A Numerical Analysis of the Influence of Bedrock Profile on the Seismic Wave Propagation Through Sri Lanka

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ABSTRACT: Sri Lanka has been considered as an aseismic country in the past considering the large distance from the island to the active plate boundaries. However, with the increased degree of urbanization the possible impact of intraplate earthquakes on population centres within the island has become important. In this context, deterministic and probabilistic seismic hazard assessments have been carried out by few researchers so far. However, these studies haven't considered the influence of variation of bedrock profile on the seismic wave propagation. In the study presented here, a numerical simulation is carried out to investigate the effect of variation of the bedrock profile on the seismic wave propagation through Sri Lanka. The acceleration time histories of seven real time earthquake record, selected from the PEER data base were used as input in a numerical finite difference model simulating the two dimensional bedrock response. The resultant spectra at the bedrock surface thus obtained are compared with those derived from the early studies. The comparison clearly shows the effect of ground elevation profile on seismic wave propagation, which should be taken into account especially when designing earthquake resistant structures in higher elevation areas.

1 INTRODUCTION

1.1 *Background*

Sri Lanka is located well away from the tectonic plate boundaries and has been considered as an aseismic country in the past. With the impact of 2004 Tsunami, the likelihood of intraplate earthquakes affect in Sri Lanka has become a matter of concern. The increase urbanization and the emergence of many high-rise buildings in the capital, Colombo has made the development of seismic zonation maps for the country an important task.

Classical deterministic method and probabilistic seismic hazard analysis (PSHA) are the commonly used macrozonation methods in the case of intraplate earthquakes, particularly when sufficient records are available.

The present study involves the impact of intraplate earthquakes on the seismic response of the bedrock profile within Sri Lanka. The main objective is to investigate the effect of bedrock profile on the attenuation/amplification of seismic waves within Sri Lanka. A numerical analysis was performed using *FLAC* software to obtain the seismic wave propagation through Sri Lanka consequent to an earthquake occurrence in the west to southwest coastal region and the results presented.

1.2 *Seismic status of Sri Lanka*

Fernando & Kulasinghe(1986) monitored some of microseismic activities within Sri Lanka and concluded that intraplate earthquakes with epicenters within the country have little impact on seismic status of Sri Lanka, with recorded magnitudes less than 3.0.

Sreejith et al (2008) has stated that the Continental Ocean Boundary (COB) lies about 250 km off the southwest coast of Sri Lanka. A relatively thin continental crust of 21 km and an oceanic crust of 10 km in thickness have been identified by the above authors in the vicinity of the boundary.

Fig. 1 shows the earthquake catalog prepared by the authors based on the data available from past researchers stated above.

The catalogs of past earthquakes around Sri Lanka prepared by several researchers (e.g. Abayakoon (1995), Uduweriya (2013), Weerasinghe et al (2013)) illustrate that Sri Lanka is most vulnerable to intraplate earthquakes originating from the sea in west to southwest of Sri Lankan coast.

A new composite earthquake catalog has been compiled by the authors based on the above data for the region demarcated by the coordinate's 2–20.7° N latitude and 68–88° E longitude. Duplicate events were eliminated from the newly compiled catalog. The composite catalog spans a period of 946 yrs from 1063 to July 2012 and incorporates 2060 earthquakes with Mw $\geq$ 3:50.

Epicenters of recent earthquakes in this catalog is illustrated in Fig. 1. It is interesting to note that the epicenters of the past earthquakes of significance are located in the vicinity of the COB, which is also called Comorin ridge. Several other earthquakes of significance have epicenters located along the Mannar lineament. The closest epicenter of the above is 90 km away from western coast. However, there are no significant earthquakes recorded within considerable distance of southern and eastern coast lines. Therefore, any inland propagation of seismic waves from the above directions do not seems to be of importance at present.

Based on the above observations, COB and the Mannar lineament, have been identified as potential earthquake boundaries in the present study.

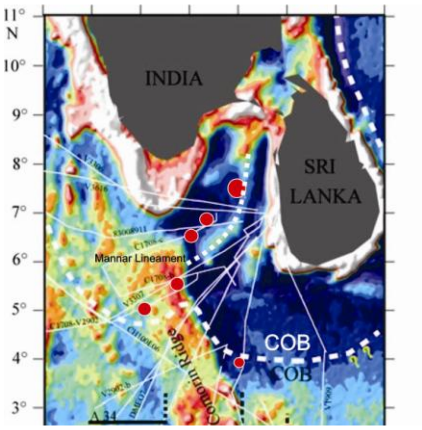

Fig. 1 Epi centers of the earthquake occurred on the comorin ridge and the surrounding area (extracted from Structure and isostatic compensation of the Comorin Ridge, north central Indian Ocean by Sreejithet. Al.)

2 DESIGN EARTHQUAKE

The fault line including the COB and the Mannar lineament can be identified as the potential earthquake zone which has the most significant influence on the seismic wave prorogation through the west coast of Sri Lanka. From the Guternberg relationships developed from the past earthquake records near the fault line, the magnitude of an earthquake with a return period of 475 years can be estimated as 6.9. The epicentral depth was assumed to be 15 km below the bedrock surface.

3 NUMERICAL SIMULATION

3.1 *Development of the model*

Five parallel cross sections shown in Fig. 2 passing through some major cities in Sri Lanka were selected for the analysis. Each cross section starts at the continental shelf of the west coast and ends at the eastern coast; they are perpendicular to the direction of Comorin ridge and lies in a SW/NE direction. The variation of the bedrock profile for each cross-section is taken from Google Maps (2012) and is verified using the 1:50000 topographical maps of survey department of Sri Lanka. The thickness of the soil overburden was ignored in preparing profiles as this will be of little importance.

The numerical simulation of the ground motion through each selected cross sections was performed using *FLAC* software (version 7.0) based on two dimensional finite difference models.

Fig. 2 Selected Cross Sections for developing the models

Each *FLAC* model is equivalent to the distance of the cross-section and depth of 15 km from the mean sea level; model is discretized into quadratic elements with the approximate size of 100 m x 100 m. Two vertical edges at the boundary are modeled as free boundaries and the horizontal base of the model is considered to be as an absorbing boundary. The latter condition was selected based on trial runs which indicated the correct attenuation characteristics with distance along the propagation direction. Fig. 3 illustrates the *FLAC* model developed for the 3rd cross section.

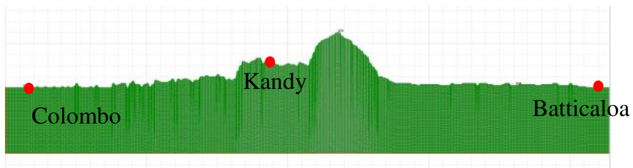

Fig. 3 *FLAC* 2D model

The shear wave velocity of the bedrock is taken as 2500 m/s. This is a typical value of wave velocity for metasedimentory rocks of precambrian period according to Jayawardena (2001). The assumed material properties are also typical for the assumed rock type and are as follows;

Density	=	2500 kg/m^3
Bulk Modulus	=	48 GPa
Shear Modulus	=	20 GPa

The two moduli conform to a compressional wave velocity of 5000 m/s and a shear wave velocity of 2500 m/s.

The explicit Lagrangian calculation scheme and the mixed-discretization zoning technique are used in *FLAC* to find approximate solution for the

2-dimensional wave equation. Because no matrices are formed, large 2-dimensional 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. A time step of 0.005 seconds is used in this analysis which is found to be satisfactory according to trial runs.

The correct input data for the model is the arrival acceleration time histories of the modeled earthquake at the continental shelf of the western coastal region. It is a complex time history depends on the characteristics of the fault, the epicentral distance and the magnitude of the earthquake. When data is available this is derived from seismograph records from the past earthquakes. As no such records are available in this case for earthquakes of magnitude 6.9 occurring at a distance of 90 km from Sri Lankan west coast, acceleration time histories based on measured data from seven similar earthquakes elsewhere in the world is used in the analysis. The detailed data of the seven earthquakes which were taken from PEER database are listed in table 1.

Table 1. Details of Selected Earthquakes

Earthquake	Mag.	Distance / km
Aqaba	7.1	93.8
ChiChi	7.6	90.3
Kobe	6.9	94.4
Northridge	6.7	84.6
Loma Prieta	6.9	83.7
Taiwan	6.8	83.4
Friuli	6.5	97.4
Average	6.9	89.65

4 RESULTS AND DISCUSSION

The peak ground acceleration (PGA) values from the numerical simulation from the cross-sections running along Colombo, Kandy and Baticaloa axis are as given in table 2.

Table 2. PGA values at different cities obtained from Numerical Model

City	PGA (g)
Colombo	0.0833
Kandy	0.0479
Baticaloa	0.0195

These results are plotted in Fig. 4 along with those obtained by PSHA (Uduweriya et. al., (2013), and by DSHA (Weerasinghe et. al., (2013).

The PGA values for Colombo given by three studies have magnitudes close to each other. DSHA shows the greatest decay of the PGA with distance and therefore the lowest PGA values at Kandy and Batticaloa. PSHA and the numerical analysis give similar values for Batticaloa. However, numerical analysis gives the highest value for Kandy. The authors are of the opinion that the reason for having higher values at higher ground elevations as given by the numerical analysis is due to the phenomenon of wave trapping Kramer (1994) which can occurred at the escarpment. The numerical analyses performed for the other five sections gave PGA values at several other cities some of which are at the highest peneplane of Sri Lanka.

These results are shown in Fig. 5. They clearly show the enhancement of PGA at higher elevations which is likely to be due to the effect of wave trapping stated above.

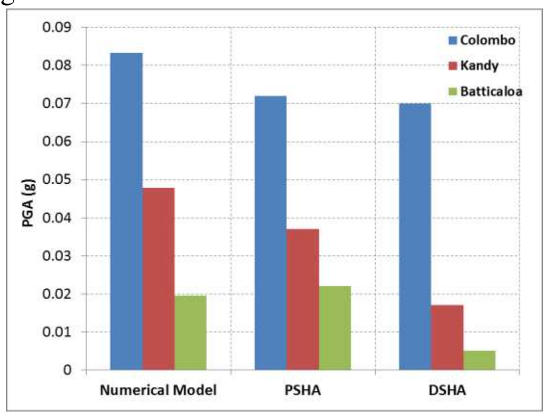

Fig. 4 Comparison of PGA obtained from different methods

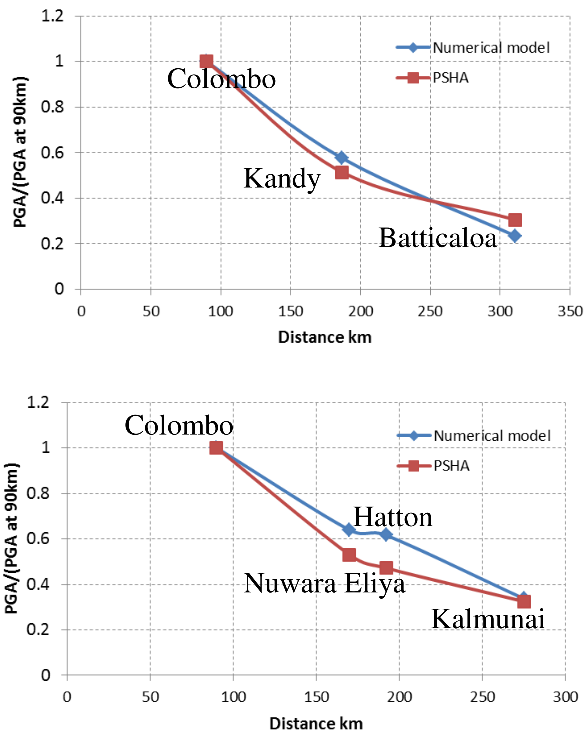

Fig. 5 Variation of normalize PGA with the distance

5 CONCLUSIONS

The Numerical analyses performed using *FLAC* software for the design earthquake originated in the Comorin ridge and Mannar lineament illustrate the seismic wave propagation similar to those predicted by PSHA and DSHA. However, higher values of PGA than those given by PSHA and DSHA are observed within the central highlands of the island with the biggest contrast in the highest peneplain. Authors believe that wave trapping at escarpment is the reason for this disagreement. This can be verified when monitored data of actual earthquakes become available. The original seismic hazard map of Sri Lanka prepared by Dananjaya et al (2013) defines the seismic hazard zone only within the area 30 km from the W/SW coast. This study shows indicate the possibility of having another hazard zone within central highland zone due to wave trapping.

ACKNOWLEDGMENT

This research work was performed under a research programme between the Disaster Management Center of Sri Lanka and the Departments of Civil Engineering and Geology of University of Peradeniya.

REFERENCES

Abayakoon, S.B.S., . (1995). Seismic Risk Analysis of Sri Lanka. *Journal of the Geological Society of Sri Lanka, Vol 6*.

Dananjaya, R.M.S., Weerasinghe, D., Uduweriya, S., Wijesundara, K., Seneviratne, H., & Dissanayake, P.B.R (2013). Development of a Seismic Zonation map for Sri Lanka. *Proceedings of the 4th International Conference on Structural Engineering and Construction Management.* Kandy.

Fernando , M., & Kulasinghe , A. (1986). Seismicity of Sri Lanka. *Physics of the Earth and Planetary Interiors, 44*, 99-106.

Jayawardena, U. (2001). A study of the engineering properties of Sri Lankan rocks. *Journal of Institution of Engineers Sri Lanka XXXIV*, 7-20.

Kramer, S. L. (1996). Geotechnical Earthquake Engineering. New Jersy: Prentice Hall.

Sreejith , K., Krishna, K., & Bansal, A. (2008). Structure and isostatic compensation of the Comorin Ridge, north central Indian Ocean. *Internationa Journal of Geophys*, 729-741.

Uduweriya, S., Wijesundara, K.K., & Dissanayake, P.B.R., (2013). Probabilistic Seismic Hazard Macrozonation in Sri Lanka.. *Proceedings of the 4th International Conference on Structural Engineering and Construction Management.* Kandy.

Uduweriya, S., Wijesundara, K.K., & Dissanayake, P.B.R., (2013). Seismic Risk In Colombo – Probabilistic Approach. *SAITM Research Symposium on Engineering Advancements 2013*, (pp. 124-128). Colombo.

Weerasinghe, D., Seneviratne , H., Jayawardene , U., & Wijesundara , K.K. (2013). A Study Of Seismic Wave Impact On Sri Lanka Due To Surrounding Earthquakes. *4th Proceedings of the International Conference on Structural Engineering and Construction Mangement.* Kandy.