सत्यमेव जयते

A report on Seismic Hazard Microzonation of NCT Delhi on 1:10,000 scale

National Center for Seismology
Ministry of Earth Sciences
Government of India
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FOREWORD

Digital seismology, which started only about 50 years back, enabled scientists to quantify the earthquake source parameters and help understand the faulting. However, it is equally important to understand the impact of the earthquakes on human habitats and to take measures to mitigate the seismic risk, due to future large earthquakes. It has been reported that major and great earthquakes which occurred in the Himalayan region caused significant damage in the Delhi region, which is located about 200 km from the source zones of these earthquakes. In the past half century, Delhi has become a major hub of urbanization. The population of Delhi has increased from 2 million to 18 million, and so has the risks. With diverse geological conditions in the 1500 km^2 area of Delhi, seismic risks cannot be uniform, and hence it is important to evaluate the seismic hazard at micro-scale.

With this view, the Earthquake Risk Evaluation Centre (which is now merged with the new institute "National Centre for Seismology") undertook the major task of microzonation of Delhi. The report includes assimilation of new and existing data from ~450 sites, related to geological, geophysical as well as engineering aspects in preparing various products, e.g., shear strength of soil, bedrock depth, ground water table, soil liquefaction potential, peak ground acceleration and its amplification, spectral acceleration at sites, etc., for seismic hazard micozonation. I hope that the report will be extensively used by the structural design professionals, architects and planners, for planning and designing earthquake-safe buildings.

(M. Rajeevan)

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Executive Summary

Earthquake is the most dreaded natural disaster especially for its intrinsic nature to unleash devastation instantaneously in large area without leaving much scope for prevention of hazard after the occurrence of the event. Given the current state of knowledge, little can be done to modify the hazard by controlling tectonic processes. However, there are variety of ways to control the risk or exposure to seismic hazards. All over the world, there is paradigm shift for the management of earthquake disaster from the response-centric regime i.e. 'Rescue', 'Relief' and 'Rehabilitation (3R)', to mitigation and preparedness-centric regime i. e. pre-disaster management which includes. Prevention, Mitigation and Preparedness (PMP), where efforts and funds are be used to address the underlying causes of vulnerability and for preparedness.

Damage to the life and property that is caused by an earthquake, can greatly be reduced by proper land use planning, engineering approaches, strengthening of existing structures etc.. Presently, the codal guidelines provided in IS: 1893 (Part I)-2002 are followed for primary structure design. These guidelines are based on the seismic zoning maps, which are prepared on the basis of seismotectonic provinces and premise that the earthquakes would re-occur in the same tectonic provinces where they have occurred in the past. These maps broadly define the geographical zones with level of expected hazard in the area either in terms of expected intensity of damage ranging between VI-IX on Intensity scale or Peak Ground Acceleration (PGA) in units of "g". It has been seen during several past earthquakes that damage to the built environment is not uniform over a populated area even when the quality of construction is near uniform. This is due to the varying response of the top layers of the soil to the propagation of seismic waves owing to several factors such as composition of the soil, local geology, and depth of water table and interaction of the buildings with the underlying soil during an earthquake. These aspects have not explicitly been considered in the present zoning map.

Seismic Hazard Microzonation study, which is the process of estimating response of soil layers under earthquake excitations and thus the variation of earthquake ground motion characteristics on the ground surface, addresses all these issues and is one of the important tools in disaster mitigation planning, as it can minimize disaster impacts of an earthquake and need to be attempted systematically.

In its first attempts EREC initiated Seismic Microzonation of NCT and collated the data, generated data in gap areas, carried out analysis and integrated multi thematic maps and evolved Seismic Hazard Microzonation Map of NCT, Delhi in collaboration with expert institutions and advise of working group of expert, constituted by DST and generated the 1st level Seismic Microzonation Map of NCT, Delhi on 1:50,000 scale. Thereafter, EREC initiated Seismic Hazard Microzonation study of NCT Delhi in more precise scale on 1:10000 with specific objectives of actual applications in land use planning and designing of area specific building codes for NCT Delhi. To initiate the study project specific base map on 1:10000 scale has been generated by the Survey of India, presenting NCT Delhi in 75 toposheets. The GSI, in association with EREC, carried out fresh geological mapping of Delhi on 1: 10,000, thus refining the available 1:25,000 geological map of the region. An intensive programme of geotechnical and Geophysical data generation was taken up for about 500 sites in NCT Delhi.

An Advisory and Monitoring Committee was constituted by Ministry of Earth Sciences, under my chairmanship with members from reputed institutions of the country for monitoring and supervising the study. On completion of generation of part of data, seismic hazard microzonation maps were generated for half of Delhi and presented in a workshop organized by EREC, IMD in November 2011, to assess the requirements of engineers, town planners. The workshop was attended by senior engineers from Central Public Work Department (CPWD), Delhi Development Authority (DDA), Municipal Corporation of Delhi (MCD), and scientist from different institutions. As per recommendation of workshop, a report for half of the Delhi was prepared based on tentative results and submitted to Ministry of Urban Development (MoUD), Government of Delhi to initiate strategy for implementation of microzonation products in design of site specific building codes. Now on completion of analysis based on all possible geotechnical/geophysical data generated at about 500 sites and making use of old geotechnical data collected from different construction agencies, seismic hazard maps for whole of NCT Delhi have been generated and a report has been formulated after several discussions and final approval by the Advisory and Monitoring Committee.

The Report consists of fifteen Chapters. The Chapter 1 'Introduction' details Seismic Scenario, definition, benefits, national, and international scenario and present status of seismic hazard evaluation in the country and engineering approaches.

The geology, Seismotectonics, and the seismicity of the area play an important role in understanding the earthquake hazard and its evaluation. Further, water table of the area also plays an important role in deriving earthquake induced effect such as liquefaction. A brief review of Geology/Geomorphology, Tectonics, Seismicity, and hydrology of Delhi and adjoining area is discussed in the Chapter-2.

Intrinsic characteristics of earthquake hazard, which differentiate from other natural disasters, warrant specialized methodology of seismic hazard evaluation. The Seismic Hazard Microzonation (SHM), requires a multi-disciplinary approach and sequence of studies to generate parameters for source, travel path & ground characterization with inputs forthcoming from 4 disciplines viz. Geosciences (geology and geophysics), Seismology, Geotechnical Engineering, and Engineering Seismology. On the basis of literature survey and earlier microzonation studies, a brief on concept of evaluation of seismic hazard, a holistic model evolved and used for Seismic Hazard Microzonation of NCT Delhi have been presented in Chapter-3.

The present study is on 1:10000 scale and to initiate the study, a base map on this scale was required and was developed in collaboration with Survey of India(SoI). In order to understand geological variation on this scale for the planning of geotechnical/geophysical investigations a geological map was developed in collaboration with GSI. Besides these basic maps several other thematic maps were also required. All these maps and their implications in the seismic microzonation are discussed in Chapter-4.

Seismic Hazard Microzonation process can broadly be classified in two processes. The first process is source characterization and generation of strong ground motion at base rock at different sites using Probabilistic or Deterministic Seismic Hazard Analysis. In the second process, these strong ground motions are used as input motion and based on soil characteristics; site response study is carried out. In the present study Probabilistic Seismic Hazard Analysis has been adopted for the first part of the study and a brief on methodology, analysis and generation of strong ground motion and its parameters at engineering bedrock are discussed in Chapter-5.

Soil play very important role in accentuation of seismic hazard. Different types of soil respond differently when subjected to the ground motion and therefore understanding of subsurface soil variation, static and dynamic properties of soil column is very important. Further, the present study is on 1: 10000 scale and therefore subsoil variability in every 100m need to be ascertained. This requires extensive geotechnical and geophysical investigations at many sites for evaluation of index and dynamic properties of soil. In the Chapter-6, requirement of such investigations, type of investigations, criteria to assess minimum number of sites for investigations to meet the requirement of the study etc have been discussed. Geotechnical/geophysical investigations have been carried out at more than 500 sites spread over Delhi. Based on this data set study of soil characteristics, development of empirical relations between different parameters derived from different techniques, such as empirical relation between SPT N values measured during drilling bore holes and in situ shear wave velocity obtained from geophysical investigations have been carried out and also discussed in this Chapter-6.

Site soil classification is one of the key issues for the prognosis of earthquake hazard parameters, because the concept and methods of site classification were put forward in the Code for seismic design of buildings in several countries and the parameters of design response spectrum have been determined by considering site classification. Site classification methods are based on geologic genesis and characteristics such as the descriptions of soil characteristics, overburden thickness of soil layer and average shear wave velocity. The present study of site characterization is based on Shear wave velocity. In the Chapter- 7, different techniques adopted for the evaluation of shear wave velocity, interpretation of data and finally classification of sites has been discussed.

Study of response of soil is the important component of Seismic Microzonation. There is variety of methods, available for estimation of site response and need to be carefully chosen according to the requirement of study, time frame, and merits of the techniques. The objective of present study of Seismic Hazard Microzonation on 1: 10,000 scale is to evaluate (i) Peak frequency of soil column above bedrock (ii) Peak Amplification Factor/ratio of soil column above bedrock (iii) Peak Ground Acceleration (PGA) at surface for different periods of exceedance and damping (iv) Amplification factor of soil column (v)Spectral acceleration at different periods (vi)Site specific response spectra and therefore a combination of experimental and numerical techniques have been adopted. Evaluation of Peak frequency and corresponding Peak amplification using both experimental and numerical techniques has been discussed in Chapter-8. In Chapter-9, ground response study based on numerical techniques, and making use of geotechnical geophysical data collected at 449 sites, evaluation of different input parameters for the analysis such as strong ground motion time histories simulation, evaluation of engineering bedrock and results of seismic hazard parameters such as PGA at surface, Peak Amplification, Peak frequency, site specific response spectra have been discussed.

Earthquake induced hazard, particularly liquefaction and land slide are also of concern for structural safety. Owing to the type of soil, flood plain of river Yamuna in north of Delhi, its migration leaving soft sediments, paleochannels and abandoned channels, liquefaction study become very important component of Seismic Microzonation of NCT Delhi. There are several methods based on empirical relation and experimental techniques based on laboratory investigation of soil. A simplified procedure based on the use of empirical correlations with standard penetration tests (SPT) is used for liquefaction susceptibility of Delhi. Detailed Methodology adopted for liquefaction study, data used and results obtained have been presented in Chapter 10.

In Seismic Hazard Microzonation based on different attributes, seismic hazard maps of different themes have been generated. In order to understand the combined effect of different themes, maps of different themes have been integrated using GIS software by giving suitable weightage to the attributes and rank to different themes and integrated map has been developed. The detailed process of integration and results are presented in Chapter-11.

In Seismic Hazard Assessment both epistemic uncertainty and aleatory uncertainty are inevitable which are reduced to the possible extent using different techniques and model. In response study several parameters are to be evaluated, simulated. In order to assess the level of accuracy available with data sets and results, assessment of sensitivity is necessary for a parameter to make the results sufficiently useful and valid. In chapter 12 sensitivity in all parameters associated uncertainty have been discussed.

Assessment of seismic hazard is an analytical methodology that estimates the likelihood that various levels of earthquake caused ground motions will be exceeded at a given location in a given future time period. Despite extensive advances in seismic knowledge, there are still major gaps in our understanding of different mechanism and the processes , that govern how an earthquake's energy propagates from its origin beneath the earth to various points near and far on the surface. These gaps in understanding mean that, there are inevitably significant uncertainties in the numerical results. Further, for the assessment of ground motion at surface which is influenced by the physical properties of the soil layers due to site effect, several field and laboratory investigations for ascertaining soil parameters are to be carried out. Based on these soil properties different input parameters, models are to be developed and used for site response study. Therefore possible uncertainties in investigations and model parameters used are to be assessed and validated. In the Chapter-12 ranges of uncertainties in different input parameters, models, intermediate and final products of Seismic Hazard Microzonation and validation of different model and results have been discussed for better judgment.

In order to easy applicability of results in building codes and to make them useful for retrofitting and land use planning, implications and adoption of different parameters derived from the study of Seismic Hazard Microzonation of NCT Delhi, for designing building codes and land use planning for NCT Delhi have been discussed, in terms of present building code in Chapter 13.

In Chapter-14, Seismic Hazard Parameters evaluated for a few individual important structures based on study have been presented to assess their present seismic strength and if required to make use of parameters for retrofitting. Summery and conclusions along with monitoring and review process adopted during the implementation of projects are discussed in Chapter-15.

The Committee hopes that the products of the study namely design response spectra generated for the various blocks of 9 districts of Delhi, will be made use of by the structural design professionals for planning and designing earthquake safe buildings and other life line and important structures, as well as the architects and town planners will use the microzonation maps in planning of future settlements and avoiding liquefiable areas.

(Prof. A.S.Arya)
Member, Bihar State Disaster Management Authority and
Chairman, Advisory and Monitoring Committee

Preface

NCT Delhi is located in seismically vulnerable domain and lying in Seismic zone IV of the macro seismic zoning map of the country. Seismic Microzonation for New Delhi Capital Region was in focus for long time. Department of Science Technology (DST), the then administrative Ministry for earthquake related matter (Now Ministry of Earth Sciences) initiated Seismic Microzonation study in 1992 by constituting an Expert Group under the Chairmanship of Prof. N.C.Nigam for Seismic Microzonation of Delhi vide office order no. DST/23(32) ESS/91, dated 17th December 1992. The deliberation of this group leads to the recommendations of carrying out multi-institutional studies to achieve this goal.

In 1998 the Department of Science Technology once again constituted a small group under the Chairmanship of Prof. A.S.Arya, which gave comprehensive proposal for achieving of Microzonation in three stages covering an area of about 50 km X 50 km of NCT Delhi (the then master plan of Delhi). This group also identified the organizations, which would provide inputs for preparation of microzonation maps of Delhi area.

In 2001 keeping in view of the above background, an expert group was constituted by the Department of Science and Technology under the Chairmanship of Dr. H. K. Gupta, the then Secretary, Department of Ocean Development (DoD), New Delhi to work out the details regarding microzonation study for Delhi area. The expert group, after detailed discussion in two meetings, recommended a multi-disciplinary and multi institutional approach for carrying out microzonation of Delhi region. The expert group also recommended approach which involves four main components of implementation relating to (i) Identification of Seismogenic Sources (ii) Evaluation of ground motion characteristics (iii) Estimation of ground motion modifications and (v) Estimation of Secondary effects of ground motion such as Liquefaction Potential. Resource Organizations had also been identified.

Accordingly, in June 2003, vide OM No. DST/23(401)/SU/2003 dated 10th June 2003 a working group under the Chairmanship of Prof. D.K.Paul, IIT Roorkee, consisting of members from India Meteorological Department (IMD), New Delhi; Geological Survey of India (GSI); Indian Institute of Technology(IIT), Delhi, Indian Institute of Technology (IIT) Roorkee, Central Ground Water Board, New (CGWB) Delhi,Central Building Research Institute, Roorkee; Wadia Institute of Himalayan Geology (WIHG), Dehradun, Central Road Research Institute (CRRI), New Delhi and University of Delhi was constituted. The group started working on different identified component of Seismic microzonation of Delhi. DST had also sanctioned projects to CRRI, Delhi to collate geotechnical data available with different construction agencies, IIT Delhi to develop infrastructure for evaluation of Shear wave velocity using MASW, WIHG to develop infrastructure for site response study. IIT Roorkee also started working on source Characterization and IMD initiated site response study through their available resources.

On setting up of Earthquake Risk Evaluation Center (EREC), a multi-disciplinary Division in India Meteorological Department (IMD) in February 2004 and with placement of core group of a multi-disciplinary scientists, in the fourth Meeting of Working Group held in December 2004, EREC was entrusted with the task of (a) Data collation (b) Data generation (c) Analysis and interpretation (d) Integration of data and (e) Preparation of seismic microzonation map of National Capital Territory (NCT, Area 1482 Sq Km). It was decided that all data generated by different projects sanctioned for Seismic Microzonation of Delhi shall be provided to EREC. Accordingly Earthquake Risk Evaluation Centre (EREC), in India Meteorological Department initiated Seismic Microzonation of NCT and collated the data, generated new inputs, integrated multi-thematic data and evolved Seismic Hazard Microzonation Map of NCT, Delhi in collaboration with expert institutions of the working group and generated the 1st level Seismic Microzonation Map of NCT, Delhi on 1:50,000 scale.

The results of Seismic Microzonation of NCT Delhi were made public by the then Hon'ble Minister of Science and Technology, Shri Kapil Sibal, through a press conference held on 23rd Dec 2005. This study was of qualitative assessment of hazard. On completion of Seismic Microzonation Study on 1:50,000 scale, EREC, (which is now merged with the newly created Centre of Seismology), had initiated Seismic Hazard Microzonation study of NCT Delhi with objectives to provide seismic microzonation products to meet all the requirements envisages from the point of view of earthquake hazard mitigation such as, formulation of site specific building codes for earthquake resistant construction, assessment of hazard to the existing structures for taking up retrofitting and land use planning.

To initiate Seismic Hazard Microzonation of Delhi on 1:10000 scale, project specific toposheets were generated by Survey of India (SoI), representing NCT Delhi in 75 toposheets. Geological map on 1:50000 scale was upgraded on 1:10000 scale in collaboration with Geological Survey of India (GSI), making use of innovative techniques and using old aerial photographs of 1960's and high resolution satellite imageries of recent origin. An intensive programme of geotechnical and geophysical investigations at more than 500 sites spread over NCT Delhi was taken up. Based on Probabilistic Seismic Hazard Analysis and subsequent ground response analysis to understand response of soil, several thematic and product maps have been developed. On integration of these maps, an integrated hazard index map has been developed; classifying NCT Delhi in Low, Moderate and High hazard Zones.

The Seismic Hazard Microzonation project was being monitored by an Advisory and Monitoring Committee constituted by Ministry of Earth Sciences, under the Chairmanship of Prof. A.S.Arya, former, National Seismic Advisor, and presently Hon'ble Member Bihar State Disaster Management Authority (BSDMA), with experts of varied disciplines as members. The report which consists of 15 chapters, tables depicting site specific parameters and maps has also undergone to rigorous review by the scientists and engineers from different disciplines. Seismic Hazard Microzonation products have also been discussed in different meetings and specially organized workshops.

(A.K.Shukla)
Scientist'F" & Head
Center of Seismology

Acknowledgement

To initiate the study project specific toposhets (Base map) were generated by Survey of India (SoI). Subsequently, geological map in collaboration with EREC were generated by Geological Survey of India (GSI) by deputing a dedicated team. The services of both these departments are acknowledged. Geotechnical field investigations were to strictly supervised to assure quality data generation. A special training course in geotechnical/geophysical field and laboratory practices was arranged by CSMRS is also acknowledged. Central Ground Water Board (CGWB), Delhi Development Authority (DDA), Central Public Work Department (CPWD) and Metro Road Corporation have provided geotechnical data and are acknowledged.

Sincere gratitude to Dr. H.K.Gupta, Hon'ble Member National Disaster Management Authority of India for his guidance in formulating methodology of Seismic Hazard Microzonation in Indian context while experimenting Seismic Microzonation of Jabalpur, which is the foundation of the present study.

Sincere gratitude to the then Secretary, Department of Science and Technology (DST), Prof. V.S. Ramamurthy, for showing confidence and entrusting this task of national importance to the center and his constant inspiration and support. Thanks to the former Chairman of the Standing Advisory Committee of EREC, Prof. V.K.Gaur and other members of the committee for their guidance and support to initiate this highly technical scientific study.

Sincere gratitude to the Secretary MoES, Dr. Shailesh Nayak, for his constant inspiration and guidance during the course of the study. Sincere gratitude also to him for his visionary approach of dealing such highly technical project and constituting an Advisory and Monitoring Committee of highest caliber, under the Chairmanship of Prof A.S Arya, former Seismic Advisor to the Ministry of Home Affair, Government of India and presently Hon'ble Member BSDMA, and members of repute such as Prof. D.K.Paul, IIT Roorkee; Prof. Sitharam, I.I.Sc. Bangalore; Prof. S.K.Nath, IIT Khargpur; Dr. Prabhas Pandey, former ADG, GSI; Dr. B.K.Bansal, Advisor, MoES; Shri A.K.Bhatnagar, former ADGM, EREC, which has facilitated coupling of their vast experience with the Center and made possible to complete the project of national importance.

Sincere gratitude to Dr. S.K.Srivastav, AVM (Dr.) Ajit Tyagi, former Director Generals of Meteorology, for their guidance and support. Thanks to Dr. L.S.Rathore, present DG, IMD who has always been inspiring source to the scientists of the Center and extended all possible support to complete the study.

Thanks to all officers and staff of the Center of Seismology who have been associated with huge amount of seismology, geotechnical, and geophysical data generation.

(A.K.Shukla)
Scientist 'F' &
Head Center of Seismology

Advisory and Monitoring Committee for Seismic Microzonation NCT Delhi, on 1:10000 scale

1.	Prof. A.S.Arya, Former Seismic Advisor Govt. of India; presently Member of Bihar Disaster Management Authority	Chairman
2.	Prof. D.K.Paul, Indian Institute of Roorkee,	Member
3.	Prof. T.G.Sitharam, Indian Institute of Science, Bangaluru	Member
4.	Prof. S.K.Nath, Indian Institute of Technology, Khargpur	Member
5.	Dr. B.K.Bansal, Advisor & Head Geosciences Ministry of Earth Sciences Government of India	Member
6.	Dr. Prabhas Pandey, Former, ADG Geological Survey of India,	Member
7.	Shri A.K.Bhatnagar Former ADG & Head, Earthquake Risk evaluation Center India Meteorological department	Member
8.	Representative of Central Ground Water Board (CGWB)	Member
9.	Representative of Survey of India	Member
10.	Dr. A.K.Shukla, Head, Earthquake Risk evaluation Center India Meteorological Department	Member/Secretary

Permanent Invitee

Prof. M.L.Sharma, IIT, Roorkee
Prof. C.S.Dubey, University of Delhi
Shri R.K.Singh, Director, EREC
Dr. H.S.Mandal, Meteorologist, EREC
Dr. A.P.Pandey, Meteorologist, EREC
Dr. H.S.Sisodia, Scientific Assistant, EREC

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3. Dr. H.S.Mandal, Meteorologist Gr.I
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Geological Survey of India

Central Ground Water Board

CHAPTER-1

INTRODUCTION

Seismicity driven by tectonic processes of continent-continent collision between Indian & Eurasian plates along Himalayas, subduction of Indian plate underneath Burma plate in the east and intra-cratonic or intra-plate activity in peninsular domain renders Indian subcontinent vulnerable to Earthquake Hazard. In India earthquakes have taken a toll of more than 100,000 lives in the last 100 years. Among the recent earthquakes in India, Latur, Maharashtra in 1993 killed 10,000 people, Jabalpur, Madhya Pradesh in 1997 killed 39 people and 8267 houses collapsed, Bhuj, Gujrat of January 26, 2001 claimed 13,805 lives and caused damage to 12, 05,198 houses.

The entire Himalayan belt is considered prone to Great earthquakes of magnitude exceeding 8.0. Recent scientific research points to the likehood of occurrence of a very severe earthquake in the Himalayan region, which could adversely affect the lives of several million people in India. Fear of the earthquake, in sensitive domains, has become part of the social psyche-causing impediment to development.As per Seismic Zoning Map of India (BIS IS 1893, Part 1:2002) about 30% of the territory of India falls in Zones IV and V, which has high probability of earthquakes causing damages of intensity of the order of VIII and IX and above.

National Capital Territory (NCT) of Delhi occupies an area of 1482 sq km spreading between Lat $28^{0}24^{'}01^{''}$ & $28^{0}53^{'}00^{''}$N and Long $76^{0}50^{'}24^{''}$ & $77^{0}20^{'}37^{''}$E (Toposheet53 D/14 & 53H/1,2,3,6, and 7)lies in Seismic Zone IV of the Seismic Zoning Map of India (BIS IS 1893, Part 1:2002). Geographically, the region is located on folded crustal ramp represented by basement rocks of DelhiSuper Group, bounded by two regional faults viz Mahendragarh-Dehradun Sub Surface Fault (MDSSF) in the west and Great Boundary Fault (GBF) in the East Delhi.The ramp trending NNE-SSW across the 'fore deep' is juxtaposed to Himalayan thrust belt. Another important structural element of the belt is NW-SE trending Delhi-Sargodha Ridge (DSR) which passes through Delhi and is flanked by basins on either side, viz Sahaspur Basin in the north and Bikaner Basin in south west.

Delhi and its environs have been affected by earthquakes from far field seismic sources in the Himalaya, such as Uttarakashi earthquake (*ML* = 6.4, 20 October 1991) and Chamoli earthquake (*ML* = 6.8, 29 March 1999, I; VIII). In addition to this, Delhi region has also been affected by earthquakes of the peninsular [Historical earthquake of Delhi (M: 6.5, 1720); Mathura earthquake (M: 6.8, 1803); Bulandshahar earthquake (M: 6.7, 1956); and Faridabad earthquake (M:6.0, 1960)]. Thus, the seismic vulnerability of built environment of Delhi need be examined *vis-a-vis* high frequency ground motions due to events endemic to faults of Peninsular Domain and also due to frequency content of attenuated events with source zone in thrust domain of the Himalayas. Fault lines of consequence in the domain are (i) Mahendragarh Fault, (ii) Great Boundary Fault, (iii) MoradabadFault, and (iv) Sohna Fault.Thus the potential seismic hazard in the area is attributed to both Himalayan thrust system and activation of fault systems of DFB.

The Structurally controlled Quartzite Ridges of Delhi have originally provided seed to growth of "Seven Cities" in the past (Historical map of Delhi, Figure1.1).However, subsequently the agglomerations have grown out and encroached on the alluvial flood plains of Yamuna River characterized by dynamically shifting thalweg-leaving palaeochannels with Holocene sediment fills. Signatures of the river migration are evident even in the last century from the topographic maps. A major part of the new sectors of the city in the North and East have developed on pediments and alluvial plain encroaching on flood plains of low return period. The western part of the city, excepting for rocky land of Anand Parbat, is mostly on Aeolian sediments characterized by conspicuous internal drainage.

The present state of Delhi (National Capital Territory) with its 9 districts (Map-1), which has 9 disticts, occupies an area of 1482 sq km. As per the 2001-based Census, the population of Delhi was 138.50 Lakhs. It was projected that the population would touch to 180 Lakhs by 2011 and 234 Lakhs by 2021. As per primary census abstract 2011, the population of Delhi is 167.87 lakh. The projection was nearly correct and with the average growth rate since the census of 1881, the population would touch to 203.47 lakh by 2021(Figure 1.2). Population density distribution in Delhi is presented inMap-2.

The geoscientific constitution of the area provides a highly variable domain with a complex scenario having scope of rapid changes in seismic accentuations. This complexity is further aggravated by long history of evolution of Delhi as a mega polis and its further growth with new emerging centers of suburban agglomeration under the new concept of National Capital Region (NCR). Thus the complex interplay of seismotectonics, lithological assemblage in terms of soft sediment accentuation, and co-existence of structures of medieval period as well as the most modern skyscrapers and well-laid modern residential buildings set unique conditions, which need closer evaluation for Seismic Hazard.

Figure 1.1: Historical Map of Delhi

In this context 'Seismic Hazard Microzonation' (SHM) which is a process of classifying the given geographic domain into small units of likely uniform Hazard (H) level (Peak Ground Acceleration/Spectral Acceleration), hazard nature (susceptibility to liquefaction and slope failure), by estimating response of soil layers under earthquake excitations and thus the variation of earthquake ground motion characteristics on the ground surface, and provides hazard parameters such as (i) frequency dependent accelerations at each site at bedrock level on future seismic shaking, (ii) site amplification due to soft sediment present at the site, (iii) probable manifestation of earthquake hazard in terms of induced ground fissuring, land deformation-landslide & liquefactionis one of the important tools for disaster mitigation planning, as it can minimize disaster impacts of an earthquake.

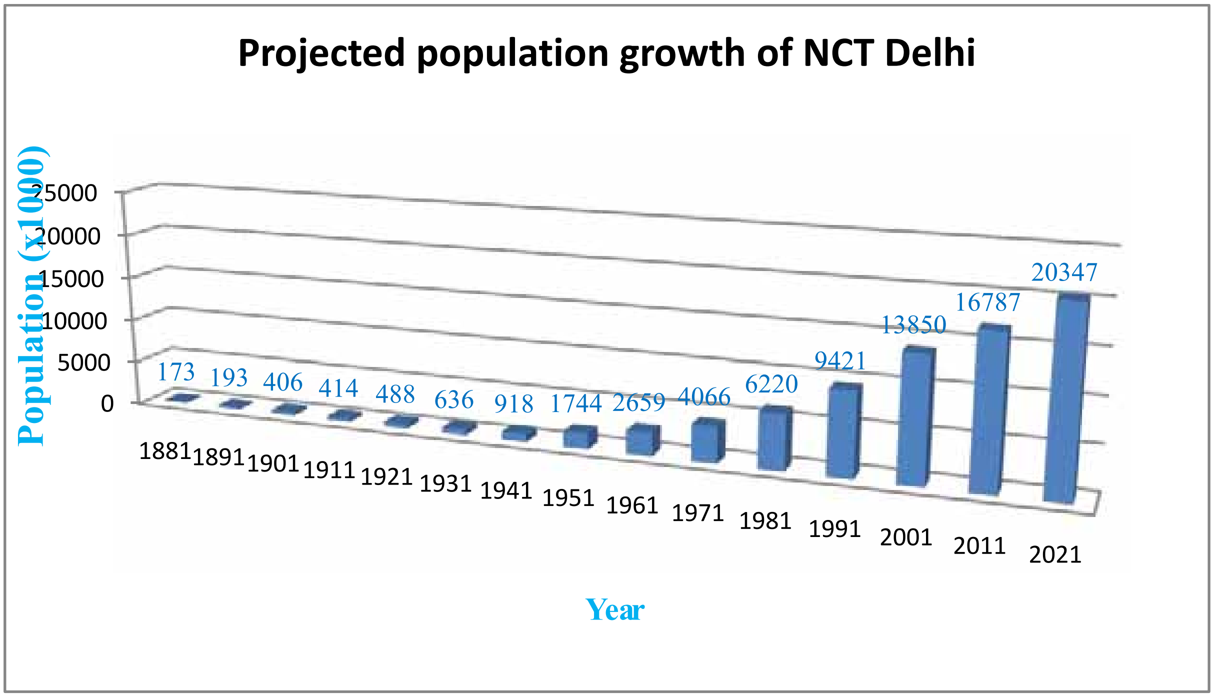


Figure1.2: Projected Population growth in NCT Delhi

In view of the cultural and administrative importance of the city, seismic-tectonic vulnerability of the domain and wide variations in ground conditions with reference to "Seismic Rigidity", Seismic Hazard Microzonation of Delhi was of great concern. The Department of Science Technology (DST), the then administrative ministry controlling the earthquake related matter, constituted an expert group under the Chairmanship of Dr. H.K.Gupta, the then Secretary, Department of Ocean Development (DoD),New Delhi to work out the details regarding microzonation study for Delhi area. The expert group, after detailed discussion in two meetings recommended a multi-disciplinary and multi institutional approach for carrying out microzonation of Delhi region. The expert group also recommended an approach which involved four main components of implementation relating to (i) Identification of Seismogenic Sources (ii) Evaluation of ground motion characteristics (iii) Estimation of ground motion modifications and (iv) Estimation of Secondary effects of ground motion such as Liquefaction Potential. Resource Organizations had also been identified.

First Level Seismic Hazard Microzonation Map of the National Capital Territory of Delhi occupies an area of 1482 sq km spreading between Lat $28^{0}24' 01''$ N& $28^{0}53' 00''$ N and Long $76^{0}50' 24''$ E & $77^{0}20' 37''$ E (Toposheets 53 D /14 & 53H /1, 2, 3, 6 , and 7) wasgenerated on 1:50,000 scale by Earthquake Risk Evaluation Center (EREC) of India Meteorological Department (IMD), Ministry of Earth Sciences(Map-3). In this study Scientists from several expert institutions, such as Geological Survey of India (GSI), Central Road Research Institute (CRRI), Indian Institute of Technology Roorkee, Survey of India and Central Ground Water Board (CGWB) made their contributions. Central Road Research Institute (CRRI) collected 441 geotechnical reports from Delhi Development Authority (DDA), Central Public Works Department (CPWD), and Delhi Metro Road Corporation (DMRC). EREC also collected 50 more reports from DDA. IIT Delhi procured Engineering Seismograms and evaluated shear wave velocity using MASW techniques at different sites.The then Hon'ble MoS, Department of Science and Technology released the same through a press conference held on 23rd Dec 2005. The Products of this study were assessed to be useful for qualitative assessment of the seismic hazard of NCT Delhi.

To make the microzonation exercise more meaningful for societal use, with specific objectives of actual applications in land use planning and designing of area specific building codes for NCT Delhi, Earthquake Risk Evaluation Center, India Meteorological Department, Ministry of Earth Sciences initiated the process of upgradation of this study on 1:10000 scale. To initiate the study project specific base map on 1:10000 scale has been generated by the Survey of India, presenting NCT Delhi in 75 toposhets. The GSI, in association with EREC, carried out fresh geological mapping of Delhi on 1: 10,000, thus refining the available 1: 50,000 geological map of the region. An intensive programme of geotechnical, geophysical and seismological data generation has been taken up at about 500 sites in NCT Delhi. An Advisory and Monitoring Committee constituted by the Ministry of Earth Sciences, under the chairmanship of Prof. A.S. Arya, Former National Seismic Advisor and presently Member of the Bihar State Disaster Management Authority and members from reputed institutions of the country has supervisedthe study. Office Memorandum is annexed as Annexure-1.

CHAPTER-2

GEOLOGY, TECTONICS, SEISMICITY AND HYDROLOGY OF THE AREA

Delhi and its environs are located in the northernmost continuity of Aravalli Ranges (Figure 2.1a).Dynamic fluvial morphology and geodynamic activity imparted to extension of Aravalli Ranges as juxtaposed to the Himalayan domain and its unique location in the Seismotectonic Map of India attracted attention of several researchers(Dasgupta et al., 2000 and references therein). Delhi and adjoining areas are set in seismotectonically vulnerable domain, where the geological structurs are juxtaposed to geodynamically active domain of the Himalaya with records of historical and recent earthquakes. Wyss (2005) has emphasized its vulnerability vis-à-vis impending seismic hazard of the Himalayan domain. In addition to vulnerability with respect to Himalayan seismicity, studies on seismicity (Tandon and Chatterjee 1968; Kamble and Chaudhury, 1979; Verma et al., 1995 and Bhattacharya et al., 2001) show that Delhi and its neighborhood have also been seismically active in the past.

2.1: REVIEW OF GEOLOGY OF THE REGION

Physiographically, Delhi and its adjoining areas are surrounded in the north and east bythe Indo-Gangetic Plains, in the west by the extension of the Great IndianThar desert and in the south by the Aravalli ranges (Figure2.1b). The terrain is generally flat, except for a low NNE–SSW trending Delhi ridge in the central portion of the region, which forms the central part of the National Capital Region (NCR) Delhi.

The rock formations exposed in the Delhi area are mainly quartzite of the Alwar series of the Delhi Supergroup that are interbeded withthinmicaceous schist bands. Srivatava et al. (1980) grouped these rocks of Delhi area as the Alwar formation of Delhi Super group while, Kachroo, and Bagchi (1999) have classified them as Barkhol formation of the Ajabgarh Group of the Delhi Supergroup. Proterozoic rocks occur along the ridge, extending from Harchandpur (Haryana) in the south to Wazirabad in the north (Delhi). Quaternary sediments directly overlie the Proterozoic rocks. The geological succession of these rocks reviewed by Kachroo and Bagchi (1999) is given in Table 2.1.

Srivastava et al. (1974) and Kachroo and Bagchi (1999) have carried out systematic geological and geomorphological mapping of the Delhi area and identified three distinct surfaces. The highest is the erosional surface forming the top of denudational hills. The second surface is Older Alluvial plain and the third is depositional Younger Alluvial plain (Yamuna). The geomorphologic features have undergone changes due to widespread and uncontrolled urban activity. Kachroo and Bagchi (1999) have further, classified Delhi region into five geomorphic units: Mehrauli-Masudpur- Wazirabad ridge, Badarpur-Okhala hillock, Older Alluvial Plain, Yamuna Older Flood Plain, and Yamuna active channels. The geological map of Delhi after Kachroo and Bagchi (1999) is shown in Figure 2.1b.

The rocks of Delhi system have undergone multiple folding and different phases of metamorphism with time (Naha et al., 1984 and 1987 and Roy, 1988). Three generations of folding have been found in the rocks of Delhi (Gangopadhyay and Sen, 1968). The fold axes of first generation fold follows the trend of main ridge i.e.NNE-SSW, the second generation fold trending NE-SW are observed at Tuglakabad-Mehraulli area, and third fold generation trending NW-SE at Anand Parbat. The rocks are highly jointed and two sets of conjugate vertical to sub-vertical joints have been reported (Kachroo and Bagchi, 1999). These are NNE-SSW and WNW-ESE joints conforming to the older and newer structural trends. Srivastava et al. (1980) have inferred a number of faults trending NNE-SSW, NE-SW and WNW-ESE.

Table 2.1: Stratigraphic succession of rocks in Delhi area (modified after Kachroo and Bagchi, 1999).

Holocene	Yamuna Channel alluvium	Grey, fine to medium sand, grit with coarse sand, silt and clay	Point bars, channel deposits
	Yamuna Older Flood Plain & Terraces	Grey sand, coarse grit, pebble beds and minor clays	Palaeochannels, abandoned channels, meander scrolls, ox-bow lakes.
	Older Alluvium	Sequence of sand-silt-clay with yellowish brown medium sand with silt, kankar with brown aeolian sand	Abandoned channels, meander scrolls
Unconformity			
Neoproterozoic	Post Delhi Intrusives	Pegmatitic, tourmaline-quartz veins and quartz veins	
Mesoproterozoic	Delhi Supergroup	Alwar Group	Quartzite with minor schist, tuff and ash beds

The river Yamuna passes through the eastern part of the Delhi area. The river has oscillated laterally along a N-S axis. At the initial stages, it migrated steadily to the east and subsequently in the last phase to the west and got contained there because of the depression caused by a N-S trending faults (Thussu, 2001). The right palaeobank of the

Yamuna River is in the north of Delhi around Narela, and from there it turns almost east-west at Wazirabad and follows the boundary of the ridge to further south (Thussu, 2001). There are a large number of paleochannels and abandoned channels of river Yamuna north of Delhi. A map showing migration of Yamuna River around Delhi during 1807 - 1985 has been generated on the basis of historical toposheets/maps of different periods available in the Archeological Survey of India (Figure2.2).

2.2: REVIEW OF MAJOR TECTONIC FEATURES OF DELHI AND ENVIRON

The northeastern part is occupied by the Himalayan tectonic belt as described above whereas; the southern part is occupied by the Proterozoic Delhi fold belt and gneissic-batholithic complex. In the area near Delhi and southward, outcrops of highly jointed and folded Alwar quartzites are observed. Two tectonic sub-provinces viz. Delhi-Moradabad province and Kasganj-Ujhani province are recognised which are separated from each other along the trace of Moradabad fault zone. In Kasganj-Ujhani province (Srivastava and Somayajulu, 1966) the Vindhyan sequence overlies the Aravalli folded basement whereas, the Neogene directly overlies the Delhi basement in Delhi-Moradabad province. The Moradabad fault zone forming the boundary between these two tectonic provinces has been found to have general trend along NE-SW direction. This tectonic feature is traceable on to the shield area as a tectonic boundary between the Delhi Foldbelt and the Vindhyans.

A north-northeastward ridge like extension of the Delhi fold belt towards the Himalayas has been postulated and called as the Delhi-Hardwar ridge. This ridge has controlled the western limit of Ganga basin and the underlying sedimentary sequence seems to have thinning effect towards this ridge. The exposed Proterozoic Delhi Foldbelt and the Frontal Fold zone of the Himalaya form the southwestern and northern limits of Delhi-Moradabad tectonic province, respectively.

The Delhi-Haridwar ridge forms the western margin of the Ganga basin. The eastern margin of the Ganga basin is limited by Monghyr-Saharsa ridge of Satpura metamorphic, whereas, the basin is abutted against Siwalik foothills in the north, which is separated from higher Himalayas by a thrust. The Bundelkhand granites/gneisses of

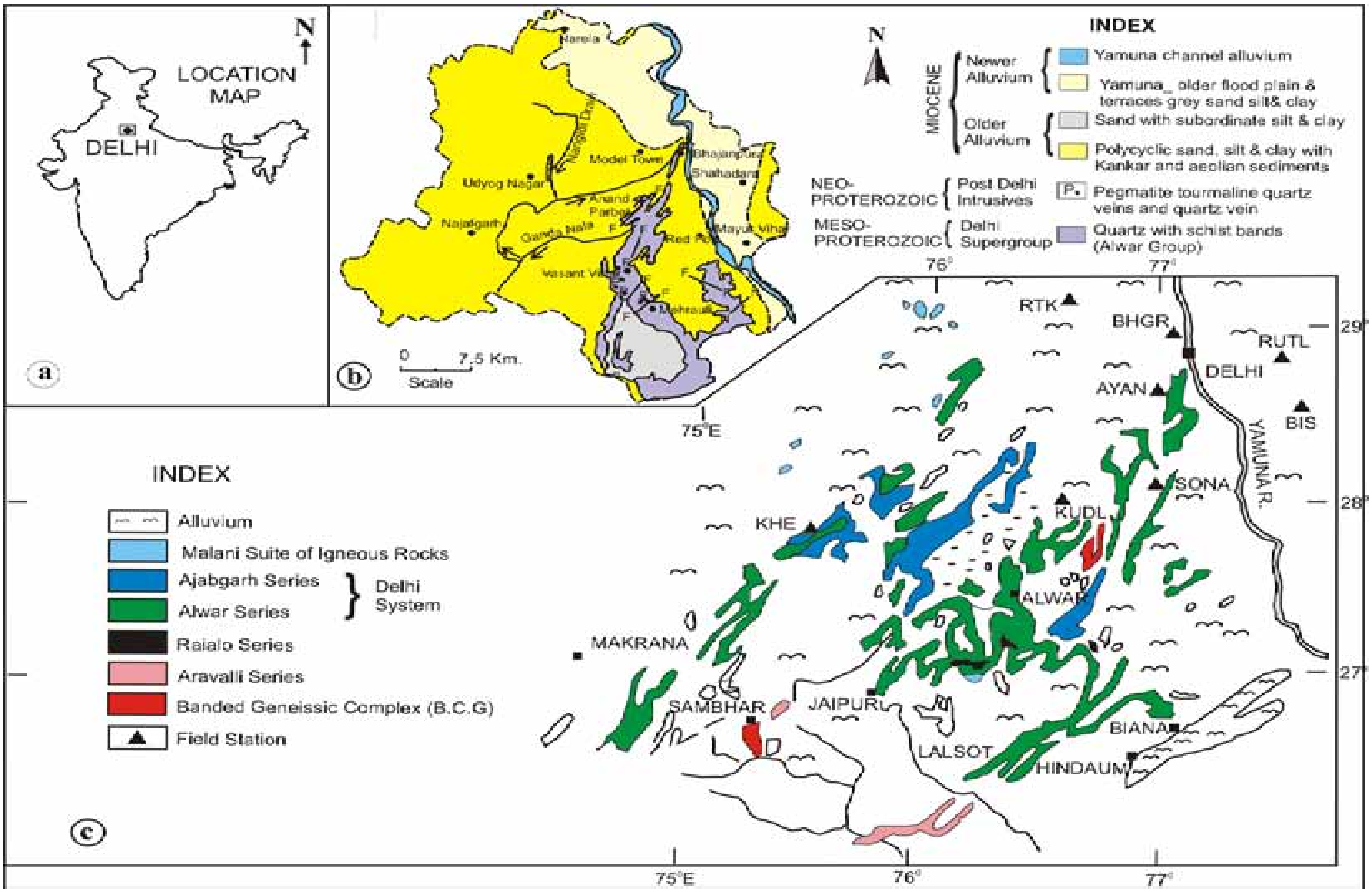


Figure2.1: Geological map of Delhi and adjoining areas where (a) shows location map of the study area, (b) Geological map of Delhi (modified after Kachroo and Bagchi, 1999) and (c) Geological map of the area, North Eastern Aravalli (modified after Heron, 1917).

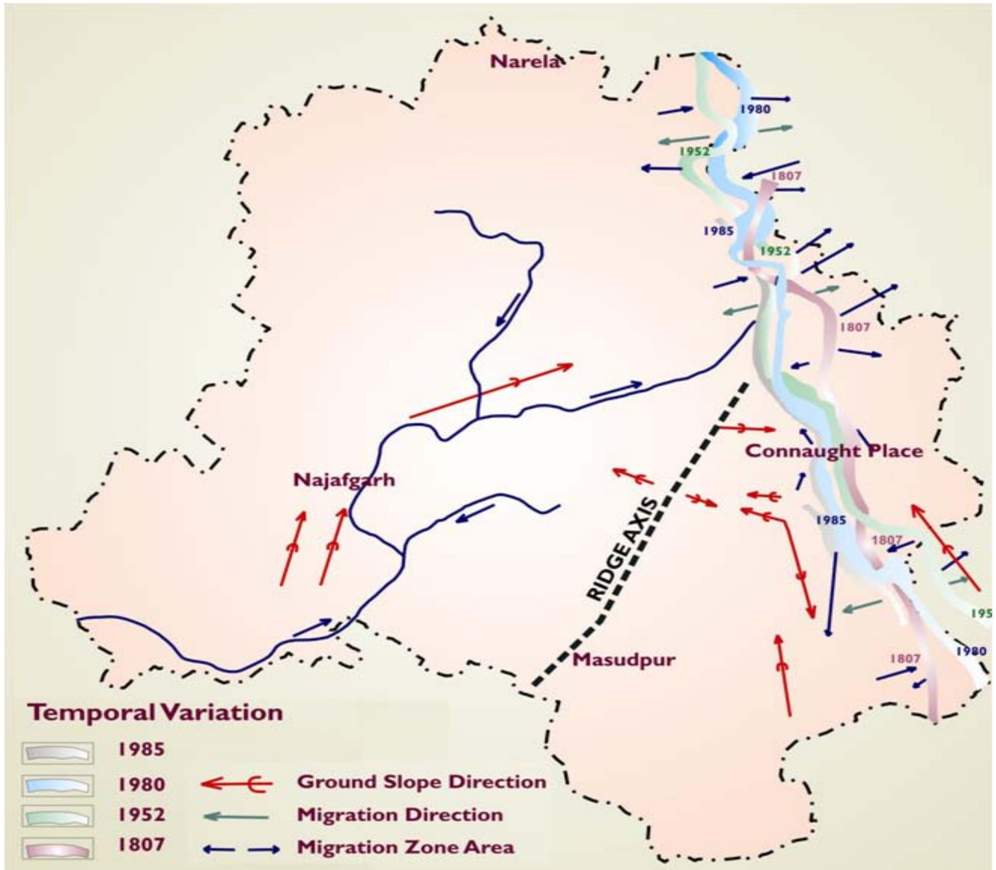


Figure 2.2 Showing migration of Yamuna River around Delhi during 1807 - 1985, generated on the basis of historical toposheets/maps of different periods available in archives of Archeological Survey of India.

Precambrian Aravalli and Satpura crystallines and Purana sediments of Vindhyan group are exposed along the southern fringes. The tectonic history of the Ganga basin adjacentto the Indian peninsular shield is different and the sediments show subsidence. It is generally believed that the subsidence of this belt isinterlinked with the Himalayan orogeny. It seems that the basement of the Ganga basin is adjusting its stress and strains of orogenic phenomena continuously (Sastri et al., 1971).

One of the most conspicuous faults in the southeast of Delhi is the Rajasthan Great Boundary Fault. Surface trace of this fault is delineated as a well-defined lineament (Chittaurgarh-Machilpur Lineament) because of the presence of contrasting geomorphic units on either side. The Great Boundary Fault along with its subsidiaries exhibits imprints of repeated reactivation at different stages of the evolutionary history of this belt. The Mahendragarh-Dehradunsubsurface fault (MDSSF) extends northeasterly up to the Himalayan foothills. North of the Great Boundary Fault (GBF), Bouguer gravity anomaly contours display a general pattern in accordance with the main tectonic grain. However, in the southeastern part they take an easterly swing.

On the basis of satellite image (remote sensing) studies it has been seen that some of major geomorphological features viz., Lahore - Delhi ridge, Delhi axis of folding, Delhi Haridwar ridge and the Himalayan Frontal Fold zone are clearly displayed following the regional trends (Srivastava and Roy, 1982). Criss-cross lineaments near Delhi (Hukku, 1966; Mehta et al., 1970 and Gupta and Sharda, 1996)show the complexity of the region probably due to conjoining of the above mentioned geological features. A fault running in N-S direction from Sohna to the west of Delhi has been mapped by the Geological Survey of India and named as Sohna fault along which a hot spring occurs at Sohna.

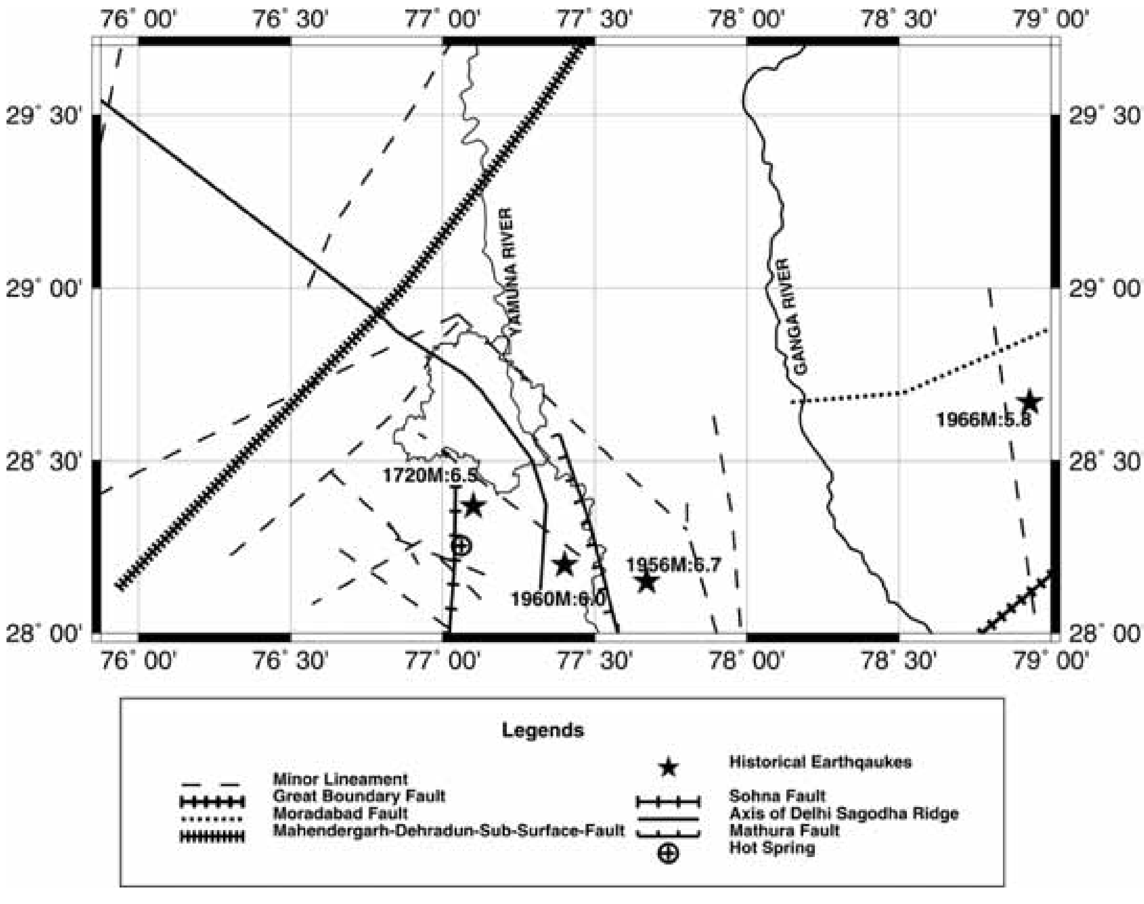


Figure2.3: Seismotectonic map around Delhi (modified after Dasgupta et al., 2000).

The geotechnical mapping, geophysical survey, and remote sensing studies have indicated presence of many lineaments around Delhi (Figure2.3). The seismotectonics in and around Delhi is shown in Figure2.3. Based on these studies, the main tectonic element of DFB having been defined in unanimity are (i) MDSSF, (ii) GBF, (iii)

Moradabad Fault, (iv) DSR and some highlighted importance of (v) Sohna Fault and (vi) Mathura Fault. The Sohna fault is associated geothermal activity. It is important to note that the MDSSF and DSR are the structures offering area source at the intersection of the two with diffused seismicity whereas other offer line sources.

2.3: REVIEW OF SEISMICITY OF DELHI REGION

In the ancient literature, Varaha Mihira, who lived in 5th-6th century, has mentioned Northern India, including Delhi and its surroundings as the felt region of severe earthquakes (Iyengar, 1999). The earthquake of 15th July 1720near Sohna has been described by Oldham (1883), in which walls of the fortress and many houses in Delhi were destroyed. It was followed by 4 to 5 aftershocks per day for 40 days and occasional shocks for 4 to 5 months. The likely magnitude for this earthquake, based on macroseismic data has been assigned by IMD as 6.5. An earthquake of inferred magnitude of 7.0 is stated to have occurred in Mathura region in 1803 (Oldham, 1883). Iyengar (2000) and Tandon (1953) mentioned damage to Qutub Minar during the 1803 earthquake in Delhi. This earthquake was felt in very large area and was responsible for damage to buildings in which 23 persons were killed in Bulandshahar and some were injured in Delhi. An earthquake known as Gurgaon earthquake, on 27th August 1960, of magnitude 6.0 near Sohna about 60 km of SE of Delhi was reported (Srivastava and Somayajula, 1966). The earthquake was felt at Kanpur and Jaipur. Minor property damages and injuries to about 50 persons were reported from Delhi. On 28 July 1994, an event of magnitude M_L= 4 caused minor damage to the minarets of Jamma Masjid (Iyengar and Ghosh, 2004). On28th February 2001 and 28th April 2001, Delhi experienced two small earthquakes of magnitude 4.0 and 3.8, respectively of local origin. Far distance Himalayan earthquake namely Uttarkashi (19th Oct., 1991, 6.4Mb) shoock Delhi to the extent of intensities V. The felt intensity of the recent Chamoli earthquake(28th March, 1999) was VI at Delhi (IMD, 2000) and maximum intensity noted in a narrow epicentral tract, in Alknanda valley was VIII (GSI Report 2000).

The history of past earthquakes experienced in and around Delhi shows that it is situated ina region liable to moderate damage by earthquakes. Some of the historical & significant past earthquakes near Delhi are given in Table 2.2 and on map in figure 2.4.Delhi and its environs have also been damaged by earthquakes from far field seismic sources in the Himalaya [Chamoli earthquake (M: 6.8, 1999)].

Instrumental studies of seismicity around Delhi region could be made possible only after setting up of Delhi Ridge Observatory on 01.12.1960, (with Benioff (SP) and Spregnether Press-Ewing (LP) seismometers) under World Wide Seismic Standard Network (WWSSN). In addition, two-component Wood Anderson seismograph was also installed to determine the magnitude of the local earthquakes. To monitor tremor activity that occurred during the period 1963-64; mobile seismic observatories were set up by

IMD at Rohtak, Sonepat, and Sohna. A Broadband seismograph, with CMG 40T, broadband sensor and 72A 07 (Reftek Make) 24-bit data acquisition system was installed at Delhi ridge observatory in December, 1999.

Table 2.2: Historical & significant past earthquakes in Delhiand around Delhi

Sl.No	Date	Epicenter		M	Region
		°N	°E		
1	15-07-1720	28.37	77.10	6.5	Delhi
2	01-09-1803	27.50	77.70	6.8	Mathura
3	16-01-1842	27.00	78.00	5.5	Near Mathura
4	10-10-1956	28.15	77.67	6.7	Near Bulandshahar
5	27-08-1960	28.20	77.40	6.0	Near Faridabad
6	15-08-1966	28.67	78.93	5.8	Near Moradabad

With the above mentioned setup of monitoring system, swarm activity was recorded in Sonipat area during 1963-65 in northwestern part of Delhi ambiance. The spatial distribution of seismicity based on these data showed seismic activity concentration at three different regions, namely west of Delhi, near Sonipat and close to Rohtak indicating extension and trends of faults buried under thick alluvium deposits. Seismic activity around Delhi is shown in Figure 2.5 for the period 1966-1974, in Figure 2.6 for the period 1975-1987 and in Figure 2.7 for the period 1988-2000.

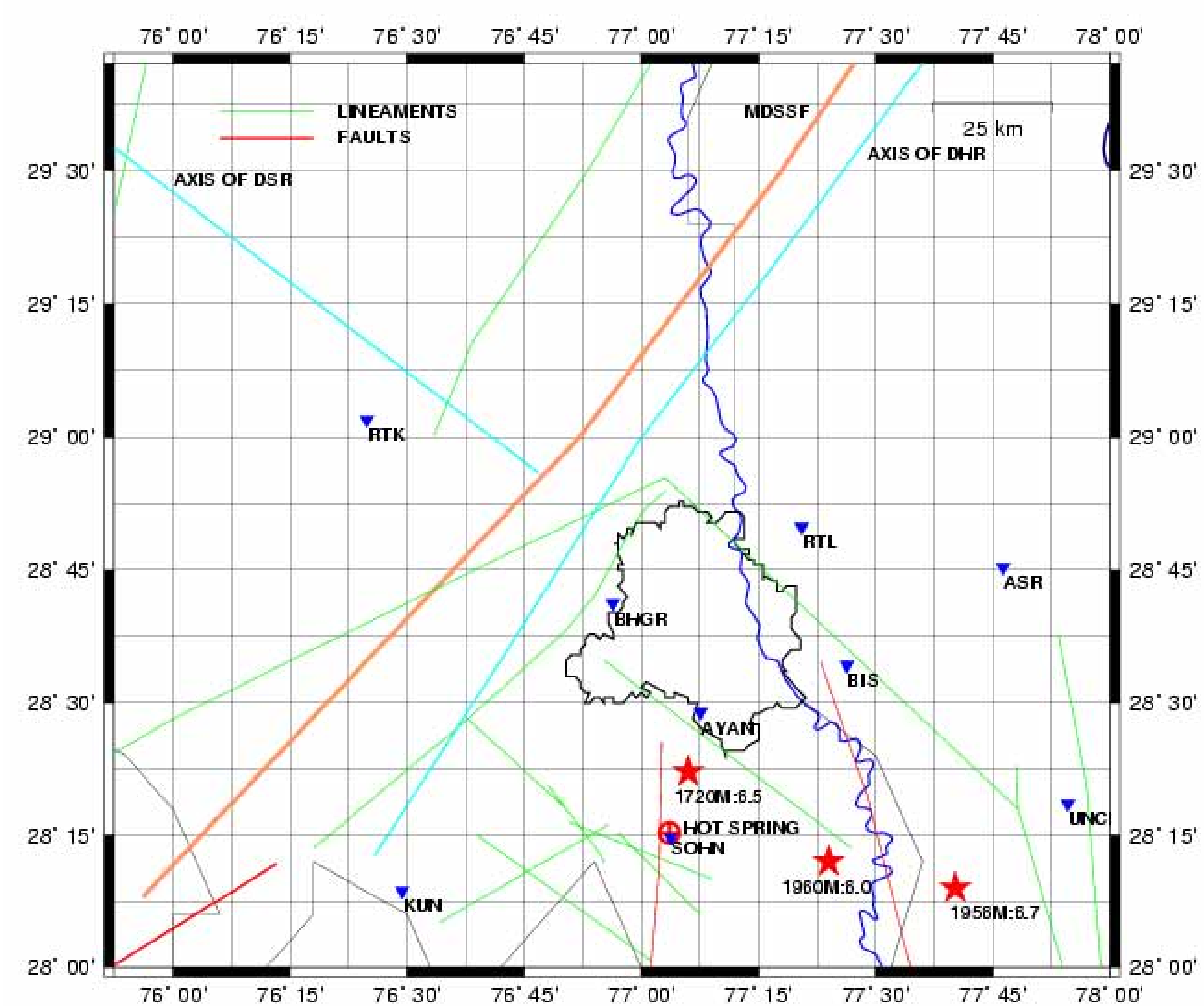


Figure 2.4: Locations of historical& significant past earthquakes near Delhi alongwith nearby seismological observatories.

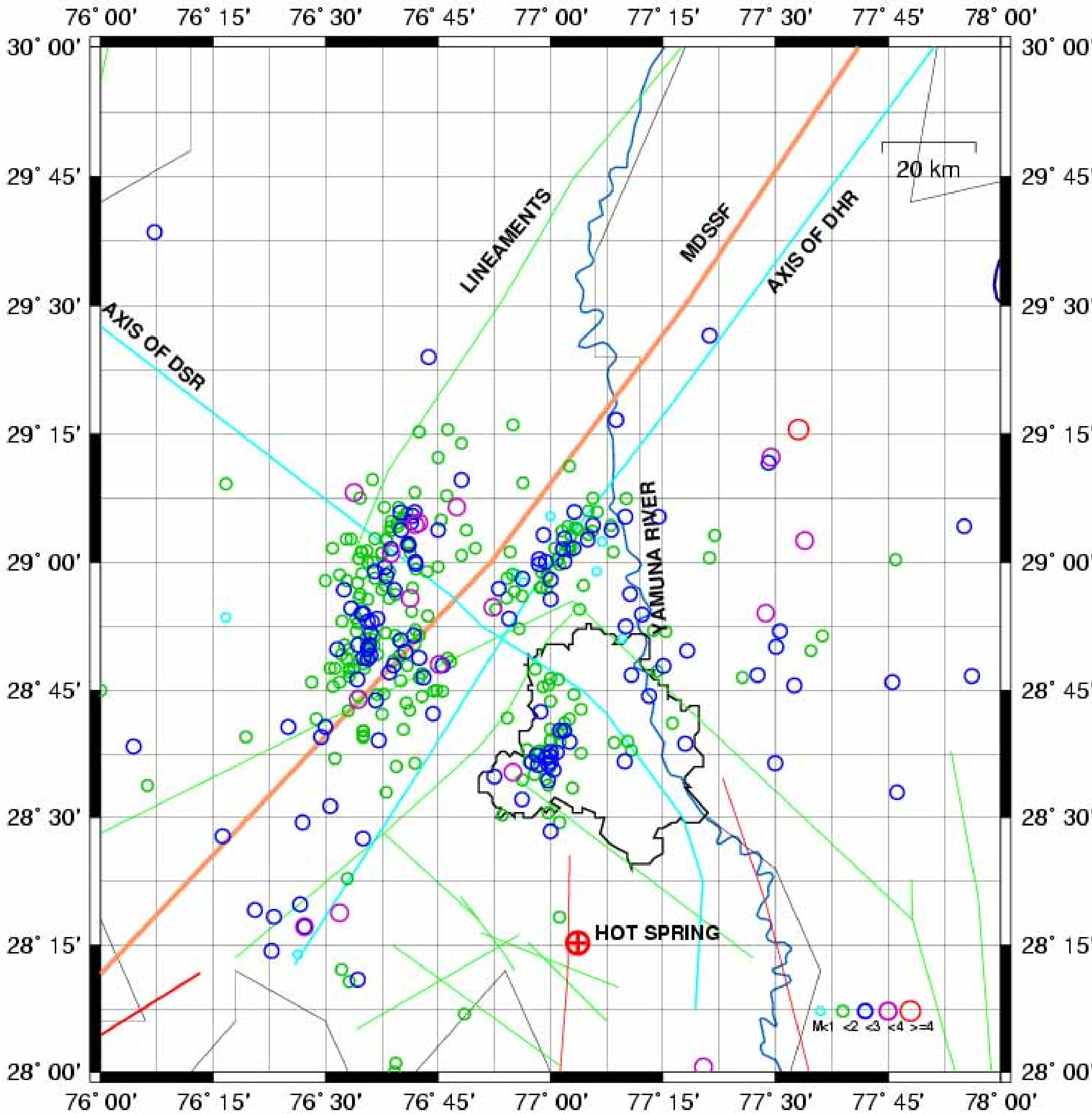


Figure2.5: Locations of Earthquakes Recorded by IMD Network aroundDelhi during 1966-1974

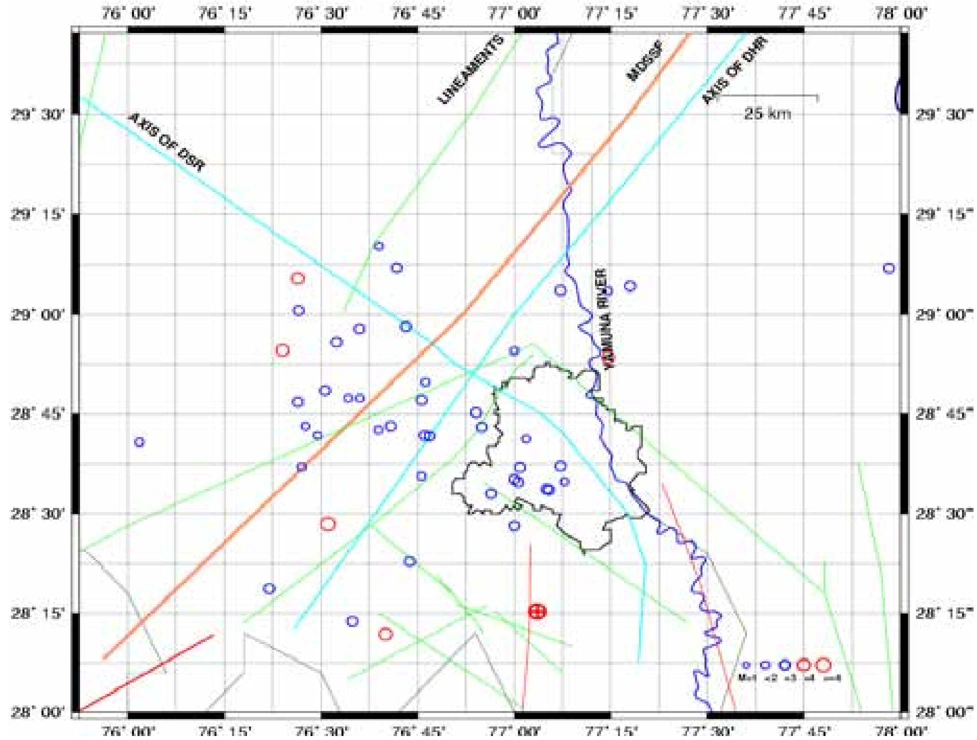


Figure 2.6: Locations of Earthquakes Recorded by IMD Network around Delhi during 1975-1987

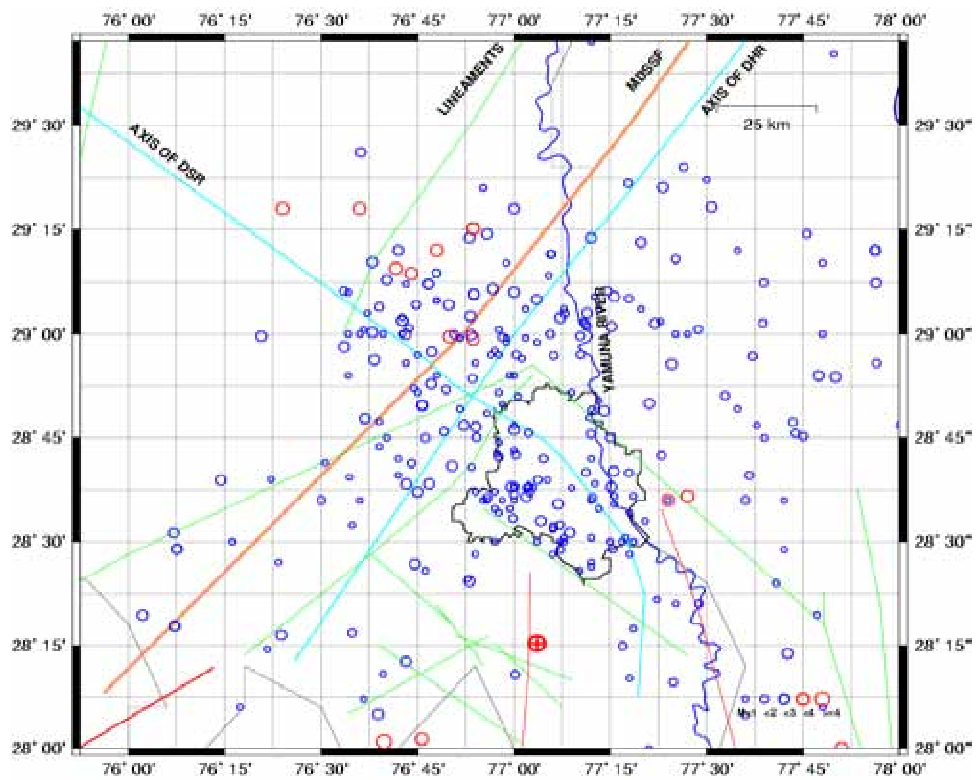


Figure2.7: Locations of Earthquakes Recorded by IMD Networkaround Delhi during 1988-2000.

2.3.1: Recent Seismicity around Delhi and Spatial Distribution

For close and continuous monitoring of seismicity in and around the Capital region, a Digital Delhi telemetered network with VSAT communication facility has been established during 1998-2000(Shukla et al., 2001,2002). This network consists of 16 field seismic observatories with VSAT communication link and Central Receiving Station (CRS) at IMD HQ at New Delhi. Out of these sixteen field stations, five are within 50 Km radius from CRS Delhi, four are in between 50 and 80 Km radius, another four are in 80 to 200 Km radius, and other three are in the range of more than 200 Km. Each field observatory is equipped with short period S-13 seismometer. Observatories at Agra, Sohna, Khetri, and Kalagarh are equipped with three component seismometers while remaining observatories are having vertical seismometer. A location map of field stations is shown in Figure 2.8.

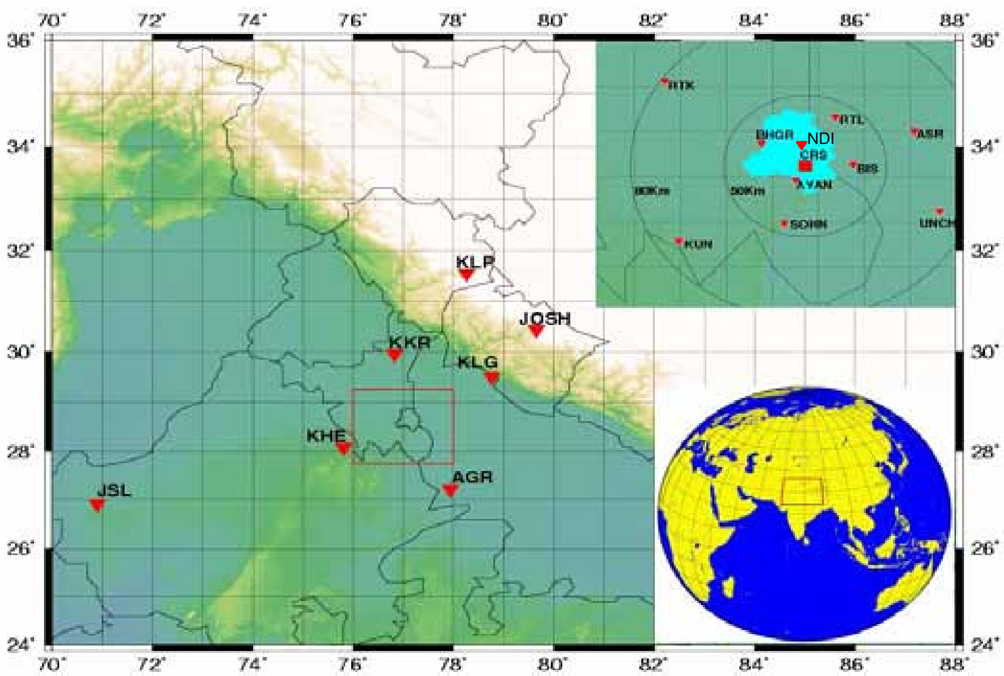


Figure 2.8: VSAT seismic telemetry network in and around Delhi. Locations of field Observatories of Delhi Telemetry Network[0-50 KM: Ayanagar (AYN), Bahadurgarh (BHGR), Bisrakh (BIS),Rataul(RTK), Sohna (SOHN); 50 - 80 KM: Kundal (KUN), Unchagaon(UNCH), Asaura(ASR), Rohtak (RTK); 80-200KM: Kurukshetra (KKR), Kalagarh (KLG), Khetri (KHE), Agara (AGR); > 200 KM: Joshimath(JOSH), Jaisalmer (JSL), Kalpa(KLP)]

Epicenter map of earthquake recorded by Seismic telemetry network during 2001-2004, which have also been considered for Hazard analysis, is shown in Figure 2.9. During the period 2001 -2004, 288 earthquake events have been located by Seismic Telemetry Network of IMD in and around Delhi. Of these, more than 90% events are of magnitude less than 3.0 with shallow focal depth ($\leq$15 km).

A total of 74 events with maximum magnitude of M_L: 3.8 (28th Apr' 2001) were recorded within the politicalboundary of NCT Delhi.The analysis of spatial distribution of seismic events (2001-2004) brings about a pattern which conforms to structural attributes of DFB. During the period of observations about 50% of events are lying proximal to trace of MDSSF, whereas about 74 % events show clustering in NW-SE direction coincident with DSR. Focal Mechanism solution of earthquake greater than three during the period 2001-2004 is also shown in Figure 2.10 (Shukla et at., 2007). The subsurface strike slip fault of MDSSF provides a major discontinuity zone for nucleation of seismicity. Another clustering along DSR reveals presence of a belt parallel to the Himalayan fold system.This belt is of significance with regards to seismic hazard as it traverses across NCT Delhi. Forthe 28 April 2001 (*Mw* 3.4) and 18 March 2004(*Mw* 2.6) Delhi earthquakes, Bansal *et al.(2009),* generatedfocal mechanism solutions based on the first motionand waveform modelling. Based on these solutions theauthors suggested that these earthquakes involvednormal faulting with a large strike–slip component.

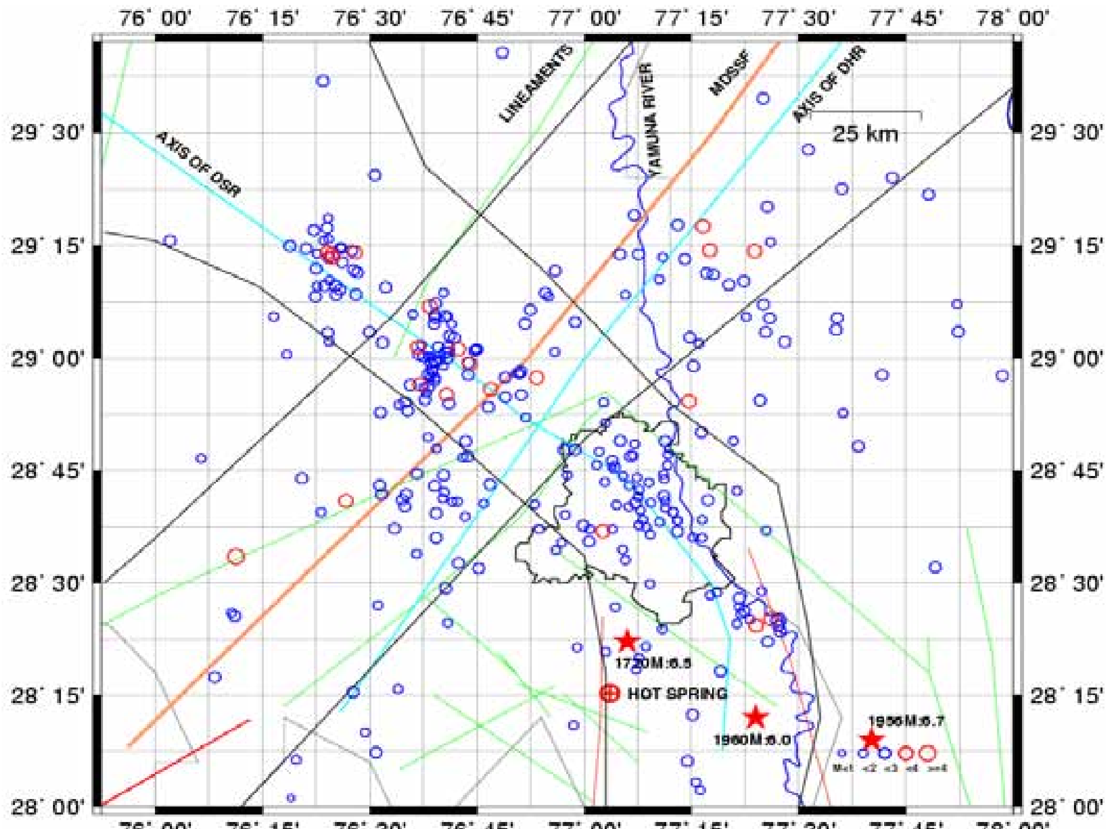
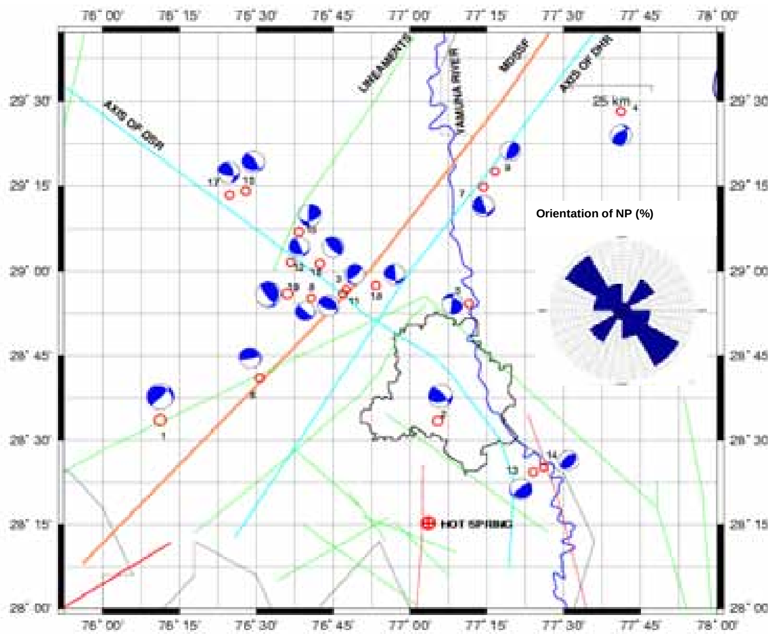


Figure 2.9: Epicenter map of earthquakes recorded by Seismic telemetry network during 2001-2004



Events	Date yy mm dd	M_L
1	2001 02 28	4.2
2	2001 04 28	3.8
3	2001 05 17	3.2
4	2001 07 07	3.3
5	2001 08 10	3.2
6	2001 09 12	3.4
7	2001 10 20	3.3
8	2002 05 10	3.0
9	2002 05 13	3.1
10	2002 06 19	3.5
11	2002 12 15	3.2
12	2003 04 02	3.1
13	2003 04 09	3.4
14	2003 06 16	3.1
15	2003 08 28	3.5
16	2003 09 13	3.4
17	2003 12 22	3.4
18	2004 03 17	3.2
19	2004 07 27	3.9

Figure 2.10: Focal Mechanism Solutions for the earthquakes of magnitude >3.0 recorded by Delhi Telemetry Network (after Shukla et al. 2007)

During 19th Dec'2003 to 31st Jan'2004 a swarm type activity around Jind was again observed and monitored by establishing a local network of six stations by IMD supplementing the Delhi Telemetry network. The swarm is characterized by 152 tremors, out of which 62 events range in magnitude between 0.5 and 3.4. On an average 5 to 6 events were recorded daily with maximum number of 18 tremors on 23rd Dec 2003 and 2nd Jan 2004. The low magnitude swarm has moment release of the order of 6.7×10^{21} Nm. The swarm events show a clustering in 2x8 km area confined to two pockets of urban area of Jind apparently coincident with NW-SE trend of DSR (IMD report 2004, Suresh et al. 2005).

Epicenter map of earthquakes recorded by Seismic telemetry network of IMD during 2005-April 2012, is shown in figure 2.11. During the period 2005 – April 2012, 422 earthquake events have been located in and around Delhi. Of these, more than 90% events are of magnitude less than 3.0, with shallow focal depth (≤15 km).The M 4.2 (7May 2006), M4.6 (25 November 2007) and M 5.1(5 March 2012) earthquakes are some of the events felt in and around Delhi.

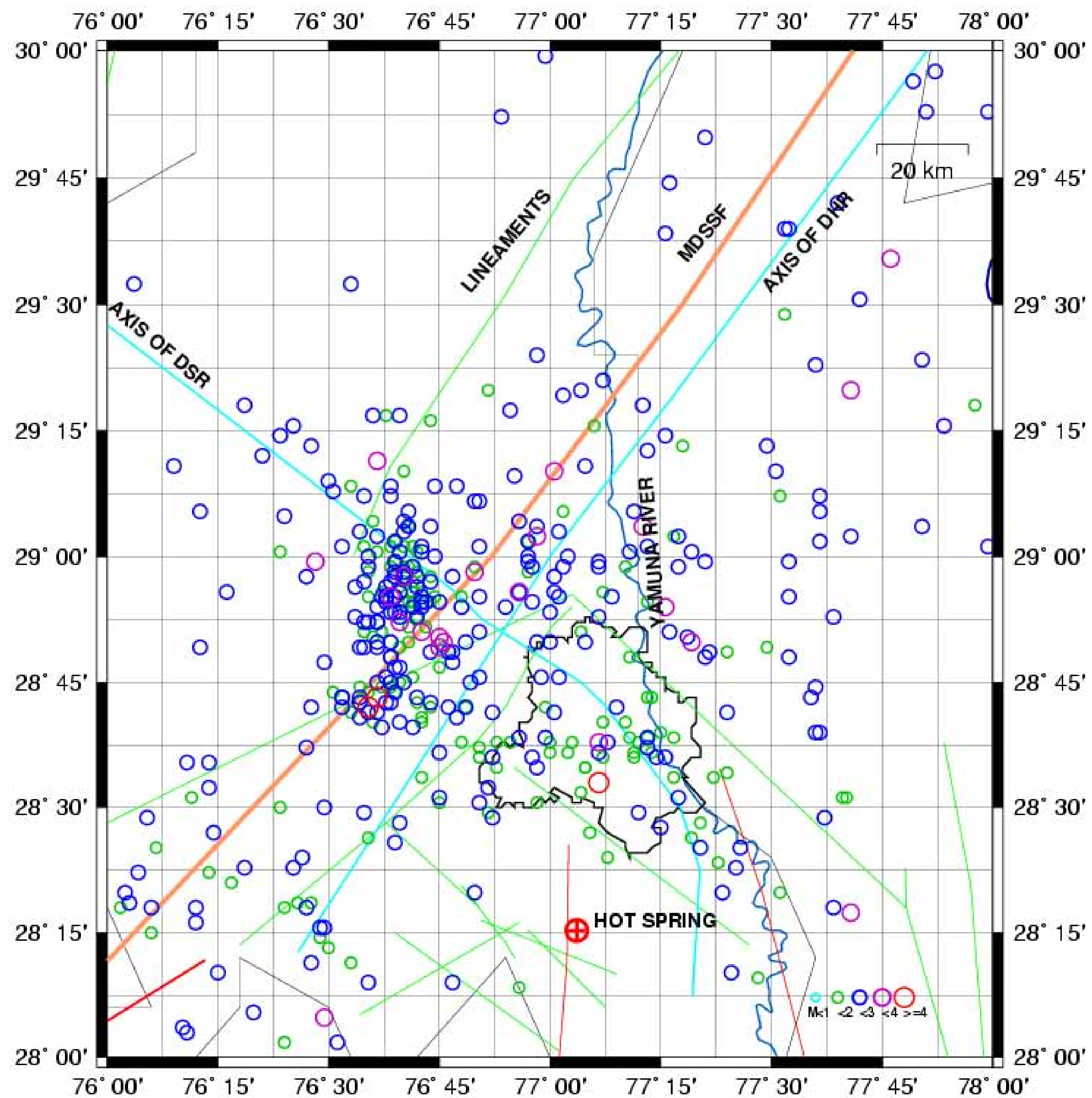


Figure 2.11: Epicenter map of earthquakes recorded by Seismic Telemetry Network during 2005 - April 2012.

The well constrained focal mechanism of the earthquake of 25 November 2007 (*Mw* 4.1 subsiquently revised to M 4.6) computed by Singh *et al.(2010)*, shows strike–slip faulting with some normal component. Immediately on occurrence of this earthquake an intensity survey was conducted by IMD and the isoseismal map of 25 November 2007, Delhi earthquake was developed using geo-statistical analysis tool with local polynomial interpolation method. The isoseismal map shows that most parts of Delhi region experienced an intensity of V on MMI scale. The maximum intensity V was estimated for a length of about 80 km along elongated track in WNW-ESE direction with mean isoseismal radii of about 29.13km. The orientation of elongated epicentral track of intensity field shows that the stress release was pronounced along Delhi-Sargodha ridge and earthquake was attributed to activities of this ridge (Prakash et al. 2011). The earthquake of 5 March 2012, with epicenter at Delhi-Haryana border was felt widely in Haryana, Delhi and neighboring states. Intensity on the MMI scale equivalent of VI was experienced in the epicentral region close to the Delhi–Haryana border. The epicenter of the earthquake falls near the surface expression of the Mahendragarh–Dehradun Fault (MDF), located to the northwest of Delhi. Peak ground acceleration recorded in the Delhi region varied from a minimum of 2.50 cm/s^2 to a maximum of 39.4 cm/s^2 on the transverse component at the Ridge Observatory and Jaffarpur stations respectively, located about 60 and 34 km away from the epicenter (Bansal and Mithila, 2012).

2.4: REVIEW OF HYDROLOGY OF NATIONAL CAPITAL TERRITORY DELHI

The ground water availability in the territory is controlled by the hydrogeological situation characterized by occurrence of different geological formations namely Delhi (Quartzite) Ridge, Older & Younger Alluvium. The NCT Delhi can be divided into following distinct hydrogeological units: Newer Alluvium - Yamuna flood plain deposits, Older Alluvium - Eastern and western sides of the ridge, Older Alluvium - Isolated andnearly closed Chattarpur alluvial basin and Quartzitic Formation - NNE-SSW trending Quartzitic Ridge. The various sources of water for the purpose of recharge are rainfall, surplus water in Yamuna River during the monsoons or floodwater and treated wastewater from treatment plants. The normal annual rainfall of NCT Delhi is 611.8mm. About 81% of the annual rainfall is received during the monsoon months July, August, and September. The rest of the annual rainfall is received in the form of winter rain. Central Ground Water Board (CGWB), a subordinate office of the Ministry of Water Resources, Government of India, is the National Apex Agency entrusted with the responsibilities of providing scientific inputs for management, exploration, monitoring, assessment, augmentation, and regulation of ground water resources of the country. Monitoring of ground water levels is one of the major activities of the CGWB, through a network of ground water observation wells comprising both large diameter open wells and purpose-built bore/tube wells (piezometers). To monitor ground water level indifferent part of NCT, CGWB has setup 162 ground water monitoring systems, which includes 25 large diameter open wells (DW) and 137 purpose-built bore/tube wells (piezometers) PZ.The ground water monitoring stations are spread over both Alluvial as well as Delhi ridge area. Nearly 60 stations fall in Delhi ridge area whereas 109 stations fall in alluvial area including Yamuna Flood Plain.District wise distribution of hydrograph network stations is highly uneven and varies from one monitoring station per 1.4 Sq. Km in New Delhi district to one monitoring station per 30 Sq. Km in North East district. Figure 2.12 shows location map of National Hydrographic Monitoring Stations in National Capital Territory, Delhi (CGWB, Year Book 2010-2011).Ground water levels are being measured four times a year during January, April/ May, August and November. On the basis of data generated from this network, CGWB generate different reports and maps.Depth to water table maps usually presented for Delhi State on appropriate scale bringing out suitable depth ranges say; 0-2 m, 2-5 m, 5-10 m, 10-20 m, 20-40 m, 40-60 m &>60 m. The depth ranges are categorized considering prevailing water levels, depth zone of water logging, depth zone of prone to water logging centrifugal pumping depths etc.

2.4.1: District wise hydrological situation in NCT Delhi

District wise hydrological situation in NCT and average water table in NCT Delhi is detailed as follows

2.4.1.1Central District

Central district of NCT Delhi is located in hard rock terrain of Delhi quartzite at one end while alluvium is underlain by Delhi quartzite at another end. Nearly 25 Sq. Km area covered in the district which is extending east to west, where eastern part is just terminating along Yamuna Flood Plain. The depth to water level varies from 2 m to 7 m.

2.4.1.2: North District

North District of NCT Delhi just lying all along Yamuna River covering 60 Sq.Km areas. Its 40% area is under Yamuna Flood Plain. The Southern part of the District have a thin veneer of alluvium cover over quartzitic rock which is an extention of Delhi Ridge (Strike-SSW to NNE), near Wazirabad Barrage. Some of the exploratory wells Drilled by CGWB falling in this area are Delhi University, Dhirpur, and Jagatpur.

2.4.1.3: East District

East district of Delhi is located in the East of Yamuna River and extends up to the borders of Gaziabad and Noida ares of Uttar Pradesh. Covering a total area of 64 Sq. Km. Virtually, East district of NCT Delhi is a domain lying in between two rivers i.e. Yamuna in the West to Hindon in the East (6 Km eastward from the Delhi border).The depth to water level in this district varies from 5 to 8 mbgl.

2.4.1.4: New Delhi District

New Delhi district is located centrally in the state occupying an area of 35 Sq. Km. with varied surface altitude due to Delhi Ridge. Nearly 10 sq. Km. area falls within ridge area having a height of 225 to 255 m Above Mean Sea Level (AMSL). The surface is sloping gradually towards east up to the Yamuna river course where altitude is 210 m AMSL. In the western part of New Delhi district covering area of Rashtrapati Bhavan, Chanakyapuri, Shantipath, South and North Avenue and Connaught Place. Ground water in the area occurs both under water table as well as under semi-confined conditions in the alluvium. The depth to water level in the district ranges from 5 to 25 m below ground level. The depth to water level varies widely depending upon the topographic elevation; it varies from 5 to 8 m in Yamuna flood plain and increases to 10 to 25 m towards the Delhi ridge.

Figure 2.1 2: Location m ap of N ational H ydrographic M onitoring S tations i nNational Capital Territory, Delhi (CGWB, Year Book 2010-2011).

2.4.1.5: North-East District

North-East district is located east of Yamuna River and bordering to Gaziabad district in the east and Merrut district in the north of Uttar Pradesh. It covers 60 Sq.Km of area. Virtually, North-East district of NCT Delhi is a domain lying in between two rivers i.e. Yamuna in the west to Hindon in the east (6 Km eastward from the Delhi border). The depth to water level in this district is 5 to 8 mbgl.

2.4.1.6: North-West District

The North-West district of NCT Delhi covers 440 Sq. km. area characterized by unconsolidated quaternary alluvium deposits. In large part of the district the water levels are shallow ranging from 2 to 8m bgl, whereas in a limited area towards the northern border (Narela) the water levels are somewhat deeper ranging from 6 to 12 mbgl.

2.4.1.7 South District

The South district of NCT Delhi covers 250 Sq. Km. of area of which 45.2 Sq. Km area shows mountainous undulating terrain exposed with Delhi quartzite. The district is also characterized by a saucer shaped vast alluvium field in the central part of the district popularly known as Chattarpur Basin.

The depth to water level varies widely in this district and is ranging from 8 m to 65 m. In the eastern tract of the district where Yamuna Flood Plain occur, depth to water level varies from 8 m to 22 mbgl but in rest of the area it ranges from 30 to 65 mbgl.

2.4.1.8 South-West District

The South-West district of NCT Delhi covers 420 Sq. km. Majority of the area characterized by unconsolidated quaternary alluvium deposits and about 18 Sq. Km area is covered by denudation hills especially in the eastern part of the district. In major part of the district the depth to water level ranges from 5 to 28 mbglwhere as in rocky area which are lying in the eastern part of the district (Central Delhi Ridge) the depth to water level is in the range of 22 m to 50 m.

2.4.1.9 West District:

West district is occupied by unconsolidated Quaternary alluvium underlain by Precambrian meta-sediments of Delhi System. Quaternary alluvium comprises of sand, clay, silt, gravels/pebbles, and kankars. The depth of water level varies in the district, 2 m to 15 m.

CHAPTER-3

A HOLISTIC MODEL OF SEISMIC HAZARD MICROZONATION

On the basis of methodology of Microzonation, aholistic model evolved for microzonation in Indian context while experimenting microzonation of Jabalpur and Seismic Hazard Microzonation of NCT Delhi on 1:50000 scale has been adopted for the present study of microzonation of Delhion 1:10000 scale (Figure3.1).A simple flow sheet is shown in figure 3.2.To achieve the objective of Microzonation defined above, the model has three work components viz. 'Source characterization', 'Ground characterization', 'Site response studies- experimental and numerical modeling'**.** These three study components finally define hazard level and its nature at surface. The Microzonation endeavor proceeds in three levels with hierarchy of input components, precision level, and scale of presentation. This model has been discussed by the expert groups in the meetings of Jabalpurand Delhi microzonation and presented in severalfora (Shukla 2006, 2007 , 2011).The model is also in agreement with the process of seismic microzonation studies adopted by different groups for Seismic microzonation of Guwahati (2007), Bangalore (2008), developed guidelines for seismic microzonation and also in agreement with international practices.

As enumerated above the seismic microzonation involves handling of large data sets generated at sources of varied specializations with different semantics and complex coding. The problem is further rendered complex as the expectations are widely different for specialists and common end user. In this regard, integration of data in GIS base and evolving Seismic Hazard and Risk Information System (SHIS) for urban agglomerations is emphasized.

In the present study, the programmes of "Source Characterization", "Ground Characterization" and Site response study have been designed keeping in view the issues enumerated above.Multi-thematic maps pertaining to 'Geoscientific', 'Geotechnical' and 'Site-Response' characterizations have been generated. Liquefaction study has also been carried out and map at different depths below ground surface have been generated. These thematic maps have been integrated assigning different ranking of significance. Following this hierarchical integration in a GIS base, seismic microzonation map of NCT Delhi on 1:10,000 scale has been evolved.

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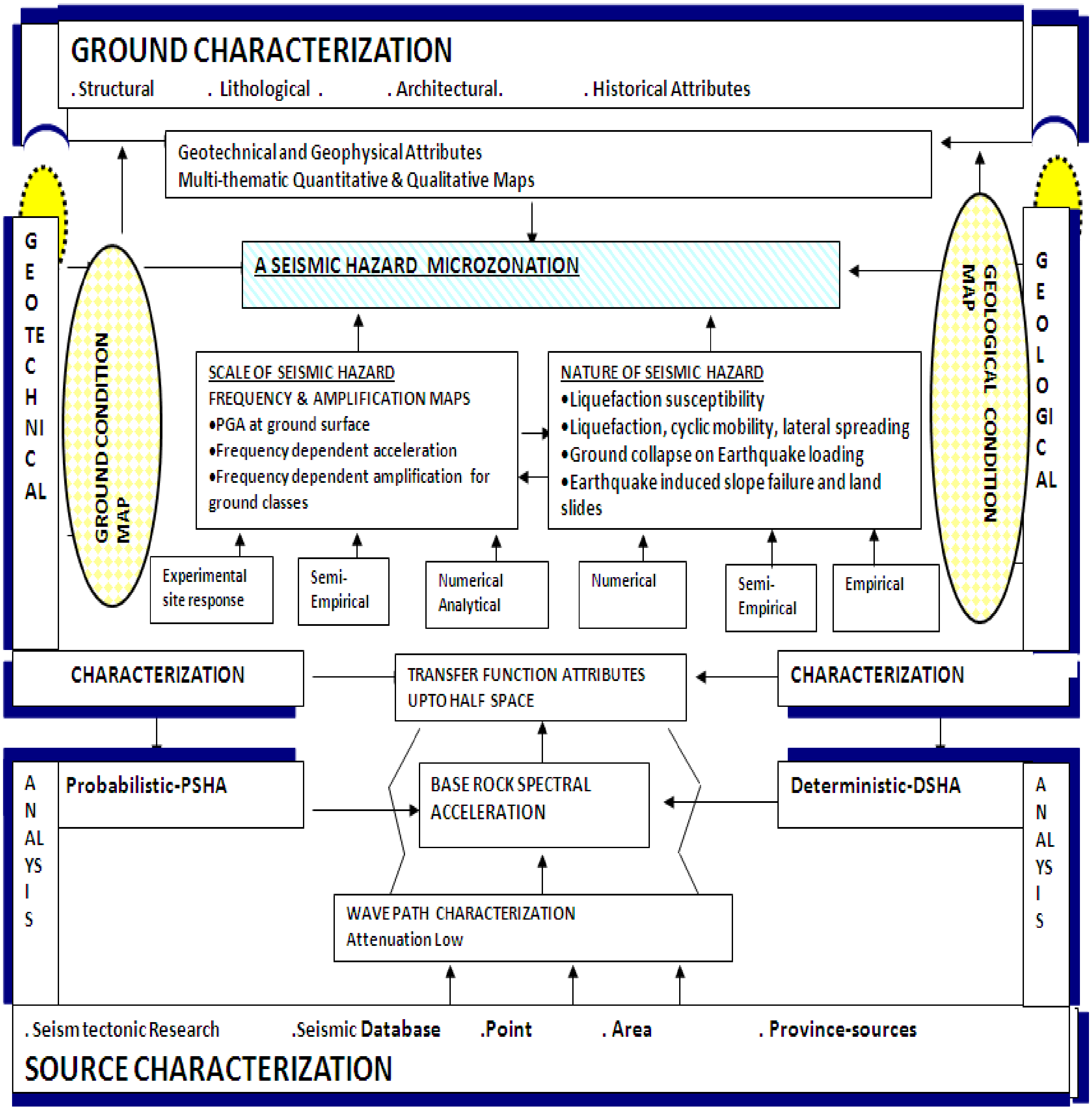


Figure3.1: A Holistic Model of Seismic Microzonation adopted for NCT Delhi

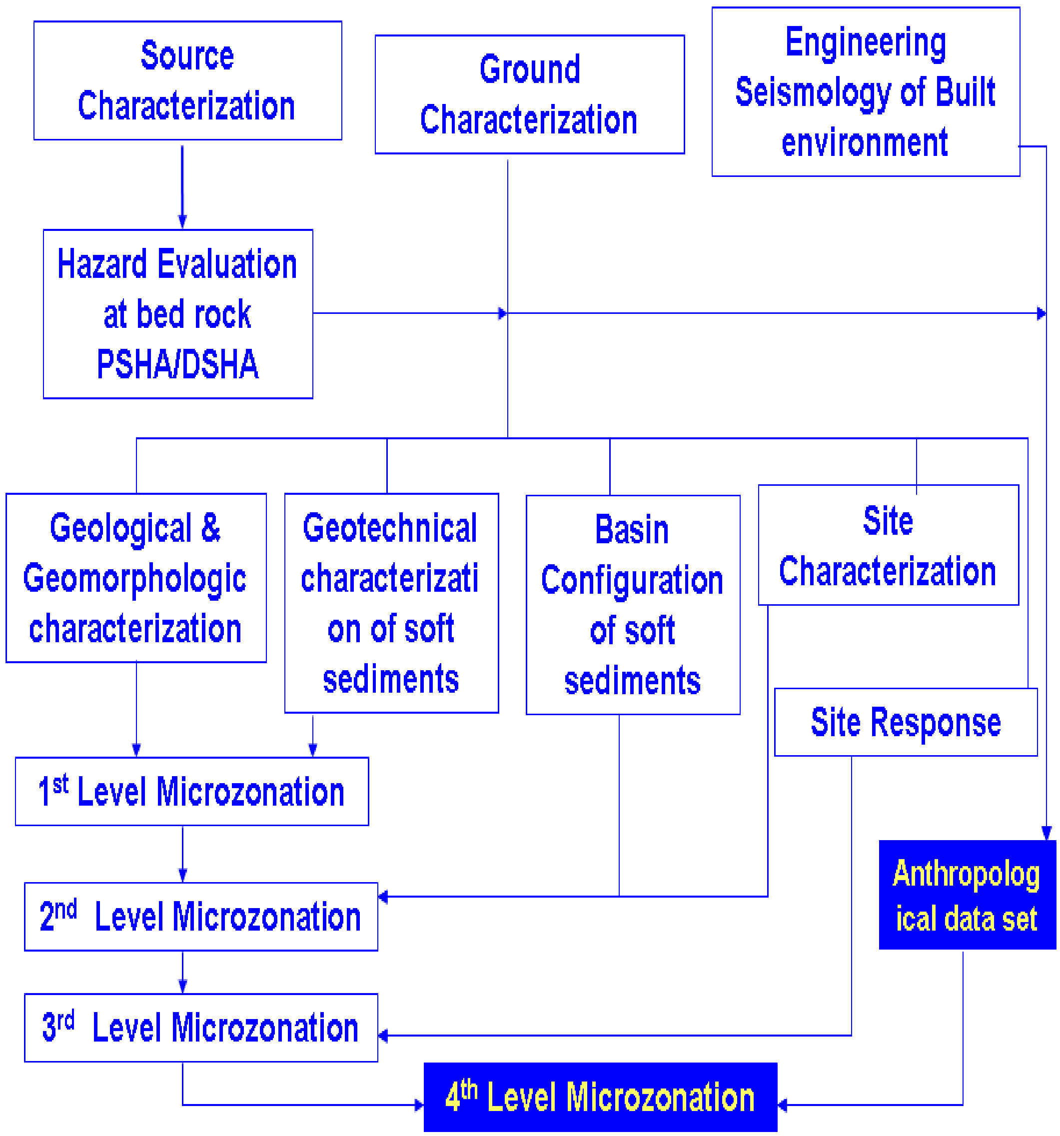


Figure3.2: Flow sheet for model adopted for Seismic Hazard and Risk Microznation of NCT Delhi.

CHAPTER-4

GENERAL THEMATIC MAPS AND GEOLOGICAL MAPPING OF NCT DELHI

4.1 BASE MAP (Toposheets)

The project specific base map on 1: 10,000 scale has been generated by Survey of India (SOI). The present state of Delhi with its 9 districts (National Capital Territory) occupies an area of about 1485 sq km spreading between Lat $28^{0}24^{'}\ 01^{''}$ N& $28^{0}53^{'}\ 00^{''}$ N and Long $76^{0}50^{'}\ 24^{''}$ E& $77^{0}20^{'}\ 37^{''}$ E is represented in 75 Toposheets on 1:10000 scale. These toposheets have been used for field based studies and generation of different thematic & product maps. Index map of NCT Delhi defining different no. of toposheets is presented in Figure 4.1 a sample map of one toposheet is attached as Map-4.

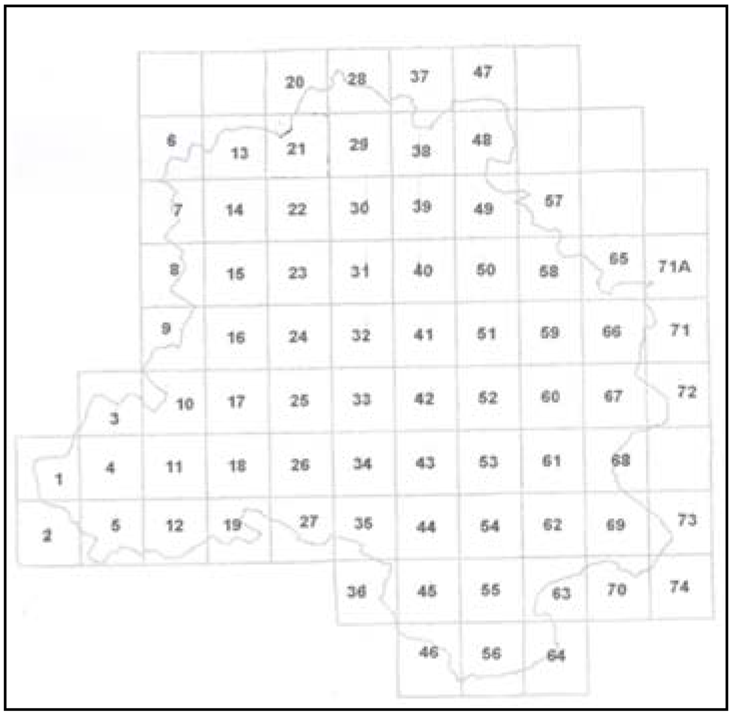


Figure 4.1: Index map of NCT Delhi defining different no. of toposheets

4.2 SEISMOTECTONIC ATLAS

As detailed in Chapter -2, while reviewing seismotectonics of the region, Delhi is located on the crustal ramp with basement rocks of Delhi Supergroup, bounded by two regional faults viz Mahendragarh- Dehradun Fault in the west and Great Boundary Fault in the East. The ramp trending NNE-SSW across 'fore deep', is juxtaposed to Himalaya thrust belt. Thus, the seismic vulnerability of built environment of Delhi need be examined *vis-a-vis* high frequency ground motions due to events endemic to faults of Peninsular Domain and also due to frequency content of attenuated events with source zone in thrust domain of Himalayas. Fault lines of consequence in the domain are (i) Mahendragarh Fault, (ii) Great Boundary Fault (iii) Moradabad Fault and (iv) Sohna Fault.

Two Seismotectonic maps (one for large environs caused by graticules Long 74^0 – 81^0N& Lat 25^0 - 33^0E and other for closer domain around Delhi bound Long76^0 – 78^0N& Lat 28^0- 30^0E) generated from Seismotectonic Atlas of GSI are shown as map 5 & 6. Seismic domain is characterized into ‘provinces/blocks’ and seismogenic lines are delineated for hazard evaluation. These maps have been used for development of seismotectonic model for Probabilistic Seismic Hazard Analysis (PSHA).

4.3 BEDROCK DEPTH MAP

Bedrock depth map generated by Central Ground Water Board (CGWB) on integrating the exploratory data on drill holes and geophysical studies has been considered. A few bore holes drilled for delineating bed rock in the gap areas have alsobeen used to update the bed rock depth map. The map forms the basis to delineate zones of (i) exposed rocky domain – the ridge and its extension, (ii) western domain of deep lacustrine/alluvial and subordinate aeolian fill, (iii) Structurally controlled closed basins (*e.g.* Chhattarpur basin) (iv) Semiclosed basin of Central Delhi with opening to the East and (v) Eastern domain of deep alluvial fill – Khadar. The bedrock depth configuration brings about possibilities of accentuation of hazard due to increased amplification and duration owing to surface waves and their constructive interference referred to as (a) Basin effect and (b) Basin Margin effect. The bed rock depth map is shown as Map- 7.

4.3.1 Basement Topography of NCT Delhi

The basement topography of NCT, Delhi is highly uneven depicting the presence of sub-surface ridges and valleys because of folding of the geological formations during the Pre-Cambrian and subsequent periods. The thickness of unconsolidated sediments towards east of the ridge gradually increases away from the ridges, with the maximum reported thickness being 170 m . In the South-Western, Western, and Northern parts of the area, the thickness of sediments is more than 300 m except at Dhansa where the bedrock has been encountered at 297m below land surface. In Chattarpur basin, the maximum thickness of sediments is 116 m.The nature of bedrock topography in different parts of NCT, Delhi is rendered uneven due to existence of sub surface ridges. Thickness of alluvium overlying the quartzites increases away from the out crops. The thickness of alluvium is 300 m or more in most parts of South West, West, and North West districts. The depth to bed rock is within 30 m on the east side of the ridge with a gradual downward slope towards river Yamuna. On the west of ridge near Mall road and VikramadityaMarg, the depth to bed rock varies from 1 to30 mbgl. Further west of it and

East of Najafgarh drain, there is a sudden increase in depth to 100 m. Near Sabjimandi, Rani Jhansi Road, Aram bagh, PaharganjChandaniChowk and Sadar Bazaar areas, thickness of alluvium is of the order of 10 to 20 m whereas near Roshanara Garden the thickness is about 200 m.

In the Central part of the city area near Dayabasti railway station, Karanpura, Patel Nagar Railway Station, the bedrock occurs within 30 m depth. But a little east of Karanpura, in DCM Chemical works, the bedrock has not been touched down to a drilling depth of 182.88 m. Such sharp and sudden change in thickness of alluvium may be due to faulting. In the Irwin Hospital, Delhi Gate, Daryaganj, Vijay Chowk, and Pusa road areas the depth to bedrock varies from 5 to 10mbgl. In LalQuila and Rajghat areas the depth to bedrock varies between 40 to 60mbgl. In Shantivan area bedrock is encountered at a depth of 23mbgl. In NanglaMachi and Zoo complex, bedrock exposures are present on surface. In Okhla village bedrock is exposed on surface within the JamiaMiliaIslamia campus. The thickness of alluvium is about 30 m at rail Bhawan and is about 100 to 150 m around India Gate. In Trans Yamuna area the thickness of alluvium varies from less than 20 (near Kailash colony) to more than 150 m away from Yamuna. In Usmanpur area bedrock is encountered at a depth of about 60 m. In Sonia Vihar area bedrock is encountered at a depth of 50mbgl. In Chattarpur basin of Mehrauli block, the alluvial thickness varies from a few meters near periphery to 115m around Satbari bund.

4.3.1.1: Bedrock depth inCentral district

Central district of NCT Delhi is located in hard rock terrain of Delhi quartzite at one end while alluvium is underlain by Delhi quartzite at another end. Nearly 25 Sq. Km area covered in the district which is extending east to west, where eastern part is just terminating along Yamuna Flood Plain. Depth to bedrock in the eastern part is ranging from 10 to 60mbgl. In the western part some of the rock exposures of Delhi ridge are also seen, sporadically covering 1.91 Sq.km area.

4.3.1.2: Bedrock depth in North district

North District of NCT Delhi just lying all along Yamuna River covering 60 Sq.Km areas. Its 40% area is under Yamuna Flood Plain. The Southern part of the District have a thin veneer of alluvium cover over quartzitic rock which is an extention of Delhi Ridge (Strike-SSW to NNE), near Wazirabad Barrage. The slope of the surface in the district is towards south by 0.40 m /km, but at the place of concealed Delhi Ridge it gets elevated. Due to this reason it forms a depression at the northern part of the upland area of the ridge leading to water logging conditions. Some of the exploratory wells Drilled by CGWB falling in this area are Delhi University, Dhirpur, and Jagatpur encountered with bed rock at the depth of 32m, 28m, and 167m respectively. The bedrock encountered have suffered moderate to high weathering in this area.

4.3.1.3: Bedrock depth in East district

East district of Delhi is located in the East of Yamuna River and extends up to the borders of Gaziabad and Noida ares of Uttar Pradesh. Covering a total area of 64 Sq. Km. Virtually, East district of NCT Delhi is a domain lying in between two rivers i.e. Yamuna in the West to Hindon in the East (6 Km eastward from the Delhi border). The basement rock condition in East district area is moderately uneven with gentle slopping towards East. It is unlike from western flank of NCT Delhi. At Ghazipur, Kalyanpuri and Mayur Vihar a mound like basement rock prevails in the depth range of 54 to 79 mbgl. The basement rock situation around Yamuna flood plain in East Delhi District is ranging from 28 to 204 mbgl. Especially around Akhsardham temple it ranges from 88 to 120 m.

4.3.1.4: Bedrock depth in New Delhi district

New Delhi district is located centrally in the state occupying an area of 35 Sq. Km. with varied surface altitude due to Delhi Ridge. Nearly 10 sq. Km. area falls within ridge area having a height of 225 to 255 m Above Mean Sea Level (AMSL). The surface is sloping gradually towards east up to the Yamuna river course where altitude is 210 m AMSL. The sub-surface configuration of New Delhi is different at various places, the western part which is adjoining to Delhi ridge is characterized by marginal alluvium of 0 to 30 m thickness overlain on weathered and fractured quartzite rocks (Delhi Ridge).The extreme eastern part of New Delhi District bounded by river Yamuna where a domain of Yamuna Flood Plain exists in a linear fashion along river Yamuna.

4.3.1.5: Bedrock depth inNorth-East district

North-East district is located east of Yamuna River and bordering to Gaziabad district in the east and Merrut district in the north of Uttar Pradesh. It covers 60 Sq.Km of area. Virtually, North-East district of NCT Delhi is a domain lying in between two rivers i.e. Yamuna in the west to Hindon in the east (6 Km eastward from the Delhi border).

Basement rock condition along the Yamuna Flood Plain in this district is shallower because Delhi central ridge which is running NNE to SSW diminishes at Wazirabad Barrage and protruding further in the same direction resulting to shallower depth of basement condition in sub-surface–horizon. In this district the depth is ranging from 54mbgl (Mandoli) to 67mbgl (Usmanpur). Further east the depth of basement rock increases.

4.3.1.6: Bedrock depth in North-West district

The North-West district of NCT Delhi covers 440 Sq. km. area characterized by unconsolidated quaternary alluvium deposits. So for 250 m depth has been explored without encountering bed rock. The expected depth of bed rock is about 300 m or beyond. Thick pile of alluvium over the basement rock possesses varied sediment strata in an alternate fashion of geological setting.

4.3.1.7: Bedrock depth in South district

The South district of NCT Delhi covers 250 Sq. Km. of area of which 45.2 Sq. Km area shows mountainous undulating terrain exposed with Delhi quartzite. The district is also characterized by a saucer shaped vast alluvium field in the central part of the district popularly known as Chattarpur Basin. Virtually this is valley fill deposit, the alluvium thickness varies from 0.0 m to 140.00 m .bgl (Satbari village), below which quartzitic basement rock prevails. Some of the villages like Chattarpur, Gadaipur, Mandi, Ghitorni, Ayanagar, FatehpurBeri and Satbari fall within this area. The area across southern Delhi Ridge which falls in South District namely Hauj-khas, Saket, Khanpur, Pushpvihar, Lal-kunwa and Saritavihar are underlain by marginal alluvium deposits with a thickness ranging from 60 m to 94 m below which Quartzitic basement rock prevails.

The bore hole constructed in Quartzites (Jaunapur, Asola, Mandiand Tughlakabad) reveals that moderately fractured zones are prevalent in the depth of 30 m to 90 m and their fractured density gradually decreasing as depth increases. The weathered zone is found at every place above hard rock but their thickness varies from place to place.

4.3.1.8: Bedrock depth inSouth-West District

The South-West district of NCT Delhi covers 420 Sq. km. Majority of the area characterized by unconsolidated quaternary alluvium deposits and about 18 Sq. Km area is covered by denudation hills especially in the eastern part of the district. Exploration upto a depth of 302 m was done to study the hydrogeological condition. The bed rock was encountered at different depth i.e. in Dhansa (297 m), Pindwalakala (300 m), Toghanpur (298m) and Jhul-jhuli(251m). Thick pile of alluvium over the basement rock possesses varied nature of sediment strata in an alternate fashion of geological setting.

4.3.1.9:West District

West district is occupied by unconsolidated Quaternary alluvium underlain by Precambrian meta-sediments of Delhi System. Quaternary alluvium comprises of sand, clay, silt, gravels/pebbles, and kankars.

4.4 GROUND WATER TABLE MAP

Soil properties are altered by moisture content. Liquefaction potential of the soil is also controlled by level of the water at particular site. Ground water level is therefore one of the parameters considered for evaluating different soil properties/parameter and their effect on different component of seismic hazard microzonation. Central Ground Water Board (CGWB), a subordinate office of the Ministry of Water Resources, Government of India, is the National Apex Agency entrusted with the responsibilities of providing scientific inputs for management, exploration, monitoring, assessment, augmentation, and regulation of ground water resources of the country. Monitoring of ground water levels is one of the major activities of the CGWB, through a network of ground water observation wells comprising both large diameter open wells and purpose-built bore/tube wells (piezometers). As on 31.03.2011 a network of 14966 ground water monitoring wells spread all over the country is used for monitoring of ground water level in different parts of the country. To monitor ground water level in different parts of NCT, CGWB has setup 162 ground water monitoring systems, which includes 25 large diameter open wells (DW) and 137 purpose-built bore/tube wells (piezometers) PZ. Ground water levels are being measured four times a year during January, April/ May, August and November. On the basis of data generated from this network, CGWB generate different reports and maps.

The post monsoon seasonground water map/data of November 2010, which provide the critical situation of ground water table in NCT Delhi in respect of induced seismic hazard,has been used for the liquefaction study (Map 8). As per the year Book of CGWB for 2010-2011, water table in May 2010 (pre monsoon) and November 2010 (post monsoon) are detailed below:

4.4.1 Depth to water level in May 2010 (Pre Manson)

The Depth to water level recorded in NCT Delhi during May-2010 ranges from 1.10 to 66.70 mbgl. The total 201 station of Delhi state have been analyzed district wise where 50% wells of south district shown more than 40 m.bgl water level and 24% wells have 20 to 40 mbgl water level. In New Delhi and South-West district 62% and 53% of the wells show water levels ranging from 10 to 20 m bgl. In 50%, 40% and 50% of the wells in Central, East and North West districts the water level ranges from of 5 to10 m .bgl respectively. The entire Yamuna flood plain the water levels are between 2 to 5 m.

4.4.1.1 Annual Fluctuation of water level in May

The fluctuation of water level between May-2009 and May-2010 of Delhi state shows rise in nearly 12% of wells with respect to the previous year water level in the districts of North, North-West, New Delhi, and South. Whereas rest of the district like Central, East, North-East, South and South-West shows fall in the range of 0.24 to 8.98 m in 70% of the wells.

4.4.1.2: Decadal Fluctuationof water level in May

South and South–West districts are sharing a continuous fall in comparison to other areas. When the data of May-2010 has been compared with 10 year mean of May water level 79% of the wells indicate fall in the range of 0.01 to more than 35 m. Only 13% wells of the North-West, and New Delhi have been observed to show rising condition in the range of 0 to 2 m. The maximum fall has taken place in district of South and South-West (i.e. 7.07 to 7.38 m)

4.4.2: Depth to water level in November 2010

The Depth to water level recorded in NCT Delhi during November-2010ranges from 0.07 to 66.84 mbgl. The data from 166 stations has been analyzed district wise. 33% wells of south district shown more than 40m bgl water level and 27% wells have 20 to 40 m .bgl water level. In South-West district 19% and 7% wells have water level between 20 to 40 mbgl and more than 40mbgl respectively. The depth to water level of East, North-East and North-West districts are in the range of 5 -10 m bgl in 36% , 43% and 26% respectively whereas in North and South districts 36% and 23% wells are in the range of 2-5 water level respectively. The water levels of entire Yamuna flood plain are in the range of 2 to 5mbgl.

4.4.2.1:Pre-Post Monsoon Fluctuation of water level

The fluctuation of water level between Pre-monsoon (May-2010) and Post Monsoon (Nov-2010) of Delhi state shows 0.01 to 32.11 m rise in 88% of the wells, but some of the districts i.e. East, North, North-East and West shows a rise in the range of 0 to 4 m in 82% of the wells. Few wells of South and East district show fall in the range of 0 to 4 m.

4.4.2.2:Annual Fluctuation of post monsoon water level

The hydrograph analyses of Nov-2009 and Nov-2010 water levels of 193 wells reveals that 21% of the wells shows fall in the range of 0 to more than 4m whereas in 30% there is no perceptible change or just above than the previous year water level. The fall of more than 4 m are recorded only in South district.

4.5 GEOLOGICAL AND GEOMORPHOLOGICAL MAPPING OF NCT DELHI ON 1:10,000 SCALE

Geomorphological mapping is being used increasingly in engineering applications, as a rapid, highly cost-effective means of assessingboth potential hazards and resources. A good subsurface geological map is therefore essentially required to understand variability of soil and further planning of geotechnical investigation. However, this itself is a huge task and normally achievedthrough a field mapping programme, and involves the correctinterpretation of landforms as to their origins, material composition,and associated present-day geomorphological processes. In the geological and geomorphological studies, the near-surface signatures pertaining to the recent sedimentary deposits - alluvium, flood plains, cliffs, slope aspects, etc can be complemented by borehole litholog, exploratory drill holes, surface elevation model, land-cover, and basement topography derived from vertical electrical resistivity soundings and other geophysical investigations.

Geological Survey of India (GSI) a nodal agency of government of India in geological mapping, through their concerted efforts for last several years, have prepared Geological map of NCT Delhi, which is presented on 1:50,000 scales. This map has been digitized and used for first level study of Seismic Hazard Microzonation on 1: 50000 scale completed by EREC in 2005(Map-9).

In carrying forward the microzonationstudy to a higher level of precision on 1:10,000 scale, it was required to geologically re-survey the area on new base map generated by SOI (scale 1:10,000) to address the following specific problems identified in first level Seismic Microzonation on 1:50000 scale (Map 3).

1. Mapping of Palaeochannels of Yamuna river and Fluvial Sediment Characterization in Khadar and Bela belts in Microzone-9
2. Mapping of structural elements with special reference to folding pattern and Fault delineation for ascertaining Basin architecture in Micro zone--7 (Chhatarpur basin) and Micro zone- 8(West of Delhi Ridge),
3. Delineation of associated meta-argillites and highly weathered units with Ridge Quartzite and in Kohi Microzones--1&-3 (Delhi Ridge and Asola area, respectively)
4. Sediment characterization and delineation of strand lines in Nazafgarh and other lake domains;
5. Characterization of Aeolian sediment fill in Chhatarpur Basin (Microzone-7) and in reported sporadic occurrence in other domains,
6. Studies to delineate Pleistocene/Holocene Boundary in soft sediment cover keeping in view the importance of characterization of liquefaction.

Geological mapping of NCT Delhi on 1:10000 scale has been carried out in collaboration with Geological Survey of India (GSI). The geological mapping of a large urban complex with high scale resolution of 1:10,000 was a challenging task. Mapping on such a scale had never been attempted for any of the Indian cities. Moreover, high density urbanization in Delhi had rendered it further difficult to capture ground geological data. To win over the constraints following innovative techniques have been used.

(i) To minimize the hindering effect of the urban masking in geological data capturing, the field work was supplemented with (i) aerial photo studies based on old series photography of 1976 generation available with SOI and high resolution remote sensing data of recent origin (ii) extensive probing with exploratory drill holes. One such aerial Photograph of a small area is given in Figure 4.2.

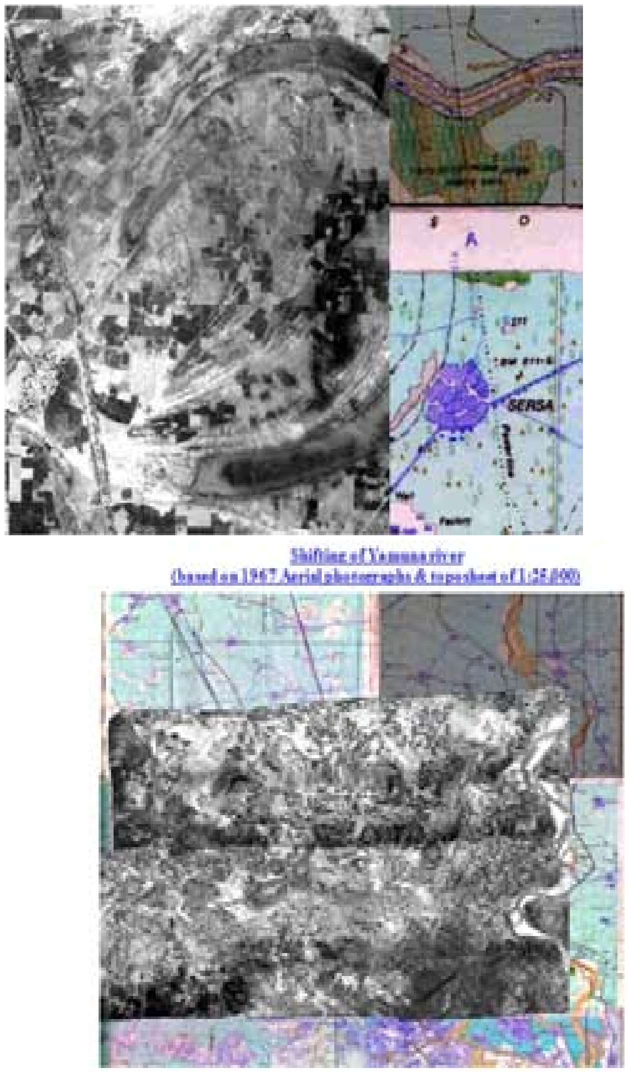
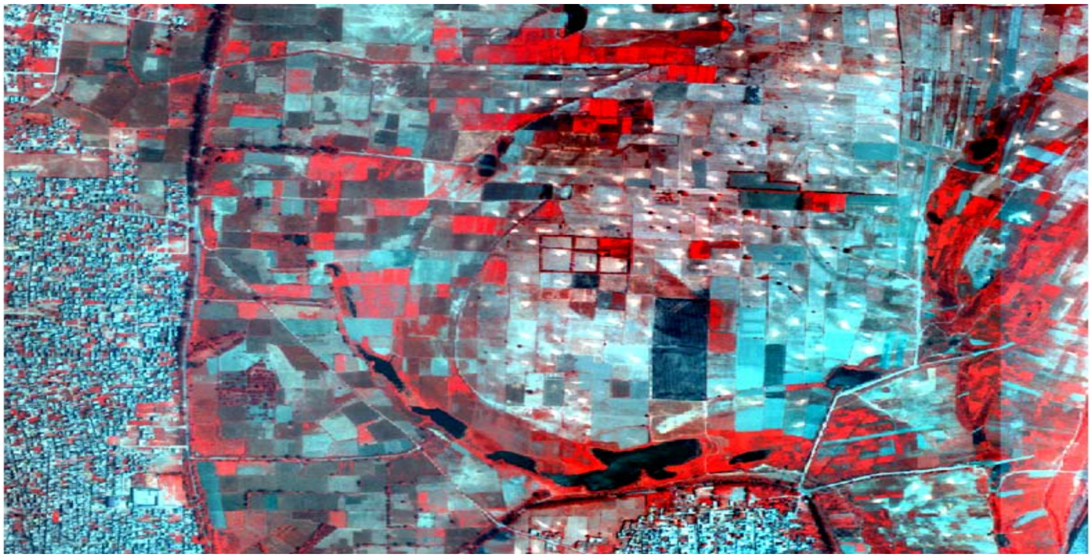


Figure 4.2: Aerial Photograph (Top) abandoned channel (Bottom) shifting of Yamuna River

(ii) SOI had provided old sequential toposheets of Delhi on Projection compatible with present toposheets for exercise on delineation of (a) palaeochannels and river migration pattern and (b) changes in the strand line of lacustrine domain.

(iii) GSI formulated a devoted group for (a) interpretation of remote sensing data and generation of photo-interpretative map and to took up specific study for characterization of (a) fluvial architecture in riverine domain, (b) Aeolian sediments in Chhatarpur basin and (c) limnological sediments in Najafgarh domain. Photo interpretative map of a small area is given in Figure 4.3.



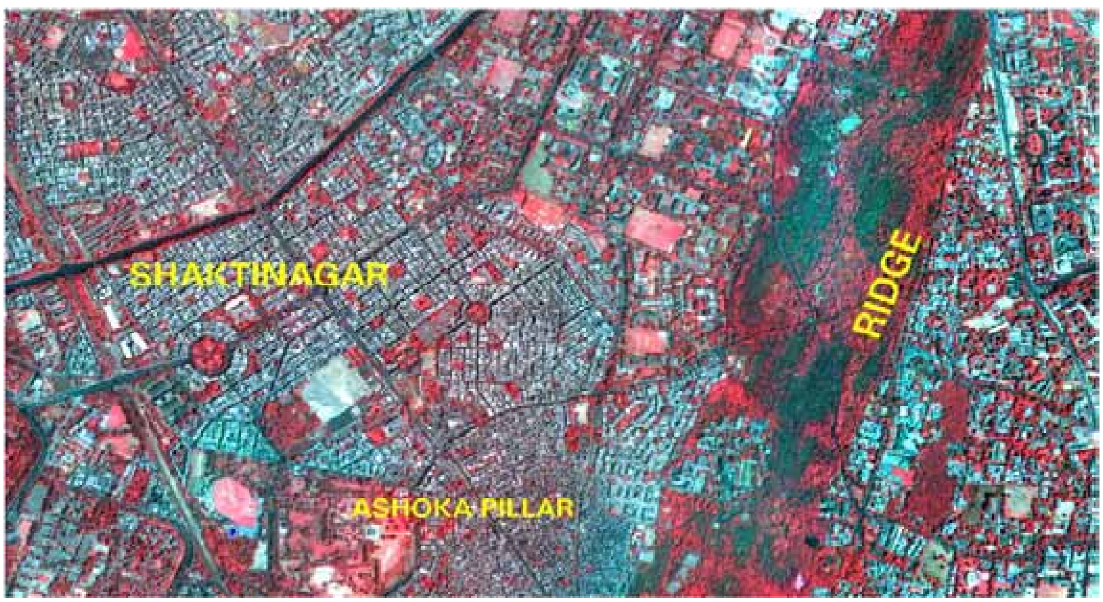


Figure 4.3: Photointerpretative map of two small areas.

(iv) GSI a lsoformulated a de voted gr oup assisted by f ield ge ologists f rom Earthquake Risk Evaluation Center (EREC) for limited field survey. A few photographs collected during field survey depicting different geomorphological features are given in Figure 4.4.

(v) Geological map of NCT Delhi on 1:10000 scale has been generated and presented in 75 Sheets overplayed on respective toposheets generated in collaboration with SoI. A small area covering one toposheet is shown asMap 10.

Figure 4.4:A few photographs collected duringfieldgeological survey depictingdifferentgeomorphological features in NCT Delhi.

4.5.1 Interpretation of geology and geomorphology of Delhi based on new maps

The National Capital Territory of Delhi covers an area of about 1484 sq km. physiographically the area represents a mature topography with vast gently undulatory plains, low linear ridges and isolated hillocks. NE to NNE trending Aravalli Range extends northwards up to Delhi and are designated as Delhi Ridge in the area. The ridge occupies the south central part of Delhi and extends up to western bank of Yamuna River as seen near Okhala in south and Wazirabaad in north-east. The general elevation of the plains varies between 213 and 305m above m.s.l. and the ridges rise 40 to 50m above the plains. Yamuna River flows across Delhi in a south-southeasterly direction with vast flood plain, marked by a bluff of 3 to 4m on either bank as seen near Narela towards west and near Baghpat towards east. The area towards east of ridge has a gentle slope of 3.5m/km towards Yamuna, and a number of tributary streams and Nalas, drain into Yamuna. The area towards west of ridge representing older Alluvial Plain is mostly covered by sand dunes and has a westerly slope. All the Nalas debouching from the western flank drain into a broad inland basin described as Sahibi-Najafgarh basin. The anthropogenic activity has considerably changed the topography of the area. A number of drainage lines and natural ponds have been completely modified or obliterated.

The oldest geological unit exposed in the area belongs to Delhi Super group of Middle to Upper Proterozoic age which is overlain by unconsolidated Quaternary sediments comprising Older Alluvium (Late Pleistocene) and Newer Alluvium (Holocene). The Delhi Supergroup comprises quartizite, gritty quartzite, arcosic grit with thin intercalation of micaceous schist. The micaceous schist occasionally contains crystals of garnet, andalusite, and staurolite. The rocks of Delhi Supergroup are intruded by pegmatite and quartz veins. The Older Alluvium mainly comprises yellowish brown, occasionally white micaceous, medium to fine sand, silt, silty clay, clay and kankar. The kankar occurs both in the form of bedded deposits and as sporadic nodular lenses. The Newer Alluvium is restricted to the Flood Plain of Yamuna River and mainly comprises grey micaceous medium to fine grained sand, intercalation of silt and clay with fine nodular kankar.
In general the entire area of NCT- Delhi can be grouped into three broad geomorphic units:

- Rocky surface, the oldest geological unit exposed in the area,
- Alluvial Plain-gently undulatory surface with rolling topography having a relief of a few meters.
- Flood Plain of Yamuna River-low lying surface.

Rocky surface
The rocky surface represents structurally controlled relict linear ridges and isolated hillocks comprising rocks of Delhi Supergroup and isolated hills mostly occurring in the south-south central part, and extends from Mahipalpur to Wazirabad in the north. Towards south of Mahipalpur the ridge gets bifurcated, one arm extends towards Mandi and further south while the other takes a turn towards southeast and traced up to Tughlakabad-Greaterkailash, Nehru Place and Okhla. It attains maximum elevation of 318 m above m.s.l which gradually diminishes towards north where rocks are exposed on the western bank of Yamuna near Wazirabad.

Older Alluvium Plain
The gently undulatory terrain on either side of the rocky surface is described as Older Alluvium Plain. This surface is separated from the Yamuna Flood Plain by a bluff. Depending upon the morphological expressions/features this unit is further divided into different sub-units: (i) Najafgarh Older Alluvial Plain (ii) Delhi Older Alluvium Plain (iii) Maidan Garhi Plain.

The Najafgarh-Dwarka area in southwest Delhi forms an inland basin drained by Sahibi and Najafgarh drains and their tributaries such as Mundela khurd, Mungeshpur, Nangloi, and Palam nalas. The area is characterized by very fine textured dendritic drainage pattern. The gently sloping surface, including the covered pediment along the eastern flank of the ridges is characterized by the Delhi Older Alluvial Plain. The older alluvial plane towards western and south western parts of the region is partly covered by sand zones and sandy sheets. Maidan Garhi Plane is a relatively higher plane surface and forms part of Chhhatarpur basin. A narrow zone of badland has formed mostly along the western margins of structural ridges due to intense development of gullies and rilles.

Flood Plain of Yamuna

The low line flat surface representing the flood plain of Yamuna is an important geomorphic unit which occupies north, north-east and eastern parts of Delhi. North of Narela, the width of flood plain varies from 15 to 17 km. The surface altitude varies from 213 m in northwest to 200 m in the southeast. The boundary of the flood plain is marked by a 3 to 4 m high bluff which on western bank of Yamuna extends south ward through Bhoragarh, Sanoth, Kherakhurd, Kherakalan, and Aalamgirpur to Azadpur and reaches Wazirabad through Kingsway Camp. South of Wazirabad the bluff extends directly in southerly direction. The flood plain is characterized by a bounded channel cut off meanders, meanders scrolls, ox-bow lakes, crevasse splays, point bars and channel bars. Presence of a number of cut off meander suggests oscillatory shifting of river. The lakes near Bhalsawa, Kondli, and Khhichdipur are remnant of large meanders.Detailed geology and Geomorphological features covering individual sheets will further be discussed while presenting seismic microzonation maps of individual sheet.

CHAPTER-5

SEISMIC HAZARD ASSESSMENT OF NCT DELHI AT ENGINEERING BEDROCK

Evaluation of Seismic Hazard at bed rock is the first process of Seismic Hazard Microzonation,as described in previous chapter, involves quantitative estimation of ground motion parameters at a particular site at bedrock due to future earthquake of a given magnitude and epicentral distance.This requires identification and characterization of all possible sources of seismic activity and their potential for generating future strong ground motion at the site. The current ability to identify and locate all earthquake sources is a relatively recent development, particularly when compared with the time scales on which large earthquakes usually occur. The fact that no strong ground motions have been instrumentally recorded in a particular area does not guarantee that they have not occurred in the past or that they will not occur in future. Therefore, in the absence of an instrumental seismic record, other clues of earthquake activity in the form of geological and tectonic evidence, or historical seismicity are to be considered. The search of geological evidence of earthquake sources centers on the identification of faults and therefore, generation of a good seimotectonic map around the area of study, generally around 300 to 350 km of radius (Iyengar and Ghosh, 2004; Gupta, 2005) is required to be generated along with associated records of earthquake since historical time(good catalogue). Two basic methodologies used for Seismic Hazard Assessment (SHA) are the Deterministic Seismic Hazard Assessment (DSHA) and the Probabilistic Seismic Hazard Assessment (PSHA) approaches.

In the Deterministic Seismic Hazard Assessment (DSHA), the strong ground motion parameters are estimated for the Maximum Credible Earthquake, assumed to occur at the closest possible distance from the site of interest, without considering the likelihood of its occurrence during a specified exposure period. On the other hand, in PSHA, rather than searching for elusive worst-case ground motion, all possible earthquake events and resulting ground motions, along with their associated probabilities of occurrence are considered to estimate the level of ground motion intensity exceeded with some tolerably low rate.

PSHA is an improvement over DSHA by considering all possible uncertainties into the hazard estimation procedure, arising in magnitude scales; types of earthquake sources and its nature of physical processes; using various kinds of earthquake recurrence models and its intermodel or intramodel assumptions and estimation of strong ground motion using appropriate ground motion prediction equations. However, incorporation of uncertainties adds some complexity to the procedure, but the resulting calculations are much more

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The strong ground motion in Delhi has been estimated at engineering bed rock (Shearwave velocity about 760m/s) level in terms of spectral strong ground motion for various exceedance rates using Probabilistic Seismic Hazard Assessment (PSHA) and considering uncertainties involved in the process.The seismic zonation for various probabilities of exceedance values in specific duration of time for strong ground motion on the engineering bed rock has been estimated based on the appropriate strong ground motion attenuation relationships. The seismotectonics modeling has been carried out for the region which is used for the probabilistic seismic hazard estimation for national capitalregion of Delhi.

5.1: ESTIMATION OF SEISMIC HAZARD PARAMETER

The seismic hazard assessment has been carried out for Delhi using Probabilistic Seismic Hazard Analysis (PSHA). The various steps of study for estimation of seismic hazard parameters are described in this section in detail. The steps described are earthquake catalogue,treatment of seismicity with respect to homogenization, de clustring, completeness analysis, estimation of hazard parameters namely, a, b, M_c and M_{max}, Strong motion estimation, selection of attenuation relationships and finally assessment of seismic hazard in Delhi using logic tree approach.Regional geological and tectonic setups of the region, around Delhi and maps described in Chapters 2 & 4 have been used for seismotectonic modeling of the region.

5.1.1: Earthquake data (Catalogue)

The present study has been carried out for Northern India region (Latitude 24^0 – 31.5^0 N and Longitude 74^0 – 81.5^0 E) with Delhi as its centre. Earthquake data have been plotted on the map showing tectonic features of the region, based on regional seisotectonic setup discussed in previous chapters and shown as Figure 5.1. The data have been compiled from national data baseof India Metrological Department(a nodal agency for earthquake monitoring in India), International Seismological Center (ISC, UK), and United States Geological Survey (USGS, USA) (International agencies). Information on earthquakes in India and neighborhood, available in various national and International publications and journals,has also been used. The earthquake catalogue has been compiled from historic to present time (1720-2004). The historical part of the catalogue covers a period from 1720 to 1956 and is extracted from Indian Society of Earthquake Technology (ISET) catalogue (1983) and Oldham (1883). After 1960 systematic recording of earthquakes were carried out, but the reporting of events have been done using different magnitude scales.

Parameters of historical earthquakes, including magnitudes were determined only from macro-seismic data. Magnitude assigned for these events was done using literature survey of different journals and publications (ISET, 1983; Iyengar, 1999; Bilham, 2004). The catalogue contains 1, 26, 21, 28, 88, 180, 344 and 751 earthquakes in the magnitude range as $M > 7$, $6 < M < 7$, $5 < M < 6$, $4 < M < 5$, $3 < M < 4$, $2 < M < 3$, and $1 < M < 2$, respectively. A total of 1411 earthquakes could be listed from various sources in the catalogue prepared for the seismic hazard assessment. The epicenters of these earthquakes are plotted in Figure5.1.

5.1.2: Seismotectonic Modelling

The earmarking of seismogenic sources in a region based on the association of prevalent seismicity to the local and regional geological and tectonic features considering the different geological and geophysical anomalies is termed, in general, as seismotectonic modeling of the area. Statistical and geological evidence are primarily used to define the geographical demarcation of seismic source zones and seismically activefaults. These geographical features can be modeled as point, line, or area sources. Seismicity related to a specific source zone is then represented by a recurrence model consisting of a random process describing the distribution of magnitude of earthquakes in a given period of time. In most cases, uniform probability distributions are assigned to each source zone, implying that earthquakes are equally likely to occur at any point within the source zone. The probability of exceeding a given level of ground motion parameters at least once in a given number of years at a given site is finally obtained through ground motion prediction equations. Thezone less seismic-hazard approach suggested by Frankel (1995) has also been used in many investigations for seismic hazard assessment. This approach is useful especially for regions where demarcation of distinct seismic-zone boundaries is difficult due to a poor understanding of tectonic settings. The method has the disadvantage of not considering the physical seismogenic sources present in the region.

5.1.2.1 Seismic Sources Zones

In case of the present study area which is covering Northern Indian region, due to its high seismicity, the seismogenic sources are demarcated to a good extent and those methods which make use of the physical sources by considering their geometry and individual behavior of earthquake occurrence should be preferred. Therefore, Seismotectonic Province Method has been used and for carrying out the seismic hazard assessment of Delhi, the seismotectonic modelling has been carried out with the aim to divide the study area (Latitude 24^{o}-31.5^{o} N and Longitude 74^{o}-81.5^{o} E) within a 350 km radiusaround Delhi, into various seismotectonic segments i.e., into various seismogenic zones having distinct characteristics.Based on the geophysical and geological characteristics of the seismogenic sources along with the prevailing tectonic regime in the region and the seismicity,discussed in Chapter-2&4, the area is divided into four zones namely Himalayan Zone (part of Himalaya falling within 350km from the center of Delhi), Delhi-Haridwar Ridge Zone, Moradabad Fault Zone and Rajasthan Great Boundary Fault zone.Seismotectonic map of the region around Delhi showing all earthquake events and its epicenters is given in Figure 5.1.

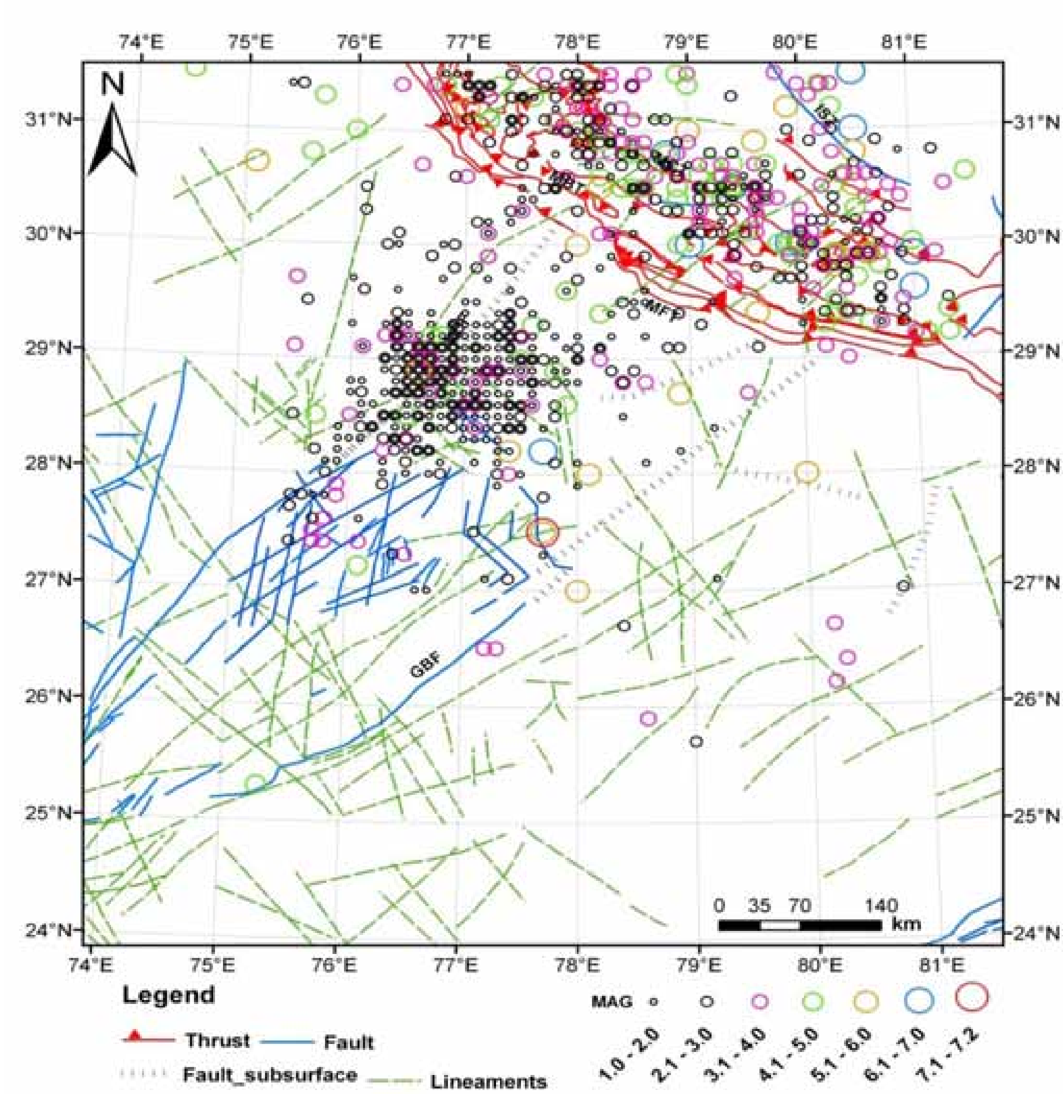


Figure 5.1: Seismotectonic map of the region around Delhi showing all earthquake events and its epicenters

5.1.2.1.1: Seismogenic Zone I: Himalayan Zone (HIM)

Himalayan mountain belt setup is broadened about 2400 km long in east-west direction with variable width of 230 to 320 km (Argand 1924; Dewey and Bird 1970; Srikantia and Bhargava 1998). The part of Himalayan mountain belt, which is within 350km of radius from the center of Delhi only falls in the considered area (Latitude 24°-31.5° N and Longitude 74°-81.5° E) for seismotectonic modelling and earthquakes occurred in this part of Himalayan mountain belt have only been considered for the study. Thus the Himalayan Zone (HIM) from the point of view of this study is not representing the seismicity of entire Himalayan mountain belt.

This part of Himalayan seismogenic zone is the most seismically active zones in the considered area of the study. The reported maximum magnitude experienced in this zone is 6.9, which occurred on 29th March, 1999 near Chamoli. This earthquake left 70 persons dead and approximately one thousand houses damaged. Since 1720 this region has experienced about 370 earthquakes of which 344 are below magnitude 5 and contain 18 in the magnitude ranges of $5 < M < 6$, and 8 earthquakes in between magnitude ranges of $6 < M < 7$. The main seismogenic features in this zone are MFT (concealed at places), MBT, and MCT.

5.1.2.1.2: Sismogenic Zone II: Delhi-Haridwar Ridge Zone (DHR)

The Delhi-Haridwar Ridge zone is considered to represent shallow NE-SW trending extension of the Delhi Foldbelt towards the Himalayas, which has controlled the western limit of the Ganga basin, and the underlying sedimentary sequence probably thins out towards this ridge. Delhi-Hardwar Ridge lies towards the northwest of the Ganga basin and is considered to be a prolongation of the NNE-SSW directed Peninsular rock (Aravalli) as a horst delimited by faults. Since 1720 the region has experienced some 894earthquakes of which 890 are below reported magnitude 5. There are 3 earthquakes of magnitude $5 < M < 6$. There is one earthquake registering magnitude 6.5 which occurred on July 15, 1720.

As in the present study, the Seismotectonic Province Method has been considered, individual faults such as the Mathura fault zone postulated by Srivastavaand Somayajulu (1966)has been included in a larger seismogenic source zone i.e., Delhi-Haridwar Ridge. This zone probably controlled the course of the Yamuna River in the tract in which the river follows a course parallel to the fault zone.

5.1.2.1.3: Seismogenic Zone III: Moradabad Fault Zone (MOR)

The Moradabad fault zone trends generally along NE-SW direction. Since 1720 the region has experienced about 45 earthquakes of which 42 are below magnitude 5. There is 1 earthquake in the region generating $5 < M < 6$ and 2 earthquakes registering $M > 6.0$, respectively in this region.The earthquake of Oct. 10, 1956 is the largest instrumentally recorded earthquake near this fault. A magnitude of 6.4 was assigned to the event on the basis of instrumental records by IMD with its epicenter at latitude 28.15^0 N and longitude 77.67^0 E. Rothe (1969) lists this event with epicenter at latitude 28.2^{0}N, longitude 77.3^0 E with origin time 15 h, 31 m, 36 sec (GMT). This earthquake was felt in a very large area and was responsible for damage to buildings in which 23 persons perished in Bulandshahar and some were injured in Delhi. The earthquake of Aug. 27, 1960 with its epicenter at latitude 28.2^0 N and longitude 77.4^0 E is generally referred to as the 1960 Delhi earthquake which had a magnitude 6.0 and reported depth of focus as 109 km. The earthquake was felt at Kanpur and Jaipur. Minor property damage and injuries to about 50 persons were reported from Delhi.

5.1.2.1.4: Seismogenic Zone IV: Rajasthan Great Boundary Fault Zone (RGBF)
Rajasthan Great Boundary Fault (RGBF) zone is a well-defined fault which runs for about 400 km NNE-SSW to NE-SW as a major dislocation zone in Rajasthan. The RGBF represents a 10 –20 km wide zone and demarcates the interface between the Vindhyan Supergroup of rocks on the eastern side and the Aravalli Supergroup of rocks on the western side.

The earthquake of Aug. 31, 1803 near Mathura is associated with this zone in addition to its association with the Mathura fault zone. This earthquake was felt as far away as Calcutta and caused extensive fissures in fields near Mathura through which water gushed out. Iyengar (2000) and Tandon (1953) noted damage to the Qutub Minar during the 1803 earthquake in Delhi.The epicentral location of this earthquake indicates that the earthquake could be due to movement along the postulated Mathura fault. Since 1720 the region has experienced about 18 earthquakes of which 14 are below magnitude 5. There are 2, 1 and 1 earthquakes in the range of $5 < M < 6$, $6 < M < 7$ and $M > 7.0$, respectively.

5.1.2.2 Line and Area Sourc Models
The line source model and the areal source models for the seismogenic sources as observed in the seismotectonics described above are shown in Figure5.2 (left panel) and Figure5.2(right panel). Hereafter, the seismic source zones are abbreviated as DHR (Delhi-Haridwar Ridge), HIM (Himalaya), MOR (Moradabad), and RGBF (Rajasthan-Great-Boundary Faults).

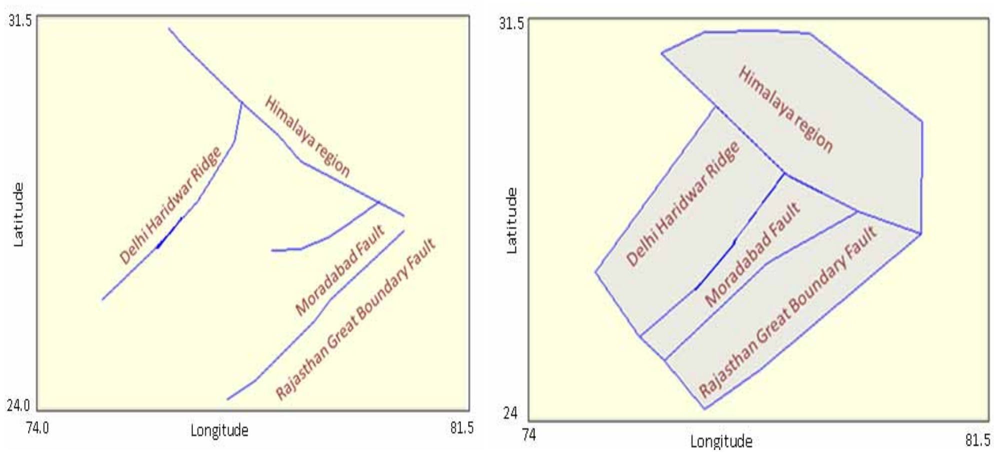


Figure5.2 Left panel: Line source model of the region, right panel: area source model of the region

5.1.3: Homogenization of Earthquake Catalogue
One of the problems while carrying out seismic hazard assessment could be related to the necessity of utilizing a long, 'nonuniform' earthquake history; having different intensity or magnitude scales for varying size of the events. So a more or less uniform, entire earthquake history has to be defined by the aid of some conversion relationships and a

more structured analysis should consider the uncertainty associated with these conversions relations.

The empirical relationships between different magnitude scales are therefore, of paramount importance for conversions to be carried out for homogenization of seismicity catalogues for further studies related to seismological statistics and for seismicity and amplitude studies**.**

Using the data set from ISC, USGS, and IMD only 61, 101 and 30 events could be compiled having the magnitude pairs given as M_b & M_s, M_L & M_b and M_L& M_s, respectively. The data sets used for analysis contain less than 15 events having the magnitudes given for both scales M_L, M_s, M_b with M_w. The earthquakes used for the present study are shallow ones with depth $\leq$ 70 km because of their greater concern in seismic hazard analysis. The historic events, for which only intensities are assigned for their size, were not considered for developing the relationships between the magnitude scales.

Since both the magnitudes to be regressed for relationship contain inherent errors, it is necessary to consider these errors in regression analysis for developing the relationships. While estimating the magnitude of any earthquake event there is always some inherent variability that the measurement is bias, called aleatory randomness. For establishing relationship between two different types of the scales it is necessary, therefore, to consider both scales having the different aleatory variables. An endeavor has been made to quantify the uncertainty due to magnitude conversions to be used for seismic hazard analysis. The relationships between various magnitude scales have been developed.

The data for developing such relationships between two magnitudes scales is generally very less and gives a selected sample choice to obtain a relationship between two magnitude scales for the region under study. For quantifying variability while making relationships between two scales, it is important to give both magnitude scales equal importance and variability of each scale should be taken into analysis. Since both types of magnitudes, as reported in catalogue, are having errors, the usual meaning of dependent and independent variable fails and the variables can be written as $Y_i = \eta_i + \epsilon_i$ and $X_i = \xi_i + \delta_i$. It is assumed that a straight-line relationship between errors in two magnitude exists and relationship given as $\eta_i = \beta_0 + \beta_1 \xi_i$ holds between the true but unobserved values η_i and the n unknown parameters ξ_i. Based on the above and substituting for ξ_i, Yi can be written as $Y_i = \beta_0 + \beta_1 X_i + (\epsilon_i - \beta_1 \delta_i)$. By fitting the two scales using usual least square fit there will be biased estimates in slope parameter of fitted equation (Draper and Smith, 2005).

All the four cases, namely fit X to Y, equal variance, univariate variance, and specific variance ratiohave been applied to regress the data on given magnitude scales. The relationships obtained are given in following Table 5.1 whereas the equation is written as Y= aX +bin w hich f irst va riable (magnitude va lues) i s de fined as X - coordinate a nd second variable (magnitude values) as Y- coordinate.

Figure 5.3, 5.4, and 5.5 show bivariate fit for M_b- M_s, M_L- M_b, and M_L- M_s, for all the four cas es. The com parison reveals t hat t he er ror c onsideration i n bot h t he m agnitude types to be r egressed f or obt aining t he r elationship i s of pa ramount i mportance and should be c omputed w hile doi ng hom ogenization of m agnitude da ta i n e arthquake catalogue, which in future are to be used for seismic hazard analysis.

Table 5.1: Empirical relationships between different magnitude scales of the form Y= aX+bfor four cases.

	Linear Fit		Fit X to Y		Equal Variance		Univariate Variance		Specific Variance Ratio	
	a	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**B**
M_b- M_s	1.15	-1.08	1.65	-3.37	1.46	-2.51	1.38	-2.12	1.34	-1.98
M_L- M_b	0.59	1.82	0.85	0.81	0.65	1.55	0.70	1.37	0.85	0.81
M_L- M_s	0.83	0.43	1.32	-1.68	1.06	-0.56	1.05	-0.50	1.17	-1.03

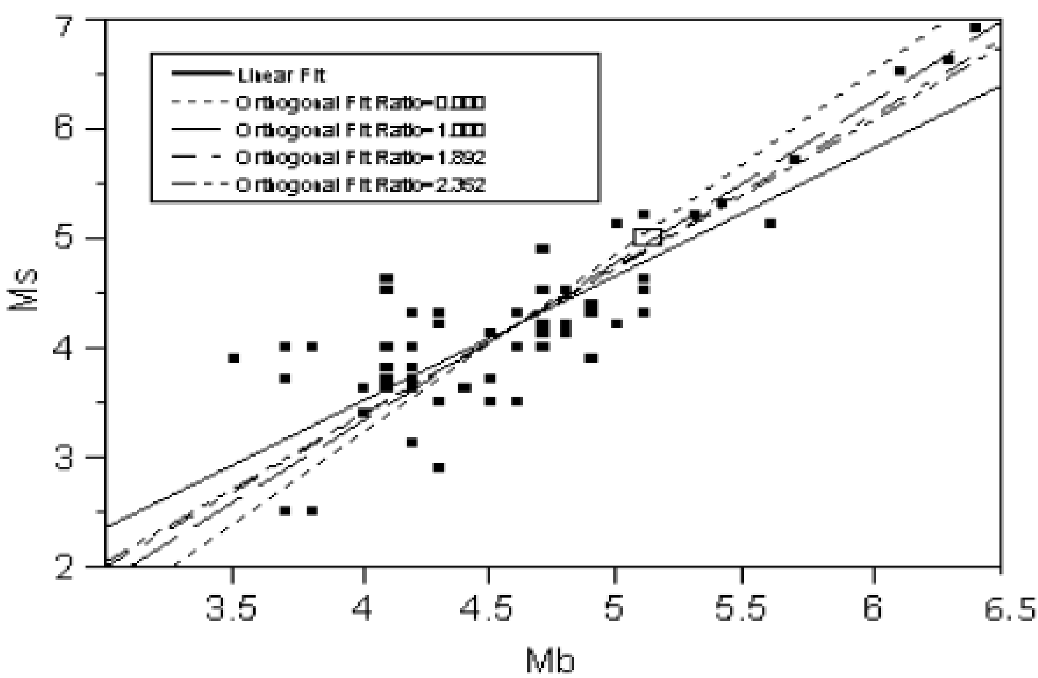


Figure 5.3:Bivariate Fit of $M_b$and Ms

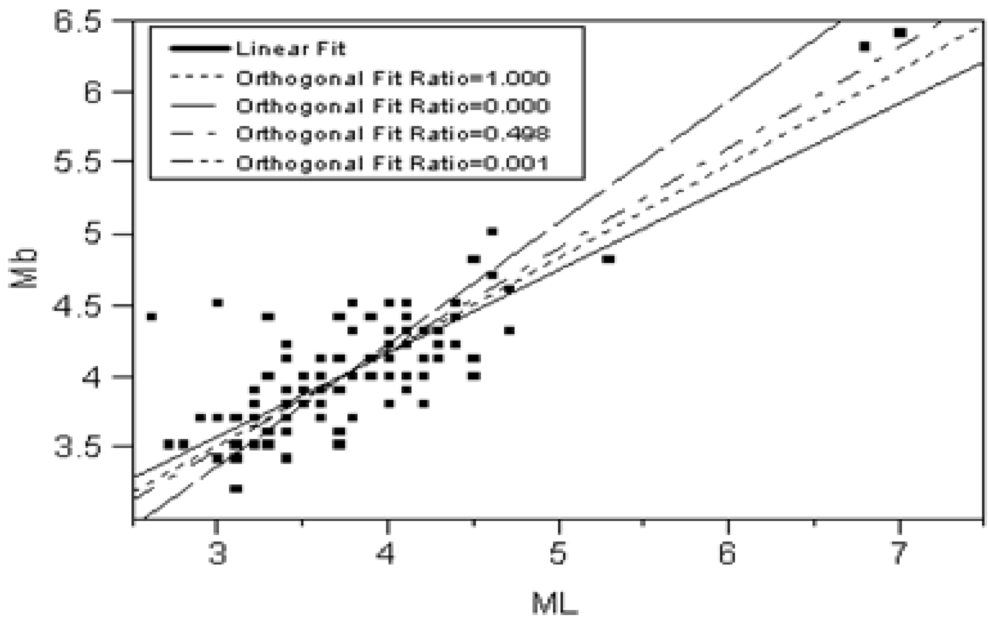


Figure 5.4: Bivariate Fit of M_L and M_b

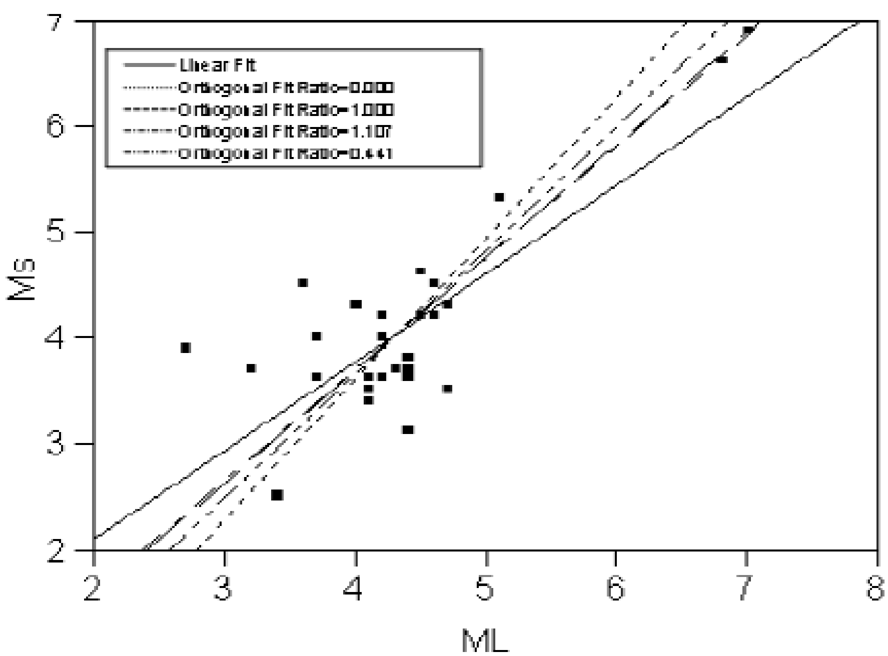


Figure:5.5 Bivariate Fit of M_L and $M_S$scale

Finally the regression as per case IV has been applied to data and the relationship thus obtained for M_b- M_s, M_L- M_b and M_L- M_s are as follows (Joshi and Sharma, 2006).

M_b- M_s: Variance ratio (2.352) $M_S = 1.34M_b-1.98$ (5.1)

M_L- M_b: Variance ratio (0.001) $M_b = 0.85M_L+0.81$ (5.2)

M_L- M_s: Variance ratio (0.441) $M_S = 1.17M_L-1.03$ (5.3)

The presently obtained relationship has been compared with Gutenberg and Richter (1956), Bath (1968), Marshal (1970) and Ameer (2005) in Figure 5.6 for M_b –M_s Scale, with Gibiwioz (1972) for M_b –M_L Scale in Figure5.7 and with Gutenberg and Richter (1956b) for M_s–M_L Scale in Figure5.8.

The comparison of the developed relationships between M_b, M_S and M_L using the bivariate orthogonal curve fitting with known variance ratio for the present study matches well with the relationships developed by Marshal (1970) and Ameer (2005) in lower range of magnitudes, while for higher range of magnitudes it matches with Gutenberg and Richter (1956) relationship. In the middle range of earthquake magnitudes the relationship is matching with Marshal (1970) relationship (see Figure5.7, 5.8 and 5.9). In the higher range of earthquake magnitudes the relationship shows lower values than the other developed relationships. In M_b–M_L Scale the developed relationship show lower values in all ranges of earthquake magnitudes as compared with relationship developed byGibiwioz (1972) and for M_s –M_L Scale the relationship is almost matching with Gutenberg and Richter (1956b) relationship in lower and middle range.

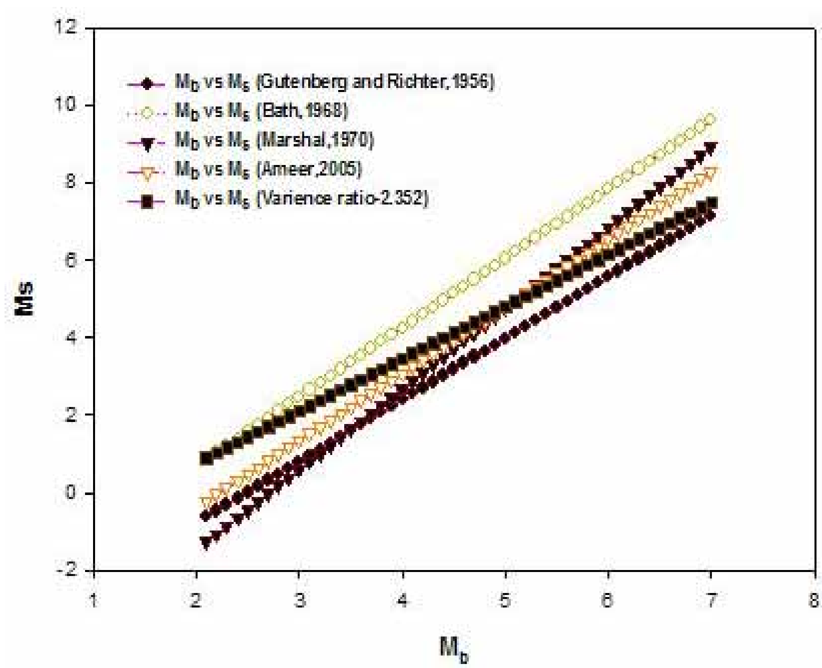


Figure5.6: Comparison between M_b –M_S Scale

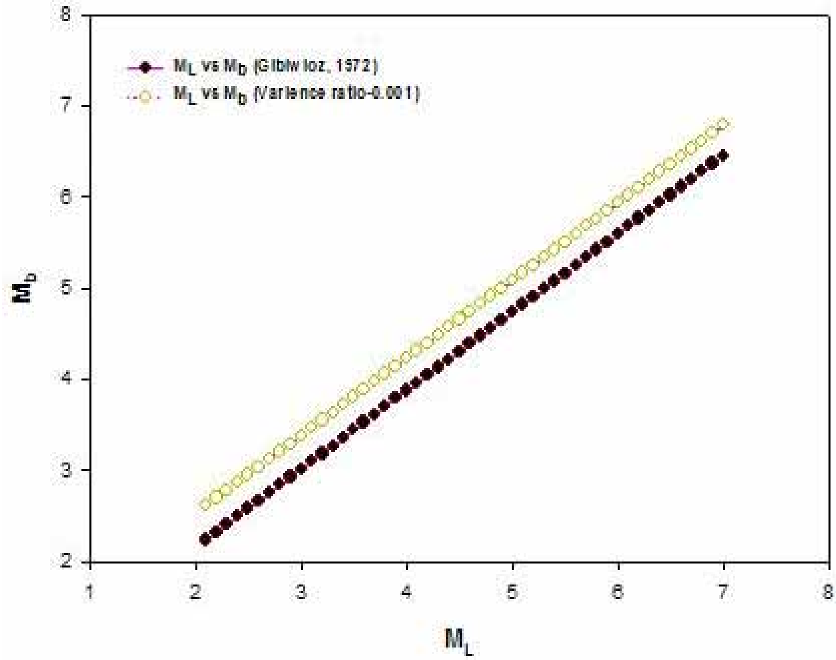


Figure5.7: Comparisons between M_b –M_L Scale

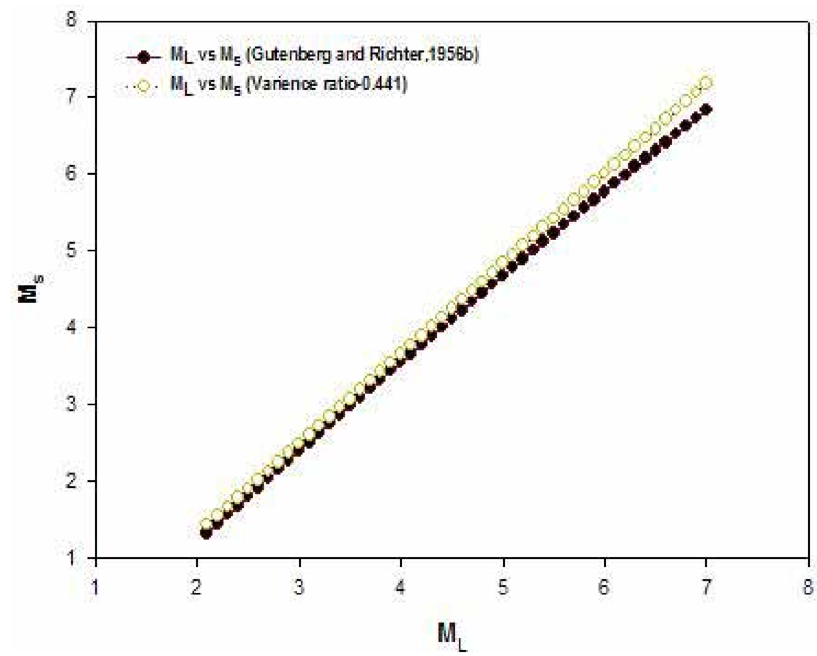


Figure5.8: Comparison between M_S –M_L Scale

5.1.4 Declustering of the Catalogue

The pr obabilistic s eismic ha zard as sessment f ollows the ba sic s tatistical the ories in which the samples are considered as mutually exclusive. The seismicity reported for a region contains the earthquake events along with their foreshocks and aftershocks. The foreshocks and aftershocks, being dependent on the main event, and should therefore be deleted from the catalogue before carrying out any statistical and probabilistic analysis.

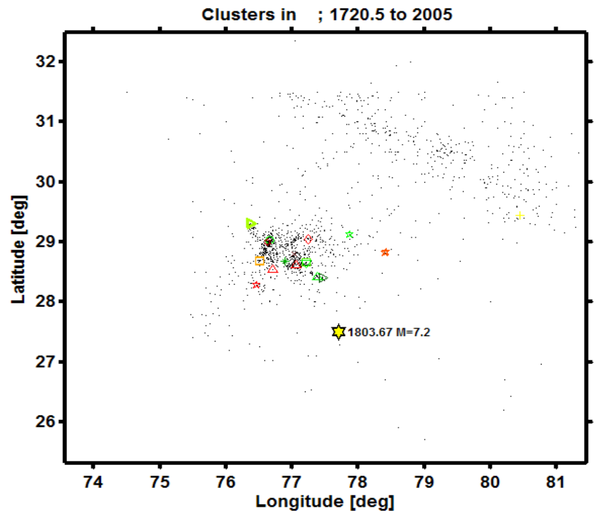


Figure 5.9 Declustered events for the region shown with different coloures

To separate the dependent from the independent seismicity, the earthquake catalogue has been de clustered. T he d ecluster a lgorithm us ed i s ba sed on R easenberg (1985). T he declustring f ound 18 c lusters of earthquakes; A tot al of 2 5 dependent events (out of 1411). The map window shows now 1386 events with magenta colour for the clusters. Figure 5.9 shows the results of the declustering process.

5.1.5 Completeness Analysis of Seismic Data

A method proposed by Stepp (1972) has been applied to determine the interval class over which that class is homogeneous. To analyze the nature of the completeness of the data sample i n detail, earthquakes are gr ouped i n s everal m agnitude cl asses and ea ch magnitude class is modelled as a point process in time. For this analysis the number of earthquakes per decade were grouped in four magnitude ranges, 1.1 < M <2; 2.1 < M <3; 3.1 < M < 4; 4.1 < M < 5; 5.1 < M < 6 and M > 6. Table 5.2 illustrates the rate of occurrence as a function of time interval for different magnitude classes. The rate is given as N/T, where N is the cumulative number of earthquakes in the time interval T. These results are shown in Figure5.10 and Table 5.2.

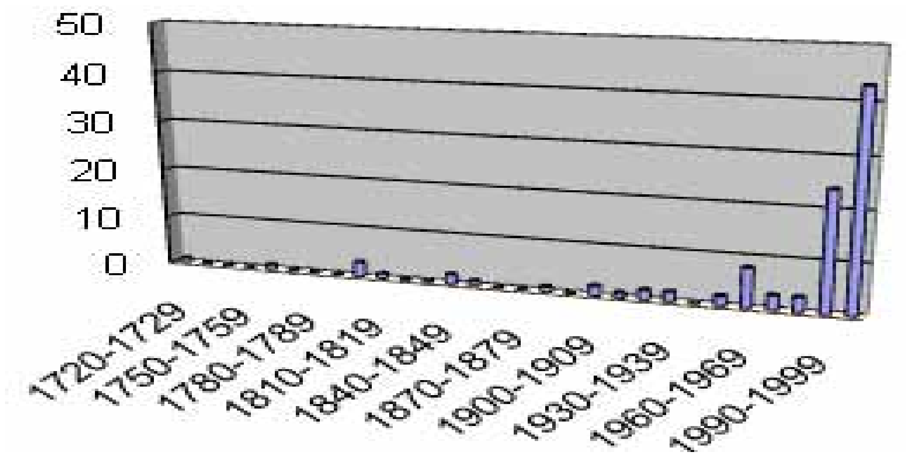


Figure 5.10 Frequency of events per decades

Table 5.2 Rate of occurrence for various magnitude range

TIME	TIME	1.1<M<2		2.1<M<3		3.1<M<4		4.1<M<5		5.1<M<6		M>6	
PERIOD	INT.	N	N/T	N	N/T	N	N/T	N	N/T	N	N/T	N	N/T
2000-2004			41.20		29.80				0.80		0.20		0.00
1990-2004	15	298	19.87	193	12.87	57	3.80	9	0.60	1	0.07	2	0.13
1980-2004	25	324	12.96	203	8.12	58	2.32	10	0.40	1	0.04	2	0.08
1970-2004	35	406	11.60	227	6.49	60	1.71	11	0.31	1	0.03	2	0.06
1960-2004	45	478	10.62	243	5.40	63	1.40	13	0.29	4	0.09	2	0.04
1950-2004	55	478	8.69	243	4.42	63	1.15	13	0.24	6	0.11	4	0.07
1940-2004	65	478	7.35	243	3.74	63	0.97	13	0.20	6	0.09	5	0.08
1930-2004	75	478	6.37	243	3.24	63	0.84	13	0.17	6	0.08	5	0.07
1920-2004	85	478	5.62	243	2.86	63	0.74	13	0.15	8	0.09	5	0.06
1910-2004	95	478	5.03	243	2.56	63	0.66	14	0.15	8	0.08	5	0.05
1900-2004	105	478	4.55	243	2.31	63	0.60	14	0.13	10	0.10	5	0.05
1890-2004	115	478	4.16	243	2.11	63	0.55	14	0.12	10	0.09	5	0.04
1880-2004	125	478	3.82	243	1.94	63	0.50	14	0.11	11	0.09	5	0.04
1870-2004	135	478	3.54	243	1.80	63	0.47	14	0.10	11	0.08	5	0.04
1860-2004	145	478	3.30	243	1.68	63	0.43	14	0.10	11	0.08	5	0.03
1850-2004	155	478	3.08	243	1.57	63	0.41	15	0.10	11	0.07	5	0.03
1840-2004	165	478	2.90	243	1.47	63	0.38	16	0.10	13	0.08	5	0.03
1830-2004	174	478	2.73	243	1.39	63	0.36	16	0.09	13	0.07	5	0.03
1820-2004	185	478	2.58	243	1.31	63	0.34	16	0.09	13	0.07	5	0.03
1810-2004	195	478	2.45	243	1.25	63	0.32	16	0.08	13	0.07	6	0.03
1800-2004	205	478	2.33	243	1.19	63	0.31	16	0.08	14	0.07	8	0.04
1790-2004	215	478	2.22	243	1.13	63	0.29	16	0.07	14	0.07	8	0.04
1780-2004	225	478	2.12	243	1.08	63	0.28	16	0.07	14	0.06	8	0.04
1770-2004	235	478	2.03	243	1.03	63	0.27	16	0.07	14	0.06	8	0.03
1760-2004	245	478	1.95	243	0.99	63	0.26	16	0.07	15	0.06	8	0.03
1750-2004	255	478	1.87	243	0.95	63	0.25	16	0.06	15	0.06	8	0.03
1740-2004	265	478	1.80	243	0.92	63	0.24	16	0.06	15	0.06	8	0.03
1730-2004	275	478	1.74	243	0.88	63	0.23	16	0.06	15	0.05	8	0.03
1720-2004	285	478	1.68	243	0.85	63	0.22	16	0.06	15	0.05	9	0.03

For each magnitude interval in Figure5.11, the plotted points are supposed to define a straight-line relation, as long as the data set for that magnitude interval is complete. For a given seismic region, the slope of the lines for all magnitude intervals should be the same and should be equal to the slope of $1/\sqrt{T}$ line, as long as data arecomplete.

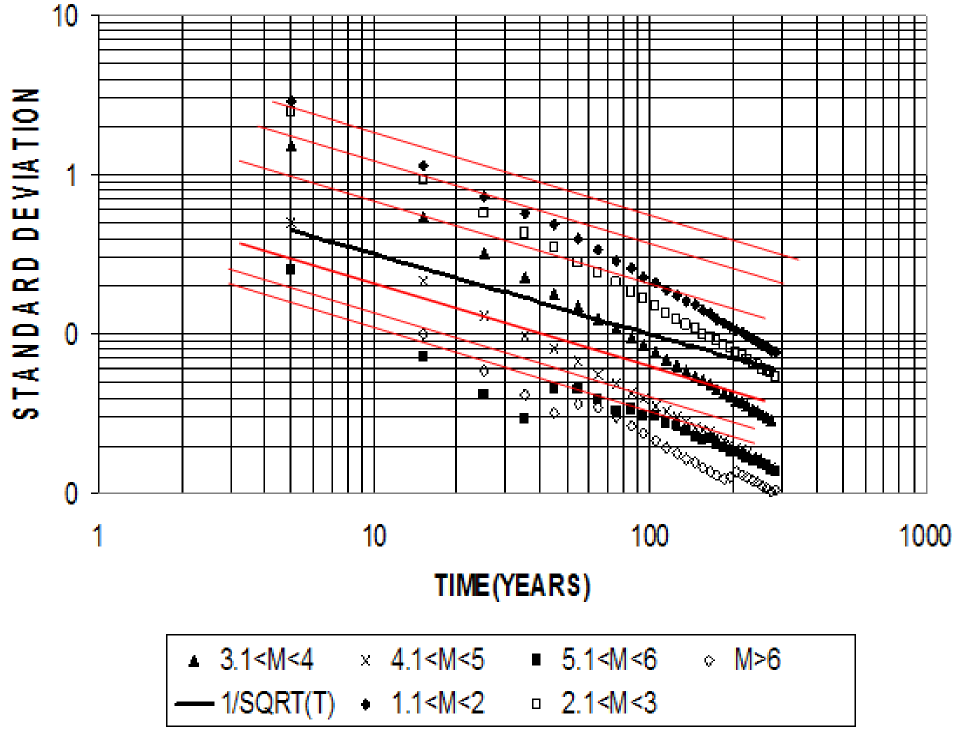
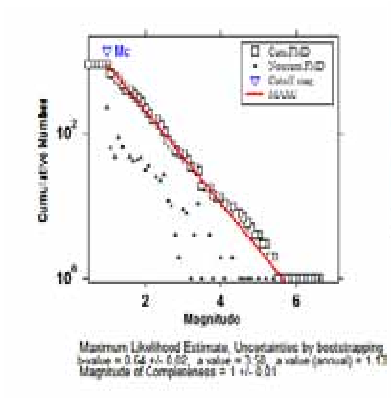


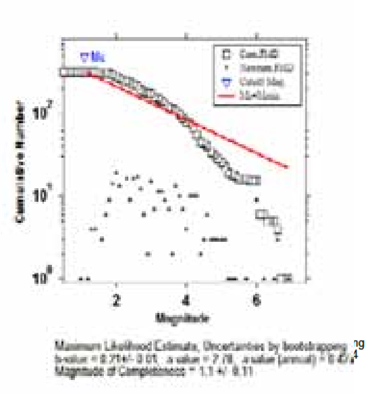
Figure 5.11: Standard deviation of the estimate of the mean of the annual numberof events as a function of sample length and magnitude class

5.1.6: Estimation of a, b and M_c

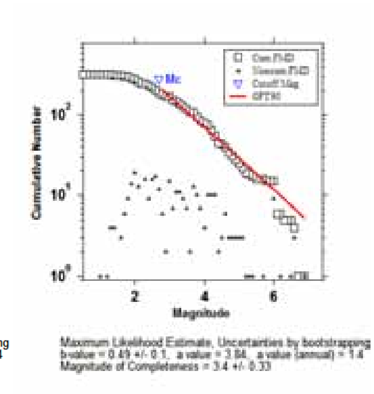
A critical issue to be addressed before carrying out seismic hazard analysis is to assess the quality, consistency, and homogeneity of the earthquake catalogue. In addition to the completeness being checked (as described in the last section), the catalogue prepared thus should undergo a quality check especially for cut off magnitude which has direct bearing on the estimation of 'a' *and* '*b*' values of Gutenberg Richter relationship. Different - methods have been used for estimation of a, b and M_c values for the catalogues (for complete part only) and all the four sources namely, Himalaya (HIM), Delhi Haridwar Ridge (DHR), Moradabad fault (MOR) and Rajasthan Great Boundary Fault (RGBF).



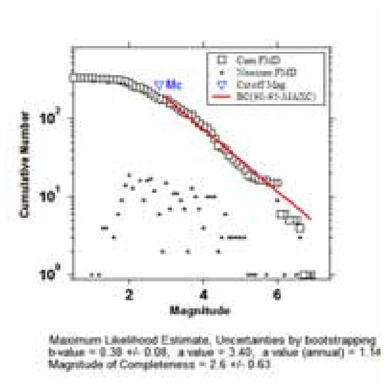
M1



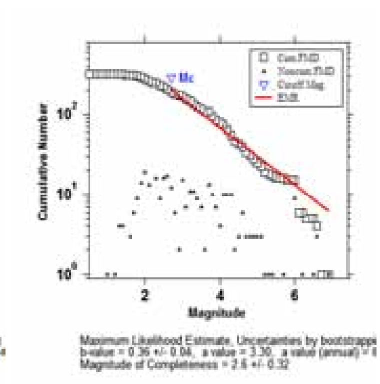
M2



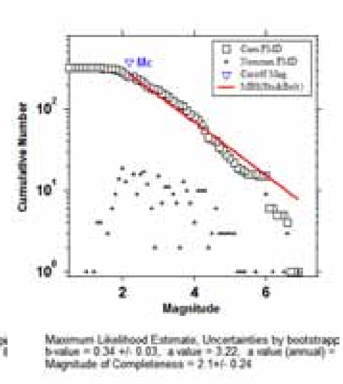
M3



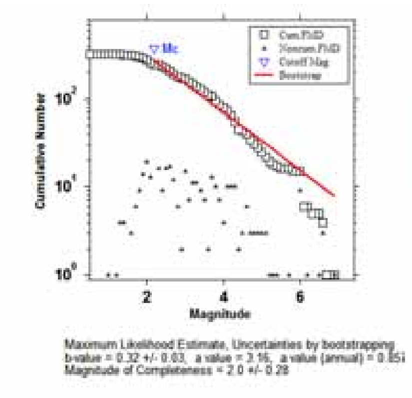
M5



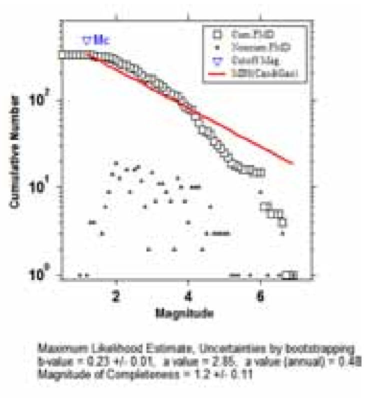
M6



M7



M8



M9

Figure 5.12: Estimation of M_c for HIM source zone using different methods

The methods include the estimation of a, b and M_c are Maximum Curvature method (M1), Fixed $M_c = M_{min}$ (M2), goodness of fit M_c90 (M3) and M_c95 (M4), best combinations of M_c90 and M_c95 and maximum curvature (M5), Entire Magnitude Range (EMR) (M6), Shi and Bolt (1982) method (M7), Bootstrap method (M8) and Cao and Gao (2002) method (M9). In this study the free code of seismicity analysis software package ZMAP (Wiemer, 2001), which is written in Mathworks' commercial software language Matlab, has been used. Figure 5.12 shows the estimation of a, b and M_c using these methods for HIM source.The results for all methods and sources are tabulated in Table 5.3 where a, b and M_c values are shown for the four sources using all the nine methods (Joshi and Sharma, 2008).

5.1.7: Estimation of M_{max}

The maximum magnitude is an important variable in the seismic hazard estimation as it reflects maximum potential of strain released in larger earthquakes. The instrumental and historical records of earthquakes are often too short to reflect the full potential of faults or thrusts. The maximum regional magnitude, M_{max}, is defined as the upper limit of magnitude for a given region or it is magnitude of largest possible earthquake. In other words it is a sharp cut-off magnitude at a maximum magnitude M_{max}, so that, by definition, no earthquakes are to be expected with magnitude exceeding M_{max}.

Table 5.3: Estimation of a, b and Mc values for all sources using different methods

		DHR	HIM	MOR	RGBF
M1	a	3.58	3.27	2.33	1.56
	b	0.64±0.02	0.35±0.02	0.45±0.13	0.27±0.01
	Mc	1±0.01	2.4±0.4	2.0±0.84	2.6±1.9
M2	a	3.59	2.78	1.92	1.50
	b	0.64±0.02	0.21±0.01	0.31±0.05	0.24±0.06
	Mc	1±0.01	1.1±0.11	1±0.01	1±0.05
M3	a	3.56	3.84	-	-
	b	0.62±0.02	0.49±0.01	-	-
	Mc	1±0.07	3.4±0.33	-	-
M4	a	3.67	-	-	-
	b	0.66±0.02	-	-	-
	Mc	1.6±0.04	-	-	-
M5	a	3.59	3.40	2.29	1.56
	b	0.63±0.01	0.38±0.08	0.44±0.11	0.27±0.01
	Mc	1.1±0.24	2.6±0.63	2.0±0.92	2.6±1.9
M6	a	-	3.30	2.25	-
	b	-	0.36±0.04	0.45±0.01	-
	Mc	-	2.6±0.32	2.1±0.22	-
M7	a	3.63	3.22	-	-
	b	0.64±0.05	0.34±0.03	-	-
	Mc	1.5±0.16	2.1±0.24	-	-
M8	a	3.64	3.16	-	-
	b	0.65±0.04	0.32±0.03	-	-
	Mc	1.5±0.17	2.0±0.28	-	-
M9	a	3.42	2.85	-	-
	b	0.55±0.02	0.23±0.01	-	-
	Mc	1.1±0.01	1.2±0.11	-	-

The probabilistic approach for estimating the maximum regional magnitude M_{max} was suggested by Kijko and Sellevoll (1989) based on the doubly truncated G-R relationship. It has been further refined by Kijko and Graham (1998) to consider the uncertainties in the input magnitude data. M_{max} from Kijko-Sellevoll-Bayes estimator is obtained following Kijko and Graham, (1998 and 2001). The results showing the values of λ, β and M_{max} are given in Table 5.4 (Joshi and Sharma, 2008) .The general trend of the variance has quite a lot of effect on the seismic hazard estimation.

Table 5.4: Estimation of λ, β and M_{max} for all sources using various methods

		DHR	HIM	MOR	RGBF
M1	λ	15.33±0.58	9.94±0.64	1.56±0.30	0.30±0.11
	β	1.55±0.03	0.88±0.03	1.0±0.14	0.62±0.02
	M_{max}	6.90±0.42	6.95±0.30	7.02±0.37	7.45±0.39
M2	λ	15.33±0.58	6.93±0.36	1.05±0.16	0.46±0.11
	β	1.55±0.03	0.50±0.01	0.67±0.06	0.62±0.02
	M_{max}	6.90±0.42	6.92±0.30	6.91±0.32	7.40±0.36
M3	λ	17.76±0.63	5.28±0.48		
	β	1.53±0.03	1.12±0.02		
	M_{max}	6.84±0.38	6.99±0.31	-	-
M4	λ	19.77±0.99			
	β	1.53±0.02			
	M_{max}	6.82±0.31	-	-	-
M5	λ	12.44±0.53	9.47±0.68	1.56±0.29	0.30±0.11
	β	1.45±0.03	1.01±0.05	0.99±0.13	0.62±0.02
	M_{max}	6.84±0.38	6.97±0.31	7.07±0.40	7.45±0.39
M6	λ		9.23±0.63	1.37±0.27	
	β		0.97±0.04	1.03±0.02	
	M_{max}	-	6.96±0.31	7.12±0.44	-
M7	λ	7.88±0.42	11.0±0.67		
	β	1.51±0.05	0.85±0.03		
	M_{max}	6.90±0.42	6.95±0.30	-	-
M8	λ	7.88±0.42	11.6±0.68		
	β	1.51±0.04	0.83±0.03		
	M_{max}	6.90±0.42	6.95±0.30	-	-
M9	λ	12.99±0.53	6.88±0.36		
	β	1.35±0.03	0.54±0.01		
	M_{max}	6.77±0.34	6.93±0.30	-	-

For example the b-value varies from 0.21 ± 0.01 to 0.66 ± 0.02, which obviously is not the case with this area. Keeping in view the high variability the estimation of seismic hazard parameters was revisited. The M_c was estimated by eye fitting as given in Figure 5.13 and Figure 5.14 for the Himalayan region and the rest of the zones. This was necessitated because the variance in seismic hazard parameters can be attributed to the sporadic and intermittent reporting of micro-earthquake in the catalogue. The micro-earthquake data were filtered and a new catalogue was found for further analysis (Figure 5.15). The earthquakes were plotted on the tectonic map after filtering of earthquakes with magnitudes less than 3.0 as shown in Figure5.16.

The b-value has been reported to be representation of the region and not the individual sources (Habermann, 1996). The area was therefore divided into two parts i.e., the part of HIMALAYAN region within 350km from Delhi and the rest of ar eaviz. DELHI-MORADABAD-RAJASTHAN (DMR) region counting of three source zones namely DHR, MOR and RGBF. The 'a' and 'b' values were recalculated for these two areas. The b-value was assigned as 0.59±0.030 forHIMALAYAN region and 0.42±0.012 for the DELHI-MORADABAD-RAJASTHAN (DMR) region. Again, a-value was re-distributed based on the area of the seismogenic source zones. A maximum magnitude (M_{max}) value for two regions was also calculated using maximum likelihood approach given by Kijko and Graham (1998). These estimated 'a' and 'b' values and its corresponding λ and β values and maximum magnitude (M_{max}) used for the study are shown in Table 5.5.

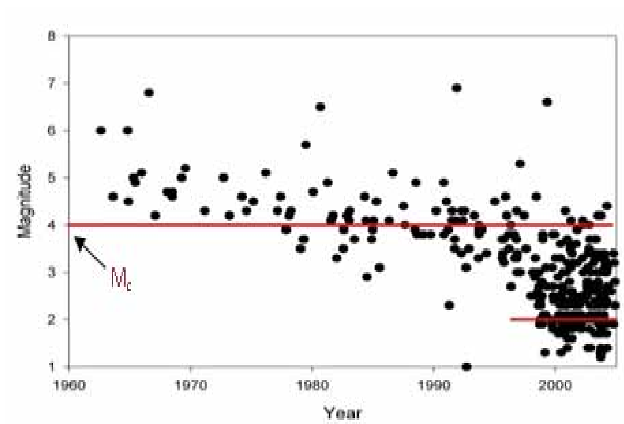


Figure 5.13 The magnitude vs. time plot for HIMALAYAN region microearthquake data included)

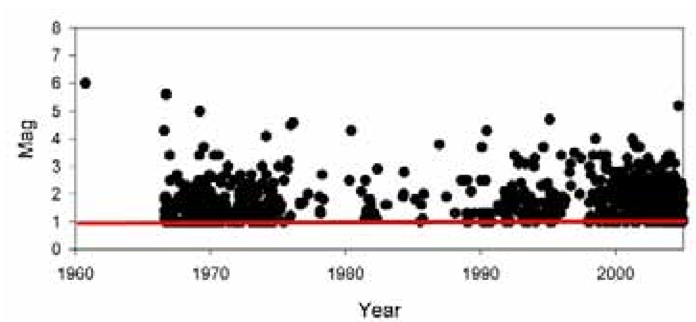


Figure 5.14 The magnitude vs. time plot for DMR region (microearthquake data included)

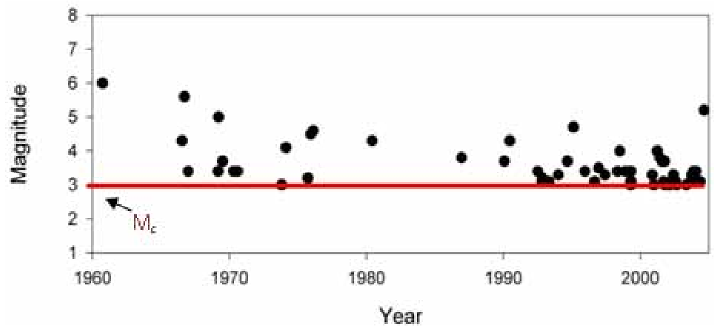


Figure 5.15 The magnitude vs. time plot for the catalogue C2 for DMR region (microearthquake data filtered)

Table 5.5 Parameters used for the seismic hazard assessment

Parameter	HIM	DHR	MOR	RGBF
a	2.64±0.16	0.93±0.08	0.62±0.08	0.89±0.08
b	0.59±0.03	0.42±0.012	0.42±0.012	0.42±0.012
M_c	4.0	3.0	3.0	3.0
M_{max}	7.2±0.37	6.42±0.47	6.42±0.47	6.42±0.47
λ	1.93±0.21	0.48±0.08	0.23±0.038	0.44±0.071
β	1.35±0.37	0.96±0.03	0.96±0.03	0.96±0.03

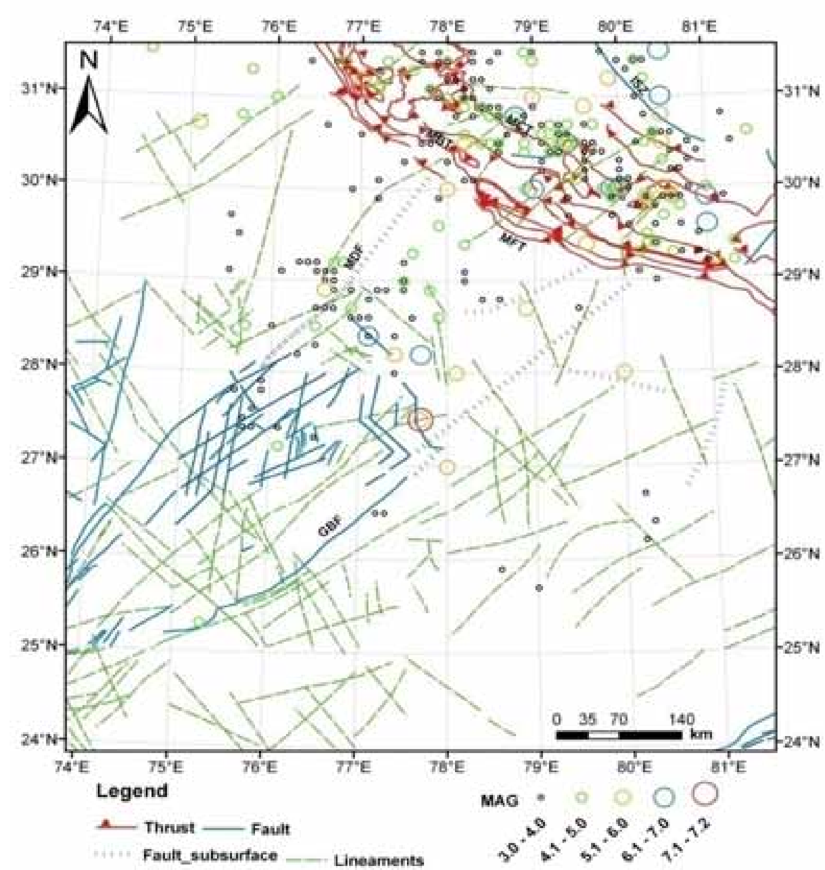


Figure 5.16: Seismotectonic map of the region around Delhi showing earthquake events and its epicenters greater than magnitude 3.0 (M_s Scale)

5.2 GROUND MOTION PREDICTION EQUATIONS

One of the important components of seismic hazard estimation is the prediction of strong ground motion (SGM). There are, rarely sufficient number of ground motion recordings available near a site or in an area for carrying out seismic hazard analysis to allow a direct estimation of the strong ground motions. It is therefore necessary to develop empirical relationships, for estimating ground motions in terms of magnitude, distance, site conditions, and other variables from the set of strong-motion data from a large region or specific tectonic set up.

Since no strong motion data are available from the region under study, use of spectral attenuation relationship based on world wide data has to be made and such relationships are known as Ground Motion Prediction Equations (GMPE). A judicious decision to estimate ground motion is therefore required for adoption in any particular situation. In the present case the spectral attenuation relationships were explored for use in Northern Indian region. The spectral attenuation relationships for the shallow crustal earthquakes are generally available.

The important points considered for selection of the GMPEs were –tectonic enviroment, focal depths, parameters available in present case vis-à-vis used in the relationship, spectral peroids for which the strong ground motion is available, etc.The GMPEs used in the present work are developed by Abrahamson and Silva (1997), Sadigh et al. (1997) and Boore and Atkinson (2008) to estimate the strong ground motion.

5.3 SEISMIC HAZARD ASSESSMENT OF NCT DELHI

The well established Probabilistic Seismic Hazard Analysis (PSHA) which was developed by Cornell (1968) and Algermissen et al., (1982) has been carried out for Delhi under collaborative project with IIT Roorkee. In the present study the CRISIS (version released in 2007) computer code for seismic hazard assessment (Ordaz et al., 2003) has been applied. The code accommodates uncertainty in a number of seismicity model parameters, and has a user-friendly interface. It accepts polygon-dipping areas as well as fault sources, and also facilitates characteristic earthquake recurrence models. CRISIS computes seismic hazard using a probabilistic model that considers the rates of occurrence, attenuation characteristics and geographical distribution of earthquakes. The seismotectonic modelling of the region around Delhi has been carried out as detailed in previous section 5.1.2 and the seismogenic sources namely DHR, HIM, MOR and RGBF have been considered for the PSHA as areal as well as line sources. The seismic hazard parameters namely λ, β and M_{max} have been estimated and are given in Table 5.5 have been used along with the three strong ground motion attenuation relationships as described above in section 5.2. The following sections describe the results obtained for the seismic hazard in Delhi.

5.3.1 Formulation of Logic Tree

For formal and quantitative treatment of uncertainties logic tree approach has been used. Logic tree analysis consists of specifying a sequence of assessments in a sequential manner. Logic tree consisting of three nodes: source, method of estimating seismic hazard parameters and ground–motion attenuation model, has been used. The structure of logic tree for assessment of seismic hazard parameters is shown in Figure 5.17. Two categories of seismic source zones has been split into two branches namely line and areal for the seismogenic sources viz. Delhi-Haridwar ridge (DHR), Himalaya(HIM), Moradabad (MOR) and Rajasthan Great Boundary (RGBF) zones. Second node is for seismic hazard parameters. The third attenuation model node consists of three branches accounting for three different attenuation relationships viz., Abrahamson and Silva (1997), Sadigh et al., (1997) and Boore and Atkinson (2008).

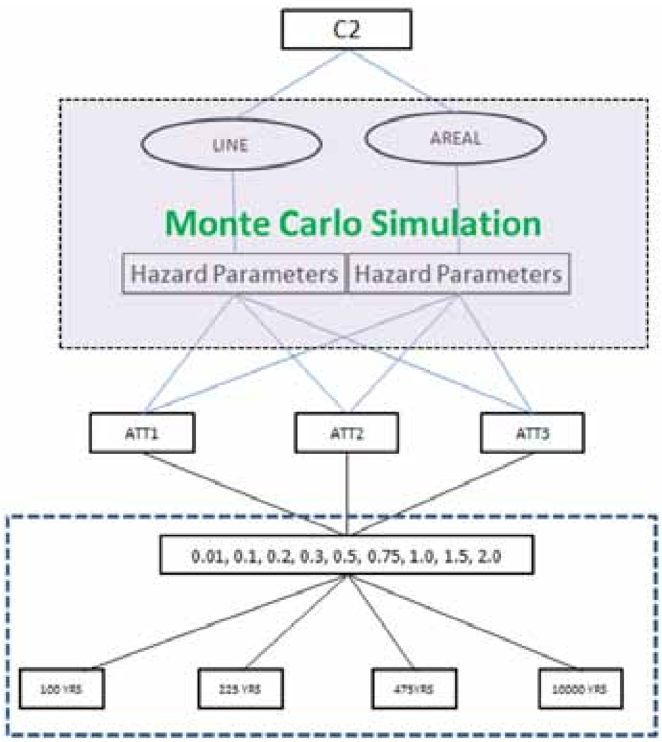


Figure 5.17: Logic tree-Monte Carlo simulation to estimate Strong Ground motion (SGM) and uncertainty

Logic tree approach has been used for this study by adding the Monte-Carlo simulation to generate seismic hazard parameters for each sesimogenic source zones described above at section 5.1.2 "Seismotectonic Modelling".To estimate the COV values Monte-Carlo simulation has been used to generate 100 samples of each of the parameters forboth type of source models (line and areal)shown in figure 5.2(left panel), andfigure 5.2(right panel). Crameret al. (1996) and Lombardi et al., (2005) have used 100 samples for such type of analysis. Some more trials with more simulations (up to 1000) do not show significantly different result (Lombardi et al., 2005). In the present study 100 samples were chosen to look for the variability in the results. Only one branch-point parameter has been varied at a time and the remaining parameters were held fixed to mean values so that COV varies about mean ground motion hazard and produce the variability of the concern parameter only.

5.3.2: Estimation of Strong Ground Motion for Delhi

The grid on which the strong ground motion is estimated is given in Figure 5.2(left panel) and 5.2(right panel). The mean PGA values (spectral acceleration at 0.01second)have been estimated for the return periods 100, 225, 475 and 2500 years. The return periods have been selected based on the parameters being used in earthquake engineering. While 100 years return period gives the idea of the hazard in the area in next 100 years, the 225 year and 475 year return periods and so on. The MCE (Maximum Considered

Earthquake) corresponds to the 2 % exceedance value in 50 years which is equivalent to the 2475 years return period.

(i) The mean PGA values for Delhi region for the 100 years return period varies from 0.04g to 0.07g

(ii) The mean PGA values for Delhi region for the 225 years return period varies from 0.06g to 0.11g

(iii) The mean PGA values for Delhi region, for the 475 return period, varies from 0.09g to 0.16g.

(iv) The mean PGA values for Delhi, region for the 2500 return period, varies from 0.18 to 0.31g

The spectral acceleration in terms of PGA has also been estimated for the periods of 0.1 sec, 0.3 sec and 1.0 seconds. In single degree of freedom the spectral periods of 0.1 sec, 0.3 sec and 1.0 seconds corresponds to approximately single, three and ten story buildings respectively. These are the type of buildings generally found in Delhi.

In the second part ground response study, mean PGA values (spectral acceleration at 0.01second) and variation of the covariances (COV) mapsfor Delhi region for 10 % exceedance values in 50 years for design basis earthquakes and 2 % exceedance value in 50 years (Maximum Considered Earthquake) have been used and shown in Figure5.18 &5.19respectively.

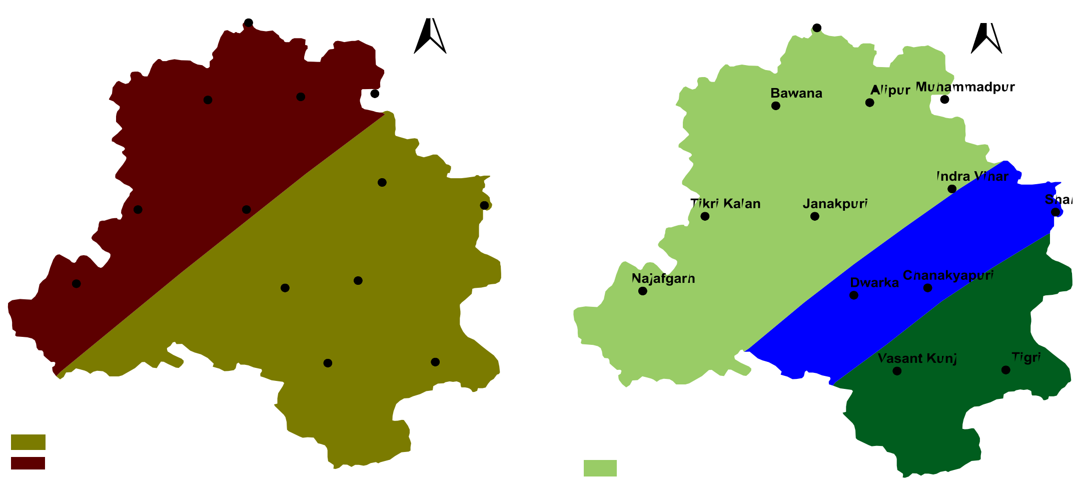


Figure5.18: Left panel, Mean PGA Mapfor Delhi region for 475 Years return period (T); right panelPGA COV Map 475 Years return period (T)

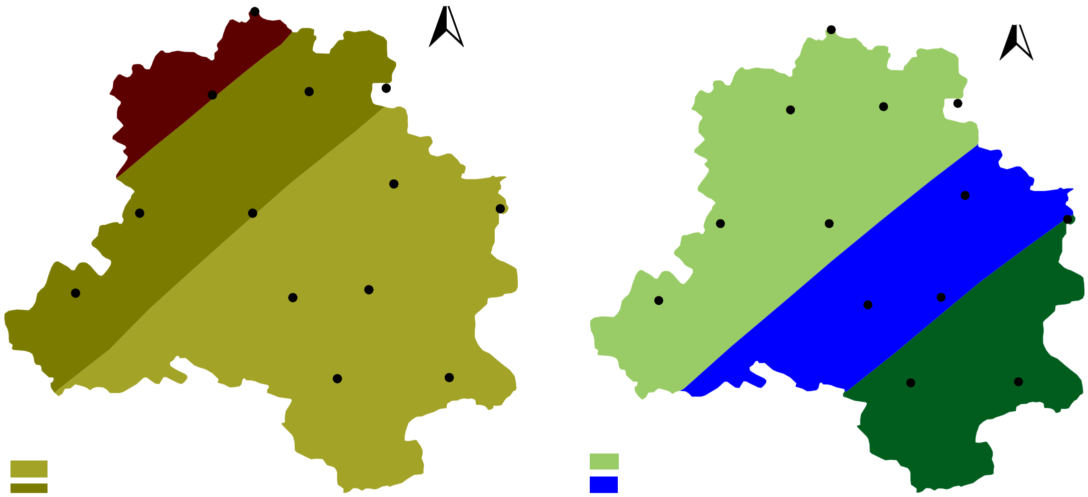


Figure5.19 Left panel, mean PGA Map for Delhi region for 2500 Years return period (T) and right panel, PGA, COV Map 2500 Years return period (T)

5.4: UNIFORM HAZARD RESPONSE SPECTRA (UHRS)

Traditionally, peak ground acceleration (PGA) has been used to characterize the strong ground motion. However, in recent times, the preferred parameter has been the spectral acceleration (S_a). It may be pointed out that the old practice of scaling a normalized response spectral shape to the design PGA level leads to different probability of exceedance over the frequency range of civil engineering structures. The present approach in engineering practice is to use design response spectra, with equal probability of exceedance over the entire frequency range of interest. Such design spectra are known as Uniform Hazard Response Spectra (UHRS). For estimating UHRS, seismic hazard curves, $S_a$are computed for a range of frequency values. From these hazard curves, response spectra for a specified probability of exceedance over the entire frequency range of interest are obtainedat various places in Delhi. The response spectra for various return periods have also been estimated. The places have been shown in Figure 5.20 on Delhi map where UHRS have been generated. The estimated UHRS at three sites for return period of 475 year and 2500 year are shown in Figure5.21(left & right)- 5.23(left & right) along with mean and mean ± sigma respectively. The general shape of the spectra reveals that these can be extended to whole Delhi either taking the closest to the site of interest or by normalising the general shape and multiplying by the PGA in that area.

Figure 5.20 Location at which response spectra have been generated for different return periods

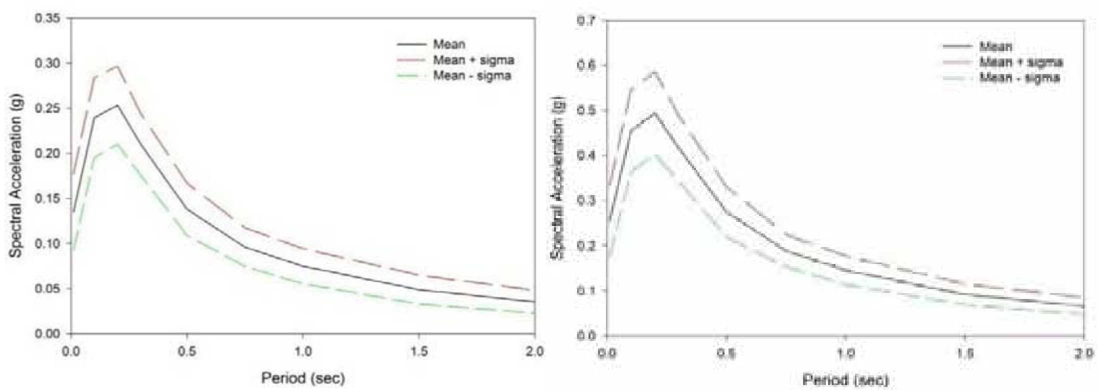


Figure5.21 Response spectra at Alipur (left) 475 years return period (right) 2500years

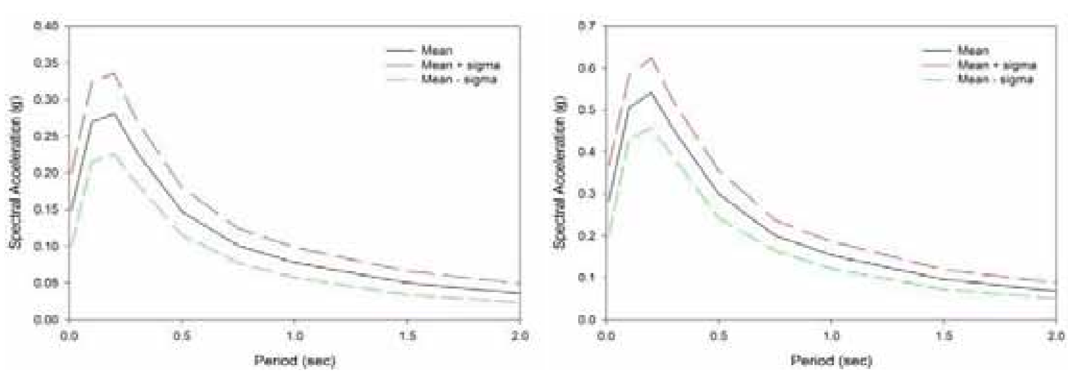


Figure 5.22 Response spectra at Bawana(left)) 475years return period (right) 2500 years return period

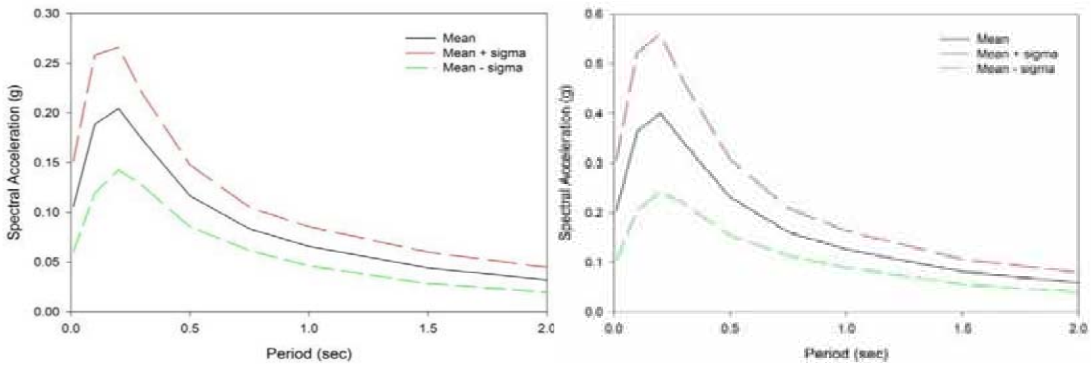


Figure 5.23 Response spectra at Tigri (left) 475 years return period (right) 2500 years return period

5.5: FREE SURFACE CORRECTION

In the previous sections Probabilistic Seismic Hazard maps for different probability of exceedance providing Peak Ground Acceleration and Spectral acceleration values at different sites for different periods and subsequent uniform hazard response spectra have been generated at engineering bedrock level having shear wave velocity of about 760m/s based on Ground Motion Prediction Equations (GMPE) and PSHA. The PGA calculated at the Bedrock using Ground Motion Prediction Equations (GMPE) is actually ascertained at out crop. Therefore, to make them use as incident wave to the bedrock PGA, free surface correction need to be applied.Sketch showing free surface correction is given in Figure 5.24

In view of the above, to incorporate free surface correction, amplitude of spectral acceleration values at different sites and subsequently response spectra evaluated, have been divided by a factor of 2 for accounting free surface correction.

In the present study, the PGA map (spectral acceleration map at .01s) for 10% probability of exceedance in 50 years corresponde to design basis earthquake of retun period 475 -year and 2% probability of exceedence in 50 years correspond to Maximum Considered Earthquakes for return period of 2500 years are obtained after applying free surface correction and presented as Figures5.25&5.26 respectively. The PGA values for 10% probability of exceedance in 50 years vary from .04g to 0.08g andfor 2% probability of exceedance in 50 years vary from .08g to 0.16g. Response spectra are also thus normalized such that the zero frequency response at the free surface is 2.

This is what the response would be at the surface in the absence of any near surface layer or gradient, and this normalization thus shows the relative amplification due to differences in near-surface structure. A few typical normalized response spectra at bedrock level for DBE and MCE for sites Alipur, Bhawana, and Tigri used for further study are shown in Figure 5.27(left & right)-5.29(left & right) respectively.

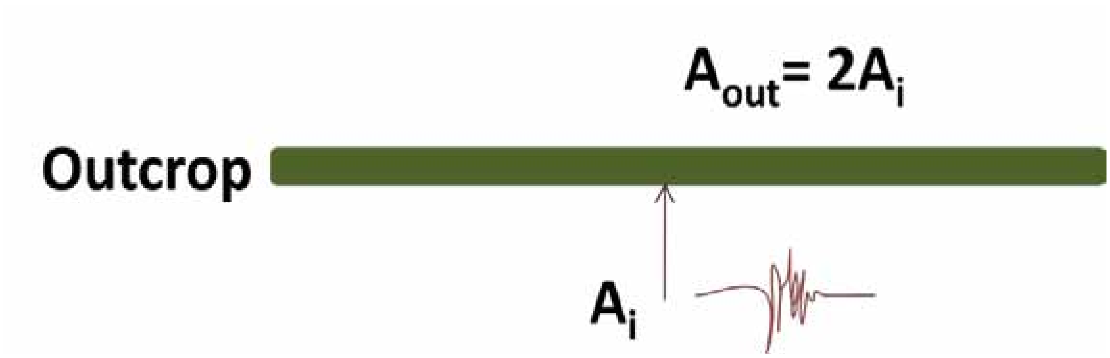


Figure5.24: Sketch showing free surface correction

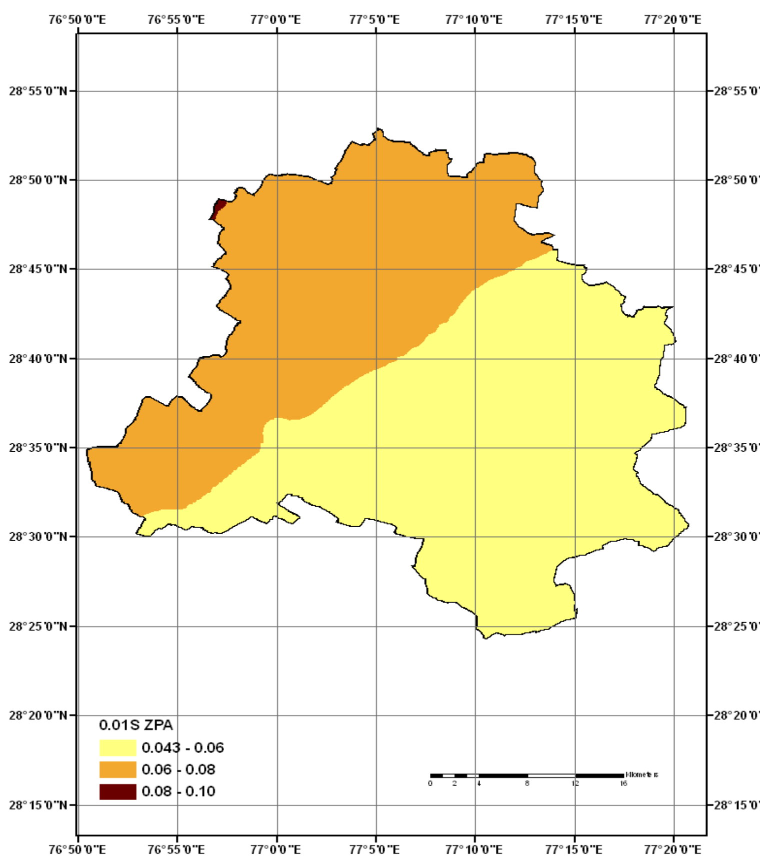


Figure5.25 Spectral Acceleration map for the period 0.01s (ZPA) after applying free surface correction for 10% probability of exceedance in 50 years (return period 475 years) at engineering bedrock (Vs 760 m/s).

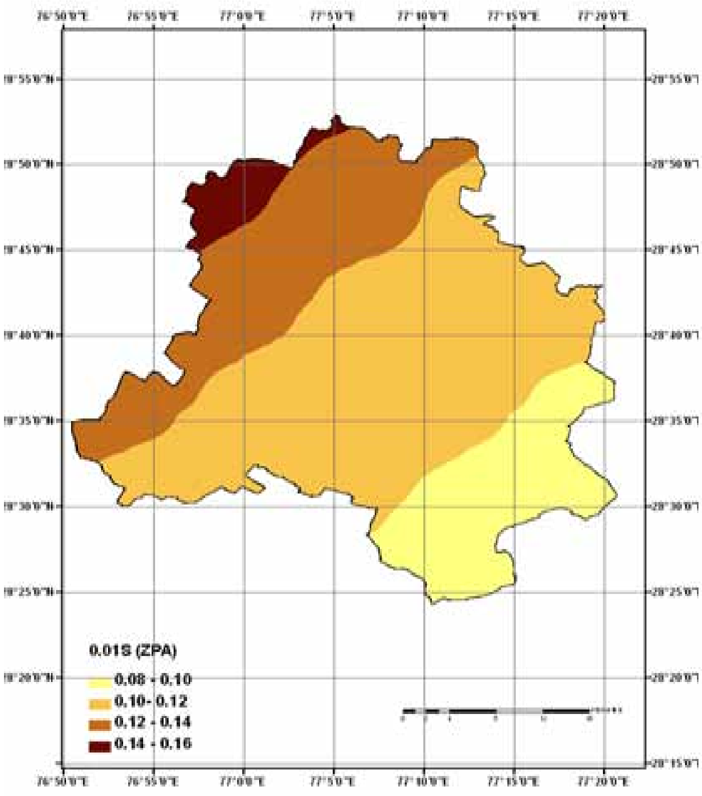


Figure 5.26 Spectral Acceleration map for the period 0.01s (ZPA) after applying free surface correction for 2% probability of exceedance in 50 years (return period 2500 years) at engineering bedrock (Vs 760 m/s).

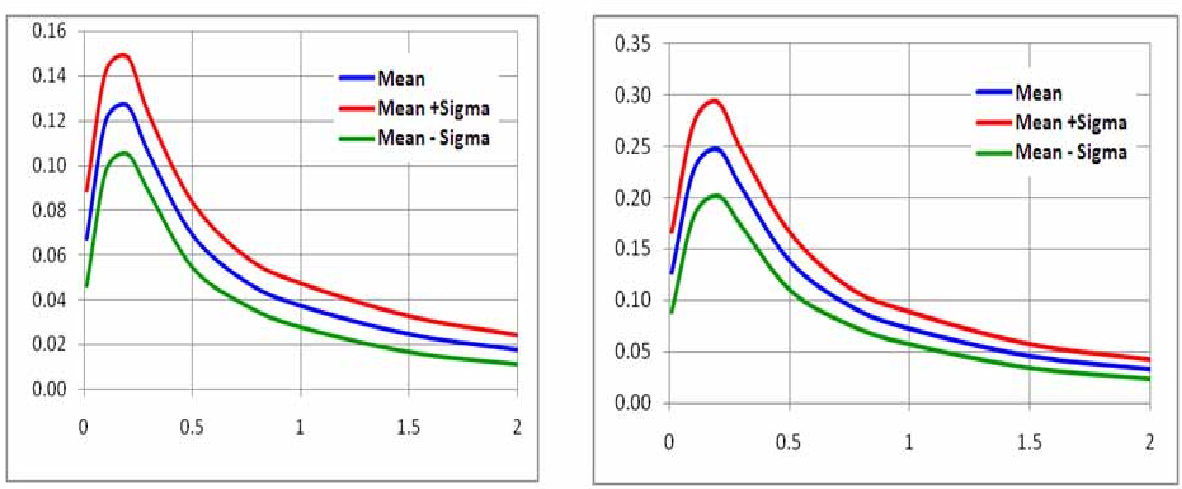


Figure 5.27 Response spectra for site Alipur after free surface correction for (left) 475 year return period and (right) 2500 year return period

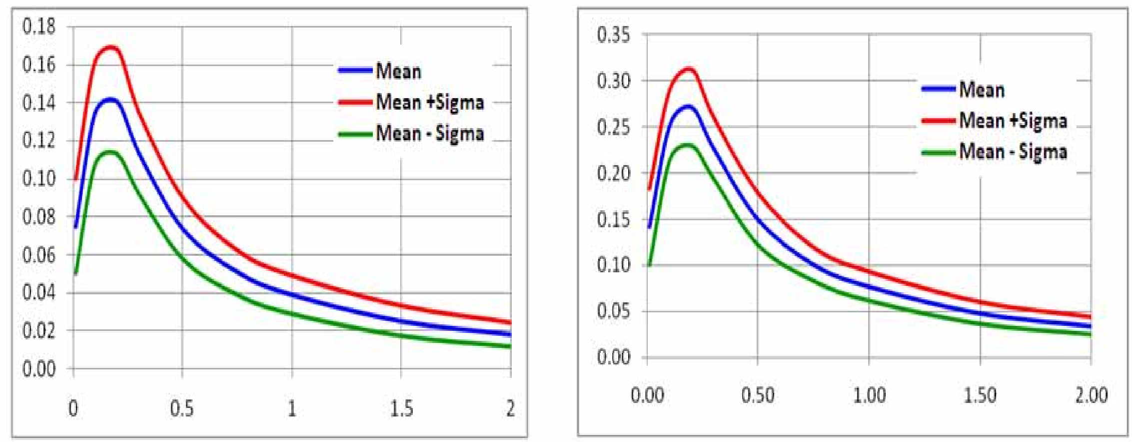


Figure 5.28 Response spectra for site Bhawana after free surface correction for (left) 475 year return period and (right) 2500 year return period

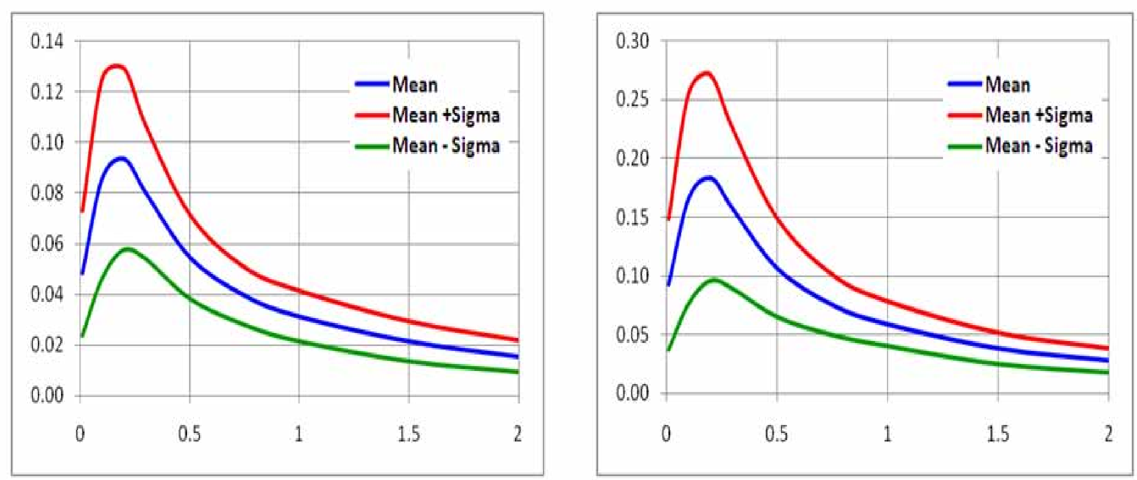


Figure5.29 Response spectra for site Tigri after free surface correction for (left) 475 year return period and (right) 2500 year return period

5.6 GENERATION OF SPECTRUM COMPATIBLE GROUND MOTION TIME HISTORIES

Ground response analysis requires a realistic ground motion as input to the engineering bedrock (Shear wave velocity around 760m/s). No actual strong motion recordis available for scenario of Delhi. Even if such recordings were available, there is no basis to expect that a future earthquake might generate same or similar ground motion. For engineering purposes, it is not necessary to produce each time history exactly to describe the ground motion adequately. It is necessary, however, to be able to describe the characteristics of the ground motion that are of engineering significance and to identify a number of ground motion parameters that reflect those characteristics. For engineering purposes, three characteristics of earthquake motion are of primary significance (i) The amplitude (ii) Frequency content and (iii) duration of motion. It is, therefore, essential that for ground response analysis, synthetic time history is to be generated which should be realistic for the specific site and match target ground motion parameters such as peak acceleration, velocities or spectral ordinates represented by uniform hazard response spectra detailed at para. 5.4.

Synthetic time histories can be developed in a number of ways. The most commonly used methods for generation of synthetic ground motions fall into four main categories:

(a) Modification of actual ground motion records,
(b) Generation of artificial ground motions in time domain,
(c) Generation of artificial motions in frequency domain, and
(d) Generation of artificial ground motions using Green's function techniques.

In the present study as the time history of ground motion is required as input motion, Synthetic time histories have been generated using Time domain generation approach, described in following para.

5.6.1Time domain generation

Generation of artificial ground motion time history in time domain, typically involves multiplying a stationary, filtered white noise (or filtered Poisson process) signal by an envelope function that describes the buildup and subsequent decay (nonstationary) of ground motion amplitude (Shinozuka, M and Deodaties, G (1988). Several authors worldwide have worked in this field and large amount of literature is available. Synthetic time history can be generated based on target response spectra of the site and estimated duration of time history.

Kumar (2006) has also developed a computer code based on suggested envelope function of Boore (1983) for generation of time history. On elaborate discussion and personal communication with Prof. Ashok Kumar, IIT Roorkee, this programme has been used for present microzonation study of NCT Delhi for generation of spectral compatible time history from the target response spectra generated from PSHA as detailed in previous section 5.4 at different sites of geotechnical/geophysical investigation for further ground response analysis. In the present study two period of exceednec i.e. (i) 2% probability of exceedance in 50 year corresponding to return period of 2500 year and (ii) 10% probability of exceedence in 50 year corresponding to return period of 475 years have been considered for generation of time histories.These periodscorresponds to Design Basis Ground motion (DBG) and Maximum Considered Earthquake (MCE) respectively. The time duration parameters based on different suggested models and scrutiny of available strong motions data of Delhiwith IIT Rookee (personal communication with

Prof. Ashok Kumar, who is maintaining a network of Strong Motion in India) has been taken as follows:

Total time duration: 40.96 second,
Rise time: 10second,
Decay Time:20 second.

In the present study 449 time histories spread over NCT Delhi have been generated for both return periods i.e 475 year and 2500 year. These time histories have been used at the sites at which geotechnical/geophysical investigations have been carried for further ground response study detailed in following chapters. Three such time histories for sites Alipur, Bhawana, and Tikri are shown in following Figures5.30-5.32for 475 year return period and figures 5.33-5.35for 2500 year return period in green colour. The time history shown in red colour is time history at surface obtained on the basis of ground response analysis described in Chapter-9.

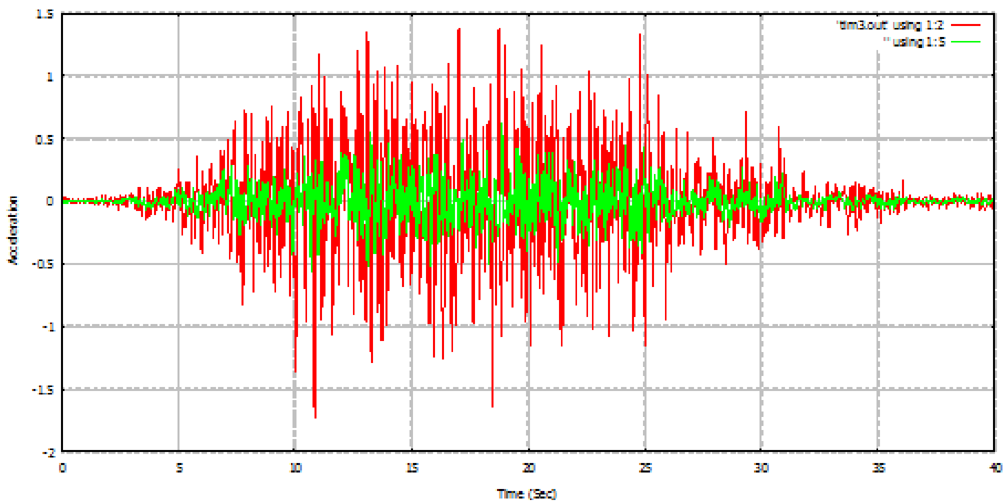


Figure5.30 Spectrum Compatible Time History at engineering bedrock for site Alipur(In green colour) for 475year return period. Time history shown in red colour is at surface.

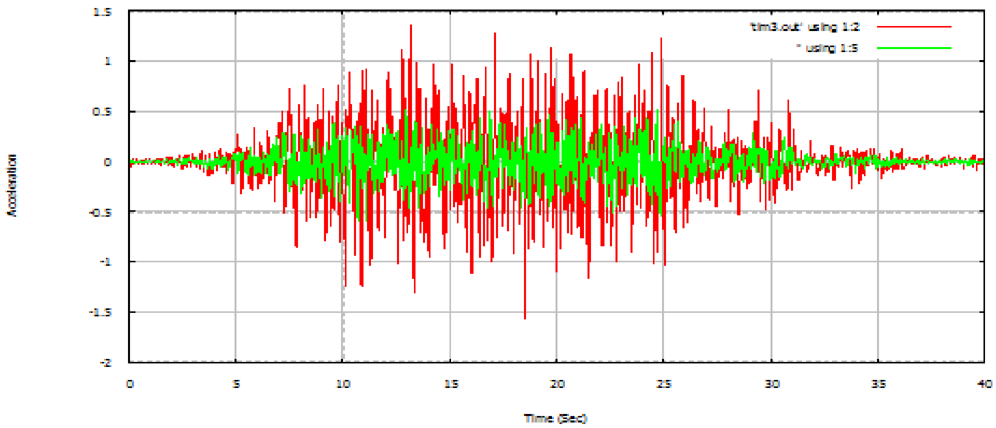


Figure5.31 Spectrum Compatible Time History at engineering bedrock for site Bhawana (in green colour)for 475 year return period.Time history shown in red colour is at surface.

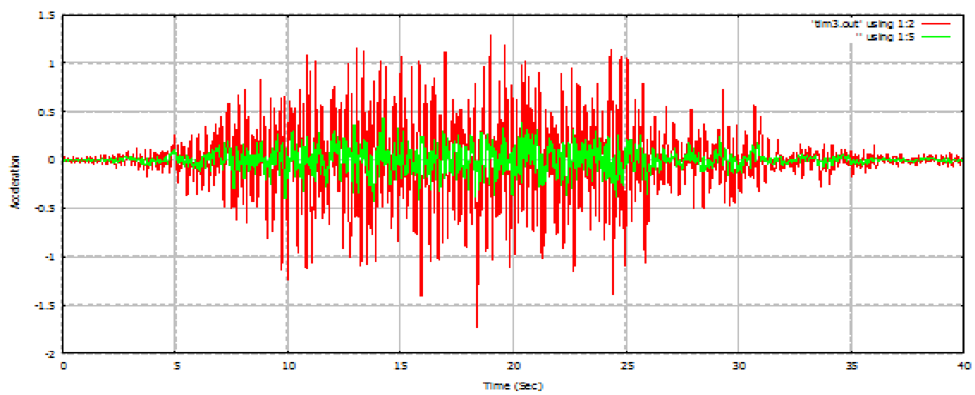


Figure5.32 Spectrum Compatible Time History at engineering bedrock for site Bhawana (in green colour)for 475 year return period.Time history shown in red colour is at surface.

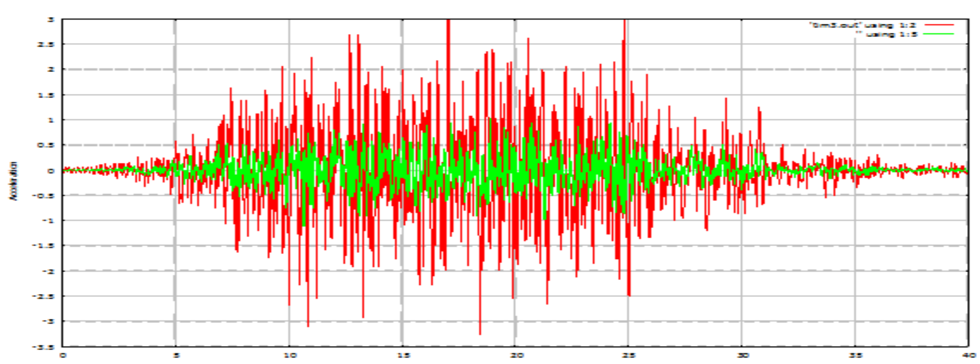


Figure5.33 SpectrumCompatible Time History at engineering bedrock for site Alipur (in green colour) for 2500 year return period.Time history shown in red colour is at surface.

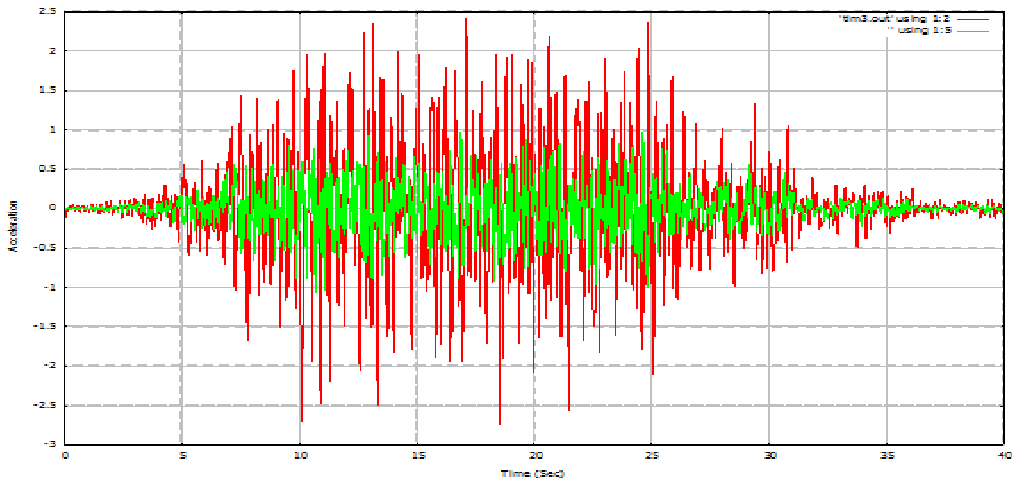


Figure5.34 Spectrum Compatible Time History at engineering bedrockfor site Bhawana(in green colour)for 2500 year return period.Time history shown in red colour is at surface.

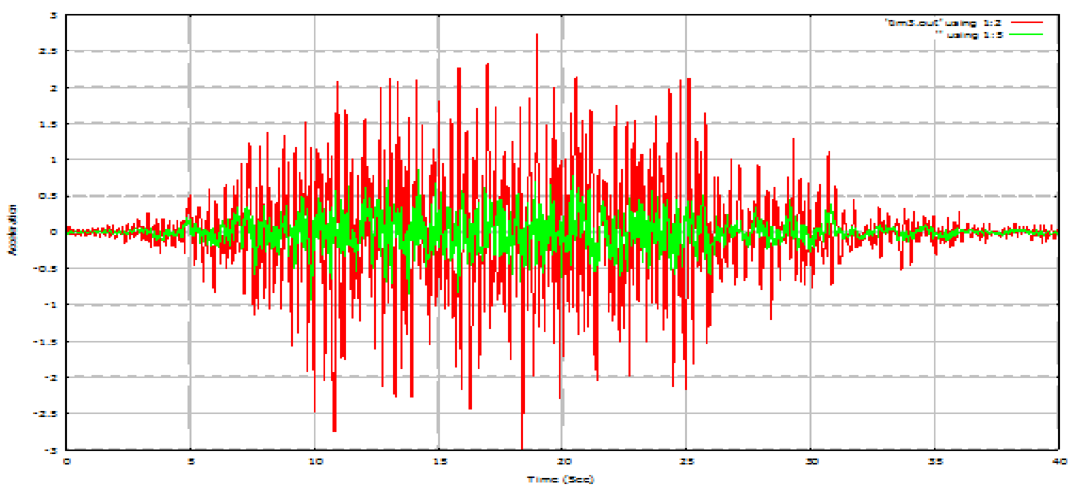


Figure5.35 Spectrum Compatible Time History at engineering bedrock for site Tikri (in green colour) for 2500 year return period.Time history shown in red colour is at surface.

5.7: PEAK GROUND ACCELERATION (PGA) AT ENGINEERING BEDROCK AFTER FREE SURFACE CORRECTION, DERIVED FROM GENERATED TIME HISTORIES

In the present study, as detailed in section 5.6., earthquake acceleration time histories at engineering bedrock have been simulated atall the geotechnical/ geophysical investigations sites for 2% probability of exceedence in 50 years and 10% probality of exceedence in 50 years based on seismic hazard curves developed from PSHA for NCT Delhi described in above section5.4.The maximum amplitude of the ground acceleration time-history thus generated gives PGA at the depth of engineering bedrock (shear wave velocity 760m/s) at different sites. On the basis of time histories generated at all the 449 sites at engineering bedrock;PGA values have been evaluated at each site and given in Table 9.4 (appended). These site specific PGA values at 449 sites have been converted in continuous surface using Inverse Distance Weighted (IDW) interpolation technique, using appropriate parameters and cross validation so that the Root Mean Square (RMS) values between predicted and actual are as minimum as possible. This is one of the most popular methods adopted by geoscientists and geographers available in GIS packages. Using this continous data PGA maps at engineering bedrock have been generated for NCT Delhi for two periods of exceedance i.e.

(i) 2% probability of exceedence in 50 yearsfor the return period of 2500 year, based on maximum credible earthquake(MCE), for 5% damping.

(ii) 10% probability of exceedence in 50 years for the return period of 475 year based on Design Basis Earthquake (DBE), for 5% damping.

These maps are attached (appended) as Map-11& 12. For 2% probability of exceedence in 50 years i.e for MCE, the PGA values at engineering bedrock varied from0. 067g to0.114g and for 10% probability of exceedence in 50 years i.e for DBE, the PGA values at engineering bedrock varied from .035g to .058g.

CHAPTER 6

GEOTECHNICAL /GEOPHYSICAL DATA GENERATION AND SOIL CHARACTERIZATION

Each soil type responds differently, when subjected to the ground motions, imposed due to earthquake loading, because of its physical property, depth to bedrock and natural frequency. Usually the younger and softer soil amplifies ground motions relative to older, more compact soils or bedrock. Large amplification of the seismic signals generally occurs in areas where layers of low seismic velocity overlie material with high seismic velocity, i.e. where soft sediments cover bedrock or more stiff soils. These soil layers over the bedrock may attenuate or amplify the base rock earthquake motion depending upon geotechnical characteristics, their depth, and arrangement of layering.

Part two of Seismic hazard microzonation study is therefore quantification of the spatial variation of the subsurface response on a typical earthquake that can be expected at a particular site and in the area when grouped in similar type of response.In order to quantify the expected ground motion, it is necessary to determine the manner in which the seismic signal is propagating through the subsurface. Propagation is particularly affected by the local geology and the geotechnical ground conditions. Thus the prerequisite of this part of the study is subsurface soil characterization through geotechnical/geophysical investigationsat appropriate number of sites. The number of sites to be investigated for ascertaining soil characteristics depends upon the geological variability of the domain and requirement of scale of the study. This requires a comprehensive planning of geotechnical/geophysical investigations to capture all important features of the soil characteristic to meet the requirement of scale of study.

6.1 OPTIMIZATION OF NUMBER OF SITES FOR GEOTECHNICAL/ GEOPHYSICAL INVESTIGATIONS

The geoscientific constitution of Delhi provides a highly variable domain with a complex scenario having scope of rapid changes in seismic accentuations. In order to understand local subsurface conditions and variability of geotechnical characteristics, a comprehensive planning, for the optimization of number of sites for geotechnical and geophysical investigations based on geological/geomorphological variability, to meet the requirement of scale of the study are required.

Thetotal area of NCT Delhi to be investigated is about 1485 square kilometers. In order to understand soil characteristics and stratigraphical variability of the domain and meet

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Thetotal area of NCT Delhi to be investigated is about 1485 square kilometers. In order to understand soil characteristics and stratigraphical variability of the domain and meet the set objectives enumerated above, as per scale of the study on 1:10,000scale, geotechnical/geophysical investigations are required in a grid of 100mX100 m. Thus the total numbers of sites to be investigated are 148,500.However,smaller the grid size the accuracy will be more in evaluating hazard in an area, but investigations at this much large number of sites is practically impossible and also not necessary, as the soil Stratigraphy over a large area does not vary in such a scale. Thus, a comprehensive planning is required to constrain the number of sites to be investigated for suitably representing the stratigraphical variation in the scale of study. An adverse geology might require more investigations than the average.Therefore, Geological/Geomorphological map provides the primary screening tool to understand the surface variability of domain and helpful for first order planning of geotechnical/geophysical investigations by constraining sites. By upgrading it into subsurface map by first order geotechnical/geophysical investigations further study can be planned for precise characterization of soil variability of domain.

ISSMGE Technical Committee for Geotechnical Earthquake Engineering classified the seismic microzonation studies into three grades. Details of these three grades of seismic microzonation studies are given in Table 6.1

Table 6.1Details of classes of seismic microzonation studies(ISSMGE Technical Committee report)

Geotechnical Phenomenon	**Grade-1**	**Grade-2**	**Grade-3****
Ground Motions	□ HistoricalEarthquakes andExisting Information □ Geological Maps □ Interviews with Local Residents	□ Microtremor □ Simplified GeotechnicalStudy	□ Geotechnical Investigation Ground Response Analysis
Slope Stability	□Historical Earthquakes andExistingInformation □Geological andGeomorphological maps	□Air Photosand RemoteSensing □Field Studies □Vegetationand PrecipitationData	□Geotechnical Investigation □Analysis
Liquefaction	□ HistoricalEarthquakes andExistingInformation □ Geological and Geomorphological map	□ Air Photosand RemoteSensing □ Field Studies Interviewswith Local Residents	□ Geotechnical Investigation and Analysis
Accepted Scale of	1:10,00,000 to 1:50,000	1:1,00,000 to 1:10,000	1:25,000 to 1:10,000

Mapping			
Grid size for testing geophysical survey and boreholes	Homogeneous subsurface – 2 km x2km to 5 km x 5km Heterogeneous Subsurface – 0.5 km x0.5 km to 2 km x 2km (selectively)	Homogeneous sub-surface – 1 km x 1km to 3 km x 3km Heterogeneous Sub-surface – 0.5 km x 0.5 km to 1 km x 1km	Homogeneous sub-surface – 0.5 km x 0.5km to 2 km x 2km Heterogeneous Sub-surface – 0.1 km x 0.1 km to 0.5 km x 0.5k

** For seismic microzonation of urban centers with high seismicity (in seismic zones II,IV &V)

For the present study of Seismic Microzonation of Delhi on 1:10,000 scale, as discussed in chapter-4, surface geological map of NCT Delhi on 1:10,000 scale has been generated in collaboration with Geological Survey of India (GSI). However, mapping programme was taken with objective to upgrade existing surface geological map of Delhi, available on 1:50,000 scale, but it was supported by subsurface information collected during field survey, geotechnical investigation of soil samples collected during field survey and digging pits, particularly in Yamuna flood plain area. Thus, even it is surface geology map, but proving quite a good insight of sub-surface geology of the area.

Further, for mutual validation of data and generation of empirical relations among data generated through different techniques, some investigations were planned at common sites. For example for validation of SPT, DCPT were also planned at all sites. Similarly for generation of empirical relations specific to the domain, among the shear wave velocity and SPT- N value, geophysical and geotechnical investigations were planned at a few common sites.

Thus to achieve the objectives set as above, an integrated programme of geotechnical and geophysical investigations for generation of datawas taken up through outsourcing and completed as detailed below: The sites are spread over NCT Delhi, represented by 75 toposheets.

6.2: DATA GENERATION

6.2.1: Geotechnical investigations

In the present study following geotechnical data has been generated

- At 302 sites shallow drilling, up to 30 meter depth(as per IS: 5313-1980)or up to 3m in rock strata if encountered within 30m depth. During the course of drilling (i) Conducted Standard Penetration Test [SPT] (as per IS: 2131 -1981) and collected disturbed Samples (DS) alternately at every 1.5m interval or change of strata (ii) Collected Undisturbed Sample (UDS) at every 3.0m interval as per IS code (IS:

2132-1986, I S: 8763 -1978, I S: 9640 -1980, I S: 10108-1982)Using a ppropriate s oil samplers.A sample copy of data sheet for one borehole indicating obs erved SPT N values and description of strata as per field observation at different depths is given in figure 6.1(a).

- At 12 sites deep drilling (variable depth up to 300 meter) to delineate bedrock. During the course of drilling (i) Conducted Standard Penetration Test [SPT] (as per IS: 2131-1981) a nd collected di sturbed S amples (DS) a lternately at e very 1.5m interval or change of strata (ii) Collected Undisturbed Sample (UDS) at every 3.0 m interval as per I S c ode (IS: 2132-1986, I S: 8763-1978, IS: 9640-1980, I S: 10108-1982) U sing appropriate soil samplers.
- Dynamic Cone Penetration Testing (DCPT) have been conducted close to all shallow and deep drilling locations (314 sites) for directly measuring shear wave velocity of soils in -situ f or c omparison. A Sample c opy o f D CPT r esults f or on e bor e hol e location is given in figure 6.1(b)
- Routine l aboratory t ests f or s oil c haracterization (On a bout 6000 di sturbed a nd undisturbed soil samples collected through bore holes at different depths– Soil type, Grain size, Atterberg Limit, Specific gravity, Relative density, water contain, Direct Shear (DS/UDS) on representative s oil samples, Triaxial s hear (DS/UDS) on representative s oil s amples, etc. A sample copy of da ta s heet f or on e bor ehole indicating index properties of soil at different depths on the basis of laboratory test is given in Table 6.2.
- Limited Special la boratory test on representative s amples: C yclic T ri-axial f or studying the e ffect of c yclic s hear s tress on s oil m odeling t he c onditions dur ing a n earthquake.
- Resonant C olumn t est: on s elected s amples of different t ypes of s oils col lected at seven sites spread over Delhi to determine shear modulus and damping ratio of soils under different confining pressure, void ratios, and shear strain amplitude, number of cycles and time of confinement.

Newly generated geotechnical data left certain gap area particularly in Central Delhi and therefore reports of geotechnical investigations consisting of data at 490sites, mostly in central Delhi, collected from different construction agencies during first phase of study have been rescrutinized and data of 120 s ites have been found to be useful for one or other study (discussed in later chapters).

6.2.2 Geophysical investigations

- Shear wave velocity measurement using 28/48, Channel Seismogram (MASW)at 110 sites was conduc ted. H owever, da ta of 83 sites w ere f ound s uitable f or s ite characterization (discussed in chapter 'site classification'). For ground response study only two sites data are used (discussed in Chapter-9).

- Shear wave velocity at selected 25 sites using Cross Hole Technique (CHT)/ Down Hole Technique (DHT). Out of these 25 sites 19 sites are common with geotechnical investigations and MASWsites and used for comparison and development of empirical relations.

Thus for the present study of Seismic Hazard Moicrozonation of NCT Delhi geotechnical data collected at 434 sites and geophysical data collected at 108 sites have been used. A documentation Map-13 shows locations of all geotechnical/geophysical investigations sites at which data have been generated/collected and used for the study.

6.3: SOIL CHARACTERISTICS IN DELHI

The data for each borehole,consists of

(i) Results of Dynamic Cone Penetration Tests. A sample sheet for one borehole is given in Figure 6.1(a)

(ii) Results of SPT N vales. A sample sheet for one borehole is given in Figure 6.1(b)

(iii) Soil characteristic of each borehole site at 1.5m interval to the drilled depth - such as, type of soil, natural moisture content(%), Specific gravity, Natural dry density, results of mechanical analysis of soil, results of consolidation test, consistency limit and Shear parameters. A sample sheet for one borehole is given in Table 6.2.

On the basis of above geotechnical data collected at 434 locations spread over NCT Delhi different characteristics of soil in NCT Delhi has been studies.

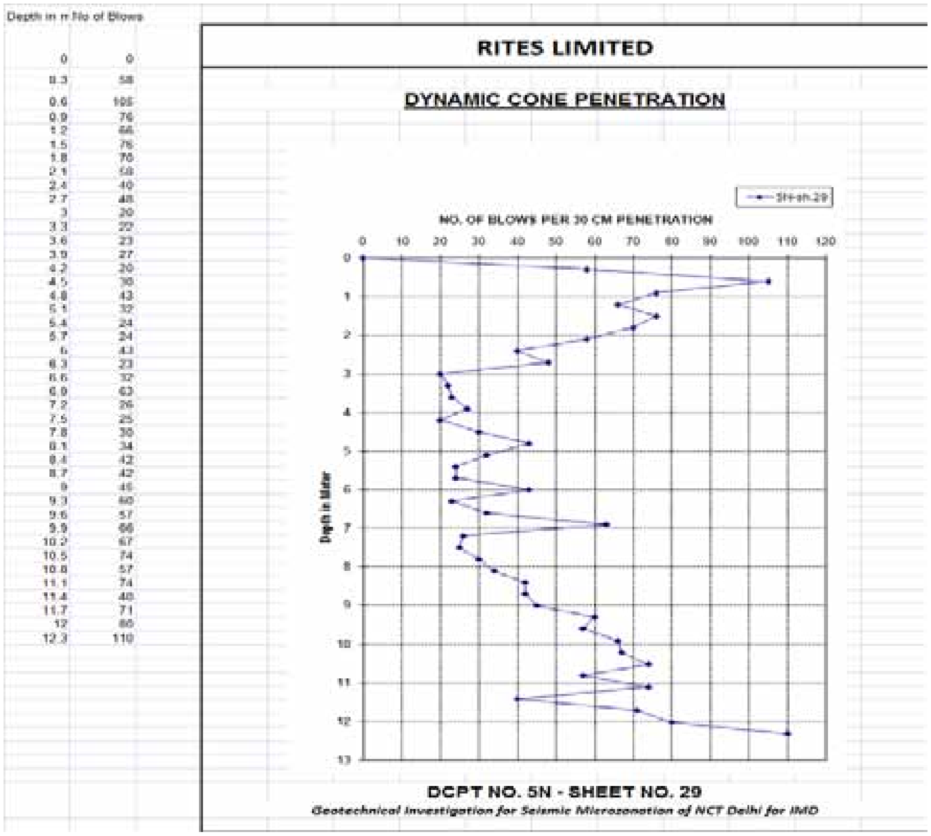


Figure 6.1(a): Sample copy of DCPT results for one borehole location.

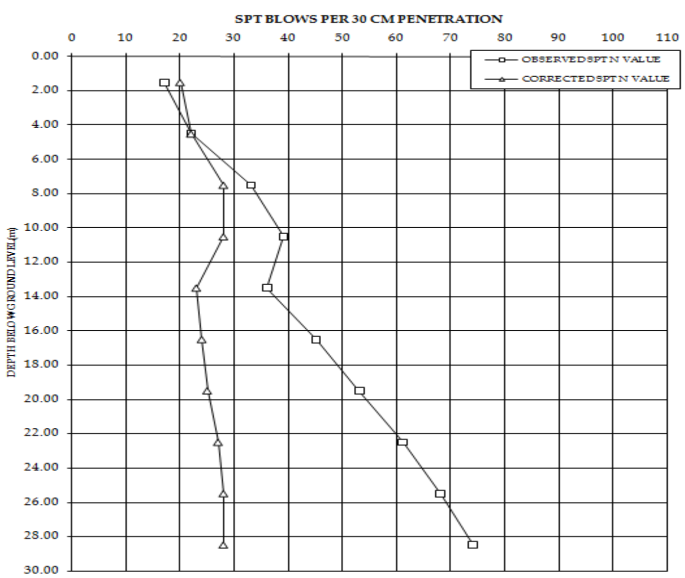


Figure 6.1(b): A Sample copy of SPT 'N' value results for one borehole location.

Table 6.2 A sample copy of data sheet for one borehole indicating index properties of soil collected at different depths on the basis of laboratory test.

LABORATORY TEST REPORT (FOR SOIL SAMPLES)

Project Name : Geotechnical Investigation for Seismic Microzonation of NCT Delhi for IMD

Location : Near CWG hostel at J.N. Stadium, New Delhi
Bore hole no. : 23
Sheet No. : 61

Co-ordinates : N 28° 34' 52" E 77° 13' 58.9"

		Details of sample							MECHANICAL ANALYSIS						Consolidation Test		CONSISTENCY LIMIT			SHEAR PARAMETER	
Sl No.	Lab sample No.	Type of sample	Depth of sample (m)	Soil classification	Legend	Natural Moisture Content %	Natural Dry Density (gm/cc)	Specific Gravity	GRAVEL (%)	COARSE SAND (%)	MEDIUM SAND (%)	FINE SAND (%)	SILT (%)	CLAY (%)	C c	Eo	Liquid limit (%)	Plastic limit (%)	Plasticity index (PI)	Cohesion c (kg/cm²)	Angle of internal friction (degree)
1	4842	DS	0.00	SM		–	–	–	0.00	0.00	1.00	63.00	36*	–	–	–	NON PLASTIC			–	–
2	4843	SPT	1.50	CL		–	–	–	4.00	2.00	1.00	19.00	74*	–	–	–	33.00	18.00	15.00	–	–
3	4844	UDS(P)	3.00	CL		20.00	1.67	–	0.00	0.00	3.00	13.00	70.00	14.00	–	–	33.00	20.00	13.00	–	–
4	4845	UDS(H)	3.00	CL		23.00	1.70	–	0.00	0.00	1.00	13.00	86*	–	–	–	33.00	21.00	12.00	–	–
5	4846	SPT	4.50	ML		–	–	–	0.00	0.00	4.00	41.00	55*	–	–	–	NON PLASTIC			–	–
6	4847	UDS	6.00	CL		14.00	1.63	–	0.00	0.00	1.00	15.00	84*	–	–	–	32.00	18.00	14.00	–	–
7	4848	SPT	7.50	CL		–	–	–	9.00	5.00	2.00	12.00	72*	–	–	–	31.00	18.00	13.00	–	–
8	4849	UDS	9.00	CL		20.00	1.69	–	0.00	0.00	2.00	11.00	74.00	13.00	–	–	32.00	17.00	15.00	–	–
9	4850	SPT	10.50	CL		–	–	–	24.00	4.00	2.00	6.00	64*	–	–	–	33.00	18.00	15.00	–	–
10	4851	UDS	12.00	SM		7.00	1.85	–	9.00	15.00	16.00	17.00	43*	–	–	–	NON PLASTIC			–	–
11	4852	SPT	13.50	SM		–	–	–	9.00	1.00	1.00	41.00	48*	–	–	–	NON PLASTIC			–	–
12	4853	UDS	15.00	CL		21.00	1.61	–	0.00	0.00	1.00	8.00	91*	–	–	–	32.00	20.00	12.00	–	–
13	4854	SPT	16.50	CL		–	–	–	8.00	7.00	3.00	7.00	75*	–	–	–	32.00	18.00	14.00	–	–
14	4855	SPT	19.50	CL		–	–	–	0.00	0.00	0.00	14.00	73.00	13.00	–	–	33.00	18.00	15.00	–	–

6.3.1 Distribution of soil types

On the basis of geotechnical data collected at 434 sites spread over different geological domains of NCT Delhi, depth wise distribution of different types of soil at each bore hole site have been studied individually and collectively for all bore holes in a toposheet. Major part of soil in Delhi consists of sandy soilembedded with silt and clay, which even extends at some borehole locations to the depth of more than hundred meters. Soil characteristics at some of the typical locations and in sheets (covering an area of about 25 sq km) are given in Figure 6.2.

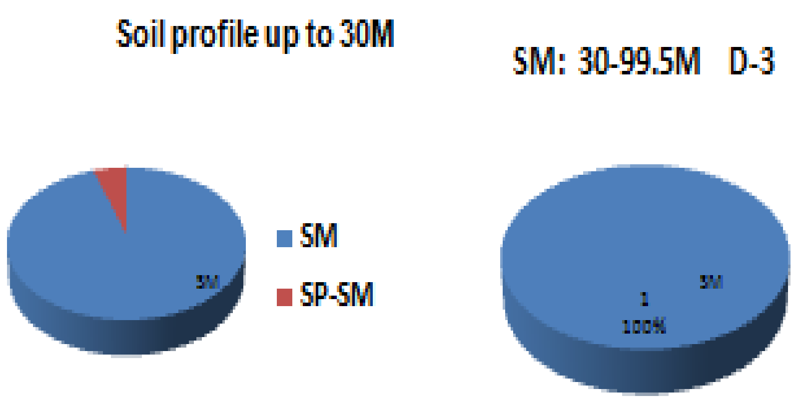
6.3.2: Cross sections:

In order to understand sufficiency of data to meet the requirement of map scale subsurface soil profiles have been studied, through different cross sections generated on the basis of borehole information. A typical example of borehole distribution, soil profile and different orientation of cross sections for one toposheet covering an area of 25 sq km. are given in Figures 6.3 (a to g). Descriptions of soil classifications as per BIS code of soil dynamics are detailed below:

CI : Inorganic clays, silty clays of medium plasticity

CL	:	Inorganic clays, silty clays, sandy clays of low plasticity
MI	:	Inorganic silts, clayey silt with medium plasticity
ML	:	Inorganic silts, silty or clayey fine sands, with slight plasticity
S	:	Sand
SC	:	Clayey sands
SG	:	Sand with gravel
SM	:	Silty sands
SM-SG	:	Silty sand and Sand with gravel
SM-SW	:	Silty sand and well graded sands, sandy soils, with little or no fines
SP	:	Poorly graded sands, sandy soils, with little or no fines
SW	:	Well graded sands, sandy soils, with little or no fines

Soil profile : Park between block 67 (ABCD) DDA colony Dilshad garden, P.S. Seemapuri. (D-3)

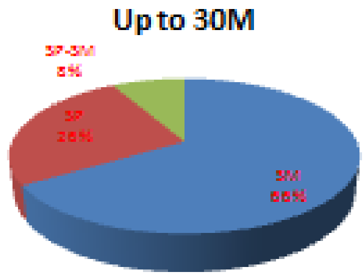


Water Table: 24.40

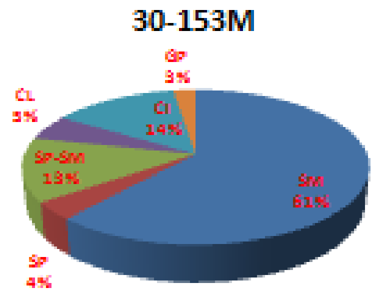
Weathered Rock : From 105M up to drill depth 107.00M

Soil profile: Akshar Dham temple (D-5)

Soil profile up to 30M



Soil profile 30-153M

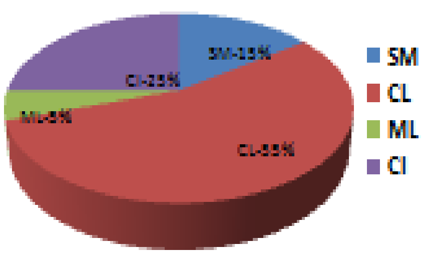


Water Table: 6.5 M b.g.l

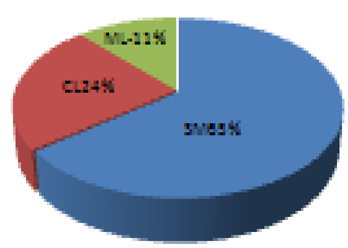
Rock : Could not be delineated due to adverse condition encountered below 153M and possibility of collapse of bore hole

Soil profile Near CWG hostel at J.N. Stadium, New Delhi (D-1)

Soil profile up to 30M

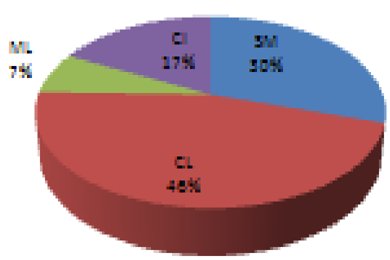


Soil Profile 30-42 M%



Soil profile up to 42 M : D1

Water Table:
12.45 M



Weathered Rock:
42.7 to 44.2M

Hard Quartzite :
44M to 47M

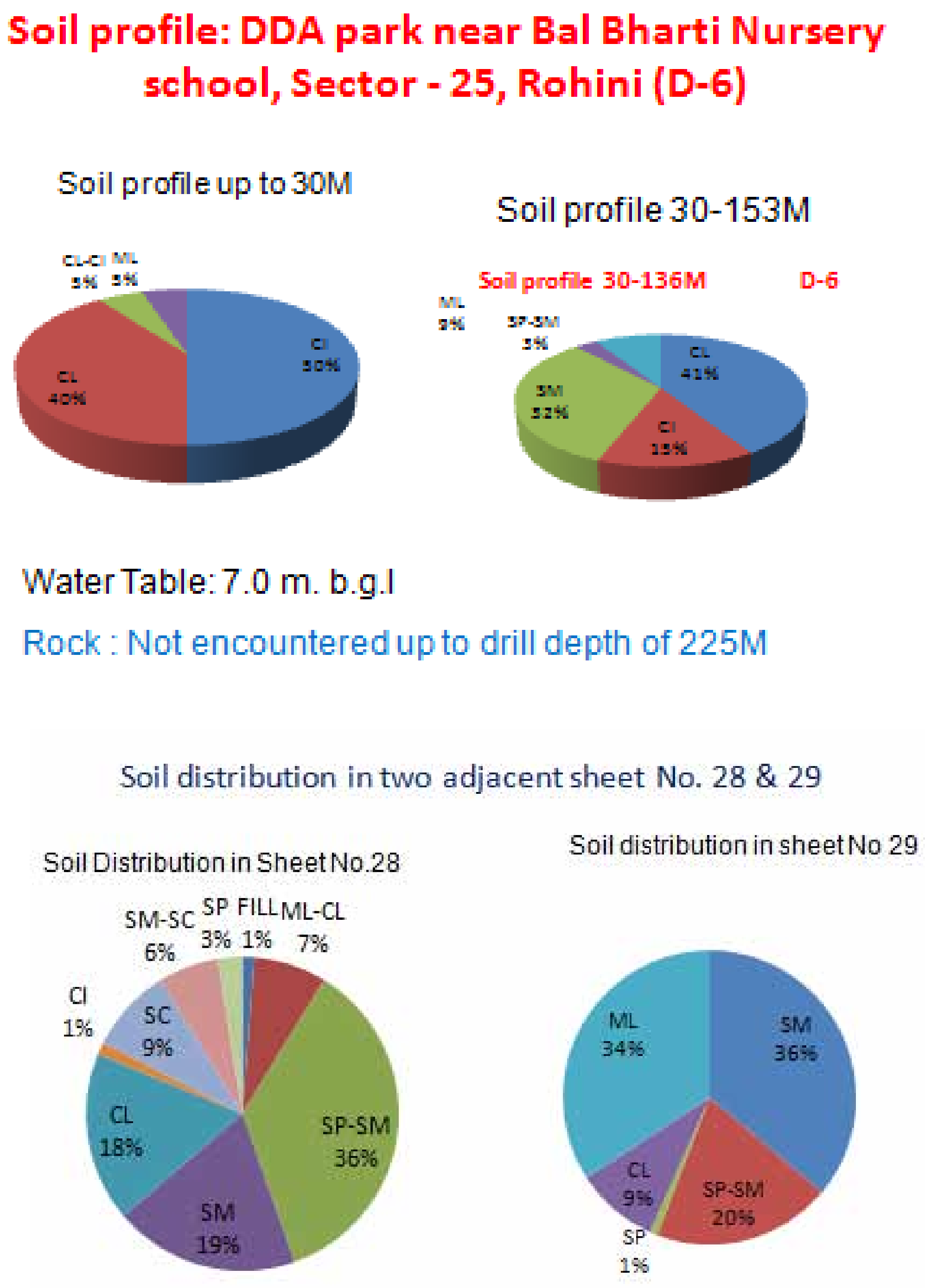


Figure 6.2: Distribution of different types of soil in typical borehole sites and in sheets covering an area of about 25 sq km.

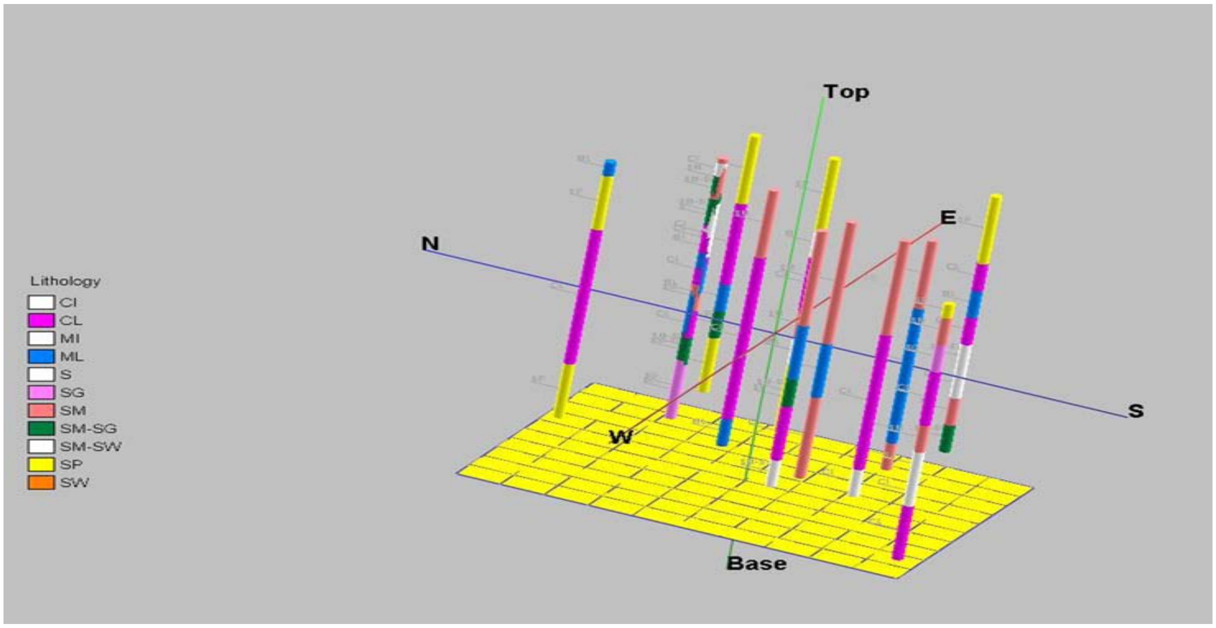


Figure 6.3(a): Typical distribution of boreholes in one sheet(No.38) covering an area of about 25 sq km.

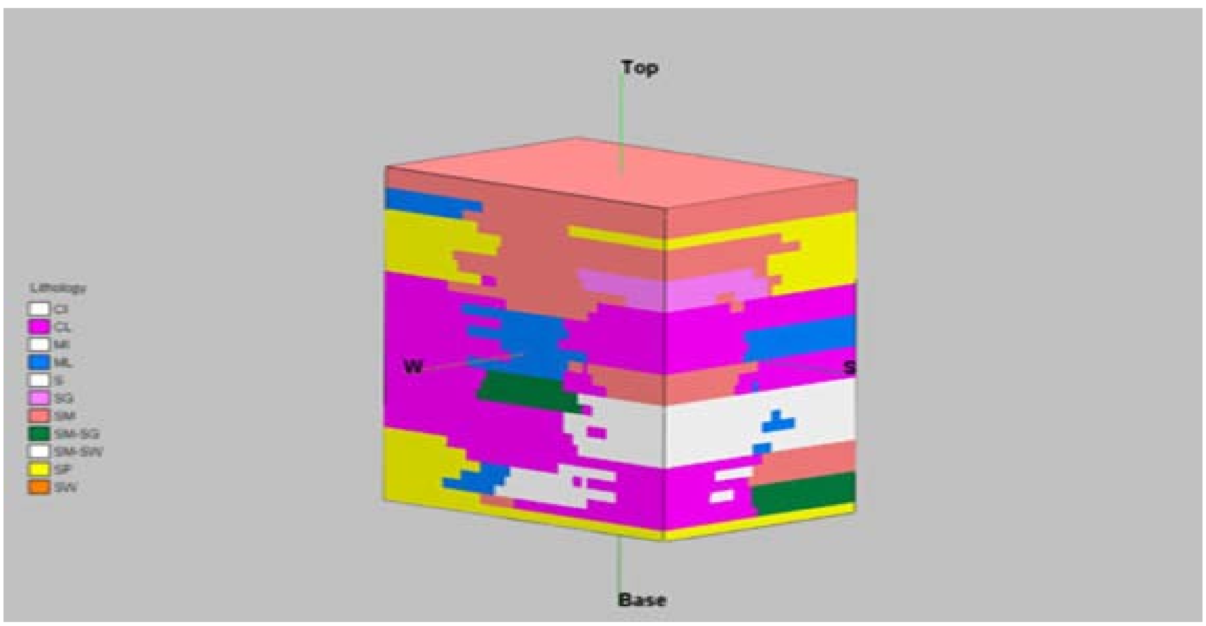


Figure 6.3(b): Typical distribution of soils in one sheet covering an area of about 25 sq km inferred from borehole shown in figure6.3(a)

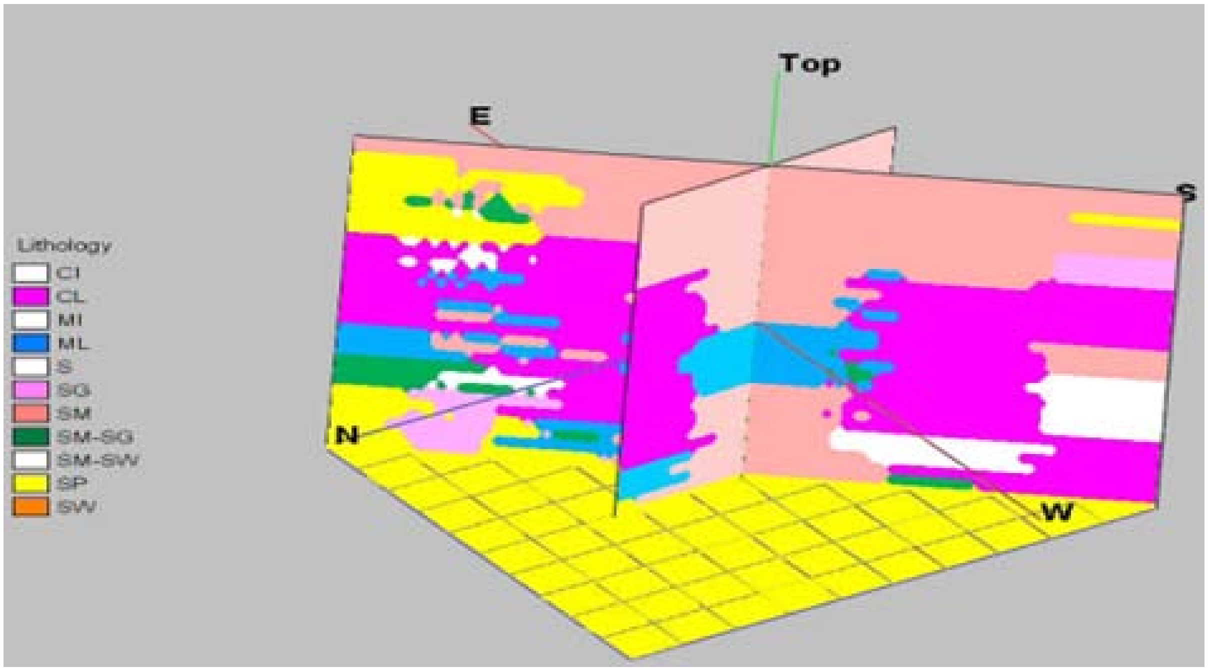


Figure 6.3(c): Typical 3-D cross section showing distribution in N-S and E-W direction in one sheet covering an area of about 25 sq km. inferred from boreholes shown in figure6.3(a)

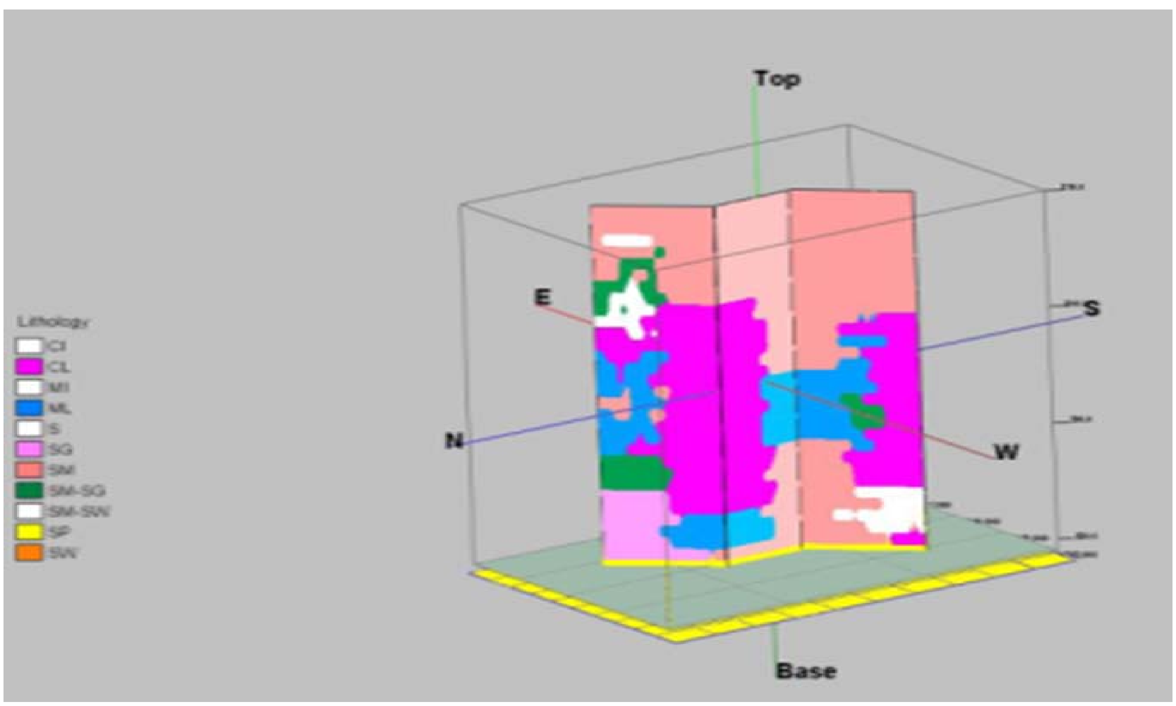


Figure6.3(d): Typical 3-D distribution of soil S-W and N-E direction in one sheet covering an area of about 25 sq km. inferred from boreholes shown in figure6.3(a)

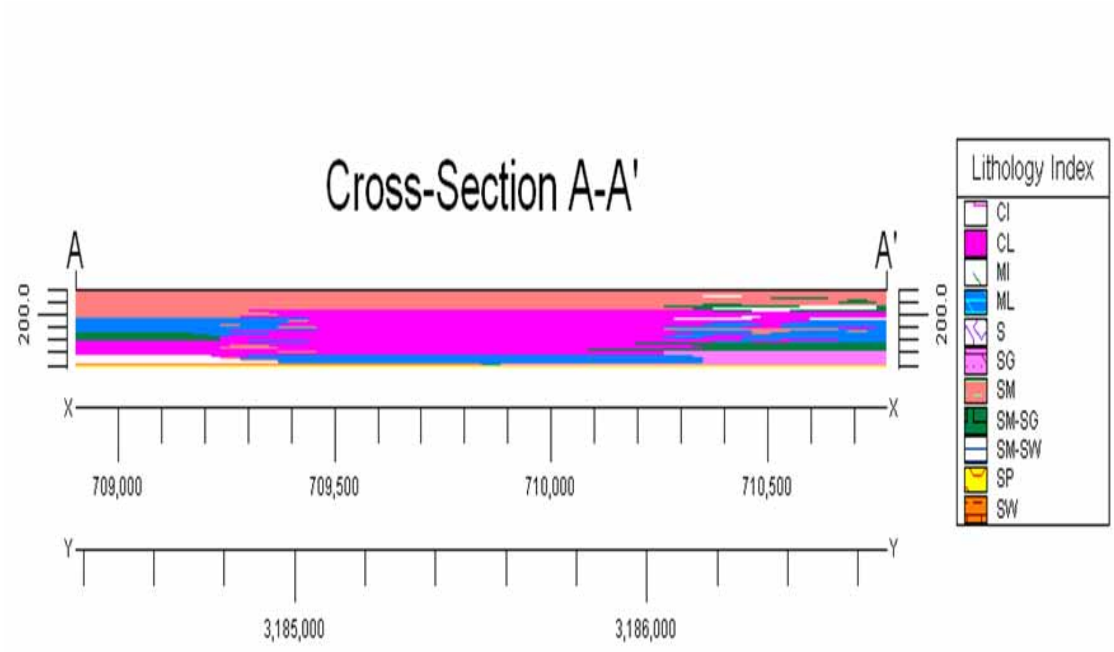


Figure6.3(e): Typical cross s ections i n one s heet c overing a n area of about 25 s q km . inferred from bore hole shown in above figure

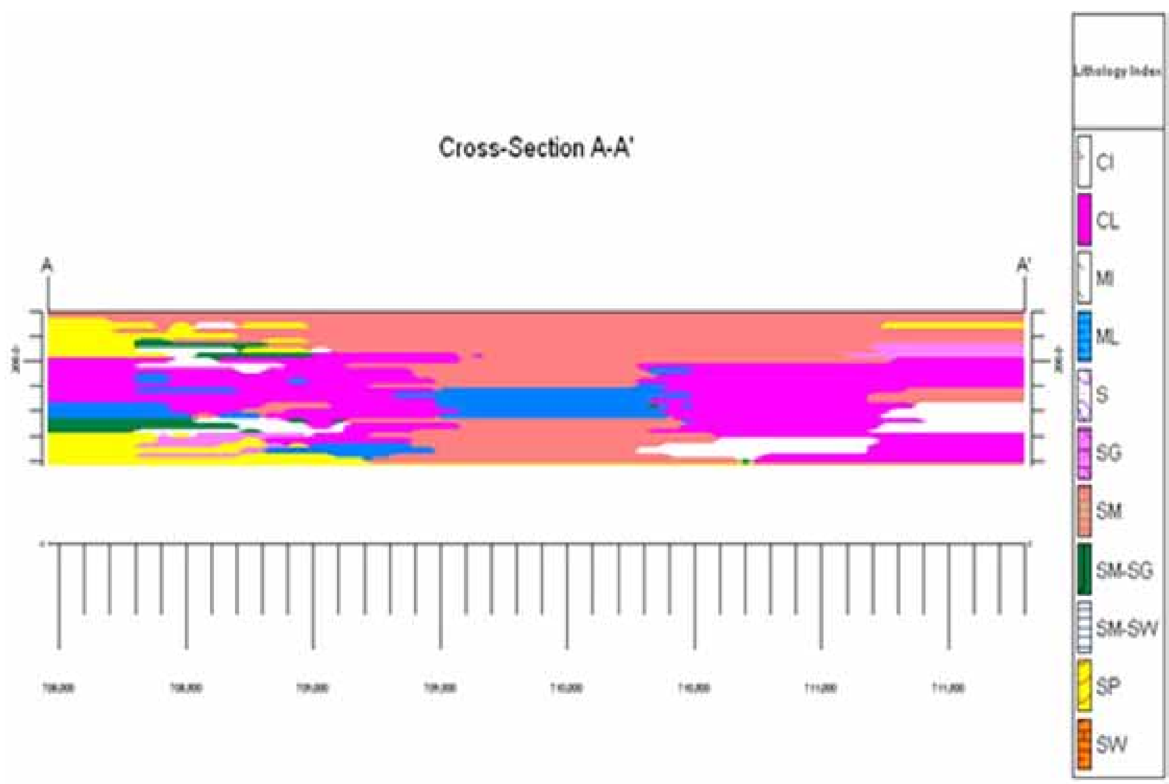


Figure 6.3(f): Typicalcross section in other sheet covering an area of about 25 sq km.

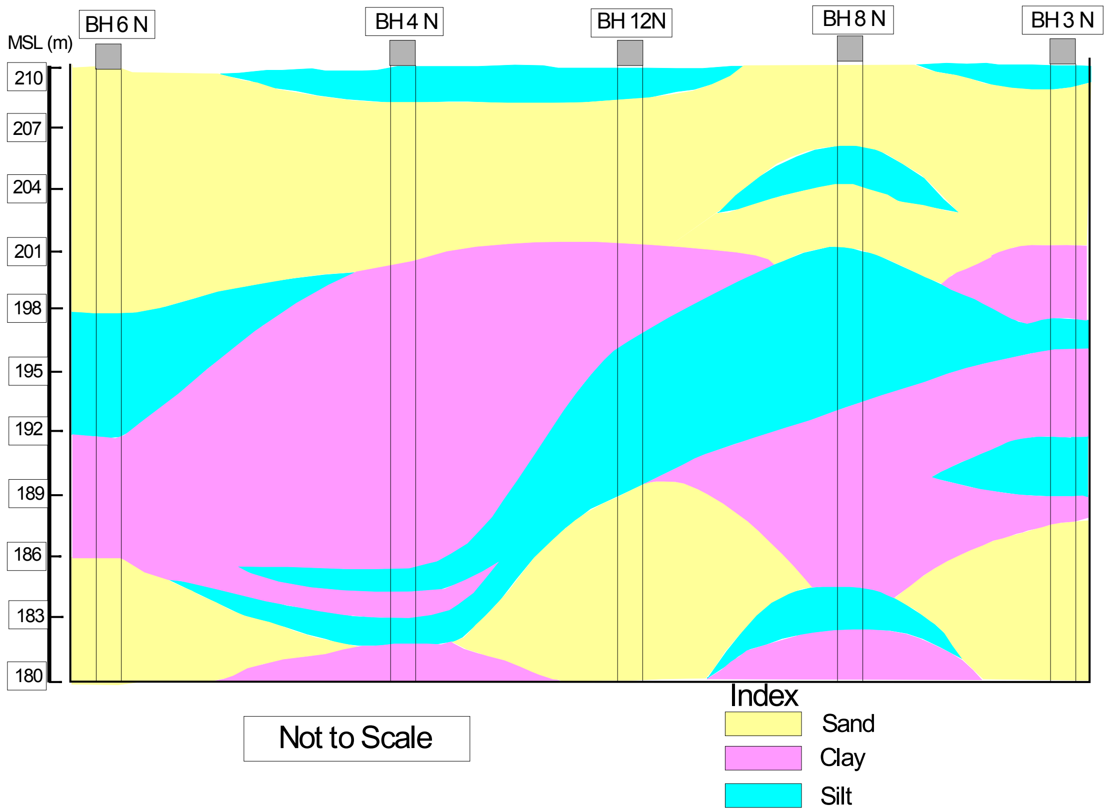


Figure 6.3(g) Typical soil cross section (along NNE-SSW direction) of sheet no.39 covering an area of about 25 sq km.

6.4 EVALUATION OF CORRECTED SPT 'N'VALUE $(N1)_{60}$

The 'Standard Penetration Test', commonly known as the 'SPT', is used for evaluationof shear wave velocity. SPT have been carried out in all boreholes, by driving a standard 'split spoon' sampler using repeated blows of a 63.5kg hammer falling through 762mm. The hammer was operated at the top of the borehole, and was connected to the split spoon sampler by rods. The split spoon sampler was lowered to the bottom of the hole, and was then driven a distance of 450mm in three 150mm intervals, and the blows were counted for each 150mm penetration. The penetration resistance (N) which is the number of blows required to drive the split spoon for the last 300mm of penetration is measured. The penetration resistance during the first 150 mm of penetration was ignored, because the soil is considered to have been disturbed. Observed 'N' value maps for 0-3m and 3-6m depth have been generated for NCT Delhi and presented as Maps14 & 15 respectively, which may be helpful for coarse assessment of the site condition in the field.

The SPT 'N' values thus measured in the field using Standard Penetration Test procedure have been corrected for various corrections, such as: (a) Overburden Pressure (C_N), (b) Hammer energy (C_E), (c) Borehole diameter (C_B), (d) presence or absence of liner (C_S),

(e) Rod length (C_R) and (f) fines content (C_{fines}) (Seed et al., 1983, 1985; Youd et al., 2001; Cetin et al., 2004, Skempton; 1986 and Pearce and Baldwin, 2005). Corrected 'N' value i.e., $(N_1)_{60}$ have been obtained using the following equation

$$(N_1)_{60} = N \times (C_N \times C_E \times C_B \times C_S \times C_R) \quad (6.1)$$

The correction factors applied are given in tables 6.3 – 6.6.

Table 6.3: Hammer Correction factor (*CE*)

Factor	Correction
Donut Hammer	0.5-1.0
Safety Hammer	0.7-1.2
Automatic-trip	0.8-1.3

Table 6.4: Correction for B.H. Diameter (*CB*)

Factor	Size	Correction
Borehole Diameter	65-115 mm	1.00
	150 mm	1.05
	200 mm	1.15

Table 6.5 Correction for Rod Length (*CR*)

Factor	Size	Correction
Rod Length	<3 m	0.75
	3-4 m	0.80
	4 -6 m	0.85
	6-10 m	0.95
	10-30 m	1.00

Table 6.6: Correction for Sampler based on method (*CS*)

Factor	Size	Correction
Sampling method	Standard samplers	1.00
	Sampler without liners	1.1-1.3

The formula used to find the correction for energy ratio is:

$$C_E = \frac{ER}{60\%} \quad (6.2)$$

Where ER (efficiency ratio is the fraction or percentage of the theoretical SPT impact energy that is actually transferred to the sampler.

A typical data sheet for one borehole location showing different corrections appliedon observed N value to obtain corrected N value $(N1)_{60}$is given in Table 6.7.

Table 6.7A typical data sheet for one borehole location showing different corrections applied on observed N value to obtaincorrected N value $(N1)_{60}$

Co-ordinates:	N 28° 37' 29" E 76° 54' 52"											
			Typical "N" Value Correction Table for Borelog of BH No. 1N, SHEET No. - 3									
Borehole												
Depth	Field	Type of strata	Density		T.S.	E.S.	C_N	Correction Factor For				$(N_1)_{60}$
m	N Value		gm/cc	kN/m³	kN/m²	kN/m²		Hammer Effect	Borehole	Rod Length	Sample Method	
1.50	15	ML	1.76	17.60	26.40	26.40	1.00	0.70	1.05	0.75	1.00	8.27
4.50	18	ML	1.76	17.60	79.20	79.20	1.00	0.70	1.05	0.85	1.00	11.25
7.50	58	ML	1.77	17.70	132.30	131.81	1.00	0.70	1.05	0.95	1.00	40.50
10.50	30	ML	1.99	19.90	192.00	162.08	1.00	0.70	1.05	1.00	1.00	22.05
13.50	21	SM	1.85	18.50	247.50	188.15	0.71	0.70	1.05	1.00	1.00	11.02
16.50	27	SM-SC	1.79	17.90	301.20	212.42	0.66	0.70	1.05	1.00	1.00	13.13
19.50	41	SM-SC	1.83	18.30	356.10	237.89	0.61	0.70	1.05	1.00	1.00	18.52
22.50	78	SC	1.87	18.70	412.20	264.56	0.57	0.70	1.05	1.00	1.00	32.80
25.50	83	SC	2.09	20.90	481.50	304.43	0.52	0.70	1.05	1.00	1.00	31.62
28.50	71	SC	2.10	21.00	538.20	331.70	0.49	0.70	1.05	1.00	1.00	25.42

6.4.1 SPT 'N' value distribution:

A Bar chart showing distribution of corrected 'N' values $(N1)_{60}$ at 0-3m depth aregiven in figure 6.4. In Delhi N value are 2-10 at 30% sites and 11-20 at about 50% sites showing very soft soil at most of the sites.

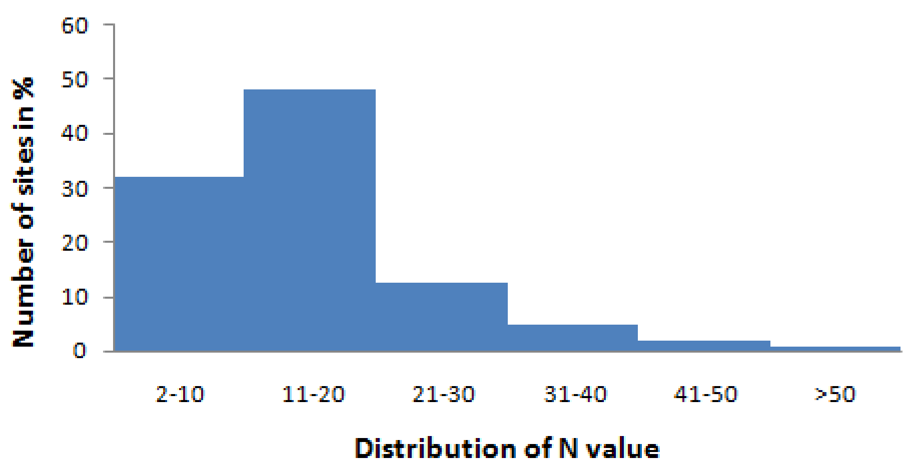


Figure 6.4 A bar chart showing distribution of corrected SPT 'N' value $(N1)_{60}$ at 0-3m depth in NCT Delhi

6.5 DEVELOPMENT OF LOCAL EMPIRICAL RELATION BETWEEN CORRECTED SPT 'N' VALUE $(N_1)_{60}$ AND MEASURED IN-SITU SHEAR WAVE VELOCITY USING CHT&DHT

Cross Hole Test (CHT)/ Doun Hole Test (DHT) is the bestin-situ methodusedforobtainingthevariationof lowstrainshearwavevelocitywithdepth, but it is not feasible to make *Vs* measurements at all the locations, due to requirement of drilling number of boreholes and also implication of high cost. Hence to make use of penetration measurements(SPT 'N' value) collected during geotechnical investigations, correlation between in-situ *Vs*measured from geophysical techniques and penetration resistance are being done for different types of soil. Several such empirical relations are available in literature. The most popular among them are from Japan Road Association (JRA, 1980) equations relating *Vs* and $(N1)_{60}$, which are given below

$$Vs = 100(N_{60})^{1/3}$$ (JRA, 1980)- For clayey soil (6.3)

$$Vs = 80(N_{60})^{1/3}$$ (JRA, 1980) - For Sandy soil (6.4)

In the SeismicHazard Microzonation study, besides Shear wave velocity, there are several other soil parameters required for deriving different components of microzonation and to be collected using Geotechnical investigations, which also provide penetration measurement SPT 'N' values. Geotechnical investigations therefore cannot be avoided and to make use of SPT N value and avoid direct measurement of Shearwave velocity through CHT/DHT at all planned sites, effort has been made to develop local empirical relations for different types of soil of NCT Delhi between corrected SPT 'N' value $(N_1)_{60}$ and directly measured shear wave velocity at common sites.

To achieve above, at 19 common sites Shear wave velocity have been evaluated usingCHT, DHT at 1.5 m depth interval up to the depth of 30m at each site.SPT 'N' values have also been collected at these sites at 3.0 m depth interval up to the depth of 30m, at each site. Thus at each site 10 in-situ shear wave velocity and 10 corrected N values $(N_1)_{60}$ have been obtained for different types of soil. The SPT 'N' value collected at these 19sites and after applying different corrections as detailed above, corrected N value $(N_1)_{60}$ with or without applying overburden, have been obtained.

Common data set for different types of soil obtained are as follows:

Sand (SP-SM, SP, SM-SC) = 54 sets; Silt (Ml) = 38 sets; Clay (CL) =52

On the basis of this sets of data, an attempt has been made to generate following empirical relations using linear regression analysis for different types of soil of Delhi.

(i) Between the *Vs (DHT)* to the corrected 'N' values, $(N1)_{60}$ with or without overburden correction

(ii) Between *Vs (CHT)* to the corrected 'N' values, $(N1)_{60}$ with or without overburden correction

6.5.1 Correlation between the *Vs (DHT)* to Corrected 'N' values $(N1)_{60}$ for Sand (SP-SM, SP, and SM-SC):

(a) Without Overburden correction on observed N value

Regression analysis has been performed using 54data pairs of *Vs* obtained from DHT and corrected SPT 'N' value $(N1)_{60}$ for sandy soil, collected at different depths at same locations and a power fit regression equation has been developed. As both SPT blow count and Shear wave velocity were measured at same depth, overburden correction has not been applied in both. The scattered plot between Shear Wave velocity obtained from DHT and corrected N value $(N_1)_{60}$, without overburden correction is shown in following Figure 6.4.

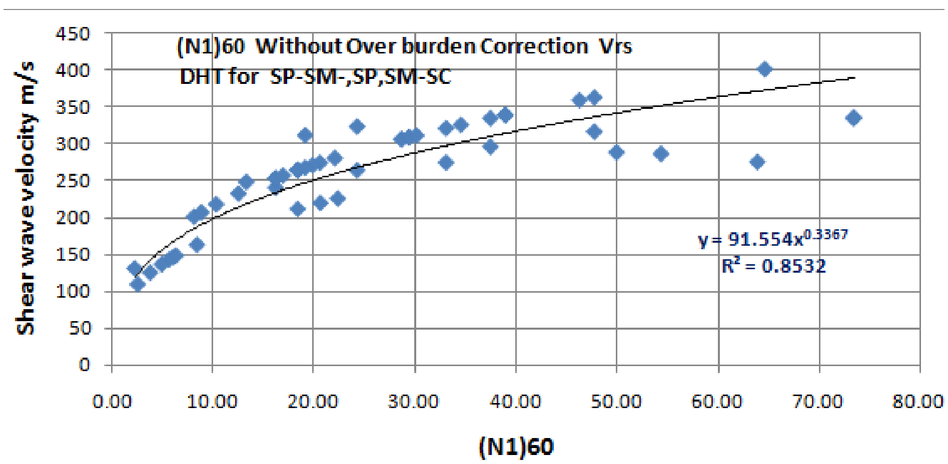


Figure 6.5 Scattered plot between $(N_1)_{60}$ without overburden correction and shear wave velocity obtained from DHT for sandy soil, with the best fit line and equation along with regression coefficient.

The regression equation developed from above dataset between Vs and $(N_1)_{60}$ without overburden correction is given in following Equation 6.5,

$$Vs=91.554\ (N_1)_{60}^{\ 0.3367} \qquad (6.5)$$

The regression coefficient comes out to be R^2 =0.8553

Where, *Vs* is the shear wave velocity in m/s and $(N_1)_{60}$ is the corrected SPT 'N' value without overburden.

It is seen from this plot, however, the regression coefficient is quite good, but the scattering of data beyond SPT N value 50 is quite high. In geotechnical practices, N value beyond 50 is representing hard strata and difficult to quantify further hardness of strata. Therefore on ignoring data beyond SPT N values 50, the scattered plat further improved and is given below in Figure6.5.

The regression equation with above dataset valid upto SPT N value 50 is as follows

$$Vs=80.686\ (N_1)_{60}^{0.3895} \qquad (6.6)$$

The regression coefficient is further improved and comes out to R^2=0.9109, Where, *Vs* is the shear wave velocity in m/s and $(N_1)_{60}$ is the corrected SPT 'N' value without overburden correction.

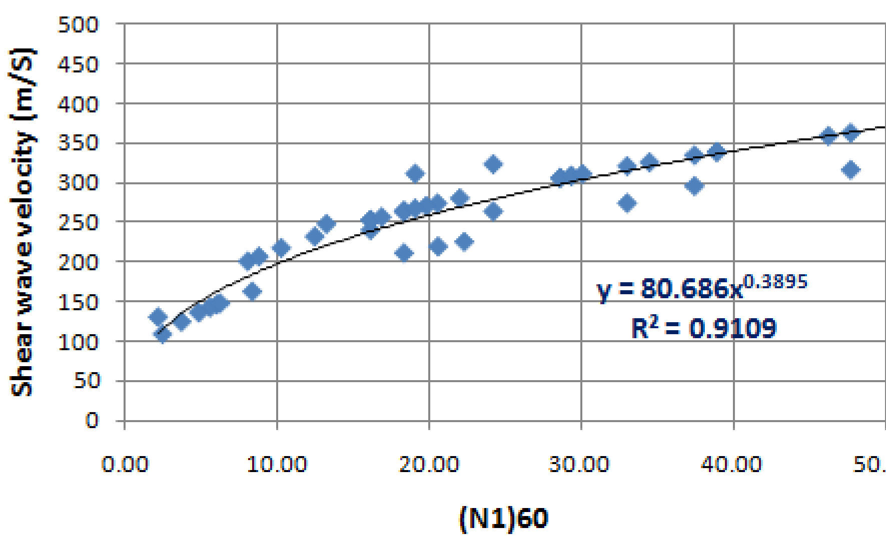


Figure 6.6 Scattered plot between $(N_1)_{60}$ up to 50, without over burden correctionand shear wave velocity obtained from DHT for sandy soil, with the best fit line and equation along with regression coefficient.

(b) With Overburden correction on observed 'N' value

Regression analysis has also been performed between $(N1)_{60}$ and DHT valid up to 50 N counts with same 52 data pairs of Vs values obtained from DHT and SPT corrected blow count for different types of sandy soil collected at different depths. To see the impact of overburden pressure, overburden correction has been applied in SPT blow count. The scattered plot between Shear Wave velocity obtained from DHT and corrected N value $(N_1)_{60}$, obtained after overburden correction is shown in following Figure 6.7.

It is seen from the above plot that lower and upper bound values are very high and regression coefficient is also low. It is obvious that on application of overburden on SPT blow counts N values are standardized for particular overburden pressure and therefore, reliability is reduced. Regression equation and coefficient obtained are as follows.

The regression equitation with above dataset valid upto SPT N value 50 is as follows

$$V_s=72.22\ (N_1)_{60}^{0.4797} \qquad (6.7)$$

The regression coefficient is improved and comes out to $R^2=0.7257$

Where, *Vs* is the shear wave velocity in m/s and $(N_1)_{60}$ is the corrected SPT 'N' value with overburden correction in observed N Values.

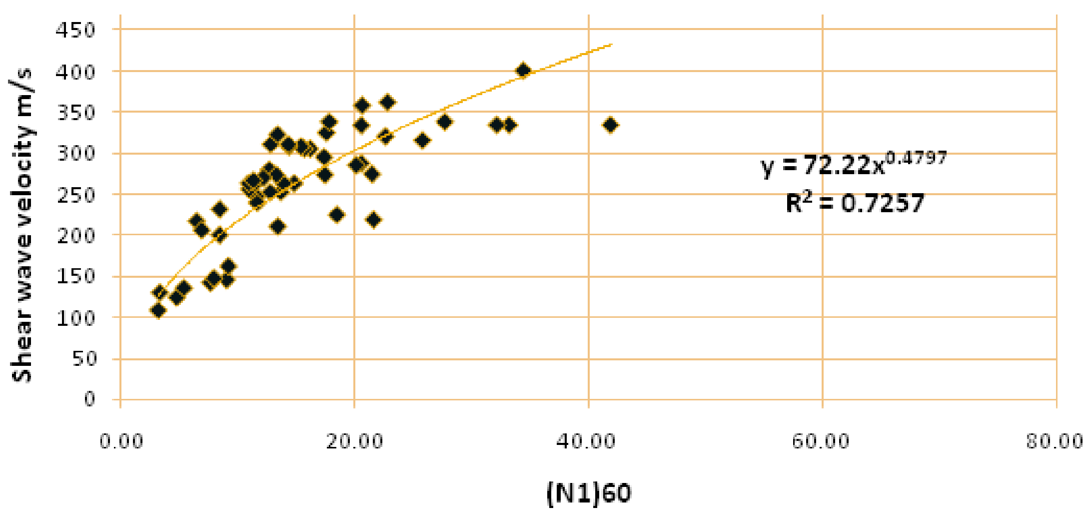


Figure 6.7 Scattered plot between $(N_1)_{60}$up to 50 with over burden correctionand shear wave velocity obtained from DHT for sandy soil, with the best fit line and equation along with regression coefficient.

6.5.2 Correlation between *Vs (DHT)* to Corrected 'N' values $(N1)_{60}$ For Silt (Ml, ML)

There are 38 data pairs of *Vs* measured from DHT and SPT corrected blow count $(N1)_{60}$ for different types of Silty soil collected at different depthsat common 19 sites have been used for generating correlation for Silt. Overburden correction for silty soil is equal to one and therefore, SPT N values are not affected. The scattered plot between Shear Wave velocity obtained from DHT and corrected N value $(N_1)_{60}$, is shown in following Figure 6.8.

It is seen from this plot, the regression coefficient is quite good, even for SPT N values up to 80.

The regression equation with above dataset is as follows

$$Vs=85.376(N_1)_{60}^{0.3774} \qquad (6.8)$$

The regression coefficient is improved and comes out to be R^2=0.9412;Where, *Vs* is the shear wave velocity in m/s and $(N_1)_{60}$ is the corrected SPT 'N' value.

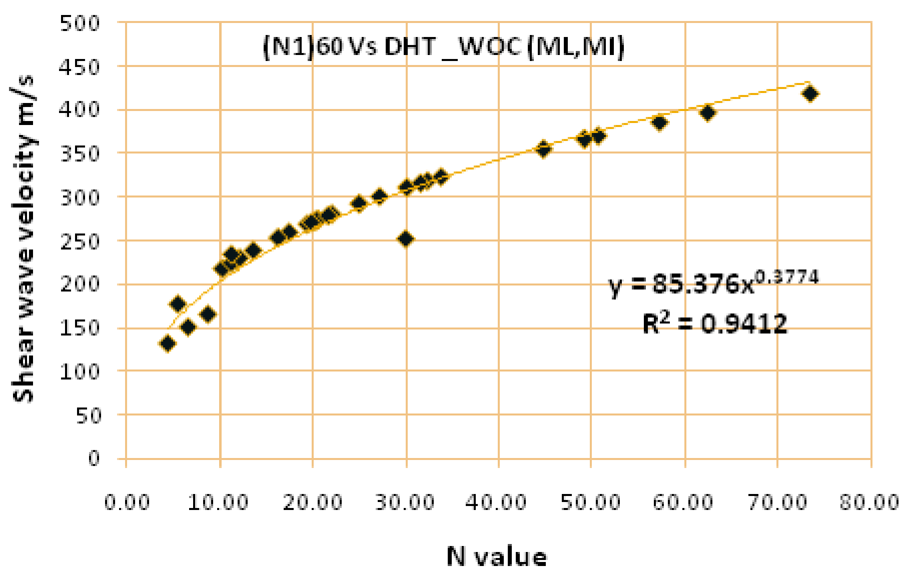


Figure 6.8 Scattered plot between $(N_1)_{60}$with or without over burden correctionand shear wave velocity obtained from DHT for Silty soil, with the best fit line and equation along with regression coefficient.

6.5.3 Correlation between *Vs (DHT)* to Corrected 'N' values $(N_1)_{60}$ For Clay (CL, CL-ML):

There are 52 data pairs of *Vs* measured from DHT and SPT corrected blow count $(N_1)_{60}$for different types of Clayey soil collected at different depthsat common 25 sites have been used for generating correlation for Clay. However, both SPT blow count and Shear wave velocity were measured at same depth, Overburden correction for clayey soil is equal to one and therefore, SPT N values are not affected. The scattered plot between Shear Wave velocity obtained from DHT and corrected N value $(N_1)_{60}$, is shown in following Figure 6.9. It is seen from this plot, the regression coefficient is quite good, even for SPT N values more than 80.

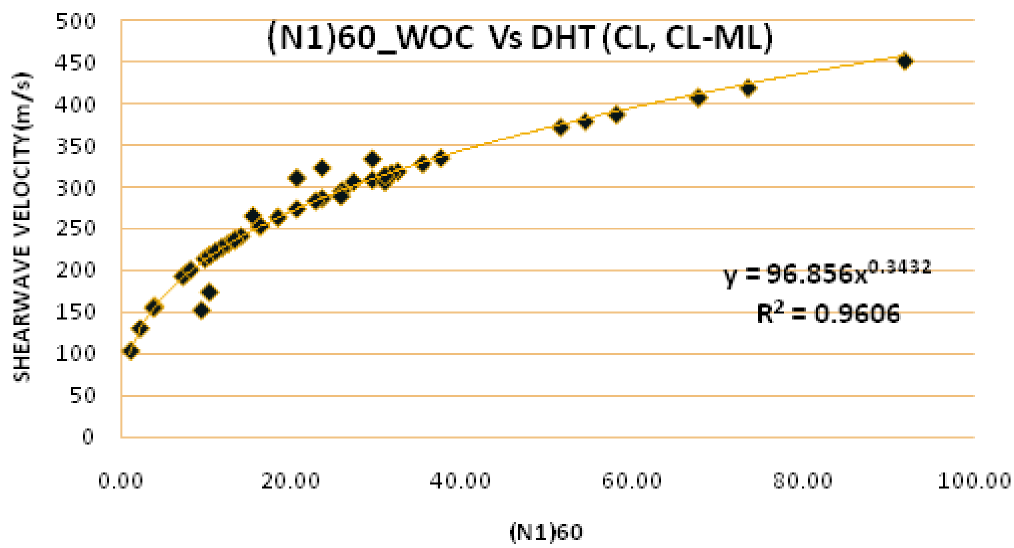


Figure 6.9 Scattered plot between $(N_1)_{60}$ with or without over burden correctionand shear wave velocity obtained from DHT for Claye soil, with the best fit line and equation along with regression coefficient.

The regression equation with above dataset valid upto SPT N value 50 is as follows

$$Vs=96.856(N_1)_{60}{}^{0.3432} \quad (6.9)$$

The regression coefficient is improved and comes out to be

$R^2=0.9606$

Where, *Vs* is the shear wave velocity in m/s and $(N_1)_{60}$ is the corrected SPT 'N' value.

6.5.4: Correlation between *Vs (DHT)* to Corrected 'N' values $(N1)_{60}$ for all types of Soil SM, ML,MI,CL:

144 data pairs of *Vs* and SPT corrected blow count for all types of soil collected at different depths have been used for generating general correlation for all types of soil in Delhi. As both SPT blow count and Shear wave velocity were measured at same depth, overburden correction has not been applied in both. The scattered plot between Shear Wave velocity obtained from DHT and corrected N value $(N_1)_{60}$, without overburden correction is shown in following Figure-6.10

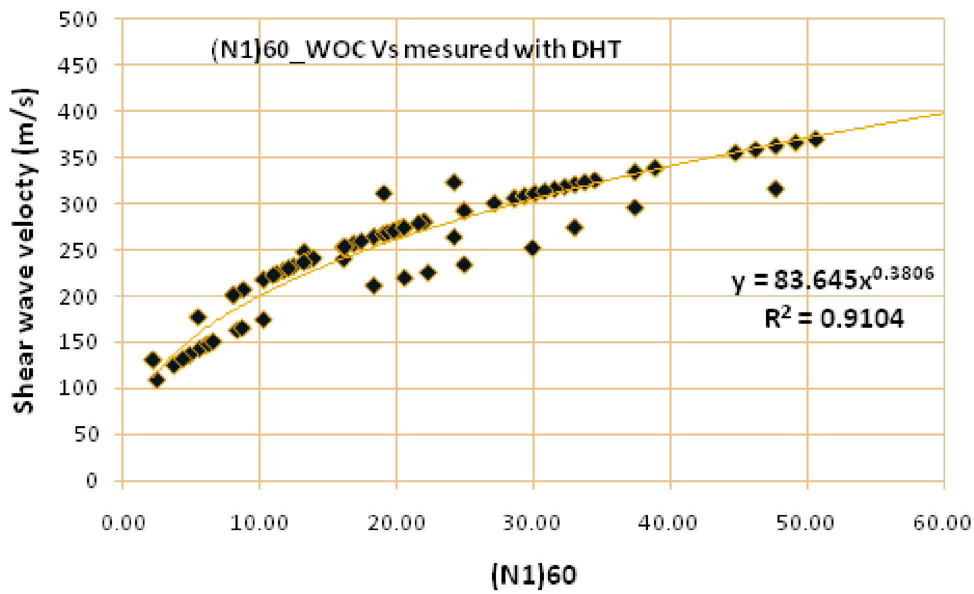


Figure 6.10 Scattered plot between $(N_1)_{60}$ without over burden correction and shear wave velocity obtained from DHT for all types of soil (Sand, Silt and Clay) collected at different depth at common sites, with the best fit line and equation along with regression coefficient.

The regression equation with above dataset valid up to SPT N value 50 is as follows

$$Vs=83.645\ (N_1)_{60}{}^{0.3806} \tag{6.10}$$

The regression coefficient is improved and comes out to be ,R^2 =0.9104; Where, *Vs* is the shear wave velocity in m/s and $(N_1)_{60}$ is the corrected SPT 'N' value.

6.5.5 Correlation between *Vs (CHT)* to the corrected 'N' values $(N1)_{60}$_ For Sand: (SP-SM, SP, and SM-SC)

(a) Without Overburden correction on SPT N

The same data set of 52 data pairs of *Vs* measured from CHT and SPT corrected blow count for different type of sandy soil collected at different depth have also been used for generating correlation between shear wave velocity measured with CHT and SPT blow count. As both SPT blow count and Shear wave velocity were measured at same depth, overburden correction has not been applied in both. The scattered plot between average Shear Wave velocity obtained from CHT and corrected N value $(N_1)_{60}$, without overburden correction is shown in following Figure 6.11

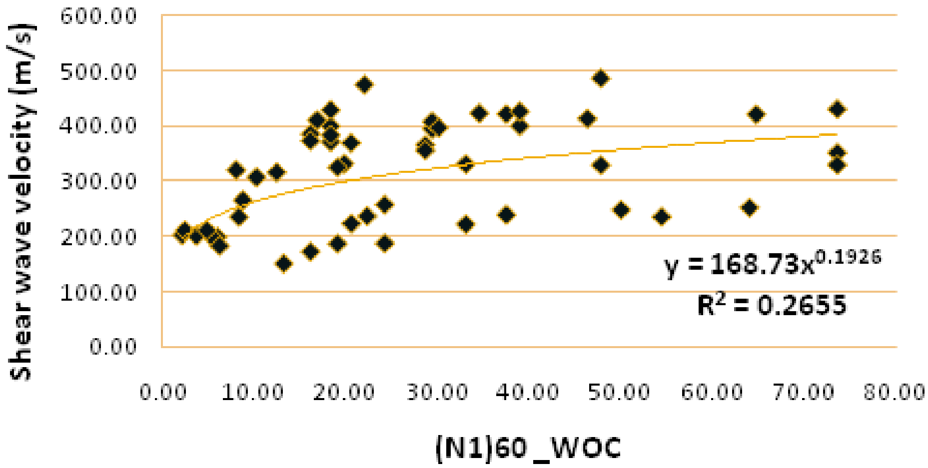


Figure 6.11 Scattered plot between $(N_1)_{60}$ up to 50 without overburden correction and average shear wave velocity obtained from CHT for sandy soil, with the best fit line and equation along with regression coefficient.

It is seen from above plot that scattering in data set is very high compared to relation obtained from DHT data. It is obvious that Shear wave velocity measure from CHT method is representative of a layer of particular depth as source and recorder are placed at the same depth. While in case of DHT since the waves have to travel through all the layers to reach the receiver, it can detect soil layers, which may go undetected in case of CHT and hence the results obtained from DHT tests are more reliable.

The regression equation with above dataset valid up to SPT N value 50 is as follows

$$Vs=168.73\,(N_1)_{60}^{0.1926} \tag{6.11}$$

The regression coefficient is improved and comes out to be R^2=0.2655
Where, *Vs* is the shear wave velocity in m/s and $(N_1)_{60}$ is the corrected SPT 'N' value.

(b) With overburden correction applied on N value

The same data set of 52 data pairs of *Vs* measured from CHT and SPT corrected blow count for different types of sandy soil collected at different depths have also been used for generating correlation between average shear wave velocity measured with CHT and SPT blow count. To see the impact of overburden pressure, overburden correction has been applied in SPT blow count. The scattered plot between average Shear Wave velocity obtained from CHT and corrected N value $(N_1)_{60}$, with overburden correction is shown in following Figure-6.12.

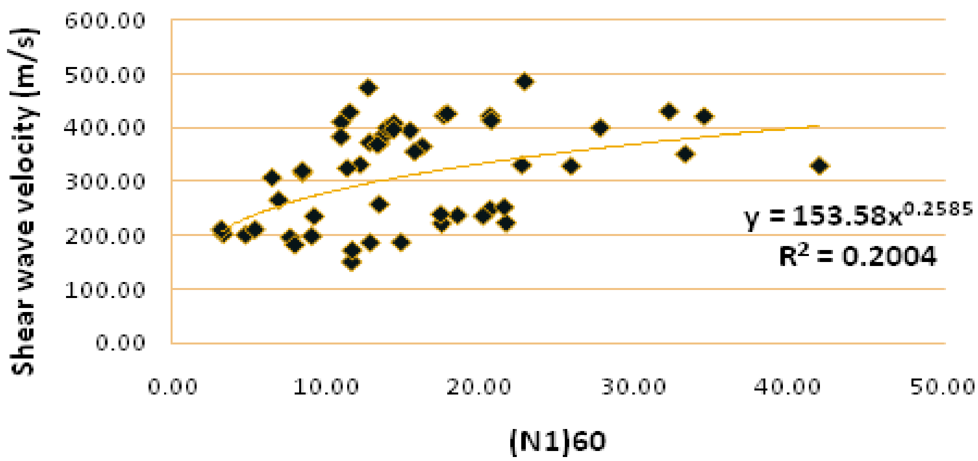


Figure 6.12 Scattered plot between $(N_1)_{60}$ up to 50 with over burden correction and average shear wave velocity obtained from CHT for sandy soil, with the best fit line and equation along with regression coefficient.

It is seen from above plot that scattering in data set is further high compared to relation obtained from CHT data and SPT N value without overburden correction. The regression coefficient has further reduced.
The regression equation with above dataset valid up to SPT N value 50 is as follows

$$Vs=153.58\ (N_1)_{60}^{0.2585} \qquad (6.12)$$

The regression coefficient is R^2=0.2004; Where, *Vs* is the shear wave velocity in m/s and $(N_1)_{60}$ is the corrected SPT 'N' value.

6.5.6 Final empirical relations obtained and used for NCT Delhi

It is seen from above regression analyses on different combinations that correlation between shear wave velocities evaluated from DHT with SPT 'N' values for sandy soil without considering over burden correction in SPT 'N' values is very good up to SPT N value 50 compared to CHT. The correlation obtained from DHT data for other types of soil such as Silt and Clay are also very good compared to CHT.In case of silt and clay, effect of overburden does not matter as correction factor is 1. The general correlation for all types of soil is also good compared to CHT data.

The empirical relations obtained from DHT are given below. These relations have been used for evaluating Shear wave velocity from corrected SPT 'N' value $(N_1)_{60}$ at all geotechnical investigation sites for all type of soil where SPT N values are available. Further, at all the sites soil classifications are available, therefore individual relations for Sand, Silt, and Clay have been used.

For Sand (SP-SM, SP, SM-SC)

$$Vs=80.686\ (N_1)_{60}^{0.3895} \text{(for corrected N value up to 50)} \qquad (6.13)$$

For Clay (CL, CL-ML)

$$Vs=96.584\ (N_1)_{60}^{0.3432} \quad (6.14)$$

For Silt (ML, MI)

$$Vs=85.378\ (N_1)_{60}^{0.3774} \quad (6.15)$$

For all types of Soil (general relation)

$$Vs=83.645\ (N_1)_{60}^{0.3806} \quad (6.16)$$

6.5.7: Comparison of shear wave velocity evaluated from newly developed empirical relations for NCT Delhi and other standard relations:

The comparison of Shear wave velocity evaluated from different standard empirical relations for different types of soil and shear wave velocity evaluated from newly developed Equations (6.13,6.14, 6.15& 6.16) are given in Figures 6.13(a), 6.13(b), 6.13(c) and 6.13(d). It is clear that the newly derived equations for all types of soil lies between most of the standard relation particularly of theJRA, Seed and Ideris and are matching well.

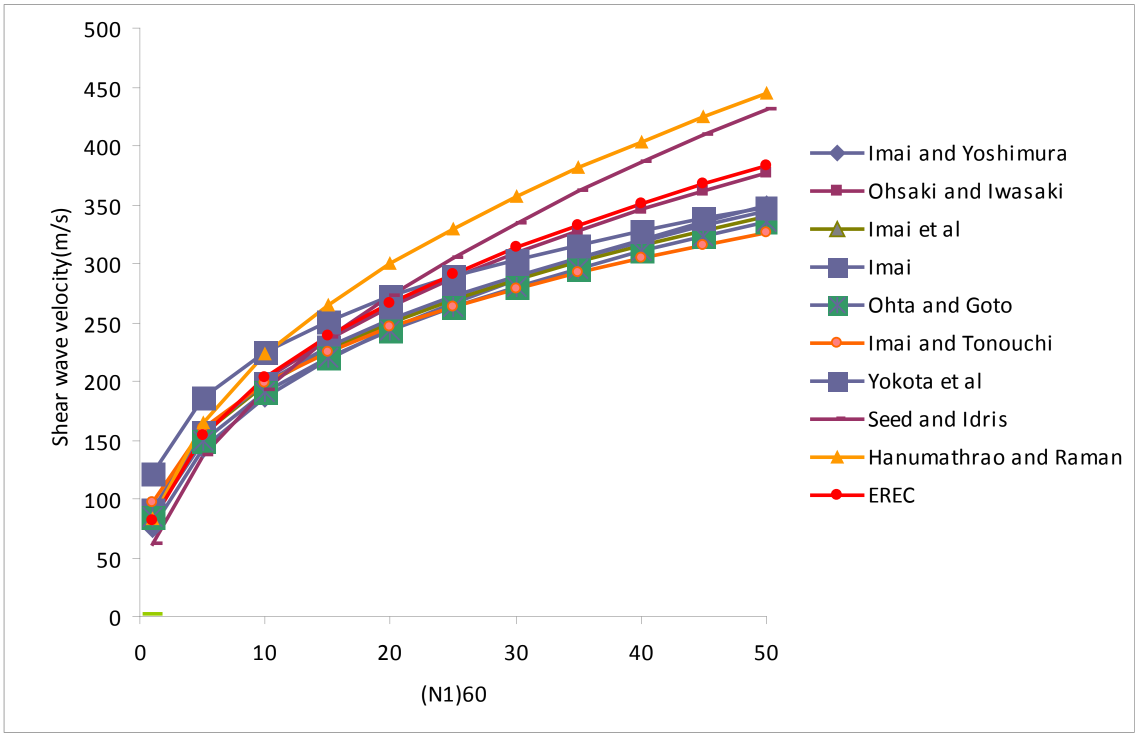


Figure 6.13 (a) Comparison of shear wave velocity evaluated from different standard relations from $(N1)_{60}$ values for all types of soil and evaluated from new relations developed for NCT Delhi

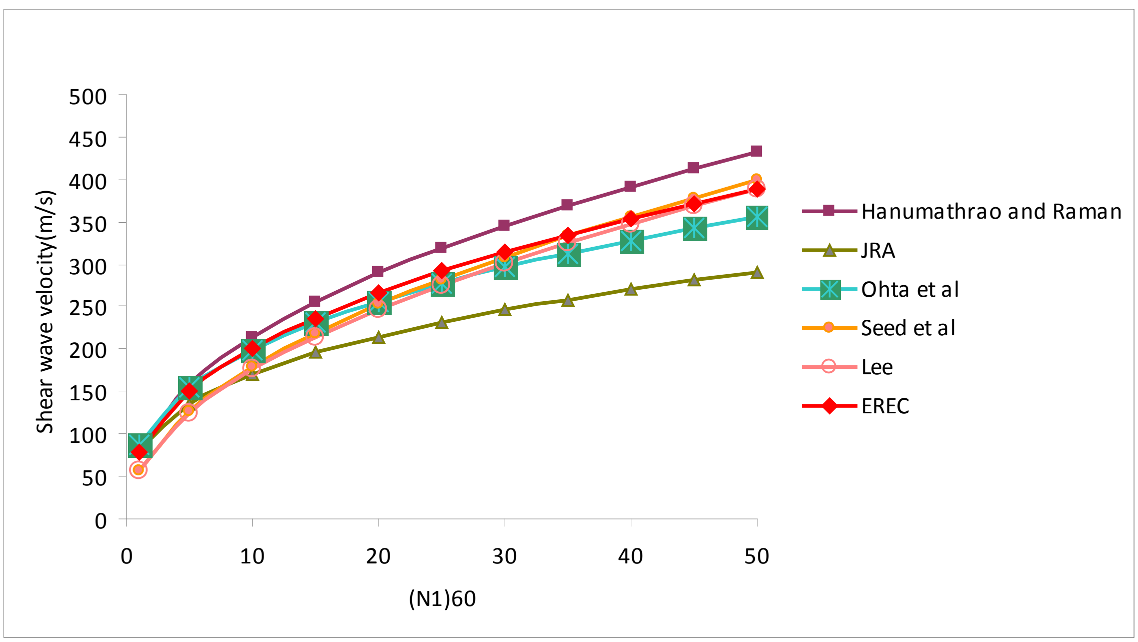


Figure 6.13 (b) Comparison of shear wave velocitiesevaluated from different standard relations from $(N1)_{60}$ values for SAND and evaluated from new relations developed for NCT Delhi

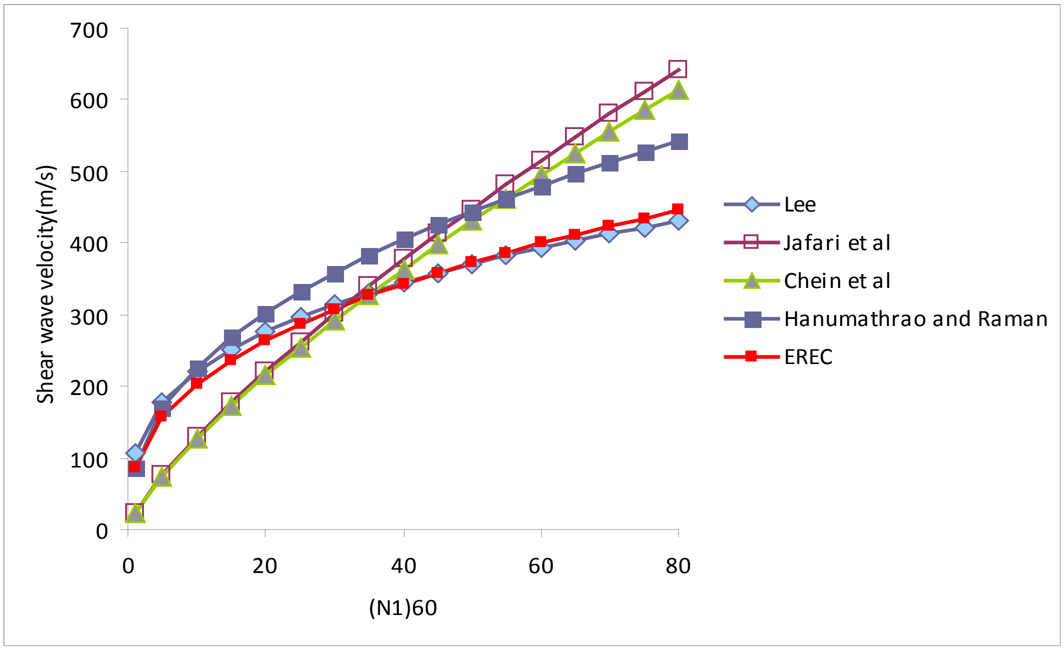


Figure 6.13 (c) Comparison of shear wave velocity evaluated from different standard relations from $(N1)_{60}$ values for Silt/Silty sand evaluated from new relations developed for NCT Delhi

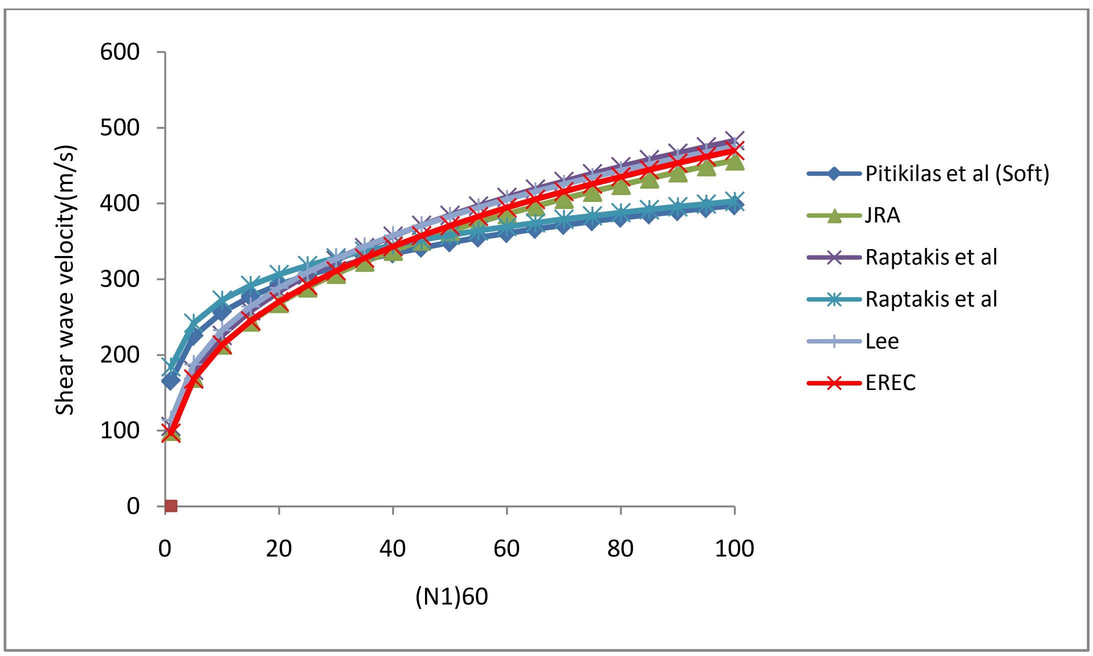


Figure 6.13 (d) Comparison of shear wave velocitiesevaluated from different standard relations from $(N1)_{60}$ values for Clay evaluated from new relations developed by EREC.

CHAPTER 7

SITE CLASSIFICATION OF NCT DELHI BASED ON SHEAR WAVE VELOCITY

Site classification is one of the key issues for the prognosis of earthquake hazard parameters, because the concept and methods of site classification were put forward in the Code for seismic design of buildings in several countries and the parameters of design response spectrum have been determined by considering site classification.Site classification methods are based on geologic genesis and characteristics such as the descriptions of soil characteristics, overburden thickness of soil layer and average shear wave velocity. Generally, one or several indexes are employed, and site is classified into 3 to 4 types.

The shear wave velocity profile of soil column is one of the important parameters for evaluating the dynamic properties of soil and used for classification of site precisely, adhering to National Earthquake Hazard Reduction Program (NEHRP, Building Seismic Safety Council 2001) and Uniform Building Code (UBC, ICBO 1994) terminology and for site response modeling as well. Indian Building codes also make use of Shear wave velocity for site classification and site response modeling. Since amplification is maximum only due to soil layers present in the top 30m, soil classification has been proposed based on average shear wave velocity of top 30m soil (V_s^{30}) (Gazetas, G. 2003).Shear wave velocity is also used for study of ground response and generation of site specific response spectra and therefore in the present study, an attempt has been made to classify the sites of NCT Delhi based on Shear wave velocity.

There are several techniques for evaluation of shear wave velocity based on actual measurement and also using empirical relations with geotechnical parameters. Accordingly a comprehensive plan for evaluation of Shear wave velocity, using different techniques was drawn as discussed in the previous chapter. In this chapter different technique adopted for evaluation of shear wave velocity and subsequently classification of sites based on shear wave velocity has been discussed. Site classification based on NEHRP scheme (BSSC, 2003) is given in following Table 7.1.

7.1 EVALUATION OF AVERAGE SHEAR WAVE VELOCITY [Vs(30)]

Several geotechnical and geophysical techniques based on field and laboratory investigations are available to obtain sub-surface shear wave velocity profiles that include,

(i) Multi-channel Analysis of Surface Waves (MASW), (Park et al., 1999),

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(i) Multi-channel Analysis of Surface Waves (MASW), (Park et al., 1999),

(ii) Spectral Analysis of Surface Waves (SASW), (Stokoe et al., 1994), and
(iii) Cone Penetration Test (CPT)
(iv) Down Hole Test (DHT) and Cross Hole Test (CHT)
(v) Using empirical equations between SPT-Nvalues obtained from geotechnical borelog, and the average shear wave velocity (Fumal and Tinsley 1985; Imai and Tonouchi, 1982)

Table 7.1: Site classification as per NEHRP scheme (BSSC, 2003)

NEHRP Site Class	Description	Vs(30)
A	Hard rock	> 1500 m/s
B	Firm and hard rock	760 – 1500 m/s
C	Dense soil, soft rock	360 – 760 m/s
D	Stiff soil	180 – 360 m/s
E	Soft clays Special sandy soils, eg. liquefiable	< 180 m/s
F	soils, sensitive clays, organic soils, soft clays > 36 m thick	

Each technique has its own merits and demerits and is often employed in combination to authenticate and maintain consistency within specified uncertainty in the interpretations of different observations. In the present study of Seismic Hazard Microzonation of NCT Delhi also, a combination of different techniques have been employed for evaluation of shear wave velocity, which are described in the following sections.

(i) Cross Hole Test (CHT) /Down Hole Test (DHT) at 25 representative sites spread over different geological domains of NCT Delhi.
(ii) MASW at 110 sites (83 have been found suitable for the study)
(iii) Shear wave velocity derived from empirical equations using SPT- Nvalues
(iv) SPT N values obtained during undertaking project specific geotechnical investigations by drilling and collecting soil samples at 314 sites.
(v) Besides this newly generated data, reports from different construction agencies containing SPT N values have also been collected and suitable data at 120 sites have been used for evaluating Shear wave velocity and site classification.

7.1.1 Shear wave velocity evaluation from SeismicCross-HoleTest (CHT)

SeismicCross-holetestingprovidesusefulinformationondynamic soil propertiessuch as Shear wave velocity required forsite classification and further study of site-specific groundresponseanalysis, liquefactionpotential studies, etc.Perhapsitisbestin-situ methodusedforobtainingthevariationof lowstrainshearwavevelocitywithdepth.

In the present study Cross Hole Test (CHT) has been carried out at 25 sites spread over representative sites of different geological domains. Locations of sites are given in documentation Map -13. At each site three bore holes were drilled at spacing of 4m and 8m. Shear wave velocity has been evaluated at each spacing and average shear wave velocity from these two spacing has been used for the study and given inappended Table 7.2.

7.1.2 Shear wave velocity evaluation from SeismicDown-holeandUp-holeTest (DHT)

The general principle of the down-hole test is to establish the shear wave (S-wave) and Compression wave (P-wave) velocities of the soil and rock layer at selected depths. The waves are generated on the surface using a suitable source device and are detected in "receiver" borehole drilled at known distance from the source point. The wave fronts detected by the geophone in the receiver borehole are recorded by a signal enhancement seismograph. The travel time of the generated P and S wave is interpreted from the wave front recorded by the seismograph. Using the travel time and the distance between the "source" point and the "receiver" borehole, P and S wave velocities are calculated.

In the present study the Down Hole Seismic Test (DHT) has been carried out up to a depth of 30m below existing ground level at 25 locations (Map-13) to determine shear wave velocity. The test was conducted in general accordance with ASTM D-7400. The horizontal distance between "source" point and the "receiver" point was kept 3.0 to 5.0 meter. The shear Wave velocity using DHT at 25 sites are given in Table 7.2(appended).

7.1.3 Shear wave velocity evaluation using Multichannel Analysis of Surface Waves (MASW)

The most widely-used techniques for evaluation of Shear wave velocity are SASW (Spectral Analysis of Surface Waves) and MASW (Multichannel Analysis of Surface Waves). The MASW has been found to be a more efficient method for unraveling the shallow subsurface properties (Park et al., 1999; Xia et al., 1999; Zhang et al., 2004). The added advantage of MASW is its non-intrusive and less time consuming geophysical method.

In the present study of Seismic Hazard Microzonation, MASW survey at 110 sites spread over NCT Delhi has also been carried out in two phases. In the first phase MASW survey has been carried in collaboration with Wadia Institute of Himalayan Geology (WIHG), Dehradun at 10 representative sites. Locations of these sites are given in Figure-7.1. In the second phase MASW has been carried at 100 sites in collaboration with Indian Institute of Technology (IIT), Roorkee. Among these 100 sites, data of 73 sites have been found suitable and used for the study. Locations of these sites are shown in documentation Map-13.

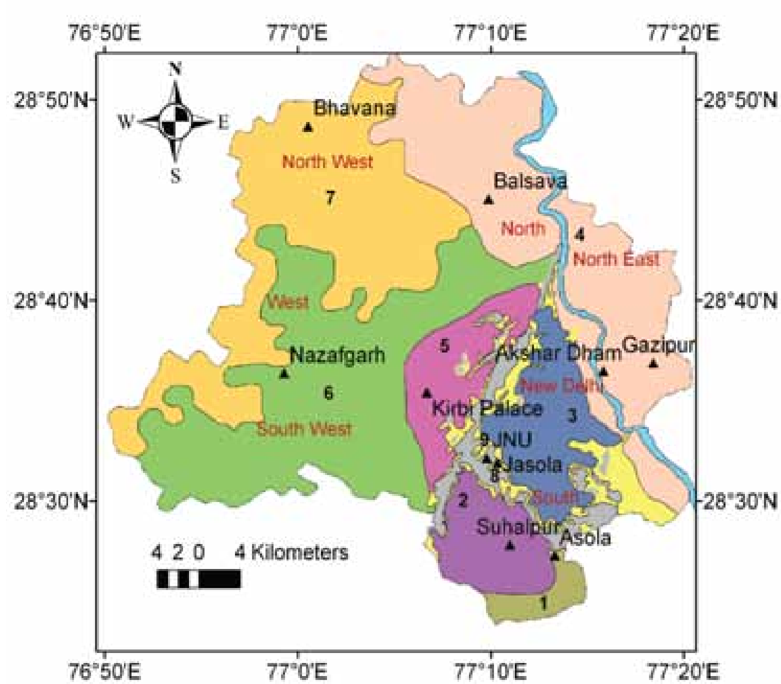

Figure 7.1 Locations of MASW sites overlaid in Geological map of NCT Delhi attempted in first phase at 10 sites in collaboration with WIHG, Dehradun.

7.1.3.1 Results of shareware velocity, from MASW Data at 10 representative sites

In the first phase of the study 10 representative sites at different geological domains were selected and were distributed on Alwar quartzite (JNU site, Asola site) of Delhi Super group, along the bank of Yamuna river (Akshar Dham site), and near lakes (Nazafgarh lake site, Bhalsawa lake site) and at locations with thick sediment covers (Bahvana, Suhalpur, Ghazipur, Kirbi Cantt., etc). Locations of these sites are shown in Figure 7.1 and also in documentation Map-13.The details of profile obtained are discussed in following paras and a brief along with shear wave velocity at these 10 representative sites of different geological domains are given in appended Table 7.3.

7.1.3.1.1 Shear wave velocity profile at Akshar Dham Site

This site is located at the eastern end of Delhi city along the bank of river Yamuna(Figure 7.1). The site is underlain by sediments of Yamuna River with sandy clay at the surface. The shear wave velocity profile carried out in this area with station spacing of one meters shows very low shear wave velocity i.e 175m/s up to a depth of 10.5 meters and there is sudden increase to 285 m/s below 10.5 meters. Thus this may represents an interface between stiff soils from overlying low velocity soft soil (Figure 7.2). The average shearwave velocity at 25 to 30m is 350m/s.The average shear wave velocity of 30 meter soil column Vs^{30}istherefore about 230m/s. As per NEHRP classification this site is characterized as Class 'D' soil.

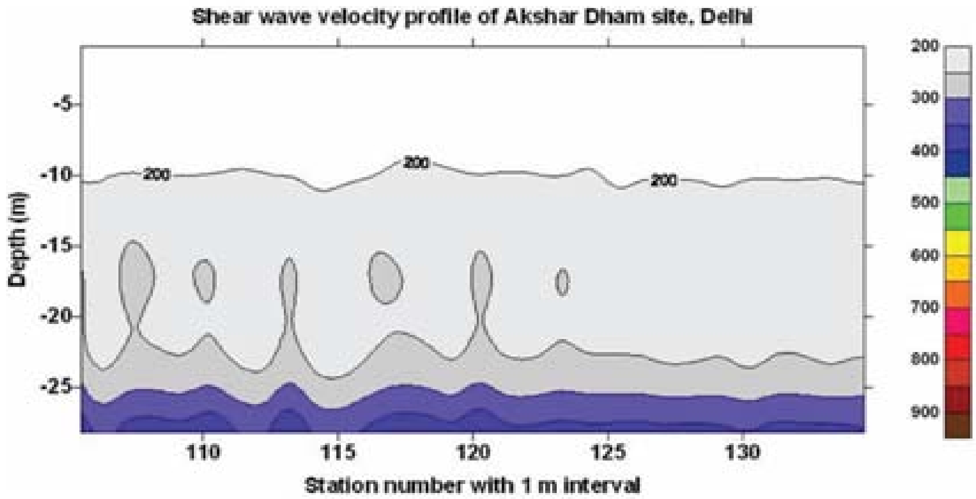

Figure 7.2 Shear wave velocity profile obtained from MASW at Akshar Dham. The bar code shows shear wave velocity in m/s.

7.1.3.1.2 Shear w ave v elocity p rofile at Jaw aharlal N ehru U niversity (JNU) an d Asola sites

The sites are located on massive and weathered Alwar quartzite rocks, which are very well exposed in an area in almost NE-SW direction in JNU (Figure 7.1). The shear wave velocity varies (600 m/s-800 m/s) at the surface to around 1200m/s at 30m depth and reaches to >2000 m/s at a depth of 50 meters (Figure 7.3 & 7.4).

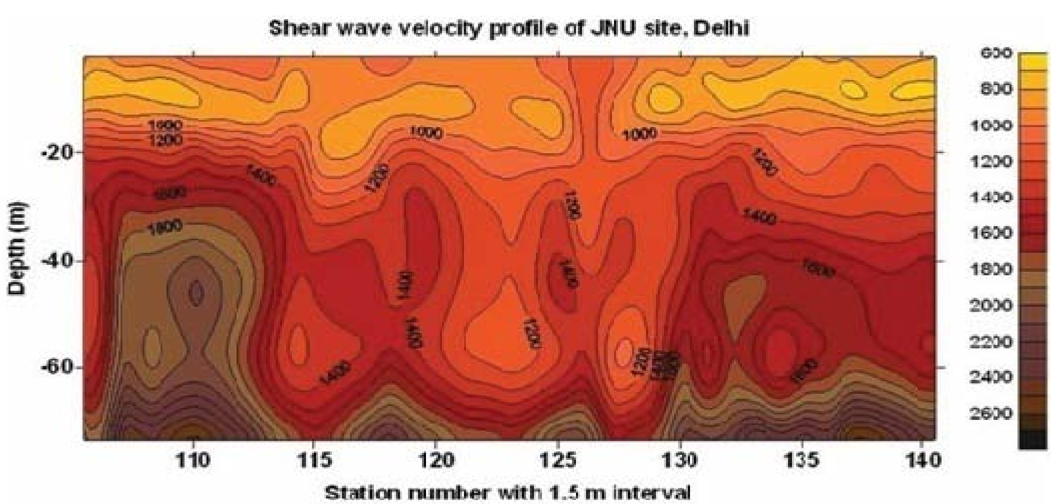

Figure 7.3: Shear wave velocity profile obtained from MASW at JNU site.The bar code shows shear wave velocity in m/s.

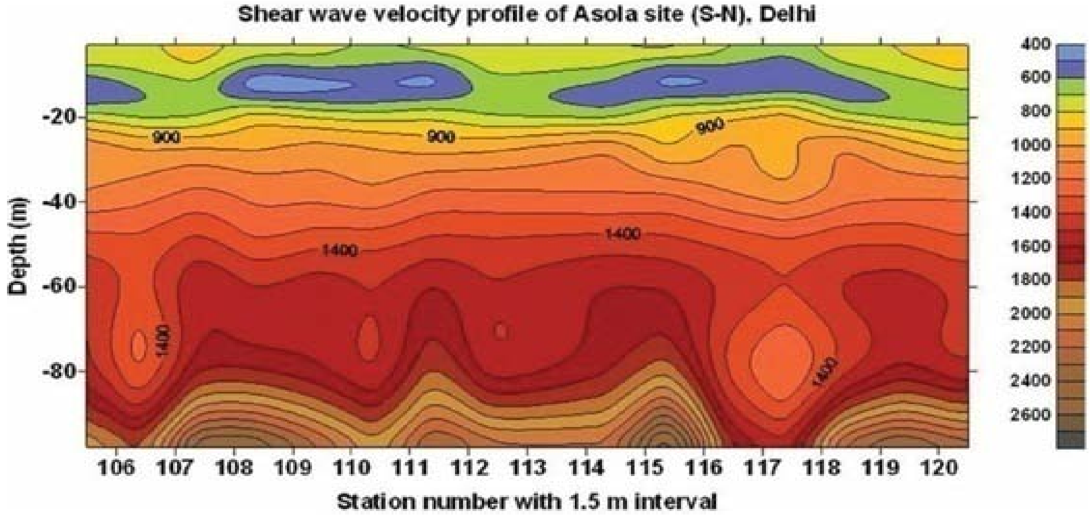

Figure 7.4 Shear wave velocity profile obtained from MASW at Asola site.The bar code shows shear wave velocity in m/s.

In JNU area massive and compact rocks (Alwarquartzite) are exposed on the surface that iswell documented by high shear wave velocity(600 m/s-800 m/s) at the surface to >2000 m/sat a depth of 50 meters. Therefore,the velocity of the quartzite varied from 1000 m/s to 2000 m /s (Figure 7.3). On the other hand in Asola area the profile runs along N-S direction perpendicular to joints and fractures shows shear wave velocity ranging from 400- 800 m/s (20 m depth), 800-1100 m/s (40 m depth), 1100- 1800 m/s (40-70 m) and > 2000 m/s below 80 m depth (Figure 7.4).

From the shear wave profiles of JNU site and Asola site, it is observed that the velocity profiles which is perpendicular to the joint/fractures direction (Asola Vs profile) shows low velocity of Alwar quartzite as compared to the massive quartzite (JNU site Vs profile). These two sites can be classified as class 'B' (Vs>760m/s) as per NEHRP provision.

7.1.3.1.3 Shear wave velocity profile at Suhalpur site and Jasola sites

The Suhalpur site is located in Chatterpur basin which is dominated by older alluvium and on the southern and northeastern side of the JNU location (Figure 7.1). The shear wave velocity profile shows of the order of 200-250 m/s at the top 15 m. The second layer which is also marked by Vs 300 m/s. Some dissolution features have been observed between 15m to 25m depth (Figure 7.5). The average shear wave velocity (Vs^{30}) of the soil column places these sites under class 'D' as per NEHRP classification.

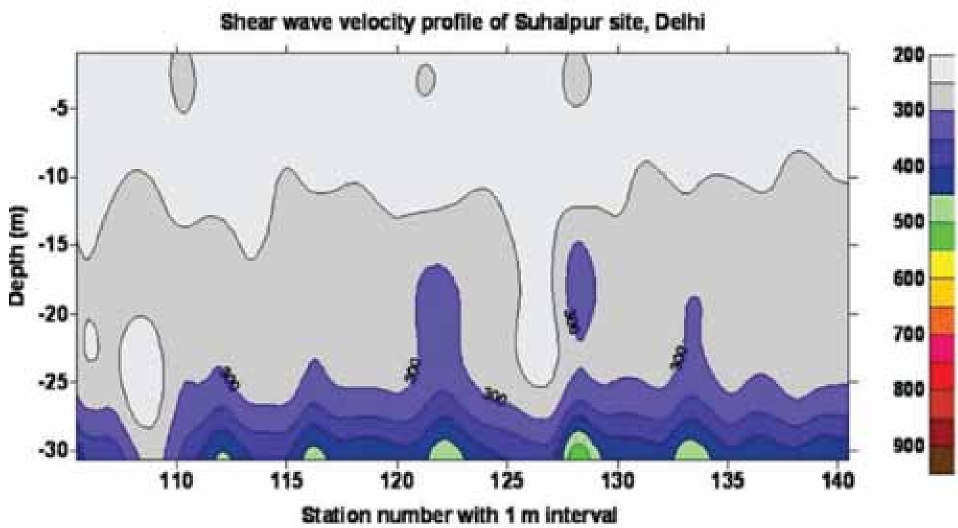

Figure 7.5 Shear wave velocity profile obtained from MASW at Suhalpur site.The bar code shows shear wave velocity in m/s.

Further, it is observed that below 24 meters, the surface is undulating in nature with shear wave velocity of the order of > 400 m/s may be indicated by the presence of weathered rock material derived from nearby quartzite of Delhi Super Group. The Jasola site is located northeastern side of the JNU in Chatterpur Basin, showing average shear wave velocity of 30meter [Vs(30)]around 340m/s.

7.1.3.2 Results from MASW Data collected at 100 sites in collaboration with IIT Roorkee

The detail profiles of shear wave velocity have been obtained at 73 sites spread over NCT Delhi. On the basis of these profiles average shear wave velocity have been estimated for different depth interval. On the basis of this average shear wave velocity for 30m soil Vs(30)has been estimated using formula given as Equation 7.1. Average shear wave velocity Vs(30)evaluated from MASW at all these sites are given in Table 7.4(appended) along with shear wave velocity evaluated from different techniques.

7.1.4 Shear wave velocity derived from empirical equations using SPT N-values obtained during drilling and collecting soil samples

SPT- N values are used for evaluation of shear wave velocity using empirical relations. In the present study geotechnical investigation has been carried out at 314 sites and SPT N values have been collected at each site during the process of drilling and soil sampling. To fill up the gap area and meet the requirement of scale of the study data for the 1:10,000 scale, old geotechnical investigation data of 120 sites have been collected from other construction agencies and used for the study. The SPT- N values collected from the field studies have been corrected, before being used for empirically evaluating shear wave velocity and empirical relations for different types of soil of NCT Delhi have also been derived and presented in Chapter-6. The empirical relation developed for different types of soil are given in equations 6.13, 6.14, 6.15, & 6.16 and reproduced below-

For Sand (SP-SM, SP, SM-SC)

$Vs=80.686\ (N1)_{60}^{0.3895}$(for corrected N value up to 50)

For Clay (CL, CL-ML)

$Vs=96.584\ (N1)_{60}^{0.3432}$

For Silt (ML, MI)

$Vs=85.378\ (N1)_{60}^{0.3774}$

For all types of Soil (general relation)

$Vs=83.645\ (N1)_{60}^{0.3806}$

From New Data

On the basis of these empirical relations developed for soil of Delhi, shear wave velocity from corrected SPT 'N' value $(N_1)_{60}$ for different depth intervals up to the depth of 30M have been evaluated at all 314 sites spread over NCT Delhi, where SPT 'N' values have been collected during geotechnical investigations.

Based on these shear wave velocities evaluated at different depths, average shear wave velocity for 30m depth (V_s^{30}) at different sites have been calculated using the following equation.

$$V_s^{30}=\frac{30}{\sum_{i=1}^{N}\left(\frac{di}{vi}\right)} \qquad (7.1)$$

Where,

d_i is thickness of the i^{th} soil layer in meters; v_i is shear wave velocity for the i^{th} layer in m/s and N is no. of layers in the top 30 m soil strata which will be considered in evaluating $V_s(30)$ values.

Table 7.5 A typical data sheet, for evaluation of Shear wave velocity at one borehole site from corrected N' value, $(N_1)_{60}$

Co-ordinates:	N 28° 37' 29" E 76° 54' 52"															
Evaluation of Shear Wave velocity from corrected "N" Value for Borelog of BH No. 1N, SHEET No. - 3																
Borehole											Natural Water		Thickness	(N1)60_ without overburden corr(Cn)	d_i/v_i	Relation given by EREC, 85.378.X^0.3774 for MI+ML,96.856.X^0.3432 for CL,CL-ML; 80.864.X^0.3886 for SP-SM,SP,SM-SC
Depth	Field	Type of strata	Density		T.S.	E.S.	C_N	Correction Factor For				$(N_1)_{60}$				
m	N Value		gm/cc	kN/m³	kN/m²	kN/m²		Hammer Effect	Borehole Dia	Rod Length	Sample Method		m			
1.50	15	ML	1.76	17.60	26.40	26.40	1.00	0.70	1.05	0.75	1.00	8.27	3.0	8.27	0.0160	189
4.50	18	ML	1.76	17.60	79.20	79.20	1.00	0.70	1.05	0.85	1.00	11.25	3.0	11.25	0.0140	213
7.50	58	ML	1.77	17.70	132.30	131.81	1.00	0.70	1.05	0.95	1.00	40.50	3.0	40.50	0.0086	345
10.50	30	ML	1.99	19.90	192.00	162.08	1.00	0.70	1.05	1.00	1.00	22.05	3.0	22.05	0.0109	274
13.50	21	SM	1.85	18.50	247.50	188.15	0.71	0.70	1.05	1.00	1.00	11.02	3.0	15.44	0.0128	234
16.50	27	SM-SC	1.79	17.90	301.20	212.42	0.66	0.70	1.05	1.00	1.00	13.13	3.0	19.85	0.0116	258
19.50	41	SM-SC	1.83	18.30	356.10	237.89	0.61	0.70	1.05	1.00	1.00	18.52	3.0	30.14	0.0098	304
22.50	78	SC	1.87	18.70	412.20	264.56	0.57	0.70	1.05	1.00	1.00	32.80	3.0	57.33	0.0077	390
25.50	83	SC	2.09	20.90	481.50	304.43	0.52	0.70	1.05	1.00	1.00	31.62	3.0	61.01	0.0075	400
28.50	71	SC	2.10	21.00	538.20	331.70	0.49	0.70	1.05	1.00	1.00	25.42	3.0	52.19	0.0080	376
														Σdi/vi=	0.1069	(Vs)30 = 30/0.1069=280.7

Shear wave velocity thus evaluated from corrected SPT 'N' values $(N_1)_{60}$ for different depth layers at all 314 sites using empirical relations developed for Delhi (equations 6.13, 6.14, 6.15 & 6.16), average shear wave velocity of 30m soil [Vs(30)] has been evaluated using Equation 7.1 and is given in appended Table 7.4. A typical data sheet for evaluation of Shear wave velocity at one borehole location up to the depth of 30m from corrected N values is given in Table 7.5.

At these sites of NCT Delhi average shear wave velocity 'V_s (30)' varies from 220 to 360 except at one site shear wave velocity is 368 and according to NEHRP scheme given in above Table 7.1. Thus thesoil at all these sites of NCT Delhi may be classified as class D (stiff soil) having shear wave velocity V_s (30) between 180 to 360 m/s. At one site shear wave velocity V_s (30) is 368 m/s, however very close to the extreme limit of class D soil but as per classification scheme site may be classified as Class C (dense soil to soft rock).

From old data collected from construction agencies

In order to fill up the gap area to meet the requirement of scale of study, geotechnical data collected from different construction agencies viz. Delhi Development Authority (DDA), Central Public Works Department (CPWD), Delhi Jal Bord (DJB) and Delhi Metro Rail Corporation (DMRC) have also been scrutinized in terms of available information and suitability of bore hole locations. On scrutiny, quality data of 120 boreholes have also been used for evaluation of shear wave velocity from SPT 'N' value and subsequently for site characterization. At a few borehole locations data are around 20 to 25 meter depth only and therefore, the technique suggested by Boore (2004), has been applied t o ge t s hear w ave v elocity of r emaining de pth.The s hear w ave v elocities [Vs(30)]thus obtained are given in the appended Table 7.4.

7.2 RESULT AND DISCUSSIONS

Average Shear wave velocity of 30m soil column [V_s (30)]evaluatedat different sites of NCT Delhi, spread over the varied geological domains of NCT Delhi, using CHT, DHT, SPT 'N' value and MASW techniques at 542 sites have been consolidated and given in Table 7.4. For a few common sites highest shear wave velocity obtained from different techniques have been included in table 7.4. These Shear wave velocities have been used for cl assification of s ites ba sed on National E arthquake H azard R eduction Program (NEHRP), Building Seismic Safety Council (2001) and Uniform Building Code (UBC, ICBO 1994) presented in Table 7.1. According to this classification, the sites of NCT Delhi, can be cl assified under t he t hree categories i .e. Class 'B' (firm a nd hard rock) having Shear wave velocity between 760 m/s and 1500m/s (JNU site), Class 'C' (Dense soil and soft rock) having shear wave velocity 360m/s and 760 m/s (such as Asola site) and , class D (Soft soil) having Shear wave velocity between 180m/sec and 360m/s at all other sites.

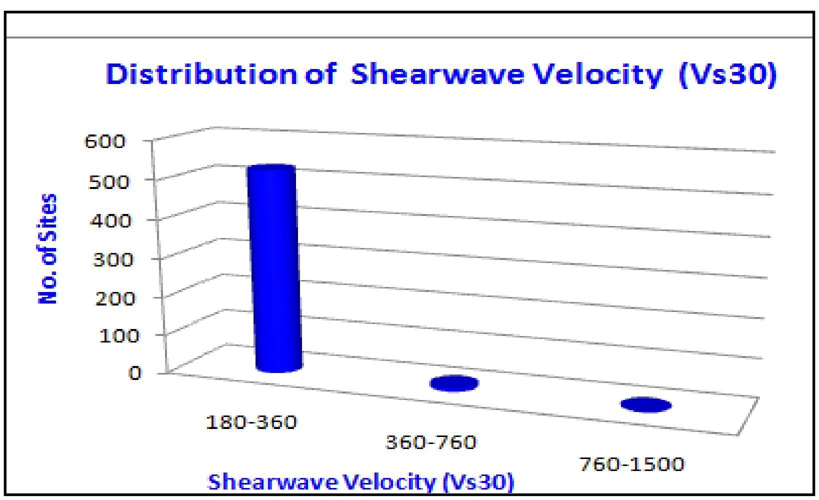

Figure 7.6 Distributionof number of sites classified based on the shear wave velocity representing class interval of NEHRP classification.

A bar chart shown in Figure 7.6 gives the distribution of number of sites classified based on the shear wave velocity representing class interval of NEHRP classification. This chart shows that most of the sites of NCT, Delhi fall under the category of soil Class 'D' having shear wave velocity between 180m/s and 360m/s, a few sites fall in the category of soil class 'C' having shear wave velocity between 360m/s and 760m/s. These sitesare mostly located on massive and weathered Alwar quartzite rocks. At JNU site which is, also located on massive and weathered Alwar quartzite rocks, but are very well exposed in the area, the average shear wave velocity of 30 meter is about 850 m/s and therefore site may be classified as site 'B'.

7.2.1 Site classification map

Based on shear wave velocities measured and evaluated using CHT, DHT, SPT 'N' value and MASW presented in Table 7.4, a map has been generated for NCT Delhi and attached with report as Map-16. In order to prepare maps, discrete site specific shear wave velocity [V_s (30)]values at 542 sites have been converted in continuous surface using Inverse Distance Weighted (IDW) interpolation technique, using appropriate parameters and cross validation so that the Root Mean Square (RMS) values between predicted and actual are as minimum as possible. This is one of the most popular methods adopted by geoscientists and geographers available in GIS packages.This map represents the Site classification based on Shear wave velocity obtained for different techniques at different sites spread over NCT Delhi.

However, for site classification as discussed above, average shear wave velocity of 30 meter soil column (V_s (30)) is used, but shear wave velocity of top few meters layer play a very important role in modifying response of soil, during earthquake loading. In view of this two maps for shear wave velocities of layers 0-3 m and 3-6 m below ground level have also been generated and presented as Map 17 & map 18, respectively.

Site classification map and Shear wave velocity mapsof layers 0-3 m and 3-6 m below ground level have also been generated for each toposheet on 1: 10,000 scale and given seerately in the form of Altus prepared for Seismic Hazard microzonation of NCT Delhi on 1:10000 scale.

7.3 Ambiguity in site classification

Analysis of MASW data shows that the sites located on Alwar quartziteof Delhi Super Group at JNU shows a shear wave velocity(Vs) varies from 770m/s at the surface to 2800 m/s at a depth of 50 meters resulting average shear wave velocity of 30 meter [V_s (30)] is 850 m/s classifying site as class 'B' type soil. Similarly the site at Asola, which is also located on massive and weathered Alwar quartzite rocks,the average shear wave velocity of 30 meter is about 700 m/s classifying site as class 'C. The geophysical investigation carried out at Kamala Nehru Ridge (Seismological Observatory of IMD) and Budha garden, both are located on Alwar quartzite of Delhi Super Group shows average shear wave velocity [V_s (30)] 307m/s and 301 m/s respectively and classified as class ‘D’. The ambiguity in shear wave velocity [V_s (30)] at different locations of Alwar quartzite rocks, may be due the presence of joints and fractures at different sites, which reduces the shear wave velocity. Thus, it shows that exposed rock (quartzite) in Delhi is highly weathered and cannot be uniformly categorized as same class, due to the presence of joints and fractures at different sites and may have different seismic accentuation.

There are a few sites however, shear wave velocity are in the range of class D, but close to upper limit of lower class, such as Akshar Dham, Ghazipur and Balsawa,etc of Yamuna river bank.Further, the geotechnical investigations carried out at seven other sites, which are in close proximity of different parts of the ridge, encountered weathered rock after 10-15 m depth below ground level and V_s (30) explicitly cannot be evaluated for these sites. The practice is generally to classify such sites on the basis of overburden i.e. considering the depth of soil only (Bangalore Microzonation report, 2009). At these sites average shear wave velocity of soil above weathered rock is around 250 m/s and therefore these sites have also been classified as site class ‘D’.

The site classification is basically used for the selection of standard response spectra of different site classes provided in building codes. In the present study, as site specific response spectra are being provided, in which shear wave velocities of individual layers are considered and therefore ambiguity in site classification may not yield to wrong assessment of seismic accentuation.

CHAPTER -8

SITE RESPONSE STUDY (Part-A):

EVALUATION OF PEAK FREQUENCY AND PEAK AMPLIFICATION

Site response study is important component of Seismic Microzonation. There are several methods available in literature for estimation of site response and used world over. Broadly these methods are classified as (i) Empirical Methods (ii) Experimental Methods and (iii) Numerical Methods. The empirical and experimental methods are useful for evaluation of Peak frequency (f_0) and to the some extent Peak amplification (A_0) of soil above firm bedrock.Numerical methods are used to predict response of soil on ground surface motion for development of design response spectra, which can be used for design of building code; to evaluate dynamic stresses & strain for evaluation of liquefaction hazard, and to determine the earthquake induced forces that can lead to instability of earth and earth-retaining structures.

The objective of present study of Seismic Hazard Microzonation on 1:10,000 scale is to evaluate all these related parameters to meet all the basic objectives of high grade Seismic Hazard Microzonation such as (i) Peak frequency of soil column above bedrock (ii) Peak Amplification Factor/ratio of soil column above bedrock (iii) Peak Ground Acceleration (PGA) at surface for different periods of exceedance and damping (iv) Amplification factor of soil column (v)Spectral acceleration at different periods (vi)Site specific response spectra and therefore a combination of experimental and numerical techniques have been adopted.

Experimental methods based on microtremors appears to be cost and time effective as a rapid screening tool for evaluation of Peak frequency and approximate estimation of Peak amplification of soil column above base rock (Shear wave velocity > 1500 m/s) and therefore used in the present study for the evaluation of Peak frequencies (f_0) and Peak amplifications (A_0) at different sites spread over NCT Delhi. Site specific ground motion parameters and response spectra etc. have been evaluated using numerical technique.

The present study based on numerical technique also permits evaluation of Peak Frequency and Peak amplification of soil column above engineering bedrock (Shear wave velocity 760 m/s) and therefore used for the validation of Peak frequencies obtained from experimental technique for different equivalent depths of soil column.

In view of the above, site response study has been discussed in two parts. In the present Chapter general overview on site response and evaluation of Peak frequency & Peak amplification based on experimental techniques are discussed. Evaluation of site specific parameters, response spectra using numerical technique and validation of peak frequencies evaluated based on experimental techniques are discussed in the next Chapter-9.

8.1 Field work/Data Acquisition

In the Seismic Hazard Microzonation study of NCT Delhi, experimental approach for site response studies for the evaluation of Peak frequency and peak amplification, has been adopted resorting to techniques of Nakamura type studies on H/V ratio based on microtremor record. The studies has been conducted by deploying Digital Triaxial Portable velocity sensor (L-4 3D) of 1Hz at 511 sites in NCT Delhi. Locations of these sites in NCT are presented in documentation Map 13, along with locations of other investigations carried out for the Seismic Hazard Microzonation of NCT Delhi. Continuous wave form data at each site was collected for 1 hour. Smooth common wave form of 120 seconds was sampled from one-hour plot and 30-second data was processed after smoothening for 300 cycles.

8.2 Analysis of Data

As regards to analysis, Fourier transform spectra for micro tremor was computed adopting SPEC program tagged with SEISAN-the earthquake analysis software developed by Jens Havskov and Larse Ottomoeller, Institute of solid Earth Physics, University of Bergen, Norway. The SPEC program has been customized to present data set for generating parameter file (default: spec. par) and event file (default spec. inp.); the program produces one output file ("spec.out"). The FT spectra were generated for a time window of 30 second of individual microtremor. The adopted program has facility of diagnosing Peak Frequency (fo), Peak Amplification (Ao) and obtaining frequency and amplification values at desired points on spectral ratio curves of horizontal to vertical component (QTS: Quasi-Transfer Spectrum) of microtremor along with error messages.

Thus in mathematical terms, the seismic signal acquired in time series A(t) is converted into frequency domain A(f) using Fast Fourier Transform(FFT) technique. This process is applied to all the three component data i.e. Vertical, EW, and NS. The amplitude of horizontal component $A_E(f)$ and $A_N(f)$ is divided by vertical component $A_Z(f)$ to get the relative spectra of horizontal (EW & NS), and the root mean square average amplitude A (f) is calculated as

$$A(f) = \sqrt{\frac{\{A_E(f)/A_Z(f)\}^2 + \{A_N(f)/A_Z(f)\}^2}{2}}$$

parameters, response spectra using numerical technique and validation of peak frequencies evaluated based on experimental techniques are discussed in the next Chapter-9.

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$$A(f) = \sqrt{\frac{\{A_E(f)/A_Z(f)\}^2 + \{A_N(f)/A_Z(f)\}^2}{2}}$$

A few examples of spectral ratio curves of horizontal to vertical component (QTS: Quasi-Transfer Spectrum) of microtremor along with error messages are shown in Figures 8.1 for different type of soils of NCT Delhi.

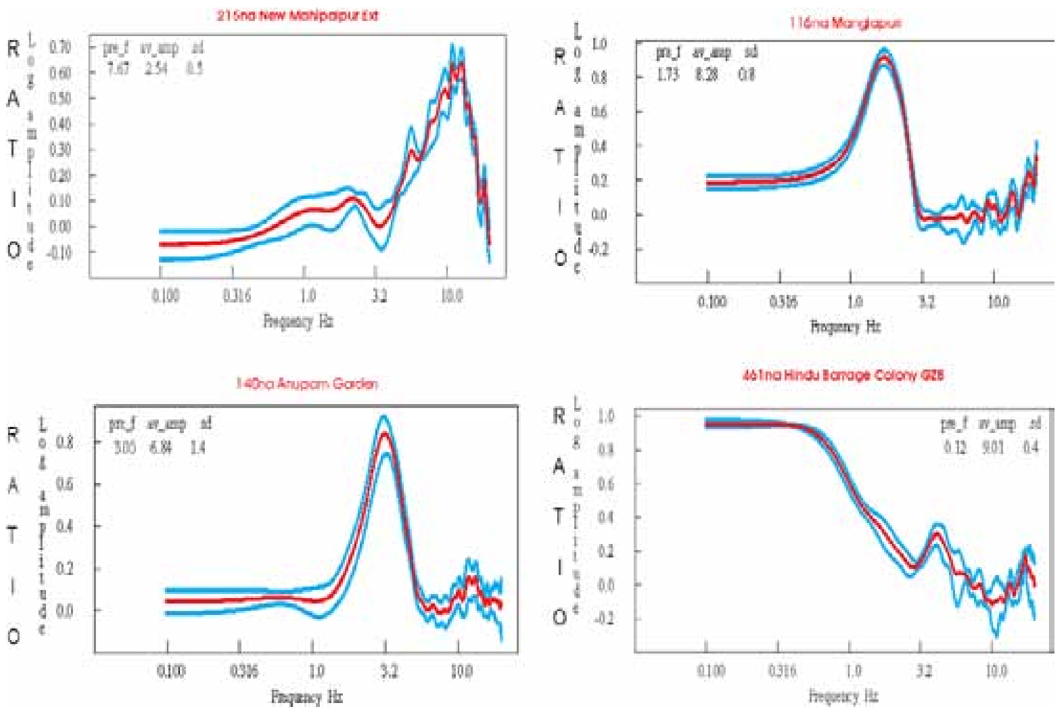

Figure 8.1A few examples of Spectral ratio curves of horizontal to vertical component (QTS: Quasi-Transfer Spectrum) of microtremor along with error messages for different types of soils of NCT Delhi.

Spectral ratio curves (QTS: Quasi-Transfer Spectrum) of horizontal to vertical component of microtremor obtained at different soil conditions can be grouped in six categories from Type A to Type F. The trend in modification of Type-A Spectral ratio curves of horizontal to vertical component of microtremor with change in nature of sediment cover ultimately developing Type-F Curve as shown inFigure. 8.2. Typology of curves can be used for characterization of ground and helpful for identification of sites in conjunction with geological map for undertaking geotechnical geophysical investigationsrequire for site response study using numerical techniques.

From the average relative spectra, the amplification factor at various peak frequencies roughly within 0.2-10Hz is calculated with standard deviations. The maximum peak amplification factors with corresponding peak frequencies are estimated for each site and presented in Table 8.1 (Appended). On the basis of these values (a) Peak frequency (b) Peak amplification maps have been generated and presented as Map-19 & Map 20.

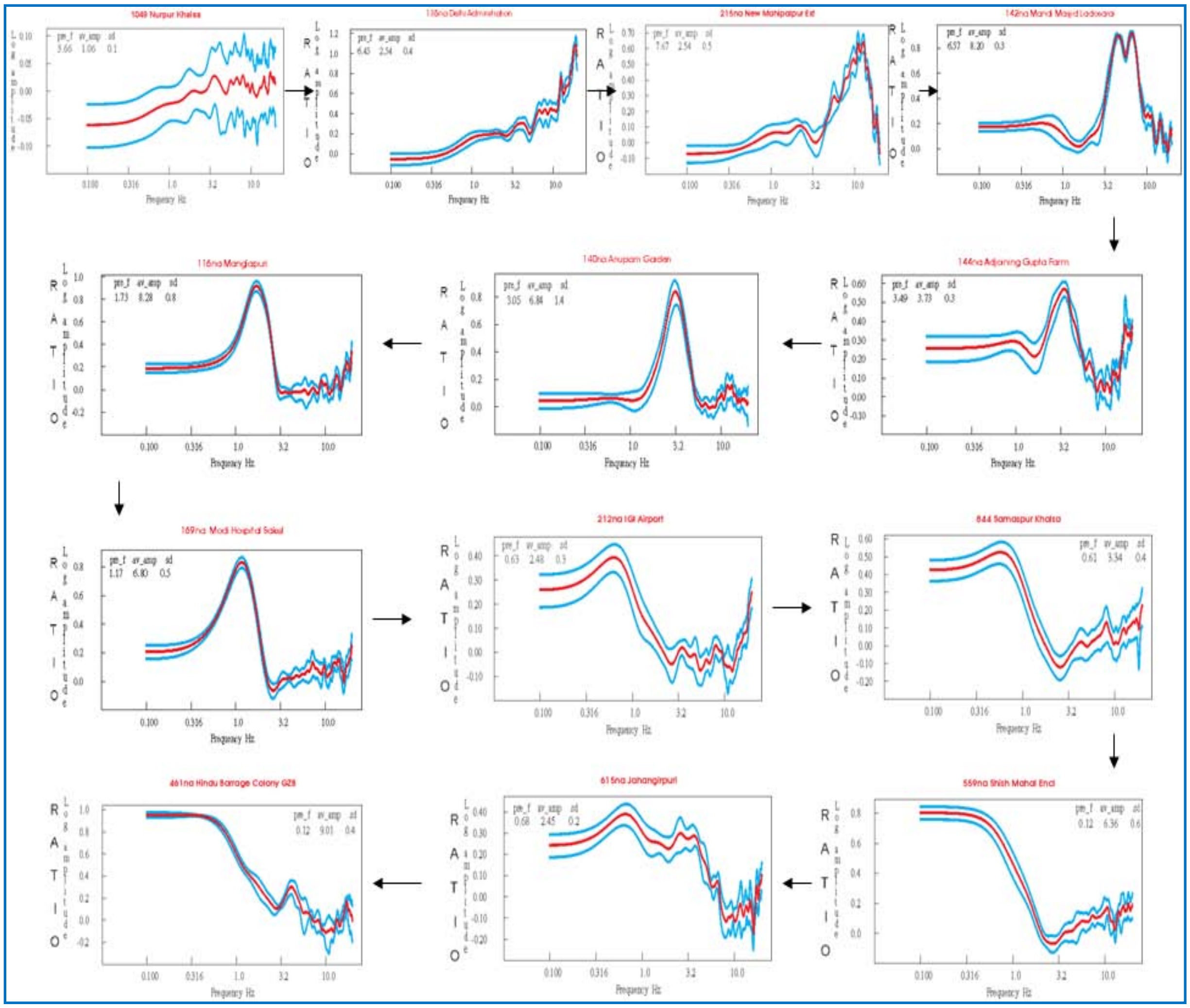

Figure 8.2 Trend in modification of Type-A Spectral ratio curves (Quasi Transfer Spectra) of horizontal to vertical component of microtremorwith change in nature of sediment cover ultimately developing Type-F Curve.

8.3 Result and Discussions

Site Response parameters viz. peak frequency (f_o) and peak amplification (A_0), of soil column above firm/seismic bedrock form the most important input in hazard evaluation and ground characterization for Seismic Hazard and Risk Microzonation. Generally, three approaches are followed to characterize ground motions: (i) empirical evaluations (ii) experimental or in situ instrumental measurements and (iii) numerical modeling.

At NCT Delhi as described above the experimental approach for evaluation of Peak Amplification and Peak frequency of soil cover above firm bedrock (site response studies) has been adopted resorting to techniques of Nakamura type studies on H/V ratio based on microtremor record. Microtremor based "Nakamura Type" studies with H/V ratio as tool to adjudge the transfer function, is gaining importance as rapid scanning tool, especially because of its cost and time effective nature. These studies have been conducted, by deploying Digital Triaxial Portable 1 Hz velocity sensor (L-4 3D) at 511 sites spread over NCT Delhi. Continuous wave form data at each site was collected for 1 hour. Smooth common wave- form of 120 seconds was sampled from one-hour plot and 30-second data was processed after smoothening for 300 cycles. As regards to analysis, the methodology described above has been adopted. Peak frequency and respective amplification at all sites are given in Table 8.1 (appended).On the basis of results of the study Peak Amplification and peak Frequency maps of NCT Delhi have also generated and presented as Map 19 & 20 respectively.

8.3.1 Peak Amplification factor (A_0)

There is no unanimity among scientists (Bard, 2000, Field & Jacob, 1995, Lermo and Garcia, 1994) as regards to reliability of amplification assessments based on microtremor based Nakamura techniques. However, the amplification being of great significance in accentuating hazard, have been ascertained for different sites in NCT Delhi for qualitative assessment following methods of Nakamura type based on microtremor by collecting data at 511 sites in NCT Delhi and methodology enumerated above.

It is evident from the maximum site amplification factor map (Map 19) that the site response (SR) or peak amplification factor generally varies from 1-8, however, at a very few locations Amplification factorshave been observed more than 8. High values of Amplification factors between4 to 8 observed in the zone of very high impedance contrast at shallow (< 100M) depth. The areas under this zone are Chatterpur Basin, areas of Central Delhi in the domain of buried ridge proximity to ridge and covering more area in eastern site of the Ridge. High amplification also observed SW part of Delhi with scattered small packets in western part of Delhi. Very low Amplification less than 2 observed in rocky domain of NCT Delhi. Moderate Amplification 2 to 4 observed on soft Sediment domain covering most part of NCT Delhi.

A frequency distribution of sites having different ranges of Peak amplification is shown in figure 8.3. Out of 511 sites amplification factor is less than 4.0 at 338 sites. Amplification factor at 66% sites is less than 4.0, at 17.4% sites between 4 and 4.9, at 6.6% sites between 5 and 5.9, at 5% sites between 6 and 6.9 and 1.5% sites between 7 and 8, at a very few sites Peak amplification are more than 8.

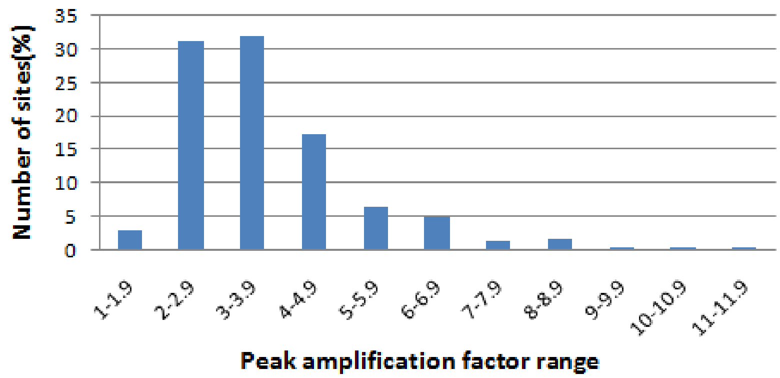

Figure 8.3 Frequency distribution of sites having different ranges of Peak Amplification factor.

8.3.2 Peak Frequency (f_0)

Variation of Peak frequency with bedrock depth which varies from 0 m to more than 300m is shown in figure 8.4.

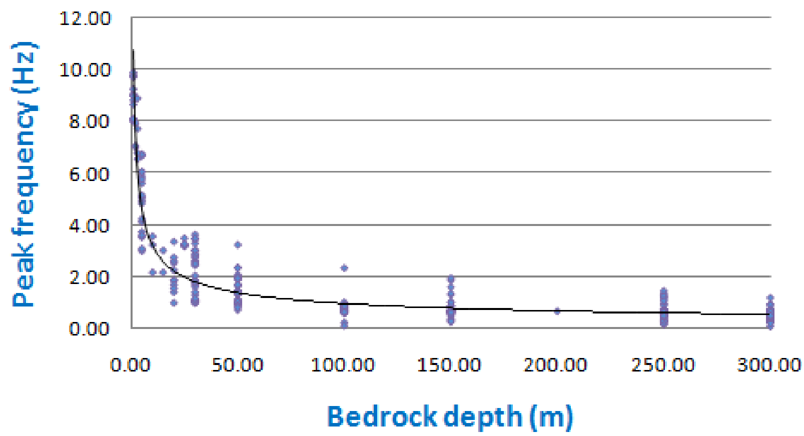

Figure8.4 Variation of Peak frequency with bedrock depth.

Bedrock depth map published by CGWB available in the form of counters for different depth interval has been used for identification of bedrock depth at all the 511 sites. It is difficult to ascertain precise bedrock depth at all the 511 individual sites form this map and therefore peak frequencies plotted in figure 8.4 are against the midile value of available contour interval. For example Peak frequencies shown against bedrock depth of 150m are distributed in class interval of 100 to 200 m depth.

Map 20illustrates the corresponding Peak frequency contour map of soil above firm bedrock. It is evident from the Peak frequency mapthat the peak frequencies at different sites in NCT Delhi mostly vary from 0.21 Hto 10Hz. At a very few sites Peak frequencies are between 0.1 to 0.2Hz. On the basis of Peak frequencies area of Delhi can be divided as (i) Low peak frequency <1.0Hzcharacterizes the domain of thick (>200m) quaternary sediment fill area. It can further be divided in two groups (a) area with peak frequencies vary from 0.3 to 0.5 Hz, which roughly corresponds to the frequencies of 20 to 30 s tories bui ldings(b) area with peak frequencies va ry from 0.5 to 1.0 Hz, which roughly corresponds to the frequencies of 10 t o 20 stories buildings.(ii) Moderate peak frequency domain of 1.0 to 2.0 Hz, which roughly corresponds to the frequencies of 5 to 10 stories buildings(iii) high peak frequency domain of 2 to 3.5 Hz surrounding the area of R idge, w hich r oughly c orresponds t o t he f requencies of 3 t o 5 s tories buildings(iv)Very high pe ak frequency dom ain >3.5 Hz characterizes r ocky ambiance with moderator thin (<30m) sediment cover and high impedance contrast at base and the Rocky domain in ridge area, which roughly corresponds to 1 t o 2 s tories bui ldings. To identify exact localities to be used in the field, large scale maps have been provided. The maps are also made available in GIS format.

A frequency distribution of sites having different ranges of Peak frequency is shown in figure 8.5. It is seen from this distribution, that out of 511 sites

(i) Peak frequency at 78 sites (15 %) are in the range of 2.1 to more than 8 Hz which roughly corresponds to the matching frequency of 1 to 5 stories buildings, which are common types of building in Delhi.

(ii) Peak f requencies at 55 s ites (10.7%) a re i n t he r ange of 1.1 t o 2 .0 H z, w hich roughly corresponds to the matching frequency of 5 t o 10 s tories buildings.Peak frequencies at 288 sites (54%) are in the range of 0.5Hz to 1.0Hz, which roughly corresponds to the matching frequency of 10 to 20 stories buildings.

(iii) Peak frequencies at 46 s ites (9.8%) are in the range of 0.3Hz to 0.49Hz, which roughly corresponds to the matching frequency of 20 to 30 stories buildings.

(iv) Peak f requencies a t 4 4 s ites (8.2%) are l ess t han 0.3H z, which r oughly corresponds to the matching frequency of high rise building more than 30 stories.

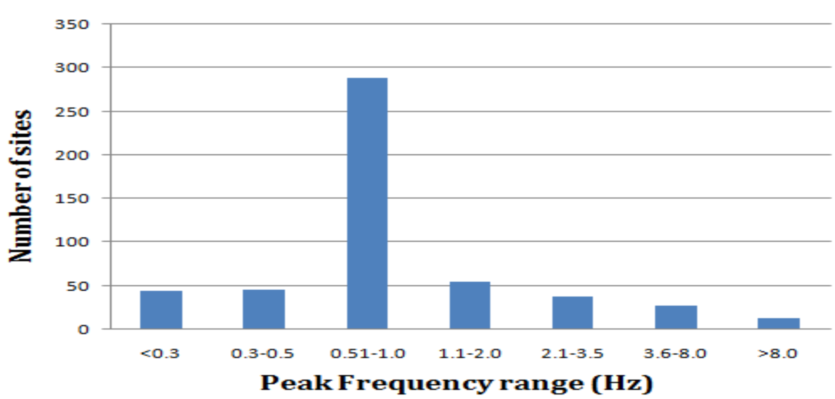

Figure 8.5: Frequency distribution of sites having different ranges of Peak Frequency.

8.4: Evaluation of Peak Frequency and corresponding Peak Amplification factor for the soil column above engineering bedrock using numerical technique

In the present study acceleration time histories have been simulated at engineering bedrock (shear wave velocity 760m/s) based on Uniform Hazard Response Spectra obtained through PSHA, as discussed in Chapter-5. These time histories have been used as input ground motion for ground response study conducted at 449 sites, through numerical techniques and site specific ground motion parameters including Peak frequency (first mode) and corresponding Peak amplification factor have been evaluated at these sites (Numerical technique discussed in Chapter-9). As the input ground motions have been applied at all the 449 sites at engineering bedrock, the site specific parameters including Peak frequency (first mode) and corresponding Peak amplification factors, obtained are the representatives of the soil column above engineering bedrock, which varies from 10m to 154m.

The Peak frequency (first mode) and corresponding Peak Amplification factor values derived from ground response study using numerical technique, for the soil column above engineering bedrock at 449 sites which varies from 10m to 154m are given in Table-8.2 (Appended). Peak frequency of soil column above engineering bedrock varies from 1.0 Hz to 12Hz. Variation of peak frequency with engineering bedrock depth is shown in figure 8.6.

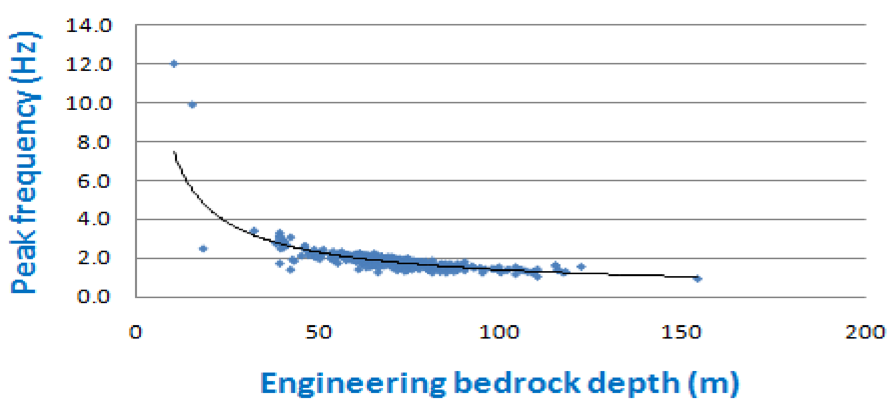

Figure 8.6 Variation of Peak frequency with engineering bedrock depth

Peak amplification factor for the soil column above engineering bedrock using numerical technique have also been evaluated at all the 449 sites and given in Table 8.2 (appended), which varies from 7 to 19. On the basis of this data set a Peak amplification map has been generated and attached as map 21.

8.5 Validation of Peak Frequency and Peak amplification factor obtained from experimental study based on H/V ratio and Numerical technique

The bedrock depth in Delhi varies from 0m to more than 300m. The variation of Peak frequency with bedrock depth obtained from experimental technique is shown in figure 8.4. The engineering bedrock depth varies from 10m to about 154 meters. The variation of Peak frequency with engineering bedrock depth obtained from numerical technique is shown in figure 8.6. The figures 8.4 and 8.6 indicate that Peak frequencies for comparable depth range 10 to 154 m are reasonably comparable.

Singh et al. (2002)used recordings from the Chamoli earthquake of 28 March, 1999, to estimate site effect at three locations of Central Building Research Institute (CBRI) network with respect to the hard site of NDI. Bansalet al. (2009)estimated the site effects at a few sites in Delhi from the earthquakes of 2001 and 2004. These studies reported amplification of the order of 10–20 at different soil sites in Delhi. Mittal et al (2011) estimated the site effect (Peak amplification) at 55different sites in Delhi using data from 13 different local and regional earthquakes, using the standard spectral ratio method and considering the site IMD Ridge (New Delhi), the reference site, and obtained significant variations in amplification factor from one place to another ranging from 3 to 25.

Recently Mittal et al. (2013a &b) used recording from the local earthquake of 5 March 2012 (M5.1) and estimated site effect using the standard spectral ratio method and considering the site IMD Ridge (New Delhi) the reference site, at three new sites, IIT Delhi, Jawahar Lal Nehru University (JNU), and National Power Training Institute, Badarpur (NPTI). They obtained amplification, at IIT of the order of 17 at a predominant frequency of 1.2 Hz., at NPTI of the order of 13 at a predominant frequency of 3.2 Hz and at JNU, of the order of 5.5 at a predominant frequency of 5.0 Hz..Peak amplification at nine old sites have also been estimated and reported to be the same order.

Iyengarand Ghosh (2004) estimated amplification at 17 drill hole sites in Delhi using results of the standard penetration test (SPT) and reported an amplification of 2–3 at the natural frequency of the sites, varying between 0.5 and 6.0 Hz. Parvez et al.(2004) carried out a site-specific ground-motion modeling for Delhi. The response spectra ratio (RSR) computed by them for the north–south profile varies from 5 to 10 in the frequency range 2.8–3.7Hz for transverse and radial components, and for the east–west profile, the RSR varies from 3.5 to 3.7 in the frequency range 3.5–4.1 Hz. The simulated synthetic results were also compared with earthquakes recorded on soft-soil sites, and it was observed that both results show consistency in terms of frequency distribution (Parvez et al., 2006). Mandal et al. (2012) determined the frequency dependent soil amplification factors using Equivalent Linear Method (ELM) at 25 sites at varying engineering bedrock depth over the Greater Delhi from a local earthquake magnitude M_L 4.3 recorded at ridge rock site. The peak amplification factors and frequencies are varies from 3.2 to 5.9 and 1.2 to 5.3 Hz repectively.

It is seen that peak frequencies (predominant frequencies) obtained from the above studies are matching well with the peak frequencies obtained from the present study.For example Mittal et al. (2013a,b) obtained Predominant frequency 5.0 Hz at JNU and from the present study predominant frequencies obtained at two different sites of JNU campus are 4.86 Hz (JNU New Campus) and 7.96 Hz (at exposed rock of JNU campus) respectively.

Peak amplificationfactors obtained at different sites from different studies are ranging from 3 to 25. Which are comparatively high from the values obtained from microtremor H/V ratio Nakamura technique and comparable with values obtained from numerical technique. Nakamura technique based on H/V ratio,underestimate the peak amplification and numerical studies yield reasonable results.

In the present study Peak amplification factors at different siteshave been obtained for the soil above engineering bedrock (shear wave velocity 760 m/s), and may slightly be more for the soil column above firm bedrock (shear wave velocity 1500 m/s) due to the increase of depth. As this parameter is used for qualitative assessment of hazard, Peak amplification factor above engineering bedrock evaluated from numerical technique may reasonably be used. Thus the Peak amplification factor Map 21 may be used for ascertaining Peak amplification factor for different sites of NCT Delhi.

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CHAPTER -9
SITE RESPONSE STUDY (PART-B)

EVALUATION OF SITE SPECIFIC GROUNDMOTION PARAMETERS AND RESPONSE SPECTRA AT SURFACE

The empirical and experimental methods described in the previous Chapter-8 are useful for evaluation of peak frequency and to the some extent peak amplification of soil above firm bedrock and are commonly used in lower grade studies as classification enumerated in Chapter-6.This will yield to second level Seismic Hazard Microzonation studies as enumerated in methodology of Seismic Hazard Microzonation in Chapter-3.The results can be used for primary screening tools and useful for planning of geotechnical/geophysical investigation required for site response study to be carried out for higher grade study of Seismic Hazard Microzonation.

The objective of highergrade SeismicHazard Microzonation study on 1: 10,000 scale is tomeet all the basic objectives of Seismic Hazard Microzonation i.e. to predict response of soil on ground surface motion for development of design response spectra, which can be used for design of building code; to evaluate dynamic stresses & strain for evaluation of liquefaction hazard and to determine the earthquake induced forces that can lead to instability of earth and earth-retaining structures. Thus the higher grade study requires evaluation of several other parameters, than Peak frequency & Peak Amplification which includedevaluation of thecombined influence of amplitude of ground motion accelerations, their frequency components on different structures at different sites, whichis represented by means of a ground response spectrum; that is plot showing the maximum response induced by the ground motion in a single-degree-of-freedom (SDOF) oscillators of different fundamental periods, but having the same degree of internal damping. These parameters can be evaluated through rigorous exercise of site response study based on numerical techniques.

Moreover, experimental technique provides Peak frequency of total soil column above firm bedrock. In the present study of Seismic Hazard Microzonation of NCT Delhi, the reference rock has been considered as engineering bedrock (shear wave velocity about760m/s) and theinput motion has been derived at this level through PSHA study as detailed in Chapter-5. Thus it is imperative to study the effect ofsoil column above this rock and derive all parameters with reference to engineering bedrock.

Therefore, detailed study based on numeral technique is called for. In the present chapter numerical techniques are further detailed and parameters listed above have been evaluated and results are presented.

9.1 GROUND RESPONSE ANALYSIS OF NCT DELHI BASED ON NUMERICAL METHODS

In the present studyanalytical methods based on multiple reflection theory of S waves in horizontally layered deposits, referred to as " 1-D analysis of soil columnsand most widely used has been adopted. Such a soil column is excited by an incoming plane S wave, generally considered as vertically incident. This techniqueallows computation of the seismic response of a given site providing spectral Acceleration at different periods. Peak frequencyand Peak amplification can also be ascertained for the soil above reference rock (in this study engineering rock). The specific parameters required for such an analysis are shear-wave velocity, density, and dampingof soil material for different layersand Shear modulus reduction & damping ratio curves of different soil type.

To consider non linear behavior of soil equivalent linear- method that uses an iterative procedure to adapt the soil parameters (i.e., rigidity and damping) to the actual strain it undergoes has been adopted. Thismethod has been shown to provide a reasonable estimate of soil response and use widely in seismic microzonation studies. Site response using above algorithm has been coded in many software. The earliest software written that uses the principle one-dimensional ground response analysis is called: SHAKE. The computer program SHAKE was written in 1970 -71 by Dr. Schnabel and Prof. John Lysmer (Schnabel et al., 1972). This is the most widely used program for computing seismic response of horizontally layered soil deposits. Other software such as SHAKE2000, SHAKE91, PROSHAKE and, DYNEQ etc are derived from this basic code and based on the same principle.

In the present study a recently developed computer programme DYNEQ,a computer Programme for Dynamic response analysis of level ground by Equivalent linear method, version 3.25 (Nozomu Yoshida and Iwao Suetomi 2004),which is similar to SHAKE and also incorporate latest development such as frequency dependent characteristics, as damping due to scattering etc. has been used. Such Non- linear analysis requires a quantitative knowledge of the actual nonlinear material behavior, which can only be obtained by means of sophisticated laboratory tests. Some generic average curves have been proposed for different types of materialas sand or clay (Seed and Idriss, 1970 and Schnabel, 1973) and available in software database, but the actual behavior of a given soil at a given site may strongly depart from these averages. Due to thisResonant Column test on representative samples of Sand, Silt and Clay of Delhi at different depthsto determine shear modulus and damping ratio of soil under different confining pressure etc have been conducted (detailed in following sections) and used in place of generic average curves provided in database of the software.

In DYNEQ programme some subroutines have been added at EREC to plot products, such as response spectra, Frequency dependent amplification plot, etc using single command, to make product generation more user friendly.

9.1.1 Input required for ground response analysis

Seismic Microzonation study in higher scale requires more rigorous site specific ground response study taking care of horizontal and lateral variability of soil and their effect for input motion at that particular site. This requires generation of a realistic ground motion as input to the base rock in the present case at engineering bedrock, geological mapping which play an important role for understanding surface geological variability for planning of further investigations, intensive geotechnical and geophysical investigation for characterization of horizontal and lateral variability of soil at the site etc. The required inputs are listed below and described in following sections,

(i) Time history (input motion)
(ii) Index and dynamic Properties of Soil (Soil Type, Unit weight, Density,Shear wave velocity)
(iii) Shear modulus reduction curves and damping curves
(iv) Delineation of engineering bedrock and generation of subsurface Soil model
(v) Ground water level maps.

9.1.1.1 Time history (input motion)

A design earthquake that adequately represents the expected ground motion that would drive the structure to its critical response, resulting in the highest damage potential is required as input motion for analysis of nonlinear problems such as response of inelastic structure by performing ground response study detailed in previous sections. In the present study this has been achieved through the Probabilistic Seismic Hazard Analysis described in Chapter-5 in whichPeak Ground Acceleration, spectral acceleration values at different sites for different periods and subsequent Uniform Hazard Response spectra have been generated at engineering bedrock level having shear wave velocity of about 760m/s. These parameters have been used for simulation of ground motion time history at each borehole location sites (449 sites), as detailed in section 5.6 of Chapter -5. The time histories at each borehole locations spread over NCT Delhi have been generated for

(i) 2% probability of exceedance in 50 years for Maximum Considered earthquake (MCE) and
(ii) 10% probability of exceedance in 50 years for Design Basis Earthquake (DBE). These time histories have been used for ground response study at each site for both probabilities of excedance.

9.1.1.2 Index and dynamic properties of Soil

The static soil properties required in the 1D ground response analysis are: type of Soil, Shear strength and Unit weight, dampingfor each layers. The other parameter required is shear wave velocity of different layers. As per plan of geotechnical/geophysical investigations for seismic Microzonation of NCT Delhi described in previous Chapter- 6, geotechnical investigations have been carried out at 314 sites. To fill up the gap area old data of 108 s ites (O ut of 120 s ites us ed f or site c haracterization, a s s ome r equired parameters were not available in remaining data), collected from different agencies have also be en us ed. CHT da ta of 25 s ites and MASW have al so been used. In gr ound response analysis shear wave velocity of individual layers up to a few meter depths below ground surface play very important role. Through MASW profile, it was found difficult to evaluate variation of shear wave velocity of layers of smaller thickness such as of 3.0 meter depth as available with geotechnical data. Therefore, to avoid ambiguity, this data except for two sites lying in hard rock have not been used in ground response study.

Thus data from 449 sites, wherea borehole have been drilled mostly up to 30m depth, and at a few sites up to deeper depth till weathered rock was encountered, have been used for ground r esponse s tudy. In e ach bo rehole, D isturbed & U ndisturbed Soil s amples have been collected at every 1.5 meter interval or change of strata and subsequently laboratory test for evaluation of type of soil and Index property of soil on collected soil samples was conducted. Thus a bout 10,000 s oil samples have been collected. Type o f s oil ha s been identified a nd index properties of s oil a t 1.5m interval up t o a t l east 30 m de pth spread over NCT Delhi have been obtained.

A sample copy of data sheet for one borehole indicating index properties of soil collected at different depths on the basis of laboratory test is given in Table 6.1 (C) of Chapter-6. A sample copy of data sheet for one borehole location showing different corrections applied on observed N value to obtain corrected N value $(N_1)_{60}$ is given in Table 6.6 of Chapter-6. A sample data s heet, f or e valuation of S hear w ave ve locity a t one bor ehole s ite f rom corrected N' v alue, $(N_1)_{60}$ is given in Table 7.3 of C hapter-7. The da ta f or t he e ntire boreholesis available in digital form in GIS format.

9.1.1.3 Shear modulus reduction curves and damping curves

Since t he a nalysis a ccounts f or t he non -linear behavior of t he s oils us ing a n i terative procedure, dyna mic s oil pr operties pl ay a n i mportant r ole. Such N on- linear ana lyses require a qu antitative know ledge of t he a ctual non linear ma terial be havior, the s hear modulus reduction curves, and damping curves which can only be obtained by m eans of sophisticated laboratory testsdata (cyclical triaxial, resonant column test, soiltests). Some generic average c urves have be en pr oposed for di fferent t ypes of m aterial, a s s and or clay, and available in software database package, but the actual behavior of a given soil at a given site may strongly depart from these averages.

In or der t o i mprove t he a ccuracy i n r esults Resonant C olumn test on r epresentative samplesof Sand, Clay and Silt of Delhi collected at different sites and at different depths to determine s hear m odulus a nd da mping r atio of s oil unde r di fferent c onfining pressure,etc ha ve been c onducted at I ndian I nstitute of S cience, Bangalore and us ed i n place of generic average cur ves pr ovided i n database of t he s oftware. The de tails of location and sample collected for Resonant Column Test for evaluation of shear modulus and damping ratio is given in following Table9.1.

Table 9.1 Details of location and sample collected for Resonant Column test for evaluation of shear modulus and damping ratio

S.N.	Name of site	Latitude	longitude	Type of soil	Depth(m)
1	Mukhmalpur	$28^0\ 47^/\ 30^{//}$	$77^0\ 09^/\ 35^{//}$	Sand (SM)	3.00-3.45
2	Kundli	$28^0\ 52^/\ 54.4^{//}$	$77^0\ 06^/\ 6.81^{//}$	Sand (SM)	6.00-6.45
3	Holombi Kalan	$28^0\ 48^/\ 45^{//}$	$77^0\ 05^/\ 15^{//}$	Mixed sand-clay (SM-SC)	15.00-15.45
4	Jangola Coloney	$28^0\ 50^/\ 30^{//}$	$77^0\ 12^/\ 45^{//}$	Clay (CL)	21.00-21.45
5	Kundli	$28^0\ 52^/\ 54.4^{//}$	$77^0\ 06^/\ 6.81^{//}$	Silt (MI) Intermediate liquid	27.00-27.45
6	Mukhmalpur	$28^0\ 47^/\ 30^{//}$	$77^0\ 09^/\ 35^{//}$	Silt (ML)Low liquid limit)	6.00-6.45
7	Teekri Khurd	$28^0\ 49^/\ 8.01^{//}$	$77^0\ 07^/\ 37.2^{//}$	Silt (ML) Low Liquid limit	6.00-6.45

Typical shear modulus and damping ratio curves for Sand, Silt and Clay obtained from RCT test on soil collected at Delhi are shown in following Figures9.1, 9.2, 9.3&9.4.

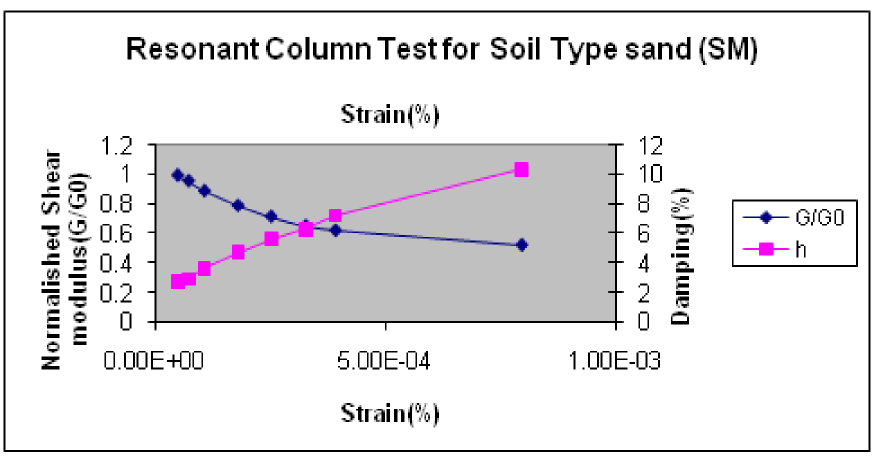


Figure 9.1 Shear modulus and damping ratio curves of soil type Sand (SM)

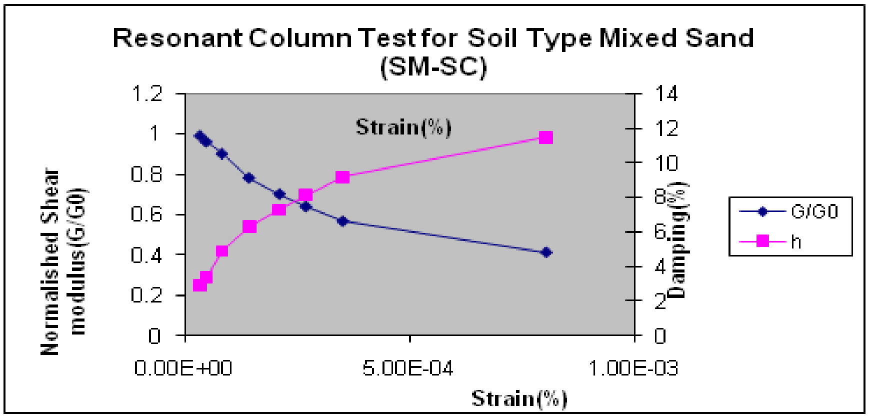


Figure 9.2 Shear modulus and damping ratio curve of soil type Mixed sand (SM-SC)

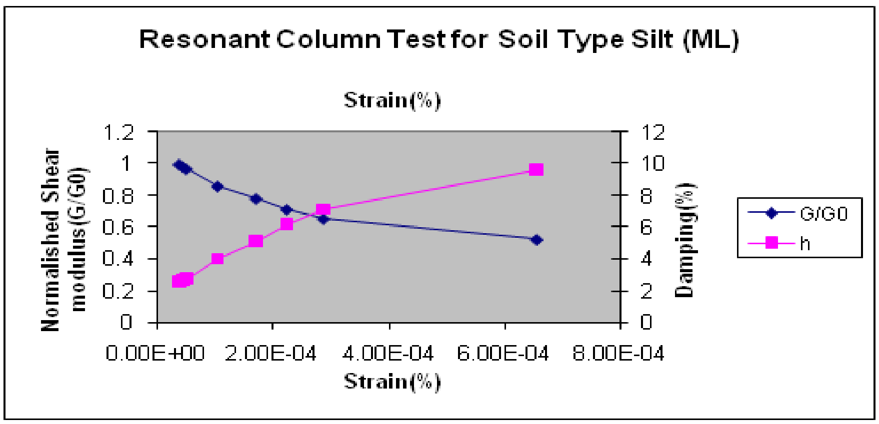


Figure9.3 Shear modulus and damping ratio curves of soil type Silt (ML)

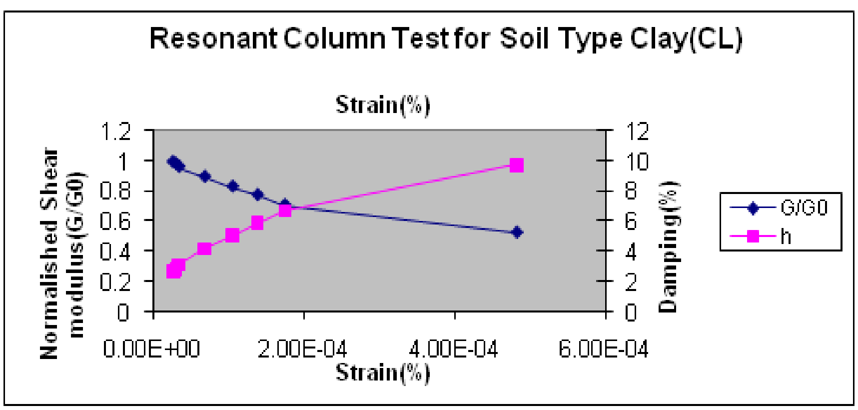


Figure9.4 Shear modulus and damping ratio curves of soil type Clay (CL)

9.1.1.4 Delineation of engineering bedrock and Soil Modeling

In the present study based on probabilistic Seismic Hazard Analysis (PSHA) Uniform Hazard Response Spectra have been evaluated at engineering bedrock using, Next

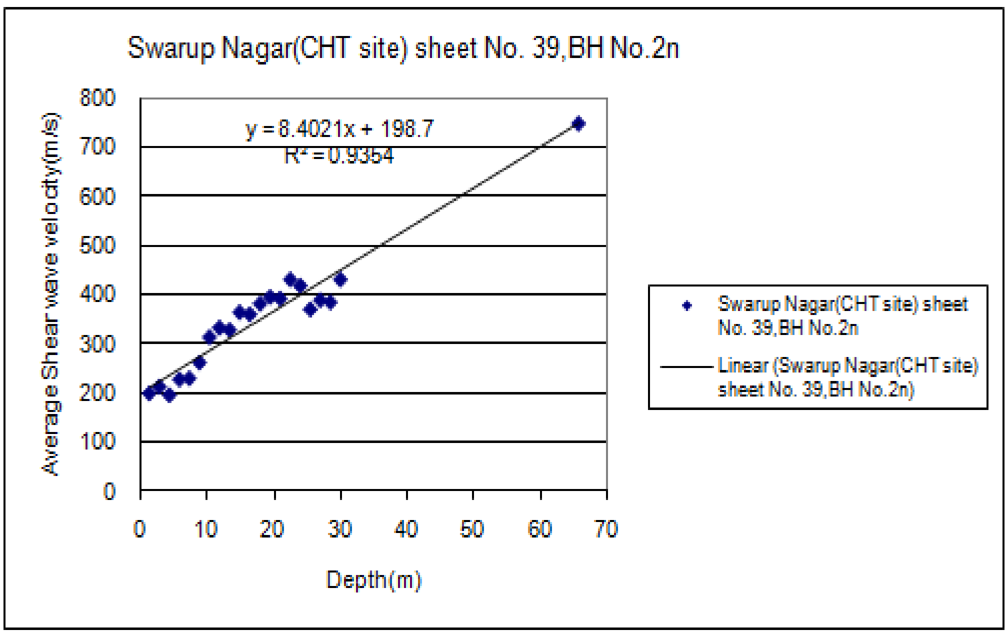
Generation Attenuation Relation and subsequently the spectrum compatible ground motion time histories have been generated at the engineering bed rock level having shear wave velocity 760m/s as detailed in Chapter-5.

The most important input information for the ground response analysis is a subsurface soil model that represents the variation of static and dynamic soil properties at different depth interval from engineering bedrock to the surface. Therefore, to perform ground response study, a soil column up to the engineering bedrock at which input motion is to be placed need to be generated. Therefore, therequirement of such study is the development of soil column, through modeling of soil up to the level of engineering bed rock depth, where input earthquake signal of is to be applied. Engineering bed rock is defined as the soil having Shear Wave velocity about760m/s. Therefore, for further study of soil response, engineering bedrock depth is required to be delineated at each site.

This can be achieved by drilling borehole up to engineering bedrock depth, which isdepend upon the nature of the soil and will be different at different sites. In the scenario like Delhi where alluvial sediment cover ranging to the depth from outcrop to the depth of more than 300m, and soil is basically D class, the engineering rock may be expected at more than 70-80m depth at most of sites in NCT Delhi. As the level of engineering rock may be different at different sites and cannot be predetermined, therefore drilling to the depth level of engineering bedrock cannot be planned in advance. It is also practicallynotpossible to drill number of boreholes to such a depth to meet the requirement of map scale of the study.

Moreover, the soil up to 30m depth play very important role, as the maximum amplification due to site effects are generally recognized to occur in the shallow subsurface when incident seismic waves encounter reduced seismic velocities near the surfaceand accordingly parameters of soil column of 30 m, such as average shear wave velocity of 30m $(Vs)^{30}$ is used for site characterization and used in different building codes (Gazetas, G., "analysis of Machine Foundation Vibrations: state-of-the-Art,1983; IBC "international Building Code" International Code Council, 2003, BIS). In view of this, an extensive programme of drilling and collection of soil samples for soil characterization and SPT value at different depth for evaluation of Shear wave velocity have been undertaken up to 30M depthas per requirement of scale as discussed in chapter-4. Shearwave velocity at each drilling sites have been evaluated at the depth interval of 3.0m. In-situ shear wave velocity has also been obtained up to 30M depth in an interval of 1.5m depth, using CHT/DHT techniques at 25 representative sites of NCT Delhi spread over different geological domain.Shear wave velocity however, has also been evaluated at 110 sites using MASW but not used in this component of present ground response analysis except at two sites as discussed earlier. Based on shear wave velocity data soil column of 30m depth have been generated at all 449 sits and used of delineation of engineering bedrock. The engineering bed rock level having shear wave velocity of 760m/s at different sites have been delineated by extrapolating 30m soil model, beyond 30m depth by suitable linear regression analysis. While performing regression analysis misplaced local variations within 30m have been ignored to achieve regression coefficient (R^2) near unity. At sites where it was not possible to obtained linearity, due to highly variable soil within 30m or ambiguity in SPT 'N' values at some level, engineering bedrock delineated at closest CHT/DHT site or nearby borehole site has been considered. Linear regression analysis for Delhi is quite suitable, as variation in soil deposits beyond a few meters depth below surface within which soil response is very significant, is expected due to normal geological ageing, and is expected to be linear, because, there is no history of unusual event capable of altering the soil deposit beyond a few meter depths.Boore (2004) has also suggested almost similar type of analysis for extrapolation of shear wave velocity data available for shorter depth within 30meter, for generation of average Shear wave velocity of 30m to be used for site characterization.

Two typical linearity curves, where in-situ shear wave velocity have been evaluated using CHTtechnique and at borehole sites where shear wave velocity evaluated through SPT 'N' value using empirical relation are shown in Figure9.5.



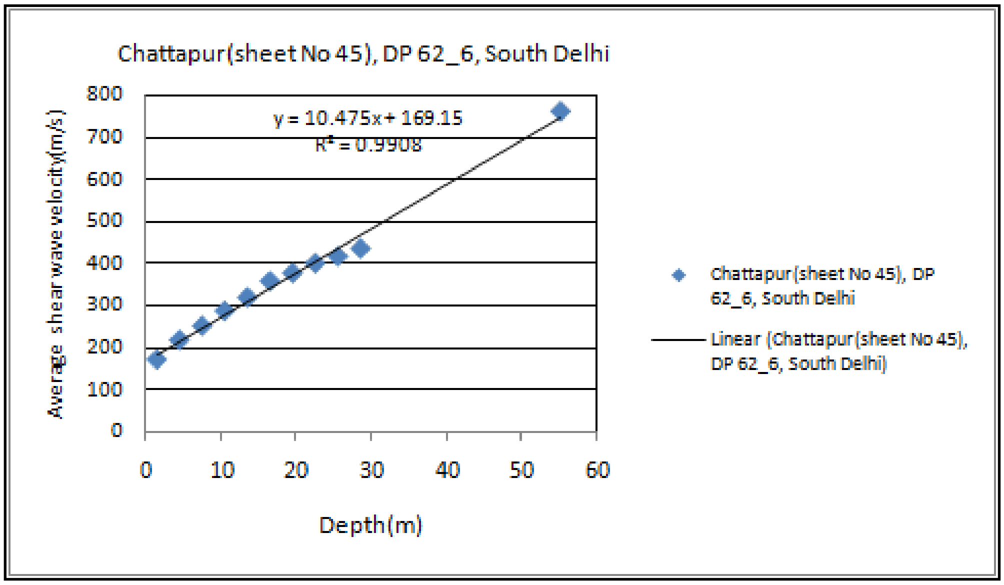


Figure9.5 Linearity curves atSwarup Nagar (left) and Chhaterpur (right) based on shearwave v elocity evaluated f rom C HT da ta a nd N va lue da tausing empirical relations developed for Delhi.

Based on t wo of t hese l inearity c urves s hown i n Figure 9.5 [Swarup Nagar (left) and Chhaterpur (right) area], the soil model generated up to the engineering bedrock depth are given i n Table 9.2,&9.3. On t he ba sis of i dentified e ngineering be d r ock de pth a t 449 sites, engineering bedrock depth map has been generated for NCT Delhi and presented as Map-22.In NCT Delhi Engineering bedrock depth varies from a few meters to 154m.

Table 9.2 Soil model generated up to the engineering bedrock depth from linearity curves based on S hear wave ve locity obt ained from CHT at Swarup N agar (Sheet No. 39), NCT Delhi shown in figure 9.5(left)

No. of layer	Depth of soil column (m)	Thickness(m)	Average Shear wave velocity (Vs) m/s)
1	1.5	1.5	199
2	3.0	1.5	212
3	4.5	1.5	195
4	6.0	1.5	227
5	7.5	1.5	229
6	9.0	1.5	262
7	10.5	1.5	314
8	12.0	1.5	333
9	13.5	1.5	328
10	15.0	1.5	364
11	16.5	1.5	360
12	18.0	1.5	382

13	19.5	1.5	396
14	21.0	1.5	392
15	22.5	1.5	431
16	24.0	1.5	419
17	25.5	1.5	370
18	27.0	1.5	389
19	28.5	1.5	385
20	30.0	1.5	431
21	40.0	10	493
22	50.0	10	577
23	60.0	10	661
24	67.0	7	732
25	(Half space)	~	760

9.1.1.5 Water table

During the drilling bore hole actual water table has also been recorded at all sites and used for evaluation of soil property such as soil density etc.

9.2 Products from Ground Response study

Ground response analysis has been carried out at 499 sites spread over NCT Delhi. The parameters derived from this study are discussed in following sections.

Table-9.3 Soil model generated up to the engineering bedrock depth from linearity curves based on Shear wave velocity evaluated from SPT N value and empirical relation obtained at Chattarpur, sheet No.45, DP: 62_6, NCT Delhi shown in Figure 9.5(left)

No. of layer	Depth of soil column (m)	Thickness (m)	Average Shear wave velocity (Vs) (m/s)
1	1.5	3	154
2	4.5	3	189
5	7.5	3	213
7	10.5	3	238
9	13.5	3	261
11	16.5	3	287
13	19.5	3	300
15	22.5	3	316
17	25.5	3	327
19	28.5	3	340
20	40.0	10	518
21	50.0	10	615
22	55.0	5	712
23	Half Space	~	760

9.2.1 Peak Ground Acceleration at Surface

Earthquake caused by sudden movement of the fault releases a great deal of energy, which then travels through the earth's crust in the form of different types of seismic waves setting earth in motion. The seismic waves travel to a great distance before finally losing most of their energy generating different ground motion at different sites, owing to the distance from the source and attenuation relations of the area under study. At particular site, when this ground motion is subjected to the soil gets amplified due to site effects, which depends upon the material properties of the subsurface sediment layers,distribution soil type, surface topography and strength of the incoming seismic motion. Peak Ground Acceleration (PGA) is a measure of earthquake acceleration (ground shaking) on the ground surface and an important input parameter for earthquake engineering practices and used to determine the maximum horizontal forces that can be expected at particular site. The maximum amplitude of the ground acceleration time-history obtained at surface at particular site is the measure of PGA at surface.

In terms of structural response, PGA corresponds to the peak value of the absolute acceleration of a single degree of freedom (SDOF) system with infinite stiffness, that is, with a natural period of vibration equal to zero. This is termed as Zero Period Acceleration (ZPA).An infinitely rigid structure, with zero natural period (T=0), does not deform. There is no relative motion between its mass and its base. The Mass has same acceleration as of the ground; hence, ZPA is same as Peak Ground Acceleration. For very low values of period, acceleration spectrum tends to be equal to PGA.Thus PGA can be obtained from an acceleration spectrum.

Peak ground acceleration is expressed in *g* (the acceleration due to earth gravity, equivalent to g force) as either a decimal or percentage; in m/s^2 (1 *g* = 9.81 m/s^2); or in Gal, where 1 Gal is equal to 0.01 m/s^2 (1 *g* = 981 Gal).

In the present study based on geotechnical/geophysical investigations and subsequently generated soil model and earthquake acceleration time histories at engineering bedrock, ground response analysis has been performed using DYNEQ software at 449 sites spread over NCT Delhifor

(i) 2% probability of exceedance in 50 year (based MCE) for 5% damping and
(ii) 10% probability of exceedance in 50 year (based on DBE) for 5% damping.

The earthquake time history generated at engineering bedrock at each site separately for MCE and DBE have been used as inputfor both, and based on response of soil earthquake acceleration time histories have been obtained at surface at all the sites for both period of exceedance. Time history of one such site at Alipur, for DBE is shown in

Figure 9.6. On the basis of time history generated at surface, Peak Ground Acceleration (PGA), which is the maximum amplitude of the ground acceleration time-history,can be evaluated. In the ground response study, using DYNEQ software vertical distribution of PGA at different depth layers of soil column are available in output files and PGA values can directly be taken from this output file at any depth layer. Part of the output file of DYNEQ for a site is shown in Table 9.4. PGA at surface at this site is 3.0210 m/s^2~(0.308g) and PGA at engineering bedrock 67m below ground is 1.0904 m/s^2~(0.10g).

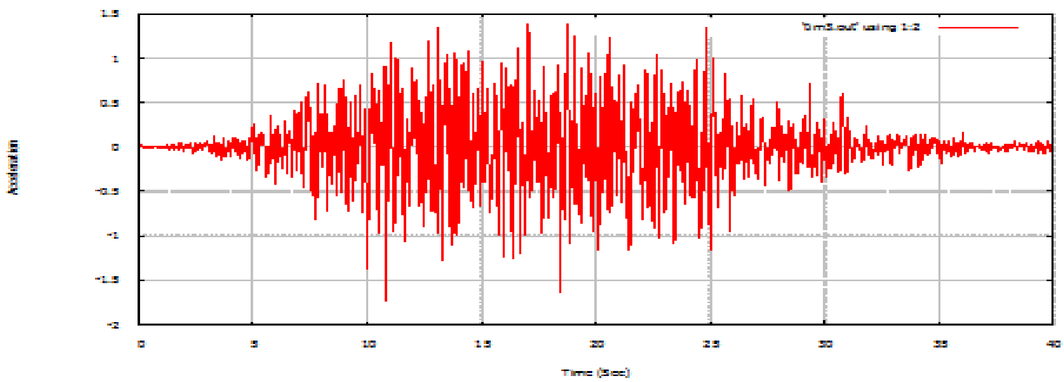


Figure 9.6 Time History at surface for site Alipur for475 yearreturn period

Table 9.4 Part of DYNEQ output file showing variation of Strong Ground Motion Parameters with Depth.

Part of DYNEQ output file showing variation of strong ground motion with depth

Layer No.	Depth	Absolute Acceleration	Time	Absolute Velocity	Time	Relative Displacement
1	0.00000e+00	-3.0214	18.4650	0.16616	24.4450	0.80074e-02
2	3.0000	-2.4375	10.8300	0.15238	24.4450	0.76315e-02
3	6.0000	-2.0972	10.8250	0.13829	24.4300	0.72700e-02
4	9.0000	-1.5817	21.4300	-0.13368	11.9400	0.69361e-02
5	12.000	1.3612	13.4650	-0.12947	11.9400	0.65983e-02
6	15.000	-1.3521	18.5200	-0.12330	11.9350	0.61880e-02
7	18.000	-1.3029	16.7900	-0.11778	11.8700	0.56660e-02
8	21.000	-1.3775	18.5450	-0.11746	11.8750	0.53355e-02
9	24.000	-1.5230	18.5450	-0.11740	11.8850	0.49316e-02
10	27.000	-1.4849	18.5450	-0.11700	11.8850	0.44123e-02
11	30.000	-1.4075	16.8150	-0.11539	11.8900	0.38038e-02
12	40.000	-1.2248	13.8500	-0.11169	11.8600	0.26169e-02
13	50.000	-1.1260	9.9150	-0.11154	11.8500	0.14931e-02
14	60.000	1.0750	18.8900	-0.10750	11.8450	-0.54957e-03
15	67.000	1.0904	18.8850	-0.10426	11.8350	0.00000e+00

```
== Amplification spectrum ==
Number of spectrum (NAMP) -------------          1
Number of predominant period ----------          3
File name for time history ------------  amp.out
Amplification ratio Freq.(Layer  0) / (Layer  0)  Data=    4096
Amplification ratio      (Layer  1) / (Layer 15)  Data=    4096
                  Mode =     1     Freq. =  2.0051        Period = 0.49873
                  Mode =     2     Freq. =  4.9157        Period = 0.20343
                  Mode =     3     Freq. =  8.3379        Period = 0.11993
```

The PGA values at surface have been thus obtained for all the 449 sites for both periods of exceedance. The PGA values obtained at all the sites for

(i) 2% probability of exceedance in 50 year (based on MCE) for 5% damping and given in table 9.5 (appended).

(ii) 10% probability of exceedence in 50 year (based on DBE) for 5% damping and are given in table 9.6 (appended).

9.2.1.1 Peak Ground Acceleration Maps at surface

In order to prepare maps, discrete site specific PGA values at 449 sites have been converted in continuous surface using Inverse Distance Weighted (IDW) interpolation technique, using appropriate parameters and cross validation so that the Root Mean Square (RMS) values between predicted and actual are as minimum as possible. This is one of the most popular methods adopted by geoscientists and geographers available in GIS packages. Using this continuous data PGA maps have been generated for

(i) 2% probability of exceedance in 50 year (based on MCE) and
(ii) 10% probability of exceedence in 50 year (based on DBE) and presented as Map 23& Map 24 respectively.

PGA maps for both period of exceedance have also been generated for area covered by individual toposheets on 1: 10,000 scale. Thus, 75 maps covering whole area of NCT Delhi have been generated for each period of exceedance. These maps are presented in the form of district wise Atlasconsisting of all product maps of Seismic Hazard Microzonation for 2% probability of exceedance in 50 years (MCE) for return period of 2475 years for 5 % damping and for 10% probability of exceedance in 50 years (DBE) for return period of 475 year and for 5 % damping.

9.2.1.2 Result and discussions on Peak Ground Acceleration at surface based on MCE

PGA values for 2% probability of exceedance in 50 years (MCE) for 5% damping varies between 0.168g to 0.479 g. PGA values at most of the sites are within 0.42g except at two sites, where PGA are .47g and .44g. At these two sitesimpedance contrast between first two layers below ground surface are very high. In the first site the observed N value at 0-3m depth is 2 and 3-6m depth is 24. Similarly, shear wave velocity of 0-3m depth is 83m/s and 3-6m is 232m/s. At another site the N value at 0-3m depth is 8, 3-6m depth is 16 and 6-9m depth is 21. Similarly, shear wave velocity of 0-3m depthlayer is144m/s, 3-6m is 198m/sand of 6-9m depth layer is 230m/s.The lower PGA value less than 0.18 is in rocky area. This contrast resulted in about two times increase in PGA at surface in comparison to layer of 3m depth below ground surface. PGA values have been grouped in four classes for generation of map.

(i) <0.18g
(ii) >0.18g to 0.30g, with the central value 0.24g,
(iii) >0.30g to 0.42g withthe central value 0.36g and
(iv) >0.42g.

The di stribution of P GA va lues a t di fferent s ites a re shown i n f ollowing ba r c hat (Figure-9.7). Figure 9.7Indicatesthat at about 60% sites PGA values are between 0.18g to 0.30gwith central value 0.24g and at about 38% sitesPGA value is between 0.31g to 0.42g.

9.2.1.3 Uncertainty in results of P eak G round A cceleration at s urface based on MCE:

As discussed in Chapter-5, strong ground motions time histories have been simulated at engineering bedrock based on Uniform Hazard Response Spectra (UHRS) obtained from Probabilistic Seismic Hazard Analysis (PSHA) at different sites.

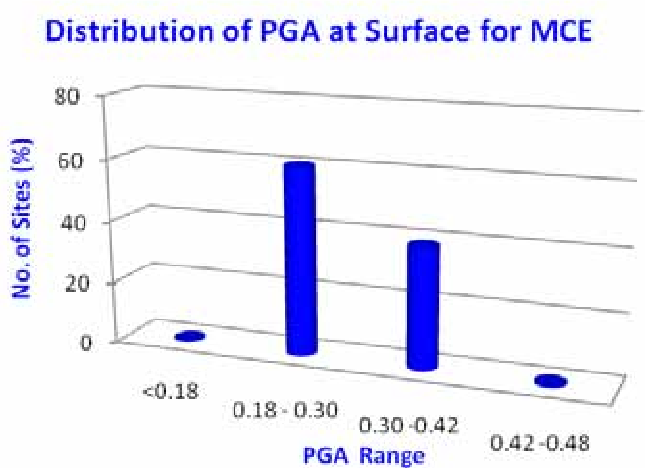


Figure 9.7 Distribution of P GA v alues at di fferent sites i n percentageconsidering Maximum Considered Earthquake (MCE).

These t ime hi stories ha ve be en us ed a s i nput gr ound m otions f or gr ound r esponse study and generation of time histories at surface. Subsequently PGA values at surface have be en evaluated from the se time hi stories. The unc ertainty i n e ach U niform Hazard Response Spectra has been presented as standard deviationi.e. Mean, Mean + sigma and Mean –sigma. In order to assess possible uncertainty in the results of PGA at engineering bedrock , at a few sites three spectrum compatible ground motion time histories have be en generated based on three Uniform H azard Response S pectra (UHRS) obtained at ea ch site i.e. for Mean, Mean + sigma and Mean –sigma and PGA values have been evaluated. The uncertainties in PGA value thus obtained have been worked out to be on an average ± 0.02g for MCE.

The average amplification factor is around 3 and therefore, the initially introduced uncertainty of ± 0.02g, will increaseby three times. Thus the uncertainty in PGA values at surface will be about ± 0.06g. Keeping this uncertainty in mind the obtained PGA values have been grouped in four groups (i) <0.18g (ii) 0>.18g - .30g, with the central value 0.24g, which is equivalent to zone factor of zone IV (IS code) (iii) >0.30g –0.42g withthe central value 0.36g, which is equivalent to zone factor of zone V (IS code), (iv) >0.42g as discussed above. The map presented as Map-22 has been generated based on these four groups. The map has been generated in GIS and site specific values can be obtained and may be used keeping in mind the assigned uncertainties of± 0.06g. Similarly large scale maps of individual topo- sheets, which will be presented in the form of Atlas, to be usedfor reading instant site specific PGA values, keeping in mind the assigned uncertainties of ± 0.06g.

9.2.1.4 Results and discussion on Peak Ground Acceleration at surface based on DBE

PGA values for 10% probability of exceedance in 50 year (DBE) for 5% damping varies between 0.089g and 0.255 g. The distribution of PGA values at different sites are shown in following bar chat (Figure-9.8). PGA values at most of the sites are within -

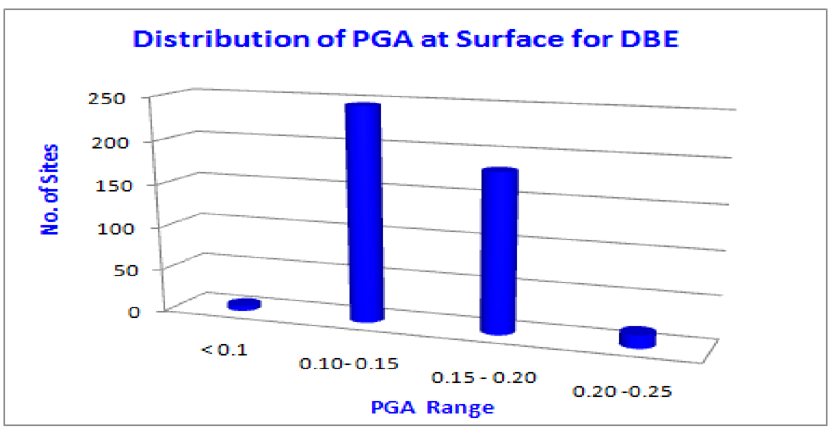


Figure 9.8 Distribution of PGA values at different sites in percentage, considering Design Basis Earthquake (DBE).

0.20g except at a few sites where PGA values are in the range of0.20 to 0.26g. PGA values have been grouped in four classes (i) 0.09g to 0.10g (ii) >0.10g to 0.15g with the central value of 0.125g (iii) >0.15g to 0.20g, with the central value 0.175g (iv) >0.20g to 0.26 with the central value 0.0.23.

9.2.1.5 Uncertainty in resultsof Peak Ground Acceleration at surface based on DBE.

On the basis of similar exercise as done for MCE (section 9.2.1.3)theuncertainty in PGA values has been worked out to be on an average ± 0.01g. The maximum probable amplification factor discussed in the later section is around 3 and therefore, the initially introduced uncertainty of ± 0.01g, will increase by three times. Thus the uncertainty in PGA evaluation at surface for DBE will be about ± 0.03g. Keeping this uncertainty in mind the obtained PGA values have been grouped in four classes (i) 0.09g - 0.1g (ii) 0.01g – 0.15g with the central value of 0.12g (iii) <0.15g –0.21g, with the central value 0.18g (iv) <0.21g –0.27 with the central value0.24. The map presented in Map-23 has been generated based on these four classes. The map has been generated in GIS and site specific values can be obtained and may be used keeping in mind the assigned uncertainty of ± 0.03g.

9.2.2 Site Amplification factor

At particular site, whenearthquake ground motion is subjected to the soil column gets amplified due to site effects, which depends upon the material properties of the subsurface sediments layers,distribution soil type, surface topography and strength of the incoming earthquake ground motion. Amplification factor of soil column is therefore ratio of strength of ground motion at surface (top layer) to the strength of incomingearthquake ground motion actually applied to the bottom of the soil column (last layer).

PGA is measure of strength of ground motion and corresponds to the peak value of the absolute acceleration of a single degree of freedom (SDOF) system with a natural period of vibration equal to zero. Thus the ratio of the PGA at zero period or infinite frequency at engineering bed rock (actual input motion to the last layer) andPGA at zero period or infinite frequency at ground surface, at particular site is considered as the Amplification factor ofsoil column. This amplification factor is different from the Peak Amplification factor derived at previous Chapter-8, which is frequency dependent and correspondstothe Peak frequency of soil column and may be achieved during the resonance.

Part of the ground response analysis output file (of DYNEQ) for a typical site is shown in Table 9.4.PGA at surface at this site is 3.0210 m/s^2~(0.308g) and PGA at bottom layer (15^{th} layer) of the soil column 67m below ground is 1.0904 m/s^2~(0.10g). The amplification factor of soil column at this site is therefore 3.0210/ 1.0904= 2.2.

Amplification factor has been evaluated for both input motions based on MCE and DBE at all 449 sites. Obviously, as amplification of soil column is the characteristic of soil at a particular site, the amplification factor for both periods of exceedance are same. The amplification factors for NCT Delhi soil are less than 4.0 except at one site where amplification factor is 4.6.

A bar chart showing distribution of amplification factor at number of sites (%) is shown in Figure 9.9. The bar chart indicates that amplification factor for more than 95% sites are below 3.5.

Amplification factor at DDA Open Land near Model town which is 4.6 is because the PGA value at the top surface layer at this site is very high. Output file of ground response analysis (DYNEQ software) of this site is shown in Figure 9.9.At this site the PGA value at top surface layer is 4.6622 m/s^2 and at bottom layer PGA is 0.9848 m/s^2.

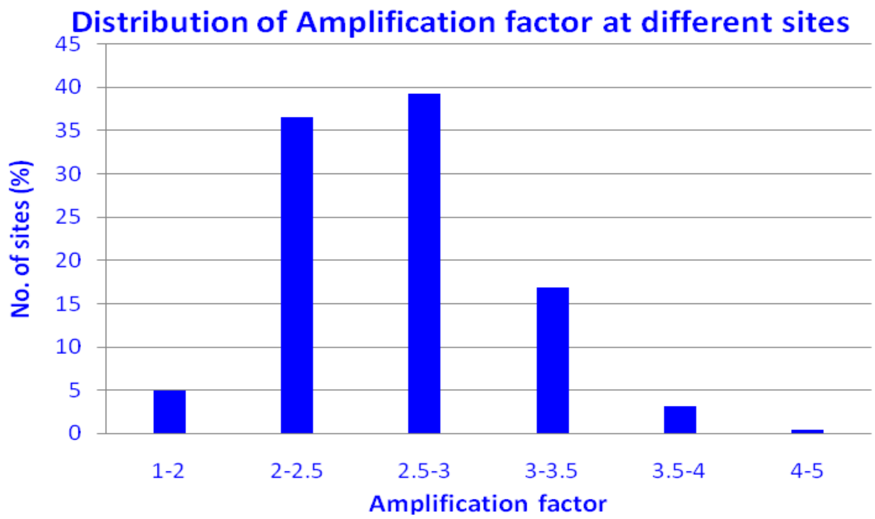


Figure 9.9 Distribution of Amplification factor at different sites in percentage.

Thus the amplification factor is about 4.6. The PGA value at this site at surface is very high due to the impedance contrast between first two top layers. This is because, the Characteristic of soil properties, such as the N value at 0-3 m depth is 2, and 3-6m depth is 24. Similarly, shear wave velocity of 0-3m depth is 83m/s and 3-6m is 232m/s, indicating loose soil at top three meter. This contrast resulted in about two times increase in PGA at surface layer of 0-3m depth in correspond to the layer of 3-6m depth below ground surface, consequently, the amplification factor has also increased.

Amplification factors have been evaluated at all the 449 sites and given in Table 9.7. In order to prepare maps, discrete site specific amplification factors values have been converted in continuous surface using Inverse Distance Weighted (IDW) interpolation technique, using appropriate parameters and cross validation so that RMS values between predicted and actual are as minimum as possible. Based on these values, amplification maps for NCT Delhi has been generated and presented as Map 25. Amplification map for areas covered by individual toposheets have also been generated for all 75 toposheets and presented in the form of atlas.

9.2.3 Response spectra

Maximum Ground Acceleration (PGA), Maximum Ground Velocity (PGV), Maximum Ground Displacement (PGD), duration of significant ground shaking are the important characteristics of any ground motion, but they alone do not describe the intensity of the shaking effects of the motion, which depends also on the frequency characteristics of the motion, that influences the amplification of building motion due to the cyclic loading of ground motion. In other words, tall building with long fundamental periods of vibration will respond differently than short buildings with short periods of vibration. As enumerated in Chapter –8 "site effect on damage pattern", a very high acceleration may appear to be potentially hazardous, but if it developed for only a very short period of time may cause little damage to many types of structures. On the other hand, a motion with relatively small amplitude that continues with a reasonably uniform frequency for a number of second can build up damaging motion in certain type of structures.

Table 9.7 Output file of ground response analysis for the site DDA Open Land near Model town showing ground motion parameters obtained at different depth along with peak frequencies of different modes.

Layer No.	Depth	Absolute Acceleration	Time	Absolute Velocity	Time	Relative Displacement	Time
1	0.00000e+00	-4.6622	18.4800	-0.20886	10.1100	-0.10772e-01	17.0550
2	3.0000	-1.9659	21.4400	0.14690	21.2700	0.74090e-02	21.4250
3	6.0000	1.6117	13.0700	0.13920	21.2600	0.68691e-02	21.4200
4	9.0000	-1.3805	10.0150	0.13241	21.2600	0.65301e-02	21.4150
5	12.000	-1.4523	21.4000	0.12322	21.2500	0.61573e-02	21.4100
6	15.000	-1.4270	21.4000	0.11909	21.2300	0.56815e-02	21.4050
7	18.000	-1.2619	21.4000	0.11684	21.2250	0.53110e-02	21.4050
8	21.000	-1.1705	18.5650	-0.11486	11.9150	0.48648e-02	21.4050
9	24.000	1.1573	12.1150	0.11551	21.1850	0.43445e-02	21.4000
10	27.000	1.1494	14.9650	0.11705	21.1800	0.35837e-02	21.3950
11	30.000	1.1114	14.9600	0.11733	21.1750	0.30153e-02	21.3850
12	40.000	-1.0889	9.9350	0.11427	21.1700	0.21278e-02	9.9450
13	50.000	-1.0156	9.9200	0.10971	21.1500	0.12941e-02	9.9400
14	60.000	-0.98812	13.8150	0.10735	21.1400	0.50430e-03	9.9350
15	67.000	-0.98484	13.8100	0.10933	21.1050	0.00000e+00	0.0000

```
== Amplification spectrum ==
Number of spectrum (NAMP) -------------          1
Number of predominant period ----------          3
File name for time history ------------   amp.out
Amplification ratio Freq.(Layer  0) / (Layer  0)  Data=    4096
Amplification ratio      (Layer  1) / (Layer 15)  Data=    4096
                     Mode =    1     Freq. =  1.9951        Period = 0.50123
                     Mode =    2     Freq. =  4.2325        Period = 0.23626
                     Mode =    3     Freq. =  5.5153        Period = 0.18131
```

The combined influence of the amplitude of ground accelerations, their frequency components and to some extent, the duration of the ground shaking on different structures is conveniently represented by means of response spectrum (Housner, 1952; Hudson, 1956 and 1979), that is, a plot showing the maximum response induced by the ground motion in single-degree-of-freedom oscillators of different fundamental periods, but having the same degree of internal damping.

9.2.3.1 Acceleration Response Spectra for different sites of NCT Delhi

Acceleration response spectra have been generated at 449 sites for 0 to 3 seconds, spread over NCT Delhi, represented by 75toposheets on 1:10,000 scale covering all 9 districts of NCT Delhi (i) North-West, Delhi (ii) North, Delhi (iii) North-East , Delhi (iv) East, Delhi (v) West Delhi (vi) South-West Delhi(vii) Central, Delhi(viii) New Delhi and (ix) South Delhi. Considering earthquake for (a) 2% probability of exceedance in 50 years(MCE) for 5% damping and (b) 10% probability of exceedance in 50 years(DBE) for 5% damping.Typical response spectra obtained from ground response study of NCT Delhi at the site Swarup Nagar is shown in Figure 9.10for MCE and Figure 9.11for DBE. All response spectra at 449 sites for MCE and DBE are attached separately.

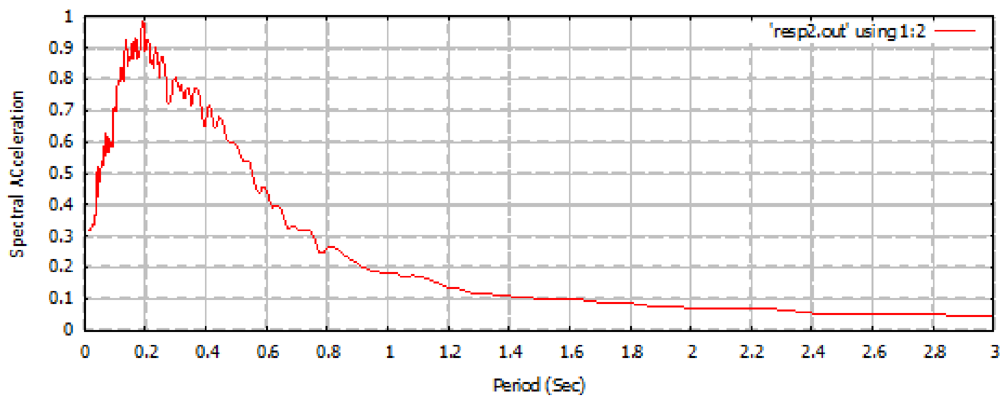


Figure 9.10 Acceleration Response Spectra (5% damping) obtained from ground response study of NCT Delhi at the site Swarupnagar (Sheet No.39, BHNo.11n), considering Maximum Considered Earthquake (MCE).

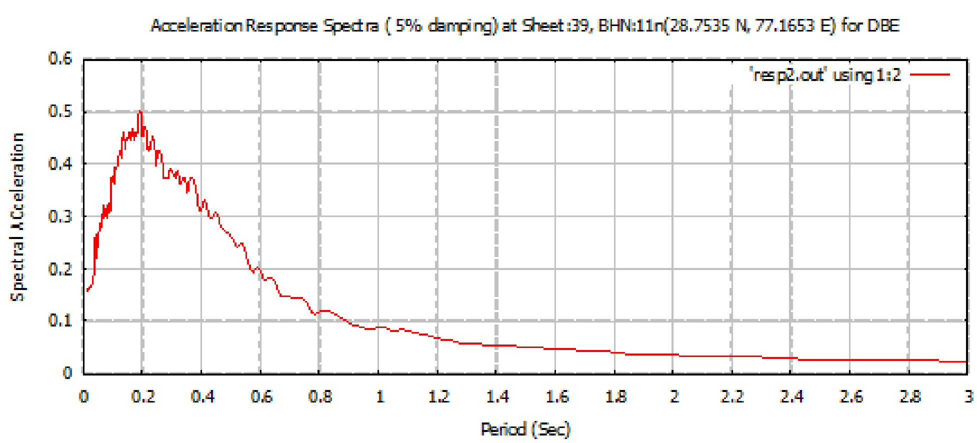


Figure 9.11 Acceleration Response Spectra (5% damping) obtained from ground response study of NCT Delhi at the site Swarupnagar (Sheet No.39, BHNo.11n), considering Design Basis Earthquake (DBE)

9.2.3.2 Classification of response spectra obtained for NCT Delhi

The shape of the acceleration response spectra is greatly influenced by the local soil condition and lithological distributionsubsurface sediments. The spectral shape representative of any group of earthquake ground motion records or geotechnical site characteristics is obtained by first determining the normalized acceleration response spectrum. A normalized response spectrum is obtained by expressing the ordinates of a conventional spectrum as a proportion of the maximum ground acceleration for the motion for which the spectrum was derived, or the zero-period ordinate value. Zeroperiod ordinate for all normalized spectra is therefore unity. In the present study Acceleration response spectra have been generated at 449 sites, spread overNCT Delhicovered under area of 75 toposheets covering all 9 districts considering both MCE and DBE. In order to classify these response spectra all 449 response spectra have been normalized. A few distinguished normalized response spectra of different site conditions, generated based on MCE are given in following Figure 9.12(a,b,c,d,e,f).Normalized Response Spectra for all 449 sites both for MCE and DBE are attached as appendix IB and Appendix IIB respectively.

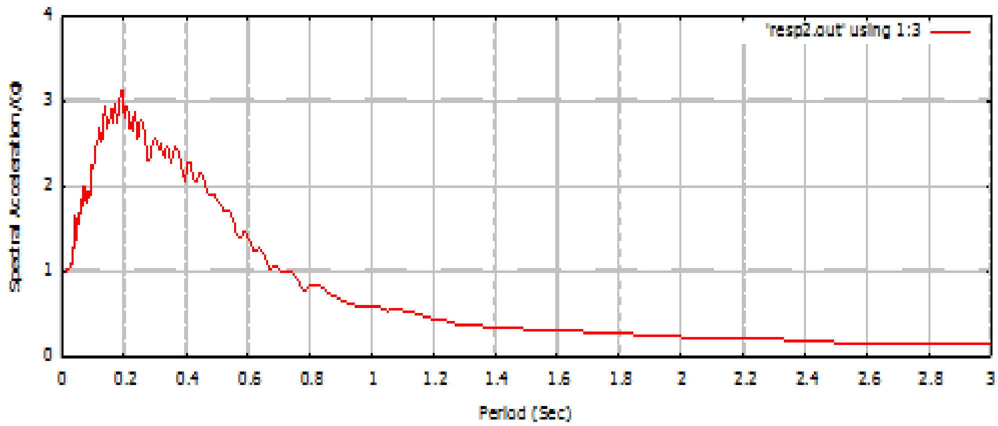


Figure 9.12(a)

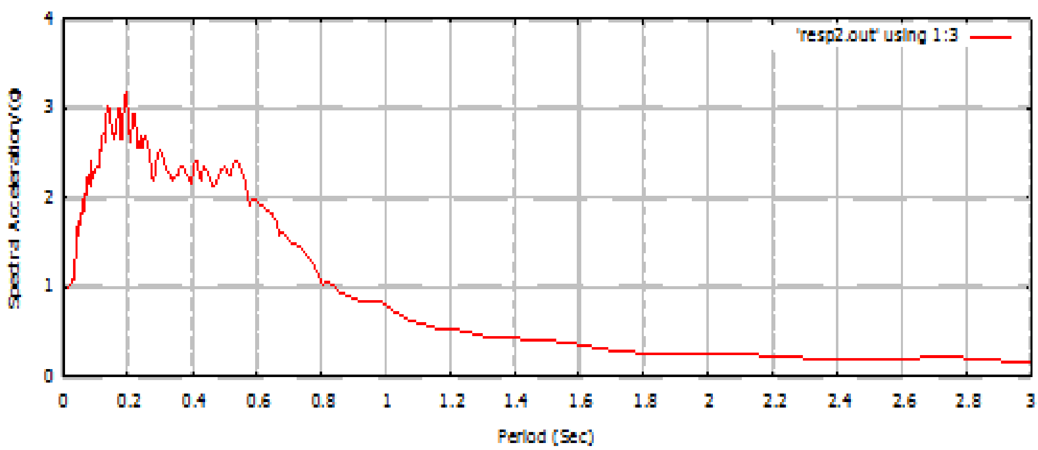


Figure 9.12(b)

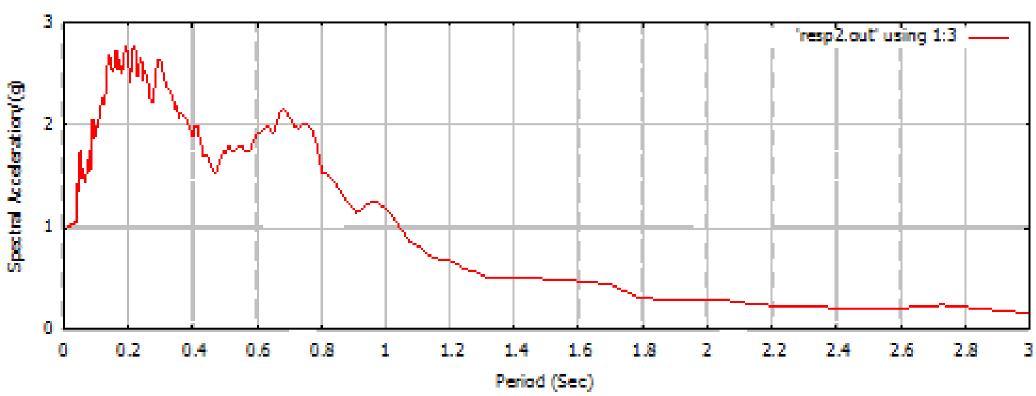


Figure 9.12 (c)

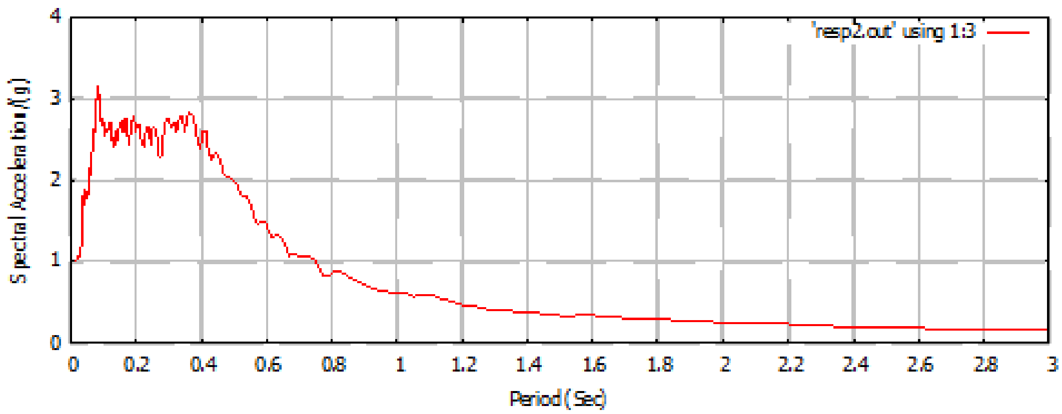


Figure9.12 (d)

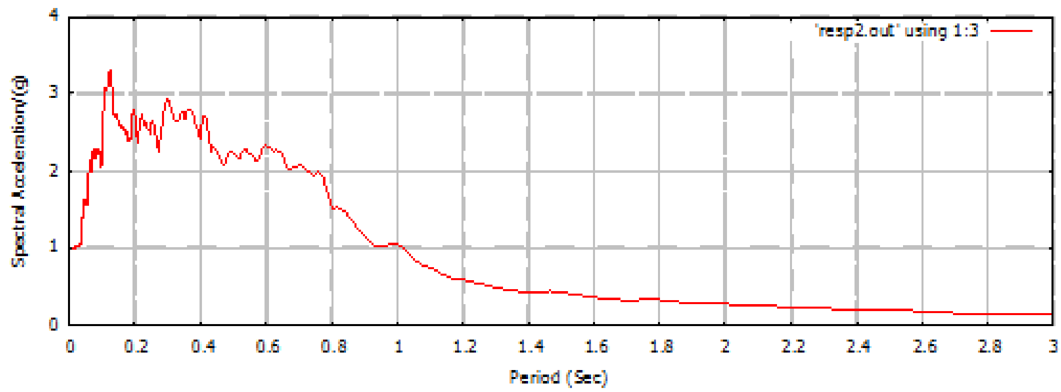


Figure 9.12(e)

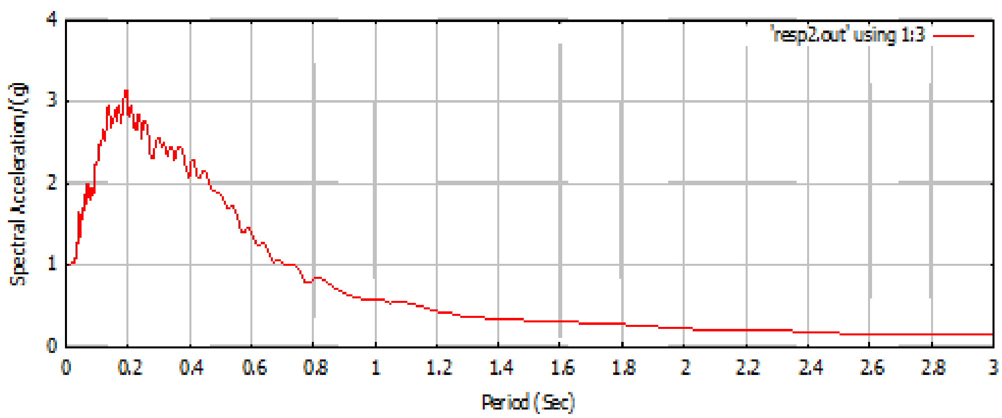


Figure 9.12(f)

Figure 9.12 (a, b , c, d , e & f)A f ew di stinguished nor malized response s pectra of different s ites conditions,generated ba sed on Maximum C onsidered Earthquake (MCE).

9.2.4 Seismic Hazard Map for different period of spectral acceleration with (i) 2% probability of exceedance in 50 years for 5 % damping (based on MCE) (ii) 10% probability of exceedence in 50 yearsfor 5 % damping (based on DBE)

Acceleration response spectra at 449 sites have been generated for NCT Delhi each for a period 0 to 3second for 10% probability of Exccedance in 50 year (DBE) and 2 % Probability of Eccedance in 50 year (MCE). On the basis of these response spectra, for MCE and DBE, spectral acceleration values for the periods of 0.1 s, 0.3 s, 0.5 s and 1.0 seconds(equivalent to frequencies of 10, 3, 2, and 1.0 Hertz) corresponds to 1,3,5 and 10 stories buildings respectivelyhave been evaluatedat all 449 sites.Spectral acceleration at each periodhasbeen evaluated after averaging the values lying between windows of ± 0.05 second. For example for 0.1 second period spectral acceleration values have been evaluated by averaging values lying between 0.05 to .15 second.

In order to prepare hazard maps, these discrete site specific Spectral Acceleration (Sa) values for each period at 449 sites have been converted in continuous surface using Inverse Distance Weighted (IDW) interpolation technique, using appropriate parameters and cross validation so that the Root Mean Square (RMS) values between predicted and actual are as minimum as possible. Using this continuous data four seismic hazard maps, have been generatedfor 0.1s, 0.3s, 0.5s and 1.0s both for DBE and MCE. These maps are attached as Map 26,27,28,and 29generated based on DBE and Map30,31,32and 33generated based on MCE. Maps 26, 27, 28, and 29can be used to evaluate response of earthquake ground motion on 1 story, 3 story, 5 story and 10 story buildings respectivelyconsidering,DBE and Map 30,31,32 and 33can be used to evaluate response of earthquake ground motion on 1 story, 3 story, 5 story and 10 story buildings respectively,considering MCE. It may be noted that Spectral acceleration values may be reduced, when spectral acceleration values will be calculated based on smoothened design response spectra generated for construction of buildings of different priority.

9.2.5 Variation of Peak Ground Acceleration Soil response with depth

Local geological conditions, characteristics of the lithological attributes and depth play significant role in ground response and variation of PGA. The significant variation in PGA is observed closed to surface below a few meter depths from ground level. Variation of PGA with depth at Swarup Nagar considering MCE and DBE are shown in Figure 9. 13(left panel & right panel). It is seen from the Figure 9.13 that at this site significant variation of ground motion (PGA) is due to top about 9 m soil. At this site in case of MCE, PGA at surface is around 0.3g, which reduces to 0.15g at about 9m depth below ground level. Similarly in case of DBE, PGA at surface is around 0.15g, which reduces to 0.07 g at about 9m depth below ground level.

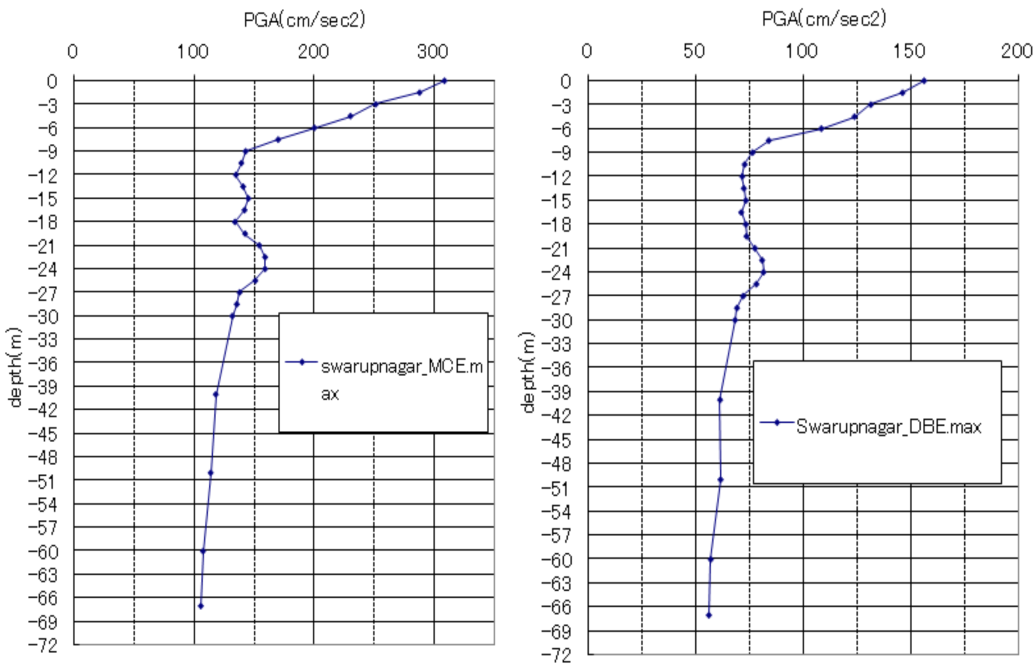


Figure 9. 13 (left panel) and (right panel) shows the vertical distributions of PGA at Swarupnagar, NCT Delhi, for MCE and DBE respectively.

The variation of PGA with depth at another site of sheet no.21, Rice Mill considering MCE and DBE are shown in Figure 9.14 (left panel & right panel). It is seen again that at this site also significant variation of ground motion (PGA) is due to top about 9-12 m soil. At this site in case of MCE, PGA at surface is around 0.35g, which reduces to 0.15g at about 12m depth below ground level. Similarly in case of DBE, PGA at surface is around 0.18g, which reduces to 0.09 g at about 12m depth below ground level.

On the basis of these vertical distributions of PGA based on MCE at all the 449 sites, PGA values have been picked up for 3m below ground level and 6m below ground level. Based on these values PGA maps at 3m and at 6m below ground surface have been generated and attached as Map 34 & 35 respectively.

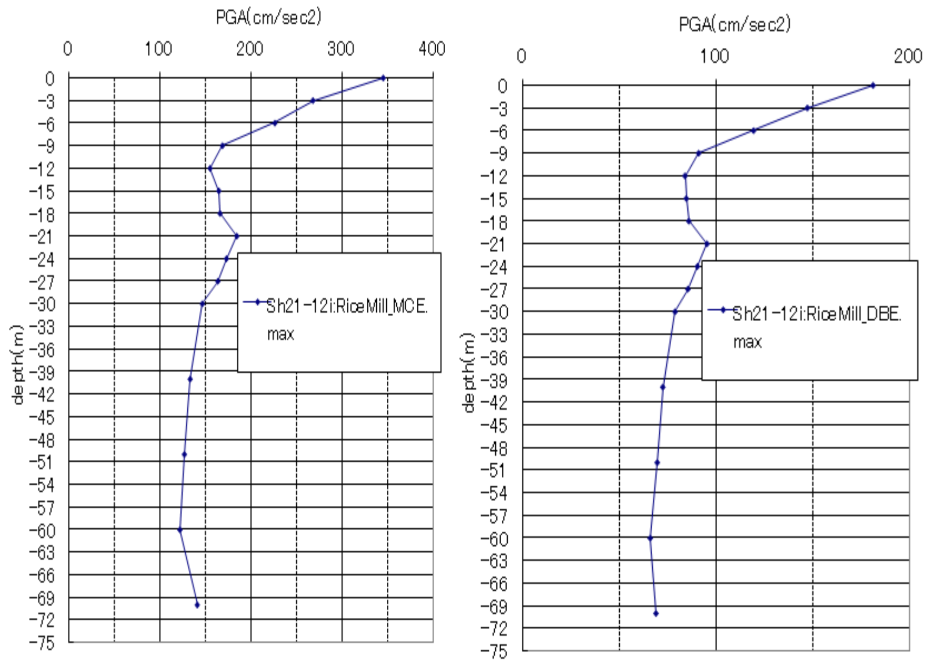


Figure 9.14 (left panel) and (right panel) vertical distribution of PGA at Sheet No.21, Rice Mill, NCT Delhi, considering MCE and DBE.

9.2.6 Multiplying Factors for obtaining PGA values for other damping

National seismic hazard maps in the United States, Canada and most of the other countries are generally provide input ground motions in the form of 2% probability of exceedance in 50-year response spectra for an assumed 5% of critical damping. 5% damping used in the standard spectra in building code application was chosen because it is appropriate for range of typical building structures. For other special structures, however, such as those used in power-generating plants, dams, transmission telecommunication facilities and construction that utilizes damping devices, the structure damping be either high or lower than 5 %. To facilitate this Multiplying Factors for obtaining values for other Damping are given in Table 9.8, which is based on repeated ground response study for different damping at a few representative sites. This is same as table provided in BIS code (Clause 6.4.2).

Table 9.8 Multiplying Factors for obtaining response spectra ordinates for other Damping

Damping (in %)	2	5	7	10	15	20	25	30
Multiplication factor	1.38	1.00	0.89	0.80	0.71	0.66	0.62	0.60

9.3 DESIGN RESPONSE SPECTRA

Response spectra are used to represent seismic loading for dynamic analysis of structures. Response spectra from earthquakes or derived from ground response study are highly irregular; very ragged with local peaks and valleys. The shapes of response spectra reflect the details of their specific frequency contents and phasing. A slight change in natural period can lead to large variation in maximum acceleration. Natural period of a civil engineering structure cannot be calculated so precisely and therefore, the design specifications should not very sensitive to a small change in natural period. Hence, the design response spectrum to be used for design specification should be a smooth or average shape without local peaks and valleys as seen in the response spectrum. Design response spectra are generally quite smooth and usually determine by smoothing, averaging, or enveloping the response spectra of multiple motions. They do not represent the particular acceleration response from a singleground motion time-history, but rather they are intended to be more representative of general characteristics for a reasonable range of expected ground motions at a given site. The use of smooth design responsespectra implicitly recognizes the uncertainty with which soil and structural properties are known by avoiding sharp fluctuation in spectral accelerations with small changes in structural period.

In earthquake resistant structure, since some damage is expected and accepted during strong shaking, design spectrum is developed considering the over strength, redundancy, and ductility in the structure. The site may be prone to shaking from large but distant earthquakes as well as from medium but nearby earthquakes: design spectrum may also account for these as well.

In the present study Site Specific Response spectra at 449 sites spread over NCT Delhi have been derived for (i) 2% probability of exceedence in 50 years for 5% damping (ii) 10% probability of exceedence in 50 years for 5% damping. Considering the engineers requirement an attempt has been made to convert these response spectra in Design Response Spectra using standard technique available in NEHRP recommended provisions for Seismic regulations for New Buildings (FEMA 450) Part1:provisions 2003 edition and presented along with response spectra for each sites so that engineers may compare both and suitably modify at their requirement.

CHAPTER- 10

LIQUEFACTION STUDY IN NCT DELHI

Liquefaction is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other dynamic loading. During the liquefaction, soil loses its shear resistance, when subjected to monotonic, cyclic, or earthquake loading, and behaves like a liquid until the shear stresses acting on the soil mass are as low as the reduced shear resistance. Therefore, when liquefaction occurs, the strength of the soil decreases and, the ability of a soil deposit to support foundations for buildings are reduced and consequent to this building can overturn or sink.

Liquefaction occurs in saturated soils, that is, soils in which the space between soil particles is completely filled with water. This water exerts a pressure on the soil particles that influences how tightly the particles themselves are pressed together. Prior to an earthquake, the water pressure is relatively low. During relatively short duration of an earthquake, the rate of densification of soil is more than the drainage through the soil pores which leads to the development of excessive pore pressure which cause the soil mass to act as a heavy fluid with practically no shear strength (Park, 1979,Sladen et al., 1985).Saturated sand, coarse sand, fine sand, silty sand and even sandy silt can liquefy when there is insufficient drainage boundary around them. Liquefaction can initiate movement of large blocks of soil (lateral spreading), causing extensive damage to manmade structures (Youd, 1991) . Liquefaction has been reported in numerous earthquakes (Seed, 1968) and has been responsible for tremendous amounts of damage in historical earthquakes around the world (Yanagisawa, 1983 ; Morales et al., 1995) . Recently in India liquefaction phenomena has been observed during the Bhuj earthquake of 26 January 2001(Mw 7.7) and a lot of damages were reported due to liquefaction and other ground failures (Rao and Mohanti, 2001).

The likelihood that an earthquake will liquefy a site depends on many site characteristics e.g. mean grain size, percentage of fines (Blazquez et al., 1980) and on the regional geology, which influences the amplification and attenuation of strong ground motion amplitudes. The qualitative assessment of liquefaction potential of soil strata is carried out using two approaches (i) Evaluation based on a comparison of stresses induced by an earthquake and the stress conditions causing liquefaction in cyclic laboratory tests on soil samples. (ii) Empirical methods based on measurements of in situ soil strength and observations of field performance in previous earthquakes.
Thus the evaluation of liquefaction is attempted in following two stages and subsequently maps are generated at different depth below ground level.

1. Identification of Liquefaction Susceptibility of Soil (Level A study)

2. Qualitative assessment of liquefaction potential, based on factor of safety (Level B study)

If based on level 'A' study, the soil at a particular site is not susceptible, liquefaction hazards will not occur.

The second step of qualitative assessment of liquefaction hazard (Label B study) is basically evaluation of liquefaction potential based on Factor of Safety, which can be evaluated on the basis of field behavior of soils based on field tests (index tests) and Laboratory testing of undisturbed samples collected at different depth through drilling bore holes. Collection of undisturbed samples is difficult task and therefore liquefaction study based on field test is generally preferred.

10.1 IDENTIFICATION OF LIQUEFACTION SUSCEPTIBILITY (LEVEL A STUDY)

The first step in a liquefaction hazard evaluation (level A study) is usually the evaluation of liquefaction susceptibility of soil, based on several criteria such as Historical Criteria, Geological Criteria, Compositional Criteria (Index properties of soil), Gradation of soil, Depth of ground water table, Natural soil deposits in water bodies etc, as all soil types are notsusceptible to liquefaction.Some of the criteria used for liquefaction susceptibility of soil at Delhi are as follows:

10.1.1 Based on Geological Criteria

Soil deposits that are susceptible to liquefaction are within a relatively narrow range of geological environments (Youd, 1991). The depositional environment, susceptibility of sedimentary deposits to liquefaction as a function of type and age of the deposit are detailed in Table 10.1(Youd and Perkins 1978).

Liquefaction susceptibility on the basis of geological attributes of the domain has been examined. Unconsolidated Quaternary sediment comprising Older Alluvium (Late Pleistocene) and Newer Alluvium (Holocene) are the main geological features of the NCT Delhi. The flood plain area of Delhi is characterized by abandoned channels cut off meanders, meanders scrolls, ox-bow lakes, crevasse splays, point bars, and channel bar. These sediments are susceptible for liquefaction. Thus the geological criteria meet the requirement of possibility of liquefaction in Delhi.

Table 10.1 Susceptibility of Sedimentary deposits to Liquefaction as a function of type and age of the deposit (Youd and Perkins 1978)

Type of deposit	Possibility of liquefaction occurrence in saturated non-cohesive soil			
	<500 ys	Holocene (<11,700 ys)	Pleistocene (<2,588,000 ys)	Pre-Pleistocene (>2,588,000ys)
CONTINENTAL DEPOSITS				
Fluvial	very high	high	low	very low
Alluvial plain	high	moderate	low	very low
Aeolian	moderate	low	low	very low
Marine terraces	-	low	very low	very low
Delta	high	moderate	low	very low
Lacustrine	high	moderate	low	very low
Colluvium	high	moderate	low	very low
Dunes	high	moderate	low	very low
Loess	high	high	high	unknown
Glacial till	low	low	very low	very low
COASTAL AREAS				
Delta	very high	High	low	very low
Estuary	high	moderate	low	very low
Beach	moderate/high	moderate/low	low/very low	very low
Lagoon	high	moderate	low	very low
ARTIFICIAL BACKFILL				
uncompacted	very high	-	-	-
compacted	low	-	-	-

10.1.2 Based on Compositional Criteria (Index Properties of Soil)

Liquefaction typically occurs in cohesion less sands, silt, and fine-grained gravel deposits of Holocene to late Pleistocene age in areas where the ground water is shallow. Some gravelly soils are vulnerable to liquefaction if encapsulation by impervious soils prevents rapid dissipation of seismically induced pore pressure. Cohesive soils with clayey content (particle size < 0.005m) greater than 15% are generally not considered susceptible to soil liquefaction.

Since liquefaction requires the development of excess pore pressure, liquefaction susceptibility is also influenced by the compositional characteristics that influence volume change behavior. Compositional characteristics associated with high volume change to be associated with high liquefaction susceptibility. These characteristics include particle size, shape, and gradation. Fine-grained soils that satisfy each of the following four Chinese criteria (Wang, 1979) may be considered susceptible to significant strength loss

Fraction finer than 0.005 mm ≤
Liquid limit, LL ≤
Natural water content ≥
Liquidity index ≤

Under the present project of Seismic Microzonation of NCT Delhi on 1: 10000 scale, geotechnical data have been collected at about 449 sites, spread over NCT Delhi, by drilling borehole up to the depth of 30 meter, collecting soil samples at 1.5m depth interval and SPT at 3.0 meter depth interval. Laboratory investigation on collected soil samples have been carried out for evaluation of soil type and other index properties of soil, such as grain size distribution (particularly the fines content), plasticity, unit weight, and moisture content etc. A typical data sheet of one borehole location indicating soil properties at different depth is shown in Table 10.2.

Based on data, at 449 sites, distribution of soil type indicating Non-liquefiable type (CL, CI, and CH) and Liquefiable Type (SP, SM, ML, CL-ML) at different depth is shown in Figure 10.1. The Figure 10.1 indicates that about at 80% locations soil type is susceptibleto liquefaction at all depth range. Other compositional criteria also meet the requirement of liquefaction susceptibility at many sites.

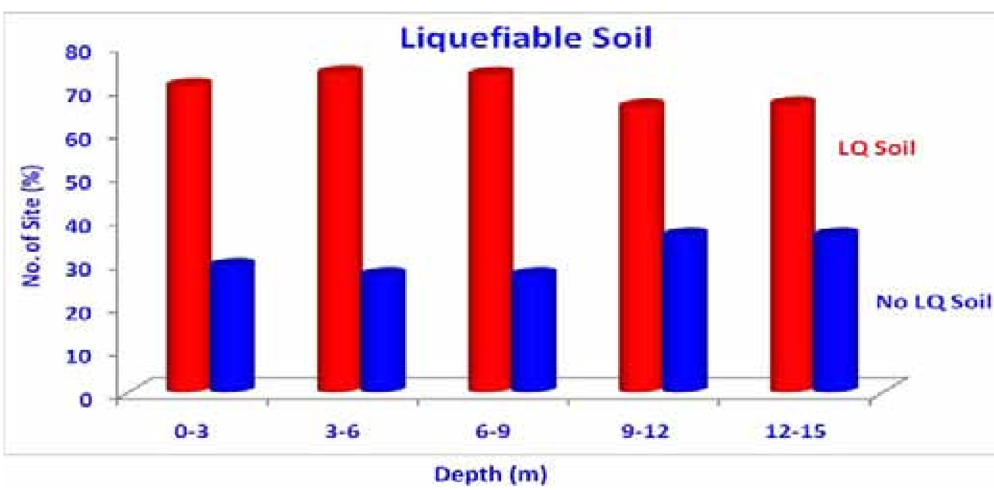


Figure 10.1 Distribution of soil type indicating Non-liquefiable type (CL,CI, CH) and Liquefiable Type (SP, SM,ML,CL-ML) at different depth

Table 10.2 A typi cal d ata s heet o f one bo rehole loc ation indicating soil pr operties a t different depth

Soil classification			Natural Moisture Content %	Specific Gravity	Bulk Density (gm/cc)	Relative Density (%)	Mechanical Analysis						Consolidation Test		Consistency Limit		
Depth of Strata	Soil Group	Soil Description					Gravel (%)	Coarse Sand (%)	Medium Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)	C c	eo	Liquid limit (%)	Plastic limit (%)	Plasticity index (PI)
0.00-1.50	-	Silty Sand	-	-	-	-	-	-	-	-	-	-			-	-	-
1.50-3.00	SM	Silty Sand	-	-	-	-	2.35	6.74	11.47	52.27	27.17	0.00			23	NIL	NP
3.00-4.50	SM	Silty Sand	18.19	2.67	1.79		4.08	7.78	10.09	55.08	22.97	0.00			24	NIL	NP
4.50-6.00	SM	Silty Sand	-	-	-		2.38	6.58	11.24	50.24	29.56	0.00			23	NIL	NP
6.00-7.50	SM	Silty Sand	19.90	-	1.83	62	4.08	8.40	13.44	46.07	28.01	0.00			25	NIL	NP
7.50-9.00	SM	Silty Sand	-	-	-		3.24	7.49	14.69	45.78	28.80	0.00			24	NIL	NP
9.00-10.50	SM	Silty Sand	21.11	-	1.86		3.28	9.06	15.08	44.90	27.68	0.00			27	NIL	NP
10.50-12.00	SM-SC	Silty Sand with Clay	-	-	-		0.00	8.24	13.74	36.54	34.07	7.41			28	21	7
12.00-13.50	SC	Silty Sand with Clay	19.91	2.72	1.87		0.00	8.84	12.86	38.06	31.99	8.25	0.13		27	19	8
13.50-15.00	SM-SC	Silty Sand with Clay	-	-	-		1.24	7.49	13.28	35.65	35.11	7.23			26	19	7
15.00-16.50	SM-SC	Silty Sand with Clay	21.14	-	1.93		1.28	5.08	14.08	33.36	39.88	6.32			27	21	6
16.50-18.00	SM-SC	Silty Sand with Clay	-	-	-		1.19	4.68	12.87	34.28	40.70	6.28			27	21	6
18.00-19.50	SC	Silty Sand with Clay	19.54	-	1.92		0.00	5.89	13.92	36.07	34.28	9.84			29	20	9
19.50-21.00	SM-SC	Silty Sand with Clay	-	-	-		0.00	4.68	11.47	37.68	38.72	7.45			27	20	7

10.1.3 Depth of Ground Water Table

Susceptibility of l iquefaction also de pends upon its de gree of s aturation a nd therefore water table play an important role in deciding the susceptibility of soil. The soil located above t he w ater t able i s uns aturated a nd h ence may not l iquefy. T herefore, f or t hose locations, where the depth of water table is very deep, the liquefaction susceptibility will be l ess. H owever, as t he w ater t able ke eps on c hanging, t he l iquefaction s usceptibility will al so fluctuate and therefore d eep w ater t able s hould not be t aken as cr iteria f or deciding further study of liquefaction hazard.

Water t able di stribution dur ing pos t m onsoon p eriod of 2010 s ourced Central G round Water B oard (CGWB) i s shown i n F igure 1 0.2. Water table at m ore than 50% of bor e holes is below 10m also indicating susceptibile to liquefaction.

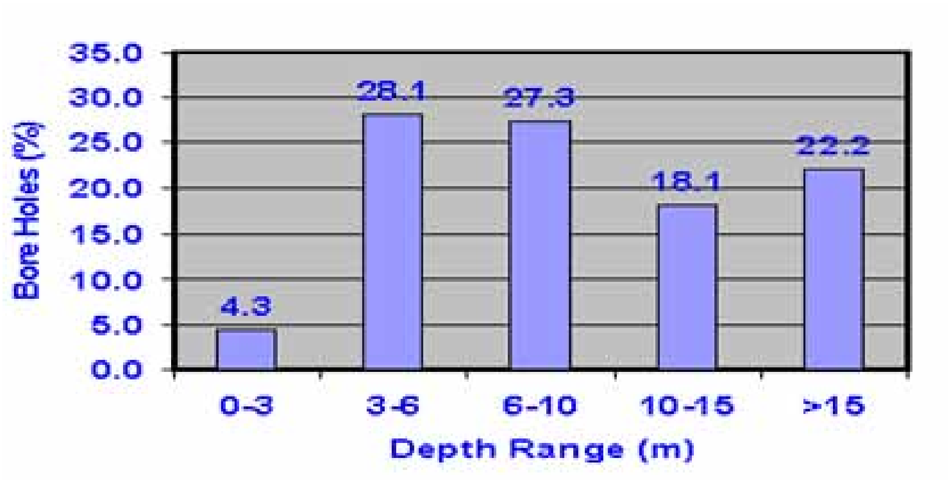


Figure 10.2 Ground water table distributions at different depth at 449 locations where geotechnical investigations have been carried out.

10.2 EVALUATION OF LIQUEFACTION POTENTIAL (LEVEL B STUDY)

Liquefaction susceptibility of soil in Delhi has been studied based on above criteria (10.1) and found that, most of these criteria indicate that soil type in NCT Delhi is susceptible to liquefaction and therefore further study for qualitative assessment of liquefaction potential based on Factor of safety (Level B study) has been carried out.A simplified procedure(Seed and Idriss, 1971) and subsequent revisions of the simplified procedures (Seed et al., 1983, 1985; Youd and Idriss, 2001; Idriss and Boulanger, 2004; Cetin et al., 2004), based on the use of empirical correlations with standard penetration tests (SPT) is widely used. In this method two variables are required for the assessment of liquefaction potential.

(a) The seismic demand of a soil layer which is represented by a Cyclic Stress Ratio (CSR).

(b) The capacity of soil to resist liquefaction represented by Cyclic Resistance Ratio (CRR).

On the basis of these two variables, Factor of safety against liquefaction can be evaluated based on the following relation

$$FS = \left(\frac{CRR_{7.5}}{CSR}\right)MSF \qquad (10.1)$$

If the Cyclic Stress Ratio (CSR)caused by an earthquake is greater than the Cyclic Resistance Ratio (CRR) of insitu soil then FS will be less than 'one' and liquefaction could occur during an earthquake. A factor of safety greater than one indicates that the liquefaction resistance exceeds the earthquake loading, and therefore liquefaction will not be expected. The higher factor of safety therefore, means that soil is having more resistance to liquefaction.

10.2.1 Evaluation Cyclic Stress Ratio (CSR)

The excess pore pressure generation to initiate liquefaction depends on the amplitude and the duration of the earthquake induced cyclic loading. In the cyclic stress approach the pore pressure generation is related to the cyclic shear stresses, hence the earthquake loading is represented in terms of cyclic shear stresses. The earthquake loading in terms of uniform cyclic shear stress amplitude has been evaluated by using Seed and Idriss (1971) simplified approachand subsequent revisions of the simplified procedures (Seed et al., 1983, 1985; Youd and Idriss, 2001; Idriss and Boulanger, 2004; Cetin et al., 2004), based on the use of empirical correlations with standard penetration tests (SPT) given below:

Cyclic Stress Ratio (CSR) $= 0.65\left(\frac{a_{\max}}{g}\right)\left(\frac{\sigma_{vo}}{\sigma_{vo}'}\right)r_d$ (10.2)

In this equation $0.65\,\frac{a_{\max}}{g}$ represents 65 % of the peak cyclic shear stress, $a_{\max}$ is peak ground surface acceleration, g is the acceleration due gravity, σ_{vo} and σ_{vo}' are the total and effective vertical stresses and r_d = stress reduction coefficient or depth reduction factor which account for flexibility of the soil column.

To adjust the equivalent number of stress cycles in different magnitude earthquakes, the equivalent uniform shear stress induced by the earthquake ground motion generated by an earthquake having a moment magnitude M = 7.5 i.e. $(CSR)_{M=7.5}$ are given byt he following equation (10.3).

$$(CSR)_{M=7.5} = 0.65\left(\frac{\sigma_{vo}a_{\max}}{\sigma_{vo}'}\right)\frac{r_d}{MSF} \quad (10.3)$$

Where, MSF is the magnitude scaling factor.

This equation has been used for the evaluation of CSR for the earthquake of moment magnitude 7.6, the Maximum Credible Earthquake (MCE) evaluated from Probabilistic Seismic Hazard Analysis for the area, on the basis of PSHA study described in previous chapters.Using the above equation CSR has been evaluatived at all the 449 sites at different depth having liquefiable soil.A typical illustration of spread sheet for the computation of CSR along with other parameters required for computation of FS is depicted in Table 10.3.

Table 10.3 Typical spread sheet for the computation of CRR, CSR, MSF and other Parameters required for computation of FS.

Lat.	Log.	Sheet No.	DP No.	depth	Soil type	N Obs.	(N1)60	FC (%)	d (N1) 60	N corr (N1) 60cs	WT (CGWB)	ρ	T Overburden	Eff. Overburden	CRR 7.5	PGA	rd	CSR	M	MSF_exp	CSR7.5_exp	CRR7.5(Mod)Cs	FS-mod_exp
28.62	76.91	3	1n	1.5	ML	15	8.27	58.39	5.61	14	10	1.76	25.89	25.89	0.10	0.1385	0.99	0.09	7.57	0.98	0.09	0.15	1.61
28.62	76.88	3	1!4	1.5	SM	14	11.63	42.81	5.60	17	10	1.73	25.45	25.45	0.13	0.1572	0.99	0.10	7.57	0.98	0.10	0.18	1.75
28.61	76.90	3	2!4	1.5	ML	15	8.27	54.23	5.61	14	10	1.7	25.30	25.30	0.10	0.1442	0.99	0.09	7.57	0.98	0.09	0.15	1.55
28.61	76.92	3	3!4	1.5	ML	22	12.13	52.90	5.61	18	10	1.75	25.74	25.74	0.13	0.1487	0.99	0.10	7.57	0.98	0.10	0.19	1.90
28.61	76.89	3	9'!4	1.5	ML	22	12.13	55.80	5.61	18	10	1.8	26.18	26.18	0.13	0.1356	0.99	0.09	7.57	0.98	0.09	0.19	2.09
28.60	76.90	3	10!4	1.5	ML	18	9.92	55.90	5.61	16	10	1.8	26.04	26.04	0.11	0.1573	0.99	0.10	7.57	0.98	0.10	0.17	1.57
28.60	76.91	3	11!4	1.5	ML	17	9.37	57.31	5.61	15	10	1.4	21.04	21.04	0.11	0.1678	0.99	0.11	7.57	0.98	0.11	0.16	1.43
28.60	76.89	4	17'!4	1.5	ML	22	12.13	55.64	5.61	18	10	1.8	26.04	26.04	0.13	0.1411	0.99	0.09	7.57	0.98	0.09	0.19	2.00
28.56	76.90	4	18!4	1.5	SM	15	12.89	36.83	5.54	18	5	1.4	20.74	20.74	0.14	0.1708	0.99	0.11	7.57	0.98	0.11	0.20	1.72
28.60	76.92	4	19'!4	1.5	ML	14	7.72	58.98	5.60	13	10	1.7	24.86	24.86	0.09	0.1731	0.99	0.11	7.57	0.98	0.11	0.14	1.24
28.58	76.88	4	25!4	1.5	SM-SC	15	12.52	43.59	5.60	18	10	1.7	24.86	24.86	0.14	0.1546	0.99	0.10	7.57	0.98	0.10	0.19	1.87
28.58	76.90	4	26!4	1.5	SM	28	23.03	35.29	5.51	29	10	1.8	26.92	26.92	0.26	0.1292	0.99	0.08	7.57	0.98	0.08	0.39	4.52

10.2.1.1 Evaluation of Stress Reduction Coefficient 'r_d'

The basis of the simplified CSR equation is Newton's second Law of motion (i.e. force is equal to mass times acceleration), which assumes rigid body motion. In reality, the soil column is not a rigid body and behaves in a very non-linear fashion, therefore Seed and Idriss (1971) introduced 'r_d' to account for the fact that the soil column is a deformable body.

For the evaluation of stress reduction coefficient many correlation are available which are discussed in detail in a 1996 NCEER workshop report (Youd et al. 2001). Youd et al. (2001) recommended that for routine practice and non-critical projects. The equations given by Liao and Whitman (1986) may be used to estimate average values of r_d, which isgiven below.

$r_d = 1.0 - 0.00765z$ for $z \leq 9.15$ m (10.4)

$r_d = 1.174 - 0.0267z$ for $9.15\text{ m} < z \leq 23$ m (10.5)

Where, z is the depth below ground surface in meters. Some investigators have suggested additional equations for estimating r_d at greater depths (Robertson and Wride ,1998), but evulation of liqufaction at these greater depths, is beyond the depths where the simplified procedure has been verified and where routine applications should be applied.

Mean values of r_d calculated from the Equations 10.4 & 10.5 are plotted in following Figure 10.4, along with the mean and range of values proposed by Seed and Idriss (1971). The mean curve plotted in Figure 10.3 .has been approximated by the following equation (Youd and Idriss, 2001) and yields essentially the same values for rd as equation 10.4 & 10.5. This equation has been used for the evaluation of rd in the present study

$$r_d = \frac{\left(1.000 - 0.4113z^{0.5} + 0.04052z + 0.001753z^{1.5}\right)}{\left(1.000 - 0.4177z^{0.5} + 0.05729z - 0.006205z^{1.5} + 0.001210z^{2}\right)} \quad (10.6)$$

Where z is the depth beneath ground surface in meter

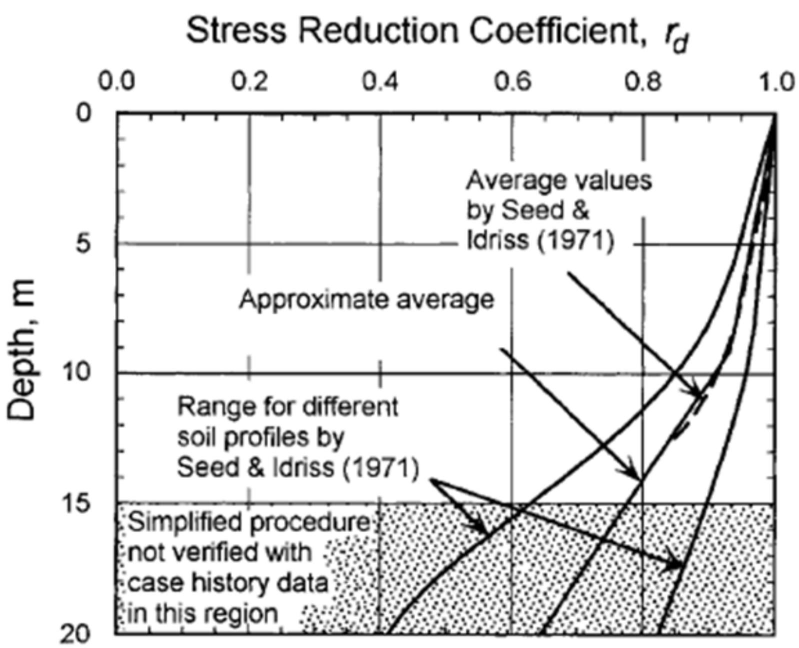


Figure 10.3 The 'r_d' relationship adopted by Youd et al. (2001), along with approximate average values from Equations 10.4 & 10.5

The liqufaction study has been carried out for 0-3m, 3-6m,6-9m, 9-12m and 12 -15m depths. A typical illustration of spread sheet for the computation of r_d along with other parameters required for computation of FS is depicted in Table 10. 3. The rd value calculated for different representative depths are given in Table 10.4

Table 10.4 Stress reduction Coefficient 'r_d' value calucted for different representative depths

S.N.	Depth interval(m)	Actual depth where data has been collected(m)	R_d
1	0-3	1.5	0.99042
2	3-6	4.5	0.96907
3	6-9	7.5	0.943207
4	9-12	10.5	0.894397
5	12-15	13.5	0.81068

10.2.1.2 Evaluation of Magnitude Scaling Factor MSF:

The magnitude scaling factor, MSF, has been used to adjust the induced CSR during earthquake magnitude M to an equivalent CSR for an earthquake magnitude, M7.6. The MSF is thus defined as.

$$MSF = CSR_M / CSR_{M=7.6}$$

Thus, MSF provides an approximate representation of the effects of shaking duration or equivalent number of stress cycles. Values of magnitude scaling factors were derived by combining: (1) correlations of the number of equivalent uniform cycles versus earthquake magnitude, and (2) laboratory-based relations between the cyclicstress ratios required to cause liquefaction and the numberof uniform stress cycles.

Seed and Idriss (1982) developed a set of MSF from average numbers of loading cycles for various earthquake magnitudes and laboratory test results. On re-evaluating the original data Idriss defined a revised set of magnitude scaling factors which are defined by the following equation:

$$MSF = 10^{2.24} / Mw^{2.56} \quad (10.7)$$

Where, M_W is the Moment Magnitude

Idriss (1999) again re-evaluated the MSF equation, based on results of cyclic tests on high quality samples obtained by frozen sampling techniques. The MSF relation produced by this re-evaluation was expressed by Idriss (1999) as:

$$MSF = 6.9\exp\left(-\frac{M}{4}\right) - 0.058 \quad (10.8)$$

$$MSF \le 1.8$$

Where M is the earthquake magnitude

There are several other relations such as Ambraseys (1988) scaling factors, Arango (1996) scaling factors, Andrus and Stokoe (1997) scaling factors and Youd and Noble (1997) scaling factors. Detailed discussion and comparison of these scaling factors are available in Youd et al. (2001) and Bhandari et al. (2003). Figure 10.4 shows values of Magnitude Scaling Factor, proposed by various investigators along with values of Magnitude Scaling Factor obtained from Equation 10.8.

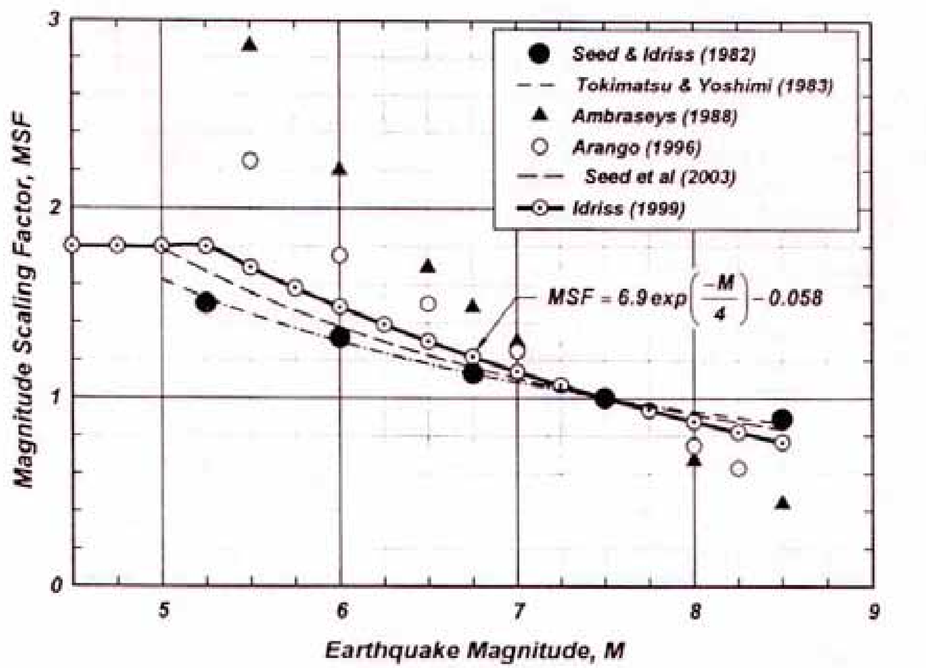


Figure 10.4 Magnitude Scaling Factor, MSF, values proposed by various investigators

In the present study of Seismic Hazard Microzonation of NCT Delhi, values of MSF have been evaluated using re-evaluated relation proposed by Idriss (1999) as given in Equation 10.8 for the Maximum Credible Earthquake of Mw7.6, evaluated from Probabilistic Seismic Hazard Analysis for the area at all sites spread over NCT Delhi at different depths having liquefiable soil.A typical illustration of spread sheet for the computation of MSFalong with other parameters required for computation of FS is depicted in Table 10.3.

10.2.1.3 Evaluation of total and effective vertical Stresses

Total stress

The total vertical stress at a point, σ_v, on average, is the weight of everything above that point per unit area. The vertical stress beneath a uniform surface layer with density ρ, and thickness '**h**' is:

$$\sigma_v = \rho g h \qquad (10.9)$$

Where 'g' is the acceleration due to gravity.

The effective vertical stress (σ_v')

The effective vertical stress (σ_v') is the combined effect of total stress and pore pressure that controls soil behaviour such as shear strength, compression, and distortion. The difference between the total stress and the pore pressure (u) is the effective vertical stress σ′.

$$\sigma_v' = \sigma_v - u \quad (10.10)$$

A typical illustration of spread sheet for the computation of vertical stresses, along with other parameters required for computation of FS is depicted in Table 10.6.

10.2.2 Evaluation Cyclic Resistance Ratio (CRR)

Liquefaction resistance of soil depends on how close the initial state of soil is to the state corresponding to "failure". The liquefaction resistance can be calculated based on laboratory tests and also in situ tests. Laboratory tests involve retrieval and testing of undisturbed soil specimens in the laboratory. It is almost impossible to obtain an undisturbed soil sample from the field with typical drilling and sampling techniques and reestablish in situ stress states in the laboratory. This problem can however be controlled, to some extent, by the use of suitable frozen sampling techniques, and consequent testing of these samples in a high quality cyclic simple shear or triaxial shear apparatus. These techniques are very expensive and cannot be attempted for the study of such a large area of NCT Delhi. Moreover, the frozen sampling is not feasible in soil with noteworthy fines content, as the low permeability of these types of soil can lead to ice expansion causing disturbance to the soil structures instead of preventing the disturbance. To avoid the difficulties associated with sampling and laboratory testing, field tests have become the state-of-practice for routine liquefaction investigations.

The Standard Penetration Test (SPT), the Cone Penetration Test (CPT), shear wave velocity measurements (Vs) and the Becker Penetration Test (BPT) are extensively being used to understand liquefaction behavior of soils. The CRR of the in-situ soil is primarily based on empirical correlation to these tests (Youd et al. 2001). These empirical correlations have been developed from case history data-bases of liquefied and non-liquefied soils documented in previous earthquakes. Figure 10.5 presents the SPT liquefaction triggering curves for magnitude 7.5 earthquakes detailed in Youd et al. (2001). In this figure, arrows indicate how the chart would be used to determine the CRR of the soil from a corrected blow count $(N_1)_{60}$ of approximately 20. Sands with higher fines contents have been shown to be more resistant to liquefaction triggering than clean sands (Seed et al. 1985), accordingly the CRR curves for fines contents greater than 5% shift up and to the left as fines content increases, with the maximum permissible shift occurring for a fines content of 35%. The CRR values for $(N_1)_{60} = 20$ are approximately 0.22, 0.30, and 0.41 for fines contents of 5%, 15%, and 35%, respectively.

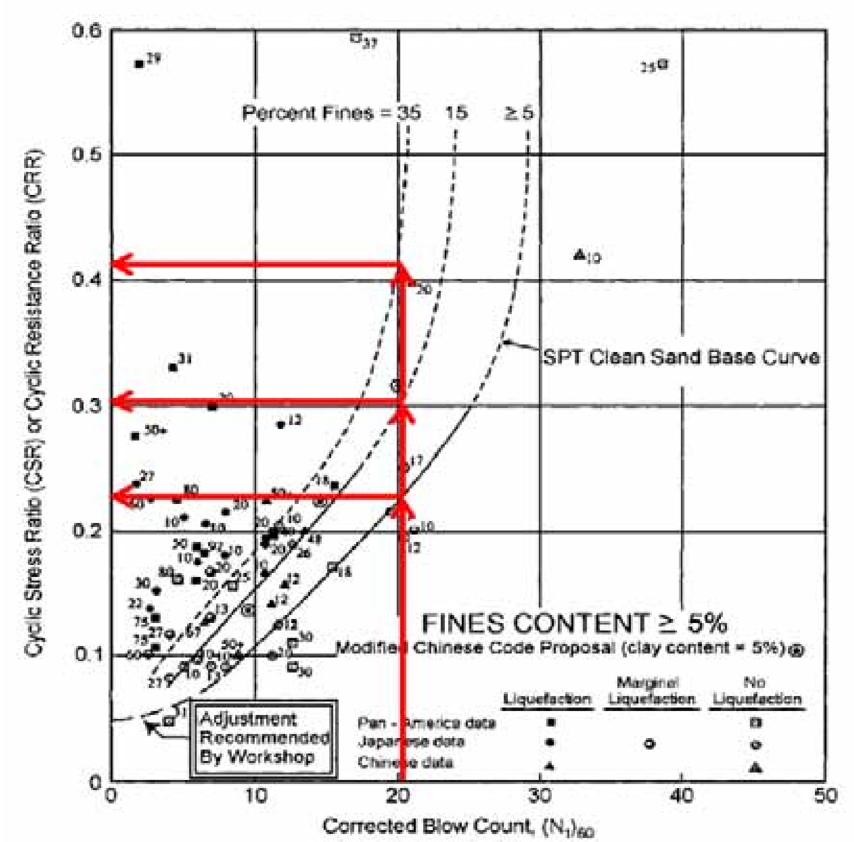


Figure 10.5 SPT CRR c urves for e arthquake of magnitude 7.5 (modified from Seed et al., 1985, obtained from Youd et al., 2001).

The CRR curve for fines contents <5% is the basic penetration criterion for the simplified procedure and is referred as the "SPT clean sand base curve."The CRR curves in Figure 10.5 are valid only for magnitude 7.5 earthquakes. The clean sand curve plotted in Figure 10.5 has been approximated by the following equation:

$$CRR_{7.5} = \left\{ \left(\frac{1}{34 - (N_1)_{60cs}} \right) + \left(\frac{(N_1)_{60cs}}{135} \right) + \left(\frac{50}{\left(10(N_1)_{60cs} + 45\right)^2} \right) - \left(\frac{1}{200} \right) \right\} \quad (10.11)$$

This equation is valid for $(N_1)_{60} < 30$. For $(N_1)_{60} < 30$, clean granular soils are too dense to liquefy and are classed as non-liquefiable.

Seed et al . (1985) not ed a n apparent increase of C RR w ith increase f ines cont ent. Arevised c orrection for fines c ontent w as then d evelopedfor c orrection of $(N_1)_{60}$ to an equivalent clean sand value, $(N_1)_{60cs}$to consider influence of fines content (FC) on C RR and to better fit the empirical database, which are given as Equation 10.12 & 10.13.

$(N_1)_{60cs}$ =a+ b $(N_1)_{60}$ (10.12)

Where'a' and'b'are the coefficients determined from the following relationships:

a = 0 for FC 5%   (10.13a)
2 a = exp[1.76 2 (190/FC)] for 5% < FC < 35%   (10.13b)
a = 5.0 for FC≥ 35% (10.13c)
b = 1.0 for FC <=   5%   (10.14a)
1.5 b = [0.99 1 (FC /1,000)] for 5% < FC < 35%   (10.14b)
b = 1.2 for FC ≥ 35% (10.14c)

Youd et al. (2001) and Cetin et al. (2004) proposed the most recent equivalent clean sand relations which convert the $(N_1)_{60}$ of silty sand to an equivalent value for clean sands, $(N_1)_{60cs}$. These recommendations obtain CRR by using $(N_1)_{60cs}$ and clean sand boundary curve (Idriss and Boulanger, 2004) for evaluating the CRR required to cause liquefaction for cohesionless soils with any fines content, which can be expressed using the followingequations. First, the SPT penetration resistance isadjusted to an equivalent clean sand value as:

$$(N_1)_{60cs} = (N_1)_{60} + \Delta(N_1)_{60} \quad (10.15)$$

$$\Delta(N_1)_{60} = \exp\left(1.63 + \frac{9.7}{FC} - \left(\frac{15.7}{FC}\right)^2\right) \quad (10.16)$$

The value of***CRR*** for a magnitude ***M*** =7.5 earthquake and an effectivevertical stress σ_v'=1 atm (~ 1 tsf) can be calculatedbased on $(N_1)_{60cs}$using the following expression:

$$CRR = \exp\left\{\frac{(N_1)_{60cs}}{14.1} + \left(\frac{(N_1)_{60cs}}{126}\right)^2 - \left(\frac{(N_1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N_1)_{60cs}}{25.4}\right)^4 - 2.8\right\} \quad (10.17)$$

These Equations (10.15, 10.16, and 10.17) have been used in spreadsheet for evaluation of CRR at all sites and at different depths having soil susceptible to liquefaction. A typical illustration of spread sheet for the computation of CRR, along with other parameters required for computation of FS is depicted in Table 10.5.

Table 10.5 Factors of Safety for Liquefaction Hazard Assessment (Martin and Lew, 1999).

Consequence of Liquefaction	$(N_1)_{60}$ Clean Sand	Factor of Safety	
		Non Critical Structure	Critical Structure
Settlement	≤ 15	1.1	1.3
	≤ 30	1.0	1.2
Surface Manifestation	≤ 15	1.2	1.4
	≤ 30	1.0	1.2
Lateral Spread	≤ 15	1.3	1.5
	≤ 30	1.0	1.2

10.2.3 Evaluation of Factor of Safety

As detailed above Factor of safety can be determined using above mentioned two variables i.e. CSR and CRR from the following formula for different bore log and depth and applying Magnitude scaling factor for the earthquake of expected magnitude in the region of study.

$$FS = \left(\frac{CRR_{7.5}}{CSR}\right) * MSF \qquad (10.18)$$

If the Cyclic Stress Ratio (CSR) caused by the earthquake is greater than the Cyclic Resistance Ratio (CRR) of in situ soil then FS will be less than 'one' and liquefaction could occur during an earthquake. A factor of safety greater than one indicates that the liquefaction resistance exceeds the earthquake loading, and therefore that liquefaction would not be expected. The higher factor of safety therefore, means that soil is having more resistance to liquefaction.

In the guidelines of some of the countries the recommended criteria for Factor of Safety depend upon the type of the structure. For example as per "Recommended Procedures for Implementation of DMG Special Publication 117 – Guidelines for Analyzing and Mitigating Liquefaction in California," Southern California Earthquake Center, University of Southern California, (Martin G.R., and Lew M., 1999), a factor of safety in the range of about 1.1 is generally acceptable for single family dwellings, while a higher value in the range of 1.3 is appropriate for more critical structures. Furthermore, consequences of different liquefaction hazards vary. For example, hazards stemming from flow failure are often more disastrous than hazards from differential settlement. Table 10.5 provides general guidelines for selecting a factor of safety.Factor of Saftey (FS) can also be understood in terms of severity index as given in Table 10.6. The result of the analysis may be presented in map format, with zones distinguished according to the value of the safety coefficient/range.

Table 10.6: Factor of Safety and severity index of liquefaction

Group	Factor of Safety range	Severity Index
1	<1	Very Critical
2	1 to 2	Critical
3	2 to 3	Low critical
4	>3	Non liquefiable

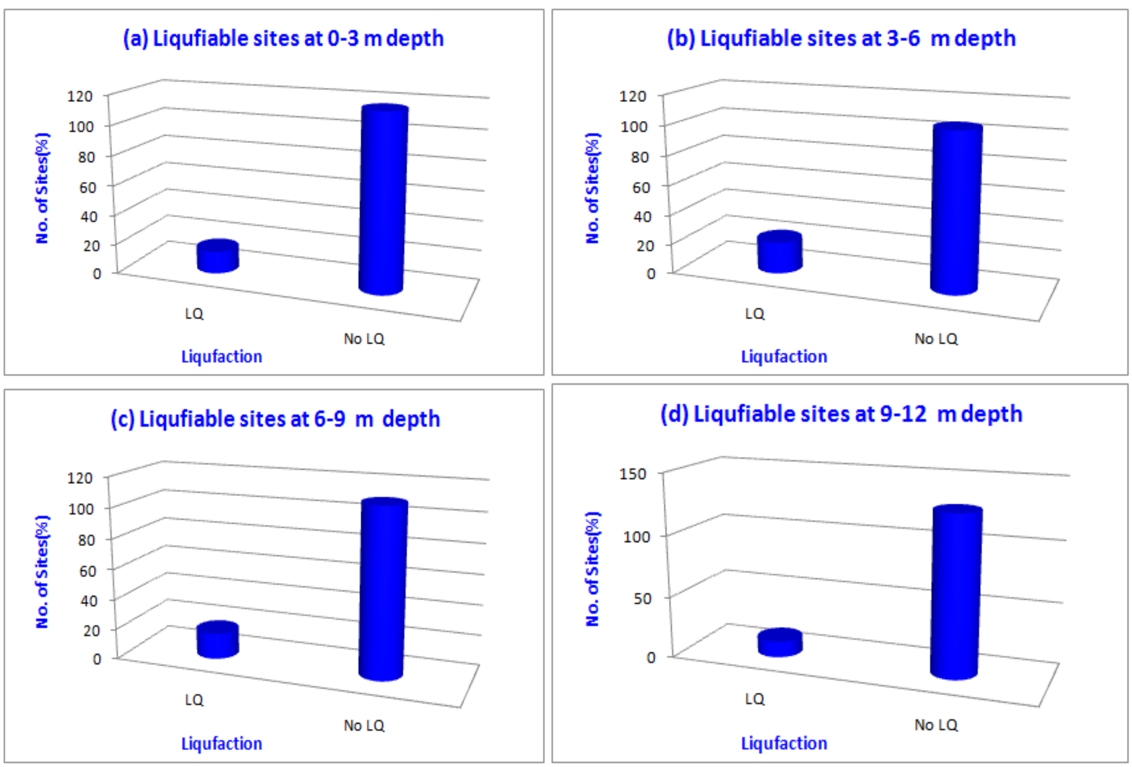
10.3 RESULTS AND DISCUSSION

Under the present project of Seismic Hazard Microzonation of NCT Delhi on 1: 10,000 scale geotechnical investigation at 314 sites spread over NCT Delhi, have been carried out by drilling borehole up to the depth of 30 meter, collecting soil samples at 1.5m depth interval and SPT N value at 3.0 meters, depth interval. Laboratory investigations have been carried out on collected soil samples and Index property, such as grain size distribution (particularly the fine content), plasticity, unit weight, and moisture content etc have been evaluated. On observed SPT N value data, instrumental correction, correction for overburden and fines content have been applied as detailed in previous chapter and corrected data denoted as $(N_1)_{60cs}$ has been obtained. A typical example of collected SPT N values at different depth interval at one borehole location and subsequent applied correction is given in Table 6.6. Besides this newly generated geotechnical data to fill up the gap area, particularly in Central Delhi, data collectedfrom different agencies and CHT data where ' N' values are also available have been used.

Thus total 314 newly generated geotechnical data, 108 Geotechnical data collected from different organizations and 11 CHT sites where 'N' values are also available have been used for liquefaction study. Thus a total data at 433 sites have been used for present liquefaction study.

In the present study of liquefaction, probabilistically derived Peak Ground Acceleration (PGA) at surface for 10% probability of exceedance in 50 years (i.e. 475-year return period) is used. In the present study, water table map published by Central Ground Water Board (CGWB) for post-monsoon period of November 2010 has been considered, which gives the maximum possible water table in NCT Delhi during the year. These data has been interpreted following the state of stress approach for liquefaction susceptibility using simplified procedures and different parameters required to evaluate FC such as CSR, r_d, MSF, CRR etc as detailed above (Sections 10.1, 10.2, and 10.3) have been evaluatedusing a spread sheet. A typical illustration of spread sheet for the computation of CRR, CSR, MSF and other parameters required for computation of FS is depicted in Table 10.6.

The earthquake of Moment Magnitude 7.57, Maximum Credible Earthquake evaluated from Probabilistic Seismic Hazard Analysis for the area, on the basis of PSHA study described in previous chapters has been considered. However, this earthquake is designated to Himalayan region falling under the study area, which is the NCT Delhi, but there are examples, where even long distance earthquakes have triggered liquefaction. A detail of a few such earthquakes available in literature is given in Table-10.7. Liquefaction potential for Moment magnitude 7.57, based on FS have been evaluated and subsequently maps at depth 0-3, 3-6, 6-9, and for consolidated depth 0-9m have been generated and presented as Map 36,37,38 and 39. These maps show that liquefaction is generally possible in areas close to Yamuna River. A few bar charts showing number of liquefiable sites at different depth are given in Figures 10.6. Liquefaction potential maps for the area covered under individual toposheets on 1: 10000 scale have also been generated.



Figures 10.6 Number of sites (%) liquefiable and non-liquefiable in different depth

Liquefaction is most commonly observed in shallow, loose, saturated cohesion less soils subjected to strong ground motions. Unsaturated soils are not subjected to liquefaction because volume compression does not generate excess pore water pressure. Therefore, water level play very important role in liquefaction study. The main source of recharge of water level in Delhi is rainfall during the monsoon season and water level is maximum (shallow) during this season. In the present study, therefore, water table map published by

Central Ground Water Board (CGWB) for post-monsoon period November, 2010 has been considered, which gives the maximum possible water table in NCT Delhi during the year. As discussed in Chapter-4, however, in the entire Yamuna flood plain, the water levels are almost same about 2to 5 m in both pre-monsoon (May) and post-Monsoon (November), but a significant reduction in water level observed in some parts of NCT Delhi during pre-monsoon season and may not be favorable for liquefaction.Thus there is possibility that some of the areas showing liquefaction potential actually may not be observed, if an earthquake occurres in a season other than monsoon.

Table10.7 Maximum Epicentral distance from documented Liquefaction Sites and Focal Depth for Some Large Earthquakes Since 1983 (After Wang, et al., 2006)

Earthquake	Magnitude	Epicentral distance (km)	Focal depth (km)	Source
1983 Nihonkai-Chubu, Japan	7.7	160	15	http://www.ce.berkeley.edu/hausler/sites/NKC001.pdf
1988 Udaipu Gahri, India	6.6	100	10	http://asc-india.org/gq/udaipur.htm
1989 Loma Prieta, California	7.1	93	18	Bardet and Kapuskar (1993)
1994 Northridge, California	6.7	50	19	www.lafire.com/famous_ fi res/940117_NorthridgeEarthquake/quake/02_EQE_geology.htm
1995 Manzanillo, Mexixo	7.3	150	30	http://sun1.pue.upaep.mx/servs/carrs/GIIS/manzanillo.html
1995 Kobe, Japan	6.9	40	10	http://www.jrias.or.jp/public/Hanshin_Earthquake/q1-2e.html
1999 Izmit, Turkey	7.8	61	17	Rothaus et al. (2004)
1999 Duzce, Turkey	7.5	56	10	http://geoinfo.usc.edu/turkey/
1999 Chi-Chi, Taiwan	7.6	80	8	Yu et al. (2000)
2001 Gujarat, India	7.7	260	17	Rajendran et al. (2001)
2001 Nisqually, Washington	6.8	75	52	Pierepiekarz et al(2001)
2002 Denali, Alaska	7.9	300	4.2	Kayen et al. (2002)
2003 Colima, Mexico	7.7	60	30	http://geoinfo.usc.edu/gees/

CHAPTER-11

INTEGRATION OF SEISMIC HAZARD MICROZONATION MAPS ON GIS PLATFORM

Seismic microzonation is subdividing a geographic domain into smaller areas having different potential for hazardous earthquake effects. The earthquake effects depend on 'Geoscientific' attributes such as geology and geomorphology, soil coverage/thickness, and rock outcrop/depth, and 'Geotechnical' attributes such as dynamic property of soil profile, and water table etc. Other attributes are the earthquake parameters, which are estimated by hazard analysis. The Peak Ground Acceleration (PGA), amplification/ site response, predominant frequency and liquefaction due to earthquakes are some of the important seismological attributes. In Seismic Hazard Microzonation based on different attributes, seismic hazard maps of different themes are generated. In order to understand the combined effect of different themes, maps of different themes are to be integrated by giving suitable weightage to the attributes and rank to different themes. Theme weights can be assigned based on the region and their contribution to the seismic hazard for example flat terrain has minimum weight and deep soil terrain and special features such as basin etc have highest weight for site response or liquefaction. Rank can be assigned within each theme based on their values closer to hazards. Usually higher rank isassigned to values, which is more hazardous in nature, for example larger PGA will have the higher rank. The integrated hazard map gives the Hazard Index (HI), which is the integrated factor depending on the weights and ranks of the geoscientific, geotechnical attributes; ground motion parameters and liquefaction susceptibility etc. hazard Index maps may be prepared for both the Design Based Earthquake DBE (10% probability of exceedence in 50 Years) and Maximum Credible Earthquake MCE (2% probability of exceedence in 50 Years). Though PGA at Surface and Amplification factor maps for DBE and MCE are different; the hazard index maps generated for DBE and MCE are similar.

Geographical Information System (GIS) provide suitable platform and is used to develop a hazard index map wherein the seismic hazard parameters are integrated /weighted overlaid and coupled with ground informationusing Analytic Hierarchy Process (AHP).

11.1GIS INTEGRATION LOGIC

The representation and interpretation of uncertainty related to the classification of individual locations provided by the fuzzy logic based on location attribute values. Fuzzy logic implements classes or groupings of data with boundaries. The central idea of fuzzy sets is aided by the Analytic Hierarchy Process (AHP). AHP is a multi-criteria decision method that uses hierarchical structures to represent a problem and then develop priorities for the alternatives based on the judgment of the user (Saaty, 1980). The idea of multi-criteria decision-making was based on the concept of McHarg (1968). McHarg (1968) introduced a systematic land use planning by using the concept of compatibility of multiple land uses. He mentioned that the factors affecting land and its relative values are different and, therefore, it is difficult to think of optimizing them for a single use. It can be optimized for multiple compatible uses. He introduced simple matrix system for determining the degree of compatibility. Saaty (1968) has shown that weighting activities in multi-criteria decision-making can be effectively dealt with hierarchical structuring and pair-wise comparisons. Pair-wise comparisons are based on forming judgments between two particular elements rather than attempting to prioritize an entire list of elements (Saaty, 1980). For multi-criteria evaluation, Saaty's Analytical Hierarchy Process (AHP) is used to determine the weights of each individual criterion (Saaty, 1990). AHP is a mathematical method to determine priority of criteria in the decision making process. It is a popular tool used by decision makers in the multi-attribute decisions. Saaty's Analytical Hierarchy process constructs a matrix of pair-wise comparisons (ratios) between the factors of Earthquake Hazard Parameters (EHP). The constructed matrix shows the relative importance of the EHP based on their weights. If 9 earthquake hazard parameters are scaled as 1 to 9, 1 meaning that the two factors are equally important, and 9 indicating that one factor is more important than the other, the reciprocals of 1 to 9 (i.e., 1/1 to 1/9) show that one is less important than the others. The allocation of weights for the identical EHP depends on the relative importance of factors and participatory group of decision makers. Then the individual normalized weights of each EHP are derived from the matrix developed by pair-wise comparisons between the factors of EHP. This operation is performed by calculating the principal Eigen vector of the matrix. The results are in the range of 0 to 1 and their sum adds up to '1' in each column. The weights for each attribute can be calculated by averaging the values in each row of the matrix. These weights will also sum to '1' and can be used in deriving the weighted sums of rating or scores for each region of cells or polygon of the mapped layers (Jones, 1997).Since EHP vary significantly and depends on several factors, they need to be classified into various ranges or types, which are known as the features of a layer. Hence each EHP features are rated or scored within EHP and then this rate is normalized to ensure that no layer exerts an influence beyond its determined weight. Therefore, a raw rating for each feature of EHP is allocated initially on a standard scale such as 1 to 10 and then normalized using the relation,

$$X_i = \frac{R_i - R_{min}}{R_{max} - R_{min}} \tag{11.1}$$

Where R_i is the rating assigned for features with single EHP, R_{min} and R_{max} is minimum and maximum rate of particular EHP.

11.2 INTEGRATION OF SEISMIC HAZARD MAPS OF NCT DELHI

In the present study of Seismic Hazard Microzonation of NCT Delhi on 1: 10000 scale maps of followings themes have been considered for GIS integration to generate the hazard index map of NCT Delhi on 1:10000 scale

i. Peak Ground Acceleration at Surface
ii. Amplification factor
iii. Liquefaction Potential
iv. Engineering Bedrock Depth
v. Site classification based on Shear-wave Velocity Vs30
vi. Predominant Frequency
vii. Geology and Geomorphology

The pair-wise comparison has been performed using Analytic Hierarchy Process (AHP) [EVM multiple inputs] template of Goepel (Vr.08.02.2013; http://bpmsg.com) where each parameter is compared in pairs to others. Table 11.1 shows the input given for pair wise comparison; wherein one parameter is selected over other in the scale 1-9 to achieve the goal; i.e. to calculate the hazard. Scale definition is given in Table 11.2. Inputs, as presented in Table 11.1 were provided for generation of pair-wise comparison matrix of the themes and normalized weights in %. Table 11.3 shows the pair-wise comparison matrix of the themes and the calculated normalized weights.

Further, within individual theme a grouping has been made according to their values. Then rank has been assigned based on the values. Using the Equation (1), these ranks have been normalized to 0-1. The assigned ranks with normalized values are given in Table 11.4. Integration of different themes has been carried out using normalized weighted overlay of GIS and hazard index maps are generated for DBE and MCE. Hazard Index of < 0.3 is attributed to low hazard; 0.3-0.6 is attributed to moderate hazard and of 0.6 -0.88 is attribute to high hazard. Figure11.1 shows the scheme for the integration of different themes for generating hazard map of Delhi based on GIS integration logic detailed above. Based on this hierarchical integration in GIS base, seismic Hazard microzonation map of NCT Delhi on 1:10000 scales has been evolved, categorizing NCT in three hazard zones (Low, Moderate, and High) and presented as Map 40.

Table: 11.1 Pair-wise comparison input for AHP Template

Criteria			
A	B	Which is more Important? (A or B)	Scale (1-9)
PGA	LQ	A	1
	AF	A	7
	EBR	A	9
	Vs(30)	A	9
	FMPF	A	9
	GG	A	9
LQ	AF	A	7
	EBR	A	9
	Vs(30)	A	9
	FMPF	A	9
	GG	A	9
AF	EBR	A	5
	Vs(30)	A	5
	FMPF	A	7
	GG	A	7
EBR	Vs(30)	A	3
	FMPF	A	5
	GG	A	7
Vs(30)	FMPF	A	5
	GG	A	7
PF	GG	A	7

Table: 11.2 Scale for pair wise comparison

Intensity	Definition	Explanation
1	Equal Importance	Two element contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over other
5	Strong Importance	Experience and judgment strongly favor one element over other
7	Very Strong Importance	One element is favored very strongly over another , its dominance is demonstrated in practice
9	Extreme Importance	Evidence favoring one element over other is of the highest possible order of affirmation

Table 11.3 Pair-wise comparison matrix of Themes and their normalized weights

	PGA_SUR	LQ	AF	EBR	Vs30	FMPF	GG	Normalized Weights (%)
PGA_SUR	1	1	7	9	9	9	9	35.4
LQ	1	1	7	9	9	9	9	35.4
AF	1/7	1/7	1	5	5	7	7	13.0
EBR	1/9	1/9	1/5	1	3	5	7	06.7
Vs(30)	1/9	1/9	1/5	1/3	1	5	7	05.0
FMPF	1/9	1/9	1/7	1/5	1/5	1	7	03.0
GG	1/9	1/9	1/7	1/7	1/7	1/7	1	01.5

Table 11.4 Normalized ranks of the themes for NCT Delhi Microzonation

Themes	Values	Weight	Rank	Normalized Rank
Peak Ground Acceleration (PGA) at Surface	<0.2	0.354	1	0
	0.2-0.3		2	0.33
	0.3-0.4		3	0.66
	0.4-0.48		4	1
Factor of Safety for Liquefaction	<1	0.354	3	1
	1-1.2		2	0.5
	>1.2		1	0
Amplification Factor	<2	0.130	1	0
	2-3		2	0.33
	3-4		3	0.66
	4-4.7		4	1
Depth of Engineering Bedrock	<40	0.067	1	0
	40-60		2	0.25
	60-80		3	0.50
	80-100		4	0.75
	100-154		5	1
Vs(30)	154-360	0.050	3	1
	360-760		2	0.5
	760-850		1	0
First mode peak frequency	0.9-1.5	0.030	3	1
	1.5-2.5		2	0.5
	2.5-15.1		1	0
Geology and Geomorphology	Out crop/Ridge	0.015	1	0
	Older Alluvium		2	0.25
	Chhatarpur basin		3	0.50
	Newer Alluvium		4	0.75
	Flood plain, River , Water body		5	1

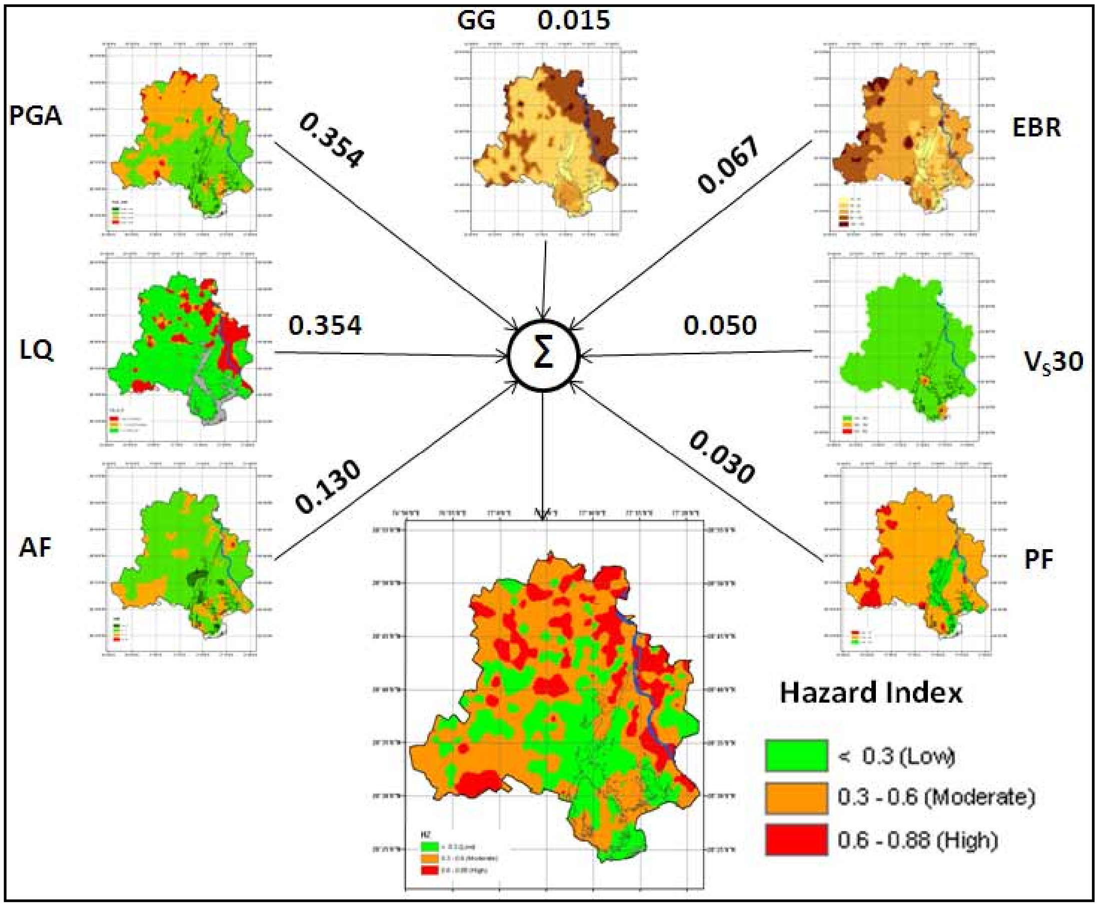


Figure 11.1 Weighted overlay/integration of thematic maps for generation of Hazard Index map

11.3 Results

Integrated seismic hazard map of Delhi has been generated using seven thematic layers viz., Peak Ground Acceleration at Surface, Amplification factor, Liquefaction Potential, Engineering Bedrock Depth, Site classification based on Shear-wave Velocity Vs30, Predominant Frequency, Geology, and Geomorphology.The integration is performed following a pair-wise comparison of Analytical Hierarchy Process (AHP), wherein each thematic map is assigned weight in the 9-1 scale: depending on its contribution towards the seismic hazard. Following the AHP, the weightage assigned to each theme are: Peak Ground Acceleration at Surface (0.354), Amplification factor(0.130), Liquefaction Potential(0.354), Engineering Bedrock Depth (0.067), Site classification based on Shear-wave Velocity Vs30 (0.50),Predominant Frequency (0.030), Geology and Geomorphology (0.015). The thematic vector layers are overlaid and integrated using GIS. The Hazard Index thus obtained varies from 0.2 to 0.88, which have been dividedin three groups (i) HazardIndex < 0.3 (ii) Hazard Index 0.3-0.6, (iii) Hazard Index 0.6 -0.88. On the basis of Hazard Index NCT Delhi has been classified into three broad zones of vulnerability to the seismic hazard i.e. Hazard Index < 0.3 is attributed to low hazard; 0.3-0.6 is attributed to moderate hazard and of 0.6 -0.88 high hazard. The “high" seismic hazard zone is observed where either PGA at surface is high or possibility of liquefaction is observed. Most of the areas along Yamuna River and flood plan, scattered parts of northern Delhi having thick alluvial sediment, and a very small part of SW Delhi fall in high hazard zone. The 'low ' seismic hazard zone occurs mostly in central part of Delhi, either side of the Delhi ridge and scattered part of SW. The 'Moderate' seismic hazard zone occupies the area between low and high hazard zone scattered mostly leaving the central part of Delhi. Intergrated Hazard of NCT Delhi is attached as Map 40.

CHAPTER-12

QUANTIFICATION OF UNCERTAINTIES AND VALIDATIONOF DIFFERENT PARAMETERS, MODELS, AND RESULTS

The Seismic Hazard Microzonation is a procedure for estimating the total seismic hazard at many sites from ground shaking and related phenomena, by taking into account the effect of both i.e. source effects with the influence of propagation path that gives the input wave to the interface (Seismic/engineering bedrock) and of local site conditions. Thus the Seismic Hazard Microzonation is attempted in two parts

(i) Assessment of seismic hazard at engineering bedrock and
(ii) Assessment of Seismic Hazard at surface considering site effect.

Assessment of seismic hazard is an analytical methodology that estimates the likelihood that various levels of earthquake caused ground motions will be exceeded at a given location in a given future time period. Despite extensive advances in seismic knowledge, there are still major gaps in our understanding of the mechanisms that cause earthquakes, and of the processes that govern how an earthquake's energy propagates from its origin beneath the earth to various points near and far on the surface. These gaps in understanding mean that, there are inevitably significant uncertainties in the numerical results.

In Seismic Hazard Analysis (SHA) for the assessment of ground motion at engineering bedrock, these uncertainties are arising in magnitude scales (measurement and conversion error), earthquake catalog incompleteness (Temporal, Spatial and minimum threshold magnitude), earthquake source modeling, methods of estimations, kinds of earthquake recurrence models and estimation of strong ground motion using different attenuation relationships. This ground motion is used as input motion for evaluation of ground motion at surface and when subjected to a site, gets further amplified along with uncertainties associated with this input ground motion due to the site effect. Therefore, uncertainties in different ground motion parameters at engineering bedrock and subsequent ground motion parameters at surface arises due to site effect need to be assessed and quantified in a rational manner to provide a more complete picture of the seismic hazard with a quantified range of possibilities in terms of ground motions parameters at the site of interest.

The present study of Seismic Hazard Microzonation of NCT Delhi on 1:10000 scale is based on Probabilistic Seismic Hazard Analysis (PSHA) for assessment of ground motion at engineering bedrock, in which uncertainties at various steps of seismic hazard assessment have been identified, quantified and combined using appropriate statistical techniques as detailed in Chapter-5.The final product in terms of Uniform Hazard Response Spectra (UHRS), for various return periods have been estimatedand probable uncertainties presented in terms of StandardDeviation. Thusat each sites, UHRS have been evaluated for the mean and mean ± sigma.

Site specific UHRS are used for the simulation of site specific synthetic strong ground motion time histories, which are used asinput ground motion forassessment of modified ground motion at surface.Uncertainties arise due to possible error in UHRS need to be ascertained. Synthetic time histories can be developed using different techniques and model parameters and therefore uncertainties arising out of this also need to be assessed and validated.

Further, for the assessment of ground motion at surface which is influenced by the physical properties of the soil layers due to site effect, several field and laboratory investigations for ascertaining soil parameters are to be carried out. Based on these soil properties different input parameters, models are to be developed and used for site response study. Therefore possible uncertainties in investigations and model parameters used are to be assessed and validated.

In this Chapter therefore ranges of uncertainties in different input parameters, models, intermediate and final products of Seismic Hazard Microzonation and validation of different model and results have been discussedfor better judgment. However, there is no strong motion earthquake which can be compared with the response spectra generated from the study, but an effort has been made to see any similarity with available near and far field week motion records.

12.1 UNCERTAINTY IN PEAK GROUND ACCELERATION AT SURFACE

Peak Ground Acceleration is the maximum amplitude of the ground acceleration time-history. To evaluate PGA at surface, time histories have been generated at engineering bedrock and subsequently used as input motion for ground response analysis, which also provides time histories at surface. Time histories at engineering bedrock have been generated using Uniform Hazard Response Spectra (UHRS) for various return periods obtained from PSHA and different model parameters such as total duration, delay and rise time etc. Thus thereis possibility of uncertainty in generation of time histories due to (i) uncertainty involved in UHRS and (ii) selection of different model parameters. Both these aspects of uncertainties have been examined in following sections.

12.1.1 Uncertainty in evaluation of Uniform Hazard Response Spectra

Uniform Hazard Response Spectra (UHRS) for various return periods have been estimated at different sites of Delhi at engineering bedrockbased on PSHA. These UHRS have been used for further study of generation of Earthquake Strong Ground Motion, time histories and subsequently used, as input motion for ground response analysis to evaluate seismic hazard parameters at ground surface. The UHRS have been evaluated for the mean and mean ± sigma.Such UHRS at a few sites for (i) 10% probability of exceedence for 475 year return period and (ii) 2% probability of exceedence for 2500 return period are given in Figures 5.30, 5.31, and 5.31 of Chapter-5. The figure 5.31 is reproduced as Figure 12.1.

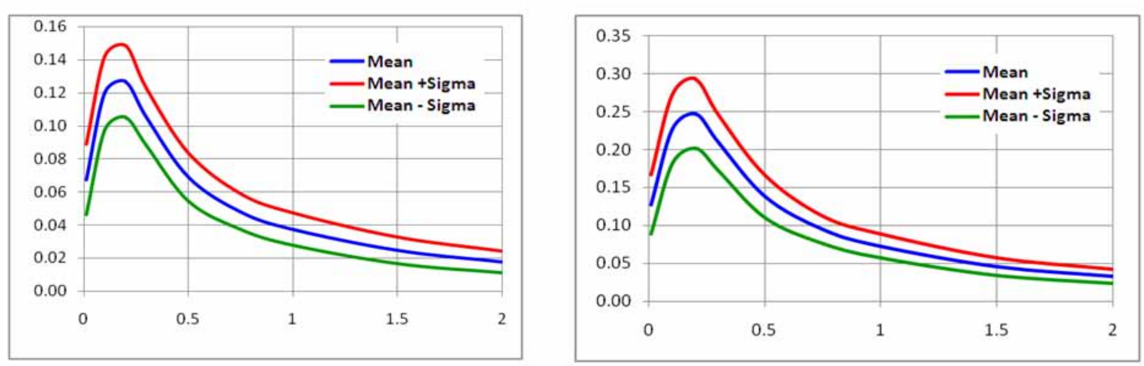


Figure 12.1 Uniform Hazard Response Spectra for site Bhawana after free surface Correction for (Left) 475year return period and (Right) 2500 yearreturn period

Based on Mean values of UHRS of respective sites, spectrum compatible ground motion time histories have been generated at 449 sites spread over Delhi at engineering bed rock as detailed in Chapter 5. Theseground motion time histories have been used as input motion for ground response study and ground motion time histories at surface have been obtained at all 449 sites. Based on these time histories atsurface at all the 449 sites, the peak ground acceleration (PGA), which is the maximum amplitude of the ground acceleration time-history, have been evaluated and subsequently a surface PGA map has been generated as detailed in Chapter-9.The PGA at surface for MCE based on mean values of UHRS varies from 0.18g to 0.42g and for DBE varies from 0.09g to 0.27g.

In order to assess possible uncertainty in the results, at a few sites three spectrum compatible ground motion time histories have been generated based on three UHRS at each site i.e. based on Mean, Mean + sigma and Mean –sigma for MCE. Considering these time histories ground response study has been repeated for all the three input ground motion time histories and subsequently three time histories at surface and corresponding three PGA values at each site have been evaluated. The process has also been repeated for DBE. The uncertainty in PGA values on an average found to be (i) ±0.06g for MCE (2% probability of exceedence in 50 years) and (ii) ±0.03g for DBE (10 % probability of exceedance in 50 years).

12.1.2 Uncertainty in selection of different model parameters for generation of synthetic time history

Synthetic time histories of engineering significancehave been generated at 449 sites spread over NCT Delhi for the return periods of 475 years and 2500 years, using different model parameters. These time histories have been used for further ground response study and evaluation of PGA at surface.In order to assess the uncertainty if any in generation of time histories itself and exercise has been carried out as detailed below.

The important parameters to generate time histories are total time duration, risetime,and decay time, which have been taken as 40.96 second, 10 seconds and 20 seconds respectively, on the basis of experience of earthquake records available in this domain and discussion with scientist associated in the field. In order to see the sensitivity of these parameters on generation of time histories and subsequent evaluation of PGA, time histories have been generated using slight variation expected to occur on these parameters and these time histories have been used as input motion at that site for site response study and evaluation of PGA. This exercise has been repeated at a few representative sites. It is observed that the uncertainty in results in terms of Standard Deviation in PGA at surface derived from these time histories is of the order of 0.012g for MCEand around half .007g for DBE. Whereas, the PGA at surface for MCE varies from 0.18g to 0.42g and for DBE varies from 0.09g to 0.27gas discussed in previous section 12.1. Thus from engineering point of view, there is insignificant variation in final result of PGA at surface due to possible error in choosing different parameters for generation of strong motion time histories. Results of a few sites based on MCE are given in Tables 12.1. Time series generated using five alternative parameters are shown in Figure 12.2. Response Spectra generated based on these five time histories as input motion are shown in Figure 12.3. Figure 12.3 indicate that all the five response spectra are matching well.

Table 12.1 Variations in Peak Ground Acceleration (PGA)for MCE, at different sites based on different time histories (TS1, TS2, TS3, TS4 & TS5) generated using different parameters

S. N.	PGA with TS1	PGA with TS2	PGA with TS3	PGA with TS4	PGA with TS5	Difference with average PGA and TS1	Difference with average PGA and TS2	Difference with average PGA and TS3	Difference with average PGA and TS4	Difference with average PGA and TS5	Average PGA	Standard deviation (SD)
1	3.0589	3.1710	2.9223	3.2296	2.8458	0.3121	0.3236	0.2982	0.3296	0.2905	0.311	0.015
2	2.7515	3.0327	2.8957	3.0795	2.7627	0.2808	0.3095	0.2955	0.3142	0.2819	0.296	0.014
3	2.9276	2.9887	2.8674	2.8192	2.8146	0.2987	0.3050	0.2926	0.2877	0.2872	0.294	0.007
4	2.2746	2.2354	2.3506	2.4490	2.0979	0.2321	0.2281	0.2399	0.2499	0.2141	0.233	0.012

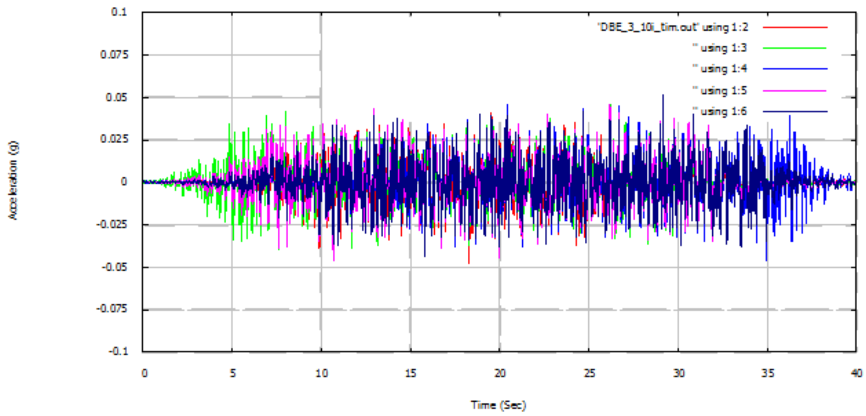


Figure 12.2 Five time series generated based on five alternate parameters

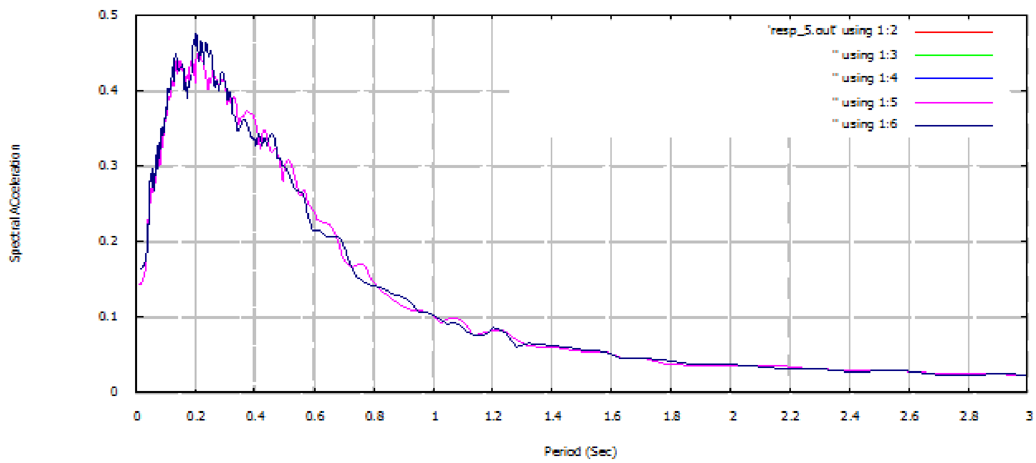


Figure 12.3 Five response spectra based on five time series generated using different alternate parameters.

12.2 UNCERTAINTY IN GEOTECHNICAL INVESTIGATIONS PRACTICES

Sources of uncertainty in geotechnical/geophysical investigations include the inherent variability of soils (a result of geological environment in which they were deposited), inherent anisotropy (a function of the soil structure or fabric), induced anisotropy (caused by anisotropic stress conditions), drilling and sampling disturbances, limitations of field/or laboratory testing equipment, testing errors, and interpretation errors. Some of these sources of uncertainty can be minimized by careful attention to test details, but other cannot due to limitations of geotechnical/geophysical practices.

Geotechnical and geophysical data have been generated for the study through outsourcing. There are possibility of certain error to be introduced in geotechnical/geophysical investigations during drilling operation, collection of Soil samples particularly undisturbed soil samples, SPT operation for N value measurements, soil transportation and laboratory investigations.

However, t here a re s et pr ocedures a nd also a vailable i n t he f orm o f c ode, but t he implementation of these depend upon experience of the individual technicians involved in the operation, the background of the engineering company.

There is no a ccepted method for the evaluation of the quality of investigation except to the l imited e xtent a scertaining pos sible c orrelation w ith ge ology of t he study s ite. T he only w ay t he qua lity c an be a ssured i s du e t o sensitizing t he t echnicians i nvolved i n operation and by strict supervision for implementing procedure through check list. In the present pr oject,all pos sible ef forts ha ve be en made t o minimize t hese e rrorsby strict supervision a nd e nforcing p rocedures, t hrough checklist;use of multiple te chniques, for example to ascertain correctness of SPT m easurement S PT and D CPT ha ve be en conducted at same sites; soil properties have been ascertained through collection of soil samples from open pi ts conducted at a few s ites; visible ins pection, a nd r eports of t he open s ections available in the area, s uch as a reas of quarries, s and m ines, generated during ge ological m appingand inspection o f nearby ongoi ng c onstruction. T hus even if by a dopting all t hese possible e fforts, if any error ha s occurred is due to limitations of geotechnical/geophysical i nvestigations pr actices i n t he c ountry and within acceptable limit.

12.3 UNCERTAINTY I N E MPIRICAL RE LATIONS F OR E VALUATION O F SHEAR WAVE VELOCITY

The best t echnique for t he m easurement of i n-situ lowstrainshearwavevelocity(Vs)withdepth, are CHT an d DHT, but it is not feasible to make Vs measurements at all the locations using these techniques, due to the requirement of dr illing num ber of bo reholes and also i mplication of hi gh c ost. Empirical r elations available i n literature for m atching soil are ge nerally used for eva luation of s hear w ave velocity f rom SPT N va lues col lected during g eotechnical i nvestigations, w hich m ay possibly introduce some error. To minimize the error, in the present study local empirical relations for different typesof soils of Delhi have been derived by evaluating shear wave velocity at common sites using different techniques.

12.4 UNCERTAINTY IN DE LINEATION O F E NGINEERING B EDROCK AN D VALIDATION OF SOIL MODEL

On t he b asis of P robabilistic S eismic H azard Analysis(PSHA) input m otion ha s be en derived at engineering bedrock (Shear wave velocity about 760m/s). In order to study the effect of soil through ground response analysis, a soil model above engineering bedrock need to be developed after delineation of engineering rockat all the 449 investigated sites.

In the present study, engineering bedrock has been delineated from extrapolating data of 30m soil through linear regression analysis (with regression coefficient more than 0.9 in most of the sites). The techniques yield satisfactory result, as in Delhi soil deposits below a few meters of ground is due to normal geological ageing and also there is no history of soil alteration due to unusual local natural events.Further, it is also noted that significant variations in r esponse of s oil i s onl y w ithin a f ew m eters be low gr ound l evel a nd therefore, the marginal error if any introduced in delineating engineering bedrock is not of much significant.

However, i n or der t o validate the s oil mode l a nd qualitatively assess the uncertaintyin delineation of e ngineering be drock, response of s oil i n t erms of P GA ha ve be en evaluated at di fferent s ites by introducing e rror of ±10m and ±20m in e ngineering bedrock at each sites. Thus at a few representative sites ground response analysis hasbeen performed using five soil models and PGA has been evaluated.

Table12.2 Result of qualitative assessment of uncertainty in varying engineering bedrock (EBR) depth by ±10 m and ±20m at each sitefor MCE.

S. N	Depth of EBR	PGA (EBR)	PGA (EBR-10m)	PGA (EBR+10m)	PGA EBR-20m	PGA EBR+20 m	Average PGA	Difference (PGA EBR-10m)	Difference (PGA EBR+10m)	Difference (.PGA EBR-20m)	Difference (PGA EBR+20m)	Average PGA	Standard deviation (SD)
1	86	1.6444	1.6971	1.5994	1.7298	1.4997	0.1678	0.1732	0.1991	0.1765	0.1530	0.166	0.009
2	41	1.7349	1.7988	1.7179	1.7907	1.6914	0.1770	0.1836	0.1793	0.1827	0.1685	0.177	0.005
3	114	1.3760	1.4288	1.3186	1.4976	1.2661	0.1404	0.1458	0.1346	0.1528	0.1292	0.141	0.008

The standard deviation on an average on surface PGA comes out to the order of 0.01g for MCE and naturally half 0.007g for DBE. This uncertainty has suitably incorporated in final r esults a nd a lso t aken c are w hile s uggesting c lass i nterval t o be c onsidered. T he results of exercise for a few sites are given in Table 12.2 for MCE.

12.5 UNCERTAINTY IN MATERIAL PROPERTIES

Technique of N on- linear a nalyses a dopted in t his s tudy r equires a qua ntitative knowledge of t he a ctual nonl inear m aterial be havior, w hich c an onl y b e obt ained by means of sophisticated laboratory tests. Some generic average curves have been proposed for di fferent types of m aterial, as sand or clay and available in literature, but the actual behavior of a given soil at a given site may strongly depart from these averages and may introduce t he e rror. In t he pr esent s tudy therefore, R esonant Column test on representative samples of Sand and Clay of Delhi at different depth, to determine shear modulus a nd da mping ratio of s oil unde r di fferent c onfining pr essure etc ha ve been conducted and used in place of generic average curves available in literature to reduced the uncertainty and improve the results.

12.6 UNCERTAINTY IN USE OF HETEROGENEOUS TECHNIQUES

In seismic microzonation study, for evaluation of different components, several geophysical/geotechnical techniques are generally used. One of the important parameters in the study is the evaluation of shear wave velocity, which is used for site classification and also in ground response analysis.Each techniquehas their own merits and demerits and may not yield the similar results. However, this is sometimes essential due to logistic reasons to enable field operation, speedy completion and also to reduce the cost of the project. In the present study also several techniques have however adopted, butonly cross validated data have been used.

12.7 UNCERTAINTY IN DEFINING BOUNDARIES OF MICRO ZONES

Subsurface geology, characteristics of litholog, arrangement of layering and also characteristics of individual layers, particularly 15 to 20 meter below ground level, play a very important role in final results of derived parameters of Seismic Hazard Microzonation. In order to assess the variability of these parameters in 1:10000 scale data is required for every 100m. In the present study, on the basis of geological attributes to fulfill the requirement of scale, data has been generated roughly in a grid of 1.5 Km X 1.5Km and need to be further extrapolated for contouring to join similar values or defining class boundaries. Roughly extrapolation can be done manually by observing geological attributes, with certain uncertainty, which may also be different in different area. The other alternative is to make use of some standardmathematical techniques to generate continuous data by extrapolation considering the attributes of nearest points and draw boundary by joining similar values or defined boundaries on the basis of class interval. Uncertainty may however, will remain in this method also, but it will be same for the entire area. In the present study therefore second approach has been adopted and a mathematical technique known as Inverse distance weighting (IDW) has been used. In this technique all the neighborhood points may be used with suitable weightage to approaching nearest points. For example say in a grid of nine square Km fourdata pints are available and all four will be used for extrapolation giving weightage to nearest point. The extrapolated point will be the weighted sum of the values of known points.

12.8 UNCERTAINTY IN CONSIDERING PEAK FREQUENCY AND PEAK AMPLIFICATION

In the present study, Peak frequency and corresponding Peak Amplification have been provided for first mode using experimental techniques and also based on Numerical technique. The experimental technique, based on H/V ratio provides peak frequency of Soil column above firm bedrock. In numerical analysis, input motion has been used at engineering bedrock, which is at most of the sites quite above firm bedrock. Thus the Peak Frequency evaluated by numerical technique, represents frequency of soil column above engineering bedrock, and may differ. Which frequencies are to be used may be discussed among the engineers. However, Peak frequency evaluated by experimental techniques which gives the frequency of soil column above firm bedrock seems more reasonable to be used.

12.9 VALIDATION OF MAXIMUM MAGNITUDE ASSESSED THROUGH PROBABILISTIC SEISMIC HAZARD ANALYSIS

The maximum magnitude which is defined as the upper limit of largest possible magnitude for a given region is an important variable in the seismic hazard estimation, as it reflects maximum potential of strain released in larger earthquakes. In the present study earthquake sources within 350 km radius of centre of Delhi (Latitude 24°-31.5° N and Longitude 74°-81.5° E) have been considered and fourdifferent seismic zones (Part of Himalayan Zone, Delhi-Hardwar Ridge Zone, Moradabad Fault Zone, and Rajasthan Great Boundary Fault Zone) have been identified. The maximum regional magnitude M_{max}have been evaluated for these four zones based onstandard methods as discussed in Chapter-6. The maximum magnitude among these seismic zones, which is 7.2±0.37for Part of Himalayan Zone, has been considered for the study. The reported maximum magnitude experienced in this zone is 6.9, which occurred on 29th March, 1999near Chamoli(30.4^{0}N and 79.4^{0}E) and therefore the evaluated maximum magnitude seems reasonable.

The maximum magnitude thus evaluated is not the representative of whole Himalayan seismic zone and only representing the part of Himalayan seismic zone falling within the area considered for identification of source zones effecting Delhi.For example the epicenter of Kangra earthquake of 4th April 1905 (lat. 32.3 ^{0}N and long. 76.2 ^{0}E) of initially reported magnitude 8.0 and the seismic gap area in Himalaya where researchers have pointed out possibility of occurrence of earthquake of magnitude 8.0 and more are beyond the considered area for the study. Further, it is seen from the following discussion that magnitude8 earthquake occurring at such a far distance may not yield significant PGA at Delhi.

The PGA values vary with distance and significantly decreases after about 100 km. One such example of Median model predictions for the vertical and horizontal PGA (Tiwan) for different magnitude earthquakes are shown in following Figure 12.4. This figure indicates that for earthquake of magnitude 8, horizontal PGA even at about 125km from the hypocenter will be only about 0.01g, which will further be reduced and for 300 km distance possibly be around 0.001g. This is insignificant in comparison to the minimum PGA 0.18g evaluated at engineering bedrockand considered for further ground response study for Delhi based on MCE.

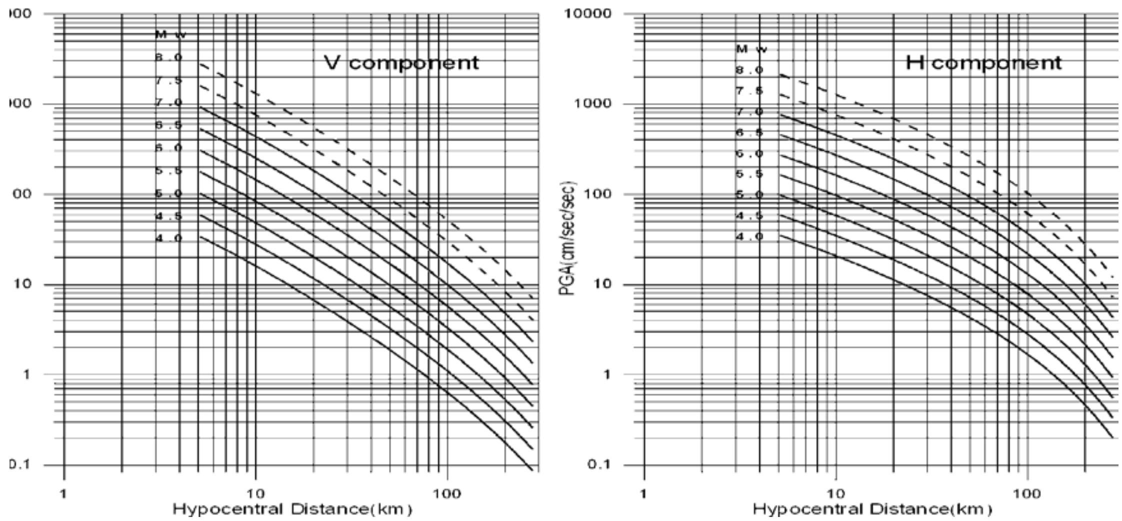


Figure 12.4: Median model predictions for the vertical and horizontal PGA (Tiwan), Kun-Sung Liu and Yi-Ben Tsai (2005).

In addition, the amplitude of ground motion decreases with increasing distance from the focus of an earthquake, the frequency content of the shaking also changes with distance. Earthquake-induced seismic wave frequencies span several orders of magnitude, from about 0.001 hertz up to several hundred hertz. Low-frequency waves can travel long distances but usually do not cause much damage, whereas the higher frequency waves which are of damaging in nature tend to dissipate in the ground very close to the earthquake source. Thus for long distance earthquakeonly low-frequency motions of the order of several tens of hertz are dominant, and may affect to the high rise buildingsand bridges only having natural frequencies corresponding to these frequencies.For example low-frequency motion of 0.1 Hz (10 second) corresponds to the natural frequency of 100 story building and may possibly affect to such buildings. The present studyis for general use and site specific response spectra have been generated up to 3 second only, which are applicable for the structures up to 30 stories, generally found in a city. For construction of high rise building more than 30 stories site specific studies are to be carried out.

12.10 COMPARISON OF RESPONSE SPECTRA WITH ACTUAL EARTHQUAKE

There is no strong motion earthquake which can be compared with the response spectra generated from the study. Comparison of weak and strong motionis not reasonable due to different frequency content, amplitude and expected nonlinearity, however, to see any similarity a comparison has been made with earthquakes of different origin. It seems that shape of the response spectra are reasonably matching to the possible extent. One such local earthquake of magnitude 3.8 occurred near Delhi and was recordedby instrument installed at Ridge Observatory. At the same location in present study geotechnical investigation has also been carried out and response spectrum has been generated. Both the response spectra are plotted in same scale and shown in following Figure 12.5. It is seen that shape of both the spectra is reasonably comparable particularly for high frequency. A few comparisons are also shown in Figure 12.6 with far field earthquakes.

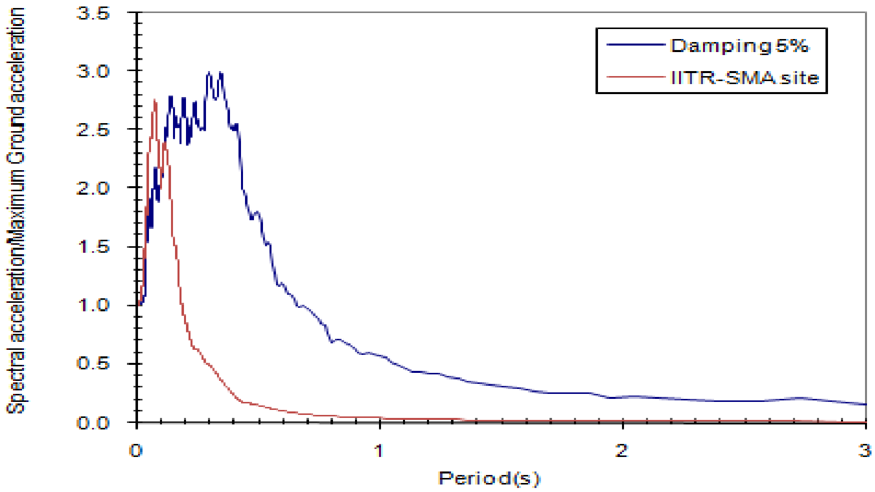
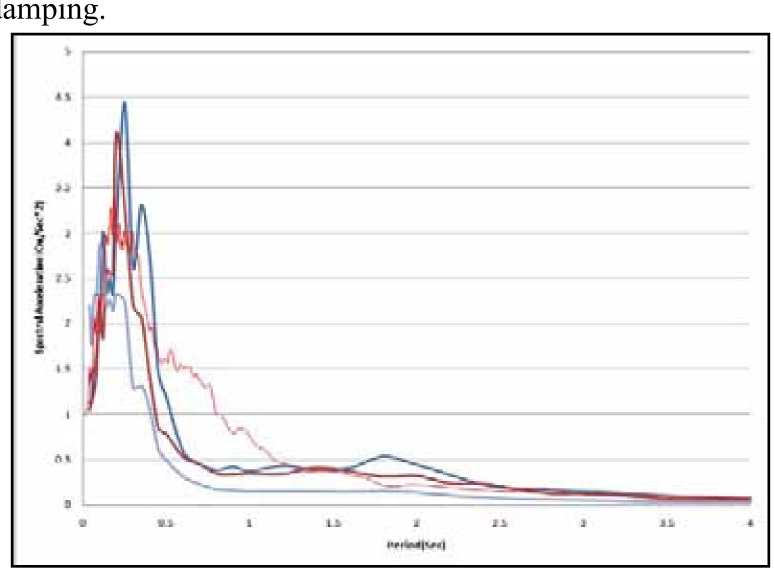
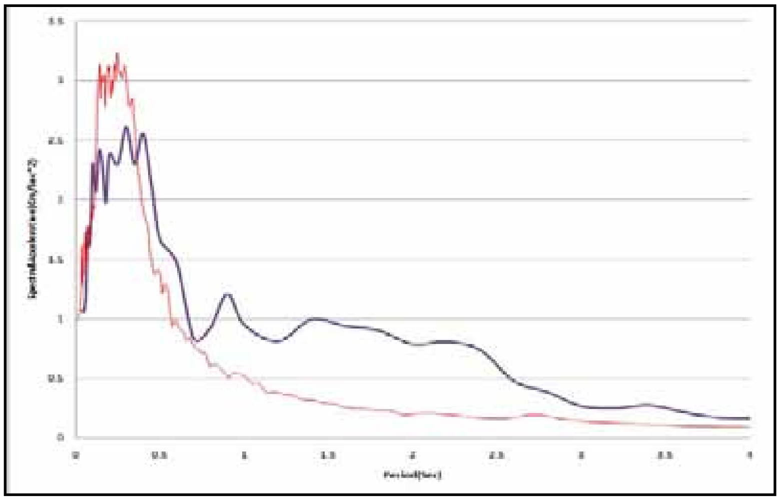


Figure 12.5 Matching normalizedobserved response spectra (local earthquake) with the generated normalized response spectra for 2% probability exceedance of ground for 50 years located at Ridge Observatory, IMD, New Delhi for 5% damping.



(a)



(b)

Figure 12.6: Matching of actual response spectra (red colour)at Jakir Husanin (a) and Karol bagh (b) sites, with far field earthquake events (Blue colour).

CHAPTER-13

SUGGESTED IMPLICATIONS OF DIFFERENT PARAMETERS DERIVED FROM SEISMIC HAZARD MICROZONATION STUDY FOR DESIGNING BUILDING CODES AND IN LAND USE PLANNING OF NCT DELHI

The Study of Seismic Hazard Microzonation for such a large scale has been attempted for the first time in our country. As per definition and requirement of scale of the study, Seismic Hazard parameters required for design of building codes and land use planning have been estimated at 449 sites. On the basis of methodology adopted for formulation of present building codes, based on present Seismic Hazard map of the county, an effort has been made after discussion with experts, to suggest certain equivalence and methodology to implement the seismic Hazard Microzonation parameters. A few broad suggestions have also been given for land use planning.

13.1 IMPLICATION OF SEISMIC HAZARD MICROZONATION PARAMETERS IN DESIGN OF BUILDING CODES

13.1.1 Implication of Peak Ground Acceleration at Surface viz-a-viz Review of Seismic Zone for NCT Delhi

In the present building code (IS1893 (Part1):2002), for the purpose of determining seismic forces, the country is classified into four seismic zones. Each zone has been assigned Zone Factor (Z), which is further used for the design of horizontal seismic coefficient 'A_h' for a structure.

The Zone Factor (Z) has been defined in the IS code as a factor to obtain the design spectrum depending on the perceived maximum seismic risk characterized by maximum Considered Earthquake (MCE) in the zone, in which the structure is located. The basic zone factors included in the present standard are said to be the reasonable estimate of Effective Peak Ground Acceleration (EPGA),which has further been defined as "0.4 times the 5% damped average spectral acceleration between period 0.1 to 0.3 s and considered as Zero Period Acceleration (ZPA). However, the Zero Period Acceleration (ZPA) has been defined as 'the value of acceleration response spectrum for period below 0.03 s (Frequency above 33HZ) (reference IS Code para 3.11, 3.33, 3.34).

Ultimately the Zoning Factor has been equated as Ground acceleration at zero period, which in the present study is Peak Ground Acceleration (PGA), which in terms of structural response, corresponds to the peak value of the absolute acceleration of a single degree of freedom (SDOF), system with infinite stiffness, that is, with a natural period of vibration equal to zero and may directly be considered as Zoning Factor. Based on this suggested Zoning Factor and their equivalence may be obtained as follows:

In the present study PGA values have been provided at 449 sites. Base on 2% probability of exceedance in 50 years i.e. MCE, PGA values are between 0.18g to 0.42g. The uncertainty in the results has been worked out to be the order of ± 0.06g. Keeping this uncertainty in mind, the obtained PGA values have been grouped in four classes (i) >0.18g (ii) 0.18g - 0.30g, with the central value 0.24g (iii) < 0.30g –0.42g with the central value 0.36g (iv) < 0.42g and accordingly area of NCT Delhi may tentatively be classified in four classes. Class (A) PGA values less than 0.18; Class (B) PGA value from 0.18g to 0.30 g, Class (C) PGA value 0.30g to 0.42g, Class (D) PGA value greater that 0.42g, however there are a very few sites of this class.

In the present building code, based on Seismic Zoning Map of the country the Zone Factor (ZPA) is used for design of buildings in different zones, are as follows(Table-13.1).

Table 13.1 Zone Factor (ZPA) used for design of building in different zones as per present BIS codes

Seismic Zone	Zone Factor (ZPA)
Zone II	0.10
Zone III	0.16
Zone IV	0.24
	0.36

Considering zoning factor (ZPA) used in the present Seismic Zoning Map of the country for different Zones, the area lying in class "A"of NCT Delhi may be considered equivalent to Zone III; Area lying under class "B" may be considered equivalent to Zone IV and area of NCT Delhi lying under class "D" may be considered V. Two sites occupying a very small area have PGA more than PGA assigned to zone V(Table 13.2). PGA Map-23 for 2% probability of exceedance in 50 years for 5% damping may be referred for identification of sites in different zones.

Table13.2 Proposed Zones and their equivalence with present zoning map and corresponding Zone Factor:

Class	Class interval (PGA)	Suggested Zone of NCT Delhi	Suggested Zone Factor
Class A	less than 0.18g	Zone III	0.16
Class B	0.18g to 0.30g	Zone IV	0.24
Class C	0.30g to 0.42g	Zone V	0.36
Class D	0.42g to 0.476	More than Zone V	0.44 (based on PGA at two sites, occupying a very small area)

13.1.2 Implication of response spectra and derived parameters viz-a-viz evaluation of horizontal Seismic coefficient 'A_h'

As per the present building code, the design horizontal Seismic Coefficient A_h for structureis being determined by the following expression, using parameters of response spectra (Sa/g) along with other parameters, as described below:

$$A_h = Z\, I\, S_a / 2\, R\, g \qquad 13.1$$

(Provided that for any structure with T <= 0.1s, the value of A_h will not be taken less than Z/2 whatever be the value of I/R)

Where;

Z= is the zone factor, which has been described in above para.

I=Importance factor, depending upon the functional use of the structure, characterized by hazardous consequences of its failure, post-earthquake functional needs, historical value or economic importance based on engineering judgment/assessment of the structure. In present building code 1.5 is used for critical structure and 1 for other structures.

R= Response reduction factor, depending on perceived seismic damage performance of the structure, characterized by ductile or brittle deformations. However, the ratio (I/R) shall not be greater than 1.0. The values of R for building are given in table 7 of the code. This factor varies from 1.5 to 5.0 for different type of building system and purely engineering parameter based on engineering judgment/Assessment.S_a/g= Average response acceleration coefficient for rock or soil sites based on appropriate natural period and damping of the structure.

In present building code this parameter is evaluated on the basis of three normalized design response spectra presented for Rock, medium soil and soft soil sites for 5% damping. Multiplication factors have also been given in code for various other damping. Thus in the present code only two response spectra have been used for all soil types.

On the basis of NEHRP classification, which is based on average shear wave velocity of soil up to 30 meter depth $(Vs)^{30}$, Delhi soil type in most part of the Delhi excluding Ridge area is same and is class 'D' type except at a few sites. Thus for soil of Delhi of in present code is represented by response spectra of soft soil and therefore only one response spectra may be applicable for whole Delhi.

The response of the soil is not only dependent upon the average shear wave velocity, but also depends upon the shear wave velocity of individual layers of litholog and their arrangement of layering. In highly geologically variable domain of Delhi, lithological variations are predominant in a very short distance. Keeping in view in mind and as per requirement of scale of Seismic Hazard Microzonation study of Delhi, response spectra presently have been generated for 449 sites, spread over different domains of NCT Delhi for

(i) 10% Probability of Exceedance in 50 years for return period of 475 years (DBE), for 5% damping, and

(ii) 2% Probability of exceedance in 50 years for return period of 2475 years (MCE) for 5% damping.

For normal structure, Response Spectra of nearest sites based on DBE may be used for evaluation of design horizontal Seismic Coefficient 'A_h'. For Critical structure nearest Response Spectra based on MCE may be used directly for calculation of design horizontal Seismic Coefficient.

These response spectra can be used to evaluate site specific horizontal Seismic Coefficient 'A_h' as follows

(1) For using the above formula to evaluate design horizontal Seismic Coefficient A_h the Response spectra at each site are to be normalized with PGA values of respective sites. Normalized spectra will also be provided. The ordinate value corresponding to the period of interest will then provide acceleration coefficient (Sa/g) corresponding to that period (Building period). As per present code for soil type of Delhi only two values of spectral coefficient at each period are used. For example for the period of .2 second the values used are 2.5 for medium soil and 1.67 for soft soil. From the present study site specific values can be evaluated.

(2) The equation for design horizontal Seismic Coefficient may be written as $A_h = A_h^1 (I / 2R)$ where $A_h^1 = (Z.Sa/g)$ said to be equivalent seismic coefficient of Response spectra directly provide value of (A_h^1) at each site for different period by simply reading the ordinate value of response spectra to the corresponding period.

Thus using direct method (2) response spectra can directly be used for evaluating Seismic Coefficient (A_h), by evaluating (A_h^1) at each site and may be used for design of building code particularly for critical structures. Further, the above calculation is based on MCE and beingdivided by 2. In the present study PGA based DBE have also been evaluated which can be used directly in the following formula. Map-24 of the report may be referred for PGA at surface for 10% probability of exceedance in 50 year and 5% damping.

$$A_h = A_h^1 (I/R) \quad 13.2$$

A_h^1 can directly be read from PGA map based on DBE.

To make use for normal structures, on the basis of response spectra generated at 449 sites, value of A_h^1 for different periods have been evaluated at each site and spectral acceleration maps of different periods (0.1s, 0.3s, 0.5s, and 1.0s) have been generated assigning class values to take average value of class. For example at 0.3 second period spectral values which correspond to three story buildings varies from 0.2g to 1.4g (which will be considerably reduced when design basis spectra to be constructed) and therefore equivalent value of A_h^1 will vary from 0.2 to 1.4 (MCE). In case DBE based Spectral Acceleration varies from 0.1 to 0.8g and corresponding equivalent Ah1will be 0.1 to 0.8 (need not be divide by 2 as being done presently).

13.1.3 Implication of Soil Amplification:

In view of the use of Peak Ground acceleration (PGA) at surface for defining different parameters of building code, such as Zone Factor etc, Amplification factor has explicitly been included and therefore not required to be considered separately. However, these values can be used to assign Importance Factor, Reduction Factor for different type of structures, used for deriving Seismic Coefficient (A_h). Map-25 of the report may be referred for Amplification factor.

13.1.4 Implication of Peak frequency and Peak amplification

If the building frequency matches with Peak frequency of the soil of the site, resonance may occur and subsequently ground motion may increase many fold depending upon the peak amplification factor. Peak frequency evaluated at each sites and map subsequently generated may be used to avoid selection of such sites.

However, in the present Seismic Zoning map aspect of Peak Frequency has not been included and assumed (Para 6.2 of IS code) that "earthquake cause impulsive ground motions, which are complex and irregular in character, changing in period and amplitude each lasting for a small duration. Therefore, resonance of the type as visualized under steady–state sinusoidal excitation will not occur, as it would need time to build up such amplitude." It is also mentioned in the note that there are exceptions to this. Site specific values and subsequent maps have been produced under the present study and therefore, engineers to decide to make use of these parameters appropriately.

Further, in the present study, Peak frequency and corresponding Peak amplification have been provided for first mode using both experimental and Numerical techniques. The experimental technique based on H /V ratio provides peak frequency of Soil column above seismic bedrock (Shear wave velocity more than 1500m/s). In numerical analysis, input motion has been used at engineering bedrock(Shear wave velocity 760m/s), which is at most of the sites quite above seismic bedrock. Thus the Peak Frequency evaluated using numerical technique, represents frequency of soil column above engineering bedrock and used for validation of resultsfrom experimental technique. However, experimental technique under estimate the Peak amplification factor but, numerical technique even for above engineering bedrock gives reasonable estimate of peak amplification and may be considered for qualitative assessment. Based on Numerical analysis , Peak Frequency and Peak Amplification can be provided for second and third mode to perform dynamic analysis of number of modes, as per requirement para 6.6.3.of IS code. Peak frequency map -20 attached with the report generated based on experimental technique and Peak amplification Map-21 generated based on Numerical technique may be referred.

13.1.5 Implication of PGA values at different depth below ground level

At all the 449 sites variation of PGA with depth have also been evaluated up to the depth of engineering bedrock and presented in the form of graph showing vertical distribution of PGA. Vertical distribution of PGA at one site is given below (Figure 13.1). On the basis of PGA values evaluated at 3m and 6m meter below ground levels two maps has been generated. The values at different depth can be used for evaluation of seismic coefficient (A_h) at different depth to be used for construction of underground structures in place of recommendation of IS codes at para 6.4.4. These values may also be used for deciding actual PGA values to be used at the level of foundation. PGA Maps-34 & Map-35 may be referred for ascertaining PGA and 3m and 6m depths below ground level at different sites.

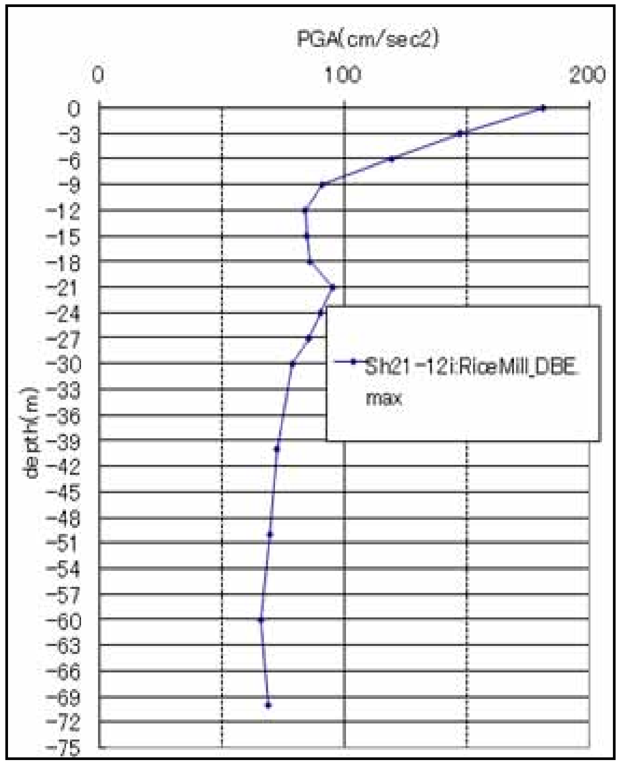


Figure 13.1 Vertical distribution of PGA at one site

13.1.6 Implication of Liquefaction maps

In the present building code 'N' values have been specified for possible liquefaction, with recommendation to avoid such sites for new settlement and important project OR appropriate methods of compaction or stabilization need to be adopted after study of liquefiable area. The present Seismic Microzonation Study provides liquefaction maps identifying possible liquefiable areas in NCT Delhi. At each liquefiable site, possibility of liquefaction at different depth below ground level has also been provided. This information may used as per recommendation of IS code.

Liquefaction susceptibility Maps 36,37,38,39 and 40 may be referred for identifying liquefiable sites for different depths.

13.2 Implication of Seismic Hazard Microzonation parameters in land use planning

(i) Areas having high hazard zone such as liquefiable zone, high amplification factor may be avoided for public utility structures.Integrated Map-40 attached with the report may be referred for identification of sites lying in Low, Moderate and High hazard zones.

(ii) Liquefiable areas may be identified based on Liquefaction susceptibility Maps 36,37,38,39 and 40 and accordingly marked for providing special treatment suitable to resist liquefactionfor construction of buildings in these areas. However, high rise buildings need to be avoided.

(iii) Areas matching with Peak frequency of soil and frequency of type of building to be constructed need to be avoided. In case of matching frequencies, resonance may occur, which may amplify the ground motion by 7 to 20 times at different sites.

Peak frequency Map-20 attached with the report generated based on experimental technique may be referred for ascertaining Peak frequency of site and Peak amplification Map-21 generated based on Numerical technique may be referred for assessment of Peak amplification.

(iii) Planning of different types of structures in NCT Delhi.

Response spectra at 449 sites have been provided from 0 to 3s and may be used for construction of buildings up to 30 stories. For easy applicability, based on spectral ordinate values of response spectra at different periods, Spectral acceleration maps (Map 26 to Map 29 based on MCE and Map 30 to Map 33 based on DBE) have also been provided for 0.1s, 0.3s, 0.5s and 1.0s , which may directly be used for the construction 1,3,5and 10 stories buildings respectively.

Forexample Spectral acceleration Map of 0.1 second (Map-26 or Map-30), may be used for ascertaining Spectral acceleration (Sa) for the construction of 1 story buildings at different sites in NCT Delhi. Spectral acceleration at different sites at 0.1s varies from 0.18g to 0.7g. Therefore the priority should be to construct 1 stories building in areas where Sa is less. However, to select the sites for the construction of 1 story building Peak frequency Map-19 and Peak amplification factor Map-21 are also to be referred and areas having matching frequencies need to be avoided. For example in JNU campus spectral acceleration at 0.1s is lowest (0.18g), but as per the Peak frequency Map-19, the Peak frequencies of the different sites in the JNU campus are around 5.0 Hz to 7 Hz, which corresponds to one to two stories buildings and thus resonance may occur. Thus in such areas construction of one story buildings need to be avoided.

CHAPTER -14

SEISMIC HAZARD PARAMETERS OF IMPORTANT STRUCTURES OF NCT DELHI

Based on seismic Hazard Microzonation of NCT Delhi and site specific hazard parameters provided at 449 sites and also map, site specific values of seismic hazard can be evaluated for any important structures of NCT Delhi. Presently for a few important structures, such as hospital, historical structure "Qutubminar" representative seismic hazard parameters and response spectra have been given in following sections (Table 14.1 to 14.3 and Fig.14.1 to 14.6). These parameters may be used to evaluate present seismic response of the building and in case fails to meet the requirement, these parameters can be used for retrofitting.

Table 14.1 Resultsof site at Sheet No. 32; Borehole no. 1n; near Sultanpuri,about 600m from Sanjay Gandhi Memorial Hospital (SGMH)

Sanjay Gandhi Memorial Hospital		
Lattitude	28.693^0 N	
Longitude	77.080^0E	
Nearest BoreHole	**0.6 Km from SGMH**	
Latitude	28.696^0N	
Longitude	77.0779^0E	
Sheet	32	
BHN	1n	
Ground Response Results	**MCE(2%)**	**DBE(10%)**
PGA at Surface	0.315 g	0.161g
PGA at Engineering bedrock	0.088g	0.045g
Amplification Factor	2.9	2.6
First Mode Peak Frequency (Hz)	1.8Hz	1.8Hz
Engineering bedrock depth (Shear wave vel. ,760m/s)	62meters	
Peak Amplification (at first mode)	12.6	16.6
Spectral Acceleration at 0.1 S	0.589g	0.327g
Spectral Acceleration (S_a) at 0.3	0.743g	0.398g
Spectral Acceleration (S_a) at 0.5	0.680g	0.331g
Spectral Acceleration (S_a) at 1.0	0.201g	0.105g

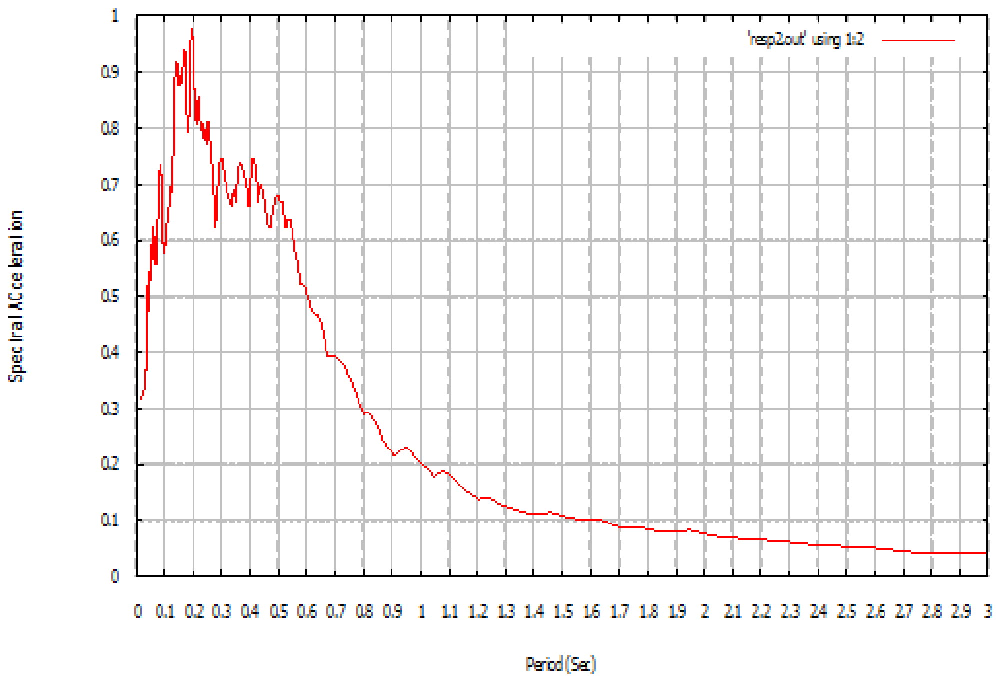


Figure 14.1 Response Spectra for Sheet No. 32; Borehole no. 1n; near Sultanpuri, based on 2% probability of Exceedance in 50 year (MCE) with 5% damping.

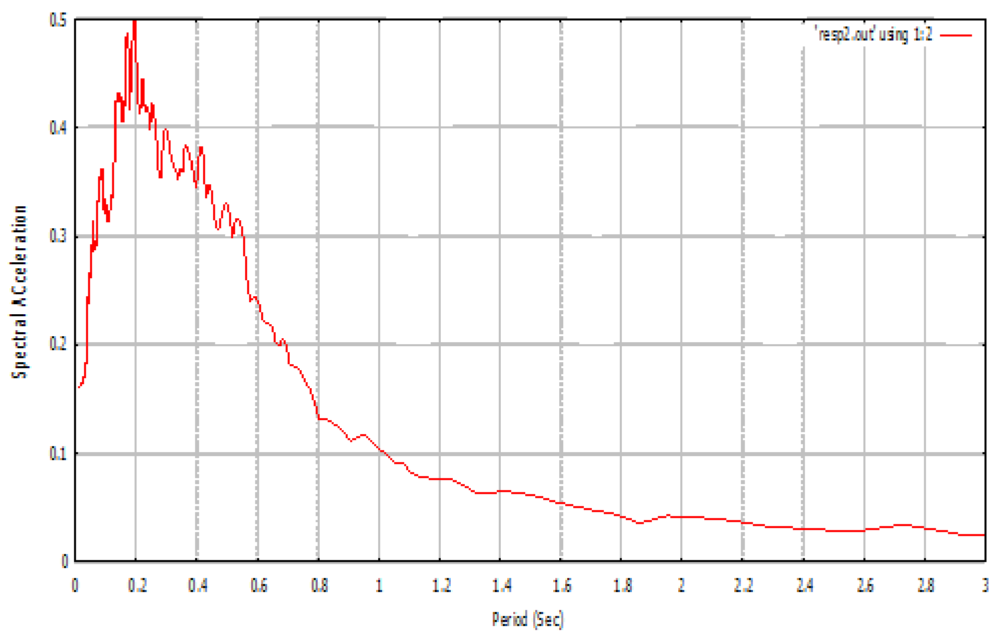


Figure14.2 Response Spectra for Sheet No. 32; Borehole no. 1n; near Sultanpuri, based on 10% probability of Exceedance in 50 year (DBE) with 5% damping

Table 14.2 Results of site at Sheet No. 33; Borehole no. 3n; near Tihar village,which is about 990m from Deen Dayal Upadhyaya Hospital.

Deen Dayal Upadhyaya Hospital		
Latitude	28.6280432^0 N	
Longitude	77.1123082^0 E	
Results of Nearest BoreHole	**0.990 Km from DDU**	
Latitude	28.630556^0 N	
Longitude	77.106944^0 E	
Sheet	33	
BHN	3n	
Ground Response Results	**MCE(2%)**	**DBE(10%)**
PGA at Surface	0.237 g	0.132g
PGA at Engineering bedrock	0.087g	0.041g
Amplification Factor	2.5	2.5
First Mode Peak Frequency	1.3Hz	1.7Hz
Engineering bedrock depth (Shear wave vel. ,760m/s)	116 meters	
Peak Amplification (at first mode)	16.5	17.2
Spectral Acceleration at 0.1 S	0.699g	0.317g
Spectral Acceleration (S_a) at 0.3	0.579g	0.3361g
Spectral Acceleration (S_a) at 0.5	0.549g	0.252g
Spectral Acceleration (S_a) at 1.0	0.234g	0.099g

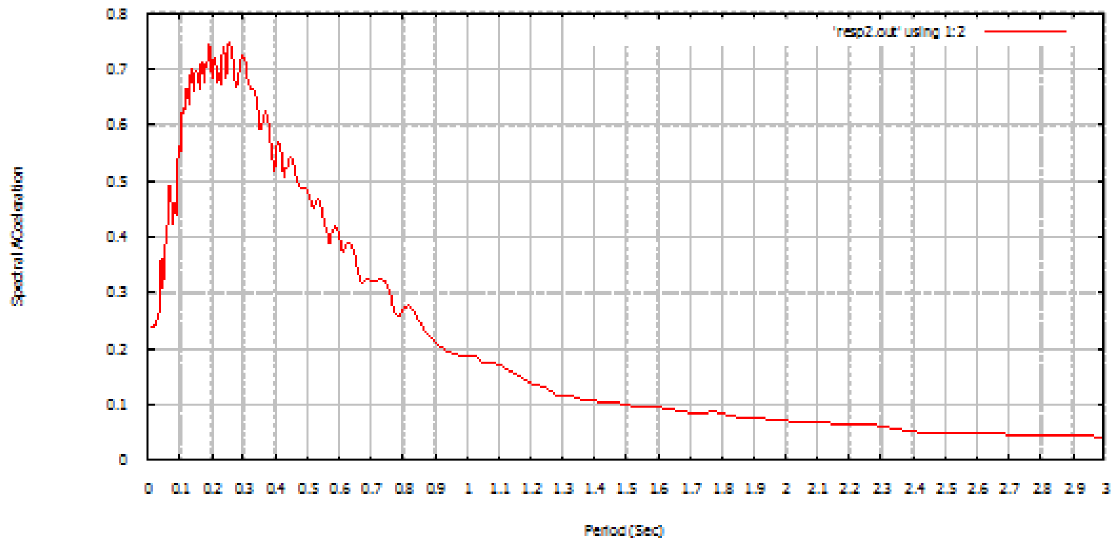


Figure 14.3 Response Spectra for Sheet No. 33; Borehole no. 3n; near Tihar Village, based on 2% probability of Exceedance in 50 year (DBE) with 5% damping

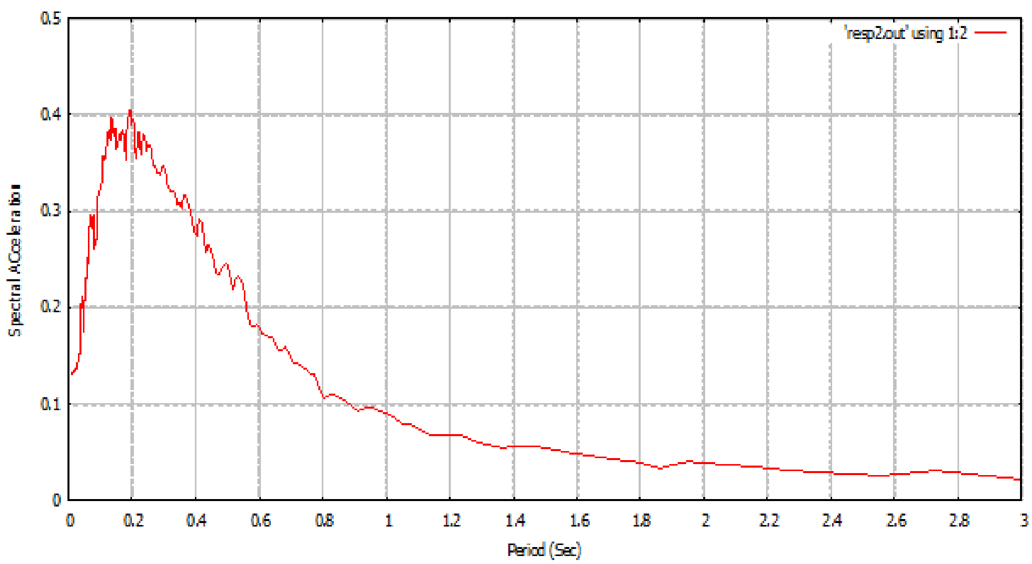


Figure14.4 Response Spectra for Sheet No. 33; Borehole no. 3n; near Tihar Village, based on 10% probability of Exceedance in 50 year (DBE) with 5% damping

Table 14.3 Results of site at Sheet No. 66; Borehole no. 24; near Mansarowar Park,about 600m from GTB Hospital Dilshad Garden.

GTB Hospital Dilshad Garden		
Latitude	28.686^{0} N	
Longitude	77.309^{0} E	
Nearest BoreHole	**0.6 Km from GTB Dilshad Garden**	
Latitude	28.677^{0} N	
Longitude	77.298^{0}E	
Sheet	66	
BHN	24	
Ground Response Results	**MCE**	**DBE**
PGA at Surface	0.268 g	0.152g
PGA at Engineering bedrock	0.074g	0.047g
Amplification Factor	2.5	3.2
First Mode Peak Frequency (Hz)	1.8Hz	3.1Hz
Engineering bedrock depth (Shear wave vel. ,760m/s)	75 meters	
Peak Amplification (at first mode)	16.1	16.1
Spectral Acceleration at 0.1 S	0.676g	0.347g
Spectral Acceleration (S_a) at 0.3	0.669g	0.332g
Spectral Acceleration (S_a) at 0.5	0.504g	0.242g
Spectral Acceleration (S_a) at 1.0	0.174g	0.087g

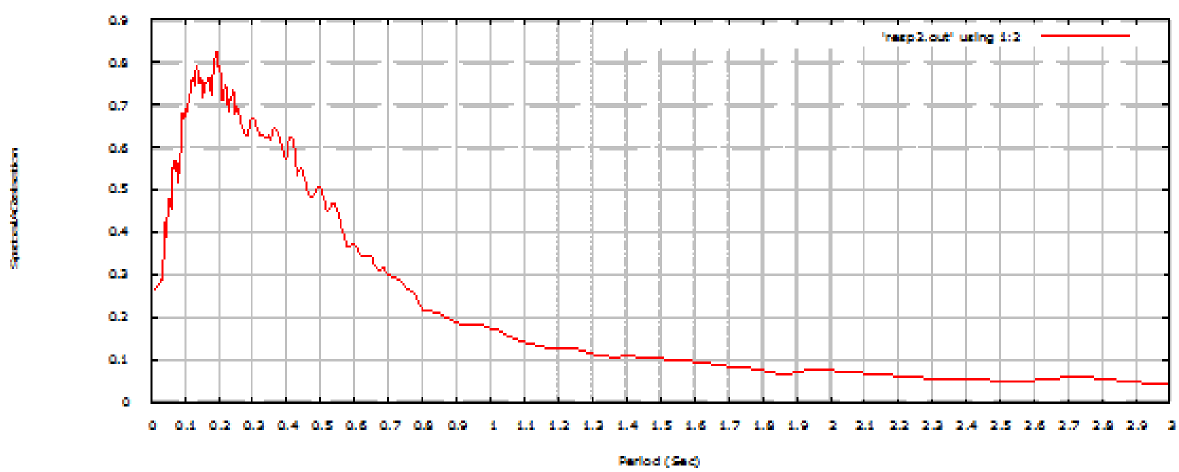


Figure14.5 Response Spectra forSheet No. 66; Borehole no. 24; nearMansarovar Park, based on 2% probability of Exceedance in 50 year (MCE) with 5damping.

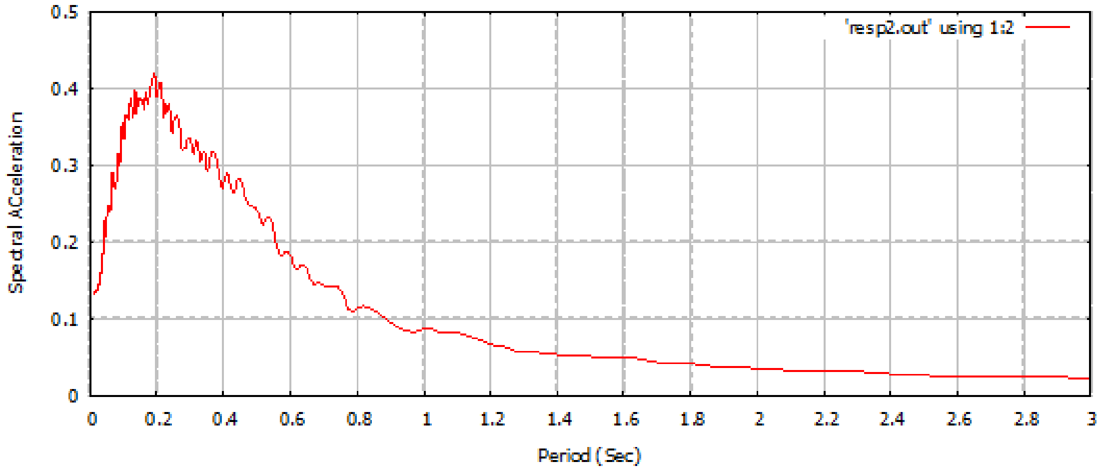


Figure14.6 Response Spectra forSheet No. 66; Borehole no. 24; nearMansarovar Park, based on 10% probability of Exceedance in 50 year (DBE) with 5% damping

CHAPTER – 15

SUMMARY AND CONCLUSIONS

National Capital Territory (NCT) of Delhi occupies an area of 1482 sq km spreading between Lat $28^{0}24' 01'' \& 28^{0}53' 00''$ N and Long $76^{0}50' 24'' \& 77^{0}20' 37''$ E lies in Seismic Zone IV of the Seismic Zoning Map of India . The geoscientific constitution of the area provides a highly variable domain with a complex scenario having scope of rapid changes in seismic accentuations which need closer evaluation for Seismic Hazard. In the present study therefore an attempt has been made to investigate the seismic hazard and generate Seismic Hazard Microzonation Maps of NCT Delhi on 1:10000 scale.

To initiate the Seismic Hazard Microzonation, study of NCT Delhi, project specific toposheets have been generated by Survey of India (SoI), presenting NCT Delhi in 75 sheets. Each sheet covering an area of about 20 to 25sq km. Available Geological Map on 1: 25,000 scale has been upgraded on 1 :10000 scale in collaboration with Geological Survey of India, using high resolution old aerial photographs, quick bird satellite imagery and limited field check. Seismic Hazard Microzonation has been carried out in six parts. In the first part, estimation of Seismic hazard at engineering bedrock (Shear wave velocity 760m /s) using seismotectonic and earthquake information within a radius of 350 km from NCT Delhi in collaboration with IIT Roorkee. The second part dealt with study of soil characteristics based on generated geotechnical and geophysical data at 552 sites. In the third part site characterization based on shear wave velocity evaluated from geotechnical and geophysical techniqueshas been carried out . In the fourth part Predominant frequency (Peak frequency) and Peak amplification corresponding to the peak frequency of soil columns above Seismic bedrock has been assessed using experimental technique based on H/V ratio of microtremors. In the fifth part strong ground motion parameters at surface have been evaluated at 449 sites spread over NCT Delhi by carrying out one-dimension (1-D) ground response analysis, using DYNEQ software. In the sixth part, liquefaction susceptibility has been evaluated using Seed and Idriss simplified approach (Idriss and Boulanger 2005) . Further, all these parameters have been integrated in GIS and integrated Hazard Map of NCT Delhi has been developed.

The study is based on newly data generated, (i) geotechnical data by drilling borehole (Shallow/Deep) at 314 sites, (ii) data generated using CHT/DHT at 25 sites,(19 are common sites) (iii) data generated using MASW at 83 sites and old Geotechnical Data collected from different organizations for 120 sites. Besides routine laboratory investigationsof soil samples collected during the drilling, Cyclic Tri-axial test and Resonant Column test have also been conducted on selected soil samples of different types of soils at different depths.

The following sections list the brief descriptions of each component of the study and major conclusions drawn from all the six parts of the study.

15.1 PROBABILISTIC SEISMIC HAZARD ANALYSIS

1. **Earthquake data (Catalogue)**
   The earthquake catalogue has been compiled from historic to present time (1702-2004) for the area considered for the study (Latitude 24^0 – 31.5^0 N and Longitude 74^0 – 81.5^0 E) with Delhi as its centre, which contains a total of 1411 earthquakes. There are 1, 26, 21, 28, 88, 180, 344 and 751 earthquakes in the magnitude range as M > 7, 6 < M < 7, 5 < M < 6, 4 < M < 5, 3 < M < 4, 2 < M < 3, and 1 < M < 2, respectively.
2. **Seismotectonic Modelling**
   The seismotectonic modelling has been carried out using Seismotectonic Province Method and the considered area (Latitude 24.0^0 – 31.5^0 N and Longitude 74.0^0 – 81.5^0 E) has been divided into four zones namely, part of Himalayan Zone (falling within 350 km from centre of Delhi), Delhi-Haridwar Ridge Zone, Moradabad Fault Zone and Rajasthan Great Boundary Fault zone. Based on these zones and fault system, line and the areal source models have been developed. Seismotectonic atlas published by Geological Survey of India (GSI, 2000) has been used for identification of faults in the region (Map-5 & 6).
3. **Homogenization of Earthquake Catalogue**
   Homogenization of Earthquake Catalogue has been carried out using different relationships developed between Mb- M_s, M_L- M_b and M_L- M_s from available data of different magnitude scales (Joshi and Sharma, 2006).
4. **Declustering of the Catalogue**
   To separate the dependent from the independent seismicity, the earthquake cataloguehas been declustered. The decluster algorithm used is based on Reasenberg (1985).The declustering found 18 clusters of earthquakes, a total of 25 events (out of 1411).
5. **Completeness Analysis of Seismic Data**
   A method proposed by Stepp (1972) has been applied to determine the interval class over which that class is homogeneous.
6. **Estimation of a, b and Mc**
   Estimation of the a, b and M_c values for the catalogues (for complete part only) for all the four sources, nine methods have been used. The methods are (i) Maximum Curvature method (M1), (ii) Fixed $M_c = M_{min}$ (M2), (iii) goodness of fit M_c90 (M3) (iv) goodness of fit M_c95 (M4), (v) best combinations of M_c90 and M_c95 and maximum curvature (M5), (vi) Entire Magnitude Range (EMR) (M6), (vii) Shi and Bolt (1982) method (M7), (viii) Bootstrap method (M8) and (ix) Cao and Gao (2002) method (M9). In this study the free code of seismicity analysis software package

ZMAP (Wiemer, 2001), which is written in Mathworks' commercial software language Matlab, has been used (Joshi and Sharma, 2008).

7. **Estimation of M_{max}**

The probabilistic approach for estimating the maximum regional magnitude M_{max} was suggested by Kijko and Sellevoll (1989) based on the doubly truncated G-R relationship. It has been further refined by Kijko and Graham (1998) to consider the uncertainties in the input magnitude data. M_{max} from Kijko-Sellevoll-Bayes estimator is obtained (Kijko and Graham, 1998 and 2001) using eight different methods.

8. The parameters used for the study are given in following table

Parameter	HIM	DHR	MOR	RGBF
a	2.64±0.16	0.93±0.08	0.62±0.08	0.89±0.08
b	0.59±0.03	0.42±0.012	0.42±0.012	0.42±0.012
M_c	4.0	3.0	3.0	3.0
M_{max}	7.2±0.37	6.42±0.47	6.42±0.47	6.42±0.47
λ	1.93±0.21	0.48±0.08	0.23±0.038	0.44±0.071
β	1.35±0.37	0.96±0.03	0.96±0.03	0.96±0.03

9. **Ground Motion Prediction equations**

Since no strong motion data are available from the region under study, spectral attenuation relationship based on world wide data has been used. The important points considered for selection of the GMPE's were –tectonic enviroment, focal depths, parameters available in present case vis-à-vis used in the relationship, spectral peroids for which the strong ground motion is available, etc. The GMPEs used in the present work are developed by Abrahamson and Silva (1997), Sadigh et al. (1997) and Boore and Atkinson (2008) to estimate the strong ground motion.

10. Seismic Hazard Analysis of NCT Delhi

The well established Probabilistic Seismic Hazard Analysis (PSHA) which was developed by Cornell (1968) and Algermissen et al., (1982) has been carried out for Delhi under collaborative project with IIT Roorkee (Prof. M.L.Sharma, Project Investigator). In the present study the CRISIS (version released in 2007) computer code for seismic hazard assessment (Ordaz et al., 2003) has been applied.For formal and, quantitative treatment of uncertainties logic tree approach consisting of three nodes: source, method of estimating seismic hazard parameters and ground–motion attenuation model, has been adopted.

11. Estimation of Strong Ground Motion for Delhi

The mean Peak Ground Acceleration (PGA) values (spectral acceleration at 0.01second)have been estimated for both the return periods 475 and 2500 years. For

475 years return periods are used as the design basis earthquakes. Considering the Poisson occurrence of earthquakes whose 10 % probability of excedance of ground motion in 50 years. Similarly the 2 % probability of exceedance of ground motion in 50 years is equivalent to the 2500 years return period of an earthquake is MCE (Maximum Considered Earthquake).

12. Spectral Acceleration

The spectral acceleration (S_a) in terms of PGA has also been estimated for the periods of 0.1 sec, 0.3 sec and 1.0 seconds. In single degree of freedom the spectral periods of 0.1 sec, 0.3 sec and 1.0 seconds corresponds to approximately single, three and ten story buildings respectively. These are the types of buildings generally found in Delhi.

13. Uniform Hazard Response Spectrum (UHRS)

For estimating UHRS, seismic hazard curves, S_a are computed for a range of frequency values. From these hazard curves, response spectra for a specified probability of exceedance over the entire frequency range of interest are obtained at various places in Delhi. The response spectra for various return periods have also been estimated.

14. Free surface correction

The PGA calculated at the Bedrock using Ground Motion Prediction Equations (GMPE) is actually ascertained at outcrop. Therefore, to make them use as incident wave to the bedrock PGA, free surface correction need to be applied. Therefore to incorporate free surface correction amplitude of spectral acceleration values at different sites and subsequently response spectra evaluated, have been divided by a factor of 2 for accounting free surface correction.

15. Acceleration Time History:

In the present study spectral compatible time history at 449 sites spread over NCT Delhi based on target response spectra generated from PSHA, have been simulated at engineering bedrock for (i) 2% probability of exceedance in 50 year corresponding to return period of 2500 year (MCE) and (ii) 10% probability of exceedance in 50 year corresponding to return period of 475 years (DBE). The time duration parameters has been taken as: Total time duration: 40.96 second, Rise time: 10second, Decay Time: 20 second.

16. Peak Ground Acceleration (PGA) at engineering bedrock after free surface correction , derived from simulated acceleration time histories

On the basis of time histories generated at all the 449 sites at engineering bedrock; PGA values have been evaluated at each site. These site specific PGA values at 449 sites have been converted in continuous surface using Inverse Distance Weighted

(IDW) interpolation technique, using appropriate parameters and cross validation, so that the Root Mean Square (RMS) values between predicted and actual are as minimum as possible. Using this continuous data PGA maps (Map 11& Map 12) at engineering bedrock have been generated for NCT Delhi for two periods of exceedance i.e.

(i) 2% probability of exceedence of ground motion in 50 years for the return period of 2500 year, based on maximum credible earthquake (MCE), for 5% damping.

(ii) 10% probability of exceedence of ground motion in 50 years for the return period of 475 years based on Design Basis Earthquake (DBE), for 5% damping.

For MCE, the PGA values at engineering bedrock vary from 0.067g to 0.114g and for 10% probability of exceedence in 50 years i.e for DBE the PGA values at engineering bedrock vary from .035g to .058g.

15.2 SOIL CHARACTERISTICS IN DELHI

1. **Distribution of soil types**

   On the basis of geotechnical data generated/collected at 434 sites spread over different geological domains of NCT Delhi, depth wise distribution of different types of soil at each bore hole site have been studied individually and collectively for all bore holes in a toposheet. Several cross sections and 3-D profiles have been drawn. Major part of soil in Delhi consists of sandy soil embedded with silt and clay, which even extends at some borehole locations to the depth of more than hundred meters.

2. **Local empirical relations between corrected SPT'N'Values $(N_1)_{60}$ and measured in-situ shear wave velocity using CHT& DHT**

   On the basis of CHT/DHT data and SPT N values data collected at 19 common sites, corrected N value $(N_1)_{60}$ have been evaluated, after applying appropriate corrections. Empirical relations for different types of soils of Delhi between $(N_1)_{60,}$ and measured in situ shear wave velocity have been developed and compared with internationally developed relations. These relations have been used for evaluation of shear wave velocity form SPT 'N' values for other sites.

15.3 SITE CHARACTERIZATION

1. Average Shear wave velocity of 30m soil column [*V*s(30)]evaluatedat different sites of NCT Delhi, spread over the varied geological domains of NCT Delhi, using CHT, DHT, SPT 'N' value and MASW techniques, at 542 sites These Shear wave velocities have been used for classification of sites based on National Earthquake

Hazard Reduction Program (NEHRP), Building Seismic Safety Council (2001) and Uniform Building Code (UBC, ICBO 1994). According to this classification, the sites of NCT Delhi, can be classified under the three categories i.e. Class 'B' (firm and hard rock) having Shear wave velocity between 760 m/s and 1500m/s (JNU site), Class 'C' (Dense soil and soft rock) having shear wave velocity 360m/s and 760 m/s (such as Asola site) and , class D (Soft soil) having Shear wave velocity between 180m/sec and 360m/s at all other sites.

2. **Site classification map**

In order to prepare maps, discrete site specific shear wave velocity (Vs^{30}) values at 542 sites have been converted in continuous surface using Inverse Distance Weighted (IDW) interpolation technique, using appropriate parameters and cross validation so that the Root Mean Square (RMS) values be tween predicted and actual are as minimum as possible.This map represents the Site classification based on Shear wave velocity obtained for different techniques at different sites spread over NCT Delhi (Map-16).Shear wave velocity of top few meters layer play a very important role in modifying response of soil, during earthquake loading. In view of this two maps for shear wave velocities of layers 0-3 m and 3-6 m below ground level have also been generated (Map 17 & 18).

15.4: SITE RESPONSE STUDY (EVALUATION OF PEAK FREQUENCY AND PEAK AMPLIFICATION OF SOIL)

Amplification factor is equal to the ratio of the free surface motion amplitude to the bedrock motion amplitude, determines how each frequency in the bedrock (input) motion is amplified, or de amplified, by the soil column above bedrock. The frequencies that correspond to the local maxima (first mode) are natural frequencies of the soil deposit and termed as Peak frequency. The corresponding amplitude of the local maxima is the Peak Amplification factor/ratio. Peak frequencies and Peak amplification factor have been evaluated using experimental and numerical techniques.

Experimental technique based on H /V ratio of microtremor data (Nakamura type study) has been used for evaluation of Peak frequency of the soil above seismic bedrock and generation of Peak frequency map.However, there is no unanimity among scientists (Bard, 2000, Field & Jacob, 1995, Lermo and Garcia, 1994) as regards to reliability of amplification assessments based on microtremor based Nakamura techniques.Quasi Transfer Spectra (QTS) obtained from Nakamura type study are stable enough to characterize a site and the study of soil variability in conjunction with geological map and used for constraining number of sites for generation of geotechnical/geophysical data. These studies have been conducted, by deploying Digital Triaxial Portable 1 Hz velocity sensor at 511sites in NCT and adjoining terrain of NCR. Peak frequency and corresponding Peak amplification factor have also been evaluated using numerical technique.

Peak Frequency (f_0)

Map 20illustrates the corresponding Peak frequency contour map of soil above firm bedrock. It is evident from the Peak frequency mapthat the peak frequencies at different sites in NCT Delhi mostly vary from 0.21 H to 10Hz. At a very few sites Peak frequencies are between 0.1 to 0.2Hz. On the basis of Peak frequencies area of Delhi can be divided as (i) Low peak frequency <1.0 Hzcharacterizes the domain of thick (>200m) quaternary sediment fill area. It can further be divided in two groups (a) area with peak frequencies vary from 0.3 to 0.5 Hz, which roughly corresponds to the frequencies of 20 to 30 stories buildings (b) area with peak frequencies vary from 0.5 to 1.0 Hz, which roughly corresponds to the frequencies of 10 to 20 stories buildings.(ii) Moderate peak frequency domain of 1.0 to 2.0 Hz, which roughly corresponds to the frequencies of 5 to 10 stories buildings (iii) high peak frequency domain of 2 to 3.5 Hz surrounding the area of Ridge, which roughly corresponds to the frequencies of 3 to 5 stories buildings (iv) Very high peak frequency domain >3.5 Hz characterizes rocky ambiance with moderator thin (<30m) sediment cover and high impedance contrast at base and the Rocky domain in ridge area, which roughly corresponds to 1 to 2 stories buildings. To identify exact localities to be used in the field, large scale maps have been provided. The maps are also made available in GIS format. The peak frequency distribution of sites having different ranges of Peak frequency shows that out of 511 sites

(i) Peak frequency at 78 sites (15 %) are in the range of 2.1 to more than 8 Hz which roughly corresponds to the matching frequency of 1 to 5 stories buildings, which are common types of building in Delhi.

(ii) Peak frequencies at 55 sites (10.7%) are in the range of 1.1 to 2.0 Hz, which roughly corresponds to the matching frequency of 5 to 10 stories buildings.

(iii) Peak frequencies at 288 sites (54%) are in the range of 0.5Hz to 1.0Hz, which roughly corresponds to the matching frequency of 10 to 20 stories buildings.

(iv) Peak frequencies at 46 sites (9.8%) are in the range of 0.3Hz to 0.49Hz, which roughly corresponds to the matching frequency of 20 to 30 stories buildings.

(v) Peak frequencies at 44 sites (8.2%) are less than 0.3Hz, which roughly corresponds to the matching frequency of high rise building more than 30 stories.

Peak Amplification

Peak amplification factor is used to estimate the qualitative assessment of seismic hazard at different sites. Experimental techniques underestimate the Peak amplification factor and therefore need to be evaluated from numerical technique. In the present study Peak amplification factors have been evaluated at 449 sites for the soil above engineering bedrock and reasonably used for the qualitative assessment of seismic hazard in different sites in Delhi. Peak amplification factor for the soil column above engineering bedrock obtained using numerical technique varies from 7 to 19. On the basis of this data set a Peak amplification factor map has been generated and attached as Map 21.

15.5 SITE RESPONSE STUDY, EVALUATION OF SITE SPECIFIC GROUND MOTION PARAMETERS AND RESPONSE SPECTRA AT SURFACE

1. In the present study analytical method based on multiple reflection theory of S waves in horizontally layered deposits, referred to as "1-D analysis of soil columns and most widely used has been adopted. To consider non linear behavior of soil equivalent linear- method that uses an iterative procedure to adapt the soil parameters (i.e., rigidity and damping) to the actual strain it undergoes has been adopted. Recently developed computer programme DYNEQ, a computer Programme for **DYN**amic Response Analysis due to **E**arth**Q**uake(**DYNEQ**) at level ground by using **E**quivalent **L**inear **M**ethod(ELM), version 3.25 (Nozomu Yoshida and Iwao Suetomi 2004),which is similar to SHAKE and also incorporate latest development such as frequency dependent characteristics, as damping due to scattering etc. has been used. In DYNEQ programme some routine has been added at EREC to make more user friendly plotting of final products.

2. Shear modulus reduction curves and damping curves

Non- linear analyses require a quantitative knowledge of the actual nonlinear material behavior, the shear modulus reduction curves, and damping curves. Some generic average curves have been proposed for different types of material, as sand or clay, and available in software database package, but the actual behavior of a given soil at a given site may strongly depart from these averages. In order to improve the accuracy in results, Resonant Column Test on representative samples of Sand, Clay and Silt of Delhi collected at different sites and at different depths to determine shear modulus and damping ratio of soil under different confining pressure, etc have been conducted at Indian Institute of Science, Bangalore and used in place of generic average curves provided in database of the software.

3. Soil Model above engineering bedrock

The most important input information for the ground response analysis is a subsurface soil model that represents the variation of static and dynamic soil properties at different depth interval from engineering bedrock to the surface. Therefore, to perform ground response study, a soil column up to the engineering bedrock (Shear wave velocity about 760m/s) at which input motion is to be placed need to be generated.

This can be achieved by drilling borehole up to engineering bedrock depth, which depend upon the nature of the soil and will be different at different sites. In the scenario like Delhi where alluvial sediment cover ranging to the depth from outcrop to the depth of more than 300m, and soil is basically D class, the engineering rock (Shear wave velocity 760m/s) may be expected at more than 70-80m depth at most of sites in NCT Delhi. As the level of engineering rock may be different at different sites and cannot be predetermined, therefore drilling to the depth level of engineering bedrock cannot be planned in advance. It is also practically not possible to drill number of boreholes to such a depth to meet the requirement of map scale of the study.

In the present study the engineering bed rock depth having shear wave velocity of 760m/s at different sites have been delineated by extrapolating 30m soil model, beyond 30m depth by suitable linear regression analysis and comparing at a few sites with available deep boreholes data. While performing regression analysis misplaced local variations within 30m have been ignored to achieve regression coefficient (R^2) near unity. At the sites where it was not possible to obtained linearity, due to highly variable soil within 30m or ambiguity in SPT 'N' values at some level, engineering bedrock delineated at closest CHT/DHT site or nearby borehole site has been considered.

4. Peak Ground Acceleration at Surface

In the present study based on geotechnical/geophysical investigations, subsequently generated soil model and earthquake acceleration time histories at engineering bedrock, ground response analysis has been performed using DYNEQ software at 449 sites spread over NCT Delhi for (i) 2% probability of exceedance in 50 year (based MCE) for 5% damping and(ii) 10% probability of exceedance in 50 year (based on DBE) for 5% damping and site specific strong ground motion parameters and response spectra have been obtained. Based on acceleration time histories obtained at surface at all the sites for both period of exceedance, Peak Ground Acceleration (PGA), which is the maximum amplitude of the ground acceleration time-histories have been evaluated.

PGA values for 2% probability of exceedance in 50 years (MCE) for 5% damping varies between 0.168g to 0.479 g. The lower PGA values less than 0.18 are in rocky areas. PGA values at most of the sites are within 0.42g except at two sites, where PGA values are 0.47g and 0.44g respectively due to high impedance contrast between first two layers below ground surface. PGA values for 10% probability of exceedance in 50 year (DBE) for 5% damping varies between 0.089g and 0.255 g. PGA values at most of sites is below 0.21g except at a few site where PGA is between <0.21 to 0.255g.

5. **Peak Ground Acceleration Maps at surface**
   Discrete site specific PGA values at 449 sites have been converted in continuous surface using Inverse Distance Weighted (IDW) interpolation technique, using appropriate parameters and cross validation. Using this continuous data set, PGA maps have been generated for (i) 2% probability of exceedance in 50 year (based on MCE) and (ii) 10% probability of exceedence in 50 year (based on DBE), (Map 22 & Map 23). PGA maps for both period of exceedance have also been generated for area covered by individual toposheets on 1:10,000 scale.

6. **Uncertainty in results of Peak Ground Acceleration at surface based on MCE**
   Strong ground motions time histories have been simulated at engineering bedrock based on Uniform Hazard Response Spectra (UHRS) obtained from Probabilistic Seismic Hazard Analysis (PSHA) at different sites. These time histories have been used as input ground motions for ground response study and generation of time histories at surface. Subsequently PGA values at surface have been evaluated from these time histories. The uncertainty in each Uniform Hazard Response Spectra has been presented as standard deviationi.e. Mean, Mean + sigma and Mean –sigma. In order to assess possible uncertainty in the results of PGA at engineering bedrock , at a few sites three spectrum compatible ground motion time histories have been generated based on three Uniform Hazard Response Spectra (UHRS) obtained at each site i.e. for Mean, Mean + sigma and Mean –sigma and PGA values have been evaluated. The uncertainties in PGA values thus obtained at engineering bedrock have been worked out to be on an average ± 0.02g for MCE and 0,01g for DBE. The average amplification factor obtained from ground response is around 3 and therefore, the initially introduced uncertainty will increase by three times at surface.

   Thus, the uncertainties in the resultsof PGA values evaluated at surface on an average are (i) ±0.06g for MCE (2% probability of exceedence in 50 years) and (ii) ±0.03g for DBE (10 % probability of exceedance in 50 years). These uncertainties have been considered deciding the class interval for generating the maps and subsequently Seismic Micro zones.

7. **Vertical Distribution of PGA**
   Local geological conditions, characteristics of the lithological attributes and depth play significant role in variation of PGA. The significant variation in PGA is observed closed to surface i.e. below a few meter depths from ground level. For example at Swarup Nagar, significant variation of ground motion (PGA) is due to the top about 9 m soil. At this site in case of MCE, PGA at surface is around 0.3g, which reduces to

0.15g at about 9m depth below ground level. The PGA at engineering bedrock at this site is 0.1g. PGA maps at 3m below ground and 6m below ground level have been presented as Maps 34 & 35 respectively.

8. Amplification Factor

The ratio of the PGA at zero period or infinite frequency at ground surfaceat particular site and the PGA at engineering bedrock at zero period or infinite frequency is considered as the Amplification factor of soil column. Amplification factors have been evaluated for both input motions based on MCE and DBE at all the 449 sites, which are same. The amplification factors for NCT Delhi soil are less than 4.0 except at DDA Open Land near Model town, where amplification factor is 4.6.Amplification factors for more than 75% sites are below 3.0.

Discrete values of site specific amplification factors have been converted in continuous surface using Inverse Distance Weighted (IDW) interpolation technique and based on this continuous data set amplification maps for NCT Delhi has been generated (Map 25). Amplification map for areas covered by individual toposheets have also been generated for all the 75 toposheets.

9. Acceleration Response Spectra for different sites of NCT Delhi

Response spectra is a plot showing the maximum response induced by the ground motion in single-degree-of-freedom oscillators of different fundamental periods, but having the same degree of internal damping. Thus the response spectrum describes the maximum response of a single-degree-of-freedom (SDOF) system to a particular input motion, as a function of the natural frequency (or natural period) and damping ratio of the SDOF system and is of great importance in earthquake engineering and useful tool for characterization of strong ground motion. Acceleration response spectra have been generated at 449 sites for 0 to 3 seconds, spread over NCT Delhi, for (a) 2% probability of exceedance in 50 years (MCE) for 5% damping and (b) 10% probability of exceedance in 50 years (DBE) for 5% damping and presented as district wise atlas.

10. Seismic Hazard Map for different period of spectral acceleration with (i) 2% probability of exceedance in 50 years for 5 % damping (based on MCE) (ii) 10% probability of exceedence in 50 years for 5 % damping (based on DBG)

On the basis of Acceleration response spectra, spectral acceleration values for the periods of 0.1s, 0.3s, 0.5s and 1.0 seconds(equivalent to frequencies of 10, 3, 2, and 1.0 Hertz) corresponds to 1,3,5 and 10 stories buildings respectively have been evaluated at all the 449 sitesfor both period of exceedance. On the basis of these values based on DBE and MCE, fourseismic hazard maps have been generated for 0.1s, 0.3s, 0.5s and 1.0s, periods, which roughly corresponds to the natural frequency of 1, 3, 5 and 10 stories buildings respectively. Maps26, 27, 28 and 29 are based on DBE, and Map30, 31, 32, 33 corresponds to MCE. These maps can be used to evaluate response of earthquake ground motion on 1 story, 3 story, 5 story and 10 story buildings respectively.

11. Design Response Spectra

Response spectra derived from ground response study are highly irregular; very ragged with local peaks and valleys. A slight change in natural period can lead to large variation in maximum acceleration. It is understood by engineers that Natural period of a civil engineering structure cannot be calculated so precisely and therefore, the design specifications should not very sensitive to a small change in natural period. In view of this actual response spectra are converted in design response spectra, which are usually determined by smoothing, averaging, or enveloping the response spectra. Therefore for actual engineering application in vogue, an effort has been made to develop design response spectra at all the 449 sites and given as district wise Atlas.

12 Multiplying Factors for obtaining PGA values for other damping

Seismic Hazard Microzonation Maps and response spectra have been generated based on an assumed 5% of critical damping. 5% damping used in the standard spectra in building code application was chosen because it is appropriate for range of typical building structures. For other special structures, however, such as those used in power-generating plants, dams, transmission telecommunication facilities and construction that utilizes damping devices, the structure damping be either high or lower than 5%.

To facilitate this Multiplying Factors for obtaining values for other Damping have been provided.

15.6 LIQUEFACTION SUSCEPTIBILITY

A simplified procedure(Seed and Idriss, 1971) and subsequent revisions of the simplified procedures (Seed et al., 1983, 1985; Youd and Idriss, 2001; Idriss and Boulanger, 2004; Cetin et al., 2004), based on the use of empirical correlations with standard penetration tests (SPT) has been used for evaluation of liquefaction susceptibility of soil at different depth. Based on this Liquefaction susceptibility maps, for 0 -3m, 3 -6m and 6 -9m depths and for consolidated depth of 0 -9m have been generated (Maps 36,37,38, and 39).

15.7 INTEGRATION OF SEISMIC HAZARD MAPS OF NCT DELHI

Different thematic and product maps have been integrated in GIS platform and integrated hazard index map of NCT Delhi on 1:10000 scale has been developed. The high hazard zones are in the area where either PGA at surface is high or possibility of liquefaction has been observed. Most of the areas along Yamuna flood plan, scattered parts of northern Delhi having thick alluvial sediment, and a very small part of SW Delhi fall in high hazard zone. The low hazard zone mainly occupies the area of central Delhi and along the ridge (Map 40).

15.8 QUANTIFICATION OF UNCERTAINTIES

There are various types of uncertainties in the process of Seismic Hazard Microzonation and an effort has been made to identified, quantified and combined using appropriate statistical techniques. There are certain uncertainties particularly in data generation practices and all possible efforts have been made to reduce to the possible extent by proper supervision and strictly compliance of codes.

15.9 COMPARISON OF RESPONSE SPECTRA WITH ACTUAL EARTHQUAKE

There is no strong motion earthquake which can be compared with the response spectra generated from the study. Comparison of weak and strong motion is not reasonable proposition due to different frequency content, amplitude, and expected nonlinearity; however, to see any similarity, a comparison has been made with earthquakes of different origins. It seems that shape of the response spectra are reasonably matching to the possible extent.

15.10 SUGGESTIVE IMPLICATIONS OF DIFFERENT PARAMETERS DERIVED FROM THE STUDY OF SEISMIC HAZARD MICROZONATION FOR DESIGN OF BUILDING CODES AND LAND USE PLANNING OF NCT DELHI

The Study of Seismic Hazard Microzonation for such a large scale has been attempted for the first time in the country. As per definition and requirement of scale of the study, Seismic Hazard parameters required for design of building codes and land use planning have been estimated at 449 sites. On the basis of methodology adopted for formulation of present building codes based on present Seismic Hazard map of the county, an effort has been made to suggest certain equivalence and methodology to implement the seismic Hazard Microzonation parameters.

15.11 SEISMIC HAZARD PARAMETERS OF IMPORTANT STRUCTURES OF NCT DELHI

For a few important structures, such as hospital, historical structure "Qutubminar" representative seismic hazard parameters, and response spectra have been given. These parameters may be used to evaluate present seismic response of the structures.

15.12 MONITORING AND REVIEW OF SEISMIC HAZAR MICROZONATION PROJECT

Seismic Hazard Microzonation requires multidisciplinary data collocation, generation, integration of the different types of informations (geologic, seismotectonic, Geotechnical, Geophysical, Earthquake), application of different mathematical tools (statistics, probability, and models) and decision making, which requires aproject structure and implementation process that assure proper quality data generation, selection of appropriate models, appropriate analytical approach, and integration. Further, there is not likely to be "consensus" among the various experts and no single interpretation concerning a complex earth-sciences issue is the "correct" one. Therefore, to address a difficult technical issue and to reach near consensus results (i) a representation of the legitimate range of technically supportable experts among the entire informed technical community, throughout the process of microzonation (ii) assurance of good quality data generation, under the guidance of experts,proper supervision, application of available guidelines, codes etc. (iii) Selection of appropriate techniques and models (iv) regular review by technical experts, are required.

Keeping above in mind to make use of expertise available in the country, for better representation and for continuous monitoring and guidance of the project, Ministry of Earth Sciences had constituted a multidisciplinary Advisory and Monitoring Committee under the Chairmanship of Prof. A.S.Arya, Former Seismic Advisor, Government of India, presently Hon'ble Member Bihar Disaster Management Authority and experts of different disciplines as members of the committee. For continuous supervision and guidance, Advisory and Monitoring Committee met eight times during the course of study. To interact with legitimate range of technically supportable experts several interactive meetings and workshops were also organized during the course of study and formulation of report. Report has been reviewed by the members of the committee and made suggestions, which have appropriately been incorporated. A brief on review and monitoring process adopted during the course of implementation and preparation of report is given in Annex-II.

15.13 CONCLUSIONS

The seismic hazard analysis of NCT Delhi is based on a state-of-the-art Probabilistic Seismic Hazard Analysis (PSHA) using different source models (Line and Aerial) and attenuation relations. Earthquake sources and parameters have been considered for the area covered under 350 km radius from Delhi, (Latitude $24^0 - 31.5^0$ N and Longitude $74^0 - 81.5^0$ E), similar to the other such studies (Iyenger and Ghosh 2004, Gupta 2005). This area includes part of Himalayan region in which earthquake of maximum magnitude recorded so for is the Chomali earthquake (M 6.9) of 1999, which is about 300 km from Delhi and produced horizontal PGA of $11cm/s^2$ at Delhi. Selections of models and attenuation relations etc have been made after elaborate discussion among the experts. To incorporate uncertainty associated with different modeling parameters as well as spatial and temporal uncertainties logic tree approach has been adopted. On the basis of PSHA, Spectral Acceleration maps and site specific Uniform Hazard Response Spectra (UHRS) for different probability of exceedance at engineering bedrock (shear wave velocity 760 m/s) have been derived. These Uniform Hazard Response Spectra (UHRS) for different probability of exceedance have been used for generation of spectrum compatible acceleration time histories.

The PGA for Delhi obtained for PSHA analysis at engineering bedrock varies from 0.18g to 0.31g for MCE and 0.09g to 0.16g for DBE.Iyengar and Ghosh (2004) carried out PSHA analysis for Delhi and obtained PGA at rock level for MCE varied from 0.186 to 0.241g, which are comparable and small difference is due to reference rock level.

There have been a few studies on regional level and generated Probabilistic Seismic Hazard Map of the country and assigned representative values of PGA for Delhi. A working group constituted by NDMA has generated PSH map of the country which is in the process of adoption by BIS, assigned PGA value for Delhi 0.170g for MCE and 0.08g for DBE at 'A' type rock, having Shear wave Velocity 1500m/s Iyengar et al. (2010). As a part of Global Seismic Hazard Programme (GSHAP), Probabilistic Seismic Hazard Map has been generated for India and adjoining region and the representative value of PGA for Delhi is 0.15g based on DBE at rock level (Bhatia et al., 1999).

A Probabilistic Seismic Hazard Map of India has also been generated by Nath and Thingbaijam (2011) and assigned PGA value for Delhi 0.24g at rock level based on DBE. A Probabilistic Seismic Hazard Map of India has also been generated by Sitharam and Kolathayar(2012) using different source modelsand evaluated different PGA values for Delhi at rock level from different source models (i) based on Aerial Source model PGA worked out 0.16g based on DBE and 0.43g based on MCE (ii) based on gridded seismicity model 0.18g for DBE and 0.36g for MCE (iii) based on Linear Source model 0.33g for DBE and 0.6 for MCE.

The PGA values obtained from city specific studies are comparable. The representative values assigned from the regional studies are also comparable, except from PSHA map generated by Nath and Thingbaijam (2011), where PGA values are comparatively high for all the cities due to the reason briefed in the paper.

Site specific Uniform Hazard Response Spectra have been used for generation of site specific spectrum compatible acceleration time histories at 449 sites after adopting due procedure, applying free surface correction etc and used as input motion for further ground response study. On the basis of time histories free surface corrected Peak Ground Acceleration values at the all 449 sites for different period of exceedance have been evaluated. The Peak Ground Acceleration after free surface correction at engineering bedrock varies from 0.067g to 0.114g for MCE andfrom 0.035g to 0.058g, for DBE.

A comprehensive programme of geotechnical, geophysical investigations have been taken up for site characterization, and ground response study. At 449 sites geotechnical data have been collected by drilling boreholes, mostly up to 30m depth and DS/UDS soil sampling at each 1.5 m depth. Index properties of soil from all collected soil samples have been evaluated in laboratories. On a few samples special tests such as triaxial /cyclic triaxial and Resonant Column tests have also been performed for evaluation of 'C', 'Ø', Shear modulus reduction and damping curves etc. Geophysical investigations such as MASW at 110 sites and CHT/DHT at 25 sites have also been carried out for evaluation of in-situ shear wave velocity. On the basis of in-situ shear wave velocity and N values collected at a few common sites local empirical relations have been developed for different types of soil, to make use of N value for evaluation of shear wave velocity.

Making use of the above data and input time histories generated based on UHRS, ground response study have been performed at all the 449 sites, using DYNEQ software. Based on ground response study PGA at surface, PGA at different depth, Amplification factor, Peak frequency, Peak amplification, have been evaluated at all the 449 sites. Site specific different types of response spectra have also been generated at all the 449 sites. Based on response spectra spectral acceleration values at different periods have been evaluated for all the 449 sites.

Discrete site specific values of different parameters evaluated at all the 449 sites have been converted in continuous surface using Inverse Distance Weighted (IDW) interpolation technique. Making use of this continuous data different thematic maps have been generated for (i) 2% probability of exceedance in 50 year (based on MCE) and for (i) 10% probability of exceedence in 50 year (based on DBE). Site specific values can be picked up from these GIS base maps and may be used for design of buildings at those particular sites

The PGA at surface is one of the important parameters used for design of buildings in conjunction with response spectra and other parameters. Zone factors assigned to the different seismic zones in seismic zoning map of the country are equivalence of PGA. PGA at surface obtained from the ground response study for 2% probability of exceedance in 50 years (MCE) for 5% damping varies between 0.168g to 0.479 g. The lower PGA values less than 0.18 are in a very small area of ridge. PGA values at most of the sites are within 0.42g except at two sites, where PGA values are 0.47g and 0.44g respectively due to high impedance contrast between first two layers below ground surface. PGA values for 10% probability of exceedance in 50 year (DBE) for 5% damping varies between 0.089g and 0.255 g. PGA values at most of sites is below 0.21g except at a few site where PGA is between <0.21 to 0.255g.

Uncertainties in evaluation of PGA at surface have also been worked out which are ± 0.06g for MCE and ±0.03g for DBE. In order to develop microzonation map of NCT Delhi, similar to the zoning map of the country, considering uncertainties of ± 0.06g, the PGA values based on MCE have been grouped in following three classes, with center values equivalent to the zone factors assigned to the different zones in BIS map of the country.
>0.18 g equivalent of zone factor of Zone III
<0.18 to 0.30 with central value 0.24 g equivalent of zone factor of Zone IV
<0.30 to 0.42 with central value 0.36g equivalent to zone factor of Zone V
<0.42 more than zone factor of zone V

PGA map at surface based on MCE indicates that (i) Most of the area of NCT Delhihave PGA values equivalent to the zone factor of zone IV i.e. 0.24 (ii) An area of about 500 sq km (33 % of the total area of NCT Delhi), mostly west of NCT Delhi, with small microzones in other parts of NCT Delhi have PGA values equivalent to the zone factor of zone V i.e.0.36 (iii) A very small area of about one squire km has even more PGA values, due to very specific local soil conditions (iv) The PGA values in ridge area are not uniformly distributed. PGA values in a very small area near JNU are equivalent to zone factor of zone III and in remaining part of the ridge PGA values are equivalent to zone factor of zone IV.

Thus, the structures in the areas having high PGA values i.e. equivalent to zone V need to be reassessed about the seismic vulnerabilities. However, based on vertical distribution of PGA, it is noted that the significant variations in PGA is observed closed to the surface below a few meter depths from ground level. For example at a few sites PGA values at 6-9m below ground surface reduces half to the PGA values of surface. PGA map of 3 m below ground level indicates that distribution of PGA values at entire NCT Delhi is equivalent to the zone factor of zone IV. The structures having foundation below such depths may possibly not be affected with high PGA values at surface.

Peak frequency (Natural frequency) and Peak amplification of soil column above seismic bedrock have been evaluated at 500 sites using Nakamura technique based on noise survey and Peak frequency and Peak amplification of soil column above engineering bedrock have also been evaluated at 449 sites using numerical technique, to be used for deciding sites for construction of buildings of appropriate height to avoid resonance.

Liquefaction susceptibility of soil at different depths has also been carried out and site specific factor of safety have been evaluated using a simplified procedurebased on empirical correlations with standard penetration tests (SPT).

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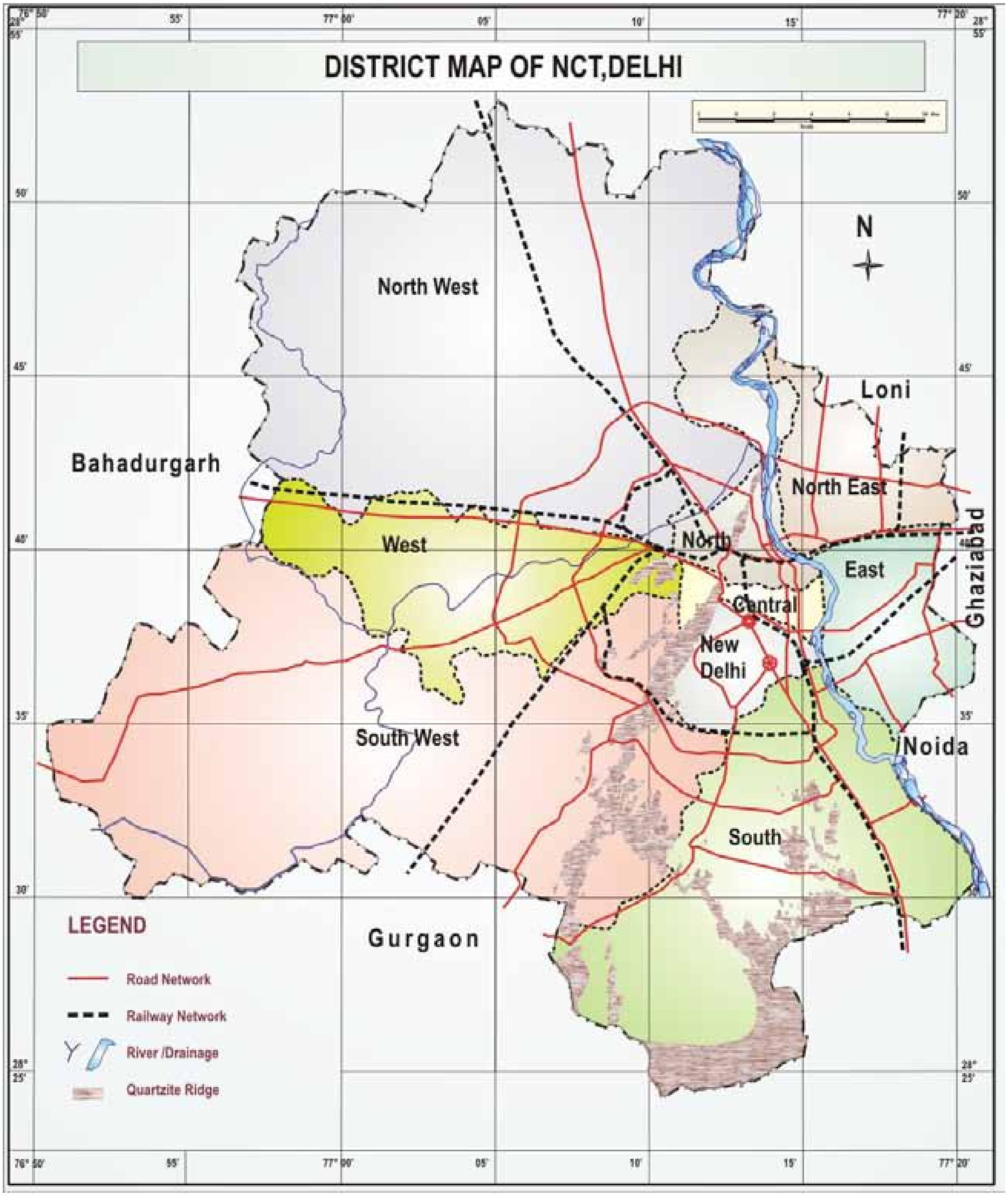
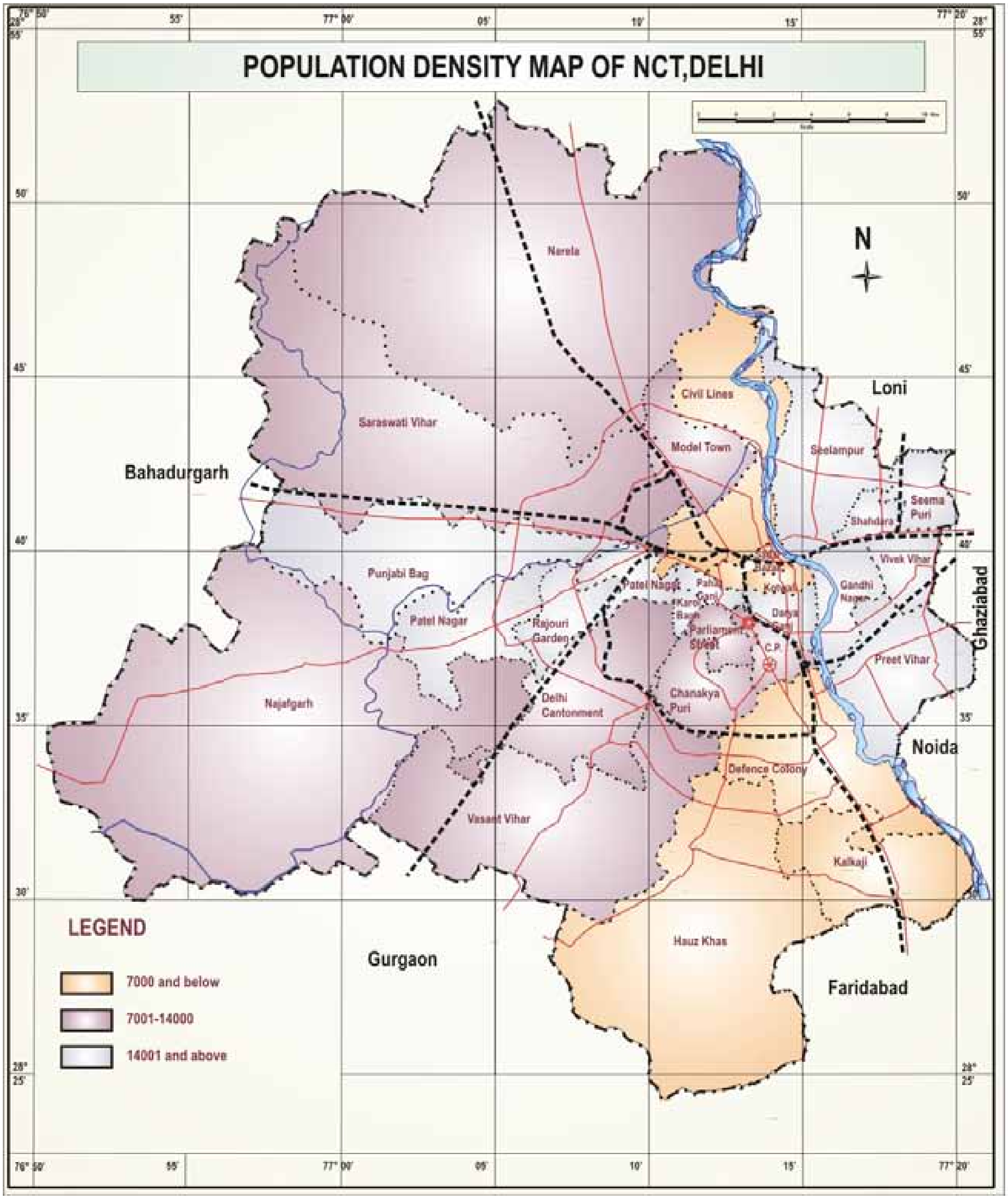
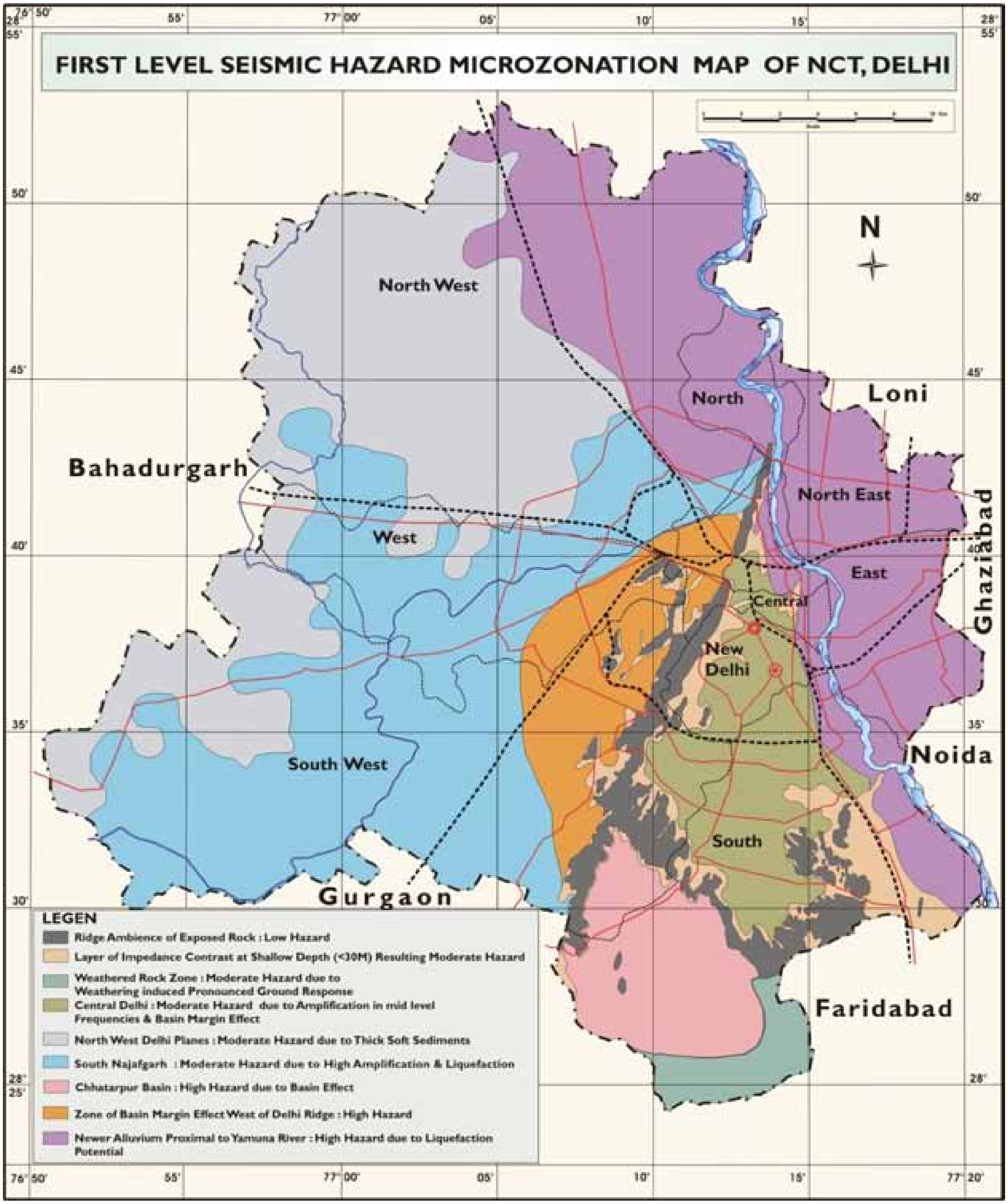

DISTRICT MAP OF NCT,DELHI
N
North West
Bahadurgarh
Loni
North East
West
North
East
Ghaziabad
Central
New Delhi
South West
Noida
South
Gurgaon
LEGEND
Road Network
Railway Network
River /Drainage
Quartzite Ridge

MAP-1

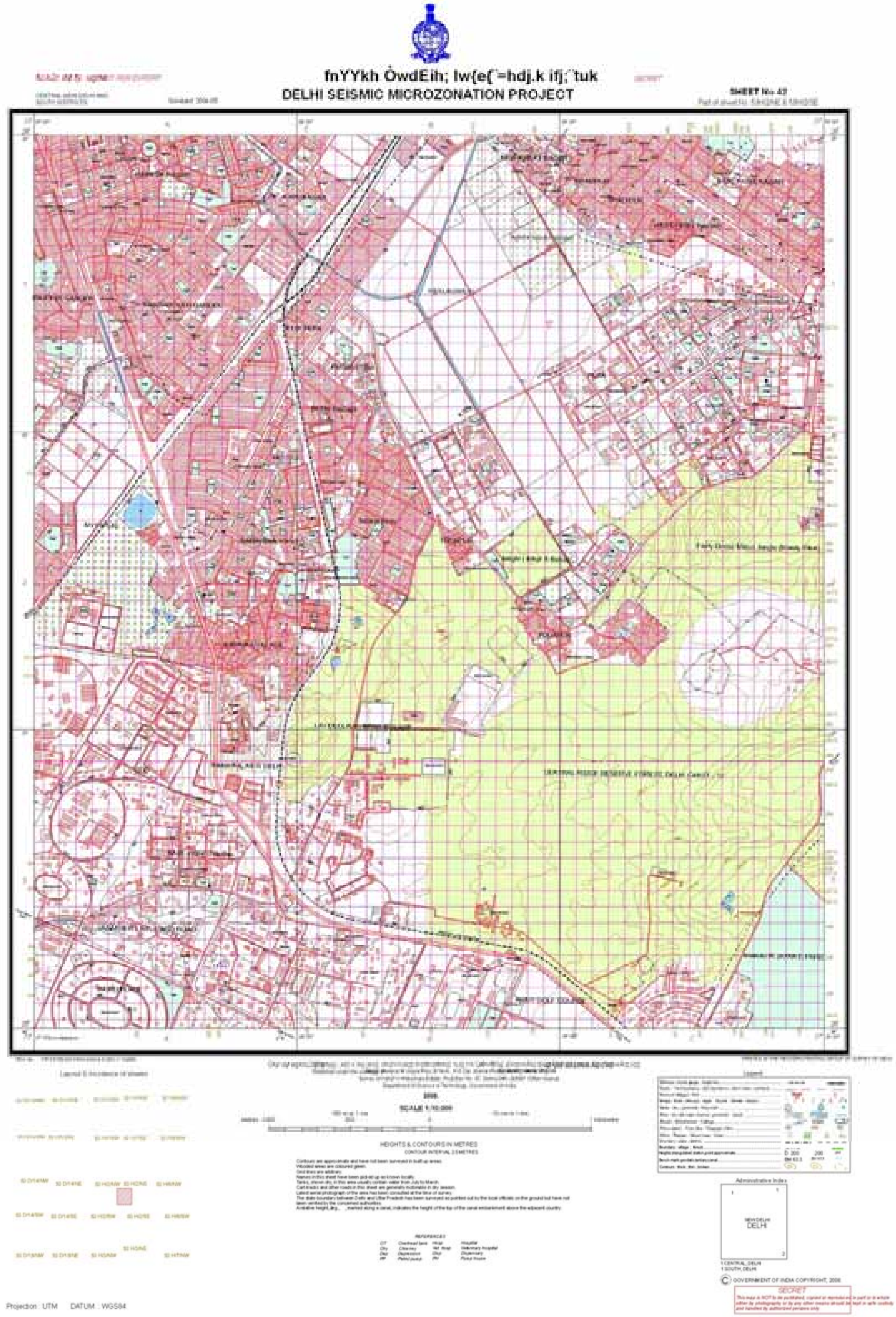


POPULATION DENSITY MAP OF NCT,DELHI
N
Narela
Saraswati Vihar
Bahadurgarh
Civil Lines
Model Town
Seelampur
Loni
Seema Puri
Shahdara
Vivek Vihar
Punjabi Bag
Patel Nagar
Rajouri Garden
Gandhi Nagar
Ghaziabad
Preet Vihar
Parliament Street
Chanakya Puri
C.P.
Delhi Cantonment
Najafgarh
Noida
Defence Colony
Vasant Vihar
Kalkaji
Hauz Khas
Gurgaon
Faridabad
LEGEND
7000 and below
7001-14000
14001 and above

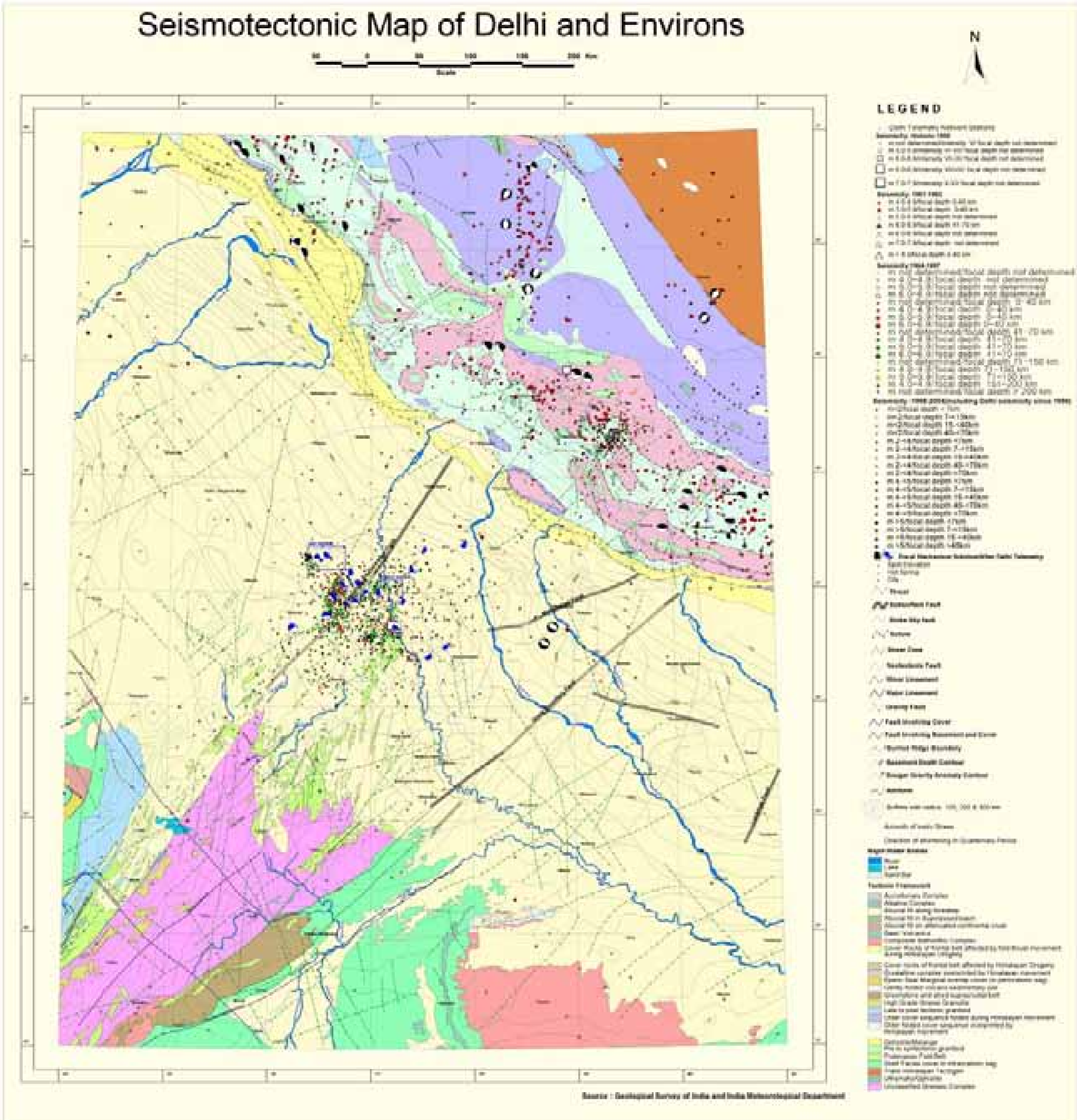
Map-2


FIRST LEVEL SEISMIC HAZARD MICROZONATION MAP OF NCT, DELHI
N
North West
North
Loni
Bahadurgarh
North East
West
East
Ghaziabad
Central
New Delhi
South West
Noida
South
Gurgaon
Faridabad
LEGEN
Ridge Ambience of Exposed Rock : Low Hazard
Layer of Impedance Contrast at Shallow Depth (<30M) Resulting Moderate Hazard
Weathered Rock Zone : Moderate Hazard due to Weathering induced Pronounced Ground Response
Central Delhi : Moderate Hazard due to Amplification in mid level Frequencies & Basin Margin Effect
North West Delhi Planes : Moderate Hazard due to Thick Soft Sediments
South Najafgarh : Moderate Hazard due to High Amplification & Liquefaction
Chhatarpur Basin : High Hazard due to Basin Effect
Zone of Basin Margin Effect West of Delhi Ridge : High Hazard
Newer Alluvium Proximal to Yamuna River : High Hazard due to Liquefaction Potential
76° 50'
55'
77° 00'
05'
10'
15'
77° 20'

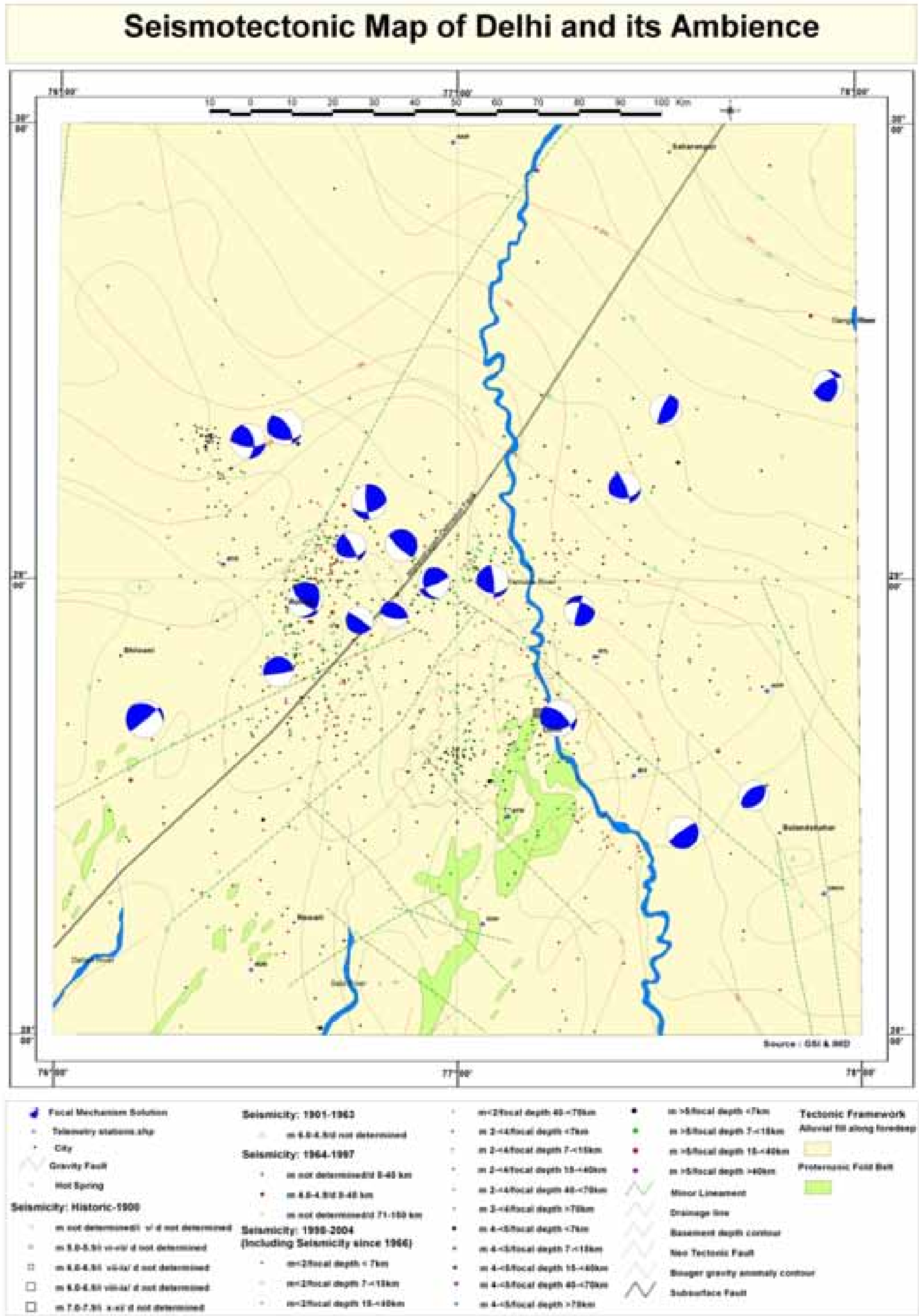
Map-3



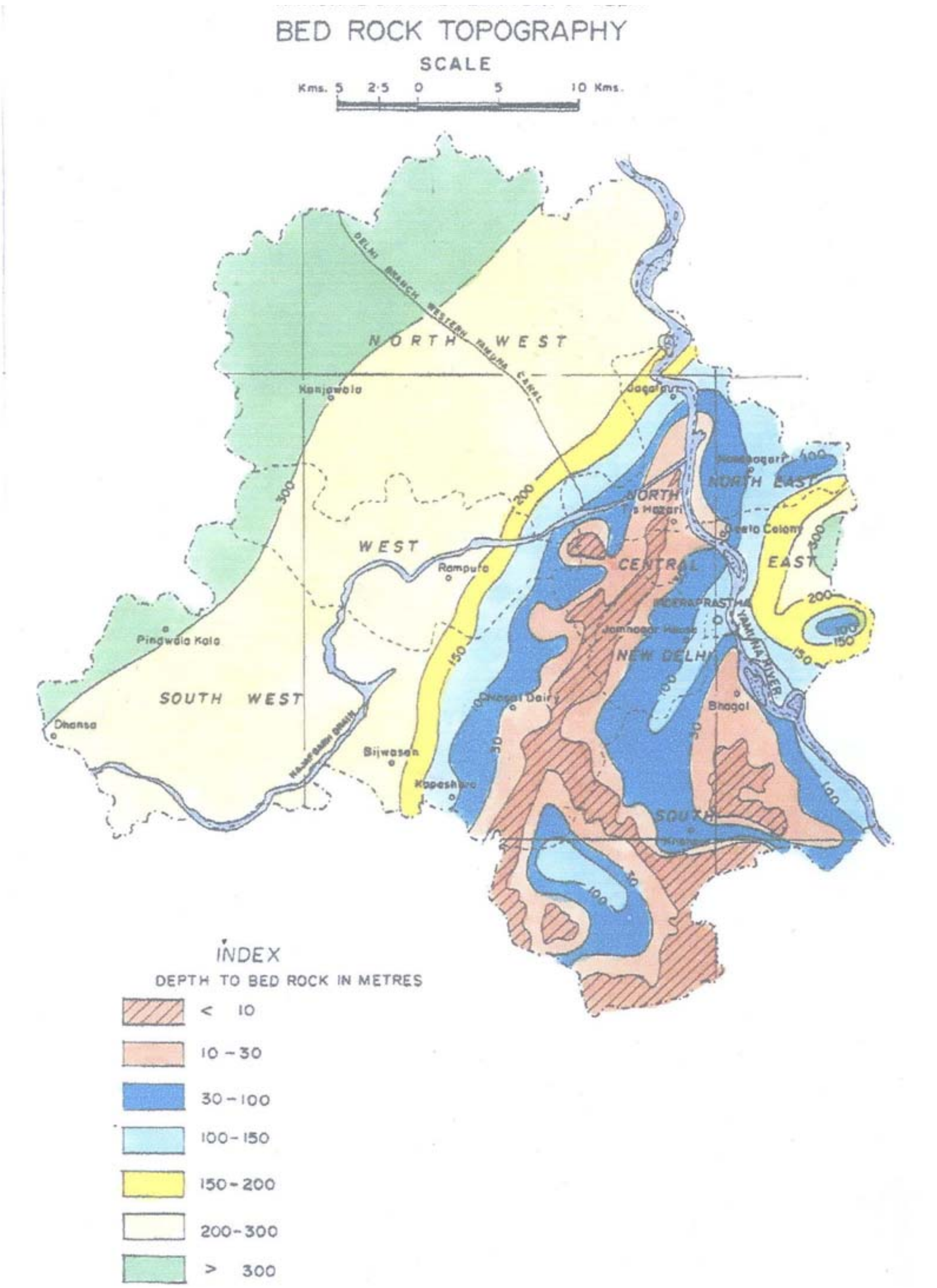
Map-4: A sample map of one toposheet



Map -5: Seismo-Tectonic maps (large environs caused by graticules Long 74^0 – 81^0 & Lat 25^0 - 33^0) generated from Seismotectonic Atlas of GSI

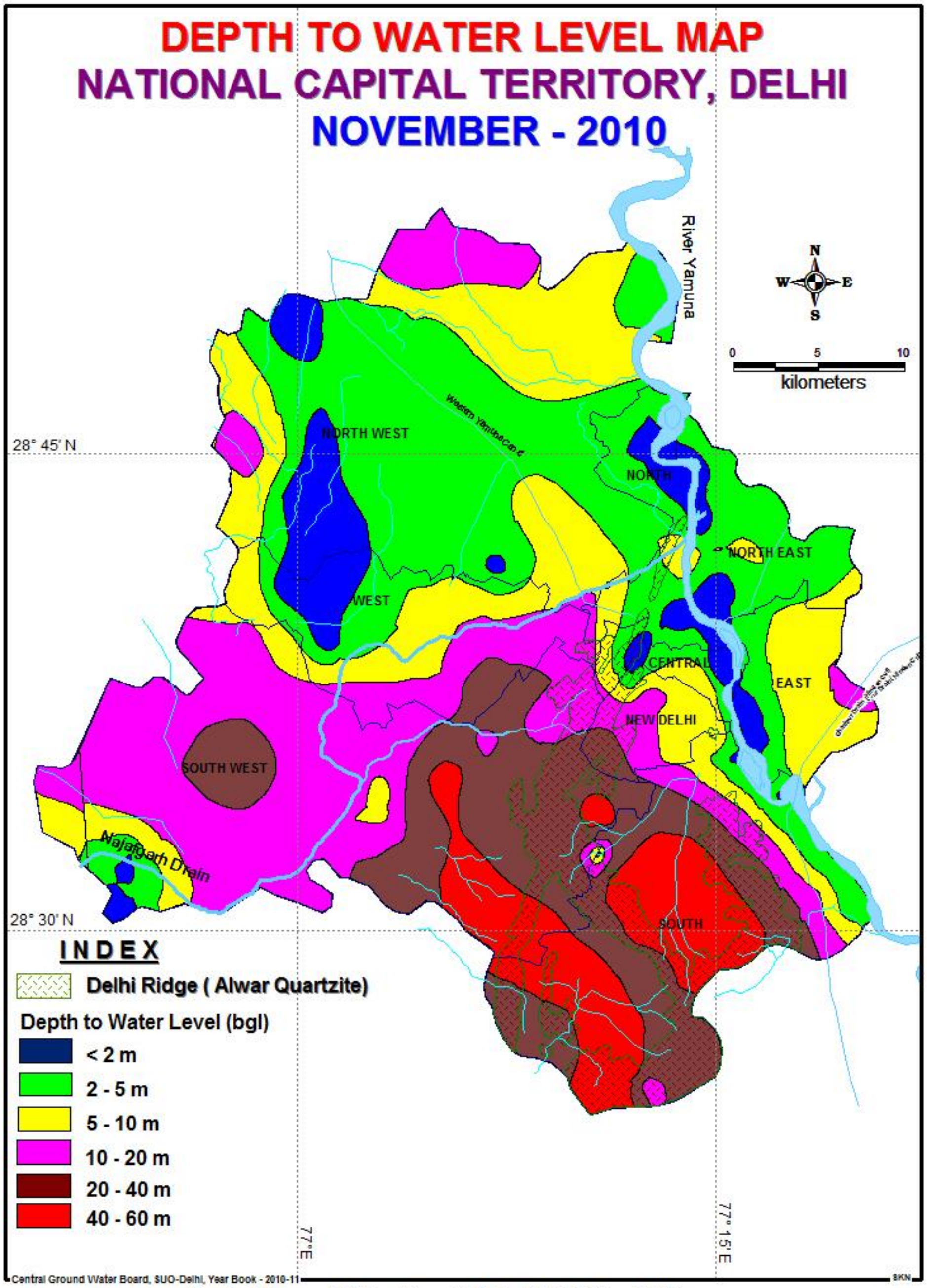


Map -6: Seismo-Tectonic maps (closer domain around Delhi bound Long 76^0 – 78^0 & Lat 28^0- 3^0) generated from Seismotectonic Atlas of GSI



Map7: Bedrock depth map (Generated by CGWB)

"



Central Ground Water Board, State Unit Office-Delhi
18/11, Jamnagar House, Mansingh Road, New Delhi, 110 011

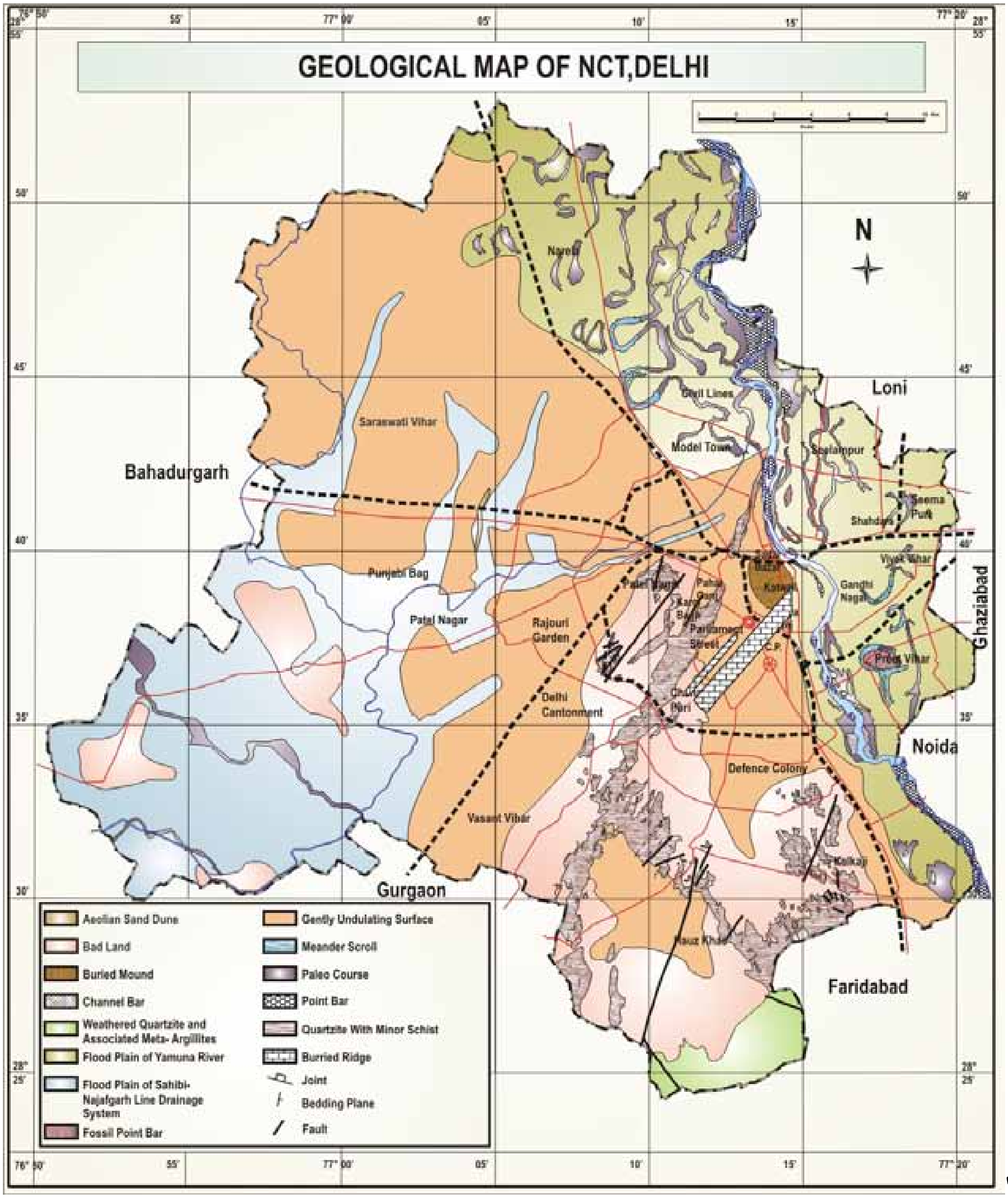
"

"

Map 8: The post monsoon season water table map of 2010 (CGWB)

"

"



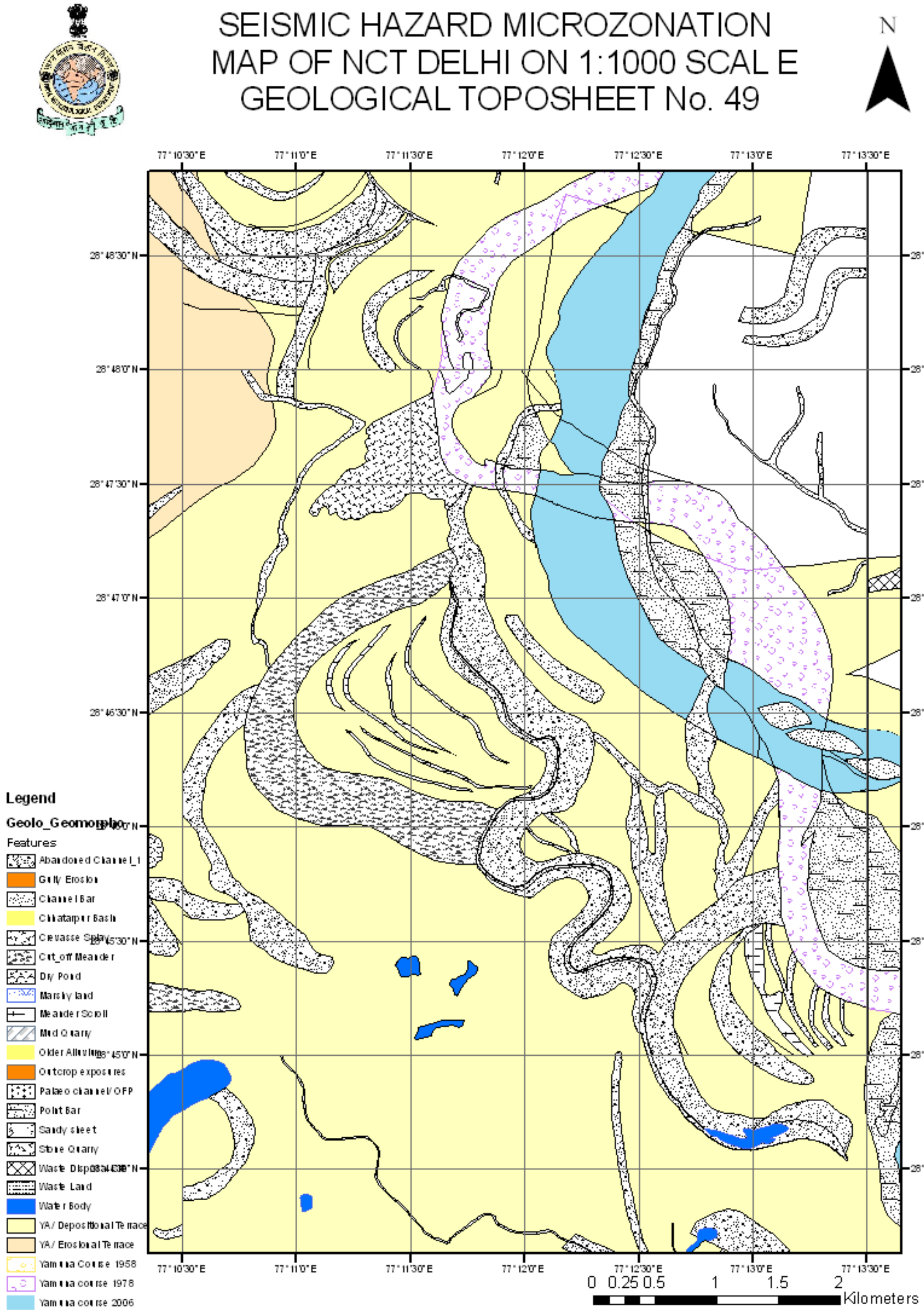
GEOLOGICAL MAP OF NCT,DELHI
N
Narela
Civil Lines
Model Town
Seelampur
Loni
Shahdara
Seema Puri
Vivek Vihar
Gandhi Nagar
Preet Vihar
Ghaziabad
Noida
Saraswati Vihar
Bahadurgarh
Punjabi Bag
Patel Nagar
Rajouri Garden
Patel Nagar
Karol Bagh
Parliament Street
C.P.
Delhi Cantonment
Defence Colony
Vasant Vihar
Kalkaji
Hauz Khas
Gurgaon
Faridabad
Aeolian Sand Dune
Bad Land
Buried Mound
Channel Bar
Weathered Quartzite and Associated Meta- Argillites
Flood Plain of Yamuna River
Flood Plain of Sahibi-Najafgarh Line Drainage System
Fossil Point Bar
Gently Undulating Surface
Meander Scroll
Paleo Course
Point Bar
Quartzite With Minor Schist
Burried Ridge
Joint
Bedding Plane
Fault

"

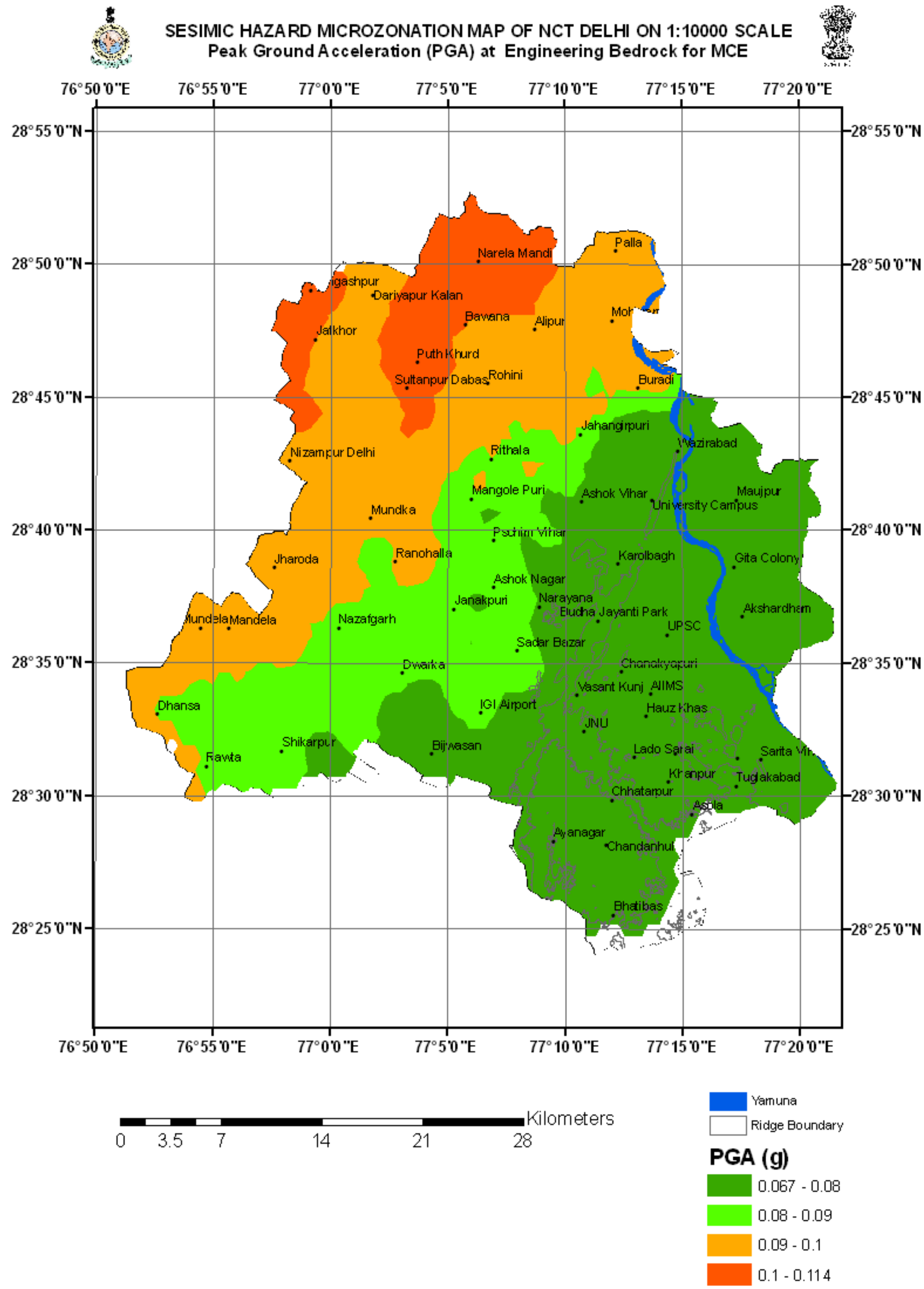
Map-9

"

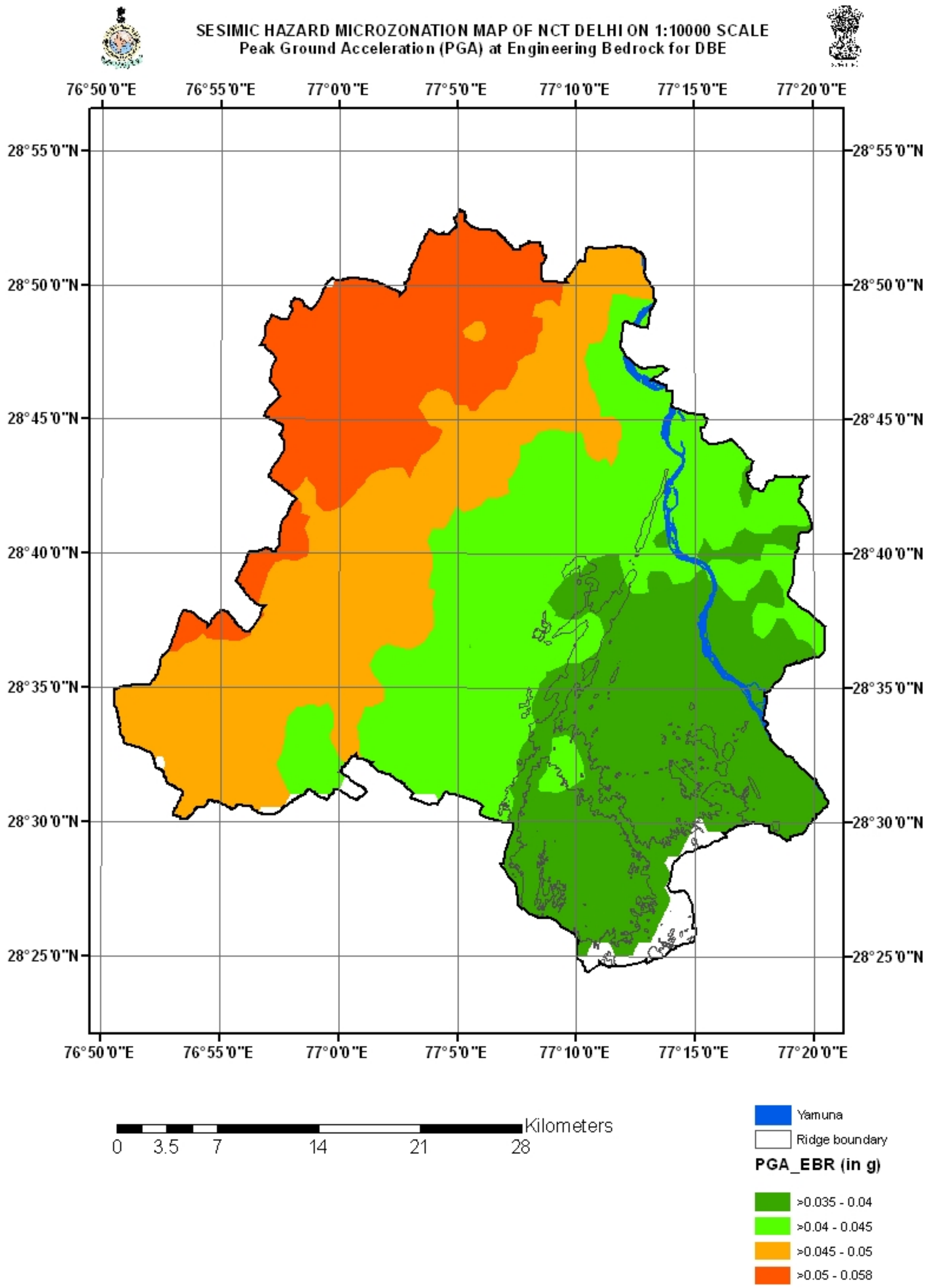
SEISMIC HAZARD MICROZONATION
MAP OF NCT DELHI ON 1:1000 SCAL E
GEOLOGICAL TOPOSHEET No. 49



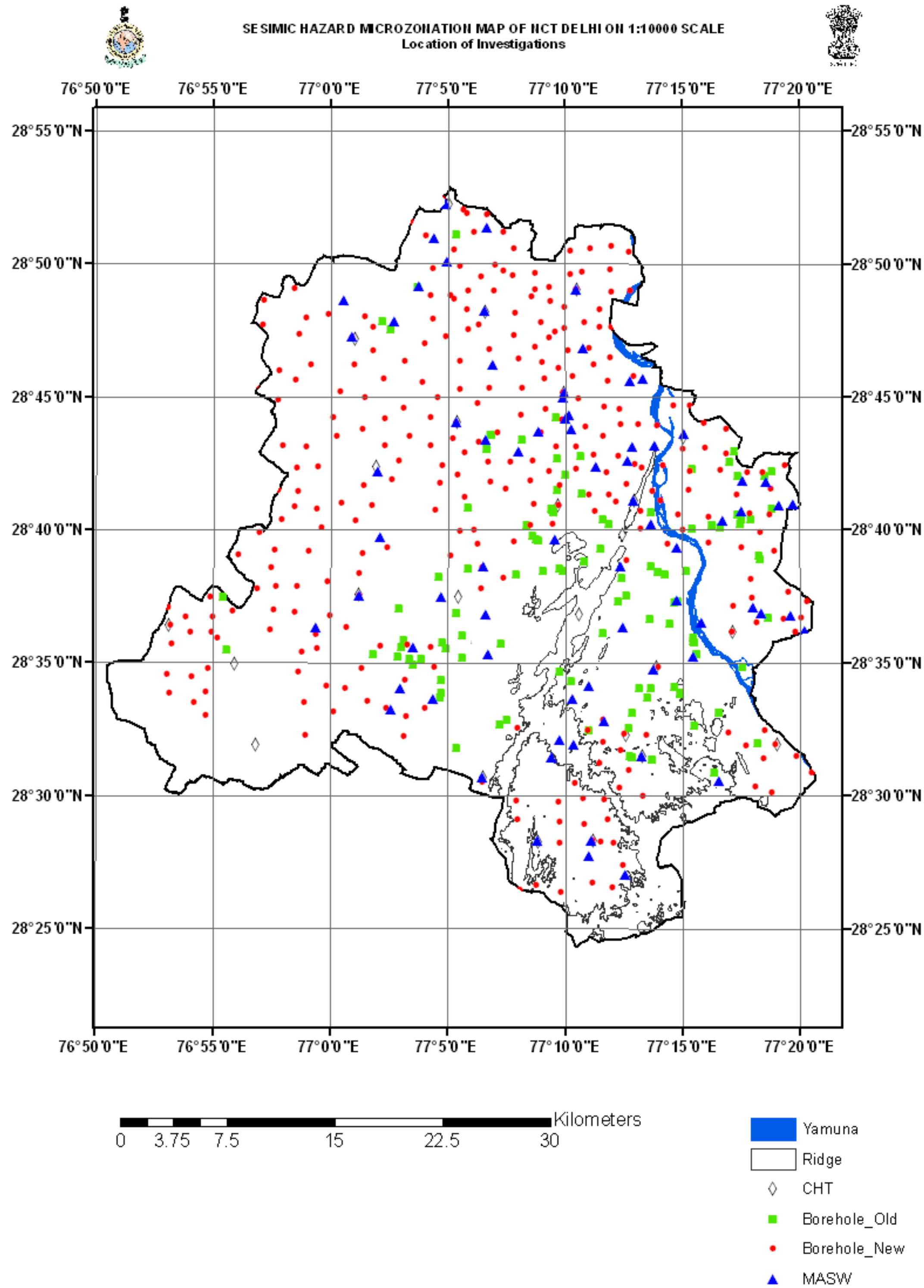
Map 10



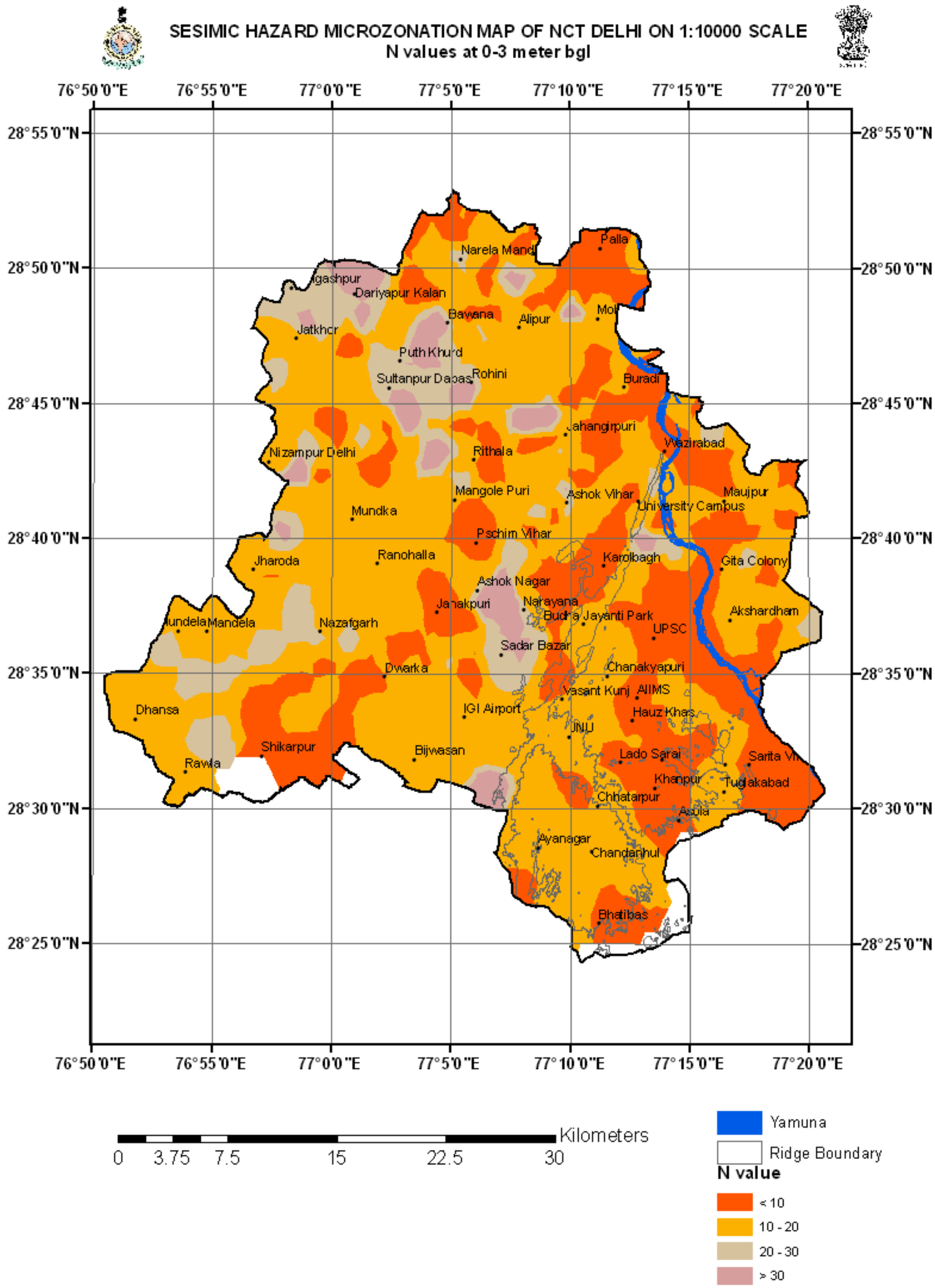
Map 11: PGA map at engineering bedrock for 2% probability of exceedance in 50 years for 5% damping



Map 12: PGA map at engineering bedrock for 10% probability of exceedance in 50 years for 5% damping

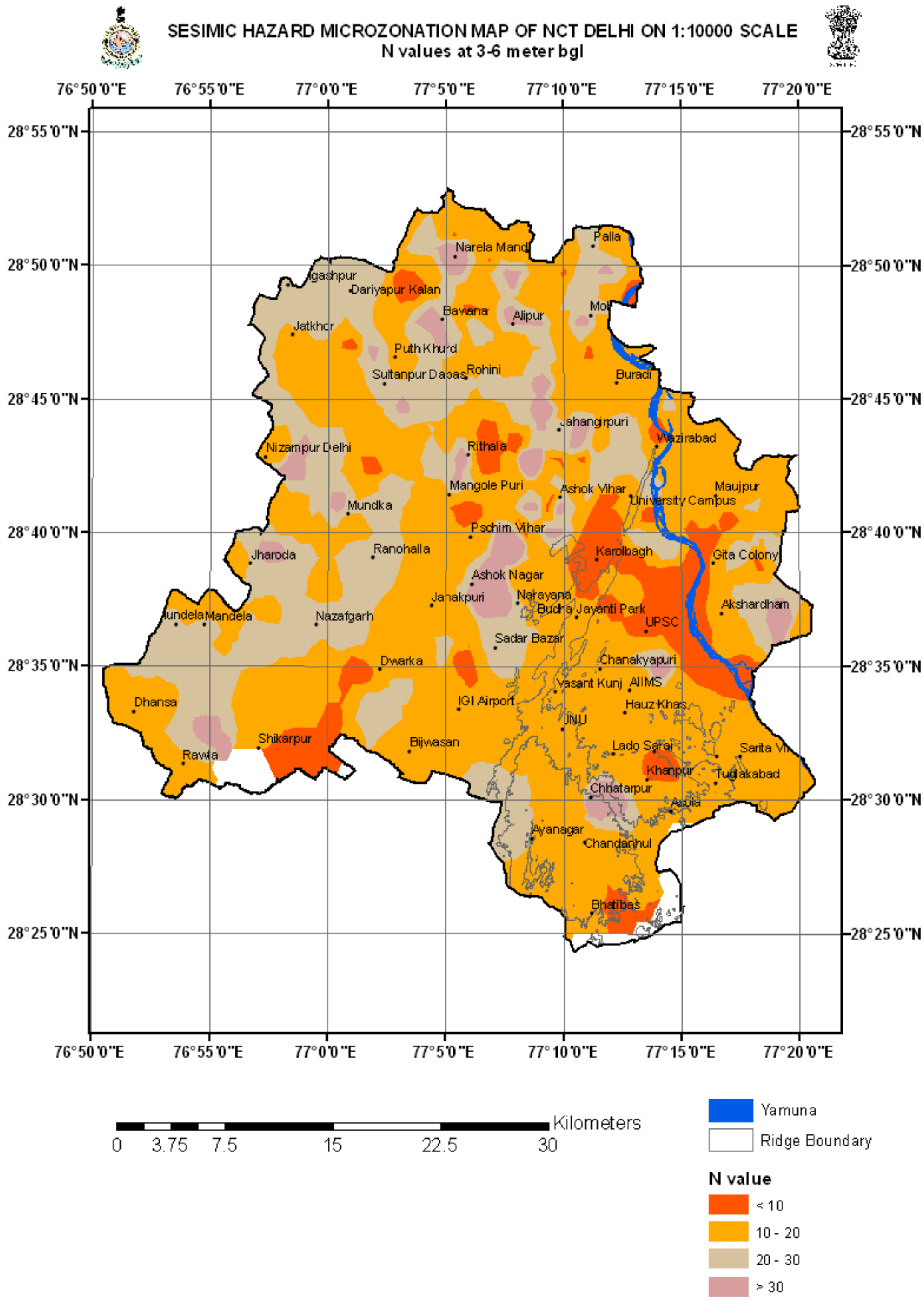


Map-13 A documentation map showing locations of all geotechnical/geophysical investigation undertaken for the study of Seismic Hazard Microzonation of NCT Delhi on 1:10000 scale

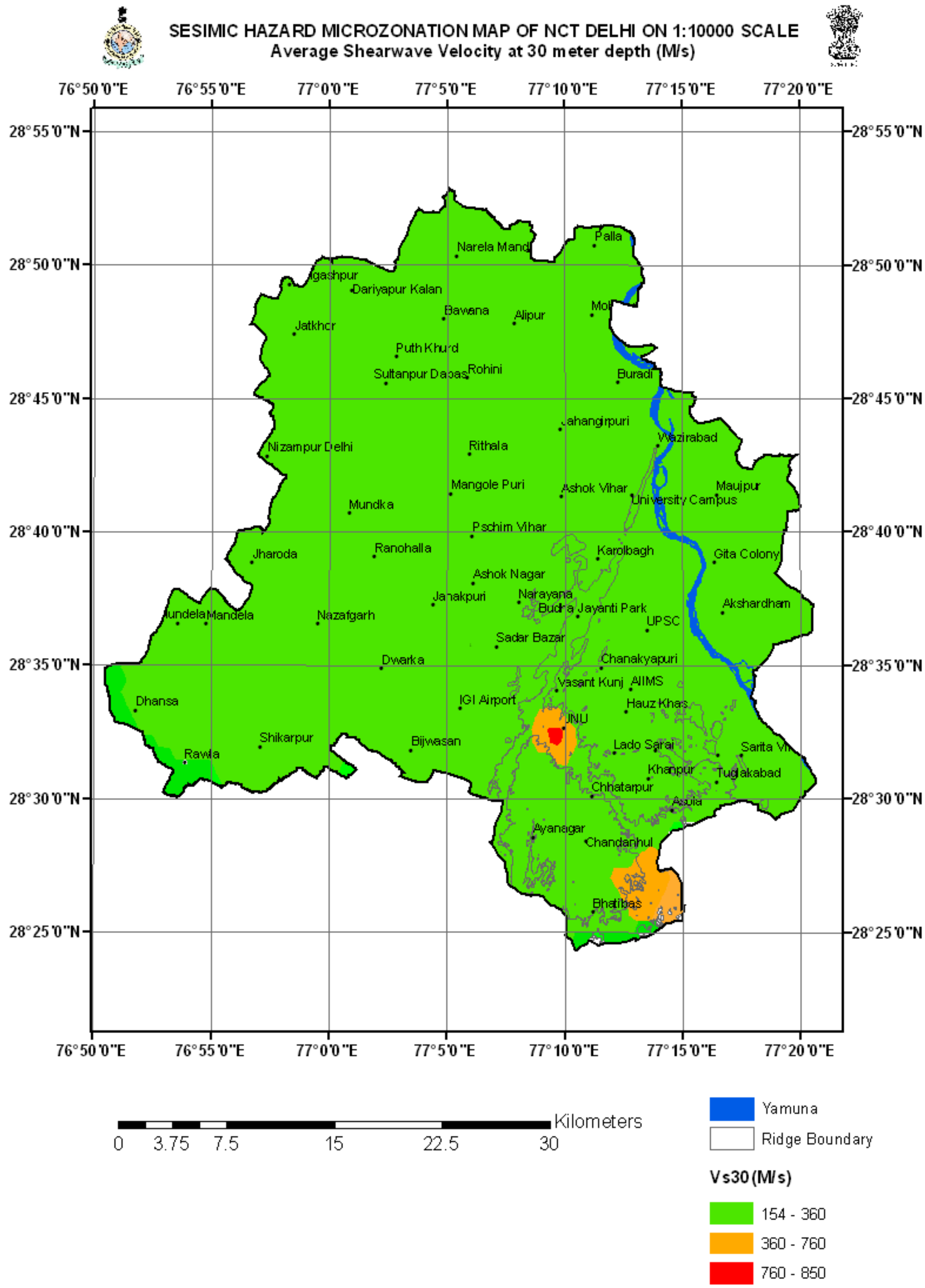


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
N values at 0-3 meter bgl
Narela Mandi
Palla
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Nizampur Delhi
Rithala
Wazirabad
Mangole Puri
Ashok Vihar
Maujpur
University Campus
Mundka
Pschim Vihar
Karolbagh
Gita Colony
Jharoda
Ranohalla
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Rawla
Khanpur
Tuglakabad
Chhatarpur
Ayanagar
Chandanhul
Bhatibas
Kilometers
0 3.75 7.5 15 22.5 30
Yamuna
Ridge Boundary
N value
< 10
10 - 20
20 - 30
> 30

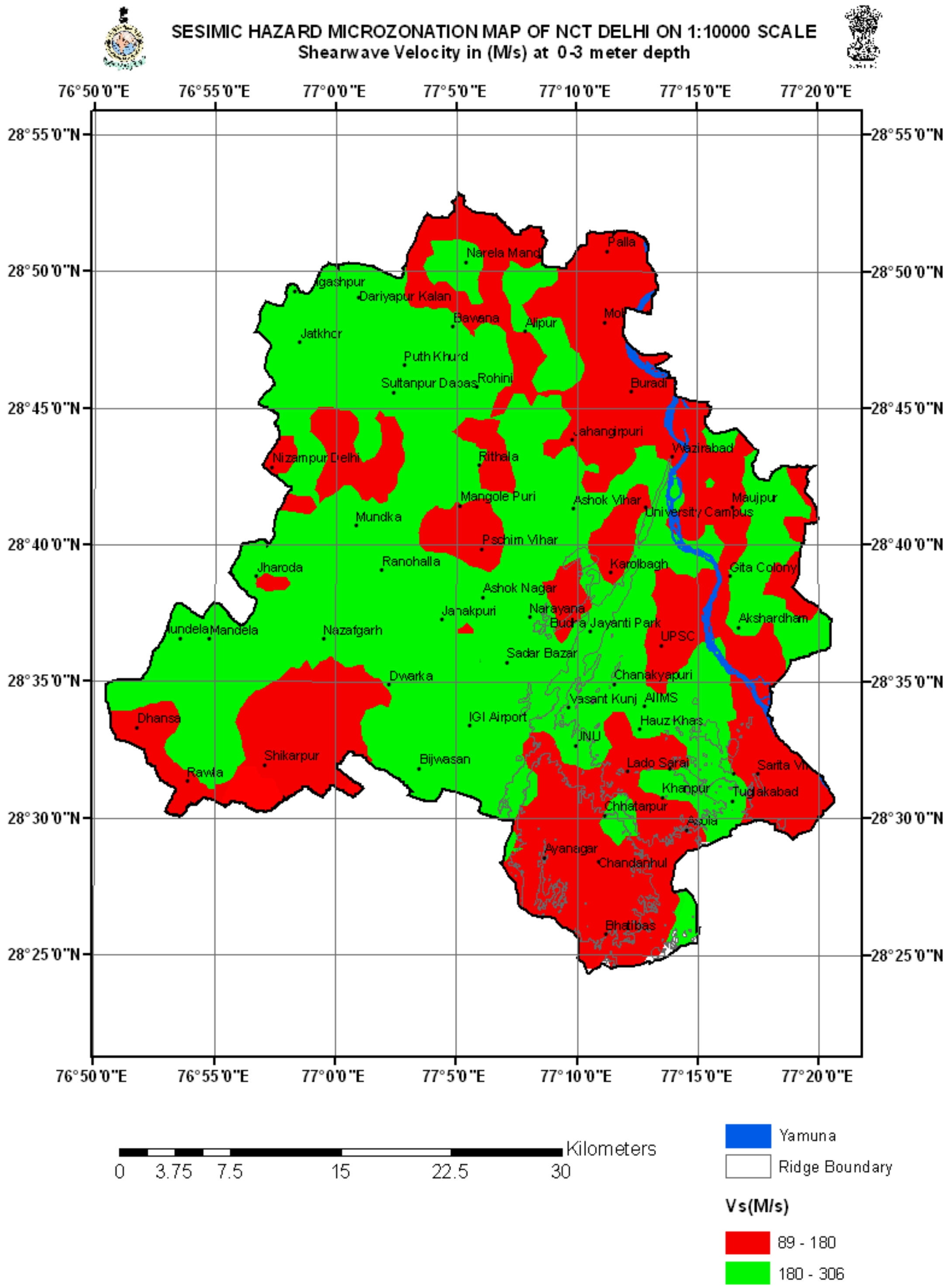
Map-14


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
N values at 3-6 meter bgl
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Narela Mandi
Palla
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Nizampur Delhi
Rithala
Wazirabad
Mangole Puri
Ashok Vihar
Maujpur
University Campus
Mundka
Pschim Vihar
Jharoda
Ranohalla
Karolbagh
Gita Colony
Ashok Nagar
Janakpuri
Narayana
Buddha Jayanti Park
Akshardham
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Rawla
Khanpur
Tuglakabad
Chhatarpur
Ayanagar
Chandanhul
Bhatibas
Kilometers
0
3.75
7.5
15
22.5
30
Yamuna
Ridge Boundary
N value
< 10
10 - 20
20 - 30
> 30

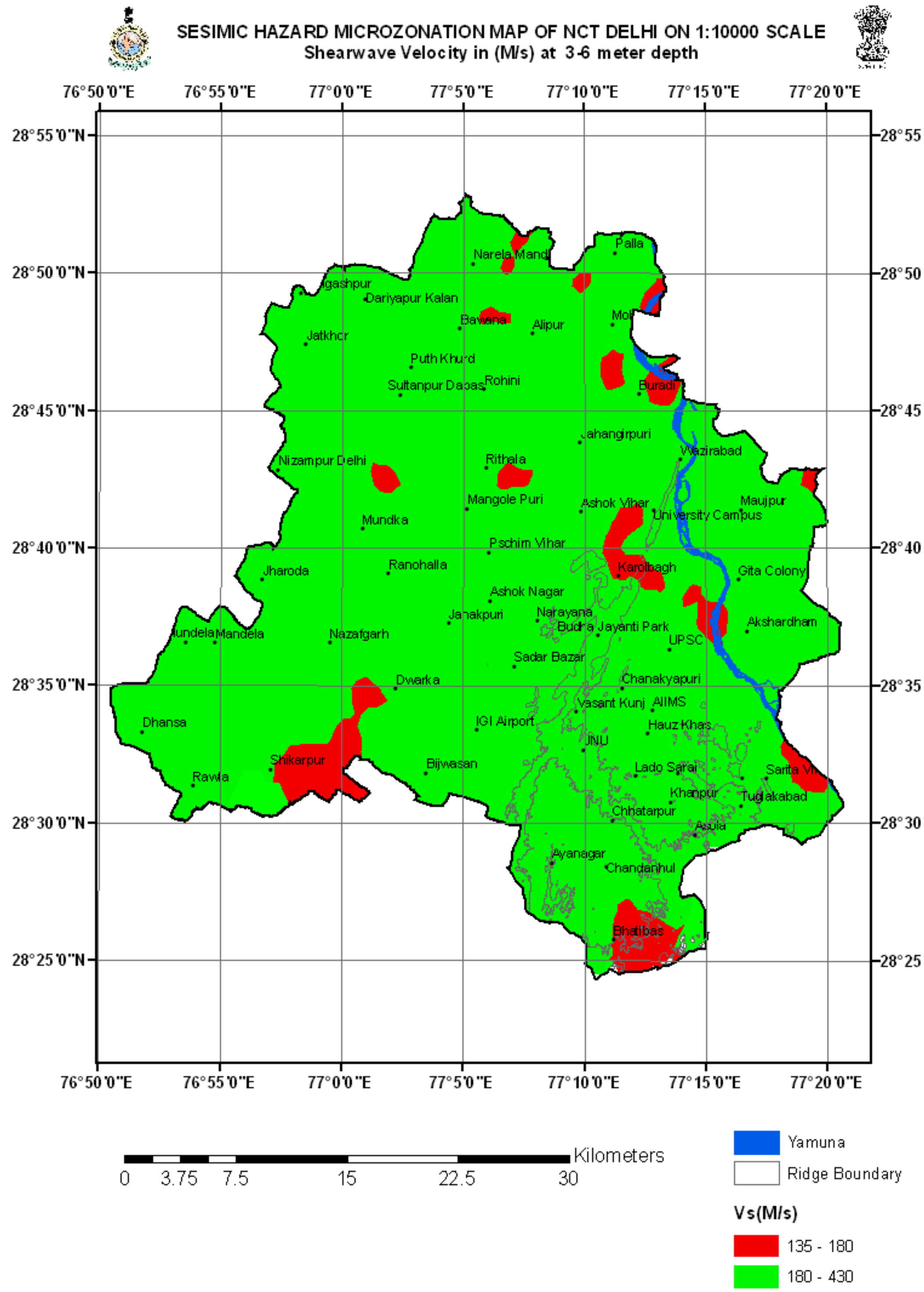
Map-15


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Average Shearwave Velocity at 30 meter depth (M/s)
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Narela Mandi
Palla
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Mangole Puri
Ashok Vihar
Maujpur
University Campus
Mundka
Paschim Vihar
Karolbagh
Gita Colony
Jharoda
Ranohalla
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Rawta
Khanpur
Tuglakabad
Chhatarpur
Asola
Ayanagar
Chandanhul
Bhatibas
Kilometers
0
3.75
7.5
15
22.5
30
Yamuna
Ridge Boundary
Vs30 (M/s)
154 - 360
360 - 760
760 - 850

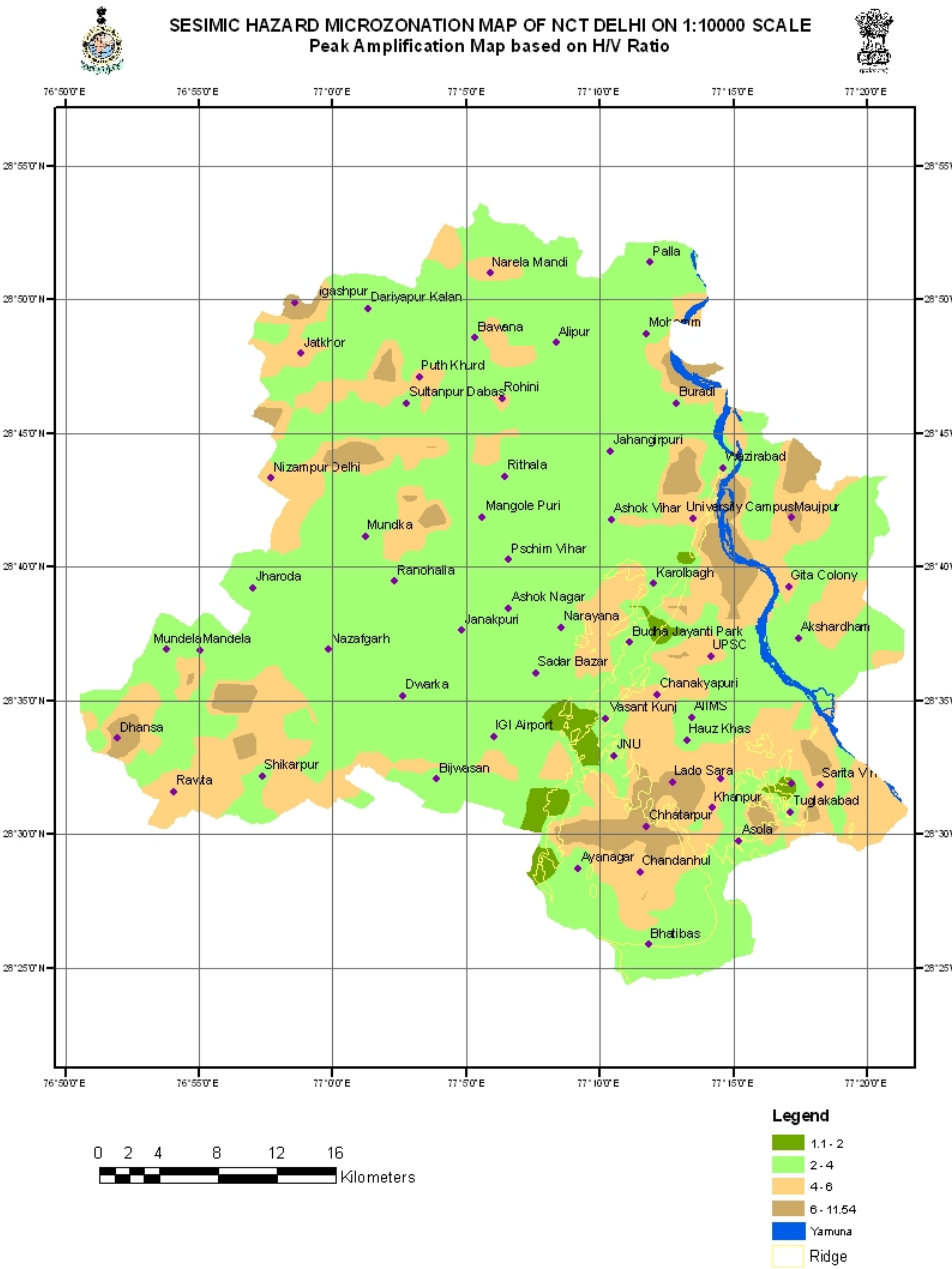
Map-16



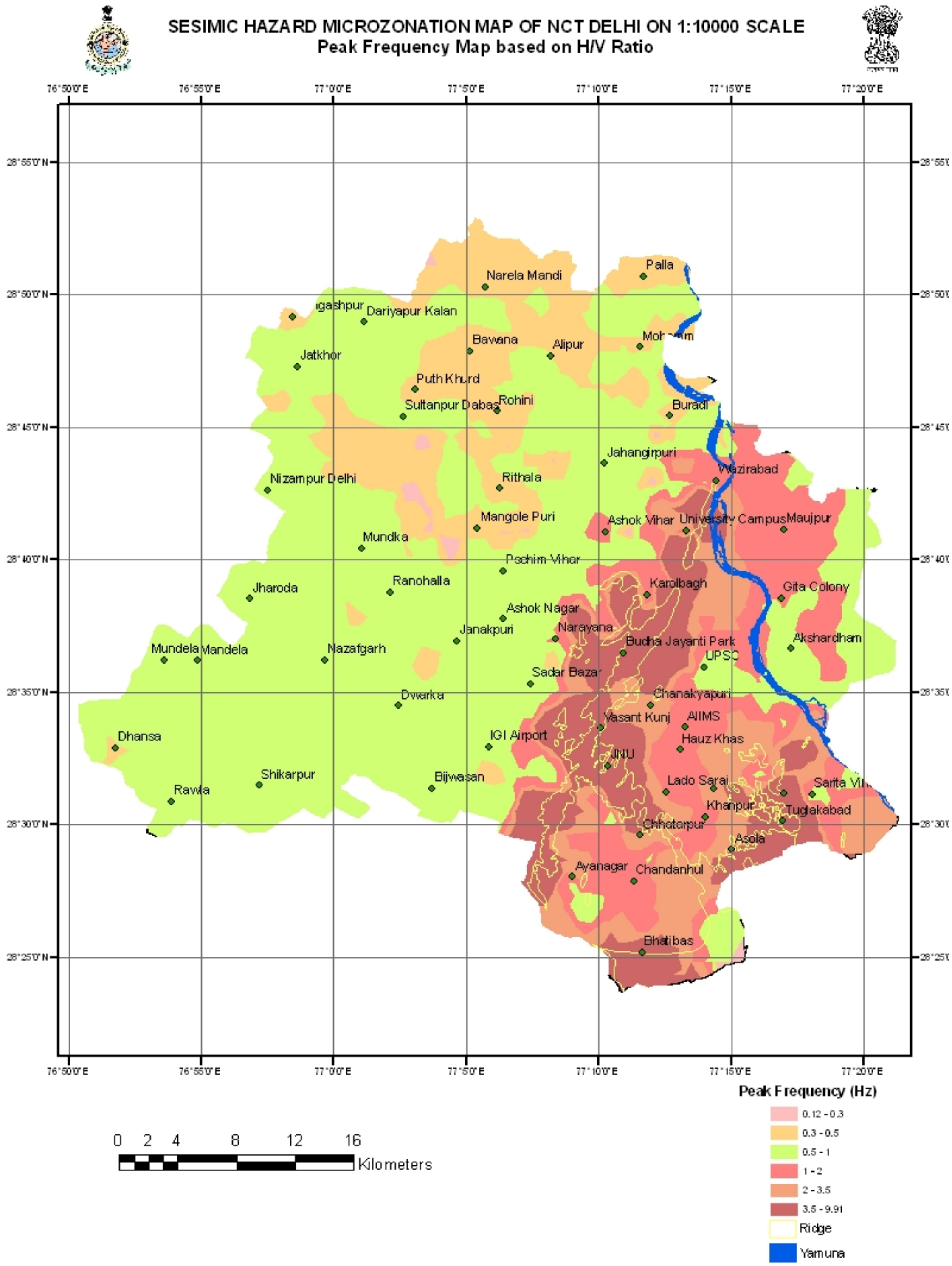
Map-17: Shearwave velocity map of layer 0-3meter below ground level.



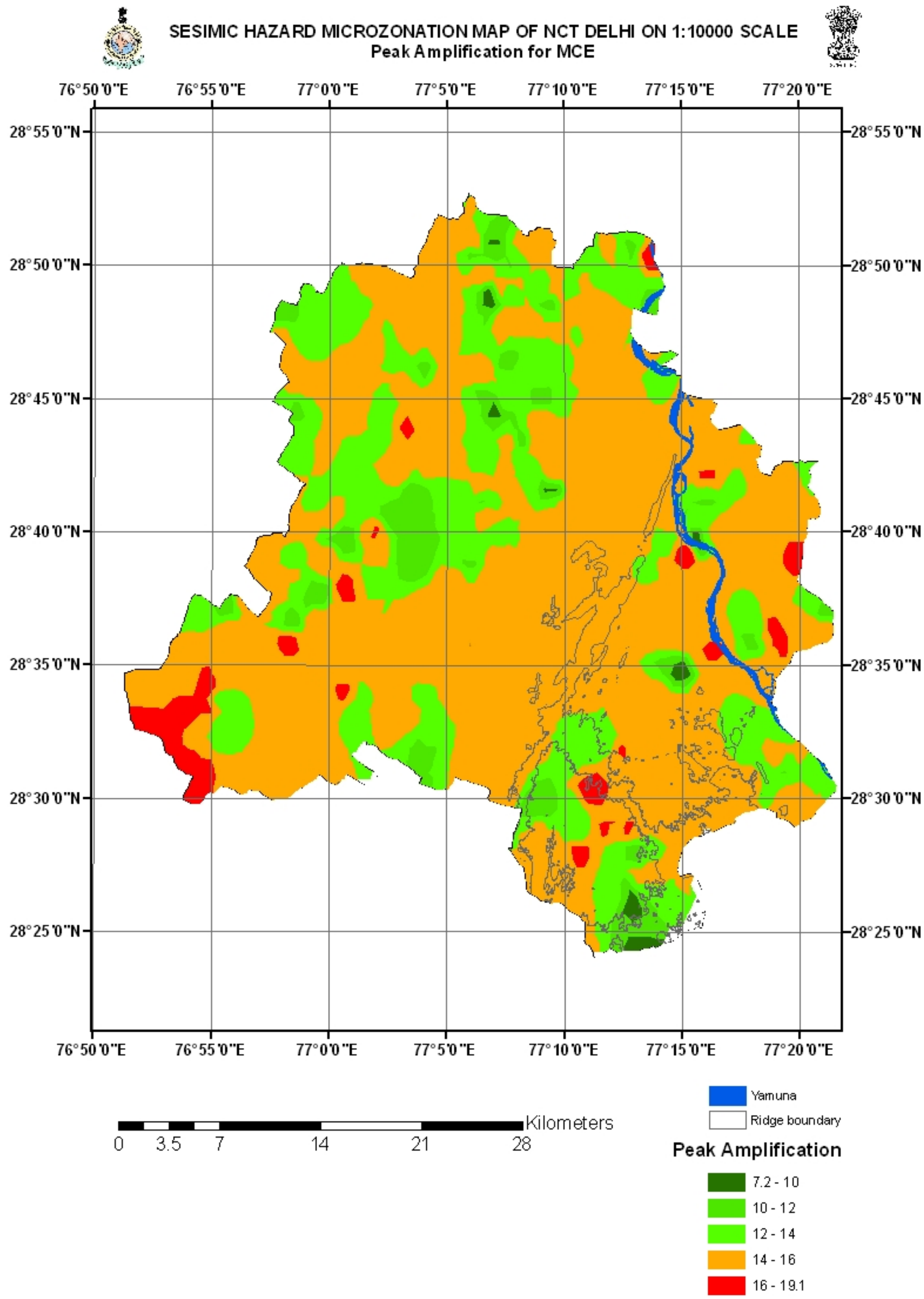
Map-18: Shearwave velocity map of layer 3-6meter below ground level.


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Peak Amplification Map based on H/V Ratio
Narela Mandi
Palla
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Nizampur Delhi
Rithala
Wazirabad
Mangole Puri
Ashok Vihar
University Campus
Maujpur
Mundka
Pschim Vihar
Jharoda
Ranohalla
Karolbagh
Gita Colony
Ashok Nagar
Narayana
Janakpuri
Budha Jayanti Park
Akshardham
Mundela
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sara
Ravta
Khanpur
Tuglakabad
Chhatarpur
Asola
Ayanagar
Chandanhul
Bhatibas
Legend
1.1 - 2
2 - 4
4 - 6
6 - 11.54
Yamuna
Ridge
0 2 4 8 12 16
Kilometers

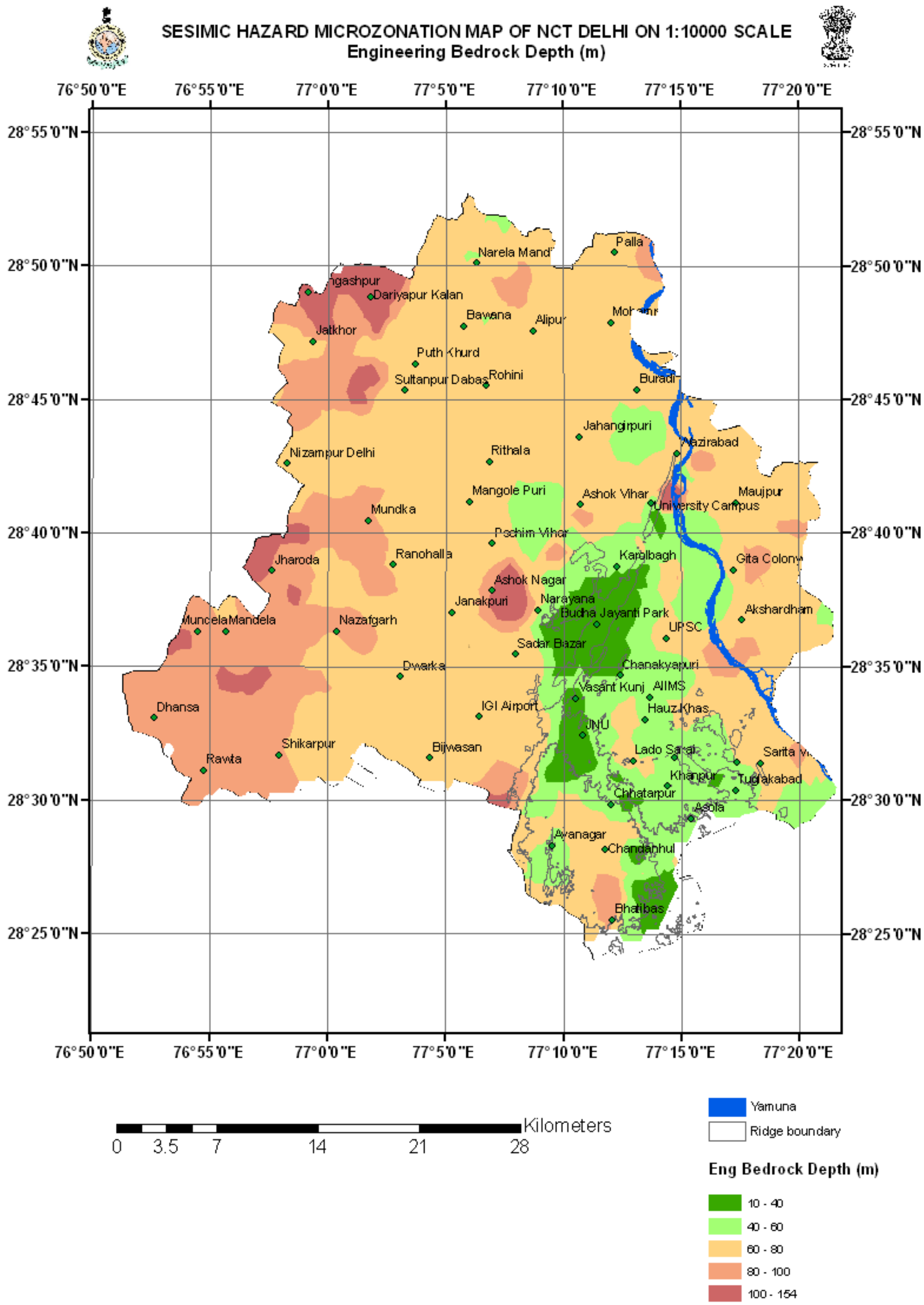
Map 19


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Peak Frequency Map based on H/V Ratio
Narela Mandi
Palla
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Mangole Puri
Ashok Vihar
University Campus
Maujpur
Mundka
Paschim Vihar
Karolbagh
Gita Colony
Jharoda
Ranohalla
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
Mundela
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Rawla
Khanpur
Tuglakabad
Chhatarpur
Asola
Ayanagar
Chandanhul
Bhatibas
0 2 4 8 12 16
Kilometers
Peak Frequency (Hz)
0.12 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2 - 3.5
3.5 - 9.91
Ridge
Yamuna

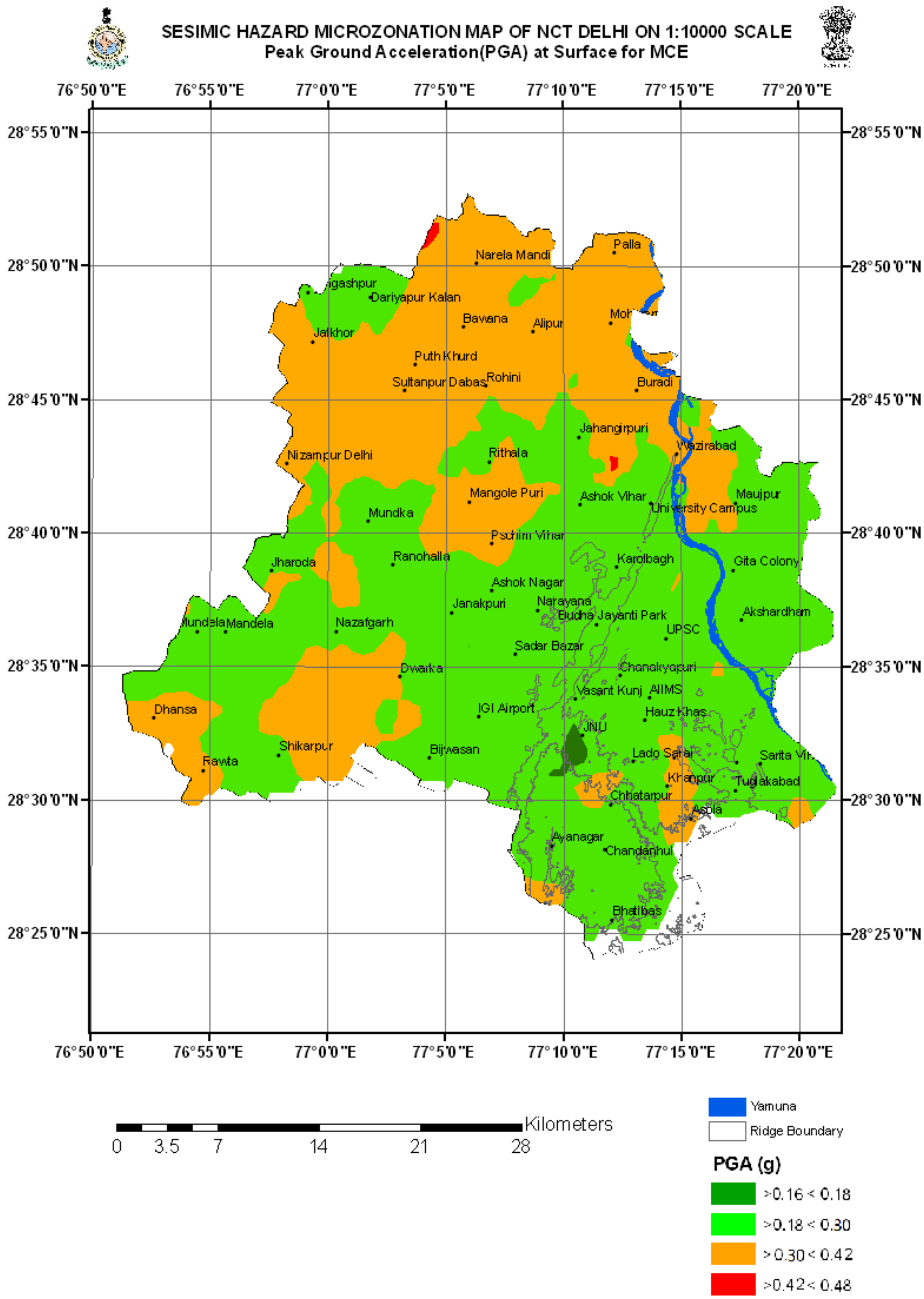
Map-20


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Peak Amplification for MCE
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
0 3.5 7 14 21 28 Kilometers
Yamuna
Ridge boundary
Peak Amplification
7.2 - 10
10 - 12
12 - 14
14 - 16
16 - 19.1

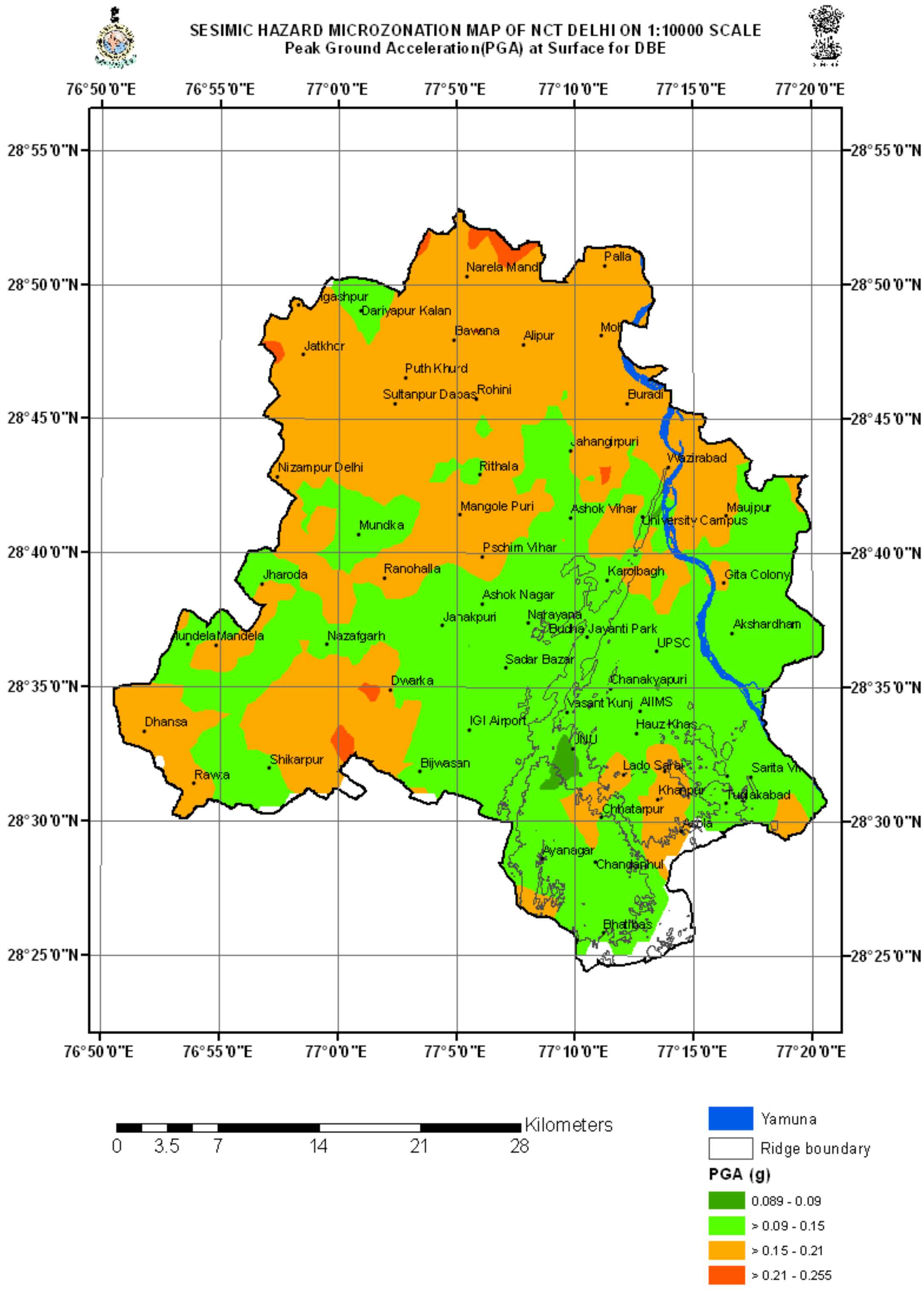
Map-21


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Engineering Bedrock Depth (m)
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Palla
Narela Mand
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Mangole Puri
Ashok Vihar
Maujpur
University Campus
Mundka
Paschim Vihar
Ranohalla
Karolbagh
Gita Colony
Jharoda
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
UPSC
Muncela
Mandela
Nazafgarh
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Rawta
Khanpur
Tuglakabad
Chhatarpur
Asola
Ayanagar
Chandanhul
Bhatibas
Kilometers
0
3.5
7
14
21
28
Yamuna
Ridge boundary
Eng Bedrock Depth (m)
10 - 40
40 - 60
60 - 80
80 - 100
100 - 154

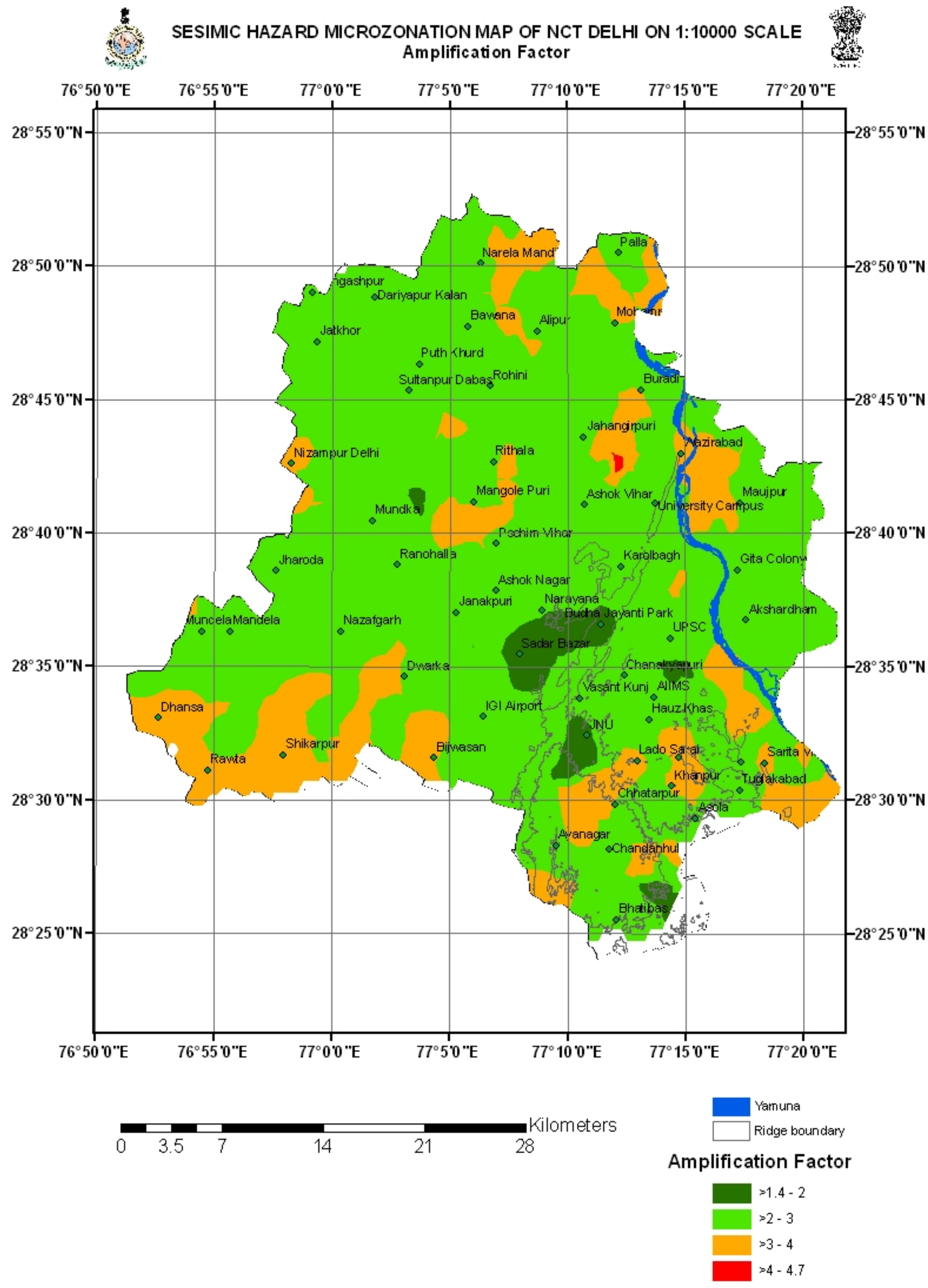
Map-22


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Peak Ground Acceleration(PGA) at Surface for MCE
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Palla
Narela Mandi
Dariyapur Kalan
Bawana
Alipur
Jaitkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Mangole Puri
Ashok Vihar
Maujpur
University Campus
Mundka
Jharoda
Ranohalla
Karolbagh
Gita Colony
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Rawta
Khanpur
Tuglakabad
Chhatarpur
Aspla
Ayanagar
Chandanhul
Bhatibas
Kilometers
0
3.5
7
14
21
28
Yamuna
Ridge Boundary
PGA (g)
>0.16 < 0.18
>0.18 < 0.30
>0.30 < 0.42
>0.42 < 0.48

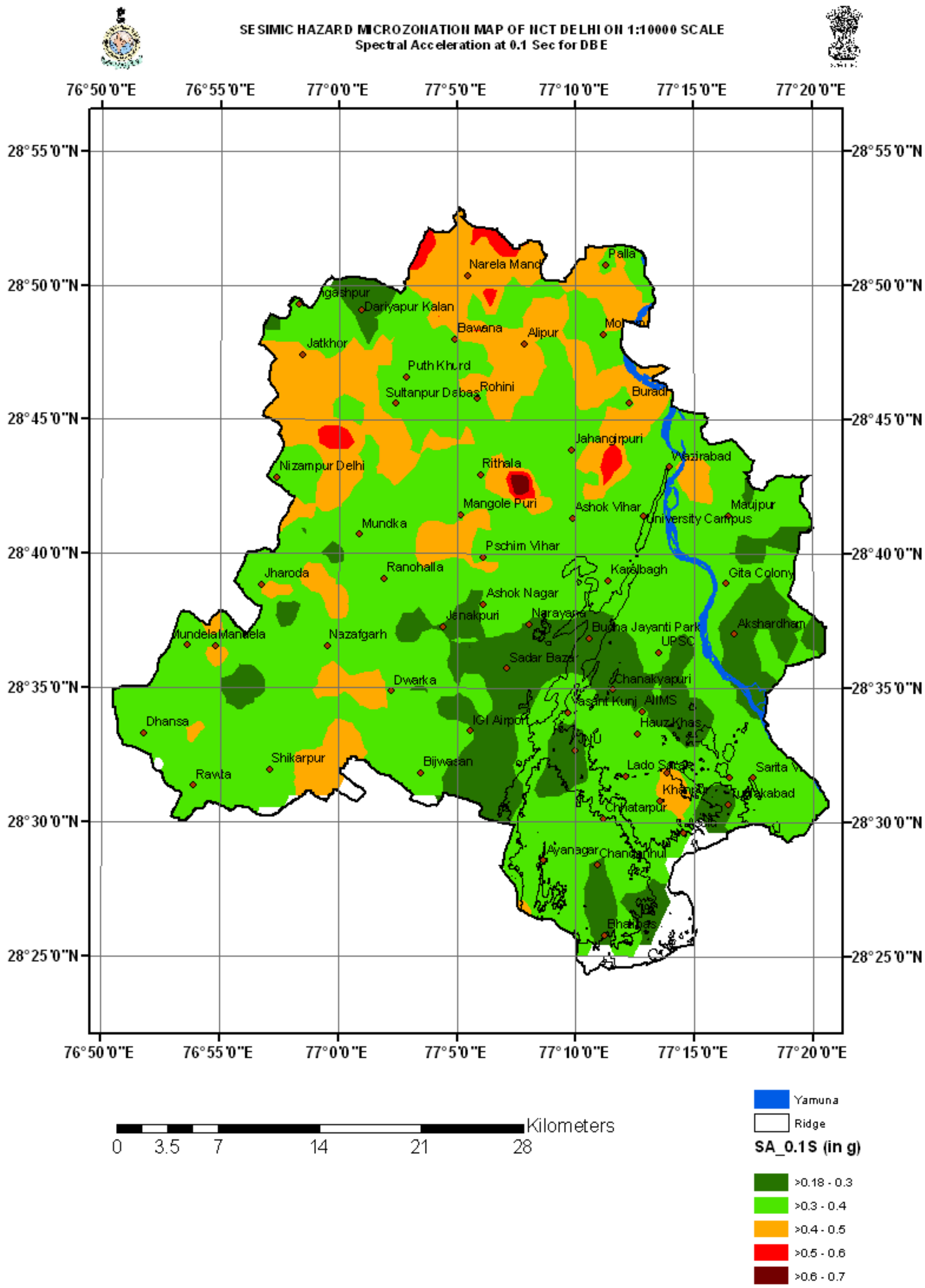
Map 23


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Peak Ground Acceleration(PGA) at Surface for DBE
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Palla
Narela Mandi
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Mangole Puri
Ashok Vihar
University Campus
Maujpur
Mundka
Pschim Vihar
Karolbagh
Gita Colony
Jharoda
Ranohalla
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Rawta
Khanpur
Tuglakabad
Chhatarpur
Ayanagar
Chandanhul
Bhatibas
Kilometers
0
3.5
7
14
21
28
Yamuna
Ridge boundary
PGA (g)
0.089 - 0.09
> 0.09 - 0.15
> 0.15 - 0.21
> 0.21 - 0.255

Map-24

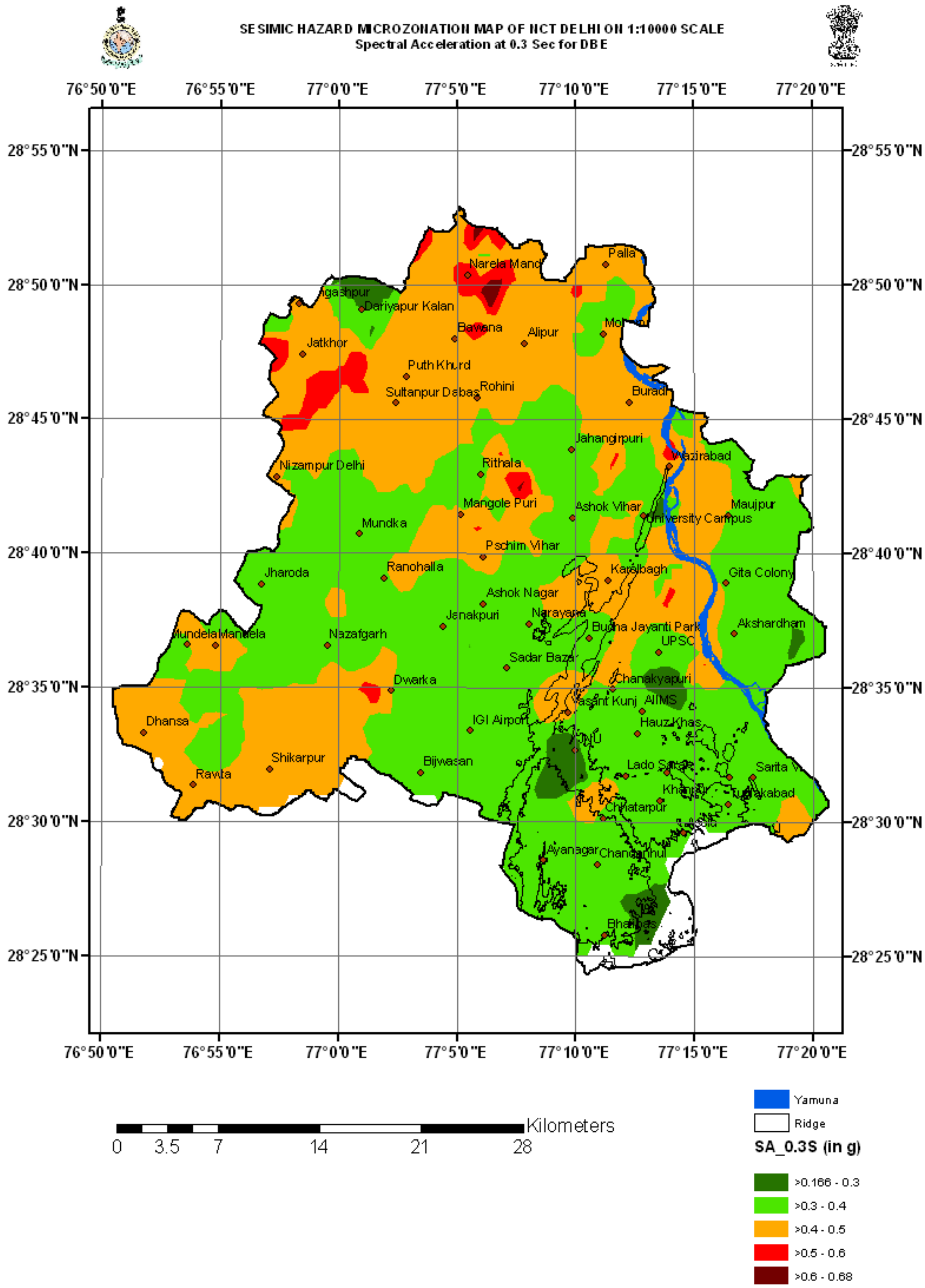

SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Amplification Factor
Yamuna
Ridge boundary
Amplification Factor
>1.4 - 2
>2 - 3
>3 - 4
>4 - 4.7
Kilometers
0 3.5 7 14 21 28

Map 25

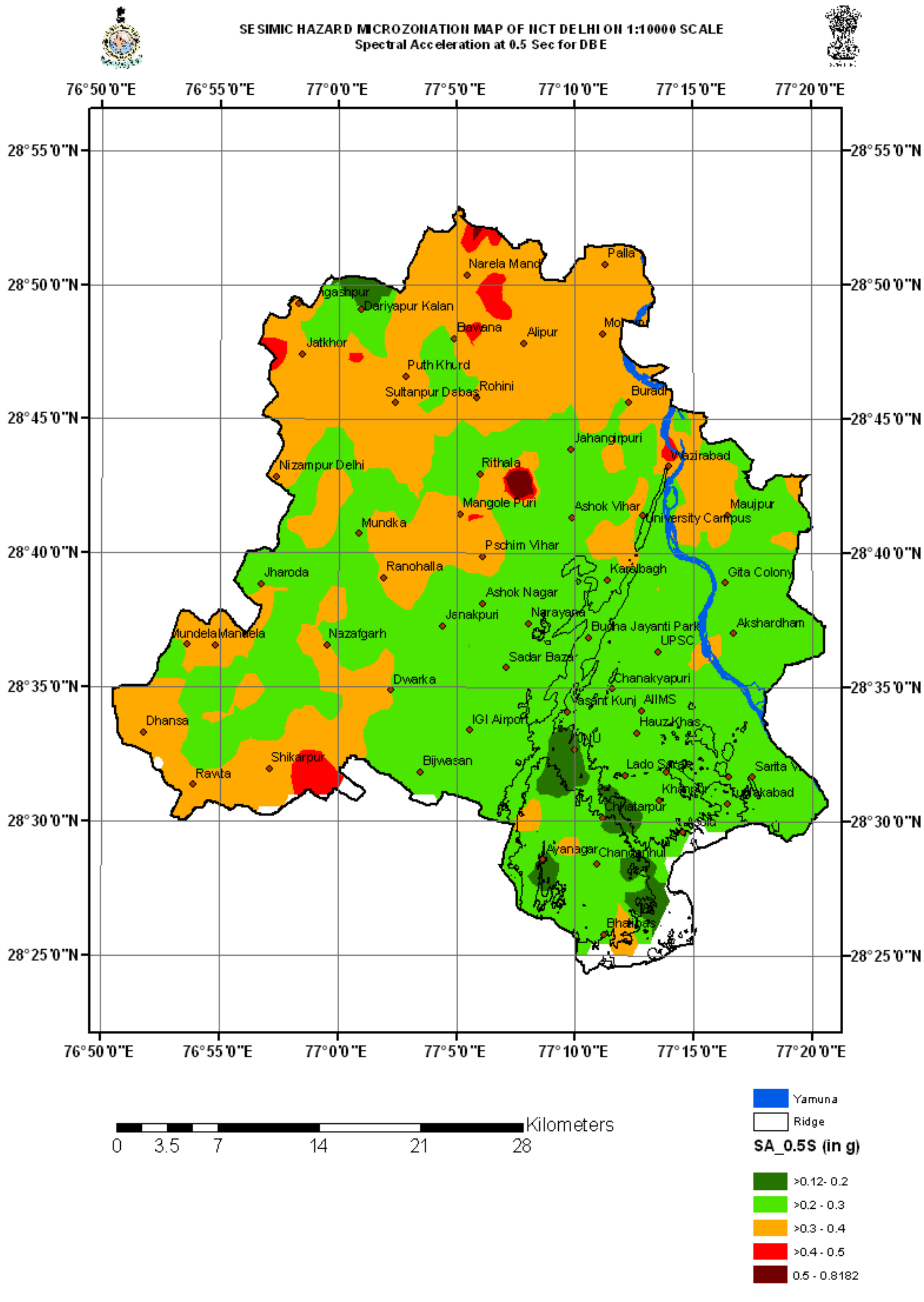


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Spectral Acceleration at 0.1 Sec for DBE
Kilometers
0 3.5 7 14 21 28
Yamuna
Ridge
SA_0.1S (in g)
>0.18 - 0.3
>0.3 - 0.4
>0.4 - 0.5
>0.5 - 0.6
>0.6 - 0.7

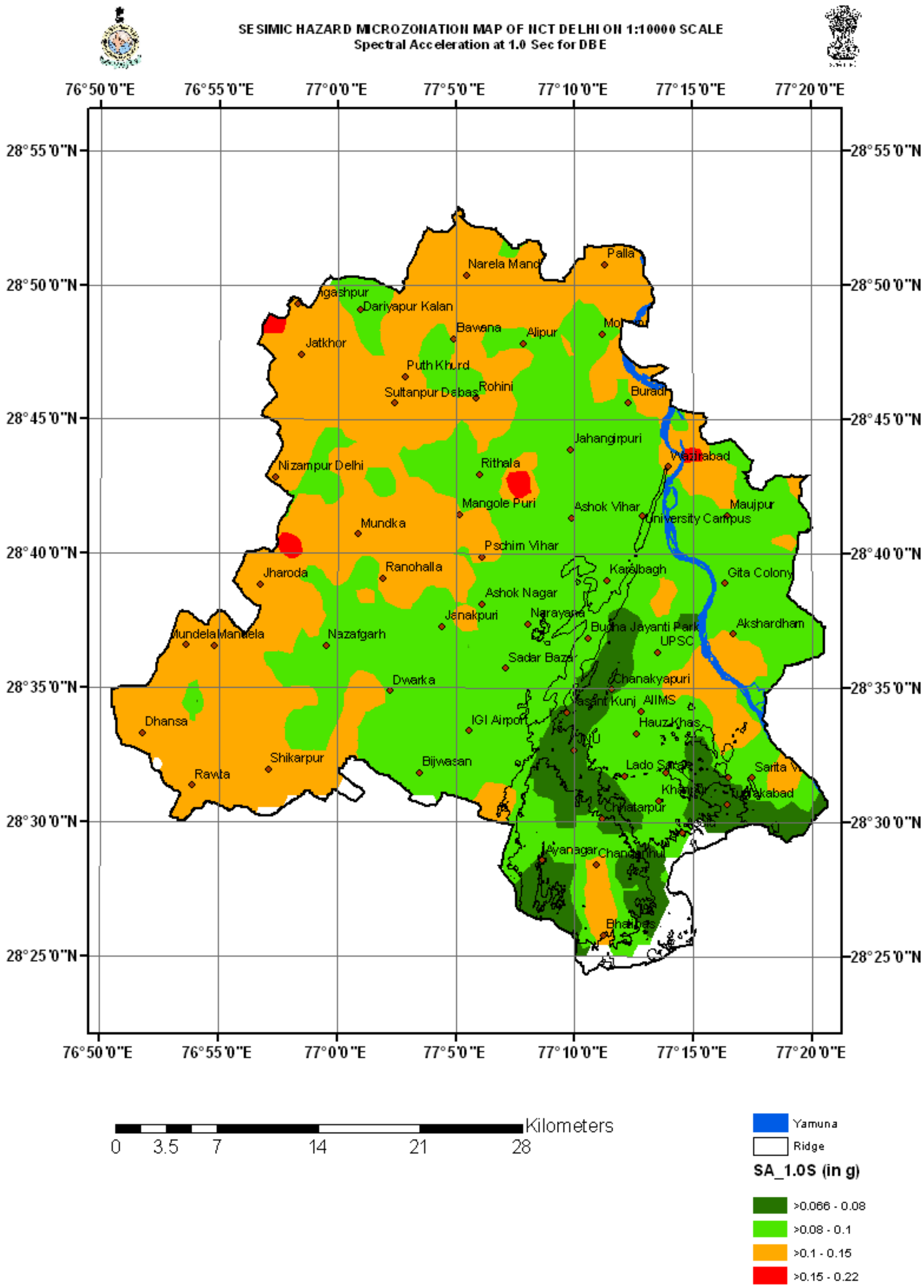
Map -26


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Spectral Acceleration at 0.3 Sec for DBE
Narela Mandi
Palla
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Rohini
Sultanpur Dabas
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Mangole Puri
Ashok Vihar
University Campus
Maujpur
Mundka
Pschim Vihar
Jharoda
Ranohalla
Karolbagh
Gita Colony
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
Mundela
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Rawta
Chhatarpur
Tughlakabad
Ayanagar
Chandanhul
Bhatibas
Yamuna
Ridge
SA_0.3S (in g)
>0.166 - 0.3
>0.3 - 0.4
>0.4 - 0.5
>0.5 - 0.6
>0.6 - 0.68
Kilometers
0 3.5 7 14 21 28

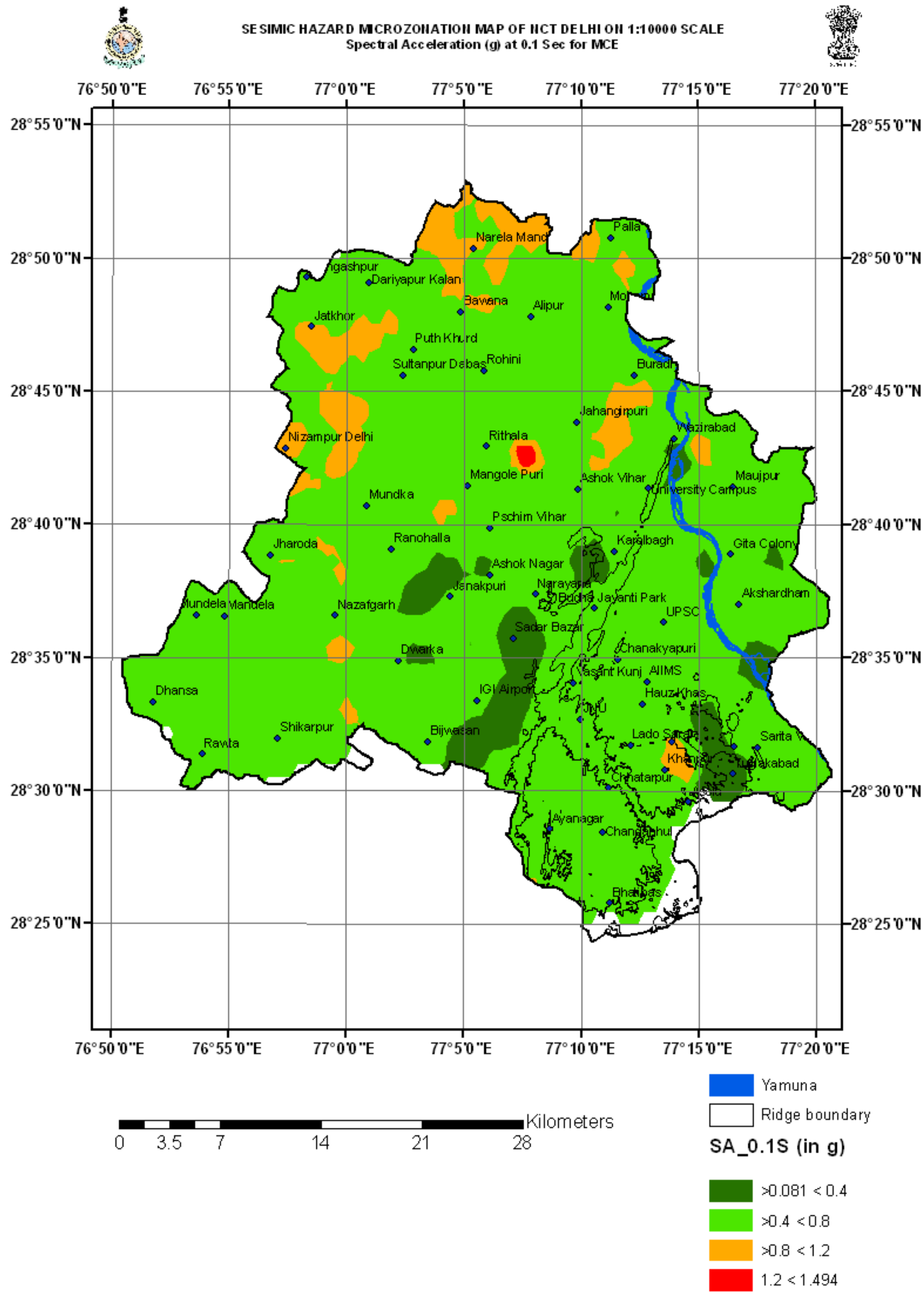
Map-27


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Spectral Acceleration at 0.5 Sec for DBE
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Palla
Narela Mand
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Rohini
Sultanpur Dabas
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Mangole Puri
Ashok Vihar
Maujpur
University Campus
Mundka
Pschim Vihar
Jharoda
Ranohalla
Karolbagh
Gita Colony
Ashok Nagar
Janakpuri
Narayana
Akshardham
Mundela Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Sarita V
Rawta
Khanpur
Tughlakabad
Chhatarpur
Ayanagar
Bhatias
Kilometers
0
3.5
7
14
21
28
Yamuna
Ridge
SA_0.5S (in g)
>0.12- 0.2
>0.2 - 0.3
>0.3 - 0.4
>0.4 - 0.5
0.5 - 0.8182

Map-28

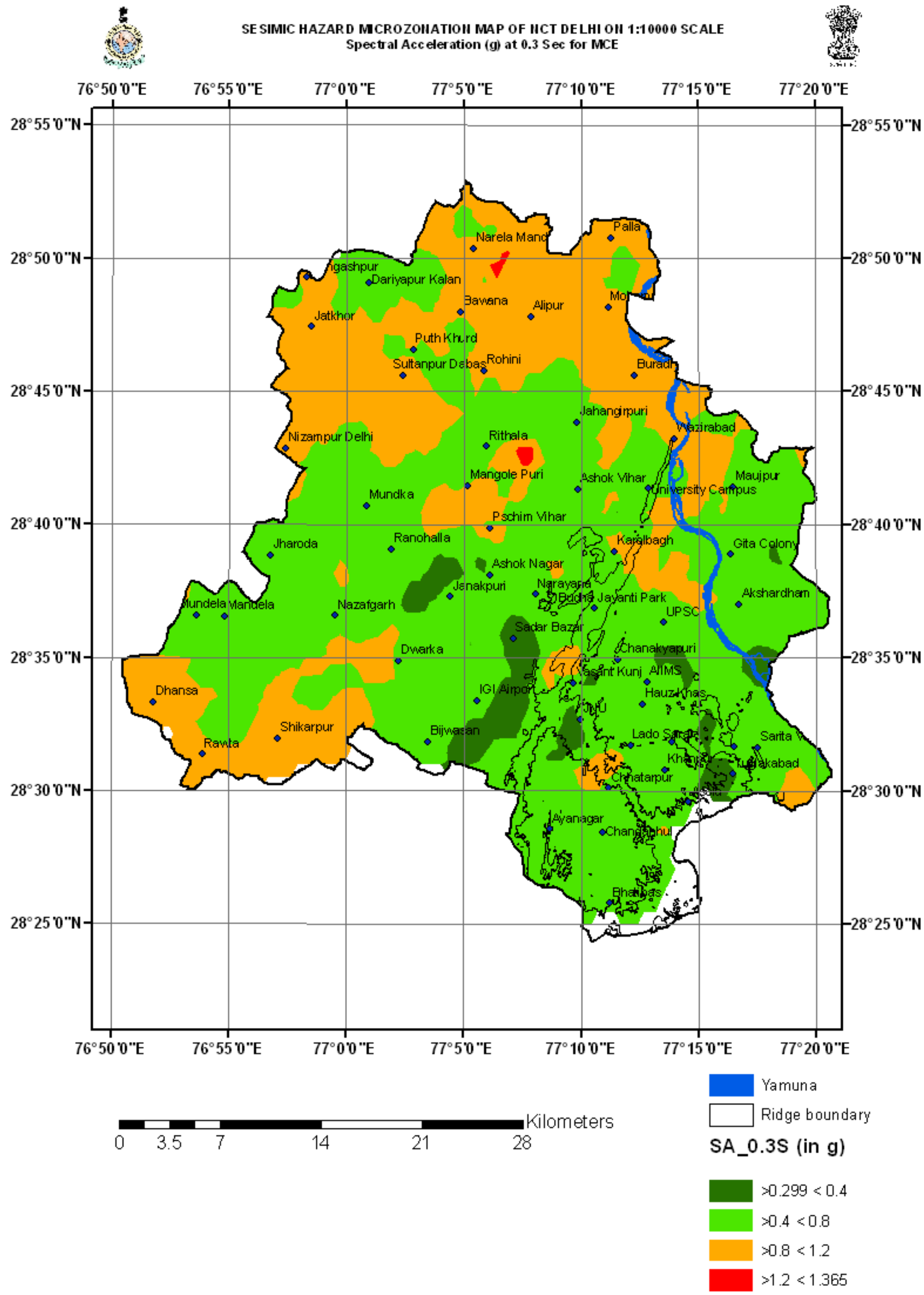

SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Spectral Acceleration at 1.0 Sec for DBE
Narela Mandi
Palla
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Burari
Jahangirpuri
Nizampur Delhi
Rithala
Wazirabad
Mangole Puri
Ashok Vihar
Maujpur
University Campus
Mundka
Pschim Vihar
Jharoda
Ranohalla
Karolbagh
Gita Colony
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
UPSC
Nazafgarh
Sadar Bazar
Chanakyapuri
Dwarka
AIIMS
Dhansa
IGI Airport
Hauz Khas
Shikarpur
Bijwasan
Lado Sarai
Sarita Vihar
Rawta
Chhatarpur
Ayanagar
Bhatti
Yamuna
Ridge
SA_1.0S (in g)
>0.066 - 0.08
>0.08 - 0.1
>0.1 - 0.15
>0.15 - 0.22
Kilometers
0 3.5 7 14 21 28

Map-29

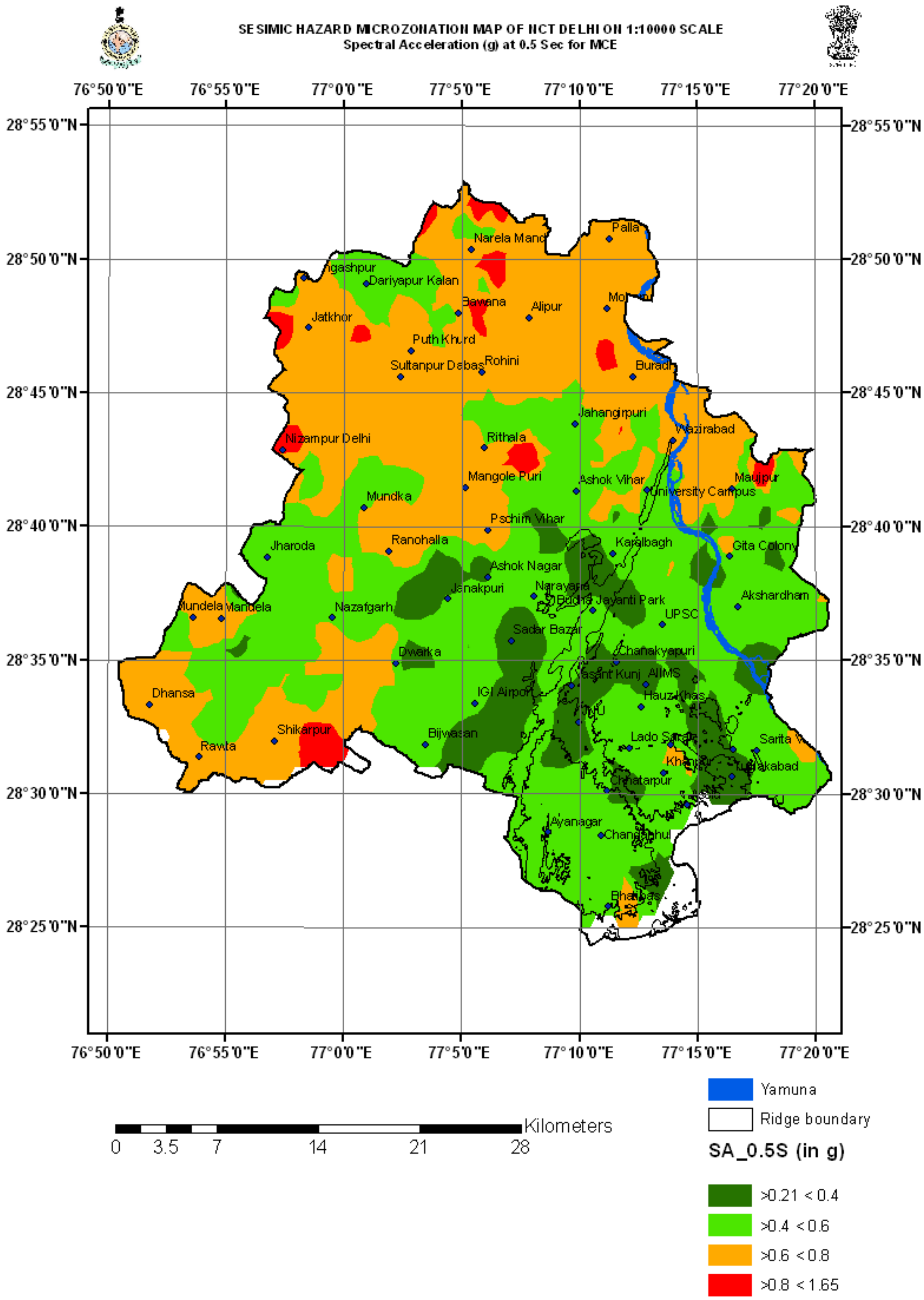


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Spectral Acceleration (g) at 0.1 Sec for MCE
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Palla
Narela Mand
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Mangole Puri
Ashok Vihar
University Campus
Maujpur
Mundka
Pschim Vihar
Karolbagh
Gita Colony
Jharoda
Ranohalla
Ashok Nagar
Janakpuri
Budha Jayanti Park
Akshardham
Mundela
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
Shikarpur
Bijwasan
Lado Sarai
Sarita V
Rawta
Chhatarpur
Ayanagar
Yamuna
Ridge boundary
SA_0.1S (in g)
>0.081 < 0.4
>0.4 < 0.8
>0.8 < 1.2
1.2 < 1.494
0
3.5
7
14
21
28
Kilometers

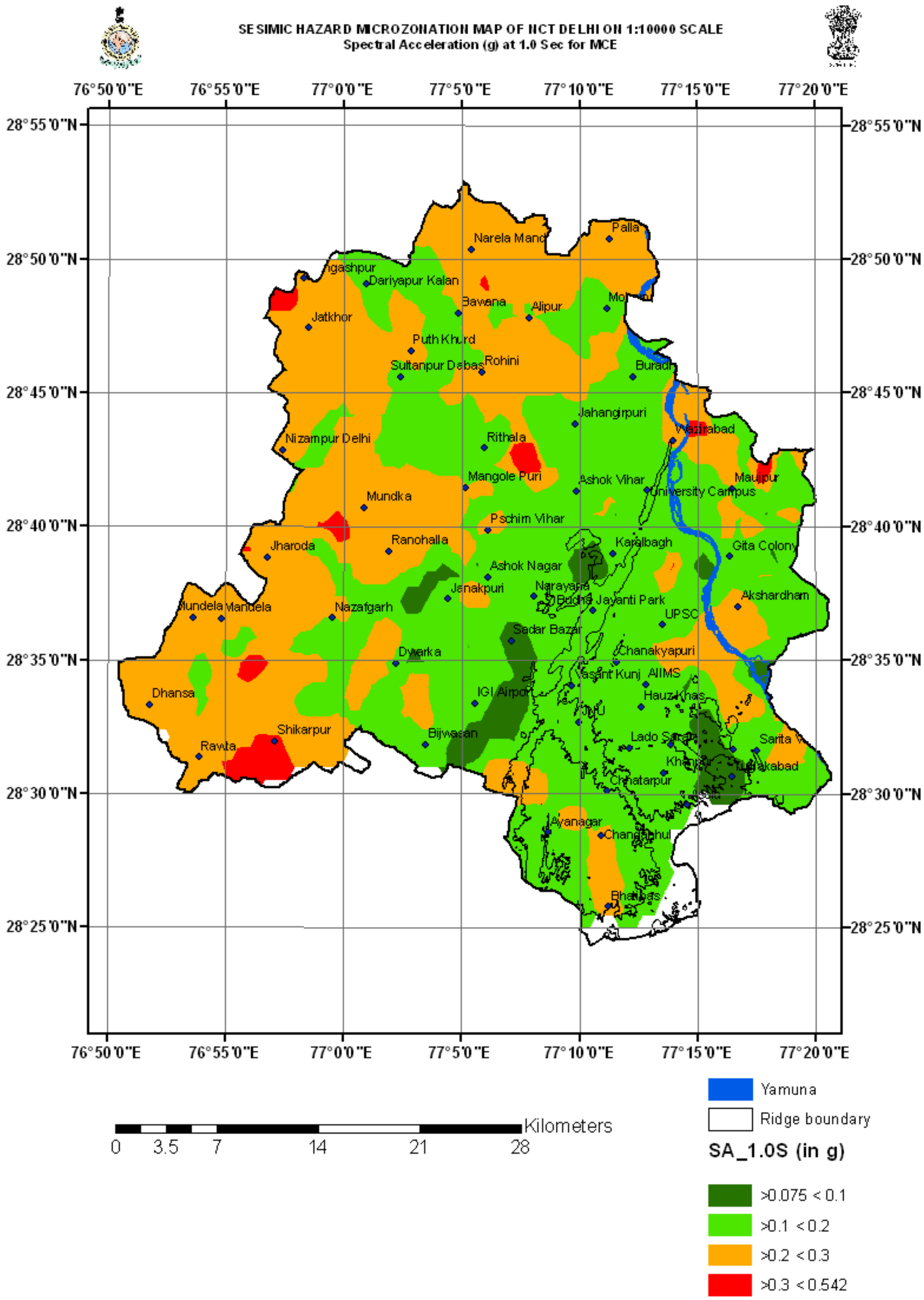
Map-30


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Spectral Acceleration (g) at 0.3 Sec for MCE
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Palla
Narela Mand
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Mangole Puri
Ashok Vihar
University Campus
Maujpur
Mundka
Pschim Vihar
Karolbagh
Gita Colony
Jharoda
Ranohalla
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
Mundela
Mandela
Nazafgarh
UPSC
Sadar Bazar
Chanakyapuri
Dwarka
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Sarita V
Rawta
Chhatarpur
Ayanagar
Bhatbas
Yamuna
Ridge boundary
Kilometers
0
3.5
7
14
21
28
SA_0.3S (in g)
>0.299 < 0.4
>0.4 < 0.8
>0.8 < 1.2
>1.2 < 1.365

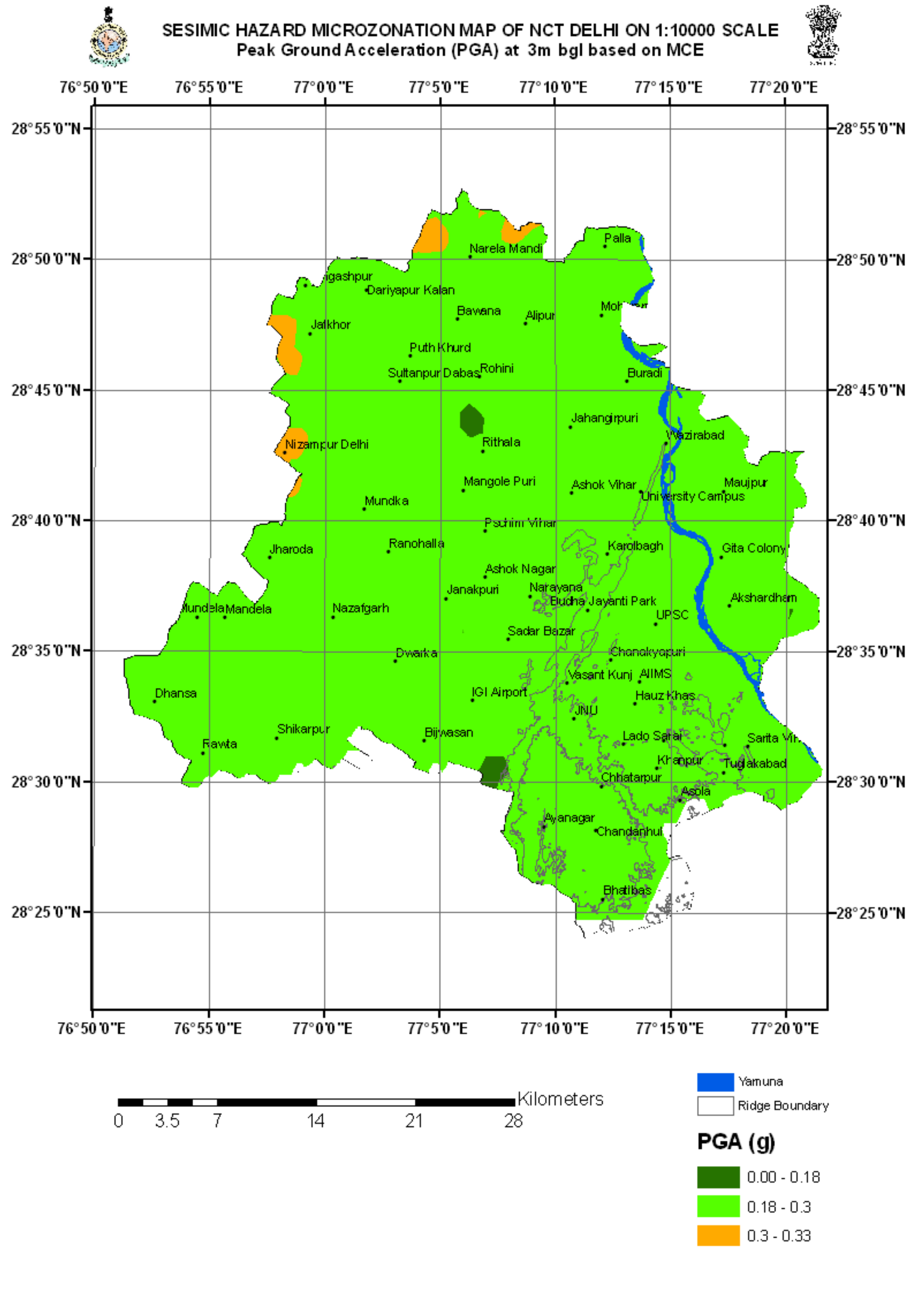
Map-31


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Spectral Acceleration (g) at 0.5 Sec for MCE
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Narela Mand
Palla
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Nizampur Delhi
Rithala
Wazirabad
Mangole Puri
Ashok Vihar
University Campus
Maujpur
Mundka
Pschim Vihar
Ranohalla
Karolbagh
Gita Colony
Jharoda
Ashok Nagar
Janakpuri
Budha Jayanti Park
Akshardham
Mundela
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
AIIMS
Dhansa
IGI Airport
Hauz Khas
Shikarpur
Bijwasan
Lado Sarai
Rawta
Chhatarpur
Ayanagar
Kilometers
0
3.5
7
14
21
28
Yamuna
Ridge boundary
SA_0.5S (in g)
>0.21 < 0.4
>0.4 < 0.6
>0.6 < 0.8
>0.8 < 1.65

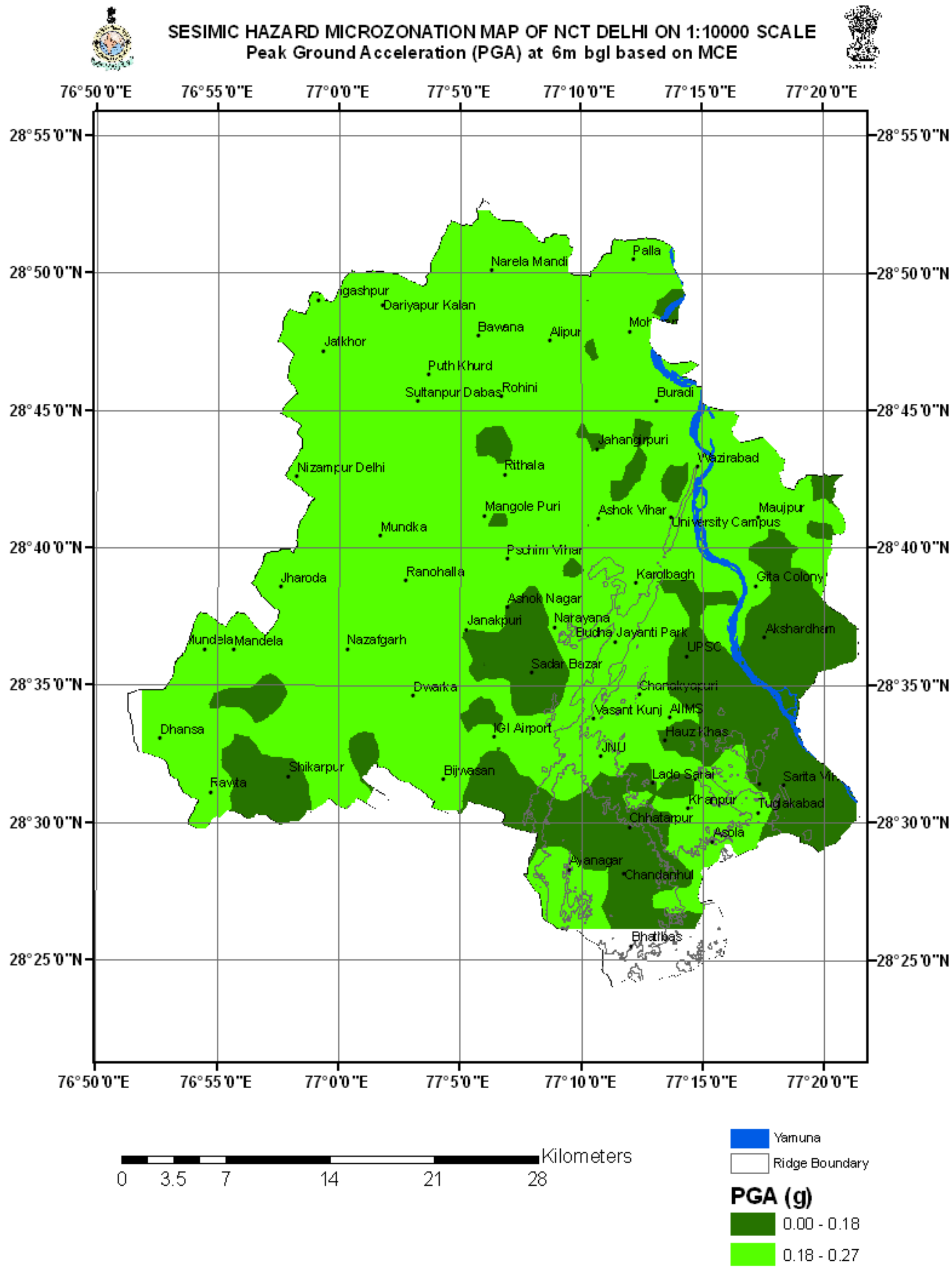
Map-32


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Spectral Acceleration (g) at 1.0 Sec for MCE
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Narela Mand
Palla
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Nizampur Delhi
Rithala
Wazirabad
Mangole Puri
Ashok Vihar
Maujpur
University Campus
Mundka
Pschim Vihar
Ranohalla
Karolbagh
Gita Colony
Jharoda
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
Shikarpur
Bijwasan
Lado Sarai
Sarita V
Rawta
Chhatarpur
Ayanagar
Chandanhul
Bhatti
Yamuna
Ridge boundary
SA_1.0S (in g)
>0.075 < 0.1
>0.1 <0.2
>0.2 <0.3
>0.3 <0.542
Kilometers
0
3.5
7
14
21
28

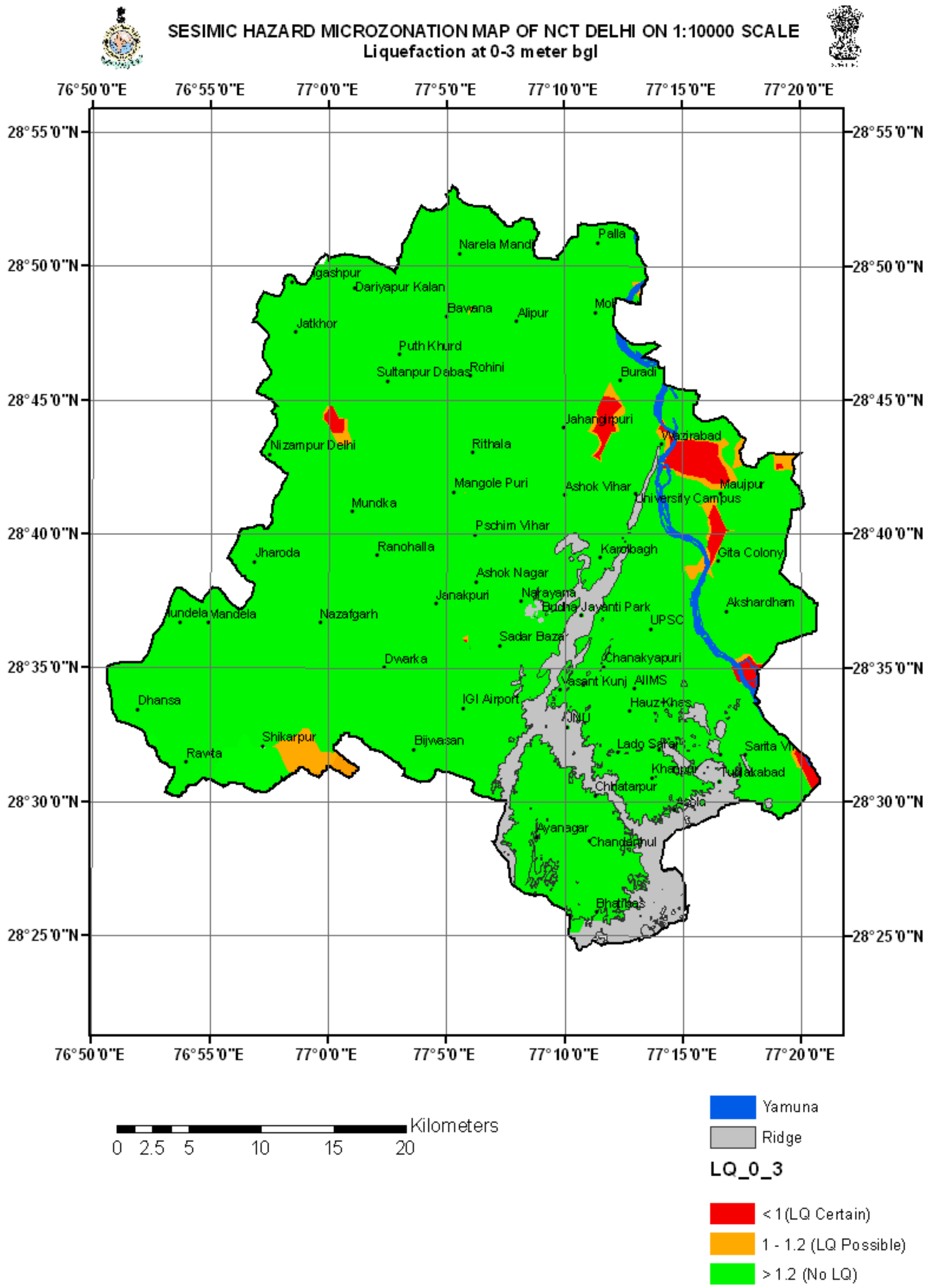
Map-33


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Peak Ground Acceleration (PGA) at 3m bgl based on MCE
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Narela Mandi
Palla
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Mangole Puri
Ashok Vihar
Maujpur
University Campus
Mundka
Paschim Vihar
Karolbagh
Gita Colony
Jharoda
Ranohalla
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Rawta
Khanpur
Tuglakabad
Chhatarpur
Aspla
Ayanagar
Chandanhul
Bhatibas
0
3.5
7
14
21
28
Kilometers
Yamuna
Ridge Boundary
PGA (g)
0.00 - 0.18
0.18 - 0.3
0.3 - 0.33

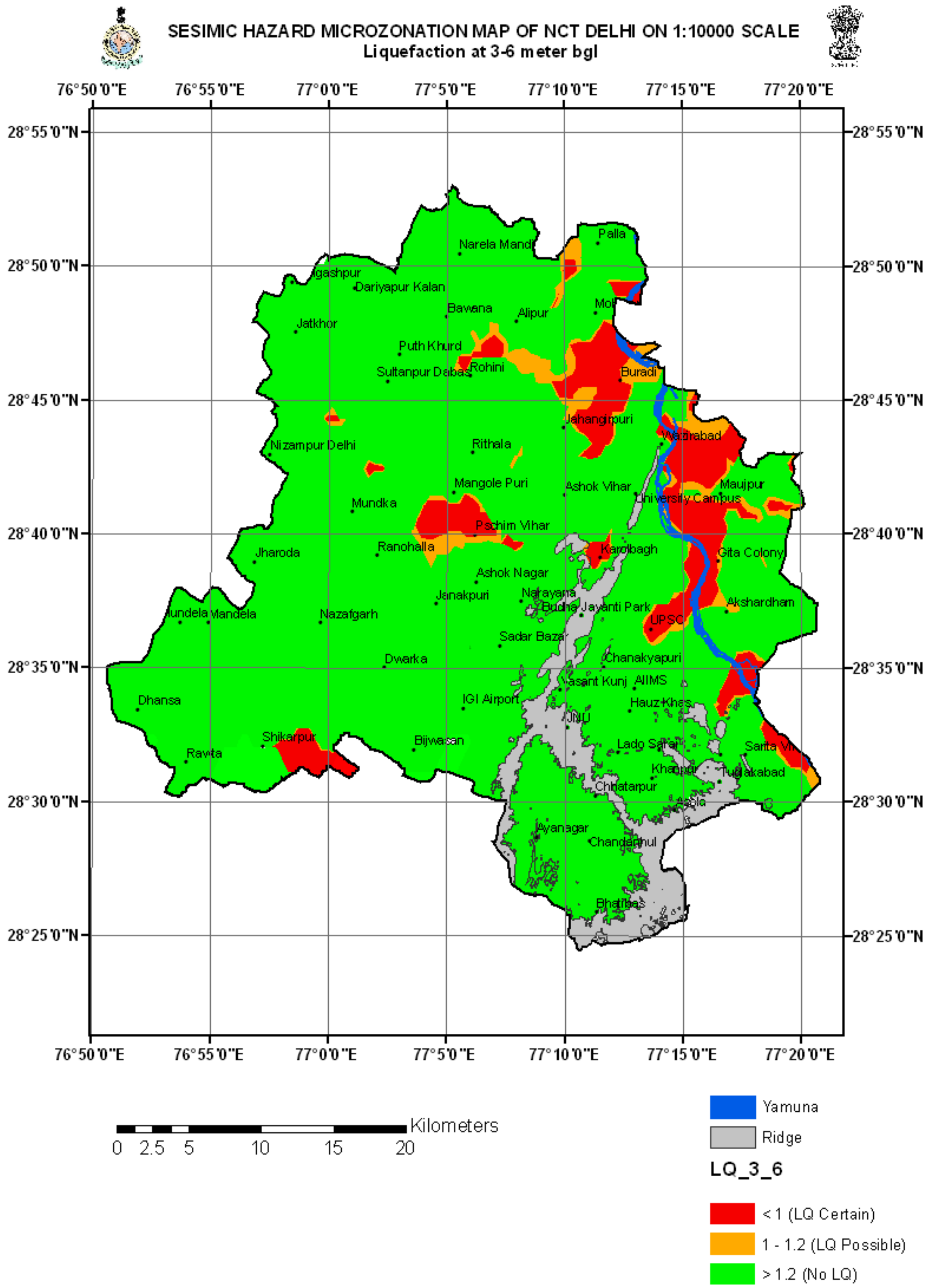
Map - 34


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Peak Ground Acceleration (PGA) at 6m bgl based on MCE
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Narela Mandi
Palla
Dariyapur Kalan
Bawana
Alipur
Jaitkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Mangole Puri
Ashok Vihar
Maujpur
University Campus
Mundka
Pschim Vihar
Karolbagh
Gita Colony
Jharoda
Ranohalla
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Sarita Vi
Ravita
Khanpur
Tuglakabad
Chhatarpur
Asola
Ayanagar
Chandanhul
Bhatibas
Kilometers
0
3.5
7
14
21
28
Yamuna
Ridge Boundary
PGA (g)
0.00 - 0.18
0.18 - 0.27

Map - 35

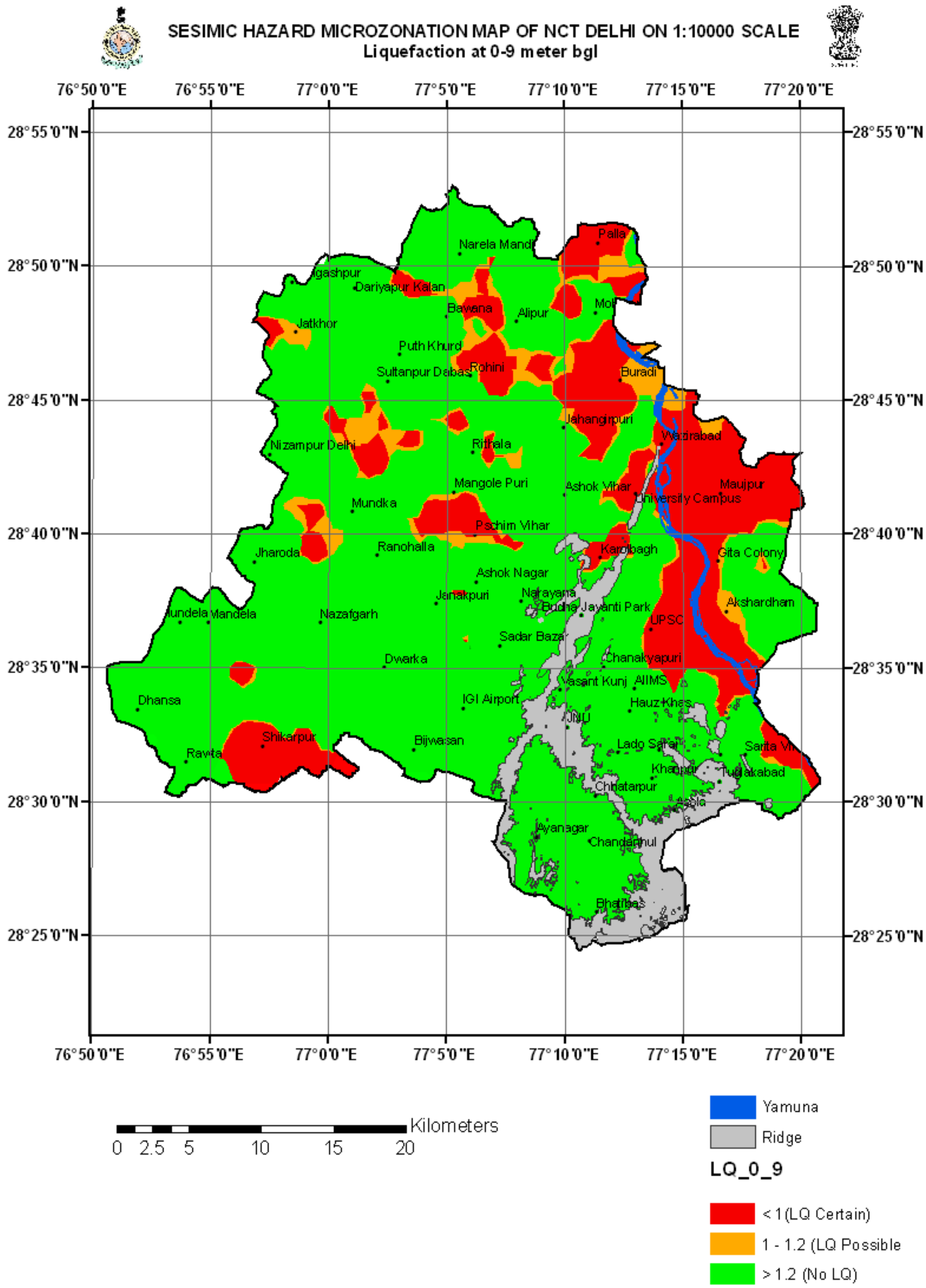

SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Liquefaction at 0-3 meter bgl
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Palla
Narela Mandi
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Ashok Vihar
Maujpur
University Campus
Mangole Puri
Mundka
Pschim Vihar
Jharoda
Ranohalla
Karolbagh
Gita Colony
Ashok Nagar
Janakpuri
Akshardham
Mandela
Nazafgarh
UPSC
Sadar Bazar
Dwarka
Chanakyapuri
AIIMS
Dhansa
IGI Airport
Vasant Kunj
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Ravita
Tughlakabad
Chhatarpur
Ayanagar
Chandanhul
Kilometers
0
2.5
5
10
15
20
Yamuna
Ridge
LQ_0_3
< 1 (LQ Certain)
1 - 1.2 (LQ Possible)
> 1.2 (No LQ)

Map-36

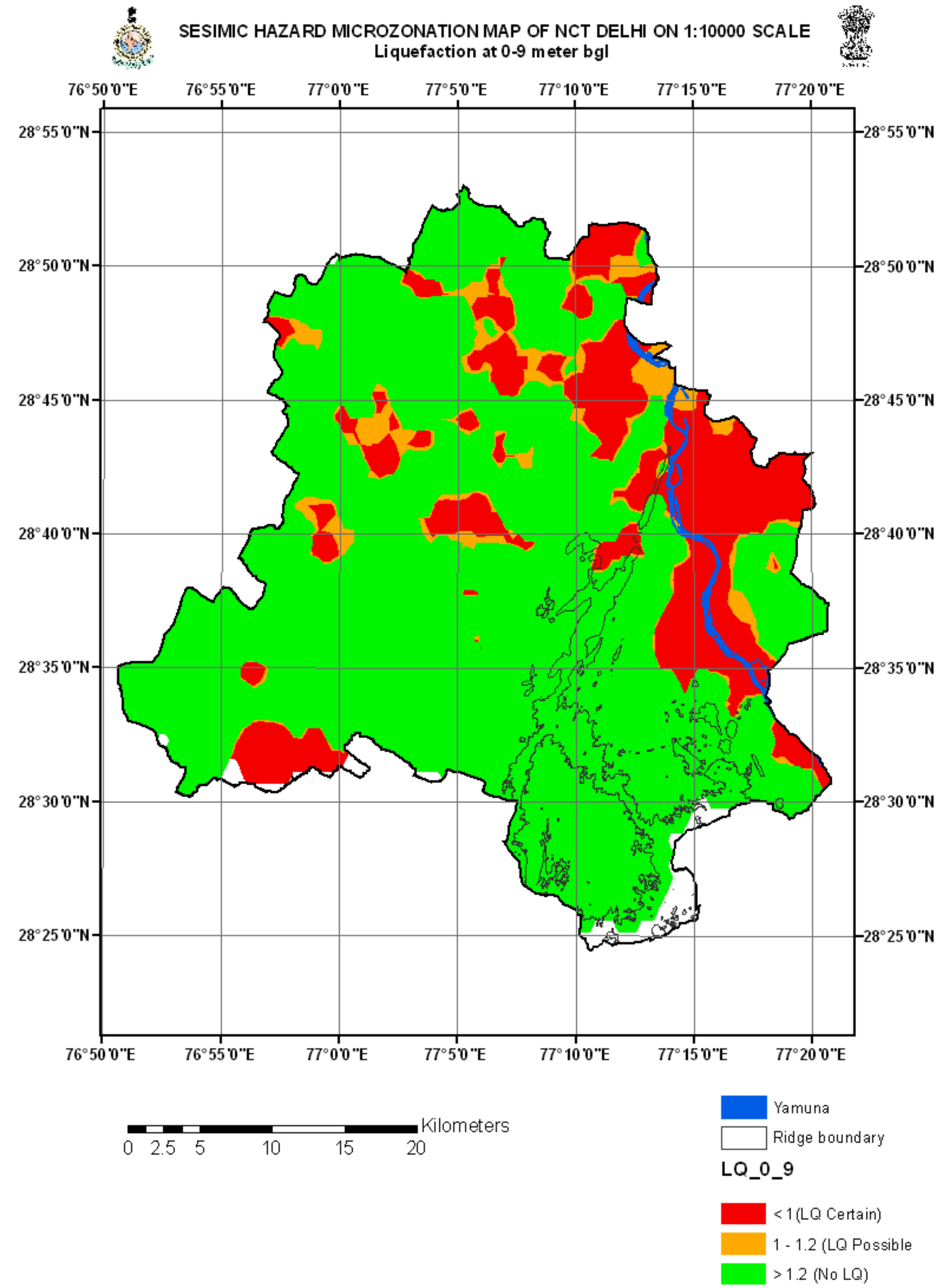


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Liquefaction at 3-6 meter bgl
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Palla
Narela Mandi
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Rohini
Sultanpur Dabas
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Mangole Puri
Ashok Vihar
Maujpur
University Campus
Mundka
Pschim Vihar
Karolbagh
Ranohalla
Gita Colony
Jharoda
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
UPSC
Mandela
Nazafgarh
Sadar Bazar
Dwarka
Chanakyapuri
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Ravita
Tuglakabad
Chhatarpur
Ayanagar
Chandanhul
Kilometers
0 2.5 5 10 15 20
Yamuna
Ridge
LQ_3_6
< 1 (LQ Certain)
1 - 1.2 (LQ Possible)
> 1.2 (No LQ)

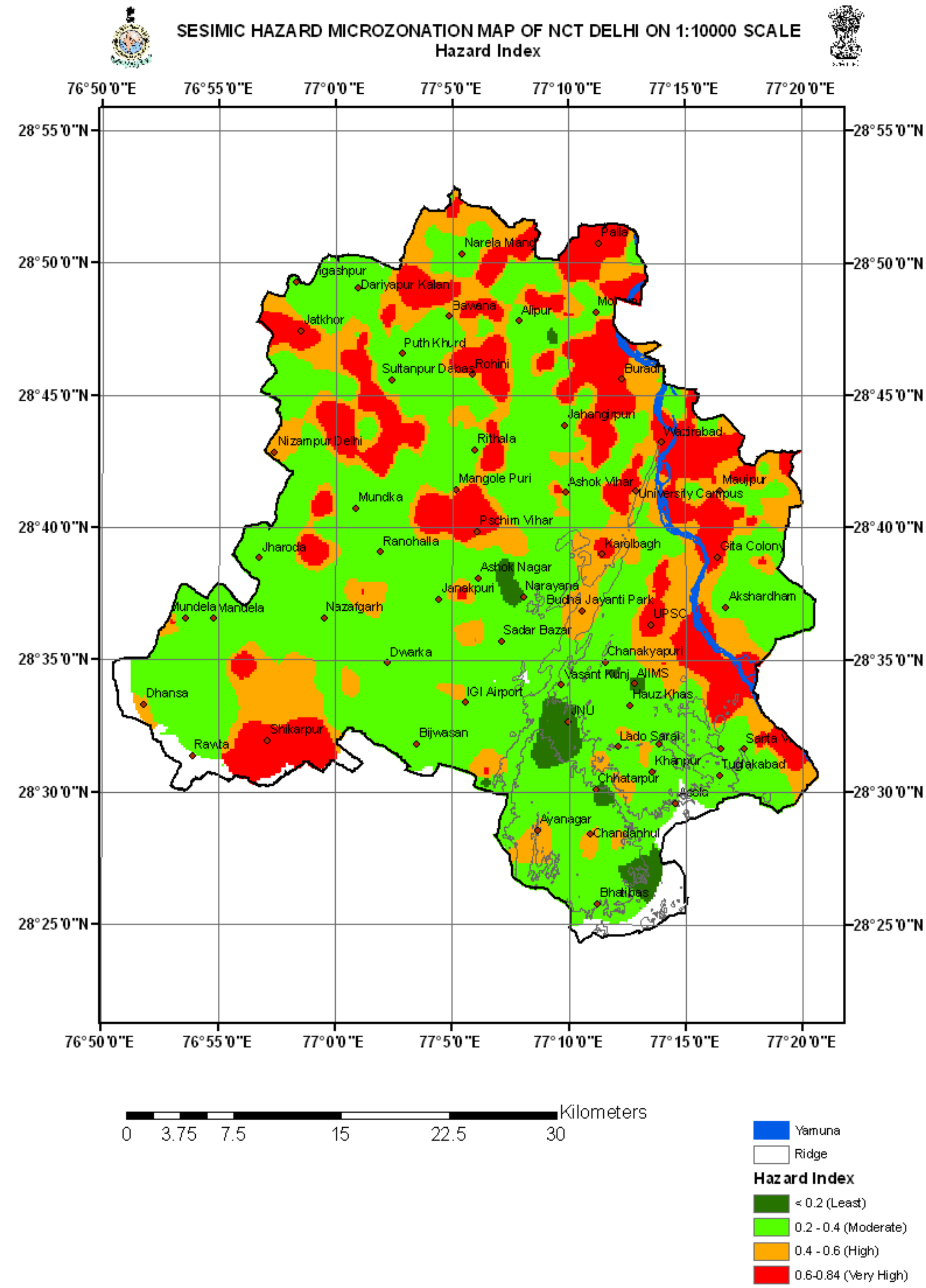
Map -37


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Liquefaction at 0-9 meter bgl
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Palla
Narela Mandi
Dariyapur Kalan
Bawana
Alipur
Jatkhor
Puth Khurd
Sultanpur Dabas
Rohini
Buradi
Jahangirpuri
Wazirabad
Nizampur Delhi
Rithala
Mangole Puri
Ashok Vihar
Maujpur
University Campus
Mundka
Pschim Vihar
Jharoda
Ranohalla
Karolbagh
Gita Colony
Ashok Nagar
Janakpuri
Narayana
Budha Jayanti Park
Akshardham
Mandela
Nazafgarh
UPSC
Sadar Baza
Dwarka
Chanakyapuri
Vasant Kunj
AIIMS
Dhansa
IGI Airport
Hauz Khas
JNU
Shikarpur
Bijwasan
Lado Sarai
Ravta
Chhatarpur
Tuglakabad
Ayanagar
Chandanhul
Kilometers
0 2.5 5 10 15 20
Yamuna
Ridge
LQ_0_9
< 1 (LQ Certain)
1 - 1.2 (LQ Possible
> 1.2 (No LQ)

Map – 38


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Liquefaction at 0-9 meter bgl
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
77°10'0"E
77°15'0"E
77°20'0"E
28°55'0"N
28°50'0"N
28°45'0"N
28°40'0"N
28°35'0"N
28°30'0"N
28°25'0"N
Kilometers
0 2.5 5 10 15 20
Yamuna
Ridge boundary
LQ_0_9
< 1 (LQ Certain)
1 - 1.2 (LQ Possible
> 1.2 (No LQ)

Map -39


SESIMIC HAZARD MICROZONATION MAP OF NCT DELHI ON 1:10000 SCALE
Hazard Index
Kilometers
0 3.75 7.5 15 22.5 30
Yamuna
Ridge
Hazard Index
< 0.2 (Least)
0.2 - 0.4 (Moderate)
0.4 - 0.6 (High)
0.6-0.84 (Very High)

Map -40

Table 7.2: 30 meter depth profile of shear wave velocity (m/sec) at 25 sites based on Down Hole Test (DHT) and Cross Hole Test (CHT) with 4 meter and 8 meter spacing DHT, CHT(4m), CHT (8m) and CHT(Avg) are shear wave velocities in m/sec computed by these methods at different depth intervals.

	BH/SH: 43/31 Rohini				**BH/SH: 1n/14 Bawana Khanjawala**				**BH/SH: 1n/28 Narela**			
Depth (m)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)
1.5	118.67	183.57	212.33	197.95	192.34	195.12	195.12	195.12	162.03	231.21	173.91	202.56
3	129.53	205.41	212.33	208.87	155.76	169.49	181.82	175.655	171.07	215.05	187.35	201.20
4.5	150.52	245.16	253.27	249.22	151.64	228.57	202.02	215.295	200.31	289.86	181.00	235.43
6	168.09	256.76	317.62	287.19	206.59	204.08	231.21	217.645	222.86	275.86	212.20	244.03
7.5	188.05	301.59	357.14	329.37	220.78	207.25	271.19	239.22	233.46	300.75	273.04	286.90
9	202.24	314.05	374.4	344.23	254.52	281.69	327.87	304.78	240.17	300.75	285.71	293.23
10.5	212	324.79	397.44	361.12	274.82	298.51	350.88	324.695	266.35	300.75	296.30	298.53
12	230.82	365.38	379.9	372.64	260.82	285.71	360.36	323.035	283.70	285.71	293.04	289.38
13.5	239.46	283.58	363.85	323.72	273.4	277.78	398.01	337.895	298.05	263.16	307.69	285.43
15	248.39	304	329.79	316.90	275.18	275.86	370.37	323.115	293.05	294.12	347.83	320.98
16.5	261.2	314.05	327	320.53	279.28	303.03	346.32	324.675	295.26	275.86	366.97	321.42
18	272.77	273.38	342.92	308.15	287.68	327.87	300.75	314.31	296.24	317.46	307.69	312.58
19.5	288.49	273.38	389.45	331.42	303.51	350.88	326.53	338.705	298.48	314.96	294.12	304.54
21	282.77	368.93	387.5	378.22	285.45	322.58	396.04	359.31	301.75	289.86	318.73	304.30
22.5	296.4	336.28	376.21	356.25	302.25	380.95	336.13	358.54	305.51	360.36	350.88	355.62
24	298.54	408.6	469.7	439.15	307.2	449.44	379.15	414.295	308.90	336.13	416.67	376.40
25.5	305.83	493.51	506.54	500.03	332.6	373.83	353.98	363.905	308.23	487.80	481.93	484.87
27	305.99	463.41	508.21	485.81	311.89	425.53	373.83	399.68	307.31	408.16	454.55	431.36
28.5	312.14	469.14	509.87	489.51	311.47	470.59	441.99	456.29	311.16	404.04	434.78	419.41
30	315.27	463.41	513.25	488.33	316.3	533.33	547.95	540.64	320.06		470.59	

Table 7.2 continue

	BH/SH: 3n/29, Holambi Khurd				**BH/SH: 11n/38, Bakhtiyarpur**				**BH/SH: BH/SH: 57/41, Lawrence road, Kanhaiya nagar**			
Depth (m)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (8m)	Depth (m)	CHT (4m)
1.5	159.72	180.18	207.79	193.99	148.41	176.21	229.23	202.72	190.57	209.42	1.00	268.46
3	169.71	184.33	208.33	196.33	160.10	204.08	251.57	227.83	196.42	266.67	2.50	279.72
4.5	160.01	183.49	181.82	182.66	179.68	198.02	248.45	223.24	251.55	297.40	4.00	320
6	176.53	225.99	199.50	212.75	184.80	204.08	249.22	226.65	244.82	297.40	5.50	298.51
7.5	201.94	207.25	233.92	220.59	204.50	192.31	281.69	237.00	254.82	297.40	7.00	344.83

9	198.89	289.86	352.42	321.14	227.50	187.79	254.78	221.29	261.35	379.15	9.50	384.62
10.5	208.00	336.13	308.88	322.51	230.87	298.51	295.20	296.86	281.45	353.98	11.00	380.95
12	219.31	163.27	349.34	256.31	266.58	325.20	336.13	330.67	298.78	306.51	12.50	250
13.5	230.49	380.95	333.33	357.14	291.14	333.33	279.72	306.53	280.51	295.20	14.00	336.13
15	251.60	373.83	400.00	386.92	304.12	330.58	333.33	331.96	280.68	305.34	15.50	353.98
16.5	274.93	360.36	388.35	374.36	304.36	272.11	343.35	307.73	297.35	317.46	17.00	298.51
18	268.36	392.16	410.26	401.21	308.25	353.98	361.99	357.99	294.33	317.46	21.00	317.46
19.5	263.06	388.35	414.51	401.43	311.19	370.37	414.51	392.44	300.75	331.95	22.50	325.2
21	259.97	251.57	412.37	331.97	313.34	380.95	434.78	407.87	319.96	346.32	24.00	325.2
22.5	275.47	366.97	457.14	412.06	313.52	434.78	476.19	455.49	316.14	330.58	25.50	325.2
24	282.56	416.67	444.44	430.56	314.52	416.67	390.24	403.46	313.30	340.43	27.00	333.33
25.5	288.49	388.35	380.95	384.65	317.38	336.13	360.36	348.25	307.50	352.42	28.50	322.58
27	295.93	416.67	536.91	476.79	317.73	338.98	384.62	361.80	322.26	327.87	29.50	336.13
28.5	298.52	421.05	425.53	423.29	319.48	370.37	334.73	352.55	318.06	330.58		
30	302.71	408.16	437.16	422.66	320.06	388.35	476.19	432.27	323.15	316.21		

Table 7.2 continue

Depth (m)	**BH/SH: 49/67; Flood Plain opp Akshardham**				**BH/SH: 23/61; Jawaharlal Nehru Stadium**				**BH/SH: 11n/39; J J Colony, Swaroop nagar**			
	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)
1.5	142.12	147.78	153.56	150.67	152.50	303.03	281.69	292.36	237.33	177.78	219.78	198.78
3	161.93	150.95	162.38	156.67	181.16	322.58	301.89	312.24	241.55	194.17	230.55	212.36
4.5	183.96	144.36	166.33	155.34	251.88	344.83	406.09	375.46	241.80	190.48	200.00	195.24
6	162.82	137.64	171.55	154.60	324.77	392.16	410.26	401.21	269.07	215.05	239.52	227.29
7.5	184.85	140.66	154.72	147.69	265.63	412.37	392.16	402.27	252.23	199.00	259.74	229.37
9	218.09	147.38	168.03	157.70	295.80	294.12	304.18	299.15	266.19	223.46	299.63	261.55
10.5	253.96	140.91	171.91	156.41	333.53	412.37	432.43	422.40	281.61	317.46	310.08	313.77
12	284.35	155.24	182.22	168.73	290.14	408.16	430.11	419.14	281.09	325.20	340.43	332.82
13.5	311.47	180.84	192.49	186.66	300.21	298.51	313.73	306.12	287.35	357.14	299.63	328.39
15	296.45	186.67	204.49	195.58	291.18	294.12	278.75	286.44	287.48	347.83	380.95	364.39
16.5	302.17	186.67	193.85	190.26	289.27	310.08	271.19	290.64	297.86	360.36	360.36	360.36
18	282.92	187.50	195.70	191.60	289.48	283.69	258.90	271.30	305.79	373.83	390.24	382.04
19.5	323.43	223.40	250.00	236.70	306.31	242.42	240.24	241.33	299.34	380.95	410.26	395.61
21	321.41	300.00	260.32	280.16	301.55	330.58	352.42	341.50	318.12	363.64	421.05	392.35
22.5	323.35	251.50	264.52	258.01	306.30	373.83	347.83	360.83	306.75	392.16	470.59	431.38
24	318.25	341.46	288.73	315.10	309.15	294.12	320.00	307.06	303.76	416.67	421.05	418.86
25.5	283.71	344.26	350.43	347.35	310.96	303.03	301.89	302.46	305.47	370.37	370.37	370.37
27	319.98	347.11	341.67	344.39	308.71	312.50	279.72	296.11	308.41	388.35	390.24	389.30
28.5	316.31	318.18	341.67	329.93	323.01	330.58	337.55	334.07	316.60	400.00	370.37	385.19
30	324.19	280.00	320.31	300.16	311.74	363.64	358.74	361.19	312.66	392.16	470.59	431.38

Table 7.2 continue

Depth (m)	BH/SH: 52/23; Mubarakpur, Rani Khera				BH/SH: 3n/17; Prem Vihar near Najafgarh nala				BH/SH: 6n/51; Azad Market			
	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)
1.5	190.71	173.16	226.63	199.90	167.45	212.77	253.16	232.97	139.60	168.78	194.17	181.48
3	215.52	204.08	217.39	210.74	197.63	275.86	291.97	283.92	165.40	186.05	205.66	195.86
4.5	226.35	204.08	217.98	211.03	218.91	314.96	285.71	300.34	139.04	188.68	212.77	200.73
6	253.91	220.99	243.90	232.45	240.33	320.00	317.46	318.73	169.86	202.02	238.10	220.06
7.5	247.09	219.78	264.03	241.91	266.46	341.88	300.75	321.32	208.04	219.78	246.15	232.97
9	293.12	259.74	272.11	265.93	243.81	320.00	352.42	336.21	230.04	225.99	253.16	239.58
10.5	272.06	279.72	301.89	290.81	257.21	360.36	390.24	375.30	214.09	228.57	261.44	245.01
12	284.89	294.12	303.03	298.58	273.22	353.98	398.01	376.00	247.19	233.92	267.56	250.74
13.5	285.60	380.95	320.00	350.48	267.17	300.75	333.33	317.04	265.11	236.69	286.74	261.72
15	289.63	366.97	373.83	370.40	323.33	291.97	337.55	314.76	289.86	275.86	298.51	287.19
16.5	289.73	317.46	347.83	332.65	315.61	330.58	350.88	340.73	302.50	261.44	283.69	272.57
18	293.15	333.33	318.73	326.03	310.44	296.30	303.03	299.67	295.92	264.90	288.81	276.86
19.5	287.66	363.64	370.37	367.01	339.18	392.16	343.35	367.76	294.92	268.46	298.51	283.49
21	307.59	373.83	340.43	357.13	313.95	322.58	360.36	341.47	297.40	296.30	330.58	313.44
22.5	296.79	396.04	396.04	396.04	316.04	487.80	529.80	508.80	308.55	270.27	311.28	290.78
24	305.28	416.67	432.43	424.55	308.76	327.87	465.12	396.50	315.37	273.97	299.63	286.80
25.5	298.75	400.00	418.85	409.43	314.37	416.67	479.04	447.86	318.50	300.75	334.73	317.74
27	308.07	388.35	408.16	398.26	311.89	425.53	500.00	462.77	311.10	317.46	350.88	334.17
28.5	297.00	425.53	430.11	427.82	318.36	380.95	439.56	410.26	318.26	330.58	366.97	348.78
30	308.52	425.53	404.04	414.79	333.00	373.83	449.44	411.64	318.18	347.83	382.78	365.31

Table 7.2 continue

Depth (m)	BH/SH: 4/52; Budha garden				BH/SH: 28'/11; Khera Dabar				BH/SH: 64/35; Rajokri Village			
	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)
1.5	131.45	153.26	171.67	162.47	117.69	186.92	198.51	192.72	157.64	189.57	231.21	210.39
3	175.44	170.94	225.99	198.47	136.99	195.12	197.04	196.08	174.83	164.61	229.23	196.92
4.5	125.70	231.21	312.50	271.86	153.98	125.00	170.21	147.61	208.33	157.48	208.88	183.18
6	175.88	268.46	333.33	300.90	178.49	148.70	163.27	155.99	209.63	199.00	266.67	232.84
7.5	210.40	263.16	313.73	288.45	170.00	177.78	183.07	180.43	230.98	219.78	285.71	252.75

9	322.91	291.97	303.03	297.50	213.18	204.08	190.48	197.28	239.63	217.39	248.45	232.92
10.5	246.95	285.71	336.13	310.92	209.63	224.72	208.88	216.80	232.63	256.41	291.97	274.19
12	248.51	322.58	300.75	311.67	230.40	176.21	194.17	185.19	247.05	264.90	301.89	283.40
13.5	271.82	344.83	318.73	331.78	311.51	220.99	204.08	212.54	253.24	246.91	336.13	291.52
15	270.93	327.87	372.09	349.98	264.47	191.39	208.33	199.86	270.46	231.21	277.78	254.50
16.5	278.33	412.37	363.64	388.01	272.08	198.02	228.57	213.30	275.17	196.08	325.20	260.64
18	280.23	465.12	406.09	435.61	280.23	205.13	245.40	225.27	297.40	248.45	343.35	295.90
19.5	302.52	473.37	396.04	434.71	288.91	256.41	250.00	253.21	271.94	212.77	333.33	273.05
21	300.25	459.77	410.26	435.02	327.88	251.57	274.91	263.24	284.65	236.69	320.00	278.35
22.5	292.61	459.77	414.51	437.14	299.91	273.97	285.71	279.84	285.66	238.10	360.36	299.23
24	304.14	430.11	418.85	424.48	328.80	270.27	250.78	260.53	287.94	175.44	290.91	233.18
25.5	309.87	449.44	432.43	440.94	307.28	277.78	262.30	270.04	301.54	186.05	265.78	225.92
27	299.28	459.77	457.14	458.46	296.68	291.97	270.27	281.12	295.40	225.99	384.62	305.31
28.5	310.46	459.77	465.12	462.45	302.94	298.51	282.69	290.60	301.35	224.72	392.16	308.44
30	328.62	540.54	479.04	509.79	299.66	307.69	289.86	298.78	304.79	250.00	400.00	325.00

Table 7.2 continue

Depth (m)	**BH/SH: 5'/58; PTS Wazirabad**				**BH/SH: 48/54; Begumpur**				**BH/SH: ../51; Ridge Observatory**			
	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)
1.5	170.20	114.29	123.65	118.97	149.37	174.67	201.51	188.09	236.20	178.57	205.66	192.12
3	181.82	137.46	119.76	128.61	173.61	193.24	218.58	205.91	271.96	239.52	212.20	225.86
4.5	207.61	132.01	144.40	138.21	143.69	208.33	220.99	214.66	314.44	224.72	211.08	217.90
6	221.88	137.93	134.91	136.42	173.76	224.72	251.57	238.15	344.01	225.99	224.09	225.04
7.5	207.82	137.46	138.89	138.18	211.44	217.39	287.77	252.58	229.48	236.69	229.23	232.96
9	237.32	137.46	156.25	146.86	232.83	253.16	299.63	276.40	264.26	281.69	220.99	251.34
10.5	251.37	136.52	166.32	151.42	216.08	238.10	290.91	264.51	275.07	289.86	235.29	262.58
12	264.07	156.86	184.33	170.60	249.00	236.69	308.88	272.79	264.30	281.69	341.88	311.79
13.5	264.66	176.99	213.90	195.45	265.16	245.40	334.73	290.07	279.95	279.72	321.29	300.51
15	274.76	198.02	182.23	190.13	261.79	285.71	322.58	304.15	291.93	320.00	326.53	323.27
16.5	279.24	211.64	204.08	207.86	278.33	238.10	305.34	271.72	280.44	434.78	352.42	393.60
18	293.15	210.53	206.19	208.36	278.96	289.86	306.51	298.19	291.51	392.16	392.16	392.16

19.5	296.66	210.53	225.35	217.94	283.16	325.20	310.08	317.64	306.36	449.44	423.28	436.36
21	287.33	213.90	219.78	216.84	288.50	270.27	333.33	301.80	300.90	459.77	421.05	440.41
22.5	283.89	245.40	238.81	242.11	299.12	273.97	327.87	300.92	305.10	465.12	416.67	440.90
24	308.77	273.97	200.50	237.24	295.64	264.90	283.69	274.30	301.58	481.93	427.81	454.87
25.5	309.49	259.74	241.69	250.72	298.40	298.51	350.88	324.70	310.47	449.44	437.16	443.30
27	304.63	259.74	258.06	258.90	299.28	298.51	308.88	303.70	311.18	454.55	451.98	453.27
28.5	318.36	183.49	263.16	223.33	301.99	298.51	379.15	338.83	313.20	487.80	493.83	490.82
30	338.54	236.69	275.86	256.28	299.36	298.51	423.28	360.90				

Table 7.2 continue

	BH/SH: 9'/3; Mundela				**BH/SH: 53'/12; Shikarpur. Najafgarh**			**BH/SH: 53/54; Pushp Vihar**				
Depth (m)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	CHT (4m)	CHT (8m)	CHT (Avg)	Depth(m)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)
1.5	160.00	224.72	220.99	222.86	103.09	135.14	119.12	1	147.25	181.82	176.21	179.02
3	185.87	239.52	254.78	247.15	103.81	139.37	121.59	2.5	151.67	189.57	191.39	190.48
4.5	207.61	256.41	291.97	274.19	120.00	150.38	135.19	4	145.80	310.08	202.53	256.31
6	212.09	216.22	253.97	235.10	114.94	142.35	128.65	5.5	162.31	310.08	303.03	306.56
7.5	219.64	246.91	256.41	251.66	132.74	141.34	137.04	7	185.34	300.75	278.75	289.75
9	251.25	338.98	370.37	354.68	136.36	148.15	142.26	8.5	217.46	279.72	349.34	314.53
10.5	254.79	344.83	355.56	350.20	142.86	149.53	146.20	10	233.12	353.98	357.14	355.56
12	264.63	296.30	330.58	313.44	179.64	214.48	197.06	11.5	259.61	360.36	416.67	388.52
13.5	280.48	277.78	290.91	284.35	201.34	235.29	218.32	13	270.95	231.21	360.36	295.79
15	186.42	330.58	360.36	345.47	241.94	277.78	259.86	14.5	276.50	259.74	344.83	302.29
16.5	286.79	322.58	333.33	327.96	270.27	280.70	275.49	16	271.26	281.69	344.83	313.26
18	295.03	289.86	310.08	299.97	300.00	268.46	284.23	17.5	284.94	277.78	337.55	307.67
19.5	291.02	312.50	307.69	310.10	315.79	303.03	309.41	19	291.10	277.78	365.30	321.54
21	297.74	317.46	299.63	308.55	283.02	285.71	284.37	20.5	282.25	344.83	400.00	372.42
22.5	303.09	333.33	316.21	324.77	270.27	283.69	276.98	22	295.00	363.64	465.12	414.38
24	303.76	338.98	318.73	328.86	272.73	287.77	280.25	23.5	293.57	258.06	384.62	321.34
25.5	311.74	341.88	352.42	347.15	254.24	308.88	281.56	25	290.68	327.87	370.37	349.12
27	303.61	325.20	366.97	346.09	270.27	336.13	303.20	26.5	302.49	281.69	398.01	339.85
28.5	309.12	341.88	353.98	347.93	300.00	317.46	308.73	28	316.73	333.33	390.24	361.79
30	306.64	344.83	357.14	350.99				29.5	319.42	363.64	444.44	404.04
								31	298.54	540.54	406.09	473.32
								32.5	313.65	296.30	366.97	331.64
								34	307.04	285.71	388.35	337.03

Table 7.2 continue

Depth (m)	BH/SH: 75/45; Jaunapur				BH/SH: 6'/33; Janakpuri				BH/SH: 77'/55; Chandanhulla			
	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)	DHT	CHT (4m)	CHT (8m)	CHT (Avg)
1.5	194.18	296.30	250.00	273.15	117.04	144.93	191.85	168.39	135.62	159.36	191.39	175.38
3	214.59	307.69	257.23	282.46	151.98	150.94	203.56	177.25	139.28	161.29	209.97	185.63
4.5	240.83	320.00	261.44	290.72	161.42	157.48	208.33	182.91	160.55	162.60	182.23	172.42
6	274.19	285.71	275.86	280.79	219.18	165.98	213.90	189.94	149.30	123.84	166.32	145.08
7.5	303.57	289.86	296.30	293.08	200.00	177.78	222.84	200.31	161.29	125.79	212.20	169.00
9	328.30	294.12	320.00	307.06	226.41	189.57	238.10	213.84	190.50	170.94	167.71	169.33
10.5	307.00	281.69	275.86	278.78	254.79	205.13	261.44	233.29	198.87	212.77	204.60	208.69
12	306.27	294.12	318.73	306.43	275.58	232.56	270.27	251.42	201.42	156.25	183.91	170.08
13.5	332.86	333.33	372.09	352.71	257.41	248.45	277.78	263.12	205.25	228.57	224.09	226.33
15	269.05	388.35	402.01	395.18	292.91	258.06	290.91	274.49	211.21	156.86	226.63	191.75
16.5	273.84	400.00	410.26	405.13	282.97	273.97	303.03	288.50	230.37	209.42	227.27	218.35
18	269.18	384.62	425.53	405.08	279.38	277.78	296.30	287.04	243.26	170.94	197.53	184.24
19.5	267.55	392.16	434.78	413.47	319.01	245.40	249.22	247.31	252.61	203.05	219.18	211.12
21	278.35	392.16	423.28	407.72	310.27	227.27	254.78	241.03	261.98	205.13	246.15	225.64
22.5	280.06	444.44	459.77	452.11	322.78	273.97	287.77	280.87	264.19	246.91	256.41	251.66
24	283.58	493.83	479.04	486.44	311.94	283.69	297.40	290.55	300.75	251.57	336.13	293.85
25.5	287.76	506.33	484.85	495.59	314.78	287.77	300.75	294.26	283.96	259.74	318.73	289.24
27	291.61	519.48	516.13	517.81	314.09	291.97	307.69	299.83	298.30	236.69	343.35	290.02
28.5	292.47	571.43	540.54	555.99	330.80	305.34	326.53	315.94	294.27	270.27	333.33	301.80
30	296.72	588.24	575.54	581.89	343.93	325.20	340.43	332.82	271.44	298.51	305.34	301.93

Table 7.2 continue

Depth (m)	BH/SH: 35/69; J J Colony, Sarita Vihar			
	DHT	CHT (4m)	CHT (8m)	CHT (Avg)
1.5	194.18	106.67	102.17	104.42
3	186.57	108.70	107.82	108.26
4.5	206.19	122.70	116.96	119.83
6	233.37	142.35	133.33	137.84
7.5	247.81	152.09	148.42	150.26
9	231.74	166.67	159.68	163.18
10.5	240.09	187.79	156.56	172.18
12	249.98	180.18	190.48	185.33
13.5	263.67	187.79	186.92	187.36
15	258.31	186.05	207.79	196.92
16.5	274.28	216.22	227.92	222.07
18	289.01	236.69	222.22	229.46
19.5	295.78	253.16	225.35	239.26
21	279.45	258.06	243.16	250.61
22.5	288.18	251.57	245.40	248.49
24	285.91	258.06	255.59	256.83
25.5	286.16	239.52	231.88	235.70
27	289.45	246.91	269.36	258.14
28.5	275.14	258.06	246.91	252.49
30	283.65	264.90	257.23	261.07

Table 7.3: Site classification of 10 representative sites based on Shear wave velocity measurement using MASW Technique

Site and Location	Description of site and Shear wave velocity at different identified layers	Classification based on NEHRP
Akshar Dham Site 28^0 36' 32.13'' N & $77^0$15' 51.01''E	The site is located near Akshar Dham temple, New Delhi at the bank of river Yamuna. The site is underlain by sediments of the Yamuna River. The shear wave velocity profile carried out in this area with station spacing of one meters shows very low shear wave velocity i.e. 175 m/s up to a depth of 10.5 meters and then increases to 285 m/s below 20 meters depth. The average shear wave velocity at 25 to 30m is about 350m/s. The average shear wave velocity of 30 meter soil column (Vs30) is therefore about 230m/s.	180 <*V*s(30)<= 360 Class 'D'
Ghazipur 28^0 36' 52.79'' N & 77^0 18' 24.40'' E	The site is located further east of Akshar Dham with thick deposits of sandy material with minor amount of clay and silt. The shear wave velocity (Vs) of the top 8 m soil is < 180 m/sec. Below 8 m depth there is slight increase in shear wave velocity to 200m /s which goes up to a depth of 17m. Below, 17m the Vs increase to more than 250 m/sec. The average shear wave velocity of 30 meter soil is therefore about 212m/s	180 <*V*s(30)<= 360 Class D
Balsava 28^0 45' 01.14'' N & $77^0$09' 55.19'' E	This site is located in the northern most part of the city adjacent to the Balsava Lake. The site shows velocity Vs 100-250 m/s up to depth of 15-18 meters. Below 18 m depth, the Vs increase to 350 m/s. Further below 25 m the Vs increases to 400 m/s. The average shear wave velocity of 30 meter soil is therefore about 250m/s.	180 <*V*s(30)<= 360 Class D
Kirbi Cantt 28^0 35' 21.85'' N, &77^0 06' 42 57'' E	This site is located in the central part of the city and shows almost two layer up to 25 m depth and third layer represent velocity more than 300 m/s and the last layer is the half space. The top 8 m soil is the fill deposits has the shear wave velocity ~200 m/s. Down to depth below eight meter the velocity increase to 250 m/s . Below 25 m depth velocity is 300-350 m/s. The average shear wave velocity of 30 meter is therefore about 245m/s.	180 <*V*s(30)<= 360 Class D
Nazafgarh 28^0 36' 21.80'' N & 76^0 59' 21.65'' E)	The Nazafgarh site represents the flood plain of Sahibi- Nazafgarh drainage system and is located within Roshnabad stadium in Nazafgarh village situated in the western extremity of the NCT region. The shear wave velocity profile indicates a velocity in the range of 300-400 m/s up to a depth of 8 meter and velocity decrease to 280-290 m/s upto the depth of 15m. Below 15 m the Vs again increase to >400 m/s. The average	180 <*V*s(30)<= 360 (340m/s) Class D

	shear wave velocity of 30 meter is therefore about 240m/s.	
Bhavana Site 28^0 48' 41.97'' N & 77^0 00' 34.41'' E	The site is located in the play ground of village Dariya Gaon located in the northern part of the city. The ground has been made by reclaimed soil that is reflected by the top soil shear wave velocity 200 m/s-250 m/s. Below 4 m depth, shear wave velocity found to be very low of the order of 150 m/s-180 m/s. Further, down to 14 m depth the Vs increase to > 300 m/s. Below 20 m depth, the surface is highly undulating from 25m depth down to 35 m. Below 35 m depth the velocity increase of > 400 m/s. The average shear wave velocity of 30 meter is therefore about 250m/s.	180 <*V*s(30)<= 360 (250m/s) Class D
JNU Site 28^0 32' 07.63'' N, & 77^0 09' 45.42''E	The site is located on massive and weathered Alwar quartzite rocks, which are very well exposed in an area in almost north east south west direction in JNU. The shear wave velocity varies (600 m/s-800 m/s) at the surface to around 1200m/s at 30m depth and reaches to >2000 m/s at a depth of 50 meters. The average shear wave velocity of 30 meter is therefore about 850 m/s.	760 < *V*s(30) <= 1500 Class B
Asola Site 28^0 27' 02.71'' N, & 77^0 12' 33.96'' E)	The site is located on massive and weathered Alwar quartzite rocks, which are very well exposed in an area in south north direction in Asola area. In Asola area the profile runs along N-S direction perpendicular to joints and fractures shows shear wave velocity ranging from 400- 800 m/s (20 m depth), 800-1100 m/s (40 m depth), 1100- 1800 m/s (40-70 m) and > 2000 m/s below 80 m depth. The average shear wave velocity of 30 meter is therefore about 700 m/s.	360 < *V*s(30) <= 760 Class C
Suhalpur 28^0 27' 45.14'' N & 77^0 11' 00.41''E)	The Suhalpur in Chattarpur basin, which is dominated by older alluvium. The shear wave velocity profile shows of the order of 200-250 m/s at the top 15 m. The second layer which is also marked by Vs 300 m/s. Some dissolution features have been observed between 15m to 25m depth. The average shear wave velocity of 30 meter is therefore about 340 m/s.	180 <*V*s(30)<= 360 (340m/s) Class D
Jasola Site 28^0 31' 57.06'' N & 77^0 10' 22.36'' E)	The site is located northeastern side of the JNU in Chatterpur Basin. showing average shear wave velocity of 30meter (Vs30) around 340m/s.	180 <*V*s(30)<= 360 Class D

Table 7.4: Average Shear Wave Velocity (m/s) for 30m (Vs^{30}) along with Shear Wave Velocities at different depths below ground level.

S.N.	Lat	Long	Sh-eet No.	Locality name	Shear Wave Velocity (m/s) at various depths (m)										Vs30	Site Class
					(0-3)	(3-6)	(6-9)	(9-12)	(12-15)	(15-18)	(18-21)	(21-24)	(24-27)	(27-30)		
1	28.6247	76.9144	3	Kair	189	213	345	274	234	258	304	390	400	376	280	D
2	28.6186	76.8843	3	Mandhela Khurd	179	211	234	267	312	294	317	333	352	369	273	D
3	28.6128	76.8972	3	Mandhela Kalan	189	217	267	269	269	295	318	340	365	394	279	D
4	28.6128	76.9158	3	Kair	219	221	279	291	278	297	328	352	367	380	291	D
5	28.6075	76.8862	3	Mandhela Kalan	219	244	272	314	317	264	297	359	372	394	295	D
6	28.6028	76.9000	3	Mandhela Kalan	203	226	259	288	309	317	335	345	359	386	291	D
7	28.6029	76.9149	3	Jafarpur Kalan	199	230	279	303	294	320	340	359	370	382	295	D
8	28.5953	76.8871	4	Baqargarh	219	261	300	278	267	304	324	336	340	353	292	D
9	28.5591	76.9028	4	Ujwa	184	224	274	292	318	380	403	396	374	370	302	D
10	28.5991	76.9198	4	Jafarpur Kalan	185	217	266	284	309	374	394	410	359	367	297	D
11	28.5766	76.8839	4	Quazipur	184	216	311	230	254	304	319	303	333	363	270	D
12	28.5751	76.9009	4	shamaspur Khalsa	234	224	269	309	318	345	359	398	382	410	312	D
13	28.5798	76.9129	4	Ujwa	221	265	395	318	298	295	277	307	323	357	298	D
14	28.5647	76.8853	4	Quazipur	174	203	251	272	295	322	350	361	340	351	276	D
15	28.5654	76.9111	4	Ujwa	185	217	262	284	309	320	330	343	374	354	284	D
16	28.5509	76.9115	4	Daryapur Khurd	233	264	331	356	361	340	320	335	363	388	322	D
17	28.8188	76.9738	6	Mungashpur	230	239	257	303	294	312	335	325	345	365	294	D
18	28.8111	76.9528	6	Qutubgarh	213	242	189	327	273	259	170	263	314	410	250	D
19	28.7961	76.9515	7	Qutubgarh	188	237	165	272	286	312	361	376	392	407	275	D
20	28.7673	76.9632	7	Khor Punjab	213	216	246	281	297	312	340	357	370	380	289	D
21	28.7576	76.9466	7	Jonti	188	261	235	252	331	295	327	349	363	334	282	D
22	28.7486	76.9623	8	Jonti	201	239	222	252	235	244	277	292	314	343	256	D
23	28.7203	76.9658	8	Nizampur Rashid	157	182	222	277	304	322	334	353	365	382	266	D
24	28.6923	76.9623	9	Tikri Kalan	169	198	303	315	333	345	349	408	410	432	299	D
25	28.6736	76.9650	9	Tikri Kalan	258	208	253	340	260	264	309	277	301	324	274	D
26	28.6816	76.9744	9	Tikri Kalan	211	209	202	221	230	280	252	244	312	392	245	D
27	28.6653	76.9494	9	Jharoda Kalan	185	248	266	306	295	324	331	340	327	353	287	D
28	28.6514	76.9342	9	Jharoda Kalan	200	218	235	248	231	312	322	283	240	278	251	D
29	28.6546	76.9598	9	Jharoda Kalan	211	279	278	405	340	354	317	286	271	274	293	D
30	28.6437	76.9574	10	Jharoda Kalan	151	237	266	294	312	326	350	338	349	361	280	D
31	28.6048	76.9573	10	Mitraon	223	255	253	286	298	315	331	350	380	396	299	D
32	28.6161	76.9300	10	Kair	185	207	242	304	279	303	314	330	336	352	273	D
33	28.6167	76.9592	10	Mitraon	197	193	270	262	401	279	262	243	234	286	253	D
34	28.6306	76.9478	10	Surakhpur	194	226	247	264	276	314	328	312	322	350	274	D
35	28.6318	76.9607	10	Najafgarh	203	226	247	354	415	432	354	312	354	301	302	D
36	28.5383	76.9818	12	Kangan heri	137	151	185	226	259	289	312	327	376	421	236	D
37	28.8014	77.0240	13	Nangal Thakuran	250	246	277	298	320	338	323	340	354	378	306	D
38	28.8006	76.9821	13	Katewara	259	249	257	292	312	318	331	350	359	363	303	D
39	28.8025	76.9981	13	Bajidpur Thakran	213	246	274	292	323	315	331	340	365	384	299	D
40	28.7903	76.9771	14	Khorjat	174	203	246	282	292	304	327	340	353	361	273	D
41	28.7612	76.9753	14	Chatesar	193	198	253	286	298	304	323	331	340	361	277	D
42	28.7880	77.0151	14	Nangal Thakuran	154	193	212	211	267	288	314	325	335	382	249	D
43	28.7542	77.0071	14	Budhanpur	200	193	226	244	262	276	298	323	331	345	260	D
44	28.7503	77.0244	14	Karala	185	204	216	312	283	256	304	330	430	432	273	D
45	28.7710	77.0166	14	Sultanpur Dabas	174	193	264	312	269	288	303	378	365	340	272	D
46	28.7709	76.9863	14	Salahpur Majra	189	199	260	260	238	309	315	320	325	340	265	D
47	28.7067	76.9908	15	Suda	168	230	309	336	372	243	349	357	307	301	281	D
48	28.7303	77.0231	15	Karala	213	182	234	374	380	289	312	414	432	432	322	D
49	28.7381	77.0014	15	Ladpur	125	204	262	398	286	292	329	399	422	423	274	D

50	28.7192	76.9828	15	Nizampur Rashid	231	268	265	273	286	367	394	423	430	432	320	D
51	28.7261	77.0042	15	Khanjwala	157	237	264	283	306	322	306	371	361	351	279	D
52	28.7061	76.9758	15	Suda	287	313	347	406	291	340	356	412	419	432	326	D
53	28.6953	77.0239	16	Mundka	179	207	225	254	295	221	238	286	289	243	238	D
54	28.6840	77.0076	16	Mundka	226	268	354	338	335	320	338	298	292	309	303	D
55	28.6729	77.0179	16	Mundka	252	194	243	274	297	309	328	338	350	361	285	D
56	28.6526	77.0232	16	Bakarwalan	189	228	260	286	323	312	340	354	372	390	291	D
57	28.6914	76.9766	16	Tikri Kalan	151	207	253	289	282	221	274	252	256	294	239	D
58	28.6805	76.9904	16	Tikri Kalan	199	226	202	226	256	288	303	317	335	347	259	D
59	28.6684	76.9936	16	Hiran Kudna	209	188	201	169	298	176	247	264	274	284	222	D
60	28.6535	76.9840	16	Dhichaon Kalan	180	226	314	312	333	340	359	354	372	384	301	D
61	28.6400	77.0206	17	Bagrola	189	244	336	292	286	350	318	348	365	378	298	D
62	28.6262	77.0202	17	Mohan Garden	163	213	251	274	288	309	322	432	406	376	280	D
63	28.6062	77.0112	17	Najafgarh	213	239	324	286	317	338	356	369	384	374	309	D
64	28.6159	76.9748	17	Najafgarh	224	239	246	279	292	309	331	318	359	374	289	D
65	28.6136	76.9992	17	Najafgarh	199	230	266	281	294	317	327	338	351	361	287	D
66	28.6014	76.9894	17	Roshanpura	219	241	266	281	267	291	300	328	350	363	284	D
67	28.6316	76.9758	17	Dhichaon Kalan	223	220	225	307	221	234	221	254	282	345	247	D
68	28.6345	76.9974	17	Dhichaon Kalan	180	204	259	278	274	325	352	363	372	384	281	D
69	28.5586	76.9811	18	Rewla Khanpur	179	207	242	286	304	318	348	372	398	418	286	D
70	28.5906	76.9796	18	Paprawat	179	220	249	295	304	320	345	361	384	400	288	D
71	28.5927	76.9903	18	Dinarpur	129	171	216	243	282	301	326	354	380	418	249	D
72	28.5801	77.0218	18	Qutubpur	125	149	190	252	281	297	309	333	365	401	236	D
73	28.5782	76.9773	18	Paprawat	149	194	222	252	267	282	298	312	333	359	250	D
74	28.5678	77.0104	18	Chhawla	154	175	189	230	256	269	289	326	357	410	242	D
75	28.5694	76.9967	18	Chhawla	184	217	257	304	320	312	338	353	378	397	290	D
76	28.5534	77.0019	18	Chhawla	134	164	212	271	284	318	333	354	372	421	253	D
77	28.8608	77.0566	20	Lampur	144	198	230	279	307	328	363	382	400	430	230	D
78	28.8692	77.0555	20	Lampur	168	199	238	276	312	329	353	369	359	394	274	D
79	28.8683	77.0944	20	Narela	180	230	207	262	292	312	336	382	402	423	259	D
80	28.8521	77.0675	20	Lampur	180	235	275	309	334	361	369	380	397	423	299	D
81	28.8147	77.0711	21	Sanoth	151	203	246	279	309	333	363	378	409	430	234	D
82	28.8315	77.0723	21	Bankner	185	213	255	289	317	322	357	382	404	430	289	D
83	28.7946	77.0299	22	Bawana	201	239	338	354	363	385	407	423	387	389	331	D
84	28.7998	77.0729	22	Holambi Khurd	278	282	272	292	392	430	430	389	432	395	346	D
85	28.7800	77.0300	22	Sultanpur Dabas	221	256	297	317	271	331	350	324	412	357	304	D
86	28.7732	77.0526	22	Barwala	246	188	212	398	264	317	324	432	430	430	314	D
87	28.7842	77.0670	22	Khera Khurd	264	230	266	320	312	314	405	430	430	430	324	D
88	28.7619	77.0375	22	Sultanpur Dabas	248	244	265	312	340	347	430	430	416	430	330	D
89	28.7601	77.0653	22	Barwala	221	252	281	304	430	430	424	430	430	430	368	C
90	28.7371	77.0386	23	Karala	149	226	255	291	324	349	380	430	430	430	337	D
91	28.7439	77.0517	23	Karala	304	268	217	234	355	283	263	432	430	430	312	D
92	28.7378	77.0714	23	Pansali	197	230	217	295	328	374	306	432	430	430	326	D
93	28.7200	77.0383	23	Mohammadpur Majar	161	222	222	367	378	286	330	368	430	430	326	D
94	28.7257	77.0563	23	Karala	204	193	196	267	432	345	317	423	430	374	312	D
95	28.7200	77.0711	23	Rohini Sec-23	289	220	262	343	343	294	304	367	423	432	325	D
96	28.7106	77.0489	23	Mubarakpur Dabas	197	199	222	361	340	284	309	430	430	430	314	D
97	28.6988	77.0438	24	Kirari Suleman Nagar	217	255	287	295	301	314	328	350	380	398	303	D
98	28.6558	77.0401	24	Ranhola Shafipur	188	220	253	279	295	331	359	378	403	412	293	D
99	28.6828	77.0297	24	Mundka	199	242	278	272	307	331	352	365	382	414	300	D
100	28.5550	77.0394	26	Dwarka Sec-25	180	226	288	320	343	387	384	407	430	430	314	D
101	28.5946	77.0352	26	Dwarka Sec-13	163	211	246	258	328	343	352	365	388	423	283	D
102	28.5949	77.0543	26	Dwarka Sec-5	149	183	217	244	271	309	329	340	371	404	257	D
103	28.5939	77.0711	26	Dwarka Sec-6	169	204	247	281	294	323	338	350	397	432	281	D
104	28.5730	77.0528	26	Dwarka Sec-19	163	233	262	288	312	328	347	361	382	407	288	D

105	28.5814	77.0737	26	Pappan Kalan	189	221	251	283	295	312	359	369	390	408	291	D
106	28.5597	77.0262	26	Dwarka Sec-24	200	230	266	288	320	351	347	382	404	417	304	D
107	28.5498	77.0540	26	Dwarka Sec-26	179	216	242	320	336	361	372	390	416	430	301	D
108	28.5550	77.0675	26	Dwarka Sec-21	195	222	281	304	331	347	389	400	408	423	310	D
109	28.5378	77.0517	27	Dwarka Sec-27	185	217	262	294	317	350	363	392	410	429	300	D
110	28.8658	77.0967	28	Mamurpur	151	188	211	309	324	338	365	392	430	423	278	D
111	28.8544	77.1225	28	Mamurpur	163	177	246	312	333	356	374	403	405	430	287	D
112	28.8544	77.1018	28	Mamurpur	169	203	253	286	284	312	323	331	352	394	274	D
113	28.8655	77.1113	28	Mamurpur	163	193	238	262	279	340	383	400	430	430	281	D
114	28.8261	77.1069	29	Narela	137	198	230	266	272	301	324	334	340	345	254	D
115	28.8147	77.0856	29	Bhorgarh	174	235	264	240	278	306	292	338	392	430	277	D
116	28.8431	77.0881	29	Narela	213	290	272	291	303	414	432	432	432		323	D
117	28.8173	77.0976	29	Rajpur Kalan	185	182	221	216	238	234	276	361	382	410	250	D
118	28.8327	77.0921	29	Bhorgarh	211	262	295	307	354	361	374	312	421	419	318	D
119	28.8336	77.1169	29	Tikri Khurd	137	158	211	266	289	331	350	345	354	357	250	D
120	28.8053	77.0972	29	Holambi Kalan	125	161	163	252	267	432	278	392	432	356	240	D
121	28.8172	77.1165	29	Shahpur Garhi	174	198	196	225	251	356	374	392	394	430	269	D
122	28.7884	77.0819	30	Naya Bansh	215	271	281	317	398	372	335	384	388	410	324	D
123	28.7500	77.0765	30	Pehladpur Banger	238	253	239	289	349	303	335	368	371	428	306	D
124	28.7932	77.0975	30	Holambi Khurd	185	213	227	247	274	380	374	386	386	426	285	D
125	28.7958	77.1052	30	Holambi Khurd	228	246	327	327	335	382	398	424	423	394	334	D
126	28.7731	77.0923	30	Khera Khurd	211	194	287	333	350	378	352	314	350	404	301	D
127	28.7806	77.1125	30	Khera Khurd	188	211	225	331	314	354	380	378	407	430	298	D
128	28.7556	77.0921	30	Pehladpur Banger	275	248	260	350	424	409	430	343	430	430	344	D
129	28.7561	77.1131	30	Sirsapur village	179	238	314	298	322	359	418	423	404	430	315	D
130	28.7244	77.0867	31	Rohini Sec-25	235	213	239	276	419	252	298	383	430	423	305	D
131	28.7283	77.1187	31	Rohini Sec-12	204	193	212	256	405	328	318	295	320	423	276	D
132	28.7161	77.0957	31	Rithala	185	271	226	380	430	419	295	430	432	432	319	D
133	28.7098	77.1119	31	Rohini Sec-6, Blk-F	127	152	225	319	430	395	370	351	414	423	333	D
134	28.7464	77.1042	31	Shiv Vihar	180	209	243	280	244	273	289	327	357	430	328	D
135	28.7079	77.0798	31	Sultanpuri	213	238	287	252	363	411	298	423	397	423	278	D
136	28.7016	77.0904	31	Mangolpuri Blk-Y	224	271	231	430	430	322	421	423	378	423	276	D
137	28.6969	77.0779	32	Sultanpuri	185	217	283	304	336	357	371	355	384	407	301	D
138	28.6970	77.1136	32	Pushpanjali Enclave, Rohini	195	222	247	301	322	343	363	367	392	417	299	D
139	28.6508	77.0857	32	Gurunanak Nagar	200	194	247	267	280	282	304	333	363	392	273	D
140	28.6583	77.1042	32	Khayala	154	177	235	259	267	322	327	345	369	421	262	D
141	28.6800	77.0742	32	Nangloi Jat	169	177	255	279	312	340	348	370	400	412	280	D
142	28.6881	77.0956	32	Mangolpuri	144	198	216	251	286	303	335	374	390	426	263	D
143	28.6661	77.0917	32	Sunder Aptt, Sunder Vihar	149	204	222	264	306	324	359	359	397	399	271	D
144	28.6670	77.1023	32	Jwala Heri, Paschim Vihar	161	183	211	248	304	312	343	354	380	400	264	D
145	28.6439	77.1083	33	Park, Near Tagor Garden	209	285	292	430	423	309	312	324	343	385	322	D
146	28.6306	77.1069	33	Tihar Village	255	288	324	324	351	369	390	392	392	423	343	D
147	28.6367	77.1225	33	Subhash Nagar, Blk-10	306	307	332	369	349	353	385	400	363	322	348	D
148	28.8436	77.1304	38	Singhola	144	188	207	256	263	266	272	292	328	345	240	D
149	28.8283	77.1450	38	Hamidpur	201	216	264	276	272	309	328	336	350	357	281	D
150	28.8423	77.1704	38	Tajpur Kalan	129	198	225	258	292	304	309	320	331	338	249	D
151	28.8269	77.1296	38	Khanpur	250	265	295	277	376	405	423	383	430	376	335	D
152	28.8135	77.1429	38	Bankoli	129	182	225	234	254	276	304	326	243	230	225	D
153	28.8194	77.1551	38	Hamidpur	137	188	257	312	301	312	301	276	312	309	252	D
154	28.8277	77.1702	38	Bakhtawarpur	129	151	185	304	298	413	421	251	416	424	250	D

155	28.8031	77.1313	38	Alipur	190	265	280	258	256	432	430	412	430	432	312	D
156	28.8072	77.1663	38	Bakhtawarpur	264	216	253	254	276	354	363	394	430	430	306	D
157	28.8108	77.1564	38	Bankoli	168	182	274	322	270	331	340	345	376	405	279	D
158	28.8180	77.1744	38	Bakhtawarpur	190	262	270	309	317	372	411	430	430	430	320	D
159	28.7890	77.1301	39	Alipur	151	198	230	263	298	284	309	326	333	370	258	D
160	28.7973	77.1495	39	Alipur	261	259	298	340	345	353	394	383	411	419	337	D
161	28.7938	77.1663	39	Mukhmelpur	169	203	329	267	349	367	380	430	400	426	302	D
162	28.7820	77.1454	39	Budhpur, Bijapur	169	211	238	270	286	298	314	359	361	403	273	D
163	28.7796	77.1686	39	Near Ibrahampur	184	224	260	281	301	331	384	380	430	430	298	D
164	28.7745	77.1335	39	Khera Ghari	179	203	246	289	345	359	392	392	423	430	298	D
165	28.7726	77.1501	39	Kadipur	213	228	211	225	276	410	356	298	328	340	274	D
166	28.7634	77.1722	39	Nathupura	137	193	225	248	291	306	320	334	348	370	254	D
167	28.7621	77.1524	39	Near Swaroopnagar	174	271	238	312	271	274	288	301	331		294	D
168	28.7563	77.1364	39	Rana Park, Sirsapur	179	228	242	258	317	298	314	324	375	390	278	D
169	28.7535	77.1654	39	Swaroopnagar, New Colony	163	198	211	216	230	234	262	314	319	329	236	D
170	28.7881	77.1552	39	Mukhmelpur	244	220	329	256	314	325	432	430	426	430	321	D
171	28.7688	77.1625	39	Kadipur	221	203	260	278	248	312	336	365	403	411	288	D
172	28.7429	77.1526	40	Sanjay Gandhi Transport Nagar Blk AG	278	282	306	340	304	303	319	331	338	430	319	D
173	28.7393	77.1358	40	Rohini Sec-18, Blk A, Pkt8	285	238	255	353	430	394	378	387	423	430	342	D
174	28.7364	77.1646	40	Bhalsawa	174	216	327	333	292	390	423	423	423	430	314	D
175	28.7286	77.1493	40	Haiderpur	146	259	317	345	380	336	336	426	430	430	309	D
176	28.7096	77.1280	40	Rohini Sec-14	189	177	243	273	407	351	368	284	350	403	281	D
177	28.7108	77.1436	40	North Pitampura, Pkt-NU	197	317	311	289	307	343	411	292	423	430	316	D
178	28.7194	77.1601	40	Sahipur, Near Shalimar Bagh	219	235	292	423	270	298	343	430	430	430	317	D
179	28.7191	77.1747	40	Aadarsh Nagar	156	265	377	264	298	359	386	380	430	430	306	D
180	28.7041	77.1551	40	Pitampura, Blk-TP Pocket	203	216	260	348	338	343	335	345	430	430	306	D
181	28.7056	77.1744	40	Wazirpur Indl area, Blk-B	115	230	332	309	352	365	372	373	423	423	286	D
182	28.6928	77.1249	41	Saraswati Vihar	180	209	212	320	401	384	390	405	430	430	303	D
183	28.6981	77.1419	41	South Pitampura, Blk Pocket-KD	156	193	222	347	244	430	430	396	430	430	296	D
184	28.6953	77.1631	41	ashok Vihar, Ph-I, Blk-E	262	262	275	378	226	252	298	372	430	423	303	D
185	28.6597	77.1302	41	Near Raja Garden	238	313	327	314	361	378	329	353	363	371	334	D
186	28.6833	77.1450	41	Sakurpur Village	238	276	332	351	345	423	361	365	397	392	345	D
187	28.6703	77.1417	41	East Punjabi Bagh	174	245	275	368	388	407	352	428	430	430	329	D
188	28.6708	77.1581	41	Karampura Block, Indl Area	188	271	309	334	401	375	298	394	345	387	315	D
189	28.5431	77.1327	44	CISF Rd, Mahipalpur Extn	169	213	281	306	343	361	392	417	430	430	298	D
190	28.4972	77.1325	45	Ghitorni Village	174	220	253	289	320	359	378	401	418	436	247	D
191	28.4964	77.1622	45	Sultanpur Village	169	193	247	272	292	338	372	385	394	411	282	D
192	28.4858	77.1331	45	Saink Nivas MES, Ghitorni	180	242	265	277	301	327	357	382	405	422	274	D
193	28.4839	77.1628	45	HK Farm House, near Godaipur	157	188	234	247	262	298	318	347	349	400	228	D
194	28.4706	77.1631	45	Jaunapur	180	208	259	292	301	345	359	375	382	423	297	D

195	28.4440	77.1464	46	Farm house, Mandi Village	169	213	259	294							-	
196	28.4416	77.1347	46	KH No.66/6, Mandi Village	134	213	239	282	307	354	373	343	398	430	275	D
197	28.4400	77.1636	46	SEPAL Farm Dera, Mandi Rd, Mandi	169	213	242	278	303	312	340	369	395	431	283	D
198	28.8441	77.1848	48	MCD School, Palla	156	239	257	289	292	320	328	336	340	348	275	D
199	28.8455	77.2001	48	Palla	129	177	179	194	188	273	348	331	326	328	221	D
200	28.8294	77.1788	48	Bakhtawarpur	144	224	207	221	243	269	262	272	304	340	236	D
201	28.8308	77.1986	48	School Jhangla	137	259	277	194	251	262	279	295	312	350	245	D
202	28.8175	77.2134	48	Palla Police Post	137	151	260	238	258	421	423	402	286	306	251	D
203	28.8167	77.1994	48	Near Jal Board Palla	161	203	289	312	312	328	352	359	368	370	285	D
204	28.7978	77.1807	49	Hiranki Village	174	259	309	345	359	327	430	430	430	430	324	D
205	28.7708	77.1875	49	Uttarakhand Coloney	144	165	191	211	295	309	333	400	418	424	251	D
206	28.7639	77.2153	49	Shank No.1, Burari village	149	170	196	216	295	309	333	400	418	424	255	D
207	28.7948	77.1911	49	Near Shank 22, Hiranki Village	174	193	230	282	326	345	365	372	390	411	284	D
208	28.7946	77.1998	49	Tedi Daulatpur	188	193	207	200	266	312	340	357	380	430	263	D
209	28.7810	77.1838	49	Resid. area, Hiranki, Nr Ibrahampur	134	158	201	234	292	291	292	306	376	407	240	D
210	28.7757	77.1992	49	Silampur Majra	163	198	274	262	276	315	350	407	414	424	282	D
211	28.7604	77.1976	49	Behind Shani temple, Burari	174	211	249	279	357	378	390	380	382	407	297	D
212	28.7445	77.1943	50	Sant Nagar	115	177	292	278	274	330	407	390	430	430	265	D
213	28.7144	77.1874	50	Nr Model Town	89	232	322	347	351	430	423	423	376	423	274	D
214	28.7135	77.2047	50	Radio Coloney, Nr Dhaka Village	190	253	295	387	270	294	328	329	383	412	299	D
215	28.7319	77.1810	50	Near Jahangirpuri Blk-JJC	151	268	289	297	327	359	387	350	430	430	302	D
216	28.7336	77.2064	50	Jharoda Dairy Coloney	179	249	286	323	345	356	430	423	430	430	320	D
217	28.7331	77.2185	50	Nr Milan Vihar, Burari	180	220	295	343	430	430	430	430	430	430	329	D
218	28.7260	77.1939	50	Nirankari Ground, nr Jharoda Majra	103	188	207	251	276	359	363	430	430	423	250	D
219	28.7031	77.1966	50	Model Town	207	259	276	323	388	347	382	396	430	430	326	D
220	28.7059	77.2210	50	Timarpur	237	234	345	357	423	273	354	378	423	432	320	D
221	28.6793	77.2205	51	Civil Lines	217	188	290								-	
222	28.6962	77.2104	51	Khalsa College, Nr Univ campus	154	188	185	216	251	282	307	331	354	368	243	D
223	28.6893	77.1978	51	CC Colony		157	227	294	352	280	356	382	388	405	322	D
224	28.6896	77.1834	51	Near Satyavati Colony		228	246	277	276	300	319	430	430	430	318	D
225	28.6478	77.2109	51	Azad Market	206	152	234								-	
226	28.6788	77.1878	51	Shiv Temp, Fakira Bagh, Shastri Nagar	174	164	202	226	267	286	312	338	372	409	251	D
227	28.6850	77.2033	51	Roopnagar Blk-6	163	177	217	235	262	279	307	333	378	392	253	D
228	28.6680	77.2208	51	Civil Lines, Nr Tis Hazari	270	245	265	287							-	
229	28.5208	77.1910	54	Lado Sarai		203	253								-	
230	28.5340	77.1936	54	Govt Nursery, Adhichini	125	204	235	270	282	295	318	328	340	361	252	D

231	28.5413	77.1829	54	Lal bahadur Vidyapith, Katwariasarai	185	204	259	294	312	325	343	354	401	414	295	D
232	28.5056	77.2058	54	Neb Sarai, Mehrauli											317	D
233	28.5478	77.1937	54	Rose Garden, Haus Khas	163	204	251	282	306	318	350	352	403	411	249	D
234	28.5388	77.2088	54	Begampur,Malviya Nagar	151	188	239	300	314	338	356	375	411	457	270	D
235	28.5387	77.2244	54	Shek Sarai,Ph.-I	137	193	221	286	322	343	365	380	397	426	256	D
236	28.5288	77.2066	54	Hauz Rani Saket	161	204	239	283	306	324	343	371	408	425	282	D
237	28.5080	77.1739	54	Kusum Nursery Vasant Kunj	144	177	272	279	324	355	363	392	423	430	259	D
238	28.5161	77.2119	54	Saket-Bdarpur Rd	174	209	239	279	319	351	369	378	385	394	282	D
239	28.5001	77.2220	54	Sainik Farm, Nr Sangam Vihar	144	226	247	323	350	380	378	412	432	443	283	D
240	28.4986	77.1792	55	Near Chhatarpur Mandir	169	207	246	276	318	348	386	392	416	430	256	D
241	28.4978	77.1942	55	DDA, Maidan Garhi	215	430	421								-	
242	28.4828	77.1806	55	10 Farm, DLF, Chhatarpur	169	198	235	267	301	324	347	363	387	411	276	D
243	28.4856	77.1971	55	Rajpur Khurd	179	230	258	319	309	328	359	370	400	409	297	D
244	28.4717	77.1922	55	Saharpur Extn, ND	169	207	242	251	269	269	361	374	388	431	231	D
245	28.4567	77.2075	55	Forest, Asola Village	180	204	246	303	338	359	372	401	412	430	270	D
246	28.7176	77.2510	58	PT School, Wazirabad	110	188	230	262	298	318	328	348	352	384	247	D
247	28.7325	77.2325	58	Ramp No.3, Near Jagatpur Bund	134	135	196	282	221	320	430	336	350	254	231	D
248	28.7450	77.2559	58	Burari Village	151	182	216	243	292	304	323	343	361	407	258	D
249	28.7079	77.2364	58	Pantan Bridge, Wazirabad											282	D
250	28.7338	77.2657	58	Govt School, Karwal Nagar	243	220	257	286	320	368	378	396	320	390	305	D
251	28.7188	77.2664	58	Near Priya Convent Sch, Dayalpur	144	177	211	238	258	266	286	312	326	380	241	D
252	28.7039	77.2554	58	Garai Mandu Village	129	165	238	262	289	315	328	343	350	418	252	D
253	28.6857	77.2350	59	New Usmanpur Village	169	193	201	262	269	359	338	347	356	405	267	D
254	28.6587	77.2401	59	MG Park, Lal Quila	217	248	230	252	345	352	356	352	372	432	300	D
255	28.6924	77.2548	59	Pusta-4, Usmanpur	179	232	260	286	318	340	369	376	369	430	297	D
256	28.6769	77.2471	59	Opp DMRC off, Shatri Park	157	177	238	276	301	307	361	422	421	423	275	D
257	28.6753	77.2692	59	Silampur	163	182	216	269	301	323	315	359	372	384	266	D
258	28.6668	77.2503	59	Shastri Park			216	254	272	295					-	
259	28.6589	77.2692	59	SK School, Geeta Colony											261	D
260	28.7304	77.2814	65	Kali Mandir, Shiv Vihar	163	188	211	230	322	335	432	432	414	414	277	D
261	28.7073	77.3232	65	Harsh vihar	144	165	211	238	269	298	357	365	376	380	251	D
262	28.7149	77.2815	65	Chamanpark, Johripur	157	193	225	286	300	314	325	359	368	376	268	D
263	28.7029	77.3076	65	Nand Nagari	209	320	336	368	338	347	367	376	426	430	339	D
264	28.7044	77.2769	65	Gokulpuri colony	144	188	211	238	266	286	320	348	372	388	252	D
265	28.7029	77.2962	65	East Gokulpur	169	182	201	230	392	397	426	432	424	429	285	D
266	28.6895	77.2893	66	Near Jyoti colony	188	203	234	256	301	340	396	430	430	430	274	D
267	28.6925	77.3129	66	Nand Nagari, Blk-E4	200	216	269	294	357	430	430	430	430	430	321	D

268	28.6777	77.2984	66	Mansarovar Park	224	235	277	301	314	324	349	392	386	423	310	D
269	28.6560	77.2923	66	Arjun Nagar	221	239	319	312	326	340	363	350	370	412	314	D
270	28.6653	77.3056	66	Jhilmil Coloney	188	220	270	315	318	331	357	407	384	411	301	D
271	28.6537	77.3157	66	Anand Vihar, Blk-C	179	228	246	306	282	329	355	347	430	430	292	D
272	28.6192	77.2865	67	Pandav Nagar, Blk-A	188	207	234	254	282	292	309	374	430	430	279	D
273	28.6242	77.3001	67	Vinod Nagar West, Blk-D	188	249	277	307	295	309	326	370	430	430	301	D
274	28.6092	77.3028	67	Mayur Vihar, Ph-I, Pkt 2	151	220	246	279	386	397	392	403	430	430	297	D
275	28.6111	77.3225	67	Durga park Coly, near Kundali	201	306	322	338	353	365	376	397	430	430	337	D
276	28.5398	77.2831	69	Park, near Appolo Hosp., Jasola	174	194	255	274	300	314	333	352	397	414	280	D
277	28.5234	77.3083	69	near Badarpur Thermal Plant, Khadar	157	182	221	216	247	262	292	331	345	396	245	D
278	28.5321	77.2956	69	DDA Park, Sarita Viahar, Blk-D	137	203	234	269	295	345	368	378	400	428	272	D
279	28.5412	77.3089	69	Kalindikunj, Jaitpur Road	144	177	230	262	276	292	312	331	376	392	255	D
280	28.5322	77.3161	69	DDA park, JJ Colony	151	171	221	238	279	315	331	370	382	407	258	D
281	28.5062	77.3017	69	Govt School, near NTPC,Badarpur	144	188	314	376	357	326	354	376	400	423	291	D
282	28.5025	77.3141	69	Near Irrigation Dept, Hari Nagar	157	198	234	336	354	424	430				257	D
283	28.6281	77.3253	72	Near Gaziur, Blk-D	169	246	264	282	286	315	343	430	430	430	295	D
284	28.6121	77.3348	72	Gharoli Dairy Farm, Blk-A	224	207	249	327	336	345	367	423	430	430	313	D
285	28.6032	77.3308	72	Near Kundli, Blk-A1	201	207	260	276	292	295	369	403	417	430	294	D
286	28.5147	77.3417	73	Jaitpur Extn	144	207	253	279	338	350	370	392	426	436	286	D
287	28.5253	77.3313	73	Near Police post, Jaitpur	144	177	230	262	276	292	312	372	392	407	258	D
288	28.8746	77.0795	20	Safiabad	163	228	238	271	263	378	349	382	382	390	281	D
289	28.8757	77.1114	28	Kundli	184	203	230	264	318	340	406	374	408	403	288	D
290	28.8125	77.0875	29	Holambi kalan	177	221	243	185	266	338	365	387	505	454	272	D
291	28.8300	77.1229	29	Tikri Khurd	279	265	275	270	312	334	324	324	373	331	305	D
292	28.7222	77.1056	31	DCE, Rithala	185	188	278	258	318	286	298	338	389	384	303	D
293	28.8183	77.1458	38	Bankoli	163	188	331	286	295	433	361	348	367	394	289	D
294	28.7499	77.1763	39	Bhalsawa Dairy	180	198	201	221	289	380	357	357	373	390	270	D
295	28.7917	77.1597	39	Mukhmelpur	144	193	246	240	294	294	402	383	386	399	268	D
296	28.8417	77.2125	48	Jangola	179	198	230	282	307	318	300	347	352	384	273	D
297	28.8056	77.1917	49	Fatehpur Jat	197	228	292	279	318	372	418	394	407	390	310	D
298	28.8583	77.2417	49	Sankrot	294	228	234	312	345	370	420	435	421	403	329	D
299	28.7083	77.2167	50	Indira Vihar	185	245	255	170	271	338	292	447	455	460	278	D
300	28.7427	77.2053	50	Salarpur	129	193	238	221	247	295	370	382	382	421	253	D
301	28.6917	77.2292	51	Majnu Ka Tila	206	252	296	252	286	263	390	336	309		310	D
302	28.7450	77.2442	58	Libaspur	174	220	211	252	274	347	405	336	363	370	275	D
303	28.5811	77.2330	3	Mandhela Kalan	209	308	247	309	269	295	314	301	273	286	277	D
304	28.4724	77.1860	11	Khera Dabas	169	193	211	221	283	276	288	363	361	357	254	D
305	28.4704	77.2013	12	Shikarpur	174	188	238	430							227	D
306	28.4458	77.1866	14	Bawana, Khanjawala	157	182	196	221	282	289	318	333	318	292	243	D
307	28.4431	77.2006	17	Mohan Garden	149	158	185	216	216	238	430	430			234	D
308	28.6830	77.1622	23	Madanpur Dabas	228	282	409	430	430	430	388	398	430	423	368	C
309	28.6029	77.2855	28	Narela	209	228	257	230	254	262	276	279	350	363	263	C

310	28.6361	77.2986	29	Holambi Kalan	180	226	242	254	272	301	365	333	372	361	276	D
311	28.6768	77.3123	31	Rohini Sec-25											343	D
312	28.6222	77.3388	33	Janakpuri Blk-B3B		197	239	269	306	398	216	426	430		292	D
313	28.7342	77.0891	35	Rajokri village	185	218	269	277	334	349	319	416	432	392	350	D
314	28.5089	77.1083	38	Bakhtawarpur	280	245	258	309	298	331	298	369	463	367	312	D
315	28.5889	77.2596	39	Swaroopnagar, New Colony											256	D
316	28.5889	77.2596	41	Keshavpuram											266	D
317	28.5963	77.2578	45	Akoi Farm, Jaunapur											294	D
318	28.5997	77.2569	51	Ridge, Near Univ Campus											250	D
319	28.5976	77.2575	51	Azadpur Market											275	D
320	28.6783	77.1583	52	Budha Jayanti Park											287	D
321	28.6699	77.2704	54	Begampur,Malviya Nagar											293	D
322	28.6783	77.1583	54	Pushpa Vihar, Sec-1											306	D
323	28.5524	77.2758	55	Chandan Hulla											299	D
324	28.5233	77.2279	58	PTS Wazirabad											273	D
325	28.5431	77.2113	61	Jawaharlal Nehru Stadium											277	D
326	28.6783	77.1583	67	Nangal											249	D
327	28.7177	77.1103	69	JJ Colony, Sarita Vihar											272	D
328	28.5248	77.2137	61	Jawaharlal Nehru Stadium											265	D
329	28.6813	77.0971	61	Sarai Kale Khan											281	D
330	28.6407	77.2320	61	Sarai Kale Khan											322	D
331	28.6379	77.0761	61	Rajiv Gandhi Smriti Van, Nr Zoo	208	222	245								253	D
332	28.5877	77.0474	61	Rajiv Gandhi Smriti Van, Nr Zoo	215	226	263								252	D
333	28.5933	77.0492	61	Rajiv Gandhi Smriti Van, Nr Zoo	162	206	242								238	D
334	28.6736	77.2981	41	Tri Nagar	194	216	258								258	D
335	28.5926	77.0815	59	Seelampur	229	262	286								277	D
336	28.6175	77.0480	41	Tri Nagar	227	247	244								253	D
337	28.5963	77.0788	68	Sukhdev Vihar	225	244	284								268	D
338	28.6699	77.1389	62	Pushpa Vihar	211	183	218								242	D
339	28.5963	77.2578	54	Paschimshila Park, South Blk-S	190	182	203								223	D
340	28.8197	77.0612	41	Tri Nagar	175	184	204								206	D
341	28.6222	77.2042	31	Rohini Sec-5, Pkt-6	220	246	267								269	D
342	28.5300	77.0890	54	Saket	213	230	266								262	D
343	28.5449	77.1198	32	Udyog Nagar, Nr Paschim Vihar	236	247	255								267	D
344	28.5477	77.1250	60	Ramlila Ground	203	225	256								257	D
345	28.5861	77.0551	55	Chandan Hulla	237	190	216								233	D
346	28.5958	77.1200	55	Saharpur Extn, ND	285	261	259								255	D
347	28.7119	77.1601	56	Fatehpur Beri	212	186	237								236	D
348	28.8528	77.0889	56	Bhati Mines	180	209	227								228	D
349	28.6250	76.9231	41	Keshavpuram	217	237	250								245	D
350	28.5889	77.0292	67	Nangal	203	234	253								247	D
351	28.5917	76.9250	67	Indraprastha Extn	265	255	262								271	D
352	28.6417	77.1647	66	Dilshad Garden, Blk R	183	224	213								227	D

353	28.6611	77.1458	72	NearMayur Vihar Ph-III	205	211	264								248	D
354	28.6431	77.0972	31	Rohini Sec-25	207	243	255								262	D
355	28.6636	77.1433	35	Rajokri village	198	256	260								261	D
356	28.6919	77.1602	35	Rajokri village	222	202	211								246	D
357	28.6736	77.1931	39	Swaroopnagar, New Colony	163	176	226								221	D
358	28.6797	77.1573	38	Bakhtawarpur	197	211	219								239	D
359	28.6475	77.1797	29	Holambi Kalan	187	189	229								236	D
360	28.5827	77.0579	20	Narela	231	243	245								251	D
361	28.6431	77.1625	-	Across NCT boundary in the East	156	210	244								222	D
362	28.6506	77.3042	58	PTS Wazirabad	170	198	238								245	D
363	28.6484	77.3046	51	Ridge, Near Univ Campus	177	185	216								223	D
364	28.5807	77.2924	41	Dilshad Colony, Blk-J	161	207	235								227	D
365	28.6417	77.2522	61	Lodi Colony, Blk-B, nr Rly colony	169	184	215								223	D
366	28.6681	77.2564	45	Akoi Farm, Jaunapur	206	196	210								227	D
367	28.5150	77.2722	-	Across NCT boundary in the East	193	222	246								244	D
368	28.5686	77.2436	33	Near Janakpuri, Blk-2	199	213	253								252	D
369	28.5681	77.2189	55	Chandan Hulla	186	220	223								228	D
370	28.5444	77.2583	17	Mohan Garden	190	250	252								247	D
371	28.5722	77.1708	14	Nangal Thakuran	217	286	301								280	D
372	28.5781	77.1625	23	Rani Khera	182	201	215								226	D
373	28.6222	77.2467	31	Rohini Sec-25	162	140	232								224	D
374	28.6903	77.1778	54	Push Vihar Sec-1	210	236	267								260	D
375	28.6556	77.1917	59	Vijay Ghat, nr Lal Quila	162	173	210								208	D
376	28.6083	77.2403	58	Wazirabad nr Jagatpur	174	196	195								225	D
377	28.6111	77.2264	61	Sarai Kale Khan	152	196	238								231	D
378	28.6367	77.2064	28	Mamurpur	204	244	232								242	D
379	28.6417	77.1508	29	Bhorgarh	176	203	217								218	D
380	28.5651	77.0783	40	Prashant Vihar, Rohini Sec-14	238	199	227								246	D
381	28.6389	77.2375	20	Bankner	141	168	216								212	D
382	28.6260	77.2099	43	RK Puram, Sec-5	218	226	229								248	D
383	28.6735	77.2916	50	Model Town	213	224	276								263	D
384	28.5889	77.2596	69	Tuglakabad	186	184	202								222	D
385	28.5644	77.2479	26	Pochanpur	240	227	265								275	D
386	28.6021	77.1928	44	Vasant Kunj, Blk-B	253	266	253								264	D
387	28.5233	77.2279	-	Across NCT boundary in the East	195	213	263								255	D
388	28.5523	77.2140	-	Across NCT boundary in the East	191	227	253								242	D
389	28.5524	77.2758	52	Aram Bagh, Nr Jhandewalan Extn	179	196	220								226	D
390	28.5616	77.2242	-	Across NCT boundary in the East	183	202	237								236	D
391	28.5677	77.2272	-	Across NCT boundary in the East	217	243	210								237	D

392	28.6390	77.1316	42	Nangal Raya, nr Mayapuri Indl area	208	261	282							272	D
393	28.5248	77.2137	33	Park, Near Tagor Garden	194	244	232							243	D
394	28.5255	77.2120	-	Across NCT boundary in the East	187	224	262							247	D
395	28.7177	77.1103	41	Prem Nagar, Blk-B	134	197	230							231	D
396	28.6407	77.2320	40	Jahangirpuri Blk-C3	137	198	217							211	D
397	28.5862	77.0639	40	Water SportsComplex,Bhalsawa	191	190	240							232	D
398	28.7982	77.0362	50	East Mukharji Nagar	191	212	241							243	D
399	28.6805	77.3130	50	Near east Mukharjee Nagar	174	198	232							241	D
400	28.7100	77.2835	49	Hiranki	203	215	242							248	D
401	28.6217	77.2440	40	Bhalsawa	161	224	256							237	D
402	28.7011	77.3078	49	Burari	182	175	212							229	D
403	28.5417	77.1833	59	Civil Lines, Nr ISBT	203	246	296							264	D
404	28.5332	77.3029	66	RhtasNagar East	201	182	181							196	D
405	28.7135	77.1774	66	Silampur Ph-III	207	189	274							243	D
406	28.5646	77.2477	66	Dilshad Garden, Blk-F	240	227	265							276	D
407	28.7238	77.1353	40	Haiderpur	205	198	226							235	D
408	28.7378	77.1594	31	Rohini Sec-25, nr STP	161	185	235							227	D
409	28.5621	77.0769	22	Bawana	190	233	273							253	D
410	28.6607	77.1474	30	Sirsapur village	186	230	265							256	D
411	28.6779	77.2274	26	Dwarka Sec-5	178	186	213							225	D
412	28.5730	77.0777	65	Nand Nagari	265	258	256							259	D
413	28.5867	77.0933	58	Chitrakut, East of Loni	189	216	245							248	D
414	28.7265	77.1125	57	Burari	175	201	240							235	D
415	28.7268	77.1136	52	South block residential area	167	197	233							232	D
416	28.6444	77.2269	21	Sanoth	162	190	197							215	D
417	28.6006	77.0931	24	Ranhola Shafipur	241	253	228							257	D
418	28.6150	77.0889	-	Across NCT boundary in the East	160	193	248							226	D
419	28.6153	77.0886	72	Kundli	197	232	250							249	D
420	28.6708	77.2903	72	Kundli Gharoli Sec-G	187	204	234							239	D
421	28.6683	77.2762	-	Across NCT boundary in the East	156	217	240							225	D
422	28.7012	77.2888	54	Hauz Khas Park	196	215	231							229	D
423	28.7164	77.2863	43	West Block, nr Bhikaji Cama Place	198	189	226							227	D
424	28.7054	77.2566	34	Pappan Kalan	196	215	225							231	D
425	28.6764	77.2889	34	Pappan Kalan	157	186	210							214	D
426	28.6764	77.2889	67	Mayur Vihar, Ph-II, Blk-A	177	173	213							215	D
427	28.6699	77.2704	67	Mata Sundari Rly Coloney	176	201	221							228	D
428	28.5979	77.0510	-	Across NCT boundary in the East	191	187	236							249	D
429	28.6806	77.1561	33	Vikaspuri Blk-C	161	205	222							221	D
430	28.6708	77.1972	26	Dwarka Sec-11	153	186	218							216	D

431	28.6117	77.3103	26	East of Dwarka Sec-12	206	200	211							218	D
432	28.7042	77.3131	66	Shahdara	178	179	213							223	D
433	28.7931	77.0417	34	Nr Palam Village	220	188	207							229	D
434	28.7019	77.1667	25	Sainik Nagar	205	209	236							223	D
435	28.6072	76.8844	34	Dwarka Sec-1										302	D
436	28.5828	76.9311	41	West Punjabi Bagh										217	D
437	28.5324	76.9461	61	Rajiv Gandhi Smriti Van, Nr Zoo										199	D
438	28.7872	77.0164	21	Sanoth	134	158	151	230	192	248	252	267	226	322	300	D
439	28.6264	77.0197	52	Nr MP's Club, Rakabganj	180	238	314	369	343	247	309	328	396	421	346	D
440	28.7072	77.0322	35	Samalka, Nr Kapashera	100	150	198	226	273	258	298	301	301	336	306	D
441	28.8714	77.0833	35	Intl Airport Authority, Nr Mahipalpur	110	185	239	206	216	251	251	315	251	279	307	D
442	28.8042	77.1094	35	Intl Airport Authority, Nr Mahipalpur	154	165	221	216	235	238	336	243	251	331	303	D
443	28.7347	77.0892	26	Dwarka Sec-10	127	194	234	251	216	200	235	314	263	363	332	D
444	28.6250	77.0903	34	Sadar Bazar (Delhi Cantt)											240	D
445	28.5117	77.1083	40	Shalimar Bagh, Pkt-BD											254	D
446	28.8180	77.1744	29	Narela	103	207	226	194	230	206	94	254	304	350	301	D
447	28.7535	77.1653	3	Kair	127	165	216	248	331	368	331	295	352	315	308	D
448	28.6828	77.1615	26	Dwarka Sec-17	125	221	221	281	239	262	216	238	243	176	319	D
449	28.4717	77.1475	4	Jafarpur Kalan											365	D
450	28.6857	77.2159	42	West Patel Nagar											307	D
451	28.6645	77.2074	41	New Motinagar, Blk-17											261	D
452	28.6144	77.1763	33	Chaukhandi, nr Hind Nagar											301	D
453	28.5386	77.2092	41	New Motinagar, Blk-B											272	D
454	28.5252	77.2215	41	Lawrence Rd Coloney, Blk-C-7											311	D
455	28.4723	77.1860	51	Gulabi Bagh											208	D
456	28.7250	77.2510	41	Omkar Nagar											180	D
457	28.5811	77.2313	52	Prasad Nagar, Nr E. Patel nagar	137	185	210	230	256	262	258	200	251	320	328	D
458	28.6029	77.2855	26	Dwarka Sec-10	115	158	181	264	270	216	211	292	279	254	206	D
459	28.5325	77.3167	42	Pusa Institute											183	D
460	28.5117	77.1082	66	Karkarduma											269	D
461	28.7534	77.1659	67	Karkarduma											222	D
462	28.8180	77.1744	68	Trans Yamuna, nr Chilla											210	D
463	28.8046	77.1094	60	Rajghat											283	D
464	28.8717	77.0816	59	Shastri Park, BLK-A											215	D
465	28.6030	77.4438	62	Close to Tuglakabad Village											173	D
466	28.7275	77.2515	61	Lajpatnagar, part-II											184	D / E
467	28.6855	77.2159	53	South Ex Part-II											627	C
468	28.6832	77.3290	62	Kalkaji, Blk-D											154	E
469	28.5795	77.2295	43	RK Puram, Sec-8											251	D
470	28.4725	77.1468	43	Anand Niketan, Blk-D											370	C

471	28.5822	77.4299	60	Mata Sundari Rly Coloney											488	C
472	28.6254	77.0790	51	Satyawati Coloney, Blk-A, Pkt-A											264	D
473	28.4723	77.1857	51	Karol Bagh, Blk-D, Pkt52											275	D
474	28.6261	77.0205	60	Bapa Nagar											246	D
475	28.7882	77.0150	60	Vigyan Bhawan											262	D
476	28.7043	77.0338	52	Govt Quarters, Nr Gole Market											255	D
477	28.7350	77.0897	42	Pusa Institute											275	D
478	28.5250	77.2216	34	IGI nr Pappan Kalan											238	D
479	28.6562	77.2463	60	West of F.S.Kotla stadium											208	
480	28.7203	77.2306	52	Bangla Saheb Gurudwara											414	C
481	28.5875	77.2581	66	Makki Sarai											178	E
482	28.8570	77.1108	61	Sarai Kale Khan											251	D
483	28.8356	77.0830	61	Lajpat Nagar, Part-IV											281	D
484	28.7163	77.1338	52	Chanakyapuri, Nr JLN Memorial Museum											273	D
485	28.8503	77.0738	62	Pushpa Vihar, Sec-4											263	D
486	28.5611	77.1719	53	Siri Fort Sports Complex											296	D
487	28.7073	77.1891	68	Sukhdev Vihar											192	D
488	28.5100	77.2766	53	Aayurvugyan Nagar											281	D
489	28.5676	77.0495	61	Andrews Ganj											241	D
490	28.5243	77.1569	42	Mansarover Garden, Blk-WZ											293	D
491	28.5859	77.4555	54	Saket											256	D
492	28.5283	77.4061	54	Saket											241	D
493	28.6442	77.2064	31	Rohini Sec-5											286	D
494	28.5737	77.4533	60	Ramlila Ground											323	D
495	28.5368	77.4719	26	Dwarka Sec-10											291	D
496	28.6144	77.1106	22	Bawana											212	D
497	28.6444	77.1091	66	Dilshad Garden, Blk-C											343	D
498	28.5843	77.4949	65	Bhagirath Vihar											258	D
499	28.6615	77.1598	60	Pragati Maidan											229	D
500	28.7302	77.1714	65	Mandoli Extn											209	D
501	28.7392	77.1695	54	Qutub Indl Area											218	D
502	28.7107	77.2113	69	Madanpur Khadar Village											269	D
503	28.7192	77.2145	50	Majlis Park											183	D / E
504	28.7815	77.1793	61	Lajpat Nagar, Part-IV											220	D
505	28.7369	77.1673	40	Rohinin Sec-13, nr Vikrant Apartment											198	D
506	28.7619	77.2224	40	Bhalsawa Dairy											183	D / E
507	28.6706	77.2279	34	IGI, nr Dwarka Sec-21											279	D
508	28.6792	77.2920	41	Najafgarh Indl Area											224	D
509	28.6733	77.2788	59	Civil Lines											216	D
510	28.6827	77.3186	34	Dwarka Sec-8											215	D

511	28.7292	77.1483	34	Sadh Nagar, Palam coloney											223	D
512	28.7242	77.1106	31	Rohini Sec-25											307	D
513	28.7985	77.0452	31	Rohini Sec-25											235	D
514	28.7708	77.1157	60	Kamla Market											258	D
515	28.5937	77.0587	33	Mahaveer Enclave-II, nr Kailashpuri west											265	D
516	28.6970	77.3099	33	Janakpuri Blk C-3											215	D
517	28.6977	77.2928	33	Janakpuri Blk C-3											201	D
518	28.7603	77.2133	66	Teli Bara											192	D
519	28.6058	77.2078	66	Seelampur											273	D
520	28.8202	77.0631	65	South of Gokulpur											234	D
521	28.6629	77.0353	65	Nr Kardam Farm, Johripur											230	D
522	28.5851	77.4038	58	Khajuri Khas											235	D
523	28.6135	77.3271	66	Naveen Shahdara											203	D
524	28.6038	77.3372	66	Naveen Shahdara											223	D
525	28.8143	77.4910	59	Seelampur											249	D
526	28.5475	77.1943	26	Dwarka Sec-4											287	D
527	28.5696	77.1837	41	Lawrence Rd Indl Area											233	D
528	28.5613	77.0728	51	Andha Mughal, Nr Gulabi Bagh											230	D
529	28.5542	77.0428	67	Patparganj, nr Trilokpuri-I											227	D
530	28.6188	77.3006	65	Mandoli											237	D
531	28.6229	77.2461	22	Bawana											255	D
532	28.7974	77.2247	40	Wazirpur Indl Area											257	D
533	28.5355	77.1626	44	JNU											850	B
534	28.4508	77.2094	55	Asola											700	B
535	28.4625	77.1834	55	Suhalpur											340	D
536	28.5325	77.1729	44	Jasola											340	D
537	28.8117	77.0096	13	Bhawana, Daryapur Kalan											250	D
538	28.6061	76.9893	17	Nazafgarh											240	D
539	28.5894	77.1118	34	Kirbi cantt											245	D
540	28.7503	77.1653	39	Balsava											250	D
541	28.6147	77.3068	67	Ghazipur											212	D
542	28.6089	77.2642	67	Akshar Dham											230	D

Table 8.3: Peak frequency and Peak amplification obtained from experimental technique (h/v of microtremor) and Indicative No. of stories of building matching with peak frequency

S.N.	Site Location	Latitude	Longitude	Peak frequency (Hz)	Peak amplification factor (ratio)	Indicative No. of stories of building matching with Peak frequency
1	Asola Wildlife FBD	28.4928	77.2425	3.56	2.33	3
2	Rocky Area FBD	28.4873	77.2332	3.59	2.30	3
3	South of Sainik Farm FBD	28.4933	77.2163	1.90	5.11	5,6
4	Rajpur Shitalkunj Farm	28.4847	77.1998	3.32	4.15	3
5	Satwadi	28.4843	77.1857	1.51	5.28	6,7
6	DLF Firm	28.4857	77.1690	1.49	6.19	7,6
7	Gadipur Farm	28.4807	77.1457	3.52	2.74	3
8	Arjungarh	28.4838	77.1252	9.81	1.75	1
9	JJC Ghatozani	28.4967	77.1369	2.08	6.70	5
10	Vatikafarm	28.5004	77.1512	1.73	7.69	5,6
11	Manglapuri	28.4989	77.1678	1.73	8.28	5,6
12	Chhatarpur	28.5017	77.1863	3.30	6.11	3
13	Sainikfarm	28.4996	77.2169	1.03	3.24	10
14	Durga Vihar	28.4994	77.2283	1.64	4.79	6
15	Prem Nagar	28.5030	77.2770	8.05	4.29	1
16	West Suresh Vihar	28.5120	77.3175	3.05	5.57	3
17	NPC Colony	28.5112	77.3027	1.05	3.48	9,10
18	Delhi Adminstration	28.5100	77.2858	8.12	6.50	1
19	Tuglakabad	28.5105	77.2742	7.03	2.16	1
20	Tuglakabad Picnic Hut	28.5118	77.2563	3.52	9.09	3
21	Vayusenabad	28.5125	77.2405	2.47	2.08	4
22	Khanpur	28.5130	77.2260	1.44	4.40	7
23	Anupam Garden	28.5128	77.2085	3.05	6.84	3,4
24	Datta Farm Freedomfighter Viha	28.5148	77.1982	3.64	4.20	3
25	Mandi Masjid Ladosarai	28.5148	77.1852	6.57	8.20	1,2
26	Vasantkunj Sec A	28.5133	77.1677	0.85	4.35	11,12
27	Adjoining Gupta Farm	28.5152	77.1528	3.49	3.73	3
28	Kishangarh	28.5148	77.1315	7.08	1.60	1
29	Rajokari Pahari	28.5133	77.1207	9.91	1.13	1
30	Chawala Farm	28.5182	77.1038	0.68	3.05	15,14
31	Krishna Farm	28.5196	77.0908	0.71	3.09	14

32	Surya Vihar (Sec 21)	28.5188	77.0673	0.66	3.63	15
33	Palam Ganostic Centre	28.5181	77.0586	0.71	3.01	14
34	New Palam Vihar - II	28.5146	77.0071	0.76	3.52	13,14
35	Ragopur Village	28.5245	76.9981	0.68	5.12	14,15
36	Raghuvan Nursery GGN	28.5287	77.0377	0.71	3.12	14
37	Bijwasan	28.5306	77.0580	0.68	3.10	14,15
38	Mange RAm FArm	28.5288	77.0728	0.71	2.97	14
39	Gita Nursery	28.5279	77.0904	0.59	3.75	17
40	Green Retreat	28.5398	77.0943	0.32	4.18	30
41	ICGEB Vasantkunj	28.5247	77.1699	8.67	2.47	1
42	Mehrauli near Qutub Minar	28.5237	77.1835	6.08	7.31	1,2
43	Lado Sarai Quila Rai Pithora	28.5286	77.2019	1.98	8.11	5
44	Modi Hospital Saket	28.5266	77.2148	1.17	6.80	9,8
45	Pushp Vihar Sec 7	28.5307	77.2313	2.83	4.50	3,4
46	Greater Kailash Ph II	28.5307	77.2437	3.76	3.51	3
47	Tuglakabad	28.5235	77.2630	5.64	1.32	2
48	Okhala Industrial Area Ph-II	28.5277	77.2750	8.11	1.55	1
49	Sarita Vihar	28.5272	77.2920	0.66	5.51	15
50	Ali Vihar	28.5227	77.3070	1.12	2.81	9
51	East of Alipur	28.5180	77.3123	2.39	5.77	4,5
52	Zamrudpur	28.5376	77.3140	0.78	4.40	13
53	Kalindikunj	28.5421	77.3095	1.25	3.43	8
54	Sports Complex Jasola	28.5395	77.2901	2.61	6.90	4,3
55	Sanjay Colony Park	28.5383	77.2803	3.27	5.42	3
56	Kalkaji Gupta Apts	28.5385	77.2592	0.66	4.44	15
57	Greater Kailash Encl-I	28.5437	77.2400	2.76	4.66	4,3
58	Sheik Sarai	28.5401	77.2248	1.78	5.94	6,5
59	Bhavishyanidhi Encl	28.5419	77.2104	1.10	4.12	9
60	NCERT	28.5395	77.1961	1.93	4.00	5,6
61	Qutub Institutional Area	28.5397	77.1809	4.98	6.06	2
62	JNU	28.5447	77.1661	7.96	2.17	1
63	Defence Encl Mahipalpur	28.5409	77.1317	0.63	4.70	16,15
64	Rangpuri GGN	28.5460	77.1214	0.90	3.50	11
65	Old Jaipur Road GGN	28.5401	77.0948	0.54	4.56	18,19
66	Pushpanjali Farms G-12	28.5369	77.0728	0.71	3.93	14
67	BIjwasan (near H.P.)	28.5369	77.0561	0.59	4.21	17
68	Borthal - Bamnauli	28.5381	77.0398	0.71	4.74	14

69	Ishapur Khera	28.5377	77.0235	0.68	4.12	14,15
70	Bajghera Village	28.5380	77.0127	0.66	4.19	15
71	North of Kangan Heri	28.5567	76.9993	0.76	2.65	13,14
72	South of Chawala Farm	28.5585	77.0168	0.71	2.62	14
73	East of Dhul Sirs	28.5515	77.0385	0.76	2.81	13,14
74	Dwaraka	28.5545	77.0642	0.73	2.57	14,13
75	Shahbad Muhammadpur	28.5528	77.0745	0.68	2.73	15,14
76	IGI Airport	28.5565	77.0927	0.63	2.48	16,15
77	Nangal Dewat	28.5520	77.1027	0.68	2.21	15,14
78	Import Wear House	28.5523	77.1122	1.20	3.17	8,9
79	East of Mahipalpur	28.5487	77.1477	9.01	1.51	1
80	DDA Flats Munirka	28.5548	77.1797	6.69	5.41	1,2
81	Hauz Khas (Hauz Ali)	28.5539	77.1960	1.07	4.28	9,10
82	Hauz Khas	28.5545	77.2107	1.07	3.69	9,10
83	Shri Fort	28.5538	77.2284	2.93	3.85	3,4
84	Kailash Colony Park	28.5530	77.2570	2.20	5.86	4,5
85	Ajal Bagh, Nur Nagar	28.5563	77.2858	8.03	6.46	1
86	Abul Fazal Encl	28.5563	77.2950	2.64	4.58	4,3
87	Batla House Masjid	28.5622	77.2829	2.56	3.65	4
88	New Friends Colony	28.5671	77.2746	0.83	4.17	12
89	Friends Colony West	28.5647	77.2625	2.88	4.86	3,4
90	Lajpat Nagar	28.5679	77.2435	2.54	3.52	4
91	Defence Colony	28.5685	77.2296	0.98	3.59	10,11
92	AIIMS	28.5684	77.2139	1.10	2.10	9
93	Naroji Nagar	28.5683	77.1928	3.05	5.31	3
94	Vasant Kunj	28.5677	77.1614	3.39	3.17	3
95	Muradabad Pahari	28.5687	77.1532	9.72	1.87	1
96	Police Colony	28.5678	77.1342	6.81	1.63	2,1
97	Dwarka Sector 23 Marble Market	28.5682	77.0668	0.59	3.24	17
98	Dwarka sector 23 Cremation Gd	28.5658	77.0505	0.44	4.79	22,23
99	Dwarka Sector 24	28.5738	77.0472	0.29	5.54	33-35
100	Qutub Vihar	28.5720	77.0308	0.73	2.60	14,13
101	Chhawala Camp	28.5667	77.0040	0.73	2.65	14,13
102	Reola Khanpur	28.5697	76.9880	0.66	2.81	15
103	Paprawat	28.5918	76.9782	0.71	2.47	14
104	Khurd	28.5852	77.0103	0.73	2.72	14,13
105	Goela Dairy	28.5820	77.0238	0.66	2.72	15

106	Dwarka Sector 18	28.5815	77.0372	0.71	2.82	14
107	Dwarka Sector 19	28.5795	77.0537	0.76	2.54	13,14
108	Dwarka Sector 9	28.5818	77.0660	0.68	2.47	14,15
109	Rajnagar II	28.5805	77.0797	0.73	2.77	14,13
110	Pehladpur Palam	28.5808	77.1033	0.71	3.53	14
111	Maudi Line	28.5808	77.1178	0.76	2.59	13,14
112	Subroto Park	28.5787	77.1505	5.18	2.09	2
113	Moti Bagh	28.5827	77.1786	2.78	4.47	3,4
114	Chanakyapuri	28.5821	77.1926	2.29	4.81	4,5
115	Civil Aviation Colony	28.5843	77.2149	1.86	4.67	5,6
116	Pragati Vihar	28.5820	77.2317	1.90	3.65	5
117	Sidharth Ext	28.5809	77.2626	0.98	3.63	10,11
118	Vasundhara Enclave Noida	28.5900	77.3081	0.56	3.97	18,17
119	Nangli	28.5999	77.2804	0.61	3.08	16,17
120	Delhi Golf Club	28.5936	77.2392	0.71	2.89	14
121	Shyam Prasad Vidyalaya	28.5969	77.2254	0.88	3.48	11,12
122	Tuglak Crescent	28.5950	77.2120	1.05	4.46	10
123	Nehru Park	28.5917	77.1920	4.27	3.59	2,3
124	Jesis Mery College	28.5960	77.1804	3.27	3.08	3
125	Saint Martin School	28.5962	77.1460	2.37	4.04	4,5
126	Kaval Lines	28.5953	77.1294	0.68	2.63	15,14
127	Sadar Bazar	28.5953	77.1186	0.71	3.17	14
128	Indira Park	28.5969	77.1023	0.78	2.64	13,12
129	Mahavir Encl II	28.5938	77.0838	0.66	2.69	15
130	Dwarka Sector 6	28.5942	77.0697	0.61	2.89	16,17
131	Dwarka Sector 12	28.5921	77.0409	0.66	2.78	15
132	Dwarka MIG Flats	28.5933	77.0309	0.66	3.56	15
133	Shyam Vihar	28.5893	77.0080	0.66	3.08	15
134	Shyam Encl Papravat	28.5900	76.9838	0.24	2.53	40-41
135	Nazafgarh	28.6097	76.9921	0.68	2.32	14,15
136	West of Kakravla	28.6070	77.0071	0.73	2.81	14,13
137	Bharat Vihar	28.6097	77.0250	0.66	2.95	15
138	Netaji Subhash Inst of Tech	28.6107	77.0390	0.66	3.42	15
139	Jain Colony	28.6103	77.0546	0.32	3.69	30
140	Mahavir Encl III	28.6087	77.0702	0.66	4.26	15
141	Dabri	28.6091	77.0854	0.32	3.06	30
142	Janakpuri Inst Area	28.6104	77.1026	0.63	3.66	16,15

143	Nangal	28.6082	77.1209	0.66	2.44	15
144	Kirby Place	28.6109	77.1325	0.37	2.66	27
145	PIgri Farm	28.6086	77.1529	6.76	4.95	1,2
146	Kamraj Road	28.6071	77.2067	5.79	6.24	2
147	UPSC	28.6054	77.2255	0.88	5.01	11,12
148	Delhi High Court	28.6115	77.2376	0.93	3.23	11,10
149	Kali Basti	28.6116	77.2543	1.12	3.65	9
150	Akshardham	28.6166	77.2789	0.68	3.21	14,15
151	Hindu Cultivated Land	28.6051	77.2878	0.66	3.32	15
152	Mayur Vihar Ph-I	28.6054	77.3054	1.39	3.48	7,8
153	Trilok Puri	28.6103	77.3148	0.71	3.64	14
154	Kondli	28.6076	77.3328	0.78	4.18	13,12
155	Indl Area near Mullapur Colony	28.6205	77.3328	0.51	3.13	19,20
156	Khichripur	28.6210	77.3126	0.73	3.96	13,14
157	Vinod Nagar West	28.6226	77.2967	1.49	4.89	7
158	Ganesh Nagar	28.6360	77.2867	1.17	4.10	9,8
159	Center Secretariate	28.6203	77.2011	6.76	1.10	1,2
160	Narayana	28.6230	77.1342	1.05	2.94	10,9
161	Nanakpura	28.6227	77.1175	0.71	2.54	14
162	Nari Niketan Tihar Jail	28.6213	77.1025	0.63	2.89	16,15
163	Poshangipur	28.6223	77.0873	0.66	2.70	15
164	Janakpuri	28.6215	77.0735	0.71	2.40	14
165	Mohan Garden	28.6212	77.0548	0.66	2.42	15
166	Sevak Park Extension	28.6212	77.0428	0.73	2.80	14,13
167	Kakrala Mor	28.6223	77.0258	0.73	2.85	14,13
168	Nangli Sakrasti (West)	28.6218	77.0070	0.66	2.56	15
169	Nangli Sakrasti	28.6265	76.9923	0.12	3.19	80-85
170	Dichaon Kalan	28.6397	76.9898	0.71	2.42	14
171	West of Baprola	28.6403	77.0013	0.66	2.46	15
172	Baprola	28.6400	77.0097	0.30	2.49	33-35
173	Vijay Vihar	28.6345	77.0412	0.61	2.62	16,17
174	Hast Sol	28.6340	77.0555	0.66	1.99	15
175	Vikas Puri	28.6338	77.0735	0.63	2.29	16,15
176	Ganesh Nagar	28.6350	77.0897	0.98	2.50	10,11
177	Ashok Nagar	28.6352	77.1018	0.81	2.63	12,13
178	Subhash Nagar Mahila Park	28.6360	77.1187	0.68	2.74	15,14
179	Kirti Nagar Wear Housing	28.6355	77.1338	0.71	3.32	14

180	IARI Colony	28.6348	77.1478	6.08	4.23	2,1
181	Push Institute	28.6369	77.1624	1.07	3.98	9,10
182	Sindhi Sch New Rajindernagar	28.6354	77.1787	7.74	1.86	1
183	Telegraph Sq Panchkuya Road	28.6360	77.2072	4.15	6.35	2, 3
184	Minto Road	28.6358	77.2249	1.90	3.55	5,6
185	Maulana Azad Medical College	28.6363	77.2398	2.20	6.60	4,5
186	Gandhi Darshan	28.6367	77.2509	1.90	4.31	5,6
187	Vishwakarma Park	28.6432	77.2665	0.81	3.98	12,13
188	Guru Nanak Nagar	28.6393	77.2834	0.68	3.14	14,15
189	Madhu Vihar	28.6386	77.3013	1.00	4.62	10
190	Kinoria Steels	28.6482	77.3188	0.66	4.05	15
191	Karkar Duma	28.6482	77.3053	1.29	4.63	8
192	Jagat Pur	28.6464	77.2891	0.95	3.64	10,11
193	Gita Colony	28.6480	77.2731	1.07	4.07	9,10
194	Pantoon Bridge	28.6512	77.2656	1.44	4.15	7
195	Parda Bagh	28.6494	77.2423	3.03	7.01	3
196	Kucha Pandit	28.6491	77.2232	3.22	5.56	3,4
197	Jhandewalan	28.6472	77.2062	8.84	3.11	1
198	Karolbagh	28.6501	77.1901	1.03	3.28	10
199	East Patel Nagar	28.6472	77.1777	8.91	6.06	1
200	New Ranjit Nagar	28.6491	77.1584	0.78	4.07	13,12
201	Kirtinagar Ind Area (Bajaj Aut	28.6517	77.1443	0.85	3.09	11,12
202	Ramesh Nagar	28.6508	77.1286	0.71	3.29	14
203	Tagore Garden	28.6500	77.1135	0.71	2.83	14
204	Vishnu Garden	28.6543	77.0972	0.59	3.27	17
205	Gurunanak Nagar	28.6507	77.0847	0.63	2.80	16,15
206	Himgiri Encl	28.6484	77.0689	0.66	2.75	15
207	Nilothi	28.6526	77.0482	0.63	2.66	16,15
208	West of Ranohalla	28.6514	77.0322	0.71	3.09	14
209	Tilangpur	28.6445	77.0140	0.66	2.68	15
210	East of Dichhaon Kalan	28.6421	76.9969	0.63	2.65	16,15
211	North of Dichhaon Kalan	28.6489	76.9819	0.56	3.78	18,17
212	Near Neelwal	28.6645	76.9801	0.63	2.74	16,15
213	Hiran Kudna	28.6660	77.0143	0.68	2.89	14,15
214	Bakriwala	28.6580	77.0175	0.66	2.94	15
215	Laxmi Park	28.6637	77.0462	0.73	2.58	14,13
216	Adhyapak Nagar	28.6645	77.0611	0.56	3.11	18,17

217	Nihal Vihar	28.6627	77.0737	0.61	3.58	16,17
218	Jivan Niketan	28.6635	77.0856	0.61	2.81	16,17
219	Pschim Vihar	28.6646	77.1016	0.73	2.64	14,13
220	Pschimpuri	28.6631	77.1166	0.73	3.46	14,13
221	Panjabi Bagh West	28.6626	77.1291	0.76	2.87	13,14
222	New Motinagar	28.6644	77.1434	0.76	3.05	13,14
223	Nazafgarh Rd Ind Area	28.6629	77.1591	1.15	3.14	9,8
224	Bara Hindu Rao	28.6617	77.2033	1.59	2.98	6,7
225	Swami Hariharnand School	28.6633	77.2397	2.54	7.81	4
226	Rajgarh Colony School	28.6635	77.2729	0.68	3.98	14,15
227	Vishwash Nagar	28.6625	77.2874	1.05	3.56	9,10
228	Yojana Vihar	28.6638	77.3088	0.78	2.59	13,12
229	Jhilmil Industrial Area	28.6748	77.3191	0.78	2.50	13,12
230	Salimpur Housing Complex	28.6750	77.2601	1.64	4.22	6
231	Saraswati Kunj	28.6772	77.2232	2.64	7.22	4,3
232	Malkaganj	28.6754	77.2099	9.81	2.81	1
233	Roshan Ara club	28.6759	77.1943	0.88	3.72	11,12
234	Shastri Nagar	28.6761	77.1760	0.93	2.87	11,10
235	Deva Ram Park	28.6754	77.1640	0.76	2.69	13
236	Rampur Electricity Colony	28.6741	77.1466	0.78	2.53	13,12
237	Shakur Vasti	28.6770	77.1342	0.71	2.68	14
238	Pschim Ext	28.6753	77.1167	0.71	2.55	14
239	Mianawali Nagar DAV Sch	28.6760	77.0856	0.63	2.52	16,15
240	Hanuman Encl	28.6765	77.0693	0.23	2.63	40-45
241	Kamruddin Nagar	28.6775	77.0544	0.73	2.89	14,13
242	Arvind Enclave	28.6769	77.0461	0.49	5.47	20,21
243	Mundika Village	28.6746	77.0323	0.51	4.84	19,20
244	Mundika	28.6788	77.0143	0.66	2.66	15
245	Hiran Kudna Morh	28.6811	77.0026	0.56	2.71	18,17
246	Jafarpur	28.6793	76.9845	0.68	2.40	14,15
247	Ghevara	28.6925	76.9953	0.61	2.66	16,17
248	East of Ghevra	28.6906	77.0131	1.22	1.58	8,9
249	Mundika Ext	28.6927	77.0271	0.95	2.22	10,11
250	Hind Vihar	28.6895	77.0414	0.51	5.88	19,20
251	Premnagar III Laxmi Vihar	28.6937	77.0475	0.34	5.37	30
252	Prem Nagar III	28.6907	77.0560	0.29	8.71	33-35
253	Sultanpuri (Women Trg Centre)	28.6900	77.0686	0.34	2.83	29

254	Mangole Puri	28.6909	77.0860	0.37	3.43	27
255	Nava Sena Apartments	28.6894	77.1019	0.29	4.05	33-35
256	Pushpanjali	28.6918	77.1173	0.29	3.71	33-35
257	Shant Nagar	28.6910	77.1300	0.68	2.76	15,14
258	Shakur Pur	28.6905	77.1472	0.88	2.45	11,12
259	Ashok Vihar	28.6890	77.1645	1.42	3.55	7
260	Deep Enclave	28.6902	77.1773	0.15	4.75	65-70
261	DTC Colony	28.6907	77.1936	1.34	4.10	7,8
262	University Campus	28.6898	77.2148	1.73	4.59	6,5
263	Khyber Pass	28.6915	77.2237	5.91	5.74	2
264	Kartar Nagar	28.6892	77.2562	1.34	2.73	7,8
265	Maujpur	28.6902	77.2745	1.98	6.13	5
266	Jyoti Colony	28.6899	77.2955	1.90	4.05	5,6
267	GTB staff Colony	28.6898	77.3077	0.90	3.29	11
268	Prem Nagar	28.6879	77.3217	0.68	2.79	14,15
269	East of Timarpur	28.7043	77.2334	3.22	9.43	3
270	Delhi Admin Flats Timarpur	28.7043	77.2243	9.08	3.55	1
271	Police Colony M Town	28.7011	77.1996	3.27	5.64	3
272	Lalbagh	28.7003	77.1874	0.68	2.14	14,15
273	Shalimar Bagh	28.7007	77.1748	0.76	3.01	13
274	Purvi Pitampura	28.7025	77.1482	0.76	2.58	13
275	Daxini Pitampura	28.7040	77.1372	0.73	2.83	14,13
276	Rohini Sector 8 (Advance Tech)	28.7031	77.1178	0.42	2.76	23,24
277	Rohini Sec 3 School	28.7045	77.1013	0.61	2.75	16,17
278	Aman Vihar	28.7024	77.0670	0.63	2.61	16,15
279	Pratap Vihar	28.7032	77.0582	0.29	2.81	33-35
280	Shish Mahal Encl	28.7018	77.0400	0.34	6.14	29
281	Rani Kheda	28.7058	77.0283	0.71	2.63	14
282	Rasulpur	28.7137	77.0084	0.61	2.42	16,17
283	Nizampur	28.7137	76.9930	0.63	2.89	16,15
284	South of Ladpur	28.7268	76.9930	0.71	2.88	14
285	SW of Kanjhavla	28.7256	77.0118	0.39	6.95	25,26
286	Veterinary Hospital	28.7241	77.0292	0.32	2.38	30
287	Shyam Encl	28.7153	77.0442	0.27	3.53	35-40
288	Dhur Enclave	28.7258	77.0548	0.37	3.40	27
289	Rohini Sector 21	28.7162	77.0705	0.73	2.44	14,13
290	Harshdev Colony	28.7164	77.0851	0.54	2.95	18,19

291	Rithala	28.7157	77.0998	0.34	2.66	29
292	Rohini Sec 12 Picnic Hut	28.7323	77.1187	0.39	1.88	25,26
293	Prashant Vihar	28.7166	77.1338	0.61	2.58	16,17
294	South of Haiderpur	28.7199	77.1474	0.66	2.40	15
295	Navin Orchard	28.7175	77.1625	0.73	2.19	13,14
296	Majlis Park	28.7193	77.1747	0.71	7.57	14
297	Coronation Piller Jal Board	28.7211	77.1938	0.27	3.69	35-38
298	Nirankari Colony School	28.7165	77.2085	0.63	10.90	16,15
299	Gopal Pur	28.7187	77.2252	0.95	2.49	10,11
300	Wazirabad	28.7206	77.2332	1.73	3.71	5,6
301	Sonia Vihar	28.7207	77.2543	1.39	3.24	7,8
302	Johirpur	28.7164	77.2863	0.93	8.25	11,10
303	Jharoda Mazra Buradi	28.7307	77.2116	2.37	6.06	4,5
304	Nursery Burari	28.7447	77.1963	0.66	2.39	15
305	North of Jahangirpuri	28.7293	77.1836	0.73	2.93	13,14
306	Jahangirpuri	28.7311	77.1640	0.68	2.44	14,15
307	Ravi Das Ashram	28.7290	77.1490	0.71	2.33	14
308	Shivam Apartments	28.7305	77.1340	0.29	2.49	33-35
309	Rohini Sector II (opp police s	28.7296	77.1177	0.61	2.21	16,17
310	Rohini Sector II(cremation grd	28.7327	77.1054	0.68	2.38	15,14
311	Rohini Sector-24 Pocket-26	28.7307	77.0877	0.49	5.07	20,21
312	Begam Vihar Extension	28.7298	77.0706	0.71	2.39	14
313	Jain Nagar, Qutubgarh Road	28.7300	77.0559	0.37	6.28	27
314	Majri, Qutubgarh Road	28.7272	77.0418	0.44	5.26	22,23
315	Karola Shiv Vihar	28.7276	77.0275	0.32	6.26	30
316	Kanjhawala Indl Estateillage F	28.7290	77.0097	0.34	8.39	29
317	Ladpur Village Shahuda Rd	28.7264	76.9937	0.34	8.83	29
318	Ladpur	28.7477	76.9838	0.49	2.81	20,21
319	West of Chandpur	28.7498	76.9971	0.34	2.00	29
320	Kanjhavla North	28.7463	77.0155	0.37	2.31	27
321	North Karala	28.7479	77.0375	0.34	3.66	29
322	South of Puth Khurd	28.7470	77.0526	0.27	3.54	35-40
323	Prahlad Vihar	28.7458	77.0697	0.51	2.70	19,20
324	Prahlad Vihar	28.7440	77.0849	0.34	3.95	29
325	Rohini Sector 26	28.7421	77.1042	0.29	4.47	33-35
326	Rohini Sec 17	28.7438	77.1189	0.63	3.26	16,15
327	Suraj Park	28.7430	77.1356	0.59	3.02	17

328	Samaypur	28.7430	77.1511	0.51	2.55	19,20
329	North of Mukandapur	28.7437	77.1821	1.10	2.34	9
330	Gali No. 29 Santnagar	28.7490	77.1969	0.20	4.71	50?
331	NE of Milan Vihar	28.7439	77.2090	0.56	3.38	18,17
332	Jagatpur	28.7440	77.2254	0.93	2.39	11,10
333	Loni Police Chaowki	28.7103	77.2903	1.34	4.41	7,8
334	Buradi Village	28.7604	77.2043	0.42	2.26	23,24
335	North of Gaidiepur	28.4823	77.1601	1.68	5.64	6
336	West of Chhattarpur	28.4860	77.1764	1.51	4.86	6,7
337	Gautam Farm Chhattarpur Road	28.4943	77.1868	2.12	6.48	4,5
338	Rajpur Khurd Extn (Jungle)	28.4878	77.1954	0.66	11.54	15
339	South of Ayanagar	28.4760	77.1444	0.76	2.97	13,14
340	Bandh Road Chandanhul	28.4736	77.1822	1.37	5.50	7,8
341	Mandir Road Junapur	28.4566	77.1518	0.73	2.98	14,13
342	Asola Fathepur Beri	28.4582	77.1864	2.03	6.04	5
343	South of Asola	28.4507	77.1885	1.42	3.90	7
344	Dadronwala Johr	28.4534	77.2124	3.05	3.14	3
345	Mandi Valley Haryana Border	28.4460	77.1361	3.12	2.97	3
346	Asthal Mandir near Dera More	28.4450	77.1802	1.98	4.93	5
347	Dhakuwala Village near Shiv Ma	28.4432	77.2064	3.49	3.25	2,3
348	Jatonwala Johr (Forest Area)	28.4451	77.2252	0.83	3.82	12
349	Dera Village	28.4366	77.1731	3.66	3.36	3
350	Bhatibas Village	28.4295	77.1872	5.08	2.85	2
351	South West of Jhatikra Village	28.5055	76.9498	0.66	3.61	15
352	Jhatikra Village (near school)	28.5249	76.9653	0.68	5.67	14,15
353	Ghummenhera (Community Centre)	28.5323	76.9191	0.61	4.48	16,17
354	Rawta Village (Chalibpur Road)	28.5227	76.8976	0.68	5.54	14,15
355	West of Sarang	28.5380	76.8733	0.68	3.60	14,15
356	Sarangpur	28.5420	76.8905	0.61	3.35	16,17
357	Ghumonhera	28.5393	76.9249	0.56	4.57	18,17
358	Shikarpur	28.5326	76.9513	0.61	3.78	16,17
359	Badosra Road Kanganheri	28.5394	76.9877	0.59	3.49	17
360	West of Kangaheri	28.5524	76.9740	0.61	4.11	16,17
361	North of Daulatpur	28.5503	76.9568	0.66	4.50	15
362	Hasanpur Village	28.5550	76.9416	0.59	7.51	17
363	West of Hasanpur	28.5548	76.9267	0.61	4.04	16,17
364	Daryapur Khurd	28.5523	76.9149	0.59	4.23	17

365	Malakpur Village	28.5543	76.9009	0.59	3.12	17
366	East of Dhansa	28.5526	76.8861	0.61	4.37	16,17
367	Dhansa Village	28.5554	76.8627	0.46	9.49	21,22
368	West of Dhansa Village	28.5558	76.8545	0.51	3.28	19,20
369	East of Dhansa Border	28.5623	76.8471	0.54	4.16	18,19
370	North of Airforce Station	28.5690	76.8707	0.68	6.32	14,15
371	West of Ojwah Village	28.5666	76.8916	0.61	3.17	16,17
372	Ojwah Village Cremation Ground	28.5643	76.9110	0.56	3.50	18,17
373	West of Kharkhari Round	28.5639	76.9309	0.51	3.15	19,20
374	North of Kharkhari Round	28.5654	76.9406	0.59	4.47	17
375	West of Pandwala Kalan	28.5681	76.9565	0.63	4.51	16,15
376	East of Pandwala Kalan	28.5653	76.9744	0.61	2.83	16,17
377	RE Reola Village Cre'tion grou	28.5681	76.9848	0.66	4.28	15
378	South of Paptavat	28.5851	76.9773	0.61	4.05	16,17
379	South of Kharkhari Naher	28.5788	76.9667	0.59	5.33	17
380	Hans Nagar	28.5740	76.9474	0.56	4.36	18,17
381	Khera Dabar	28.5803	76.9346	0.51	11.37	19,20
382	Samaspur Khalsa	28.5783	76.9106	0.61	3.34	16,17
383	West of Samaspur	28.5793	76.8965	0.54	3.67	18,19
384	Qazipur	28.5767	76.8771	0.59	5.22	17
385	Isapur Cremation Ground	28.5774	76.8596	0.54	3.16	18,19
386	West of Bakargarh	28.5914	76.8744	0.54	3.71	18,19
387	Mira School Bakargarh	28.5929	76.8992	0.61	3.42	16,17
388	West of Jaffarapur	28.5919	76.9063	0.76	6.72	13,14
389	Jaffarpur	28.5927	76.9187	0.59	3.34	17
390	Sureda Village	28.5952	76.9356	0.59	3.08	17
391	West of Khekhari	28.5902	76.9552	0.59	4.41	17
392	Kheara Village	28.5958	76.9728	0.59	3.56	17
393	Prem Nagar	28.6091	76.9775	0.68	2.85	14,15
394	Gopal Nagar	28.6120	76.9665	0.76	2.83	13,14
395	Mitrao	28.6101	76.9486	0.61	2.67	16,17
396	West of Mitrao	28.6069	76.9274	0.54	3.09	18,19
397	East of Mandela	28.6094	76.9131	0.56	3.58	18,17
398	Mundela Village	28.6097	76.8931	0.61	3.96	16,17
399	North of Bagargarh	28.6017	76.8763	0.59	3.63	17
400	South of Laskar	28.6121	76.8532	0.56	4.96	18,17
401	Mandela Khurd	28.6175	76.8887	0.51	2.97	19,20

402	Kair Village	28.6239	76.9214	0.54	3.47	18,19
403	Suralhpur Road Najafgarh	28.6213	76.9592	0.59	3.95	17
404	Dichaon Kalan	28.6198	76.9781	0.59	4.06	17
405	CRP Camp Jharoda Road	28.6369	76.9605	0.56	3.14	18,17
406	West of Jharoda Village	28.6476	76.9456	0.61	3.19	16,17
407	Tikri Kalan Road	28.6661	76.9557	0.54	3.71	18,19
408	South of Tikri Kalan	28.6784	76.9659	0.54	4.99	18,19
409	Baba Haridas Colony	28.6918	76.9639	0.59	4.20	17
410	Nizampur Delhi	28.7145	76.9563	0.59	4.35	15
411	Sauda Village	28.7126	76.9820	0.61	5.11	16,17
412	Garhi Rindhaula School	28.7308	76.9676	0.61	3.33	16,17
413	Jaunti Village (Ladpur Road)	28.7451	76.9757	0.59	3.19	17
414	Kanaunda Jaunti Road	28.7522	76.9554	0.68	6.56	14,15
415	Jonti-Jhimarpur Road	28.7584	76.9872	0.63	4.53	16,15
416	Sultanpur Kanjawala Road	28.7666	77.0208	0.61	4.55	16,17
417	Puth Khard-Begumpur Road (Kach	28.7605	77.0505	0.68	4.12	14,15
418	Pahladpur Dispensary	28.7492	77.0889	0.56	2.57	18,17
419	Shabad Dairy (North Side)	28.7491	77.1039	0.34	3.53	29
420	Swaroop Nagar	28.7531	77.1550	0.51	3.82	19,20
421	Baba Kathia Ashram	28.7555	77.1712	0.32	5.23	30
422	Kamalpur	28.7538	77.1897	0.54	4.95	18,19
423	South of Burari	28.7556	77.2025	0.54	3.60	18,19
424	West of Shubhpur-1	28.7481	77.2371	0.32	5.55	30
425	West of Shubhpur-2	28.7502	77.2467	1.29	3.67	8
426	Burari East	28.7676	77.2056	0.51	6.88	19,20
427	Shankarpura	28.7639	77.1918	0.51	3.28	19,20
428	Nathu Colony	28.7661	77.1783	0.54	3.54	18,19
429	Kushak Khurd	28.7649	77.1625	0.59	3.19	17
430	Akashwani Nangli	28.7703	77.1416	0.63	2.16	16,15
431	Khera Kalan	28.7688	77.1127	0.49	2.99	20,21
432	Rohini Sec-27	28.7633	77.0978	0.32	4.20	30
433	SE of Puth Khurd	28.7560	77.0668	0.56	2.86	18,17
434	Sultanpur Dabas(South Side)	28.7602	77.0398	0.68	3.50	14,15
435	Jhimarpura-Majra Road	28.7685	76.9900	0.39	4.63	25,26
436	South Khor-Panjab	28.7712	76.9596	0.46	2.67	21,22
437	Khor-Panjab-Ladrawan Road	28.7815	76.9550	0.59	4.57	17
438	Majra-Jathkhot Road	28.7782	76.9853	0.73	2.83	14,13

439	Kanjawala Bawana Road	28.7814	77.0264	0.71	7.55	14
440	North of Puth Khurd	28.7766	77.0475	0.32	4.32	30
441	West of Kharakhurd	28.7771	77.0934	0.49	3.15	20,21
442	Kher Kalan & Khurd	28.7743	77.1031	0.54	3.57	18,19
443	Bhudapur	28.7819	77.1360	0.51	3.25	19,20
444	Nangli Puna East	28.7806	77.1541	0.49	2.89	20,21
445	East of Kush??..	28.7771	77.1712	0.46	4.12	21,22
446	Ebrahimpur East	28.7777	77.1865	0.37	3.64	27
447	Burari North	28.7764	77.1972	0.61	3.94	16,17
448	Yamuna West	28.7827	77.2050	0.34	10.17	29
449	Pusta	28.7904	77.1937	0.59	4.33	17
450	East of Makhmalpur	28.7901	77.1661	0.61	3.47	16,17
451	Zindapur East	28.7936	77.1565	0.49	3.98	20,21
452	Jindpur	28.7964	77.1465	0.44	3.77	22,23
453	Alipur Govt School	28.7972	77.1309	0.51	2.32	19,20
454	SW of Alipur	28.7946	77.1118	0.61	4.32	16,17
455	South Halambi Khurd	28.7919	77.0968	0.32	4.44	30
456	South of Bawana	28.7843	77.0415	0.56	3.12	18,17
457	Nangal-Thakran Prempiyau Road	28.7860	77.0163	0.66	3.33	15
458	Jatkhor Village	28.7907	76.9747	0.51	4.58	19,20
459	Qutubgarh Sohti Road	28.8043	76.9609	0.56	3.82	18,17
460	Wazirpur-Kateora Road	28.8043	76.9820	0.66	3.82	15
461	North of Bawana	28.8079	77.0227	0.56	3.49	18,17
462	NE of Bawana	28.7903	77.0736	0.32	3.63	30
463	Bawana Indl Area	28.8001	77.0814	0.32	2.98	30
464	West of Halambi Kalan	28.8031	77.0928	0.32	5.14	30
465	Halambi Kalan	28.8056	77.1093	0.46	2.57	21,22
466	Alipur East	28.8062	77.1390	0.32	8.34	30
467	Bankoli SE	28.8051	77.1509	0.44	2.59	22,23
468	Mukhmalpur West	28.8042	77.1654	0.49	3.41	20,21
469	Mohammadpur	28.8028	77.1861	0.49	3.69	20,21
470	Sungorpur	28.8166	77.2096	0.49	4.43	20,21
471	Tiggipur South	28.8193	77.1875	0.56	3.30	18
472	Baktawarpur South	28.8183	77.1923	0.49	3.40	20,21
473	Triveni Colony	28.8171	77.1618	0.54	3.98	18,19
474	Bankoli North	28.8199	77.1428	0.49	3.07	20,21
475	Sahpur Gari	28.8182	77.1128	0.34	2.71	29

476	West of Sahpur	28.8178	77.1004	0.56	2.79	18,17
477	NW of Sanoth	28.8173	77.0690	0.51	6.82	19,20
478	GRPF Camp Ghoga	28.8170	77.0390	0.51	2.48	19,20
479	Dariyapur Kalan	28.8183	77.0159	0.68	3.59	14,15
480	Mungashpur	28.8217	76.9717	0.46	8.27	21,22
481	Hareol -Chandi Road	28.8213	77.0052	0.61	3.19	16,17
482	Hareol Village(North Side)	28.8387	77.0075	0.56	3.85	18,17
483	East of Ghoga	28.8287	77.0666	0.59	3.11	17
484	West of Bhorgarh	28.8296	77.0899	0.61	3.19	16,17
485	East of Tirki	28.8327	77.1236	0.59	2.77	17
486	Hamidpur NW	28.8350	77.1349	0.32	3.39	30
487	Hamidpur North	28.8347	77.1517	0.42	3.23	23,24
488	Tajpur South	28.8305	77.1653	0.66	2.83	15
489	Garhi Mazra	28.8339	77.1838	0.54	3.13	18,19
490	Jhangola	28.8353	77.2019	0.59	3.44	17
491	Gobind Colony	28.8374	77.2168	0.61	3.80	16,17
492	Polla Mandir	28.8500	77.2083	0.32	3.33	30
493	Palla East	28.8463	77.1883	0.32	3.68	30
494	Tajpur North	28.8446	77.1744	0.32	3.84	30
495	Krishnanagar	28.8554	77.1069	0.56	2.37	18,17
496	East of Sangola	28.8433	77.1321	0.32	4.04	30
497	West of Sangola	28.8462	77.1195	0.32	3.64	30
498	Narela Sec-10	28.8466	77.1017	0.32	4.37	30
499	Narela Mandi	28.8397	77.0906	0.32	4.65	30
500	North of Ghoga	28.8420	77.0490	0.30	2.91	33-35
501	North of Lampur	28.8575	77.0568	0.30	5.62	32,33
502	Narela NE	28.8644	77.0918	0.32	2.79	30
503	Narela Sec-5	28.8638	77.1005	0.32	3.14	30
504	NE Singo Village	28.8583	77.1361	0.49	2.77	20,21
505	Mamurpur	28.8567	77.1159	0.32	2.66	30
506	Safaibad South	28.8684	77.0837	0.32	3.02	30
507	JNU New Campus	28.5519	77.1693	4.86	3.12	2
508	Vasant Kunj B2	28.5233	77.1619	1.03	5.82	9,10
509	Budha Jayanti Park	28.6142	77.1761	9.28	2.84	1
510	Rajendra Nagar R-Block (Jungle	28.6300	77.1718	0.88	5.23	11,12
511	Tis Hazari Court	28.6679	77.2097	9.01	1.45	1

Table 8.5: Peak Frequency (First Mode) and Peak Amplification factor for the soil above Engineering Bedrock, derived from Numerical technique

S.N.	Lat (Deg)	Long (deg)	Sheet	Locality name	Engineering Bedrock Depth	Peak Frequency (FMPF)	Peak Amplification
1	28.6247	76.9144	3	Kair	71	1.7	10.5
2	28.6186	76.8843	3	Mandhela Khurd	85	1.5	11.6
3	28.6128	76.8972	3	Mandhela Kalan	90	1.5	13.2
4	28.6128	76.9158	3	Kair	89	1.5	15.4
5	28.6075	76.8862	3	Mandhela Kalan	89	1.5	13.8
6	28.6028	76.9000	3	Mandhela Kalan	87	1.6	15.4
7	28.6029	76.9149	3	Jafarpur Kalan	82	1.6	14.9
8	28.5953	76.8871	4	Baqargarh	98	1.4	14.9
9	28.5591	76.9028	4	Ujwa	85	1.7	16.1
10	28.5991	76.9198	4	Jafarpur Kalan	88	1.5	13.1
11	28.5766	76.8839	4	Quazipur	90	1.5	14.8
12	28.5751	76.9009	4	shamaspur Khalsa	84	1.5	17.1
13	28.5798	76.9129	4	Ujwa	109	1.3	14.6
14	28.5647	76.8853	4	Quazipur	90	1.5	16.4
15	28.5654	76.9111	4	Ujwa	87	1.5	12.3
16	28.5509	76.9115	4	Daryapur Khurd	98	1.4	12.5
17	28.8188	76.9738	6	Mungashpur	104	1.5	13.8
18	28.8111	76.9528	6	Qutubgarh	95	1.2	10.4
19	28.7961	76.9515	7	Qutubgarh	71	1.8	14.1
20	28.7673	76.9632	7	Khor Punjab	83	1.6	15.8
21	28.7576	76.9466	7	Jonti	78	1.6	13.3
22	28.7486	76.9623	8	Jonti	86	1.4	11.8
23	28.7203	76.9658	8	Nizampur Rashid	71	1.7	13.7
24	28.6923	76.9623	9	Tikri Kalan	63	2.1	14.4
25	28.6736	76.9650	9	Tikri Kalan	109	1.2	14.2
26	28.6816	76.9744	9	Tikri Kalan	84	1.4	14.2
27	28.6653	76.9494	9	Jharoda Kalan	105	1.3	14.3
28	28.6514	76.9342	9	Jharoda Kalan	109	1.2	14.6
29	28.6546	76.9598	9	Jharoda Kalan	84	1.5	13.5
30	28.6437	76.9574	10	Jharoda Kalan	90	1.5	14.5
31	28.6048	76.9573	10	Mitraon	99	1.5	16.3
32	28.6161	76.9300	10	Kair	93	1.4	14.0
33	28.6167	76.9592	10	Mitraon	87	1.3	10.9
34	28.6306	76.9478	10	Surakhpur	81	1.5	15.1
35	28.6318	76.9607	10	Najafgarh	107	1.2	13.6
36	28.5383	76.9818	12	Kangan heri	62	1.7	14.6
37	28.8014	77.0240	13	Nangal Thakuran	115	1.6	14.1
38	28.8006	76.9821	13	Katewara	106	1.3	14.8
39	28.8025	76.9981	13	Bajidpur Thakran	94	1.4	13.4
40	28.7903	76.9771	14	Khorjat	75	1.6	12.5
41	28.7612	76.9753	14	Chatesar	82	1.5	14.8
42	28.7880	77.0151	14	Nangal Thakuran	78	1.6	14.1
43	28.7542	77.0071	14	Budhanpur	102	1.3	15.0
44	28.7503	77.0244	14	Karala	66	1.8	12.0
45	28.7710	77.0166	14	Sultanpur Dabas	107	1.3	15.0

46	28.7709	76.9863	14	Salahpur Majra	96	1.4	15.3
47	28.7067	76.9908	15	Suda	71	1.7	13.4
48	28.7303	77.0231	15	Karala	68	1.8	12.7
49	28.7381	77.0014	15	Ladpur	66	1.9	15.5
50	28.7192	76.9828	15	Nizampur Rashid	63	2.0	14.4
51	28.7261	77.0042	15	Khanjwala	76	1.7	13.2
52	28.7061	76.9758	15	Suda	61	2.1	14.0
53	28.6953	77.0239	16	Mundka	81	1.4	12.6
54	28.6840	77.0076	16	Mundka	85	1.5	12.0
55	28.6729	77.0179	16	Mundka	89	1.5	16.1
56	28.6526	77.0232	16	Bakarwalan	81	1.7	14.7
57	28.6914	76.9766	16	Tikri Kalan	86	1.3	12.8
58	28.6805	76.9904	16	Tikri Kalan	86	1.5	15.6
59	28.6684	76.9936	16	Hiran Kudna	85	1.2	10.3
60	28.6535	76.9840	16	Dhichaon Kalan	77	1.8	15.3
61	28.6400	77.0206	17	Bagrola	90	1.3	12.1
62	28.6262	77.0202	17	Mohan Garden	70	1.8	13.5
63	28.6062	77.0112	17	Najafgarh	84	1.7	16.2
64	28.6159	76.9748	17	Najafgarh	90	1.5	15.5
65	28.6136	76.9992	17	Najafgarh	90	1.5	14.2
66	28.6014	76.9894	17	Roshanpura	76	1.7	15.5
67	28.6316	76.9758	17	Dhichaon Kalan	76	1.4	10.3
68	28.6345	76.9974	17	Dhichaon Kalan	72	1.8	16.4
69	28.5586	76.9811	18	Rewla Khanpur	67	1.9	15.5
70	28.5906	76.9796	18	Paprawat	73	1.8	15.4
71	28.5927	76.9903	18	Dinarpur	64	1.9	15.0
72	28.5801	77.0218	18	Qutubpur	66	1.7	15.0
73	28.5782	76.9773	18	Paprawat	85	1.4	15.2
74	28.5678	77.0104	18	Chhawla	70	1.6	13.2
75	28.5694	76.9967	18	Chhawla	77	1.7	16.2
76	28.5534	77.0019	18	Chhawla	64	1.7	12.8
77	28.8608	77.0566	20	Lampur	69	1.8	15.7
78	28.8692	77.0555	20	Lampur	71	1.7	14.5
79	28.8683	77.0944	20	Narela	70	1.7	13.2
80	28.8521	77.0675	20	Lampur	71	1.9	15.7
81	28.8147	77.0711	21	Sanoth	69	1.8	15.2
82	28.8315	77.0723	21	Bankner	70	1.8	14.6
83	28.7946	77.0299	22	Bawana	54	2.3	13.4
84	28.7998	77.0729	22	Holambi Khurd	66	2.1	14.3
85	28.7800	77.0300	22	Sultanpur Dabas	75	1.7	12.7
86	28.7732	77.0526	22	Barwala	62	1.9	11.7
87	28.7842	77.0670	22	Khera Khurd	65	2.0	15.5
88	28.7619	77.0375	22	Sultanpur Dabas	71	2.0	15.3
89	28.7601	77.0653	22	Barwala	74	1.9	15.9
90	28.7371	77.0386	23	Karala	61	2.1	16.3
91	28.7439	77.0517	23	Karala	66	1.9	14.7
92	28.7378	77.0714	23	Pansali	65	2.0	15.7
93	28.7200	77.0383	23	Mohammadpur Majar	64	2.0	15.8
94	28.7257	77.0563	23	Karala	66	2.0	15.5
95	28.7200	77.0711	23	Rohini Sec-23	70	1.8	15.6
96	28.7106	77.0489	23	Mubarakpur Dabas	62	1.9	14.4

97	28.6988	77.0438	24	Kirari Suleman Nagar	69	1.6	10.8
98	28.6558	77.0401	24	Ranhola Shafipur	68	1.6	10.4
99	28.6828	77.0297	24	Mundka	64	1.6	10.9
100	28.5550	77.0394	26	Dwarka Sec-25	61	2.1	15.2
101	28.5946	77.0352	26	Dwarka Sec-13	65	1.9	14.2
102	28.5949	77.0543	26	Dwarka Sec-5	68	1.7	14.8
103	28.5939	77.0711	26	Dwarka Sec-6	66	1.8	13.1
104	28.5730	77.0528	26	Dwarka Sec-19	72	1.8	13.5
105	28.5814	77.0737	26	Pappan Kalan	71	1.8	12.7
106	28.5597	77.0262	26	Dwarka Sec-24	70	1.9	15.4
107	28.5498	77.0540	26	Dwarka Sec-26	65	2.0	13.4
108	28.5550	77.0675	26	Dwarka Sec-21	70	2.0	13.3
109	28.5378	77.0517	27	Dwarka Sec-27	64	1.9	11.7
110	28.8658	77.0967	28	Mamurpur	57	1.8	12.5
111	28.8544	77.1225	28	Mamurpur	79	1.8	14.6
112	28.8544	77.1018	28	Mamurpur	79	1.4	9.8
113	28.8655	77.1113	28	Mamurpur	54	1.9	11.6
114	28.8261	77.1069	29	Narela	82	1.5	14.3
115	28.8147	77.0856	29	Bhorgarh	73	1.6	13.3
116	28.8431	77.0881	29	Narela	57	2.1	11.4
117	28.8173	77.0976	29	Rajpur Kalan	71	1.3	8.7
118	28.8327	77.0921	29	Bhorgarh	71	1.9	15.1
119	28.8336	77.1169	29	Tikri Khurd	70	1.5	11.8
120	28.8053	77.0972	29	Holambi Kalan	59	1.9	11.5
121	28.8172	77.1165	29	Shahpur Garhi	83	1.5	13.7
122	28.7884	77.0819	30	Naya Bansh	65	1.9	13.8
123	28.7500	77.0765	30	Pehladpur Banger	65	1.7	14.3
124	28.7932	77.0975	30	Holambi Khurd	61	1.8	12.2
125	28.7958	77.1052	30	Holambi Khurd	64	2.0	15.0
126	28.7731	77.0923	30	Khera Khurd	66	1.9	15.6
127	28.7806	77.1125	30	Khera Khurd	62	1.7	11.5
128	28.7556	77.0921	30	Pehladpur Banger	62	1.8	11.9
129	28.7561	77.1131	30	Sirsapur village	61	1.9	13.7
130	28.7244	77.0867	31	Rohini Sec-25	64	1.8	13.4
131	28.7283	77.1187	31	Rohini Sec-12	64	1.5	10.1
132	28.7161	77.0957	31	Rithala	62	1.8	12.3
133	28.7098	77.1119	31	Rohini Sec-6, Blk-F	61	1.8	14.1
134	28.7464	77.1042	31	Shiv Vihar	65	1.6	9.7
135	28.7079	77.0798	31	Sultanpuri	64	1.9	14.4
136	28.7016	77.0904	31	Mangolpuri Blk-Y	66	2.0	15.0
137	28.6969	77.0779	32	Sultanpuri	62	1.8	12.6
138	28.6970	77.1136	32	Pushpanjali Enclave, Rohini	64	2.0	14.7
139	28.6508	77.0857	32	Gurunanak Nagar	65	1.5	11.8
140	28.6583	77.1042	32	Khayala	64	1.8	15.1
141	28.6800	77.0742	32	Nangloi Jat	64	1.6	12.1
142	28.6881	77.0956	32	Mangolpuri	63	1.7	11.7
143	28.6661	77.0917	32	Sunder Aptt, Sunder Vihar	63	1.9	13.4
144	28.6670	77.1023	32	Jwala Heri, Paschim Vihar	64	1.7	12.3
145	28.6439	77.1083	33	Park, Near Tagor Garden	118	1.2	15.7
146	28.6306	77.1069	33	Tihar Village	116	1.3	16.1
147	28.6367	77.1225	33	Subhash Nagar, Blk-10	116	1.3	15.5

148	28.8436	77.1304	38	Singhola	76	1.5	14.2
149	28.8283	77.1450	38	Hamidpur	77	1.6	14.1
150	28.8423	77.1704	38	Tajpur Kalan	75	1.6	13.5
151	28.8269	77.1296	38	Khanpur	74	1.6	13.0
152	28.8135	77.1429	38	Bankoli	74	1.4	10.7
153	28.8194	77.1551	38	Hamidpur	76	1.5	12.9
154	28.8277	77.1702	38	Bakhtawarpur	72	1.6	14.5
155	28.8031	77.1313	38	Alipur	73	1.9	15.6
156	28.8072	77.1663	38	Bakhtawarpur	73	1.8	14.7
157	28.8108	77.1564	38	Bankoli	73	1.7	15.5
158	28.8180	77.1744	38	Bakhtawarpur	72	1.9	16.1
159	28.7890	77.1301	39	Alipur	69	1.7	13.5
160	28.7973	77.1495	39	Alipur	70	2.0	14.9
161	28.7938	77.1663	39	Mukhmelpur	66	1.9	14.4
162	28.7820	77.1454	39	Budhpur, Bijapur	69	1.8	12.5
163	28.7796	77.1686	39	Near Ibrahampur	67	1.9	15.9
164	28.7745	77.1335	39	Khera Ghari	66	1.9	14.0
165	28.7726	77.1501	39	Kadipur	68	1.7	12.7
166	28.7634	77.1722	39	Nathupura	72	1.7	14.6
167	28.7621	77.1524	39	Near Swaroopnagar	65	1.7	12.4
168	28.7563	77.1364	39	Rana Park, Sirsapur	70	1.7	11.5
169	28.7535	77.1654	39	Swaroopnagar, New Colony	72	1.4	12.2
170	28.7881	77.1552	39	Mukhmelpur	67	1.9	14.2
171	28.7688	77.1625	39	Kadipur	70	1.7	14.9
172	28.7429	77.1526	40	Sanjay Gandhi Transport Nagar Blk AG	63	1.8	13.9
173	28.7393	77.1358	40	Rohini Sec-18, Blk A, Pkt8	67	2.0	15.5
174	28.7364	77.1646	40	Bhalsawa	67	1.9	16.0
175	28.7286	77.1493	40	Haiderpur	67	2.0	15.6
176	28.7096	77.1280	40	Rohini Sec-14	67	1.6	12.4
177	28.7108	77.1436	40	North Pitampura, Pkt-NU	66	2.0	15.7
178	28.7194	77.1601	40	Sahipur, Near Shalimar Bagh	67	1.9	15.6
179	28.7191	77.1747	40	Aadarsh Nagar	67	2.0	15.6
180	28.7041	77.1551	40	Pitampura, Blk-TP Pocket	67	1.9	15.0
181	28.7056	77.1744	40	Wazirpur Indl area, Blk-B	68	1.9	16.4
182	28.6928	77.1249	41	Saraswati Vihar	46	2.3	14.0
183	28.6981	77.1419	41	South Pitampura, Blk Pocket-KD	51	2.2	9.3
184	28.6953	77.1631	41	ashok Vihar, Ph-I, Blk-E	49	2.0	12.3
185	28.6597	77.1302	41	Near Raja Garden	58	2.0	13.9
186	28.6833	77.1450	41	Sakurpur Village	49	2.4	14.9
187	28.6703	77.1417	41	East Punjabi Bagh	46	2.5	15.4
188	28.6708	77.1581	41	Karampura Block, Indl Area	48	2.2	13.6
189	28.5431	77.1327	44	CISF Rd, Mahipalpur Extn	63	2.0	14.1
190	28.4972	77.1325	45	Ghitorni Village	55	1.7	10.0
191	28.4964	77.1622	45	Sultanpur Village	64	1.9	12.9
192	28.4858	77.1331	45	Saink Nivas MES, Ghitorni	68	1.8	14.5
193	28.4839	77.1628	45	HK Farm House, near Godaipur	73	1.5	12.2
194	28.4706	77.1631	45	Jaunapur	67	1.9	16.4
195	28.4440	77.1464	46	Farm house, Mandi Village	60	2.1	13.2
196	28.4416	77.1347	46	KH No.66/6, Mandi Village	62	2.0	15.8
197	28.4400	77.1636	46	SEPAL Farm Dera, Mandi Rd, Mandi	65	1.9	14.5
198	28.8441	77.1848	48	MCD School, Palla	77	1.6	14.6

199	28.8455	77.2001	48	Palla	77	1.4	11.6
200	28.8294	77.1788	48	Bakhtawarpur	73	1.5	12.7
201	28.8308	77.1986	48	School Jhangla	74	1.5	12.7
202	28.8175	77.2134	48	Palla Police Post	76	1.5	11.5
203	28.8167	77.1994	48	Near Jal Board Palla	74	1.5	13.0
204	28.7978	77.1807	49	Hiranki Village	67	2.0	15.7
205	28.7708	77.1875	49	Uttarakhand Coloney	64	1.8	13.9
206	28.7639	77.2153	49	Shank No.1, Burari village	65	1.9	13.6
207	28.7948	77.1911	49	Near Shank 22, Hiranki Village	67	1.9	15.4
208	28.7946	77.1998	49	Tedi Daulatpur	67	1.7	13.6
209	28.7810	77.1838	49	Resid. area, Hiranki, Nr Ibrahampur	67	1.6	13.2
210	28.7757	77.1992	49	Silampur Majra	66	1.8	15.0
211	28.7604	77.1976	49	Behind Shani temple, Burari	67	1.9	14.8
212	28.7445	77.1943	50	Sant Nagar	56	2.0	15.9
213	28.7144	77.1874	50	Nr Model Town	67	2.0	19.0
214	28.7135	77.2047	50	Radio Coloney, Nr Dhaka Village	60	1.9	15.3
215	28.7319	77.1810	50	Near Jahangirpuri Blk-JJC	67	1.9	16.0
216	28.7336	77.2064	50	Jharoda Dairy Coloney	60	2.0	15.7
217	28.7331	77.2185	50	Nr Milan Vihar, Burari	56	2.3	14.2
218	28.7260	77.1939	50	Nirankari Ground, nr Jharoda Majra	50	2.0	13.1
219	28.7031	77.1966	50	Model Town	70	2.0	15.1
220	28.7059	77.2210	50	Timarpur	76	1.8	16.0
221	28.6793	77.2205	51	Civil Lines	39	3.1	14.6
222	28.6962	77.2104	51	Khalsa College, Nr Univ campus	70	1.5	13.4
223	28.6893	77.1978	51	CC Colony	61	2.1	15.0
224	28.6896	77.1834	51	Near Satyavati Colony	62	2.0	14.5
225	28.6478	77.2109	51	Azad Market	39	2.8	12.6
226	28.6788	77.1878	51	Shiv Temp, Fakira Bagh, Shastri Nagar	68	1.8	15.1
227	28.6850	77.2033	51	Roopnagar Blk-6	68	1.8	15.4
228	28.6680	77.2208	51	Civil Lines, Nr Tis Hazari	40	2.8	12.1
229	28.5208	77.1910	54	Lado Sarai	39	3.0	14.5
230	28.5340	77.1936	54	Govt Nursery, Adhichini	79	1.6	16.5
231	28.5413	77.1829	54	Lal bahadur Vidyapith, Katwariasarai	70	1.8	12.2
232	28.5056	77.2058	54	Neb Sarai, Mehrauli	39	3.3	14.7
233	28.5478	77.1937	54	Rose Garden, Haus Khas	67	1.9	14.7
234	28.5388	77.2088	54	Begampur,Malviya Nagar	58	2.1	13.6
235	28.5387	77.2244	54	Shek Sarai,Ph.-I	59	2.0	16.9
236	28.5288	77.2066	54	Hauz Rani Saket	63	2.0	13.2
237	28.5080	77.1739	54	Kusum Nursery Vasant Kunj	57	2.1	17.2
238	28.5161	77.2119	54	Saket-Bdarpur Rd	57	2.1	16.0
239	28.5001	77.2220	54	Sainik Farm, Nr Sangam Vihar	56	2.3	15.7
240	28.4986	77.1792	55	Near Chhatarpur Mandir	60	2.1	15.4
241	28.4978	77.1942	55	DDA, Maidan Garhi	39	3.1	14.2
242	28.4828	77.1806	55	10 Farm, DLF, Chhatarpur	67	1.9	16.4
243	28.4856	77.1971	55	Rajpur Khurd	69	1.9	16.2
244	28.4717	77.1922	55	Saharpur Extn, ND	64	1.8	12.5
245	28.4567	77.2075	55	Forest, Asola Village	61	2.1	15.2
246	28.7176	77.2510	58	PT School, Wazirabad	70	1.7	15.8
247	28.7325	77.2325	58	Ramp No.3, Near Jagatpur Bund	65	1.7	14.1
248	28.7450	77.2559	58	Burari Village	68	1.8	15.8
249	28.7079	77.2364	58	Pantan Bridge, Wazirabad	55	2.1	14.2

250	28.7338	77.2657	58	Govt School, Karwal Nagar	57	2.0	16.0
251	28.7188	77.2664	58	Near Priya Convent Sch, Dayalpur	75	1.6	15.6
252	28.7039	77.2554	58	Garai Mandu Village	65	1.8	16.4
253	28.6857	77.2350	59	New Usmanpur Village	53	1.9	11.8
254	28.6587	77.2401	59	MG Park, Lal Quila	53	2.2	16.7
255	28.6924	77.2548	59	Pusta-4, Usmanpur	65	2.0	11.7
256	28.6769	77.2471	59	Opp DMRC off, Shatri Park	57	2.0	12.9
257	28.6753	77.2692	59	Silampur	70	1.8	14.9
258	28.6668	77.2503	59	Shastri Park	18	2.4	7.2
259	28.6589	77.2692	59	SK School, Geeta Colony	74	1.7	15.3
260	28.7304	77.2814	65	Kali Mandir, Shiv Vihar	61	1.9	13.5
261	28.7073	77.3232	65	Harsh vihar	64	1.7	12.1
262	28.7149	77.2815	65	Chamanpark, Johripur	73	1.7	14.6
263	28.7029	77.3076	65	Nand Nagari	81	1.8	16.0
264	28.7044	77.2769	65	Gokulpuri colony	70	1.6	12.2
265	28.7029	77.2962	65	East Gokulpur	54	1.8	10.5
266	28.6895	77.2893	66	Near Jyoti colony	68	1.9	15.7
267	28.6925	77.3129	66	Nand Nagari, Blk-E4	70	1.9	16.2
268	28.6777	77.2984	66	Mansarovar Park	75	1.8	16.1
269	28.6560	77.2923	66	Arjun Nagar	88	1.7	16.0
270	28.6653	77.3056	66	Jhilmil Coloney	70	1.9	15.9
271	28.6537	77.3157	66	Anand Vihar, Blk-C	70	1.8	16.7
272	28.6192	77.2865	67	Pandav Nagar, Blk-A	70	1.7	12.3
273	28.6242	77.3001	67	Vinod Nagar West, Blk-D	86	1.7	15.7
274	28.6092	77.3028	67	Mayur Vihar, Ph-I, Pkt 2	64	2.0	17.0
275	28.6111	77.3225	67	Durga park Coly, near Kundali	70	1.9	15.8
276	28.5398	77.2831	69	Park, near Appolo Hosp., Jasola	72	1.8	12.8
277	28.5234	77.3083	69	near Badarpur Thermal Plant, Khadar	73	1.5	11.8
278	28.5321	77.2956	69	DDA Park, Sarita Viahar, Blk-D	63	1.9	13.9
279	28.5412	77.3089	69	Kalindikunj, Jaitpur Road	70	1.7	12.8
280	28.5322	77.3161	69	DDA park, JJ Colony	60	1.8	12.2
281	28.5062	77.3017	69	Govt School, near NTPC,Badarpur	63	2.0	13.9
282	28.5025	77.3141	69	Near Irrigation Dept, Hari Nagar	41	2.6	15.7
283	28.6281	77.3253	72	Near Gaziur, Blk-D	70	1.8	13.3
284	28.6121	77.3348	72	Gharoli Dairy Farm, Blk-A	62	2.0	15.3
285	28.6032	77.3308	72	Near Kundli, Blk-A1	63	1.9	13.7
286	28.5147	77.3417	73	Jaitpur Extn	60	2.0	13.9
287	28.5253	77.3313	73	Near Police post, Jaitpur	60	1.8	12.5
288	28.8746	77.0795	20	Safiabad	77	1.7	13.0
289	28.8757	77.1114	28	Kundli	66	1.8	12.0
290	28.8125	77.0875	29	Holambi kalan	60	1.9	13.9
291	28.8300	77.1229	29	Tikri Khurd	102	1.4	15.6
292	28.7222	77.1056	31	DCE, Rithala	76	1.6	13.0
293	28.8183	77.1458	38	Bankoli	71	1.8	15.0
294	28.7499	77.1763	39	Bhalsawa Dairy	70	1.8	16.0
295	28.7917	77.1597	39	Mukhmelpur	70	1.8	13.1
296	28.8417	77.2125	48	Jangola	88	1.6	16.8
297	28.8056	77.1917	49	Fatehpur Jat	62	2.1	16.0
298	28.8583	77.2417	49	Sankrot	50	2.3	14.6
299	28.7083	77.2167	50	Indira Vihar	60	1.9	11.7
300	28.7427	77.2053	50	Salarpur	58	1.9	14.4

301	28.6917	77.2292	51	Majnu Ka Tila	154	0.9	14.5
302	28.7450	77.2442	58	Libaspur	79	1.6	15.1
303	28.6072	76.8844	3	Mandhela Kalan	117	1.2	14.8
304	28.5828	76.9311	11	Khera Dabas	104	1.1	14.8
305	28.5324	76.9461	12	Shikarpur	80	1.3	14.9
306	28.7872	77.0164	14	Bawana, Khanjawala	70	1.9	16.5
307	28.6264	77.0197	17	Mohan Garden	74	1.9	14.6
308	28.7072	77.0322	23	Madanpur Dabas	68	1.9	16
309	28.8714	77.0833	28	Narela	64	1.9	15.5
310	28.8042	77.1094	29	Holambi Kalan	60	2.1	15.4
311	28.7347	77.0892	31	Rohini Sec-25	65	2.2	14.4
312	28.6250	77.0903	33	Janakpuri Blk-B3B	80	1.5	15.3
313	28.5117	77.1083	35	Rajokri village	88	1.3	15.4
314	28.8180	77.1744	38	Bakhtawarpur	60	2.0	13.42
315	28.7535	77.1653	39	Swaroopnagar, New Colony	67	1.9	16.1
316	28.6828	77.1615	41	Keshavpuram	122	1.5	14.6
317	28.4717	77.1475	45	Akoi Farm, Jaunapur	42	3.0	14.7
318	28.6857	77.2159	51	Ridge, Near Univ Campus	39	2.4	13.3
319	28.6645	77.2074	51	Azadpur Market	62	1.7	15.2
320	28.6144	77.1763	52	Budha Jayanti Park	38	2.7	14.5
321	28.5386	77.2092	54	Begampur,Malviya Nagar	47	2.1	16.1
322	28.5252	77.2215	54	Pushpa Vihar, Sec-1	45	2.1	16.4
323	28.4723	77.1860	55	Chandan Hulla	73	1.3	14
324	28.7250	77.2510	58	PTS Wazirabad	66	1.2	12.2
325	28.5811	77.2313	61	Jawaharlal Nehru Stadium	39	1.7	12.2
326	28.6029	77.2855	67	Nangal	81	1.2	12.6
327	28.5325	77.3167	69	JJ Colony, Sarita Vihar	110	1.0	16.6
328	28.5811	77.2330	61	Jawaharlal Nehru Stadium	42	1.4	7.7
329	28.5889	77.2596	61	Sarai Kale Khan	81	1.3	14.1
330	28.5889	77.2596	61	Sarai Kale Khan	80	1.4	16.4
331	28.5963	77.2578	61	Rajiv Gandhi Smriti Van, Nr Zoo	100	1.3	18.0
332	28.5997	77.2569	61	Rajiv Gandhi Smriti Van, Nr Zoo	66	1.4	12.6
333	28.5976	77.2575	61	Rajiv Gandhi Smriti Van, Nr Zoo	100	1.3	19.1
334	28.6783	77.1583	41	Tri Nagar	43	1.8	12.9
335	28.6699	77.2704	59	Seelampur	61	1.4	8.6
336	28.6783	77.1583	41	Tri Nagar	63	1.7	13.4
337	28.5524	77.2758	68	Sukhdev Vihar	74	1.3	12.5
338	28.5233	77.2279	62	Pushpa Vihar	53	2.0	14.6
339	28.5431	77.2113	54	Paschimshila Park, South Blk-S	46	2.6	17.8
340	28.6783	77.1583	41	Tri Nagar	74	1.7	15.4
341	28.7177	77.1103	31	Rohini Sec-5, Pkt-6	49	2.0	14.9
342	28.5248	77.2137	54	Saket	63	1.5	15.0
343	28.6813	77.0971	32	Udyog Nagar, Nr Paschim Vihar	76	1.7	15.8
344	28.6407	77.2320	60	Ramlila Ground	83	1.2	15.1
345	28.4724	77.1860	55	Chandan Hulla	73	1.6	13.3
346	28.4704	77.2013	55	Saharpur Extn, ND	32	3.4	11.3
347	28.4458	77.1866	56	Fatehpur Beri	100	1.2	13.0
348	28.4431	77.2006	56	Bhati Mines	43	1.9	8.9
349	28.6830	77.1622	41	Keshavpuram	90	1.8	14.7
350	28.6029	77.2855	67	Nangal	81	1.4	11.1
351	28.6361	77.2986	67	Indraprastha Extn	80	1.6	14.7

352	28.6768	77.3123	66	Dilshad Garden, Blk R	92	1.5	15.3
353	28.6222	77.3388	72	NearMayur Vihar Ph-III	50	1.9	10.7
354	28.7342	77.0891	31	Rohini Sec-25	55	2.2	11.8
355	28.5089	77.1083	35	Rajokri village	110	1.4	14.9
356	28.6379	77.0761	33	Vikaspuri Blk-C	77	1.8	15.5
357	28.5877	77.0474	26	Dwarka Sec-11	68	2.0	15.4
358	28.5933	77.0492	26	East of Dwarka Sec-12	67	2.0	15.7
359	28.6736	77.2981	66	Shahdara	74	1.9	15.2
360	28.5926	77.0815	34	Nr Palam Village	69	2.0	15.1
361	28.6175	77.0480	25	Sainik Nagar	72	1.8	15.4
362	28.5963	77.0788	34	Dwarka Sec-1	68	1.9	14.7
363	28.6699	77.1389	41	West Punjabi Bagh	51	2.4	15.7
364	28.5963	77.2578	61	Rajiv Gandhi Smriti Van, Nr Zoo	40	2.6	15.3
365	28.8197	77.0612	21	Sanoth	69	1.8	16.1
366	28.6222	77.2042	52	Nr MP's Club, Rakabganj	40	2.9	14.6
367	28.5300	77.0890	35	Samalka, Nr Kapashera	69	2.0	15.1
368	28.5449	77.1198	35	Intl Airport Authority, Nr Mahipalpur	63	2.1	15.2
369	28.5477	77.1250	35	Intl Airport Authority, Nr Mahipalpur	61	2.2	15.3
370	28.5861	77.0551	26	Dwarka Sec-10	68	1.9	15.6
371	28.5958	77.1200	34	Sadar Bazar (Delhi Cantt)	71	1.8	15.3
372	28.7119	77.1601	40	Shalimar Bagh, Pkt-BD	66	1.9	15.4
373	28.8528	77.0889	29	Narela	66	1.9	15.6
374	28.6250	76.9231	3	Kair	83	1.6	15.3
375	28.5917	76.9250	4	Jafarpur Kalan	84	1.6	14.9
376	28.6417	77.1647	42	West Patel Nagar	40	2.6	14.5
377	28.6611	77.1458	41	New Motinagar, Blk-17	99	1.4	15.3
378	28.6431	77.0972	33	Chaukhandi, nr Hind Nagar	78	1.8	15.1
379	28.6636	77.1433	41	New Motinagar, Blk-B	76	1.8	15.2
380	28.6919	77.1602	41	Lawrence Rd Coloney, Blk-C-7	63	2.1	15.6
381	28.6736	77.1931	51	Gulabi Bagh	59	2.1	15.9
382	28.6797	77.1573	41	Omkar Nagar	71	1.9	15.6
383	28.6475	77.1797	52	Prasad Nagar, Nr E. Patel nagar	40	2.7	15.2
384	28.5827	77.0579	26	Dwarka Sec-10	69	1.9	15.4
385	28.6506	77.3042	66	Karkarduma	75	1.8	15.4
386	28.6484	77.3046	67	Karkarduma	65	1.8	15.4
387	28.5807	77.2924	68	Trans Yamuna, nr Chilla	78	1.7	15.7
388	28.6417	77.2522	60	Rajghat	40	2.7	15.3
389	28.6681	77.2564	59	Shastri Park, BLK-A	46	2.4	15.3
390	28.5150	77.2722	62	Close to Tuglakabad Village	40	2.8	14.9
391	28.5686	77.2436	61	Lajpatnagar, part-II	67	2.0	15.4
392	28.5681	77.2189	53	South Ex Part-II	58	2.1	15.6
393	28.5444	77.2583	62	Kalkaji, Blk-D	40	2.6	14.3
394	28.5722	77.1708	43	RK Puram, Sec-8	40	2.8	14.1
395	28.5781	77.1625	43	Anand Niketan, Blk-D	40	2.7	15.1
396	28.6222	77.2467	60	Mata Sundari Rly Coloney	40	2.8	16.3
397	28.6903	77.1778	51	Satyawati Coloney, Blk-A, Pkt-A	60	2.1	15.1
398	28.6556	77.1917	51	Karol Bagh, Blk-D, Pkt52	40	2.5	15.1
399	28.6083	77.2403	60	Bapa Nagar	78	1.7	15.7
400	28.6111	77.2264	60	Vigyan Bhawan	69	1.9	15.7
401	28.6367	77.2064	52	Govt Quarters, Nr Gole Market	40	2.7	14.6
402	28.6417	77.1508	42	Pusa Institute	40	2.5	14.8

403	28.5651	77.0783	34	IGI nr Pappan Kalan	67	2.0	15.6
404	28.6389	77.2375	60	West of F.S.Kotla stadium	40	2.6	15.6
405	28.6260	77.2099	52	Bangla Saheb Gurudwara	40	2.7	14.9
406	28.6735	77.2916	66	Makki Sarai	63	2.0	14.9
407	28.6021	77.1928	52	Chanakyapuri, Nr JLN Memorial Museum	40	2.8	14.5
408	28.5523	77.2140	53	Siri Fort Sports Complex	60	2.2	15.5
409	28.5616	77.2242	53	Aayurvugyan Nagar	60	2.1	15.5
410	28.5677	77.2272	61	Andrews Ganj	60	2.1	15.7
411	28.6390	77.1316	42	Mansarover Garden, Blk-WZ	61	2.2	15.1
412	28.5255	77.2120	54	Saket	70	2.0	15.6
413	28.5862	77.0639	26	Dwarka Sec-10	69	2.0	16.1
414	28.7982	77.0362	22	Bawana	71	1.9	15.4
415	28.6805	77.3130	66	Dilshad Garden, Blk-C	72	1.9	15.6
416	28.7100	77.2835	65	Bhagirath Vihar	71	1.9	15.4
417	28.6217	77.2440	60	Pragati Maidan	40	2.8	15.2
418	28.7011	77.3078	65	Mandoli Extn	80	1.7	15.8
419	28.5417	77.1833	54	Qutub Indl Area	40	2.8	14.4
420	28.5332	77.3029	69	Madanpur Khadar Village	73	1.6	16.2
421	28.7135	77.1774	50	Majlis Park	68	1.9	15.6
422	28.5646	77.2477	61	Lajpat Nagar, Part-IV	70	2.0	15.2
423	28.7238	77.1353	40	Rohinin Sec-13, nr Vikrant Apartment	68	1.9	15.6
424	28.5621	77.0769	34	IGI, nr Dwarka Sec-21	68	2.0	15.2
425	28.6779	77.2274	59	Civil Lines	40	2.6	15.2
426	28.5730	77.0777	34	Dwarka Sec-8	70	1.9	15.2
427	28.5867	77.0933	34	Sadh Nagar, Palam coloney	70	1.9	15.4
428	28.7265	77.1125	31	Rohini Sec-25	40	2.8	15.2
429	28.7268	77.1136	31	Rohini Sec-25	40	2.7	15.2
430	28.6444	77.2269	60	Kamla Market	72	1.7	15.9
431	28.6006	77.0931	33	Mahaveer Enclave-II, nr Kailashpuri west	72	1.9	15.4
432	28.6150	77.0889	33	Janakpuri Blk C-3	78	1.7	15.8
433	28.6153	77.0886	33	Janakpuri Blk C-3	78	1.8	15.4
434	28.6708	77.2903	66	Teli Bara	74	1.3	13.4
435	28.6683	77.2762	66	Seelampur	79	1.7	15.5
436	28.7012	77.2888	65	South of Gokulpur	67	2.0	16.0
437	28.7164	77.2863	65	Nr Kardam Farm, Johripur	61	1.9	15.3
438	28.6764	77.2889	66	Naveen Shahdara	74	1.7	16.0
439	28.6764	77.2889	66	Naveen Shahdara	74	1.7	15.9
440	28.6699	77.2704	59	Seelampur	88	1.5	15.5
441	28.5979	77.0510	26	Dwarka Sec-4	67	2.0	15.6
442	28.6806	77.1561	41	Lawrence Rd Indl Area	73	1.8	15.7
443	28.6708	77.1972	51	Andha Mughal, Nr Gulabi Bagh	55	2.2	15.8
444	28.6117	77.3103	67	Patparganj, nr Trilokpuri-I	71	1.8	15.8
445	28.7042	77.3131	65	Mandoli	75	1.7	15.9
446	28.7931	77.0417	22	Bawana	75	1.7	15.9
447	28.7019	77.1667	40	Wazirpur Indl Area	64	2.1	15.4
448	28.5355	77.1626	44	JNU	10	15.1	12.8
449	28.4508	77.2094	55	Asola	15	9.9	13.98

Table 9.4: Peak Ground Acceleration (PGA) (i) at base of soil column (ii) at 6m & 3m below Ground surface and (iii) Amplification Factor (based on MCE).

S.No.	Latitude (deg)	Longitude (deg)	Sheet No	Locality name	PGA at base of soil column	PGA at 6m depth below Ground Surface	PGA at 3m depth below Ground Surface	PGA at Ground Surface	Amplification Factor
1	28.6247	76.9144	3	Kair	0.128	0.195	0.213	0.274	2.1
2	28.6186	76.8843	3	Mandhela Khurd	0.097	0.198	0.229	0.305	3.1
3	28.6128	76.8972	3	Mandhela Kalan	0.095	0.193	0.215	0.270	2.9
4	28.6128	76.9158	3	Kair	0.104	0.209	0.248	0.291	2.8
5	28.6075	76.8862	3	Mandhela Kalan	0.110	0.194	0.217	0.256	2.3
6	28.6028	76.9000	3	Mandhela Kalan	0.107	0.209	0.255	0.315	2.9
7	28.6029	76.9149	3	Jafarpur Kalan	0.117	0.234	0.274	0.342	2.9
8	28.5953	76.8871	4	Baqargarh	0.104	0.188	0.212	0.254	2.4
9	28.5591	76.9028	4	Ujwa	0.109	0.229	0.284	0.361	3.3
10	28.5991	76.9198	4	Jafarpur Kalan	0.098	0.202	0.257	0.326	3.3
11	28.5766	76.8839	4	Quazipur	0.098	0.207	0.228	0.284	2.9
12	28.5751	76.9009	4	Shamaspur Khalsa	0.103	0.179	0.216	0.236	2.3
13	28.5798	76.9129	4	Ujwa	0.109	0.173	0.192	0.228	2.1
14	28.5647	76.8853	4	Quazipur	0.098	0.210	0.261	0.330	3.4
15	28.5654	76.9111	4	Ujwa	0.097	0.194	0.223	0.291	3.0
16	28.5509	76.9115	4	Daryapur Khurd	0.090	0.169	0.188	0.220	2.4
17	28.8188	76.9738	6	Mungashpur	0.119	0.229	0.250	0.290	2.4
18	28.8111	76.9528	6	Qutubgarh	0.125	0.263	0.278	0.333	2.7
19	28.7961	76.9515	7	Qutubgarh	0.154	0.270	0.325	0.382	2.5
20	28.7673	76.9632	7	Khor Punjab	0.125	0.235	0.307	0.343	2.7
21	28.7576	76.9466	7	Jonti	0.134	0.232	0.269	0.340	2.5
22	28.7486	76.9623	8	Jonti	0.110	0.220	0.243	0.299	2.7
23	28.7203	76.9658	8	Nizampur Rashid	0.135	0.240	0.315	0.415	3.1
24	28.6923	76.9623	9	Tikri Kalan	0.109	0.236	0.325	0.390	3.6
25	28.6736	76.9650	9	Tikri Kalan	0.119	0.196	0.225	0.244	2.1
26	28.6816	76.9744	9	Tikri Kalan	0.100	0.208	0.242	0.290	2.9
27	28.6653	76.9494	9	Jharoda Kalan	0.108	0.215	0.233	0.285	2.6
28	28.6514	76.9342	9	Jharoda Kalan	0.118	0.219	0.238	0.287	2.4
29	28.6546	76.9598	9	Jharoda Kalan	0.119	0.188	0.195	0.245	2.1
30	28.6437	76.9574	10	Jharoda Kalan	0.117	0.205	0.247	0.322	2.7
31	28.6048	76.9573	10	Mitraon	0.103	0.194	0.223	0.275	2.7
32	28.6161	76.9300	10	Kair	0.098	0.209	0.227	0.297	3.0
33	28.6167	76.9592	10	Mitraon	0.095	0.185	0.235	0.267	2.8
34	28.6306	76.9478	10	Surakhpur	0.117	0.218	0.236	0.309	2.6
35	28.6318	76.9607	10	Najafgarh	0.114	0.185	0.216	0.266	2.3
36	28.5383	76.9818	12	Kangan heri	0.113	0.186	0.258	0.338	3.0

37	28.8014	77.0240	13	Nangal Thakuran	0.119	0.214	0.231	0.258	2.2
38	28.8006	76.9821	13	Katewara	0.117	0.217	0.239	0.267	2.3
39	28.8025	76.9981	13	Bajidpur Thakran	0.110	0.218	0.234	0.280	2.5
40	28.7903	76.9771	14	Khorjat	0.138	0.243	0.287	0.366	2.6
41	28.7612	76.9753	14	Chatesar	0.116	0.238	0.281	0.340	2.9
42	28.7880	77.0151	14	Nangal Thakuran	0.108	0.248	0.270	0.368	3.4
43	28.7542	77.0071	14	Budhanpur	0.111	0.209	0.244	0.290	2.6
44	28.7503	77.0244	14	Karala	0.133	0.236	0.279	0.335	2.5
45	28.7710	77.0166	14	Sultanpur Dabas	0.114	0.211	0.263	0.312	2.7
46	28.7709	76.9863	14	Salahpur Majra	0.112	0.229	0.269	0.336	3.0
47	28.7067	76.9908	15	Suda	0.127	0.205	0.236	0.307	2.4
48	28.7303	77.0231	15	Karala	0.129	0.208	0.281	0.322	2.5
49	28.7381	77.0014	15	Ladpur	0.136	0.210	0.301	0.382	2.8
50	28.7192	76.9828	15	Nizampur Rashid	0.116	0.250	0.265	0.313	2.7
51	28.7261	77.0042	15	Khanjwala	0.122	0.215	0.251	0.320	2.6
52	28.7061	76.9758	15	Suda	0.123	0.220	0.230	0.264	2.2
53	28.6953	77.0239	16	Mundka	0.099	0.201	0.252	0.287	2.9
54	28.6840	77.0076	16	Mundka	0.126	0.183	0.191	0.236	1.9
55	28.6729	77.0179	16	Mundka	0.107	0.210	0.268	0.297	2.8
56	28.6526	77.0232	16	Bakarwalan	0.114	0.214	0.250	0.308	2.7
57	28.6914	76.9766	16	Tikri Kalan	0.100	0.201	0.269	0.297	3.0
58	28.6805	76.9904	16	Tikri Kalan	0.098	0.213	0.247	0.310	3.2
59	28.6684	76.9936	16	Hiran Kudna	0.105	0.200	0.252	0.295	2.8
60	28.6535	76.9840	16	Dhichaon Kalan	0.127	0.224	0.255	0.318	2.5
61	28.6400	77.0206	17	Bagrola	0.104	0.177	0.187	0.242	2.3
62	28.6262	77.0202	17	Mohan Garden	0.127	0.204	0.241	0.319	2.5
63	28.6062	77.0112	17	Najafgarh	0.111	0.188	0.221	0.277	2.5
64	28.6159	76.9748	17	Najafgarh	0.105	0.193	0.232	0.280	2.7
65	28.6136	76.9992	17	Najafgarh	0.102	0.183	0.204	0.259	2.5
66	28.6014	76.9894	17	Roshanpura	0.120	0.199	0.221	0.273	2.3
67	28.6316	76.9758	17	Dhichaon Kalan	0.108	0.191	0.220	0.257	2.4
68	28.6345	76.9974	17	Dhichaon Kalan	0.133	0.214	0.252	0.331	2.5
69	28.5586	76.9811	18	Rewla Khanpur	0.110	0.201	0.249	0.318	2.9
70	28.5906	76.9796	18	Paprawat	0.126	0.199	0.239	0.313	2.5
71	28.5927	76.9903	18	Dinarpur	0.129	0.183	0.273	0.390	3.0
72	28.5801	77.0218	18	Qutubpur	0.108	0.176	0.246	0.389	3.6
73	28.5782	76.9773	18	Paprawat	0.096	0.195	0.230	0.311	3.2
74	28.5678	77.0104	18	Chhawla	0.102	0.193	0.226	0.323	3.2
75	28.5694	76.9967	18	Chhawla	0.118	0.197	0.228	0.307	2.6
76	28.5534	77.0019	18	Chhawla	0.125	0.170	0.239	0.385	3.1
77	28.8608	77.0566	20	Lampur	0.165	0.249	0.310	0.449	2.7

78	28.8692	77.0555	20	Lampur	0.166	0.255	0.289	0.405	2.4
79	28.8683	77.0944	20	Narela	0.161	0.253	0.272	0.351	2.2
80	28.8521	77.0675	20	Lampur	0.138	0.256	0.310	0.368	2.7
81	28.8147	77.0711	21	Sanoth	0.149	0.221	0.275	0.381	2.6
82	28.8315	77.0723	21	Bankner	0.144	0.231	0.274	0.353	2.4
83	28.7946	77.0299	22	Bawana	0.128	0.253	0.297	0.352	2.8
84	28.7998	77.0729	22	Holambi Khurd	0.111	0.231	0.281	0.326	2.9
85	28.7800	77.0300	22	Sultanpur Dabas	0.152	0.224	0.237	0.299	2.0
86	28.7732	77.0526	22	Barwala	0.142	0.209	0.247	0.297	2.1
87	28.7842	77.0670	22	Khera Khurd	0.124	0.242	0.288	0.325	2.6
88	28.7619	77.0375	22	Sultanpur Dabas	0.122	0.241	0.285	0.336	2.8
89	28.7601	77.0653	22	Barwala	0.117	0.230	0.262	0.312	2.7
90	28.7371	77.0386	23	Karala	0.118	0.220	0.303	0.369	3.1
91	28.7439	77.0517	23	Karala	0.137	0.242	0.284	0.321	2.3
92	28.7378	77.0714	23	Pansali	0.112	0.250	0.303	0.385	3.4
93	28.7200	77.0383	23	Mohammadpur Majar	0.119	0.223	0.282	0.363	3.0
94	28.7257	77.0563	23	Karala	0.127	0.237	0.311	0.381	3.0
95	28.7200	77.0711	23	Rohini Sec-23	0.121	0.198	0.244	0.274	2.3
96	28.7106	77.0489	23	Mubarakpur Dabas	0.121	0.218	0.268	0.342	2.8
97	28.6988	77.0438	24	Kirari Suleman Nagar	0.125	0.191	0.185	0.232	1.9
98	28.6558	77.0401	24	Ranhola Shafipur	0.114	0.193	0.237	0.290	2.6
99	28.6828	77.0297	24	Mundka	0.131	0.216	0.220	0.269	2.1
100	28.5550	77.0394	26	Dwarka Sec-25	0.104	0.222	0.264	0.310	3.0
101	28.5946	77.0352	26	Dwarka Sec-13	0.108	0.221	0.284	0.331	3.1
102	28.5949	77.0543	26	Dwarka Sec-5	0.115	0.206	0.264	0.325	2.8
103	28.5939	77.0711	26	Dwarka Sec-6	0.113	0.207	0.262	0.302	2.7
104	28.5730	77.0528	26	Dwarka Sec-19	0.118	0.205	0.244	0.298	2.5
105	28.5814	77.0737	26	Pappan Kalan	0.116	0.194	0.247	0.274	2.4
106	28.5597	77.0262	26	Dwarka Sec-24	0.111	0.208	0.264	0.288	2.6
107	28.5498	77.0540	26	Dwarka Sec-26	0.091	0.202	0.263	0.299	3.3
108	28.5550	77.0675	26	Dwarka Sec-21	0.090	0.207	0.242	0.272	3.0
109	28.5378	77.0517	27	Dwarka Sec-27	0.092	0.200	0.245	0.280	3.0
110	28.8658	77.0967	28	Mamurpur	0.147	0.224	0.310	0.424	2.9
111	28.8544	77.1225	28	Mamurpur	0.133	0.211	0.310	0.406	3.1
112	28.8544	77.1018	28	Mamurpur	0.107	0.207	0.271	0.355	3.3
113	28.8655	77.1113	28	Mamurpur	0.148	0.201	0.296	0.403	2.7
114	28.8261	77.1069	29	Narela	0.105	0.191	0.276	0.369	3.5
115	28.8147	77.0856	29	Bhorgarh	0.120	0.226	0.287	0.384	3.2
116	28.8431	77.0881	29	Narela	0.118	0.239	0.274	0.357	3.0
117	28.8173	77.0976	29	Rajpur Kalan	0.102	0.195	0.251	0.308	3.0
118	28.8327	77.0921	29	Bhorgarh	0.139	0.256	0.296	0.366	2.6

119	28.8336	77.1169	29	Tikri Khurd	0.103	0.185	0.278	0.368	3.6
120	28.8053	77.0972	29	Holambi Kalan	0.143	0.209	0.269	0.409	2.9
121	28.8172	77.1165	29	Shahpur Garhi	0.102	0.225	0.253	0.290	2.8
122	28.7884	77.0819	30	Naya Bansh	0.118	0.232	0.256	0.307	2.6
123	28.7500	77.0765	30	Pehladpur Banger	0.116	0.219	0.247	0.296	2.6
124	28.7932	77.0975	30	Holambi Khurd	0.122	0.228	0.264	0.323	2.6
125	28.7958	77.1052	30	Holambi Khurd	0.113	0.238	0.294	0.332	2.9
126	28.7731	77.0923	30	Khera Khurd	0.116	0.235	0.288	0.328	2.8
127	28.7806	77.1125	30	Khera Khurd	0.138	0.216	0.281	0.373	2.7
128	28.7556	77.0921	30	Pehladpur Banger	0.116	0.228	0.266	0.308	2.6
129	28.7561	77.1131	30	Sirsapur village	0.110	0.220	0.250	0.324	3.0
130	28.7244	77.0867	31	Rohini Sec-25	0.119	0.201	0.243	0.278	2.3
131	28.7283	77.1187	31	Rohini Sec-12	0.120	0.186	0.213	0.268	2.2
132	28.7161	77.0957	31	Rithala	0.108	0.196	0.208	0.271	2.5
133	28.7098	77.1119	31	Rohini Sec-6, Blk-F	0.129	0.199	0.264	0.381	3.0
134	28.7464	77.1042	31	Shiv Vihar	0.120	0.194	0.216	0.273	2.3
135	28.7079	77.0798	31	Sultanpuri	0.106	0.220	0.250	0.301	2.8
136	28.7016	77.0904	31	Mangolpuri Blk-Y	0.108	0.217	0.244	0.313	2.9
137	28.6969	77.0779	32	Sultanpuri	0.109	0.206	0.253	0.315	2.9
138	28.6970	77.1136	32	Pushpanjali Enclave, Rohini	0.101	0.229	0.253	0.310	3.1
139	28.6508	77.0857	32	Gurunanak Nagar	0.113	0.180	0.210	0.265	2.3
140	28.6583	77.1042	32	Khayala	0.123	0.212	0.282	0.357	2.9
141	28.6800	77.0742	32	Nangloi Jat	0.114	0.183	0.270	0.383	3.4
142	28.6881	77.0956	32	Mangolpuri	0.119	0.178	0.214	0.334	2.8
143	28.6661	77.0917	32	Sunder Aptt, Sunder Vihar	0.112	0.220	0.270	0.348	3.1
144	28.6670	77.1023	32	Jwala Heri, Paschim Vihar	0.126	0.202	0.249	0.338	2.7
145	28.6439	77.1083	33	Park, Near Tagor Garden	0.099	0.182	0.200	0.234	2.4
146	28.6306	77.1069	33	Tihar Village	0.095	0.175	0.212	0.237	2.5
147	28.6367	77.1225	33	Subhash Nagar, Blk-10	0.100	0.161	0.184	0.195	2.0
148	28.8436	77.1304	38	Singhola	0.117	0.229	0.288	0.396	3.4
149	28.8283	77.1450	38	Hamidpur	0.125	0.213	0.240	0.297	2.4
150	28.8423	77.1704	38	Tajpur Kalan	0.118	0.201	0.267	0.363	3.1
151	28.8269	77.1296	38	Khanpur	0.122	0.221	0.259	0.282	2.3
152	28.8135	77.1429	38	Bankoli	0.108	0.172	0.243	0.379	3.5
153	28.8194	77.1551	38	Hamidpur	0.113	0.179	0.261	0.347	3.1
154	28.8277	77.1702	38	Bakhtawarpur	0.106	0.186	0.262	0.351	3.3
155	28.8031	77.1313	38	Alipur	0.135	0.228	0.267	0.356	2.6
156	28.8072	77.1663	38	Bakhtawarpur	0.136	0.206	0.253	0.288	2.1
157	28.8108	77.1564	38	Bankoli	0.136	0.199	0.265	0.353	2.6
158	28.8180	77.1744	38	Bakhtawarpur	0.113	0.232	0.252	0.329	2.9
159	28.7890	77.1301	39	Alipur	0.127	0.216	0.273	0.390	3.1

160	28.7973	77.1495	39	Alipur	0.104	0.237	0.252	0.296	2.8
161	28.7938	77.1663	39	Mukhmelpur	0.105	0.209	0.254	0.318	3.0
162	28.7820	77.1454	39	Budhpur, Bijapur	0.133	0.219	0.268	0.340	2.5
163	28.7796	77.1686	39	Near Ibrahampur	0.111	0.234	0.287	0.345	3.1
164	28.7745	77.1335	39	Khera Ghari	0.123	0.224	0.286	0.339	2.7
165	28.7726	77.1501	39	Kadipur	0.132	0.204	0.281	0.331	2.5
166	28.7634	77.1722	39	Nathupura	0.113	0.198	0.255	0.368	3.3
167	28.7621	77.1524	39	Near Swaroopnagar	0.127	0.203	0.220	0.303	2.4
168	28.7563	77.1364	39	Rana Park, Sirsapur	0.131	0.203	0.244	0.321	2.5
169	28.7535	77.1654	39	Swaroopnagar, New Colony	0.098	0.184	0.220	0.305	3.1
170	28.7881	77.1552	39	Mukhmelpur	0.108	0.222	0.267	0.298	2.8
171	28.7688	77.1625	39	Kadipur	0.128	0.208	0.261	0.286	2.2
172	28.7429	77.1526	40	Sanjay Gandhi Transport Nagar Blk AG	0.115	0.179	0.200	0.226	2.0
173	28.7393	77.1358	40	Rohini Sec-18, Blk A, Pkt8	0.115	0.229	0.271	0.303	2.6
174	28.7364	77.1646	40	Bhalsawa	0.107	0.178	0.230	0.284	2.7
175	28.7286	77.1493	40	Haiderpur	0.112	0.185	0.239	0.285	2.6
176	28.7096	77.1280	40	Rohini Sec-14	0.125	0.204	0.238	0.276	2.2
177	28.7108	77.1436	40	North Pitampura, Pkt-NU	0.110	0.218	0.229	0.292	2.7
178	28.7194	77.1601	40	Sahipur, Near Shalimar Bagh	0.106	0.182	0.208	0.250	2.4
179	28.7191	77.1747	40	Aadarsh Nagar	0.093	0.223	0.256	0.322	3.5
180	28.7041	77.1551	40	Pitampura, Blk-TP Pocket	0.109	0.194	0.230	0.287	2.6
181	28.7056	77.1744	40	Wazirpur Indl area, Blk-B	0.110	0.162	0.227	0.318	2.9
182	28.6928	77.1249	41	Saraswati Vihar	0.117	0.229	0.271	0.331	2.8
183	28.6981	77.1419	41	South Pitampura, Blk Pocket-KD	0.121	0.154	0.208	0.316	2.6
184	28.6953	77.1631	41	ashok Vihar, Ph-I, Blk-E	0.119	0.189	0.212	0.238	2.0
185	28.6597	77.1302	41	Near Raja Garden	0.120	0.199	0.208	0.232	1.9
186	28.6833	77.1450	41	Sakurpur Village	0.120	0.211	0.224	0.251	2.1
187	28.6703	77.1417	41	East Punjabi Bagh	0.116	0.234	0.254	0.306	2.6
188	28.6708	77.1581	41	Karampura Block, Indl Area	0.125	0.200	0.212	0.259	2.1
189	28.5431	77.1327	44	CISF Rd, Mahipalpur Extn	0.094	0.199	0.229	0.275	2.9
190	28.4972	77.1325	45	Ghitorni Village	0.095	0.171	0.193	0.274	2.9
191	28.4964	77.1622	45	Sultanpur Village	0.085	0.174	0.225	0.275	3.2
192	28.4858	77.1331	45	Saink Nivas MES, Ghitorni	0.106	0.184	0.205	0.236	2.2
193	28.4839	77.1628	45	HK Farm House, near Godaipur	0.081	0.163	0.197	0.282	3.5
194	28.4706	77.1631	45	Jaunapur	0.090	0.184	0.226	0.262	2.9
195	28.4440	77.1464	46	Farm house, Mandi Village	0.094	0.189	0.245	0.307	3.3
196	28.4416	77.1347	46	KH No.66/6, Mandi Village	0.085	0.185	0.243	0.309	3.7
197	28.4400	77.1636	46	SEPAL Farm Dera, Mandi Rd, Mandi	0.094	0.184	0.229	0.267	2.8
198	28.8441	77.1848	48	MCD School, Palla	0.122	0.215	0.229	0.313	2.6
199	28.8455	77.2001	48	Palla	0.102	0.173	0.225	0.301	2.9

200	28.8294	77.1788	48	Bakhtawarpur	0.101	0.221	0.254	0.326	3.2
201	28.8308	77.1986	48	School Jhangla	0.105	0.205	0.218	0.303	2.9
202	28.8175	77.2134	48	Palla Police Post	0.107	0.168	0.233	0.332	3.1
203	28.8167	77.1994	48	Near Jal Board Palla	0.109	0.182	0.264	0.324	3.0
204	28.7978	77.1807	49	Hiranki Village	0.111	0.214	0.249	0.308	2.8
205	28.7708	77.1875	49	Uttarakhand Coloney	0.135	0.186	0.259	0.341	2.5
206	28.7639	77.2153	49	Shank No.1, Burari village	0.133	0.195	0.249	0.338	2.5
207	28.7948	77.1911	49	Near Shank 22, Hiranki Village	0.125	0.206	0.254	0.343	2.7
208	28.7946	77.1998	49	Tedi Daulatpur	0.133	0.213	0.241	0.285	2.1
209	28.7810	77.1838	49	Resid. area, Hiranki, Nr Ibrahampur	0.111	0.185	0.259	0.364	3.3
210	28.7757	77.1992	49	Silampur Majra	0.124	0.195	0.234	0.309	2.5
211	28.7604	77.1976	49	Behind Shani temple, Burari	0.113	0.206	0.249	0.347	3.1
212	28.7445	77.1943	50	Sant Nagar	0.102	0.169	0.282	0.366	3.6
213	28.7144	77.1874	50	Nr Model Town	0.100	0.164	0.201	0.476	4.7
214	28.7135	77.2047	50	Radio Coloney, Nr Dhaka Village	0.104	0.193	0.215	0.267	2.6
215	28.7319	77.1810	50	Near Jahangirpuri Blk-JJC	0.101	0.204	0.239	0.310	3.1
216	28.7336	77.2064	50	Jharoda Dairy Coloney	0.125	0.198	0.253	0.288	2.3
217	28.7331	77.2185	50	Nr Milan Vihar, Burari	0.125	0.212	0.268	0.310	2.5
218	28.7260	77.1939	50	Nirankari Ground, nr Jharoda Majra	0.104	0.176	0.265	0.387	3.7
219	28.7031	77.1966	50	Model Town	0.099	0.223	0.230	0.266	2.7
220	28.7059	77.2210	50	Timarpur	0.109	0.186	0.212	0.246	2.2
221	28.6793	77.2205	51	Civil Lines	0.102	0.190	0.243	0.293	2.9
222	28.6962	77.2104	51	Khalsa College, Nr Univ campus	0.105	0.198	0.216	0.310	3.0
223	28.6893	77.1978	51	CC Colony	0.097	0.199	0.255	0.310	3.2
224	28.6896	77.1834	51	Near Satyavati Colony	0.094	0.199	0.232	0.265	2.8
225	28.6478	77.2109	51	Azad Market	0.111	0.177	0.263	0.303	2.7
226	28.6788	77.1878	51	Shiv Temp, Fakira Bagh, Shastri Nagar	0.114	0.218	0.279	0.312	2.7
227	28.6850	77.2033	51	Roopnagar Blk-6	0.112	0.216	0.279	0.322	2.9
228	28.6680	77.2208	51	Civil Lines, Nr Tis Hazari	0.108	0.214	0.228	0.258	2.4
229	28.5208	77.1910	54	Lado Sarai	0.094	0.182	0.234	0.306	3.3
230	28.5340	77.1936	54	Govt Nursery, Adhichini	0.090	0.166	0.206	0.274	3.1
231	28.5413	77.1829	54	Lal bahadur Vidyapith, Katwariasarai	0.105	0.180	0.213	0.251	2.4
232	28.5056	77.2058	54	Neb Sarai, Mehrauli	0.090	0.165	0.190	0.225	2.5
233	28.5478	77.1937	54	Rose Garden, Haus Khas	0.104	0.186	0.238	0.286	2.7
234	28.5388	77.2088	54	Begampur,Malviya Nagar	0.089	0.186	0.249	0.305	3.4
235	28.5387	77.2244	54	Shek Sarai,Ph.-I	0.084	0.181	0.250	0.319	3.8
236	28.5288	77.2066	54	Hauz Rani Saket	0.085	0.182	0.231	0.281	3.3
237	28.5080	77.1739	54	Kusum Nursery Vasant Kunj	0.086	0.172	0.275	0.329	3.8
238	28.5161	77.2119	54	Saket-Bdarpur Rd	0.093	0.194	0.232	0.283	3.0

239	28.5001	77.2220	54	Sainik Farm, Nr Sangam Vihar	0.104	0.189	0.249	0.304	2.9
240	28.4986	77.1792	55	Near Chhatarpur Mandir	0.088	0.190	0.237	0.287	3.2
241	28.4978	77.1942	55	DDA, Maidan Garhi	0.092	0.169	0.173	0.231	2.5
242	28.4828	77.1806	55	10 Farm, DLF, Chhatarpur	0.103	0.185	0.237	0.279	2.7
243	28.4856	77.1971	55	Rajpur Khurd	0.097	0.182	0.207	0.254	2.6
244	28.4717	77.1922	55	Saharpur Extn, ND	0.095	0.175	0.203	0.237	2.5
245	28.4567	77.2075	55	Forest, Asola Village	0.086	0.187	0.231	0.284	3.3
246	28.7176	77.2510	58	PT School, Wazirabad	0.105	0.181	0.241	0.377	3.6
247	28.7325	77.2325	58	Ramp No.3, Near Jagatpur Bund	0.101	0.175	0.248	0.329	3.2
248	28.7450	77.2559	58	Burari Village	0.113	0.200	0.256	0.321	2.8
249	28.7079	77.2364	58	Pantan Bridge, Wazirabad	0.100	0.219	0.267	0.325	3.3
250	28.7338	77.2657	58	Govt School, Karwal Nagar	0.108	0.220	0.242	0.274	2.5
251	28.7188	77.2664	58	Near Priya Convent Sch, Dayalpur	0.094	0.191	0.233	0.312	3.3
252	28.7039	77.2554	58	Garai Mandu Village	0.113	0.176	0.262	0.359	3.2
253	28.6857	77.2350	59	New Usmanpur Village	0.099	0.233	0.285	0.332	3.4
254	28.6587	77.2401	59	MG Park, Lal Quila	0.115	0.225	0.238	0.293	2.5
255	28.6924	77.2548	59	Pusta-4, Usmanpur	0.086	0.218	0.251	0.314	3.6
256	28.6769	77.2471	59	Opp DMRC off, Shatri Park	0.093	0.210	0.289	0.336	3.6
257	28.6753	77.2692	59	Silampur	0.110	0.208	0.265	0.338	3.1
258	28.6668	77.2503	59	Shastri Park	0.130	0.206	0.209	0.253	2.0
259	28.6589	77.2692	59	SK School, Geeta Colony	0.102	0.194	0.238	0.310	3.0
260	28.7304	77.2814	65	Kali Mandir, Shiv Vihar	0.098	0.216	0.262	0.297	3.0
261	28.7073	77.3232	65	Harsh vihar	0.107	0.177	0.224	0.291	2.7
262	28.7149	77.2815	65	Chamanpark, Johripur	0.107	0.195	0.240	0.301	2.8
263	28.7029	77.3076	65	Nand Nagari	0.106	0.195	0.210	0.261	2.5
264	28.7044	77.2769	65	Gokulpuri colony	0.107	0.184	0.207	0.288	2.7
265	28.7029	77.2962	65	East Gokulpur	0.098	0.192	0.189	0.273	2.8
266	28.6895	77.2893	66	Near Jyoti colony	0.101	0.184	0.231	0.268	2.7
267	28.6925	77.3129	66	Nand Nagari, Blk-E4	0.097	0.197	0.224	0.266	2.7
268	28.6777	77.2984	66	Mansarovar Park	0.105	0.204	0.228	0.268	2.5
269	28.6560	77.2923	66	Arjun Nagar	0.104	0.178	0.208	0.237	2.3
270	28.6653	77.3056	66	Jhilmil Coloney	0.094	0.198	0.212	0.253	2.7
271	28.6537	77.3157	66	Anand Vihar, Blk-C	0.107	0.192	0.232	0.272	2.5
272	28.6192	77.2865	67	Pandav Nagar, Blk-A	0.105	0.171	0.196	0.238	2.3
273	28.6242	77.3001	67	Vinod Nagar West, Blk-D	0.099	0.165	0.192	0.220	2.2
274	28.6092	77.3028	67	Mayur Vihar, Ph-I, Pkt 2	0.092	0.176	0.237	0.289	3.1
275	28.6111	77.3225	67	Durga park Coly, near Kundali	0.095	0.171	0.176	0.240	2.5
276	28.5398	77.2831	69	Park, near Appolo Hosp., Jasola	0.098	0.168	0.204	0.250	2.6
277	28.5234	77.3083	69	near Badarpur Thermal Plant, Khadar	0.086	0.156	0.169	0.238	2.8
278	28.5321	77.2956	69	DDA Park, Sarita Viahar, Blk-D	0.085	0.167	0.212	0.280	3.3
279	28.5412	77.3089	69	Kalindikunj, Jaitpur Road	0.095	0.153	0.195	0.273	2.9

280	28.5322	77.3161	69	DDA park, JJ Colony	0.097	0.160	0.207	0.268	2.8
281	28.5062	77.3017	69	Govt School, near NTPC,Badarpur	0.084	0.143	0.219	0.261	3.1
282	28.5025	77.3141	69	Near Irrigation Dept, Hari Nagar	0.097	0.178	0.239	0.304	3.1
283	28.6281	77.3253	72	Near Gaziur, Blk-D	0.102	0.164	0.193	0.231	2.3
284	28.6121	77.3348	72	Gharoli Dairy Farm, Blk-A	0.096	0.182	0.209	0.237	2.5
285	28.6032	77.3308	72	Near Kundli, Blk-A1	0.098	0.172	0.213	0.235	2.4
286	28.5147	77.3417	73	Jaitpur Extn	0.080	0.160	0.208	0.267	3.3
287	28.5253	77.3313	73	Near Police post, Jaitpur	0.098	0.155	0.209	0.282	2.9
288	28.8746	77.0795	20	Safiabad	0.143	0.241	0.269	0.363	2.5
289	28.8757	77.1114	28	Kundli	0.136	0.224	0.268	0.343	2.5
290	28.8125	77.0875	29	Holambi kalan	0.127	0.239	0.260	0.344	2.7
291	28.8300	77.1229	29	Tikri Khurd	0.108	0.194	0.234	0.264	2.4
292	28.7222	77.1056	31	DCE, Rithala	0.113	0.178	0.213	0.278	2.5
293	28.8183	77.1458	38	Bankoli	0.132	0.186	0.274	0.351	2.7
294	28.7499	77.1763	39	Bhalsawa Dairy	0.134	0.213	0.243	0.310	2.3
295	28.7917	77.1597	39	Mukhmelpur	0.132	0.137	0.198	0.321	2.4
296	28.8417	77.2125	48	Jangola	0.109	0.206	0.268	0.332	3.1
297	28.8056	77.1917	49	Fatehpur Jat	0.106	0.228	0.272	0.346	3.3
298	28.8583	77.2417	49	Sankrot	0.105	0.222	0.275	0.311	3.0
299	28.7083	77.2167	50	Indira Vihar	0.104	0.129	0.153	0.263	2.5
300	28.7427	77.2053	50	Salarpur	0.112	0.191	0.273	0.344	3.1
301	28.6917	77.2292	51	Majnu Ka Tila	0.092	0.141	0.161	0.190	2.1
302	28.7450	77.2442	58	Libaspur	0.105	0.199	0.238	0.286	2.7
303	28.6072	76.8844	3	Mandhela Kalan	0.114	0.191	0.211	0.226	2.0
304	28.5828	76.9311	11	Khera Dabas	0.088	0.165	0.232	0.232	2.6
305	28.5324	76.9461	12	Shikarpur	0.088	0.175	0.203	0.295	3.4
306	28.7872	77.0164	14	Bawana, Khanjawala	0.137	0.260	0.328	0.381	2.8
307	28.6264	77.0197	17	Mohan Garden	0.100	0.188	0.219	0.255	2.5
308	28.7072	77.0322	23	Madanpur Dabas	0.112	0.241	0.275	0.334	3.0
309	28.8714	77.0833	28	Narela	0.132	0.243	0.255	0.319	2.4
310	28.8042	77.1094	29	Holambi Kalan	0.113	0.234	0.294	0.381	3.4
311	28.7347	77.0892	31	Rohini Sec-25	0.112	0.217	0.226	0.286	2.6
312	28.6250	77.0903	33	Janakpuri Blk-B3B	0.098	0.186	0.225	0.247	2.5
313	28.5117	77.1083	35	Rajokri village	0.088	0.156	0.179	0.203	2.3
314	28.8180	77.1744	38	Bakhtawarpur	0.105	0.216	0.262	0.329	3.1
315	28.7535	77.1653	39	Swaroopnagar, New Colony	0.108	0.204	0.256	0.315	2.9
316	28.6828	77.1615	41	Keshavpuram	0.116	0.165	0.193	0.223	1.9
317	28.4717	77.1475	45	Akoi Farm, Jaunapur	0.096	0.185	0.198	0.232	2.4
318	28.6857	77.2159	51	Ridge, Near Univ Campus	0.116	0.218	0.245	0.201	1.7
319	28.6645	77.2074	51	Azadpur Market	0.116	0.200	0.226	0.271	2.3
320	28.6144	77.1763	52	Budha Jayanti Park	0.110	0.182	0.188	0.207	1.9

321	28.5386	77.2092	54	Begampur,Malviya Nagar	0.111	0.191	0.201	0.238	2.1
322	28.5252	77.2215	54	Pushpa Vihar, Sec-1	0.123			0.241	2.0
323	28.4723	77.1860	55	Chandan Hulla	0.079	0.154	0.211	0.262	3.3
324	28.7250	77.2510	58	PTS Wazirabad	0.097	0.181	0.230	0.316	3.3
325	28.5811	77.2313	61	Jawaharlal Nehru Stadium	0.119	0.172	0.194	0.185	1.6
326	28.6029	77.2855	67	Nangal	0.084	0.153	0.198	0.249	2.9
327	28.5325	77.3167	69	JJ Colony, Sarita Vihar	0.080	0.142	0.178	0.266	3.3
328	28.5811	77.2330	61	Jawaharlal Nehru Stadium	0.122	0.177	0.183	0.241	2.0
329	28.5889	77.2596	61	Sarai Kale Khan	0.084			0.288	3.4
330	28.5889	77.2596	61	Sarai Kale Khan	0.086			0.323	3.8
331	28.5963	77.2578	61	Rajiv Gandhi Smriti Van, Nr Zoo	0.088			0.243	2.7
332	28.5997	77.2569	61	Rajiv Gandhi Smriti Van, Nr Zoo	0.100			0.245	2.4
333	28.5976	77.2575	61	Rajiv Gandhi Smriti Van, Nr Zoo	0.084			0.286	3.4
334	28.6783	77.1583	41	Tri Nagar	0.117			0.308	2.6
335	28.6699	77.2704	59	Seelampur	0.097			0.307	3.2
336	28.6783	77.1583	41	Tri Nagar	0.103	0.213	0.219	0.307	3.0
337	28.5524	77.2758	68	Sukhdev Vihar	0.082			0.302	3.7
338	28.5233	77.2279	62	Pushpa Vihar	0.091			0.318	3.5
339	28.5431	77.2113	54	Paschimshila Park, South Blk-S	0.103			0.262	2.5
340	28.6783	77.1583	41	Tri Nagar	0.111			0.309	2.8
341	28.7177	77.1103	31	Rohini Sec-5, Pkt-6	0.092			0.369	4.0
342	28.5248	77.2137	54	Saket	0.103			0.302	2.9
343	28.6813	77.0971	32	Udyog Nagar, Nr Paschim Vihar	0.087			0.307	3.5
344	28.6407	77.2320	60	Ramlila Ground	0.087			0.309	3.5
345	28.4724	77.1860	55	Chandan Hulla	0.098	0.172	0.196	0.253	2.6
346	28.4704	77.2013	55	Saharpur Extn, ND	0.093	0.162	0.232	0.312	3.3
347	28.4458	77.1866	56	Fatehpur Beri	0.078	0.144	0.181	0.234	3.0
348	28.4431	77.2006	56	Bhati Mines	0.095	0.150	0.183	0.253	2.7
349	28.6830	77.1622	41	Keshavpuram	0.108	0.188	0.218	0.253	2.3
350	28.6029	77.2855	67	Nangal	0.078	0.147	0.173	0.205	2.6
351	28.6361	77.2986	67	Indraprastha Extn	0.094	0.181	0.194	0.233	2.5
352	28.6768	77.3123	66	Dilshad Garden, Blk R	0.086	0.189	0.199	0.227	2.6
353	28.6222	77.3388	72	NearMayur Vihar Ph-III	0.107	0.172	0.184	0.245	2.3
354	28.7342	77.0891	31	Rohini Sec-25	0.113	0.000	0.000	0.320	2.8
355	28.5089	77.1083	35	Rajokri village	0.084	0.157	0.180	0.193	2.3
356	28.6379	77.0761	33	Vikaspuri Blk-C	0.111	0.188	0.206	0.253	2.3
357	28.5877	77.0474	26	Dwarka Sec-11	0.109	0.182	0.202	0.241	2.2
358	28.5933	77.0492	26	East of Dwarka Sec-12	0.107	0.190	0.232	0.278	2.6
359	28.6736	77.2981	66	Shahdara	0.100	0.167	0.200	0.240	2.4
360	28.5926	77.0815	34	Nr Palam Village	0.096	0.180	0.188	0.230	2.4
361	28.6175	77.0480	25	Sainik Nagar	0.121	0.183	0.208	0.248	2.0

362	28.5963	77.0788	34	Dwarka Sec-1	0.106	0.174	0.187	0.228	2.2
363	28.6699	77.1389	41	West Punjabi Bagh	0.109	0.194	0.247	0.277	2.5
364	28.5963	77.2578	61	Rajiv Gandhi Smriti Van, Nr Zoo	0.111	0.180	0.219	0.249	2.2
365	28.8197	77.0612	21	Sanoth	0.139	0.227	0.266	0.337	2.4
366	28.6222	77.2042	52	Nr MP's Club, Rakabganj	0.098	0.194	0.198	0.237	2.4
367	28.5300	77.0890	35	Samalka, Nr Kapashera	0.099	0.173	0.193	0.227	2.3
368	28.5449	77.1198	35	Intl Airport Authority, Nr Mahipalpur	0.100	0.184	0.195	0.231	2.3
369	28.5477	77.1250	35	Intl Airport Authority, Nr Mahipalpur	0.098	0.184	0.205	0.241	2.5
370	28.5861	77.0551	26	Dwarka Sec-10	0.114	0.185	0.221	0.250	2.2
371	28.5958	77.1200	34	Sadar Bazar (Delhi Cantt)	0.118	0.165	0.197	0.216	1.8
372	28.7119	77.1601	40	Shalimar Bagh, Pkt-BD	0.111	0.185	0.247	0.269	2.4
373	28.8528	77.0889	29	Narela	0.143	0.232	0.265	0.330	2.3
374	28.6250	76.9231	3	Kair	0.125	0.198	0.224	0.266	2.1
375	28.5917	76.9250	4	Jafarpur Kalan	0.120	0.185	0.221	0.248	2.1
376	28.6417	77.1647	42	West Patel Nagar	0.115	0.212	0.232	0.263	2.3
377	28.6611	77.1458	41	New Motinagar, Blk-17	0.093	0.170	0.194	0.213	2.3
378	28.6431	77.0972	33	Chaukhandi, nr Hind Nagar	0.112	0.182	0.196	0.245	2.2
379	28.6636	77.1433	41	New Motinagar, Blk-B	0.114	0.178	0.191	0.241	2.1
380	28.6919	77.1602	41	Lawrence Rd Coloney, Blk-C-7	0.103	0.198	0.242	0.264	2.6
381	28.6736	77.1931	51	Gulabi Bagh	0.102	0.186	0.244	0.294	2.9
382	28.6797	77.1573	41	Omkar Nagar	0.111	0.184	0.234	0.261	2.4
383	28.6475	77.1797	52	Prasad Nagar, Nr E. Patel nagar	0.109	0.192	0.232	0.260	2.4
384	28.5827	77.0579	26	Dwarka Sec-10	0.114	0.180	0.204	0.242	2.1
385	28.6506	77.3042	66	Karkarduma	0.093	0.160	0.201	0.249	2.7
386	28.6484	77.3046	67	Karkarduma	0.099	0.172	0.218	0.248	2.5
387	28.5807	77.2924	68	Trans Yamuna, nr Chilla	0.090	0.156	0.191	0.240	2.7
388	28.6417	77.2522	60	Rajghat	0.110	0.179	0.230	0.275	2.5
389	28.6681	77.2564	59	Shastri Park, BLK-A	0.124	0.196	0.221	0.248	2.0
390	28.5150	77.2722	62	Close to Tuglakabad Village	0.098	0.184	0.195	0.239	2.4
391	28.5686	77.2436	61	Lajpatnagar, part-II	0.091	0.168	0.203	0.230	2.5
392	28.5681	77.2189	53	South Ex Part-II	0.093	0.184	0.214	0.254	2.7
393	28.5444	77.2583	62	Kalkaji, Blk-D	0.100	0.181	0.190	0.234	2.4
394	28.5722	77.1708	43	RK Puram, Sec-8	0.097	0.186	0.186	0.223	2.3
395	28.5781	77.1625	43	Anand Niketan, Blk-D	0.108	0.192	0.219	0.249	2.3
396	28.6222	77.2467	60	Mata Sundari Rly Coloney	0.107	0.189	0.240	0.284	2.6
397	28.6903	77.1778	51	Satyawati Coloney, Blk-A, Pkt-A	0.104	0.195	0.220	0.251	2.4
398	28.6556	77.1917	51	Karol Bagh, Blk-D, Pkt52	0.125	0.184	0.254	0.268	2.2
399	28.6083	77.2403	60	Bapa Nagar	0.096	0.174	0.221	0.257	2.7
400	28.6111	77.2264	60	Vigyan Bhawan	0.098	0.167	0.209	0.271	2.8
401	28.6367	77.2064	52	Govt Quarters, Nr Gole Market	0.105	0.202	0.204	0.235	2.2

402	28.6417	77.1508	42	Pusa Institute	0.119	0.203	0.237	0.269	2.3
403	28.5651	77.0783	34	IGI nr Pappan Kalan	0.109	0.184	0.212	0.243	2.2
404	28.6389	77.2375	60	West of F.S.Kotla stadium	0.119	0.179	0.253	0.279	2.4
405	28.6260	77.2099	52	Bangla Saheb Gurudwara	0.104	0.199	0.200	0.234	2.2
406	28.6735	77.2916	66	Makki Sarai	0.099	0.171	0.208	0.240	2.4
407	28.6021	77.1928	52	Chanakyapuri, Nr JLN Memorial Museum	0.103	0.192	0.195	0.224	2.2
408	28.5523	77.2140	53	Siri Fort Sports Complex	0.093	0.178	0.205	0.241	2.6
409	28.5616	77.2242	53	Aayurvugyan Nagar	0.092	0.170	0.205	0.251	2.7
410	28.5677	77.2272	61	Andrews Ganj	0.089	0.186	0.215	0.238	2.7
411	28.6390	77.1316	42	Mansarover Garden, Blk-WZ	0.108	0.201	0.210	0.249	2.3
412	28.5255	77.2120	54	Saket	0.095	0.164	0.198	0.234	2.5
413	28.5862	77.0639	26	Dwarka Sec-10	0.108	0.182	0.217	0.258	2.4
414	28.7982	77.0362	22	Bawana	0.142	0.233	0.258	0.318	2.2
415	28.6805	77.3130	66	Dilshad Garden, Blk-C	0.098	0.167	0.212	0.251	2.6
416	28.7100	77.2835	65	Bhagirath Vihar	0.104	0.168	0.214	0.238	2.3
417	28.6217	77.2440	60	Pragati Maidan	0.099	0.183	0.209	0.257	2.6
418	28.7011	77.3078	65	Mandoli Extn	0.095	0.177	0.216	0.244	2.6
419	28.5417	77.1833	54	Qutub Indl Area	0.098	0.183	0.186	0.227	2.3
420	28.5332	77.3029	69	Madanpur Khadar Village	0.084	0.161	0.189	0.217	2.6
421	28.7135	77.1774	50	Majlis Park	0.108	0.177	0.238	0.260	2.4
422	28.5646	77.2477	61	Lajpat Nagar, Part-IV	0.089	0.168	0.193	0.215	2.4
423	28.7238	77.1353	40	Rohinin Sec-13, nr Vikrant Apartment	0.115	0.186	0.251	0.278	2.4
424	28.5621	77.0769	34	IGI, nr Dwarka Sec-21	0.104	0.177	0.199	0.241	2.3
425	28.6779	77.2274	59	Civil Lines	0.117	0.192	0.237	0.259	2.2
426	28.5730	77.0777	34	Dwarka Sec-8	0.113	0.170	0.200	0.227	2.0
427	28.5867	77.0933	34	Sadh Nagar, Palam coloney	0.110	0.182	0.204	0.249	2.3
428	28.7265	77.1125	31	Rohini Sec-25	0.110	0.205	0.244	0.305	2.8
429	28.7268	77.1136	31	Rohini Sec-25	0.115	0.200	0.251	0.309	2.7
430	28.6444	77.2269	60	Kamla Market	0.099	0.175	0.224	0.263	2.7
431	28.6006	77.0931	33	Mahaveer Enclave-II, nr Kailashpuri west	0.114	0.176	0.204	0.239	2.1
432	28.6150	77.0889	33	Janakpuri Blk C-3	0.111	0.170	0.198	0.253	2.3
433	28.6153	77.0886	33	Janakpuri Blk C-3	0.107	0.178	0.191	0.241	2.3
434	28.6708	77.2903	66	Teli Bara	0.091	0.144	0.171	0.187	2.1
435	28.6683	77.2762	66	Seelampur	0.093	0.161	0.195	0.249	2.7
436	28.7012	77.2888	65	South of Gokulpur	0.100	0.176	0.218	0.248	2.5
437	28.7164	77.2863	65	Nr Kardam Farm, Johripur	0.110	0.177	0.229	0.252	2.3
438	28.6764	77.2889	66	Naveen Shahdara	0.097	0.175	0.215	0.256	2.6
439	28.6764	77.2889	66	Naveen Shahdara	0.096	0.177	0.222	0.249	2.6
440	28.6699	77.2704	59	Seelampur	0.087	0.166	0.195	0.228	2.6
441	28.5979	77.0510	26	Dwarka Sec-4	0.107	0.187	0.228	0.267	2.5

442	28.6806	77.1561	41	Lawrence Rd Indl Area	0.105	0.179	0.228	0.274	2.6
443	28.6708	77.1972	51	Andha Mughal, Nr Gulabi Bagh	0.105	0.186	0.244	0.296	2.8
444	28.6117	77.3103	67	Patparganj, nr Trilokpuri-I	0.094	0.157	0.206	0.224	2.4
445	28.7042	77.3131	65	Mandoli	0.095	0.174	0.217	0.246	2.6
446	28.7931	77.0417	22	Bawana	0.136	0.227	0.270	0.314	2.3
447	28.7019	77.1667	40	Wazirpur Indl Area	0.102	0.197	0.234	0.262	2.6
448	28.5355	77.1626	44	JNU	0.124			0.168	1.4
449	28.4508	77.2094	55	Asola	0.129			0.181	1.4

Table 9.5: PGA at Engineering Bedrock and Ground Surface based on DBE

S.N.	Lat (Deg)	Long (deg)	Sheet No.	Locality name	PGA at Engineering Bedrock	PGA at Ground Surface
1	28.6247	76.9144	3	Kair	0.051	0.1385
2	28.6186	76.8843	3	Mandhela Khurd	0.051	0.1572
3	28.6128	76.8972	3	Mandhela Kalan	0.050	0.1442
4	28.6128	76.9158	3	Kair	0.050	0.1487
5	28.6075	76.8862	3	Mandhela Kalan	0.050	0.1356
6	28.6028	76.9000	3	Mandhela Kalan	0.049	0.1573
7	28.6029	76.9149	3	Jafarpur Kalan	0.049	0.1678
8	28.5953	76.8871	4	Baqargarh	0.048	0.1411
9	28.5591	76.9028	4	Ujwa	0.046	0.1708
10	28.5991	76.9198	4	Jafarpur Kalan	0.050	0.1731
11	28.5766	76.8839	4	Quazipur	0.047	0.1546
12	28.5751	76.9009	4	Shamaspur Khalsa	0.047	0.1292
13	28.5798	76.9129	4	Ujwa	0.047	0.1190
14	28.5647	76.8853	4	Quazipur	0.047	0.1708
15	28.5654	76.9111	4	Ujwa	0.046	0.1565
16	28.5509	76.9115	4	Daryapur Khurd	0.045	0.1179
17	28.8188	76.9738	6	Mungashpur	0.058	0.1618
18	28.8111	76.9528	6	Qutubgarh	0.058	0.1506
19	28.7961	76.9515	7	Qutubgarh	0.057	0.2165
20	28.7673	76.9632	7	Khor Punjab	0.057	0.1762
21	28.7576	76.9466	7	Jonti	0.056	0.1908
22	28.7486	76.9623	8	Jonti	0.056	0.1479
23	28.7203	76.9658	8	Nizampur Rashid	0.054	0.2085
24	28.6923	76.9623	9	Tikri Kalan	0.051	0.1962
25	28.6736	76.9650	9	Tikri Kalan	0.051	0.1882
26	28.6816	76.9744	9	Tikri Kalan	0.050	0.1467
27	28.6653	76.9494	9	Jharoda Kalan	0.051	0.1464
28	28.6514	76.9342	9	Jharoda Kalan	0.052	0.1412
29	28.6546	76.9598	9	Jharoda Kalan	0.049	0.1286
30	28.6437	76.9574	10	Jharoda Kalan	0.049	0.1730
31	28.6048	76.9573	10	Mitraon	0.048	0.1443
32	28.6161	76.9300	10	Kair	0.050	0.1541
33	28.6167	76.9592	10	Mitraon	0.049	0.1344
34	28.6306	76.9478	10	Surakhpur	0.050	0.1604
35	28.6318	76.9607	10	Najafgarh	0.049	0.1440
36	28.5383	76.9818	12	Kangan heri	0.042	0.1859
37	28.8014	77.0240	13	Nangal Thakuran	0.053	0.1404
38	28.8006	76.9821	13	Katewara	0.054	0.1474
39	28.8025	76.9981	13	Bajidpur Thakran	0.054	0.1583
40	28.7903	76.9771	14	Khorjat	0.055	0.1972
41	28.7612	76.9753	14	Chatesar	0.053	0.1890
42	28.7880	77.0151	14	Nangal Thakuran	0.053	0.2003
43	28.7542	77.0071	14	Budhanpur	0.051	0.1563
44	28.7503	77.0244	14	Karala	0.050	0.1827
45	28.7710	77.0166	14	Sultanpur Dabas	0.054	0.1717
46	28.7709	76.9863	14	Salahpur Majra	0.056	0.1828
47	28.7067	76.9908	15	Suda	0.051	0.1463
48	28.7303	77.0231	15	Karala	0.051	0.1677
49	28.7381	77.0014	15	Ladpur	0.052	0.1959
50	28.7192	76.9828	15	Nizampur Rashid	0.051	0.1665
51	28.7261	77.0042	15	Khanjwala	0.051	0.1655
52	28.7061	76.9758	15	Suda	0.049	0.1434
53	28.6953	77.0239	16	Mundka	0.050	0.1446
54	28.6840	77.0076	16	Mundka	0.049	0.1290
55	28.6729	77.0179	16	Mundka	0.048	0.1472
56	28.6526	77.0232	16	Bakarwalan	0.047	0.1537
57	28.6914	76.9766	16	Tikri Kalan	0.050	0.1488
58	28.6805	76.9904	16	Tikri Kalan	0.049	0.1701

59	28.6684	76.9936	16	Hiran Kudna	0.049	0.1425
60	28.6535	76.9840	16	Dhichaon Kalan	0.049	0.1633
61	28.6400	77.0206	17	Bagrola	0.045	0.1446
62	28.6262	77.0202	17	Mohan Garden	0.047	0.1638
63	28.6062	77.0112	17	Najafgarh	0.046	0.1455
64	28.6159	76.9748	17	Najafgarh	0.047	0.1499
65	28.6136	76.9992	17	Najafgarh	0.046	0.1436
66	28.6014	76.9894	17	Roshanpura	0.043	0.1410
67	28.6316	76.9758	17	Dhichaon Kalan	0.049	0.1256
68	28.6345	76.9974	17	Dhichaon Kalan	0.048	0.1664
69	28.5586	76.9811	18	Rewla Khanpur	0.042	0.1554
70	28.5906	76.9796	18	Paprawat	0.046	0.1599
71	28.5927	76.9903	18	Dinarpur	0.046	0.2019
72	28.5801	77.0218	18	Qutubpur	0.046	0.2155
73	28.5782	76.9773	18	Paprawat	0.046	0.1666
74	28.5678	77.0104	18	Chhawla	0.046	0.1783
75	28.5694	76.9967	18	Chhawla	0.045	0.1600
76	28.5534	77.0019	18	Chhawla	0.046	0.2177
77	28.8608	77.0566	20	Lampur	0.058	0.2169
78	28.8692	77.0555	20	Lampur	0.054	0.2095
79	28.8683	77.0944	20	Narela	0.056	0.1969
80	28.8521	77.0675	20	Lampur	0.056	0.1891
81	28.8147	77.0711	21	Sanoth	0.053	0.1937
82	28.8315	77.0723	21	Bankner	0.054	0.1848
83	28.7946	77.0299	22	Bawana	0.056	0.1782
84	28.7998	77.0729	22	Holambi Khurd	0.052	0.1664
85	28.7800	77.0300	22	Sultanpur Dabas	0.055	0.1706
86	28.7732	77.0526	22	Barwala	0.053	0.1637
87	28.7842	77.0670	22	Khera Khurd	0.052	0.1623
88	28.7619	77.0375	22	Sultanpur Dabas	0.054	0.1686
89	28.7601	77.0653	22	Barwala	0.049	0.1564
90	28.7371	77.0386	23	Karala	0.052	0.1927
91	28.7439	77.0517	23	Karala	0.052	0.1760
92	28.7378	77.0714	23	Pansali	0.050	0.1979
93	28.7200	77.0383	23	Mohammadpur Majar	0.050	0.1898
94	28.7257	77.0563	23	Karala	0.050	0.1958
95	28.7200	77.0711	23	Rohini Sec-23	0.049	0.1408
96	28.7106	77.0489	23	Mubarakpur Dabas	0.050	0.1751
97	28.6988	77.0438	24	Kirari Suleman Nagar	0.047	0.1297
98	28.6558	77.0401	24	Ranhola Shafipur	0.047	0.1644
99	28.6828	77.0297	24	Mundka	0.045	0.1410
100	28.5550	77.0394	26	Dwarka Sec-25	0.041	0.1601
101	28.5946	77.0352	26	Dwarka Sec-13	0.043	0.1696
102	28.5949	77.0543	26	Dwarka Sec-5	0.042	0.1738
103	28.5939	77.0711	26	Dwarka Sec-6	0.041	0.1575
104	28.5730	77.0528	26	Dwarka Sec-19	0.041	0.1533
105	28.5814	77.0737	26	Pappan Kalan	0.041	0.1393
106	28.5597	77.0262	26	Dwarka Sec-24	0.042	0.1526
107	28.5498	77.0540	26	Dwarka Sec-26	0.041	0.1479
108	28.5550	77.0675	26	Dwarka Sec-21	0.041	0.1461
109	28.5378	77.0517	27	Dwarka Sec-27	0.040	0.1503
110	28.8658	77.0967	28	Mamurpur	0.053	0.2551
111	28.8544	77.1225	28	Mamurpur	0.053	0.2203
112	28.8544	77.1018	28	Mamurpur	0.054	0.1851
113	28.8655	77.1113	28	Mamurpur	0.055	0.2177
114	28.8261	77.1069	29	Narela	0.052	0.2022
115	28.8147	77.0856	29	Bhorgarh	0.052	0.1931
116	28.8431	77.0881	29	Narela	0.054	0.1870
117	28.8173	77.0976	29	Rajpur Kalan	0.051	0.1542
118	28.8327	77.0921	29	Bhorgarh	0.053	0.1951
119	28.8336	77.1169	29	Tikri Khurd	0.048	0.2187
120	28.8053	77.0972	29	Holambi Kalan	0.048	0.2179
121	28.8172	77.1165	29	Shahpur Garhi	0.051	0.1624

122	28.7884	77.0819	30	Naya Bansh	0.051	0.1550
123	28.7500	77.0765	30	Pehladpur Banger	0.050	0.1498
124	28.7932	77.0975	30	Holambi Khurd	0.051	0.1717
125	28.7958	77.1052	30	Holambi Khurd	0.051	0.1746
126	28.7731	77.0923	30	Khera Khurd	0.051	0.1698
127	28.7806	77.1125	30	Khera Khurd	0.051	0.1983
128	28.7556	77.0921	30	Pehladpur Banger	0.050	0.1558
129	28.7561	77.1131	30	Sirsapur village	0.049	0.1660
130	28.7244	77.0867	31	Rohini Sec-25	0.049	0.1493
131	28.7283	77.1187	31	Rohini Sec-12	0.047	0.1941
132	28.7161	77.0957	31	Rithala	0.046	0.1411
133	28.7098	77.1119	31	Rohini Sec-6, Blk-F	0.046	0.2011
134	28.7464	77.1042	31	Shiv Vihar	0.050	0.1473
135	28.7079	77.0798	31	Sultanpuri	0.048	0.1589
136	28.7016	77.0904	31	Mangolpuri Blk-Y	0.046	0.1595
137	28.6969	77.0779	32	Sultanpuri	0.045	0.1608
138	28.6970	77.1136	32	Pushpanjali Enclave, Rohini	0.044	0.1517
139	28.6508	77.0857	32	Gurunanak Nagar	0.043	0.1307
140	28.6583	77.1042	32	Khayala	0.043	0.1787
141	28.6800	77.0742	32	Nangloi Jat	0.045	0.1976
142	28.6881	77.0956	32	Mangolpuri	0.044	0.1835
143	28.6661	77.0917	32	Sunder Aptt, Sunder Vihar	0.044	0.1772
144	28.6670	77.1023	32	Jwala Heri, Paschim Vihar	0.043	0.1816
145	28.6439	77.1083	33	Park, Near Tagor Garden	0.042	0.1284
146	28.6306	77.1069	33	Tihar Village	0.041	0.1316
147	28.6367	77.1225	33	Subhash Nagar, Blk-10	0.042	0.1207
148	28.8436	77.1304	38	Singhola	0.052	0.2014
149	28.8283	77.1450	38	Hamidpur	0.051	0.1530
150	28.8423	77.1704	38	Tajpur Kalan	0.050	0.1871
151	28.8269	77.1296	38	Khanpur	0.051	0.1559
152	28.8135	77.1429	38	Bankoli	0.050	0.1944
153	28.8194	77.1551	38	Hamidpur	0.050	0.1675
154	28.8277	77.1702	38	Bakhtawarpur	0.049	0.1985
155	28.8031	77.1313	38	Alipur	0.051	0.1815
156	28.8072	77.1663	38	Bakhtawarpur	0.049	0.1496
157	28.8108	77.1564	38	Bankoli	0.049	0.1785
158	28.8180	77.1744	38	Bakhtawarpur	0.049	0.1651
159	28.7890	77.1301	39	Alipur	0.050	0.1840
160	28.7973	77.1495	39	Alipur	0.049	0.1484
161	28.7938	77.1663	39	Mukhmelpur	0.045	0.1639
162	28.7820	77.1454	39	Budhpur, Bijapur	0.049	0.1694
163	28.7796	77.1686	39	Near Ibrahampur	0.048	0.1708
164	28.7745	77.1335	39	Khera Ghari	0.049	0.1753
165	28.7726	77.1501	39	Kadipur	0.048	0.1739
166	28.7634	77.1722	39	Nathupura	0.047	0.1747
167	28.7621	77.1524	39	Near Swaroopnagar	0.048	0.1509
168	28.7563	77.1364	39	Rana Park, Sirsapur	0.048	0.1597
169	28.7535	77.1654	39	Swaroopnagar, New Colony	0.047	0.1451
170	28.7881	77.1552	39	Mukhmelpur	0.049	0.1502
171	28.7688	77.1625	39	Kadipur	0.048	0.1473
172	28.7429	77.1526	40	Sanjay Gandhi Transport Nagar Blk AG	0.045	0.1245
173	28.7393	77.1358	40	Rohini Sec-18, Blk A, Pkt8	0.045	0.1438
174	28.7364	77.1646	40	Bhalsawa	0.044	0.1495
175	28.7286	77.1493	40	Haiderpur	0.044	0.1691
176	28.7096	77.1280	40	Rohini Sec-14	0.044	0.1442
177	28.7108	77.1436	40	North Pitampura, Pkt-NU	0.044	0.1504

178	28.7194	77.1601	40	Sahipur, Near Shalimar Bagh	0.043	0.1423
179	28.7191	77.1747	40	Aadarsh Nagar	0.043	0.1801
180	28.7041	77.1551	40	Pitampura, Blk-TP Pocket	0.043	0.1428
181	28.7056	77.1744	40	Wazirpur Indl area, Blk-B	0.042	0.1869
182	28.6928	77.1249	41	Saraswati Vihar	0.044	0.1742
183	28.6981	77.1419	41	South Pitampura, Blk Pocket-KD	0.043	0.1669
184	28.6953	77.1631	41	ashok Vihar, Ph-I, Blk-E	0.042	0.1288
185	28.6597	77.1302	41	Near Raja Garden	0.042	0.1235
186	28.6833	77.1450	41	Sakurpur Village	0.043	0.1304
187	28.6703	77.1417	41	East Punjabi Bagh	0.042	0.1618
188	28.6708	77.1581	41	Karampura Block, Indl Area	0.043	0.1377
189	28.5431	77.1327	44	CISF Rd, Mahipalpur Extn	0.039	0.1445
190	28.4972	77.1325	45	Ghitorni Village	0.038	0.1437
191	28.4964	77.1622	45	Sultanpur Village	0.037	0.1449
192	28.4858	77.1331	45	Saink Nivas MES, Ghitorni	0.038	0.1269
193	28.4839	77.1628	45	HK Farm House, near Godaipur	0.037	0.1454
194	28.4706	77.1631	45	Jaunapur	0.037	0.1321
195	28.4440	77.1464	46	Farm house, Mandi Village	0.036	0.1549
196	28.4416	77.1347	46	KH No.66/6, Mandi Village	0.036	0.1608
197	28.4400	77.1636	46	SEPAL Farm Dera, Mandi Rd, Mandi	0.036	0.1395
198	28.8441	77.1848	48	MCD School, Palla	0.047	0.1626
199	28.8455	77.2001	48	Palla	0.046	0.1576
200	28.8294	77.1788	48	Bakhtawarpur	0.046	0.1745
201	28.8308	77.1986	48	School Jhangla	0.045	0.1550
202	28.8175	77.2134	48	Palla Police Post	0.044	0.1682
203	28.8167	77.1994	48	Near Jal Board Palla	0.044	0.1635
204	28.7978	77.1807	49	Hiranki Village	0.045	0.1613
205	28.7708	77.1875	49	Uttarakhand Coloney	0.043	0.1821
206	28.7639	77.2153	49	Shank No.1, Burari village	0.043	0.1808
207	28.7948	77.1911	49	Near Shank 22, Hiranki Village	0.044	0.1701
208	28.7946	77.1998	49	Tedi Daulatpur	0.044	0.1569
209	28.7810	77.1838	49	Resid. area, Hiranki, Nr Ibrahampur	0.041	0.1851
210	28.7757	77.1992	49	Silampur Majra	0.044	0.1638
211	28.7604	77.1976	49	Behind Shani temple, Burari	0.043	0.1680
212	28.7445	77.1943	50	Sant Nagar	0.046	0.1939
213	28.7144	77.1874	50	Nr Model Town	0.045	0.2343
214	28.7135	77.2047	50	Radio Coloney, Nr Dhaka Village	0.044	0.1329
215	28.7319	77.1810	50	Near Jahangirpuri Blk-JJC	0.046	0.1502
216	28.7336	77.2064	50	Jharoda Dairy Coloney	0.045	0.1455
217	28.7331	77.2185	50	Nr Milan Vihar, Burari	0.044	0.1599
218	28.7260	77.1939	50	Nirankari Ground, nr Jharoda Majra	0.045	0.2086
219	28.7031	77.1966	50	Model Town	0.044	0.1445
220	28.7059	77.2210	50	Timarpur	0.044	0.1159
221	28.6793	77.2205	51	Civil Lines	0.041	0.1623
222	28.6962	77.2104	51	Khalsa College, Nr Univ campus	0.042	0.1665

223	28.6893	77.1978	51	CC Colony	0.042	0.1659
224	28.6896	77.1834	51	Near Satyavati Colony	0.042	0.1429
225	28.6478	77.2109	51	Azad Market	0.041	0.1714
226	28.6788	77.1878	51	Shiv Temp, Fakira Bagh, Shastri Nagar	0.042	0.1743
227	28.6850	77.2033	51	Roopnagar Blk-6	0.042	0.1770
228	28.6680	77.2208	51	Civil Lines, Nr Tis Hazari	0.041	0.1519
229	28.5208	77.1910	54	Lado Sarai	0.039	0.1572
230	28.5340	77.1936	54	Govt Nursery, Adhichini	0.039	0.1601
231	28.5413	77.1829	54	Lal bahadur Vidyapith, Katwariasarai	0.040	0.1373
232	28.5056	77.2058	54	Neb Sarai, Mehrauli	0.039	0.1098
233	28.5478	77.1937	54	Rose Garden, Haus Khas	0.040	0.1497
234	28.5388	77.2088	54	Begampur,Malviya Nagar	0.040	0.1655
235	28.5387	77.2244	54	Shek Sarai,Ph.-I	0.040	0.1693
236	28.5288	77.2066	54	Hauz Rani Saket	0.039	0.1542
237	28.5080	77.1739	54	Kusum Nursery Vasant Kunj	0.039	0.1716
238	28.5161	77.2119	54	Saket-Bdarpur Rd	0.039	0.1527
239	28.5001	77.2220	54	Sainik Farm, Nr Sangam Vihar	0.039	0.1645
240	28.4986	77.1792	55	Near Chhatarpur Mandir	0.039	0.1548
241	28.4978	77.1942	55	DDA, Maidan Garhi	0.039	0.1256
242	28.4828	77.1806	55	10 Farm, DLF, Chhatarpur	0.039	0.1509
243	28.4856	77.1971	55	Rajpur Khurd	0.038	0.0000
244	28.4717	77.1922	55	Saharpur Extn, ND	0.038	0.1333
245	28.4567	77.2075	55	Forest, Asola Village	0.039	0.1535
246	28.7176	77.2510	58	PT School, Wazirabad	0.044	0.1795
247	28.7325	77.2325	58	Ramp No.3, Near Jagatpur Bund	0.044	0.1934
248	28.7450	77.2559	58	Burari Village	0.045	0.1782
249	28.7079	77.2364	58	Pantan Bridge, Wazirabad	0.044	0.1706
250	28.7338	77.2657	58	Govt School, Karwal Nagar	0.044	0.1488
251	28.7188	77.2664	58	Near Priya Convent Sch, Dayalpur	0.043	0.1763
252	28.7039	77.2554	58	Garai Mandu Village	0.043	0.1969
253	28.6857	77.2350	59	New Usmanpur Village	0.043	0.1897
254	28.6587	77.2401	59	MG Park, Lal Quila	0.042	0.1602
255	28.6924	77.2548	59	Pusta-4, Usmanpur	0.042	0.1679
256	28.6769	77.2471	59	Opp DMRC off, Shatri Park	0.042	0.1885
257	28.6753	77.2692	59	Silampur	0.042	0.1754
258	28.6668	77.2503	59	Shastri Park	0.042	0.1382
259	28.6589	77.2692	59	SK School, Geeta Colony	0.041	0.1603
260	28.7304	77.2814	65	Kali Mandir, Shiv Vihar	0.043	0.1752
261	28.7073	77.3232	65	Harsh vihar	0.042	0.1735
262	28.7149	77.2815	65	Chamanpark, Johripur	0.043	0.1647
263	28.7029	77.3076	65	Nand Nagari	0.042	0.1408
264	28.7044	77.2769	65	Gokulpuri colony	0.043	0.1992
265	28.7029	77.2962	65	East Gokulpur	0.042	0.1510
266	28.689500	77.289333	66	Near Jyoti colony	0.042	0.1368
267	28.692472	77.312861	66	Nand Nagari, Blk-E4	0.043	0.1444
268	28.677722	77.298417	66	Mansarovar Park	0.041	0.1330
269	28.656000	77.292278	66	Arjun Nagar	0.041	0.1263
270	28.665333	77.305583	66	Jhilmil Coloney	0.042	0.1374
271	28.653694	77.315667	66	Anand Vihar, Blk-C	0.042	0.1504
272	28.6192	77.2865	67	Pandav Nagar, Blk-A	0.039	0.1281
273	28.6242	77.3001	67	Vinod Nagar West, Blk-D	0.041	0.1253
274	28.6092	77.3028	67	Mayur Vihar, Ph-I, Pkt 2	0.040	0.1500

275	28.6111	77.3225	67	Durga park Coly, near Kundali	0.040	0.1250
276	28.5398	77.2831	69	Park, near Appolo Hosp., Jasola	0.039	0.1380
277	28.5234	77.3083	69	near Badarpur Thermal Plant, Khadar	0.039	0.1364
278	28.5321	77.2956	69	DDA Park, Sarita Viahar, Blk-D	0.038	0.1481
279	28.5412	77.3089	69	Kalindikunj, Jaitpur Road	0.039	0.1500
280	28.5322	77.3161	69	DDA park, JJ Colony	0.038	0.1504
281	28.5062	77.3017	69	Govt School, near NTPC,Badarpur	0.037	0.1336
282	28.502500	77.314083	69	Near Irrigation Dept, Hari Nagar	0.038	0.1723
283	28.6281	77.3253	72	Near Gaziur, Blk-D	0.041	0.1319
284	28.6121	77.3348	72	Gharoli Dairy Farm, Blk-A	0.040	0.1303
285	28.6032	77.3308	72	Near Kundli, Blk-A1	0.040	0.1326
286	28.5147	77.3417	73	Jaitpur Extn	0.038	0.1370
287	28.5253	77.3313	73	Near Police post, Jaitpur	0.038	0.1377
288	28.8746	77.0795	20	Safiabad	0.054	0.1947
289	28.8757	77.1114	28	Kundli	0.056	0.1831
290	28.8125	77.0875	29	Holambi kalan	0.050	0.1894
291	28.8300	77.1229	29	Tikri Khurd	0.050	0.1410
292	28.7222	77.1056	31	DCE, Rithala	0.045	0.1447
293	28.8183	77.1458	38	Bankoli	0.049	0.1714
294	28.7499	77.1763	39	Bhalsawa Dairy	0.045	0.1684
295	28.7917	77.1597	39	Mukhmelpur	0.047	0.1698
296	28.8417	77.2125	48	Jangola	0.049	0.1639
297	28.8056	77.1917	49	Fatehpur Jat	0.045	0.1716
298	28.8583	77.2417	49	Sankrot	0.049	0.1566
299	28.7083	77.2167	50	Indira Vihar	0.044	0.1420
300	28.7427	77.2053	50	Salarpur	0.043	0.1842
301	28.6917	77.2292	51	Majnu Ka Tila	0.044	0.0889
302	28.7450	77.2442	58	Libaspur	0.045	0.1506
303	28.6072	76.8844	3	Mandhela Kalan	0.050	0.1189
304	28.5828	76.9311	11	Khera Dabas	0.049	0.1446
305	28.5324	76.9461	12	Shikarpur	0.045	0.1480
306	28.7872	77.0164	14	Bawana, Khanjawala	0.049	0.2033
307	28.6264	77.0197	17	Mohan Garden	0.047	0.1273
308	28.7072	77.0322	23	Madanpur Dabas	0.049	0.1698
309	28.8714	77.0833	28	Narela	0.056	0.1710
310	28.8042	77.1094	29	Holambi Kalan	0.051	0.1952
311	28.7347	77.0892	31	Rohini Sec-25	0.046	0.1522
312	28.6250	77.0903	33	Janakpuri Blk-B3B	0.042	0.1296
313	28.5117	77.1083	35	Rajokri village	0.039	0.1071
314	28.8180	77.1744	38	Bakhtawarpur	0.048	0.1693
315	28.7535	77.1653	39	Swaroopnagar, New Colony	0.047	0.1591
316	28.6828	77.1615	41	Keshavpuram	0.043	0.0964
317	28.4717	77.1475	45	Akoi Farm, Jaunapur	0.040	0.1230
318	28.6857	77.2159	51	Ridge, Near Univ Campus	0.041	0.1064
319	28.6645	77.2074	51	Azadpur Market	0.041	0.1483
320	28.6144	77.1763	52	Budha Jayanti Park	0.041	0.1137
321	28.5386	77.2092	54	Begampur,Malviya Nagar	0.040	0.1322
322	28.5252	77.2215	54	Pushpa Vihar, Sec-1	0.040	0.1334
323	28.4723	77.1860	55	Chandan Hulla	0.039	0.1187
324	28.7250	77.2510	58	PTS Wazirabad	0.044	0.1641
325	28.5811	77.2313	61	Jawaharlal Nehru Stadium	0.040	0.0951
326	28.6029	77.2855	67	Nangal	0.040	0.1169

327	28.5325	77.3167	69	JJ Colony, Sarita Vihar	0.039	0.1387
328	28.5811	77.2330	61	Jawaharlal Nehru Stadium	0.040	0.1074
329	28.5889	77.2596	61	Sarai Kale Khan	0.037	0.1315
330	28.5889	77.2596	61	Sarai Kale Khan	0.037	0.1598
331	28.5963	77.2578	61	Rajiv Gandhi Smriti Van, Nr Zoo	0.038	0.1254
332	28.5997	77.2569	61	Rajiv Gandhi Smriti Van, Nr Zoo	0.038	0.1275
333	28.5976	77.2575	61	Rajiv Gandhi Smriti Van, Nr Zoo	0.041	0.1592
334	28.6783	77.1583	41	Tri Nagar	0.042	0.1655
335	28.6699	77.2704	59	Seelampur	0.039	0.1418
336	28.6783	77.1583	41	Tri Nagar	0.042	0.1537
337	28.5524	77.2758	68	Sukhdev Vihar	0.036	0.1388
338	28.5233	77.2279	62	Pushpa Vihar	0.037	0.1714
339	28.5431	77.2113	54	Paschimshila Park, South Blk-S	0.037	0.1298
340	28.6783	77.1583	41	Tri Nagar	0.042	0.1695
341	28.7177	77.1103	31	Rohini Sec-5, Pkt-6	0.045	0.2182
342	28.5248	77.2137	54	Saket	0.037	0.1510
343	28.6813	77.0971	32	Udyog Nagar, Nr Paschim Vihar	0.044	0.1953
344	28.6407	77.2320	60	Ramlila Ground	0.039	0.1781
345	28.4724	77.1860	55	Chandan Hulla	0.039	0.1417
346	28.4704	77.2013	55	Saharpur Extn, ND	0.036	0.1563
347	28.4458	77.1866	56	Fatehpur Beri	0.039	0.1121
348	28.4431	77.2006	56	Bhati Mines	0.039	0.1446
349	28.6830	77.1622	41	Keshavpuram	0.043	0.1391
350	28.6029	77.2855	67	Nangal	0.040	0.1065
351	28.6361	77.2986	67	Indraprastha Extn	0.040	0.1357
352	28.6768	77.3123	66	Dilshad Garden, Blk R	0.039	0.1242
353	28.6222	77.3388	72	NearMayur Vihar Ph-III	0.040	0.1382
354	28.7342	77.0891	31	Rohini Sec-25	0.046	0.1671
355	28.5089	77.1083	35	Rajokri village	0.042	0.1144
356	28.6379	77.0761	33	Vikaspuri Blk-C	0.045	0.1323
357	28.5877	77.0474	26	Dwarka Sec-11	0.044	0.1262
358	28.5933	77.0492	26	East of Dwarka Sec-12	0.044	0.1456
359	28.6736	77.2981	66	Shahdara	0.039	0.1247
360	28.5926	77.0815	34	Nr Palam Village	0.043	0.1196
361	28.6175	77.0480	25	Sainik Nagar	0.046	0.1301
362	28.5963	77.0788	34	Dwarka Sec-1	0.043	0.1188
363	28.6699	77.1389	41	West Punjabi Bagh	0.045	0.1454
364	28.5963	77.2578	61	Rajiv Gandhi Smriti Van, Nr Zoo	0.037	0.1293
365	28.8197	77.0612	21	Sanoth	0.055	0.1791
366	28.6222	77.2042	52	Nr MP's Club, Rakabganj	0.038	0.1230
367	28.5300	77.0890	35	Samalka, Nr Kapashera	0.041	0.1230
368	28.5449	77.1198	35	Intl Airport Authority, Nr Mahipalpur	0.041	0.1201
369	28.5477	77.1250	35	Intl Airport Authority, Nr Mahipalpur	0.041	0.1252
370	28.5861	77.0551	26	Dwarka Sec-10	0.044	0.1308
371	28.5958	77.1200	34	Sadar Bazar (Delhi Cantt)	0.043	0.1122
372	28.7119	77.1601	40	Shalimar Bagh, Pkt-BD	0.042	0.1410
373	28.8528	77.0889	29	Narela	0.056	0.1751
374	28.6250	76.9231	3	Kair	0.051	0.1409
375	28.5917	76.9250	4	Jafarpur Kalan	0.050	0.1309
376	28.6417	77.1647	42	West Patel Nagar	0.039	0.1373
377	28.6611	77.1458	41	New Motinagar, Blk-17	0.041	0.1113
378	28.6431	77.0972	33	Chaukhandi, nr Hind Nagar	0.045	0.1284

379	28.6636	77.1433	41	New Motinagar, Blk-B	0.045	0.1262
380	28.6919	77.1602	41	Lawrence Rd Coloney, Blk-C-7	0.041	0.1384
381	28.6736	77.1931	51	Gulabi Bagh	0.040	0.1538
382	28.6797	77.1573	41	Omkar Nagar	0.041	0.1368
383	28.6475	77.1797	52	Prasad Nagar, Nr E. Patel nagar	0.039	0.1357
384	28.5827	77.0579	26	Dwarka Sec-10	0.044	0.1263
385	28.6506	77.3042	66	Karkarduma	0.038	0.1295
386	28.6484	77.3046	67	Karkarduma	0.038	0.1288
387	28.5807	77.2924	68	Trans Yamuna, nr Chilla	0.037	0.1245
388	28.6417	77.2522	60	Rajghat	0.038	0.1430
389	28.6681	77.2564	59	Shastri Park, BLK-A	0.039	0.1293
390	28.5150	77.2722	62	Close to Tuglakabad Village	0.035	0.1182
391	28.5686	77.2436	61	Lajpatnagar, part-II	0.036	0.1195
392	28.5681	77.2189	53	South Ex Part-II	0.037	0.1318
393	28.5444	77.2583	62	Kalkaji, Blk-D	0.036	0.1217
394	28.5722	77.1708	43	RK Puram, Sec-8	0.038	0.1160
395	28.5781	77.1625	43	Anand Niketan, Blk-D	0.038	0.1293
396	28.6222	77.2467	60	Mata Sundari Rly Coloney	0.037	0.1476
397	28.6903	77.1778	51	Satyawati Coloney, Blk-A, Pkt-A	0.040	0.1311
398	28.6556	77.1917	51	Karol Bagh, Blk-D, Pkt52	0.039	0.1401
399	28.6083	77.2403	60	Bapa Nagar	0.037	0.1281
400	28.6111	77.2264	60	Vigyan Bhawan	0.037	0.1406
401	28.6367	77.2064	52	Govt Quarters, Nr Gole Market	0.038	0.1224
402	28.6417	77.1508	42	Pusa Institute	0.040	0.1404
403	28.5651	77.0783	34	IGI nr Pappan Kalan	0.043	0.1266
404	28.6389	77.2375	60	West of F.S.Kotla stadium	0.038	0.1455
405	28.6260	77.2099	52	Bangla Saheb Gurudwara	0.038	0.1217
406	28.6735	77.2916	66	Makki Sarai	0.039	0.1249
407	28.6021	77.1928	52	Chanakyapuri, Nr JLN Memorial Museum	0.037	0.1162
408	28.5523	77.2140	53	Siri Fort Sports Complex	0.036	0.1251
409	28.5616	77.2242	53	Aayurvugyan Nagar	0.037	0.1303
410	28.5677	77.2272	61	Andrews Ganj	0.037	0.1235
411	28.6390	77.1316	42	Mansarover Garden, Blk-WZ	0.040	0.1303
412	28.5255	77.2120	54	Saket	0.036	0.1213
413	28.5862	77.0639	26	Dwarka Sec-10	0.044	0.1348
414	28.7982	77.0362	22	Bawana	0.056	0.1686
415	28.6805	77.3130	66	Dilshad Garden, Blk-C	0.039	0.1304
416	28.7100	77.2835	65	Bhagirath Vihar	0.039	0.1237
417	28.6217	77.2440	60	Pragati Maidan	0.037	0.1339
418	28.7011	77.3078	65	Mandoli Extn	0.039	0.1266
419	28.5417	77.1833	54	Qutub Indl Area	0.037	0.1177
420	28.5332	77.3029	69	Madanpur Khadar Village	0.035	0.1128
421	28.7135	77.1774	50	Majlis Park	0.041	0.1359
422	28.5646	77.2477	61	Lajpat Nagar, Part-IV	0.037	0.1115
423	28.7238	77.1353	40	Rohinin Sec-13, nr Vikrant Apartment	0.043	0.1463
424	28.5621	77.0769	34	IGI, nr Dwarka Sec-21	0.043	0.1253
425	28.6779	77.2274	59	Civil Lines	0.039	0.1350
426	28.5730	77.0777	34	Dwarka Sec-8	0.043	0.1183
427	28.5867	77.0933	34	Sadh Nagar, Palam coloney	0.043	0.1294
428	28.7265	77.1125	31	Rohini Sec-25	0.048	0.1610

429	28.7268	77.1136	31	Rohini Sec-25	0.048	0.1632
430	28.6444	77.2269	60	Kamla Market	0.038	0.1372
431	28.6006	77.0931	33	Mahaveer Enclave-II, nr Kailashpuri west	0.043	0.1244
432	28.6150	77.0889	33	Janakpuri Blk C-3	0.043	0.1318
433	28.6153	77.0886	33	Janakpuri Blk C-3	0.043	0.1258
434	28.6708	77.2903	66	Teli Bara	0.039	0.0971
435	28.6683	77.2762	66	Seelampur	0.039	0.1292
436	28.7012	77.2888	65	South of Gokulpur	0.039	0.1287
437	28.7164	77.2863	65	Nr Kardam Farm, Johripur	0.039	0.1308
438	28.6764	77.2889	66	Naveen Shahdara	0.039	0.1328
439	28.6764	77.2889	66	Naveen Shahdara	0.039	0.1292
440	28.6699	77.2704	59	Seelampur	0.039	0.1188
441	28.5979	77.0510	26	Dwarka Sec-4	0.045	0.1399
442	28.6806	77.1561	41	Lawrence Rd Indl Area	0.041	0.1437
443	28.6708	77.1972	51	Andha Mughal, Nr Gulabi Bagh	0.040	0.1543
444	28.6117	77.3103	67	Patparganj, nr Trilokpuri-I	0.037	0.1162
445	28.7042	77.3131	65	Mandoli	0.039	0.1275
446	28.7931	77.0417	22	Bawana	0.055	0.1662
447	28.7019	77.1667	40	Wazirpur Indl Area	0.041	0.1373
448	28.5355	77.1626	44	JNU	0.041	0.0898
449	28.4508	77.2094	55	Asola	0.038	0.0922

भारत सरकार
GOVERNMENT OF INDIA
पृथ्वी विज्ञान मंत्रालय
MINISTRY OF EARTH SCIENCES
महासागर भवन, ब्लाक–12, सी.जी.ओ. काम्पलैक्स, लोदी रोड,
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संख्या
No. MoES/Seismo/2(01)/2007

नई दिल्ली-110003
New Delhi-110003
Dated: 28th Nov., 2007

Sub: Constitution of Advisory and Monitoring Committee on Microzonation study of Delhi region.

OFFICE MEMORANDUM

Earthquake Risk Evaluation Centre (EREC), IMD is in process of preparing microzonation maps of Delhi on 1:10,000 scale. In order to oversee this, Ministry of Earth Sciences has constituted an advisory & monitoring committee with following composition and terms of reference.

(A)Composition

1. Prof. A S Arya, National Seismic Advisor, Ministry of Home Affairs, New Delhi — **Chairman**
2. Prof. D. K. Paul, Department of Earthquake Engineering, Indian Institute of Technology, Roorkee- 247 667 — Member
3. Prof. S. K. Nath, Department of Geology & Geophysics, Indian Institute of Technology, Kharagpur- 721 302 — Member
4. Dr. T. G. Sitharam, Department of Civil Engineering, Indian Institute of Science Bangalore Bangalore-560012 — Member
5. Dr. Prabhash Pandey, Director, Geological Survey of India, Northern Region, Vasundhara, GSI Complex, Sector-E, Aliganj, Lucknow- 226 024. — Member

Contd. P-2/-

6. Dr. A. K. Bhatnagar, Member
   Additional Director General (Sesimology),
   India Meteorological Department
   Mausam Bhawan
   Lodhi Road, New Delhi- 110 003.

7. Programme Officer, Member
   Seismology, MoES

8. Dr. A. K. Shukla, **Convener**
   Director, EREC
   India Meteorological Department
   Mausam Bhawan
   Lodhi Road, New Delhi- 110 003.

B-Terms of reference

- The Committee will guide the activities and monitor the progress of the project on regular basis, preferably every 45 days and suggest the mid term corrections required, if any.
- The Committee may recommend the short-term studies required to be taken up for completion of the task.
- The Committee may co-opt any expert(s) required for any specific issue.
- The Committee will guide/help in preparation of the final report.

C-Tenure

The tenure of the Committee will be co-terminus with the completion of microzonation study and release of final report.

TA & DA to experts and non-official members of the Committee will be met by EREC. Also, members of the committee will be entitled for an honorarium of Rs.500/- per day of the meeting.

This issues with approval of Secretary, MoES.

Vandana Chaudhary
Scientist-C
Seismology Division

To,

Chairman and all members of the Committee

Contd. P-3/-

Copy Forwarded for information:

1. Director General, India Meteorological Department, Mausam Bhawan, Lodhi Road, New Delhi- 110 003
2. Sr. PPS to Secretary, Ministry of Earth Science, Mahasagar Bhawan, CGO Complex, New Delhi
3. PS to JS (A), Ministry of Earth Science, Mahasagar Bhawan, CGO Complex, New Delhi
4. Office Copy

Vandana Chaudhary
Scientist-C
Seismology Division

ANNEXURE-II

A BRIEF ON MONITORING AND REVIEW PROCESS OF SEISMIC HAZARD MICROZONATION PROJECT ON 1: 10K SCALE

Seismic Hazard Microzonation requires multidisciplinary data collocation, generation, integration of the different types of information (geologic, seismotectonic, Geotechnical, Geophysical, Earthquake), application of different mathematical tools (statistics, probability, and models) and decision making which requires a project structure and implementation process that assure proper quality data generation, selection of appropriate models, appropriate analytical approach, and integration keeping in view of (i) p**roper** and full incorporation of uncertainties, (ii) data generation practices in vogue (iii) inclusion of the range of diverse techniques, interpretations (iii) consideration of site- specific knowledge and data sets, (iv) complete documentation of the process and results, (v) proper peer review.

Further, there is not likely to be "consensus" among the various experts and no single interpretation concerning a complex earth-sciences issue is the "correct" one. Therefore, to address a difficult technical issue and to reach near consensus results **(i)** a representation of the legitimate range of technically supportable experts among the entire informed technical community, throughout the process of microzonation (ii) assurance of good quality data generation under the guidance of technical experts, regular supervision during the process of data generation, application of available guidelines, codes etc. (iii) Selection of appropriate techniques and models (iv) regular review by technical experts, are required.

Earthquake Risk Evaluation Center (EREC) of India Meteorological Department, (which has recently been merged with Center of Seismology)Ministry of Earth Science is a multidisciplinary Center. Scientists from the Center have completed Seismic Hazard Microzonation (SHM) of NCT Delhi in 1:50000 scale and participated in collaborative projects of SHM studies, undertaken for other cities of the country by different organizations. Scientists of the Center have also undergone long and short term training courses related to hazard analysis, Geological/ Geophysical/Seismological field data collection practices, laboratory investigation practices and operational aspects. Further, to make use of expertise available in the country, better representation, continuous monitoring and guidance of the project “Seismic Hazard Microzonation of NCT Delhi on 1:10000 scale” Ministry of Earth Sciences had constituted a multidisciplinary Advisory and Monitoring Committee vide MoES/Seismo/2(01)/2007 dated 28.11.2007, under the Chairmanship of Prof. A.S.Arya, Former Seismic Advisor, Government of India, presently Hon’ble Member Bihar Disaster Management Authority and experts of different disciplines as members of the committee (Annexure-1). For continuous supervision and guidance, Advisory and Monitoring Committee met eight times during the course of study. To interact with legitimate range of technically supportable experts, several interactive meetings and workshops were also organized during the course of study and formulation of report. Report has been reviewed by the members of the committee and their suggestions have appropriately been incorporated. A brief on review and monitoring process of individual components and entire project of Seismic Hazard Microzonation is as follows.

1. Probabilistic Seismic Hazard Analysis at engineering bedrock

The important components of Probabilistic Seismic Hazard Analysis (PSHA) are seismic source identification, selection of ground motion models, seismicity parameters, etc. There are inevitable uncertainties in selecting these parameters due to large uncertainties in all the geosciences data and in their modeling, lack of proper understanding of the mechanisms that cause earthquakes, and of the processes that govern how an earthquake's energy propagates from its origin beneath the earth to various points near and far on the surface. This problem is aggravated in regions where large earthquakes are very uncommon and multiple model interpretations are often possible. The complexity, importance and diversity of Judgments regarding any one of these issues vary between study location**,** range of the study (site-specific vs. regional), and other factors. Therefore, a proper representation of the legitimate range of technically supportable experts are essential during the process of selection of data set, different models and process to be adopted. Keeping this in mind, in the present Seismic Hazard Microzonation study, the PSHA has been carried out in collaboration with an expert institution, IIT Roorkee. To further address these issues several interactive meetings of Seismologist, Geologist, and Earthquake engineers were held at IIT Roorkee and most appropriate, consensus parameters were selected. Seismotectonic Modeling has been carried out using published Seismotectonic atlas by Geological Survey of India (GSI), an expert organization. All innovative techniques have been adopted to address the uncertainties such as Logic tree approach, Monte Carlo approach etc. The results of PSHA have been peer reviewed by way of presentation in Seminar/workshop, publication in research Journals and during the process of evaluation of Ph.D. thesis, as it also form part of the thesis one of IIT, Roorkee student.

2: Interactive session and a lecture of renowned Geologist Prof. S.K.Tondan, the then Pro-Vice Chancellor, University of Delhi held in May 2007 before undertaking geological mapping.

In carrying forward the microzonation to a higher level of precision on 1:10000 scale, it was required to generated base map on the same scale and geologically re-survey the area on new base map (scale 1:10,000). Project specific base map on 1:10000 scale was generated by Survey of India (SoI), representing Delhi in 75 toposheets. The geological mapping of a large urban complex with high scale resolution of 1:10,000 was a challenging and time consuming task. Mapping on such a scale has never been attempted for any of the Indian cities. Moreover, capturing ground geological data due to high density urbanization in Delhi was rendering further difficulty. In view of this an interactive session and a lecture of renowned Geologist Prof. S.K.Tondan, the then Pro-Vice Chancellor, University of Delhi, was arranged in the first week of May 2007 to assess the geological parameters required for Microzonation and innovative techniques to be used to complete the task in a minimum time frame. In this session about 20 Geologist of GSI Lucknow/Faridabad and officials from CGWB, SOI and EREC have participated. Subsequently, a working group consisting of scientists from GSI, Lucknow & Faridabad, Central Ground Water Board (CGWB) Delhi, SOI Delhi and EREC was constituted. The Geological Mapping was carried out in collaboration with Geological Survey of India, a nodal agency of Government of India by constituting two dedicated groups of geologist, one at GSI Faridabad and other at EREC. To minimize the hindering effect of the urban masking in geological data capturing, the field work was supplemented with (i) aerial photo based on old series photography of 1976 generation available with SOI and high resolution remote sensing data of recent origin (ii) extensive probing with exploratory drill holes. The Geological Mapping was completed in 2011.

3: Review Meeting held on 15.11.2007

This meeting was attended by 20 experts from varied disciplines such as Seismology, Geology, Geophysics, Earthquake Engineering, Geotechnical Engineering, and reviewed ongoing work, methodology being adopted and recommended field and laboratory tests to be undertaken through proposed outsourcing at 550 sites.

4: Meetings of Advisory and Monitoring Committee

During the process of Seismic Hazard Microzonation of NCT Delhi and formulation of the report eight meetings of Advisory and Monitoring Committee were held under the Chairmanship of Prof. A.S.Arya. In these meetings committee was continuously monitoring the progress of work, process of data generation, methodology being adopted to generate different components of SHM, and providing technical guidance. Committee was also reviewing the results generated by EREC at different stages. A brief of minutes of these meetings are as follows.

4.1: First Meeting of Advisory and Monitory Committee held on 23rd January 2008

Geological mapping on 1:10000 scale was initiated in collaboration with GSI. In this meeting committee reviewed the progress. In the mean time, it was decided to identify sites for proposed geotechnical and geophysical investigations on the basis of available geological map on 1:25000 scale, which may be reviewed on completion of geological mapping on 1:10000 scale. A subcommittee was also constituted to work out criteria for identification of suitable sites, requisite number of sites required for investigations and resource organizations for undertaking some of the components of work.

4.2: Sub Committee meeting held on 6th October 2008

Subcommittee formulated criteria for the selection of sites. On the basis of available geological map on 1:25000 scale, 567 sites for geotechnical and geophysical investigations were tentatively identified on the map. These identified sites were roughly in a grid of 1.5 X 1.5 km. Resource institutions for measurement of Shear wave velocity using MASW were also identified.

4.3: Second Meeting of Advisory and Monitory Committee held on 24th October 2008

The Second meeting of the Advisory and Monitoring Committee was held on 24th October 2008 and reviewed the recommendations of subcommittee and sites identified for geotechnical geophysical investigations. Progress of work was also reviewed.

4.4: Third meeting of Advisory and Monitoring Committee was held on 19th June 2009.

In this meeting status of outsourced geotechnical, geophysical investigations were reviewed. The observations made by the team of EREC during their field visits, particularly regarding SPT and collection of UDS were discussed and representatives of outsourced agency were suitably advised to strictly follow specified codes/guidelines of the field and laboratory investigations and all precautions should be taken for SPT measurement and collection of Disturbed & Undisturbed Soil samples, their indexing, storing and transporting to labs, as suggested by the team of EREC.

The list of 567 tentative sites for drilling bore holes and geotechnical investigations presented by EREC was further reviewed and decided that, in uniform geology where not many variations are expected in sub surface geology, grid spacing may be increased to 3 X 3 km instead of 1.5 X 1.5 Km" and the sites may be reduced to about 500. On study of the subsurface variations, on the basis of the result of these 500 selected sites, further course of actions will be decided. A criterion for identification of twenty five sites for CHT/DHT has also been worked out. The need of proper supervision during the field investigations and geological logging in the supervision of a geologist was emphasized.

4.5: Fourth meeting of the Advisory and Monitoring Committee was held on 4th December 2009.

In this meeting status of geotechnical and geophysical investigations was reviewed. The issues of deployment of hydraulic drilling machines particularly for Undisturbed Soil Sampling, and difficulty expressed by outsourced agency in arranging large number of such machines was discussed. It was noted that the disturbances may not only be created by the process of collection of soil samples, but disturbances are also added at all further stages of processing, such as during the process of withdrawing sampler from the borehole, packing of sampler, transporting sampler, storing samples, removal of samples from samplers during the process of lab test and preparation of samples during loading on machines for different tests.

In view of this and as BIS code does not specify type of machines to be used, it was decided that however, Hydraulic machines are best suited for the UDS collection at field, but on taking precautions at different stages as listed above even mechanical machines may be used. Representative of outsourced agency present during the meeting were advised to strictly follow these precautions during the operation.

4.6: Field visit of the members of Advisory and Monitoring Committee

In the afternoon of 4th December 2011, Committee members visited field investigations site at Dilshad Garden, where both Hydraulic and Non hydraulic (CAYLEX) Rotary machine were put on operation. Different types of samplers including Piston Samplers to be used during field operation were also demonstrated. Process of SPT and UDS sampling by both the machines were also demonstrated. It was advised that, on taking all the precautions discussed during the meeting both types of machines may be used. Further, Committee members again emphasized that Proper supervision should be made by EREC during field investigations. Outsourced agency was also requested that geological logging should be carried out under the supervision of geologist.

4.7: Fifth meeting of the Advisory and Monitoring Committee held on 13th September 2010

In this meeting Dr. A.K.Shukla, EREC made a presentation on the status of the Seismic Microzonation project particularly on ongoing Geotechnical investigations, which were going in a very slow pace. Dr. Shukla also presented on studies so far carried out by EREC, on the basis of laboratory test results made available by outsourced agencies for review by the committee.

Prof. Sharma, IIT Roorkee made also made a presentation on updated Probabilistic Seismic Hazard Analysis (PSHA) and generated maps. The Salient features of the new study and subsequent generated maps presented by Prof. Sharma are as follows:

1. On the basis of seismotectonic maps and Seismicity four source zone have been considered for the study viz-a-viz (i) Himalayan Source Zone falling within 350 km radius of Delhi (ii) Delhi-Haridwar Ridge, source zone (iii) Moradabad Fault Zone and (iv) Rajasthan Great Boundary Fault zone.
2. New generation attenuation relation has been used for evaluating PGA value at the engineering bed rock level having shear wave velocity about 760 m/second.
3. The 'b' values for the above source zone have been worked out to be (i) Himalayan source Zone0.59±0.03 (ii) Delhi-Haridwar Ridge, source zone 0.42±0.012 (iii) Moradabad Fault Zone and 0.42±0.012 (iv) Rajasthan Great Boundary Fault zone 0.42±0.012.
4. The maximum credible earthquake for these zone have been worked out are (i) Himalayan Source Zone is 7.2±0.37 (ii) Delhi-Haridwar Ridge, source zone is

6.42±0.47 (iii) Moradabad Fault Zone is 6.42±0.47 (iv) Rajasthan Great Boundary Fault zone is 6.42±0.47

5. The mean PGA values estimated for different probability of exceedance and return periods. The PGA values for return period (i) for 475 years varies from 0.09 to 0.16 (ii) for 2500 years varies from 0.18 to 0.31
6. The strong ground motion has been estimated for different periods.

Representative of M/S RITES presented the status of the ongoing Geotechnical study and highlighted the difficulty being experienced in drilling of deep bore hole due to lose strata, collapsing of bore hole which is taking enormous time. An alternate methodology was proposed for deep drilling to reduce the time frame of drilling. They also explained reasons in delay of execution of work and assured that RITES is making all efforts to complete the work.

Representative of M/S Fugro also made a presentation on CHT/DHT project and results. The shear wave velocity shown at ridge observatory sites was quite low. He informed that this point was already raised by EREC and therefore all the data has been reanalyzed and the low velocity is basically due to highly weathered rock. After elaborate discussions following decisions were taken

(1) EREC should intensify analysis efforts and on the basis of data available/ being made available, efforts should be made to present the results of at least about 800 sq.km area by the end of December 2010.
(2) The PGA values particularly for 2500 years return period which varies from 0.18 to 0.31 seems to be very high. Committee requested Prof. Sharma to look in to.
(3) Noting the practical difficulty in deep drilling by conventional method and as PGA values are being made available at the depth level having shear wave velocity 760 m/s, it may not necessary to drill up to bed rock at all proposed sites and therefore, quantum of deep drilling up to the bed rock level having more than 120m may be reduced from 25 drill sites to only to 15 drill sites.

4.8: Sixth Meeting of the Advisory and Monitoring Committee held in second half on 21st November 2011

In the first half on 21st November 20111, a workshop was organized. Prof.A.S.Arya, Chairman, placed his appreciation for completing Seismic Microzonation of NCT Delhi for Northern Delhi and holding workshop/ interactive meet to discuss the products of Seismic Microzonation with user agencies and scientific experts. He expressed his desire that, as recommended in the workshop, EREC may generate a report on completed study and circulate among the users and concern government agencies to initiate modality of implementing the products of Seismic Microzonation in different process of earthquake mitigation strategy.

Status of data geotechnical, geophysical data generation and analysis was reviewed on the basis of presentation made by Dr.A.K.Shukla, and Prof. M.L.Sharma, IIT Roorkee.

In view of the slow process of ongoing geotechnical investigation and possibility of not completing investigations at all proposed sites, committee decided that some of the borehole data collected during the first phase study of 1:50000 scale, from different organizations may be used after re- scrutiny to fill up the gap area.

4.9: Seventh meeting of the Advisory and Monitoring Committee was held on 5th February 2011

Prof.A.S.Arya, Chairman, appreciated the systematic approach being adopted to ensure generation of good quality controlled validated and cross checked data with different approaches for Seismic Microzonation of NCT Delhi on 1:10000 scale, being undertaken by EREC in guidance of the committee.

Dr. A.K.Shukla, Head, EREC presented various product maps generated on 1:10,000 scale, pertaining to identification of engineering bedrock through linearity and modeling of soil column up to engineering bedrock; Site characterization; ground response study and evaluation of amplification factor, Peak Ground Acceleration(PGA); and Liquefaction susceptibility for different depth ranges. The Major issues discussed in the meeting were as follows:

1. Estimation of shear wave velocity through linearity with depth to the Vs of 760m/s was accepted by the committee.
2. Response calculated using Dyne Q, as shown in the meeting, was discussed elaborately and approved by the committee members.
3. Committee had prolonged discussion on the way of interpretation of “Amplification/Amplitude/Amplification factor due to site as well as due to building structure”. Chairman suggested for careful use of these terminologies with proper explanation.
4. Discussion was also held on application of free surface correction and decided that a factor of 2 is to be used for all the sites and results obtained through PSHA should be divided by 2 to bring the result at engineering bedrock level.

4.10: Eight Meeting of extended Advisory Committee held on 6th July 2012,

In order to make use of the Seismic Hazard Microzonation products as per objectives of the study, in design of building codes and land use planning, a suitable strategy need to be worked out. Formulation of strategy for implementation of Seismic Microzonation products, for design of building codes and land use planning, need intensive discussion and may take time. In view of this, to initiate the process of such discussions, Secretary, MoES was of the view that, the process of such discussions may be initiated on the basis of available results even of tentative in nature, so that immediately on completion of study results may be put on use.

In view of the above, a brief report was generated on the basis of available results, consisting of methodology adopted for generating different products, data used, integrated maps of NCT Delhi for different themes, and a set of large scale maps for sheet no 39. An implementation strategy for formulation of building codes, based on present practice (using present BIS code) and land use planning was also drafted and included in the report.

Report was circulated among the members of Advisory and Monitoring Committee, practicing engineers, planners, and officials of MoUD, DDA, CPWD, and Disaster Management of Delhi Government for their comments and was also invited for this extended group of Advisory and Monitoring committee meeting to discuss following issues.

(i) Review of Seismic Microzonation results/products before finalization and printing.
(ii) Review/drafting implementation strategy for incorporating results of seismic microzonation products in building codes and land use planning of NCT Delhi.
(ii) In view that outsourced agency M/S RITES have stooped execution of geotechnical data generation, formulate strategy for data generation of the remaining part of NCT Delhi to complete the study

Some of the important discussion and suggestions made were as follows:

(i) In the present study Maximum magnitude in Himalayan region has been estimated as Mw 7.2 ± .35 considered for deriving Hazard parameters. In view of the scientific prediction of M 8.0, in seismic gap in Himalayan region, some of the members were of the view that maximum magnitude is under estimated. The following explanation given by Dr. M.L.Sharma, the project coordinator of this work component was discussed and accepted.

” In the present study seismotectonic modeling has been carried out considering the sources within 350 km of from Delhi, which cover only part of Himalayan region. Thus the estimated maximum magnitude is not the representative of whole Himalayan region. The maximum magnitude reported in the considered area is Chamoli earthquake of Magnitude 6.8 occurred in 1999. Moreover, results of degradation study shows that earthquakes of higher magnitude occurring beyond considered distance of 350 km may not affect on PGA at Delhi. The frequency contents of such a large distance earthquakes may only affect very high rise structures. The present study is valid only for common buildings up to 20 to 30 stories, as response spectra being provided up to 3 second only”.

(ii) Uncertainty in field operation, particularly collection of SPT ‘N’ values, which are used in deriving shear wave velocities at different depths and is one of the important parameter, generally being done by untrained staff. However, special care has been taken in this project by strict monitoring and supervision.

(iii) There was consensus about the procedures followed in conducting seismic microzonation studies for NCT Delhi and members were of the view that these have been discussed many times at different forum and there is no doubt and/or ambiguity in the processes adopted and described in the report.

(iv) The average shear wave velocity (Vs30) based on CHT results obtained in Ridge area near Seimo observatory Ridge is found to be only 300m/s and based on this Ridge was shown as class 'D'. Obviously, it was surprise for a geologist. However from the fact that (i) the result was repeatedly confirmed from the outsourced agency M/S Fugro, (ii) qualified rock could not be traced even further drilling of several meters, after encountering the rock in that area, (iii) high shear wave velocity at some other parts of exposed ridge, it seems that the exposed ridge may be segmented and quality of rock exposed in ridge area may be different in different segments.

(vii) In view of the outsourced agency stopped execution of contract and some area remains without investigation of proposed number of sites, but noting the uniform geological variation, similarity with areas where analysis has already completed, and absence of special features, which may possibly alter the subsurface features, the data available seems to yield satisfactorily results within the accuracy of engineering requirement, the results presented on extrapolation are seems acceptable. Further, as suggested in earlier meetings old data available with EREC may be re-scrutinized and suitable data may be incorporated for early completion of study. He further suggested that maps may be presented preferably on district wise maps or Sheet wise.

(viii) There should be two types of report – one purely Scientific and other from Engineering and planning point of view, which would give complete guidelines.

(ix) In general members particularly practicing engineers appreciated inclusion of suggested strategy for implementation of Seismic Hazard Microzonation products in land use planning and design of building codes in the report, which seems sufficient to work in this direction. Elaborate discussion took place on how to make use of different products of seismic microznation such as PGA, spectral acceleration, response spectra, peak frequency, liquefaction susceptibility and vertical distribution of PGA etc.

On request of Prof. A.S.Arya, a committee consisting of engineers was constituted to review the chapter of "suggested strategy for implementation of Seismic Hazard Microzonation products in land use planning and design of building codes"

4.11: Meeting of the subgroup committee constituted for further discussion and finalization of "Suggested implication strategy for using Seismic Hazard Microzonation Products" was held on 1st Aug 2012, under the chairmanship of Prof. A.S.Arya.

Members were of the view that it is highly scientific study and large numbers of site specific parameters have been derived, which may have different types of implications in building construction practices. It is good initiative that a chapter has been devoted for actual applications of different parameters derived from the study. Bureau of Indian Standards (BIS) is the national body responsible for drafting building codes. The suggested implication strategy included in the report is presently sufficient to initiate further discussions in BIS committee's to appropriately accommodate Seismic Hazard Microzonation products in BIS code. A few specific comments were made to be incorporated in the report such as identify (a) Areas which will behave as more than zone IV, (b) Areas which will have construction design for less than the effects of Zone IV, and (c) Areas for which one should not go for construction in normal course.

5: A brief on Report of workshop on Seismic Hazard Microzonation of NCT Delhi on 1:10000 scale, held on 21st November 2011, at India International Center, New Delhi

An interactive meet/workshop was organized by Earthquake Risk Evaluation Center (EREC), India Meteorological Department (IMD), on 21/11/2011, at India International Center, (IIC), New Delhi to discuss the results of Seismic Hazard Microzonation of NCT Delhi on 1:10000 scale among user agencies, engineers and scientific experts, before being finalized and published. In this workshop scientist and Engineers from different institutions and organizations such as IIT's, Universities, Central Public Work Department (CPWD), Delhi Development Authority (DDA), and Municipal Corporation of Delhi (MCD) etc had participated. The workshop was inaugurated by Prof. A.S.Arya, former National Seismic Advisor of Government of India, presently and Member of Bihar State Disaster Management Authority (BSDMA). Other members of the Advisory and Monitoring Committee of Seismic Microzonation of NCT Delhi were also participated in this workshop. The technical session of the workshop was chaired by Prof. S.K.Nath, IIT Khargpur and Co-chaired by Er. G.R. Siromani, Chief Engineer, Delhi Development Authority (DDA). Two presentations were made in this workshop and followed by panel discussion.

The first presentation was made by Prof. M.L.Sharma, Department of Earthquake Engineering, Indian Institute of Technology, Roorkee on Probabilistic Seismic Hazard Analysis for NCT Delhi. In his presentation Prof. Sharma elaborated detailed methodology adopted for probabilistic seismic hazard, data used, and earthquake source considered for the analysis. He also presented different steps of the study such as generation of earthquake catalog, treatment on this catalog, magnitude homogenization, evaluation of completeness of data, use of different predictive attenuation relation and process of map generation. The maps generated on the basis of analysis and presented by Prof. Sharma are as follows.

1. Probabilistic Seismic Hazard Map of different probably of exceedance at engineering bedrock level
2. Uniform Hazard Response Spectra (UHRS) for different probably of exceedance at engineering bedrock level at several sites of NCT Delhi.

The second presentation was made by Dr. A.K.Shukla, Head, EREC, on ground response analysis. He informed that project specific base and Geological maps on 1:10000 scale in which Delhi has been represented in 75 sheets form the basic requirement of the study and were generated in collaboration with expert organizations Survey of India (SoI) and Geological Survey of India (GSI) respectively. In his presentations Dr. Shukla, covered different steps involved in the study, such as free surface correction, generation of engineering compatible site specific earthquake time histories at engineering bed rock based on UHRS generated from the first part of the study, delineation of engineering bed rock, Shear wave velocity evaluation through different techniques such as MASW & SPT 'N' values, site classification, site response study using equivalent –Linear analysis technique & parameters required for the analysis, generation of site specific Response spectra, and Liquefaction study etc. He also made presentation on criteria used for selection of sites for geotechnical/geophysical and other investigations. He informed that about 500 sites geotechnical investigation, at 25 sites CHT/DHT and about 100 sites MASW investigations are being carried out. Presently based on investigations completed so far, Seismic Hazard analysis for an area of about 700 sq km covering North Delhi has been carried out. On the basis of completed study following maps of North Delhi were generated and presented in the workshop.

1. Documentation map showing locations of different type of Geotechnical/Geophysical investigations planned at NCT Delhi.
2. Geological Geomorphological map of NCT Delhi
3. Peak Ground Acceleration (PGA) map at bed rock after necessary correction on the map generated and presented in the first presentation
4. Engineering bedrock depth map for north Delhi.
5. Amplification map for north Delhi.
6. Peak frequency map for north Delhi.
7. Peak Ground Acceleration (PGA) map at Surface for north Delhi.
8. Map embedded with Acceleration response spectra generated at 25 sites spread over NCT Delhi, where in-situ shear wave velocities have been evaluated using CHT techniques .
9. Map of north Delhi embedded with average acceleration response spectra for each toposheets consisting of about 25sq km area
10. Spectral Acceleration map of 10% probability of exceedance in 50 Years for different time periods (0.1S, 0.3S, 0.5 S, 1.0Seconds etc corresponds to differ heights of buildings) for north Delhi.

11. Liquefaction potential map for different depth level (0-3m, 3-6m,6-9m,9-12m bgl) based on Factor of safety for north Delhi.

These maps were also displayed in the conference hall for easy visualization and discussion.

Participants were very excited to see the products of Seismic Microzonation study on such a large scale, providing site specific seismic earthquake loading parameters. Participants were trying to understand & discussed efficacy of each and every site specific parameters, as most of the participants involved in building design and construction practices were presently convergent to use of uniform Seismic loading parameters for entire area as provided in building code.

After presentations and discussion on outcome of the study and generated maps panel discussion took place. After elaborate discussion, participants were of the view that seismic microzonation products which have been presented in the workshop are very important and need to be incorporated in the BIS code. However, as presently uniform Seismic Loading parameters are being used for building design, therefore a methodology need to be formulated to make use of site specific parameters.

Following specific comments and points were raised by Prof Arya and other participants.

(i) From the study it seems that however, PGA is maximum at the surface, but major increase in PGA starts from depth of 9-12 meters bgl and above. In view of the fact, as presently buildings are constructed 3 levels below the ground surface, with foundation nearly about 9-12 m beneath the ground, design engineers may therefore think of making use of PGA values at the level of foundation depth, which may substantially reduced the seismic loading parameter required for designing of the buildings.

(ii) In view of the above, he expressed the need of generation of soil columns and corresponding amplification and response spectra, so that application may become simpler for the Engineers.

(iii) Considering the seismic microzonation products as standard and requirement for better design, a strategy need to be worked out for incorporating these results/ products in building codes.

(iv) It has also been felt that field practices of geotechnical investigations need to be improved and extensive check list for field supervision need to be developed and incorporated in respective codes.

5.1: Recommendations of the Workshop:

1. Based on completed study, Earthquake Risk Evaluation Center, India Meteorological Department may finalize the report of North Delhi and supplement the report with proposed methodology of implementation. The report may be provided to different stake holders such as Delhi Government, Ministry of Urban Development, and Bureau of

Indian Standard to initiate further discussion to formulate methodology for incorporating results in building codes and strategy of implementation.

2. Ministry of Urban Development may be requested to constitute a national level committee consisting of expert from different stake holders to discuss the products of the report and formulate strategy of implementation of seismic microzonation products in national level.
3. The study of remaining part of Delhi may be completed on priority.
4. Seismic Microzonation Study need to be taken up for cities lying in high hazard seismic zones.

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Annexure-III

LIST OF PARTICIPANTS IN MONITORING AND REVIEW PROCESS OF SEISMIC HAZARD MICROZONATION OF NCT DELHI ON 1:10000 SCALE

S.No.	Name	Organization from
1.	Prof A.S. Arya,	Former Seismic Advisor, Govt. of India, presently Hon’ble Member Bihar State Disaster management Authorty & Chairman Advisory and Monitoring Committee of Seismic Hazard Microzonation of Delhi
2.	S.K.Tondan,	Then Pro-Vice Chancellor, University of Delhi,
3.	AVM(Dr). Ajit Tyagi	Then Director General of Meteorology, India Meteorological Department
4.	Dr. L.S.Rathore	Director General of Meteorology, India Meteorological Department
5.	Prof. D.K.Paul	Former Professor & Dean Department of Earthquake Engineering, IIT, Roorkee and presently Scientist Emetrous, IIT, Roorkee & Chairman, BIS committee. Member, Advisory and Monitoring Committee of SHM of Delhi
6.	Prof. T. G. Sitharamm	Civil Engineering Department, Indian Institute of Science, Bangalore and Member Advisory & Monitoring Committee of SHM of Delhi
7.	Prof. S.K.Nath	Department of Geophysics , IIT Khargpur and Member Advisory & Monitoring Committee of SHM of Delhi
8.	Dr. Prabhas Pandey	Former Additional Director General, GSI, Kolkatta and Member Advisory & Monitoring Committee of Seismic Hazard microzonation of Delhi
9.	Dr.B.K.Bansal	Advisor, Ministy of Earth Sciences and Member Advisory & Monitoring Committee of Seismic Hazard microzonation of Delhi
10.	Shri A.K.Bhatnagar	Former Additional Director General, IMD, and Member Advisory & Monitoring Committee of Seismic Hazard microzonation of Delhi
11.	Prof M.L. Sharma	Department of Earthquake Engineering IIT Rookee, Project Director, PSHA, and Invitee Member Advisory & Monitoring Committee of Seismic Hazard microzonation of Delhi
12.	Er. Mahendra Raj	Architectural Engineering, Head, MRC & Former President of IAstructE
13.	Prof. C.S.Dube	Department Geology, University of Delhi, Invitee

		Advisory & Monitoring Committee of Seismic Hazard microzonation of Delhi
14.	Dr.A.K.Shukla	Head, Earthquake Risk Evaluation Center and Member/Secretary, Advisory & Monitoring Committee of Seismic Hazard microzonation of Delhi
15.	Smt. Binu Manghat	Superintend Surveyor, Survey of India (SOI), New Delhi and Representative of SoI in Advisory & Monitoring Committee of Seismic Hazard microzonation of Delhi
16.	Shri Bed Prakash	Survey Officer, Survey of India (SOI), New Delhi and Representative of SoI in Advisory & Monitoring Committee of Seismic Hazard microzonation of Delhi
17.	Shri M.Kanwar	Representative of CGWB in Advisory & Monitoring Committee of Seismic Hazard microzonation of Delhi
18.	Dr. Y B Kaushik	Scientist-D & officer-in- Charge, CGWB, Jamnagar House, New Delhi.
19.	Dr. Sailesh Kumar Agrawal,	Executive Director, (Building Material and Technology Promotion Council(BMTPC), New Delhi
20.	Dr. A.K.Dhawan	Then Director, Center of Soil and Material Research Station, (CSMRS), New Delhi
21.	Er. G.R. Shiromini	Chief Engineer Delhi Development Authority (DDA), Vikas Sadan New Delhi-23
22.	Shri S.B.Khodankar	Director,(Planning),Master Plan, Delhi Development Authority (DDA), New Delhi
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