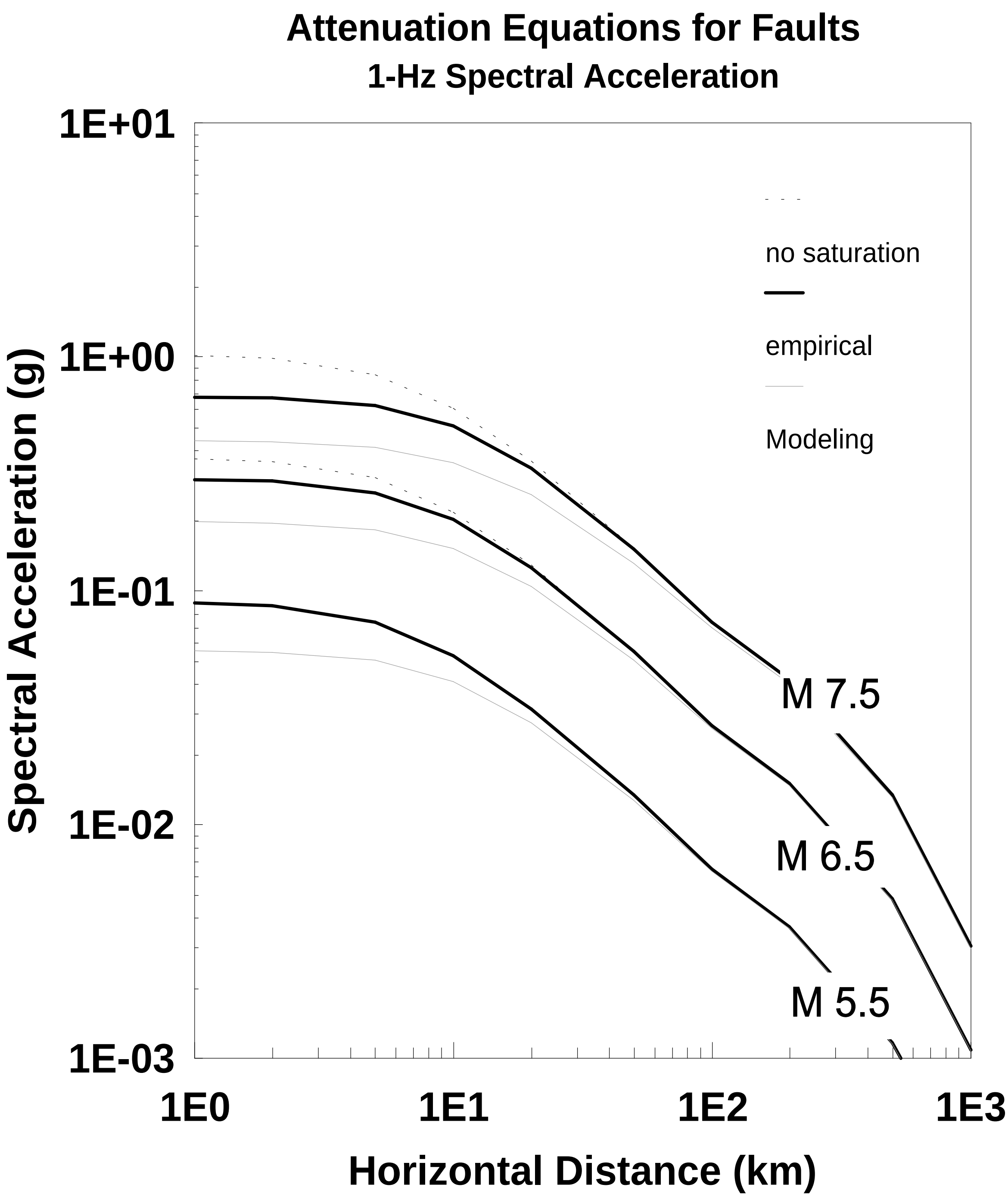

Figure 4-5. Median extended-source attenuation equations for 1-Hz spectral acceleration.. Note: the no-saturation and empirical predictions for M 5.5 are identical.