SEISMIC RISK IN COLOMBO – PROBABILISTIC APPROACH

S.B. Uduweriya[1], K.K.Wijesundara[2] and P.B.R. Dissanayake [1]

[1] Departments of Civil Engineering, Faculty of Engineering, University of Peradeniya
[2] Department of Civil AND Infrastructure Engineering, Faculty of Engineering, South Asian Institute of Technology and Medicine (SAITM), Sri Lanka. Email: kushan.saitm@gmail.com

ABSTRACT

The objective of this study is to develop a response spectrum for Colombo City of Sri Lanka which can be used for design community of Sri Lanka. In this study probabilistic seismic hazard assessment was carried out for the Colombo city to produce response spectrum. A comprehensive earthquake catalogue has been complied for the region bounded by latitudes 0ºN to 20ºN and longitudes 70ºE to 90ºE based on historical and instrumental earthquake data from 1063 to 2012. The PGA and SA were calculated within logic tree frame work incorporating different parameters such as maximum cutoff magnitude and ground motion predictive equations for shallow crustal intraplate earthquakes. The study produced a PGA of 0.1g for 10% probability of exceedance in 50 years or 475 year return period.

***Keywords*:** Earthquake Catalogue, PGA, SA, attenuation

1. INTRODUCTION

Final paper should not exceed 4 pages including references, tables and illustrations without pagination. Abstracts, extended abstract or the final paper should be written in Standard (either American or British Style) English only. Font should be Times New Roman. For the title, font size should be 16 and bold. Font size should be 10 for other parts. The manuscript should be divided into sections such as Abstract, Key words, Introduction, Materials and methods, Results, Discussion and References. Sri Lanka is located within a tectonic plate known as "Indo-Australia plate". According to the historical records a very few number of earthquakes were recorded within the country. Historical records indicate that there was a devastating earthquake (Mw=6.4) in 1615 in Sri Lanka. The epicenter of this earthquake was situated in Colombo and it caused to damage about 200 houses with a casualty figure of over 2000. The Indian Ocean Tsunami hit on 26th December 2004 following the Magnitude of 9.4 due to Sumatra earthquake damaged most of the coastal areas in Sri Lanka. But there were no observed significant direct damages due to ground shaking. After the Tsunami many local and international organizations were involved in reconstruction process. Local insurance companies demanded for paying damaged properties. They highly emphasized that damaged buildings were not designed to accommodate seismic and tsunami loads. So, there is a demand for designing of structures for earthquake loadings.

Now Sri Lanka is developing fast after the end of civil war in 2009. Government of Sri Lanka has taken necessary action to orient the country's development plans to meet Millennium Development goals. According to that Colombo city will be developed as commercial hub such as Singapore and Dubai. Lot of high rise buildings will be constructed in the Colombo city. Then seismic resistant design will be playing a major role in the design process. There are no specific guidelines for seismic resistant designs available locally on how to meet the new requirements in order to satisfy the expectations of various parties. Cost factor is very important in any project. So, new optimizations tools will be used to carrying out economical designs. The performance based design methodology is the most common method that engineers can be used to produce economical designs. The objective of this study was set out to fulfill this requirement by introducing a suitable response spectrum by carrying out a Probabilistic Seismic Hazard Assessment (PSHA) for Colombo City. Because PSHA is the most widely used procedure to determine the ground motion parameters such as peak ground acceleration to which structure has to be designed by an engineer.

The basic procedure of PSHA was initially developed by Cornell [1968] and its computerized form was implemented by McGuire [1976 and 1978]. Modern PSHA has gradually evolved by incorporating additional terms and computational tools in order to better represent seismic hazard. The basic methodology involves computing how often a suite of specified levels of ground motion will be exceeded at the site. The general procedure for a Cornell-McGuire PSHA comprises four fundamental steps.

The first step involves the identification and delineation of all potential sources of seismicity that may affect the site or sites of interest. These sources of seismicity may be represented as area sources, fault sources, or, point sources, depending upon the geological nature of the sources and available data. In the second step, the temporal behavior of earthquakes is assumed to follow a Poissonian process and it is determined for each source by establishing a magnitude recurrence relationship over the range of magnitudes that are likely to be generated by each seismic source. The third step involves the use of GMPEs to establish the conditional probability of exceedance of a pre-specified ground motion value for each site given the occurrence of an earthquake at a particular magnitude and location and the final step of the analysis computes the annual number of events that produce a ground motion parameter, e.g. SA that exceeds a specified level, z. This number of events per year, ν, is also called the “annual frequency of exceedance”. The inverse of ν is called the “return period”. Several probability distributions for each seismic source defined in the previous steps are introduced.

2. EARTHQUAKE CATALOGUE

The An earthquake catalogue was compiled for an area bounded by latitudes 0ºN to 20ºN and longitudes 70ºE to 90ºE based on historical and instrumental earthquake data from 1063 to 2012. Data was collected from different sources such as Menon et al.(2010), Chandra (1977), Rao and Rao (1984), Guha and Basu (1993), Iyengar et al.(1999), Jaiswal and Sinha (2007), Abeykoon (1995), Navin Peris (2007), Earthquake catalogue prepared by National Disaster Management Authority, New Delhi, India (2011) and Internationally recognized earthquake databases on the internet, such as the National Earthquake Information Centre (NEIC), the International Seismological Centre (ISC), the Incorporated Research Institutions for Seismology (IRIS), and the Geological Survey and Mines Bureau, Sri Lanka (GSMB). Duplicate events were manually detected and deleted.

To remove foreshocks and aftershocks Declustering method proposed by Gardner and Knopoff (1974) was used. Completeness analysis of the catalogue was done according to the method proposed by Stepp (1973).

3. SEISMIC SOURCE ZONATION AND MAGNITUDE RECURRENCE

The seismic zonation is usually defined by associating the seismic to the tectonic and geologic settings in the area. The major tectonic structures aground Sri Lanka are located on the boundaries of the Indo-Australian plate. The nearest structure are the Sumatra subduction zone to the east and the extensional/transform fault structures of the central Indian Ridge to the west.

The geological history of Sri Lanka is such that90% of the island consists of Precambrian metamorphic and granitoid rocks. The Precambrian basement is divided into three major units: central Highland Complex (HC), Wanni Complex (EC) and the Vijayan Complex (VC). The Kadugannawa Complex (KC) is a minor unit within the Highland Complex. HC is the oldest unit thrusting upward to form the central highlands with the highest uplift along a SW-NE-ENE belt from Galle-Rakwana- Horton Plains to Batticaloa. The uplift in the Jurassic (post-Precambrian) period was attributed to the movement of the Sri Lanka mini-plate in S-SE direction relative to the Indian plate (Vithanage ,1995).

Numerous lineaments were therefore identified in the HC with major lineaments along the belt of highest uplift and the N-S trending Mahaweli lineament where the Mahaweli River takes a straight course for about 60km. The micro-seismicity within the island recorded by the Kotmale micro-seismic network could be closely associated with these lineaments in the central highland region (Vitanage, 1995 and Fernando,Kulasinghe,1986).

Seismicity of Sri Lanka that could have an impact on the island is located outside as well as within the island. Various researchers have studied the seismicity and tectonics within and outside of Sri Lanka in order to highlight the potential seismic hazard. Many Indian scientists have carried out studies to define seismic characteristic of peninsular India. A. Menon, T. Ornthammarath, M. Corigliano, and C. G. Lai had carried out a Probabilistic Seismic Hazard Macrozonation of Tamil Nadu in Southern India in 2010. They have scientifically identified eleven seismogenic zones related to the Southern part of the India around Tamil Nadu including Sri Lanka. Based on above information, Same seismogenic zones classification is used for this study because Tamil Nadu is geographically very close to Sri Lanka. Figure 1 shows these seismic zones.

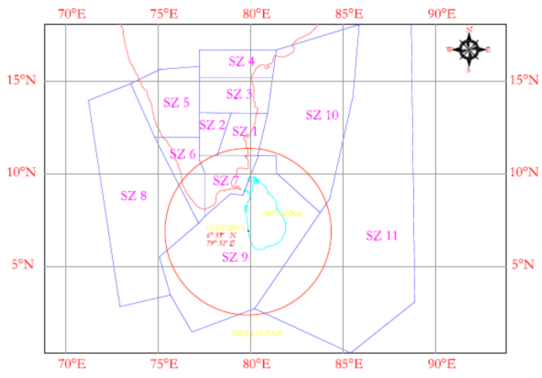

Figure 1: Different Seismic Zones

Eight out of these eleven seismic zones are related to the current study. Then, Truncated Gutenberg-Richter relationships were developed to these seismic area sources. Table 1 shows the parameters *a* and *b* of the G-R Recurrence relationship in the current study.

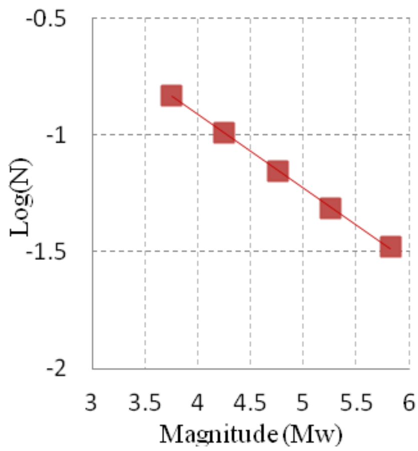

Figure 2: Different Seismic Zones

4. ATTENUATION RELATIONSHIPS

Three ground motion attenuation relationships were used in this PSHA to derive the PGA and the spectral acceleration values. The relationship by Abrahamson and Silva (1997) was developed from earthquakes recorded in worldwide specially west and north America and recommended to use for shallow crustal events worldwide. Raghu Knath and Iyenga r(2007) developed an empirical relationship for Peninsular India based on a stochastic seismological model and subsequently compared to instrumental data from Koyona (1967) and Bhuj (2001) earthquakes in India. In addition to these two equations, the attenuation relationship developed by Campbell and Bozorgnia (2008) which suitable for western United States and similar tectonically active regions of shallow crustal faulting has been chosen. The shortest distance to the area source boundary was used as epicentral distance in these attenuation relationships to calculate the PGAs and spectral accelerations except Zone 9 which Sri Lanka lies.

5. DEAGGREGATION AND LOGIC TREE

The hazard curve gives the combined effect of all magnitudes and distances on the probability of exceeding a given ground motion level. Since all of the sources, magnitudes, and distances are considered together, it is difficult to understand of what is controlling the hazard from the hazard curve by itself. To provide insight into what events are the most important for the hazard, the hazard at a given ground motion level is broken down into its contributions from different earthquake scenarios. This process is called deaggregation [e.g. Bazzurro and Cornell, 1999]. This process was carrying out for Zone 9 to find the PGA and SA.

Logic tree methodology was used to address the epistemic uncertainty of various parameters and relationships in the PSHA calculation. The maximum cut off magnitude is based on the maximum historical earthquake (MHE) in each source zone of the earthquake catalogue. As an alternative, the MHE increased by 0.3 units has been considered. 60% of weights have been assigned to the maximum magnitude and balance 40 % of weight was assigned to MHE increased by 0.3 units. For GMPEs, it was difficult to assign a higher weight to one equation over the other, and hence equal weights have been assigned. Figure 3 shows this distribution.

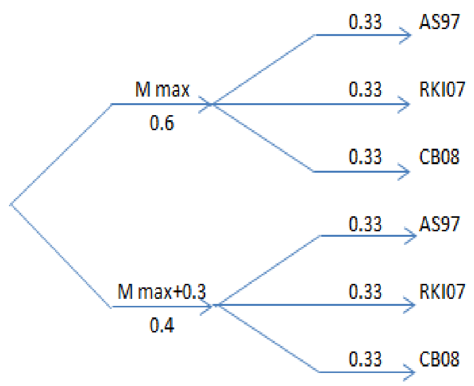

Figure 3: Parameters and weighting factors adopted in the logic tree.

6. RESULTS

Figure 4 shows the calculated Response Spectrum for 475 year return period at bed rock level in Colombo. The results shows that the PGA at rock site for 10% of probability of exceedance in 50 years or 475 years return period is 0.1g for Colombo City. Furthermore, Figure 4 shows comparison of corresponding response spectrum of 0.1g ground acceleration at the bed rock as specified in Indian Code.

The same Response Spectrum was obtained for the PGA at rock site for 2% of probability of exceedance in 50 years or 2475 years return period. Because moment magnitude related to 475 year return period and 2475 year return periods were out of the TGR recurrence relationship. Then the maximum possible earthquake (M max or M max+0.3) was considered as the related magnitude for these two cases in GMPEs.

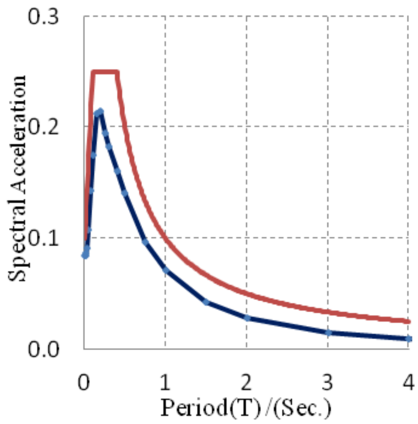

Figure 4- Design Response Spectrum.

7. CONCLUSION

The scope of the research work presented here was to carry out probabilistic seismic hazard assessment and to develop Response Spectra for Colombo City of Sri Lanka which can be used for design community in Sri Lanka. The study produced a PGA of 0.1g for 10% probability of exceedance in 50 years or 475 year return period.

8. REFERENCES

[1] Abrahamson, N.A. and Silva, W.A.[1997], Emperical response spectral attenuation relations for shallow crustal earthquakes, Seism. Res. Lett. 68, no. 1 94-127.

[2] Abrahamson, N.[2006], seismic Hazard assessment: problems with current practice and future developments, First European conference on earthquake engineering and seismology.

[3] Biswas, S., Majumdar, R.K. [1997] “Seismicity and tectonics of the Bay of Bengal: Evidence for intraplate deformation of the Northern Indian Plate”, Tectonophysics, Vol. 269, pp. 323-336.

[4] Campbell, K. W., and Y. Bozorgnia[2008] , NGA ground motion model for the geometric mean horizontal component of PGA, PGV, PGD and 5% damped linear elastic response spectra for periods ranging from 0.01 to 10 s, Earthq. Spectra 24, no. 1, 139–171.

[5] Chandra, U. [1977] “Earthquakes of Peninsular India - A seismotectonic study”, Bulletin of the Seismological Society of America, Vol. 87, No. 5, pp. 1387-1413.

[6] Guha, S.K., Basu, P.C. [1993] “Catalogue of earthquakes (M ≥ 3.0) in Peninsular India”, Tech. Document No. TD/CSE-1, Atomic Energy Regulatory Board, Mumbai, India, pp. 1-70.

[7] Iyengar, R.N., Sharma, D., Siddiqui, J.M. [1999] “Earthquake history of India in medieval times”, Indian Journal of History of Science, Vol. 34, No. 3., pp. 181-237.

[8] Jaiswal, K., Sinha, R. [2007] “Probabilistic seismic-hazard estimation for peninsular India,” Bull. Seismol. Soc. Am. Vol. 97, No. 1, pp. 318–330

[9] Johnston, C., Seismic moment assesment of earthquakes in stable continental regions-I Instrumental seismicity. Geophysics. J. Int. [1996],124,381-414.

[10] Rao, R.B., Rao, S.P. [1984] “Historical seismicity of Peninsular India”, Bulletin of the Seismological Society of America, Vo. 74, No. 6, pp. 2519 – 2533.

[11] Rao, R.B. [1992] “Seismicity and geodynamics of the low-to high-grade transition zone of Peninsular India”, Tectonophysics, Vol. 201, pp. 175-185.

[12] Rao, R.B. [2000] “Historical seismicity and deformation rates in the Indian Peninsular Shield”, Journal of Seismology, Vol. 4, pp. 247 – 258.

[13] Ramasamy, S.M. [2006] “Remote sensing and active tectonics of South India”, International Journal of Remote Sensing, Vol. 27, No. 20, pp.

4397 – 4431.

[14] Ramasamy, S.M., Balaji, S. [1995] “Remote sensing and Pleistocene tectonics of Southern Indian Peninsula”, International Journal of Remote Sensing, Vol. 16, No. 13, pp. 2375 – 2391.

[15] Menon A, Ornthammarath T, Corigliano M, Lai CG [2010] “Probabilistic Seismic Hazard Macrozonation of Tamil Nadu in Southern India” Bull. Seism. Soc. Am. Vol. 100, no. 3, pp. 1320-1341.

[16] L. A. Zadeh, “*Fuzzy Sets*,” Journal of Information and Control, vol. 8, pp. 338-353, 1965.