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Horizontal to vertical spectral amplitude ratio of seismic waves as an effective tool for site classification: A study from Chennai, Tamilnadu

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ABSTRACT
Passive and active seismic studies were carried out in and around Chennai city to estimate H/V spectral ratio for site classification for use in microzonation. Passive seismic studies included monitoring of ambient seismic noise over a period of time. Active seismic studies carried out using hammer impact as a seismic source to determine the fundamental frequency and the related amplification of soils. The results of the studies conducted at 204 sites in Chennai region revealed good correlation with with different near surface geological data. Hence, we conclude H/V spectral ratio obtained from the short duration data is adequate to classify the sites for the purpose of microzonation of a region.

INTRODUCTION

The characteristics of seismic waves generated and propagated through different geological formations during the earth quakes will be dependent on local site conditions. It is evident from the past history that the damage due to earth quakes is very high in the regions with thick alluvial cover. Most of such damage is attributed to the amplification of certain frequencies in the near surface alluvium cover during the propagation of waves. The spectral ratio of Horizontal to Vertical (H/V) travelling seismic noise has become an important tool to estimate the frequencies and amplifications during ground motion. Several experimental studies on H/V spectral ratio technique were carried out over soft deposits by using the long duration ambient seismic noise and recorded earthquake data (Ohmachi et al. 1991; Field and Jacob, 1993; Lachet and Bard, 1994; Lermo and Chavez-Garcia, 1994; Lachet, et al. 1996; Fäh et al. 1997; Stefan Parolai, et al. 2004). These studies have lead to reliable estimation of the fundamental frequency. Haghshenas, et al., (2008) calculated the H/V spectral ratio by using recorded earthquake data and also ambient vibration data. The long duration data was obtained by Panou, et al. 2005, for a week during evening and night period for over 20 min. The noise recordings are acquired continuously for nearly 3 months from the stations deployed in Cologne (Stefano Parolai, et al. 2004) and in Bonn for nearly 5 months (Baliva, et al. 2004) and the H/V spectral ratios are estimated using the conventional Nakamura technique (Nakamura, 2000). Data acquisition using this technique takes a minimum of two days where as the advantage with the present study , detailed in this presentation, using exploration seismograph takes few minutes. The present study is aimed at determining the fundamental frequencies by using the short duration data of 30s with ambient seismic noise and also by hammer impact. The acquisition of short duration data is less expensive, fast, and several locations can be covered with in a shorter period for site characterization/microzonation studies. On the other hand, recording of long duration data is a difficult task in urban environment due to the traffic and cultural noise, expensive, and time consuming apart from problems related to site preparation for installation of seismometers. Similar studies were carried out at Jabalpur (Seshunarayana, 2002) for microzonation studies and the results are encouraging.

The paper presents the results of analysis of the short duration data using Passive seismic studies with ambient seismic noise and active seismic studies with hammer impact.

The studies have been carried out in different geological formations of Chennai city and surrounding areas with varying soil cover. The H/V spectral ratio of ambient seismic noise (microtremors) has been widely used in microzonation studies due to their cost-effectiveness of the method. The H/V spectral ratio of seismic noise and with hammer source shows a peak (Figs. 2, 3, and 4) which indicates the fundamental frequency of the site under investigation.

The major objective of the study is estimating the seismic amplification of soils over low frequencies, using short duration data of ambient seismic noise and the hammer source. The study also proved that the H/V spectral ratio curves show identical shape with ambient noise and hammer impact records.

LOCATION AND GEOLOGY OF THE STUDY AREA

The entire study can be classified in to three different near surface geological conditions, namely (1) region with thick alluvial soils (> 30m), (2) thin alluvial soils (< 30m), (3) shallow hard rock with (< 5m) with very thin soil cover, in Chennai city (Fig. 1).

Eastern part of the Chennai comprises with thick alluvial and Western part covers with igneous, metamorphic, and sedimentary formations with thin alluvial cover.

Chennai is covered by alluvium of varying thickness from few meters to tens of meters, deposited by two rivers namely Coovum and Adyar. The eastern and northern parts of the city comprise marine sediments containing clay-silt, sands and sandy clays. Igneous/metamorphic rocks are

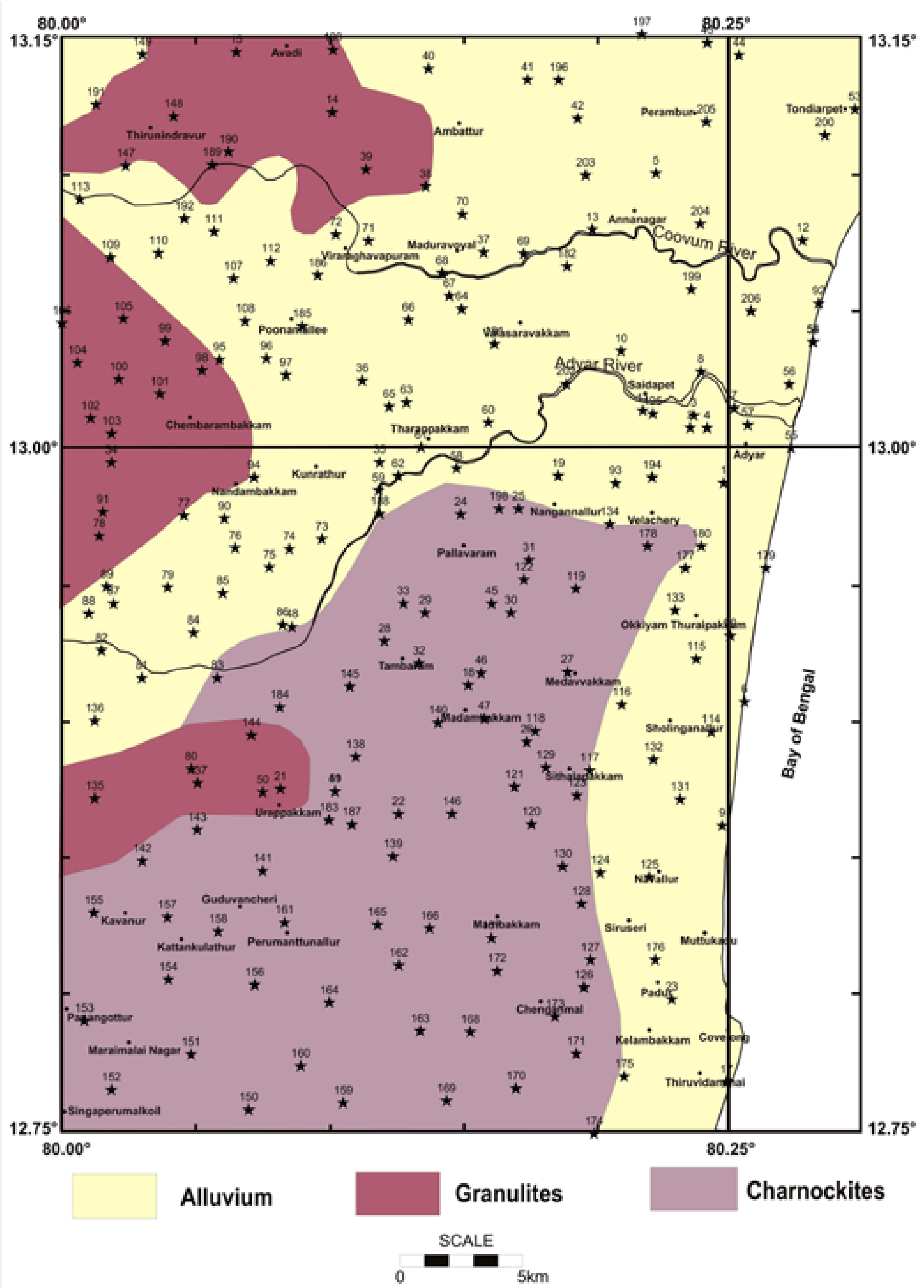

Figure 1. Geology of Chennai region and stars indicate the study locations

found in the southwestern parts. Exposures of charnockite have been observed near Pallavaram area. A thin layer of laterite is also found at some places. It is seen in general that the eastern coastal zone is predominantly sandy, while the northwestern region is mostly clayey in nature.

DATA ACQUISITION AND PROCESSING

Both passive and active seismic data was acquired from 204 suitable locations in and around Chennai city with different geological and geomorphologic features. The locations are selected in such a way that the site is least affected by vehicular and cultural noise. The acquisition of field data took 10 weeks in three field seasons. If the data acquisition is done using conventional Nakamura technique that would have been taken a minimum of 36 weeks.

The recordings of ambient seismic noise and hammer source were taken by using the three-component geophone of 1 Hz with the conventional 24-channel seismograph. Although the data was acquired for different record lengths, finally optimum parameters of 30s record length and 2-ms sampling interval were selected. The recordings were performed in the thick, moderate, and thin soil cover areas. In all, six records were obtained for each site: three records were obtained for recording the ambient seismic noise and three records were taken by using the hammer source. The hammer source was located at an offset of 30–50 m. The data was processed using the simple MATLAB program. High cut filter was applied to entire data set to remove the ambient and cultural noise >30Hz. Fast Fourier transform is applied to each of the components to obtain the spectral amplitudes. The entire data was smoothed by using moving average method. The spectra of the NS and EW components for ambient and hammer recording merged to obtain a horizontal component spectrum by means of computing their root mean square average. The H/V spectral ratio is computed using the Eq. 1 (Wenzel, 2005).

$$r(f) = \frac{\sqrt{FNS^2 + FEW^2}}{2*FUD} \tag{1}$$

Where r(f) is the horizontal to vertical (H/V) spectral ratio, and FNS, FEW, and FUD are the Fourier amplitude spectra in the NS, EW, and UD directions, respectively.

Three H/V plots as example are presented in Figure 2, 3 and 4. In the plots red lines represent the spectra for hammer source and blue line represents the spectra of ambient seismic noise.

RESULTS AND DISCUSSIONS

Three graphs of H/V, with thin soil cover, medium soil cover and thick soil cover are presented in Figs. 2, 3 and 4 as examples. The sites with thick alluvial cover are showing high amplifications at low frequency indicating the presence of deeper bedrock at > 30m (Fig. 2). Moderate amplifications are observed at low frequency in areas with

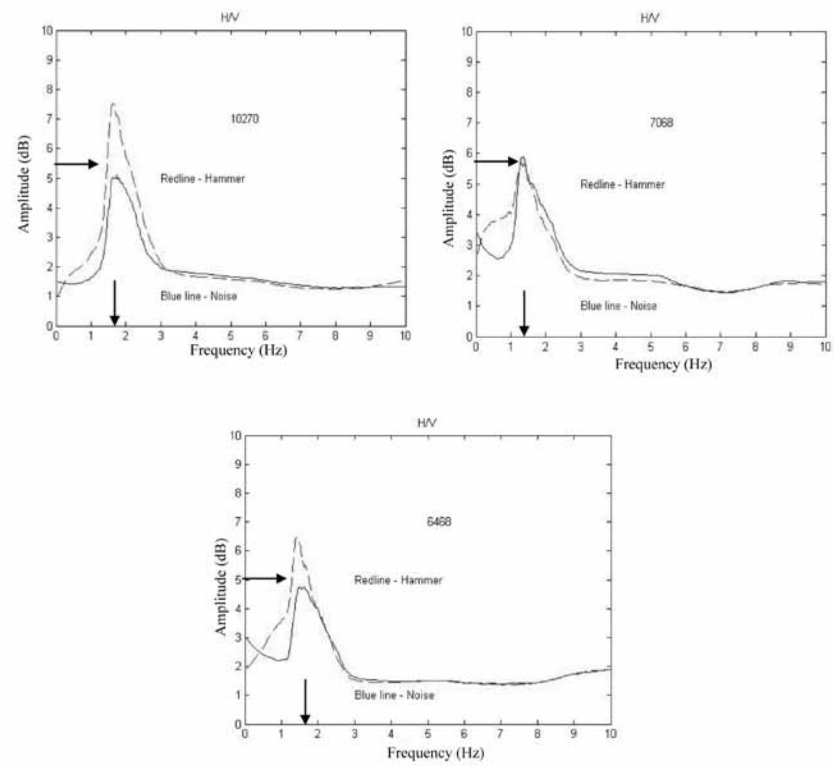

Figure 2. H/V spectral ratios in thick sediments and deeper bedrock formations. The figure shows high amplifications at low frequency

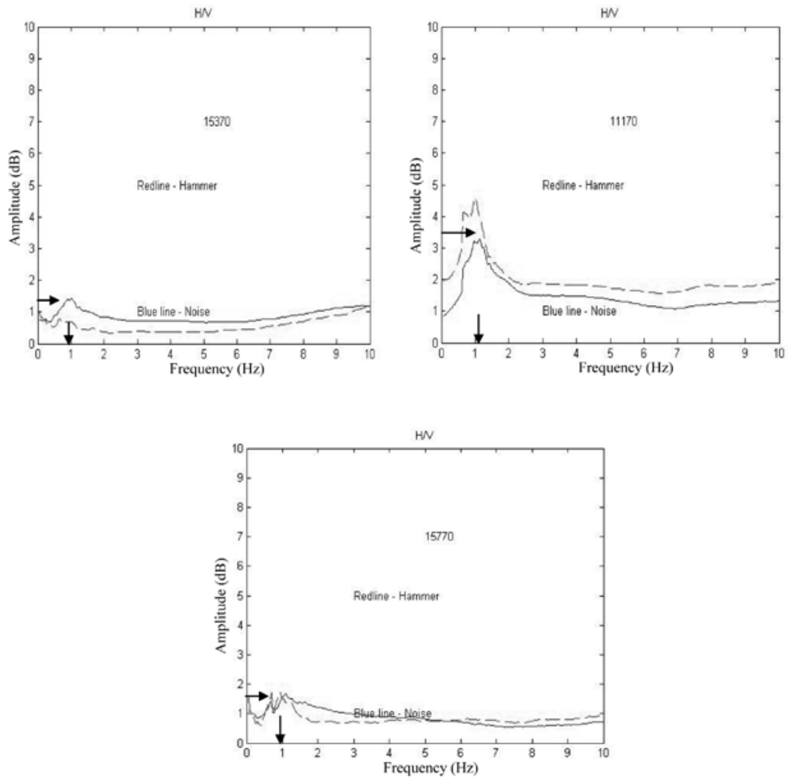

Figure 3. H/V spectral ratios in medium thick soil cover and moderate bedrock depth. Figure 3 shows the spectral ratio of thick sediment cover and moderate bed rock zones (<30 m). Figure shows moderate to high amplifications at a frequency of 1.0 Hz to 1.5 Hz. frequency

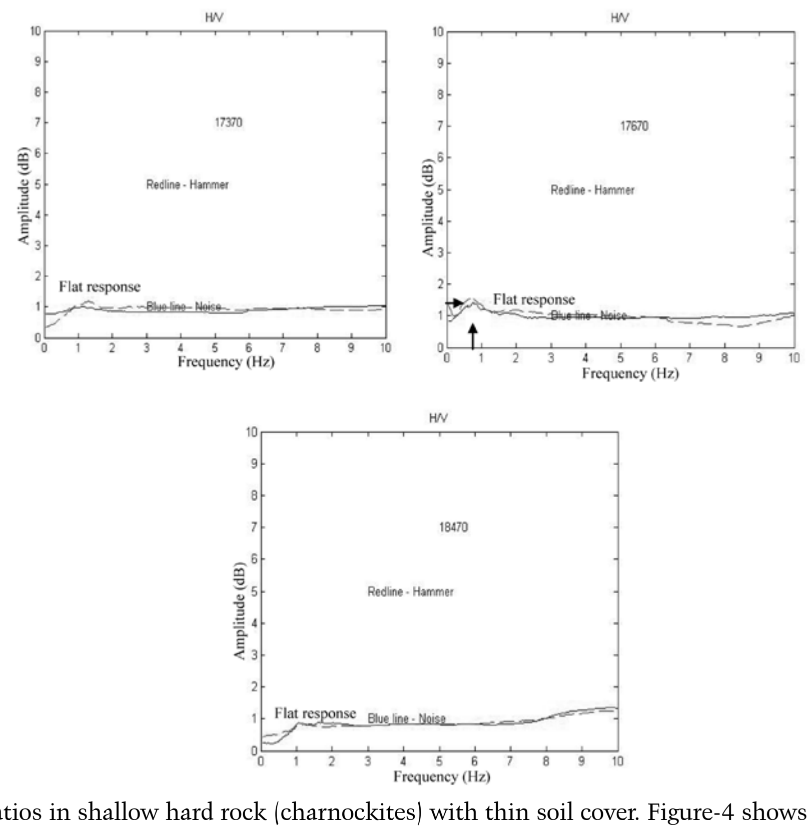

Figure 4. H/V spectral ratios in shallow hard rock (charnockites) with thin soil cover. Figure-4 shows H/V ratios in charnockite formations at shallow depths (<5m). Flat response is observed at shallow bed rock locations from the obtained data.

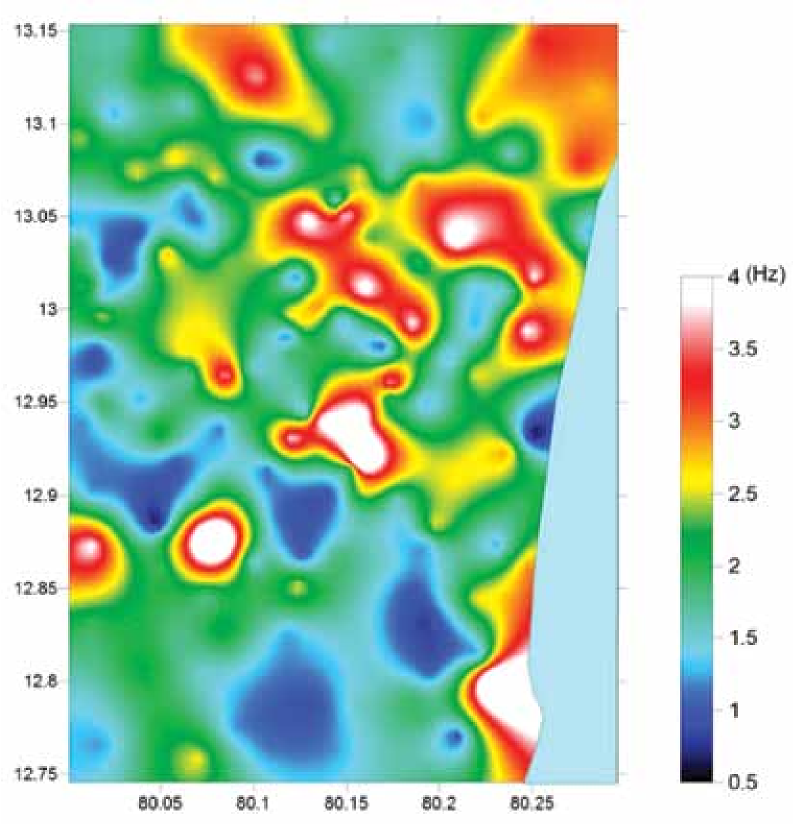

Figure 5. Frequency map of Chennai City

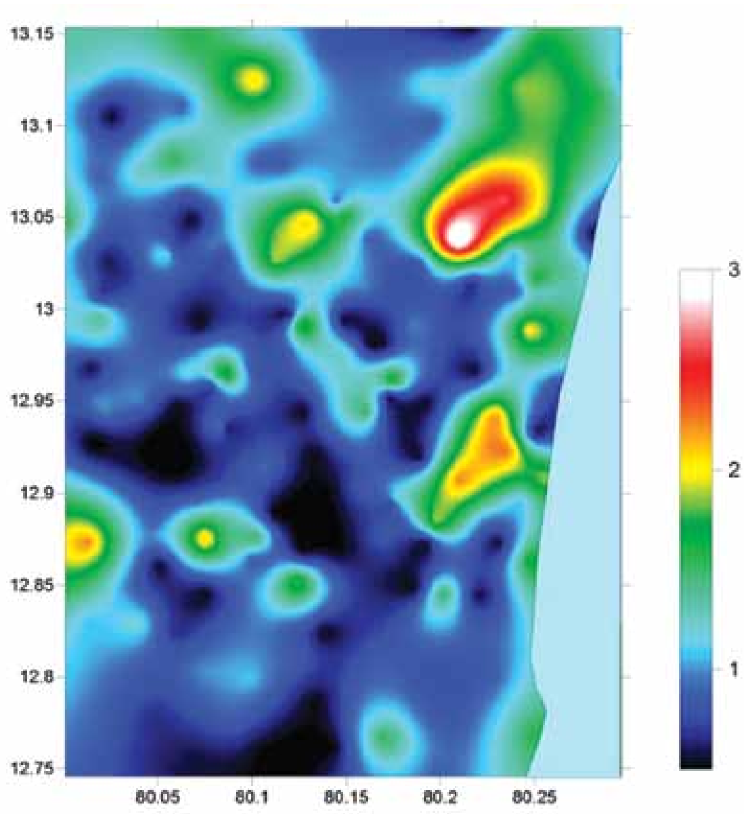

Figure 6. Amplification map of Chennai City

moderate soil cover (granulites and charnockites of Chennai formations) corresponding to moderate bedrock depth (Fig.3). Fig. 4 shows H/V spectral ratios in undisturbed/ intact charnokite formations with thin soil cover. At these places, shallow bedrock is observed (< 5m). The significant high amplifications at low frequencies of H/V are mainly due to the presence of thick and soft soils. The distribution of frequency and amplification maps for all the study locations are shown in the Fig. 5 and Fig. 6 respectively. The variation of frequencies is in the range of 0.5 to 4 Hz for the study area. The low frequencies in the range of 0.5 to 1.5 Hz in the northern part of the study area are observed in the thick alluvial regions. In the weathered formations, frequencies are varying in the range of 2 to 3.5 Hz and in the charnockites, frequencies > 3.5 Hz are observed. In the northern part of the study area, high amplifications of 3 are observed indicating the presence of alluvial formations. In the weathered formations, moderate amplifications of 2 are observed. Low amplifications of 1 are observed in the southern part of the study area corresponding to charnockites.

CONCLUSIONS

In this study, the ambient vibrations and the hammer recordings were used to evaluate the H/V spectral ratio in different geological formations with varying soil thickness. The high amplification levels are corresponding thick sediments.

The high amplification values of 3.0 to 6.0 are observed at low frequencies (1–2 Hz), in thick and soft sediments and deeper bed rock zones (> 30 m). In the thick stiff soils, moderate bedrock depth (< 30 m), the moderate amplification of 1.5 to 3.0 are noticed at low frequencies (1 to 4 Hz) with varying soil cover (< 20 m). The broad frequency (1–4 Hz) or shift towards higher frequency (2 to 4 Hz) may be due to the combined effect of soil thickness and its stiffness as observed in some spectra. In hard rock areas with thin soil cover (< 2 to 3 m), no significant amplification is observed.

Analysis of the results shows that the short duration data, with passive and active seismic methods, is adequate to estimate the H/V spectral ratio. This is a more efficient tool for site classification and microzonation studies. The study also proves that hammer impact at far distance can be used in estimating H/V spectral ratio instead of ambient noise alone.

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