SEISMIC MICROZONATION OF DELHI REGION

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D. NEELIMA SATYAM
Department of Civil Engineering

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Dedicated

to

Mother, Father, Satish and Balu

CERTIFICATE

This is to certify that the thesis entitled "**Seismic Microzonation of Delhi Region**" being submitted by Mrs. D.Neelima Satyam to the Indian Institute of Technology Delhi for the award of the degree of **DOCTOR OF PHILOSOPHY** is a record of the bonafide research work carried out by her. Mrs. D. Neelima Satyam has worked under my guidance for the submission of this thesis, which to my knowledge has reached the requisite standard.

The thesis or any part thereof has not been presented or submitted to any other University or Institute for any degree or diploma.

Dr. K.Seshagiri Rao
Professor
Department of Civil Engineering
Indian Institute of Technology Delhi
Hauz Khas, New Delhi 110016
INDIA

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ABSTRACT

Microzonation is the subdivision of a seismic zone into smaller zones according to a certain criterion to facilitate the implementation of seismic measures. Based on extensive and site-specific studies, microzonation has been carried out for major cities in Japan, the USA and other advanced countries in the recent past. However, no such serious attempt has been taken up so far for Indian cities. Safety against earthquake hazard has two aspects: firstly, structural safety against potentially destructive dynamic forces and secondly the safety of a site itself related with geotechnical phenomena such as amplification, subsidence, landsliding and liquefaction. It is evident that microzonation requires extensive inputs related to seismicity, attenuation of ground motion intensity, geology, geotechnical characteristics, local site effects and susceptibility of local soils to liquefaction.

After the devastating 2001 Bhuj earthquake the National Capital Region of Delhi attracted major attention of several scientific studies. This region has experienced many earthquakes, in past and recent times, and it also faces the danger of severe seismic threat from the central Himalayan seismic gap. The most recent Kashmir earthquake on 8th October 2005 has shaken Delhi for more than 30 seconds period and caused damage to poorly constructed structures near Gurgaon area. According to seismic zonation map of India, Delhi is classified in the category of moderate to high earthquake prone zone (IV), with intensity of VIII on modified Mercalli scale. In the recent past earthquakes of magnitude up to 6.2 have been reported in Delhi and near by region. In the present thesis detailed seismological, geological, geotechnical and geophysical studies have been carried out for the seismic microzonation of the Delhi region.

Geology of Delhi is interesting 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 plains, 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. 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.

Several soil profiles are made covering almost the entire Delhi region based on the collected geotechnical borehole data from several organizations to study the sub soil heterogeneity. Silt is very predominant in the trans Yamuna region. Using the data collected grain size distribution curves are drawn at 4 different depths (3.5, 5, 7.5 and 10m) for north, south, east, west and central blocks in Delhi. This GSD curves are also used in the preliminary assessment of liquefaction potential. For carrying out ground response analysis in seismic microzonation, knowledge of the depth to bedrock is essential. The bedrock depth is less than or equal to 30m in south and central part of Delhi. In north and western part of the area the sedimentary thickness goes upto150m. But the soils in these locations are comparatively dense silty sands with clay seams. In trans Yamuna region the bedrock depth is at around 200m and soils are loose sandy silts and silty sands. Also, the ground water contour map is prepared using this data. The water table is high in trans Yamuna region and very low in south and central Delhi. The X-ray diffraction and scanning electron microscopic studies on Delhi alluvium have been conducted. Quartz was the predominant mineral with lesser amounts of felspar, mica, kaolinite, illite, chlorite and calcite. From this study it is clear that the quartz percentage is very high for the soil sample collected in the southern part of the area than the samples collected from rest of the locations. Also, the percentage of Kaolinite is comparatively high in trans Yamuna and north western side of Delhi.

The detailed site characterization of Delhi region is carried out by conducting the geophysical methods i.e., seismic refraction and Multi channel Analysis of Surface Wave (MASW) tests at 118 different locations in the region. The latitude and longitude of the test locations is also measured using the GPS system. The 48 channel digital Engineering Seismograph (McSeis SX 48) with a frequency band of 4.5 to 4600Hz is used. Two varieties of geophones i.e., 28 Hz (refraction) and 4.5 Hz (MASW) were used to acquire the seismic data. In the refraction test, 24 geophones were used with a spacing of 3m and seismic energy is generated using propelled energy generator (PEG). Whereas, in MASW testing a wooden hammer of 11kg weight is used as a source generator and 12 geophones with 6m spacing is adopted. The generated seismic wave data has been processed using SeisImager/2D (refraction) and SeisImager/SW (MASW) softwares for getting two-dimensional P and S wave velocity models.

The two dimensional P and S wave velocity models for all the 118 sites are made. Also, the 2D contour maps at every 5m interval from the ground surface is also generated for both V_P and V_S. The average shear wave velocity at 30m depth i.e., V_{S30} is also calculated and is ranging from 185 to 495 m/s. Soil amplification factor is estimated from shear wave velocities using DEGTRA software and the microzonation map with respect to soil amplification factor (SAF) is generated and a correlation between V_{S30} and SAF is developed. The detailed site characterization based on V_{S30} is done by dividing the area into four zones ZA, ZB, ZC1 and ZC2. These zones are exactly matching with the geology and soil characteristics of the region. That is the zone ZA (V_{S30} > 350m/s) is falling in the central and southern part of Delhi where quartzite rock outcrop is available with dense gravely sands and the zone ZB (V_{S30} = 250 to 350 m/s) is having dense sandy silts and silty sands with clay seams i.e., Pleistocene soils. The zones ZC1 and ZC2 (V_{S30} < 250m/s) are falling in the trans Yamuna region where soils are very loose sandy silts with low N value (Holocene). Also, several correlations among V_S, V_P, SPT 'N' and depth are also developed as given in Table 1.

Table 1 Proposed Correlations for All the Three Zones

ZONE A : ZA (South and South Central Delhi)	ZONE B: ZB (West and North Western Delhi)	ZONE C: ZC1, ZC2 (Trans Yamuna)
$V_{S30} > 350$ m/s	$V_{S30} = 250$ to 350 m/s	$V_{S30} < 250$ m/s
$V_S = 280.6\ D^{0.08}$	$V_S = 216.7\ D^{0.13}$	$V_S = 140\ D^{0.24}$
$V_S = 66\ N^{0.48}$	$V_S = 48.02\ N^{0.54}$	$V_S = 39.2\ N^{0.61}$
$V_P = 1.6\ V_S + 310.0$	$V_P = 1.8V_S + 66.5$	$V_P = 0.99\ V_S + 208.5$

Since Delhi is seismically very active and geographically important there is a great need to estimate the peak ground acceleration, which is essential in any seismic hazard analysis. The computer code FINSIM, a finite fault simulation technique is used in this study and based on this analysis PGA maps at bedrock level are generated considering both near and far field sources. The PGA value estimated using the source S5 is discarded because its influence on the final PGA value is very high. The final PGA map is generated considering the first four near field sources and a map is also generated. Using the average spectral amplification factor (SAF) estimated from the shear wave velocities, the peak ground acceleration at the surface is calculated by multiplying the PGA at bedrock with SAF and a map is generated. Several attenuation laws are available in the literature for assessing the seismic ground motion parameters. No such attenuation law is available for Delhi region so far. Based on this, an attenuation law for Delhi region is also developed as given in Eqn. 1. This equation is suitable for both near and far field earthquake sources.

$$\log(PGA) = a \log R + b M_W \quad (1)$$

where, $a = -2.445$; $b = 0.25$ and $R < 200$km (for near field sources)
$a = -1.717$; $b = 0.249$ and $R > 200$km (for far field sources)

This empirical attenuation law can be very useful when the instrumental data is not available and is also a basic input in the analysis of liquefaction potential.

A qualitative and quantitative estimation of site effects is often expressed by the resonance/fundamental frequency, which depends on soil condition and bedrock depth. The Nakamura (1996) method has proved to be the most convenient technique to estimate fundamental frequencies of soft deposits. The microtremor measurements at 144 sites were performed in Delhi region using MR2002 CE equipment exactly at the same locations where the seismic refraction and MASW tests were carried out to find the site response. One-hour data is recorded at each test location and analysis was done for getting the average H/V resonance spectra. Based on the analysis, a classification is proposed with four categories (T1, T2, T3 and T4) based on the shape of the H/V spectra, predominant frequency, vulnerability index and soil characteristics. Table 2 gives the predominant frequency, vulnerability index value and soil type for each category. It is observed that the peak is shifted to lower frequency values with increasing sedimentary thickness. That means the resonance frequency depends inversely on the soil thickness. It is concluded that in places with high vulnerability index, the susceptibility for the liquefaction is also high. This index can be used to identify possible areas or structures that may be damaged in the future by earthquakes. The correlation between fundamental frequency and the average shear wave velocity at 30m is developed for Delhi region as given below:

$$V_{S30} = 303.2 * f^{0.22} \tag{2}$$

Table 2 Range of Fundamental Frequency, Kg and Zones Proposed along with Soil Type for each Classification Type

Proposed Classification	Soil Type	Fundamental Frequency	Vulnerability Index	Zone
T1	Silty sand with gravel, kankar deposits/Weathered Quartzite (High 'N' value)	>4.0 Hz	< 2.0	ZA
T2	Dense Sandy silt and Silty sand with high 'N' value	2.0 –4.0 Hz	2.0 to 6.0	ZB
T3	Sandy silt and Silty sand with seams of clay (Older alluvium: Pleistocene)	1.0 –2.0 Hz	6.0 to 8.0	ZB
T4	Sandy silt and Silty sand with low 'N' value (Newer alluvium: Holocene)	< 1.0 Hz	> 8.0	ZC1 and ZC2

Since Delhi falls in the high seismic risk zone, there is a great need for the assessment of liquefaction potential also. With the collected borehole data and generated PGA values analysis for liquefaction is attempted using SPT based three methods e.g. Seed and Idriss (1971), Seed and Peacock (1971) and Iwasaki et al. (1982) and the liquefaction potential map is prepared. The liquefaction potential is severe in the trans Yamuna region. In northern side, the liquefaction potential is very less but in few places the probability is severe. In western side of Delhi the probability is moderately severe. In south Delhi it is remote due to rock out crops and presence of gravelly sands with high N value. Also, using the estimated shear wave velocities liquefaction analysis based on Andrus and Stokoe (2000) method is done. It is clear that the liquefaction is not occurring in places with the Vs greater than or equal to 190m/sec. The liquefaction hazard map with respect to factor of safety is also prepared. These maps will help in selecting a suitable ground improvement technique and a foundation system for future constructions in the region. The microzonation maps generated are very useful in the pre and post disaster mitigation methods in the event of future earthquakes.

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