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EMPIRICAL MODELS OF SITE RESPONSE EFFECTS

N. A. ABRAHAMSON
5319 Camino Alta Mira, Castro Valley, CA 94564, USA

ABSTRACT

Response spectral site amplification factors from strong motion attenuation relations are compared for deep soil sites relative to generic rock. Since the different attenuation relations use different classification methods, care is taken to use as consistent site categories for the different models as possible. At short periods, the attenuation relations that allow for non-linear response produce similar site amplification factors, but they differ from the amplification factors for attenuation relations that assume linear site response by up to a factor of 1.7. At long period, the non-linear and linear models are reasonably consistent with each other because the site response is more linear at long periods. The main cause of the differences in the amplification factors is the different site classification methods.

KEYWORDS

Seismic ground shaking; site response; ground motion attenuation relations

INTRODUCTION

As part of the special session on the effect of site geology on ground motions, this paper presents a summary of empirically based models of site response. Empirical models of site response are usually based either on strong motion data or weak motion data.

The site effect is considered in terms of the ratio of median response spectral values on soil sites to those on rock sites. This ratio is called the site amplification factor (it may be amplification of deamplification). The non-linear aspect of the site response is considered by analyzing the dependence of the amplification factor on the rock peak acceleration (for the same magnitude, distance, and style-of-faulting).

ATTENUATION RELATIONS

Response spectral attenuation relations that consider the effects of the local geology are considered in this study. That is, only attenuation relations that provide estimates of ground motion at rock and soil sites (without simply grouping them into a single category) are used. There are two main classes of attenuation models: those that assume linear site response and those that allow non-linear site response.

Linear Site Response Models

Two recent attenuation relations are based on the assumption of linear site response: Boore et al (1993) and Lee and Trifunac (1995). Both of these models assume that the site response is linear. They find that the data do not require non-linear site response. There is some recent empirical evidence from the 1994 Northridge earthquake to support this position (Frankel, 1996).

Non-Linear Site Response Models

The other four attenuation relations considered here accommodate possible non-linear soil response. This is done by either allowing different magnitude and/or distance dependent attenuation relations for soil and rock sites (Idriss, 1991; Campbell, 1993, 1994; Sadigh, 1993,1994) or by directly incorporating a non-linear site amplification factor (Abrahamson and Silva, 1995). These models do not assume that non-linear response effects occur, but rather allow for that possibility in the regression analysis.

SITE CLASSIFICATION

An important issue in a comparison of site amplification from different models is the definition of "soil" and "rock" used in each model. The different attenuation models often use different site classification schemes; however, there are some general similarities. All of the attenuation relations separate soft-soil sites from typical stiff soil sites. In this paper, soft-soil sites will not be considered.

The most quantitative site classification is that used by Boore et al. (1993). This classification is based on the average shear wave velocity in the top 30m (Table 1). Because of its quantitative nature, this classification scheme is being considered for a wide number of applications. (The NEHRP classification scheme shifts the Boore et al. classification by one letter: e.g. BJF class A is NEHRP class B and so on). Typical rock sites in the western U.S. which include some shallow weathering (ref) are class B. Typical deep soil sites are class C.

Table 1. Site Classification Used by Boore, Joyner, Fumal (1993)

A	Vs > 750 m/s
B	360 m/s < Vs < 750 m/s
C	180 m/s < Vs < 360 m/s
D	Vs < 180 m/s

In contrast to the quantitative classification scheme used by Boore et al (1993), most attenuation relations are based on more qualitative classification schemes because in most cases direct measurements of the shear wave velocity at the site are not available. The classification scheme used by Sadigh et al (1993) listed in Table 2 is a mix of quantitative and qualitative. This classification separates shallow soil sites from rock sites because shallow soil sites can have strong resonances (e.g. Tsai et al, 1994), however, the attenuation models of Sadigh et al (1993) and Abrahamson and Silva (1995) which use this classification method combine the rock and shallow soil categories into a single "rock" category because there are not enough data to develop separate models for these two categories. The deep soil sites in narrow and broad canyons (class C and D) are also combined into a single deep soil category. Other qualitative classification schemes are used by Idriss (1991), Campbell (1993), and Lee and Trifunac (1995) (Table 3). These qualitative classes do not, however, correspond directly to class A, B and C as defined by Boore et al. but in general, soft-rock and stiff soil sites correspond to BJF class B and deep soil sites correspond to BJF class C.

The comparisons in site amplification made in this paper will be for deep soil sites relative to a rock (average of hard-rock, soft-rock/stiff soil) site. The specific site categories used for each attenuation relation are listed in Table 4.

Table 2. Geomatrix Site Classification used by Sadigh et al. (1993) and Abrahamson and Silva (1995)

A	Rock (Vs > 600 m/s) or very thin soil (< 5m) over rock
B	Shallow Soil: Soil 5-20 m thick over rock
C	Deep Soil in Narrow Canyon: Soil > 20 m thick, Canyon < 2 km wide
D	Deep Soil in Broad Canyon: Soil > 20 m thick, Canyon >2 km wide
E	Soft Soil (Vs < 150 m/s)

Table 3. Other Qualitative Classifications

Idriss (1991)	Campbell (1994)	Lee and Trifunac (1995)
Rock & stiff soil	Hard rock	Rock
	Soft rock	Stiff soil
	Shallow soil (excluded)	
Deep soil	Alluvium	Deep soil
Soft soil	Soft soil	Soft soil
	(plus depth to basement rock)	(plus local geology class)

Table 4. Site Catagories Used in the Site Amplification Comparison

Attenuation Relation	"Generic Rock"	"Deep Soil"
Boore et al (1993)	Ave of BJF class A & B	BJF class C
Sadigh et al (1993), Sadigh (1994)	Rock (Geomatrix class A&B)	Soil (Geomatrix class C & D)
Idriss (1987,1991,1994)	rock and stiff soil	Deep Soil
Campbell (1993,1994)	Soft-rock	Alluvium
Lee and Trifunac (1995)	Ave of rock and stiff soil	Deep soil
Abrahamson & Silva (1995)	Rock (Geomatrix class A&B)	Soil (Geomatrix class C & D)

COMPARISON OF SITE AMPLIFICATIONS

The site amplification from the six strong motion attenuation relations are compared in Figures 1-3 for spectral periods of 0.0,, 0.3, and 1.0 seconds, respectively. In each figure, the site amplification is compared for magnitude 5.5, 6.5, and 7.5 events and is plotted versus the median peak acceleration on rock for an average of strike-slip and reverse events. If the models have different magnitude scaling between soil and rock , then the amplification factor will depend on the magnitude (as well as the rock PGA level).

The four models that accomodate non-linear response all indicate that the site amplification decreases with increasing rock PGA at the high frequencies (T<1 sec). However, at T=1 seconds and longer, some of the models become more linear (flatter slopes). In particular, the Abrahamson and Silva (1995) model is strongly non-linear at high frequencies, but is linear at 1 Hz.

At short periods, the non-linear models are reasonably consistent with each other, but are very different from the linear models. At long periods, the differences between the differences between the four non-linear models are similar to the differences between non-linear and linear models.

The centroid of the strong motion data used in developing the attenuation relations is about 0.15g (on rock). The different models tend to be closer to one other at this PGA level, but there are still significant differences that are probably related to the different site classification schemes. The median attenuation relation for a magnitude 6.5 strike-slip event for periods of 0.0 and 1.0 seconds on deep soil sites is compared in Figure 4a,b. This Figure shows that the attenuation relations are in resonably good agreement at distances of about 20-30 km. The differences in the amplifications factors are related to the differences in the rock attenuation (Figure 4c,d).

Currently, the California Div. Mines and Geology and the Southern California Earthquake Center are working at developing a correlation between the Boore et al site class and the surface geology which will help to make the Boore et al. classification more widely applicable.

CONCLUSIONS

Despite the effort to account for some of the differences in the site classification schemes used in the different empirical studies, there is still a large range of site amplification factors implied by recent strong motion attenuation relations. At short periods, the attenuation relations that allow for non-linear response produce similar site amplification factors, but they differ from the amplification factors for attenuation relations that assume linear site response by up to a factor of 1.7. At long period, the non-linear and linear models are reasonably consistent with each other because the site response is more linear at long periods. The main cause of the differences in the amplification factors is the different site classification methods. The uncertainty in the strong motion amplification factors impacts the development of spectral amplification factors for use in building codes.

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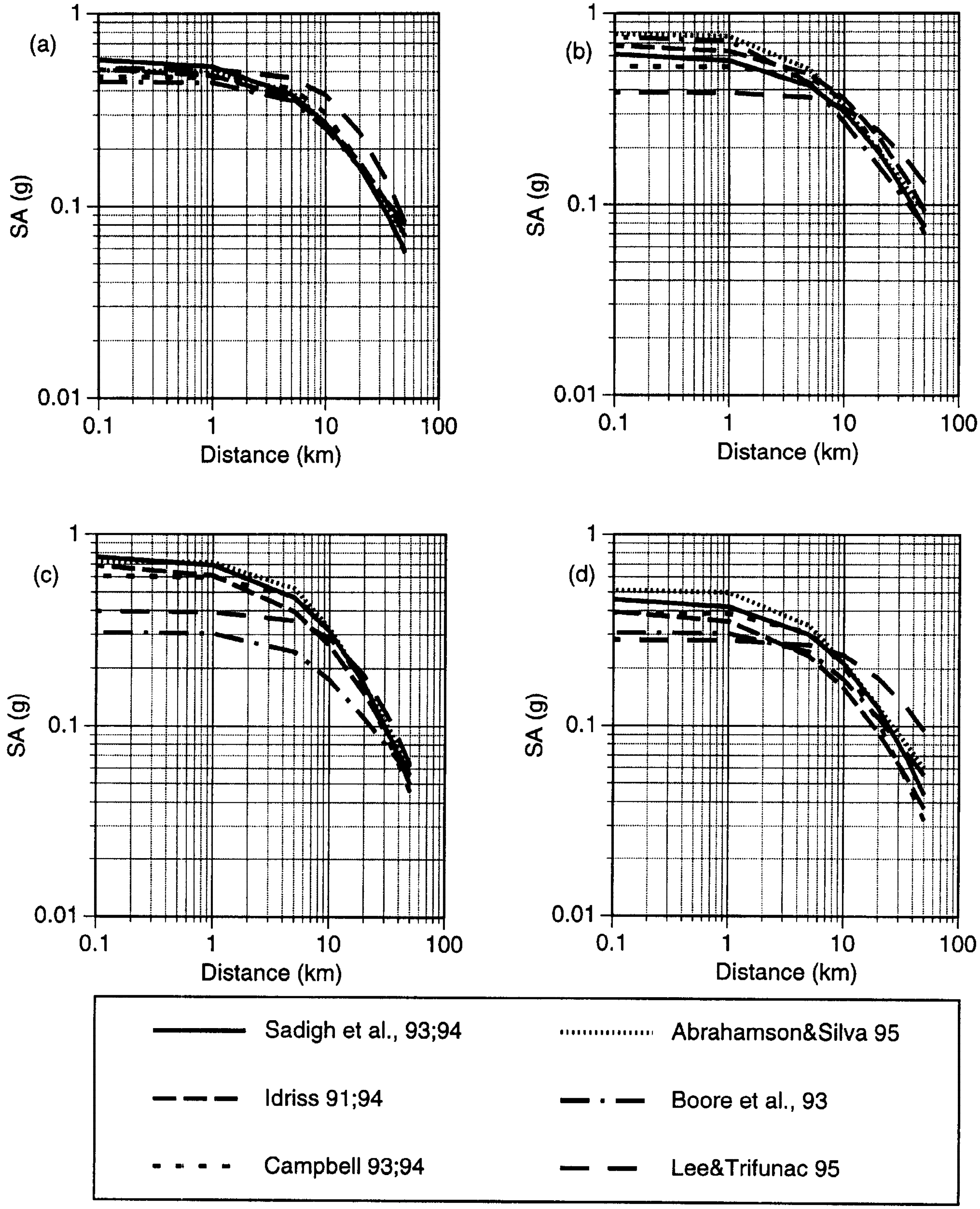

Figure 4. Comparison of attenuation relations for a vertical strike-slip fault, M=6.5. (a) Soil PGA (b) Soil, T=1.0 sec (c) Rock PGA (d) Rock, T=1.0 sec.

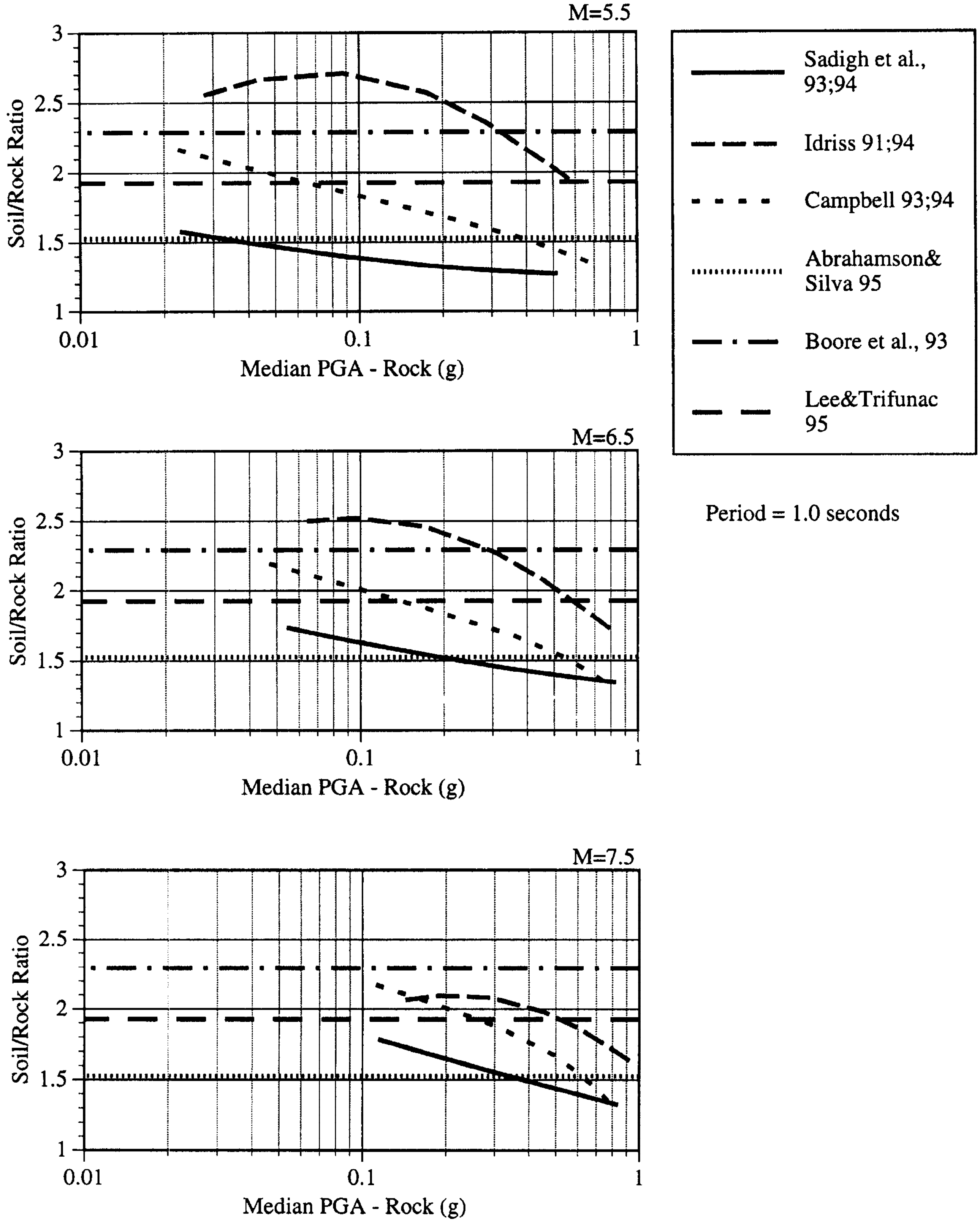

Figure 3. Comparison of site amplification for Deep Soil sites at T=1.0 seconds.

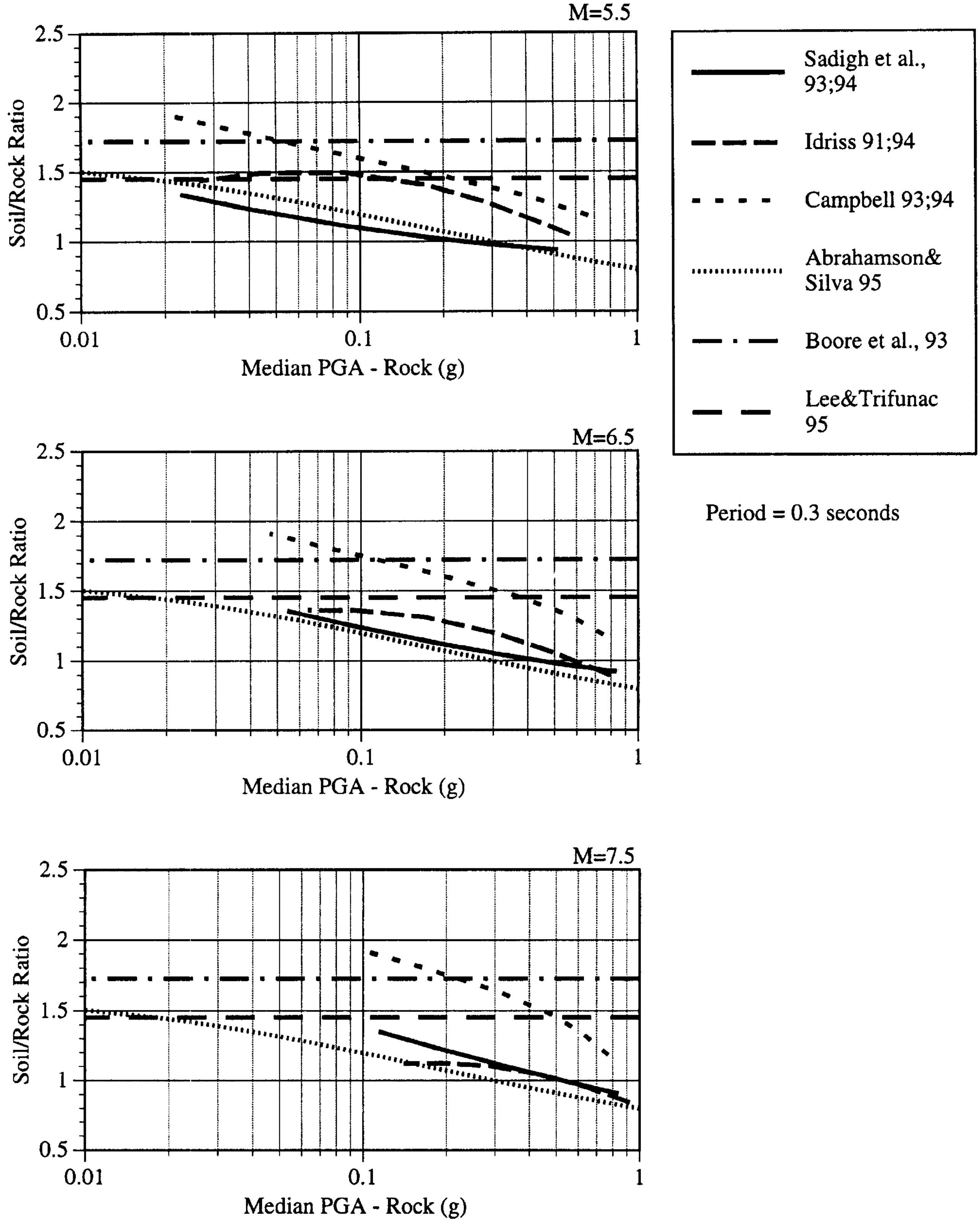

Figure 2. Comparison of site amplification for Deep Soil sites at T=0.3 seconds.

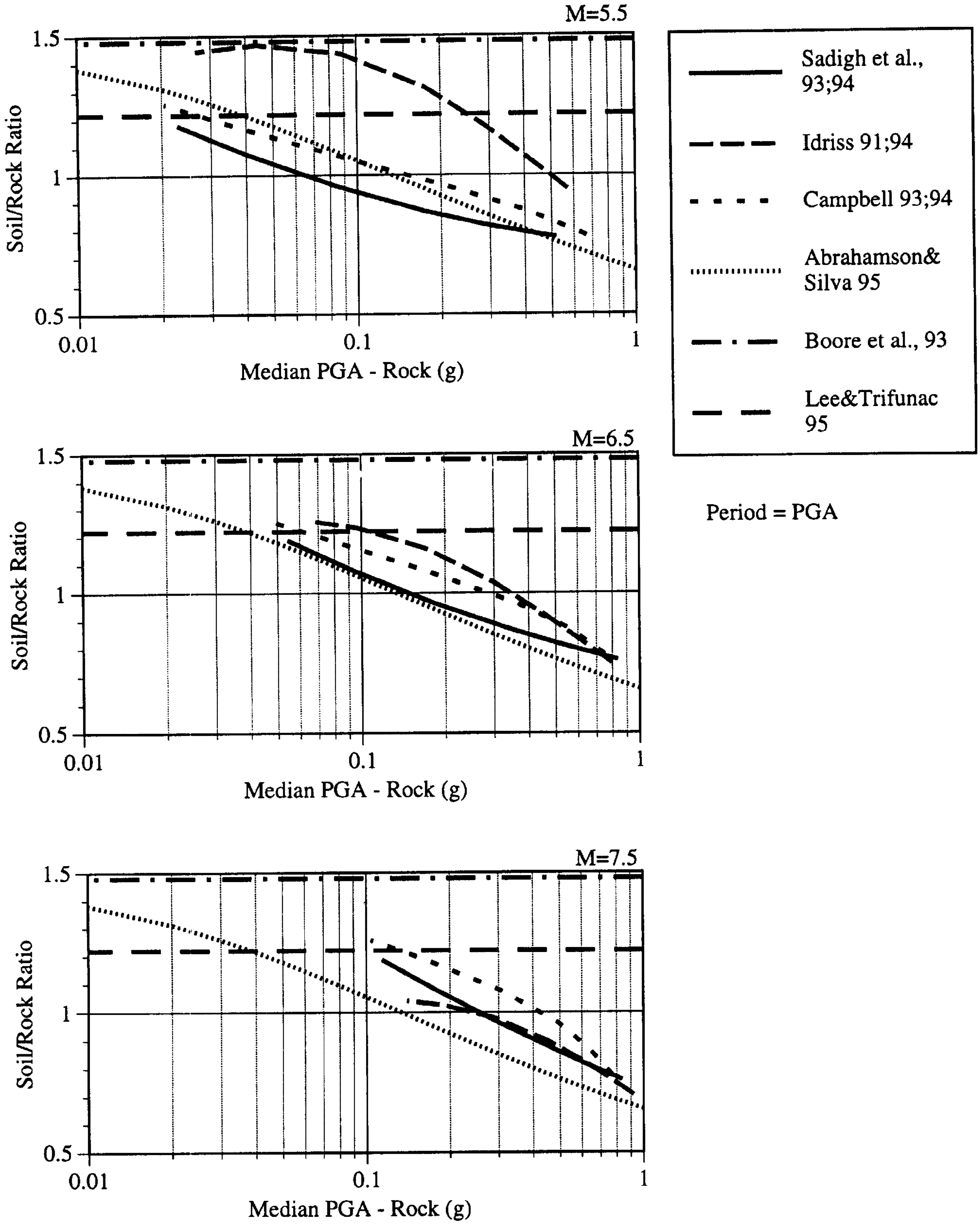

Figure 1. Comparison of site amplification for Deep Soil sites at PGA.