Abstract

India, with its unique geological setting and socio-economic conditions is highly vulnerable to Natural disasters. According to the Vulnerability Atlas of India prepared by BMTPC, more than 59% of the total land-cover in the country is susceptible to seismic hazard of which 30% is falling in Seismic Zones III, IV and V. The Seismic Risk Map of the subcontinent developed in the present study by integrating the vulnerability elements, *viz.* population density and Landuse and Landcover, Building rural wall, Building rural Roof, Building urban wall, Building urban Roof, Building density with the probabilistic seismic hazard theme demarcates five zones viz. severe, high, moderately high, moderate and low. The entire Himalayan belt and Indo-gangetic plains fall under severe risk while few patches of high risk have also been spotted in that region.

At the backdrop of the high risk Indian subcontinent the city of Kolkata placed at the boundary between Seismic Zone III and IV is one of the most urbanized and densely populated regions in the world and a major industrial and commercial hub of the eastern and northeastern region of India. 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 and around Bengal Basin as well as the Bihar-Nepal seismic zone, Assam Seismic Gap, Shillong Plateau, and the N-E Himalayan extent pose constant seismic threat to the city of Kolkata. Seismic hazard zonation and risk assessment is undertaken for Kolkata to assess the likely effects of earthquakes as site specific implications.

A synoptic probabilistic seismic hazard model of Kolkata has been developed considering 33 polygonal seismogenic sources and 158 active tectonic sources (faults/lineaments). The probabilistic hazard in terms of PGA distribution for 10% probability of exceedance in 50 years shows a variation from 0.109g to 0.151g at the bedrock level. All the geomorphological units in Kolkata have the potential of a high liquefaction susceptibility during strong seismic shaking. Effective shear wave velocity (V_s^{30}) for 30m soil column is used as a proxy site classification parameter for Kolkata following NEHRP, USGS and FEMA regulations placing the City in D1 (V_s^{30}: 320-360ms^{-1}), D2 (V_s^{30}: 320-280ms^{-1}), D3 (V_s^{30}: 280-240ms^{-1}), D4 (V_s^{30}: 240-180ms^{-1}) and E (V_s^{30}: <180ms^{-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.

A deterministic liquefaction susceptibility scenario of the City created with PGA at 10% probability of exceedance in 50 years at the surface consistent level generated a high liquefaction hazard zone at the depth range of 5-10m due to the presence of coarse grained sediments viz. sand, silty sand, clayey silty sand and shallow ground water conditions. 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 the northern and southwestern corners of the City.

The Seismic Hazard Zonation (SHZ) map of the entire city classifies it into 'Severe' in Salt Lake, 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.

Four broad divisions of socio-economic risk index (SERI) have been identified in Kolkata with Risk Index (SERI) defined as $0.75<SERI\leq1.0$ indicating severe risk condition, $0.50<SERI\leq0.75$ high risk, $0.25<SERI\leq0.50$ moderate risk, while $SERI<0.25$ presents a completely risk free regime. On the other hand four broad divisions have been identified in the City with Structural Risk Index (SRI) defined as $0.75<SRI\leq1.0$ indicating severe risk condition, $0.50<SRI\leq0.75$ indicating high risk, $0.25<SRI\leq0.50$ moderate risk, while $SRI<0.25$ presents a completely risk free regime.

In order to understand the implication of Probabilistic Seismic Hazard with 10% probability of exceedance in 50 years at surface level the same has been exposed to buildings and essential facilities. The building stock used in this study consists of 554,907 buildings with different occupancy classes such as, residential, commercial, residential-commercial, religious, governmental and educational. Damage probability of different model building types have been computed in five different damage states *viz.* none, slight, moderate, extensive, and complete in terms of damaged area or number of damaged buildings using capacity spectrum method in SELENA. Out of 554,907 buildings of Kolkata approximately 34% is expected to suffer from 'moderate' damage followed by ~26% 'complete', ~18% 'extensive', and 15% 'slight' damage. Approximately 7% buildings are seen to be seismic resistant in the City. The estimated building damage is converted to economic loss by using the available inventory database of the City, including the floor area, construction cost estimates per square meter provided by the local

competent authorities. Construction cost for individual model building type has been provided for each geounit and a complete economic loss profile for the City has been generated. The estimated possible loss for this probable hazard scenario with 475 years of return period is about 231 billion Rupees from building damage point of view. The damage is also estimated for the essential facilities like Schools, Hospitals, Police Stations and Fire stations using HAZUS. Out of 1455 Schools 66% is expected to exceed 'slight' damage, 23% will exceed 'moderate' damage and 11 % of the school buildings will exceed 'complete' damage state. From 1060 medical care facilities in the City 48% of the buildings is expected to exceed 'slight' damage, 28% will exceed 'moderate' damage and 24% will exceed 'extensive' damage state. The estimation of damage for 17 fire stations in the City indicates that 67% of these facilities will exceed 'slight' damage, 22% will exceed 'moderate' damage and 11% will exceed 'extensive' damage state. Out of 62 Police stations considered in the present analysis 64% is expected to exceed 'slight' damage, 23% will exceed 'moderate' damage and 13% will exceed 'extensive' damage state. Transportation network of the City will face 'slight' to 'moderate' damage states while exposed to the probabilistic hazard level assessed in this study. The economic loss projected for the Highway, Railway, Bridges, Ferry and Bus terminals is about 76 billion Rupees for the City. 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.

Keywords: Probabilistic Seismic Hazard, NEHRP Site Classification, Deterministic Liquefaction Susceptibility Scenario, Seismic Hazard Zonation, Socio-economic Risk Index, Structural Risk Index, GIS, Capacity Spectrum Method, SELENA, HAZUS, Economic Loss, Kolkata, India.