Determination of site-response and attenuation in Brisbane, Australia

Michael Winter, Steven Jaumé and Russell Cuthbertson

QUAKES, Department of EarthSciences, The University of Queensland, Brisbane, Australia (e-mail: winter@earthsciences.uq.edu.au; jaume@earthsciences.uq.edu.au; russell@earthsciences.uq.edu.au, phone +61-7 3365 4853; fax: +61-7 3365 3473).

Abstract

Determining the degree to which local and regional geology contributes to earthquake damage is of great importance for the estimation of seismic hazard. Typically this factor, called site-response, is measured through a variety of techniques including the reference-site method, ground motion inversion and Nakamura's method. We have analyzed both the reference-site and inversion based techniques for use in Brisbane, Australia and found that due to high levels of ground noise and weak signal strength they are impractical for use in an intraplate setting. We have formulated a new method for the determination of site-response based on the generalized inverse approach, which incorporates the signal-to-noise ratio of the ground motion. Using this approach we have combined data from quarry blasts, teleseisms, and local earthquakes to determine site-response at seven sites throughout Brisbane. A preliminary estimate of seismic attenuation for the region has also been obtained.

Introduction

Earthquake hazard is presently accepted to be a combination of three factors: the magnitude, location and frequency of earthquakes, the effect of the wave path of seismic energy, and the degree to which local geological conditions contribute to damage. In a number of recent earthquakes, local geology has been shown to be either a significant or the largest single factor in determining earthquake damage (c.f. the Mexico City earthquake, 1985; Singh *et. al.*, 1988 [5]). Because of this, there has been increasing interest in quantifying the effects of local geology on seismic hazard. This effect, called site-response, can be estimated through a number of processing techniques with varying degrees of success.

The original quantitative method for the determination of site-response, formulated by Borcherdt (1970 [4]), is the "reference-site" technique. Seismograms are often assumed to be a combination of linear filters, each expressing the effect of separate phenomena (Aki and Richards, 1980 [1]). If this is the case, then a transfer function for the sediment layer can be found using a spectral-ratio. By dividing the ground motion spectra at a site by that at a nearby reference site (assumed to have no influence on seismic waves) the sediment transfer function (site-response) can be found. Borcherdt showed that the sites from which amplification was predicted using this method correlated well with isoseismal maps from the 1906 San Francisco earthquake. Deriving site-response through inversion of ground motion data was originated by D. J. Andrews (1986 [3]). He proposed a two-parameter model of ground motion from an event: an earthquake source spectra and a site-response as a function of frequency. These equations are then solved by inversion. A third method, "Nakamura's method" estimates site-response using a simple horizontal to vertical ratio of ground noise spectra.

At present, accurate determination of site-response appears to require the use of either the reference-site method or an inversion based technique. These techniques were developed for seismically active regions, where local earthquakes are common. Local earthquakes provide a relatively noise free signal for use in forming an estimate of site-response. In an intraplate region such as Brisbane, local earthquakes are rare enough that it is impractical to use them as the prime source of data.

In an effort to better quantify seismic hazard and to ascertain the accuracy of the Nakamura estimates we have made in previous experiments, we have placed seismometers at a series of sites in Brisbane. Six months into this field experiment we have still not recorded one event with significant signal-to-noise ratio (at least 3) at all frequencies of interest. In this situation it would be impossible to determine an accurate site-response by using either the reference-site method or a traditional inversion based approach, as these methods require a good signal-to-noise ratio across all frequencies of interest. A previous attempt at determining site-response in northeastern Queensland (Winter and Jaumé, 1998) required restricting the observational spectra to below 5 *Hz* because of noise considerations. Nonetheless, in order to obtain an estimate of seismic hazard, an estimate of site-response across a reasonably broad range of frequencies (0-10 *Hz*) is of great importance.

To overcome problems related to low signal quality, we have used a signal-to-noise weighted simple parameterization of the equation of ground motion from an earthquake, based on that used by Andrews (1986 [3]). Regional seismic efficiency (Q) was determined through both analysis of the attenuation term found through examination of earthquake coda waves.

Parameterizing ground motion

Ground motion as a function of frequency (f) for arrival k ($G_k(f)$) can be modeled as a convolution of three terms; a source spectra (either an earthquake or blast) ($E(f)$), a path term ($P_k(f)$) and a site-response term ($S(f)$):

$$G_k(f) = E_i(f)P_k(f)S_j(f) \ , \tag{1}$$

where i is the earthquake number and j is the site number for event k.

Path-effects

With the assumption that there is no crustal focusing, the path term can be modeled as:

$$P_k = \frac{1}{r_{ij}^n} e^{-\frac{\pi f}{V_s Q(f)}} \ , \tag{2}$$

with r being the distance from event i to receiver j, n being the coefficient of geometric spreading, V_s is the shear wave velocity, and Q is regional seismic efficiency. For this study, Q was determined through the analysis of coda decay of regional earthquakes (Aki and Chouet, 1975 [2]), (see Figure 1).

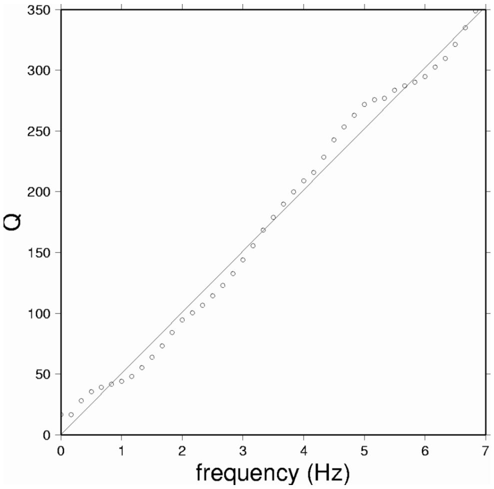

Figure 1: $Q(f)$ determined through the analysis of coda waves, shown by the dotted line, against a linear fit of $Q = 50f$ (solid line).

Equation 1 can be linearized by taking the logarithm and solved using a linear regression with an added constraint. Commonly, rock sites are assumed to experience no site-response. Four sites on igneous and metamorphic rock were chosen to be reference-sites. In order to remove the noise dominated portions of the records, a weighted inversion was then used to calculate both site-responses and earthquake source functions. The weighting function ($W_k(f)$) is modified from the signal-to-noise ratio (W_k^*) to reduce the effect of both noise and directional bias of site-amplification (see Figure 2).

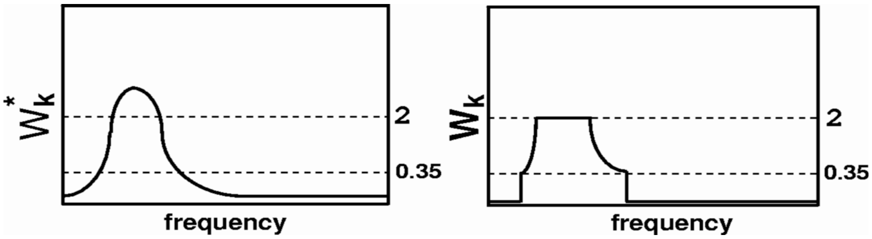

Figure 2: The weighting function is equal to the signal-to-noise ratio with a maximum of 2.0 to account for bias and a minimum of 0.35 to reduce the influence of noisy records.

The experiment

We have attempted to place sites on geologic areas representative of a large percentage of the urban area (see Figure 3). Sites are moved as soon as the site-response estimate stabilizes, enabling the maximum area coverage with just a half dozen stations.

Site name	Local geology
BSEV	Granite
BGAP	Granite
BWIN	Paleozoic meta-sediment
BEVE	Paleozoic meta-sediment
BQUT	Tertiary sediment
BWYN	Mesozoic sandstone
BGEE	Mesozoic sandstone
BTAI	Tertiary sediment
BMCD	Paleozoic meta-sediment

Figure 3: Local geology for sites used thus far in the experiment.

Results

The reference-sites placed on igneous and metamorphic rock do not exhibit significant site-response. This was verified by leaving the rock sites unconstrained in turn. This is comforting as it verifies the physical assumptions made when using a reference-site. The site-responses calculated for the other sites should be absolute, rather than relative to any site-response at the reference-sites.

The results indicate that sites situated on sediment / meta-sediment (BQUT, BGEE, BYWN, BTAI) and in some cases metamorphic rock (BMCD) experience significant amplification of seismic waves (see Figure 4). The fact that a site on metamorphic rock experiences some mid-frequency amplification is somewhat surprising, as it is generally accepted that these sites should experience little amplification. Other sites placed on metamorphic rock (BEVE, BWIN; not shown) exhibited only minor amplification.

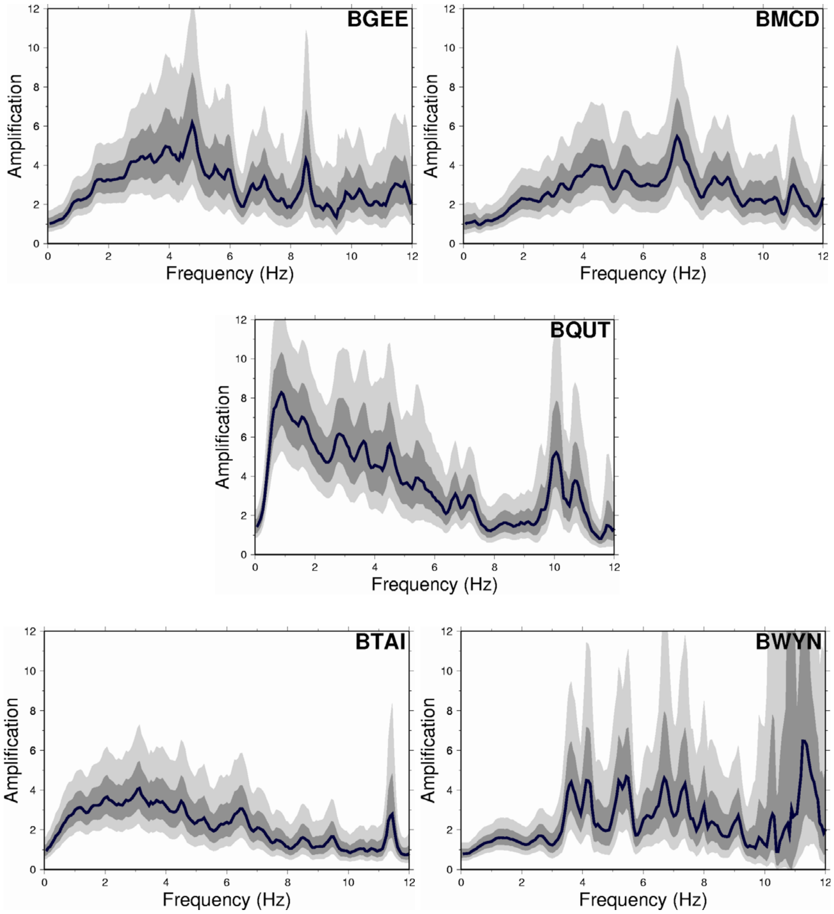

Figure 4: Site-response calculated for five sediment sites. Shaded regions denote one and two standard deviation limits.

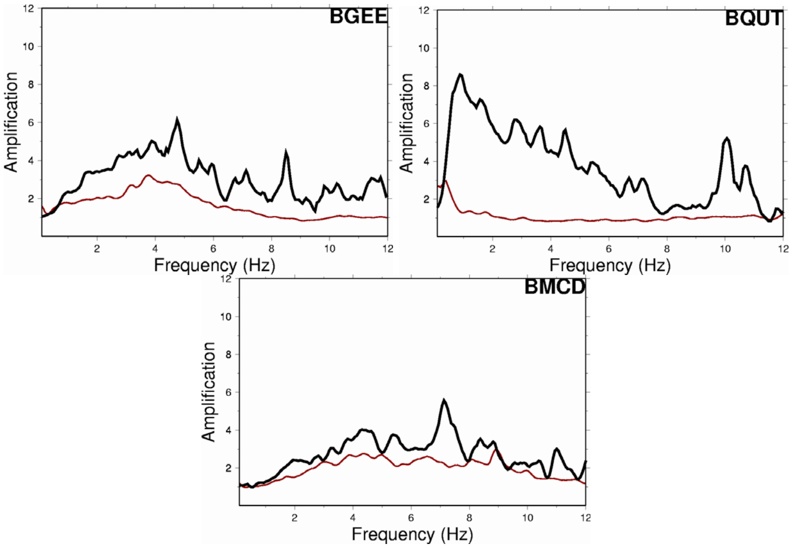

Figure 5: A comparison of the inversion based estimates (black line) with the Nakamura based estimates (light line) for three sites. Nakamura's estimate should predict the fundamental frequency of amplification, but it fails, noticeably at BQUT.

The site-responses calculated using Nakamura's method, when compared to those calculated with the inversion based approach, are in poor agreement (see Figure 5).

Conclusions

Determining site-response in an intraplate setting is difficult, as no single event has a sufficient signal-to-noise ratio to allow an estimate to be made using the classical methods. We have demonstrated the viability of a weighted inversion based technique for the determination of site-response in an intraplate setting. We used an estimate of noise-to-signal as a proxy for the standard deviation of the ground motion data. Using this weighting scheme, we were able to compute the site-response in circumstances in which it would have been impractical using other methods.

Preliminary results from this inversion show that sediment sites in Brisbane experience significant amplification, up to a factor of eight at some frequencies. Furthermore, based on these results, it would appear that Nakamura's method does not adequately predict amplification in a quantitative sense.

Acknowledgments

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