Preface and Executive Summary

Quantifiable threat to human lives and properties due to a natural or man-made phenomenon is referred to as hazard that in conjunction with vulnerability represents the possible risk. Thus, hazard is mainly controlled by the environmental setting and the risk is primarily influenced by socio-economic and demographic variable. The difficulties associated with hazard and risk management are mostly due to inherent unpredictability of the hazard and the dearth of outright absence of damage statistics in many jurisdictions across India. The challenges of disaster management dominantly lies in the rampant utilization and manipulation of natural resources, lack of proper guidelines, economic conditions, inadequate capacity and non-obligatory regulations. Various governmental, non-governmental and private organizations form the core of the management process that should address (1) a focus on pre-disaster actions, (2) hazard mitigation consideration for development projects, (3) common information requirements, (4) long-term mitigation, (5) vulnerability of lifeline infrastructure, (6) information for hazard management practitioners, (7) participation of local communities, (8) incorporation of updated knowledge in post-disaster reconstruction activities, and (9) awareness.

India, with its unique geological setting and socio-economic conditions is highly vulnerable to disasters. The subcontinent has a complex geological and tectonic setting that consists of Precambrian cratons of Archean age and rift zones filled with Proterozoic and Phanerozoic sediment. The Indian subcontinent can be divided into three main sub-regions spread over 3.2 million km^2 based on the geologic and tectonic regime namely: (i) The Himalayan frontal arc in the north, which results from the Mesozoic subduction and the collision between the Indian and Eurasian plates. The great Himalayan arc extending from north-west to the Arakan-Yoma mountain ranges covering a distance of 2500 km, (ii) The Indo-Gangetic plains, which are located between the abruptly rising Himalayas in the north and the Indian Peninsula in the south, and which extend from east to west. The sub-region is formed by the vast alluvial plains in the north along the basin of river Ganges and Sindhu (Indus), and (iii) The Indian Peninsula in the south, which comprises the Indian Shield with the Deccan Traps and the Dharwar cratons, all of these being highly seismogenic. Seismic vulnerability in India is well evidenced by numerous past earthquake-related calamities. According to the vulnerability atlas of India prepared by Building Materials and Technology Promotion Council (BMTPC), more than 59% of the total land-cover in the country is susceptible to seismic hazard.

West Bengal has been no exception so far as sufferings inflicted by natural and man-made hazards are concerned. The State has been frequented by cyclones, floods, droughts, landslides, subsidence, and occasional earthquakes. Progressive trends of any region are controlled to a large extent by the requirements of the inhabitants, agriculture, industries, transportation, communication, education, and culture, which generally form the vulnerability attributes. Because of the high population density and concentration of industrial and agricultural activities across West Bengal, risk or vulnerability to natural or man-made disasters are particularly high. With increasing developmental activities in high hazard zones, *e.g.* the coastal regions, the vulnerability scenario appears to be worsening with time. The State of West Bengal, covering an area of 88,752 km^2 is located in the western foreland of the Assam Arakan orogenic belt, Himalayan foothills and Surma Valley. The Bengal fan basin which was predominantly considered seismically stable is identified with sparse seismicity. However occurrence of the devastating earthquakes *viz.* 1897 Great Shillong Earthquake of M_w 8.1, 1950 Assam Earthquake of M_w 8.7, 1934 Bihar-Nepal Earthquake of M_w 8.1, 1964 Sagar Island Earthquake of M_w 5.4, and recent 2011 Sikkim Earthquake of M_w 6.9 in and around the region has made the province seismically vulnerable. Historical records also indicate that this region is prone to damages due to moderate to large earthquakes.

The city of Kolkata, the State Capital of West Bengal is one of the most urbanized and densely populated regions in the world and a major industrial & commercial hub of the eastern & northeastern region of India which has developed primarily along the eastern bank of the River Hooghly about 150 km north of the Bay of Bengal, right over the Ganges delta in the Bengal Basin, a huge pericratonic Tertiary basin. The major tectonic framework of Eocene Hinge Zone, Main Boundary Thrust (MBT), Main Central Thrust (MCT), Main Frontal Thrust (MFT), Dhubri Fault, Dauki Fault, Oldham Fault, Garhmoyna–Khandaghosh Fault, Jangipur-Gaibandha Fault, Pingla Fault, Debagram-Bogra Fault, Rajmahal Fault, Malda-Kishanganj Fault, Sainthia-Bahmani Fault, Purulia Shear Zone, Tista Lineament, and Purulia Lineament in an around Bengal Basin as well as the Bihar-Nepal seismic zone, Assam Seismic Gap, Shillong Plateau, and the N-E Himalayan extent posing seismic threat to West Bengal and its capital city of Kolkata.

The fatalities due to earthquakes and environmental disaster in terms of collapse of building and infrastructure, disruption in economic productivity, human resettlement can be reduced by long term prevention policy *viz.* (a) Assessment of Seismic Hazard and Risk, (b) Implementation of safe building construction codes, and (c) strategy for land-use planning considering seismic hazard. Seismic hazard, in a broad perspective, refers to any kind of phenomena related to earthquakes capable of imparting potential damages to the built and social environment. It is, therefore, necessary to predict ground shaking levels to facilitate building codal-provisions for earthquake-resistant design of structures. This involves extensive analyses towards the development of appropriate seismological models namely seismogenic sources, seismic site conditions, and ground motion predictions. The hazard products, *viz.* data and maps, constitute important tools for framing up public policies towards land-use planning, building regulations, insurance, and emergency preparedness. Seismic microzonation and risk endeavor is one such strategy which is undertaken to assess the likely effects of earthquakes on urban centers as site specific implications towards earthquake inflicted disaster mitigation and management.

A synoptic probabilistic seismic hazard model of West Bengal and Kolkata have been developed considering 33 polygonal seismogenic sources at two hypocentral depth ranges: 0-25 km and 25-70 km based on seismicity patterns, fault networks and similarity in the style of focal mechanisms; 158 active tectonic sources (faults/lineaments) extracted from seismotectonic map of India and additional from Landsat^{TM}/MSS & SRTM data through edge enhancement filtering & principal component analysis which have the potential of generating earthquakes of M_w 3.5 and above; appropriate seismicity analysis using a homogeneous earthquake catalog in M_w scale; 14 Ground Motion Prediction Equations (GMPE) including 6 Next Generation Attenuation (NGA) models for three seismotectonic provinces *viz.* Bengal Basin, East Central Himalaya and Northeast India selected through suitability tests and fixing appropriate weights in a logic tree framework. The contribution of background seismicity in the hazard perspective is estimated using smoothened gridded seismicity models at a regular grid interval of 0.1° for the threshold magnitudes of M_w 3.5, 4.5 and 5.5 respectively at both the hypocentral depth ranges 0-25 km and 25-70 km. It is seen that at the threshold magnitude 3.5 patches of stress concentration in terms of clustered activity rate are within the Bengal Basin itself, while at higher threshold magnitudes, maximum stress accumulation is seen to occur in the Northeast and Northwestern part of West Bengal. At higher hypocentral depth range *i.e.* at 25-70 km the stress is seen to accumulate in the Arakan Yoma subduction belt as the activity rate concentration is high there. The ground motion parameters at a site of interest are evaluated by using a ground motion prediction equation that relates a specific strong motion parameter of ground shaking to one or more seismic attributes through a nonlinear regression analyses performed for different shaking parameters Y (*i.e.* PGA/ PSA at different periods) by least square error minimization for the estimation of the coefficients of Next Generation Attenuation (NGA) models using the strong ground motion data base comprising of seismic events of small to moderate magnitude recorded by the Darjeeling-Sikkim Strong Motion Network (DSSMN) of IIT Kharagpur, PESMOS of IIT Roorke, IIT Guwahati Strong Motion Network in the Northeast India region and the IIT Kharagpur Broadband Seismological Observatory amalgamated with the simulated ones. The probabilistic seismic hazard analysis involves computation of ground motion thresholds which are exceeded with a mean return period of 475 years/2475 years at a particular site of interest combining the effects of all the earthquakes of different sizes occurring at various locations for all the seismogenic sources at various probabilities of occurrences integrated into one curve that depicts the probability of exceeding different levels of a ground motion parameter at the site during a specified time period. Therefore, an attempt has been made to generate the Probabilistic Hazard scenario in the province for both 2% and 10% probability of exceedance in 50 years. The PGA distribution across the State of West Bengal for 2% probability of exceedance in 50 years varies from 0.17g to 0.83g. The estimated maximum PGA of 0.83g is associated with Darjeeling and Northern part of West Bengal region. Furthermore it has been observed that the regions in and around Raiganj, Malda, Purulia and Bankura exhibits relatively higher hazard. The 2% Probability of exceedance in 50 years is generally considered to replicate Deterministic seismic scenario of the region. The PSA distribution for short period at 0.2 second varies from 0.33g to 1.60g while for longer period spectral acceleration at 1.0 second varies from 0.07g to 0.39g. The PGA distribution for 10% probability of exceedance in 50 years shows a variation from 0.10g to 0.44g for the entire West Bengal region. The State capital Kolkata shows a hazard variation from 0.109g to 0.151g. The PSA at 0.2 sec exhibits a variation from 0.21g to 0.85g while for 1 sec it ranges from 0.03g to 0.19g. The 5% damped design response spectra have also been estimated using PSA at 1.0 and 0.2s with 10% probability of exceedance in 50 years following the International Building Code.

The surface geology and soil condition at a site have significant effects on the level of ground shaking which necessitates performing site characterization of any region. The site characterization attribution requires (i) precise geomorphologic definition of the terrain, including the lithological characterization and sediment classification, (ii) in-depth surface geophysical and geotechnical investigations for shallow shear wave velocity estimation and site classification following the NEHRP, USGS and FEMA nomenclature, (iii) site response analysis through a 1-D sediment column and performing equivalent linear analysis of an otherwise nonlinear system through DEEPSOIL, and (iv) assessment of Liquefaction Potential Index from insitu borehole geotechnical data and SPT-N value/shear wave velocity profiles. Geomorphologically, Kolkata is a typical deltaic flat land with surface elevation ranging between 5.5 m and 9.5 m above m.s.l sloping mostly southwards. The deltaic plains, interdistributary marshes, palaeochannels, younger levees adjacent to the River Hoogly and older levees on both the sides of the old Adi Ganga are the important geomorphological units present in Kolkata. All the geomorphological units in the region have potential of liquefaction susceptibility during strong seismic shaking. Effective shear wave velocity (V_s^{30}) for 30 m soil column is used for site characterization of the terrain derived from both the geophysical and geotechnical investigations at 654 boreholes, MASW survey along 85 profiles, Microtremor survey at 1200 locations and 18 insitu Downhole survey in the City. The nonlinear regression analysis has established relations between the corrected SPT-N values and the 1-D shear wave velocity (V_s) profiles derived from downhole seismic tests for various subsurface litho-stratigraphic units. These in turn are used for calibrating MASW generated surface consistent shear wave velocity profiles turning those into pseudo-insitu shear wave velocities as would have been obtained through downhole seismic survey at those locations which eventually benchmark the inverted HVSR driven 1-D shear wave velocity profile and thus assesses effective V_s^{30} for site classification purposes in the city of Kolkata. The Horizontal-to-Vertical (H/V) response spectra reflecting the fundamental site frequency have been estimated at 1200 locations through microtremor ambient noise survey. The Site classification of Kolkata performed based on NEHRP, USGS and FEMA regulations places the City in D1 (V_s^{30}: 320-360 ms^{-1}), D2 (V_s^{30}: 320-280 ms^{-1}), D3 (V_s^{30}: 280-240 ms^{-1}), D4 (V_s^{30}: 240-180 ms^{-1}) and E (V_s^{30}: <180 ms^{-1}) classes. Some patches of E site class whichever have shown the tendency of liquefaction under seismic excitation is further reclassified into F site class. The nonlinear effect of the alluvial soil on the propagated ground motion is measured by Amplification spectra which are considered as one of the governing factors in the design of new structures and performance assessment of the existing ones. Using the input time series obtained from stochastic simulation of both the near- & far-source earthquakes at engineering bedrock and 5% damping of all soil types, both the predominant frequency and site amplification at each of the 1957 locations in the City is estimated as the ratio between the Fourier spectra at the rock to the soil. Site Class E mostly comprising of soft sediment is seen to be associated with a predominant frequency of 0.6-1.7 Hz and an average site amplification factor of 4.5. Site Class D4 is associated mostly with a predominant frequency of 1.0-2.25 Hz and an average amplification factor of 3.9. Site Class D3 is seen to have an excitation predominant frequency of 1.2-2.5 Hz and an amplification factor of 3.4. The predominant frequency for Site Class D2 lies in the range of 1.4-3.9 Hz with a site amplification factor of 2.8, Site Class D1 is seen to be associated with highest predominant frequencies in the range of 1.9-4.42 Hz and an average amplification factor of 2.3. Site coefficients in terms of both short-period (0.1 to 0.5 sec) and mid-period (0.4 to 2.0 sec) *viz.* F_a and F_v are quantified for the design response spectra of buildings and urban infrastructures. For Site Class D1: F_a<1.87 and F_v<1.67 while for Site Class D2, F_a varies in the range of 2.06-1.873 and F_v varies in the range of 1.79-1.67. In the Site Class D3 both F_a and F_v vary in the range of 2.28-2.06 and 1.95-1.79 respectively. The same in the Site Class D4 are 2.78-2.28 and 2.26-1.95 respectively. In the Site Class E both F_a and F_v are >2.78 and >2.26 respectively. The variation in PGA for 10% probability of exceedance in 50 years at surface level depicts a range of 0.14g to 0.34g in the City. Shepard's diagram of the City's subsurface exhibit highly liquefiable sediments *viz.* sand, sand-silt clay, sandy clay, silty sand and silty clay upto about ~5 m which in contact with the shallow groundwater fluctuations is expected to trigger soil liquefaction under earthquake loading and is, therefore, considered an integral part of site characterization for the City.

Soil liquefaction is a secondary phenomenon triggered by a large earthquake in an alluvium filled terrain like Kolkata which causes increase in pore water pressure resulting in the reduction of shear strength of soil when monotonic, cyclic or shock loading is applied. The subsurface stratigraphic sequence underlying the city of Kolkata is composed of potentially liquefiable alluvial fan deposits of Ganga-Bramhaputra river system containing varying amount of clay, silt, sand, and gravel inter-bedded with decomposed wood and peat. Considering the favorable geological, geomorphological & hydrological conditions, an attempt has been made to create liquefaction hazard scenario for Kolkata city due to the occurrence of near-and-far source earthquakes. Therefore, stochastically synthesized ground motion of the considered earthquakes convolved with local site effects generated peak ground acceleration (PGA) at surface level which triggers soil liquefaction measured in terms of Factor of Safety (FOS) and Probability of Liquefaction (P_L) for each litho-stratigraphic stratum while the Liquefaction Potential Index (LPI) and Liquefaction Risk Index (I_R) are assessed for the entire soil column. The spatial distribution of Liquefaction Potential Index (LPI) providing the liquefaction susceptibility map of Kolkata due to 1934 Bihar-Nepal Earthquake of M_w 8.1 categorized LPI values in four sub-classes: Low Susceptibility (LPI=0), Moderate Susceptibility (0<LPI≤5), High Susceptibility (5<LPI≤15) and Severe Susceptibility (LPI>15) which places the patches in Eastern and Central Kolkata encompassing parts of Rajarhat and Gobra in Severely liquefaction susceptible zone with LPI value greater than 15, while majority of the Northeastern and Eastern regions *viz.* Saltlake, Niccopark, New Town, Baguiati, Baubazar, Dhapa *etc.* are in the Highly Liquefaction Susceptible Zone (5≤LPI<15). Patches of Highly Susceptible Liquefaction Zone have also been observed in Central, Southwestern and Northern regions encompassing Belur, Thakurpukur, Teghari *etc.* leaving the rest of the City to be associated with Low to Moderate Susceptibility Zone (0<LPI≤5). The spatial distribution of Liquefaction Potential Index (LPI) provides the liquefaction susceptibility mapping of Kolkata due to 1897 Shillong Earthquake of M_w 8.1, which places Dhapa in Severe liquefaction zone (LPI>15), on the other hand, parts of Saltlake and Dhapa are in the High liquefaction zone (5<LPI≤15) and Beliaghata, Jagtala, Paikpara are in the Moderate liquefaction zone (0<LPI≤5), the rest of the City falls in Low Liquefiable zone (LPI=0) for this earthquake. A deterministic liquefaction susceptibility scenario of the City created with PGA at 10% probability of exceedance in 50 years at the surface consistent level with a mean magnitude of M_w 6.8 (for MSF calibration) expectedly generated a high liquefaction hazard zone at the depth range of 5-10 m due to the presence of coarse grained sediments *viz.* sand, silty sand, clayey silty sand and shallow ground water conditions. The Liquefaction Risk Mapping of the City for the surface level PSHA scenario with a return period of 475 years exhibited regions at Extreme risk (I_R>30), High risk (20<I_R≤ 30) and Low risk (I_R<20) to soil liquefaction. It is seen that extremely high risk zones encompass the Northeastern and Southeastern parts of the City along with parts of Central Kolkata and a small patch of the Southwestern corner of the City. The rest of the City is at High liquefaction risk except for the two patches of Low risk areas in Northern and Southwestern corners of the City.

Seismic hazard microzonation has emerged as an important issue in high-risk urban centers across the globe and is considered an integral part of earthquake-related disaster mitigation practices. The holistic seismic hazard microzonation mapping achieved through Multi-criteria based decision support system formulated as Analytical Hierarchal Process (AHP) incorporates all the hazard themes *viz.* (i) Surface consistent Peak Ground Acceleration with 10% probability of exceedance in 50 years, (ii) Liquefaction Potential Index, (iii) NEHRP Site Class, (iv) Sediment Class, (v) Geomorphology, (vi) Geology, and (vii) Ground Water Table materialized on the GIS platform. The pair wise comparison matrix is used to derive the individual normalized weights of each element. The weights of each criterion are calculated by summing up all the ratios in the relative matrix column and then dividing each element in the matrix by its column total to generate a normalized pair wise matrix, and then the weighted matrix is generated by dividing the sum of the normalized row by the number of criteria used. Thereafter, the corresponding weights, the ranks of each thematic layer, and the theme attribute score are assigned according to the apparent contribution of the layers to the overall seismic hazard. All the georeferenced thematic layers are integrated using the aggregation method in GIS to generate a Seismic Hazard Microzonation (SHM) map of the entire city which is holistically microzoned into 'Severe' in Saltlake, New Town areas, 'High' mostly in Barabazar, Anandapur, Belgachiya, Bagdoba areas of the expanding City, 'Moderate' in most parts of South and West Kolkata and Low zones. The predictive power of the final integrated weight map has been tested by analyzing the success rate curve and R-Index. SHM generated in this study exploit the R-index method to assess the relationship between the hazard index and the reported damage sites. It is seen that R-index increases with the level of hazard index thus indicating consistency in the hazard levels.

Unplanned urbanization defying building codes are continuously increasing the earthquake vulnerability of Kolkata, necessitating systematic assessment of seismic vulnerability by identifying those factors contributing to seismic risk in terms of socio-economic and structural aspects. To understand the vulnerability of the built-up environment and infrastructure, a spatial/non-spatial database of building typology, building height, building age, land use/land cover, population density and lifeline utilities has been created. These earthquake risk elements have been studied for different vulnerability levels on being exposed to seismic hazard in the seismic risk microzonation perspective. Vulnerability index of various factors is calculated by defining an ordinal scale; overall vulnerability index maps of the study region have been prepared representing both the socio-economic and structural entities. In the present study, the structural and socio-economic vulnerability exposures derived from satellite imagery in case of building typology and landuse/landcover and that generated from Google Earth 3-D aspect for building height are used as "classified" data, while those derived through rapid visual screening from 1200 survey locations being considered as "reference" data have been used for the accuracy assessment of all the themes. In the present investigation, AHP is used for the estimation of weights of various factors of vulnerability exposures for the computation of risk index in an attempt to generate a multi-criteria risk evolution protocol in both the socio-economic and structural perspectives. The Socio-economic risk elements i.e. Population Density (PD) and Landuse/Landcover (LULC) are overlaid on the Seismic Hazard Microzonation (SHM) themes on GIS and integrated to demarcate the most vulnerable zones in the view of socio-economic activities of the region. Four broad divisions of Socio-Economic Risk Index (SERI) have been identified in Kolkata with Risk Index (SERI) defined as $0.75<\text{SERI}\leq 1.0$ indicating severe risk condition in BBD Bag, Saltlake, Kalidaha, Barabazar, Baguiati areas, $0.50<\text{SERI}\leq 0.75$ indicating high risk mostly in central Kolkata, $0.25<\text{SERI}\leq 0.50$ moderate risk in most part of West Kolkata, while $\text{SERI}<0.25$ presents a completely risk free regime. On the other hand, the structural risk (SR) elements namely Building Typology (BT), Building Height (BH) and Building Age/growth (BA) have been overlaid and integrated with the SHM depending on their contribution to seismic vulnerability to identify the most vulnerable buildings along with the seismic risk associated with those and suggest appropriate preventive measures. Four broad divisions have been identified in the City with Structural Risk Index (SRI) defined as $0.75<\text{SRI}\leq 1.0$ indicating severe risk condition in Saltlake, Park Street, Barabazar, Baguiati areas, $0.50<\text{SRI}\leq 0.75$ indicating high risk mostly in Behala, Dum Dum, Alipur, Jadavpur, Dhakuria regions, $0.25<\text{SRI}\leq 0.50$ moderate risk mostly in Bali, Kona, Kalighat and part of West Kolkata, while $\text{SRI}<0.25$ presents a completely risk free regime.

The probability of damage in each seismic hazard zone is estimated in relationship with a given ground motion parameter to evaluate the building performance for a particular seismic event in an open-source seismic risk assessment tool like SELENA which follows the computation protocol of HAZUS considering the model buildings typologies *viz.* A1, RS2, C1L, C1M, C1H, C3L, C3M, C3H, URML, URMM, HER and their capacity curves. The demand spectrum curve of a spectral acceleration which is defined as a function of spectral displacement, spectral response at the fundamental periods of 0.3 and 1.0 sec through a judicious interaction with the building capacity curve and fragility curve yields the damage state probability in terms of slight, moderate, extensive and complete hazard. In the present investigation, human casualty levels have also been computed based on SELENA methodology for three different times *i.e.* Nighttime (at 02:00 am), Daytime (at 10:00 am) and Commuting time (at 05:00 pm).The economic losses for building repair (mostly for damage states: slight and moderate) and replacement (mostly for damage states: extensive and complete) have been estimated based on the construction cost of building floor area (per m^2) for eleven different model buildings available within 300 socio-economic clusters in Kolkata. HAZUS has also been used to estimate the damage and loss associated with the essential facilities, transportation network and emergency services in the City.

A new perspective of multi-criteria holistic seismic hazard, vulnerability and structural aspects of Kolkata have been presented in this Atlas. The seismic hazard, vulnerability, risk, damage and economic loss scenario for Kolkata may be used for land use planning and up-gradation of seismic building codal provisions. The emergency response capabilities can be significantly improved to reduce casualties by permitting rapid, selective and effective use of provided resources. The architects and civil engineers may also use this information to assess the failure risk of the existing structures and to design future earthquake resistant structures.

This mammoth "**Seismic Microzonation**" Project for the city of Kolkata under the aegis of the Geoscience Division, Ministry of Earth Sciences, Govt. of India has been supported by the Ministry itself vide sanction order no. MOES/P.O.(seismo)/1(60)/2009. I am indebted to Dr. Shailesh Nayak, then Secretary and now a Distinguished Scientist at MoES and Dr. B. K. Bansal, Advisor and Head, Geoscience Division of MoES for their enormous support, continuous monitoring, guidance and constructive suggestions during the progress of the project. The animated discussions with Dr. O. P. Mishra, Dr. S. Chopra, Dr. Arun Gupta and the members of the PAC and GMC of Seismicity Program of the Ministry of Earth Sciences helped in maintaining the quality of data acquisition and processing of the same and the smooth execution of the project. The colleagues collaborating from West Bengal Council of Science & Technology, Jadavpur University, Indian Institute of Engineering Science & Technology, Shibpur, IIT Kharagpur and the Center for Ground Water Studies, Kolkata participated at various stages of the project. The enormous support received for the smooth execution of the project from the Department of Disaster Management and Civil Defence, Government of West Bengal, especially from Janab Javed Ahmed Khan, the Hon'ble Minister-in-Charge of the Department and the said Ministry is thankfully acknowledged. The Hon'ble Minister took personal interest in the project and kept in constant touch with the Principle Investigator Prof. Nath. Dr. D. R. Nandy, Ex. GSI Director advised in the earlier conceived pilot project for the Geotechnical bench marking effort of the city of Kolkata at a small ward level investigation. Shri Sujit Dasgupta, Ex. DDG, GSI helped us through simulated discussions at various stages of the project. Prof. Santanu Bhanja, National Institute of Technical Teachers Training and Research Institute, Kolkata and Er. Indrajit Chowdhury, IIEST, Shibpur made several useful suggestions for probable mitigation of seismic hazard and risk of the city of Kolkata.

The data support and assistance received from Paras Equipments & Engineering Pvt. Ltd., New Delhi, Drilltech Consultant Pvt. Ltd., Kolkata, C.E. Testing Company Pvt. Ltd., Kolkata, Geological Survey of India, Kolkata Metropolitan Development Authority, Kolkata Municipal Corporation, Kolkata Metro Railway, Central Ground Water Board, Kolkata Metro Rail Corporation Ltd. and NATMO is thankfully acknowledged. All the participating Students, Research Fellows, Project Assistants and Scientists have put forth tremendous efforts in data acquisition in a three yearlong Geophysical and Geotechnical field investigations in Kolkata in very hostile climatic conditions and also in the processing of the huge volume of data that facilitated the accomplishment of all the project objectives successfully within the stipulated time frame of the project. I would finally acknowledge the support received from the subsequent Directors of the Institute, subsequent Deans of Sponsored Research and Industrial Consultancy Cell of the Institute and the subsequent Heads of the Department of Geology and Geophysics in the smooth execution of this gigantic endeavor continued over a span of four years and a half. My family stood by me during this period of exhaustive investigations as it had always been doing so in the past.

Prof. Sankar Kumar Nath
Department of Geology and Geophysics
Indian Institute of Technology Kharagpur
Kharagpur Technology – 721302,
Midnapore (west), West Bengal,
nath@gg.iitkgp.ernet.in
nathsankarkumar@gmail.com
Cell# 9734634942, 9434005953