Seismic Microzonation for Kochi City, India in GIS Environment

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ABSTRACT

An attempt has been made to prepare seismic microzonation map for Kochi city, Kerala state, India in GIS environment using site response data estimated through H/V technique. For this, ambient noise measurements at 988 closely spaced sites in and around the city has been used. It is observed that the estimated resonance frequency varies significantly within short distances. Low resonance frequency values (≤ 1.0 Hz) coupled with higher levels of site amplification were observed in coastal and backwater areas covered with younger alluvial deposits and high resonance frequency values (> 5 Hz) with charnockites and laterites in the hinterlands. Three Seismic Microzones I, II and III were identified based on spatial variability of resonance frequency and site amplification which are elongated in northwest-southeast direction parallel to the coast. Microzones I and III occupy the easternmost and westernmost parts of the city respectively whereas Microzone II is sandwiched between them and these zones are associated with distinct site response characteristics. The results revealed that the buildings and structures in Microzone III have highest probability to achieve resonance as compared to Microzones II and I when the natural frequency of ground motion matches with that of the structures. It is estimated that longer duration ground shaking will occur in Microzone III and adjoining areas of Microzone II. The Microzone I and the adjoining portions of the Microzone II are relatively safer as compared to the remaining portions of Microzones III and II.

Keywords: Seismic microzonation; Resonance frequency; GIS environment.

1. INTRODUCTION

It has now been accepted that chances of predicting location, time and magnitude of an impending earthquake is remote, the current emphasis is to predict the seismic hazards at a particular site. A significant part of damage observed in destructive earthquakes around the world is associated with seismic wave amplification due to local site effects. Investigations on the damage patterns caused by the recent earthquakes have revealed that most damages occur due to local geological conditions that affect the ground motion. Severe damage is often limited to zones of unfavourable geotechnical conditions that give rise to significant site effects in the epicentral tracts or at some distance depending upon the size of the earthquake. Damage distribution in the near source area of large events is also significantly affected by fault geometry and rupture history besides enhanced influence of the non-linear behaviour in soft soils. Many large earthquakes are known to have tremendous site effects even in the near-field (Craigo, 1998, 2004; Somerville, 1995; Mauricio et al., 2000; USGS, 2000; Elenas, 2003; Hough et al., 2002). It has been established that seismic energy gets trapped at sites having soft soil or topographical undulations resulting in enhanced ground vibrations that may increase damage to the manmade structures. Based on theoretical analysis and observational data, Bard (2000) 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 is 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.

There are several methods used for estimation of site responses (Bard, 1999, 2000; Field and Jacob, 1995; Chatelain et al., 2000; Gueguen et al., 1998). The ambient noise (microtremor) measurement is widely used for site response studies (Nakamura, 1989; Lermo et al, 1988, Mukhopadhyay et al, 2002, Mukhopadhyay and Bormann, 2004). Ambient noise, a low-level vibrations caused by natural (wind, ocean tides etc.) and the cultural sources (Hough, 2002), is the property of each and every site differently on the surface of the earth and mostly dependent on the characteristics of the materials lying between ground surface and basement rocks. The interest in ambient noise arises because seismic stations situated on soil sites record higher amplitudes of ground vibration than stations on bedrock sites. This shows that earthquake related ground motion is very much dependent on local surficial conditions especially the character of top soils about 100 m thick above the basement and soft soil beneath any site. Under certain conditions, such sites give rise to a more conspicuous effect on the level of earthquake related ground motion than the magnitude of the earthquake itself. This circumstance has led many to utilize measurements of ambient noise to estimate the frequency at which the soil amplifies the ground motions as well as to quantify them (Field et al., 1990; Fischer et al., 1995). The method is found to be more advantageous in the regions of low seismic activity. Bard (1999, 2002) has explained in detail the measurement of ambient noise and its importance for site effect estimation. This method can be used to demarcate those areas that may experience strong ground motions should a large earthquake occur nearby. Seismic microzonation, that identifies individual critical areas based on their potential for hazardous earthquake effects, is especially applicable in urban areas where risk due to ground motion is highest.

2. STUDY AREA AND GEOLOGY

Kochi, the main commercial and industrial city of Kerala state, which has witnessed tremendous growth almost in all the fields during the past 50 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 (Fig. 1). Most of the waterlogged low-lying areas have been reclaimed for various developmental activities such as residential, commercial and industrial settlements. Geologically, two distinct litho-units are discernible in and around Kochi city (GSI, 2001). The eastern part is occupied by hard rocks 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. The seismicity in and around its close vicinity has been extremely poor since historical past in which only two earthquakes with maximum magnitude 5 have occurred in 1953 and 1986 (Oldham, 1883; Rajendran and Rajendran, 2004; Singh and Mathai, 2004) as shown in Fig. 1.

3. AMBIENT NOISE DATA ACQUISITION

In order to make quantitative estimates of ground shaking amplification resonances in the deep soil/sand zones and landfill areas of Kochi city, closely spaced ambient noise measurements have been obtained. A CityShark II 3-component Seismic Recorder and a Lennartz LE-3Dlite triaxial active geophone with 1 Hz natural frequency were used for ambient noise data acquisition, while site locations were determined using a handheld Garmin GPS MAP 76S (Singh et al, 2005). The data acquisition 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. About 95% of total recorded data were obtained at 100 Hz sampling rate and the remaining data at 150 and 200 Hz sampling rates. The handheld GPS provided positional accuracy of the observation sites between 5 to 15 m in the horizontal direction. Over 1000 sites were occupied out of which 988 ambient noise records were found suitable for site response parameters estimation. The spatial distribution of ambient noise recorded sites over the geological map of Kochi city is shown in Fig.1.

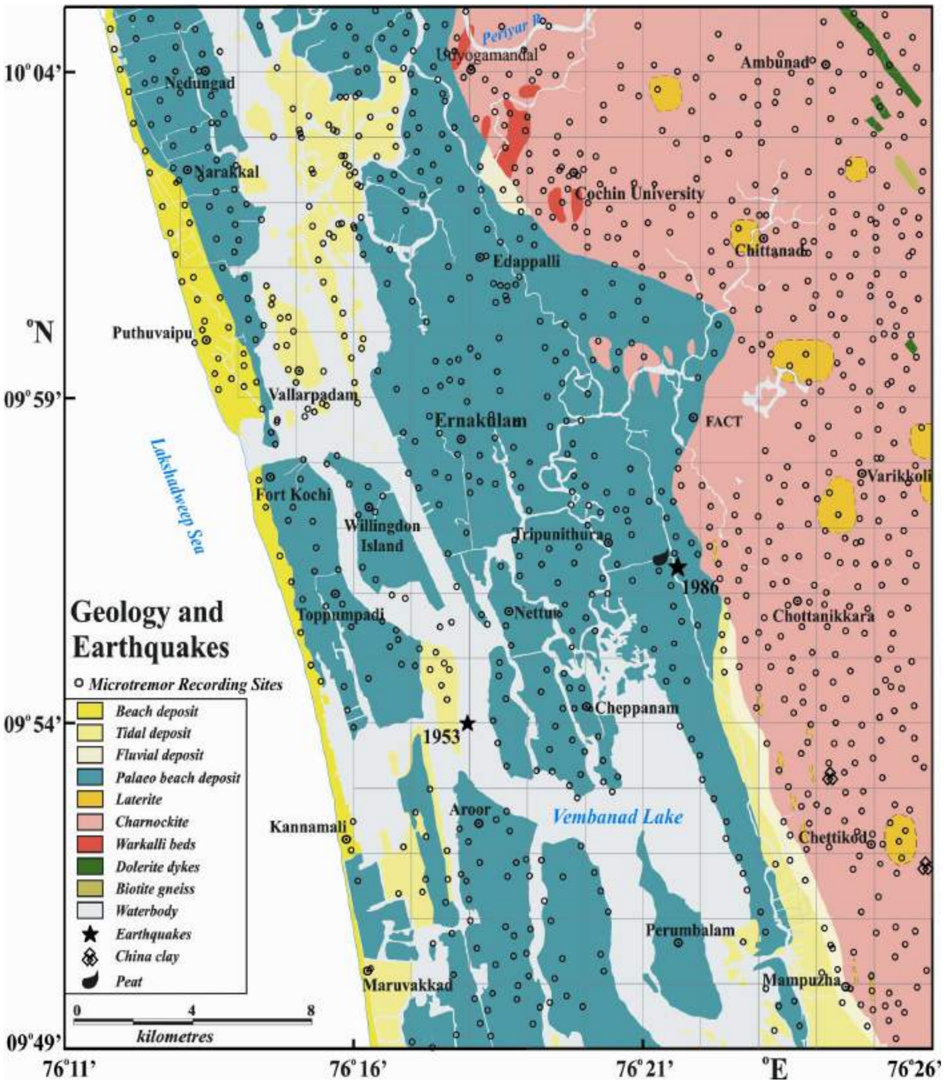

Fig. 1- Spatial distribution of ambient noise recorded sites over the geological features of Kochi city

3.1 Data Processing and Estimation of Site Response Parameters

The H/V technique developed by Nakamura (1989) was used for estimating site response parameters. Data processing and estimation of site response parameters 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 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). Traces of ground motion at each site were generated for further processing. 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. Likewise all the 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 (F_o)	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

4. PREPARATION OF SEISMIC MICROZONATION MAP FOR KOCHI CITY

Digital map layers on geology, soil, landform, land use, relief, drainage, transport network etc were prepared. The database was geocoded and integrated in GIS core. This helps to visualize distribution patterns of site response parameters and interpret them in relation to existing geographical and environmental conditions of the area. 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 geocoded ambient noise database for understanding spatial distribution of observation sites, preparing contours/isolines, DEMs and 3D view maps. Isolines of resonance frequency, F_o, from the F_o 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 F_o class interval were identified and logically combined in GIS. Integrating F_o 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 (T_s) was estimated using the formula $T_s = 2\pi/F_o$ (Siefko et al., 2002) where F_o is the resonance frequency. The range of resonance frequency and the characteristic site period in each microzone is given in Table 2.

Table 2 - Delineated seismic microzones in terms of resonance frequency (F_o) and characteristic site period (T_s) for Kochi city.

Zones	F_o (Hz)	T_s (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

4.1 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). High frequency sites (stable areas) generally produce low level site amplification but likely to generate high amplification of ground motion at limited sites. This zone occupies an area of about 190 km^2 and mostly confined to the eastern most 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. The remaining area has resonance frequency more than 10 Hz where site specific moderate to high amplification can be expected depending upon the ground conditions. This information indicates that one to two storey buildings will be practically unaffected due to ground motion since such structures possess natural frequency more than 5 Hz (Kramer, 1995). This zone is comparatively safer than Microzones II and III for settlement

4.2 Seismic Microzone II

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). This zone is the smallest among the three identified zones and occupies an area of about 152 km2. It is sandwiched between the microzones I and III and oriented in the northwest-southeast direction (Fig. 2). Palaeo-beach deposits constitute the main geological formation in this zone but tidal and fluvial deposits are also present towards south side bordering zones III and I. About 65% area of this zone exhibits site amplification in the range 5-10. It is also estimated that about 52% of the total area falls in the resonance frequency range of 1.1-3.0 Hz and the remaining in 3.1-5.0 Hz range. In view of long duration of characteristic site period ranging from 6.3-1.2 sec, the structures and the buildings in this zone may have higher probability to achieve resonance as compared to Microzone I. This investigation indicates that resulting damage in Microzone II will be much higher than Microzone I but lesser than Microzone III. This zone is moderately safe and proper building codes are to be followed for constructing safe structures in order to avoid damage due to ground motion in an earthquake.

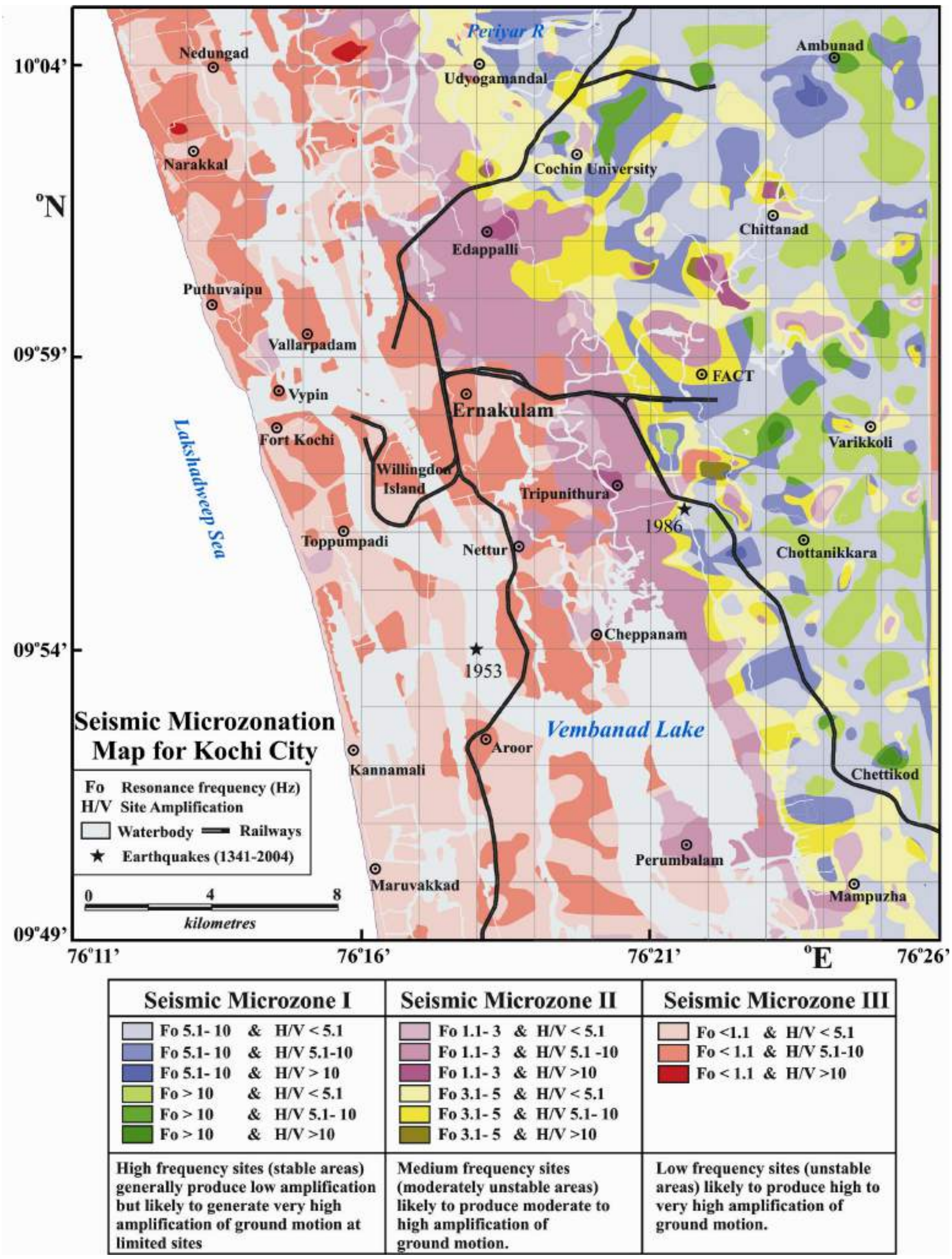

Fig. 2: Seismic microzonation map for Kochi city. Three Seismic Microzones I, II and III were delineated based on estimated values of resonance frequency and site amplification on analysis of ambient noise records

4.3 Seismic Microzone III

This zone occupies low frequency sites (unstable areas) which are likely to produce high to very high amplification of ground motion. This is the western most zone and covers entire coastal belt, backwaters and islands and spread over an area of about 175 km^2 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. It is characterized by lowest resonance frequency (≤ 1.0 Hz) and longest duration of characteristic site period > 6.3 sec (Fig. 2). Site amplification ranging from 4 to 10 is observed through out 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.

5. CONCLUDING REMARKS

The resonance frequency estimated through analysis of ambient noise data in Kochi city of Kerala state is spatially distributed in three northwest- southeast trending regions parallel to the coast which differ appreciably in their site response characteristics and geological setup. 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. Three Seismic Microzones I, II and III were delineated based on spatial variability of resonance frequency and site amplification. The Microzone I and the adjoining portion of Microzone II are relatively safer as compared to the remaining areas of Microzones III and II. 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.

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