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Simulation of Bedrock Motion to Obtain PGA Values

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ABSTRACT

This study is focused on producing the Peak Ground Acceleration (PGA) values for important cities in Sri Lanka, which would provide the base to develop the national annex to the *Euro Code*, the current guideline in designing structures. In order to find out the magnitude and the epicenter distance of a 475-year return period earthquake, an earthquake catalog was developed. To simulate the bedrock motion *FLAC* Software, which uses the *Finite Difference* approach, was used. Five 2-D *FLAC* models representing five cross sections of Sri Lanka were developed. Due to the lack of local data records, a dataset of seven earthquakes with the magnitude of a 475-year return period was selected from the Pacific Earthquake Engineering Research Center (PEER) database. The model was then analyzed—one cross section for each of the seven earthquakes. The resultant acceleration time histories were converted into a response spectrum, and the average spectrum for each city was obtained.

1. INTRODUCTION

Sri Lanka was previously considered a country safe against earthquakes. But with the recent tremors around the country and the occurrence of intraplate earthquakes in the world, an alarm has been triggered especially for structural engineers. Sri Lanka is situated far from plate boundaries, but with the increase of intraplate events around the world, no country can be considered 100% safe against earthquakes. One of the best examples is the recent earthquake in Bhuj, India, in 2001. The distance to the epicenter from the plate boundary was approximately 400 km. Therefore, distance from a plate boundary is not a deciding factor in whether or not an earthquake will occur.

With recent development in Sri Lanka, construction of many high rise and important structures have started. As a result, structural engineers have faced the issue of designing these structures against earthquake loading due to the unavailability of Peak Ground Acceleration (PGA) values in Sri Lanka. As a consequence, the structural engineers use the Indian or Australian codes to design these structures. Hence, the development of seismic hazard microzonation has become very important in Sri Lanka. This research is targeted on developing the PGA values and response spectrums for important cities in Sri Lanka.

2. METHODOLOGY

Five parallel cross sections were selected, as shown in Figure 1, covering major cities in Sri Lanka. Each cross section starts at the western costal line and ends at the eastern coastal line. The major cities of each cross section were identified. Variations of ground profiles are drawn by plotting the ground elevation from the mean sea level obtained at every 100 m intervals along the selected cross sections. The ground elevations are extracted from Google Earth. It must be noted that the ground profile is assumed to be the same as the bedrock profile.

For the numerical simulation of the ground motion in two-dimensions, a finite difference model for each selected cross section was developed using *FLAC* Software. *FLAC* is a two-dimensional finite difference program for engineering mechanics computation.

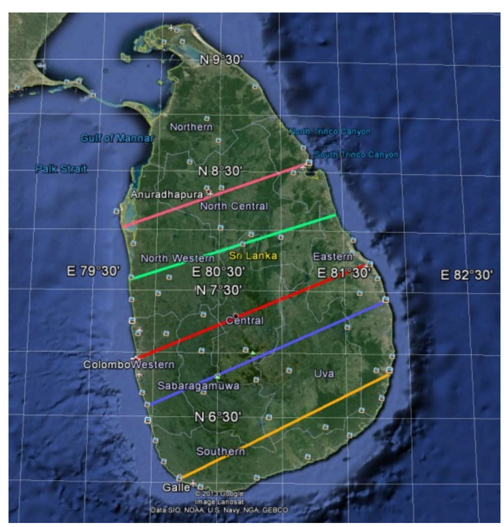

Figure 1. Analyzed cross sections

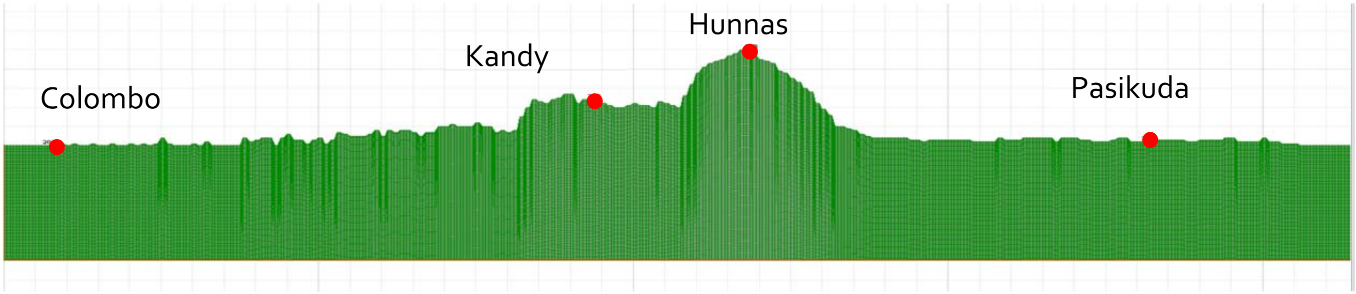

Figure 2. A developed FLAC model

FLAC's analysis capabilities include a wide range of dynamic problems in disciplines such as earthquake engineering, seismology, and mine rock bursts.

Each *FLAC* model is equivalent to the distance of the cross section and depth of 15 km from the mean sea level and discretized into the quadratic elements with the approximate size of 100 m x 100 m. To get rid of numerical difficulties, the model is developed by the quadratic elements avoiding the use of triangular elements. Two vertical edges at the boundary are modeled as absorbing boundaries, and the horizontal base of the model is fixed. Figure 2 illustrates the *FLAC* model developed for the third cross section

The length of an element *Δ* is to be less than or equal to one-tenth of the wave length *λ* of the input wave.

$\Delta \leq \lambda/10$

$\lambda = C/f$

Where *C* is shear wave velocity and *f* is the highest frequency. The shear wave velocity for the rock profile (igneous rock), which is underneath Sri Lanka, is 5000 m/s. The assigned material properties are as follows:

- Density = 2000 kg/m^3
- Bulk Modulus = 0.3 GPa
- Shear Modulus = 0.3 GPa

The explicit Lagrangian calculation scheme and the mixed-discretization zoning technique are used in *FLAC* to find an approximate solution for the 2-D wave equation. Because no matrices are formed, large 2-D calculations can be made without excessive memory requirements. The drawbacks of the explicit formulation (i.e., small time step limitation and the question of required damping) are overcome to some extent by automatic inertia scaling and automatic damping that do not influence the mode of failure. However, a 0.005 second time step is used in this analysis.

2.1. Input Acceleration

After identifying the fault location and the moment of magnitude of the earthquakes, it is essential to select the set of seven acceleration time histories recorded at the outcrop of the bedrock corresponding with the considered distance and the moment of magnitude. However, the number of recorded acceleration time histories (Earthquake records) in Sri Lanka is very few, and their magnitude is considerably lower than intended magnitudes of the earthquakes. But for this analysis a set of seven acceleration records are needed. So to overcome this issue, the seven sets of acceleration records measured approximately at the required distance from the epicenter of an earthquake of the relevant magnitude were selected from USGS and PEER databases. It is important to note that these records were measured at the bedrock.

The recorded acceleration time histories at the outcrop of the bedrock have to be modified for input at the base of the *FLAC* model. Therefore, each acceleration history is modified by deconvolution analysis using a one-dimensional wave propagation code. So each of the deconvoluted records is then applied at the base of the model to obtain the response at the free surface of the model.

The next important step is to predict the magnitude of future earthquakes which can occur at the faults. This could be done through the data accumulated to formulate the earthquake catalog and a Gutenberg-Richter relationship. First, a dataset within a diameter of 200 km was selected from the newly completed catalog by this study.

By using the dataset in Table 1, a Gutenberg-Richter relationship, which describes the relationship of the annual rate of exceedance that is one over the return period of an earthquake (N) and the magnitude of the earthquake, was formulated as seen in Equation 1.

From the equation, developed relationship for a return period of 475 years yields a respective magnitude of 6.5. So when selecting the acceleration histories from the databases, the earthquake records with the magnitudes around 6.5 were selected.

Table 1. The dataset within 200 km radius

No	Year	Month	Date	Latitude /(North)	Longitude /(East)
2	1615	4	14	6.88	79.86
11	1823	2	9	7.00	80.00
14	1823	11	26	7.00	80.00
19	1843	6	19	6.90	79.90
20	1848	3	1	6.92	79.87
25	1857	8	16	7.00	80.00
42	1866	12	19	7.00	80.00
47	1871	9	1	6.92	79.87
48	1871	12	1	7.40	81.00
53	1882	1	1	8.60	81.20
60	1891	4	7	7.40	81.00
65	1900	9	9	6.92	79.87
84	1939	8	7	4.00	77.50
86	1938	9	10	7.50	79.00
103	1953	1	29	6.70	82.50
108	1956	12	15	6.50	78.00
252	1986	8	20	4.60	78.90
267	1989	10	15	2.80	79.00
280	1993	12	6	6.82	78.30
296	1997	11	5	3.00	79.00
301	1998	9	1	5.49	78.24
303	1998	11	17	5.51	77.78
323	2003	9	7	8.31	79.09
347	2009	4	15	6.80	82.62
348	2010	7	25	6.60	76.78
350	2011	11	19	3.96	79.03

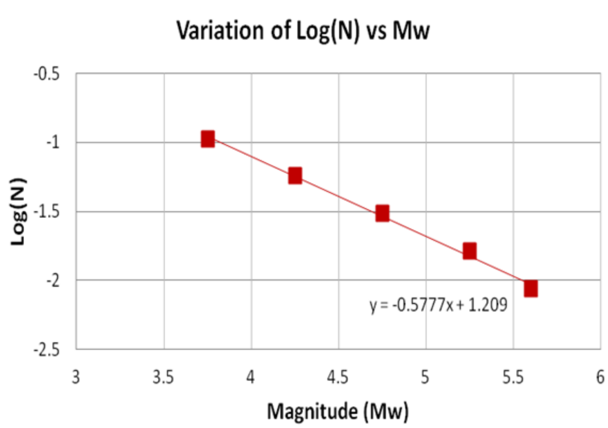

Figure 3. Variation of log(N) versus Mw. Gutenberg-Richter relationship

Table 2. Selected earthquakes

No.	Mw	Closest distance(km)	Location	PGA (g)
1	7.1	93.8	Aqaba	0.097
2	7.6	90.2	Chichi	0.118
3	6.9	94.2	Kobe	0.141
4	6.7	84.2	Northridge	0.1
5	6.9	83.6	Loma Prieta	0.117
6	6.8	83.0	Taiwan	0.028
7	6.5	97.1	Friuli	0.033

$$N = \frac{1}{475} \qquad x = \frac{1.209 - \log(N)}{0.5777} \approx 6.5 \quad (1)$$

As described earlier, these earthquake records were selected considering the area and the ground profile.

As these records are not from a local station, it is a must to modify these records in order to be used in the analysis for local conditions. The general procedure is as follows.

After selecting an earthquake, the PGA value for a required distance was found using the attenuation relationships. There were several such relationships developed. Then each PGA value of the above records was divided by the PGA value of the required distance to obtain the scaling factor. Finally each accelerogram was scaled using the above factor and obtained the input acceleration time history for the model.

The records were subject to baseline correction in order to avoid continuing residual displacements due to the integral of complete time history not always equaling zero.

This acceleration time history was then applied at the base of the model, and the responses were taken at the required points which represent the cities. These response acceleration time histories were then subject to Fourier transformation. and the Spectral acceleration values were obtained

3. RESULTS

The acceleration history of each earthquake was applied to the base and the resultant history was obtained at predefined points which represent the location of the cities. These resultant histories were then converted into spectral acceleration values. After a model is subjected to all the seven earthquakes, the seven spectral accelerations for each city were averaged and the final spectral values were obtained. After this, the average PGA value for each city was taken.

PGA values for some cities are showed in Table 4.

Table 4. PGA values

City	PGA Value (g)
Colombo	0.12
Kandy	0.06
Kaluthara	0.14
Nuwara Eliya	0.04
Trincomalee	0.03
Batticaloa	0.03

4. CONCLUSION

The seismic hazard zonation map for Sri Lanka was prepared depending on the PGA values obtained by the numerical simulation. The country was divided into three zones depending on the values.

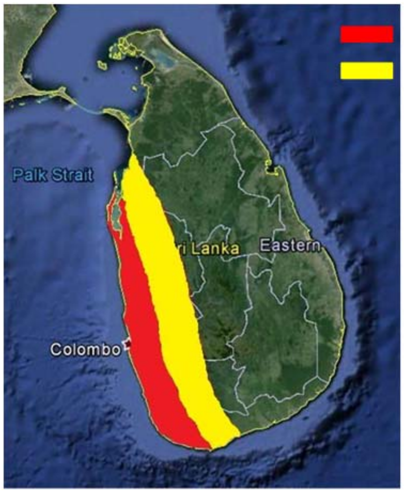

Figure 4. Micro zonation map

Table 5. PGA values by zone

Zone	PGA Value(g)
Zone 1	0.12
Zone 2	0.07
Zone 3	0.05

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