Malaysian Journal of Civil Engineering 28(3):394-406 (2016)

ANALYTICAL FRAGILITY CURVES FOR REINFORCED CONCRETE BUILDING USING SINGLE POINT SCALED SPECTRUM MATCHED GROUND MOTION ANALYSES

Ram Krishna Mazumder[1]*, Muhammad Saif Uddin[1], Rajen Dey[1] & Mehedi Ahmed Ansary[2]

[1] *Institute of Earthquake Engineering Research, Chittagong University of Engineering and Technology, Chittagong 4349, Bangladesh*
[2] *Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh*

*Corresponding Author: *rkmazumder@cuet.ac.bd*

Abstract: Seismic performance is obtained for a five-storied reinforced concrete frame building performing non-linear dynamic time history analyses. Performance of the building was obtained as a mean of fragility function of spectral acceleration. Earthquake ground motion records are selected from online source considering local earthquake faults scenario proposed in Comprehensive Disaster Management Program (CDMP) and then scaled to fit with Bangladesh National Building Code (BNBC) 1993 design response spectra. Since the structure is considered as typical reinforced concrete ordinary moment resisting frame located in Bangladesh, mechanical properties and other associated parameters are chosen according to Bangladeshi perspective. Each ground motion spectrum is matched with design code spectrum at fundamental time period of the building. Non-linear static pushover analysis is performed to determine damage states from pushover curve. Four damage states (from slight to collapse) are defined based on simplified assumptions. A set of dynamic time history analyses are carried out in order to obtain probability density function of the displacement demand correspond to different level of ground motions. Cumulative distribution of each associated damage states allows deriving fragility curves. Finally four fragility curves are obtained for four damge grades (slight, moderate, severe and collapse).

Keywords: *Ground Motion Scaling, Fragility Curves, Time History, Reinforced Concrete*

1.0 Introduction

Bangladesh is located in a moderate seismic region in the southern part of Asia. This country has a long history of earthquakes (Chowdhury, 1993, SDMC, 2009) but database of time history record of earthquakes are limited due to insufficient seismic recording instruments. In the last one decade, about 40 Strong Motion Accelerometers

(SMA) have been deployed all over the country under Geological Survey of Bangladesh-Bangladesh University of Engineering and Technology (BUET) partnership program funded both by United Nation Development Program (UNDP) and Bangladesh Bridge Authority (Ansary, 2006). Most of the recent earthquakes are light to moderate intensity where time history records for strong ground shaking are absent. Due to lack of strong ground shaking, earthquake records collected from these SMAs are not sufficient. The most notable large earthquake surroundings Bangladesh is 1897 Assam Earthquake (widely known as Great Indian Earthquake) with moment magnitude of M_w 8.7 near India and Bangladesh border region in the north (Oldham, 1899; Bilham, 2004; Morino *et al*., 2014). Recently occurring relatively small size earthquakes have made people aware about the future risk of earthquake in this region. Most of the low to mid rise buildings constructed in this country rarely follows national seismic code provision. Seismic vulnerability assessment for existing building stock is given topmost priority especially those which are located in the region of moderate to high seismicity of Bangladesh. The aim of this study is to derive seismic fragility function of a Reinforced Concrete building with unreinforced masonry infill based on stochastic approach. The main approach is to perform non-linear dynamic analysis of the building using a set of ground motions which are fitted and scaled with BNBC design response spectra on fundamental time period of the structure. Analytical fragility curves are derived from story displacement obtained from results of dynamic analyses.

Reinforced Concrete building with unreinforced clay brick masonry infill walls is the common and most popular construction type in urban areas of Bangladesh. Implementation of seismic code has not been made mandatory in our Construction Industry. BNBC has been first adopted in 1993 and later published as Bangladesh Gazette in 2006 (BNBC, 1993; BRTC-BUET, 2010). For the purpose of non-linear time history analyses, a set of ground motion records have been selected from online databank and existing local records. These ground motion records are scaled and matched on fundamental time period of the building with the BNBC 1993 design response spectrum. The structure is assumed to be standard residential building located in Dhaka, the capital of Bangladesh with a seismic zone coefficient 0.15g (BNBC, 1993). Non linear static analyses are performed in order to define damage states from global pushover curve. Seismic fragility curves have been derived for each damage states using time history analyses results.

2.0 Seismicity

Bangladesh is one of the most earthquake prone countries in the southern part of Asia (Chowdhury, 1993; SDMC, 2009). The country is located near the junction of the Indo-Australian plate and Eurasian plate, the tectonic evaluation of Bangladesh can be explained as a result of collision of the north moving Indo-Australian plate with the Eurasian plate (Ali and Chowdhury, 2002). A number of faults are active in this junction area which are the sources of the seismic event. Four major sources were defined by Bolt (Bolt, 1987) with probable magnitude for each source (see Table 1). Most recent study has been conducted under Comprehensive Disaster Management Program (CDMP) where five faults zones are defined with a maximum possible earthquake within each zone (see Table 2 and Figure 1) (CDMP, 2009).

Table 1: Seismic sources in Bangladesh (Bolt, 1987)

Faults	Probable magnitude (in Richter scale)
Assam fault zone	8.0
Tripura fault zone	7.0
Sub Dauki fault zone	7.3
Bogra fault zone	7.0

Table 2: Existing fault scenario (CDMP, 2009)

Case	Name of the Fault	Coordinate of Epicentre		M_w	Depth to top of fault (km)	Dip Angle	Fault type
		Latitude	Longitude				
1	Dauki Fault	25.1	91.0	8.0	3	60°	Reverse
2	Madhupur Fault	24.3	90.1	7.5	10	45°	Reverse
3	Plate Boundary Fault -1	21.1	92.1	8.5	17.5	30°	Reverse
4	Plate Boundary Fault -2	23.8	91.1	8.0	3	20°	Reverse
5	Plate Boundary Fault -3	25.7	93.7	8.3	3	30°	Reverse

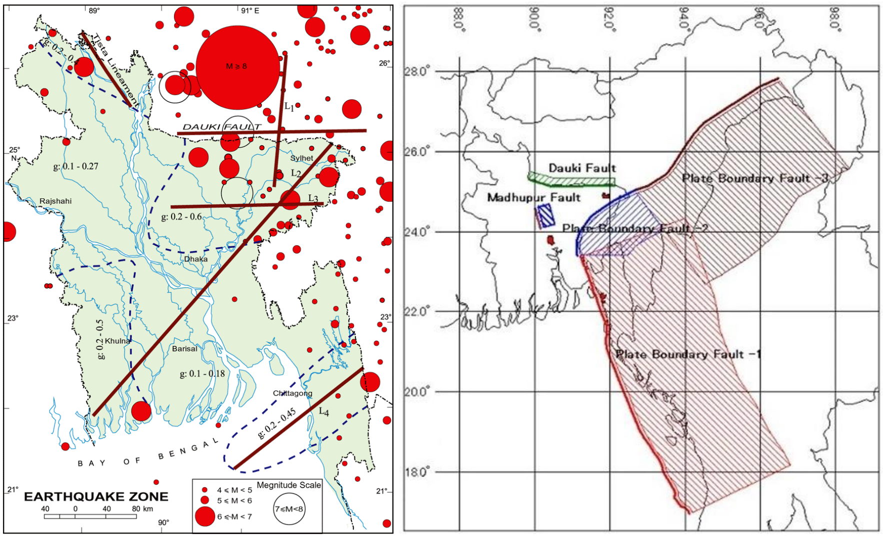


Figure 1 : a) Seismo-tectonic map and past earthquakes (Banglapedia, 2015) and b) Earthquake fault zones proposed in the time-predictable fault model study (CDMP, 2009)

The country has a long history of earthquakes and the largest one that occurred here is the M_w 8.7 Great Indian Earthquake. Several International researchers (GEM, 2014 and Steckler, 2016) showed the possibility of large earthquake to occur in this area in near future, which will cause a large human casualty, damages of infrastructure and other losses. In Bangladesh complete earthquake monitoring facilities are not available. Due to the lack of available seismic recording instruments, past earthquake time history records are absent. Figure 1a shows location of seismo-tectonic faults and past earthquakes surroundings Bangladesh. Figure 1b shows earthquake faults scenario proposed in the time-predictable fault modeling study (CDMP, 2009).

3.0 Configuration of the Reference Building

The reference structure considered for this study is a typical five storied residential building in urban areas of Bangladesh. The typology of the structure is reinforced concrete (RC) frame building with symmetrical and regular floor plan. The building has been modeled in the structural analysis software SAP2000 v15 (CSI, 2012). The plan dimensions of the building is 67.3 ft × 35.25 ft with uniform floor height of 10 ft. Figure 2 shows the floor plan and reference frame of the building. The building is assumed to meet the seismic code provision of BNBC 1993. The major parameters used for the seismic load calculation are shown in Table 3.

Table 3: Seismic Design Parameters (BNBC, 1993)

Parameter	Zone II
Seismic Zone Coefficient, Z	0.15
Site Coefficient, S	1.20
Response Modification Factor, R	6.00
Structural Importance Factor, I	1.00

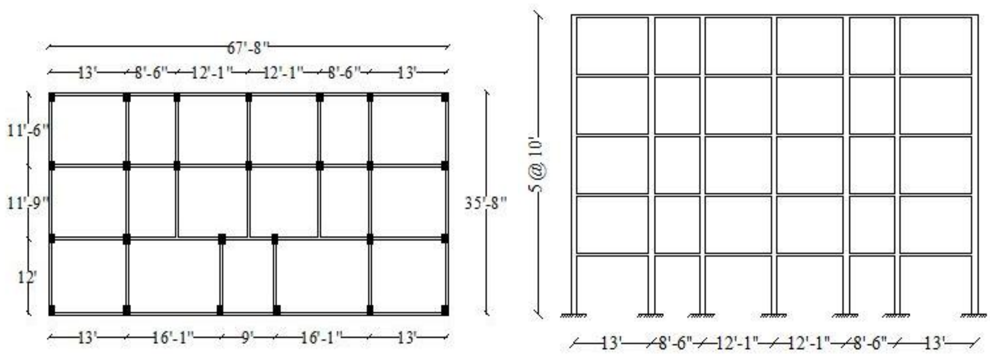


Figure 2: Building plan dimension and elevation

The seismic design base shear obtained for the structure is 84.29 kips. The approximate code based fundamental period is 0.56 second while the true first mode periods based on input material and element properties is determined 0.71 second. The final design is based on using normal weight concrete [150 pcf] with a compressive strength f'_c=3000 psi [20 MPa] and reinforcing steel with nominal yield strength f_y= 60000 psi [400 MPa]. The live loads and floor finish on floors are taken as 40 psf [2 kPa] and 20 psf [1 kPa], respectively.

4.0 Selection of Ground Motion Records

In order to carry out dynamic time history analyses, an appropriate set of acceleration time histories is required. Acceleration time history data is selected from the real accelerogram database or can be generated artificially (Rota *et al*., 2010). The advantage of real records over artificial accelerograms is that genuine records of ground motion shaking are more realistic, since they carry all the ground motion characteristics (amplitude, frequency, energy content, duration, number of cycles and phase) and reflect all the factors that influence accelerograms (source, path and site) (Fahjan, 2008; Rota *et al*., 2010). In current approach, online strong motion databank (e.g. peer.berkeley.edu) records are selected and fitted with BNBC response spectra. Single-record time history analysis cannot fully capture the behavior of a building, since results may be strongly dependent on the record chosen. A set of 20 past earthquake time history records are chosen to be allowed to use average results instead of the most unfavorable ones, as suggested by several modern seismic codes and research works (Heo *et al*., 2011). Figure 3 shows the BNBC 1993 Design Response Spectra for different soil types (soft soil to rock type), this design code response spectra is prepared based on estimated earthquake return period of 200 years (BNBC, 1993).

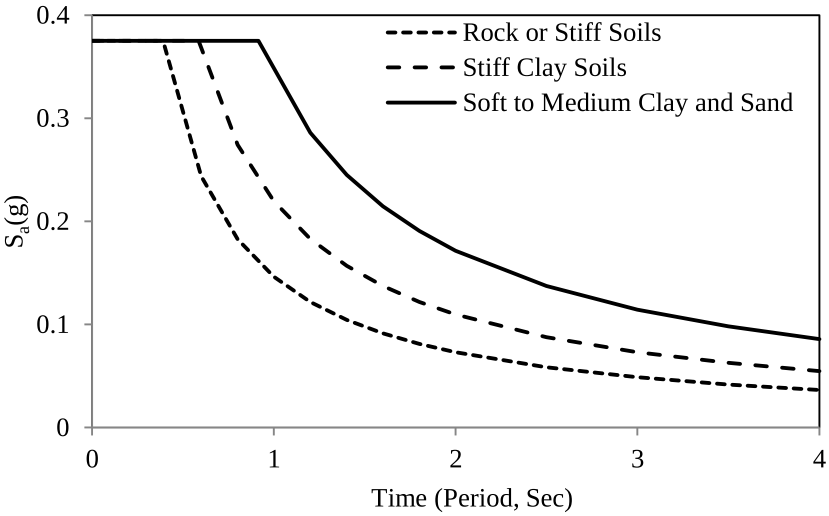


Figure 3 : Design Response Spectra (BNBC, 1993)

Table 4: Selected ground motion records (source: PEER NGA, 2015)

Sl.	Earthquake Name	Station Name	Record #	Scale Factor	Year	S_a	Epicentre Distance (km)	M_w	Fault Type
1	Kern County	Taft Lincoln School	15	0.70	1952	0.66	43.49	7.4	Reverse
2	San Fernando	Santa Felita Dam (Outlet)	88	2.11	1971	0.20	31.55	6.6	Reverse
3	Coalinga 01	Parkfield - Fault Zone 10	335	1.10	1983	0.30	41.20	6.4	Reverse
4	N. Palm Springs	Palm Springs Airport	530	0.98	1986	0.40	21.14	6.1	Reverse Oblique
5	Loma Prieta	Crystal Springs	736	1.43	1989	0.28	61.49	6.9	Reverse Oblique
6	Loma Prieta	Anderson Dam (L Abut)	740	1.80	1989	0.24	26.57	6.9	Reverse
7	Loma Prieta	Coyote Lake Southwest Abutment	755	0.35	1989	1.01	30.78	6.9	Reverse
8	Cape Mendocino	Fortuna - Fortuna Blvd	827	1.04	1992	0.33	29.55	7.0	Reverse
9	Northridge-01	Leona Valley #5 - Ritter	1031	0.79	1994	0.41	52.44	6.7	Reverse
10	Northridge-01	Sunland - Mt Gleason Ave	1083	0.77	1994	0.54	24.13	6.7	Reverse
11	Chi-Chi Taiwan	CHY042	1206	0.95	1999	0.46	59.80	7.6	Reverse Oblique
12	Chi-Chi Taiwan-06	CHY006	3865	0.78	1999	0.59	56.64	6.3	Reverse
13	San Simeon CA	San Antonio Dam - Toe	4013	1.36	2003	0.19	21.41	6.5	Reverse
14	Niigata Japan	NIGH08	4225	1.40	2004	0.43	68.54	6.6	Reverse
15	Chuetsu-oki Japan	TokamachiMat sunoyama	4844	0.84	2007	0.55	50.47	6.8	Reverse
16	Chuetsu-oki Japan	SawaMizuguti Tokamachi	4872	1.04	2007	0.27	42.46	6.8	Reverse
17	Chuetsu-oki Japan	Ojiya City	4882	0.64	2007	0.70	29.85	6.8	Reverse
18	Iwate Japan	Kami, Miyagi Miyazaki City	5776	1.33	2008	0.31	47.24	6.9	Reverse
19	Iwate Japan	Sanbongi Osaki City	5779	1.13	2008	0.31	56.17	6.9	Reverse
20	Iwate Japan	Yuzawa	5815	1.26	2008	0.31	29.33	6.9	Reverse

The ground motion records used in thisstudy are chosen from the Pacific Earthquake Engineering Research Center (PEER NGA) ground motion record database with a condition of selecting those records which have spectral acceleration values close to the spectral acceleration values in seismic zone II of BNBC code. Table 4 represents basic characteristics of ground motion records selected for dynamic time history analyses and Figure 4 represents the distribution of magnitude-distance of earthquakes from seismic data recording station.

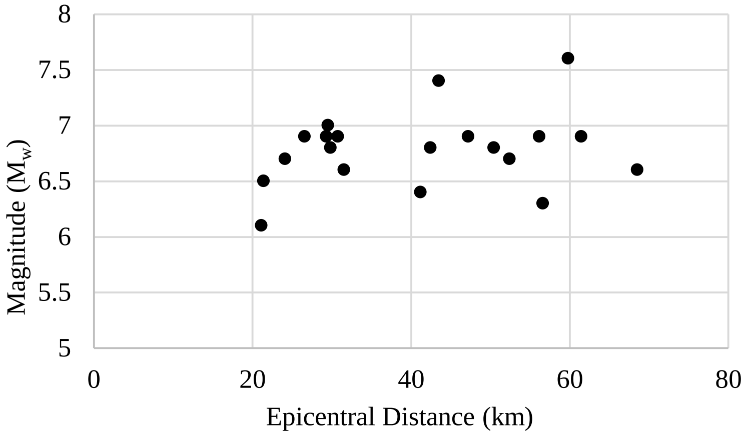
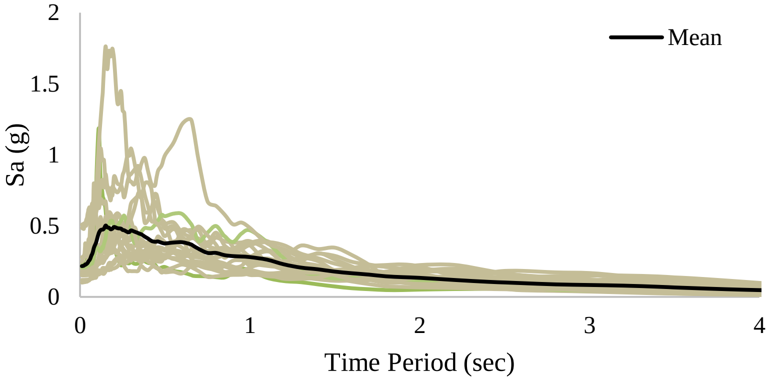


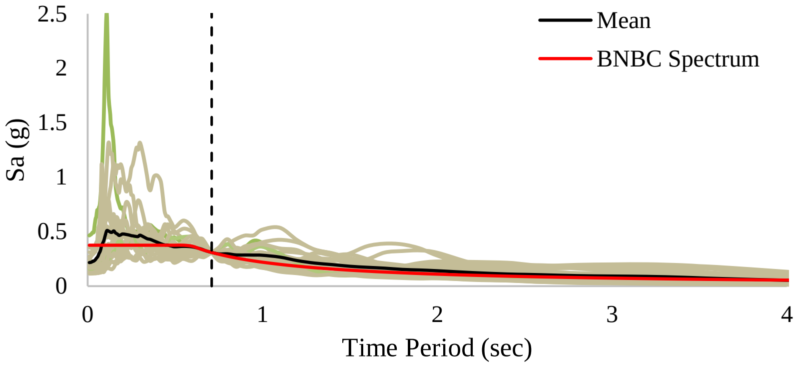
Figure 4 : Relationship of the ground motion record parameters

5.0 Ground Motion Scaling

Scaling of real recorded accelerogram is becoming popular in contemporary research issues due to increase in availabilty of strong motion databases. Spectral matching using real accelerograms may be performed through either the time domain or the frequency domain analysis (Fahjan, 2008). Several ground motion scaling strategies exist worldwide to fit with design code spectra. In current study, most common and simplest single point amplitude-scaling approach is used. The scaling of the motion is such that the ordinate of the spectral acceleration matches the design spectral acceleration at the fundamental period of the structure. This process is typically less scatterings than other scaling approach (Fahjan, 2008). A set of 20 ground motion records is selected with a magnitude randomly varying from M_w 6 to M_w 8. These selected records are basically from three groups according to their acceleration scenario. The first group comprises those records that have mean spectral value less than design spectrum at the fundamental period. The records having mean spectral value higher than design spectrum are grouped as two and final group consists of records with spectral value relatively closer to the design spectrum at the fundamental period. (Heo *et al.*, 2011) Selected ground motions are matched to the target BNBC spectra in order to obtain a good response of the index building. Figure 5 shows scaled ground motion records with respect to fundamental period (T1) of the building. Design response spectrum is chosen associated to stiff clay soil type.



(a)



(b)

Figure 5 : Response Spectra of selected records a) Unscaled b) Scaled at T1=0.71 sec

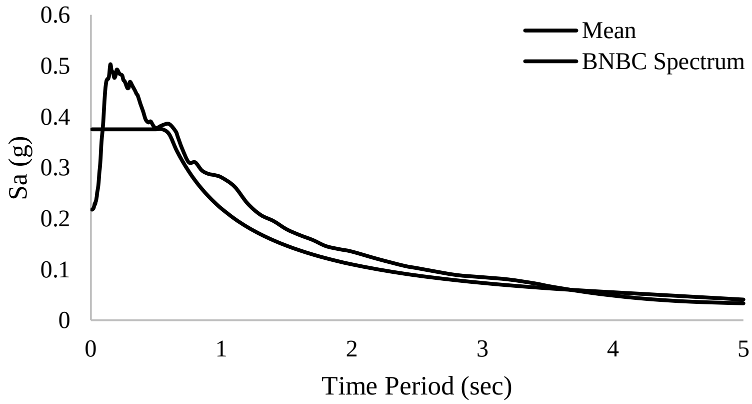


Figure 6 : Comparison of the mean spectrum with BNBC design response spectrum for stiff clay

6.0 Structural Analyses and Results

The selected building is modelled in the structural analysis software SAP 2000 v15. In order to incorporate nonlinear characteristics, the individual frame members are defined by non-linear hinge property which is the relationship loads with associated deformation as per FEMA 273 (1997) guideline. Mechanical damage states are obtained from pushover analyses as per ATC 40 guideline (ATC, 1996). The damage states are derived from global pushover analysis result as per simplified assumption provided by Risk-UE project (Risk-UE, 2004; Milutinovic and Trendafiloski, 2003; Lagomarsino and Giovinazzi, 2006). Damage states are related to the yielding (D_y) and ultimate capacity (D_u) points are shown in as in Table 5.

Table 5: Pushover Curves and Damage States (Risk-UE, 2004)

Damage State	Damage state thresholds
Slight (Sd1)	$0.7D_y$
Moderate (Sd2)	D_y
Severe (Sd3)	$D_y + 0.25\,(D_u - D_y)$
Collapse (Sd4)	D_u

Figure 7 shows global pushover curves obtained from non linear static analysis indicating four damage states S_{d1}, S_{d2}, S_{d3} and S_{d4} which are found to be 0.44, 0.63, 1.50, 4.10 respectively. The damage states are defined from slight to collapse level. This assumption is based on expert opinion and relates the expected damage to the stiffness degradation of the structure. In order to obtain best estimated results, dynamic time history analyses are performed using scaled and code matched ground motions dataset.

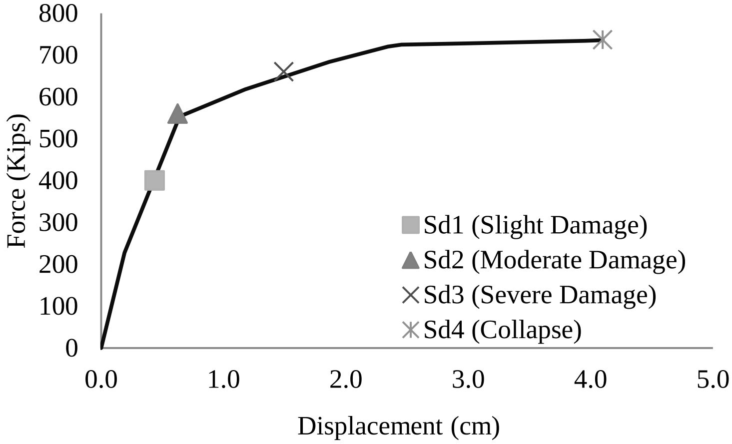


Figure 7 :Global pushover curve

The primary response variable considers for this study is maximum inter story displacement. The relationship between story displacement and spectral acceleration of ground motions is represented in Figure 8. After distribution of spectral acceleration values into damage limit states, Probability Density Functions (PDFs) associated to each of the four damage states are drawn (as shown in Figure 9). Ground motion records are scaled with code spectrum linearly at the point of fundamental period of the structure.

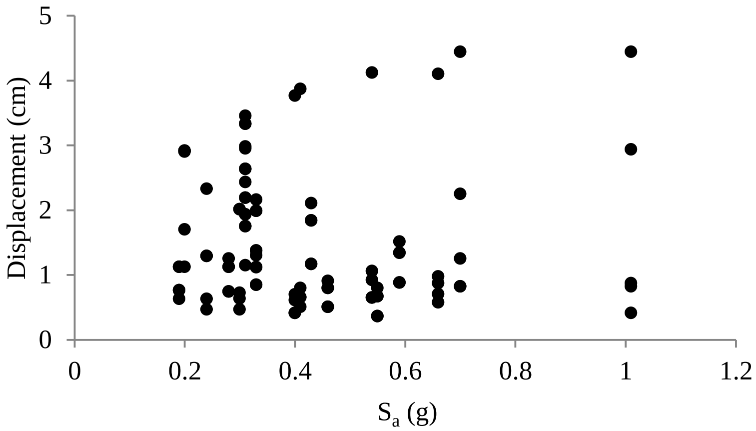


Figure 8 : Correlation of story displacement and spectral acceleration

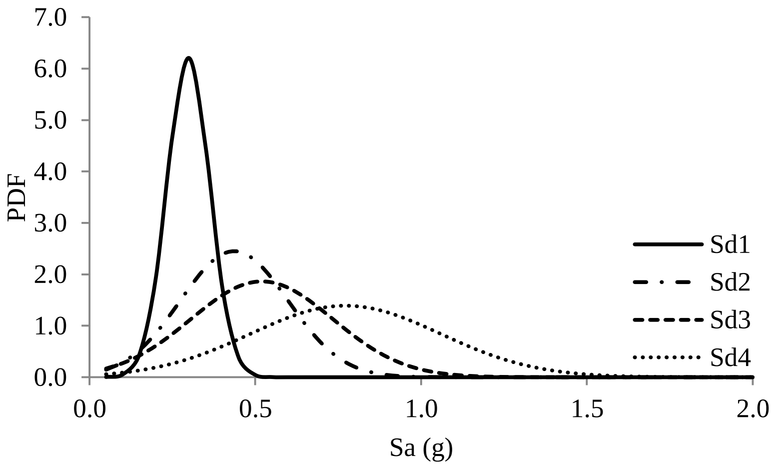


Figure 9 :Probability Density Functions for damage states

Once probability density functions of the different considered damage levels are defined and displacement demand imposed for the buildings from time history analyses, it is possible to derive fragility curves. Using the information in Figure 8, the median and standard deviation of the spectral acceleration values for each limit state is calculated.

The fragility curves are obtained in the form of a two-parameter lognormal distribution function as follows.

$$F(X) = P(d > D) = \Phi\left[\frac{ln(X)-\mu}{\sigma}\right] \quad (1)$$

Where Φ is the standard normal cumulative distribution function, X is the distributed engineering demand parameter (e.g., S_a) and μ and σ are the median and standard deviation of the natural logarithm of the engineering demand parameters (i.e., displacement) (Karbassi and Lestuzzi, 2014). Figure 10 shows derived fragility curves associated to each damage states.

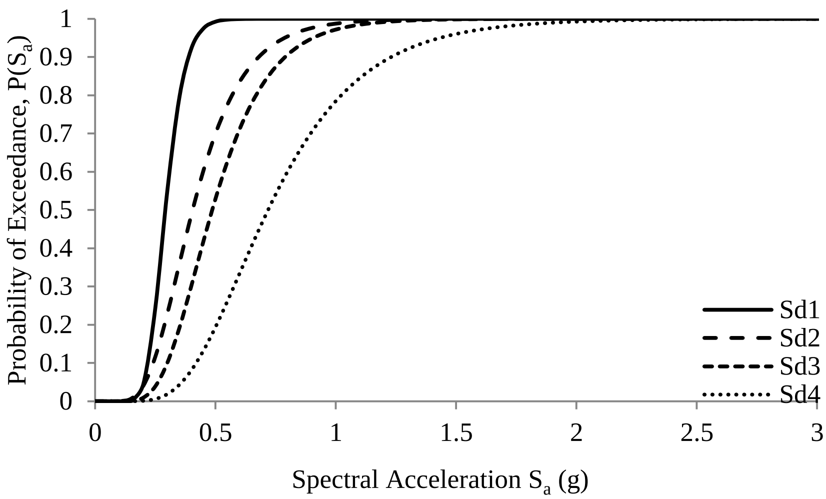


Figure 10 :Fragility curves for each damage states

7.0 Conclusions

The current approach is to perform the seismic vulnerability of a typical five story reinforced concrete building where local ground motion records are not available. Online ground motion records are selected and fitted with BNBC response spectra to perform non-linear time history analyses. A set of twenty ground motions records from online resource is chosen for the purpose of non linear time history analyses. The fragility curves associated to each of the four considered damage states are determined and summarized in figure 10. The normal distribution of displacement demand measures used to develop the acceleration-based fragility curves. The method is useful for the seismic vulnerability evaluation of buildings in regions of which limited observed earthquake damage data is available.

References

Ali and Chowdhury J.R. (2002) *Earthquake Hazard in Bangladesh and Measures for Mitigation*, Weekend Independent, 4 January, 2002

Ansary, M.A. (2006) *Installation of an Earthquake Monitoring System for Bangladesh*, Safer Cities Project, COSMOS-WSSI.

ATC (1996) *Seismic Evaluation and Retrofit of Reinforced Concrete Buildings*, Applied Technology Council, ATC- 40.

Banglapedia (2015) *en.banglapedia.org/index.php?title=Earthquake*

Bilham, R. (2004) *Earthquakes in India and the Himalaya: tectonics, geodesy and history,* Annals of Geophysics,Vol. 47, N. 2/3, 839-858

BNBC (1993. *Bangladesh National Building Code,* Housing and Building Research Institute, Dhaka, Bangladesh.

Bolt, B.A (1987) *Site Specific study of seismic intensity and ground motion parameters for proposed Jamunariver bridge, Bangladesh,* A report of Jamuna bridge study.

BRTC-BUET (2010) Bureau of Research Testing and Consulancy, Bangladesh University of Engineering and Technology*, Updating of National Building Code 1993,* Inception Report.

CDMP (2009) *Time-predictable fault modelling for seismic hazard and vulnerability assessment of Dhaka, Chittagong and Sylhet,* Comprehensive Disaster Management Programme, Ministry of Food and Disaster Management, Bangladesh

Chowdhury, J.R. (1993) *Seismicity in Bangladesh*, Incede Report 5, Bangkok (http://cidbimena.desastres.hn/docum/crid/Nov-Dic2003/pdf/eng/doc6965/doc6965-a.pdf)

CSI (2012) *Structural Analysis Program 2000 Version 15 integrated finite element analysis and design of structures basic analysis reference manual*. Computers and Structures Inc.

Fahjan, Y. M. (2008) *Selection and Scaling of Real Earthquake Accelerograms to Fit the Turkish Design Spectra,* Teknik Dergi Vol. 19, No. 3, pp: 4423-4444

FEMA 273 (1997) *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, Federal Emergency Management Agency

GEM (2014), *A Global Earthquake Model,* GEM Foundation, Pavia, Italy.

Heo, Y., Kunnath, S. K. and Abrahamson, N. (2011), *Amplitude-Scaled versus Spectrum-Matched Ground Motions for Seismic Performance Assessment,* J. Struct. Eng. 2011.137:278-288.

Karbassi, A. and Lestuzzi P. (2014) *Seismic risk for existing buildings in Switzerland – development of fragility curves for masonry buildings,* Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland, report prepared under contract to the Federal Office for the Environment (FOEN), 55 p.

Lagomarsino S, Giovinazzi S (2006) *Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings,* Bull EarthqEng 4:415–443

Milutinovic ZV, Trendafiloski GS (2003) *Vulnerability of current buildings RISK-UE project of the EC: an advanced approach to earthquake risk scenarios with applications to different European towns*

Morino, M., Maksud Kamal, A.S.M., Akhter, S.H., Rahman, M.J., Alic, R.M.E., Talukder, A., Khanc, M.M.H., Matsuod, J. and Kanekod, F. (2014). *A paleo-seismological study of the Dauki fault at Jaflong, Sylhet, Bangladesh: Historical seismic events and an attempted rupture segmentation model,* Journal of Asian Earth Sciences, 91: 218–226.

Oldham, R.D. (1899) *Report on the Great Earthquake of 12 June 1897,* Mem. Geol. Soc. India, Geol. Surv. India, 29, pp. 379.

PEER NGA (2015) *PEER Ground Motion Database - PEER Center* (ngawest2.berkeley.edu/)

Risk-UE (2004) *An advanced approach to earthquake risk scenarios with applications to different European towns,* Contract number: EVK4-CT-2000-00014 Project of the European Commission

Rota, M., Penna, A. and Magenes, G (2010) *A methodology for deriving analytical fragility curves for masonry buildings based on stochastic nonlinear analyses,* Engineering Structures 32 (2010) 1312-1323

SDMC (2009) *SAARC workshop on earthquake risk management in South Asia*, SAARC Disaster Management Center, 8-9 October, Islamabad, Pakistan

Steckler, M. S., Mondal, D. R., Akhter, S. H., Seeber, L, Feng, L., Gale, J., Hill, E. M. and Howe, M. (2016) *Locked and loading megathrust linked to active subduction beneath the Indo-Burman Ranges,* Nature Geoscience, DOI: 10.1038/NGEO2760.