SEISMIC GROUND RESPONSE ANALYSIS AND MICROZONATION STUDIES FOR AHMEDABAD REGION

by

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Dedicated

to

My loving Parents

CERTIFICATE

This is to certify that the thesis entitled "**Seismic Ground Response Analysis and Microzonation Studies for Ahmedabad Region**" being submitted by Mr. Sandip S. Trivedi 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 him. Mr. Sandip S. Trivedi has worked under our guidance for the submission of this thesis, which to our 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.

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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 mitigation measures. Microzonation has been carried out for major cities in Japan, the USA and other advanced countries in the recent past, based on extensive site-specific studies. However, the microzonation efforts are in a primitive stage in India.

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, land sliding 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.

The state of Gujarat, has areas with high seismic activity, with seismic zones varying from III to V. The Kutch region in Gujarat falls in seismic zone V, and has been subjected to high magnitude earthquakes. The Bhuj earthquake of January 26, 2001, in the state of Gujarat in India, struck at 8:46 am Indian Standard time and had a Richter magnitude of 7.7 . The epicentre was located at 23.36°N and 70.34°E. The city of Ahmedabad, in Gujarat, being in seismic zone III and approximately at 250 Km east from the epicentre, located on the bank of Sabarmati River, received an unexpectedly high damage. There are number of causes put forward, to be responsible for such high damage. One of the major causes envisaged for the extent of damages, is a strong possibility that the recently deposited sediments and loose soils could be a factor contributing to the damage pattern in the city.

This region has experienced many earthquakes, in past and recent times, and it also faces the danger of severe seismic threat from the Kutch region. According to seismic

zonation map of India, Ahmedabad falls in Seismic zone III. Ahmedabad is having a typical geological set up, which can sustain large amplified shaking not only due to earthquakes in and around Ahmedabad, but also due to strong earthquakes in the Kutch region of Saurashtra. This imposes a very high risk of an earthquake disaster in Ahmedabad in future again, resulting into high casualties and great damage to properties. To determine the potential hazard, appropriate site characterization and determination of the soil properties are very essential in order to design a structure with safety and stability. This establishes the great need of doing seismic microzonation of Ahmedabad region. In the present thesis detailed seismological, geological, geotechnical and geophysical studies have been carried out for the seismic microzonation of the Ahmedabad region.

The Ahmedabad region is largely covered by Quaternary alluvium and forms a part of the petroliferous Tertiary Cambay basin. The Cambay basin is one of the three major marginal rift basins of the Indian craton which developed subsequently during India's drift after the break up of Gondwanaland. The architecture of the basin is controlled by three Precambrian orogenic trends viz, the ENE-WSW Satpura trend paralleling the Narmada-Son lineament, the NE-SW Aravalli trend and the NNW-SSE Dharwar trend, Within the Cambay basin, the Deccan basalt forms the basin floor over which Tertiary and Quaternary sediments have been deposited. Combined thickness of these sediments in most parts of the basin varies from 3000 to 5500 m. The steep en-echelon boundary faults delimiting the basin width, simultaneous shoulder uplift of the basin with concomitant sedimentation etc. are some of the major features of the basin. Based on structural styles, such as fault pattern, symmetry, size and orientation of the depression, the Cambay basin is divided into five tectonic blocks, namely, (1) Tharad-Sanchor block, (2) Ahmedabad-Mehsana block, (3) Cambay-Tarapur block, (4) Broach-Jambusar block and (5) Narmada Ankleshwar block.

Several soil profiles are made covering almost the entire Ahmedabad region based on the large geotechnical borehole data collected from several organizations, and also from confirmatory drilling of boreholes to study the sub soil heterogeneity. Using the data so collected, grain size distribution (GSD) curves are drawn at different depths for different locations of Ahmedabad. These GSD curves are also used in the preliminary assessment of liquefaction potential. The bedrock is not encountered in Ahmedabad up to great depth, hence, for carrying out ground response analysis in seismic microzonation, the hypothetical engineering depth to bedrock, on the basis of shear wave velocity has been used. This depth is taken equal to 30m. The soil layers observed in the region at different depths mainly include clayey silt, silty sand, clayey sand, sandy silt, besides the filled up soils at many locations. Also, the data regarding levels of ground water table, has been collected. The X-ray diffraction studies on Ahmedabad soil samples have been conducted. Quartz was the predominant mineral with lesser amounts of kaolinite, illite, mica, chlorite and others.

The detailed site characterization of Ahmedabad region is carried out by conducting the geophysical methods i.e., seismic refraction and Multi channel Analysis of Surface Wave (MASW) tests at 54 different locations in the region. The latitude and longitude of the test locations are 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 (for refraction tests) and 4.5 Hz (for MASW tests) 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). And in the MASW testing, a wooden hammer of 11 kg weight is used as a source generator and 24 geophones with 3 m spacing are adopted. The seismic wave data so generated, has been processed using SeisImager/2D (refraction) and SeisImager/SW

(MASW) software for getting two-dimensional P and S wave velocity models respectively.

The two dimensional P and S wave velocity models for all the 54 locations are made. Also, the 2D contour maps at every 5m interval from the ground surface are 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 209 to 483 m/s. The detailed site characterization based on V_{S30} is done by dividing the area into three zones SA, SB and SC. Several correlations among V_S, V_P, SPT value 'N' and depth are developed as given in Table 1.

Table 1 Proposed Correlations for All the Three Zones

ZONE: SA	ZONE: SB	ZONE: SC
$V_{S30} > 370$ m/s	$270 < V_{S30} < 370$ m/s	$V_{S30} < 270$ m/s
$V_S = 256.6\ D^{0.12}$	$V_S = 207.7\ D^{0.15}$	$V_S = 116\ D^{0.30}$
$V_S = 72\ N^{0.55}$	$V_S = 55\ N^{0.34}$	$V_S = 29.2\ N^{0.46}$
$V_P = 1.55\ V_S + 278.3$	$V_P = 1.12 V_S + 52.3$	$V_P = 0.82\ V_S + 92$

Since Ahmedabad is seismically very active, 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 three different PGA maps at bedrock level, for three source epicenters from different faults, are generated. The actual instrumented time history of Bhuj Earthquake of 2001, is also used, and the PGA values are also generated using the ProShake software, and other measured input values of shear wave velocity, density, plasticity index, type of soil etc. The final PGA map is generated considering these four sources. The peak ground acceleration at the surface is calculated with help of ProShake software.

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 and reliable technique to estimate fundamental frequencies of soft deposits. The microtremor measurements at 118 sites were performed in Ahmedabad region using MR2002 CE equipment, inclusive of same 54 locations where the seismic refraction and MASW tests were carried out to find the site response. The 30 minutes 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 three categories (ZA, ZB, and ZC) 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.

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

Proposed Classification	Soil Type	Fundamental Frequency	Vulnerability Index (Kg)	Zone
ZA	Stiff to hard clayey silt, Dense silty sand/ silty sand with high 'N' value	> 3.0 Hz	2.0 to 4.0	SA
ZB	Clayey silt, sandy silt and silty sand with seams of clay, relatively higher "N" value, (Older alluvium: Pleistocene)	1.0 –3.0 Hz	4.0 to 8.0	SB
ZC	Clayey silt and silty sand with low 'N' value, lower density, soft/ loose soils (Newer alluvium: Holocene)	< 1.0 Hz	> 8.0	SC

The resonance frequency depends inversely on the soil thickness. This 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 Ahmedabad region as given below:

$$V_{S30} = 243.2 * f^{0.12} \tag{2}$$

Site specific ground response analysis is required to determine the response of a soil deposit to the motion of the bedrock immediate below the soil and also determining the effect of local soil conditions on amplification of seismic waves and hence estimating the ground response spectra for future design purposes. Soft deposits of soil amplify (increase) certain frequencies of ground motion thereby increasing earthquake damage. Thus local soil conditions have significant role to play, on amplification of seismic waves. The one dimensional equivalent linear ground response analysis for 54 sites is carried out, using ProSHAKE software, and site specific response spectra have been developed. The ground motion data (time history), which was recorded at Passport Office during 26th January 2001 Bhuj Earthquake, is considered. This earthquake time history data, along with other actual site-specific measured data for grading, plasticity, density, shear wave velocity from MASW tests etc., is provided as input data. The graphs for response spectrum for 54 locations of Ahmedabad region have been obtained and are compared with the normalized response spectra available from IS: 1893-2002. The zonation map for peak normalized spectral acceleration, is made for Ahmedabad region.

Since Ahmedabad 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 PGA values so generated, analysis for liquefaction is attempted using SPT based two methods e.g. Seed and Idriss (1971), and Idriss and Boulanger (2004) and the liquefaction potential map is prepared. 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 for the pre and post disaster mitigation in the event of future earthquakes.

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CHAPTER 3 GEOLOGICAL AND GEOTECHNICAL ASPECTS OF AHMEDABAD REGION

CHAPTER 4 SITE CHARACTERIZATION THROUGH SEISMIC REFRACTION AND MASW METHODS FOR AHMEDABAD REGION

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