13 Damage and Loss Assessment in Kolkata using SELENA and HAZUS

13.1 Introduction

Earthquake is the worst natural hazard causing widespread damage and destruction to the society. India is considered an earthquake prone country as it has experienced a large number of major to great earthquakes in the past causing lakhs of fatalities and destroying properties worth billions of rupees, thus necessitating a sound disaster mitigation and management plan through a judicious inter play of seismic hazard, vulnerability, damage, casualty and economic loss. At the onslaught of a destructive earthquake in a region, the pre-disaster preparedness and post-disaster relief, rescue and rehabilitation are worked out using any of the tools such as, HAZUS (Hazard-US), RADIUS (Risk Assessment Tools for Diagnosis of Urban areas against Seismic Disasters), ELER (Earthquake Loss Estimation Routine), EPEDAT (The Early Post-Earthquake Damage Assessment Tool), SELENA (SEismic Loss EstimatioN using a logic tree Approach) either individually or in unison. Kolkata, the state capital of West Bengal face seismic threat from any of the three seismogenic provinces namely, the Central Himalaya, the Northeast India and the Bengal Basin itself even though there is sparse seismicity in the region as such. The surface consistent Probabilistic Seismic Hazard of the City on integration with other hazard attributes divides it into four hazard zones *viz.* '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 in the rest. Evidently the City which was earlier placed at the boundary between BIS Seismic Zones III and IV is no more associated with it rather drifted to much higher PGA values with higher zone factors as illustrated in details in Chapter 11. In order to understand the implications of the new seismic hazard microzones, an attempt has been made here to assess the building damage scenario and the economic loss estimate thereof considering 300 socio-economic clusters in Kolkata. Since the earthquakes not only damage the built environment, but also disrupt the essential facilities *viz*. transportation system, schools, hospitals, medical offices *etc*. Therefore, in the present study HAZUS (FEMA, 2000) and SELENA (Molina and Lindholm, 2005; Lang *et al*., 2008; Molina *et al*., 2010) protocol has been used for seismic damage and loss estimation. Towards a conservative deterministic prediction, the probabilistic seismic hazard in terms of PGA, PSA at 0.3 and 1.0 sec for 10% probability of exceedance in 50 years with a return period of 475 years have been used for the estimation of structural damage, earthquake casualty and probable economic loss for the city of Kolkata.

13.2 Damage and Loss Estimation using SELENA

SELENA is an open source MATLAB based seismic risk estimation tool developed by NORSAR (Norwegian Seismic Array/International Center for Geohazards, Norway) and the University of Alicante (Spain) for systematic seismic risk assessment using the Capacity Spectrum Method (Molina and Lindholm, 2005; Lang *et al.*, 2008; Molina *et al.*, 2010). Yang *et al.* (2011) used this technique to estimate seismic damage and human loss associated with primary schools during the M_w 7.9 Wenchuan earthquake that occurred on 12 May 2008 at China. Lang *et al.* (2012) carried out an analytical based damage and loss estimation for Dehradun city in Northern India using the SELENA based approach. The risk estimates are satisfactorily compared with an earlier empirical intensity-based study. To compute the probability of damages and losses, a detailed information regarding number of buildings, building area, building footprint, the earthquake sources, empirical ground motion prediction relationships, soil map, capacity and fragility functions and cost schedules of different model building types are essential. The basic principle underlying SELENA and HAZUS is the Capacity Spectrum Method, where the input ground motion in terms of response spectra are combined with the building specific capacity curve (Molina *et al.*, 2010). Capacity curve changes with model building types implicating local building regulations and construction practices thus influencing the methodology and the results thereof. Based on typology and height and using the stipulated building nomenclature given in HAZUS (1999), WHE-PAGER (2008) and FEMA (2000), eleven model building types have been identified in Kolkata namely, A1, RS2, URML, URMM, C1L, C1M, C1H, C3L,C3M, C3H and HER with the respective capacity curves obtained from NIBS (2002). The building stock used in this study consists of 554,907 buildings with various occupancy classes such as, residential, commercial, residential-commercial, religious, governmental and educational. The probability of attaining or exceeding discrete states of damage *viz.* ‘none’, ‘slight’, ‘moderate’, ‘extensive’ and ‘complete’ is estimated. It considers assessment at the level of a geographical unit termed geounit which is a tiny area. For Kolkata 300 geounits are considered. 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 total damaged area or the number of damaged buildings. Human casualty in terms of total injury at three different times of the day (*e.g.* 10:00 am, 5:00 pm and 2:00 am) has been estimated for 300 socio-economic clusters of the City. The computational protocol in SELENA is depicted in Figure 13.1.

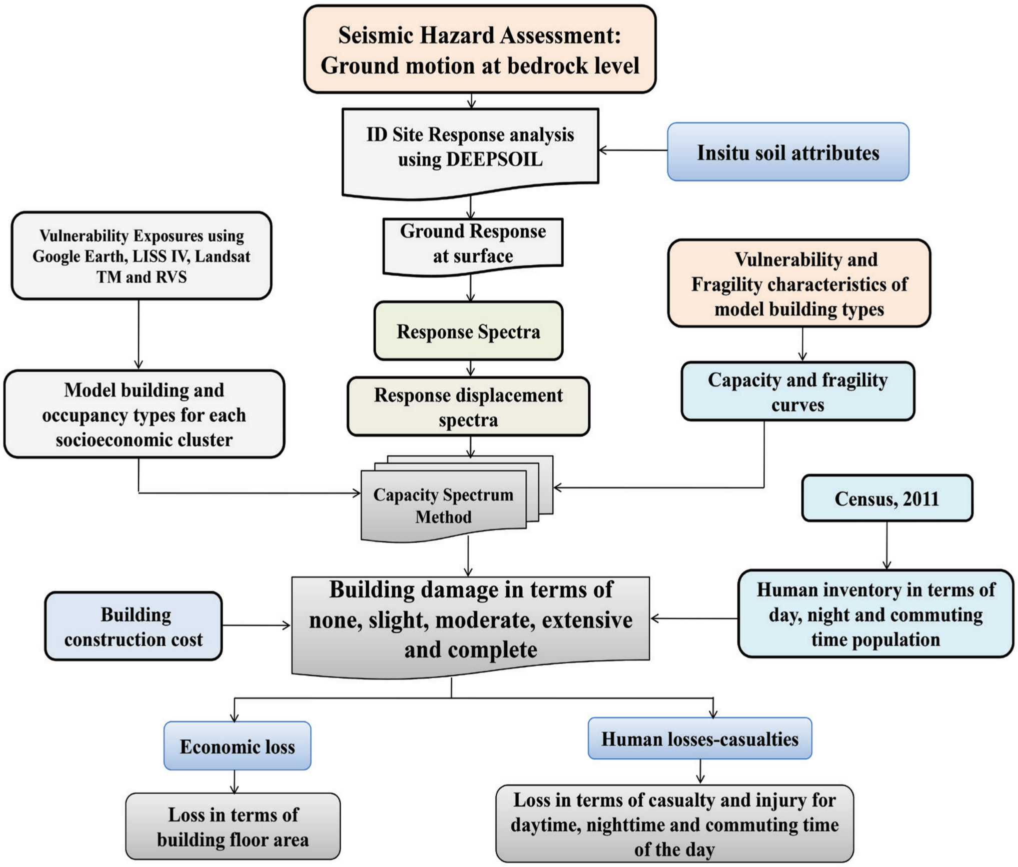


Figure 13.1 Computational Framework used in the SELENA for Seismic Damage and Economic Loss Assessment.

13.2.1 Model for Structural Damage, Economic Loss and Casualties

13.2.1.1 Structural Damage Assessment through Capacity Spectrum Method

The Capacity Spectrum Method (CSM) is a nonlinear static analysis, which compares the capacity curve of a structure in terms of force and displacement with seismic response spectrum (Freeman, 1998; Badoux, 1998). The probability of damage in each geounit has been calculated in relationship with the provided ground motion (Freeman *et al.*, 1975; Freeman, 1978; ATC–40, 1996) as illustrated in Figure 13.2.

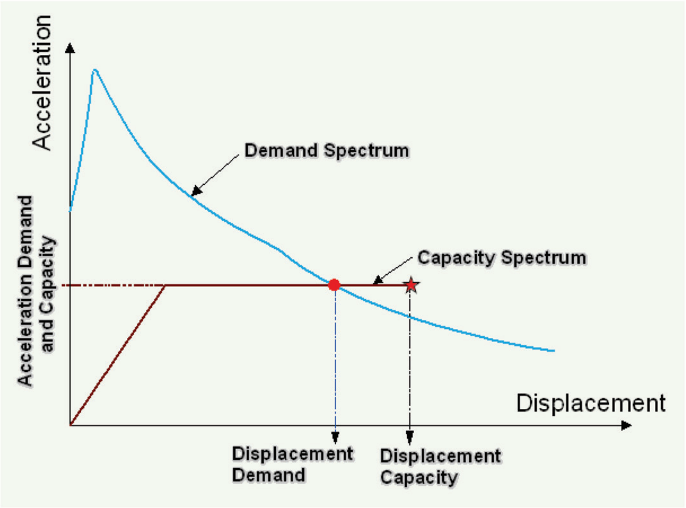
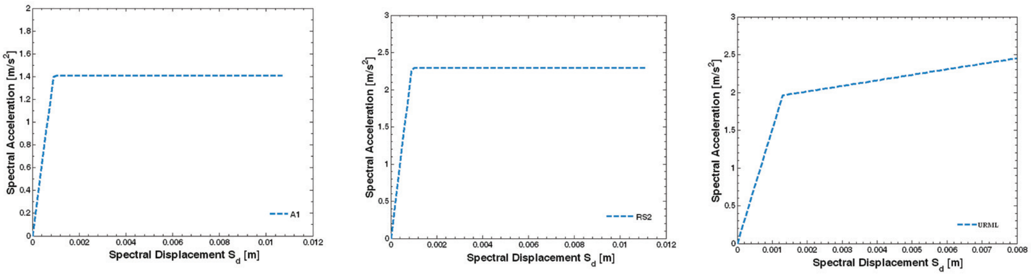


Figure 13.2 Illustration of Capacity Spectrum Method (after Fajfar, 1999).

It consists of following steps: Generation of capacity spectrum, Computation of demand spectrum and Determination of performance point. Structural capacity is represented by a force-displacement curve. A pushover analysis is performed for a structure with increasing lateral forces, representing the inertial forces of the structure under seismic demand. The process is continued till the structure becomes unstable. The seismic demand curve is represented by the response spectrum curve in the spectral displacement – spectral acceleration space. The performance point is the intersection between the seismic demand curve and the building capacity curve.

(a) Capacity Curve: To calculate the peak building response and the cumulative damage probabilities of all eleven model building types, demand spectrum curve as a function of spectral displacement, at the period 0.3 and 1.0 sec has been considered. The building capacity curve has three control points: Design, Yield and Ultimate capacity. It is assumed that building capacity curve behave elastically linearly up to the yield point, the curve changes from elastic to plastic state from yield point to ultimate point and the curve behaves totally plastically as it crosses the ultimate point. Figure 13.3 represents the capacity curve for eleven model building types of Kolkata as obtained from NIBS (2002).



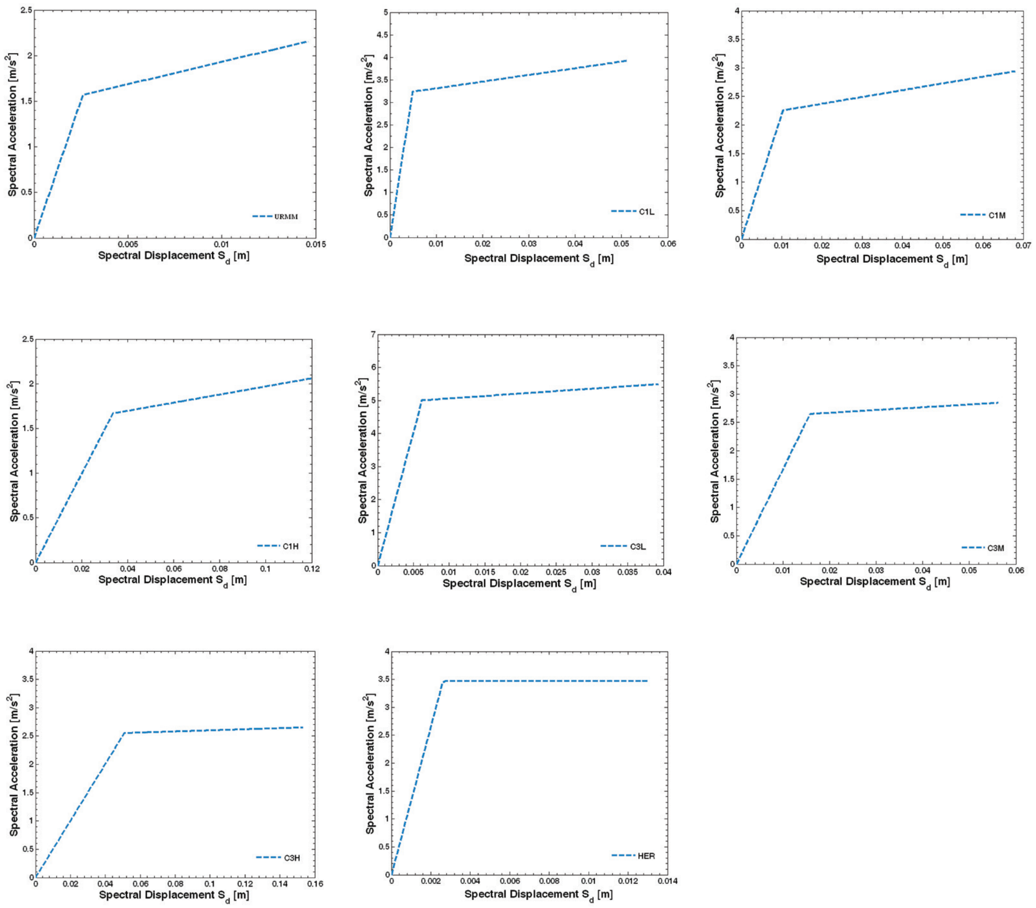
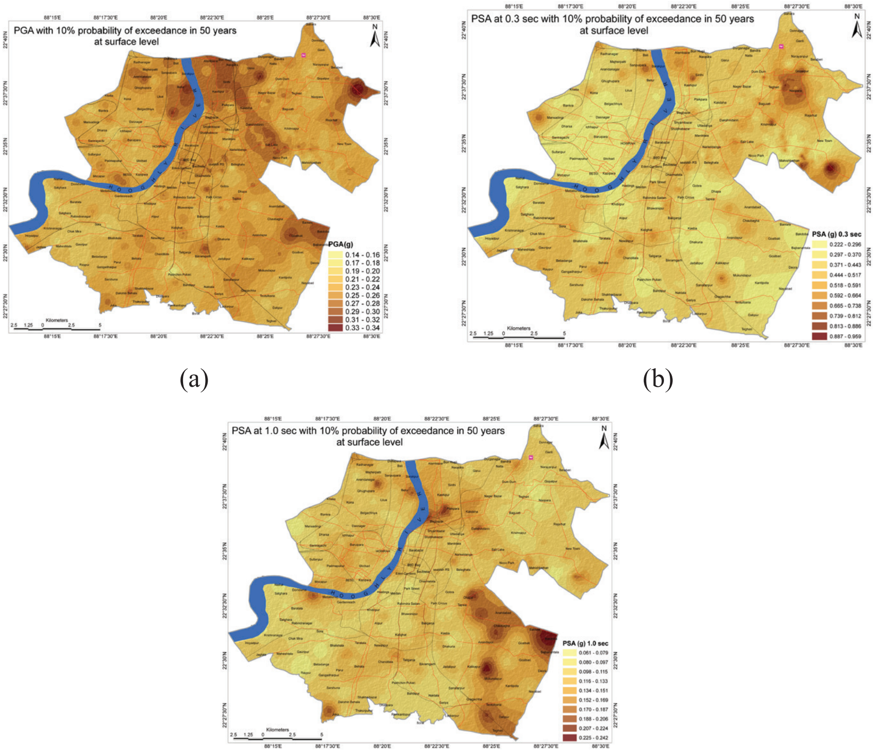


Figure 13.3 Capacity curves for A1, RS2, URML, URMM, C1L, C1M, C1H, C3L, C3M, C3H and HER model building types (NIBS, 2002).

b) Seismic Demand Input: To generate a damage scenario for Kolkata while built-up environment is exposed to surface level probabilistic PGA and PSA distributions, the spectral ordinates in each geounit in terms of PGA, PSA at 0.3 and 1.0 sec at surface level for 10% probability of exceedance in 50 years (discussed in greater details in Chapter 4 and Chapter 8) has been used as shown in Figure 13.4 to assign ground motion at each geographical unit. The response spectra computed based on PGA, PSA at 0.3 sec and 1.0 sec spectral period is used for seismic vulnerability and risk assessment protocol. Thereafter, the spectral displacement has been calculated from the response spectra for the assessment of ultimate capacity of the building by using the following equation

$$S_D=9.8*S_A*T^2 \tag{13.1}$$

where, S_D is the spectral displacement, S_A is the spectral acceleration in g and T is the time period.



(a) (b)

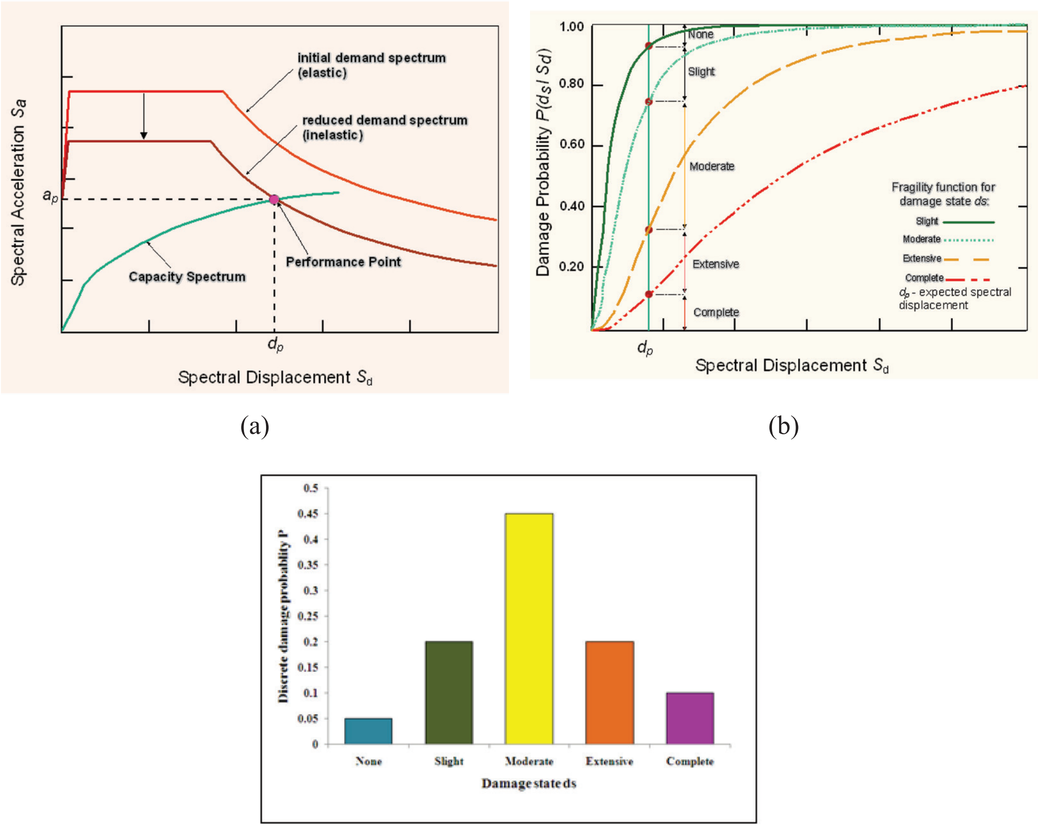
(c)

Figure 13.4 Seismic hazard in Kolkata in terms of probabilistic (a) PGA, (b) PSA at 0.3 sec, and (c) 1.0 sec at surface consistent level.

c) Determination of performance point to calculate the fragility curve: The performance point (d_p) is identified from the intersection between the seismic demand and building capacity curve as illustrated in Figure 13.5(a). For the computation of damage probabilities, vulnerability curves or fragility curves for four damage states are essential, which are developed as lognormal probability distribution of damage from the capacity curve as shown in Figure 13.5(b). The cumulative damage probabilities have been calculated as (NIBS, 2002)

$$p\left[ds / S_d\right] = \phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{S_d}{S_{d,ds}}\right)\right] \tag{13.2}$$

where, $p[ds|S_d]$ is the probability of being in or exceeding a damage state, *ds*; S_d is the given spectral displacement in inches; $\overline{S}_{ds}$ is the median value of S_d at which the building reaches the threshold of the damage state *ds*; β_{ds} is the lognormal standard deviation of spectral displacement of damage state, *ds*; and ϕ is the standard normal cumulative distribution function. Both $S_{d,ds}$ and β_{ds} depend on a building type and its seismic design level (FEMA, 2003). The damage state (*ds)* of a structure is divided into five states: 'none', 'slight', 'moderate', 'extensive' and 'complete' as depicted in Figure 13.5(b). For an expected displacement cumulative probabilities are defined to obtain discrete probabilities of being in each of the five different damage states as depicted in Figure 13.5(c).

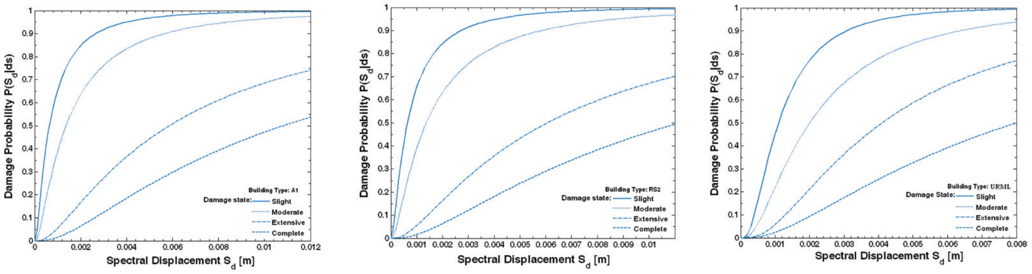


(a) (b)

(c)

Figure 13.5 **(a) Building specific capacity spectrum intersected by the demand spectrum representing the performance point, (b) Fragility curves showing extent of different damage states (*ds*), and (c) The discrete probabilities of different damage states, *ds*.**

The fragility curves for eleven model building typology in Kolkata are depicted in Figure 13.6. The fragility curve parameters have been adopted from NIBS (2002).



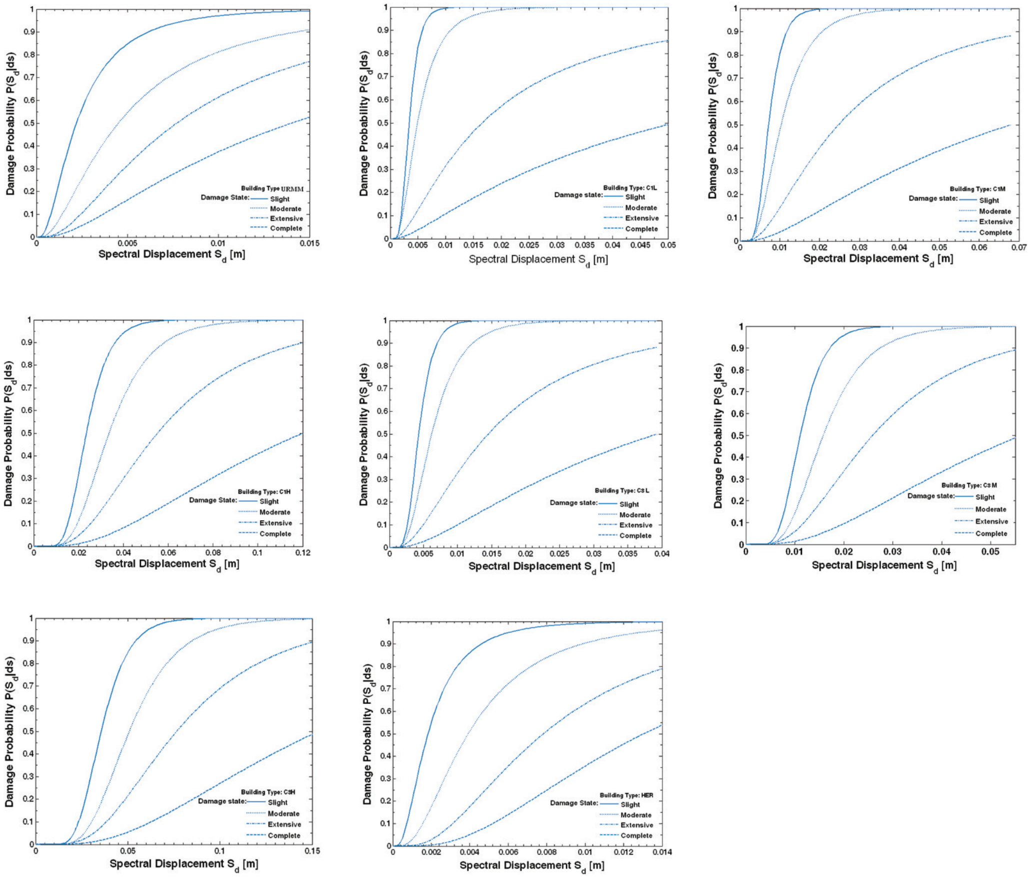


Figure 13.6 Estimated fragility curves for A1, RS2, URML, URMM, C1L, C1M, C1H, C3L, C3M, C3H and HER model building types for Kolkata.

13.2.1.2 Human Casualties

Casualty is the indirect effect of earthquake impact, while the building damage is the direct one. Earthquake is the cause of explosion in pipeline, power cut, communication disruption which may increase the casualties. The number of casualty has initially been calculated by following HAZUS, later modified using the formulation of Coburn and Spence (2002) as

$$K = K^S + K' + K_2 \qquad (13.3)$$

where,

K^S = Number of casualties due to structural damage,

K' = Number of non-structural damage,

K_2 = Number of casualties due to follow on hazards, such on landslide, fires *etc*.

By considering the severity of injury the equation is further modified by Coburn and Spence (2002) as

$$K_i = K_i^S + K_i' + K_{2i} \tag{13.4}$$

where *i* is the representative level of injury ranging from low injury (*i*=1), moderate injury (*i*=2), heavy injury (*i*=3) to death (*i*=4).

SELENA computes the injury level by using two types of methodologies: Basic methodology and HAZUS methodology. In the present study casualties have been estimated using the formulation of Molina *et al.* (2010)

$$K_s^i = \{Injuries(Severitiy)\} = \sum_{J=1}^{N_{BT}} \sum_{K=1}^{N_{DS}} c_{i,j}^{CSR} P_{i,j} N_j^{POP} \tag{13.5}$$

in which, $c_{i,j}^{CSR}$ = Casualty rate of severity i for damage state *j*, $P_{i,j}$ = Structural damage probability for the damage state *k* for the model building type *j*, N_j^{POP} = Number of people in the model building type *j*. As the number of casualties is strongly depended on time of the day at which the estimation is performed, injury level is, therefore, calculated at three times of the day: daytime (at 10:00 am), nighttime (at 02:00 am) and commuting time (at 05:00 pm). The demographic distribution of the City for the estimation of casualty is discussed in Chapter 12 in sections 12.2.1 which has been taken into consideration here.

13.2.1.3 Economic Loss Assessment

The total economic loss caused due to damage to all model building types in each geounit has been primarily estimated by considering the loss due to direct physical damage to the structural components. Construction cost (per m^2) for different building typology of Kolkata is shown in Table 13.1. The economic loss for building structural damage has been computed by following the equation of Molina *et al.* (2010) given by

$$L_{eco} = C_r \sum_{i=1}^{N_{OT}} \sum_{j=1}^{N_{BT}} \sum_{k=1}^{N_{DS}} A_{i,j} P_{j,k}, C_{i,j,k} \tag{13.6}$$

where, N_{OT}= Number of occupancy type, N_{BT}=Number of building typology, N_{DS}=Number of damage state *ds*, C_r = Regional cost multiplier, $A_{i,j}$= Built area of the model building type *j* in the occupancy type *i*, $P_{j,k}$= Damage probability of structural damage *k* for the model building type *j*, $C_{i,j,k}$= Cost (by m^2) in the input currency of damage state *k* for occupancy *i* and model building type *j*.

Table 13.1 Construction cost (per m^2) for different model building typology of Kolkata (KMDA)

Building Types/Stories	Stories 1	Stories 2	Stories 3	Stories 4	Stories 5	Stories 6	Stories 7	Stories 8+
C1L	15441	9157	9695	-	-	-	-	-
C1M	-	-	-	10104	10138	10332	10462	-
C1H	-	-	-	-	-	-	-	41175
C3L	14928	11261	10039	-	-	-	-	-
C3M	-	-	-	9768	9325	9035	8986	-
C3H	-	-	-	-	-	-	-	10350
A1	8608	-	-	-	-	-	-	-
RS2	-	8925	8630	-	-	-	-	-
URML	12500	12360	-	-	-	-	-	-
URMM	-	-	14200	13525	-	-	-	-

13.2.2 Compilation of Input and Inventory Data for Seismic Damage and Loss Scenario

13.2.2.1 Model Building Types

After obtaining information about building height, age and types as discussed in Chapter 12, a total of 554,907 buildings of Kolkata are reclassified into eleven model building types according to FEMA (2000) and WHE-PAGER (2008) nomenclature as given in Table 13.2 and the percentage distribution of buildings of each model type existent in Kolkata is depicted in Figure 13.7. Damage is computed based on model building types, as the structural parameters are directly related to building performance under seismic loading.

Table 13.2 Different model building types used in the present study (After FEMA, 2000 and WHE-PAGER, 2008)

Model Building Type	Description	Height	Stories
HER	Heritage building	-	-
C1L	Ductile reinforced concrete frame with or without infill	Low-Rise	1 – 3
C1M		Mid-Rise	4 - 6
C1H		High-Rise	7+
C3L	Non-ductile reinforced concrete frame with masonry infill walls	Low-Rise	1 - 3
C3M		Mid-Rise	4 - 6
C3H		High-Rise	7+
A1	Adobe Block, Mud Mortar, Wood Roof and Floors	Low-Rise	1-2

Model Building Type	Description	Height	Stories
RS2	Rubble stone masonry walls with timber frame and roof	Low-Rise	1-2
URML	Unreinforced masonry bearing wall	Low-Rise	2-3
URMM		Mid-Rise	3-4

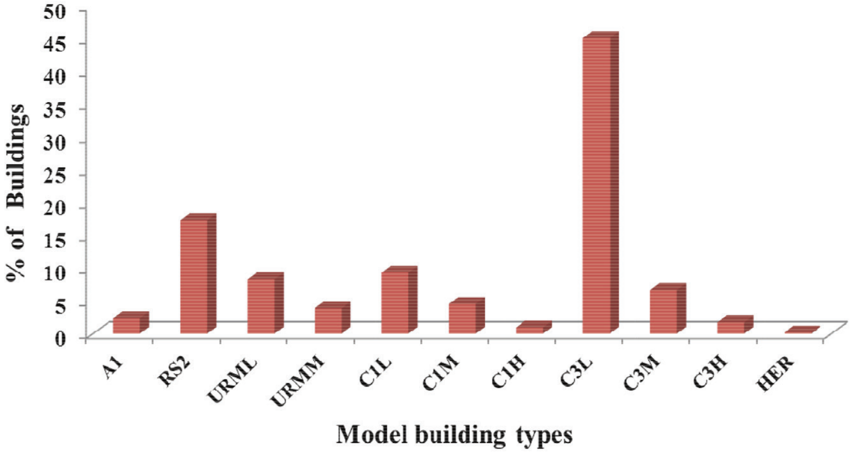


Figure 13.7 Percentage of buildings in each model building type as existent in Kolkata.

(i) 'A1' Type Buildings

This is a typical rural construction found throughout India, in which the main load-bearing system consists of mud walls, which carry the roof load. In some cases wooden posts are provided at the wall corners and at intermediate locations. The wooden posts and walls are not structurally integrated, and, therefore, the loads are shared by the walls and the frame. In general, this type of construction is built by the owners and the local unskilled masons and the craftsmanship is very poor. This is a low-strength masonry construction and it is considered extremely vulnerable to seismic forces. During the present investigation some field photographs were taken as shown in Figure 13.8.

Figure 13.8 Some photographs of the 'A1' building type taken in the City.

The distribution of ‘A1’ model building type in the City is depicted in Figure 13.9 on GIS platform. Maheshtala has the highest number of this model building type, whereas most of the region has low density of the same. Saltlake, Rajarhat, Howrah, Jadavpur *etc*. has less than 100 numbers of ‘A1’ buildings.

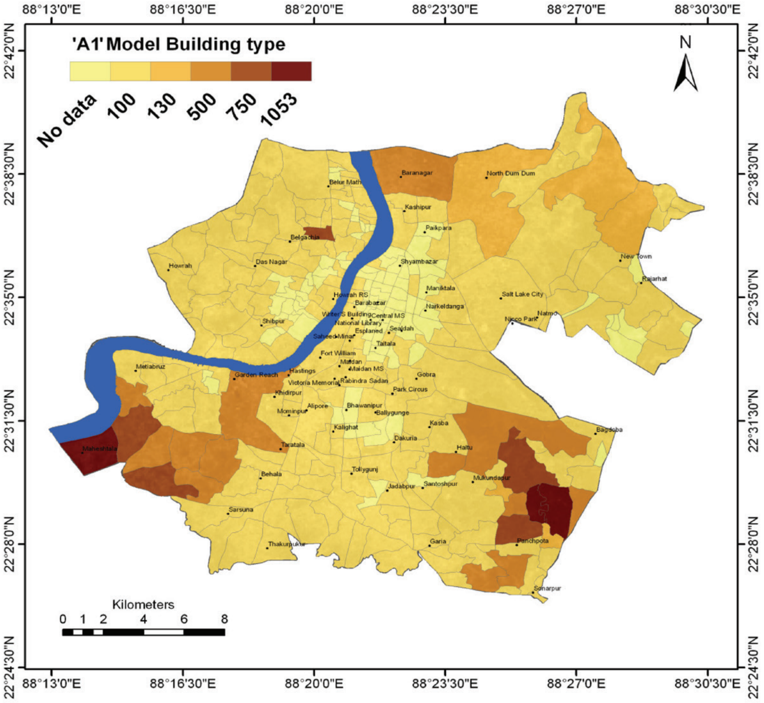


Figure 13.9 Distribution of ‘A1’ model buildings in the City.

(ii) ‘RS2’ Type Buildings

This typical rural construction present in the City is cheap to construct using field stones and boulders, but because of its heavy roofs and poorly constructed walls these are extremely vulnerable to earthquakes. The load-bearing structure is a timber frame system with thick stone walls provide enclosure and partial support to the roof. Walls are either supported by strip footings of rubble masonry or are without any footings at all. The roof structure consists of timber planks and joints. Figure 13.10 presents a few ‘RS2’ model buildings.

Figure 13.10 Some examples of ‘RS2’ model buildings in the City.

The spatial distribution of ‘RS2’ model building type in Kolkata is presented in Figure 13.11 which indicates that North Dum Dum, Garden Reach and Baranagar have the largest density of these buildings as compared to other regions of the City.

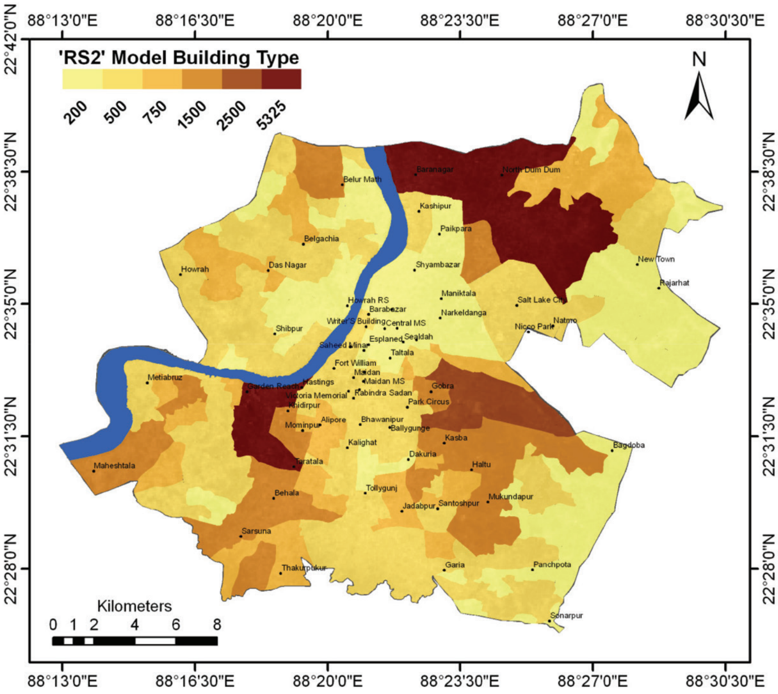


Figure 13.11 Distribution of ‘RS2’ model building type in the City.

(iii) Un-reinforced Masonry Buildings

Un-reinforced masonry buildings (‘URM’ building) are made up of brick, tiles, adobe or other masonry material and are not braced by any reinforcing beams. These building types can be low-rise (‘URML’) or mid-rise (‘URMM’) and are vulnerable to seismic hazard. ‘URML’ buildings are generally 1-2 floors; whereas ‘URMM’ are consisting of 2-4 floors. Some photographs of this type of buildings are given in Figure 13.12.

Figure 13.12 Some example of ‘URM’ model building type in the City.

The spatial distribution of Un-reinforced masonry type of buildings in the City is depicted in Figure 13.13. Dum Dum, Thakurpukur, Belur *etc.* have the highest density of these buildings.

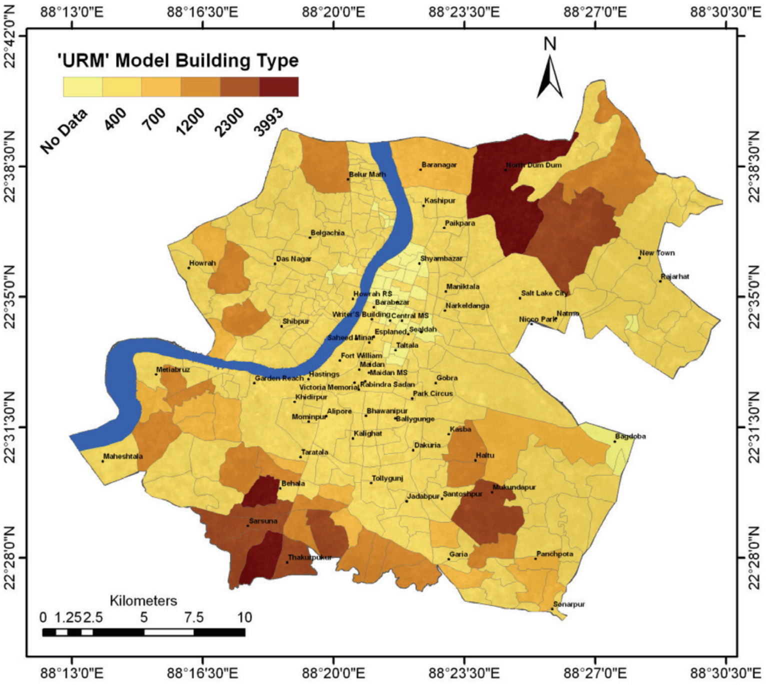


Figure 13.13 Distribution of 'URM' type buildings in the City.

(iv) 'C1' Type Buildings

'C1' type of buildings is ductile resistant concrete structures with or without masonry infill walls. 'C1' type are generally categorized as high- (C1H), mid- (C1M) or low-rise (C1L) buildings. Buildings consisting of 1-3 floors are termed as 'C1L' type, 4-7 floor buildings are 'C1M' type, whereas 8+ floor buildings are 'C1H' type. Most of the buildings of the study region generally fall in 'C1L' category. Some typical field photographs are shown in Figure 13.14.

Figure 13.14 Some example of 'C1' model building type in the City.

The spatial distribution of ‘C1’ type of buildings in the City is shown in Figure 13.15. Dum Dum, Thakurpukur, Baranagar and Saltlake possess highest number of ‘C1’ type buildings.

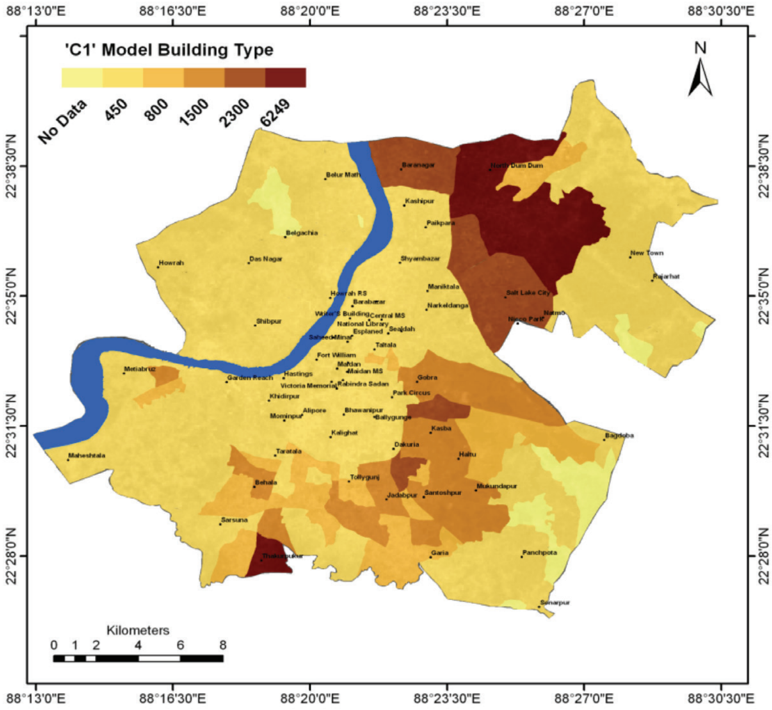


Figure 13.15 Distribution of ‘C1’ type buildings in Kolkata.

(v) ‘C3’ Type Buildings

‘C3’ type of buildings is non-ductile reinforced concrete frames with masonry infill walls as defined by FEMA. This type of buildings also can be divided into high-rise (C3H), mid-rise (C3M) and low-rise (C3L) categories. This type of building is susceptible to earthquakes because of their brittle behavior. Due to its large height to base ratio, end or corner columns could fail under compression, leading to partial collapse. Some photographs taken during the field investigation have been presented in Figure 13.16.

Figure 13.16 Some example of ‘C3’ model building type in the City.

The spatial distribution of 'C3' type of buildings in the City is shown in Figure 13.17. Major part of the City has highest distribution of this model building type.

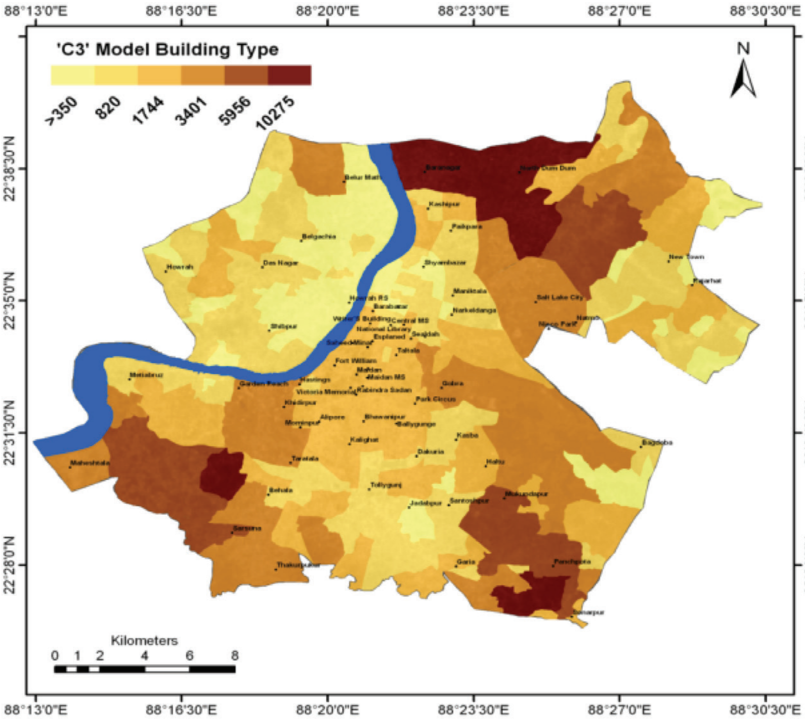


Figure 13.17 Distribution of 'C3' type buildings in Kolkata.

(vi) 'HER' Type Buildings

Heritage buildings are mostly distributed in Central Kolkata and they follow the traditional practice of building construction. These are very important structures of Kolkata and are seismic resistant. Photographs of a few of this building type are presented in Figure 13.18. The spatial distribution of Heritage buildings in Kolkata is depicted in Figure 13.19.

Figure 13.18 Some example of 'HER' model building type in the City.

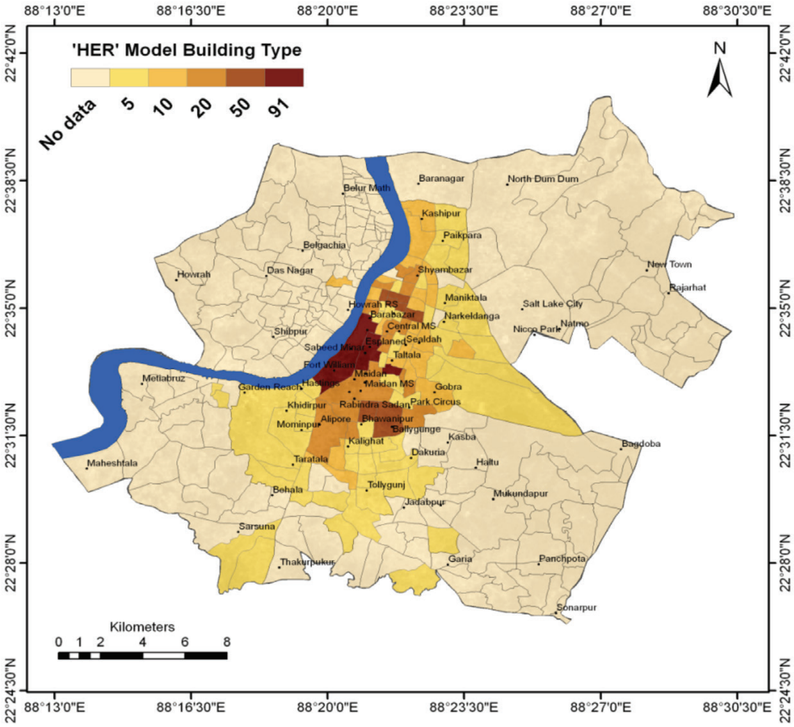


Figure 13.19 Distribution of 'HER' type buildings in the City.

13.2.3 Probabilistic Seismic Damage and Loss Prediction for Kolkata considering Surface Consistent PGA distribution with 10% Probability of Exceedance in 50 years

13.2.3.1 Building Damage Assessment

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 seismic resistant in the City as collectively shown in Figure 13.20. Un-reinforced masonry buildings are the most seismically vulnerable (Spence, 2007) ones and, therefore, face the chance of 'complete' damage.

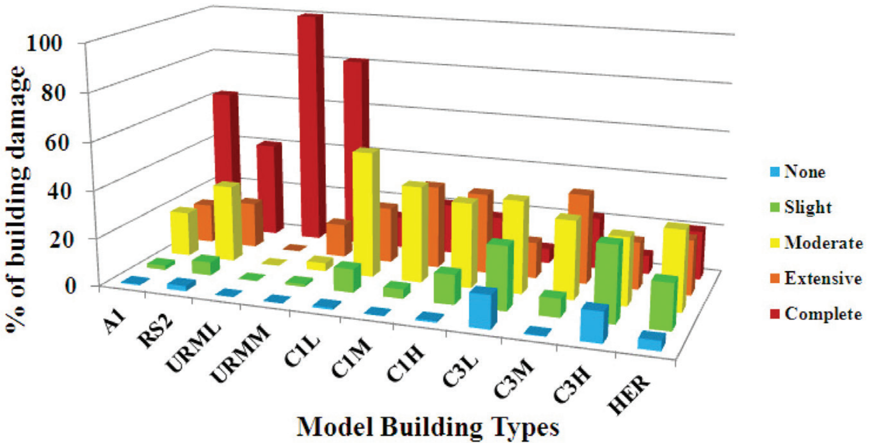


Figure 13.20 Predicted damage probability in terms of 'none', 'slight', 'moderate', 'extensive', and 'complete' for the identified model building types in the City.

a) Damage Estimation for 'A1' Model Building Type

'A1' building type is non-engineered and mainly made up of adobe block, mud mortar, wood roof and floors. This building type is vulnerable to earthquakes and, therefore, 62% of this type of buildings will be completely damaged as shown in Figure 13.21.

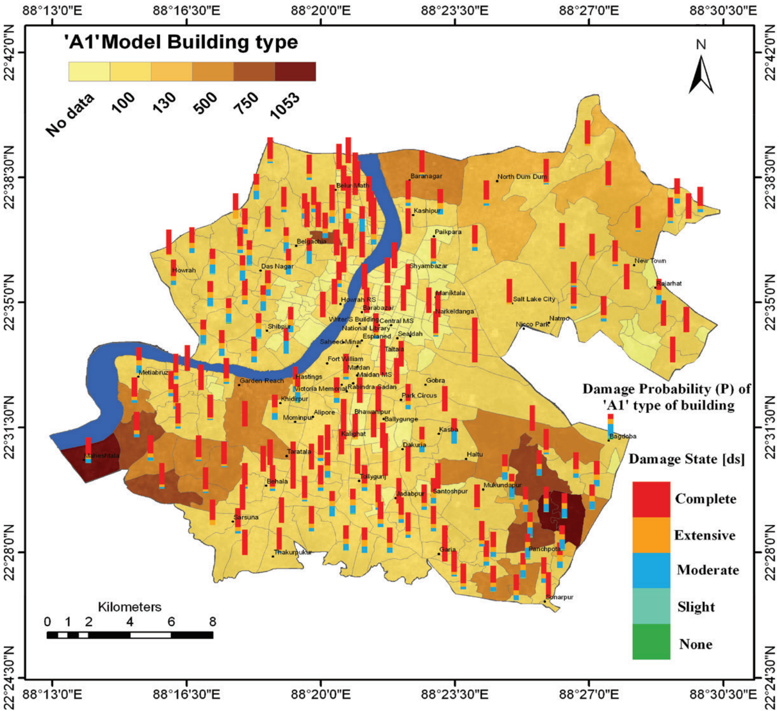


Figure 13.21 Damage distribution for 'A1' type buildings in Kolkata.

b) Damage Estimation for 'RS2' Model Building Type

'RS2' Model building type is also vulnerable to earthquakes and will face 'moderate' to 'complete' damage if the City surge by any moderate to large earthquakes in future. The different damage states for this model building type as shown in Figure 13.22 depicts that most of the buildings of various parts of the City will be destroyed completely. It is evident that 40% of the total 'RS2' model buildings of Kolkata is expected to damage completely, followed by 20% 'extensive', 32% 'moderate' and 6% 'slight' damage.

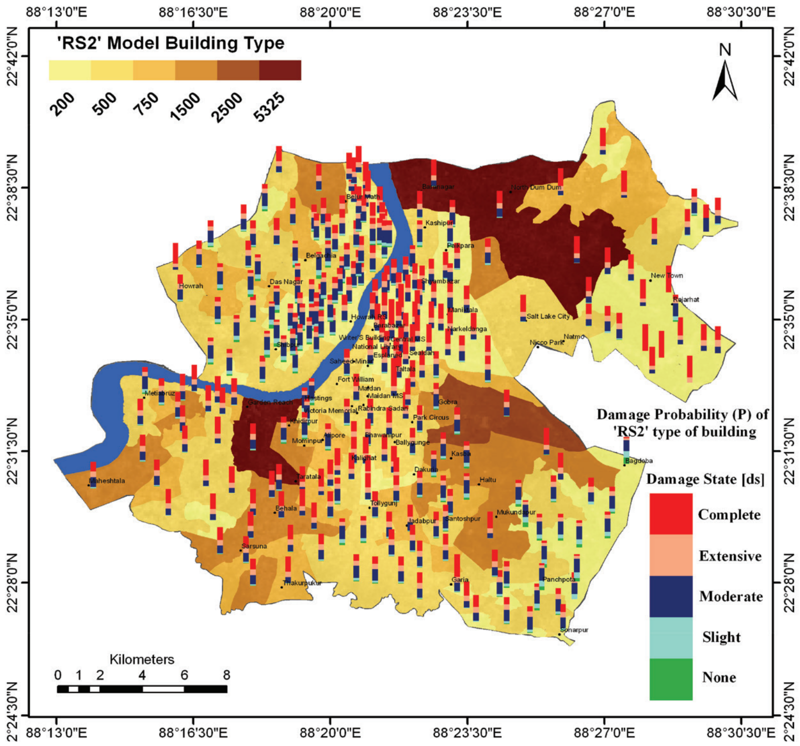


Figure 13.22 Damage distribution for RS2 type buildings in Kolkata.

c) Damage Estimation for 'URM' Model Building Type

Un-reinforced masonry buildings are the most seismically vulnerable (Spence, 2007) and, therefore, the chance of 'complete' damage state of this type of buildings are very high. About 90% of both the low-rise (URML) and mid-rise (URMM) buildings of this type will face 'complete' damage in Kolkata as presented in Figures 13.23(a-b) respectively.

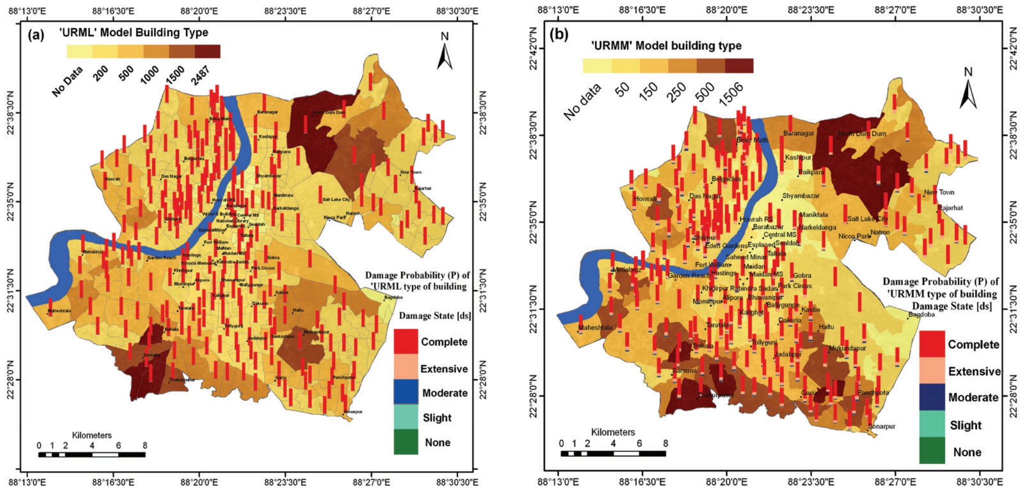
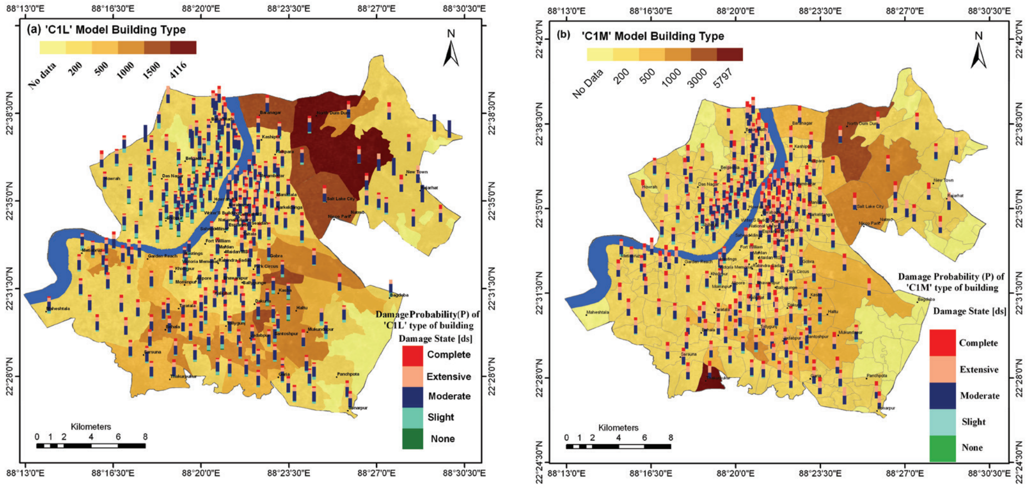


Figure 13.23 Damage distribution for (a) 'URML', and (b) 'URMM' type buildings in Kolkata.

d) Damage Estimation for 'C1' Model Building Type

'C1' building type is mostly ductile reinforced concrete frame with or without infill. The damage distributions of 'C1' type of buildings (low-rise, mid-rise and high-rise) are shown in Figure 13.24(a-c) respectively. Mid-rise and high-rise buildings of this type of building will face 'moderate' to 'extensive' damage, while low-rise will face 'slight' to 'moderate' damage.



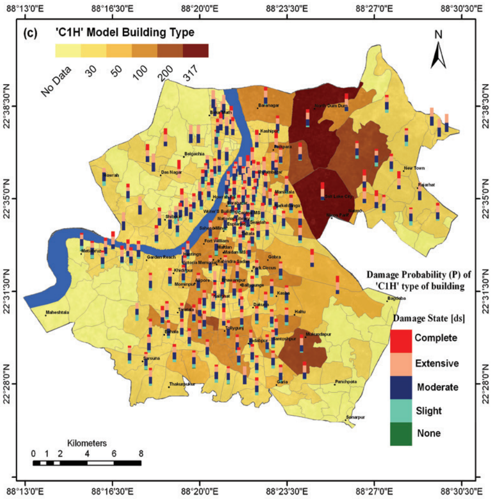
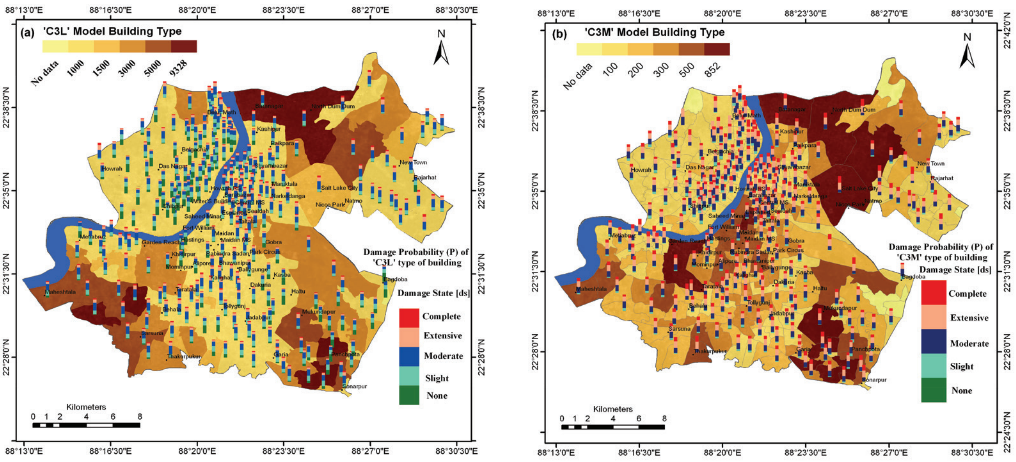


Figure 13.24 Damage distribution for (a) 'C1L', (b) 'C1M', and (c) 'C1H' type buildings in Kolkata.

e) Damage Estimation for 'C3' Model Building Type

'C3' building type is mainly ductile reinforced concrete frame with infill and they are mostly seismic resistant. The damage distribution of 'C3' model building type represents that most of the concrete building of low- and high-rise will suffer 'slight' to 'moderate' damage as shown in Figure 13.25(a) and (c), while mid-rise buildings (C3M) will face 'moderate' to 'extensive' damage as depicted in Figure 13.25(b) which is attributed to high hazard conditions at these building localities and also the proportionate increase in the construction of these type of mid-rise buildings as compared to the low-rise and high-rise ones.



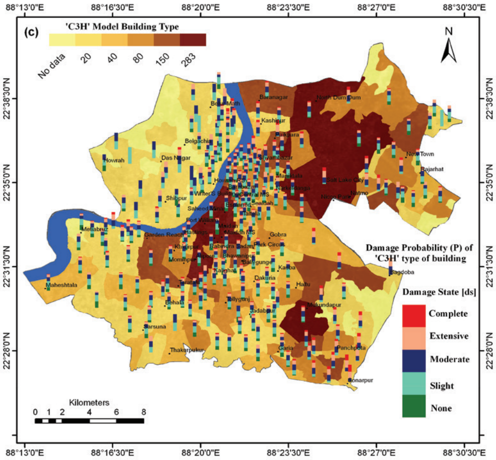


Figure 13.25 Damage distribution for (a) 'C3L', (b) 'C3M', and (c) 'C3H' type buildings in Kolkata.

f) Damage Estimation for 'HER' Model Building Type

The damage distribution pattern for heritage type buildings have been depicted in Figure 13.26. It is evident that most of the Heritage buildings of Kolkata are mainly present in Central Kolkata and will face 'slight' to 'moderate' damage. Less than 15% of these buildings are expected to face 'complete' damage as per the conservative estimate through SELENA.

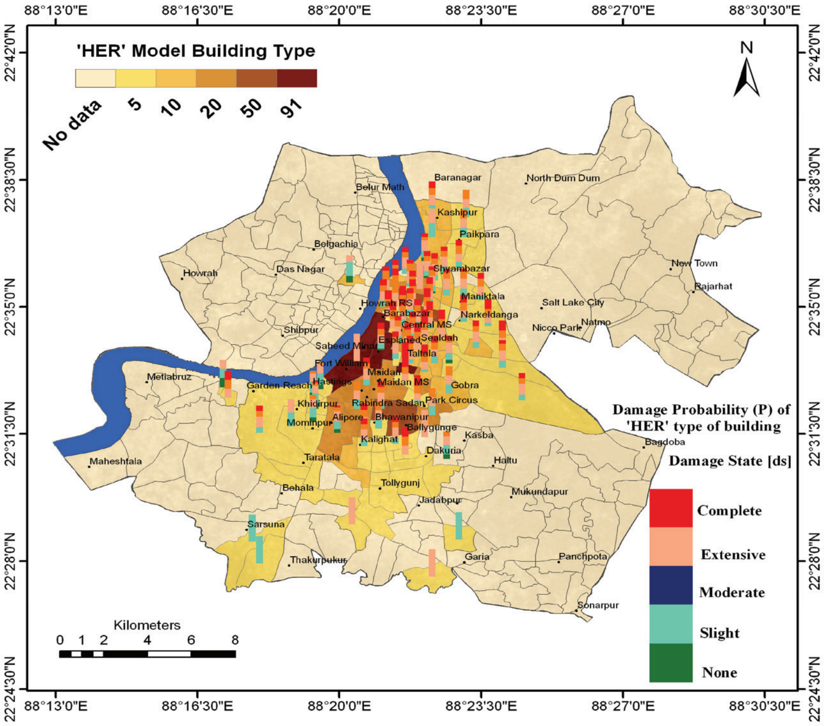


Figure 13.26 Damage distribution for 'HER' buildings in Kolkata

13.2.3.2 Human Casualty Assessment

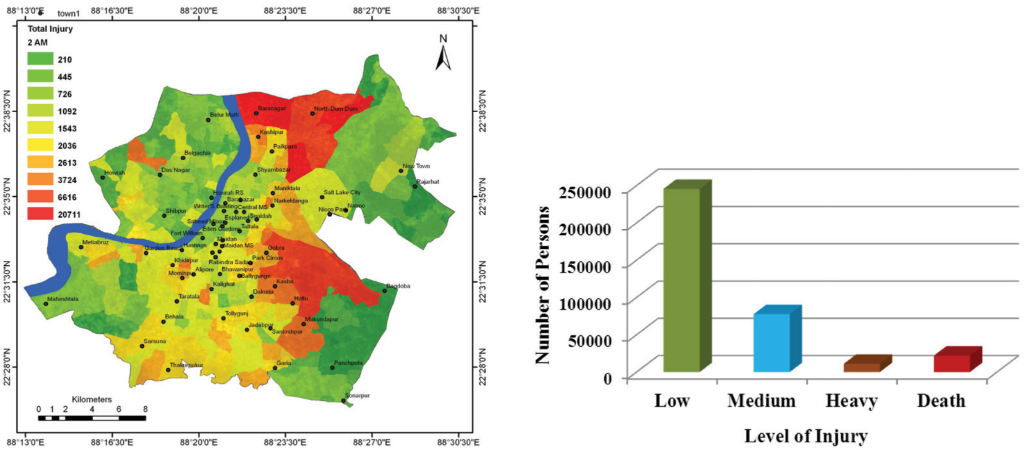
Human casualty/injury levels are then computed using SELENA considering the probabilistic seismic hazard condition for 10% probability of exceedance in 50 years at surface level. In order to consider extreme cases of occupancy which are strongly dependent on the time of the day, the number of casualties have been computed for three different times of the day *viz.* nighttime scenario (at 02:00 am) *i.e.* considering earthquake striking during nighttime; daytime scenario (at 10:00 am) considering earthquake striking during daytime; commuting time scenario (at 05:00 pm) *i.e.* considering earthquake striking during the commuting time (rush hour). The methodology provides estimations regarding the number of human casualties (indoor and outdoor both) caused only by building collapse. The percentage of indoor and outdoor population at a particular time is adopted from Molina *et al.* (2010) and illustrated in Table 13.3.

Table 13.3 **Percentage of indoor and outdoor people dependent on the time of the day (Molina *et al.*, 2010)**

Occupancy Class	Night (at 2:00 am)	Day (at 10:00 am)	Commuting (at 5:00 pm)
Indoor	98 %	90%	36%
Outdoor	2%	10%	64%
Sum Σ	**100 %**	**100 %**	**100 %**

a) Nighttime Scenario (at 02:00 am)

This scenario is expected to generate the highest casualty numbers for the population at home in the nighttime. The methodology assumes that at night 98% population resides indoors. Distribution of casualty/injury at different places is shown in Figure 13.27(a), where it is evident that Saltlake, Behala, New Town and parts of Howrah region will suffer moderate to high casualty in terms of different levels of injury from low to heavy and even death. According to this scenario more than 245,616 persons of the study region will suffer from minor injury and approximately 21,962 persons will die as depicted in Figure 13.27(b).

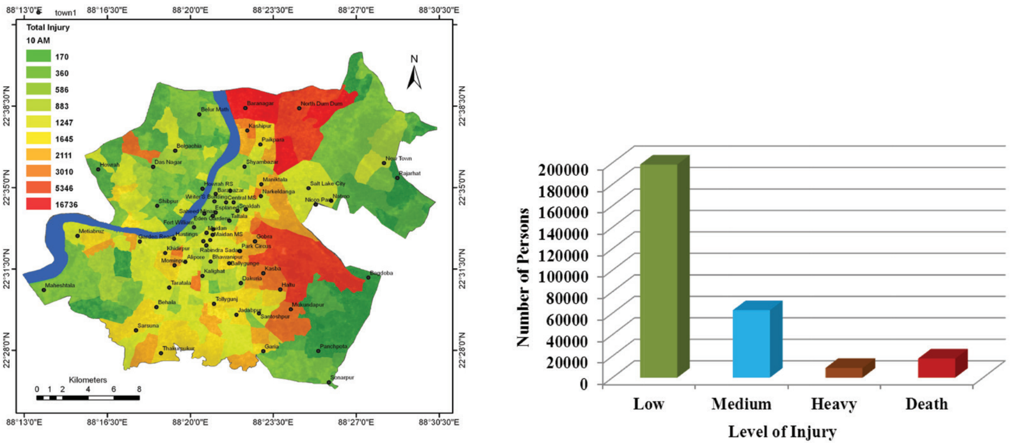


(a) (b)

Figure 13.27 **(a) Distribution of injured population at nighttime (at 2:00 am), and (b) predicted nighttime scenario in terms of different severity levels.**

b) Daytime Scenario (at 10:00 am)

Daytime scenario (at 10:00 am) has also been generated, when most of the people are at their work or educational institutions. Here also it is assumed that 90% population was residing indoors and 10% was outdoors. Figure 13.28(a) depicts that the population of Saltlake, Behala, New Town, Park Circus and parts of Howrah will suffer moderate to high casualty, while Dum Dum will be the extensive sufferers. Therefore, the estimated casualty for daytime scenario reveals that more than 198,450 persons will suffer from minor injury, followed by ~20,000 persons suffering from medium injury while ~62,761 persons will be critically injured as depicted in Figure 13.28(b). Approximately 17,746 persons from different localities will die under the futuristic hazard condition for the City.

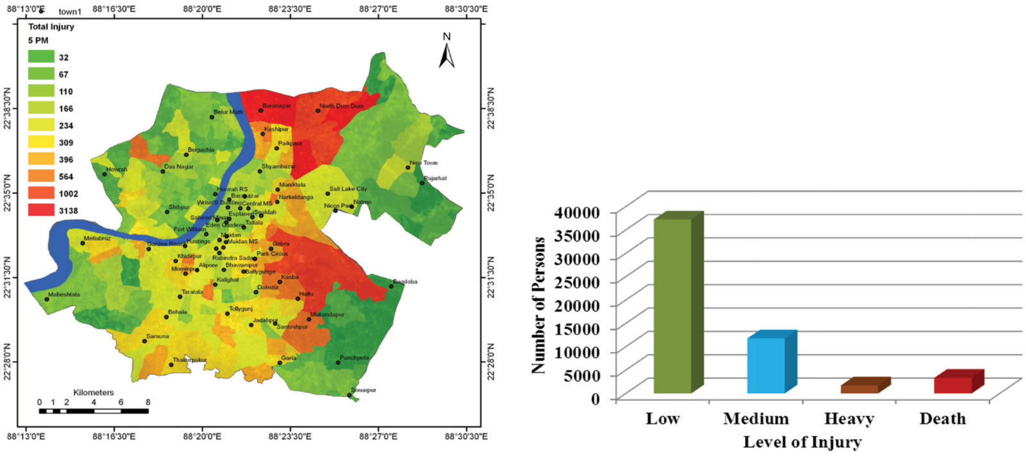


(a) (b)

Figure 13.28 **(a) Distribution of injured population at daytime (at 10:00 am), and (b) predicted daytime scenario in terms of different severity levels.**

c) Commuting Time Scenario (at 05:00 pm)

The scenario has been generated for the commuting time *i.e.* the rush hour by assuming that maximum number of people was outdoors (64%). It reduces the chances of casualty by only building damage and generates the minimum casualty scenario for the hazard in question. Figure 13.29(a) depicts that the population at Saltlake, Behala, Thakurpukur, New Town, Tollygunge and part of Howrah will suffer moderate to high casualty, while Dum Dum will suffer the most. The population distribution for five types of severity level are depicted in Figure 13.29(b) from which it is evident that ~37,215, ~11,767 and ~1,685 persons will have injury in terms of minor, medium and critical respectively, while ~3,326 persons will die.



(a) (b)

Figure 13.29 **(a) Distribution of injured population at commuting time (at 5:00 pm), and (b) predicted commuting time scenario in terms of different severity levels.**

13.2.3.3 Economic Loss Assessment due to Structural Damage

The main purpose of earthquake loss assessment studies is to generate reliable estimates of expected structural damages as well as the economic and social losses that are integral to the damages either in a direct or indirect way. To compute the total economic loss caused by the damage to a certain model building type, specific construction values are essential. Here the estimated building damage is converted to economic loss by using the available inventory database, including the floor area, construction cost estimates, *viz.* the amount of money (in Rupees) per square meter provided by the local authorities. The economic loss of a building is mainly dependent on the building type, occupancy class and the structural damage state. 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 maximum probable hazard is ~ 231 billion Rupees for the city of Kolkata only from building damage point of view. The map in Figure 13.30 shows that Saltlake, Baranagar, North Dum Dum, Garden Reach and part of Central Kolkata will suffer the maximum economic loss.

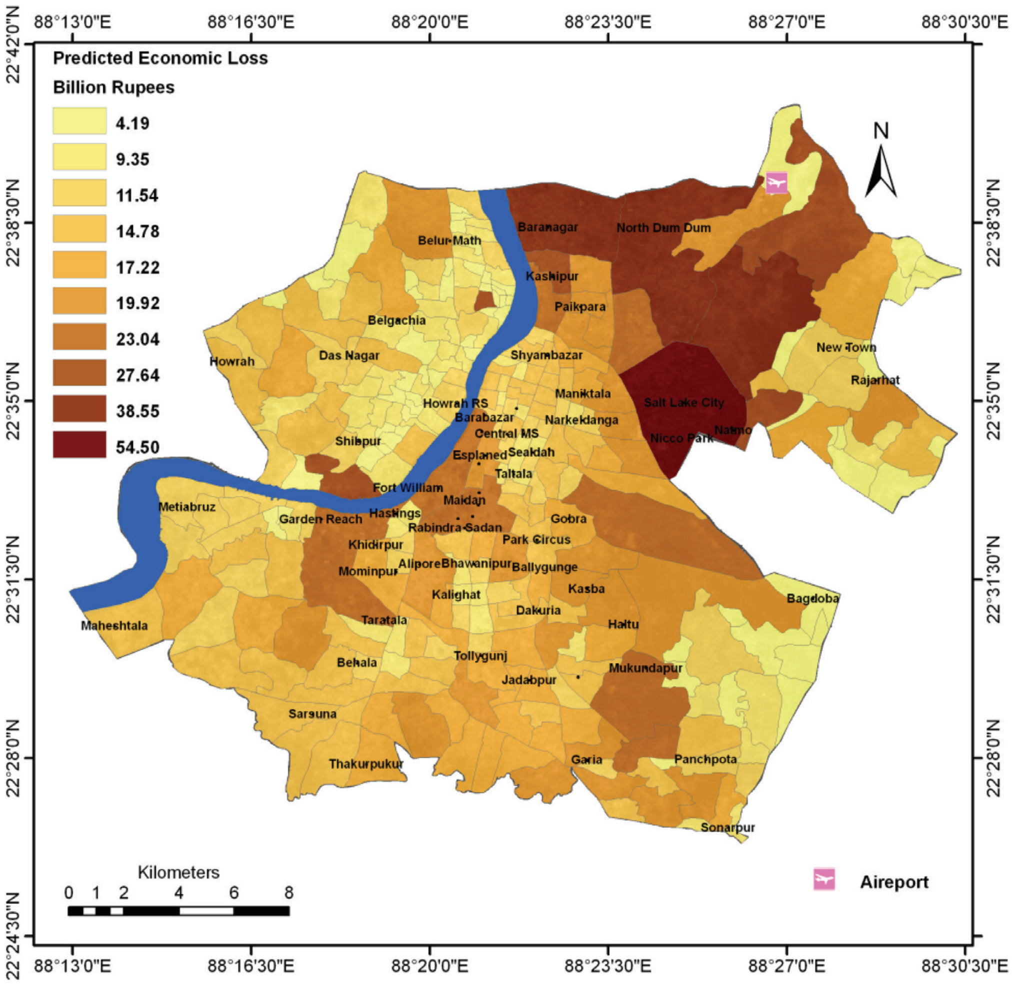


Figure 13.30 Economic loss estimation for the probable maximum hazard in Kolkata.

13.3 Damage and Loss Estimation using HAZUS

HAZUS generates site-specific loss estimation based on ground acceleration, ground failure and census tract (here: geounit) for lifeline facilities and essential utilities in the region using Capacity Spectrum Method. It produces quantitative estimates of damage, functionality and economic loss of selected facilities. Estimation of functionality includes restoration time for essential facilities *viz.* schools, hospitals, police stations and fire stations. HAZUS uses six analyses "modules" for the estimation of consequences, *viz*. Potential Earth Science Hazard (PESH), Structural Inventory, Direct Physical Damage, Induced Physical Damage, Direct Socio-economic Loss and Indirect Economic Loss. In the present study, HAZUS is adopted for Direct Physical Damage and economic loss estimation associated with essential facilities and transportation network (highway, bridge, bus terminals, ferry and railway). Modules used for the present study have been depicted in Figure 13.31. Site class and liquefaction maps have been considered for both the ground motion and ground failure estimation of the City. To generate the probabilistic scenario of this seismically active region PGA, PSA at 0.3 sec and 1 sec have been considered from Chapter 8 in section 8.3.

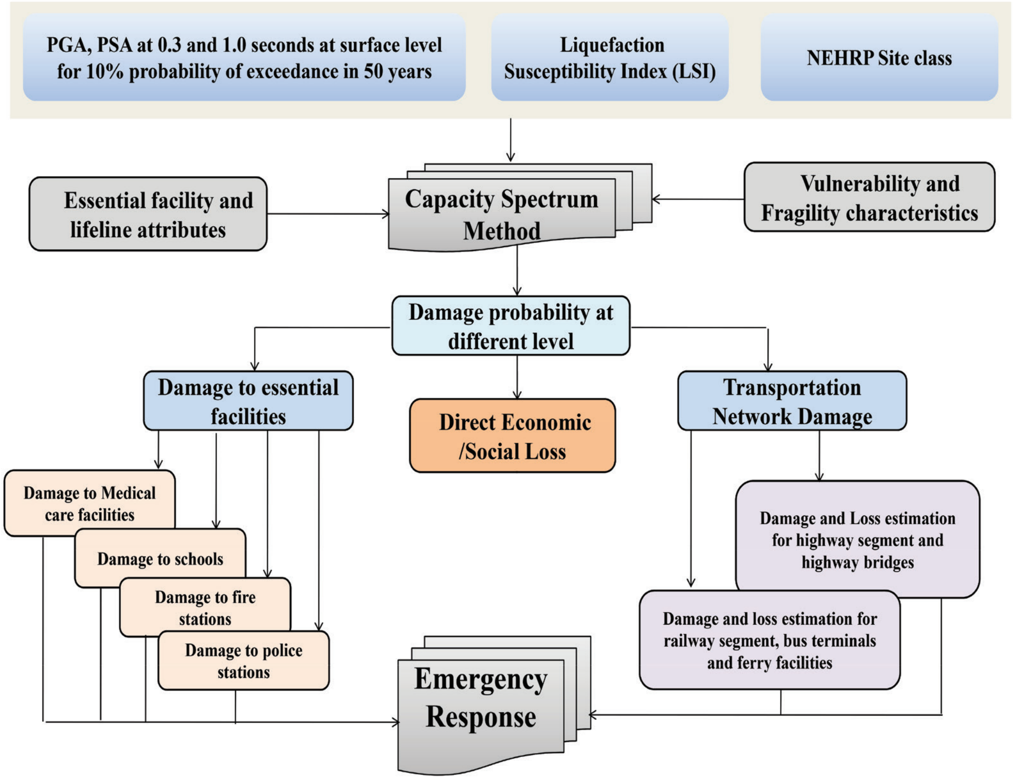


Figure 13.31 Vulnerability and Loss assessment modeling (Modified after FEMA, 2000 and Sousa *et al.*, 2004).

13.3.1 HAZUS Methodology

The basic methodology of HAZUS is Capacity Spectrum Method, which is already discussed in Section 13.2 and is associated with Potential Earth Science Hazard (PESH) and inventory module to provide a complete damage and loss Scenario for essential facilities and lifeline utilities of the city of Kolkata.