# Ambient Noise H/V Spectral Ratios in Estimation of Site Effects along coastal transect from Kakinada to Haldia

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***Abstract*** - *Local site effect is a crucial component of seismic risk assessment studies. For this, analysis of ambient noise of site is an important tool for estimation of local site effects, which in turn is also influenced by geological composition of the site as it plays a significant role amplifying certain frequencies of ground motion. Thus, in order to estimate the site effects, a study involving identification of critical geological features using satellite imagery and surface geological details was done followed by Horizontal-to-Vertical (H/V) Spectral Ratios (HVSR) with the short duration data in different geological formations, along the transect from Kakinada to Haldia. Of the seventy-three (73) lineaments that were identified, site response analysis was conducted at fifty-one (51) different structural lineaments. Of them, the NW-SE trending major lineaments were identified along the corridor and the study at these lineaments using the ambient noise analysis; fundamental frequency and the corresponding amplification of soils are discussed in this paper. The results of the study summarize the local site effects and probable impact during an earthquake, could be useful for any proposed critical structures in the region.*

**Keywords**: *Ambient noise, H/V spectral ratios, Frequency, Nakumura technique, Amplification*

## I. INTRODUCTION

The importance of local site geology in seismic design along transect area is well established. It is obvious from the history of human civilization that man has been struggling to defeat the natural disasters since its origin. Earthquakes are one of those deadliest events that change the entire landscape, and they are associated with tectonic processes. Heavy life losses, disaster to property, disturbance to the normal life pattern, and termination of the developmental processes of a country or region are some of disastrous impacts of these inevitable events (Ram Kumar, 2009). The evaluation of site effects on strong ground motion has been extensively studied during the last two decades and is thoroughly reviewed by Aki (1988, 1993) and Finn (1991). The most standard method for characterizing site amplification is the spectral ratio technique. Local site conditions can significantly enhance the risk factor in areas adjacent and remote from the epicenter. Every site exhibits its seismic response at which ground motion can be amplified. If it coincides or corresponds with the fundamental frequencies of manmade infrastructures, then there is great possibility of disaster. Most coastal tracts and river basins have thick alluvial cover that tends to amplify certain frequencies of ground motion and thereby increasing earthquake damage.

The horizontal-to-vertical (H/V) spectral ratio of seismic noise has become a widely used tool for obtaining frequencies and amplifications over a given area. Several experimental studies (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) have found that the H/V spectral ratio technique provides reliable estimation of the fundamental frequency of soft deposits. In 2001, the epicenter of Bhuj earthquake was about 400 km away from Ahmedabad (India), but it was highly affected by earthquake because the city was located over the younger alluvial deposits (Ranjan, 2005). The H/V spectral ratio is performed by using recorded earthquake data and ambient vibration data (Haghshenas et al. 2008). In the work done by (Panou et al. 2005), the records were obtained for a week during evening and night period for over 20 min. The noise recordings acquired continuously for nearly 3 months by 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 were estimated using the conventional Nakamura technique (Nakamura, 2000). Instead of using the long duration data, the present study is aimed at determining the fundamental frequencies by using the short duration data of 30 s with ambient seismic noise and by hammer impact. H/V method is

a very reliable method for estimating alluvium thickness by means of fundamental frequencies of the soft sediments (Morales et al. 1991; Yamanaka

et al. 1994; Parolai et al. 2002; Panou et al. 2005). Similar studies were carried out at Jabalpur (Seshunarayana 2002) for microzonation studies and the results are satisfactory. The paper presents the acquisition, processing, and analysis of the short duration data.

The studies have been carried out at 51 locations (Fig. 1) out of them; six major lineaments/faults site effects were presented in this paper. Such as Nagavali fault (L-27), Vamsadara faults (L-28), Rushikulya (L-41), Mahanadi (L-55), Kanada - Kumili fault (L-62), and Brahmoni fault (L-64) zone in different geological formation with varying soil thickness. These lineaments were situated in the east coast of southern India (Fig. 2). The H/V spectral ratio of ambient seismic noise and with hammer source shows a peak (Figs. 3, 4, and 5) which indicates the fundamental frequency of each site near the lineament/fault shown in Table.1. The major objective of the study is aimed at estimating the amplification of soils over low frequencies using short duration data of ambient seismic noise and the hammer source. The findings of the study will be beneficial for the town planners as well as for the policy makers to design the mitigation strategies to combat the effects of frequent earthquakes with local or distant epicentral locations.

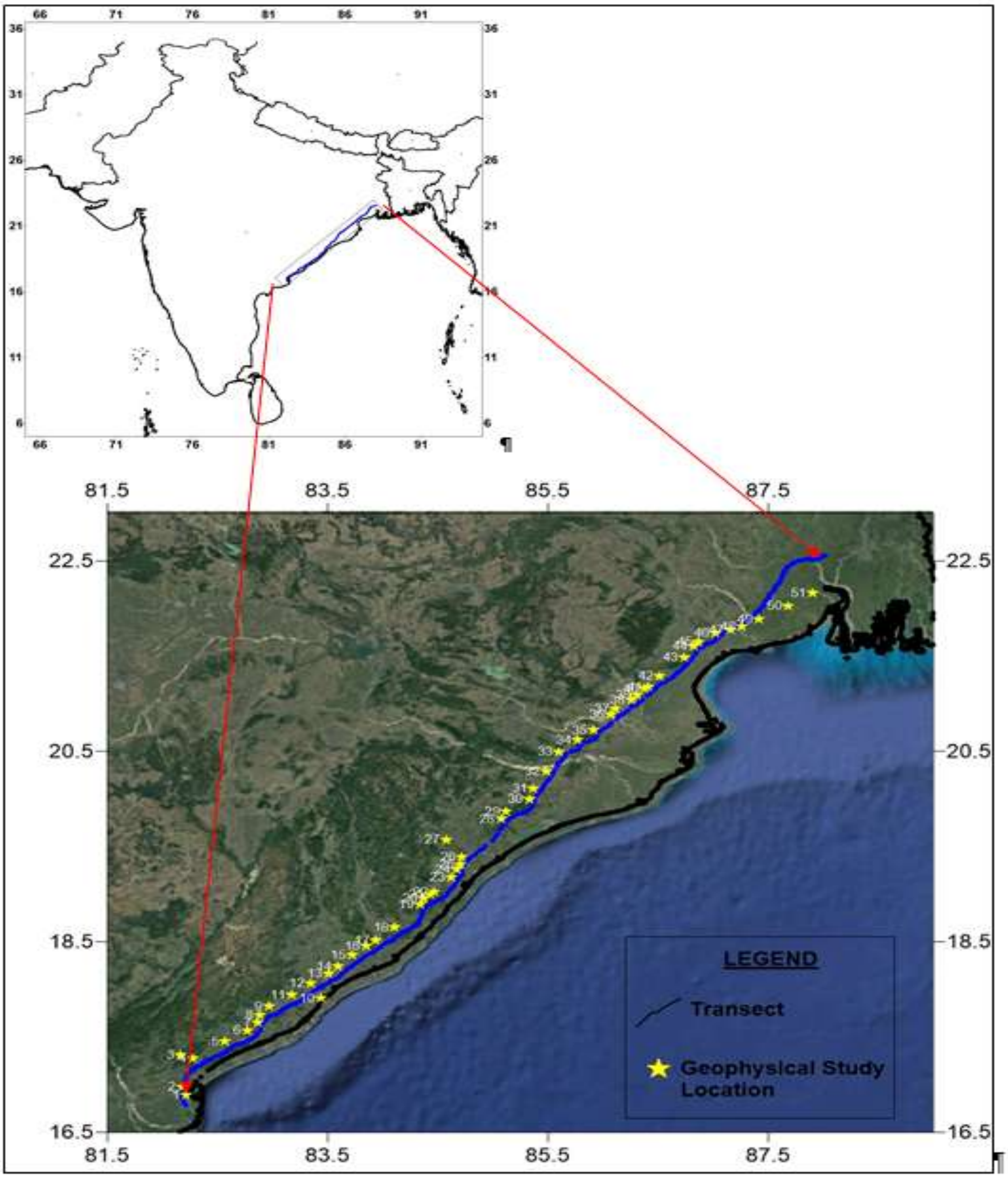


Figure-1: Location map of the Geophysical studies along the coastal regions of Kakinada-Haldia transect

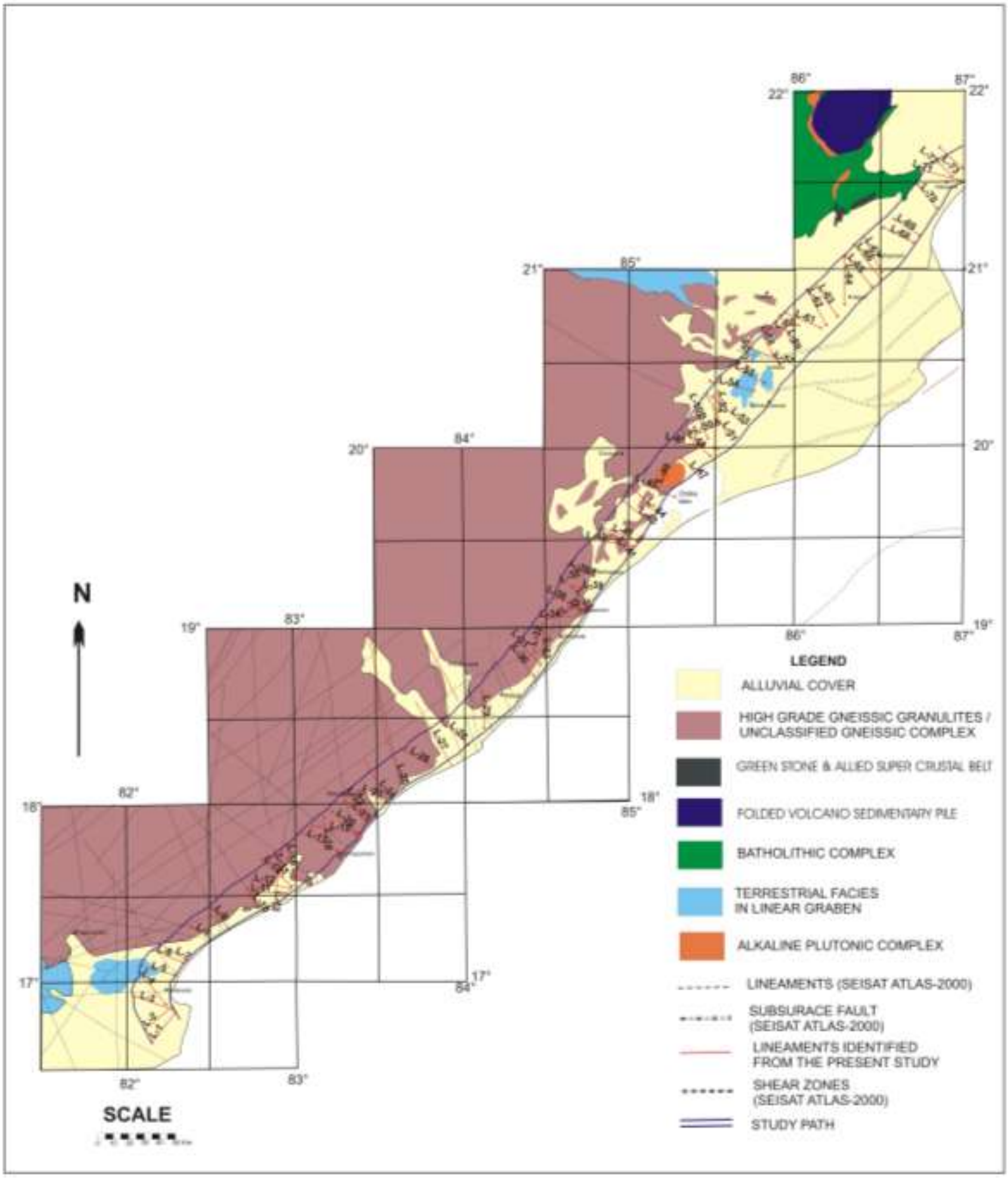


Figure-2: Transect location and Geology with Lineaments along the coastal regions of Kakinada-Haldia transect

**TABLE-1:** **H/V spectral ratios of fundamental frequency range observed at each site are show in below**

| S. No | Latitude | Longitude | Nearest place | Frequency Range |
|---|---|---|---|---|
| L-1 | 16° 46’ 30.9” | 82° 13’ 10.7” | Kesavapuram | 1.8-2.0Hz |
| L-3 | 16° 52’ 4.24” | 82° 10’ 52.55” | Vemulavada | 2.0-2.5Hz |
| L-4 | 17° 12’ 12.67” | 82° 10’ 16.50” | Karakuduru | 1.3-1.5Hz |
| L-7 | 17° 10’ 6.7” | 82° 16’ 44.3” | Gollaprolu | 2.0 Hz |
| L-9 | 17° 20’ 56.20” | 82° 34’ 36.2” | Aratlakota | 2.3-2.5 Hz |
| L-10 | 17° 27’ 59.9” | 82° 46’ 40.2” | Kotta agraharam | 3.0-4.0Hz |
| L-12 | 17° 32’ 55.4” | 82° 52’ 24.9” | Elamanchili | 1.5-2.5Hz |
| L-14 | 17° 37’ 39.4” | 82° 53’ 31.7” | Bangarayya peta | 3.5-4.5Hz |
| L-16 | 17° 43’ 10.3 | 82° 58’ 29.1” | Venkupalem | 3.5-4.5Hz |
| L-17 | 17° 48’ 24” | 83° 27’ 07.8” | Antakapalli | 3.5-4.5Hz |
| L-18 | 17° 50’ 34.45” | 83° 11’ 12.39” | Gavarapalem | 2.0-2.5Hz |
| L-21 | 17° 58’ 07.2” | 83° 21’ 34.4” | Pandrangi | Flat response |
| L-24 | 18°04’ 11.6” | 83° 31’ 22.8” | Singavaram | Flat response |
| L-25 | 18° 08’ 35.8” | 83°36’ 32.1” | Kamavaram | 2.0-2.5Hz |
| L-26 | 18° 16’00.7” | 83°44’ 17.9” | Adapaka | 1.5-2.5Hz |
| L-27 | 18° 21’ 34.0” | 83° 51’ 54.8” | Dusi | 2.0-4.5Hz |
| L-28 | 18° 25’ 14.9” | 83° 57’ 19.3” | Lukalam | 3.0-3.5Hz |
| L-29 | 18° 33’ 36.7” | 84° 07’49.7” | Kurudu | 2.5-3.5Hz |
| L-30 | 18° 48’ 17.9” | 84° 21’ 35.0” | Ramakrishna Puram | Flat response |
| L-31 | 18° 52’ 06.1” | 84° 23’ 38.4” | Goppili | 1.0-2.0Hz |
| L-32 | 18° 54’ 39.1” | 84° 27’ 12.3” | Chilipi | Flat response |
| L-33 | 18° 56’ 07.0” | 84° 29’ 25.8” | Sinkuli/Chowkapet | 2.0-3.0 Hz, &3.0-5.5 Hz |
| L-35 | 19° 05’ 38.5” | 84° 38’ 41.8” | Nuvagaon | 3.0-5.0Hz |
| L-37 | 19° 10’ 36.5” | 84° 41’ 29.1” | Danapur | 2.5-3.5Hz |
| L-38 | 19° 13’ 51.8” | 84°43’ 50.6” | Chandanapur | 3.5-4.5Hz |
| L-39 | 19° 18’ 22.5” | 84° 44’ 30.8” | Chirakunjupalli | 3.5-4.5Hz |
| L-41 | 19° 29’ 37.9” | 84° 35’ 51.1” | Raipur | Flat response |
| L-44 | 19° 42’ 39.9” | 85° 05’49.0” | Raipada | 1.5-2.5Hz |
| L-45A | 19° 47’ 19.5” | 85°08’ 50.5” | Banpur | Flat response |
| L-47 | 19° 55’ 31.6” | 85° 21’ 21.4” | Panaspur | 2.0-3.0Hz |
| L-49 | 20° 02’ 12.3” | 85° 23’ 53.6” | Natima | Flat response |
| L-51 | 20° 13’ 11.4” | 85° 30’ 51.5” | Khurda Road | 7.5-8.5 Hz |
| L-55 | 20° 25’ 41.9” | 85° 37’ 47.8” | Mahanadi River | 1.0-2.5Hz |
| L-57 | 20° 33’ 03.2” | 85° 47’ 58.7” | Orando | 3.0-4.5Hz |
| L-59 | 20° 39’ 17.2” | 85° 56’ 37.6” | Koranji | Flat response |
| L-62 | 20° 49’ 24.2” | 86° 06’ 05.9” | Kustira | 1.0-2.5Hz |
| L-63 | 20° 52’ 58.4” | 86° 08’ 50.9” | Routarapur | 1.5-2.0 Hz |
| L-64 | 20° 58’ 37.3” | 86° 17’ 17.5” | Baitarani River/Jutana village | 2.0-5.0Hz |
| L-65 | 21° 01’ 52.3” | 86° 20’ 37.3” | Taroga | 1.0-1.5Hz |
| L-66 | 21° 05’ 50.4” | 86° 24’ 30.9” | Naiparigadia | 1.0-1.5Hz |
| L-67 | 21° 06’ 51.2” | 86° 26’ 55.5” | Johotpada | 0.5-1.0Hz |
| L-68 | 21° 14’ 02.1” | 86°33’ 0.2” | Dularpur | Flat response |
| L-70 | 21° 25’ 53.8” | 86° 46’ 25.4” | Patapara | Flat response |
| L-71 | 21° 33’ 02.1” | 86°51’ 39.7” | Mukundapur | 1.5-2.5Hz |
| L-73 | 21° 35’ 48.5” | 86° 54’ 19.2” | Kendudiha | 1.5-2.0Hz |

## II. LOCATION AND GEOLOGY OF THE STUDY AREA

The Transect passes through mainly three different geological formations, namely (a) thick alluvial soil cover areas greater than 30 m depth (L-27, 28, L-62 and L-64), (b) alluvial soil formations overlain with shallow hard rock less than 30 m depth (L-55) and (c) hard rock areas with less than 5 m (L-41) cover areas namely Nagavali fault, Vamsadara faults, Rushikulya, Mahanadi, Kanada - Kumili fault, and Brahmoni faults major faults were selected for site response studies. The Kakinada to Haldia transect passes through eastern coastal parts of Andhra Pradesh, Orissa and West Bengal encountering a series of geological formations ranging from Archaean to Recent it comprises a Precambrian basement over which younger rocks commencing with Jurassic, Cretaceous, tertiary and Quaternary have given rise to varying sequences if different parts. These show considerable diversity in respect of depositional process and environments.

Nagavali and Vamsadara shear zone/faults are the long, linear or curvilinear belts of distinct topographic and textural expression constituting closely spaced lineaments with well reflected tonal variation on the satellite data are interpreted as major shear zones which are later confirmed in the field. It is well established that major ductile shear zones do not occur in isolation and are invariably interconnected (White et al., 1983). This region is mostly covered by sedimentary formations ranging in age from cretaceous to recent period. Geologically, it consists of cretaceous beds and tertiary sand stones which are mostly covered by alluvium. The shear zones under the study show similar kinematic movements despite their different disposition and geometry. This is consistent with the regional deformation history of the Eastern Ghats Mobile Belt considered to be a major dextral transpressive mobile belt (Chetty and Murthy, 1998; Dobmeier and Simmat, 2002). They are genetically related either to the Easternghat Trend (NE-SW) or to the Nagavali-Vamsadara Trend (NW-SE). The ones related to the NE-SW are Easternghat boundary fault, east coast lineament. Along the lineament Brahmoni River passes through Konnada-Kumilini shear zone fault.

Rushikulya fault zone northern half of the area constitutes a segment of Mahanadi Basin and is drained by the Mahanadi River system with its major tributaries like Brahmoni, while the southern half of the area is drained by Rushikulya river and its tributaries. It is covered with alluvium of few meters to hundred meters thick with basement of granulite’s, gneisses, and schists. The thickness of the alluvium decreases from east– west direction. Both the above river systems flow southeasterly to debouch into Bay of Bengal. Earthquakes events have been reported by GSI-2000 seismotectonic map near to this lineament indicates it is seismically active zone.

Mahanadi and Brahmoni fault zones basin are one of the five sedimentary basins occurring along the east coast of India. The sediments are mostly deposited by the rivers Mahanadi, Brahmani, Baitarani and their tributaries. Mahanadi delta is a complex delta formed due to the coalescence of three sub-deltas formed by Brahmani–Baitarani river in the north, Mahanadi river in the central part and Devi river in the south. Mahanadi Basin, a peri-cratonic basin was initiated probably during Late Jurassic by rifting and subsidence of the Pre-Cambrian Basement by several major faults with a dominant ENE-WSW trend and subordinate NNE-SSW and NNW-SSE trends. The main soil types found in the Mahanadi basin are red and yellow soils, mixed red and black soils, laterite soils and deltaic soils. The North Orissa Boundary Fault is a major ESE-WNW trending regional fault extending from eastern coast of India through Brahmani and Mahanadi river valleys into Central India. In Orissa, it approximately marks the boundary between Eastern Ghats mobile belt and north Orissa craton. They are abruptly terminated against the north Orissa craton along Brahmani river valley by a series of east-west trending faults (Mahalik, 1994).

## III. DATA ACQUISITION AND PROCESSING

This study was carried out during, December 2009 and was followed by ground checks during January & February 2010. This study thus serves many objectives: providing a comparatively very less expensive map in a short period of time, directing field work for logistics of seismicity related structural designs and keeping such a database confidential prior to ground work. 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. The experimental data recordings were performed near the lineaments i.e., alluvial soil cover areas, between soil cover & unclassified hard rock gneissic areas, and near the thick/hard soil cover areas. Finally, the different record lengths and 30-s record length with 2-ms sampling interval was fixed for acquired the data along transect. The source wave was generated with an offset of about 30–50 m, by hitting the hammer on a stake plate.

This technique is based on recording of microtremors or ambient noise which is short-period vibration, which resulting from coastal effects, atmospheric loading, wind interaction with structure and vegetation, and cultural sources like traffic, trains, construction, and factories. The H/V method has received worldwide concentration from all over the world due to its simple methodology along with its ability to produce quick information about dynamic characteristics of ground and structures (Nakamura, 1989). Another advantage of this technique is the simplicity in data collection and its implementation in areas of moderate-to-low seismicity. Site amplification for the study region has been computed using 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 Equation. 1 (Wenzel, 2005).

$$r(f) = \sqrt{(FNS^2 + FEW^2)/2} \times FUD \quad \text{------(1)}$$

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.

## IV. RESULTS AND DISCUSSION

Near the lineaments local existing soils effect such as fundamental frequency, amplification factor and thickness of soils over bedrock were estimated using H/V spectral method. In the plots shown in (Figs. 3, 4 and 5), red lines represent the spectra for hammer source and blue line represents the spectra of ambient seismic noise. Along the transect near Nagavali (L-27), Vamsadara (L-28), Konnada-Kumilini (L-62) and Brahmoni (L-64) shear zone/faults are showing thick alluvial cover are showing high amplification at low frequencies, it indicates that the presence of deeper bedrock up to a depth of greater than 30m near the lineament Fig. 3 (a, b, c and d). The peak amplifications are related to sharp impedance contrast between layers and reveal the fundamental frequencies of layers below the recording site.

Moderate amplification is observed at low frequency near Mahanadi (L-55) fault zone. This lineament has showing moderate alluvial soil cover overlain unclassified high-grade gneissic granulite formations corresponding to moderate bed rock depth (<30) shown in Fig.4.

Fig.5 shows shallow bed rock is observed with in the depth of <5m near Rushikulya fault (L-41) shear zone. Earthquake events have been reported by GSI-2000 seismotectonic map near to this shear zone it is seismically active. A low to minimal design critically factor may be taken into consideration for about 300m on either side of transect.

## V. CONCLUSIONS

In this present study, the ambient vibrations and the hammer recordings were used to evaluate the H/V spectral ratio near major lineaments with varying soil thickness from Kakinada to Haldia transect. The high amplification values of 2.5 to 5.5 are observed at low frequencies (0.5-2 Hz), in thick and soft alluvial and deeper bed rock zones (>30 m). In the thick stiff soils, moderate bed rock depth (<30 m), the moderate amplification of 1.0 to 3.5 are noticed at low frequencies (1.0-3.5 Hz) with varying soil cover (<20 m). In hard rock areas along transect with in soil cover (2 to 3 m), no significant amplification is observed.

Therefore, the acquired results of the study will help in understanding the soil behavior during earthquakes near the major lineament and it will be useful for establishing the power plants, dams, irrigation lines, nuclear power projects in the vicinity of the seismogenic lineaments/faults along the coastal parts i.e., from Kakinada to Haldia of the Indian subcontinent. Also, the parameters will help in safe design of the structures for long term functioning and it will be providing valuable information to take required precautions to minimize the local site effects during earthquake/natural hazard.

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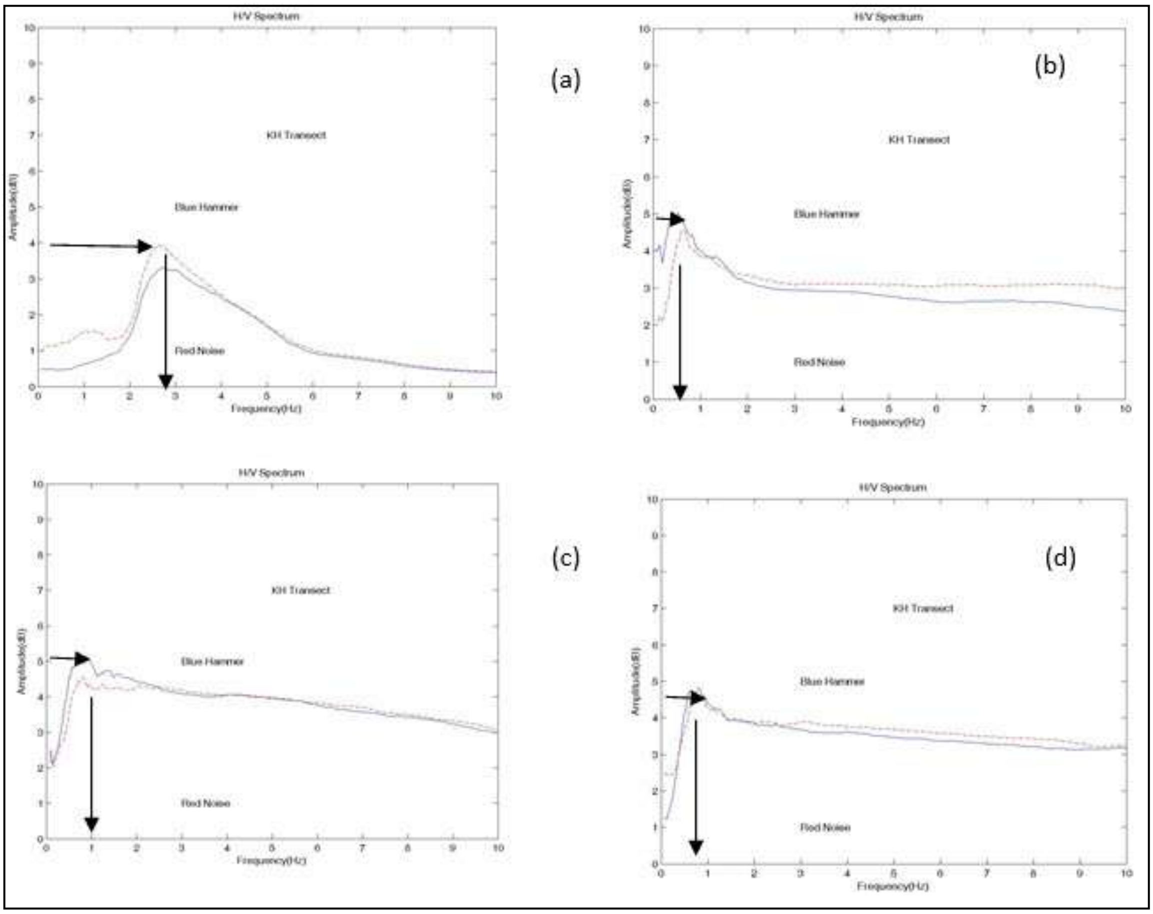


**Figure-3:** Shows H/V spectral ratios in thick alluvial soil cover and deeper bed rock formation along (a) Nagavali fault zone passes near Dusi village, (b) Vamsadara fault zone passes Lukalam village, (c) Konnada-Kumilini fault zone crossing near Kustira village and (d) Brahmoni fault passes through Baitarani River/Jutana village along transect. The figure shows high amplification at low frequency.

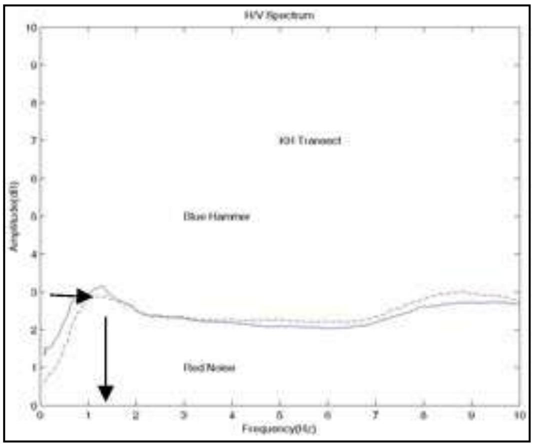


**Figure-4:** Shows H/V spectral ratios in medium thick soil cover and moderate bedrock depth (<30 m) and spectral ratio of thick alluvial overlain high-grade gneissic formation near Mahanadi fault zone. Moderate to high amplifications were observed (1.0 Hz to 3.5 Hz) at a frequency. It is seismically active zone.

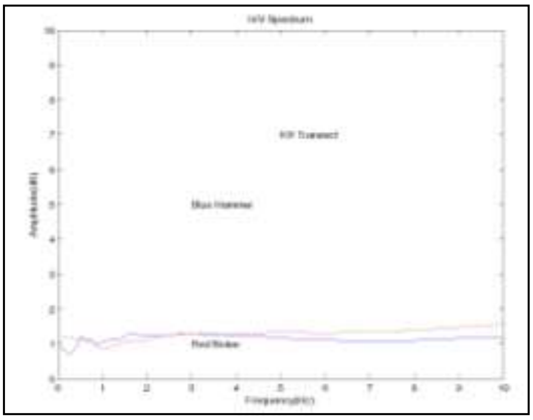

**Figure-5:** H/V spectral ratios correspond in shallow hard rock is cover gneissic granulite formation with thin soil cover the depth is less than 5m near Rushikulya fault zone. Flat response is observed at shallow level. This fault is passes through Raipur village and seismically it is active zone.

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