Seismic vulnerability assessment of RC bridge

Sruthi Chandran, P R Sreemahadevan Pillai

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. To address the physical aspects of the seismic performance of bridges, fragility curves are developed and used for evaluation purposes. These fragility curves represent the probability of structural damage due to various ground shakings. And more so they describe a relationship between ground motion and level of damage. In this paper, fragility curves are developed. The seismic vulnerability of a Multi span Simply Supported RC bridge is assessed based on developed fragility curves. Effect on the seismic performance of the bridges with and without the restrainer are studied. Important aspects of this study are; modeling of bridges using 3D nonlinear models (with and without the restrainers). Software used for the modelling of Bridge and bearings are SAP 2000. Also Incremental Dynamic Analysis were performed for the development of fragility curves along two horizontal directions.

- **Index Terms**—. vulnerability assessment, intensity measure, seismic retrofitting, fragility curve

◆

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 considerations. 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 ASSESEMENT

Multispan simply supported (MSSS) bridges were the most commonly constructed bridges all over the world during the 1970s. Most of these bridges were not rigorously designed for earthquake forces, and as a result, many suffered extensive damages in the last several earthquakes. Some notable earthquakes that caused widespread damage to these bridges are the 1971 San Fernando earthquake, the 1989 Loma Prieta earthquake, the 1994 Northridge earthquake, and the 1995 Kobe earthquake. It has been generally concluded that a prior assessment of the dynamic behavior of existing bridge structures and the likelihood of various failure mechanisms will significantly help in developing appropriate retrofitting strategies that can reduce their seismic vulnerability.

The seismic vulnerability of a structure can be described as its susceptibility to damage by ground shaking of a given intensity. The aim of a vulnerability assessment is to obtain the probability of a given level of damage to a given structure due to scenario earthquake. 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. Hence, it is important to know the degree of damage to the highway bridge structures due to earthquakes. To estimate a damage level for highway bridge structures, fragility curves are found to be a useful tool. 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.

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 vulnera-

---

- *Sruthi chandran is currently pursuing post gratuation in Structural Engineering in APJ Abdul Kalam Technological University, NSS College of Engineering, Palakkad, India.*
- *P R Sreemahadevan Pillai is working as Professor in Department of Civil Engineering, NSS College of Engineering, Palakkad, India.*

bility 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.

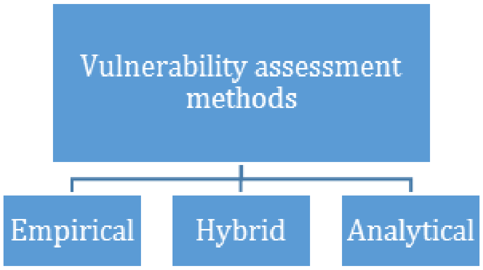

Fig 2.1 Vulnerability Assessment methods

2.1 FRAGILITY ANALYSIS

Seismic fragility is a conditional probability that gives the likelihood that a structure or its components will meet or exceed a specified level of damage during a given ground motion intensity measure. There are a number of different methodologies that have been employed for the determination of structural fragilities. These methodologies can be classified into three main categories of fragility functions:

1. Expert based fragility functions.
2. Empirical fragility functions.
3. Analytical fragility functions.

The expert based fragility functions were developed in 1980's and can be considered as the initiation of the concept of fragility analysis. These fragility functions only depend on the experience and number of experts involved. With the availability of extensive amount of damage data collected during earthquakes around the world and progress in analytical probabilistic methods, this kind of fragility functions are no longer being used. Consequently, very few recent references could be found, except for the work done by Padgett and DesRoches (2006).

Empirical fragility curves are developed based on the actual damage data collected during the past earthquakes. The research on the development of empirical fragility curves still has its own limitations, such as the lack of number and different levels of earthquakes due to frequency of occurrence of earthquake. Even though these limitations exist, empirical fragility curves still serve as benchmark for analytical fragility curves described below. These curves also present more realistic risk of damages during earthquakes.

Analytical fragility curves are being developed rapidly for different types of bridges during the past decade. These fragility curves are usually used to assess the vulnerability of bridges under different levels of earthquakes when actual bridge damage and ground motion data are not available. However, when used with experimental or actual damage data, analytical fragility curves can also reliably predict the probability of different levels of bridge damages, even when there is no history of past earthquake in a region.

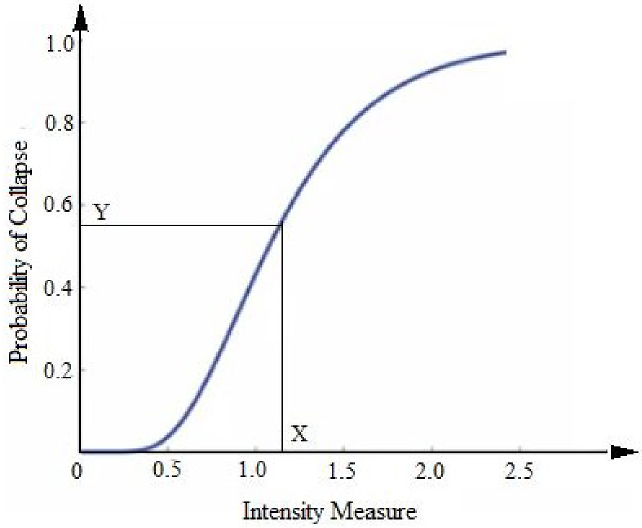

Fig 2.2. Fragility curve

Figure 2 shows a typical fragility curve with PGA along the x-axis and probability of collapse 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.

3. MODEL DETAILS

The superstructure is multi-span (Three span) simply supported RC deck slab. Length of the span is 10 meter. Two lanes of traffic are considered with width of each lane as 3.6 m. Total carriage way width considered is 9.3 m including footpath. Four numbers precast concrete girders (I-beams) are used with spacing of 2.3 m to support cast-in-place RC deck slab. The thickness of RC deck slab is assumed as 0.2 m based on details available for existing bridges. As per standard practice, 0.25 m thick and 1.0 m high RC parapet wall is assumed. A carpeting load and floor finish load of 1.0 kPa is considered on entire carriage way width of the bridge

Substructure consists of RC circular piers and suitable foundation. The pier height, H is taken as the distance from the bottom of a pier to the top of pier cap beam (see Figure 3.1). Pier height considered is 5 m H= 5m, For the present study foundations and abutments are considered rigid enough to consider that design ground acceleration is directly applied to the bottom of the pier and bottom of the abutment bearings.

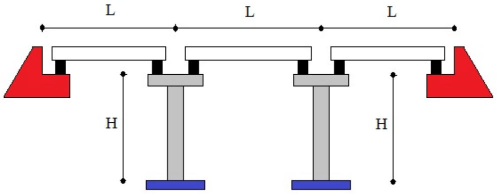

Fig 3.1bridge model

Table 3.1 Fundamental period of 20 m span bridge without arrester

Direction	Fundamental period (s)
Longitudinal direction	1.25
Transverse direction	1.07

Table 3.2 Fundamental period of 20 m span bridge with arrester

Direction	Fundamental period (s)
Longitudinal direction	0.87
Transverse direction	0.75

It can be noticed that due to the presence of restrainers, the dynamic characteristics of the bridge improved significantly.

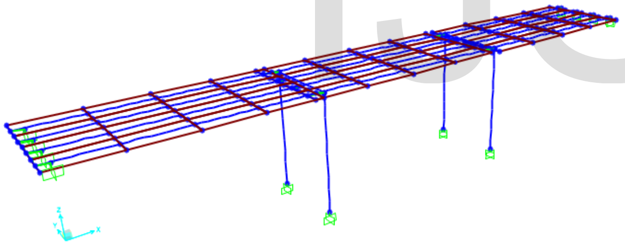

Fig 3.4 Fundamental mode along longitudinal direction

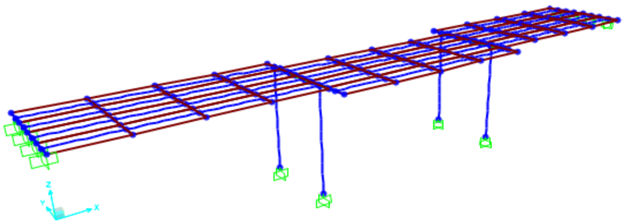

Fig 3.5 Fundamental mode along longitudinal direction

4. INCREMENTAL DYNAMIC ANALYSIS

Incremental dynamic analysis (IDA) is a powerful tool to generate such statistical data. A set of 20 far field ground motions recorded on firm soil or soft rock is used for the present study to perform IDA. This set of ground motion is suitably scaled to represent various hazard levels. IDA is performed over four sample bridges and displacement of bearing is recorded along the longitudinal and transverse directions which are used for further vulnerability analysis.

The pair of ground motions are applied such that major component (component of a pair with higher PGA) is along the longitudinal direction and the minor component is along transverse direction; The pair of 20 ground motions are applied such that it represents 10 hazard levels, i.e., ground motions are scaled to hazard level of 0.1g to 1.0g at an increment of 0.1g. Each bridge was subjected to 400 different time history analysis (20 set of ground motions, 10 hazard levels, applied to two directions). Hence, a total of 1600 analysis cases have been performed.

5. DAMAGE STATE DEFENITION

- Instability limit State

Instability occurs in elastomeric bearings when the maximum bearing displacement along transverse direction of the bridge exceeds the half width of the bearings. For the present study size of bearing is considered as 400x250mm.Hense 200mm is the maximum capacity that an elastomeric bearing can accommodate without instability.

- Unseating limit State

The deck unseating occurs when the maximum bearing displacement along longitudinal direction of the bridge exceeds the value obtained by Equation 1. Table 4.1 gives the capacity of elastomeric bearings for unseating of bridge deck along longitudinal direction.

$$S = 305 + 2.50L + 10.0 \qquad (5.1)$$

For the present study, the above expression is used to calculate the provided seating width. Draft IS:1893-Part III specifies the above mentioned empirical formula for minimum seating width, S (in mm) to be provided as a function of span length L (in m) and pier height H (in m) for a bridge located in Zone V. In this study seating width provided is 405 mm.

6. RESULT AND DISCUSSION

Using the procedure described in the previous section, IDA curves are plotted for 4 sample bridges and two damage states. In this study, displacement of the elastomeric bearing in both longitudinal and transverse direction are considered as the damage states. And the spectral acceleration at the fundamental period taken as the intensity measure.

From the results of incremental dynamic analysis, it is observed that the probability of failure is highest for instability damage state when compared to unseating damage state. Also from the IDA results it can be note down that

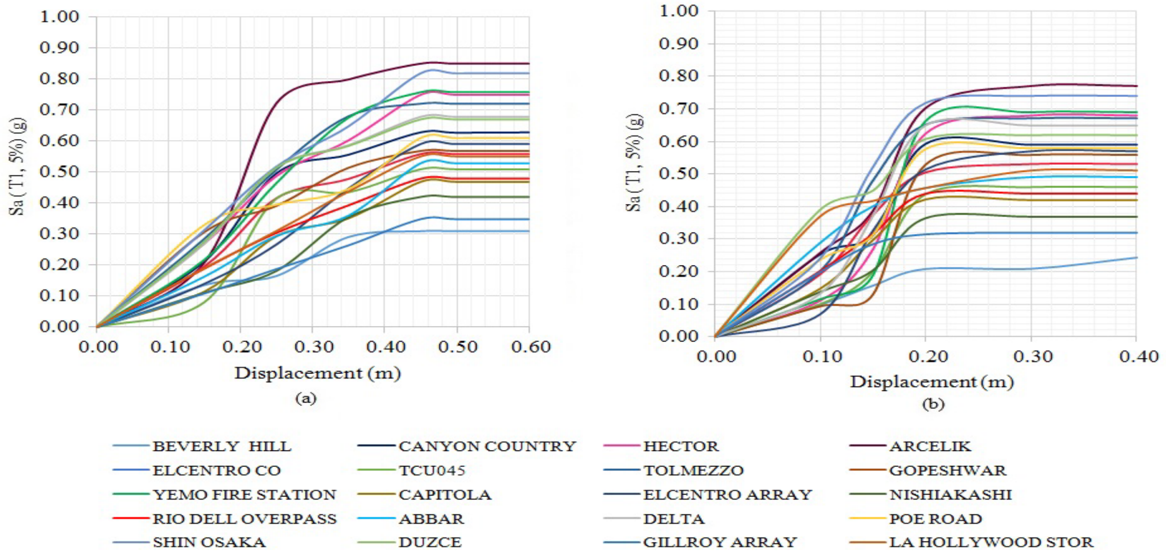

Figure 6.1 Bridge without restrainer (a) Longitudinal direction (b) transverse direction

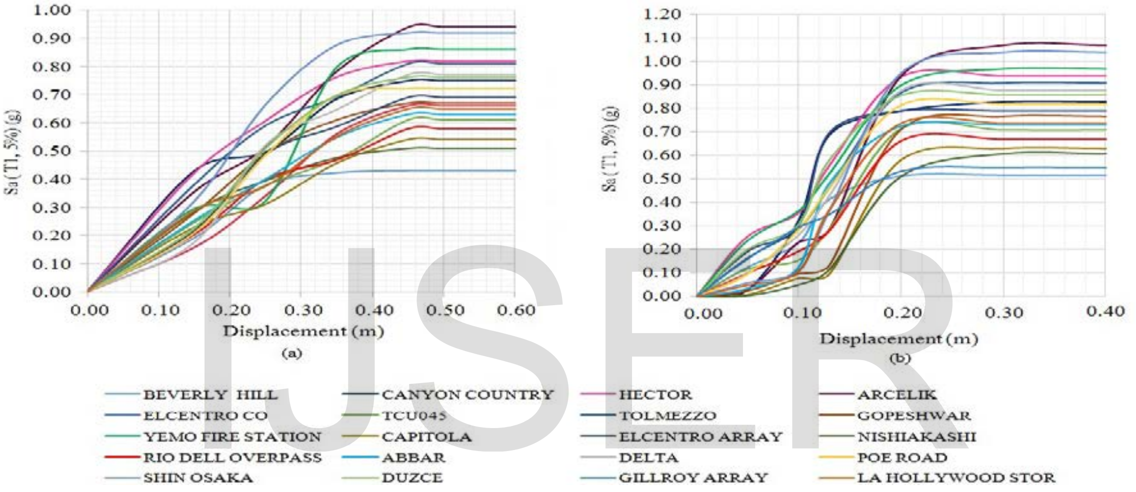

Figure 6.2 Bridge with restrainer (a) Longitudinal direction (b) transverse direction

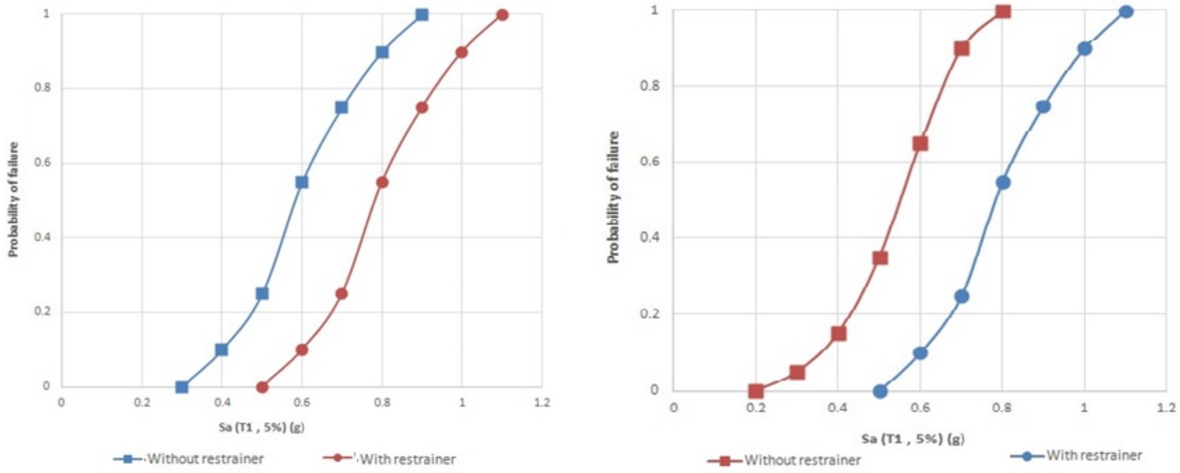

Figure 6.3 Fragility curve of Bridge (a) Longitudinal direction (b) transverse direction

displacement in both longitudinal as well as transverse direction is considerably reducing by the use of restrainer. And extent of reduction is more in the transverse direction. From the fragility curves plotted for four bridge sample, it can be seen that bridge with restrainers are less vulnerable to ground motions. For example, when comparing the fragility curve drawn for bridge with H= 5m, L=20 m, 50 % probability of failure is occurring at a spectral acceleration of 0.4 g which increases considerably to the double after the use of restrainer.

7. CONCLUSIONS

The main aim of the present study was to investigate the behavior of RC bridges with elastomeric pad as bearings. Focus of the study was on the comparison of bridges with no detailing for displacement arrester, along longitudinal direction and transverse direction and bridges provided with transverse displacement arrester.

Bridge without seismic restrainer is more vulnerable than bridge with seismic restrainer, and bridge without seismic restrainer were the first ones to fail for almost all hazard levels and for all ground motions as seen through IDA analyses. Further, analyses indicate that the study bridge without was more vulnerable along the transverse direction than longitudinal the direction. 50 % probability of failure is occurring at a spectral acceleration of 0.4 g which increases considerably to the double after the use of restrainer.

REFERENCES

[1]. Howard Hwang, Jing Bo Liu, and Yi-Huei Chiu "Seismic Fragility Analysis of Highway Bridges" Technical Rep., Center for Earthquake Research and Information,@2001 Univ. of Memphis, Memphis, TN.

[2]. Vamvatsikos, D., & Cornell, C. (2002). Incremental dynamic analysis. Submitted to Earthquake Engineering and Structural Dynamics, John Wiley & Sons, Ltd

[3]. Fariborz Nateghi A. and Vahid L. Shahsavar "Development Of fragility and Reliability curve for seismic evaluation of a major Pre stressed concrete Bridge" 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004 Paper No. 1351

[4]. Neha Parool , Durgesh C Rai " Seismic Fragility Analysis of Multi span simply supported bridge with drop span and steel bearings" J. Bridge Engg.2015@ ASCE

[5]. P. Pottatheere and P. Renault "Seismic Vulnerability Assessment of Skew Bridges" The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China.

[6]. M. Shinozuka, Swagata Banerjee and Sang-Hoon Kim "Statistical and Mechanistic Fragility Analysis of Concrete Bridges" by Technical Report MCEER-07-0015 September 10, 2007

[7]. Thakkar N, Rai DC. "Seismic vulnerability of bridges with elastomeric pad: A case study. "Proceedings of the 10th National Conference in Earthquake Engineering, Earthquake Engineering Research Institute, Anchorage, AK, 2014

[8]. Tehrani, P. and Mitchell, D. "Seismic Performance Assessment of Bridges in Montreal Using Incremental Dynamic Analysis," submitted to Canadian. Journal of Civil Engineering. 2012

[9]. Abder Rahmane and Fouad Kehila "Development of fragility curves for seismic evaluation of a reinforced concrete bridge" Second European conference on earthquake Engineering and seismology Istanbul Aug 25-29 2014