A TENTATIVE METHODOLOGY TOWARDS SEISMIC FRAGILITY ASSESSMENT OF HIGHWAY BRIDGES IN BANGLADESH

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ABSTRACT
Bridges are the economic benchmark for the countrywide transportation development which facilitates emergency rescue operation, first aid, fire fighting, medical services and relief operation for disaster prone areas. As a transportation lifeline, it seems very important to minimize the seismic induced losses of bridge function as much as possible. At past, the performance of highway bridges against moderate to high seismic thrust was quite unsatisfactory at different part of the world which proves that bridges are highly susceptible to damages during earthquake. A significant amount of global bridges collapsed in the recent years have exposed inadequacy of the design of existing bridge structures which pushes engineers to rethink about the optimization of seismic provision. A fragility curve (FC) illustrates the conditional probability that a structure surpasses some defined limit states at different levels of load or seismic shock. This study clarifies the research importance of developing the seismic fragility functions (FF) and FC for the major bridge classification in Bangladesh. This literature based study reconfirm the necessity of FF and FC of existing bridges in a particular territory so that, the prediction of damage probability for a certain ground motion may possible. Both the FF and FC could be fruitful in damage state assessment for a defined seismic event as well as financial seismic losses prediction following density and speed of traffic, environmental exposure, soil condition, degree of uses and structural importance of the major bridge classification in Bangladesh. To do so, at the very infant stage of this study, a tentative methodology flowchart have been tried to establish which cordially urges further refinement.

Keywords: Fragility function; fragility curve; seismic induced losses; damage state analysis; seismic performance; highway Bridge

INTRODUCTION
Bridges are a crucial part of the overall transportation system as they play very important roles in evacuation and emergency routes for rescues, first-aid, fire fighting, medical services and transporting disaster commodities to expatriates. In this regard, bridges serve as a transportation lifeline of modern society. In view of the importance of the bridge structure, it is a contemporary key issue to minimize as much as possible the loss of the bridge functions against earthquakes to enhance continued functioning of the community life. A large number of bridge structures collapsed in recently occurred destructive earthquakes in different places in the world have exposed inadequacy of the design of existing bridge structures, which have led engineers rethink widely on how to design bridge structures against earthquakes. These occurrences have indicated that the necessity to construct/rehabilitate bridge structures to withstand seismic forces in earthquake prone regions is more than a mere philosophy (Khan, 2014; Khan and Bhuiyan, 2015). The performance of highway bridge systems observed in past earthquakes — including the 1971 San Fernando earthquake, the 1994 Northridge earthquake, the 1995 Great Hanshin earthquake in Japan, the 1999 Chi-Chi earthquake in Taiwan, the 2010 Chile earthquake, and the 2010 Haiti earthquake — have demonstrated that bridges are highly susceptible to damages during earthquakes (Alim et al., 2015). Bridges give the impression of being rather simple structural systems. Indeed, they have always occupied a special place in the affections of structural designers because their structural form tends to be a simple expression of their functional

requirement. Bridges, possibly because of their structural simplicity, have not performed well as might be expected under seismic thrust. In recent earthquakes in California in 1989, Japan in 1995, etc. modern bridges designed specifically for seismic resistance have collapsed or have been severely damaged when subjected to ground shaking of an intensity that has frequently been less that corresponding to current code intensities (Alim, 2014; Alim et al., 2015). FC displays the conditional probability that a structure surpasses some defined limit state at different levels of load or other actions. For seismic fragility, the curves represent the probability of seismic damage at various levels of ground shaking, which is described for the purposes of this research in terms of peak ground acceleration (PGA).

LITERATURE REVIEW

Since last decade, several authors have tried to explain this term with different parameters from different seismic eyesight's (Alim, 2014; Alim et al., 2015). Most of these assumptions and explanations were mainly focused on different civil engineering structures - particularly on buildings and bridge structures. Yamazaki et al. (2000) developed a set of empirical FC based on the actual damage data acquired from the 1995 Hyogo-ken Nanbu (Kobe) earthquake. Shinozuka et al. (2000) presented both empirical and analytical approaches for FC. Kim and Shinozuka (2004) then developed FC for concrete bridges retrofitted by column steel jacketing. The FC were expressed in the form of a two parameter lognormal distribution function with the estimation of the two parameters performed an optimization algorithm, and it could be achieved through ground motion records and seismic structural response analyses (Alim, 2014; Alim et al., 2015).

In the seismic fragility analysis, different forms of engineering demand parameters (EDP) are used to monitor the structural responses under earthquake ground motion and measure the damage states (DS) of the bridge components. DS for bridges should be defined in such a way that each DS indicates a particular level of bridge functionality. A capacity model is needed to measure the damage of bridge component based on prescriptive and descriptive DS in terms of EDP (Choi et al., 2004; Neilson, 2005). Four DS as defined by Federal Emergency Management Authority (FEMA, 2000) through HAZUS are commonly adopted in the seismic vulnerability assessment of engineering structures, namely slight, moderate, with extensive and collapse damages. Bridge piers are one of the most critical components, which are often forced to enter into nonlinear range of deformations under strong earthquakes. Alim et al. (2015) affirmed that, the displacement ductility of the bridge pier is adopted as damage index (DI). Hwang et al. (2001) recommended four different DS for bridge pier based on ductility limit. But retrofit affects the seismic response and demand of the bridge pier and the capacity as well. For the retrofitted bridge pier new limit states (LS) need to be defined (Alim, 2014). LS capacities for the retrofitted bridge bent might be obtained by transforming the ductility LS proposed by Hwang et al. (2001). The use of ductility limit for retrofitted reinforced concrete (RC) columns is well documented in literature of Ramanathan et al. (2012), Billah and Alam (2012), Alim (2014) and Alim et al. (2015).

In Incremental Dynamic Analysis (Vamvatsikos and Cornell, 2002; Alim, 2014; Alim et al., 2015), the structure is subjected to a series of non-linear time-history analysis of the increasing intensity (e.g. Peak ground motion acceleration is incrementally scaled from a low elastic response value up to the attainment of a pre-defined post-yield target limit state). Incremental Dynamic Analysis (IDA) is a new methodology which may postulate a clear indication of the relationship between the seismic capacity and the demand. An analysis scheme was carried out for the as-built and retrofitted concrete bridge bent (Alim, 2014). The peak values of base shear are plotted against their top displacement counterparts, for each of the dynamic runs, giving rise to the so-called dynamic pushover or IDA envelop curves (Alim et al., 2015). FC allows the evaluation of potential seismic risk assessment of any structure. Fragility function describes the conditional probability i.e., the likelihood of a structure being damaged beyond a specific damage level for a given ground motion intensity measure (Alim, 2014; Alim et al., 2015). In order to develop FC, different methods and approaches have been developed. Depending on the available data and resources, fragility functions can be generated empirically based on post-earthquake surveys and observed damage data from past earthquakes

(Basoz and Kiremidjian, 1999; Yamazaki et al., 2000; Alim, 2014). However, limited damage data and subjectivity in defining DS limits the application of empirical FC (Padgett and DesRoches, 2008).

In absence of adequate damage data, fragility functions can be developed using a variety of analytical methods such as elastic spectral analyses (Hwang et al., 2001), nonlinear static analyses (Shinozuka et al., 2000) and nonlinear time-history analyses (Hwang et al., 2001; Choi et al., 2004). In order to generate analytical FC, structural demand and capacity needs to be modelled. Alim (2014) and Alim et al. (2015) studied the Probabilistic Seismic Demand Model (PSDM) that was used to derive the analytical FC using nonlinear time-history analyses of the retrofitted bridge bents. Though this is the most rigorous method, yet this is a dominating reliable analytical method (Shinozuka et al., 2000). The PSDM establishes a correlation between the EDP and the ground intensity measures (IM). Displacement ductility demand of retrofitted bridge bent was considered as the EDP, and the PGA was utilized as IM of each ground motion records (Alim, 2014; Alim et al., 2015). Two approaches are used to develop the PSDM. These are (i) the Scaling Approach and (ii) the Cloud Approach (Alim, 2014; Alim et al., 2015). Following Scaling Approach, all the ground motions are scaled to selective intensity levels and an IDA is conducted at each level of intensity; however, in the Cloud Approach, un-scaled earthquake ground motions are used in the nonlinear time-history analysis and then a PSDM is developed based on the nonlinear time history analyses results. Alim (2014) and Alim et al. (2015) studied the Cloud method that was utilized in evaluating the seismic fragility functions of the retrofitted bridge bents. In this approach, a regression analysis is carried out to obtain the mean and standard deviation for each limit state by assuming the power law function (Cornell et al., 2002), which gives a logarithmic correlation between the median EDP and selected IM. In order to create sufficient data for the Cloud Approach, IDA is carried out instead of nonlinear time history analysis where the median and dispersion value of the DS are described by Ramanathan et al. (2012).

Effect of isolation on FC of thirty highway bridges based on simplified method was assessed by Karim and Yamazaki (2007) where strong ground motion records were utilized for dynamic analysis towards FC development. Another fragility assessment of a multi-span highway bridge (i.e., isolated by shape memory alloy restrainers and lead rubber bearing) was postulated by Bhuiyan and Alam (2012). The authors offered fragility functions of the bridge components that are generated and then combined to approximate the overall system fragility functions at different damage states. A comprehensive Bayesian methodology for developing probabilistic capacity and demand model for structural component of highway bridge system was formulated by Gardoni et al. (2002) where both aleatory and epistemic uncertainties were considered. The PSDM are used in conjunction with the component capacity models to objectively assess the seismic fragilities of RC bridge bent for a set of ground excitations. Analytical probabilistic fragility studies require extensive computer simulations to account for the randomness in both input motions and response characteristics. Jeong and Elnashai (2007) initiated an approach where a set of fragility relationships with known reliability was derived based on the fundamental response quantities of stiffness, strength and ductility of bridge frames.

A set of seismic FC for the bridges commonly found in the Central and Southern United States (CSUS) was developed to predict economic losses due to earthquake and prioritization of retrofit action (Choi and Jeon, 2003). The authors assessed the seismic resistance of several retrofitted bridges and also evaluated using fragility analysis and compared with that of the as built bridges to verify the effect of each retrofit measures aggressively. A method was presented for the evaluation of seismic fragility function of RC bridge structures subjected to both rigid and spatially varying excitation in association with nonlinear dynamic analysis and plain Monte-Carlo simulation (Lupoi et al., 2004). An expanded methodology for the generation of analytical FC for highway bridges in CSUS was presented by Nielson and DesRoaches (2007a). The methodology considered the contribution of the major bridge components (i.e., pier, abutment and bearing) to its overall bridge system fragility. The fragility of individual bridge component was then compared with the overall bridge system and it was observed that, the overall bridge as a system is more fragile than any one of the individual components. Seismic FC for nine major classes of highway bridges at CSUS was developed by Nielson and DesRoaches (2007b). The methodology adopted three dimensional analytical models and nonlinear time history analysis to develop FC and further compared with the HAZUS-MH procedure.

Analytical FC for typical Algerian RC bridge piers was developed by Kibboua et al. (2011) in association with forty one worldwide accelerometer records and nonlinear dynamic analysis to assess the damage indices express in terms of the bridge displacement ductility, the ultimate ductility, the cyclic loading factor and the cumulative energy ductility. Combining the damage indices defined for five damage rank with the ground motion indices, the FC for the bridge piers were derived assuming a lognormal distribution. Mackie and Stojadinovic (2004) addressed the analytical and numerical formulation of FC for single bent RC highway bridges. FC was derived at the demand, damage and decision variable levels that are useful for traffic network modelling. El-Arab (2012) proposed an analytical methodology of seismic FC for RC pier bridges in Egypt. The study strongly argued that, the peak ground acceleration for 50% probability of exceeding slight, moderate and severe damage ranges from approximately 0.15g to 0.4g for the typical Egyptian RC pier bridges.

FC for two span simply supported concrete bridge pier in near fault region was developed by Shirazian et al. (2011) incorporating several earthquake time histories. To assess the loss estimation due to bridge damage, FC (both empirical and analytical) have been developed for various bridge types across America (Nielson, 2003). FC alone cannot predict the indirect losses associated with a given level of damage. Therefore, damage-functionality relationships are required in addition to FC that might be able to assess the indirect losses associated with a particular seismic event. Dukes et al. (2012) studied the sensitivity of design parameters used to develop bridge specific FC. A bridge specific fragility methodology can be developed that takes into account certain design aspects of a bridge design in order to provide FC particular to a bridge design. The authors conducts a sensitivity study to test which design parameters have a significant impact on bridge response and should therefore be consider as predictive variables in bridge specific fragility analysis used in the design procedures.

Tanaka et al. (2000) presented a methodology for developing the seismic fragility function that takes both physical and functional aspects into account. The authors deals with the fragility functions that can be used for post earthquake transportation management system where both space and time factors are relevant and follows three step procedure. (i) Construct the GIS based damage database, (ii) estimates spatial distribution of ground motion and assign to facility and (iii) develops the seismic FC for the highway bridges to estimate possible seismic losses. Fragility analysis of wall pier supported highway bridges of Southern Illinois in USA was initiated by Bignell and LaFave (2010). A series of hammerhead and regular wall pier supported bridges were randomly selected to analytical procedure and hundred three dimensional finite element model that are excited by synthetic earthquake records. Second stage liquefaction potentiality was also considered in the fragility analysis and it was observed that, the Southern Illinois wall pier supported bridges are moderately vulnerable to structural damage in a 2% probability of exceeding in a 50 years earthquake, and in some cases they could be highly vulnerable to on-site liquefaction arousal.

Evaluation of effectiveness and optimum design of isolation devices for highway bridges might be possible by using fragility function methodology (Zhang and Huo, 2009). The author adopts the performance based evaluation approach to investigate the effectiveness of isolation devices incorporating probabilistic seismic hazard analysis and IDA to produce fragility functions. The study shows that, the mechanical properties of isolation devices have significant effect on the damage probability of isolated bridges and these issues should be effectively considered under the fragility function framework. PSDM and fragility estimates for highway bridges with single column bent was assessed by Huang et al. (2010). The PSDM was proposed considering ground motion characteristics, prevailing uncertainties, statistical uncertainties and model errors in association with Bayesian updating approach. The uni-variate deformation shear fragility and the bi-variate deformation shear fragility were crucially assessed for the target bridge.

Fragility analysis of a highway overcrossing bridge with soil structure interaction was comprehensively discussed by Kwon and Elnashai (2010) for Central and Eastern USA. Four different modelling methods were adopted to represent abutment and foundations of the bridges and

FC of the components and bridge system are derived. Four different SSI approaches results different seismic FC. The authors argued that, careful consideration is necessary when selecting an analytical representation of a soil and foundation system to obtain reliable seismic impact assessment. It was also observed that, abutment bearings are the most critical components of the bridge systems.

Mechanistic quantification of RC bridges DS under earthquake through fragility analysis was performed by Banerjee and Shinozuka (2008). Bridge damageability information in a succinct from as FC is needed to pursue the seismic risk assessment of a highway network consisting of as large as thousand of bridges that could be affected by a high magnitude earthquake with in and near the service area of the network. FC for seismically retrofitted RC bridge was evaluated by Kim (2003). The CALTRANS specified bridges were seismically strengthened and then Monte-Carlo simulation was performed to study nonlinear dynamic responses of the bridges before and after retrofit. The effect of retrofit is expressed in terms of the increase of the median value of the FC for retrofitted bridge from that of the before retrofit. The comparison clarifies that, the retrofitting effort shows excellent performance for the ascertained damage states. Preliminary study on the FC for highway bridges in Taiwan was initiated by Liao and Loh (2004). The FC was used to represent the probabilities that structural damage, under various levels of seismic excitation, exceeds specific DS. Since, it is neither necessary nor practical to evaluate individual bridges, bridge classification and mapping scheme plays an important role. Calculation of site-specific seismic demand and demand function (i.e., capacity curves and fragility curves) are the key factors in bridge damage assessment and seismic losses prediction.

In the light of above discussion, it becomes appealing to critically assess the fragility functions of highway brides in Bangladesh based on which a meaningful and representative fragility curves should be developed. Both these fragility function and fragility curves will be synergistically supportive in damage state assessment for a particular seismic event as well as financial seismic loss prediction incorporating the socio-economic context, density and speed of traffic, environmental exposure, soil condition, degree of use and structural importance of the major bridge classifications in this seismic region.

OBJECTIVES OF THE PROPOSED RESEARCH WORK

Motivated by the study done so far, the current work is aimed to conduct the following works stated hereunder:

i) To propose a major classification of bridges in terms of structural importance and serviceability based on existing bridge inventory in Bangladesh.

ii) To develop physical and analytical modelling scheme of the proposed bridge classification for probabilistic seismic hazard analysis.

iii) To select a set of ground motion records for incremental dynamic analysis incorporating the finite element procedure of the major bridge classification towards seismic performance assessment.

iv) To derive the analytical seismic fragility function for the major bridge classification considering engineering demand parameters, different damage states, ground motion intensity measures and probabilistic seismic demand model based on available literature.

v) To develop seismic fragility curves following steps (iii) and (iv) for major bridge classification of Bangladesh that will best suited for seismic losses determination and retrofit prioritization.

POSSIBLE OUTCOMES

A meaningfully sophisticated and more objectively tuned fragility function and fragility curves for major bridge classification of Bangladesh will be developed. It is expected that, this more comprehensive fragility function with fragility curves will be better capable of evaluating the probabilistic seismic hazard analysis by accurately assess damage states that are important to estimate possible loss estimation and taking retrofitting decision for overall bridge systems in Bangladesh.

TENTATIVE FLOWCHART OF METHODOLOGY

A tentative flowchart of the research methodology have been tried to discussed by following steps given hereunder which might helpful to reach the research goal positively [Fig. 1]. This research work still in very primary stage which needs further modification and cordially promote comments and valuable suggestions from research community.

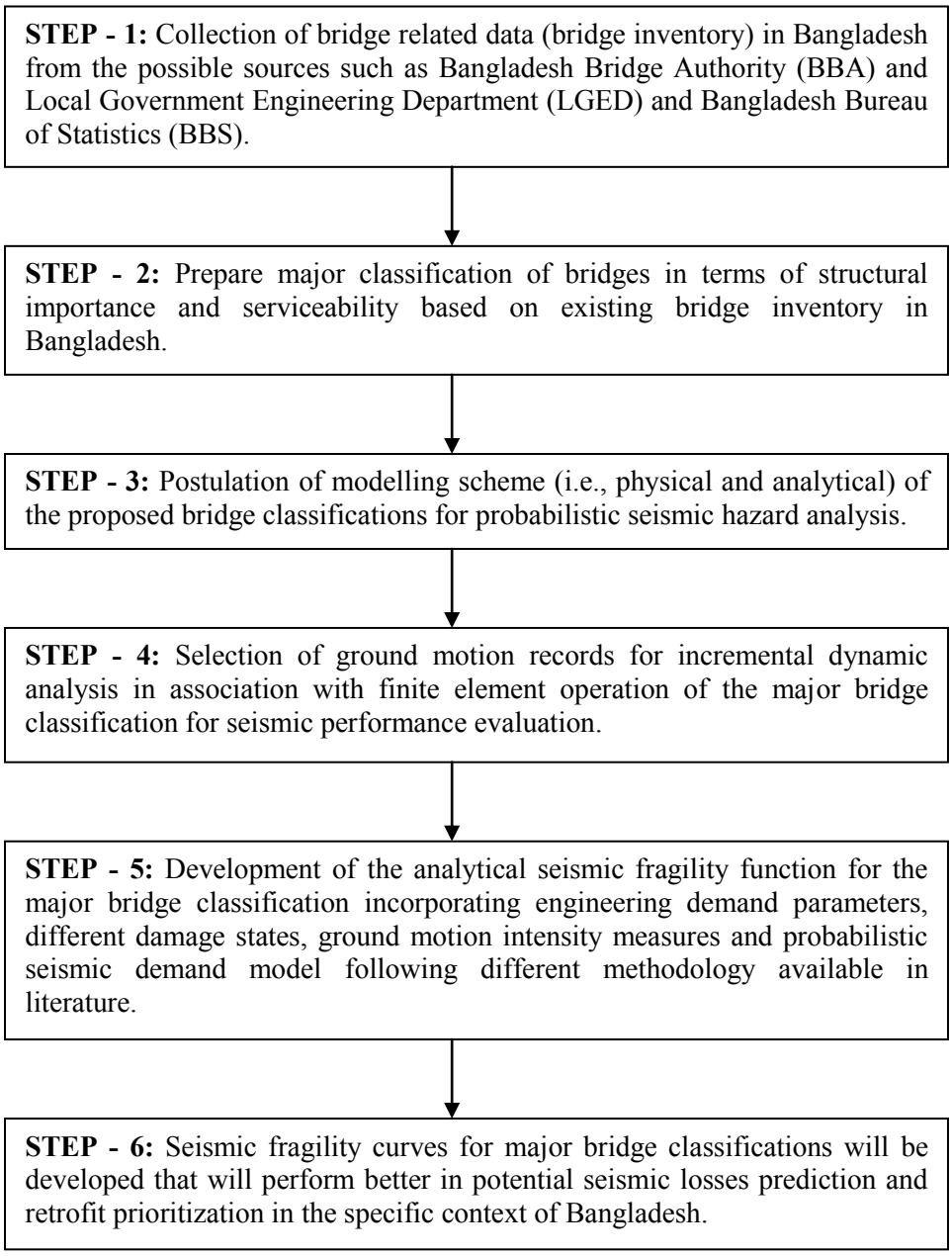

Fig. 1: Proposed methodology flowchart for fragility assessment of highway bridges in Bangladesh

REFERENCES

Alim, H. 2014. *Reliability Based Seismic Performance Analysis of Retrofitted Concrete Bridge Bent,* M. Engineering Thesis, Department of Civil Engineering, Chittagong University of Engineering and Technology (CUET), Chittagong, Bangladesh.

Alim, H; Khan, AKM. TA and Bhuiyan, MAR. 2015. *Reliability Bases Seismic Performance Analysis of Retrofitted Bridge Bent,* IABSE-JSCE Joint Conference on Advances in Bridge Engineering III, 21-22 August, Bangladesh.

Banerjee, S and Shinozuka, M. 2008. Mechanistic Quantification of RC Bridge Damage States under Earthquake through Fragility Analysis, *Probabilistic Engineering Mechanics,* 23: 12–22.
Basoz, N and Kiremidjian, AS. 1999. *Development of Empirical Fragility Curves for Bridges,* Proceedings of the 1999 5th U.S. Conference on Lifeline Earthquake Engineering: Optimizing Post-Earthquake Lifeline System Reliability, August 12-14, 16: 693–702.
Bhuiyan, AR and Alam, MS. 2012. *Seismic Fragility Assessment of Multi-span Continuous Highway Bridge Isolated by Shape Memory Alloy Restrainer and Lead Rubber Bearing,* Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon, Portugal.
Bignell, J and LaFave, J. 2010. Analytical Fragility Analysis of Southern Illinois Wall Pier Supported Highway Bridges, *Earthquake Engineering & Structural Dynamics,* 39: 709–729.
Billah, AHMM and Alam, MS. 2012. *Development of Fragility Curves for Retrofitted Multi-Column Bridge bent Subjected to Near Fault Ground Motion,* Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon, Portugal.
Choi, E DesRoches, R and Nielson, B. 2004. Seismic Fragility of Typical Bridges in Moderate Seismic Zones, *Engineering Structures,* 26(2): 187–199.
Choi, E and Jeon, JC. 2003. Seismic Fragility of Typical Bridges in Moderate Seismic Zone, *KSCE Journal of Civil Engineering,* 7(1): 41-51.
Cornell, CA; Jalayer, F; Hamburger, RO and Foutch, DA. 2002. Probabilistic Basis for 2000 SAC Federal Emergency Management Agency Steel Moment Frame Guidelines, *Journal of Structural Engineering,* 128(4): 526–532.
Dukes, J; DesRoaches, R and Padgett, E. 2012. *Sensitivity Study of Design Parameters used to Develop Bridge Specific Fragility Curves,* Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon, Portugal.
El-Arab, IME. 2012. Analytical methodology of Seismic Fragility Curve for Reinforcement Concrete Pier Bridges in Egypt, *International Journal of Engineering and Advanced Technology (IJEAT),* ISSN: 2249 – 8958, 2(2): 392-299.
FEMA 366/September 2000. *HAZUS®99 Estimated Annualized Earthquake Losses for the United States,* Reported by Federal Emergency Management Agency, Washington D.C., US.
Gardoni, P; Kiureghian, AD and Mosalam, KM. 2002. Probabilistic Models and Fragility Estimates for Bridge Components and Systems, *Pacific Earthquake Engineering Research Center, PEER Report 2002/13,* University of California, Berkeley.
Huang, Q; Gardoni, P and Hurlebaus, S. 2010. Probabilistic Seismic Demand Models and Fragility Estimates for Reinforced Concrete Highway Bridges with One Single-Column Bent, *Jour. of Engg. Mech. @ ASCE,* ISSN 0733-9399/2010/11, 136(11): 1340–1353.
Hwang, H; Liu, JB and Chiu, YH. 2001. *Seismic Fragility Analysis of Highway Bridges.* Reported under Project MAEC RR-4, Mid-America Earthquake Center, USA.
Jeong, SH and Elnashai, AS. 2007. Probabilistic Fragility Analysis Parameterized by Fundamental Response Quantities, *Engineering Structures,* 29: 1238–1251.
Karim, KR and Yamazaki, F. 2007. Effect of isolation on fragility curves of highway bridges based on simplified approach, *Soil Dynamics and Earthquake Engineering,* 27: 414–426.
Khan, A.K.M. TA. 2014. *An Improved Rheology Model of Laminated Rubber Bearings for Seismic Analysis of Multi-Span Highway Bridge*, M.Sc. Engg. Thesis, Dept. of Disaster and Environmental Engineering, Chittagong University of Engineering & Technology (CUET), Chittagong, Bangladesh.
Khan, AKMTA and Bhuiyan, MAR. 2015. *Damage State Analysis of Seismically Isolated Multi-Span Continuous Bridge,* IABSE-JSCE Joint Conference on Advances in Bridge Engineering III, 21-22 August, Bangladesh.
Kibboua, A; Naili, M; Benouar, D and Kehila, F. 2011. Analytical Fragility Curves for Typical Algerian Reinforced Concrete Bridge Piers, *Structural Engineering and Mechanics,* 39(3): 411-425.
Kim, SH. 2003. *Fragility Curves for Seismically Retrofitted Concrete Bridges,* Proceedings of the Pacific Conference on Earthquake Engineering, New Zealand, Paper ID – 168, pp. 1-8.
Kim, SH and Shinozuka, M. 2004. Development of Fragility Curves of Bridges Retrofitted by Column Jacketing, *Probabilistic Engineering Mechanics,* 19: 105–112.
Kwon, OS and Elnashai, AS. 2010. Fragility Analysis of a Highway Over-Crossing Bridge with Consideration of Soil–Structure Interactions, Structure and Infrastructure Engg., 6(1–2): 159–178.

Liao, WI and Loh, CH. 2004. Preliminary Study on the Fragility Curves for Highway Bridges in Taiwan, *Journal of the Chinese Institute of Engineers,* 27(3): 367-375.
Lupoi, G; Franchin, P; Lupoi, A and Pinto, PE. 2004. Seismic Fragility Analysis of Structural Systems, Proceedings of the *13th World Conference on Earthquake Engineering,* Paper ID - 4008, August 1-6, Vancouver, B.C., Canada.
Mackie, K and Stojadinovic, B. 2004. *Fragility Curves for Reinforced Concrete Highway Overpass Bridges,* Proceedings of the 13th World Conference on Earthquake Engineering, Paper ID - 1553, August 1-6, Vancouver, B.C., Canada.
Nielson, BG. 2003. Bridge Seismic Fragility-Functionality Relationships: A Requirement for Loss Estimation in Mid-America, Reported by *CBE Institute, Texas A&M University,* US.
Neilson, BG. 2005. *Analytical Fragility Curves for Highway Bridges in Moderate Seismic Zones,* Ph. D. Thesis, School of Civil and Env. Engineering, Georgia Institute of Technology.
Nielson, BG and DesRoches, R. 2007a. Seismic Fragility Methodology for Highway Bridges Using a Component Level Approach, *Earthquake Engineering and Structural Dynamics,* 36: 823–839.
Nielson, BG and DesRoches, R. 2007b. Analytical Seismic Fragility Curves for Typical Bridges in the Central and Southeastern United States, *Earthquake Spectra,* 23(3): 615–633.
Padgett, JE and DesRoches, R. 2008. Methodology for the Development of Analytical Fragility Curves for Retrofitted Bridges, *Earthquake Engineering & Structural Dynamics,* 37: 1157–1174.
Ramanathan, K; DesRoches, R and Padgett, JE. 2012. A Comparison of Pre and Post-seismic Design Considerations in Moderate Seismic Zones through the Fragility Assessment of Multi-span Bridge Classes, *Engineering Structures,* 45: 559–573.
Shirazian, S; Ghayamghamian, MR and Nouri, GR. 2011. Developing of Fragility Curve for Two-Span Simply Supported Concrete Bridge in Near-Fault Area, Reported by *World Academy of Science, Engineering and Technology,* 51: 571-575.
Shinozuka, M; Feng, MQ; Lee, J and Naganuma, T. 2000. Statistical Analysis of Fragility Curves, *Jour. of Engineering Mechanics @ ASCE,* 126(12): 1224-1231.
Tanaka, S; Kameda, H; Nojima, N and Ohnishi, S. 2000. *Evaluation of Seismic Fragility for Highway Transportation Systems,* Proceedings of the 12th World Conference on Earthquake Engineering, Paper ID - 0546, New Zealand.
Vamvatsikos, D and Cornell, CA. 2002. Incremental Dynamic Analysis, *Earthquake Engineering and Structural Dynamics,* 31(3): 491-514.
Yamazaki, F; Motomura, H and Hamada, T. 2000. *Damage Assessment of Expressway Networks in Japan Based on Seismic Monitoring,* Proceedings of the 12th World Conference on Earthquake Engineering, Paper ID – 0551, Auckland, New Zealand.
Zhang, J and Huo, Y. 2009. Evaluating Effectiveness and Optimum Design of Isolation Devices for Highway Bridges Using the Fragility Function Method, *Engineering Structures,* 31: 1648-1660.