Local Site Effect and Microzonation in Assessing and Managing Earthquake Risk

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SUMMARY
Generally, the most intense shaking experienced during earthquakes occurs near the rupturing fault, and decreases with distance away from the fault. In a single earthquake, however, the shaking at one site can several fold stronger than at another site, even when their distance from the ruptured fault is the same. The local geologic conditions are the main cause of this difference in shaking intensity, but it have not been certain of the particular conditions that are most responsible, and the degree to which they affect earthquake shaking. Kochi city (76.18^{o}-76.43^{o} E; 9.82^{o}-10.08^{o} N), Kerala have been undertaken with the objective of defining the site effects as this form the most important input associated with local geological conditions constitute an important part of seismic hazard assessment and microzonation. Measurement of micro tremor (ambient noise) was carried out using a three component CityShark seismic recorder and a tri-axial 1 sec. seismometer. A total of 988 records of microtremor at different sites were collected in Kochi city in area associated with 28 km x 29 km. H/V technique developed by Nakamura was used for the estimation of Site response parameters. The processing of data and estimation of site response parameters mainly the resonance frequency and site amplification were estimated using J-SESAME software. A general map contains three classes for both of resonance frequency (<1.1, 1.1-5.0 and >5.1 Hz) and site amplification (<5.1. 5.1-10.0, >10.0). These class intervals of resonance frequency and site amplification have been used for preparing microzonation map. The resonance frequency varies significantly within short distances in and around Kochi city and is spatially distributed in three NW-SE trending regions parallel to the coast which differ appreciably in their site response characteristics. The lowest resonance frequency values (≤ 1.0 Hz) coupled with high site amplification were observed in coastal and backwater areas covered with younger alluvial deposits (tidal, fluvial and palaeo beach deposits), and high resonance frequency values (> 5 Hz) to charnockites and laterites in the hinterlands. Similar patterns of distribution of resonance frequency and site amplification are also obtained along profiles across and parallel to the coast. When considering new planning and rebuilding it can be helpful in assessing and managing earthquake risk.

Keywords: earthquake shaking, ambient noise, resonance frequency, microzonation

1. INTRODUCTION

It is established fact that the earthquake generated ground motion is very much dependent on local surficial site conditions. (e.g., Milne 1898; Kanai 1951, 57; Borcherdt 1994;, Kramer 1995). Understanding of the site-specific behaviour is important for the prediction of seismic hazard due to local and/or distant earthquakes. When earthquakes emerge from the base of more competent rocks into the soil or the uppermost 100 m, ground motion could transform spectacularly. This impedance disparity near the surface affects the frequency–amplitude content of earthquake ground motion. Besides, it can also change the duration of shaking, one of the most important parameters controlling the damage of earthquake ground motion. In view of this, the damage pattern in any particular locality can be forecast with the help of site response data derived through various techniques. The three effects; amplification, resonance and attenuation all depend on the depths and the properties of the sediments (Gibson, 1990). Any large region needs subdivision if the variations of some characteristics of interest within that region has to be studies and understood in detail. The greater the accuracy of details needed, the finer are the sizes of the zones. This zoning may with respect to many factors such as contours of elevation of ground, rain fall, population density, political boundaries of nations etc.

In earthquake engineering, such zoning may be done with respect to various manifestations of seismic ground motions and the factors influencing the same. Therefore, microzonation of a region may be defined as subdivision of the region into smaller regions or microzones such that any characteristic of interest may be considered to be reasonably uniform over the microzone. When such factors or characteristics are related to seismic activity, the process may be called Seismic Microzonation. When the area under consideration is very large, the first attempt of seismic zoning may result into very coarse zoning which may also be called as Seismic Macro Zoning. Seismic zoning map of India given in Indian Standard Code of Practice (IS:1893-1984) may be considered to be a typical example where in each seismic zone may cover many hundreds of square kilometers of area. Obviously, the characteristics of ground and factors affecting the seismic ground motions may vary considerably from place to place within each seismic zone. The actual value of the seismic coefficient may be somewhat larger than or smaller than what is assigned to that seismic zone. It is obvious that for a better picture of seismic zoning, each such area need be divided into smaller regions or microzones to give due regard to local variations of factors that influence the seismic zoning. Obviously, seismic zoning map is one of the many microzonation maps which may be of interest. Seismic zonation of any region needs knowledge of factors which affect seismic ground motions. Gathering such scientific information is expensive. Larger the population which shares such cost, the more economical and affordable it would be for that community. Microzonation of cities is a need for development and to assess the level of hazard of the area. As such microzonation is strongly influenced by socio-economic factors. Urban population centers and centers of industrial activities are targets of microzonation as these results into microzonation at a cheaper per capita cost. India is a poor country with a large population. As such, microzonation activities are essential for giving detailed information for better protection from earthquakes to masses at affordable cost per head. It is essential to create awareness in minds of people and to educate them about the need for supporting seismic microzonation. It is defined as the process of subdividing a potential seismic or earthquake prone area into zones with respect to some site specific geological and geophysical characteristics such as ground shaking, liquefaction, susceptibility, landslide and rock fall hazard, earthquake related flooding, so that seismic hazards at different locations within the area can correctly be identified (Tulladhar et al., 2004).

In most general terms, seismic microzonation is the process of estimating the response of soil layers under earthquake excitations and which correspond to the measurement of the variation of earthquake induced ground motion at the ground surface (Finn, 1991). This paper focuses mainly on the assessment of site specific hazards due to ground motion resulting in an earthquake and preparation of seismic microzonation map in GIS environment for the Kochi city of Kerala State, India, using computed values of site specific response parameters by analyzing ambient noise records.

2. GEOLOGY AND BACKGROUND OF STUDY AREA

Geologically, two distinct litho-units are visible in and around Kochi city (GSI, 2001). The eastern part is occupied by hard rock's representing Precambrian metamorphosed rocks while the coastal tract in the west is covered by soft rock or the unconsolidated coastal alluvium. The structural features in the city are masked by extensive water bodies and thick vegetation. Kochi, the main commercial and industrial city of Kerala state, which has witnessed tremendous growth almost in all the fields during the past fifty years, is selected for site response study and preparation for seismic microzonation map using site response data derived through ambient noise measurements. The study area is bounded by longitude 76^0 11'- 76^0 26' E and latitude 09^0 49'- 10^0 05' N and covers an area of 630 km^2 including 120 km^2 water-bodies (Fig. 1). The city falls mainly into two physiographic zones, coastal plain and midland. The coastal plain, a low lying area (elevation <10 m) is characterized by backwaters, marshy lands, sandy flats and alluvial plains. The midland region has a rolling topography with low hills and narrow valleys. The hills are generally covered with laterite or laterite soils and the valleys are alluviated. There are about 13 small islands along the backwaters, which are formed by alluvial deposits. The city and its surroundings are situated mostly on loose sediments of alluvium, clay, loamy sands, silt, laterites etc. and have vast area of intermittent water bodies. Most of the waterlogged low-lying areas have been reclaimed for various developmental activities such as residential, commercial and industrial settlements.

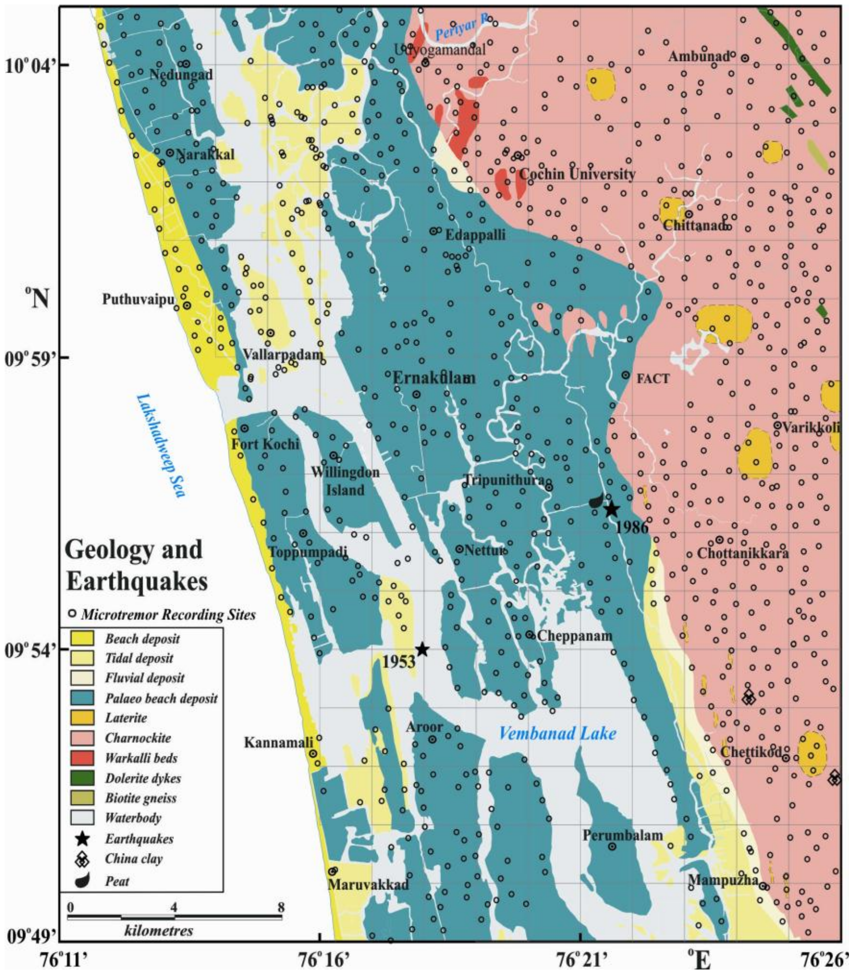

Figure 1. Spatial distribution of ambient noise recorded sites over the geological features of Kochi city. Two small earthquakes occurred in 1953 and 1986 are also shown (Kumar, 2011).

3. THE DATA

Closely spaced ambient noise data have been obtained through survey conducted with a CityShark II 3-component Seismic Recorder and a Lennartz LE-3Dlite triaxial active geophone with 1 Hz natural frequency, while site locations were determined using a handheld Garmin GPS MAP 76S (Singh et al, 2005). The data collection was performed during day time between 5.30 AM to 6.30 PM with station interval 1-2 km. Surveys in heavy traffic area (main city) were carried out on Sundays and holidays mainly to avoid traffic disturbance. In order to minimize disturbances by traffic and other cultural noise, most of the measurement sites were selected away from roads by 200-300 m. Ambient noise data recording was done for a period of 15 minutes at all the sites with the recorder gain set appropriately between 64 and 8192 depending on the noise levels.

4. DATA PROCESSING

Data processing and estimation of site response were carried out using J-SESAME software (version 1.08) developed under European Project SESAME 2000-2004 (SESAME European project 2003, 2004) for processing of ambient noise data. The H/V technique developed by Nakamura (1989) was used for estimating site response parameters. The cutoff frequency used in the present work is 25 Hz. The time window length selected for processing the noise data of N-S, E-W and vertical (V) components is 20 sec. A minimum of 10 windows was taken for obtaining reliable results on site parameters (but less than 10 windows at a few important locations were also taken for comparing the results). H/V is computed by merging the horizontal (NS and EW) components with a geometric mean option. A Konno and Ohmachi smoothing technique (Konno and Ohmachi, 1998) was applied to the three spectral amplitudes with a bandwidth of 40 and geometric average. Spectral ratios of horizontal and vertical components recorded at each site were used to estimate amount of ground shaking amplification that can be expected at sites and the frequencies at which strong resonances occur. Total 988 records were processed, and estimated level of ground amplification and resonance frequency at each site and compiled a database using date, place names, latitude, longitude, morphology and soils, H/V and resonance frequency. The ambient noise recorded sites were classified according to their fundamental frequency F_o (Duval et al, 2004) as given in Table 1.

Table 1. Classification of sites based on resonance frequency.

Types of sites	Resonance frequency (Fo)	Number of computed data	% of total data
Low frequency	$F_o \leq 1$ Hz	347	35.12
Medium frequency	1 Hz < $F_o \leq 5$ Hz	311	31.48
High frequency	F_o >5 Hz	330	33.40

5. RESULT AND DISCUSSION

Bard (2002) has observed that each site has a specific resonance frequency at which ground motion gets amplified. In such condition, manmade structures having resonance frequency matching with that of the site have the maximum likelihood of getting damaged. Such resonances and amplifications of ground motion are not observed on relatively flat surface where hard rock is exposed. In view of this, site specific response characteristics of a particular site play vital role in the construction of seismically safe structures. Keeping in view GIS analysis was carried out to retrieve computed resonance frequency and site amplification in various class intervals along with site details and important field observations from the geo-coded ambient noise database for understanding spatial distribution of observation sites, preparing contours/isolines, DEMs and 3D view maps.. Isolines of resonance frequency, Fo, from the Fo grid based on three and five classes of resonance frequency were generated. Similarly isolines of site amplification were also generated from the H/V grid using three classes of site amplification. The results were used for delineation of hazardous zones in Kochi city. Regions having different H/V values within each Fo class interval were identified and logically combined in GIS. Integrating Fo and H/V isolines detailed seismic microzonation map for Kochi city containing five classes of resonance frequency (<1.1, 1.1-3.0, 3.1-5.0, 5.1-10.0 and >10.0 Hz) and three classes of site amplification (<5.1. 5.1-10.0, >10.0) was prepared as shown in Fig. 2. Three zones Microzone I, II and III were identified in the map and some of their important characteristics are given in Table 2. Characteristic site period (Ts) was estimated using the formula $Ts = 2\pi/Fo$ (after Siefko et al, 2002) where Fo is the resonance frequency. The range of resonance frequency and the characteristic site period in each microzone is given in Table 2.

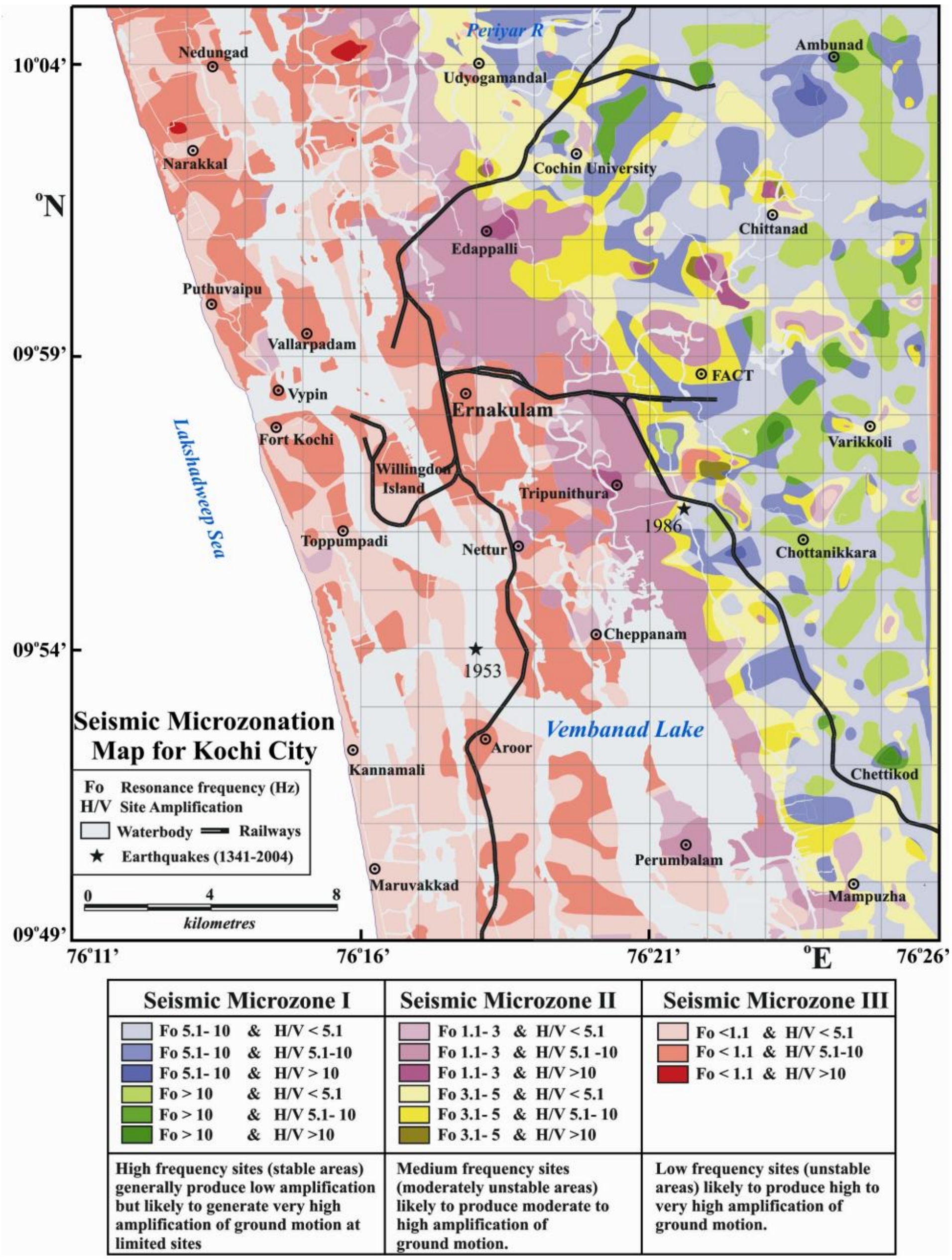

Figure 2. Prepared Seismic microzonation map for Kochi city: Three Seismic Microzones I, II and III were delineated based on estimated values of resonance frequency and site amplification.

Table 2. Delineated seismic microzones in terms of resonance frequency (F_0) and

Zones	F_o (Hz)	Ts (sec)
Seismic Microzone III	≤ 1.0	>6.3
Seismic Microzone II	1.1- 5.0	6.3- 1.2
Seismic Microzone I	≥ 5.1	≤ 1.2

Three Seismic Microzones I, II and III were delineated based on spatial variability of resonance frequency and site amplification. High frequency sites (stable areas) generally produce low level site amplification but likely to generate high amplification of ground motion at limited sites have been designated here as Seismic Microzone I. The zone is characterized by comparatively high resonance frequency (>5 Hz) and short characteristic site period ⩽ 1.2 sec (Table 2) coupled with moderate site amplification values (< 5.1). This zone occupies an area of about 190 Km2 and mostly confined to the easternmost portion which has moderately rugged topography (Fig. 2). About 74% area of this zone has resonance frequencies between 5.1-10 Hz where low to medium amplification can be expected. Medium frequency sites (moderately unstable) likely to produce moderate to high amplification of ground motion). This zone is characterized by medium resonance frequency ranging from 1.1 to 5.0 Hz (in two classes 1.1-3.0 Hz and 3.1-5.0 Hz) and also medium characteristic site period between 6.3-1.2 sec. (Table 2, Fig. 2), and designated as Seismic Microzone II; occupies an smallest area of about 152 km^2. It is sandwiched between the microzones I and III and oriented in the northwest-southeast direction. Microzone III occupies low frequency sites (unstable areas) which are likely to produce high to very high amplification of ground motion. This is the westernmost zone and covers entire coastal belt, backwaters and Islands and spreadover an area of about 175 km2 and constitutes ~34% of total city area. Palaeo beach deposits are the main geological formation covering almost entire zone but scattered patches of fluvial, tidal and beach deposits are also present mainly along the coastal belt and Islands (Fig. 1). The zone is covered with soft soil /sand and has thick sediments column. Site amplification ranging from 4 to 10 is observed throughout the zone which is especially high in and around Vypin, Vallarpadam, Wellingadon, Kadamakudi, Chittur, Fort Kochi, Aroor, Vaduthala, Pannangad and Turtibhagam. The longest duration characteristic site period indicates that the structures and buildings in this zone have very high probability to achieve resonance as compared to Microzones I and II, when the natural frequency of ground motion resulting due to an earthquake matches with that of the natural frequency of structures. It is expected that prolonged ground shaking will occur and the ground motion amplification may result in severe damage as compared to Microzones I and II. Proper building codes are to be followed strictly for this zone and, as far as possible, construction of tall and high rise buildings have to be avoided especially in the coastal segment of this zone.

It is observed that the estimated resonance frequency varies significantly within short distances in and around the city. Low resonance frequency values (⩽ 1.0 Hz) coupled with high site amplification were observed in coastal and backwater areas covered with younger alluvial deposits and high resonance frequency values (> 5 Hz) to charnockites and laterites in the hinterlands (Singh et al 2012). The seismic microzonation map for the Kochi city showing distribution of site response parameters provides useful information to structural engineers and building designers in order to construct seismically safe buildings.

As may be understood from above discussion of site response used in microzonation is of interest to a vast variety of people with different interests and perceptions and end use in their mind. Besides, they are often not experts of seismic microzonation methods. As such, the final results in the form of microzonation should be user friendly and in a ready to use/easily to understand. To access and manage the earthquake hazard and risk, Socio-economic factors have the most important effect on microzonation. This decides on the aspiration and need for microzonation of a region. It represents the realistic collective will of the Society to understand, appreciate, demand and gainfully utilize the data generated by microzonation. A society too poor may find their pre-occupation with the fight against hunger, disease, education etc to be of higher priority than earthquake resistance capacity of houses. Before demanding the microzonation data, the society needs to understand benefits of such a study. Education increases the capacity of the Society to do so. So, a more educated society is more likely to go for microzonation of the region. Presence of industries indicates activities generating wealth in the society. So, areas with larger industrial density (Kochi) are likely to spare more money for microzonation studies. The nature of the business also decides whether the society needs mictozonation or not and the degree of priority assigned to it. Based on the results of the microzonation studies, the master plan of land use for the metropolitan cities or areas of the provinces are prepared. Areas with minimum potential danger to structures are identified for location of residential and industrial structures. Amongst such areas, the best sites are reserved for location of important institutions like Parliaments, assembly halls, public meeting places, temples and other monuments of public interest. Similar care is given for location of schools and hospitals as they house individuals who are not in a position to take care of them. Land use maps are also essential for encouraging orderly development of the areas at minimum penalty to the community. However, The greater the accuracy of details needed, the finer are the sizes of the zones. This zoning may results better with respect to many factors such as contours of elevation of ground, rain fall, population density, political boundaries of nations/states etc. Site response and its inclusion in microzonation is one way to manage risk at particular locality. Larger data of natural hazards like floods, droughts, winds, cyclones, landslide and liquefaction may report detail risk for the region.

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