EMPIRICAL EVIDENCE FROM THE NORTHRIDGE EARTHQUAKE FOR SITE-SPECIFIC AMPLIFICATION FACTORS USED IN US BUILDING CODES

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SUMMARY

Site-specific amplification factors, F_a and F_v used in current US building codes are dependent on amplitude of the input motion. The Northridge earthquake of January 17, 1994 provided a large set of in-situ recordings of input "base" motions up to about 0.5g. Extensive sets of borehole geotechnical data, collected at many of these sites since the earthquake, provide an improved basis to reexamine the dependency of site specific amplification factors on input base shaking level. This paper summarizes recent results for this dependency as implied by empirical amplification factors inferred with respect to nearby "rock" stations underlain by granite. Preliminary results suggest that the site factors are in good agreement with those suggested for the code provisions at the 0.1 g base acceleration level. At successively higher input ground-motion levels the preliminary empirical estimates do not show a well-defined tendency to decrease with increasing amplitude. The detailed geotechnical data recently available for the Northridge recording sites and further study is expected to better define the dependency of site-specific amplification factors on amplitude, distance and azimuth with respect to the earthquake source.

INTRODUCTION

The Northridge earthquake of November 17,1994 provided a set of ground-motion records with peak ground accelerations that exceeded 0.4g at 31 sites within 40 km of the epicenter. This relatively large set of high amplitude records provides an important opportunity to evaluate the amplitude dependency of site amplification factors F_a and F_v used in current US building codes.

Previous studies of the Northridge data by the author were based on geotechnical information at the sites inferred from GIS digital maps of the Los Angeles basin (Borcherdt, 1996). Since this study, additional borehole geotechnical data have been collected (see e.g. ROSRINE, http://rccg03.usc.edu/Rosrine/, Gibbs et al., 1999) and a thorough review of the site conditions has been completed by one of the authors (T. Fumal). These new geotechnical data are being used to reexamine the amplitude dependency of empirical amplification factors as inferred with respect to local rock stations. Results are reported here only for those sites located near rock sites underlain by granite. Results for other sites for which normalization to soft sedimentary rock sites are considered less certain are still being evaluated.

COMPARATIVE GROUND MOTION MEASUREMENTS VERSUS INPUT GROUND-MOTION AMPLITUDE

A complete listing of inferred empirical amplification ratios for each of the strong-motion sites is provided by Borcherdt (1996). Amplification ratios for peak acceleration, velocity, and displacement and average spectral amplification ratios computed for the short (0.1 -0.5 s), intermediate (0.5 - 1.5 s), mid (0.4 - 2.0 s), long (1.5 - 5.0

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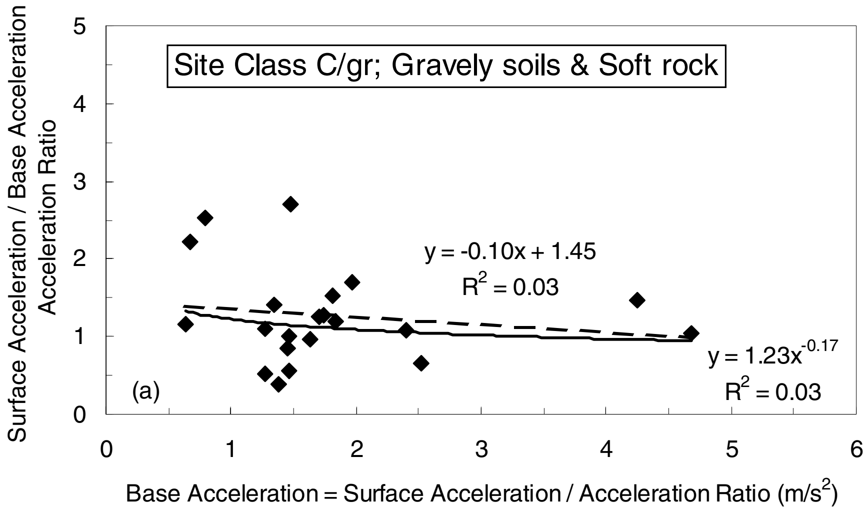
s) and entire period-band (0.1 - 5.0 s) are tabulated. These ratios and subsequent geotechnical information are used herein to further consider the nature of the amplitude dependency of site amplification factors.

In brief summary, the ratios were derived from a uniformly processed data set (Borcherdt, 1996). The peak motions and amplitude spectra for each component were normalized by the corresponding quantity determined for a nearby station on metamorphic rock (weathered granite, gneiss) or to a station on sedimentary rock. Only those normalized to metamorphic rock are reported here. Each ratio was also normalized by the corresponding reciprocal ratio of distances to the zone of largest energy release at a depth of about 18 km. Groups of stations for normalization were determined from 22.5 degree azimuthal windows measured with respect to a polar coordinate system oriented parallel to the strike of the fault (122^{o}) and segmented into 25 km distance intervals to minimize the influences of distance, radiation pattern, and directivity. Corresponding "base" levels, defined as the recorded motion normalized by the corresponding amplification ratio, are tabulated for each site.

To examine the dependence of the measured amplifications on input ground motion level, plots of acceleration ratios and average spectral amplification are provided as a function of the "input" or base acceleration and the acceleration recorded at the site for NEHRP site classes C and D (Figures 1, 2 and 3).



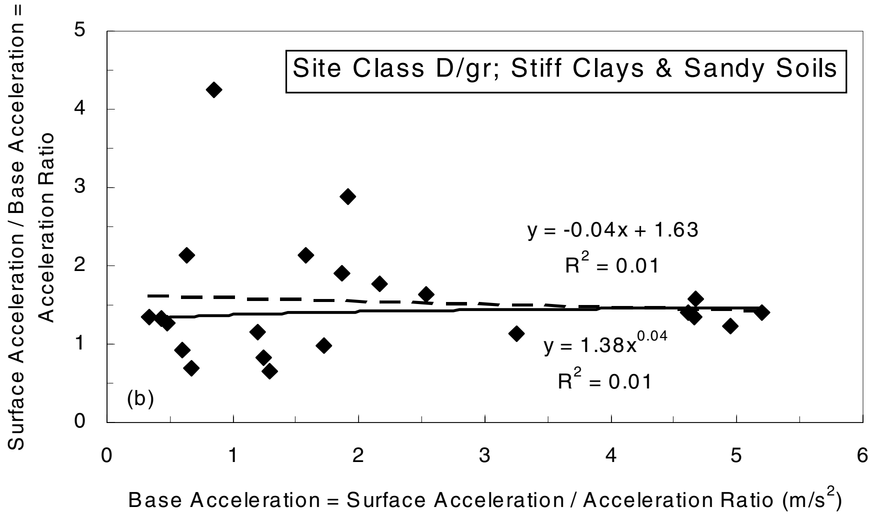


Figure 1. Acceleration ratio versus "base acceleration" for sites underlain by NEHRP site-class C (a) and D (b) type materials as determined from shear-wave velocity to 30m. Corresponding power law and linear regression curves are superimposed.

Plots are shown for "acceleration ratio" (Figures 1a and 1b), average spectral ratio F_a for the short-period band (0.1 -0.5 s) (Figures 2a and 2b), and the average spectral ratio F_v for the mid-period band (0.4 - 2.0 s) (Figure 3a and 3b). Power law and linear regression curves for each of the data sets are shown.

Ratios of average peak horizontal acceleration for both site classes show a slight tendency to decrease with increasing "base" acceleration level (Figures 1a and 1b). This decrease is evident in the slightly negative slope of the linear regression curve and in the negative exponent of one of the power law regression curves.

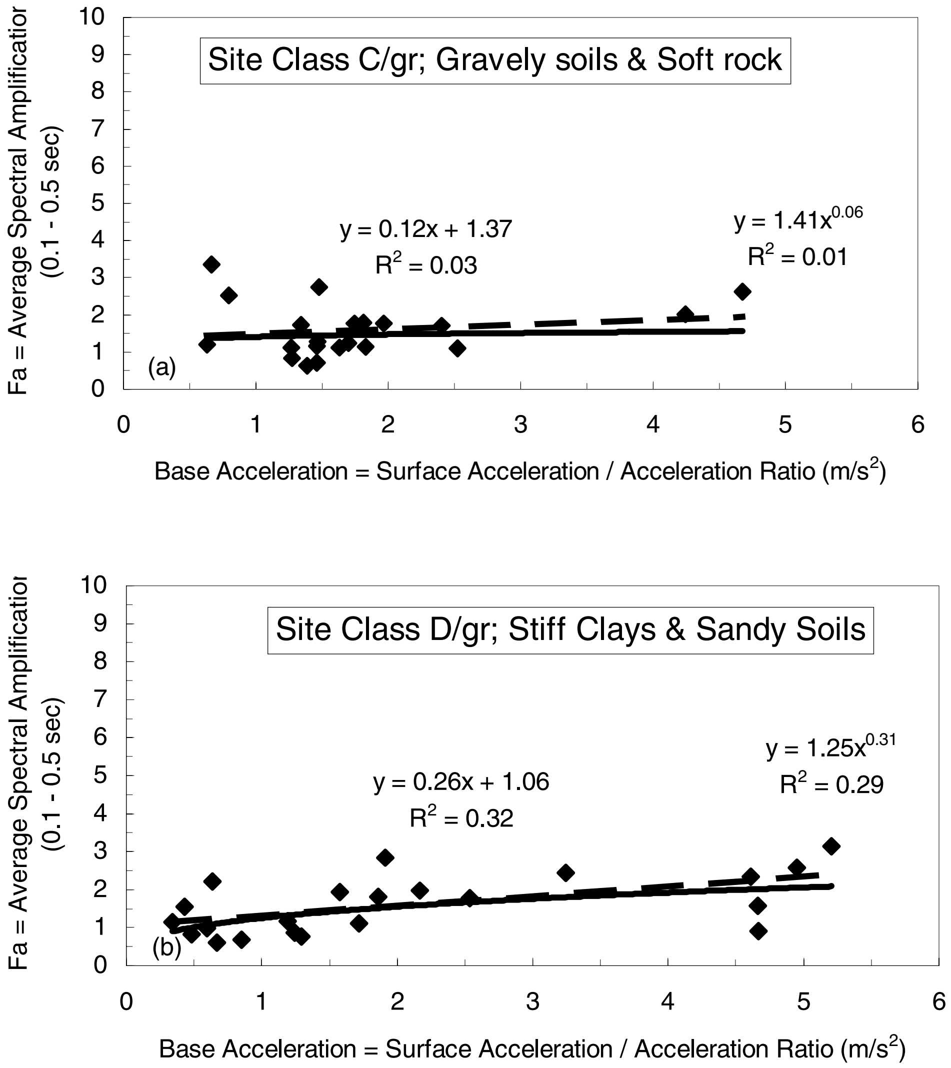
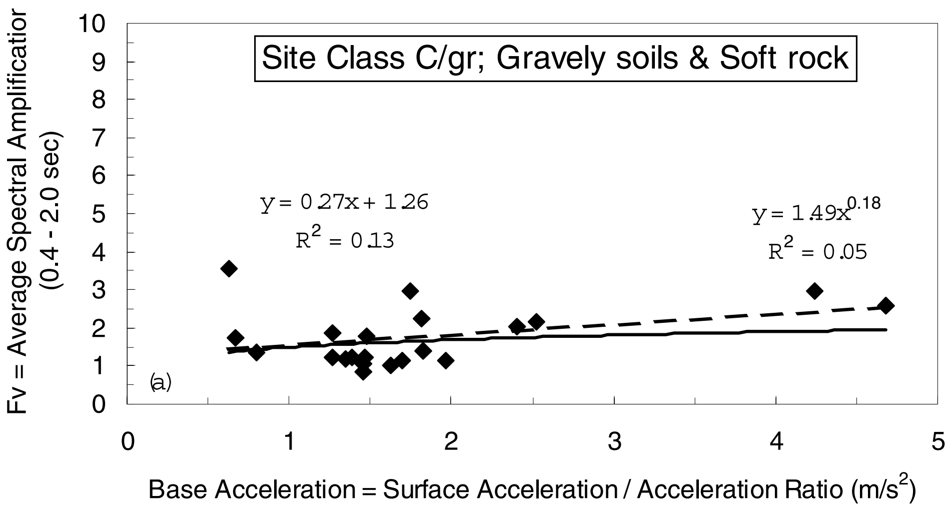


Figure 2. Acceleration ratio versus "base acceleration" for sites underlain by NEHRP site-class C (a) and D (b) type materials as determined from shear-wave velocity to 30m. Corresponding power law and linear regression curves are superimposed.

The spectral ratios for the short-period band (0.1 - 0.5 s; F_a; Figures 1b and 2b) indicate little or no tendency to decrease with increasing base acceleration level for sites either on stiff clays and sandy soils or sites on gravely soils or soft rock. This lack of a well-defined trend is consistent with earlier results based primarily on geotechnical The spectral ratios for the mid- or long-period band (0.1 - 0.5 s; F_v; Figures 3a and 3b) also show no tendency to decrease with increasing base acceleration level for sites either on stiff clays and sandy soils or sites on gravely soils or soft rock. This lack of a well-defined trend to decrease with increasing input ground motion level also is consistent with earlier results based primarily on geotechnical properties inferred from digital GIS maps (Borcherdt, 1996).



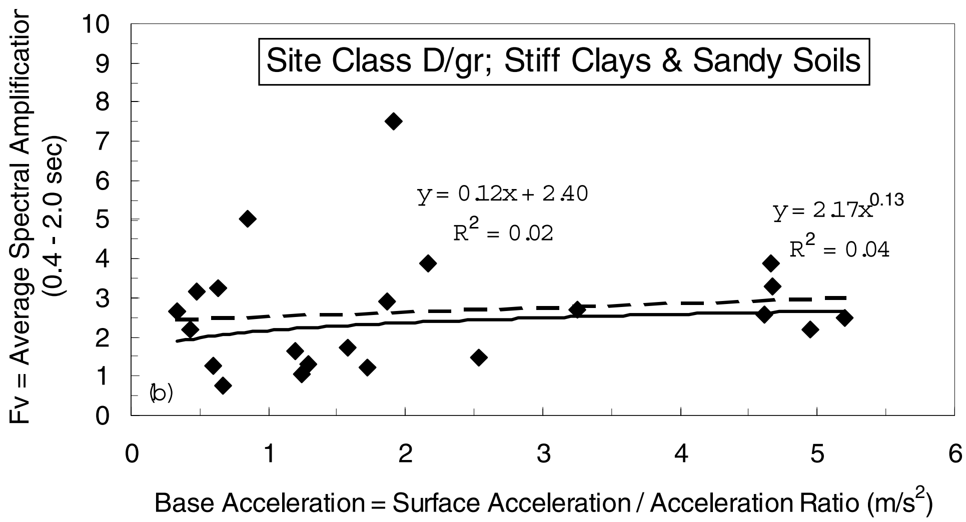


Figure 3 Average spectral amplification ratio for the mid-period band (0.4 - 2.0 s) versus "base acceleration" for sites underlain by NEHRP site-class C (a) and D (b) type materials as determined from shear-wave velocity to 30m. Corresponding power law and linear regression curves are superimposed.

PRELIMINARY COMPARISON WITH SEISMIC DESIGN PROVISIONS

Procedures for improved estimates of site-dependent, earthquake-resistant design spectra have been adopted in recent versions of United States building code provisions (e.g., NEHRP, 1994, 1997). These new developments better account for the amplification effects of local geological deposits in earthquake resistant design. They are based on unambiguous definitions of site classes in terms of shear-wave velocity and amplification factors derived from empirical and numerical modeling results.

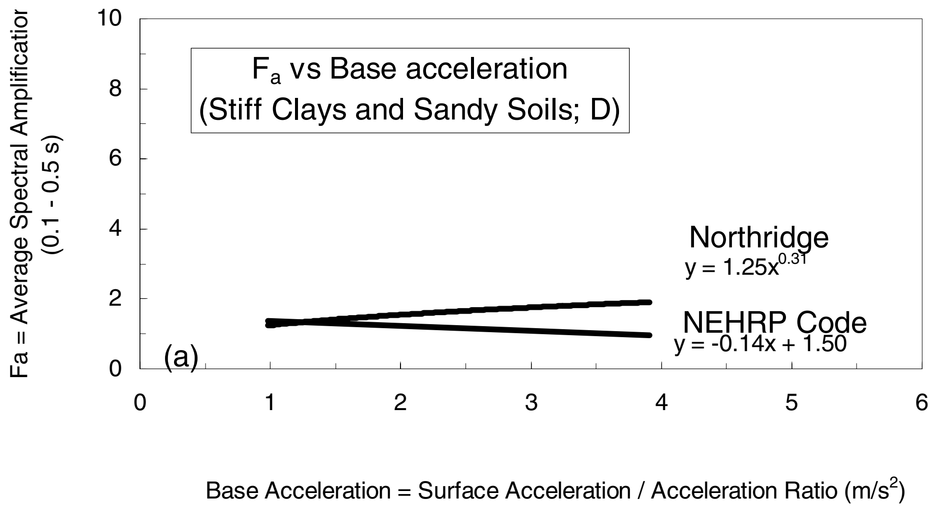
The amplification factors F_a and F_v for short- and mid- period motion may be predicted as a function of mean shear-wave velocity v for various input ground-motion levels, I, with respect to a reference ground condition by the following equations:

$$F_a(v, I) = (v_o / v)^{m_a}, \quad (1a)$$

and

$$F_v(v, I) = (v_o / v)^{m_v}, \quad (1b)$$

where, m_a and m_v are exponents which depend on the level of base input motion. These



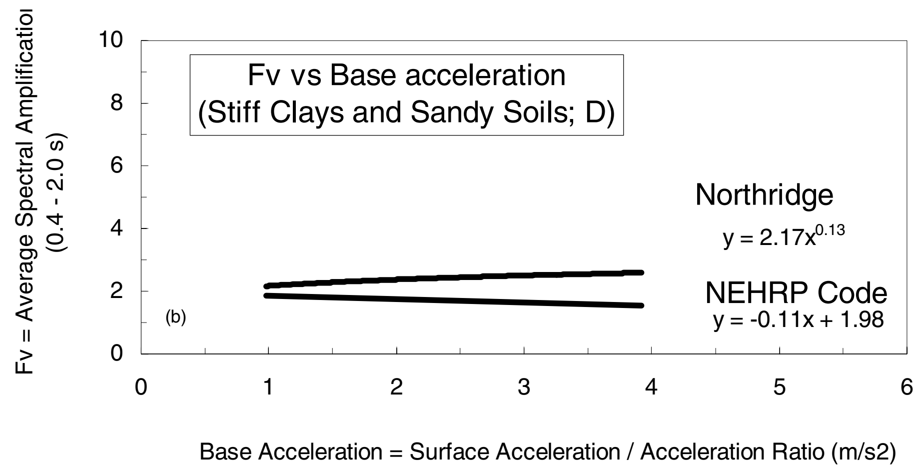


Figure 4. Site-specific amplification factors versus base acceleration for sites on *NEHRP D* (stiff clays and sandy soils) implied by the Northridge earthquake and the NEHRP code provisions for the short-period band (a) and the mid-period band (b).

equations allow the empirical results as derived from the Northridge earthquake to be compared rigorously to the factors as adopted in recent building code provisions.

Results derived from the Northridge earthquake for sites on NEHRP D materials (stiff clays and sandy soils) suggest that the amplification factors F_a and F_v do not show a tendency to decrease with increasing "base" acceleration. This trend as specified in Figures 2b and 3b by the power law regression curves is plotted in

Figures 4a and 4b. Superimposed on these trends are those implied by recent NEHRP code provisions. (The code trends are specified by equations 1a and 1b with v = 321 m/s, v_0 = 835 m/s, ma = 0.35 and -0.05 and m_v = 0.65 and 0.45 for input acceleration levels of 0.1 and 0.4g; Borcherdt, 1994. Values for the shear wave velocities of 321 and 835 were derived as averages for the NEHRP D sites sampled.)

CONCLUSIONS

Recent shear-wave velocity data provide an improved classification of sites according to recent definitions of site classes used in US building codes. These classifications are used to reexamine the dependency of empirical site factors on input or base level ground motion for sites normalized to metamorphic rock (granite).

Amplification factors inferred from the Northridge earthquake are in good agreement with those suggested for the code provisions at the 1 m/s^2 (0.1 g) base acceleration level. For higher levels of acceleration the factors implied by Northridge become increasingly greater than those proposed for the NEHRP code provisions. These differences are slightly larger than previous differences reported (Borcherdt, 1996) for the combined site class NEHRP C + D. The reasons for the tendency for the Northridge values to increase with increasing base level is not yet understood and is being studied further. These preliminary Northridge results are consistent with earlier empirical results and suggest that the decrease in code amplification factors with input amplitude needs further evaluation.

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