Study on Fragility Analysis of Reinforced Concrete Bridges in India

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Abstract - *Bridges are essential parts of transportation networks. Bridges reliability and effectiveness ensured continuous transportation, recovery activities, and avoiding the risk of damage during earthquakes. Seismic evaluation of bridges by fragility curve is used to assess seismic damage of bridges network. The fragility curve is the most popular tool for pre-earthquake planning, retrofitting and loss evaluation of bridges. Global trends affirm that research publication on fragility analysis of bridges has tremendously increased, but in India, limited seismic estimation of RC highway bridges has been done. The aim of the present work is an in-depth study of existing approaches for developing the fragility curve from literature available in India. This research is mainly focused on key features of analytical method as most of researchers have performed analysis by this method. This study disclosed seismic fragility approaches; its application which motivates, the use of fragility curves is increasing among administrators and researchers.*

Key Words: Bridge, Reinforced concrete, Fragility curve, Approaches, Seismic performance, Time history analysis, PSC

1. INTRODUCTION

In the past, Indian has experienced several earthquakes, such as Assam (1950),Koyna (1967), Latur (1993), Bhuj (2001), Kashmir (2005), Sikkim (2011).Earthquake causes extensive damage to structures which leads to Injuries, human losses and adversely affects the nation's economy[1]. Bridges are key components of transportation networks; assessing their seismic vulnerability is critical to estimating economic losses. Bridge failures and structural damages created awareness among experts, researchers, and designers. According to a fragility curve, the demand due to earthquakes exceeds the structural capacity indicated by the damaged condition. It can estimate losses, which makes it useful for disaster relief and emergency planning.

The primary purpose of this study is to review stepwise procedures, existing approaches, and current trends in seismic evaluation by fragility curves. This present work highlights information on the various facets of seismic assessment and development of this tool to help better decision-making.

The literature review commences with the historical background of earthquake data available in India. The next part of the review explained different approaches to developing fragility curves and procedures for creating fragility curve. This research paper concludes with the use of this tool by expert and researchers for fragility assessment. Fragility curves have been utilized for many purposes, including seismic risk assessment, design verification, retrofit priority, and post-earthquake reaction plans.

2. FRAGILITY CURVE FOR RC HIGHWAY BRIDGES

Fragility is the property of being readily broken or damaged. For the first time in earthquake engineering, the term fragility function has been used to create a probabilistic connection between the frequency with which a part of a nuclear plant collapses and the peak ground acceleration [15].The fragility curve is derived from a structure's capacity, demand, and a set of ground motion data. Fragility curves show how likely a particular damaged condition will be exceeded as a function of demand parameter that reflects record of ground motion. Incorporating fragility curves into the seismic risk assessment framework enables decision-makers to make risk-based decisions using simple tools derived from dependable probabilistic approaches.

The damage level damage level of bridge component or bridge system is DL at particular value of ground motion (GM = y), then the fragility (F) can be calculated by following equation,

$$\text{Fragility Function } (F) = (P\,(DL)\,/GM=y) \qquad (1)$$

Fragility function is a graphical representation of Intensity measures (IM) on the axis of X - Horizontal and the Failure Probability on the Y- Vertical as given in **Fig -1**. Fragility curve which is derived from bridge structure and ground motion selected [2].

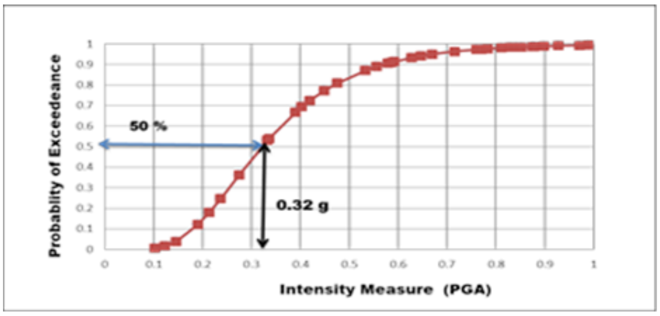

Fig -1: Graphical Presentation of Fragility Curve

Various parameters related to ground motion intensity parameters, such as drift percentages, base shears, etc., are displayed as a curve. As a percentage, the fragility curve for an Intensity Measure (PGA) indicates the exceedance in probability and the limiting damage state. The data can be used to examine, evaluate, and improve seismic performance of non-structural and structural structures. Figure 1 shows a fragility curve with a 50% probability of failure at an intensity measure of 0.4g.

3. APPROACHES TO DEVELOPING FRAGILITY CURVES

Researchers and academics have explored different methodologies and approaches for constructing fragility curves such as Professional opinion, records, experimental results, analytical and hybrid methods. Usually, the fragility curve is developed by using five main approaches i) Expert Opinion ii) Empirical method iii) Analytical method iv) Experimental Method v) Hybrid method.[3].**Fig -2** shows main five approaches for development of fragility curves.

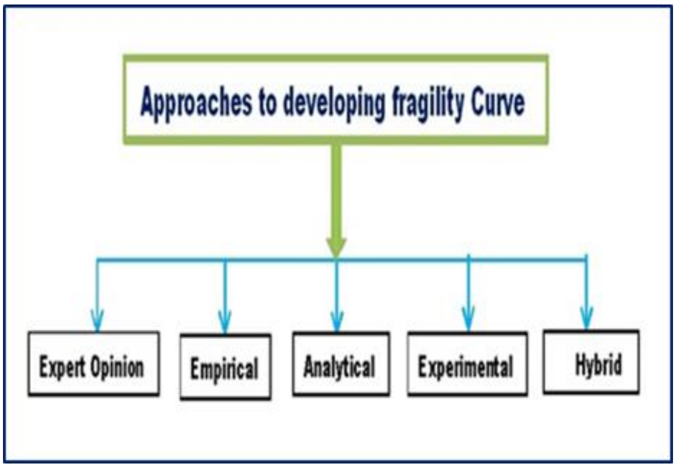

Fig -2: Main approaches to developing fragility curve

3.1 EXPERT OPINION

Simple and Unique method of deriving fragility curves which is based on professional judgment. Expert opinion depend on the principles of reproducibility of results, accountability of data sources, empirical control of an expert's evaluations, and neutrality of the expert's viewpoints are all important factors to consider. This method included all of the parameters which have impacting seismic reaction of structures. However, this approach is depending upon expertise and experiences of individual expert neglecting actual structural damage. The applied technical council (ATC 13, 1985) Introduced risk assessment and damage matrices for bridge structures based on expert opinion [4]

3.2 EMPIRICAL APPROACH

For the region with extensive earthquake data are available, empirical approaches have been employed to generate fragility curve. The damage from previous earthquakes is used to develop empirical curves. These are the most realistic fragility curves, but they are very particular to a specific earthquake and structure, and their uses are restricted. [5]

3.3 EXPERIMENT APPROACH

On the basis of experimental data, it is rare to develop curves of bridge fragility. Because of the high cost of large-scale studies, including whole bridges or components, the creation of fragility curves by using shake table testing has been limited. Experimental results have the potential to be utilized in place of analytic fragility analysis, but their implementation is still limited. In spite of this, experimental fragility curves have limitations in their utility. The absence of data at damage levels and the correlation between geometry and structure properties are the primary reasons behind this. The results of the cyclic load and shaking table test on bridge piers have compared with analytical method [12] fragility curve. The damage from previous earthquakes is used to develop empirical curves. These are the most realistic fragility curves, but they are very particular to a specific earthquake and structure, and their uses are restricted. [5]

3.4 HYBRID APPROACH

As a result of the shortcomings of previous methodologies, including insufficient damage data from genuine earthquakes, subjective and uncertain judgmental data, and faulty analysis methods, researchers developed the hybrid fragility curves. This is intended to minimize the computing costs associated with analytical modeling. In this study, author developed hybrid fragility curve by combining experiment data and analytical approach [12].

3.5 ANALYTICAL APPROACH

When earthquake history is not available, analytical approaches are used to create fragility curves such as in India. In recent years, researchers have developed a number of sophisticated analytical fragility curves for bridges. This paper presented the response spectrum method to estimate the performance of a solid slab bridge. Nonlinear static analysis (NSA) is used for the development of the fragility curve. [9,13].The author used linear time history analysis to study the different frequency content of ground motion on Reinforced Concrete Bridges.[8] Nonlinear Time History and Incremental dynamic method are the more reliable method have used to create bridge fragility curves [6,7,9,12].

The study covers key features of different approaches of seismic evaluation, application, and limitation is shown in **Fig-3**.

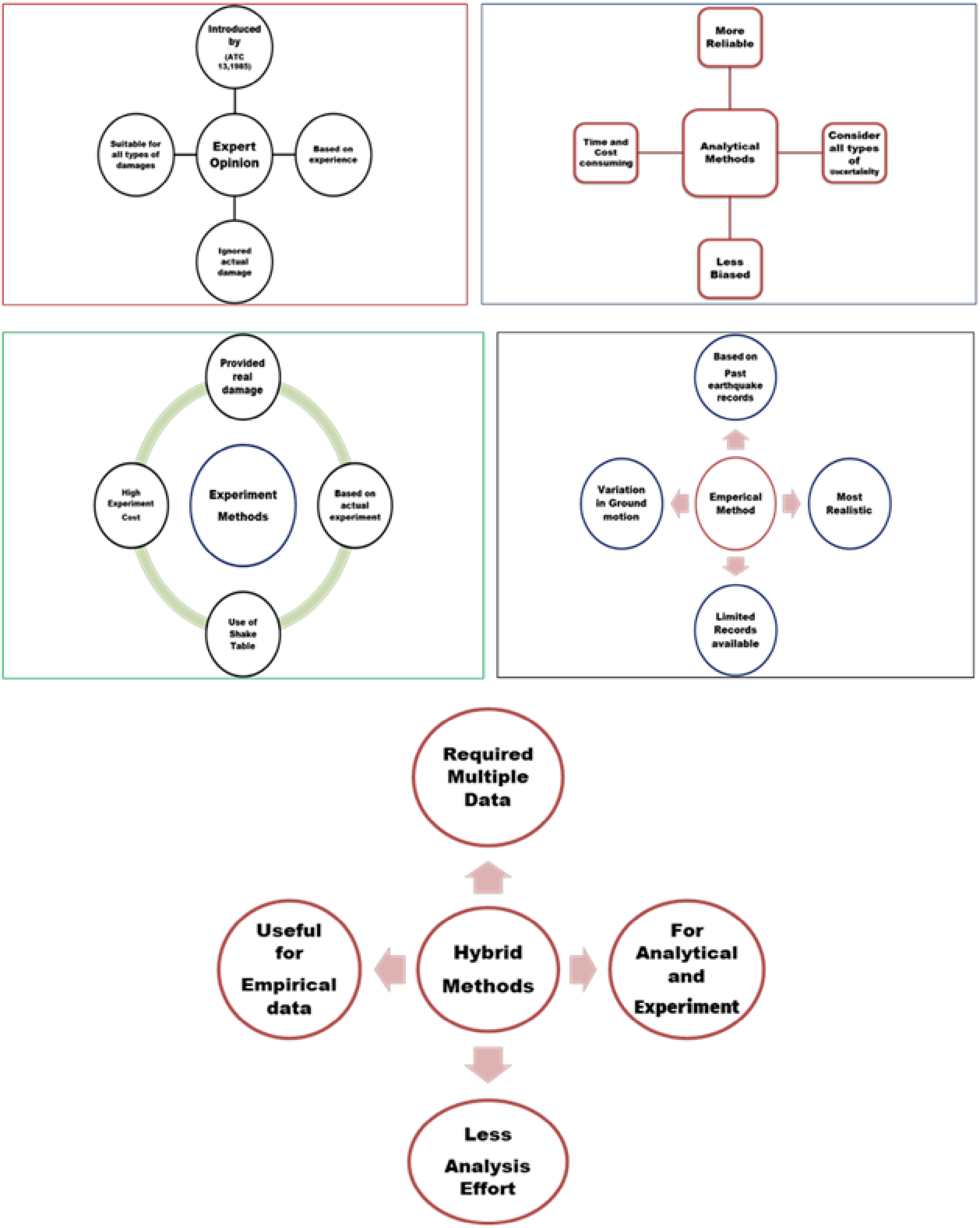

Fig-3: Comparison of fragility curve development approaches

4. LITERATURE REVIEW

In the literature review, the author broadly highlights different method of creating fragility curve for seismic assessments.

The seismic analysis of single pile subjected to different earthquakes of variable PGA has been presented in this research. Fourteen natural time history data has been chosen for nonlinear dynamic analysis. Uncertainties in soil qualities have also been included. Relative displacement at the top of the stack is observed to increase with increasing PGA. The piles examined in this study were not designed for seismic loads and show that they are likely to exceed small PGA. [6]

This paper analyzed seismic vulnerability multi span bridges with drop spans and bearings in Northern India. Finite element method was used to find the lateral force-deformation response of rocker and roller cum rocker bearings. By using 20 sets of ground motion, Incremental dynamic analysis to develop a fragility curve. It observed that the main reason for the bridge failure was steel bearing failure, and the drop span showed less impact on seismic demand. The research recommends replacing the steel bearings with an elastomeric pad to modify the bridge and to use lateral constraints to reduce the risk of deck shifts. [7]

The research summarized that ground motion of weak frequency has a notable impact on the response of conventional reinforced concrete bridges. However, the high-frequency ground motion has minimal effect on the RC bridge behavior. According to research, the ground motion of intermediate- and high-frequency data on a bridge has greater effects than lower-frequency data. [8]

This article evaluated single and multi-span concrete I-girder highway bridges by using probabilistic methods and pushover analysis. For assessment purposes, fragility curves are created and used. It also explains the relationship between ground movement and damage. This article presents methods and based on two damage functions shows results in relation between structural dependability and vulnerability. This article presented methods and shows results in the relation between structural dependability and vulnerability based on two damage functions. It has been found that the drift capacity of the I-beam Bridge designed according to the Indian seismic code is low from the IDA result [9]

In this research paper, Seismic analysis of a Solid Slab Bridge is done to estimate the performance of that structure during an earthquake. Response spectrum analysis is used to determine the need for that displacement and force. Performance-based analysis is the popular trend towards the superstructures design. [11]

The motive of research is to evaluate the RC bridge's seismic behavior, particularly the bridge piers, because they can lead to the collapse of the entire bridge if they fail. This study aimed to generate a Fragility curve, the probability of specified damage variables of the pier under ground motion given. The present paper found that the central pier is the most vulnerable in both regular and irregular bridges. However, the central pier may not be the most vulnerable if the height variances between adjacent piers are significant. It concluded that if all the piers are the same height, the probability of exceeding the damage level increases as the PGA (g) value rises. [12]

The paper examined seismic analysis of reinforced concrete pier of multi span bridge under various ground movements. The dynamic analysis was conducted to examine the bridge performance. The bridge pier capacity was determined utilizing a nonlinear static (Pushover), and the nonlinear time history methods, the demand on the pier has been calculated. From the strong ground motion data, four types of time history records were analyzed. From fragility curves, It has concluded that, in the bridge pier, shear or flexural collapse have not occurred.[13]

This paper deals with the pushover analysis of existing RC bridge located in Zone IV of Indian and utilizes the FEM method. According to result, it appears that the considered bridge cannot meet performance levels as the demand exceeds the capacity. It concluded that the RC bridge evaluated by the pushover analysis does not meet seismic needs as per desired codes; therefore, bridge component (piers, abutments, and bent caps) retrofitting is necessary. [14]

Table -1: An overview of existing research on analytical fragility approaches in India

Author	Types of bridge	Method	Component	Demand Parameter (DP)	Intensity Measure (IM)
Ganesh &et.al. (2013)	RC bridge	Nonlinear Times history	Single pile	Displacement	PGA(g)
Parool Neha & et.al (2014)	PSC	Nonlinear dynamic (IDA)	Pier, Bearing	Displacement	PGA(g)
Srusty krishna & et.al (2016)	PSC	Linear Time History	Column	Displacement, Velocity	PGA(g) PGV
Patil dnyanraj & et.al (2017)	PSC	Nonlinear static and dynamic	Single and Multi-Column bents	Drift ratio, Displacement , Base shear	PGA(g)
Preety pande, & et.al (2019),	PSC	Linear static and Dynamic	Column	Base shear, displacement	PGA(g)
Ishani, & et.al, (2020),	Solid slab RC bridge	Response spectrum	Pier	Displacement, Forces	PGA(g)
Ankit, Jain, & et.al (2020),	Slab girder	Nonlinear Time History	Pier	Displacement	PGA(g)
Babita, Sharma& et.al (2020),	RC bridge	Pushover and Nonlinear Time History	Pier	Displacement, Ductility	PGA(g)
Firoj, Mohd. &et.al (2020)	RC bridge	Pushover Analysis	Pier	Spectral displacement, Acceleration	Time (Sec)

The studies employed in existing review are given in **Table 1**.based on literature reviews; analytical approaches are preferable to other approaches in India for developing fragility curves, which is consistent with the findings. Prior research has focused on analyzing the fragility of bridge components.

5. CONCLUSIONS

An effective method of generating seismic fragility curves for RC highway bridges was demonstrated in this study. Based on the results of this research, the following conclusions can be drawn.

The paper provides an overview of existing approaches and applications in the field of highway bridge seismic evaluation in India. The fragility curve is a critical aspect of seismic risk assessment approaches, owing to its breadth of use. The aim of this paper was to summarize the progress of the various techniques used to create fragility curves and to describe their uses in India, in addition to their characteristics and limits. Individual approaches have been established based on a variety of assumptions, each of which emphasizes a distinct component of the problem while downplaying or even ignoring others. A study of this research found that frailty analysis can help evaluate the earthquake resistance of highway bridges. It has not yet been incorporated into the Indian code or recommendations as a tool for assessing the seismic analysis of bridges under varying hazard conditions. There is a scope for research efforts to be taken for fragility curve methodologies of the abutment impact, soil interaction of piles, retrofitting, and isolation in India.

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