

Seismic Loss Assessment of Dhaka for Scenario Earthquakes Using A Displacement-based Method

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Abstract— Earthquake loss assessment is very useful for the design of insurance and reinsurance schemes and in the planning of urban/regional-scale emergency response, disaster planning and earthquake protection/retrofitting schemes. Traditionally, vulnerability assessment studies have employed macro seismic intensity scales to represent the ground shaking. But, where the assessment of a structure is concerned it is the displacement that gives an indication of the damage that can be expected and hence the state-of- the-art is now to use in some way the displacement response spectrum to represent the destructive capacity of the ground motion. The application of a displacement-based methodology instead of that of a traditional intensity-based method for loss assessment of Dhaka (the capital as well as political, cultural and economic center of Bangladesh and one of the major cities of South Asia), is thus the focus of this study. A displacement-based earthquake loss assessment methodology (DBELA), developed by applying basic principles of mechanics of materials, is applied to Dhaka and the damage is predicted based on the comparison of displacement capacity of buildings and displacement demand by scenario earthquakes.

Index Terms—displacement, earthquake, loss, response-spectra, sensitivity study.

I. INTRODUCTION

BAKLANDESH, being located close to the plate margins of the Indian and Eurasian plates, is susceptible to earthquakes. In the past, several strong earthquakes have occurred in and around Bangladesh. Some of these earthquakes have caused significant damage to buildings within the country, including Dhaka. In a study by Cardona et al. [1999] on 20 cities of the world, Dhaka appeared to have one of the highest values of earthquake disaster risk index (EDRI) mainly due to its inherent vulnerability of building infrastructure which lacks earthquake resistant features, high population density and poor emergency response and recovery

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capability. Assessment of the seismic vulnerability of the building stock in Dhaka is of growing importance since such information is needed for the reliable estimation of the losses that possible future earthquakes are likely to induce. The outcome of such loss assessment exercises can be used for the design of insurance and reinsurance schemes and in the planning of urban/regional-scale emergency response, disaster planning and earthquake protection/retrofitting strategies.

Traditionally, vulnerability assessment studies including those of Dhaka city have employed macro seismic intensity scales to represent the ground shaking. Crowley et al. [2004a] have discussed the limitations of different current methodologies of seismic loss estimation including that of intensity based methodologies. Where assessment of a structure is concerned, it is the displacement that gives an indication of the damage that can be expected and hence the state-of- the-art now uses the displacement response spectrum to represent the destructive capacity of the ground motion [Calvi, 1999].

II. DISPLACEMENT-BASED EARTHQUAKE LOSS ASSESSMENT (DBELA)

The methodology used herein for seismic loss estimation of Dhaka is based on the comparison of displacement capacity and displacement demand [Crowley et al. 2004a]. The first step of the method is the generation of a random population of buildings which should represent the urban building stock. Monte Carlo simulation is used to generate thousands of buildings, each with different material and geometrical properties (e.g. storey height, beam length, section dimensions, steel yield strain or pier height for masonry structures); the variability of each property is defined a priori using a mean, standard deviation and probabilistic distribution. Once the population has been generated, the period of vibration of each building is estimated using an empirical relationship between the yield period of vibration (T_y) and the height of the building. For reinforced concrete buildings, the following formula, derived by Crowley and Pinho [2004b] for infilled RC European buildings, is adopted:

$$T_y = 0.055H \quad (1)$$

where H is the height in meters. The coefficient of variation of this formula has been estimated as 25%. For masonry

buildings, additional studies are still necessary in order to define a yield period of vibration, hence at present a 20% increase to the period-height equation suggested in Eurocode 8 [CEN, 2003] has been adopted:

$$T_y = 1.2 \times 0.05 H^{3/4} = 0.06 H^{3/4} \quad (2)$$

The displacement capacity of each building in the random building population is then estimated at different limit states of damage (moderate, extensive and complete damage). Formulae for the displacement capacity of a single-degree-of-freedom SDOF representation of the building class have been derived from simple structural mechanics principles. For reinforced concrete buildings, different building classes are defined as a function of the assumed response mechanism; buildings may respond with a global response mechanism (beam-sway), or a soft storey response mechanism (column-sway). Masonry buildings are assumed to have a column-sway response mechanism at the ground floor. The formula for the displacement capacity at the centre of seismic force of the beam-sway mechanism is presented in (3) whilst that for column-sway mechanism (for either RC or masonry) is shown in (4):

$$\Delta_{LS} = \theta_{by} \kappa_1 H + (\theta_{bLS} - \theta_{by}) \kappa_1 H \quad (3)$$

$$\Delta_{LS} = \theta_{cy} \kappa_1 H + (\theta_{cLS} - \theta_{cy}) \kappa_2 h_s \quad (4)$$

where θ_{by} and θ_{cy} are the yield rotation capacities of the beams and columns, respectively; κ_1 is the effective height coefficient (to obtain the equivalent height of the deformed SDOF system); H is the height of the building; θ_{bLS} and θ_{cLS} are the rotation capacities at a given post-yield limit state of the beams and columns, respectively; h_s is the ground floor story height for RC frames and the pier height for masonry buildings; κ_2 is the effective height coefficient of the masonry piers (for RC buildings this is taken as 1).

For reinforced concrete buildings, the calculation of the rotation capacity of the beams and columns and the effective height coefficients for the two mechanisms is further described in Crowley et al. [2004a]. For masonry buildings, the effective height coefficients for buildings of 1 to 6 stories calculated by Restrepo-Velez and Magenes [2004] have been adopted.

An equivalent linearization approach is applied in DBELA and hence for post-yield limit states, if an elastic-perfectly plastic behavior is assumed, the buildings can be modeled using the secant period of vibration, based on the following formula:

$$T_{Lsi} = T_y \sqrt{\mu_{Lsi}} \quad (5)$$

where μ_{Lsi} is the ductility at the limit state in question. The next step in defining the vulnerability of the building stock involves the comparison of the structural capacity of the

buildings with a prediction of the ground motion from a given scenario earthquake.

In DBELA, ground-motion prediction equations are used to define the demand in terms of over-damped displacement response spectra. The damping correction equation presented in the 1994 version of EC8 [CEN, 1994] has been assumed herein following the recommendations given in Priestley et al. [2007]:

$$\eta = \sqrt{\frac{7}{2 + \xi_{eq}}} \quad (6)$$

where η is the correction factor and ξ_{eq} is the equivalent viscous damping, which for reinforced concrete frames has been Priestley et al. [2007], whilst for masonry buildings Restrepo-Velez and Magenes [2004] is used.

For a given displacement response spectrum, the displacement demand for the limit state period of vibration of a given building in the random population can be compared with its limit state displacement capacity (Fig. 1.); the sum of all buildings whose displacement capacity is lower than the displacement demand divided by the total number of buildings gives an estimation of the probability of exceeding a given limit state (slight, moderate, extensive and complete).

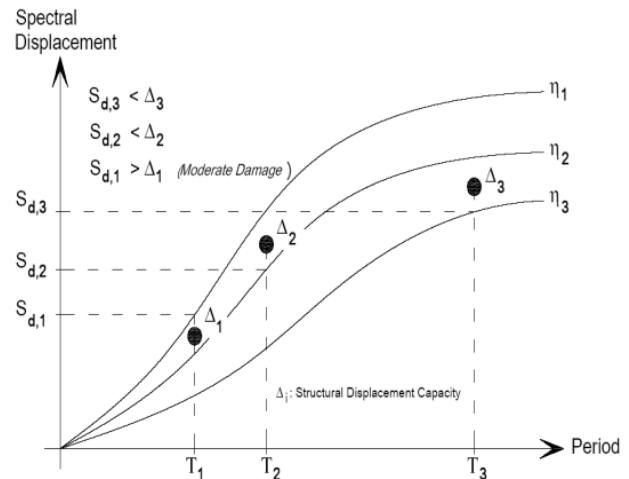


Fig. 1. A displacement-based seismic vulnerability assessment procedure, DBELA [after Bal, 2008].

III. MODEL INPUT & BUILDING PARAMETERS OF DHAKA

A. Geology of Dhaka

Dhaka at present has seven principal thanas (administrative unit) and fourteen auxiliary thanas. It has 130 wards. Dhaka is situated on the southern tip of a Pleistocene Terrace, called the Madhupur Tract. The moisture content and liquid limit result shows that Madhupur clay is normally consolidated to slightly over-consolidated. The clay has intermediate to high plasticity overlain by Dupi Tila formation of medium to coarse sand. The incised channels and depression within the city are

floored by recent alluvial flood plain deposits and is further subdivided into lowland alluvium and high land alluvium. For this study the simplified geological map of Fig. 2 is used for soil type distribution of different thanas.

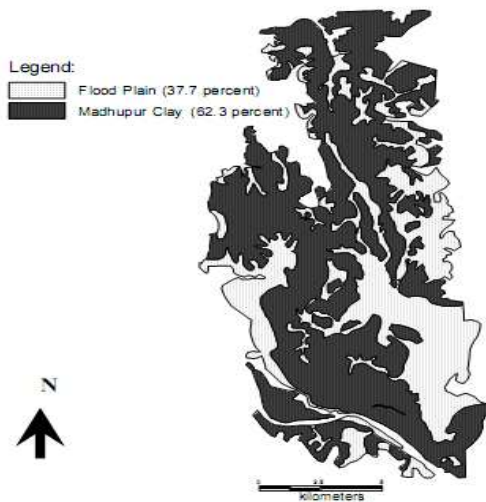


Fig. 2. Simplified geological map of Dhaka [after Ansary, 2004]

B. Earthquake Scenario and Soil Condition

Due to the non-availability of reliable seismo-tectonic data on lineaments and their level of activity, historical scenario events were estimated using earthquake catalogues. An intensity attenuation law (7) developed recently for Bangladesh and surrounding region by Ansary and Sabri [2003] was used for estimating the intensities of sixty-six earthquakes within a 200 km radius of Dhaka.

$$I = 8.378 + 1.283(M_s) - 0.0007483(R) - 4.9(\log R) \pm 0.93P \quad (7)$$

Where, I represent intensity, M_s corresponds to surface wave magnitude, R and P indicate epicentral distance and standard deviation, respectively. From these sixty-six earthquakes, five earthquakes have been selected as scenarios that produce an intensity of VII and above in Dhaka. These scenario earthquakes are listed in Table 1.

TABLE 1 SELECTED SCENARIO EARTHQUAKE FOR LOSS ESTIMATION STUDY

Scenario	Magnitude (M)	Epicenter distance (km)	Epicenter location		Intensity (+1p)	Intensity (-1p)
			latitude	longitude		
1	7.14	152.83	24°9'36"N	91°45'0"E	7.65	5.79
2	6.91	125.83	24°42'0"N	89°33'0"E	7.79	5.93
3	6.25	95.53	24°15'0"N	89°30'0"E	7.55	5.69
4	7.8	37.76	24°N	90°E	11.56	9.70
5	5.73	22.24	24°N	90.3°E	10.04	8.18

As a part of site classification according to the Current European Norms [CEN, 2004], the older Pleistocene age Modhupur Clay areas are assigned as site class B ($360 \text{ m/s} \leq V_{s30} < 800 \text{ m/s}$) whereas recent alluvial deposits in the Flood

plain are assigned as site class C ($180 \text{ m/s} \leq V_{s30} < 360 \text{ m/s}$).

C. Prediction of displacement spectral ordinates

In this study the attenuation equation of Cauzi et al. [2008] is used motivated by its ability to directly predict spectral ordinates up to very long period range of 20 second consistent with the requirement of the DBELA methodology. The functional form of the predictive equation is

$$\log DRS(T, \xi)(cm) = a_1 + a_2 M + a_3 \log R + a_B S_B + a_C S_C + a_D S_D + \varepsilon \quad (8)$$

where, $T(s)$ is the vibration period; ξ is the damping ratio; a_i ($i=1,..,D$) are numerical coefficients that are a function of period and damping ratio to be determined through regressions; ε denotes a random error term, assumed normally distributed with zero mean and standard deviation $\sigma_{\log DRS}$; S_B , S_C , S_D are dummy variables accounting for the main ground categories considered in CEN,2004.

D. Definition of Building Class and Material properties

Building up to 15- storeys high are considered in this study. Due to lack of any building inventory, all the buildings are classified in two broad classes as suggested by Al-Husaini [2003], un-reinforced brick masonry (URM) and reinforced concrete frame (RCF) buildings. The distribution of buildings in different thanas provided in Ansary [2004], is used with slight modifications taking into account the current trend of constructing high rise RCF buildings. Buildings below 3-storey height are assumed to consist of Tin-shed, URM with reinforced concrete slab and RCF construction where as buildings above 3-storey height are assumed to be solely RCF construction. Table 2, shows the probabilistic distributions of the geometrical properties, which have been produced from a database of reinforced concrete and masonry buildings, provided by Ansary through written communication.

Limit state strain values of steel and concrete, as presented in Table 3, are considered as discrete following the recommendation of Priestley [1997] and Calvi [1999]. The inter-story drift capacity of different types of masonry buildings has been taken from Italian experiments as presented in Table 4 due to unavailability of test data in Bangladesh.

TABLE 2 ADOPTED GEOMETRICAL CHARACTERISTICS OF RCC BUILDINGS

Capacity parameter	Min (m)	Max (m)	Mean value (m)	Coefficient of Variation	Probabilistic distribution
Regular storey height			3		deterministic value
Ground floor storey height			3		deterministic value
Beam length	4	6			uniform
Beam depth			0.5	16%	Lognormal
Column depth					
up to 4-storey			0.35	37%	
5-6 storey			0.4	35%	
7-10 storey			0.46	34.70%	Lognormal
> 10 storey			0.51	29%	

TABLE 3 ADOPTED MATERIAL AND LIMIT STATE PROPERTIES

Material	Minimum strain	Maximum strain	Probabilistic distribution
Concrete			
Limit state 2 strain, ϵ_{c2}	0.37%	0.75%	uniform
Limit state 3 strain, ϵ_{c3}	0.50%	1%	
Steel			
Limit state 2 strain, ϵ_{s2}	1.12%	2.25%	uniform
Limit state 3 strain, ϵ_{s3}	1.50%	3%	

TABLE 4 INTER-STORY DRIFT CAPACITIES OF MASONRY WALLS ADOPTED

Limit State	Mean value	CoV	Probabilistic Distribution	Reference
1	0.13%	35%	Lognormal	Abrams (1997), Magenes et al. (1997), Calvi (1999)
2	0.34%	30%	Lognormal	
3	0.45%	30%	Lognormal	Restrepo-Velez (2003)

IV. PREDICTED DAMAGE

The results of the five scenario earthquake indicate that that earthquake scenario-4 causes the most devastation (Fig. 3) on the building stock compared to the other scenarios, which is consistent if one considers the magnitude and site to source distance. Due to scenario-4, 32.81% of buildings will be slightly damaged, 12% and 5.92% of buildings will suffer moderate and extensive damage, respectively, and 49.28% buildings will completely collapse, as found from the analysis. In terms of mean damage ratio, it is very high at about 54% (Fig. 4).

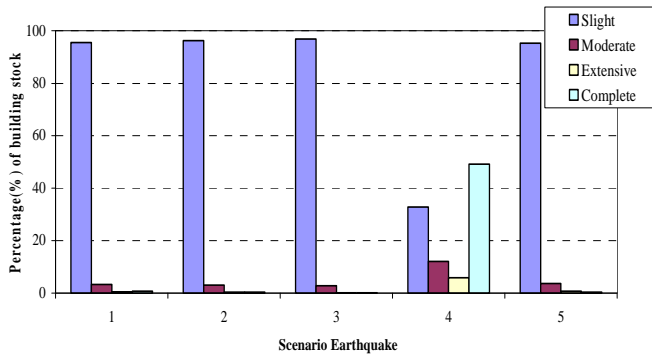


Fig. 3. Damage prediction results of the base model for different scenario earthquake

The thana-wise damage distribution in terms of mean damage ratio (MDR) is shown in Fig.5 for scenario-4. Thanas, which are situated in the north-east and south-east part of Dhaka, showed a greater building damage ratio which is very much consistent with the existing soil conditions in those areas. Most of the buildings in these areas are built on marshy land with soil fill.

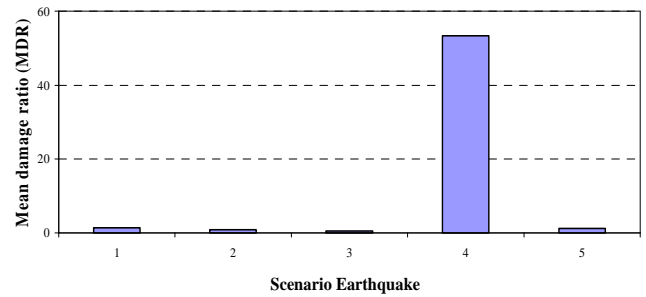


Fig. 4. Damage prediction based on MDR of the base model for different scenario earthquake

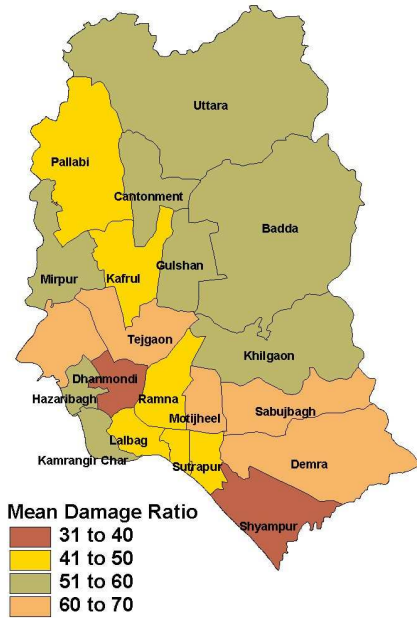


Fig. 5. Spatial distribution of MDR of the base model for scenario-4 earthquake

The choice of mean damage ratios (MDR), a composite measure of damage, should ideally be based on detailed local data on insurance claims rates for different damage states of distinct building types. The variation in the damage ratios for different part of the world is illustrated in Table 5.

A comparison of the damage prediction based on the different damage ratios of Table 5, presented in Fig. 6 shows the similar damage trend for the scenario earthquakes.

TABLE 5 COMPARISONS OF DAMAGE RATIOS

Damage Band	Ansary [2004]	HAZUS	Crowley et al. [2005]
Slight	0%	2%	10%
Moderate	15%	10%	30%
Extensive	40%	50%	100%
Complete	100%	100%	100%

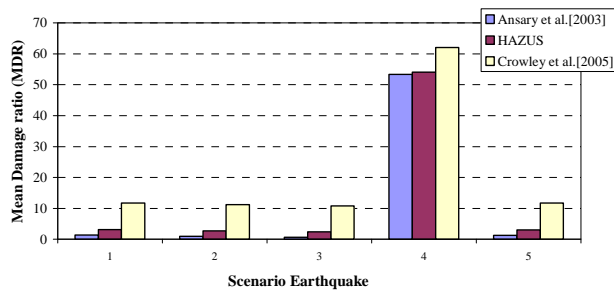


Fig. 6. Damage prediction based on different damage ratio proposals

V. SOCIAL LOSSES

The damage distributions presented above have allowed the social losses to be predicted following scenario-4, in terms of the number of fatalities and injuries using the recently proposed model by Spence [2007], as summarized in Table 6.

TABLE 6 INJURY DISTRIBUTIONS FOR SPECIFIC BUILDING TYPES
 UI=uninjured; I₁=slight injuries; I₂=moderate injuries; I₃=serious injuries;
 I₄=critical injuries; I₅=deaths.

	Complete Damage State					
	UI	I ₁	I ₂	I ₃	I ₄	I ₅
Masonry(1F)	23.6%	50.0%	12.0%	8.0%	0.4%	6.0%
Masonry(2-3F)	16.5%	50.0%	15.0%	10.0%	0.5%	8.0%
Masonry(≥ 4F)	9.4%	50.0%	18.0%	12.0%	0.6%	10.0%
RC(1F)	32.9%	30.0%	19.0%	3.0%	0.2%	15.0%
RC(2-3F)	20.8%	30.0%	23.0%	4.0%	0.2%	22.0%
RC(≥4F)	9.7%	30.0%	27.0%	5.0%	0.3%	28.0%

Due to lack of data, it is assumed that, a RCC building of a given storey can accommodate 1.5 times more people than a masonry building of similar storey number, owing to its larger floor space. Then the number of storeys is used as the factor to apportion the population as there will be more people living in high rise than in low rise. From the analysis, it is found that there will be more fatalities in RCC buildings (14.46%) compared to people living in masonry buildings (4.28 %). It is estimated that 0.27% of people living in masonry buildings will suffer from next severe state of injure, i.e., critical injury compared to 0.15% of people living in RCC buildings. Different state of injury distributions in Dhaka are shown in Fig. 6 and Fig. 7 for masonry and RCC buildings.

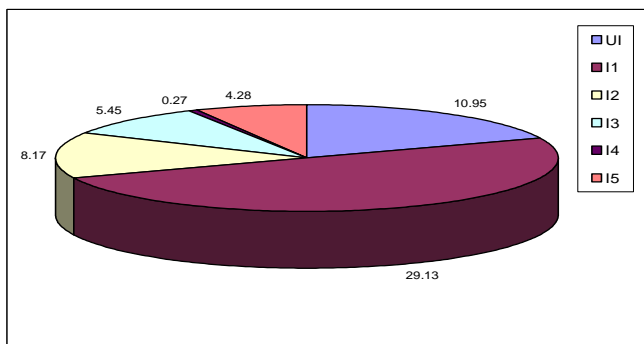


Fig.7. Percentage of people in different injury states living in masonry buildings.

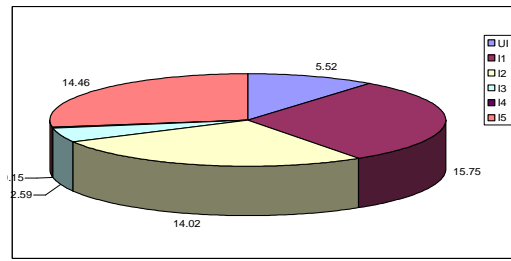


Fig. 8. Percentage of people in different injury states living in RCC buildings

VI. CONCLUSION AND FUTURE RESEARCH

A displacement-based earthquake loss assessment method (DBELA) has been applied to Dhaka to find a picture of overall damage distribution and social losses following scenario earthquakes. The damage prediction results obtained by DBELA suggest that the magnitude and source to site distance have a pronounced effect on the predicted damage. For further applications of the methodology to the Dhaka building stock, the following developments are envisaged:

- 1) A comprehensive database of the building inventory and structural characteristics will be developed and implemented for a seismic loss assessment study as they are key factor for reliable estimate of damage.
- 2) An analytical study will be carried out to formulate the yield period-height relationship for typical reinforced concrete and masonry buildings found in Bangladesh.

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