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Site characterisation through Microtremor Studies for Seismic Microzonation of Delhi

Caractérisation d'emplacement par des études de Microtremor pour Microzonation séismique de Delhi

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ABSTRACT
Microtremor method is the most inexpensive and convenient technique for dynamic site characterization of sedimentary basins. This study was done in Delhi NCR at 31 different stations and field measurements were taken using velocity sensors for a period of 1 hr at each station point and data was analyzed using SEISAN software for the estimation of fundamental resonance frequency. The results of the 31 stations were divided into 5 categories (T1, T2, T3, T4 and T5) based on the shape of the H/V spectra, resonance frequency and soil type. Since the detailed (bore hole data) soil profile at all these locations is available, the resonance frequency is compared with sedimentary thickness. It is observed that resonance frequency is high at ridge areas and very low in places with high sedimentary thickness close to Yamuna.

RÉSUMÉ
La méthode de Microtremor est la technique la plus peu coûteuse et la plus commode pour la caractérisation dynamique d'emplacement des bassins sédimentaires. Cette étude a été faite à la NCR de Delhi à 31 stations différentes et des mesures sur le terrain ont été prises à l'aide des sondes de vitesse pendant une période de 1 heure à chaque point de station et des données ont été analysées en utilisant le logiciel de SEISAN pour l'évaluation de la fréquence fondamentale de résonance. Les résultats des 31 stations ont été divisés en 5 catégories (T1, T2, T3, T4 et T5) basées sur la forme des spectres de H/V, de la fréquence de résonance et du type de sol. Puisque le profil détaillé de sol (de données de trou d'alésage) à tous ces endroits est disponible, la fréquence de résonance est comparée à l'épaisseur sédimentaire. On l'observe que la fréquence de résonance est haute aux secteurs d'arête et très basse dans les endroits avec l'épaisseur sédimentaire élevée près de Yamuna.

1. INTRODUCTION

Microzonation of a region may be defined as subdivision of the region into smaller regions of micro zones such that any characteristics of interest may be considered to be reasonably over the micro zones. When such factors of characteristic are related to seismic activity, the process is called Seismic Microzonation. A qualitative and quantitative estimation of site effects is often expressed by the amplification factor and resonance/fundamental frequency. Resonance frequency of a soil media differs depending upon its physical nature and depth of the bedrock. The site response parameters can be used to distinguish regions where the seismic hazard will be high due to an earthquake of particular magnitude.

It is observed that large concentration of damage in specific areas during an earthquake is due to site dependent factors related to surface geologic conditions and local soil altering seismic motion. Various studies have demonstrated the ability of geological and geotechnical conditions in altering the seismic motion. It has been reported that the damaging effects associated with soft deposits, may lead to local intensity increments as large as 2 to 3 degree in MM scale (Aki,1998). Therefore,the site response and site characterization have become the most important tasks in the seismic hazard analysis.

Nakamura (1996) carried out extensive microtremor studies and demonstrated its capability for site reference studies. He applied the technique at sites in Kanonomiya and Tabata, Japan and proposed that H/V ratio is a reliable estimation of site response of S wave, and providing reliable estimates of resonant frequency and the corresponding amplification. Aki (1998) reviewed the problems associated with the determination of frequency dependent site specific amplification factors using microtremors and identified the inability to separate source-effects from site effects as a major obstacle in effective use of microtremor method. Since the sources are likely to be different from different sites, it is difficult to determine even the relative amplifications. However, Bard (2000) reviewed the problems of site characterization based on microtremor studies, and concluded that the technique would be of immense help in providing time and cost effective method of response studies.

There is no straightforward relation exists between the H/V peak amplitude and the site amplification. Toshinawa et al., (1997) gave an empirical relationship between observed H/V peaks amplitude and local intensity increment (MM Scale) based on his experimental study. Comparison with other techniques by different investigators, shows that Nakamura technique allows obtaining, very simply, the fundamental resonant frequency. However, this Nakamura version of the microtremor method has already proved to be one of the most inexpensive and convenient techniques to reliably estimate fundamental frequencies of soft deposits.

With this background the microtremor study was done in Delhi, which is seismically active. The heavily populated city has number of man made structures could be prone to damage due to an earthquake of considerable magnitude (>6). Microtremor method, which is cost and time effective, is very useful in urban areas with high noise level and gives stable response curves for site characterization and offers a scientific base for seismic microzonation. The aim of this study is to estimate resonance frequency using Nakamura method, a simple experimental technique based on microtremor recordings.

2. SEISMICITY, GEOLOGY AND GEOTECHNICAL CHARACTERISTICS OF THE AREA

According to seismic zonation map of India (IS 1893:2002) Delhi is classified in the category of moderate to high earthquake prone zone (IV), with intensity of VIII on modified Mercalli scale. Delhi has far field sources (~200 km) in Himalayas, which can produce greater magnitude earthquakes. The distribution of earthquake epicenters in Delhi region indicates that the clusters of seismic events are located to the west of Delhi and particularly between Sonepat- Rohtak- Gurgaon. These earthquakes are shallow focus events. The maximum concentration of epicenters occurring along NNE-SSW direction and around the intersection of margin of Delhi- Lahore ridge and Mahendragarh-Dehradun fault.

Delhi has interesting geology on account of its being the end of exposed ancient Aravali mountain ranges extending NE in this area. Delhi and its adjoing region is surrounded in the north and east by Indo-Gangetic plaines, in the west by the extension of the great Indian Thar desert and in the south by the aravali ranges. The rocks of Delhi have undergone multiple folding and different phases of metamorphism with some transverse features. The quarzites are bedded and highly jointed with pegmatite intrusives. The Alwar series and the post Delhi intrusives are covered by the quaternary deposits in the form of aeolian and alluvial deposits. The alluvial deposits belong to the Pleistocene period, i.e., older alluvial deposits and of recent age i.e., newer alluvium. Older alluvium deposits consists of mostly inter bedded lenticular and inter fingering deposits of clay, silt and sand along with kankar. The detailed geological map of Delhi is shown in Fig 1 (Rao, 2003).

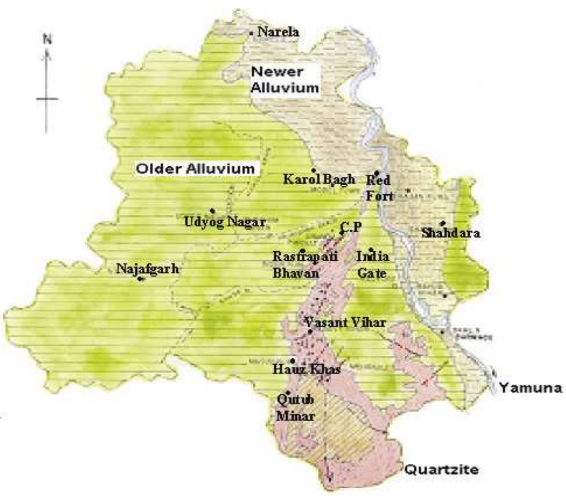

Figure 1. Geological Map of Delhi

Based on the collected borehole data, soil profiles are made covering almost entire region to study the sub soil heterogeneity. Generally in trans-Yamuna, silt is very predominant. The silty soils have high apparent cohesion in the dry state, which reduces rapidly with increase in water content. The water table is high in areas near to Yamuna.Grain size distribution curves are also drawn at 4 different depths (3.5, 5, 7.5 and 10m) for north, south, east, west and central blocks in Delhi. The grain size distribution (GSD) curves in eastern block are steeper than for other blocks. In this block the soils are sandy silts/silty sands with high percentage of medium to fine sand (30-90%). The percentage of silt is 10-80% with very less percentage of clay (P.I=0-5%) with D_{50}= 0.03-2mm. Northern block has silty sands with D_{50}=0.002-0.1mm, sand =20-75%, silt = 30-80%, clay =0-10%, P.I = 0-7% i.e., very low plasticity. Western block has reasonable percentage of clay with P.I =0-20% with D_{50} =0.005-0.8 mm, sand = 15-60%, silt 50-80%. The GSD curves of northern and western blocks are almost similar. The south and central blocks have gravelly sands with percentage of gravel=0-8%, D_{50}=0.003-0.8mm. For a particular block, at shallow depths the curves are steeper when compared to deeper depths.

3. METHOD ADOPTED

Nakamura (Nakamura, 1996) developed an experimental method, which is very widely used in site response studies. This method is based on the basic assumption that the effect of surface waves can be either eliminated or neglected such that the end result is in direct relationship with the transfer function for S waves. It is a very quick method to estimate resonance frequency and site effects of any urban area for the microzonation. The Nakamura method is discussed below. Nakamura separated ambient noise into body waves and surface waves.

$$S^{NH}(f) = S_b{}^{H}(f) + S_s{}^{H}(f) = H_T(f).\ R_b{}^{H}(f) + S_s{}^{H}(f) \quad (1)$$

$$S^{NV}(f) = S_b{}^{V}(f) + S_s{}^{V}(f) = H_V(f).\ R_b{}^{V}(f) + S_s{}^{V}(f) \quad (2)$$

where, $R_b{}^{H}(f)$ is the horizontal spectrum of the body wave part of the noise at the reference site.

H/V ratio between $S^{NH}(f)$ and $S^{NV}(f)$ can be written as:

$$A^{NHV} = [H_T\ .\ A_r{}^{NHV} + \beta\ A_S] / [V_T + \beta] \quad (3)$$

where, $A_r{}^{NHV}$ = Noise H/V ratio at rock site

β = Relative proportion of surface waves in the noise $= S_s{}^{V}(f) / R_b{}^{V}(f)$

A_S = Horizontal to vertical ratio due to surface waved only $= S_s{}^{H}(f) / S_s{}^{V}(f)$

It is clear that the microtremor method is useful for determining local site effects in seismically active regions such as Delhi, where ground motions are few and the noise levels are high due to urbanization. This study was carried out in Delhi during September and October 2002 at 31 different stations and measurements were taken using velocity sensors for a period of 1 hr at each station point. The data thus collected was analyzed using SEISAN software to find the resonance frequency as explained below. The microtremor recordings are taken on places located both on ridge area and on very thick sedimentary deposits to find the response.

4. DATA ACQUISITION AND ANALYSIS

The microtremor study was conducted by deploying the following velocity sensor:

Digital triaxial portable velocity sensor and REFTEK digitizer

Sensor: Velocity sensor Model L-4 3D
Frequency: 1 Hz
Digitizer: Model REFTEK 72A08 with SCSI unit (72A05)
Resolution: 24 bit
Sampling rate: 100 sps
Channel: 3
Timing: TCXO synchronized with GPS

The instrument was facilitated by India Meteorological Department, New Delhi and the complete set up in the field is shown in Fig 2. The recorded data was retrieved in the field computer after completion of 1 hr recording.

For computation of spectra of horizontal versus vertical component using Nakamura method (Nakamura, 1996), the analysis was carried out using SEISAN software. The recorded data is in compressed reftek binary format was converted into SUDS (Seismic Unified Data System) format. Then the data in SUDS format is converted into SEISAN format. All the continuous data of a particular station is split into data files of each 10 min duration. Each 10 minutes files are again plotted in mulplt program of SEISAN software and a portion about 1min duration, which has no earthquake event and has no or very less ambient noise, was selected as data input file for Nakam program which requires two parameter files i.e., nakam.par and nakam.inp. Nakam.par explains about the channels to be processed, window duration, smoothening factor etc., and nakam.inp explains about the full path files representing 1 min duration. The final plot of the program includes H/V ratio with standard deviations. For clear identification of peak frequency, spectra need to be smoothened which is also been performed.

Figure 2. Instrument Setup and Accessories.

5. RESULTS AND DISCUSSION

Based on the shape of the H/V spectra, resonance frequency and soil type, response curves are divided into five categories (T1, T2,

Table 1. Station Location with Resonance Frequency and H/V Amplitude.

S.No	Location	Lattitude	Longitude	Resonance Frequency (Hz)	Amplitude of H/V Ratio	Classification Type
1	Janak Puri	28^{0}37’31.90’’	77^{0}31’46.788’’	0.17	3.20	T1
2	Karol Bagh	28^{0}38’44.996’’	77^{0}12’26.488’’	0.20	1.68	T1
3	Mandi House	28^{0}37’32.3’’	77^{0}13’44.057’’	0.24	4.08	T1
4	Mohan Nagar	28^{0}40’26.642’’	77^{0}19’59.486’’	0.20	3.56	T1
5	Pragati maidan	28^{0}37’7.37’’	77^{0}14’16.95’’	0.17	2.59	T1
6	Saraikale Khan	28^{0}35’25.765’’	77^{0}15’35.529’’	0.20	3.02	T1
7	Mohan Garden	28^{0}40’26.642’’	77^{0}19’59.486’’	0.54	3.45	T2
8	Kakrola Mode	28^{0}37’14.936’’	77^{0}1’25.012’’	0.66	3.19	T2
9	Moti Nagar	28^{0}39’27.502’’	77^{0}8’31.59’’	0.66	3.20	T2
10	Mukharji Nagar	28^{0}42’4.507’’	77^{0}12’40.912’’	0.83	3.19	T2
11	Sarita Vihar	28^{0}31’55.547’’	77^{0}17’36.856’’	0.98	3.55	T2
12	IIT Gate	28^0 32’ 58.982’’	77^{0}11’ 34.112’’	7.56	2.17	T3
13	IIT School	28^0 32’ 42.982’’	77^{0}11’ 29.112’’	7.86	2.32	T3
14	East Patel Nagar	28^{0}38’42.573’’	77^{0}10’29.018’’	7.67	2.77	T3
15	Pahad Ganj	28^{0}38’28.577’’	77^{0}12’26.488’’	7.67	1.68	T3
16	Patper Ganj	28^{0}37’’56.208’’	77^{0}18’41.35’’	16.14	2.98	T4
17	Bali Nagar	28^{0}39’18.95’’	77^{0}7’38.044’’	14.82	3.92	T4
18	I.S.B.T	28^{0}39’48.692’’	77^{0}14’17.134’’	16.31	5.52	T4
19	Sector 34, Noida	28^{0}34’55.598’’	77^{0}21’43.372’’	15.55	4.18	T4
20	Sector 49, Noida	28^{0}33’49.371’’	77^{0}21’50.589’’	15.11	4.90	T4
21	Tilak Nagar	28^{0}38’24.789’’	77^{0}6’5.445’’	18.14	3.19	T4
22	Titarpur	28^{0}38’46.58’’	77^{0}6’53.121’’	18.14	3.70	T4
23	West Patel Nagar	28^{0}39’4.655’’	77^{0}9’30.919’’	17.60	5.25	T4
24	Ashram	28^{0}34’23.345’’	77^{0}15’47.31’’	16.63	4.13	T4
25	Mansarovar Park, Noida	28^{0}34’46.684’’	77^{0}18’14.186’’	17.6	3.31	T5
26	Mall Road	28^{0}41’46.584’’	77^{0}13’1.98’’	18.46	3.88	T5
27	Nehru Nagar	28^{0}39’52.752’’	77^{0}26’15.165’’	18.65	2.89	T5
28	Okhala	28^{0}33’27.203’’	77^{0}16’20.469’’	17.94	3.48	T5
29	Kalindi Kunj	28^{0}32’46.55’’	77^{0}18’39.257’’	18.12	3.49	T5
30	Sahibabad	28^{0}38’37.32’’	77^{0}19’12.92’’	18.29	3.07	T5
31	Vasant Kunj	28^{0}34’24.184’’	77^{0}21’14.823’’	18.48	3.29	T5

T3, T4 and T5). Table 1 gives the location details with the resonance frequency and H/V amplitude of all the station points. It was observed that resonance frequency is high at locations close to ridge area and in gravelly sand deposits. It is as low as 0.17 in areas covered with high sedimentary thickness and close to river Yamuna. Each type was described as below. Table 2 shows the soil type and the location of each category.

Table 2. Location of Each Category and its Soil Type

Category	Soil Type	Location
T1	Sandy silt and Silty sand with low N value (Newer alluvium: Holocene)	Trans Yamuna Region
T2	Sandy silt and Silty sand with seams of clay (Newer alluvium:Holocene)	Trans Yamuna Region
T3	Sandy silt and Silty sand with kankar (Older alluvium: Pleistocene)	North and North-western side of Delhi
T4	Sandy silt with gravel deposits (with high N value)	South and South-central Delhi
T5	Weathered Quartzite	South Delhi

T1: In this category deamplication is in between 1 to 3 Hz then it raises little and continues with fluctuations. The soil strata in these locations falling in this category have sandy silt with the low standard penetration value.

T2: Amplification occurred between 0.1 to 1.0 Hz then it suddenly deamplifies and started fluctuating. Alternate layers of sandy silt, silty sand with seams of clayey silt are the available soil types at these locations.

T3: These are flat curves upto 3 Hz then amplifies between 3 to 10 Hz and suddenly get deamplified after 10 Hz followed by steep rise in amplitude.

T4: Deamplification is in between 1 to 3 Hz as in type T1 but after 3 Hz there is a sudden rise in the spectra with a maximum value after 10 Hz.

T5: There is a slight amplification between 1 to 3 Hz followed by sudden deamplification between 3 to 10 Hz. After 10 Hz the H/V amplitude curve goes steeply very high.

From the table it is clear that around 16 stations are having resonance frequency greater than 15Hz (Type T4 and T5). Figure 3 shows the average of relative spectra with standard deviation for each category. In some places like Karol Bagh, Saraikale Khan, Pragati Maidan, and Mandi House which falls in trans Yamuna region with alternative layers of silty sand and sandy silt (low N value and high water table) has resonance frequency less than 0.3 Hz. In places like Sarita Vihar, Kakrola mode, Moti Nagar, Janakpuri and Mohan Nagar in western side of Delhi has resonance frequency in between 0.3-1 Hz. The thickness of the sedimentary deposits is very high in this region. Some places in southern part of Delhi like Vasanth Kunj, Okhla and Mall road, which fall on the ridge, and just near to the ridge area has quiet high resonance frequency because of the presence of weathered quartzite rock or gravelly deposits with high N values. It is also observed that maximum PGA value (gals) experienced in Delhi by combining the effects of all seismological sources, it is around 0.15-0.18 in trans Yamuna region (newer alluvium), 0.24-0.27 in western side of Delhi (older alluvium) and 0.27-0.33 in southern side.

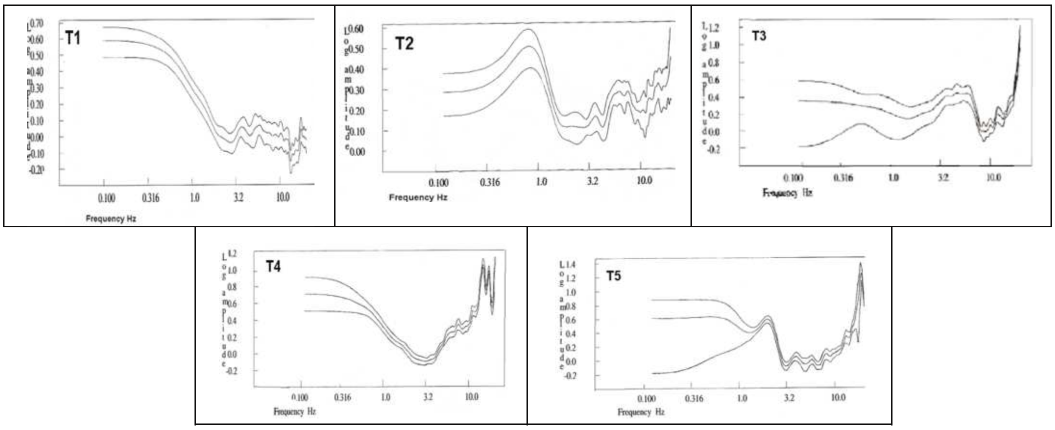

Figure 3 Typical Response Curves of all the Five Categories (T1, T2, T3, T4 and T5)

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