FRAGILITY ANALYSIS FOR SEISMIC VULNERABILITY ASSESSMENT OF BUILDINGS: A REVIEW

Tarannum Yasmin[1], Ajay Chourasia[2], S.K.Bhattacharyya[3] and Jalaj Parashar[4]

[1]M.Tech. Student, Academy of Scientific and Innovative Research, CSIR-CBRI, Roorkee, India
[2]Principal Scientist, CSIR-Central Building Research Institute, Roorkee, India
[3]Director, CSIR-Central Building Research Institute, Roorkee, India
[4]Senior technical officer, CSIR- Central Building Research Institute, Roorkee, India

---***---

Abstract - ***Fragility analysis is one of the trending probabilistic seismic performance methodologies. With the advancement in computational methodologies and large database of existing buildings, fragility analysis can be implemented for precise vulnerability assessment of buildings. The vulnerability curves can be categorized into three groups-empirical, analytical and hybrid. Empirical approach includes-Damage Probability Matrices and Vulnerability Functions, which depend on the damage-motion relationship statistics observed after an earthquake. Analytical curves adopt damage distributions simulated from the analyses of structural models. Hybrid curves overcome the deficiencies of the above two approaches by combining post-earthquake damage statistics with simulation techniques. This paper reviews the importance of fragility analysis using existing methodologies and focuses on their key features highlighting limitations. The paper suggests the way forward for selection of appropriate assessment method for seismic vulnerability assessment of existing buildings and the incorporation of experimental vibration based methods.***

Key Words: *Buildings, Seismic Assessment, Vulnerability, Fragility Analysis, Fragility Curve, Experiment*

1. INTRODUCTION

Earthquakes cause economic losses apart from the agonizing pain of loss of lives. Seismic risk assessment is the first step in disaster prevention strategy and in reducing the associated risks of infrastructures. The comprehensive study of seismic risk can be divided into three components- Hazard, Vulnerability and Exposure (Lagomarsi and Cattari, 2013). Hazard is the event capable of causing damage while Vulnerability represents the degree of loss of an element resulting from a hazard. Exposure is the quantity of elements (population, the economic activities, and the constructions and structures) exposed to a hazard. It is well understood that it is not the earthquake which kills but the failure of the buildings exposed to these earthquakes. Therefore understanding the behaviour of the buildings during Earthquake is a growing area of research. Assessing the vulnerability of the structures as seismic performance can be helpful for risk mitigation and emergency response planning.

Various methods have been proposed for the fragility analysis of the structures- empirical, analytical and hybrid methods (Calvi et. al. 2006). Rosetto and Elnashai (2003) and Rota et al. (2006) used the empirical methods by using collected data of the buildings damaged during the past earthquakes. Though empirical methods claims to be a real estimate of the seismic behaviour of the buildings, there are a number of disadvantages related to it. The lack of availability of the post earthquake data and the wide variety in the building typologies exposed to earthquake restricts the empirical method to get generalized. To overcome these issues the concept of analytical methods evolved. Fragility curves are developed for a single structure which is modelled as representative of a class of building whose seismic assessment is required (Singhal and Kiremidjian 1997, Akkar et al. 2005). Analytical method is simple and requires less data but the accurate estimation of the capacity of the buildings through synthetic model and computer aided tools has been a debated topic (Silva et al. 2012). Depending on the procedure used to define the nonlinear response of the structure various analytical methodologies can be described as Capacity Spectrum Method; Mechanics based methods and Displacement Method, each having their own advantages and disadvantages. To find the optimal balance between accuracy and complexity, the concept of hybrid method evolved, which combines the advantages of both the methods. In hybrid method analytical results are obtained by using post-earthquake damage data (Kappos et al. 2010).

The following sections describe the developments pertaining to each methodology. Emphasis has been laid on finding the optimum method of fragility analysis for reinforced concrete buildings and a new approach to incorporate the modal parameters obtained from experimental results in the vulnerability assessment procedure has been discussed.

2. EVOLUTION IN THE DEVELOPMENT OF FRAGILITY CURVES

Researches aim to give a mathematical formulation to describe the vulnerability. The attempt started in early 70's and the approaches to assess the seismic vulnerability can be distinguished as Empirical, Analytical and Hybrid Methods

2.1 Empirical Methods

Empirical methods utilize the damage data observed after earthquakes, based on the opinion of multiple experts and professionals. The two main types of empirical method formulations are- damage probability matrices (DPM) and vulnerability functions (Calvi et al. 2006). DPM's represent the discrete relationship of the conditional probability of reaching a damage level due to a ground motion, and the vulnerability functions express the probability as continuous functions. Empirical methods are further classified based on the approach of collection of data – based on expert opinion and based on actual damage data collection.

2.1.1. Approaches based on expert opinion

First attempt to formalize seismic risk assessment is found in Whitman et al. (1973). Damage probability matrices were developed for the probabilistic prediction of damage to buildings from earthquakes. Another step was taken by ATC (Applied Technology Council), seismic risk assessment for 40 different structural types in the California State was performed, by taking opinion of 58 expert. The results were documented in the report ATC-13(ATC, 1985) which presented vulnerability of infrastructure in the form of damage probability matrices (DPM). ATC-25 Report (ATC, 1991) introduced the concept of continuous fragility functions. Regression analysis was performed on the discrete values of damage probability matrices for various lifeline systems. Another attempt to push forward the seismic risk assessment method was made by FEMA. A committee of experts was constituted and a GIS (Geographic Information System) based risk assessment software Hazard United States (HAZUS99) was developed. Expert opinion technique was one of the elementary steps in seismic vulnerability assessment of infrastructure and has certain drawbacks. The procedure is totally subjective and is based on expertise and experience of the individuals with little correlation to actually observed earthquake damage, thus, the results may be misleading

2.1.2 Approaches using Actual Damage Data observed in Earthquakes

Basoz and Kiremidjian (1997) assembled damage frequency matrices and performed a logistic regression analysis to develop fragility curves for bridges. Shinozuka et al. (2003) generated fraglity curve for Caltrans expressway bridges in Los Angeles by collection of the damage data after Northridge EQ. A two-parameter log-normal distribution function was calibrated by Maximum Likelihood Method. PGA was used to represent the intensity of the ground motion. Rosette and Elnashai (2003) performed regression and sensitivity analysis for 34000 R.C. Framed buildings. Post Earthquake data of the damage distribution observed in 19 Earthquakes in Europe were considered for analysis. Concept of a single set of 'homogeneous' vulnerability relationships, applicable to different lateral load resisting systems was established. Rota et al.(2008) used advanced non-linear regression method to derive fragility curve for 163000 building stock in Italy. Italian post-Earthquake survey data was considered and damage scale was represented in terms of EMS and the buildings typology was defined as per RISK-UE.

2.2 Analytical Approaches

In this method damage data is obtained by numerical analysis. The structural systems or components are analyzed with different ground motion recorded at different levels of intensity. First Analytical approach was attempted by Singhal and Kiremidjian(1996). They developed fragility curve using Park and Ang's damage index(1985) and Monte – Carlo simulation technique for three categories of reinforced concrete frame structures. MMI was used as the ground-motion parameter and fragility functions were generated using spectral accelerations. Nonlinear dynamic analysis was performed and ARMA (autoregressive moving average) model was used for the generation of EQ time histories.
Vona (2014) also used Linear Dynamic Analysis for development of fragility curve for Moment Resisting Frame Reinforced Concrete building. EMS98 was used to describe the damge levels. However the proposed procedure was developed for European building and was applicable in large-scale vulnerability studies. Another approach was the use of Incremental dynamic analysis, Kircil and Polat (2006) developed the fragility curves for existing mid-rise RC frame buildings in Istanbul. The buildings were designed according to the Turkish seismic design code (1975 version). Incremental Dynamic Analysis was performed on two damage levels- Yielding and collapse. Fragility curve were developed for R/C framed representative 3,5,7 storied building using twelve artificial ground motion and it was established that fragility parameters vary significantly with the number of stories

of the building. Ibrahim and El-Shami (2011) analysed four storey and eight storey R.C. moment-resisting frame buildings using Seismo Struct computer program. Fragility curve was constructed using log normal distribution function. Nonlinear Static Analysis has also been used widely due to quick and easy computation. Olteau et al. (2011) conducted fragility analysis for 2-D R.C. frame design according to Romanian norm. Comparison between deterministic and probabilistic approaches of vulnerability and risk assessment was also conducted using Capacity spectrum method. Tekin and Gurbuz (2015) formed fragility curves for 1 and 2 stories reinforced concrete (RC) residential buildings in Turkey. Non-linear pushover analysis was conducted for representative of 84 RC buildings which were divided to 2 groups- one group representing buildings built in the year 1998 and later and the second group represented buildings constructed before 1998.

Based on the methods to define the nonlinear behaviour of buildings , the analytical approaches can be described as the following methods –

2.2.1 Capacity spectrum method (CSM)

Spectral demand and spectral capacity curves are used for estimating the response of a structure in CSM. It is the commonly used method for generating fragility curves. The advantage of using CSM is that it is easy, simple and consumes less time. CSM has been described in ATC-40 (ATC, 1996), where the performance of a building under a particular ground-shaking is found from the intersection of an acceleration-displacemnt spectrum and a capacity spectrum (also known as pushover curve). HAZUS Earthquake loss Estimation Methodology (1999) originally applied this procedure to derive fragility curves for unreinforced masonry with low-code design levels and for Reinforced concrete moment frames. HAZUS has been adopted all over the world. Bommer et al. (2002) carried out the loss assessment of Turkey using HAZUS, Haz-Taiwan was modified form of HAZUS for loss estimation of Taiwan (Yeh et al 2000). RISK_UE project which carried out the risk assessment of 7 European towns is called based on this method. Rosetto and Elnashai (2003) carried out adaptive pushover analysis of building considering random structural characteristic of building. Giovinazzi (2005) used bilinear capacity curves to carry out risk assessment of reinforced concrete frames. It is a cost-effective method and gives a quick estimate but the actual behaviour of the building may differ from the assumed capacity curve (Borzi et. al. 2008).

2.2.2 Mechanics-based methods

The methods are based on collapse mechanism of the structure. Cosenza et al. (2005) presented this method for the assessment of reinforced concrete buildings. The building frame was modelled as three-dimensional line model and plastic analysis approach was applied to determine the ultimate base shear capacity. A number of building model were generated to account for the uncertainties in geometrical and material properties. The seismic response is represented by lateral drift (roof displacement divided by building height) corresponding to a collapse multiplier which is ratio of base shear and seismic weight. Monte Carlo simulation technique is then applied to calculate "probabilistic capacity curves". The disadvantage of using this method is that only collapse limit state is considered in generation of the curves and there is no convolution between capacity and demand to calculate the probability of exceeding given limit states.

2.2.3 Displacement-based methods

Displacement is used as the fundamental indicator of damage and demand in displacement-based methods. Non-linear displacement capacity is determined instead of the pushover curves to define the nonlinear behaviour of reinforced concrete buildings. Calvi(1999) proposed a procedure which utilised the principles of Direct Displacement-Based Design. A MDOF structure was modelled as a single DOF system and displacements are calculated at a given limit state considering column-sway and beam-sway failure mechanism for R.C. Buildings and in-plane failure modes for masonary buildings. The fragility function was represented in the form of a curve showing intersection of capacity area and demand spectrum. The method is quick in computation but it considers only one limit state for damage representation. Work of Calvi(1999) was further developed by Pinho et al.(2002) and Crowley(2004,2006). DBELA (Displacement Based Earthquake Loss Assessment procedure) was developed as new procedure where three limit states are considered for better realistic damage condition. Simplified pushover-based method(SP-BELA) was proposed by Borzi et a. (2007) which combines the mechanics based procedure to displacement-based framework, to determine the vulnerability of building classes at four damge states (Non-structural light damge, light damge structural limit state, Significant damage limit state and collapse limit state). Lang (2002) and Oropezo(2010) proposed methodology for deriving the fragility curves for unreinforced masonary buildings by displacement-based method.

2.3 Hybrid Method

Hybrid method utilizes advantages of both analytical and empirical methods. In this method the post-earthquake damage statistics is combined with simulated damage statistics from a mathematical model of the building typology which is under consideration. Masi (2004) constructed regression curve (PGA vs. Interstorey Drift, PGA vs. ductility and PGA vs. demand) by Non-linear

dynamic analysis and DRAIN 2D+ software for R/C buildings designed only to vertical loads, representative of Italian building stock. Three main types of R/C structure- Bare frame, Regularly infilled and Pilotis frame were considered. Two sets of input motions- artificial accelerograms (generated from elastic response spectrum) and natural accelerogram (from 1997 Umbria – Marche seismic sequence) were used for the analysis. Another attempt was made by Kappos et al. (2010), they derived Fragility curve for R/C building types in Greece and southern EU countries by Inelastic static and dynamic time-history analyses using SAP2000 and DRAIN 2000. 16 accelerograms (half from actual greece seismic records and the other half synthetic) were used for analysis.
Hybrid method is considered to be theoretically superior over the other two but there are some issues which need to be addressed such as the capability of numerical models to account for human errors in the design and construction of building, which are the often neglected in the analysis and the next is the accuracy in measuring the actual damage of real structure through numerical indices. So, new approach is introduced to conduct experiments on the structure and include the values in the existing vulnerability assessment procedure.

2.4 Experiment Based Seismic Vulnerability Assessment

Modeling of the response of existing buildings is influenced by large number of uncertainties due to lack of structural plans, ageing and structural design. To reduce these errors in numerical modeling calculation, an estimate of the modal parameters of the structures is required through vibration tests in buildings. Michael et al. (2012) derived fragility curves for three RC high rise buildings built in the year 1960 in Grenoble (France). Ambient vibration measurements were taken by seismometers and the modal frequency values were used in the HAZUS methodology to derive the fragility curves. Su and Lee (2013) constructed fragility curves for low-rise masonary in-filled (MI) reinforced concrete (RC) building. Inter-story drift ratio and the period shift Factor was first related to the PGA through a regression analysis using the experimental results of MI RC buildings obtained directly from shaking table tests or psuedodynamic test (as summarized by Lee and Su (2012) through a literature Review). The analyzed buildings were regular and uniform in elevation (with minor variation in the storey height) and the masonry infilled walls were continuous along the building height without the weak or soft story. Then spectral acceleration- and spectral displacement-based fragility curves for various damage states were constructed using a suite of inter-story drift ratios and spectral acceleration and displacement data obtained by the coefficient-based method.

3. DISCUSSIONS

The huge damage caused by the recent earthquake to buildings has shifted the focus of the earthquake engineering fraternity from post-disaster mitigation to pre-disaster planning. Development of fragility estimates can be a fundamental tool in pre-disaster vulnerability assessment of any existing building. The existing fragility analysis methods are dependent on the numerical simulation techniques and post-seismic inventories. These techniques involve assumptions and uncertainties and are thus not realistic representative of the actual seismic response of the buildings. The advances in the field of data acquisition systems and signal processing algorithm can be utilized for pragmatic approach. The frequency and modal parameters of building can be determined through vibration based test. Fragility curve developed using these experimental values will reduce the epistemic uncertainities on response and will be useful in determining the realistic probability of failure or degree of damage level which can be sustained by a building, at a given level of ground motion intensity measure. The knowledge will be further utilized for identifying the deficient buildings and providing the appropriate retrofitting method thus reducing its catastrophic failure during an earthquake.

4. 4. Conclusion
5.

Analyzing the various methodologies for the fragility assessment of buildings for a given seismic intensity it can summarized that there is no single methodology which can fulfil the requirements of the optimal method and balance between the computational intensity and the amount of detailed data required. As summarized by Calvi (2006) an ideal methodology should account for all sources of uncertainty and the model should be easily adaptable to different construction practices globally. Empirical Methods do not consider the frequency characteristics of the building stock and vulnerability assessment is carried out through incorrect modelling of the seismic demand experienced by the building stock. Analytical methods are applicable only to a small number of representative buildings and there are a number of uncertainities involved in the computational modelling to represent the real structure. Influence of incorrect modelling often gets neglected in loss estimation. Inclusion of experimental methodologies to consider the modal parameters of the buildings allows incorporating design specifications in numerical modelling (Michael et al. 2012). While selecting a particular methodology one should taken into account the type of building/structure, availability of expertise, availability of ground motion data, and availability of previous earthquake damage records etc. Through the review it is observed that in most of the vulnerability assessment methods significance of elements such as staircases and lift shafts has not been considered. Therefore, there is need for further research required to develop experimental methods considering the changes in stiffness and overall resistance of buildings.

ACKNOWLEDGEMENT

The authors acknowledge the support of the director CSIR-Central Building Research Institute, Roorkee, India for their continued support and permission to publish the paper.

REFERENCES

[1] Akkar,S., Sucuaglu, H., Eeri, M., and Yakut. A. 'Displacement based fragility functions for low and mid- rise ordinary concrete buildings.' Earthquake Spectra Vol. 21, No. 4. 2005

[2] ATC, 'Earthquake damage evaluation data for California.' Report No. ATC-13, Applied Technology Council, Redwood City, CA;1985.

[3] ATC, 'Seismic vulnerability and impact of disruption of lifelines in the Coterminous United States', Report No. ATC-25, Applied Technology Council, Redwood City, CA;1991.

[4] Basoz, N., and Kiremidjian, A. S., 'Evaluation of bridge damage data from the Loma Prieta and Northridge CA Earthquakes', Report No. MCEER-98-0004, MCEER, University at Buffalo, The State University of New York, Buffalo, NY;1997.

[5] Bommer, J.J. and Crowley, H. 'The influence of ground-motion variability in earthquake loss modelling.' *Bulletin of Earthquake Engineering*, Vol. 4, No. 3, pp. 231-248;2006.

[6] Borzi, B.,Pinho R., and Crowley H., 'Simplified pushover-based vulnerability analysis for large-scale assessment of RC buildings'. Engineering Structures 30 (2008) 804–820. Available online at www.sciencedirect.com;2007.

[7] Calvi, G.M. 'A displacement-based approach for vulnerability evaluation of classes of buildings.' *Journal of Earthquake Engineering,* 3:3, 411-438;1999

[8] Calvi, G.M. et al. 'Development of seismic vulnerability assessment methodologies over the past 30 years'. *ISET Journal of Earthquake Technology* 472:3, 75-104;2006

[9] Coburn, A., and Spence, R.,'Earthquake Protection'. John Wiley, Chichester, U.K;2002

[10] Cornell CA, Jalayer F, Hamburger RO, Foutch DA, 'Probabilistic basis for 2000 SAC Federal Emergency Management Agency steel moment frame guidelines'. *Journal of Structural Engineering*, ASCE ; 128(4):526–533.;2002

[11] Cosenza G.M., Pinho, R., Calvi, G.,M. and Verderame G.,M. 'A multi-level approach to the capacity assessment of existing.' *Journal of Earthquake Engineering* 9:1.1–22;2005.

[12] Crowley, H. and Pinho, R., 'Simplified equations for estimating the period of vibration of existing buildings.' In: Proceedings of the 1st European conference of earthquake engineering and seismology. Paper no. 1122;2006.

[13] Crowley, H., Pinho, R. and Bommer, J.J.,'A probabilistic displacement-based vulnerability assessment procedure for earthquake loss estimation. Bulletin of Earthquake Engineering' 2:2,173–219;2004

[14] FEMA-273, 'NEHRP Guidelines for the seismic rehabilitation of buildings.' Report No. FEMA-273, Building Seismic Safety Council Seismic Rehabilitation Project, Federal Emergency Management Agency, Washington, DC,1997.

[15] FEMA-350, 'Recommended seismic design criteria for new steel moment-frame buildings.' Report No. FEMA-350, SAC Joint Venture, Federal Emergency Management Agency, Washington, DC; 2000.

[16] FEMA-351 'Recommended seismic evaluation and upgrade criteria for existing welded steel moment-frame buildings', Report No. FEMA-351, SAC Joint Venture, Federal Emergency Management Agency, Washington, DC;2000.

[17] FEMA-454, 'Designing for Earthquakes: A Manual for Architects, Federal Emergency Management Agency.' U.S. Department of Homeland Security, Washington, DC;2006.

[18] Giovinazzi, S., 'The vulnerability assessment and the damage scenario in seismic risk analysis.' Ph.D. Thesis. Technical University Carolo-Wilhelmina at Braunschweig, Braunschweig, Germany and University of Florence, Florence, Italy;2005.

[19] Gueguen P., Voisin C. & Mariscal A., 'Wandering of the modal parameters in existing building: application to structural health monitoring and seismic vulnerability analysis.' 15 WCEE, Lisbonia;2012.

[20] HAZUS, 'Earthquake loss estimation methodology.' Technical and user manual, Vol. 1-3, FEMA, NIBS, Washington, DC;1999.

[21] Hwang, H., Jernigan, J. B., Lin, Y. W. 'Evaluation of seismic damage to Memphis bridges and highway systems.' Journal of Bridge Engineering, 5:4, 322-330;2000.

[22] Inqualabi, K.Q., 'Seismic risk assessment of typical urban bridges using pushover analysis including soil-structure interaction.' M.Tech. Thesis. Academy of Scientific and Innovative Research at CSIR-CRRI, New Delhi. India; 2014.

[23] Kappos A.J. and Panagopoulos G. 'Fragility curves for reinforced concrete buildings in Greece' *Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance*, 6:1-2, 39-53, DOI: 10.1080/15732470802663771;2010

[24] Kaynia A.M.(ed.), 'Guidelines for deriving seismic fragility functions of elements at risk: Buildings, lifelines, transportation networks and critical facilities.' SYNER-G reference report 4. Publication Ofiice of the European Union, Luxenbourg;2013.

[25] Kircil, S.M. and Polat, Z., 'Fragility analysis of mid-rise R/C frame buildings.' Engineering Structures, 28 (9),

1335–1345. Available online at www.sciencedirect.com;2006

[26] Lagomarsino, Sergio and Cattari, Serena., 'Vulnerability of existing buildings: Observational and Mechanical Approaches for Application in Urban Areas.' In: Gueguen, Philippe(ed.). Seismic Vulnerability of Structures. Great Britain and United States: ISTE Ltd and John Wiley & Sons, Inc;2013.

[27] Lang K. 'Seismic vulnerability of existing buildings.' Ph.D. Thesis, Institute of Structural Engineering, Swiss Federal Institute of Technology, Zurich;2002.

[28] Masi, A., 'Seismic vulnerability assessment of gravity load designed R/C frames.' *Bulletin of Earthquake Engineering* **1**:371-395*;* 2013.

[29] Michel C., Gueguen P. and Causse M., ' Seismic vulnerability assessment to slight damage based on experimental modal parameters. *Earthquake Engineering and Structural Dynamics*, Wiley-Blackwell, 41:1, pp.81-98. <10.1002/eqe.1119>. <hal-00673135>;2012.

[30] Olteanu I., Vargas Y.F., Barbat A.H., Budescu M., and Pujades L.G.'Vulnerability and risk evaluation for a reinforced concrete frame.' *Bulletin of the Polytechnic Institute of Jassy*, Romania, Tomme, vol. LVIII, Fasc. 3, 9-20;2011.

[31] Oropeza,M., 'A simplified analytical methodology for fragility curves estimation in existing building.' 14th European Conference on Earthquake Engineering, Ohrid, Macedonia, August 30 - September 3. Available online at www.researchgate.net ;2010.

[32] Orsini, G., 'A model for buildings' vulnerability assessment using the parameterless scale of seismic intensity (PSI)'. Earthquake Spectra 1999;15(3):463–83:1999.

[33] Park Y.J., Ang A.H., 'Seismic damage analysis of reinforced concrete buildings.' ASCE, *Journal of Structural Engineering* ,111(ST4):740–57;1985.

[34] Pinho, R., Bommer, J.J., Glaister, S., 'A simplified approach to displacementbased earthquake loss estimation analysis.' In: Proceeding of the 12th European conference on earthquake engineering. Paper no. 738;2002.

[35] Polese, M., 'Vulnerability analysis for gravity load designed RC buildings in Naples – Italy.*' Journal of Earthquake Engineering,* 12(S2):234–245;2008.

[36] Rossetto T., Elnashai A. 'Derivation of vulnerability functions for European-type RC structures based on observational data.' Journal of engineering structures, Elsevier Available online at www.sciencedirect.com;2003.

[37] Rota M., Penna A. and Strobbia C.L., 'Processing Italian damage data to derive typological fragility curves.' *Soil Dynamics and Earthquake Engineering.* 28, 933-947;2008

[38] Silva, V., et al., 'Evaluation of analytical methodologies to derive vulnerability functions.*' Earthquake Engineering & Structural Dynamics*.Volume 43, Issue 2, 181–204;2014

[39] Singhal, A., Kiremidjian A.S., 'A method for earthquake motion damage relationships with application to reinforced concrete frames.' State University of New York at Buffalo: National Center for Earthquake Engineering Research Report NCEER-97-0008, 1997.

[40] Shinozuka, M., Feng, M. Q., Kim, H., Uzawa, T. Ueda, T. 'Statistical Analysis of Fragility Curves.' Report No. MCEER-03-0002, MCEER, University at Buffalo, The State University of New York, Buffalo, NY;2003

[41] Su R.K.L. and Lee C.L., 'Development of seismic fragility curves for low-rise masonry In-filled reinforced concrete buildings by a Coefficient-based Method.' *Earthquake Engineering and Engineering Vibrations*.12 (2).p.319-332.2013.

[42] Su R.K.L., Lee C.L. and Wang Y.P., 'Seismic spectral acceleration assessment of masonry In-filled reinforced concrete buildings by A Coefficient-based Method.' *Structural Engineering and Mechanics*. **41:4**,479-494. 2012.

[43] Tekin M. and Gurbuz A. Seismic Fragility Curves for 1 And 2 Stories R/C Buildings.' *International Journal of Engineering Technologies*, 1(2).2015.

[44] Vacareanu, R. et al., 'Seismic vulnerability of RC buildings in Bucharest, Romania.' 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada. August 1-6, 2004. Paper No. 1796: 2004

[45] Vona, M. 'Fragility curves of existing RC buildings based on specific structural performance levels.' *Open Journal of Civil Engineering*, 4, 120-134,2014. http://dx.doi.org/10.4236/ojce.2014.42011

[46] Whitman, R. V., Biggs, J. M., Brennan III, J. E., Cornell, A. C., de Neufville, R. L., and Vanmarcke, E. H., 'Seismic design decision analysis.*' Journal of Structural Division*, 101(ST5), pp: 1067-1084.1973.

[47] Xue, Q., et al., 'The draft code for performance-based seismic design of buildings in Taiwan.' *Engineering Structures* 30, 1535–1547. 2008.

[48] Yamazaki F, Murao O. 'Vulnerability functions for Japanese buildings based on damage data from the 1995 Kobe earthquake.' Implication of Recent Earthquakes on Seismic Risk, Series on Innovation and Construction: Imperial College Press 2:91–102. 2000

[49] Yasser E. Ibrahim & Mostafa M. El-Shami, 'Seismic fragility curves for mid-rise reinforced concrete frames in Kingdom of Saudi Arabia.' The IES Journal Part A: Civil & Structural Engineering, 4:4, 213-223, 2011. DOI: 10.1080/19373260.2011.609325

.

[50] Yeh, C.H., Jean, W.Y. and Loh, C.H., 'Damage building assessment for earthquake loss estimation in Taiwan", Proceedings of the 12th World Conference on Earthquake Engineering, Auckland, New Zealand, Paper No. 1500;2000.

[51] Yu. O., Allen, D. L., and Drnevich, V. P. 'Seismic vulnerability assessment of bridges on earthquake priority routes in Western Kentucky.' 3rd US National Conference on Lifeline Earthquake Engineering, Los Angeles, CA;1991.

BIOGRAPHIES

Tarannum Yasmin is pursuing M.Tech in Building Engineering and Disaster Mitigation (BEDM) from AcSIR, CBRI campus, Roorkee. She completed her B.Tech in Civil Engineering from Aligarh Muslim University in 2011.

Dr. Ajay Chourasia completed his Ph.D. (Structural Engineering) in 2015 from Indian Institute of Technology (IIT-Roorkee). He is presently working as Principal Scienstist in Structural Division at CBRI, Roorkee. He has specialization in field of earthquake resistant building design and construction practices..

Prof. S.K.Bhattacharya is a renowned Professor and Head of Civil Engineering department at IIT Kharagpur. He has also served as director of CBRI, Roorkee from 2009 to 2015. He has expertise in the field of Finite Element Analysis

Jalaj Parashar is working as Senior Technical Officer in Structural Enginnering Division at CBRI Roorkee. He has been working in the field of Instrumentation Engineering for last 20 years.