

# THE EFFECT OF ROCK MOTIONS ON SOIL AMPLIFICATION FACTORS FOR AUSTRALIAN CONDITIONS

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## ABSTRACT:

Rock motion intensity (level of ground motion measured on rock) is widely known to have significant effects on soil amplification factors. The objective of this paper is to emphasise the influence of both the rock motion intensity and earthquake magnitude on soil amplification factors. The sensitivity of soil amplification factors to rock motion intensity is studied using earthquake scenarios associated with a range of design peak ground velocities (PGV's) and peak ground accelerations (PGA's) specified for Australia. Earthquakes of varying magnitude were normalized to a constant PGA or PGV. Earthquakes with different magnitude have notably different amplification factors. It is observed from the analyses results that the variability in amplification factors is clearly affected by the choice of normalization parameter, i.e. PGA or PGV.

## 1. INTRODUCTION

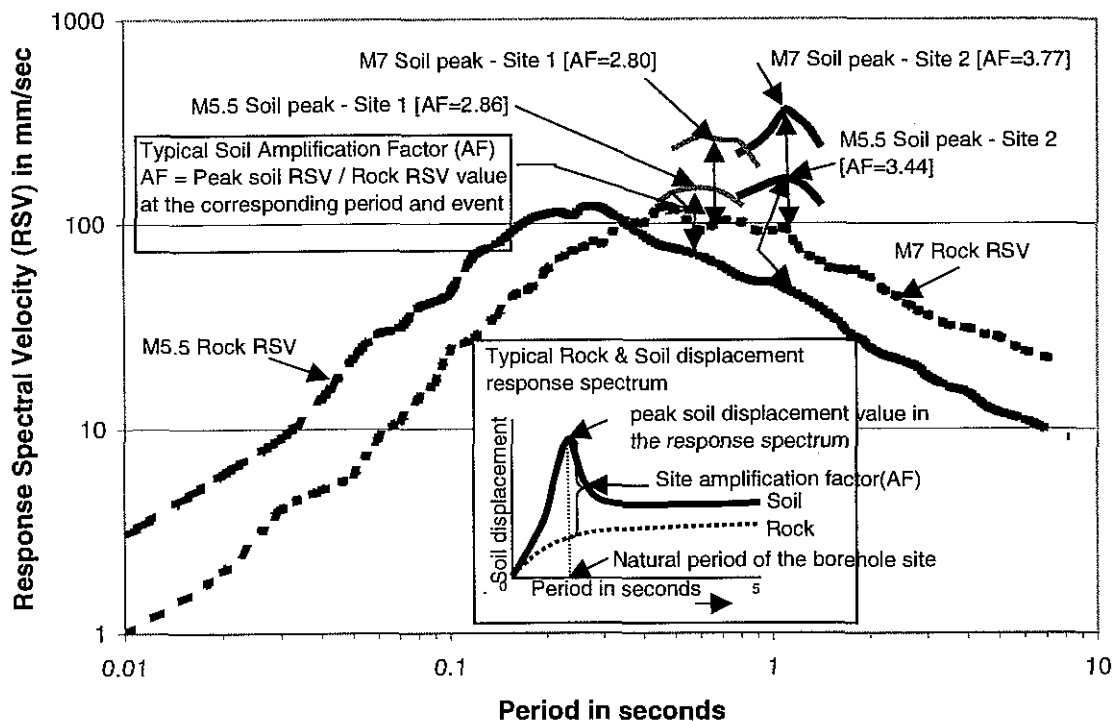
The amplitude and frequency content of seismic shear waves reaching the earth's surface is dependent on site soil conditions. Provisions have been developed in major codes of practices including the International Building Code (IBC, 2000) in the USA to address this phenomenon. Code provisions are typically based on statistical analysis of instrumented ground motion records from which amplification factors have been identified for a series of pre-defined site classes. The site classification system in the IBC, for example, is based on the average shear wave velocity (SWV) in the sedimentary soil layers and the ground motion intensity. Other codes of practice such as the draft Joint Australian-New Zealand Standard (AS/NZS, 2003) have incorporated the site natural period as one of the criteria for site classification. Soil amplification is also controlled by other parameters including the SWV gradient, thickness of soft soil layers, overall soil depth, impedance contrast at the soil-rock interface, and response spectrum representing the frequency content of seismic waves measured on bedrock. The influence of these parameters on soil behaviour is generally understood by researchers, and can be demonstrated by simple one-dimensional shear wave analysis of a soil column. However, it is believed that these effects are not necessarily appreciated by the broader spectrum of practitioners in Australia.

Research is currently being undertaken by the University of Melbourne in collaboration with Geoscience Australia to develop a generalized soil amplification model that could be applied to Australia and to other intraplate regions where local ground motion data is sparse. In addressing the scarcity of data, procedures have been developed to simulate bedrock motions based on a stochastic modelling technique [Lam 2000, Chandler 2002]. One-dimensional quasi-linear analysis of soil columns is used in this study given the limited input information. The use of this simple and inexpensive methodology for soil response analysis is well supported in the literature [Dickenson 1991, Seed 1994, Dobry 2000] despite its shortcomings in modeling 3-D effects such as the basin-edge effects (Somerville, 2000).

This paper presents preliminary research findings related to the effects of motion intensity on soil amplification factors. More specifically, this paper investigates the different trends in amplification factors observed when ground motions are normalized to different ground motion intensity measures. Two soil columns were used in the study based on borehole records from Newcastle (denoted "Site-1") and from Melbourne (denoted "Site-2"). These two soil columns possess site periods of 0.5 sec and 0.9 sec respectively, and are both site class 'D' in the IBC classification system due to the presence of soft soil layers possessing very low shear wave velocity. Bedrock accelerograms have been simulated for earthquake scenarios of magnitude ranging between M5 and M8, using a stochastic procedure [program "GENQKE" (Lam, 2000)]. The pseudo non-linear site response program SHAKE-91 (Schnabel, 1972) has been used for the 1-D site response analysis of the soil columns.

## 2. DEFINITIONS OF MOTION INTENSITY

All response spectra of rock sites have been normalized with respect to a ground motion intensity parameter [PGA or PGV to describe the level of ground motion, not the same as traditional 'intensity'] in order that the sensitivity of the soil amplification factor to the particular parameter could be identified. The peak ground velocity PGV and the peak ground acceleration PGA are the two parameters that have been used for this normalization. In this study, PGV is taken as the maximum response spectral velocity (RSV max) divided by 1.8. Thus, response spectra that have been normalized to a common PGV of 60mm/sec have RSV<sub>max</sub> equal to 110mm/sec for both the M5.5 and M7 earthquake scenarios (see Figure 1). The targeted PGV's were obtained by adjusting the hypocentral distance in each of the earthquake considered.



**Figure 1. Analyses of soil amplification actors for sites with natural periods of 0.5 sec [Site 1] & 0.9 sec [Site 2] normalised to a PGV= 60 mm/sec**

The soil response spectra representing the effects of site resonance are typified by "peaks" as shown in Figure 1. Only the part of the soil response spectrum at the resonant peak is shown in the figure (the rest of the spectrum displaying higher mode effects are not shown). The alternative displacement response spectrum format displays the fundamental resonant peak even more prominently (see inset diagram, Figure 1.). The soil amplification factor (AF) is defined herein as the maximum ratio of the soil and rock response spectrum at the resonant peak. At a PGV of 60 mm/sec, the AF's obtained from the analysis of two earthquake scenarios for the two soil columns range between 2.8 and 3.8. According to the Australian Standard AS1170.4 (1993), the acceleration coefficient ( $a$ ) in g's is defined as the PGV in millimeters per second divided by 750. Thus, the AF values similar to that shown in Figure 1 should be

obtained from bedrock excitations that have been normalised to a value of  $a = 0.08$  g or PGV of 60 mm/sec.

In order to investigate the effect of normalizing by different parameters, the ground motions used in Figure 1 were normalized to a constant PGA of 0.08 g (equivalent according to AS 1170.4 to a PGV of 60 mm/sec). These normalized ground motions were then used to calculate amplification factors for the two sites of interest (Figure 2). The AF's obtained from this analysis for the two soil columns are within the range 2.4 - 4 (compared to the range 2.8 - 3.8 at a PGV of 60 mm/sec). Interestingly, the rock response spectra and the AF's associated with the two normalization approaches are noticeably different. (compare Figure 1 with Figure 2). This suggests that the intensity parameter used for normalization might affect the AF values. This phenomenon is investigated further in the next section, which presents separate correlations of AF's with PGV and AF's with PGA.

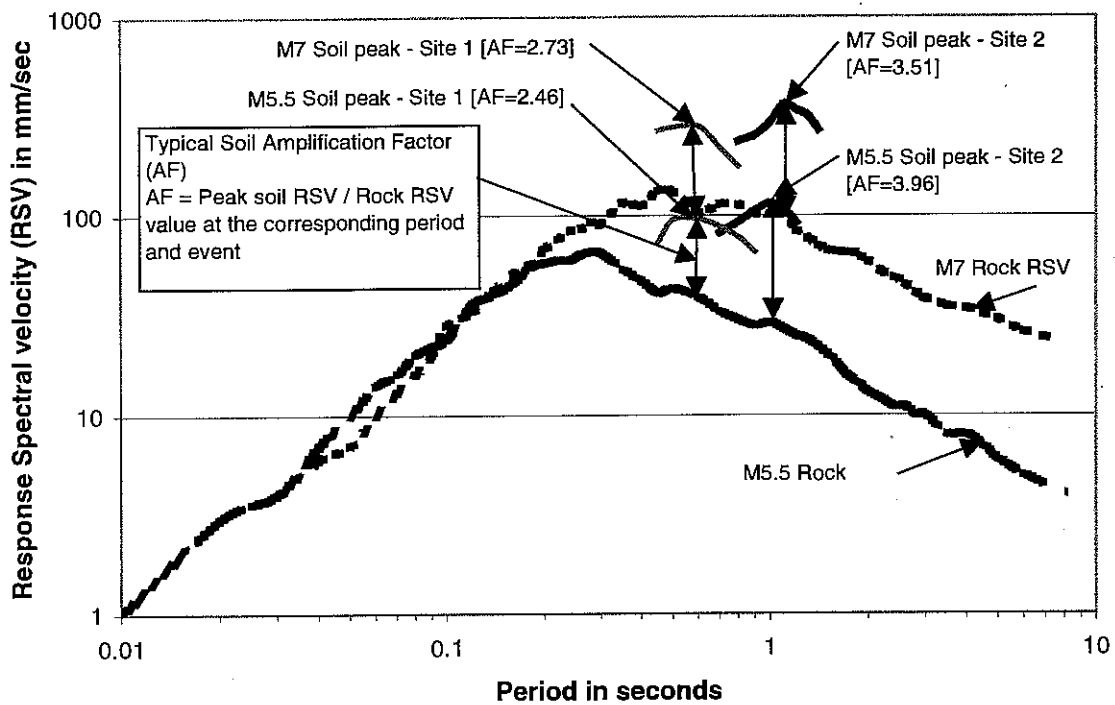


Figure 2. Analyses of soil amplification factors for sites with natural periods of 0.5 sec [Site 1] & 0.9 sec [Site 2] normalised to a PGA= 0.08g

### 3. INTENSITY AND MAGNITUDE EFFECTS ON SOIL AMPLIFICATION

Amplification factors were calculated for the 0.9 sec period site ("site-2") based on earthquake scenarios with PGV's varying between 20mm/sec and 100mm/sec. The overall trend of AF decreasing with increasing PGV is in agreement with the code provisions, and generally accepted in practice. However, the AF values are some 1.5 times higher than the recommendations by IBC for site Class D (Figure 3). The AF's associated with the M5.5 and M7 earthquake scenarios were very similar. In contrast, the correlations of AF with PGA are highly dependent on the earthquake magnitude (see Figure 4).

The AF-PGV and AF-PGA correlations obtained for the 0.5sec and 0.9 sec period sites are presented in Figures 5 & 6 respectively. A slightly higher amplification is observed for the 0.9 sec period site, but the difference is not large. Significantly, the correlations of AF's with PGV show much less scatter than the correlations of AF's with PGA.

Finally, the sensitivity of AF's to earthquake magnitude is presented in Figure 7 with PGV held constant at 60 mm/sec. A moderate (10-20%) increase in AF is shown with the earthquake magnitude increasing from M5.5 to M8.

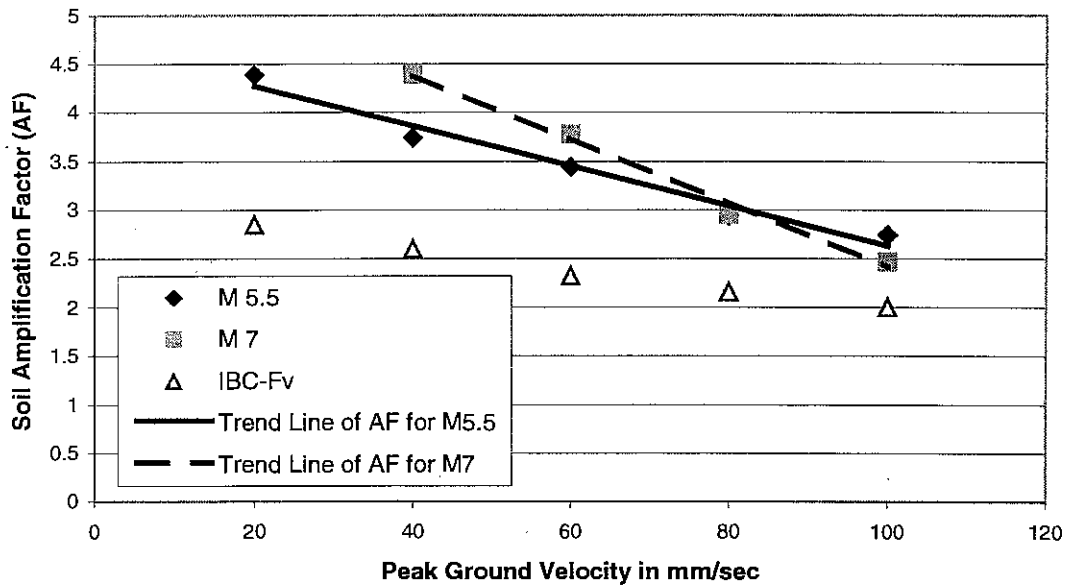


Figure 3. Soil amplification factor versus PGV for 0.9 sec site [Site-2]

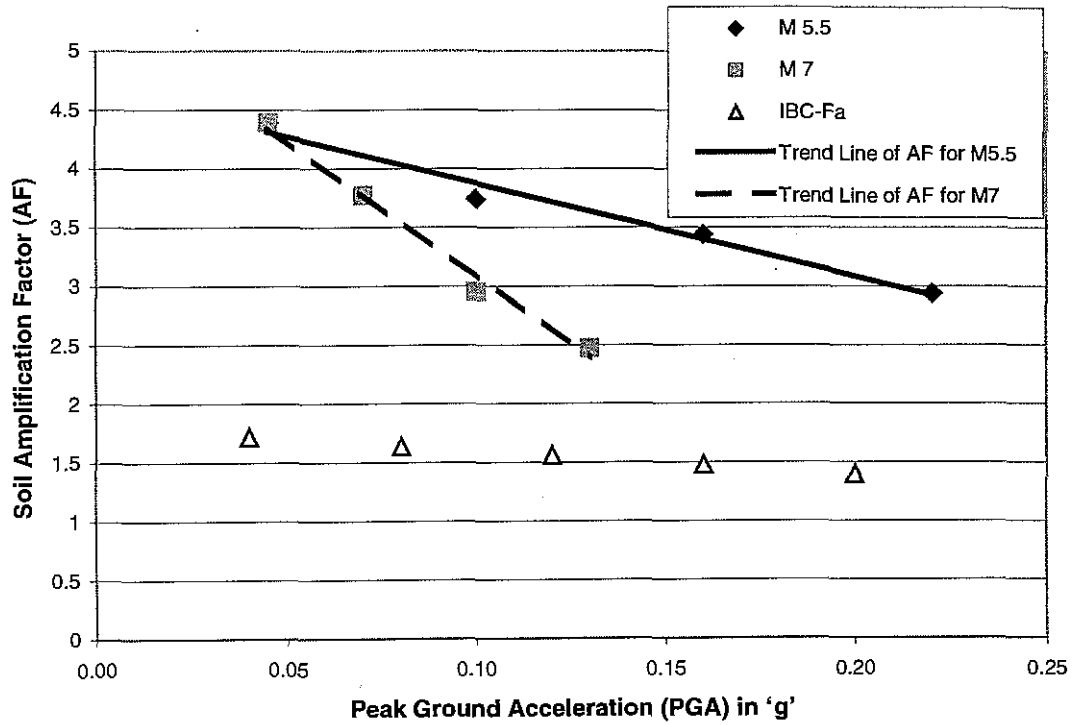


Figure 4. Soil amplification factor versus PGA for 0.9 sec site [Site-2]

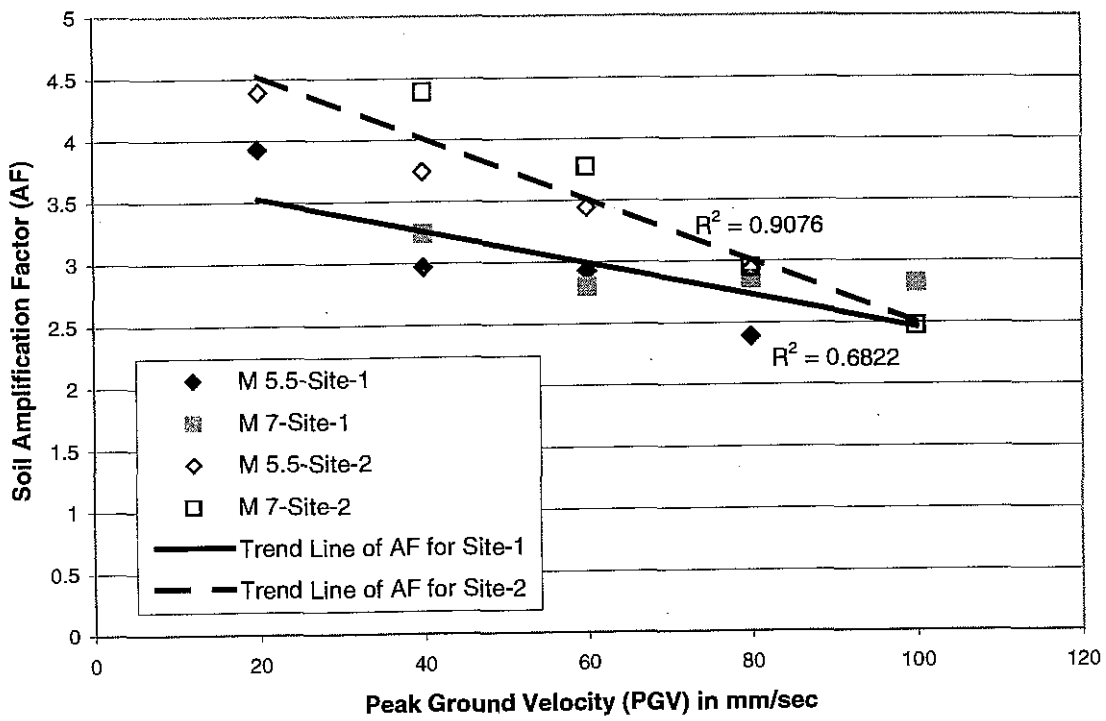


Figure 5. Influence of Magnitude and PGV on soil amplification factor

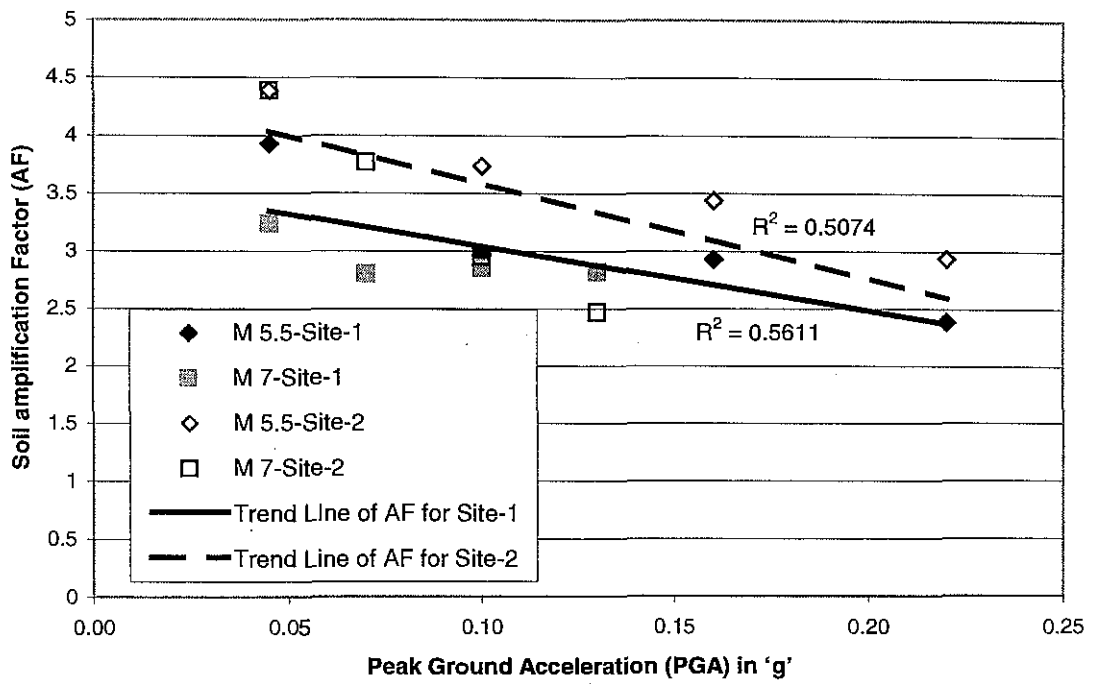


Figure 6. Influence of Magnitude and PGA on soil amplification factor

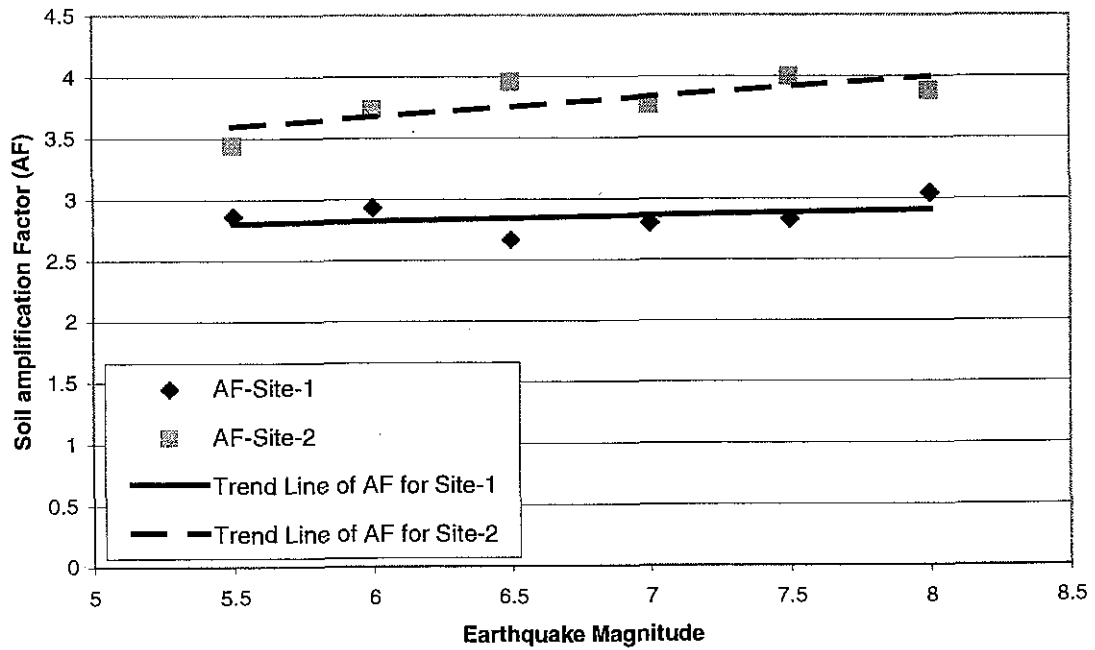


Figure 7. Influence of Magnitude on soil amplification factor with a constant PGV=60 mm/sec

## 4. CLOSING REMARKS

This paper emphasizes the dependence of soil amplification on earthquake magnitude, rock motion intensity, and site natural period. Importantly, the effects of the choice of normalization parameter (PGA or PGV) on AF's have been highlighted. Other trends that are well understood by researchers who regularly deal with site response issues and perhaps not fully appreciated by general practitioners have also been highlighted. Moreover, there are significant shortcomings in generalized AF's, with the AF's computed in this paper, some 1.5 times higher than the IBC code recommendations.

This paper only considered two distinct sites. Further investigation is being undertaken to obtain similar and more generalized correlations with a large number of sites. This work will lead to generalized relationships for soil amplification factors.

## 5. REFERENCES

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