Title	Synthetic Ground Motions for the December, 1989 Newcastle Earthquake

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A suite of synthetic ground motion time histories has been developed to represent the motion experienced in the Newcastle area from the December 1989 Newcastle earthquake. The method is known as the Phase Spectrum Method and uses the phase spectrum from recordings of the aftershock and amplitude spectra derived from an attenuation function. The results obtained are generally comparable with those using other methods.

INTRODUCTION

The Newcastle earthquake of December 1989 caused damage to a number of engineered structures. For this reason, there is considerable interest in the level of ground shaking experienced by those structures. Unfortunately, no calibrated recordings of the strong ground motion were recorded in the city, the closest being over one hundred kilometres distant near Sydney. This study is one of a number that attempted to estimate the magnitude and character of the ground motion experienced in Newcastle.

The simplest techniques of ground motion estimation use existing attenuation functions to estimate the motion using only the magnitude of the earthquake and distance to the point of interest. Either peak ground motion, or spectral ground motion can be estimated in this manner.

The best estimates of the location and size of the main shock indicate a magnitude of approximately ML 5.6 at a depth of around 13 kilometres. The horizontal distance to points of interest in Newcastle is in the range 10 to 15 kilometres.

Using a range of ground motion attenuation functions [(1)(2)(3)(4)(5)(6)(7)], peak ground velocities of 145 mm/s to 175 mm/s and peak ground accelerations of 830 mm/s^2 to 2600 mm/s^2 are obtained for an earthquake of this magnitude and distance. We would anticipate that the true peak ground acceleration was towards the upper end of this range. It should be remembered that all these attenuation functions are for bedrock or “average” site conditions and it has been widely agreed [(8)(9)(10)(11)] that the site conditions in many parts of Newcastle caused amplification of the seismic waves.

For many detailed engineering studies, a complete time history of ground motion is required rather just peak or spectral values. Therefore an attempt was made to synthesise the time history of ground motion experienced in Newcastle. A number of different techniques have been proposed over the years to do this. Each of these have advantages and disadvantages. This paper discusses a method which the author calls the Phase Spectrum Method (PSM). A companion paper describes the Greens Function or superposition method.

THE PHASE SPECTRUM METHOD

The Phase Spectrum method for producing synthetic accelerograms has been developed independently by a number of workers including the author [(12)(13)].This method requires an understanding of the Fourier transform.

The Fourier transform of a time domain signal is a frequency domain signal. It is complex valued and may be considered in either its real and imaginary components or its amplitude and phase components. For this study the representation used is amplitude and phase. The amplitude spectrum represents the amount of signal present at the given frequency, while the phase spectrum defines when that energy is present.

The Phase Spectrum

The ground motion recorded at a site depends on three independent factors: the earthquake source, the transmission path, and the site effects. The basis of the PSM is that the phase spectrum only depends on one of these - the transmission path. The PSM assumes that the effects of the transmission path as recorded in one earthquake will be the same in another earthquake occurring at the same location. Once this has been determined, it may be used for other earthquakes occurring in the same place. This means that the phase spectrum recorded from an aftershock of the December 1989 earthquake may be used to represent the phase spectrum of the main shock.

The Amplitude Spectrum

The amplitude spectrum of the Fourier transform is affected by all three of the factors mentioned above: source, transmission path and site. A number of empirical functions have been determined to describe this variation. They give the Fourier amplitude (not phase) at a range of frequencies as a function of the earthquake magnitude, source to site distance and site conditions. This empirical function can be used together with a measured phase spectrum to produce a complete Fourier spectrum that is transformed back to the time domain to produce a synthetic accelerogram. This is the basis of the PSM.

The influence of the site can be catered for in two ways. In the first method, the empirical function itself may have a parameter that can be used to specify, in a very general manner, whether the site is rock or alluvial. In the second method, it is possible to explicitly modify the amplitude spectrum produced by the empirical function before it is combined with the phase spectrum.

THE TECHNIQUE USED

A suite of synthetic accelerograms has been produced for the Newcastle area using PSM. A number of different parameters or methods are involved in the production of each synthetic and this leads to the suite produced. The parameters are:

Empirical attenuation function

> Two different functions are used. One produced by Trifunac in 1976 (14) and one by McGuire in 1978 (15).

Site effect consideration

> The site effect may be taken in to consideration using the empirical function parameter or by applying an amplification to a section of the (bedrock) spectrum. The spectral amplifications applied here are a peak factor of two, four, six or eight using a raised cosine curve between 0.6 and 3.0 hertz with its peak at 1.8 hertz. As will be seen, the results show that the peak acceleration is amplified by much smaller amounts than the spectral amplitude.

Phase spectrum source

The phase spectra being used are from recordings of the aftershock made on the portable seismographs installed after the main shock in December 1989. The sites at which we have recordings are:

CLB	The BHP Recreation Club
HCG	Hillsborough-Charlestown Golf Club
KON	Kooragang Island
MOS	Near the Rankin Park Hospital
UNI	Newcastle University

Synthetics were produced using the phase spectrum from each of the CLB, KON, MOS and UNI recordings for comparison. The HCG site was much closer to the earthquake and was not considered appropriate to use in this case.

Random variation of amplitude spectrum

The empirical functions produce an amplitude spectrum that is a smooth function of frequency. Amplitude spectra of actual seismograms and accelerograms have a considerable random component superimposed on a smooth spectrum. This has been modelled by computing each spectral amplitude using a log-normal distribution with a standard deviation of 0%, 20% and 50% of the original spectral estimate.

RESULTS

If all the combinations of parameters mentioned above were included, there would be a very large number of different synthetic accelerograms. We have chosen representative values for each parameter and then varied each in turn. The results are summarised in the tables below and Figure 1 shows a typical synthetic time series.

Figure 1 - Typical Synthetic Time Series

For purposes of tabulation, only the peak ground acceleration has been presented. However, we do not believe it is a good indicator of damage potential of the accelerogram.

The tables below indicate the peak (horizontal) amplitude for some of the synthetic accelerograms produced. Each table corresponds to the variation of one of the parameters described in the previous section.

Table 1 shows the comparison between the two attenuation functions using a variety of phase spectra and site conditions. It shows that the functions give identical values for bedrock motion and that the Trifunac function gives values about 35% higher for alluvium.

Attenuation Function	Phase Spectrum Source	Site Condition	Peak Acceleration (g)
Trifunac	CLB	"Alluvium"	0.23
McGuire	CLB	"Alluvium"	0.17
Trifunac	KON	"Alluvium"	0.19
McGuire	KON	"Alluvium"	0.14
Trifunac	CLB	"Bedrock"	0.21
McGuire	CLB	"Bedrock"	0.21
Trifunac	KON	"Bedrock"	0.18
McGuire	KON	"Bedrock"	0.18

Table 1 - Variation Due to Attenuation Function

Table 2 shows the result of the various methods for considering site conditions. The amplification referred to in the table is spectral amplification at a narrow range of frequencies between 0.6 and 3.0 hertz peaking at 1.8 hertz. It shows that the peak motion is higher on alluvium than on bedrock as expected. It also shows that if one increases the spectral amplification, the peak ground motion also increases but to a much lesser extent.

Site Condition	Peak Acceleration (g)
“Alluvium”	0.23
“Intermediate”	0.22
“Bedrock”	0.21
Bedrock with amp of 2.0	0.23
Bedrock with amp of 4.0	0.25
Bedrock with amp of 6.0	0.26
Bedrock with amp of 8.0	0.26

Table 2 - Variation in Site Condition

Table 3 shows the variation due to different phase spectra for both the McGuire and Trifunac attenuation functions, assuming alluvial site conditions. It shows that this leads to a variation in peak amplitudes of about 25%.

Attenuation Function	Phase Spectrum Source	Peak Acceleration (g)
Trifunac	CLB	0.23
Trifunac	KON	0.19
Trifunac	MOS	0.24
Trifunac	UNI	0.20
McGuire	CLB	0.17
McGuire	KON	0.14
McGuire	MOS	0.18
McGuire	UNI	0.15

Table 3 - Variation in Phase Spectrum

Table 4 shows the variation caused by the addition of a pseudo-random signal to the amplitude spectra. This shows that adding such noise increases the peak amplitude of the time series produced by up to 20%.

Attenuation Function	Phase Spectrum Source	Pseudo-random Noise Amplitude (%)	Peak Acceleration (g)
Trifunac	CLB	0	0.23
Trifunac	CLB	20	0.24
Trifunac	CLB	50	0.27
Trifunac	KON	0	0.19
Trifunac	KON	20	0.20
Trifunac	KON	50	0.23
McGuire	CLB	0	0.17
McGuire	CLB	20	0.17
McGuire	CLB	50	0.20
McGuire	KON	0	0.14
McGuire	KON	20	0.14
McGuire	KON	50	0.16

Table 4 - Variation Due to Additive Random Signal

DISCUSSION ON SITE AMPLIFICATION

In the literature on site effects in general, and regarding the Newcastle earthquake in particular, there is confusion between spectral amplification and time series amplification.

Spectral amplification is the amplification of a particular frequency or band of frequencies. This is most easily seen and analysed using the Fourier amplitude spectrum. On the other hand, time series amplification is usually used to indicate the ratio of the peak amplitude of two time series. While these two types of amplification are related, they are most certainly not the same thing.

This can be seen from Table 2. The peak acceleration of the time series using a straight “bedrock” spectrum is 0.21g. If a spectral amplification of 4.0 at a narrow range of frequencies around 1.8 hertz is applied to this spectrum, the peak acceleration of the time series only increases to 0.25g, that is a factor of 1.2 (not 4.0).

The confusion between the two types of amplification is partially responsible for the widely varying values quoted for amplification at various sites in Newcastle (by the author as well as others). In summary, we are suggesting that a peak spectral amplification of a factor of four or six is not unreasonable. However, this only leads to amplification in the peak amplitude of the time series by a factor of about 1.25. If however, a structure on the site had a natural period near the sites natural period, its response will be high because of the amplification in ground motion at this frequency.

CONCLUSION

Using the most appropriate parameters, sixteen accelerograms designed to represent the December 1989 Newcastle earthquake were produced using the PSM. They yielded a mean peak ground acceleration of 0.23g.

Even relatively high spectral amplification at certain frequencies does not lead to high peak ground acceleration amplification. In the case presented here peak spectral amplification by a factor of eight at 1.8 hertz only lead to amplification by a factor of 1.25 in peak acceleration.

The synthetic accelerograms produced by this study are available in digital form for use in computer studies.

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