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Amplification Factors for Spectral Acceleration in Active Regions

J. Stewart[1], Y. Choi[2], A. Liu[3]

Overview

A critical component of seismic hazard analyses is empirical ground motion attenuation relationships that predict the probabilistic distribution of a ground motion intensity measure (*IM*) conditional on source/path parameters such as magnitude, site-source distance, focal mechanism, and a site parameter. Site condition is often characterized in attenuation relations as either rock or soil. Actual conditions at strong motion recording sites are variable with respect to local site conditions and underlying basin structure, and hence estimates from attenuation relationships necessarily represent averaged values across the range of possible site conditions within the "rock" or "soil" categories. In this research, we evaluate ground motion amplification factors that incorporate more detailed information on site conditions that can be used to remove bias and modify the uncertainty of ground motion estimates from attenuation relations.

Applicability

We have developed amplification factors for the *IM*s of 5% damped spectral acceleration over the period range of $T = 0.01 - 5$ s. Amplification is evaluated by normalizing ground motion intensity measures from recordings by reference motions derived from modified attenuation relationships for active regions. The Abrahamson and Silva (1997) attenuation relationship for rock sites was used for the derivation of reference motions, with modifications to account for event terms and rupture directivity effects.

Strong motion sites are classified according to three geologic classification schemes: age-only, age + depositional environment, and age + material texture. Sites are also classified using the average shear wave velocity over the upper 30 m ($V_{s\text{-}30}$) (Martin, 1994) and a recently proposed geotechnical classification scheme (Rodriguez-Marek et al., 2001). Within each scheme, amplification of spectral acceleration is regressed against reference motion amplitude, and the magnitude-dependence of the residuals is evaluated.

[1] Assistant Professor of Civil Engineering, UCLA
[2] Graduate Student, UCLA
[3] Engineer, Bechtel Corporation, San Francisco, CA

Example Results

For soil categories in the geologic age + depositional environment classification scheme [i.e., Holocene lacustrine/marine (Hlm) and Quaternary alluvium (Qa)], we plot in Figure 1 averaged spectral amplification levels across the period ranges of $T = 0.1–0.5$ s (denoted F_a) and $T = 0.5–2.0$ s (denoted F_v). Also plotted are results of linear regression analyses (solid lines), ± 95% confidence intervals on the median amplification (dotted lines), median regression ± standard error, σ (dashed lines), and median regression results for Holocene (age-only) sediments.

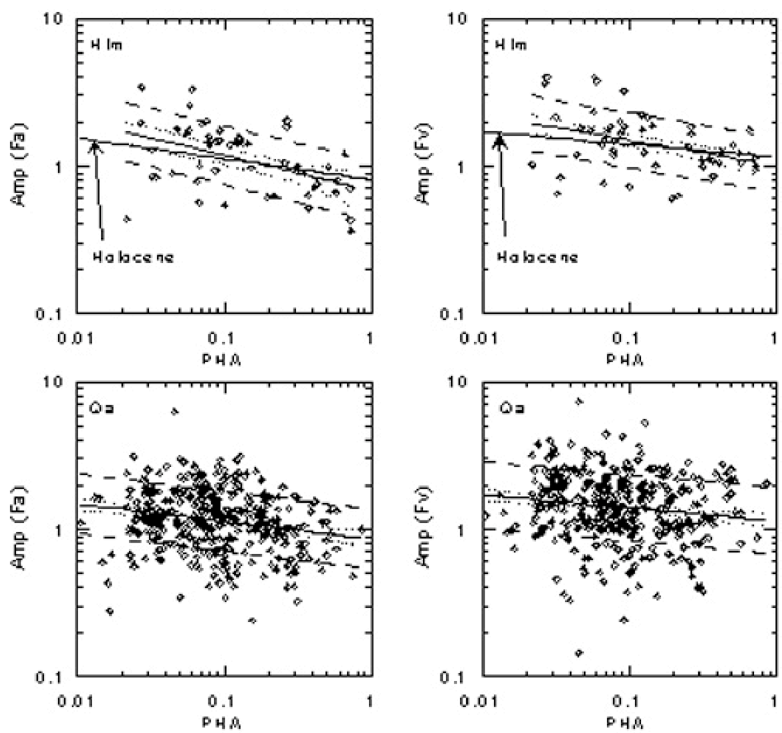

Figure 1 – Spectral Acceleration Amplification Factors For Categories In The Age + Depositional Environment Classification Scheme

Reductions of amplification factors with increasing rock PHA are inferred as evidence of sediment nonlinearity. This nonlinearity is quantified by the slope of the regression lines in Figure 1. The statistical significance of the PHA-dependence of amplification factors is assessed by comparing the absolute value of the slope to its estimation error and through statistical hypothesis testing. The data in Figure 1 have statistically significant PHA-dependence of amplification functions at small to intermediate periods (parameter F_a), with less nonlinearity at longer periods (parameter F_v).

A key issue when interpreting regression results for different site categories is the degree to which the data for different categories are distinct. We performed statistical F-tests to compare submodels with a full model. For example, a pair of submodels could be the regression results in Figure 1 for Hlm and Qa. The full model in this example would consist of a regression through all data in both categories. The F-test evaluates the average improvement in fit for the two submodels as compared to the full model. When a parameter referred to as the F statistic is large, the submodels significantly improve the fit and the data in the submodel categories is said to be "distinct." The Hlm and Qa categories are significantly distinct at small periods, but indistinct at longer periods. The lack of distinction at longer periods is typical of site categorization schemes based only on the characteristics of near-surface sediments.

Effectiveness of Classification Schemes

One of the objectives of this research was to quantify the relative ability of different classification schemes to capture site-to-site variations of spectral acceleration. Five classification schemes were considered, three of which are based on surface geology, one on near-surface shear wave velocity (V_{s-30}), and one on geotechnical data. One measure of the quality of a classification scheme is the inter-category, or scheme, standard error of residuals (σ_R), which can be calculated at each spectral period. Inter-category standard error σ_R represents the average dispersion of data within all categories belonging to a given scheme.

Inter-category standard error terms for soil categories are plotted as a function of period in Figure 2. The largest error terms at all periods except $T = 3.0$ s are obtained from the V_{s-30} -based and geotechnical classification schemes. The smallest error terms are from detailed geology schemes such as age + depositional environment or age + material texture. Maximum differences in the category dispersion values are as large as 0.1 in natural logarithmic units. These variations in dispersion are large enough to have an important effect on seismic hazard calculations. Also shown in Figures 2 for reference are the error terms from the Abrahamson and Silva (1997) attenuation relationship. Our results suggest that classification schemes based on detailed surface geology appear to provide an effective means by which to delineate site conditions for the evaluation of site amplification factors at low- to moderate periods.

For further information

See Stewart et al. (2001) reference below, or contact Jonathan Stewart by email at jstewart@seas.ucla.edu.

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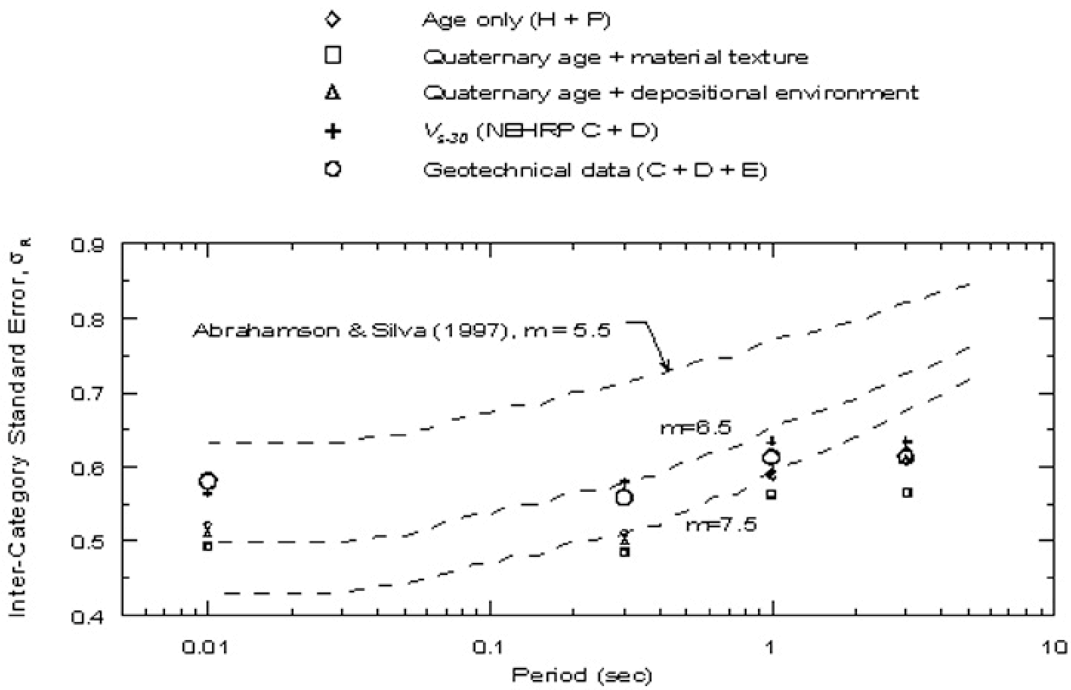

Figure 2 – Inter-category standard error terms for spectral acceleration (this study) and error terms derived by Abrahamson and Silva (1997). Results apply for categories within the respective schemes associated with sediments (soil).

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Keywords

Ground motions, seismic hazards, site response