Developing of Fragility Curve for Two-Span Simply Supported Concrete Bridge in Near-Fault Area

S. Shirazian, M.R. Ghayamghamian, G.R. Nouri

Abstract—Bridges are one of the main components of transportation networks. They should be functional before and after earthquake for emergency services. Therefore we need to assess seismic performance of bridges under different seismic loadings. Fragility curve is one of the popular tools in seismic evaluations. The fragility curves are conditional probability statements, which give the probability of a bridge reaching or exceeding a particular damage level for a given intensity level. In this study, the seismic performance of a two-span simply supported concrete bridge is assessed. Due to usual lack of empirical data, the analytical fragility curve was developed by results of the dynamic analysis of bridge subjected to the different time histories in near-fault area.

Keywords—Fragility curve, Seismic behavior, Time history analysis, Transportation Network.

I. INTRODUCTION

THERE are significant number of bridges in the world that have been designed and constructed at a time when seismic resistant requirement were nonexistent or inadequate by today's standards [4]. To avoid bridge collapses, reduce the risk of extensive damage in future earthquakes, and most effectively allocate the limited financial resources available for this task, the bridges most in need of seismic retrofit, must be identified. In other words, Ensuring of seismic behavior of bridges would be very useful in post-earthquake planning for seismic zones. In this way individual assessment of bridges due to time and economic limitations is approximately impossible.

Classifying the kinds of bridges according their seismic vulnerability by developing fragility curves is very applicable and rapid way in disaster management. Using the fragility curve is one of the emerging tools in assessing the seismic behavior of bridges. Fragility curves can be either empirical or analytical. Empirical fragility curves are base on the reported bridge damage from the past earthquakes. Analytical fragility curves are developed through seismic response data from the analysis of bridges. The fragility analysis generally includes three major parts: (a) the simulation of ground motions, (b) the simulation of bridge, (c) the generation of fragility curves from the seismic response data of the bridge models .The seismic response data can be obtain from nonlinear time history analysis, elastic spectral analysis, or nonlinear static analysis [2].

Comparisons of empirical and analytical fragility curves have shown good accordance between theory and field observation in last studies [1, 8]. Due to usual lack of empirical data, the analytical fragility curves are more common in bridges seismic behavior studies.

Despite the high seismicity of Iran, a few works on analyzing seismic performance of bridge have been done (Nateghi et al. in 2002, and Kalantari et al. in 2008). In this study one of the most common bridge types in Iran is assumed. The analytical modeling and time history analysis were done by SAP2000 finite element software and the limit states are defined for displacement ductility of bridge`s piers, and the fragility curves were developed during statistical analysis.

II. BRIDGE MODEL AND DESCRIPTIONS

As mentioned before, here one of the most common types of bridges in Iran, which is two-span simply supported reinforced concrete bridge, is assumed. The geometry of this bridge is shown in Figure1, the overall length of bridge is 43.1m and the piers have a height of 7.5m. The spans are supported by fixed bearing on the bent and by expansion bearings at the other ends on the abutments.
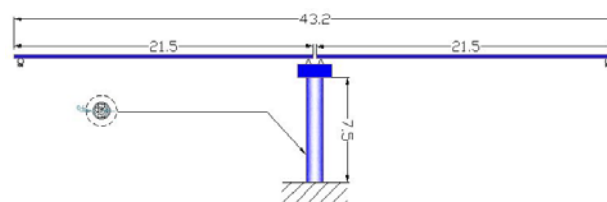

Fig.1 The geometry of the study case bridge

The bridge is analyzed with SAP 2000 finite element program [3], using a three dimensional finite element model. The bases of the piers were assumed to be fixed, while the two abutments were modeled as roller supports.

Pier is the only member that considered for exhibiting

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nonlinear behavior and are considered to have a pair of plastic zones of length L_p at each ends. The length of hinges is calculated by the following formula that recommended in FHWA95 [5]:

$$l_p = 0.08\ h + 9D_b \qquad (1)$$

where h is the column height and D_b is the bending bar of column.

III. SEISMIC LOADING

In order to perform a nonlinear dynamic analysis of the bridge, a set of earthquakes is required, which their characteristics represent near-fault ground motion characteristics. About 10 near-fault (R < 20km) acceleration time histories were selected from Berkley university website [13]. Then this ground motions are scaled from 0.1g to 1g with 0.1g steps. Providing 100 time histories for bridge's analysis. It should be noted that the focus here is on the behavior of bridge in longitudinal direction, so for each pair of horizontal components, the larger one is chosen for analyzing. Table1 shows the characteristics of the selected ground motions.

IV. PROBABILISTIC FRAGILITY FUNCTION

The probability that the seismic demand on the structure exceeds the structural capacity can be computed as follows:

$$P_f = P\left[\frac{S_d}{S_c} \geq 1\right] \qquad (2)$$

where P_f is the probability of exceeding a specific damage state, S_d is the structural demand and S_c is the structural capacity. If the structural capacity and seismic demand are described by a lognormal distribution, the probability of reaching or exceeding a specific damage state will be log-normally distributed, which can be obtained by a log-normal cumulative density function as follows:

$$P_f = \Phi\left[\frac{ln\frac{S_d}{S_c}}{\sqrt{\beta_d^2 + \beta_c^2}}\right] \qquad (3)$$

where β_c is the logarithmic standard deviation for the capacity, β_d is the logarithmic standard deviation for the demand, and $\Phi[\ ]$ is the standard normal distribution function. The seismic demand is expressed as [11]:

$$ln(S_d) = a\ ln(X) + b \qquad (4)$$

Where a and b are unknown regression coefficient, and X is the ground motion intensity parameter (which here is assumed to be PGA).

V. DAMAGE STATES

Most studies on fragility analysis of bridges use column ductility as the primary damage measure [7, 12, 14]. Hwang et al. used the capacity/demand ratio of the bridge columns to develop fragility curves [7]. Also here the deformation ductility of column has been chose as damage function. The damage state definitions used are based on recommendations from previous studies and follow the qualitative descriptions of the damage states as provided by HAZUS, which are shown in table 2. Also quantifying the limit state is possible by two main approaches, namely the prescriptive/physics based approach and the descriptive approach. In order to apply both of these approaches in setting the limit states, a Bayesian approach is available. The parameters of assumed Bayesian limit states were selected based on limits, which proposed by Nielson (2005) [11]. Due to these damage states were given in term of curvature ductility of column, here must be translated into displacement ductility. For this reason, the conversional equation, which provided by FHWA (1995b) was applied [5]. Also the standard derivations are estimated for displacement ductility using some probabilistic methods [15]. The parameters of seismic capacities and standard derivations of this study are presented in table3.

TABLE 1
THE CHARACTERISTICS OF USED GROUND MOTION IN THIS PAPER [15]

Earthquake	Record	Component	PGA(g)	Distance from Fault	Magnitude
Northridge	P1021	KAT000	0.877	14.6km	6.7
Northridge	P0928	PKC360	0.433	8.2km	6.7
Loma Prieta	P0764	GIL067	0.357	11.6km	6.9
Loma Prieta	P0745	CLS000	0.644	5.1km	6.9
Duzce	P1556	E	0.134	15.6km	7.1
Kocaeli	P1109	SKR090	0.376	3.1km	7.4
Coalinga	P0410	D-PLM360	0.29	12.2km	5.8
Coalinga	P0409	D-OLC270	0.866	8.2km	5.8
Tabas	P0140	DAY-TR	0.406	17km	7.4
Whittier Narrows	P0624	A-GRV330	0.457	12.1km	6

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TABLE II
DESCRIPTION OF BRIDGE DAMAGE [6,15]

Damage states	Description
Slight	Minor cracking and spalling to the abutment, cracks in shear keys at abutments, minor spalling and cracks at hinges, minor spalling at the column or minor cracking to the deck
Complete	Any column collapsing and connection losing all bearing support, which may lead to imminent deck collapse

TABLE III
THE BAYESIAN UPDATED LIMIT STATES FOR DISPLACEMENT DUCTILITY [15]

Column Displacement ductility	Slight		Complete	
	S_c	β_c	S_c	β_c
	1.1	0.19	2.4	0.21

VI. FRAGILITY CURVE FOR TWO-SPAN CONCRETE BRIDGE

The analytical fragility curves developed based on nonlinear time history analysis (NTHA). First, a bridge is represented by analytical model, which include the inelastic behavior in columns. Second, for each created acceleration time histories a NTHA is performed. Using predetermined damage indices, a damage state is assigned based on displacement ductility of bridge`s column. Finally by using a probabilistic seismic demand model obtained by regression analysis on the simulated of damage data, the fragility curves can be developed. Figure 2 show the probabilistic seismic demand model of two-span Bridge subjected to the selected ground motions and the developed fragility curves for slight and complete damage state are respectively presented in figure 3 and 4.

VII. RESULTS

In this study Fragility curves were developed for a two-span simply supported reinforced concrete bridge by applying selected near-fault ground motions. By this curves the vulnerability of bridge in longitudinal direction in near-fault zones was evaluated.
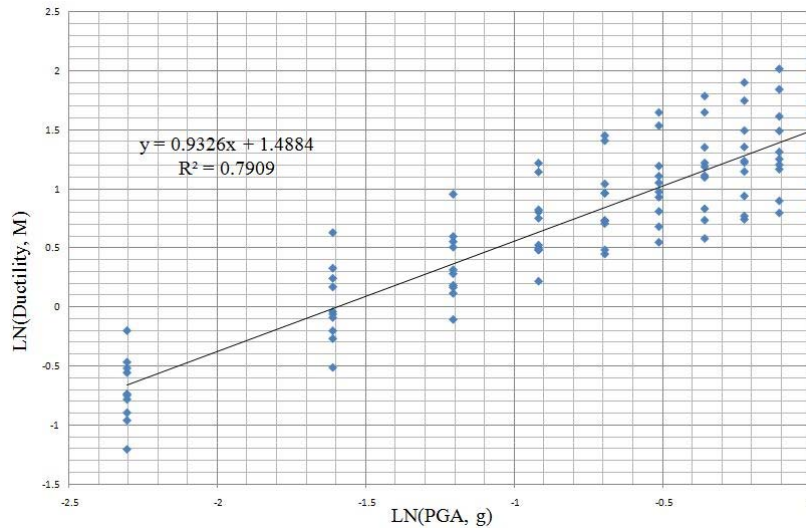

Fig. 2Regression of probabilistic seismic demand model of two-span simply supported concrete bridge for near fault motions [15].

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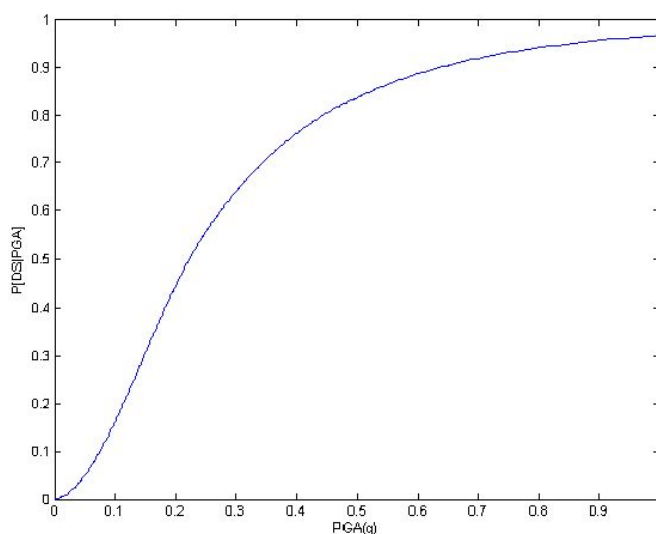International Journal of Civil and Environmental Engineering
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Fig. 3 Fragility curves of two-span simply supported concrete bridge for sight damage state [15]

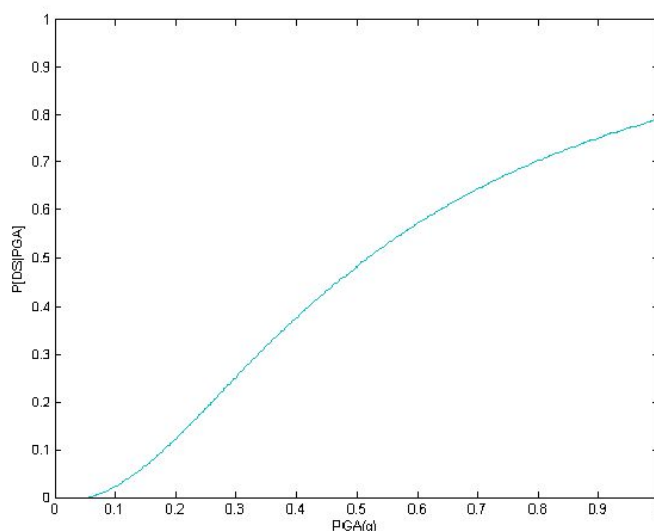

Fig. 4 Fragility curves of two-span simply supported concrete bridge for complete damage state [15]

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