Deriving S_S and S_1 Parameters from PGA Maps

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SUMMARY

It has been recognised by SHARE (Seismic Hazard Harmonization in Europe) that the code requirement of multiple design levels, such as those required by EN 1473, PIANC etc, and the client's needs for performance based seismic design, require many of the existing 475 year return period peak ground acceleration (PGA) hazard maps to be updated. This requirement should lead to the update of nationally determined Eurocode 8 code maps.

The United States Geological Survey (USGS) already provide a useful web based tool, which defines PGA, S_S and S_1 coefficients for a return period of 2475 years from the Global Seismic Hazard Assessment Program (GSHAP) 475 year PGA maps and some other relevant resources. However, it has been shown, for example by the uses of Type 1 and Type 2 spectra in Eurocode 8, that the ratio between PGA and spectral ordinates is dependent on the predominant size of earthquakes in a given region. Lubkowski (2010) provided a methodology for converting 475 year PGA values to 2475 year values based on the level of seismicity. This paper will extend that study to provide a simple methodology to define the S_S and S_1 coefficients for a return period of 2475 years.

Keywords: seismic hazard, code maps, design criteria

1. INTRODUCTION

It has been recognised by SHARE (Seismic Hazard Harmonization in Europe) that the code requirement of multiple design levels, such as those required by EN 1473, PIANC etc, and the client's needs for performance based seismic design, require many of the existing 475 year return period peak ground acceleration (PGA) hazard maps to be updated. This requirement should lead to the update of nationally determined Eurocode 8 code maps.

The United States Geological Survey (USGS) already provide a useful web based tool, see https://geohazards.usgs.gov/secure/designmaps/ww/, which defines PGA, S_S and S_1 coefficients for a return period of 2475 years from the Global Seismic Hazard Assessment Program (GSHAP) 475 year PGA maps and other resources such as the United Facilities Criteria (2005). The tool clearly notes the values quoted from GSHAP are rough approximations based on the probabilistic 10%-in-50-year peak ground accelerations (PGA's). The GSHAP values are multiplied by 2 to approximate 2%-in-50-year PGA values, and then multiplied by 2.5 and 1.0, respectively, to estimate S_S and S_1.

This is a very useful resource; however, it has been shown, for example by the uses of Type 1 and Type 2 spectra in Eurocode 8, that the ratio between PGA and spectral ordinates is dependent on the predominant size of earthquakes in a given region. Lubkowski (2010) provided a methodology for converting 475 year PGA values to 2475 year values based on the level of seismicity. This paper extends that study to provide a simple methodology to define the S_S and S_1 coefficients for a return period of 2475 years.

The study is based on a more than fifty probabilistic seismic hazard studies carried out by Arup, in regions of low, moderate and high seismicity throughout the world. In addition this development will allow existing 475year PGA maps, such as those in Eurocode 8, to be used define multiple level performance seismic design criteria, where the National Annex does not provide the necessary information. This will be particularly useful in the early stages of projects before the development of a site specific hazard assessment.

2. SEISMIC HAZARD DATABASE

The database of probabilistic seismic hazard assessments (PSHA) is based on more than fifty seismic hazard studies carried out at Arup, in numerous countries around the world, as detailed in Table 2.1.

Table 2.1. Countries Represented in Seismic Hazard Database

Africa	Americas	Australasia	Central Asia	Europe	Middle East
Algeria Egypt	Argentina Chile Mexico Panama Puerto Rico	Australia Indonesia Malaysia Philippines Thailand	China India Japan Kazakhstan Korea Kyrgyzstan Pakistan Turkmenistan Uzbekistan	England Greece Hungary Italy Malta Scotland Turkey Wales	Azerbaijan Iraq Iran Jordan Kuwait Lebanon Oman Saudi Arabia UAE

Many of these studies have not been published, however, for the following countries details can be found in the references noted below:
- England, Scotland & Wales (Lubkowski, Alarcon & Pappin, 2010)
- Jordan (Arango and Lubkowski, 2012)
- Hungary (Lubkowski and Pappin, 1998)
- Turkmenistan (Lubkowski, Alarcon & Razak, 2010)
- Kuwait, Oman, Saudi Arabia & UAE (Pascucci et al, 2008)

Table 2.2 notes the number of studies and whether they fall into regions of low, moderate or high seismicity.

Table 2.2. Number of Seismic Hazard studies

Seismic zone classification	10% probability of exceedance PGA (g)	Number
Low seismicity studies	PGA ≤ 0.10g	25
Moderate seismicity studies	0.10 < PGA ≤ 0.3g	20
High seismicity studies	PGA > 0.30g	12
Total number of studies		57

In each case the calculations were carried out using the program *Oasys* SISMIC, which calculates the annual frequency or rate at which specified hazard values are likely to be exceeded at a site due to area and fault sources. The program has recently been validated using the Pacific Earthquake Engineering Research Center (PEER) tests (Thomas et al, 2010).

Figure 1 shows the elements used to carry out the PSHA. These elements are as follows:
- A definition of the seismotectonic source zones that define the geographical variation of earthquake activity. These source zones are based on the distribution of observed seismic activity together with geological and tectonic factors and represent areas where the seismicity is assumed to be homogenous; (i.e. there is an equal chance that a given earthquake will occur at any point in the zone). Source zones can be described as being area sources or fault sources.

- A model of earthquake recurrence with respect to earthquake magnitude. There are generally more, small low magnitude earthquakes than high magnitude earthquakes. Observed seismicity or geological data can be used to determine the earthquake recurrence relationships.
- A ground motion prediction model (also known as attenuation relationship) is required which defines what ground motion should be expected at the Site location due to an earthquake of known magnitude at known distance from the Site. Published attenuation relationships are derived from observations from past earthquakes and/or from theoretical modelling of the source and transmission mechanisms. Many give a measure of the variability of the ground motion parameter (i.e. the range of ground motion amplitude found to correspond to a given magnitude and distance).

For the studies reported in Table 1 the results are for the geometric mean component of ground motion on bedrock ($V_{s30} \geq 760m/s$).

The basic methodology adopted is based on that originally proposed by Cornell (1968). In each case a consistent methodology was used, so there is compatibility between analyses.
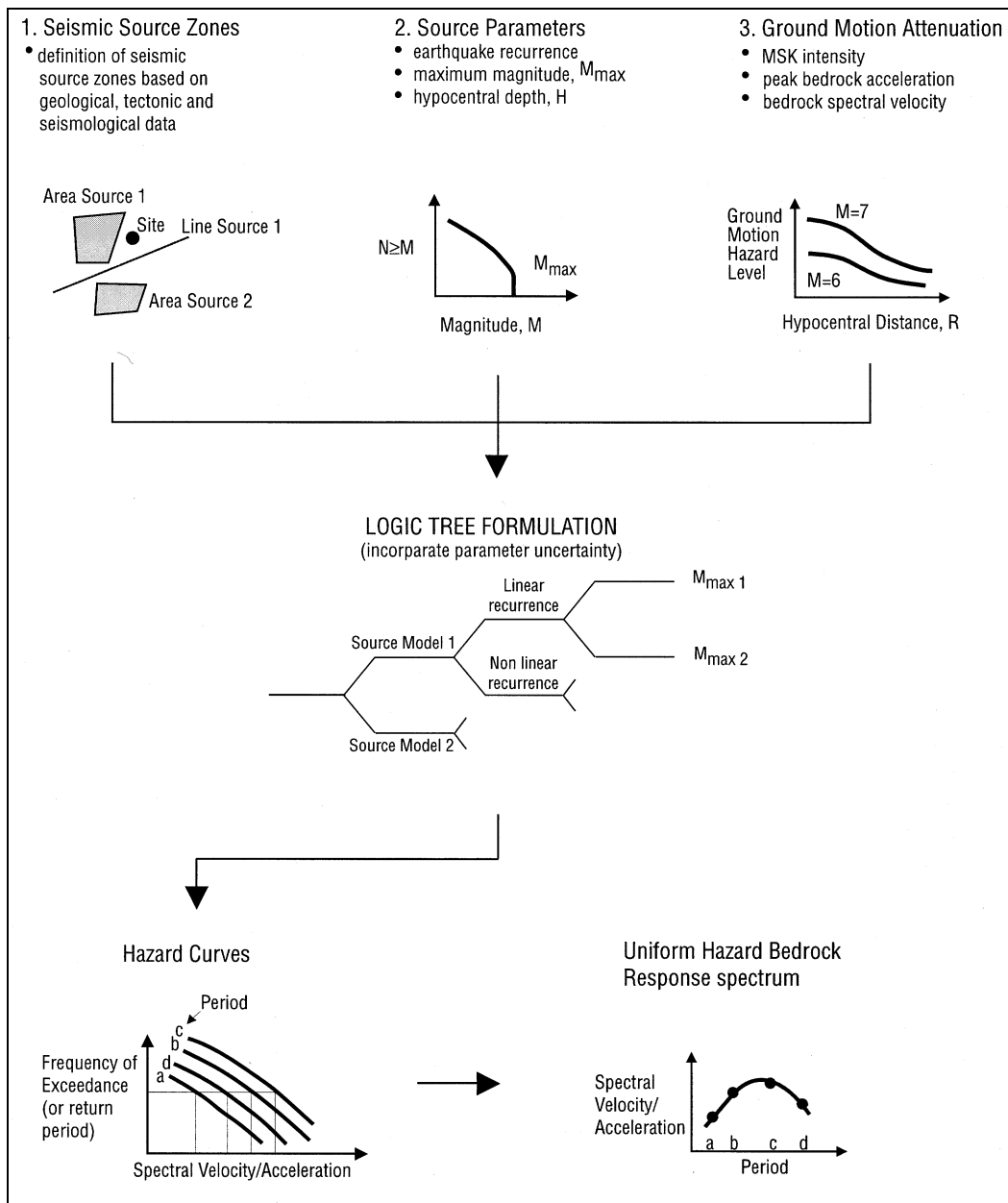

Figure 1: SISMIC Seismic Hazard Assessment Methodology

3. RATIO OF SPECTRAL ACCELERATION TO PGA

Traditionally it has been assumed that ratio of short period spectral acceleration (S_s) to PGA is about 2.5. Figure 2 presents this ratio (the blue diamonds) for the seismic hazard studies in the Arup database for a range of return periods ranging from 100 years to 10,000 years. The average S_S to PGA ratio is calculated as 2.265, which compares well with the general assumption. As can be seen from Figure 2 and Eqn 3.1 there is a slight variation with increasing PGA.

$$S_s/PGA = 0.3386\ PGA + 2.1696 \qquad \text{(Eqn 3.1)}$$

Figure 2 also presents ratio of long period spectral acceleration (S_1) to PGA (the red squares), which was assumed to be 1.0 by the USGS web tool. The average S_1 to PGA ratio is calculated as 0.753, but as can be seen from Figure 2 and Eqn 3.2 there is a significant variation with increasing PGA.

$$S_1/PGA = 0.5776\ PGA + 0.5967 \qquad \text{(Eqn 3.2)}$$

It is also clear from Figure 2 that there is significant variation in data around each of the best fit lines. This is partly a function of the different tectonic environments included in the database, stable continental, shallow crustal and subduction, which will all give rise to different spectral characteristics.
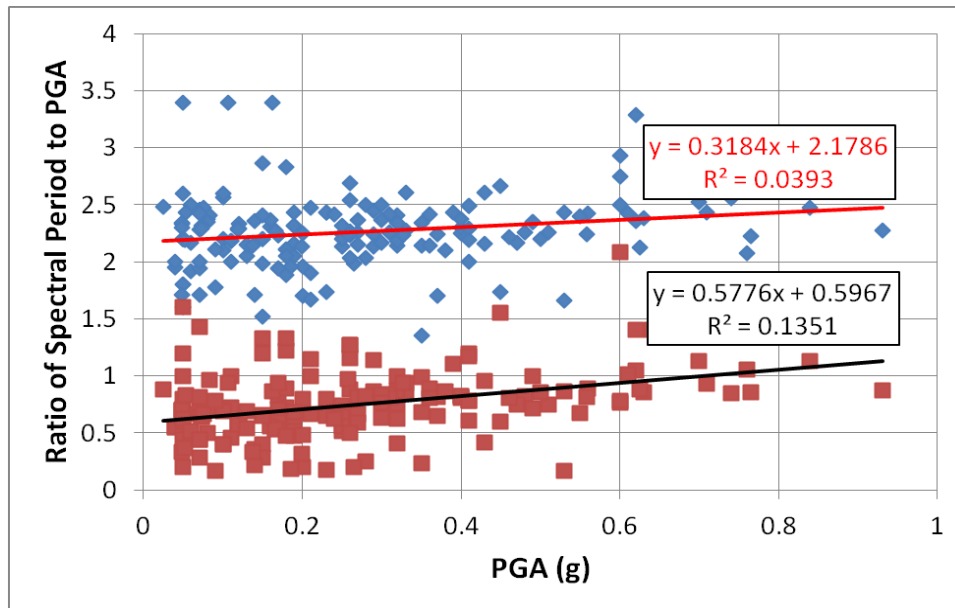

Figure 2. Ratio of Spectral Period to PGA from Seismic Hazard Database

4 DERIVATION OF SEISMICITY FOR DIFFERENT RETURN PERIODS

Lubkowski (2010) derived the variation in PGA by using the methodology suggested in the bridges section of Eurocode 8 (EN1998-2). This presented a methodology for deriving the PGA (also known as seismic action A_{gR}) for different return periods. A formula (Eqn 4.1) is provided which is dependent on an exponent k. Eurocode 8 states *"...the value of the exponent k depends on the seismicity of the region. Normally, values in the range of 0.30 – 0.40 may be used...",* but no definitive data for the appropriate value of k in regions of low, moderate or high seismicity is provided.

$$\frac{a_g}{a_{gR}} = \left(\frac{T}{T_R}\right)^k$$

$$\text{(Eqn 4.1)}$$

Where, $a_{g,R}$ is the reference peak ground acceleration; T_R is the reference return period; and k is an exponent which depends on the seismicity of the region.

The same methodology has been applied in this study, but for short period and long period spectral values. Figures 3 and 4 show the results of the analyses carried out, for short and long periods respectively. Figure 3 shows that the slope of the seismic hazard curve at short period becomes steeper in areas of higher seismicity. Interestingly the slope of the seismic hazard curve at long periods appears to be independent of seismicity.
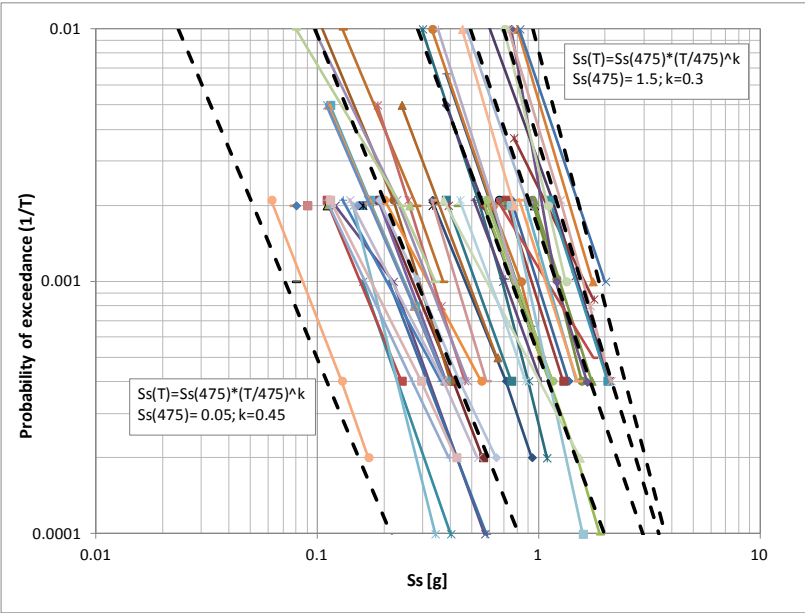
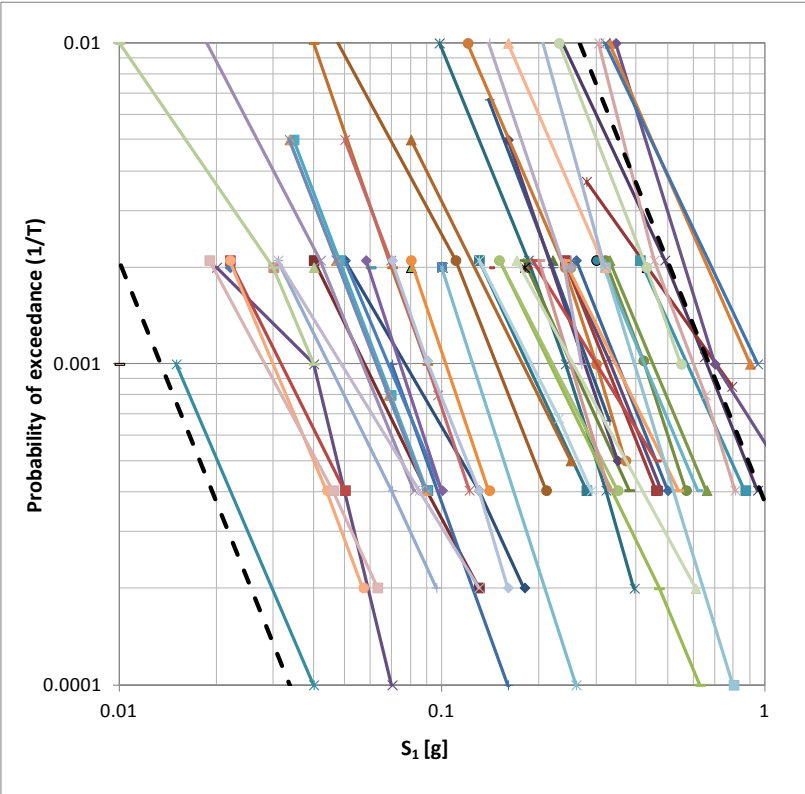Figure 3. Short Period (S$_s$) Seismic Hazard Curves

Figure 4. Long Period (S$_1$) Seismic Hazard Curves

Tables 4.1 and 4.2 present the coefficient k for short and long periods respectively.

Table 4.1. Selection of Component k for Short Periods

475 Year S_S	0.20g	0.55g	0.90g	1.20g	1.50g
k	0.46	0.42	0.39	0.35	0.30

Table 4.2. Selection of Component k for Long Periods

475 Year S_1	0.01g	0.02g	0.05g	0.10g	0.20g
k	0.40	0.40	0.40	0.40	0.40

5. CONCLUSIONS

A study was carried out to determine the S_S and S_1 coefficients that can be estimated from 475 year PGA maps, such as GSHAP. This was based on the results of more than fifty different seismic hazard studies around the world, which were carried out using a consistent methodology.

The evaluation could be extended to examine the variation between different tectonic regimes, such as stable continental, shallow crustal and subduction.

It is recommended that methodology is only used in the early stages of a project and it is not intended as a substitute for a site-specific seismic hazard study.

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