SEISMIC HAZARD ASSESSMENT AND DEVELOPMENT OF ATTENUATION RELATIONSHIP FOR NCR OF DELHI

by

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Dedicated

To

My Parents, Family and Teachers

CERTIFICATE

This is to certify that the thesis entitled, **'Seismic Hazard Assessment and Development of Attenuation Relationship for NCR of Delhi'** being submitted by **Mr. Ganesh W. Rathod** 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. Ganesh W. Rathod has worked under our supervision 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

Seismic hazard assessment has an important societal impact in describing levels of ground motions to be expected in a given region in the future. In recent years, the interest of the scientific community regarding seismology and seismotectonic has greatly increased, especially in the field related to seismic risk assessment of urban seismic areas and its possible reduction. Challenges in seismic hazard assessment are closely associated with the fact that different regions, due to their differences in seismotectonic setting and earthquake occurrence as well as socio-economic conditions, require different approaches. India's high earthquake risk and vulnerability is evident from the fact that about 59 percent of India's land area could face moderate to severe earthquakes. North India and particularly the Himalayan belt has experienced many strong to moderate earthquakes since 18th century. Some of the major earthquakes in past are having the magnitude more than 7.0 M_w. The present thesis focuses the seismic hazard in National Capital Region (NCR) of Delhi, India. For the very purpose of achieving the goal of the study and the high seismic risk posed by the region, NCR of Delhi is selected as a study area. The study area i.e. NCR of Delhi has a population more than 28 million according to 2011 census, located on the banks of river Yamuna. Being the capital of India, the city is considered as highly important viewing to social and economical issues, comes under seismic zone IV according to seismic zonation map of India (BIS:1893-2002), and thereby specifying basic peak ground acceleration (PGA) of 0.24g. The region is located near the highly active Himalayan seismic belt, in addition to that there are many near field seismic sources which would generate significant hazard in the region.

With this point of view, a detailed study has been attempted in the present work to propose the present seismic hazard scenario for NCR of Delhi at bedrock level in terms of Peak Ground Acceleration (PGA) using state of art Probabilistic Seismic Hazard Analysis

(PSHA) and Deterministic Seismic Hazard Analysis (DSHA) and then at ground surface level using 1-D seismic site response analysis.

Starting from the preparation of a new seismotectonic map of the study area considering 360 km radius around the city, which consist of the seismogenic sources, past earthquake data collected from various sources and available literature, the completeness of the data has been evaluated using Cumulative Visual Interpretation (Tinti and Mulargia, 1985), Stepp (1973) method and Maximum Likelihood technique (Kijko and Sellevoll, 1989, 1992). The data has been then analyzed statistically and recurrence relationships has been obtained using G-R method (Gutenberg and Richter, 1944).

In the dearth of recorded ground motion data, stochastic seismological modelling has been adopted for generation of synthetic ground motions. The recorded earthquake data of Uttarkashi earthquake of 20th October, 1991 and Chamoli earthquake of 28th March, 1999 are used to estimate the source parameters and to calibrate the seismological model. This synthetically generated ground motion data is then used to develop the attenuation relationship. The proposed attenuation relationship for estimation of PGA at bedrock is given as:

$$\log_{10}(PGA) = c_1 + c_2(M_w - 6) + c_3(M_w - 6)^2 + c_4(R) + c_5 \log_{10}(R) + \log_{10}(\varepsilon) \qquad (1)$$

where, *PGA* is the geometric mean of the horizontal PGA values in units of g; M_w is the moment magnitude; $R=\sqrt{(D^2+H^2)}$, R is the hypocentral distance in km, *D*= Depth, *H*= Nearest fault distance; ε is a random error. The regression coefficients and error are estimated as: c_1= 0.66845, c_2= 0.49908, c_3= -0.04665, c_4= -0.00257, c_5= -2.303x0.37329 and standard deviation of random error $\sigma(\log_{10} \varepsilon)$= 0.1118.

The proposed attenuation relationship is for the NCR of Delhi and the Himalayan region which can be extended for estimation of seismic hazard in North India also. The proposed attenuation relationship is validated against the recorded earthquake data and compared with the other attenuation relationships of various region.

The deterministic and probabilistic seismic hazard analyses are performed for the study area for estimation of bedrock level PGA. The probabilistic approach is used to estimate PGA models at bedrock level corresponding to return period of 475, 950, 2475 and 4950 years. The spatial variation in estimated bedrock PGA values are captured and PGA maps at various return periods are prepared. Results have been compared with various studies reported in the literature and also with the Indian Standard Code of practice.

In the next part of thesis, detailed geophysical site characterization has been attempted by in-situ measurement of shear wave velocity (V_S) and primary wave velocity (V_P) at 210 test locations in the study region by Multi Channel Analysis of Surface Waves (MASW) and Seismic Refraction (SR) testing using 48 channel seismograph. V_S and V_P maps are prepared at every 1.5 m depth. The average shear wave velocity up to depth of 30 m (V_{S30}) is also calculated, which is ranging from 188 to 836 m/s for Delhi region. The seismic site characterization of the study area has been carried out and five zones (ZA, ZB, ZC, ZD and ZE) of similar dynamic properties, geological and geotechnical units are defined. The ranges of V_S and V_P values at all depths and V_{S30} values for each zone are given in Table 1. According to NEHRP classification, the study area falls under class C and D.

Table 1. Range of V_P, V_S and V_{S30} Values for the Proposed Site Classification

Zones	ZA	ZB	ZC	ZD	ZE
V_P (m/s)	410-2080	400-1780	320-1600	300-1120	300-850
V_S (m/s)	260-1210	160-850	130-700	140-520	120-380
V_{S30}	501-836	381-490	300-378	260-299	188-259

More than 3500 borehole data is collected and synthesized to assess the geotechnical properties. Based on this dataset, empirical equations among various properties are proposed for the region. A systematic comparison with the available literature supported by error analysis is also presented.

Assessments of local site conditions and earthquake motion characteristics at the ground surface play a key role in determination of local site effects in geotechnical engineering practice. Local site effects are often expressed in terms of the resonance or fundamental frequency, spectral amplification and vulnerability index (Nakamura; 1996, 1997) which depends on soil condition and bedrock depth. The Nakamura (1989) method has proved to be the most convenient technique to estimate fundamental frequencies of soft deposits. From this perspective, single point ambient vibration (also referred as microtremors or seismic noise) measurements are performed at 210 locations in study area, and a classification is also proposed with five categories (F1, F2, F3, F4 and F5). The proposed classification is based on the shape of the H/V spectra, predominant frequency and vulnerability index. The proposed classification is presented in Table 2.

Since the average shear wave velocity up to 30 m depth (V_{S30}) is also available from the MASW tests, it is observed that V_{S30} is high at places with high resonance frequency and vice versa. A correlation between V_{S30} and predominant frequency is also developed for study area as given below:

$$V_{S30} = 289.08 f^{\,0.13} \tag{2}$$

This correlation will be useful in estimating the V_{S30} for the locations in and around Delhi. Thus, Nakamura method can be used as a very quick and reliable method for estimating local site effects leading to a seismic microzonation of the whole region.

Seismic site response analysis is required to determine the response of ground to the motion of the bedrock and also determining the effect of local soil conditions on amplification of seismic waves and hence estimating the free field response spectra for future design purposes. the probabilistic procedures are proposed in the present study for

Table2. Fundamental Frequency and Vulnerability Index Along with Soil Type for Each Classification Type

Proposed Classification	Soil Type	Fundamental Frequency	Vulnerability Index	Zone
F1	Silty sand with gravel, kankar deposits/Weathered Quartzite (High 'N' value)	> 5.0 Hz	< 5.0	ZA, ZB
F2	Dense Sandy silt and Silty sand With high 'N' value	3.0 –5.0 Hz	5.0 to 10.0	ZB, ZC
F3	Sandy silt and Silty sand with seams of clay (Older alluvium: Pleistocene)	2.0 –3.0 Hz	10.0 to 15.0	ZC
F4	Sandy silt and Silty sand with low 'N' value	1.0 –2.0 Hz	15.0 to 20.0	ZD
F5	Sandy silt and Silty sand with low 'N' value (Newer alluvium: Holocene)	< 1.0 Hz	> 20.0	ZD, ZE

consideration of the uncertainties in various input parameters required for site response analysis. Stochastic 1D seismic site response analysis is attempted in the present study and parametric study has been performed. The uncertainties in input ground motion, shear wave velocity and non linear soil properties are modelled in the analyses using Monte Carlo simulations. The influence of input ground motion selection, variation in shear wave velocity (i.e. $\sigma_{\ln Vs}$), number of samples used, variation in shear modulus reduction and damping curves (i.e. variation in nonlinear properties) and effect of individual layer thickness are investigated through parametric study using stochastic seismic site response analysis.

The stochastic 1D site response analyses are then applied to the various site classes (A, B, C, D and E) of NCR of Delhi. The acceleration response spectra at surface for site class A, B, C, D and E are compared with BIS:1893-2002. The results are then compared with microtremor findings also, which are in good agreement with each other.

Considering the seismic status and varied geological formation of study area, there is a great need for the assessment of liquefaction potential. The uncemented, saturated sand/silts are considered to be highly susceptible to liquefaction. Andrus *et al.* (2004a) reported that the Pleistocene soils are also prone to liquefaction and an aging factor was proposed by them and the same has been adopted in the present liquefaction analysis. The liquefaction potential of study region is evaluated using the SPT 'N' value based method by Idriss and Boulanger (2010) and shear wave velocity (V_S) based method by Andrus and Stokoe (2000) and Andrus *et al.* (2004a). The liquefaction hazard maps with respect to factor of safety from all the three methods used are prepared. These maps will help in designing the foundation system of a structure, life line structures, design of roads and reducing the risk from liquefaction through appropriate mitigation.

Based on these detailed studies, the present seismic hazard scenario of NCR of Delhi is proposed and discussed. In the present study an attempt has been made to touch every aspect required for the seismic hazard assessment of a region. Starting from the collection of earthquake data, its processing, catalogue preparation, seismological modelling in the absence of recorded ground motion data, development of attenuation relationship, geophysical and geotechnical characterization, a process for ground response analysis and liquefaction potential assessment are discussed in detail in the present research work. In combination, the studies presented here address some of the key issues associated with seismic hazard assessment and its probable solution. The present work can hopefully serve as a basis for further investigations in the future.

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