Economic Loss of Dhaka Due to an Earthquake of Intensity VIII

Mehedi Ahmed Ansary

In this study, economic loss estimation for buildings at Dhaka was predicted for a scenario earthquake of intensity VIII, based on the experience of 1897 Great Indian earthquake of magnitude 8.7. In the first phase of the study, a building inventory methodology for the city of Dhaka was developed. This involved development of a questionnaire format for the inventory, selection of survey sites, survey were undertaken by the methods of interviews and visual inspection. Their results helped to understand the nature and characteristics of the existing buildings of the city. This building inventory together with the existing census data were then used for damage estimation of buildings and consequent human casualty. For human casualty estimation a morbidity model suggested by Coburn and Spence was used. Finally economic loss estimation was estimated using the damages expected to be suffered due to the scenario event.

INTRODUCTION

The 2001 Gujarat Earthquake in India revealed the vulnerability of "non-earthquake-proof" cities and villages in the Indian subcontinent. In 1897, an earthquake of magnitude 8.7 (recently modified by Ambraseys (2000) to be 8.0) caused serious damages to buildings in the northeastern part of India (including Bangladesh) and 1542 people were killed. Recently, Bilham et al. (2001) pointed out that there is high possibility that a huge earthquake will occur around the Himalayan region based on the difference between energy accumulation in this region and historical earthquake occurrence. The population increase around this region is at least 50 times than the population of 1897 and cities like Dhaka, Kathmandu, Guwahati have population exceeding several millions. It is a cause for great concern that the next great earthquake may occur in this region at any time. According to a report published by United Nations IDNDR-RADIUS Initiative, Dhaka and Tehran are the cities with the highest relative earthquake disaster risk

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(Cardona et al., 1999). Dhaka metropolitan area is the capital of Bangladesh and the center for economy, commerce, politics and society, with a large population of more or less 10 million (BBS, 2001). Once a great earthquake occurs, Dhaka will suffer immense losses of life and property and will not be able to function as the capital of Bangladesh.

During the present study, earthquake hazard for Dhaka was reviewed, a building inventory was developed for the first time and building damage and its economic value were estimated. The ultimate purpose of this earthquake disaster analysis is to recognize the phenomena involved when an earthquake occurs in the existing active faults of Bangladesh and the surrounding region in the future. Based on the disaster scenario, the disaster prevention plan can be established. The damage estimation of buildings, which cause not only the loss of property but is also hazard to human life, was also highlighted here. Finally their economic consequence for Dhaka was forecasted.

SEISMIC SOURCE ZONES AND SEISMICITY

The seismic hazard is typically determined using a combination of seismological, morphological, geological and geotechnical investigations, combined with the history of earthquakes in the region. Bolt (1987) analyzed different seismic sources in and around Bangladesh during the feasibility stage of Jamuna bridge construction. Bolt identified four major sources of earthquakes: (i) Assam fault zone, (ii) Tripura fault zone, (iii) Sub-Dauki fault zone and (iv) Bogra fault zone. Figure 1 shows some of the active faults which are situated in and around Bangladesh.

Reliable historical data for seismic activity affecting Bangladesh is available only for the last 450 years (Gupta et al., 1986). Recently developed earthquake catalogue for Bangladesh and surrounding area (Sharfuddin, 2001) showed that sixty six earthquakes with $M_s \geq 4.0$ occurred from 1885 to 1995 within a 200 km radius of Dhaka city. The most prominent historical earthquakes affecting Dhaka is listed in Table 1.

Bangladesh National Building Code (1993) placed Dhaka in Seismic Zone 2 with PGA value of 0.15g (where g is acceleration due to gravity). The seismic zones in mentioned national code were not based on analytical assessment of seismic hazard and were mainly based on the location of historical data. An updated seismic zoning map based on analytical study was recently developed (Sharfuddin, 2001). This zoning map was based on consistent ground motion criterion such as equal peak ground acceleration levels. Based on the philosophy behind the seismic zoning and experience from recent earthquakes, it can reasonably be assumed that a major earthquake event in Dhaka region is capable of higher damage than that assumed in the existing zoning map (BNBC, 1993).

Figure 1

Isoseismal map of 1897 Great Indian earthquake

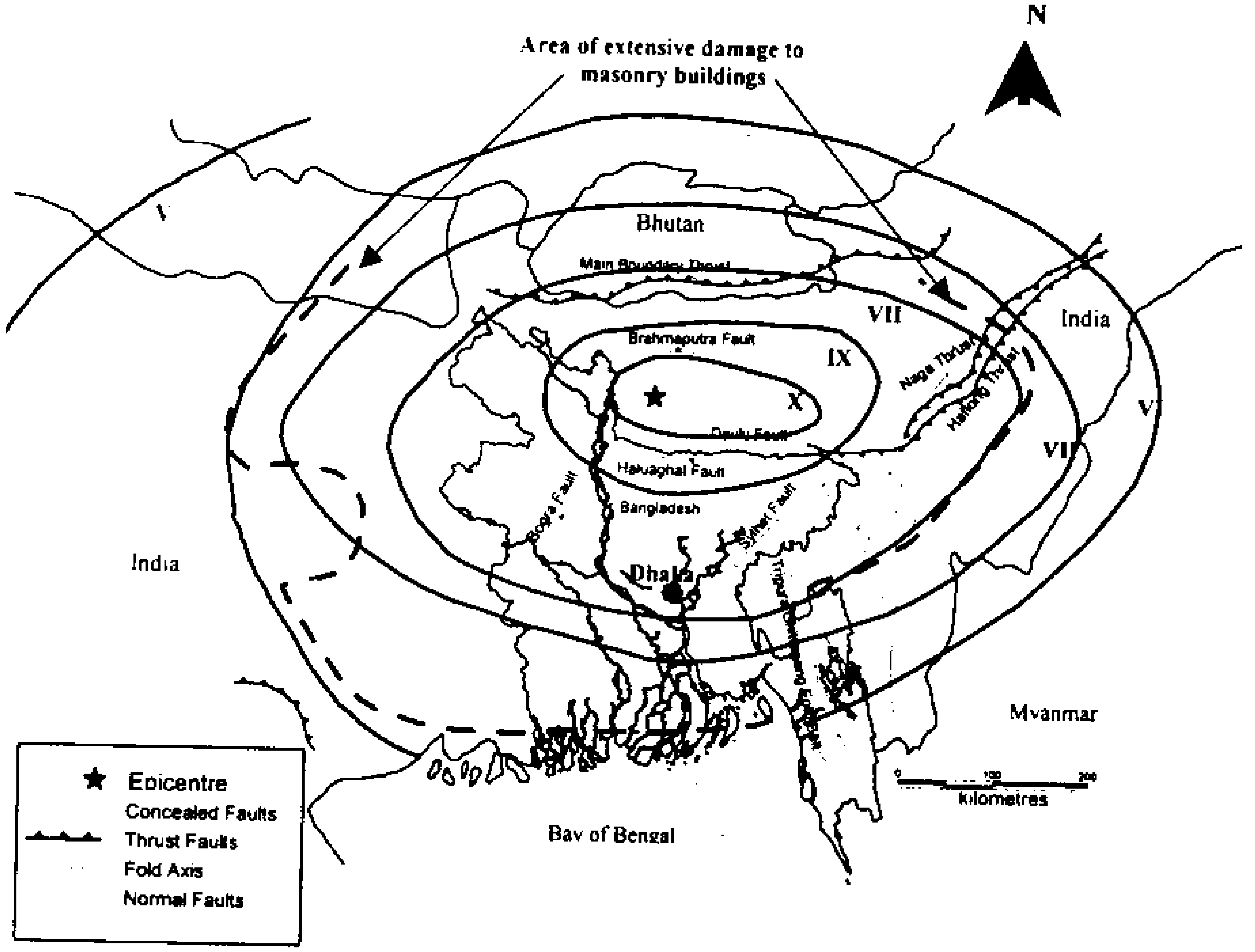

Table 1

Magnitude, EMS intensities and distances of some major historical earthquakes around Dhaka

Name of the earthquake	Magnitude	Intensity at Dhaka	Distance (km)
1869 Cachar	7.5	V	250
1885 Bengal	7.0	VII	170
1897 Great Indian	8.7	VIII+	230
1918 Srimangal	7.6	VI	150
1930 Dhubri	7.1	V+	250

Earthquake Scenarios and Associated Probabilities

Due to the non-availability of seismo-tectonic data on lineaments and their level of activity, scenario events were estimated using earthquake catalogues. The earthquake history of Dhaka presented in Table 1 shows evidence of damaging earthquakes at frequent intervals; there were already a few earthquakes with intensity V+ damage during the last 200 years. Based on historical data, it is conceivable that the Dhaka region may experience earthquakes with damage greater than intensity VIII, the level assumed based on 1897 Great Indian earthquake (Oldham, 1899) (see Figure 1). In this study, an earthquake of maximum EMS intensity (Grunthal, 1998) VIII was used for damage estimation.

Intensity attenuation law developed recently for Bangladesh and surrounding region (Equation 1) by Ansary and Sabri (2002) was used for estimating intensities of sixty-six earthquakes within a 200 km radius of Dhaka and Gutenberg-Richter recurrence relationship was developed.

$$1=3.378+1.283(Ms)-0.0007483(R)-4.9(\log R)\pm0.93P \qquad (1)$$

Annual probability of occurrence for the three scenario earthquakes was then estimated using the parameter of the Gutenberg-Richter recurrence relationship. The probability of exceedance in a design life of 50 years for EMS intensity VIII was 57 %.

For the present analysis, a GIS based map of Dhaka was developed based on 1:20000 scales Survey of Bangladesh map published in 2001. For the GIS analysis MapInfo software was used. Figure 2 shows the geological map of Dhaka based on the above GIS map. The Madhupur clay and old natural levee areas (termed as Madhupur Clay) were assumed to be non-liquefiable and the rest of the area, i.e., flood plain, active natural levee and abandoned channel areas (termed as Flood Plain) were assumed to be liquefiable.

DHAKA'S GROWTH AND POPULATION

Dhaka stands on the northern bank of the river Buriganga and about several kilometers above its confluence with the Dhaleswari River. The city, which started in the 1600 AD on a small place on the bank of river Buriganga, continued to expand mainly in the northward direction along the tableland (Madhupur clay) during subsequent times. Beels and depressions on the east, west and south, which constitute flood plains of the Jamuna and Meghna rivers, restricted growth in these directions. The growth of the urbanized areas of Dhaka City through different periods is shown in Figure 3 (Siddiqui, 1990).

Dhaka at present is one of the fastest growing cities in the world. The population of the Dhaka was around 0.9 million in 1700, around 0.2 million in 1800, around 0.1 million in 1900 and around 6 million currently. In the last 40 years, the population of the city was almost doubled. The location as well as socio-political context of Dhaka favoured and shall favour rapid growth in the city's population. Better economic opportunities attracted people of all classes towards Dhaka. Rural poverty also pushed people to Dhaka for findings ways and means for survival.

For this study, thana (administrative unit) was adopted as the basic geographical reference (geo-code) for the loss model. Dhaka at present is divided into twenty-two thanas and ninety wards. Table 2 presents population data and housing data of these twenty-two thanas and also two other thanas, which are within the city areas but officially, fall in other district area. Figure 4 presents the population density map of Dhaka.

BUILDING INVENTORY SURVEY AND RESULTS

The detailed building inventory survey was discussed in a separate paper (Ansary and Meguro, 2003). Here some salient features relevant to this study were presented.

Selection of Sample Sites

Dhaka city has ninety wards. Among these, eight wards (ward number 73, 74 and 77 of Sutrapur thana; ward number 47, 48 and 49 of Dhanmondi thana; ward number 14 and 16 of Kafrul thana) were selected based on their settlement age and locations. These are widely apart and represent the different settlement pattern of the city. Figure 4 shows the location of these wards in Dhaka city. The main target was estimating the likely building damage due to the scenario earthquakes with a certain level of ground-shaking: how the buildings are constructed and the likely response of the buildings to such shaking. The building inventory survey covered mostly urban and partly semi-urban in nature. It also covered the commercial and the industrial (light industry) areas.

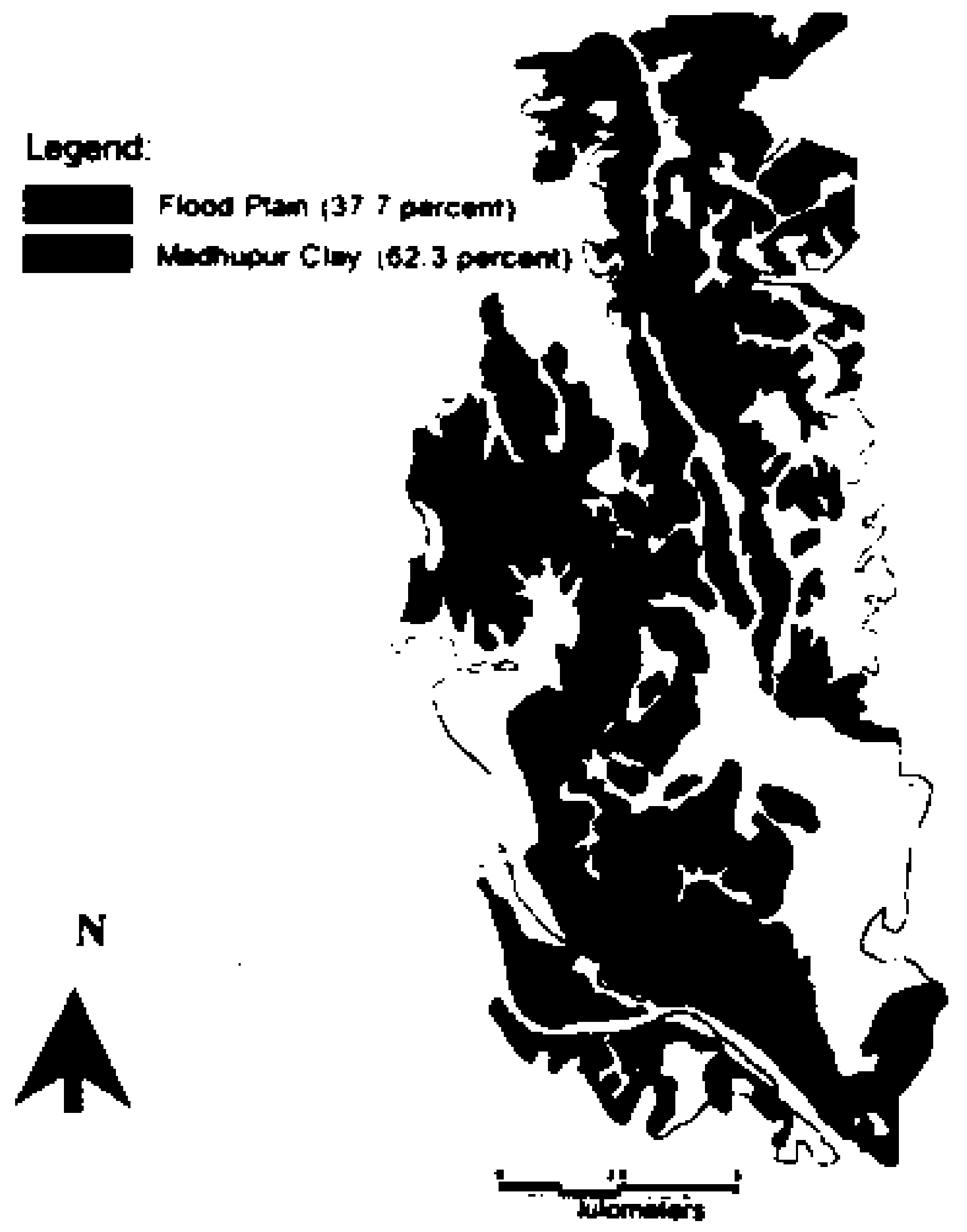

Figure 2 Geological map of Dhaka

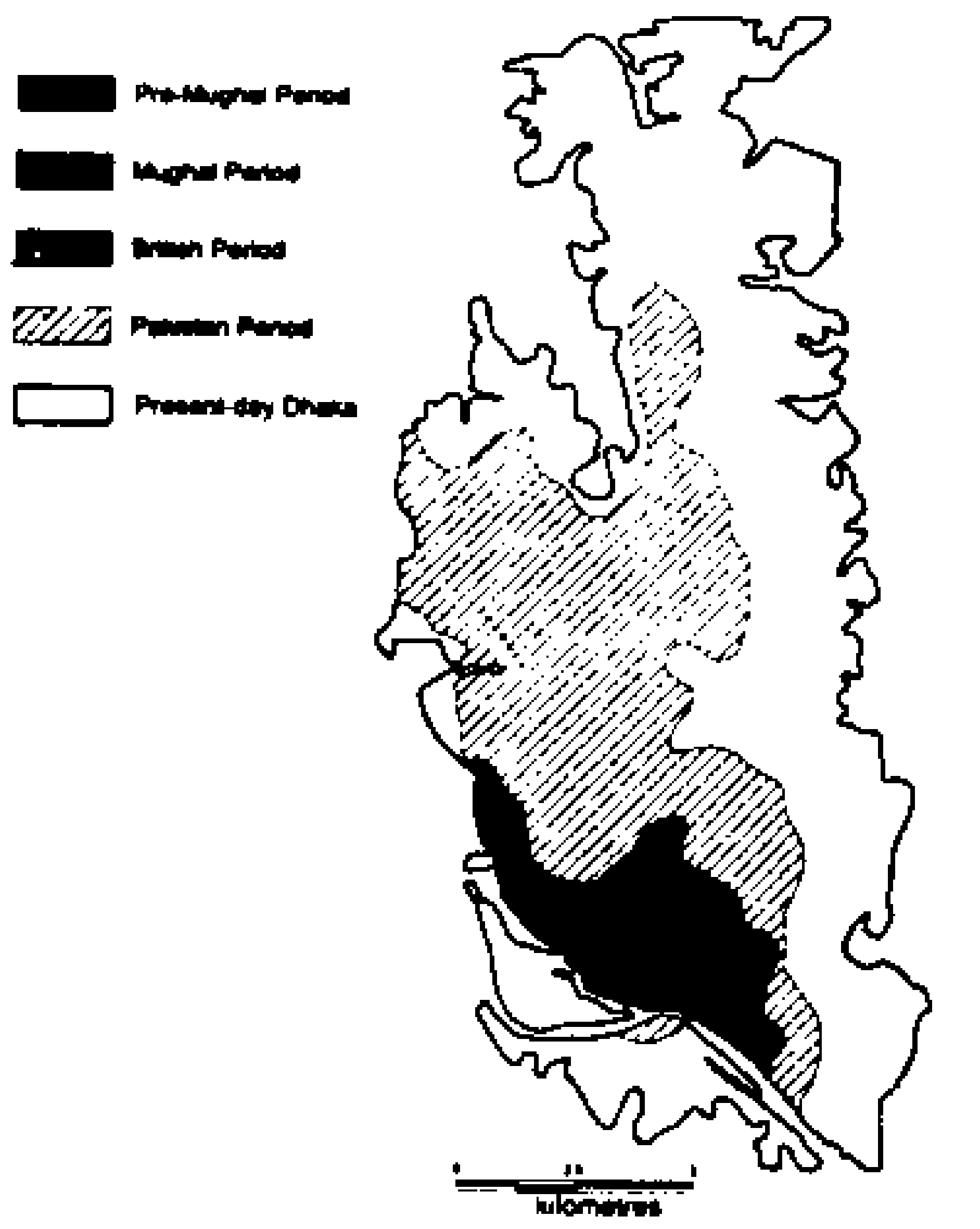

Figure 3 Growth of Dhaka city through different periods

Table 2
Thana name, population density, thana area, number of housing units for Dhaka

Thana Name	Population Density	Thana Area (sq. km)	Number of Housing Units
Airport	13333	10.08	16392
Baddha	30000	10.79	39498
Cantonment	30000	14.66	50643
Demra	30000	5.64	20663
Dhanmondi	36667	4.91	20728
Gulshan	30000	9.06	31286
Hazaribag	60000	2.45	17922
Kafrul	43333	5.34	28228
Kamrangirchar	23333	3.43	13859
Khilgaon	36667	7.59	32052
Kotwali	66667	2.24	17771
Lalbag	66667	3.38	26787
Mirpur	43333	10.07	50255
Mohammadpur	60000	7.87	54397
Motijheel	36667	4.9	15857
Pallabi	43333	8.79	43872
Ramna	36667	6.98	22617
Sabujbag	43333	2.98	15749
Shyampur	43333	4.14	21342
Sutrapur	66667	3.79	30040
Tejgaon	30000	9.82	35934
Uttara	16667	18.42	35355
Tongi	23333	5.33	21550
Keraniganj	23333	8.27	33445

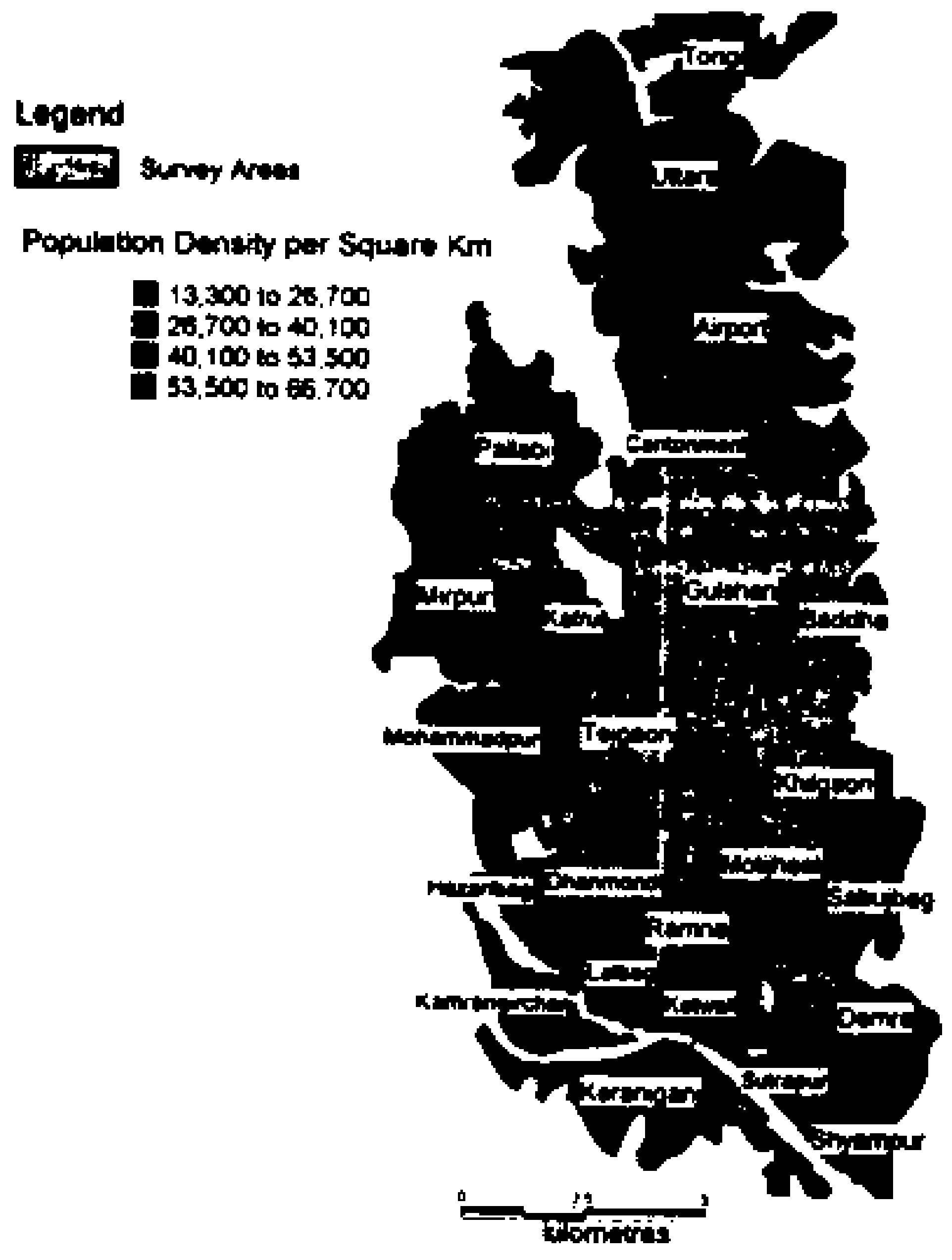

Figure 4 Population density map of Dhaka

Building Typology and Classification

The building inventory survey helped to classify all buildings in Dhaka into five types based on their definition in European Macroseismic Scale (Grunthal, 1998). Table 3 shows the description of each typology.

Table 3

Definition of building typologies in Dhaka

No.	Types	Description
1	EMSB1	1-storied brick masonry of fired bricks with cement or lime mortar; roof is either of GI sheet or other materials.
2	EMSB2	2-storied or taller brick masonry of fired bricks with cement or lime mortar; roof is generally made of RCC slab. Some weak and old reinforced concrete frame.
3	EMSC	Reinforced concrete frame with low ductility; designed for vertical load only.
4	EMSD	Reinforced concrete frame with moderate ductility; designed for both vertical and horizontal loads.
5	EMSF	Mainly bamboo, wooden and steel structures.

Number of Stories and Building Area

A majority (60% at Dhanmondi, 46% at Kafrul and 63% at Sutrapur) of the existing buildings is 2-5 storied and about 40% (37% at Dhanmondi, 46% at Kafrul and 34% at Sutrapur) is single-storied. Figure 5 shows the distribution of buildings in the three thanas according to number of stories and floor space.

In the residential areas, RAJUK (Capital Development Authority) generally do not allow structures beyond 6 stories. But from Figure 5, it can be seen that in Dhanmondi and Sutrapur areas less than 1 % is taller than 6-storied. Some of them may be approved by RAJUK and the owner may extend some beyond the approved plan. Each year at least 10 to 20 such structures collapse in Dhaka due to one reason or other. In the newly developed Kafrul area, the percentage is higher (around 2.1%), as there are many Government constructed high-rise housing complexes and offices.

In Dhanmondi area, the average house sizes are comparatively larger than Sutrapur and Kafrul areas, where residents are comparatively affluent. In Sutrapur (which is an old settlement), the house sizes may also be decreasing due to division of the original plot among successors of the original owner. Similar process has also started in Dhanmondi area recently, due to the local custom of succession of property and due to higher price of land there. Most of the old houses are demolished and the developers are constructing luxurious apartment buildings.

The weighted house area and floor space for each of the three thanas were estimated using the following equations.

$$A_j = \frac{\sum_{i=1}^{5} N_i A_i}{\sum_{i=1}^{5} N_i} \tag{2}$$

$$A_{Thana} = \frac{\sum_{j=1}^{7} \left(\left(\sum_{i=1}^{5} N_i \right) A_j \right)}{\sum_{j=1}^{7} \left(\sum_{i=1}^{5} N_i \right)} \tag{3}$$

Where, A_j = weighted area for each storey type (j = 1, 2, 3, 4, 5, 6 and >6 storey)
A_i = middle value of an area in a particular range of Table 4
N_i = number of buildings corresponding to A_i
A_{Thana} = weighted thana house area or floor space

Table 5 presents weighted house area and floor space for the three thanas and their average values and standard deviations.

According to a recent report (www.wmrc.com, 2000), an estimated 30 to 40 percent of Dhaka's population live in slums. Huq-Hussain (1996) reported that floor space per household for slum dweller's is 90 sft for Dhaka. Combining this information, for Dhaka, average floor space for each building is obtained to be 270 m^2. For economic loss estimation purpose, a value 200 m^2 was used for average floor space.

The building inventory data obtained for the three thanas together with BBS (2001) data were utilized for estimation of housing units and their story wise distribution, for the rest of the twenty-one thanas. Table 6 presents thanawise distribution of different building construction types for use in damage estimation analysis.

Figure 5

Distrbution of building types according to number of stories and floor space in three thanas

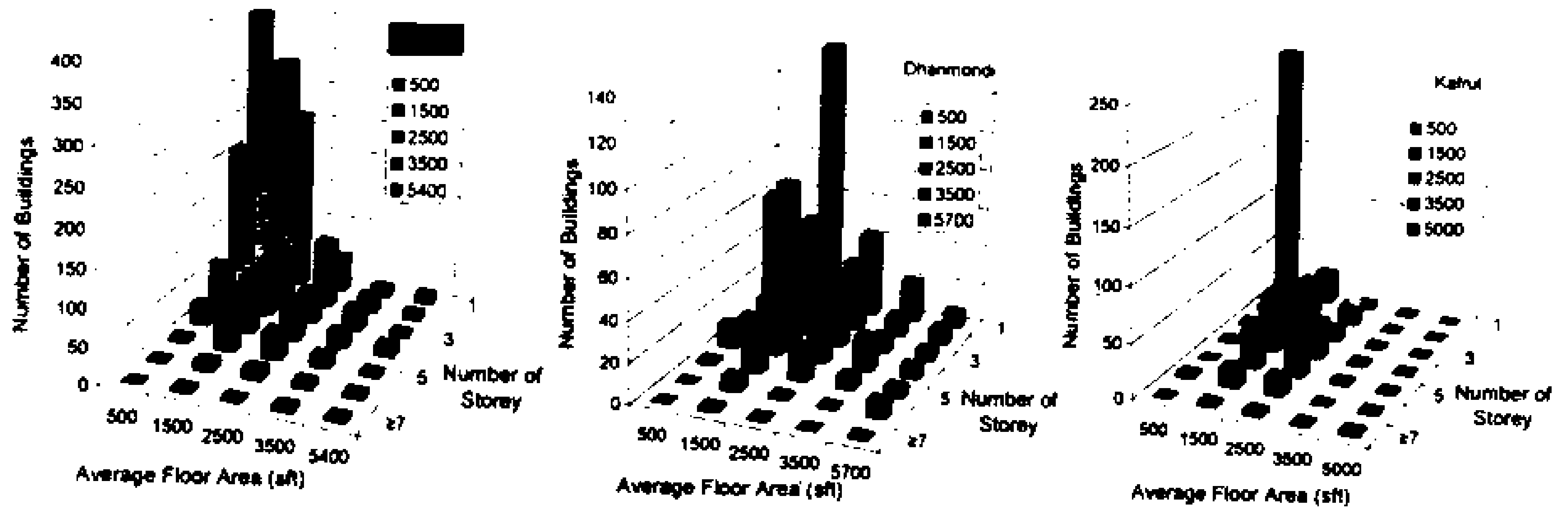

Table 4

Storey and floor space distribution of buildings at three thanas of Dhaka

Number of Stories	Less than 1000 sft(%)			1000 to 2000 sft(%)			2000 to 3000 sft(%)			3000 to 4000 sft(%)			More than and equal to 4000 sft(%)		
	Dhanmondi	Kafrul	Sutrapur	Dhanmondi	Kafrul	Sutrapur	Dhanmondi	Kafrul	Sutrapur	Dhanmondi	Kafrul	Sutrapur	Dhanmondi	Kafrul	Sutrapur
1	8.7	40.0	18.7	19.0	4.8	11.9	5.7	0.7	2.4	2.8	0.3	0.7	1.1	-	0.7
2	1.2	0.5	10.0	7.4	5.9	16.2	4.8	3.0	4.4	1.4	0.2	1.1	1.1	0.2	0.5
3	1.0	0.5	3.0	7.9	5.3	8.1	4.4	1.8	2.1	1.1	0.3	1.5	0.7	0.2	0.3
4	1.6	0.3	1.3	10.9	8.6	4.2	5.3	5.8	2.4	2.3	0.5	1.0	0.8	0.3	0.7
5	0.3	-	0.3	3.7	5.8	3.0	2.3	5.5	1.7	0.8	0.5	0.7	0.7	0.3	0.2
6	-	0.7	0.1	1.0	2.8	0.6	0.3	2.8	0.7	0.1	-	0.4	1.1	0.3	0.3
> 6	-	-	-	0.3	0.5	0.2	0.1	0.7	0.1	-	0.3	0.3	0.1	0.6	0.2

Table 5

Weighted house area and floor space of three thanas

Thana Name	Weighted House Area		Average House Area		Weighted Floor Space		Average Floor Space	
	(sft)	(m^2)	(sft)	(m^2)	(sft)	(m^2)	(sft)	(m^2)
Dhanmondi	2008	186.6			5555	516.4		
Kafrul	1394	129.6	1645	152.9	5027	467.3	4897	455.2
Sutrapur	1534	142.6	(σ = 263)	(σ = 24.4)	4108	381.8	(σ = 598)	(σ = 55.6)

DAMAGE ESTIMATION OF BUILDINGS AND HUMAN CASUALTY

Vulnerability Function

In this study, fragility curves for the buildings in Dhaka were prepared by calibrating the existing fragility curves for Indian buildings prepared by Arya (2000) and for Nepalese buildings prepared by Bothara et al. (2000). There exist a number of fragility curves for different types of structure and different earthquake intensities (Kircher et al., 1997; Fah et al, 2001; Yamazaki and Murao, 2000; Yamaguchi and Yamazaki, 2000; Bommer et al., 2002; Yoshimura and Meguro, 2003), but according to the author's experience, the Indian and Nepalese curves are most suitable for Bangladeshi structures. Figure 6 present the fragility curves for EMSB1, EMSB2, EMSC, EMSD and EMSF type structures.

Neither Arya (2000) nor Bothara et al (2000) mentioned the types of damages (i.e., collapsed or heavily or moderately damaged) to be estimated using those fragility curves. Segawa et al. (2002) used those curves after some calibration and quoted those curves to be developed for heavily damaged structures. For this study, based on some previous findings from damaging earthquakes in India (Arya, 2000; Jain et al., 2002; NSET and DEQ-UOQ, 2000), it was assumed that complete (damage grade G5) and partial collapse (damage grade G4) structures comprise 25% of EMSB and EMSC damage, heavily damaged structures (damage grade G3) comprise 40% of EMSB and EMSC damage, moderately damaged structures (damage grade G2) comprise 15% of all type total damage and low damaged structures (damage grade G1) comprise 20% of all type total damage.

Calculation and Integration of Losses

Several researchers summarized loss estimation methodology quite well (such as Kircher et al., 1997; Bendimerad, 2001; Bommer et al. 2002). The steps in the computation of earthquake losses used in this study are shown diagrammatically in Figure 7.

Different researchers (Arya, 2000; Fah et al., 2001; Bommer et al. 2002) defined different damage ratio (expected cost of loss / rebuilding cost) values for buildings. In this study for ease of calculation, for partial to total collapse 100% damage ratio, for heavy damage 40% damage ratio and for moderate damage 15% damage ratio were assumed.

For calculating loss in the city, the summation of Equation (4) was carried out.

$$L = \sum_i \frac{V_i}{N_i} \; (N_i P_i) \; Dr_i \tag{4}$$

where L is the total monetary value of the loss in the geo-code, V_i is the total reconstruction cost of buildings of class i, N_i is the total number of buildings of class i, P_i is the proportion of buildings of class i affected [these values were taken from fragility curves of Figure 6], and Dr_i is the damage ratio for buildings of class i. V_i / N_i gives the average reconstruction cost per building and $N_i P_i$ gives the number of affected buildings. N_i for each class derives from the building inventory data; the P_i is calculated by the loss modeller for each geo-code and earthquake. Values of V_i were derived from recent construction values for Dhaka. In this study, Dr values as mentioned earlier were used, for all building types in the absence of detailed local data on claims rates for the different damage states of distinct building types.

Building Damage

The intensity variation map is the same as the geological map of Dhaka as presented in Figure 2. Maximum intensity of the scenario earthquakes was assigned to the flood plain area (37.7 %) and one degree less intensity was assigned to the rest of the area with Madhupur clay (62.3 %). Damage ratios for each thana were obtained for the scenario earthquake with maximum intensity of VIII using the intensity variation as defined earlier and the fragility curves of Figure 6. In total, on an average 28% of buildings were estimated to be damaged by intensity VIII earthquake. On the other hand, for intensity VIII earthquake, thana wise damage distribution varies between 16 to 40%. Figure 8 presents thanawise damage ratios for intensity VIII earthquake. Thanas, which are situated in southeastern part of Dhaka showed greater building damage ratio, this result is consistent with the existing soil condition in those areas.

Figure 9 presents the average damage ratio for different building classes for a scenario earthquake of intensity VIII. As expected, the damage for EMSB2 type, which comprises two or more storied brick masonry structures, was the highest. This figures show percentage damage of different buildings types within the overall damage.

Table 7 presents total numbers of buildings that may be damaged in Dhaka (based on building inventory data developed for this study) due to the scenario earthquakes. As can be seen, the numbers of buildings that may be damaged are high and their repair and rehabilitation is likely to impose a heavy burden on the economy of Bangladesh.

Table 6
Thana name and distribution of different building construction types in Dhaka

Thana_Name	Construction Type (%) Based on Description Provided in Table 3				
	B1	B2	C	D	F
Airport	39.95	7.05	40	3	10
Baddha	42.5	7.5	39	1	10
Cantonment	33	22	38	2	5
Demra	42.5	7.5	35	0	15
Dhanmondi	30	20	46	2	2
Gulshan	24	16	50	5	5
Hazaribag	42.5	7.5	30	0	20
Kafrul	32.3	5.7	50	2	10
Kamrangirchar	45	5	20	0	30
Khilgaon	30	20	45	0	5
Kotwali	30	30	38	0	2
Lalbag	30	30	35	0	5
Mirpur	30	20	33	2	15
Mohammadpur	30	20	28	2	20
Motijheel	25	25	45	5	0
Pallabi	27	18	42	3	10
Ramna	25	20	45	5	5
Sabujbag	42.5	7.5	40	0	10
Shyampur	30	30	30	0	10
Sutrapur	29	29	35	2	5
Tejgaon	42.5	7.5	36	4	10
Uttara	24	16	48	2	10
Tongi	36	4	38	2	20
Keraniganj	45	5	20	0	30

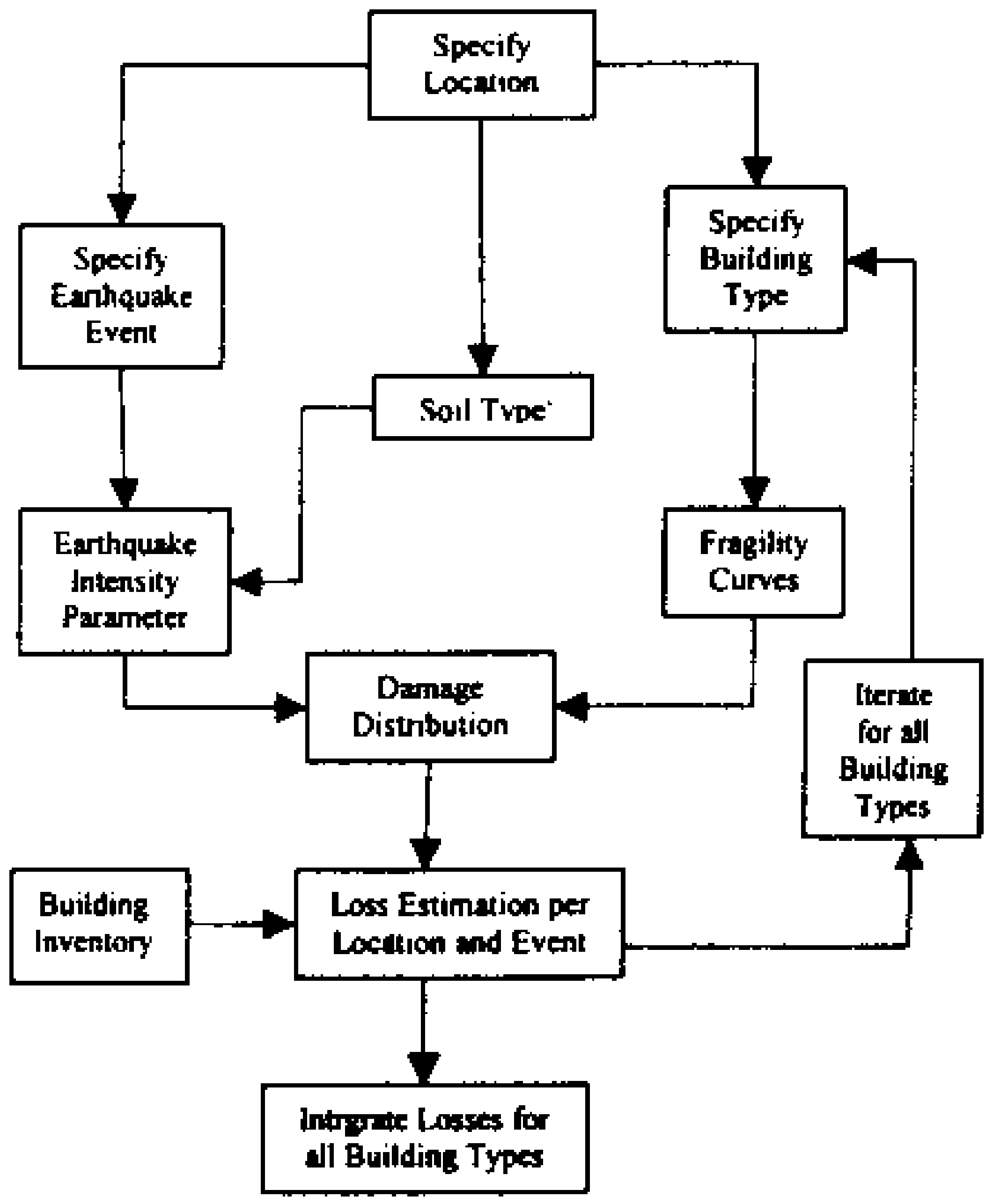

Figure 7 Flow chart of a damage estimation methodology for a given intensity and geocode

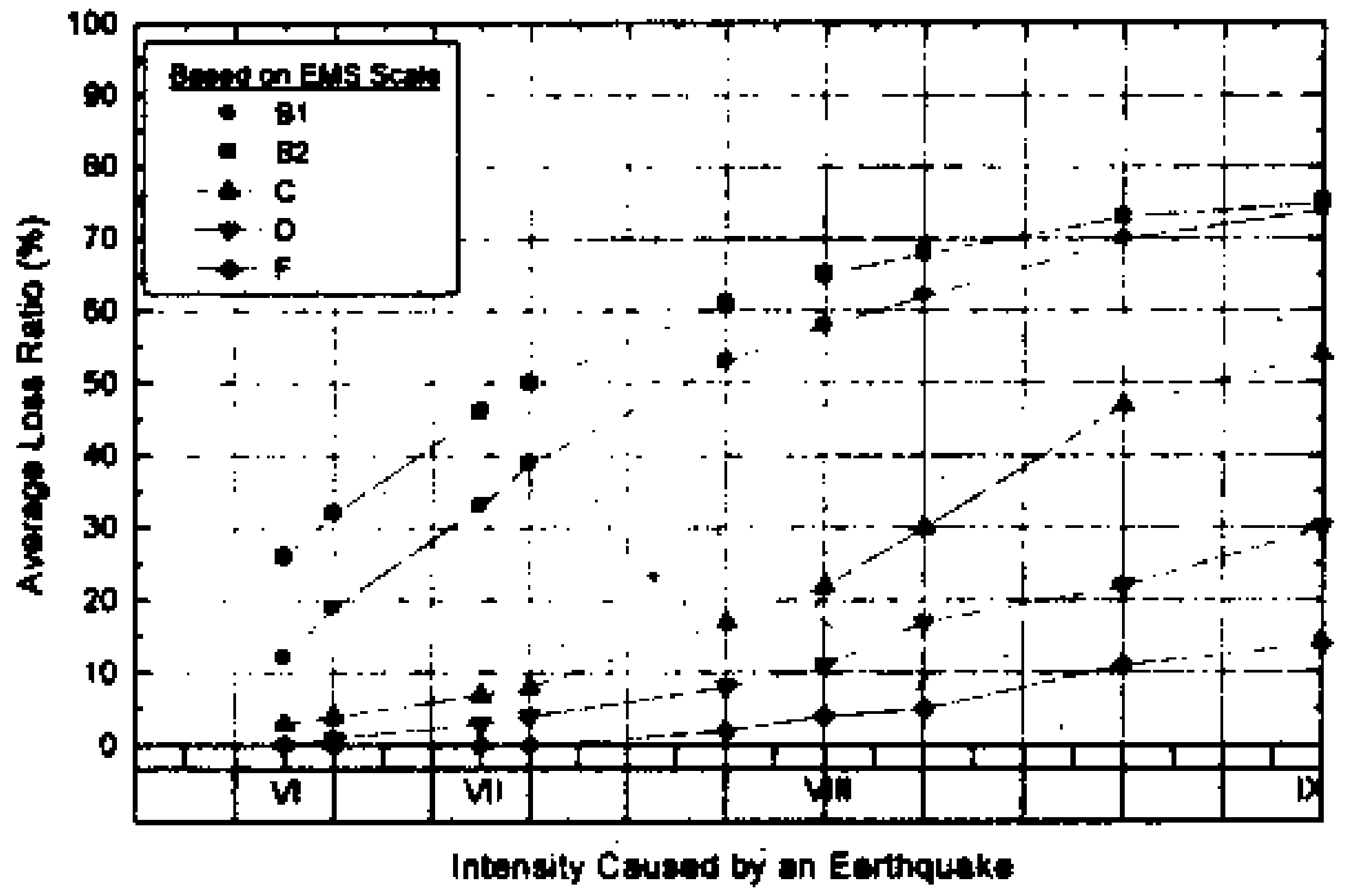

Figure 6 Fragility curves for different building types based on EMS intensity

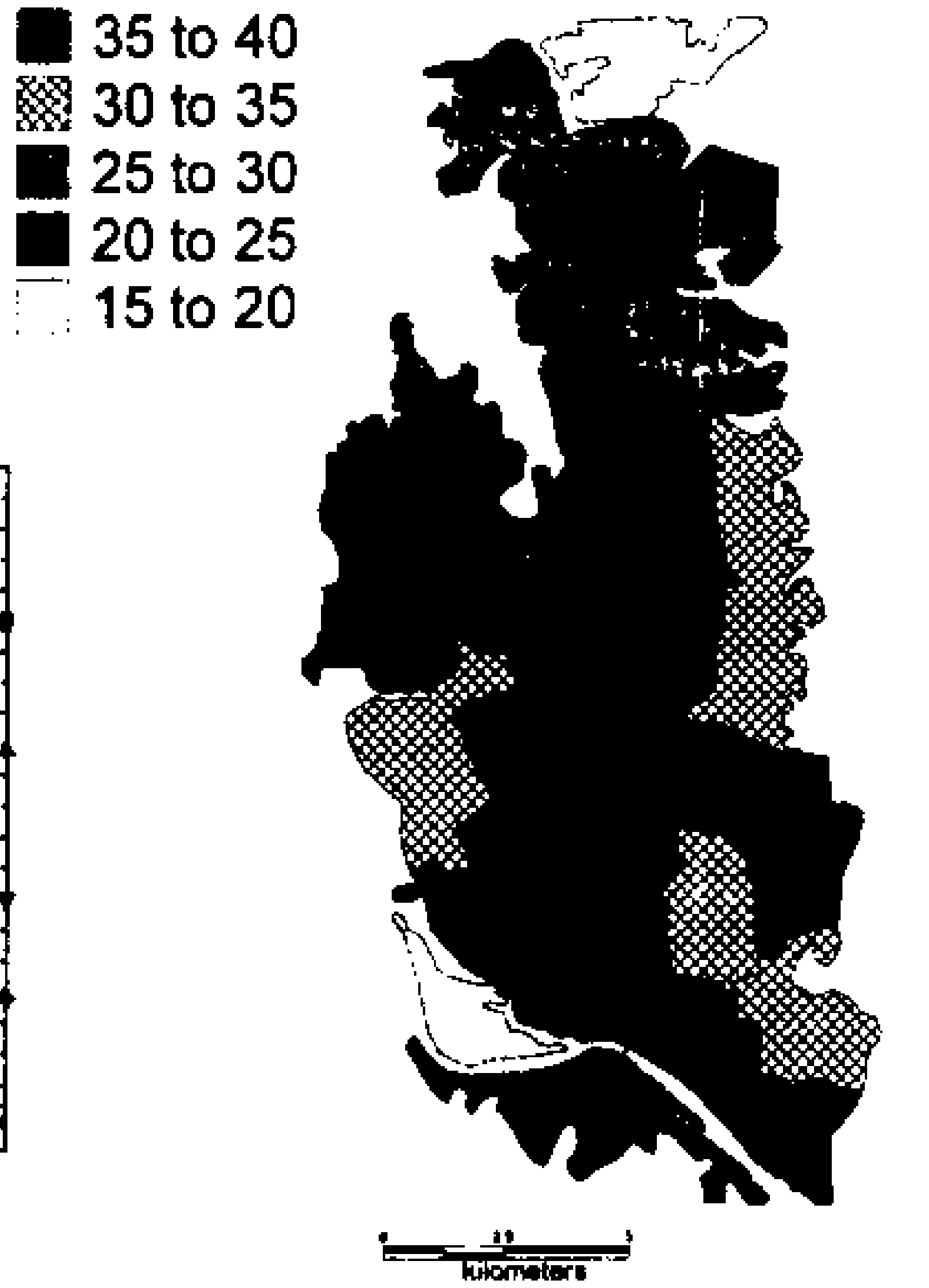

Figure 8 Thanawise average damage ratio of buildings for a scenario earthquake of intensity VIII

It is interesting to note that during the 2001 Bhuj earthquake (maximum EMS intensity X), over 980,000 masonry structures experienced medium to severe damage and 230,000 were collapsed in Gujarat (Jain et al., 2002). Total death toll was around 15,000 and injuries were 170,000. The Bhuj city (EMS intensity IX) located 70 km from the epicenter with a population of only 150,000 experienced around 10,000 deaths, 90% of masonry structures of old Bhuj collapsed and most of the reinforced concrete structures were badly damaged. Even many mid to high rise buildings of Ahmedabad (EMS intensity VII), a city 300 km away experienced collapse and heavy damages. Since Dhaka is a much larger city and the building stock is larger than Ahmedabad and Bhuj, the expected damage will be consequently much higher.

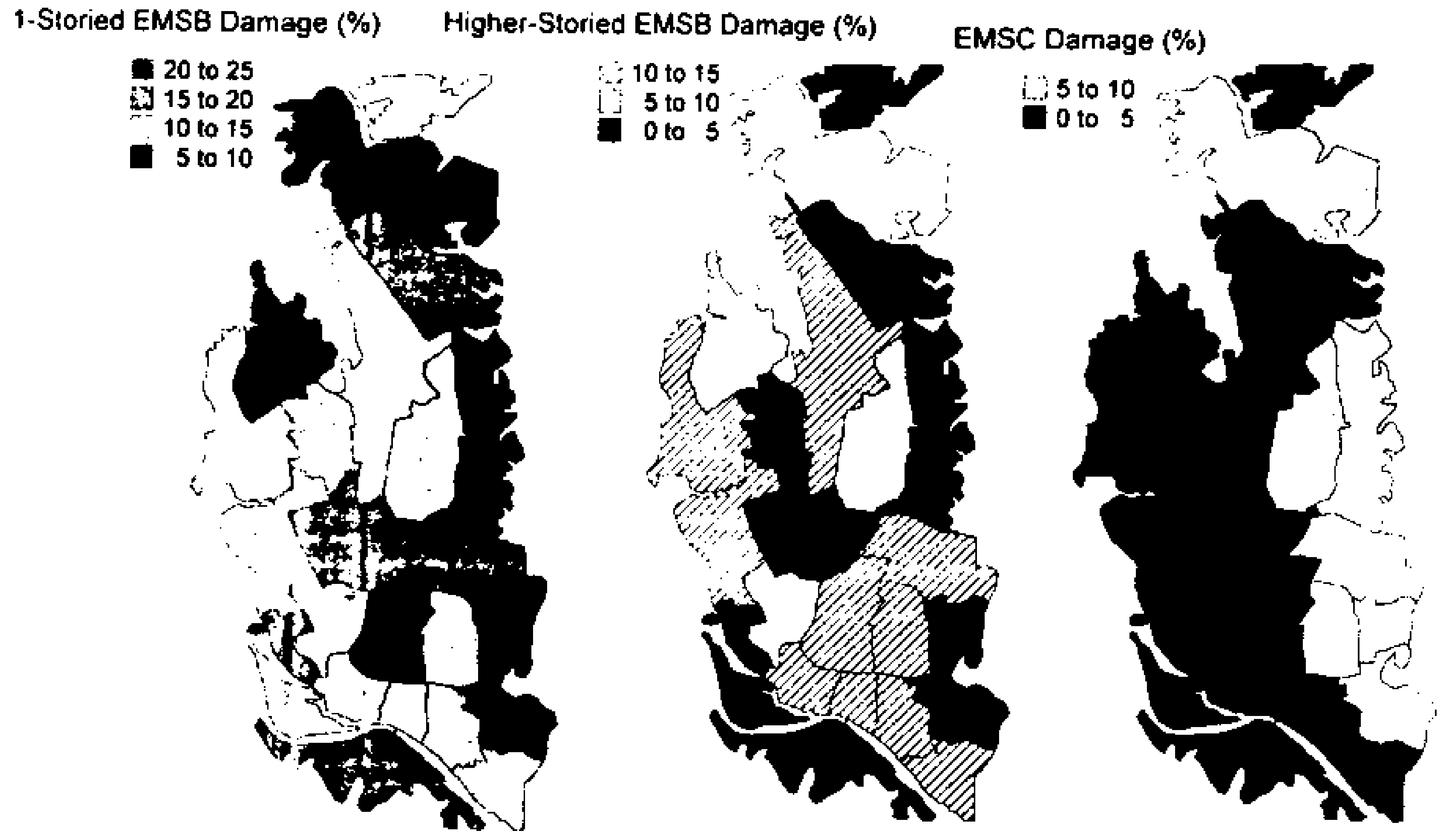

Figure 9 Thanawise average damage ratio for different building classes for a scenario earthquake of intensity VIII

Human Casualty

In order to assess the human casualty levels due to the earthquake, the estimates of average fatality and injury levels were used. Using a mortality prediction model for different categories of structures derived these figures. This prediction model is based on investigation of casualty due to several major earthquakes that occurred during this century (Coburn et al., 1992). The total number of people that may be killed due to damage of each building type can be represented by:

$$Ks_b = D_b * [M1_b * M2_b * M3_b * M4_b] \qquad (5)$$

where D_b is the total number of damaged structures of building type b, M1 is the occupant density and M2 to M4 are conditional probability factors to modify the potential casualty figures. The factor M1 represents the population per building. For this investigation, M1 was taken as 5 (BBS, 2001). M2 is the occupancy of buildings at the time of earthquake. The occupancy cycle proposed by Coburn and Spence (1992) was used. Depending on the time of the earthquake, the occupancy rate can been found from this figure. M3 is the proportion of occupants who are trapped by collapse of buildings. This depends on the type of building. For single-storied masonry structures, this was taken to be 20%, 10% and 5% for intensity IX, VIII and VII, respectively. For multi-storied masonry and reinforced concrete structures, 40%, 20% and 10% for intensity IX, VIII and VII for M3 was considered. M4 is the proportion of occupants who are either killed or injured in the earthquake. It was observed that collapsed multi-storied masonry and reinforced concrete buildings lead to death of a large number of trapped occupants, while collapsed masonry buildings lead to death of relatively small number of trapped occupants. Based on the quantitative information available from several earthquakes (Coburn et al., 1992), M4 was taken as 40% for multi-storied masonry and reinforced concrete buildings, 20% for single-storied masonry buildings for the killed occupants. Again M4 was taken as 50% for multi-storied masonry and reinforced concrete buildings, 30% for single-storied masonry buildings for the injured (both life threatening cases as well as injury requiring hospital treatment) occupants.

The Dhaka building inventory, census information, earthquake hazard and vulnerability data and the mortality information were combined to estimate the number of possible injuries and the corresponding deaths that may occur due to earthquakes of different strengths.

ECONOMIC LOSS ESTIMATION

Damage scenarios for Dhaka city were estimated in the preceding articles. In this article, economic loss estimation for those damages were made and presented in Tables 8. The cost calculations were made based on the following assumptions:

- Rebuilding cost per square meter = US dollar 100
- Partial rebuilding for heavy damage per square meter = US dollar 40
- Repair and retrofit for moderate damage per square meter = US dollar 15
- Subsidy to the family members for one fatality = US dollar 2000
- Medical bills for a hospitalized person = US dollar 400

The results were presented in Table 8, assuming that none of the buildings were retrofitted. The following results were obtained:

For intensity VIII scenario earthquake: The direct losses will amount to US dollar 1.76 billion. Since about 28109 lives may be lost and 47877 houses will be ruined completely, the trauma will be great but less than intensity IX earthquake. The cost of emergency relief will be high, as the direct loss in this case is around 66% of the country's current ADP of Tk. 16000 crore.

Figure 10 presents thanawise estimated economic losses for a scenario earthquake IX.

Tables 8 provide only the direct losses due to earthquakes. There are many more direct and indirect losses due to an earthquake, such as losses due to lifelines, business interruption losses, rental losses, relocation losses, business inventory losses, transport industry loss, lifeline leakage losses, debris removal cost etc. More detailed analysis will be required to ascertain those losses. Due to the limited scope of the current research those losses were kept unaccounted for.

For the 2001 Bhuj earthquake total indirect and direct loss was US dollar 5 billion (5 % covered by insurance), for the 1999 Turkey earthquake it was around US dollar 7 to 40 billion (around US dollar 900 million covered by insurance), for the 1995 Kobe earthquake it was US dollar 100 billion (10 % covered by insurance), for the 1994 Northridge earthquake it was US dollar 35 billion (30 % covered by insurance). Comparing to all these recent damaging earthquakes, the direct economic loss of US dollar 3.08 billion for Dhaka estimated in this study, looks reasonable.

The government should advice Dhaka and other major cities residents through the city development authority or municipality to follow BNBC (1993) guideline for earthquake resistance and obtain earthquake insurance where feasible based on the seismic zoning map of Bangladesh. Otherwise the burden after a catastrophic earthquake of such an economic loss will fall on the government, which under current economic condition will be difficult for the administration to cope with.

The government should also encourage retrofitting of already existing houses and ask the relevant banks or agencies to provide soft loans to the house owners for making their houses earthquake proof. This will save the society from trauma of a large number of death and injuries. In this regard, retrofitting promotion system developed by Yoshimura and Meguro (2003) can be used. According to this system, the government bears a portion of the building repair and reconstruction expenses after an earthquake, if retrofitting is implemented by the owner following the building code prior to an earthquake and in spite of this, the structure is damaged by an earthquake. Yoshimura and Meguro (2003) showed the effectiveness of this system for two cases: one for Shizuoka prefecture, Japan and for Istanbul city, Turkey.

Table 7
Estimated number of buildings damaged and probable injuries and fatalities due to an earthquake of intensity VIII

Thana_Name	Building Damages	Injuries Nighttime	Fatalities Nighttime
Airport	3959	1614	420
Baddha	12921	5366	1397
Cantonment	14670	8887	2343
Demra	6743	2709	705
Dhanmondi	5341	3341	882
Gulshan	8836	5763	1523
Hazaribag	5157	1953	507
Kafrul	5712	2627	687
Kamrangirchar	2519	709	181
Khilgaon	12235	7728	2040
Kotwali	4735	3263	863
Lalbag	7456	5104	1350
Mirpur	13622	8163	2152
Mohammadpur	17351	10091	2659
Motijheel	5130	3584	948
Pallabi	9764	6085	1605
Ramna	6176	4310	1141
Sabujbag	6098	2610	681
Shyampur	6232	4210	1113
Sutrapur	8230	5626	1488
Tejgaon	10169	4007	1041
Uttara	8347	5398	1426
Tongi	3543	1249	323
Keraniganj	8517	2474	634
Total	193463	106871	28109

Figure 10 Thanawise estimated direct economic losses for a scenario earthquake VIII

The Role of Insurance Industry

The insurance industry helps society to recover from natural disasters by bearing part of the cost of the disaster. It also has the potential to play a major role in mitigating the impact of the natural disasters by harnessing market forces to help sway individual decision makers to build earthquake resistant structures in locations at lower risk. While this was not possible in the past, the technology now exists to perform the site-specific analysis of seismic risks (such as shown by Ansary and Sharfuddin, 2003)

necessary for insurance companies to price insurance policies according to their individual level of risk.

By charging higher rates for poor seismic design and construction, the insurance industry would help drive individual property owners to demand that the architects and engineers build structures that can be insured at reasonable expense. Property owners, both individuals and professional developers, could similarly be steered toward better land use planning if premiums were allowed to reflect the different levels of risk associated with different locations (such different soil types and proximity to faults).

CONCLUSIONS

A comprehensive building database compilation methodology for Dhaka and a GIS based seismic damage scenario were presented. The main purpose of building inventory is to assess the nature, distribution and characteristics of existing buildings in a locality. Its results are utilized to clarify the weak as well as strong points of the existing structures, and the results finally used for formulating concrete strategies for improvement, especially for earthquakes vulnerability reduction in the present case. The results also can be used for ordinary administrative purposes like urban planning. Ideally, the building inventory should cover 100% of the existing building stocks. However, various constraints such as paucity of time and lack of funds, institutional capacity and other resources do not permit such 100% inventory in the cities of a developing county. Accordingly, the building inventory survey under the current project had to be contented with the analysis of a limited number of representative samples only. Though the sample number was only 0.5% of the total estimated six hundred and ninety six thousand buildings in Dhaka, this survey provided understandable results describing the features of the buildings and their nature and distribution in the different settlement areas. The result confirmed the appropriateness of the approach of selecting the sample sites. However, the investigation accuracy could have been improved by an increase in the number of samples for this inventory investigation. It can also be concluded that the inventory survey in Dhaka was extremely effective not only because it provided for the first time an objective and comprehensive portrayal of the existing buildings, but also because it developed a building database (in Microsoft Access platform) which can be updated from time to time.

The occurrence of an earthquake of EMS Intensity VIII at Dhaka may lead to massive loss of life and damage of buildings. Depending on the time of the day, from 22000 to 28000 people may perish due to structural collapse and damage in the earthquake. The numbers of serious injuries may also range from 86000 to 107000, possibly placing a very severe strain on the emergency relief and health-care infrastructure. Similarly, a very large number of buildings may be damaged or lost. The direct economic loss estimated for the scenario earthquake with intensity VIII is 1.76 billion US dollar for Dhaka. Compared to other recent devastating earthquakes, the estimates look reasonable. Immediately the government of Bangladesh should advice Dhaka and other major cities residents through the city development authority or municipality to follow guideline for earthquake resistance as provided in the national building code and obtain earthquake insurance where feasible based on the seismic zoning map. Otherwise the burden after a catastrophic earthquake of such an economic loss will fall on the government, which under current economic condition will be difficult for the administration to cope with.

Table 8

Direct economic losses for a scenario earthquake with intensity VIII in Dhaka (night time)

Item	Scenario intensity VIII		
	Physical damage	Loss in US Dollar (million)	% of total loss
Losses of human lives	28109	56.218	3.20
Injuries needed hospitalization	106871	42.748	2.43
Total and partial collapse of buildings (G4+G5): rebuilding is necessary	47877	957.540	54.52
Heavily damaged buildings (G3): major repair and retrofitting needed	76599	612.792	34.89
Moderately damaged buildings (G2): minor repair and retrofitting needed	29019	87.057	4.96
Total losses	**1756.355 Million**		

Note 1: Due to rounding, summation of values may not be equal to 100

Note 2: Tk. = Bangladeshi currency; 1 US Dollar equals roughly Tk. 60; Annual budget of Bangladesh in the current fiscal year is Tk. 16,000 crore (ADP)

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