Seismic vulnerability assessment of RC bridge –A Review

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Abstract - *Bridges in recent earthquakes have proven to possess the most threat to transportation system during and after earthquakes. In addition, well-being of bridges plays a major role in the post-earthquake emergency structures for earthquakes. Since bridges are one of the most critical components of highway transportation systems, it is necessary to evaluate the seismic vulnerability of highway bridges in order to assess economic losses caused by damage to highway systems in the event of an earthquake. Earthquake vulnerability analysis is a fertile area of research which needs more input from seismologists and engineers. The seismic vulnerability of a structure can be described as its susceptibility to damage by ground shaking of a given intensity measure. The vulnerability assessment of bridges is useful for seismic retrofitting decisions, disaster response planning, estimation of direct monetary loss, and evaluation of loss of functionality of highway systems*

Key Words: vulnerability assessment, intensity measure, seismic retrofitting.

1.INTRODUCTION

Structures constructed in seismically active areas are subjected to earthquake. The degree of seismic protection and level of acceptable structural damage due to an earthquake depend on many design consideration. Generally accepted seismic design philosophy requires that structure should be able to resist minor earthquake without damage but with the possibility of some non-structural damage, and resists major earthquake without collapse. But may suffer some structural and non - structural damage.

Bridges are critical elements within the highway transportation network, supporting commerce, economic vitality, and mobility. Recent records show that unpredictable extreme events, such as earthquakes, can cause significant damage to bridges, resulting in significant loss of life and property. Considering that many existing bridges were designed without consideration of seismic effects, components of current highway transportation system are at risk of significant damages during earthquakes. In order to mitigate potential life and economic losses during an earthquake, it is very important for the designer of bridges to predict the extent of probable damage to highway bridges during such unexpected earthquakes. For very important highway or railway bridges cost of severe damage in terms of loss of operating revenue and loss of life may be totally un- acceptable after a design level of earthquake. Consequently a higher seismic protection is applied to bridge structures compared to buildings.

2. SEISMIC VULNERABILITY ASSESMENT

The aim of a vulnerability assessment is to obtain the probability of a given level of damage to a structure due to a scenario earthquake. There are various methods for vulnerability assessment that have been proposed in past can be divided into two main categories: empirical or analytical, both of which can be used in hybrid methods.

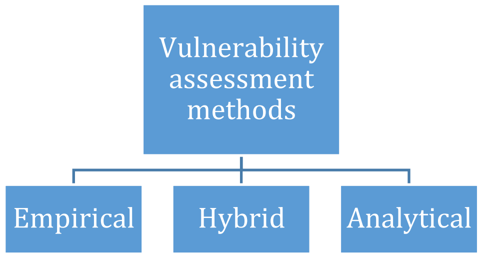

Fig 1. Vulnerability Assessment methods.

A vulnerability assessment needs to be made for a particular characterization of the ground motion, which will represent the seismic demand of the earthquake on the structure under study. The selected parameter should be able to correlate the ground motion with the damage to the buildings. Traditionally, macro seismic intensity and peak ground acceleration (PGA) have been used, whilst more recent proposals have linked the seismic vulnerability of the structures to response spectra obtained from the ground motions. To estimate a damage level (slight, moderate, extensive, and complete) for highway bridge structures, fragility curves are found to be a useful tool.

2.1 FRAGILITY CURVES

Fragility curves show the relationship between the probability of highway structure damage and the ground motion indices. They allow the estimation of a damage level for a known ground motion index. Fragility curves are derived using empirical data from past earthquakes, expert opinions or via analytical methods. Empirical fragility curves often lack adequate data and are only applicable to limited regions. Also, their refinement is highly dependent on the bridge inventory of the seismically affected region. Fragility curves based on expert opinion are also very subjective in that they rely heavily upon the expert's seismic experience with the bridges under consideration. Analytical fragility curves are developed from seismic response analysis of structures and the resulting fragility curves are verified with actual earthquake data, if available.

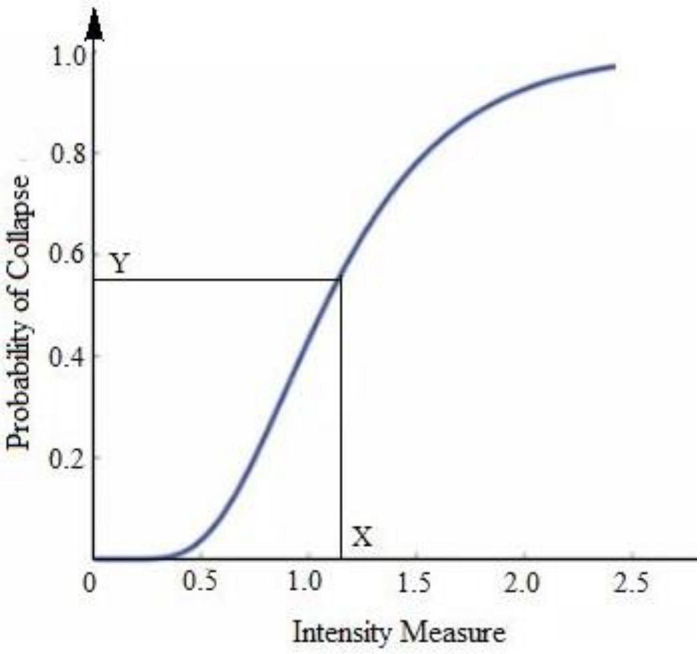

Fig 2. Fragility curve

Figure 2 shows a typical fragility curve with PGA along the x-axis and probability of failure along y-axis. A point in the curve represents the probability of exceedance of the damage parameter, which can be either failure of bearings due to exceedance of respective displacement limits or dislodgement of the bridge deck due to unseating, etc., over the limiting value mentioned, at a given ground motion intensity parameter. For a PGA of say = x, the fragility curve gives the corresponding probability of exceedance of limiting damage parameter as = p%'. It can be interpreted as if 100 earthquakes of PGA = x occur, p times the damage parameter will exceed the limiting value for which the fragility curve is plotted.

The relationship between bridge damage and ground motion intensity has been investigated since the 1980s and early 1990s, and an array of approaches and methodologies has been employed. However, only in more recent years have the first studies on probabilistic evaluation of a retrofit's influence on damage potential been initiated. Empirical fragility curves based on bridge damage data from the Northridge, Loma Prieta , and Kobe earthquakes have been developed for as-built bridges. However, as a result of the limited empirical data, developing fragility curve for retrofitted bridges using this approach is unrealistic. In the absence of adequate empirical data and in efforts to address an array of different bridge types and regions of the country while maintaining homogeneity of the data, analytical methods have often been used to develop bridge fragility curves. In these analytical studies, the structural demands and/or capacities used to evaluate failure probability are estimated through such methods as elastic spectral, non-linear static , and non-linear time history.

3. LITERATURE REVIEW

A number of works have been performed based on the seismic vulnerability assessment of bridge structures. A review of some literatures is presented in brief, summarizing the work done by different scholars and researchers in development of fragility curves for bridge structures.

Howard Hwang and Jing Bo liu (2001) presents an analytical method for the development of fragility curves of highway bridges. In this method, uncertainties in the parameters used in modeling ground motion, site conditions, and bridges are identified and quantified to establish a set of earthquake-site-bridge samples. A nonlinear time history response analysis is performed for each earthquake-site bridge sample to establish the probabilistic characteristics of structural demand as a function of a ground shaking parameter, for example, spectral acceleration or peak ground acceleration. Furthermore, bridge damage states are defined and the probabilistic characteristics of structural capacity corresponding to each damage state are established. Then, the conditional probabilities that structural demand exceeds structural capacity are computed and the results are displayed as fragility curves. The advantage of this approach is that the assessment of uncertainties in the modeling parameters can be easily verified and refined.

D. Vamvatsikos and C. Cornell (2002) described about the incremental Dynamic Analysis (IDA).it is a parametric analysis method that has recently emerged in several different forms to estimate more thorough structural performance under seismic loads. It involves subjecting a structural model to one (or more) ground motion record(s), each scaled to multiple levels of intensity, thus producing one (or more) curve(s) of response parameterized versus intensity level. This method helps in predicting the seismic structural capacity level of the structure. This method was further developed and was used for seismic vulnerability assessment of the structures and the procedure for the same was also presented in the paper.

Fariborz Nateghi and vahid L shahsavar (2004) established fragility and reliability curves for the seismic evaluation of pre- stressed concrete railway bridge. Important aspects of this study are modeling of bridge using 3D nonlinear models and modeling of abutments, bearings, effect of falling of girder on its bearings and nonlinear interaction of soil-structure action. In this document , for structures with long period (like the studied bridge), the response of the damage analysis under the peak ground acceleration and velocity was compared and was cleared that reliability ratio of the results under the maximum input acceleration is low. However, this ratio for the results under the peak ground velocity is very high. This proves that the scientists would better use the PGV in their researches on long period structures instead of the PGA.

P. Pottatheere and P. Renault (2008) investigated the seismic vulnerability assessment of skew bridges with different skew angles based on numerical simulation. The vulnerability study has been conducted by considering a sample highway skew bridge made of reinforced concrete. An analytical method for the generation of fragility curve have adopted in which the damage to the structure is derived from the response obtained from the push over analysis and time history analysis. The structural damage has been derived from the static pushover and nonlinear time history analysis of the model. In this study the elastomeric bearing and bridge columns were found to be most vulnerable components. The fragility curve for both vulnerable components was generated using an analytical approach. From the comparison of the different skew angles, the author concluded that the skew angle has a significant influence on the seismic vulnerability. The damage probability is increasing with the increase in skew angle.

Payam Tehrani and Denis Mitchell (2012) conducted a study on seismic performance assessment of continuous four span bridge with different configurations. The IDA was performed using 39 pairs of ground motions. The probability of exceeding different damage states were predicted at different hazard levels and fragility curves were developed for different damage states. The structures studied include a regular and an irregular 4-span bridge supported by single columns. Several damage states were considered in the seismic evaluation of the bridges under study including yielding, serviceability, bar-buckling and collapse. The yielding and serviceability damage states for the bridge columns were predicted using the method described by Priestley et al.(2007). For crustal earthquakes, the “basic far-field” records were used in this study. This set includes 39 crustal records from the PEER-NGA database; while a smaller subset of these records (i.e., 22 records) were used in the ATC-63 provisions for seismic performance assessments. To develop the IDA curves the spectral acceleration at the fundamental period of the bridges is used as the intensity measure (IM) and the maximum drift ratio of the critical columns is used as the damage measure (DM). The seismic performance of a regular and an irregular bridge were studied using incremental dynamic analysis. The probability of exceeding different damage states at different hazard levels was also predicted. IDA was performed using 2D and 3D modelling and the results were compared. The results indicated that the use of 3D models to perform the IDA resulted in much lower predictions of the structural capacity.

M Shizokua and Swagata Banerjee (2013) explained the seismic performance analysis of reinforced concrete bridges in the form of fragility curves which is a function of ground motion intensity. Nonlinear time history analyses of five bridges are performed before and after column retrofit with steel jacketing. In addition to the dynamic analysis, pushover (nonlinear static) analysis is also conducted as it is more practice-oriented and appealing to the profession. To be consistent, developed fragility curves are calibrated with damage data of bridges from past earthquakes. Furthermore, they reported that the issue of directionality effect of earthquake ground motion on structures in order to reflect on the fact that earthquake can come from any arbitrary direction to the structure.

Abder Rahmane and Fouad Kehila (2014) presented results of the seismic vulnerability study aimed to develop the analytical fragility curves for typical bridge piers based on numerical simulations. Bridge piers designed with the simplified seismic design method for bridges are analyzed. The fragility curves for the bridge piers are then developed by performing both, the static and the nonlinear time history analyses. In this study one pier model has been selected as a representative of all other piers for a particular bridge structure. They observed that the analytical fragility curves for the four bridge piers show a very different level of damage probability with respect to PGA. This difference is due to the shape of the cross section and the percentage of the longitudinal and tie reinforcements. Also they found out that wall pier type shows the best seismic performance while compared to the others (circular pier, hollow core pier and hammer head pier). The effect of soil-structure interaction is not taken into account for deriving the analytical fragility curves.

Nirav Thakkar and DC Rai (2014) studied the seismic vulnerability of irregular bridge with elastomeric pad as bearing. They have modelled 268 m long existing Chengappa bridge in Andaman Islands using SAP 2000 and found out that the unsatisfactory seismic performance of Chengappa bridge during the 2004 Sumatra-Andaman earthquake was primarily due to uneven distribution of pier/pile stiffness and lack of restrainers to arrest excessive displacement of the bridge deck. Out-of-phase movement is observed due to irregularity which significantly increased the displacement demand on substructure as well as connections.

Neha Parool and DC Rai (2016) have analytically investigated a multi span simply supported RC bridge with drop span and steel bearings for its seismic response. Modelling of steel bearings is done using ABACUS software and bridge is modelled in SAP2000. The critical components of studied bridges are rocker and roller bearings. Incremental dynamic analyses were performed for the development of fragility curves for failure of the bridge along two horizontal directions. The damage criteria included either failure of bearings due to exceedance of respective displacement limits or dislodgement of the bridge deck due to unseating. It was observed that seismic demands for drop spans were small, and failure of main-span steel bearings was the primary cause for the bridge failure. Retrofitting of the bridge by replacing steel bearings with unanchored elastomeric pads significantly reduce the fragility of the retrofitted bridge

4. CONCLUSIONS

A review of some of the most important contributions to the field of vulnerability assessment has been presented herein. Study conducted by different researchers shows that seismic performance of highway transportation system plays key role to post earthquake emergency management so it is necessary to assess the vulnerability of bridges earthquake after the earthquake event.
Among the different methods available to assess the seismic vulnerability of bridges, development of fragility curves is found to be effective and popular tool .Incremental dynamic analysis (IDA) is a good tool to study the nonlinear dynamic behavior of bridges subjected to various hazard level of earthquakes.

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