J. Ind. Geophys. Union (April 2009)
Vol.13, No.2, pp.75-83

Geotechnical Studies in Relation to Seismic Microzonation of Union Territory of Chandigarh

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ABSTRACT

The paper highlights the outcome of site response studies undertaken around Union Territory of Chandigarh, based on geotechnical approach. Twenty-four boreholes were drilled down to 30 m depth in order to determine the variation in the geotechnical properties of the geological units present around Chandigarh. Standard Penetration Test (SPT), as per BIS Code, was conducted in all the boreholes for determination of N values of the subsurface geological units at 1 to 3 m intervals. Shear Wave Velocities of the subsurface layers were computed based on the empirical relation. The average shear wave velocity of the sediments down to 30 m depth at different sites around Chandigarh Urban Centre varies from less than 216 to 305 m/s.

The predominant frequencies at which the seismic waves are expected to resonate in the soil column of 30 m depth were also computed using frequency-shear wave velocity relationship.

Based on the analysis of the geotechnical properties of subsurface soil samples, their disposition with respect to each other and also with ground water table conditions liquefaction potential around Union Territory has also been assessed.

INTRODUCTION

The damage pattern of past earthquakes shows that the local geology/ soil conditions at a site have a major effect on the level of shaking. The role of local geology in enhancement of earthquake ground motions was first reported by Wood (1908), who, based on the damage pattern of 1906 San Francisco earthquake concluded that the amount of damage produced by the earthquake depended chiefly upon the geological character of the ground. Where the surface was solid rock, the shock produced little damage; whereas on reclaimed land great violence was manifested. The Mexico earthquake (1985), Loma Prieta earthquake (1989) and Kobe earthquake (1995) strengthened the earlier drawn assumptions of enhancement of ground motions due to geological conditions when it was recorded that the damage patterns were found to be very high at places located 100 to 300 km away from the epicentre and were controlled by local geological variations. During 2001, Bhuj Earthquake, higher damages occurred around Ahmedabad City located at about 250 km from the epicentre because of enhanced ground motions in soft geological formations present around Ahmedabad (Pande & Kayal 2003).

Borcherdt (1970) made first experimental analysis where he correlated the ground motions generated by nuclear explosion in Nevada with the intensities generated by 1906 San Francisco earthquake and concluded that the amplifications recorded due to the nuclear explosions were in good agreement with the local intensity variations and thus the site geology. Seed, Ugas Celso & Lysmer (1976) made a statistical analysis of spectral shapes of ground motion record of 23 earthquakes in parts of western United States vis-a-vis geological site conditions in the recording stations. They concluded that different soil and geological conditions show clear differences in spectral shapes. Further studies indicated that the shear wave velocity variation in the upper 30 m column had important role in the enhancement of ground motions due to a moderate to strong earthquake (Borcherdt et al., 1991, Borcherdt 1994, Wills et al., 2000). National Earthquake Hazard Reduction Programme (NEHRP) has proposed five soil classes, based on the average shear wave velocity structure of the 30 m column (VS30) of soil/site (BSSC 1994). The recent building codes like Uniform Building Code (UBC) 1997 and International Building Code (IBC) 2000 are based on the soil classes proposed by NEHRP. European Codes, however, have utilized the NEHRP soil classes with some modifications. The IS codes for Earthquake Resistant Design of Structures take references of the above mentioned codes while assigning seismic coefficients in different types of site conditions.

Geotechnical studies were undertaken around

Chandigarh in order to study the site response of local geological units, which could be utilised as inputs for microzonation study in the area. Chandigarh falls in Zone IV of the Seismic Zoning Map of India (IS 1893, 2002), which implies that in the region earthquake shaking corresponding to a seismic intensity of VIII on MSK-64 scale is reasonably expected. During the 1905 Kangra earthquake, the seismic intensity in the area was estimated between VII and VIII on RF scale (equivalent to intensity VI and VII on MM scale). Corresponding to the above intensities, the expected ground motions in terms of ground acceleration may vary between 0.05g and 0.2g. Global Seismic Hazard Assessment Programme (GSHAP, 1999) has given PGA values for between 0.08g and 0.32g Chandigarh City (Dharmraju et al., 2007).

TECTONIC AND GEOLOGICAL SETUP OF THE AREA

The Union Territory of Chandigarh is located on the Indo-Gangetic Alluvium, very near to the active tectonic zone. The Himalayan Frontal Thrust (HFT) passes from the northern boundary of the Union Territory. Along this thrust, the sediments of the Indo-Gangetic Alluvium come in juxtaposition with the Siwalik rocks. The Main Boundary Thrust, a major tectonic plane trending in NW-SE direction, passes at about 30 km east of the Union Territory. Jwalamukhi Thrust, another tectonic discontinuity passes through the intervening area between the HFT and the Main Boundary Thrust. The movement along the Jwalamukhi Thrust is interpreted as the cause of 1905 Kangra earthquake (Joshi et al., 2005). The Main Central Thrust lies about 130 km NE of the area. Kangra block, an active seismotectonic domain, constituting the seat of one of the Great Himalayan earthquakes, is located close to Chandigarh. The block had witnessed seven damaging earthquakes after 1905 Kangra earthquake (Pande et al., 1999)

Quaternary sediments, belonging to Indo-Gangetic Alluvium mainly cover the Union Territory of Chandigarh. The semi-consolidated litho-units of Upper Siwalik Formations are exposed in the

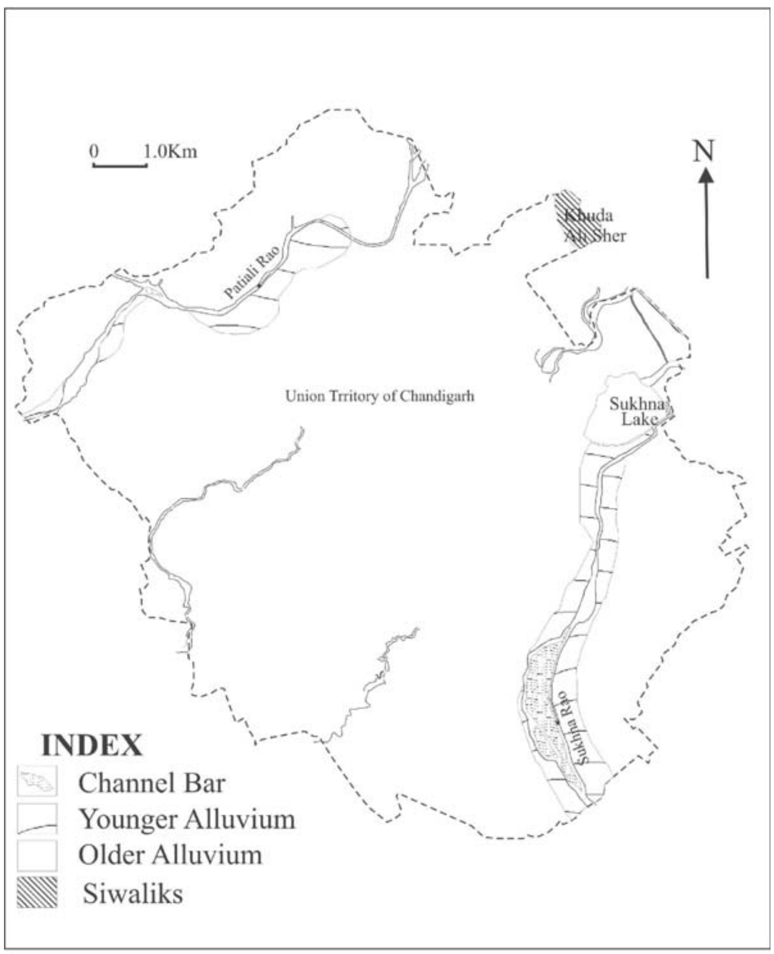

Figure 1. Geological map of Chandigarh.

northeastern fringe. The Siwalik rocks are well exposed in the northern and northeastern parts of the Union Territory around Kuda Ali Sher (Fig. 1). Dipping beds made up of maroon to chocolate coloured clay and silty clay with pebbly sand and gravel beds represent the Siwalik in this area. The general trend of rocks is in NW-SE direction with moderate dips (25°-30°) towards south.

The Older Alluvium covers major part of the area and comprises layered sequence of clay, silty clay, and sand with lenses of pebbly sand and gravel. Kankar in disseminated form is also reported in the area. Thick clay beds have been observed in some of the nala cuts. The thickness of clay layers has been observed to be more than 10 m in some of the boreholes

The younger Alluvium mainly consists of light grey micaceous sand and pebbles with interbeds of purple and red clay. These occur as recent flood plain deposits along river/nala courses, namely Patiali Rao and Sukhna Chao.

GEOTECHNICAL STUDIES

Subsurface explorlations with the help of twenty four shallow boreholes up to 30 m depth were conducted in the area in order to determine the geotechnical properties of subsurface strata so as to find out the site response of the ground with respect to the expected ground motions due to any earthquake event. The borehole cores were logged so as to find out disposition of the different sub-surface layers. Soil samples were collected with the help of the sampler while conducting SPT. Borehole locations are shown in Fig.2

The correlation of the sub-surface layers indicates wide spread distlribution of clay, sand, pebbly sand and pebble layers in the area. A total of 164 soil samples were collected from the boreholes and geotechnical properties of the samples were determined. The density of soil samples ranges between 1.62 and 2.62 gm/cc

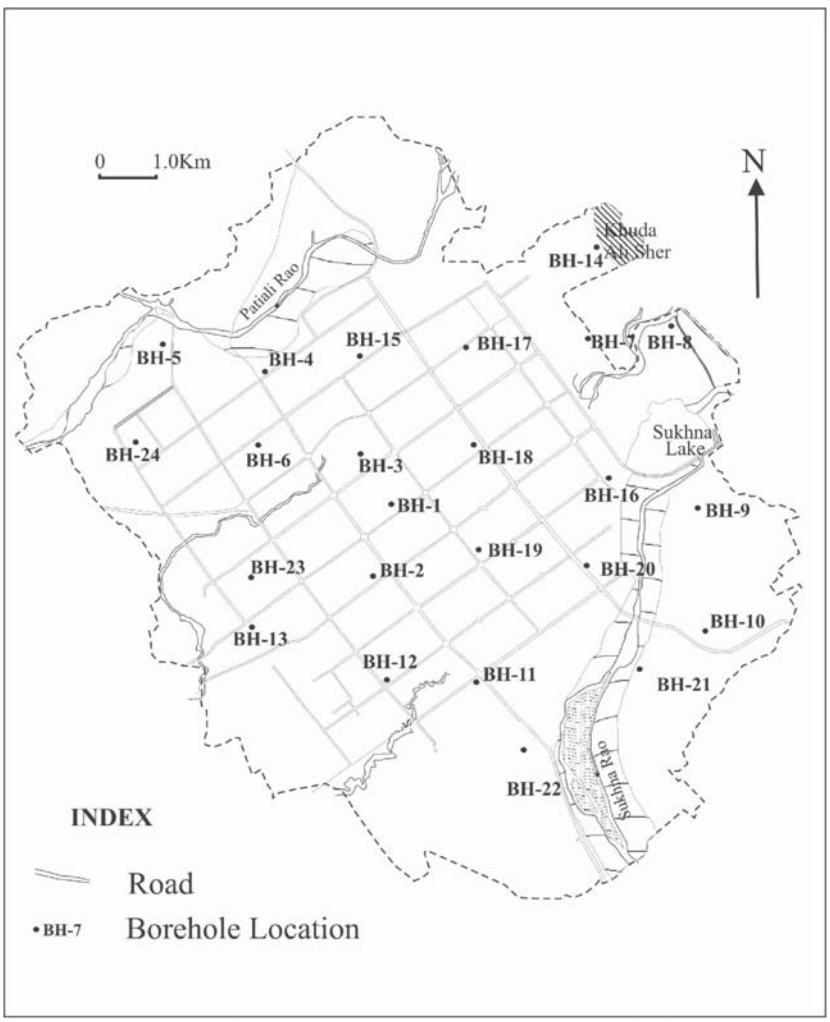

Figure 2. Map of Chandigarh area showing Borehole locations.

Standard Penetration Test (SPT) was conducted in the boreholes at 1.0 to 3 m interval for determination of N values of soil layers. The N values range between 9 and 46 in clay and sand layers. In pebbly sand horizon the values go up to 68 at certain depths.

ANALYSIS OF DATA FOR COMPUTATION OF SHEAR WAVE VELOCITY

Shear Wave Velocities of the subsurface layers based on the following empirical relation proposed by Ohta & Goto (1978), has been computed.

$$Vs = 62.14\ N^{0.129}\ H^{0.230}\ ST$$

Where Vs is shear wave velocity, N is SPT blow counts, H is the depth of the SPT test and S is factor for type of soil. Value of S is 1 for clay, 1.091 for fine sand, 1.029 for medium sand, 1.073 for coarse sand, 1.151 for sand mixed with gravel and 1.485 for gravel The above equation takes into account the N values, depth of the sediments and the type of sediments for which the SPT has been conducted. A correlation coefficient more than 0.8 has been established between the actual measured values of shear wave velocity with the help of geophysical surveys and the values calculated by the above relation by Ohta & Goto (1978).

Weighted average of shear wave velocity of the 30 m column in each of the borehole was computed with the help of a small programme developed on Microsoft Excel as computed in Borehole No-1 (Table 1). In two boreholes, SPT could not be conducted for the entire depth because of presence of thick pebble and boulder dominated horizons. For computation of the average shear wave velocity in these two boreholes the maximum values of N were considered for the depth sections, where N values could not be computed.

Shear wave velocity contour map was prepared by contouring the values determined at each borehole site

Table 1. Average Shear wave velocity calculation for upper 30 m soil column Borehole No.1.

N value	$N^{.210}$	Depth H	$Depth^{0.230}$	Soil type ST	$Vs = 62.14N^{0.219}H^{0.230}\ ST$	Vs x thickness	Average Shear Wave Velocity of 30m Column
13	1.713674	1.95	1.166025265	1	124.1673217	242.1262774	
16	1.79005	3.4	1.325074056	1	147.392911	213.7197209	
24	1.949146	5.95	1.507089007	1	182.5385144	465.4732118	
25	1.965927	6.3	1.527032662	1	186.546445	65.29125575	
22	1.913854	7.75	1.601545906	1	190.4668518	276.1769351	
18	1.834878	9.25	1.668063574	1	190.1914868	285.2872302	
16	1.79005	10.75	1.726728061	1.091	209.5487829	314.3231743	
13	1.713674	12.25	1.779390634	1.091	206.726144	310.089216	
7	1.504772	13.75	1.827299017	1	170.8643497	256.2965245	
20	1.875929	15.25	1.871337256	1.091	237.9930982	356.9896473	217.6 m/s
13	1.713674	16.75	1.912156379	1.091	222.15061	333.225915	
13	1.713674	18.25	1.950250778	1.071	222.4227897	333.6341846	
22	1.913854	19.75	1.986005436	1	236.1894228	354.2841342	
20	1.875929	21.15	2.017536431	1.091	256.5864299	359.2210019	
27	1.997958	25.75	2.110953971	1	262.0815225	1205.575004	
21	1.895248	27.25	2.138623312	1	251.8671902	377.8007854	
32	2.07053	28.75	2.165143598	1	278.5732748	417.8599122	
32	2.07053	30	2.186441634	1.029	289.4716307	361.8395384	

with the help of Surfer software (Fig. 3). The average shear wave velocity of the sediments down to 30 m depth at different sites around Chandigarh Urban Centre varies from less than 216 to 305 m/s.

National Earthquake Hazard Reduction Programme (BSSC1994) in code provisions has divided soil/ground in different classes of average shear wave velocity of the ground in the uppermost 30 m (Table 2). The values of shear wave velocity determined in the area for upper 30 m soil column corresponds to Soil Type - D of the Site classes of NEHRP.

PREDOMINANT FREQUENCY

In order to estimate the frequencies at which the seismic waves are expected to resonate in the soil column of 30 m depth, the simple relationship between the shear wave velocity (β) of the sediment column (30 m), viz. $f = \beta/4H$, was used. In this way, at each borehole site, predominant frequency was calculated. The predominant frequencies at different sites thus estimated vary from 1.8 to 2.54 Hz.

Table 2. NEHRP Soil Types based on shear wave velocity of upper 30 m.

Soil Types	Rock/ Soil Description	Average shear wave velocity (V_{S30}) m/s
A	Hard rock	> 1500
B	Rock	760-1500
C	Dense soil/soft rock	360-760
D	Stiff soil	180-360
E	Soft soil	<180
F	Special soils requiring special evaluation	

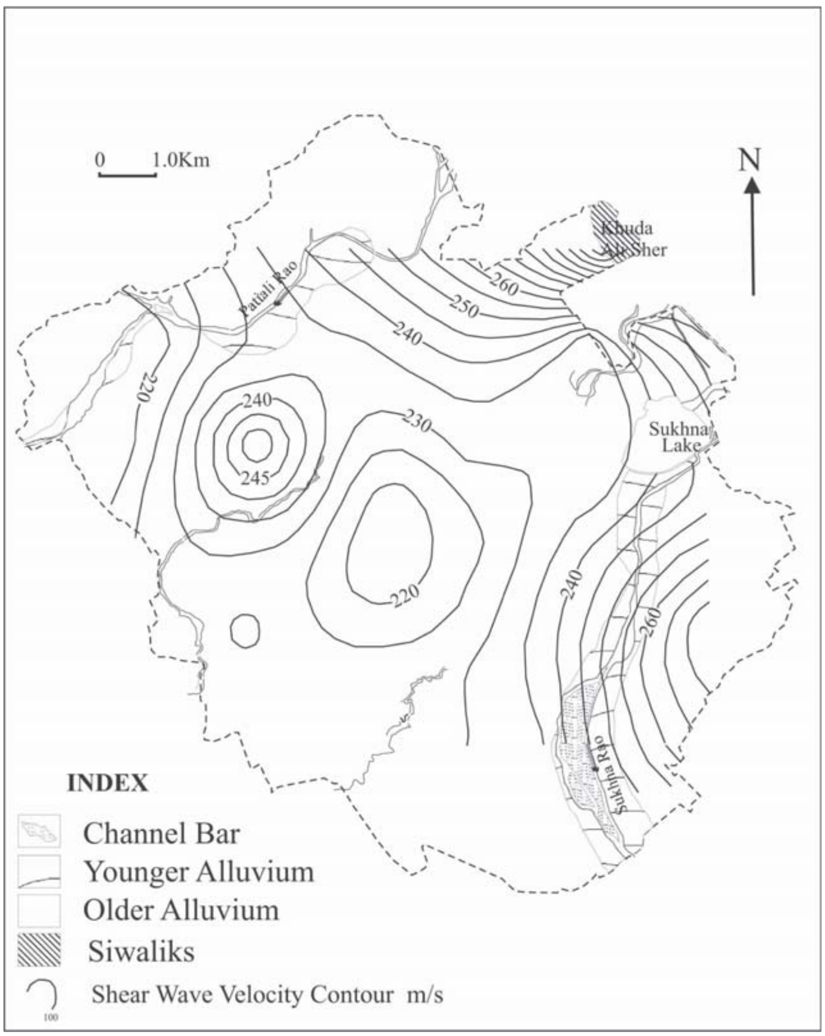

Figure 3. Shear wave velocity map up to 30 m depth, Chandigarh area.

LIQUEFACTION POTENTIAL

Liquefaction is a process by which water saturated sediments lose their shear strength and start behaving like a liquid. Youd (1973) has defined liquefaction as the transformation of a granular material from a solid state into a liquefied state as a result of increased pore water pressure. Shaking of saturated granular and cohesionless soils during an earthquake can lead to liquefaction. Liquefaction commonly follows moderate to great earthquakes under a particular set of geoenvironmental conditions. The 1964 Alaska earthquake, the 1964 Nigata, Japan earthquake, the 1967 Caracas, Venezuela earthquake and the 1971 San Fernando, California earthquake have induced liquefaction in large areas. In India, the 1934 Bihar-Nepal earthquake caused widespread liquefaction. Spectacular effects of liquefaction including lateral spreads, sand blows, sand craters, etc were produced in Kutch area during 2001 Bhuj earthquake (Pande and Kayal 2003). During 8th October 2005 Kashmir earthquake, liquefaction was witnessed in reverine sediments in Jammu area at a distance of about 250 km from the epicentre (Kandpal et al., 2007). An assessment of liquefaction potential of Chandigarh city has been attempted by Dharmraju, Ramakrishna & Gayatri Devi 2007, utilizing the conventional approach.

The data collected during the exploration for determining the site response factors have been utilised to work out liquefaction succeptibility around Chandigarh area. The subsurface lithological units encountered along the bore holes, the geotechnical properties of the sediments and the ground table conditions in the area reveal that there are chances of liquifaction in some of the sectors in the central and western parts of Chandigarh.

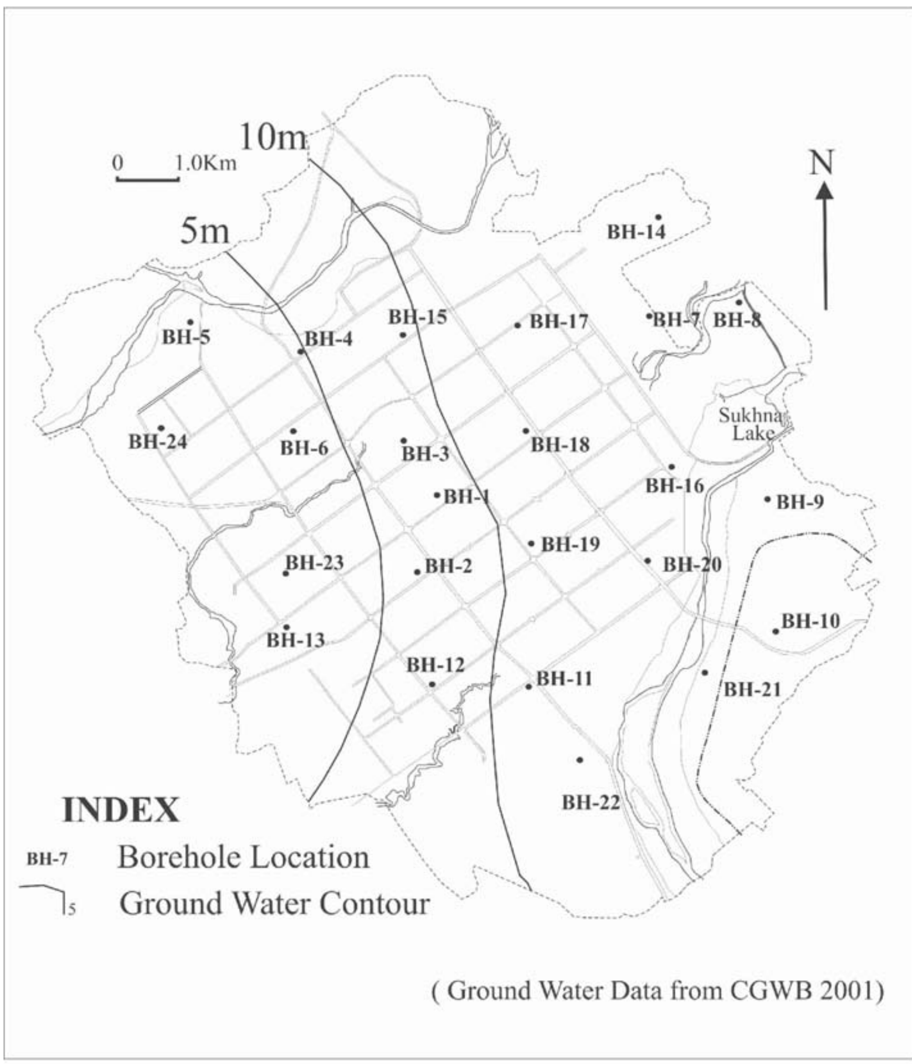

Figure 4. Depth of ground water table in shallow aquifer system in Chandigarh area.

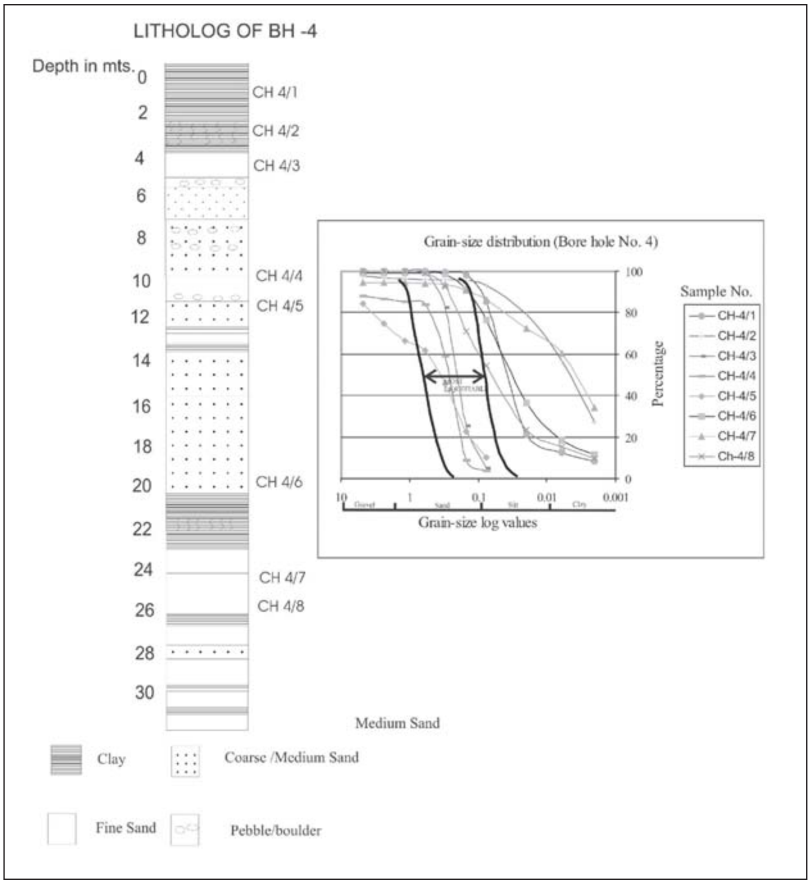

Figure 5. Litholog of most liquefiable zone vis-à-vis grain size distribution curve.

The lithologs of boreholes drilled at Chandigarh reveal that there are interlayered sequences of clay and sand in most of the boreholes, which is a very conducive geological environment for liquefaction phenomenon. The ground water configuration, as dipicted on the groundwater table contour map for shallow aquifer (CGWB 2001 Fig. 4) and also encountered during the drilling exploration reveals that the table is shallowest (< 5 m) in the western part and gradually deepens towards east and north.

The grain size analysis of the subsurface sediments indicates that many sand layers fall within the limits of the most liquefiable sands of Tsuchida & Hayashi (1971). The correlation of the sediments present in the boreholes with respect to the grain size distribution curves (Fig.5) indicates that some of the sand layers at shallow depth fall within the limits of the most liquefiable class. The analysis of the grain size distribution curves vis-a-vis groundwater table distribution indicates that the subsurface sand layers around Borehole Nos.1,2,3,4,11,12 and 13 in saturated conditions may be susceptible to liquefaction during strong shaking corresponding to an intesity more than VI on MSK scale.

DISCUSSION & CONCLUSIONS

The average shear wave velocity of upper 30 m column around Union Territory of Chandigarh corresponds to Soil Type - D of the Site classes of NEHRP. Based on the analysis of Strong Motion data and other studies, NEHRP has developed amplification factors for the soil classes for different shaking intensity for short period (0.2 s) and long period (1.0 s). The Site Specific Elastic Response Spectra proposed by Uniform Building Code (UBC-97) for different soil classes for peak rock acceleration of 2 m/s^2 (i.e. 0.2g) indicates considerable amplification of ground motion for D site class. (Fig. 6, in Bard, 2000). The predominant frequency calculated for the soil column, however, indicates that low-rise structures i.e. single or double buildings, in general, face less hazard than the high-rise structure.

The analysis of the geotechnical properties and disposition of the subsurface sediments and the ground water table conditions in the area reveal that there are chances of liquefaction in some of the sectors in the central, western and southwestern parts of Chandigarh during strong shaking, generating intensity more than VI.

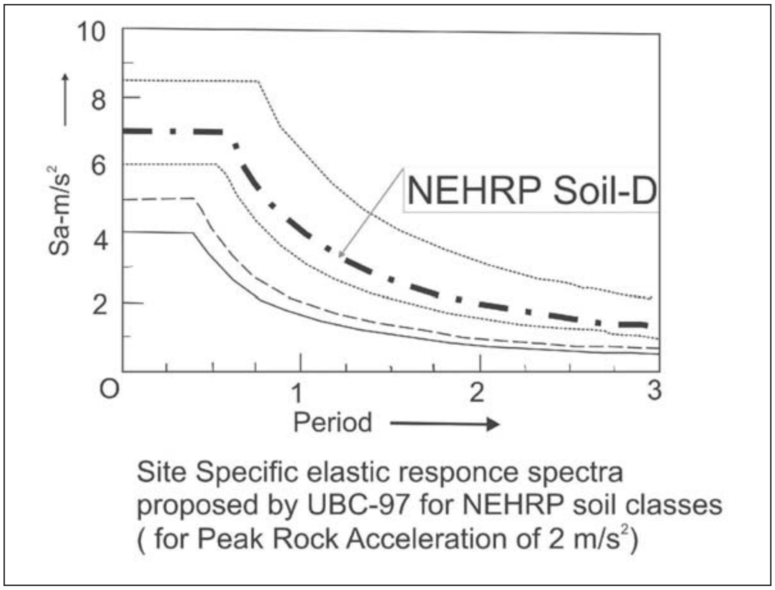

Figure 6. Response spectra for NEHRP soil classes and the comparison with site class of Chandigarh.

ACKNOWLEDGEMENTS

The authors are thankful to the Director General, Geological Survey of India, Kolkata and Senior Deputy Director General, Geological Survey of India, Northern Region, Lucknow for giving permission to publish this paper. The authors are highly grateful to Dr. Prabhas Pande, Deputy Director General, GSI, NR, for his encouragement and also for critically reviewing the paper.

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(Revised accepted 2009 March 10; Received 2008 October 23)

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He has published several papers in national and international journals. Compiled GSI Sp. Pub. No. 87 on Seismic Microzonation Studies of Delhi and GSI Bulletin Series B, No. 53 on 1999 Chamoli Earthquake, Editorial scrutiny of GSI Sp. Pub. No. 85 and remained associated with the editing / scrutiny in many other publications of GSI and ISEG.