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POTENTIAL EARTHQUAKE RISK ON BUILDINGS IN SRI LANKA

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ABSTRACT: In this paper, seismic hazard and hazard mitigation in Greater Colombo, Sri Lanka are studied. There are few studies in seismic hazard mitigation concerning Colombo area. The objectives of the study are to evaluate the characteristics of local site response against different levels of seismic action and to identify the areas vulnerable to liquefaction damage, and thereby to make a seismic evaluation and hazard level distribution of existing buildings located in the area. The methodology includes a series of investigations involving the exploration of the geotechnical structure of the study area, determination of the dynamic parameters of the local soil profiles, designing of hypothetical earthquakes to simulate the seismic action, and structural evaluation of existing building stocks against earthquake loading. The analysis demonstrates the possibility of up to twenty times variation in the level of ground shaking at two distinct locations for a particular magnitude of earthquake. A structural evaluation of buildings in the area confirms that un-reinforced masonry buildings built before 1960 are vulnerable against seismic loading. For the case of moderate to high level of shaking more than 10% of the buildings are exposed to major damage.

1. INTRODUCTION

Sri Lanka is considered to be in an aseismic zone away from major plate boundaries or any active faults. However, historically there are many seismic events within Sri Lanka and in the neighbouring areas, which had considerable influence on the island [1]. Even though some of these are very small in magnitude and some had epicentres far away from the country, the necessity to study the seismic effects on Greater Colombo area is realized by engineering professionals. In this context, geologists have suspected the formation of a new plate boundary dividing Indo-Australian plate as shown in Fig. 1. Furthermore, on the eve of Asian Tsunami disaster in 2004 and more recent earth quake in Pakistan, such studies are even more stressed.

Recent researchers have described the locations subjected to no major seismic activity as Stable Contential Regions (SCR) [2]. However, in the past there had been many devastating inter-plate earthquakes reported in many SCR causing enormous damage. It was observed that the damage caused by such earthquakes tend to be very high due to the absence of preparation against them. In 1993 Maharashtra earthquake in India, more than ten thousand people were reported killed in a supposedly Stable Contential Region [3]. Therefore, the existence of a risk of being stuck by an earthquake cannot be overlooked merely due to hard evidence to the contrary.

Colombo is the commercial capital of Sri Lanka with having more than 2 million population and further expansion of the city is expected with country's growing economy. Initial seismic risk analysis in Sri Lanka demonstrates that Colombo is more vulnerable to seismic events than any other part of the country [4, 5]. Considering the importance of Colombo, a seismic status analysis of Greater Colombo area is a contemporary issue.

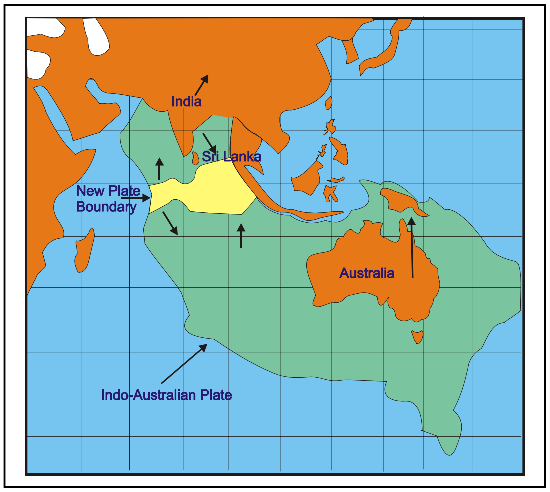

Fig. 1̃ New plate boundary

Abayakoon [5] analysed the seismic responses of soil profiles in low-lying areas in Colombo. These investigations had been focused on predicting the attenuation characteristics of the base rock motion through the soil profiles using two scaled-down acceleration history records, namely Chiba EW (Japan) and ElCentro NS (United States of America) with peak accelerations of 0.1 g and 0.2 g respectively. The computer program SHAKE [6] was used to demonstrate the site responses for five broadly identified soil sub-series in Colombo. Out of the five sub-series, the input motions tend to amplify in one series and damped to about 50% in two other series.

The seismic risk of a location can be evaluated based on the hazardous nature and the vulnerability of the location. The hazardous nature in this context is the degree of exposure of a location for a future earthquake and the vulnerability is the degree of damage or loss that may be inflicted to the elements at risk.

2. AIM AND OBJECTIVE

The aim of the paper is to study the seismic hazard and hazard mitigation of Greater Colombo area of Sri Lanka. The main outcome of the study would be an indicator of the seismic status of Greater Colombo and it will provide necessary knowledge to the geotechnical and structural engineers in assessing the local site conditions against seismic risk. It is further expected to help local engineers in introducing appropriate allowances in structural design practice within the area concerned and to adopt preventive or remedial measures to reduce the seismic risk and hazard in critical areas of interest.

The objectives of the study are as follows;

i. Identification of the geotechnical condition,
ii. Identification of locations susceptible to soil liquefaction, and
iii. Seismic evaluation of existing building stocks,

3. MATERIALS AND METHODS

3.1 Geotechnical condition & Dynamic soil parameters

About 300 boreholes at 200 locations situated within Greater Colombo area is used to determine the stratigraphy of the study area. This data is collected from the local consultancy firms and government departments which provide geotechnical investigation services for construction purposes.

Based on the dominant soil type at the location, the borehole locations can be classified into three main groups viz. locations dominated by sand profiles, clay layers, and peat deposits respectively. Based on the SPT values, the areas dominated by sand deposits can be identified as loose and dense profiles, and the areas dominated by clay deposits as soft, stiff and hard profiles [7]. Other than the three dominant soil types mentioned above, gravel is also observed, though rarely, in some of the locations within the study area.

The determination of the dynamic soil parameters involves a series of successive calculations for valuating N_{60}, corrected SPT, effective stress, total stress, relative density, untrained shear strength, void ratio, shear modulus and shear wave velocity for each of the soil layers considered. This is a time consuming process involving a series of repetitive calculations with several interpolations. Therefore, it has been decided to formulate all these calculations in a spreadsheet program. This program requires only the entry of soil type, SPT values, and the depth of water table just as it appears in a borehole log sheet. The programme processes all the necessary calculations corresponding to each soil type and displays the soil type, unit weight, shear wave velocity, and thickness along with the depth of ground water table and location details.

3.2 Design earthquakes and input motion for seismic analysis

The seismic risk of a site is influenced by many factors, such as the past and current seismic activities of the region, local site conditions, and the elements at risk. From this information, the strength and characteristics of the shaking at the ground surface can be predicted. At a particular location the response may vary depending on the magnitude and the epicentral distance of the seismic event. However, for a particular magnitude and epicenter distance combination of an earthquake the dynamic properties of the local site will determine the surface response irrespective of whether the locations are close to each other.

The North South Component of the earthquake motion recorded at El Centro during the 1940 Imperial Valley earthquake, USA has been used as the basic input motion for the surface response analysis. The characteristic of this motion has been analyzed and reported by many authors [8,9,10] and therefore, it was chosen for the present study. The attenuation relationship proposed by Seed [et al. [10] has been used to scale down the El Centro motion in both the ordinate and abscissa to adjust the peak ground acceleration and the predominant period respectively to the required values.

Even though the previous research [3] indicates that the most likely earthquake in the study area would be of magnitude 6.0 in Richter scale, the current research focused in addition on the magnitudes of 5.0 and 7.0 in Richter scale to have a broad idea of the possible seismic effects.

In the past a wide range of earthquakes and epicentral distances have been reported in the region of Sri Lanka, within and outside the island. Further, there are no active faults identified in the region. Therefore, four arbitrary epicentral distances ranging from 10 km to 160 km have been selected to design the earthquake parameters.

3.3 Assessment of potential liquefaction zones

The soil liquefaction evaluation procedure reported by Seed et al. [11] has been used to assess the potential liquefaction zones within the study area. This is an approximate method to identify the locations that are susceptible to soil liquefaction. The peak horizontal shear stress i.e. the shear capacity of the soil profile against the liquefaction was determined based on the SPT values obtained from the borehole log data. Equivalent cyclic shear stresses expected to be induced due to seismic action have been determined for five levels of peak ground accelerations ranging from 0.1 g to 0.5 g.

3.4 Seismic evaluation of existing building

There are many types of buildings in Colombo with distinct structural settings. These buildings can be classified upon many aspects such as, the number of stories, construction techniques, materials of construction, period of construction, building configuration etc. During the current study, many organizations including National Building Research Organization, National Housing Development Authority, Colombo Municipal Council, Department of Census and Statistics in Sri Lanka were contacted to explore the possibility of getting useful technical information on the building stocks of Colombo.

However, other than a report listing details of 202 historical buildings in Colombo Urban area by Lewcock [12] no data are available. Considering the general construction type of the buildings and the period where there are major changes occur in the construction practices they can be grouped into two different categories; namely, those constructed after 1960 and prior to 1960.

Most of the buildings in Colombo fall into the first category. Many of these buildings have been constructed using reinforced concrete and therefore, naturally have some shear capacity to tolerate low level of seismic shaking. The buildings in the second category, i.e. those constructed prior to 1960, lack reinforcement. According to Lewcock [12] a few hundreds of such buildings are found in the Greater Colombo area. Most of these buildings are in poor condition having no capacity to resist any seismic loading. Some of them are situated in Colombo Fort and its neighbouring areas which are thickly populated. Therefore, these buildings are the most vulnerable category in Greater Colombo. It is decided to focus on assessing this type of buildings in the current study.

The weakness of a building against seismic motion depends on the strength of the seismic action and the ability of the building to resist such actions. In general the buildings which are vulnerable to a moderate earthquake are considered as weak. As explained in the earlier sections most of the buildings constructed prior to 1960 fall into this category. A field assessment focusing on weak buildings has been carried out to investigate the structural setting and seismic vulnerability at some selected locations within the study Area. The information reported by Lewcock [12] has been used to select the buildings for evaluation.

Forty old buildings (pre 1960 era) identified as weak, and ten buildings constructed after 1960s' were considered for the seismic evaluation. These forty buildings include twenty seven un-reinforced masonry buildings, twenty two concrete frame buildings and one light metal building. Out of fifty buildings, hazard scores are given for forty buildings in the Table 1.

Evaluation is carried out in the following sequence.

i. Sketch plan showing the location of the building was drawn
ii. Details such as the year of construction, number of stories, usage of building, numbers of occupants, any special identifiers, etc. were obtained.
iii. Evaluation of the building type / facility class
iv. Efforts were made to obtain any other relevant information.

The seismic vulnerability of the structures is determined based on the evaluation procedures recommended by the FEMA of USA (Federal Emergency Management Agency of United States of America). In this procedure each building is given a set of basic and modifying scores to account for various structural conditions affecting the seismic stability. The structural weaknesses are visually inspected from outside the building. The corresponding score sets have been developed based on the expert's opinion obtained to assess the seismic vulnerability of California buildings for different levels of ground shaking and adjusted to evaluate the seismic performance of buildings in the regions out of California where low level of shaking is expected. The seismic hazard score for a particular building is the algebraic sum of the basic and modifying scores corresponding to the level of ground shaking considered. The final score typically range from 0 to 6, with higher scores corresponding to better seismic performance. These hazard scores are formulated in such a way that the antilogarithm of the negative of the hazard score of a particular building will give the probability against a major structural damage.

The analysis is carried out on all the structures against the three levels of shaking namely low, moderate and high level as reported by FEMA (1988) [13]. The performance modification factor to account for the effect of local soil profiles is another aspect to be accounted in the assessment procedure. The soil conditions within the study area generally come into SL1 representing stable deposits of sands, gravels and stiff clays and into SL3 representing the and short to medium stiff clays and sands, exceeding 30 ft in thickness [13]. The corresponding modification factors are 0.0 for SL1 and - 0.6 and - 0.8 for SL3 in respect of low rise buildings and 8 to 20 story buildings respectively. In most of the locations considered for the structural assessment there is not enough soil data available in the vicinity of the building assessed.

Therefore, it is decided to take up the worst case of the presence of soil profile SL3 in all the locations as recommended by FEMA-154 1988 [13]. The sum of the hazardous scores of each of the buildings indicates the vulnerability of the structure against the level of shaking considered.

4. OBSERVATION AND DISCUSSION

4.1 Soil/rock profiles in the project area and their properties

From the analysis of borehole logs it was found that the depth of the top soil layers is in the range of 5 m to 25 m. Sand profiles were observed in most part of the Colombo Municipal areas and some other adjoining urban areas along the Galle Road up to Moratuwa. Clay deposits were observed as isolated pockets within Colombo Municipality except near Borella where sand as well as clay layers have been observed. Rajagiriya, Malabe, Nugegoda, Nawala, Athurugiriya, Orugodawatta, Negombo, Ja-ela, Etul-Kotte, Boralesgamuwa, Wattala, Kelaniya are also some other locations where sand and clay profiles were observed. The peat deposits were generally observed in the low lying areas of Greater Colombo (some of these areas are now reclaimed) namely Peliyagoda, Orugodawatta, Blomendhal, Yakbedda, Nawala, Battramulla, Maligawatta etc. [14]. In most of the locations the soil profile ends up with the weathered rock.

4.2 Assessment of potential liquefaction zones

According to the analysis about 30% of the locations have been found to be susceptible to no liquefaction, 20% of locations were identified as having high susceptibility to soil liquefaction with low level of shaking and 50% of the locations required moderate or high levels of shaking for liquefaction to occur.

4.3 Seismic evaluation of buildings in Colombo

The final seismic hazard scores corresponding to each of the building assessed are given in Table 1.

Table 1̃ Structural hazard scores of the buildings assessed in Colombo area

Building ID	Final Score		
	Low Level of Shaking	Moderate Level of Shaking	High Level of Shaking
A1	1.9	1.4	0.4
A2	0.9	0.4	-0.6
A3	1.4	0.9	-0.1
A4	2.4	1.4	0.9
A5	1.4	0.9	-0.1
A6	0.9	0.4	-0.6
A7	0.9	0.4	-0.6
A8	0.4	-0.1	-1.1
A9	1.9	1.4	0.4
A10	0.9	0.4	-0.6
A11	0.9	0.4	-0.6
A12	1.4	0.9	-0.1
A13	1.4	0.4	-0.1
A14	1.9	1.4	0.4
A15	1.9	1.4	0.4
A16	5.9	5.4	4.9
A17	1.9	0.9	0.4
A18	1.4	0.4	0.4
A19	1.4	0.4	0.4
A20	0.9	0.4	-0.1
A21	0.9	0.4	-0.1
A22	1.4	0.9	-0.1
A23	2.4	1.4	0.9

A24	1.9	0.9	0.4
A25	1.9	0.9	0.4
A26	2.4	1.4	0.9
A27	1.9	0.9	0.4
A28	1.4	0.9	-0.1
A29	1.4	0.4	-0.1
A30	0.9	0.4	-0.6
A31	1.9	0.9	0.4
A32	0.9	0.4	-0.6
A33	0.9	0.4	-0.6
A34	1.4	0.4	0.4
A35	0.4	-0.1	-0.6
A36	0.6	-1.1	-1.6
A37	1.4	0.4	0.4
A38	0.9	0.4	-0.6
A39	1.9	1.4	0.4
A40	1.9	0.4	0.4

Table 2 shows the basic structural hazard scores and the corresponding probability against major damage for un-reinforced masonry building and concrete frame building.

Table 2̃ Basic Structural Hazard Score and corresponding probability against major damage for Un-reinforced Masonry building and Concrete Frame building

	Shaking Intensity	Un-Reinforced Masonry	Concrete Frame Building
Basic Structural Score	Low Level	2.5	3.0
	Moderate Level	2.0	2.0
	High Level	1.0	1.5
Probability Against Major Damage (%)	Low Level	0.3	0.1
	Moderate Level	1.0	1.0
	High Level	10.0	3.2

The probability against major damage for an un-reinforced masonry building and a concrete frame building due to an earthquake of magnitude 6.0 in Richter scale and epicentral distances ranging from 10 km to 160 km are given in Table 3.

Table 3̃ Probability against major damage due to an earthquake of magnitude 6.0 in Richter scale

Epicentral Distance (km)		10	20	40	80	160
Probability Against Major Damage (%)	**Un-reinforced Masonry Building**	2.0	1.3	0.7	0.1	0.0
	Concrete Frame Building	0.9	0.6	0.4	0.04	0.0

5. CONCLUSIONS

For the case of high level of shaking all the buildings considered except the light metal structure, registered with poor seismic performance with more than 10% of the buildings exposed to major damage. About 75% of the buildings considered recorded less than 1.0 structural hazard score for moderate level of shaking. All the 27 un-reinforced masonry buildings are registered with critical hazard scores for all the three levels of shaking. Out of the 22 cases corresponding to concrete framed buildings, 15 satisfied the cut-off score (2.0) for the low level of shaking. The light metal building exhibits best performance with high structural hazard scores.

In consideration of Table 2, however, as a global measure the basic structural hazard scores can be used to get the overall picture assuming that the average building has no adverse effect due to building configuration or any supplementary strength due to the adoption of any seismic provisions. From the information presented in Tables 1 & 2, it is possible to predict the vulnerability of a building against a given magnitude of earthquake.

From Table 3, it is clear that an earthquake of magnitude 6 in Richter scale and epicentral distance grater than 160 km may cause no major damage in any type of the structures present within the study area.

6. ACKNOWLEDGEMENT

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