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Site Response Studies under Seismic Hazard Microzonation of Visakhapatnam Urban Agglomeration, Andhra Pradesh – a case study

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Abstract

This paper presents the Site response characteristics in the form of amplification factors for seismic microzonation of Visakhapatnam Urban Agglomeration. Noise survey was carried out for site response parameters to determine and evaluate the predominant frequencies and the amplification of the ground motion in and around Visakhapatnam. Basically, these studies have been aimed to delineate susceptible zones of damage during an earthquake.

The khondalites, charnockites and granite gneisses form the bedrock in the area while the river alluvia, soil and beach deposits of recent times constitute the unconsolidated cover sediments.

The site response studies indicated various vulnerable zones of damage when affected by earthquake. Processing of the data obtained from noise survey at various sites in Visakhapatnam Urban Agglomeration show variations of peak frequency in the range of 1 to 10 Hz and peak amplification factors in the range of 1 to 8. It also indicates frequent lateral variations in the subsurface characteristics especially of the overburden. Maps showing relationship between maximum amplification and peak frequency and average amplification at different frequency ranges are useful many end users, including geotechnical engineers, building planners and general public at large. The maps presented in this paper are preliminary in nature and qualitative by analysis.

Introduction

Visakhapatnam is the second largest city of Andhra Pradesh and is a fast growing industrial area in A P. The general topography is rugged. Geomorphologically the city and its environs can be classified as hills, hill-slope areas, rolling plains, intermediate low-lands and coastal plain. The concept of seismic microzonation is based on the fact that the intensity of ground shaking in certain frequency bands gets amplified by the pile of unconsolidated sediments overlying the hard and competent basement, i.e., local geological conditions alter the characteristics of ground motion. Seismic microzonation can be achieved by rationally incorporating the site-specific ground motion parameters in the probabilistic seismic hazard assessment.

Microzonation can play a vital role as a proactive strategy in citiy planning and development in regions where high seismic risk is involved. Civil Engineers and Town Planners can effectively use the microzonation information to incorporate earthquake damage reduction measures like planning land-use, designing of structures etc. For example, high amplification areas can be left as lung spaces for development of parks etc., whereas low amplification areas can be used for developmental activities such as high-rise / heavy structures, public utilities etc.

Digital Earthquake Recorders manufactured by M/s Kinemetrics have been used for noise study in Visakhapatnam Urban Agglomeration. Noise survey has been carried out to determine site response parameters, viz the predominant frequencies and the amplification factor of the ground motion. In more realistic terms, these studies are aimed to delineate zones of varying site

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response and assess damage potential in case of occurrence of an earthquake in the vicinity Visakhapatnam Urban area.

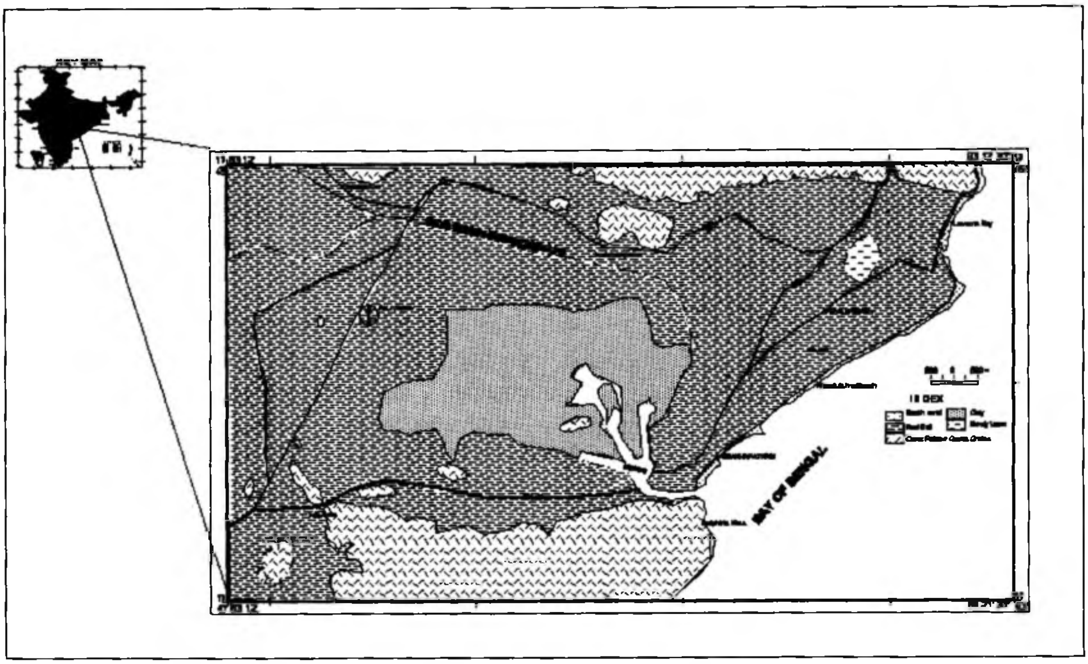
The site response parameter is a very important factor under the microzonation study of an area. It is established that the ground shaking effect caused by an earthquake can vary widely within a small distance. This is because the seismic energy, in the event of an damaging earthquake, under certain geological conditions gets amplified leading to an increase in the damage to man-made structures. Theoretical analysis and observational data have shown that each site has a characteristic frequency called 'Natural frequency' or 'Resonance frequency' at which ground motion gets amplified. Low value of seismic rigidity (velocity x density) gives rise to higher order of seismic amplification. Usually multi-storied / heavy industrial constructions are planned in the shallow bedrock areas. Man-made structures, whose Resonance frequency matches with that of the site, have the maximum chances of getting damaged. Hence, in order to construct seismically safe structures, it is important to know the site response characteristics of the specific location.

Location and geology

Visakhapatnam is the second largest city of Andhra Pradesh, and is a fast growing industrial area on the east coast of A.P. The study area has a spread of around 170 sq km falling between North latitudes 17°38'27" and 17°51'06" and East longitudes 83°08'49" and 83°21'46"E, within the Visakhapatnam Urban Agglomeration (Fig-1).

The general topography of the study area is rugged. Geomorphologically the terrain can be classified as hills, hill-slope areas, rolling plains, intermediate lowlands and coastal plain. The average annual rainfall of Visakhapatnam is of the order of 100 cm.

The area forms a part of Eastern Ghat Mobile Belt (EGMB) consisting of two major suites of rock, viz., khondalites (including garnet-sillimanite gneisses, quartzite and calc gneisses) and charnockites including pyroxene granulites. Soil, alluvium and beach-sand form the overburden in the area. Relatively higher seismic activity, coastal location, variable lithology, soil profile and presence of Konada – Kumili active fault have

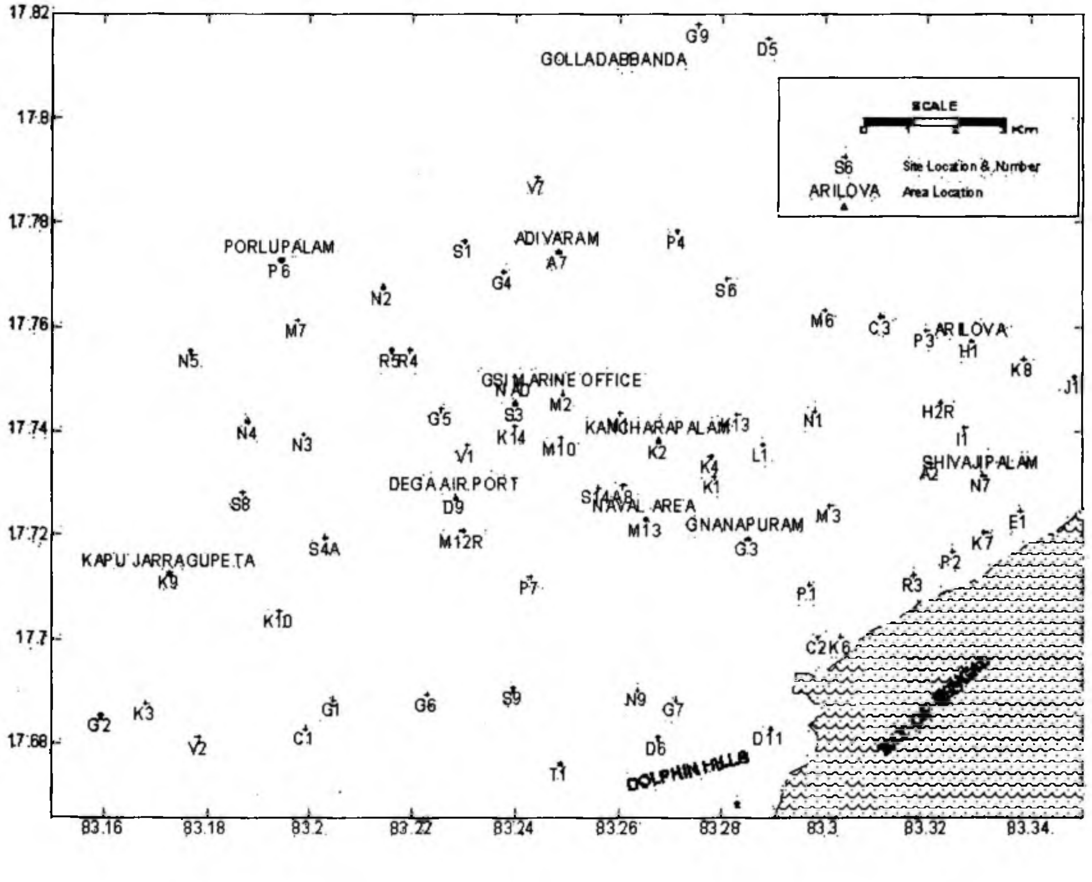


necessitated the microzonation studies in Visakhapatnam. The Konada – Kumili (K – K) fault considered as one of the possible seismogenic source fault runs in NW – SE directrion along the Champavati River and is located about 50 km northeast of Viskhapatnam city. The K-K fault has several epicenters of past seismic events spatially associated with it.

Four discernible and mappable units of likely varying site response characteristics (in the event of a damaging earthquake) viz, beach zone, red sand horizons, pediplain with moderate to thick soil cover in addition to residual / structural hills are present in this area.

Methodology

Various methods are available for estimating the site response for hazard analysis in an area. The best method is to record the strong motion caused by a large local earthquake. However, such events are not frequent in all the places. Hence, this method is not very practical for site response studies. As an alternative, data from records of local micro-earthquakes and tele-seismic events is used for site response studies in an area. One needs to have a dense array of stations to have good spatial resolution in microzonation and records over a protracted period to be able to obtain adequate data required for this purpose. Another method used for the site response studies is to carryout extensive seismic refraction and geotechnical studies to determine the structure and physical properties of the soil and rocks present in the area and then use them to theoretically determine the site response. Since this method is expensive and time consuming, spot seismic noise study and analysis is carried out by deploying digital earthquake recorders and to evaluate the predominant



range of frequencies and amplification factor.

The surveys were planned at a spot interval of 1.5 to 2 km. A total number of 135 stations were covered in an area of 170 sq. km. (Fig-2). At each site the instruments were deployed for about 12 - 24 hours duration in event mode. The data thus acquired was converted to Seisan format using Seisan software. It is compatible for execution of Nakamura software in SUN Solaris operating system. The average relative spectral ratio for horizontal (along E-W & N-S directions) components to vertical component was calculated using Nakamura software.

Results

The raw data was converted to Seisan format, which is used for selecting the data set with a window width of 60 sec. The average relative spectral ratio of horizontal çomponent to vertical component (H/V) was calculated using Nakamura method for analyzing ambient seismic noise. From the average relative spectra, the amplification factor at various peak frequencies within 1-10 Hz is calculated. The maximum site amplification with corresponding peak frequencies at each site is computed. Peak amplification contour map is presented in Fig-3.

The Peak amplification contour map indicates various zones, which are vulnerable for heavy damage during an earthquake. The processed results of noise data indicated that peak frequency varied in the range from 1 to 10 Hz while the peak amplification varied from 1 to 8. This indicates frequent lateral variations in the elastic properties of the subsurface probably due to variations in the nature and thickness of the overburden and the rock mass forming the basement.

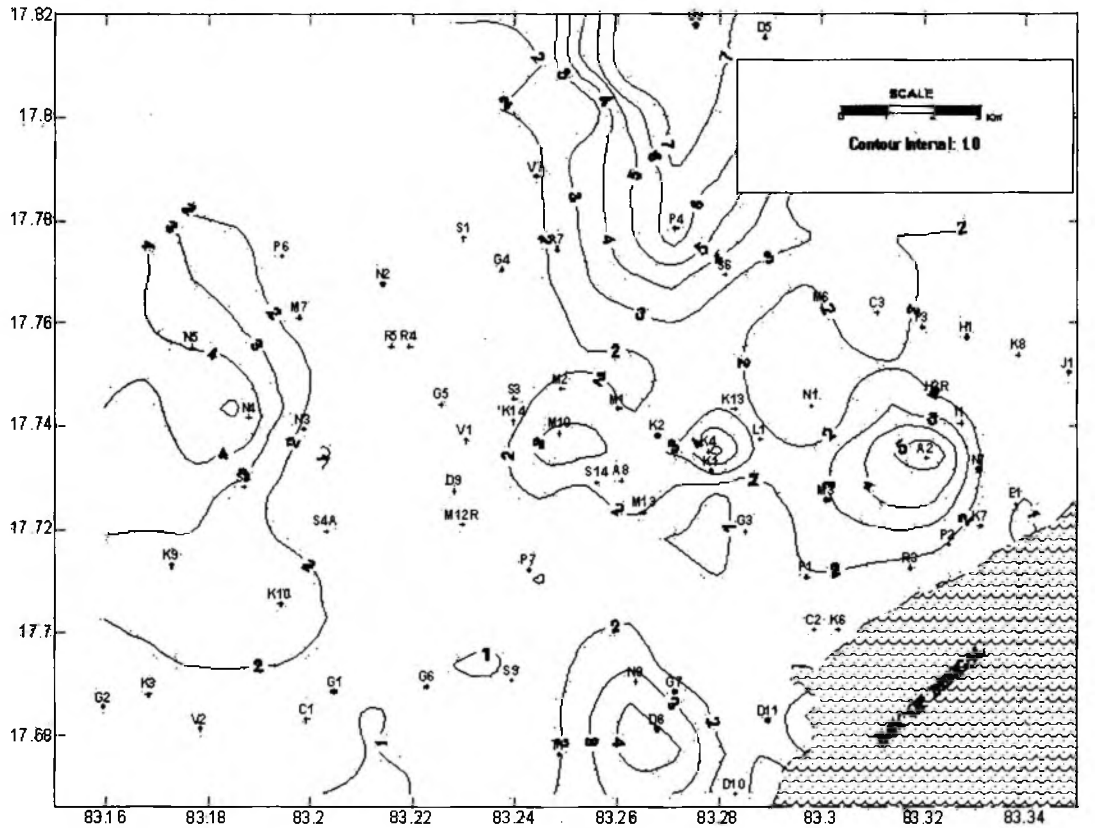


Fig. 3: Map showing the amplification factor at predominent frequency

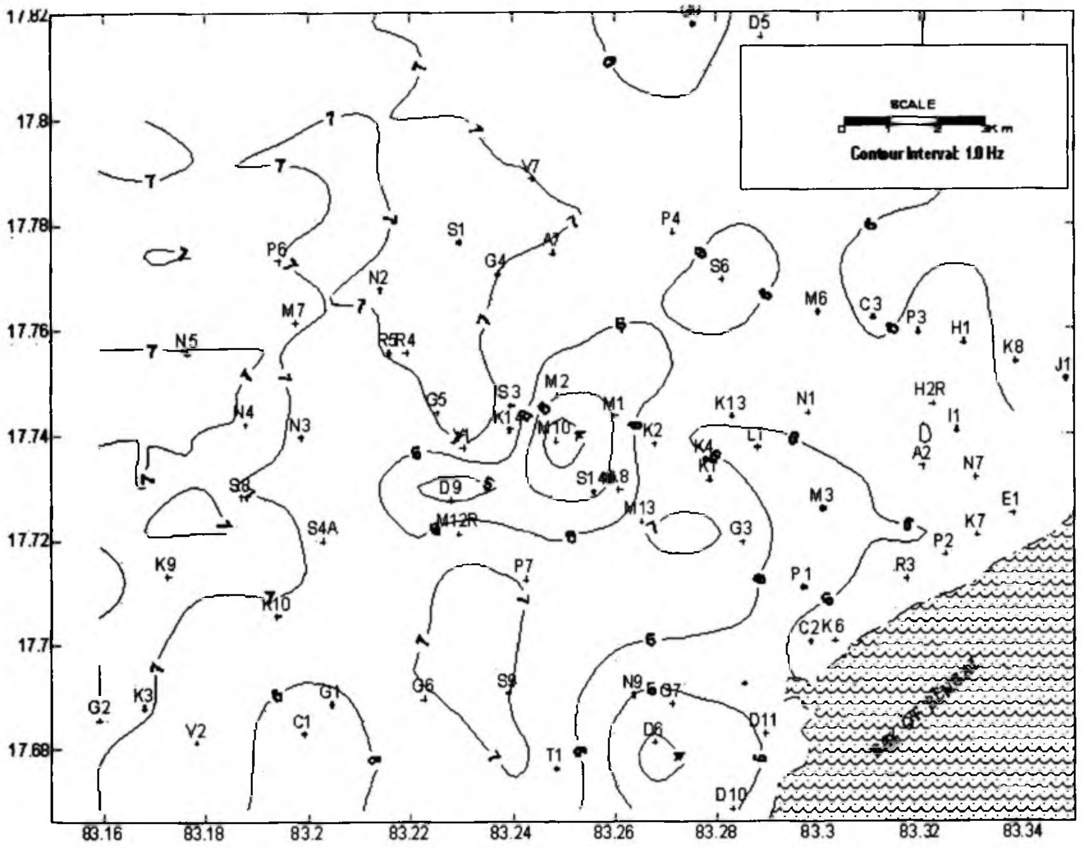


Fig. 4: Map showing predominent frequency at predominent amplification factor

Variation in peak frequency of the area is presented in Fig-4. It reveals that frequency ranges from 4 to 6 at location M10 and surrounding areas. This indicates that the overburden in this area comprises poorly cohesive material, offers higher amplification and hence may suffer more damage during an earthquake. The variation of amplification with frequency at each site in this area broadly indicates 3 to 4 layers in the subsurface. The top layer is characterized by a frequency range of 7 to 10 Hz with regular to irregular variations of amplitude with frequency (Fig-5). The second layer is characterized by a frequency range of 5 to 7 Hz (Fig-6). The next layer is characterized by frequency a range of 3 to 5 Hz (Fig-7). The bottom layer is characterized by a frequency range of 1 to 3 Hz (Fig-8).

In Fig-6, the site amplification of 6 to 7 is observed in the northern part of study area i.e., at stations G9 and P4 indicating presence of highly weathered rock and possibly thick overburden between stations G9 and P4. In this area, the foundation for heavy structures should be taken to 'hard basement'. Surprisingly this area is a 'high ground' compared to adjoining areas. This feature is also reflected in the 3 - 5 Hz frequency ranges contour map (Fig-7). This may be indicative of shearing / fracturing in the basement.

In Fig-5, amplification in the range of 2 to 5 was noticed at four different locations, viz., i) at D10, ii) K4, iii) K3 and iv) A2 sites. K4, K13, and A2 sites are aligned in an E – W direction and appear to extend westward towards Narava (Sites N3, N4) as observed for frequency ranges 5 to 7 Hz, 3 to 5 Hz and 1 to 3 Hz, in other maps (Fig-6, Fig-7 and Fig-8). This feature is attributed to bedrock at moderate depths which may be sheared /

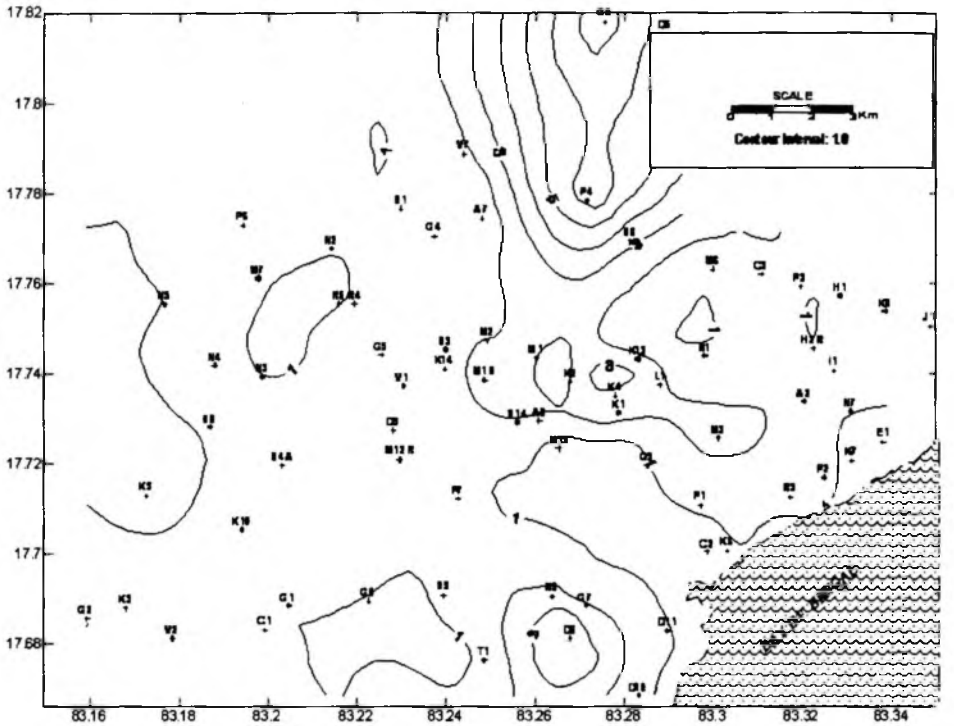


Fig. 5: Map showing amplification factor at frequency band 7-10 Hz

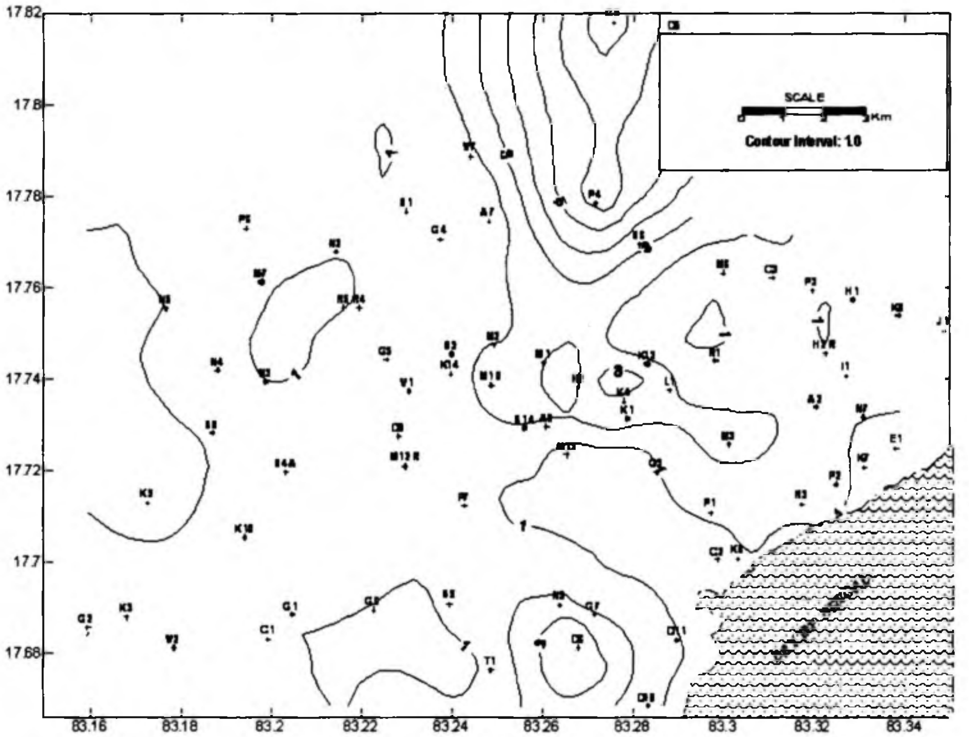


Fig. 6: Map showing amplification factor at frequency band 5-7 Hz

fractured at places. It corroborates well with the results of seismic and resistivity surveys. (Kameswara Rao, G et. al., (1981); Balakrishanan, M et. al., (2003)).

In spite of effects of soil amplification, sometimes severe damage to structures occurs due to double resonance. By double resonance we mean the large amplification of bed rock motion by the soil deposits due to resonance and further amplification of soil motion by the structure having the similar fundamental period. The fundamental period of building may be approximated by its number of stories, as N/10 seconds, where N is the number of stories.

Over the rest of the area, amplification of the order of 1 to 2 is observed indicating the presence of bedrock at shallow depth and / or the presence of compact weathered zone.

The typical Nakamura output is presented in Fig-9.

Conclusions

The seismic hazard of an area is governed by numerous parameters including nature of earthquake source, past earthquake activity and tectonic fabric of the area. The relation between earthquake magnitude and the average rate of occurrence for each area is weighted along with variations in the attenuation of ground motion with distance, in studies pertaining to seismic hazard zonation.

The natural frequency of ground provides the fundamental time period of the site, which helps in designing aseismic heavy industrial structures and multi-storied buildings at that site.

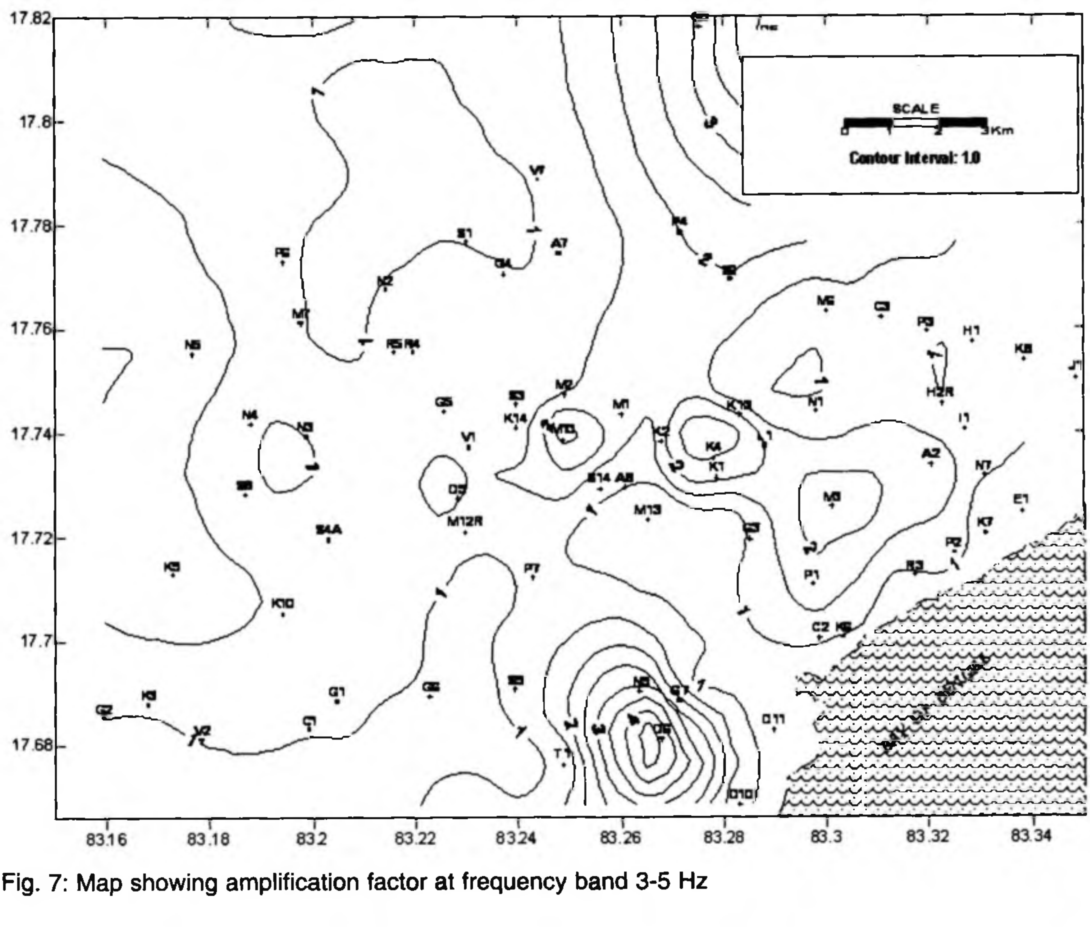


Fig. 7: Map showing amplification factor at frequency band 3-5 Hz

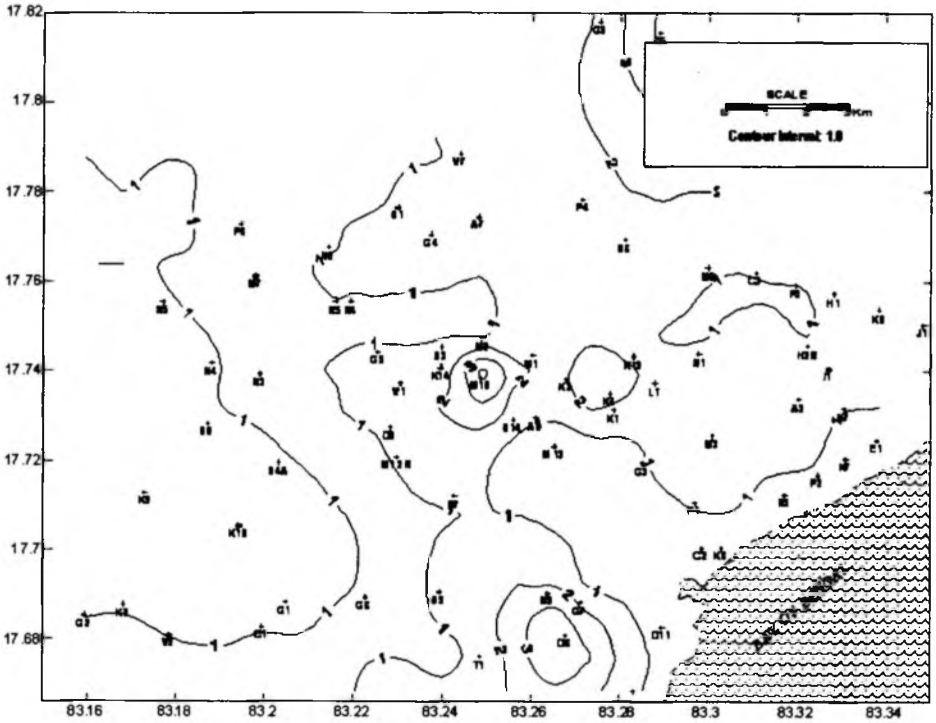


Fig. 8: Map showing amplification factor at frequency band 1-3 Hz

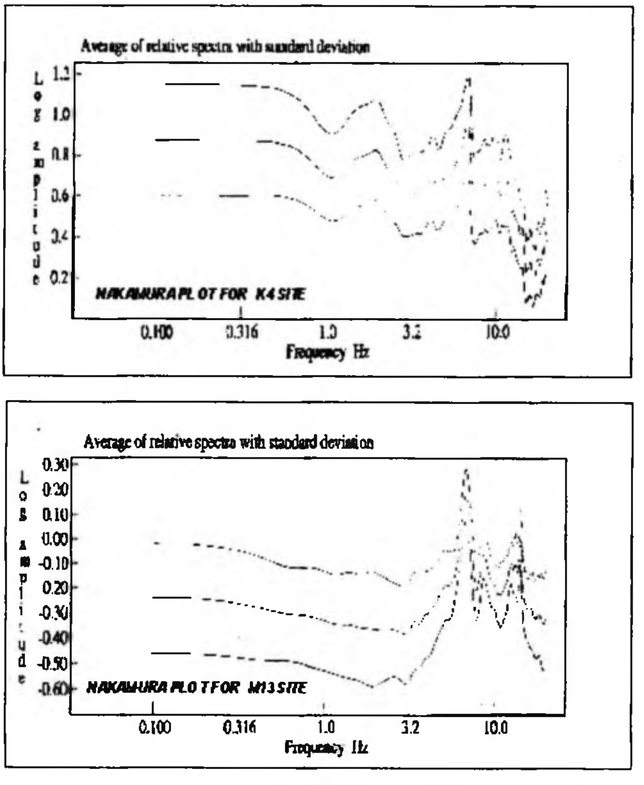


Fig. 9: Map showing typical relative log amplitude - frequency spectraplot

Large amplification factors at resonance as well as average amplification in lower frequency ranges were observed in many parts of the study area which is Visakhapatnam Urban Agglomeration. High amplification factor near Golladabbanda site and its adjoining areas with natural frequency of the order of 7 Hz indicates that the area will be subjected to relatively greater ground motion during a major earthquake. Area near Kancharlapalam and adjacent areas of Dolphin hills area indicated peak natural frequency greater than 10 Hz indicating that the area is highly vulnerable for damage in the event of an earthquake.

As far as Visakhapatnam Port and surrounding areas are concerned, the analysis was extrapolated as no station could be set in the area for reason of security. Some of the areas were not accessible due to various cultural / logistics problems.

From the above analysis, it is noticed that there may be two lineaments passing close to station K4, one in north – south direction and the other in east – west direction. K4 site and surrounding area are more vulnerable for high damage during an earthquake as compared to other areas. Hence, it is recommended to avoid construction of heavy / high-rise structures in that area.

Maps of maximum amplification at peak frequency (Site Response), average amplification factor at different frequency bands are immensely useful for many end-users, including geotechnical engineers, town planners and general public. These maps can be directly used as an input for microzonation studies of this region.

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