SEISMIC HAZARD ANALYSIS AND MICROZONATION STUDIES FOR SURAT CITY AND SURROUNDING REGION

by

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Dedicated

to

Almighty God and My lovely Family

CERTIFICATE

This is to certify that the thesis entitled "**Seismic Hazard Analysis and Microzonation Studies for Surat City and Surrounding Region**" being submitted by Mr. Tejaskumar P. Thaker 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. Tejaskumar P. Thaker 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.

Surat is the second largest city in the state of Gujarat located on the bank of river Tapti placed in seismic zone III in accordance with IS 1893 (2002). The region is having a typical geological set up, which can sustain large amplified shaking not only due to earthquakes in and around Surat, but also due to strong earthquakes in the Kutch and Saurashtra. This imposes a very high risk of an earthquake disaster in Surat in future again. Besides this, the possibility of liquefaction to occur in the region is also high especially where the soils are loose saturated sandy soil or silty sand.

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 Surat region. In the present thesis detailed seismological, geological, geotechnical and geophysical studies have been carried out for the seismic microzonation of the Surat region.

The Surat 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. As the region is in the flood plain of river Tapti, these deposits are flat and lie adjacent to streams, composed primarily of unconsolidated depositional material derived from sediment transported by the streams. The Tapti River passes through the Deccan trap from eastern side of the region. Also tidal currents from the western side through the Sea also contribute significantly in the marine deposition characteristics of the region.

Extensive geotechnical borehole data were collected from several organizations. The information so collected include, the particle size distribution, Atterberg's limits, free swell index, water table, Standard Penetration Test (SPT) values, moisture content at different depths, density values and specific gravity. Using these data several soil profiles are made covering almost entire region to study the sub soil heterogeneity. The soil layers observed in the region at different depths mainly include clayey silt, silty sand, clayey sand, sandy soil, besides the filled up soils at many locations. Further, the average SPT 'N' contour maps at various depths (e.g., 3.0, 6.0, 10.0 and 15.0m) have been generated. It has been observed that areas in the west, northwestern, southwestern and some of the areas along the river bank consist of very low average SPT-N values less than 20 whereas areas in the eastern, southeastern, some part of north and northeastern part of the region consist of very high average SPT-N values more than 30. The rest of the areas falling in the range between 20 and 30. The water table depths in the region are also studied using the data and it is observed that the water table in around 60% of the area is at shallow depth (< 4.0m).

The detailed site characterization of Surat region is carried out by conducting the geophysical methods i.e., seismic refraction and Multi channel Analysis of Surface Wave

(MASW) tests at 63 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 both the tests, 24 geophones were adopted with a spacing of 3m. In seismic refraction tests, seismic energy is generated using propelled energy generator (PEG) and five shots were taken at equal intervals whereas in the MASW testing, a wooden hammer of 11 kg weight is used as a source generator and the source is shifted every time 3m and a total of 25 shots were made at each test location. 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 63 locations are made. Also, the 2D contour maps at every 5m interval from the ground surface are also generated for both Vp and Vs. The average shear and compression wave velocity at 30m depth i.e., Vs_{30} and Vp_{30} respectively are also calculated. The sub soil classifications have also been carried out based on Vs_{30} using NEHRP (National Earthquake Hazard Research Program) classifications. According to these classifications, the entire region of Surat falls in to two site class C ($360<Vs<760$m/s) and D ($180<Vs<360$m/s). The detailed site characterization based on Vs_{30} is done by dividing the area into three zones SA, SB and SC. Several correlations among V_S, V_P, and depth are developed as given in Table 1.

Table 1 Proposed Correlations for All Three Zones

Zone SA	Zone SB	Zone SC
$Vs_{30} > 340$ m/s	270 m/s $< Vs_{30} <$ 340 m/s	$Vs_{30} < 270$ m/s
$Vp = 1.69Vs + 45.92$	$Vp = 1.42Vs + 99.84$	$Vp = 0.87Vs + 95.73$
$Vs = 178.7D^{0.343}$	$Vs = 141.9D^{0.314}$	$Vs = 96.18D^{0.354}$

The measured shear wave velocity at all locations close to the SPT boreholes are used to generate the correlations between shear wave velocity and SPT 'N' value for different types of soil as shown in Eqns. (1-3). The proposed correlations SPT-N were compared with regression equations proposed by various investigators and found that the developed correlations exhibit good prediction.

$$Vs = 59.73\ N^{0.42} \qquad (R^2 = 0.77, \text{ for all soils}) \tag{1}$$

$$Vs = 62.41\ N^{0.42} \qquad (R^2 = 0.79, \text{ for clay}) \tag{2}$$

$$Vs = 51.21\ N^{0.45} \qquad (R^2 = 0.78, \text{ for sand}) \tag{3}$$

Since Surat is nearer to the seismically very active sources, there is a great need to carryout seismic hazard analysis. The earthquake catalogue for the area surrounding 350km radius around the city was prepared by combining and consolidating available information from different sources (i.e., Geological Survey of India (GSI), Indian Meteorological Department (IMD), International Seismological Centre (ISC), National Geophysical Research Institute (NGRI), Gujarat Engineering Research Institute (GERI), Institute of Seismological Research (ISR), United States Geological Survey (USGS) and catalogues published in literature) covering the time period from 1818-2008. All the data have been converted to common magnitude scale and dependant events have been removed from the catalogue. The seismic sources in the study area were identified from the Seismotectonic Atlas (SEISAT, 2000), published by GSI. Earthquake data and seismic sources like major faults, lineaments are superimposed on the base map of the area and new seismotectonic map for the study area considering up to date seismicity has been prepared.

Deterministic Seismic Hazard Analyses (DSHA) have been carried out to identify Maximum Credible Earthquake (MCE) in the region considering 17 seismic sources identified from the seismotectonic map of study area out of which 12 are the major faults and five are the major lineaments. Maximum moment magnitude (M_{max}) has been assigned to each source based on maximum reported earthquake in the past, proximity to each source. The attenuation relationship developed for the western-central part of India by Iyengar and Raghukanth (2004) is considered for the analysis.

The completeness of the seismic catalogue has been checked using both cumulative visual interpretation techniques (CUVI) (Tinti and Mulargia, 1985) and Stepp (1973) and compared. It has been observed that the results from both the procedures are in good agreement. Seismic parameters are then evaluated by establishing recurrence relationship for the region and compared with the other studies reported in the literature for PI. It is found that the seismic parameters obtained in the present study matches well with the earlier studies reported for PI. The probabilities of distance, magnitude and peak ground acceleration have been evaluated for the five most vulnerable sources using Probabilistic Seismic Hazard Analysis (PSHA). The mean annual rate of exceedance has been calculated for all five sources at the rock level. The cumulative probability hazard curves have been generated at rock level for peak ground acceleration and spectral acceleration. Finally peak ground acceleration maps at rock level corresponding to 10 and 2% probability of exceedance in 50 years have been developed for the Surat area. Further Uniform Hazard Response Spectrum (UHRS) at rock level for 5% damping and 10 and 2% probability of exceedance in 50 years and the same has been also developed for the city considering site classes C and D (From Vs_{30} map) according to NEHRP. It is observed that the PGA values for 475 years return period considering different site classes vary from 0.075g - 0.115g at rock level to 0.24g and 0.27g for Class 'C' and 'D' respectively indicating that the Indian Seismic Code IS 1893: 2002 overestimates PGA values for rock and underestimates for soil sites.

In the absence of a robust database of strong-motion records, the strong motion for Bhuj (2001) earthquake have been simulated on hard rock and B/C boundary (NEHRP) levels using recently developed stochastic finite fault modeling based on dynamic corner frequency (Motazedian and Atkinson,2005). Parametric studies have been carried out and simulations were taken up at 13 sites in the state of Gujarat where SRR recordings are available. In addition, the qualitative and quantitative comparisons made for simulated spectral accelerations at 5% damping and recorded with SRRs for different sites are also found to be in reasonable agreement. Further, accelerogram were simulated at B/C boundary at large number of points distributed on a grid and compared with intensity map. Further, the recorded time history of 2001 Bhuj earthquake at Passport Office of Ahmedabad was simulated by carrying out one dimensional ground response analysis using the actual shear wave velocity, soil type and generated synthetic ground motion at the site. The response spectrum of the generated ground motion at the surface has been comparable with the response spectrum of the recorded event. Taking the same ground motion generation parameters, ground motions of Bhuj (2001) earthquake for for firm rock conditions in the Surat city along with other cities in the state of Gujarat have been obtained.

The most severe earthquake scenarios for the region have been selected from the deterministic hazard analysis and it has been observed that the three faults namely, Son Narmada Fault (SNF), Tapi North Fault (TNF) and West Coast Fault (WCF) are responsible for producing significant PGA in the region. These faults are capable of generating the earthquakes in the range of Mw 5.0 to 6.3 and situated in the distance range of 10 to 55km from the Surat city. Considering this, ten synthetic ground motions were generated adopting suitable path and site parameters simulated for firm rock conditions in the region. These ground motions are further used to carryout ground response analysis of the region.

The site specific earthquake characteristics on the ground surface have been obtained by conducting one dimensional equivalent linear site response analysis using widely used DEEPSOIL software at around 66 locations covering entire Surat region. The hypothetical engineering bedrock depth of 30m has been taken on the bases of shear wave velocity. Hazard compatible synthetic time histories (in terms of fault distance, earthquake magnitude and fault type etc) simulated in the previous section (i.e., 10nos. of synthetic ground motions) have been used as an input and scaled to a PGA of 10% probability at 50 years of exceedance level at rock level. In addition, the other geotechnical and geophysical data such as soil layer depth, soil type, plasticity index, shear wave velocity, density, water table etc have been used as an input. The average response spectra along with standard deviation and 95% confidence interval limits as a conservative estimate have been proposed for 66 locations in the Surat region and compared with the response spectra available from IS 1893:2002. Further ground responses for far field earthquakes have also been carried out considering Bhuj (2001) actual recording at Ahmedabad and synthetic time histories of same event simulated at Surat city. It has been observed that the average response spectral accelerations at ground surface for Bhuj (2001) event are lesser for almost all the periods than the proposed average spectrum obtained from the near field events for most of the locations in the region.

Further, PGA at surface, spectral accelerations corresponding to 0.1, 0.2, 0.3, 0.5, 0.7 and 1.0s have been obtained and mapped. The predominant frequency of the soil has been obtained from Fourier spectrum and compared well with natural period of soil column obtained from empirical equation. Also it has been found that the high rise buildings are most vulnerable in the western side of the Surat region where soil having the shear wave velocity in the range of 180 to 270m/s. In addition to this, average spectral amplification factor between 0.1 to 1.0s periods estimated from the elastic acceleration response spectrum calculated at surface and bedrock have been computed and mapped to represent amplification in the surface ground motion. It has been observed that sites with clayey soils have larger amplifications compare to sandy soil with similar shear wave velocities. Since, the response spectra are also reflect the geology and subsurface characteristics of the region, the response curves of all 66 locations are grouped into three categories of soils i.e., soft, moderate and highly dense based on the Vs_{30} zones and generalized for simplicity.

Nakamura (1996) method has proved most convenient and reliable technique to estimate fundamental frequencies of soft deposits. The microtremor measurements at 63 sites were performed in Surat region and measurements were taken using velocity sensor MR2002CE for a period of 60 minutes at each station point. These test locations also included the 63 sites where seismic refraction and MASW testing were conducted to study the detailed site response. Analysis was done using VIEW 2002 software for getting the average H/V resonance spectra. For clear identification of peak frequency, the spectra need to be smoothened. In the present study smoothening was performed using moving average technique. The analysis was performed for all 63 sites and a classification is proposed with three categories (ZA, ZB and ZC) based on the shape of the H/V spectra, predominant frequency, and vulnerability index and soil characteristics. The vulnerability index (Kg), which is very important in hazard assessment, is estimated for Surat region and map is generated. These zones are observed to be in good agreement with the zone proposed from the Vs_{30}. The predominant frequency estimated from Nakamura method compared well with the same estimated from the 1D ground response analysis. A correlation between V_{S30} and predominant frequency is also developed for Surat region presented below,

$$f_0 = 0.010Vs_{30} - 0.713 \quad (4)$$

where, f_0 is the predominant frequency

Since the Surat region falls in the high flood zone of river Tapti, the water table is very high, there is great need for assessment of liquefaction potential also. Using subsurface data and PGA values so generated, quantitative assessment for liquefaction has been attempted using SPT [e.g. Seed and Idriss (1971), and Idriss and Boulanger (2004)] and Vs based [Andrus and Stokoe (2000)] methods and liquefaction hazard maps have been generated at different depths. Analysis reveals that the soft soils near the western coastal area and some area along the bank of river Tapti maximum up to 10.0m from the ground surface are susceptible to liquefaction. Further, The liquefaction potential Index (*LPI*) has been estimated for Surat region considering the factor of safety estimated using both SPT and Vs based methods. The damages to engineering structures tend to be severe if the liquefied layers are thick and at shallow depth. The *LPI* index is observed to be in the range between 5 and 15 in the west and south western parts and some in the northern parts of the region. This region has high liquefaction potential on account of thick shallow liquefied deposits.

The microzonation maps generated in the present study are very useful for the pre and post disaster mitigation in the event of future earthquakes.

CONTENTS

CHAPTER-10 SUMMARY AND CONCLUSIONS