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Seismic Vulnerability Assessment of an Existing Railway Bridge

Shashikant G. Kothalkar[1] and Sachin B. Kadam[2]

[1]*S.Y. M.Tech (Structure), Walchand college of Engineering, Sangli*
[2]*Walchand College of Engineering, Sangli*
E-mail: [1]shashi2665@gmail.com, [2]sachin.kadam@walchand sangli.ac.in

Abstract—*Bridges plays a very important role in transportation network of any country, as in India, fifty percent area of country is susceptible to damaging earthquakes so the serviceability of bridges is a challenging issue for transportation. Seismic assessment of existing bridges comparative to existing buildings is less. So it is important to evaluate the seismic risk associated with an existing bridges and anticipate the possible damages that will occur in it under damaging seismic events. From the seismic assessment of an existing bridges, we will be able to take a rational decision whether an existing bridge can be left as it is or need retrofitting for future earthquakes.*

In the present study, a two span 18.3m P.S.C. Girder Bridge existed at chainage 74110m in railway route from Amravati–Narkhed (Amravati, Maharashtra, India) across Sukhi river is taken as a case study. Non-linear pushover analysis method can be used to evaluate the structural behaviour of bridges in the inelastic range and to get the failure pattern in different components of bridges when subjected to damaging seismic events. But in pushover analysis, only fundamental mode is considered as dominant. So this limitation of the pushover analysis method increases our attention towards seismic vulnerability assessment and development of fragility curves. So fragility curves are also developed for four different damage states ranging from slight damage to complete damage along with pushover analysis for the case study.

Keywords*: Prestressed Bridge, Seismic Vulnerability, Fragility curves, Nonlinear Static (Pushover) Analysis, SAP 2000*

1. INTRODUCTION

Indian Railways have many bridges and most of them are not designed according to modern seismic design codes. And also older structures show insufficient capacity like low deformation capacity. So it is requisite to do seismic assessment of an existing bridges.

In the linear method of analysis, bridge action is within elastic range and results of the method like force and displacement are quite high. So it will make uneconomical bridge design. That's why nowadays non-linear analysis like pushover analysis method can be used to know the non-linear behavior of the structure as well as to draw the failure pattern for different components of the bridges. So the first step of the project work is to carry out pushover analysis for the case study. But the main assumption of pushover analysis method is the response of the structure is mainly controlled by its fundamental mode. This force us to give attention on seismic vulnerability assessment and development of fragility curves.

Modal analysis of a 3D bridge model reveals that it has many closely-spaced modes. Participating mass ratio for the higher modes is very high. Therefore, pushover analysis with single load pattern may not yield correct results for a bridge model.

Fragility curves of bridges can be developed empirically as well as analytically. Empirical fragility curves are usually developed based on the damage reports from past earthquakes. Since earthquake damage data are very scarce in developing countries like India, analytical development of fragility is the only feasible approach of development of fragility curve. Analytical fragility curves are developed from seismic response analysis of bridges, and regression analysis of simulated response data to establish the probabilistic characteristics of structural demand as a function a ground motion parameter.

2. SCOPE AND OBJECTIVES:

In this paper, an attempt is made to study and compare the effects of earthquake on an existing railway bridge using SAP2000 and to check its vulnerability. By using methodology of Hazard–US (HAZUS) (MH-MR1, 2003) variability in demand and capacity will be estimated and to obtain the fragility curves for the existing railway bridge by analytical approach.

3. NONLINEAR STATIC (PUSHOVER) ANALYSIS:

Pushover analysis is a simplified, static, nonlinear analysis under a predefined pattern of permanent vertical loads and gradually increasing lateral loads. Typically, the first pushover load case is used to apply gravity load and then subsequent lateral pushover load cases are specified to start from the final conditions of the gravity pushover. Typically, a gravity load pushover is force controlled and lateral pushovers are displacement controlled.

The range AB is elastic range, IO, LS and CP stand for Immediate Occupancy, Life Safety and Collapse Prevention respectively.

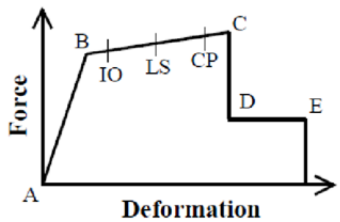

Fig. 3.1 Nonlinear static analysis curve (ASCE41, 2007)

Kulkarni and Karadi (2014) have reported that performance levels of bridge can be studied by using pushover analysis method. And also they have identified the critical members of an existing bridge by comparing spectral displacement demand and spectral displacement capacity from the pushover curve. Nicknam et al. (2011) observed that Bridges designed according to older codes are considerably expected to be vulnerable due to earthquake recurrence and should be retrofitted accordingly. For improving the performance of the bridge, use of lateral diaphragm is recommended.

4. FRAGILITY CURVES:

Fragility curves are the log-normal curves which describe the probability of exceeding or reaching a damage state (ds) as a function of a parameter representing severity of ground motion (for example spectral acceleration, spectral displacement, peak ground acceleration, etc.). For fragility analysis, capacity curve of bridge is required. Seismic fragility can be expressed in two ways:

a) Damage Probability Matrix:

It expresses seismic fragility numerically in the form of discrete values.

b) Fragility curves:

It expresses the data in a graphical format as continuous curve.

In the present study, the analytical fragility functions for the considered bridge have been obtained using the hybrid approach of HAZUS-MH MR1 (2003). The capacity curves obtained from the analysis conducted have been used to obtain the fragility functions.

In the development of analytical fragility functions, two crucial steps are definition of damage states, and various variabilities associated with the process. These are being discussed in the following Section.

1) Defining the damage states:

Defining damage states and their threshold limits is an important task in developing fragility functions. We can easily define damage states by using intensity scale. The values of spectral displacement at yield (S_{dy}), and spectral displacement at ultimate point (S_{du}), which can be obtained from capacity curve can also be used for defining damage states. In the present study, the four states damage classification proposed by Barbat et al. (2006) has been utilized, as it is consistent with the four grade damage definitions used in HAZUS.

Table 4.1 Damage State Definitions as per (Barbat et al., 2006)

Damage Grade	Damage State	Spectral Displacement
DS 1	Slight Damage	$0.7S_{dy}$
DS 2	Moderate Damage	S_{dy}
DS 3	Extensive Damage	$S_{dy}+0.25(S_{du}-S_{dy})$
DS 4	Complete Damage	S_{du}

2) Damage probability estimation:

In HAZUS methodology, the fragility curves are represented as lognormal distributions, representing probability of being in or exceeding a given damage state, given as

$$P[ds/S_d] = \Phi\left[\frac{1}{\beta_{ds}}\ln\left(\frac{S_d}{\overline{S}_{d,ds}}\right)\right] \quad (4.1)$$

where, is median spectral displacement for damage state ds, Φ is normal cumulative distribution function, and βds is the standard deviation of the natural logarithm of the spectral displacement for damage state ds, which describes the combined variability, given as

$$\beta_{ds} = \left\{\left(CONV\left[\beta_C,\beta_D,\overline{S}_{d,ds}\right]\right)^2 + \left(\beta_{M(ds)}\right)^2\right\}^{(1/2)} \quad (4.2)$$

where, β_C is the lognormal standard deviation parameter representing variability in the capacity properties of the building, β_D represents the variability in the demand spectrum due to variability of the ground motion, and $\beta_{M(ds)}$ represents the variability associated with the uncertainty in estimation of damage state threshold. CONV is a convolution process used to combine the effect of individual contribution of capacity and demand to get the total variability.

Kurian et. al (2006) have presented the analytical method of construction of fragility curves for railway over bridge for the assessment of seismic vulnerability. They have reported that structural modeling that is lumped mass model and distributed mass model affect the analytical fragility curves significantly for the higher damage levels.

5. DESCRIPTION AND MODELING OF THE RAILWAY BRIDGE:

For the present study, a 2 Span of 18.3m Prestressed Concrete Bridge existed at chainage 74110m in Railway route from

Amravati–Narkher (Amravati, Maharashtra, India) across Sukhi River is taken as a case study.

Fig. 5.1 Photograph sample of Railway bridge

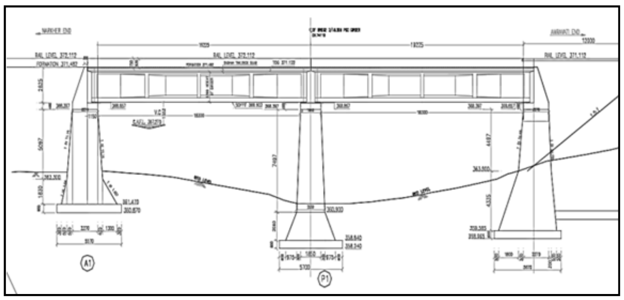

Fig. 5.2 Schematic drawing of Railway bridge

Table 5.1 Bridge details

Bridge Details		
Sr. No.	Description	
1.	Type of Bridge	Prestressed Concrete Bridge(PSC)
2.	Span of Bridge	2 X 18.3m
3.	Width of Bridge	4.7m
4.	Number of Lane	1 Lane
5.	No. of Girder	2 No's
6.	Details of 18.3m Prestressed concrete girder & deck slab as per Drawing No. RDSO B/1596 (Sheet 1 to 4)	
7.	Grade of Concrete Sub Structure RCC Works PSC	M20 M25 M40
8.	Safe Bearing Capacity of Soil	400kN/m²

5.1. Elastomeric Bearing:

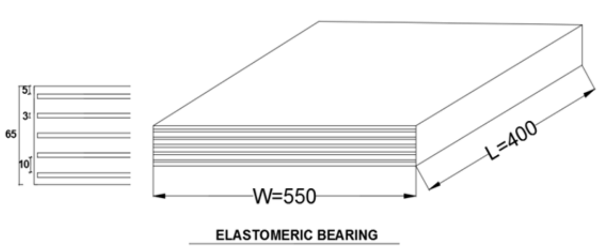

Fig. 5.3 Elastomeric bearing

Table 5.2 Properties of Elastomeric Bearings considering under study

Elastomeric bearing Length L (mm)	400
Elastomeric bearing Width W(mm)	550
Elastomeric bearing Height H (mm)	65
Total elastomer Thickness H_r (mm)	50
Elastomer gross Plan Area A(mm^2)	$220x10^3$
Amount of bearing n (at end of girder)	2
Modulus of rigidity G_{eff} (kg/mm^2)	0.08

5.2. 3D Modelling of bridge:

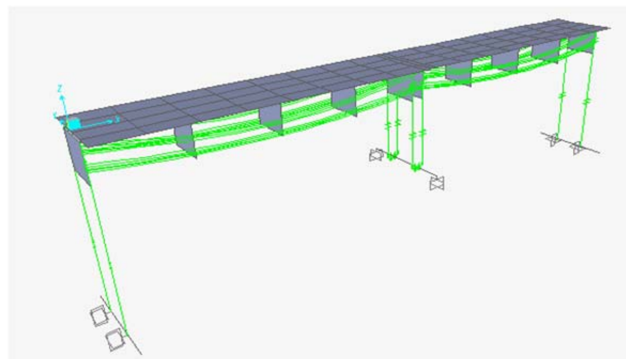

Fig. 5.4 Snapshot of 3D modelling of existing Railway Bridge

6. RESULTS AND DISCUSSIONS:

The analytical fragility curves for all the damage levels have been developed using the parameters obtained from the linear regression analysis of damage data. An analytical study has been performed on existing bridge to estimate the relative performance.

The results of pushover curves in two different directions are plotted as shown in Fig. 6.1 and 6.2 respectively.

Pushover curve in longitudinal direction:

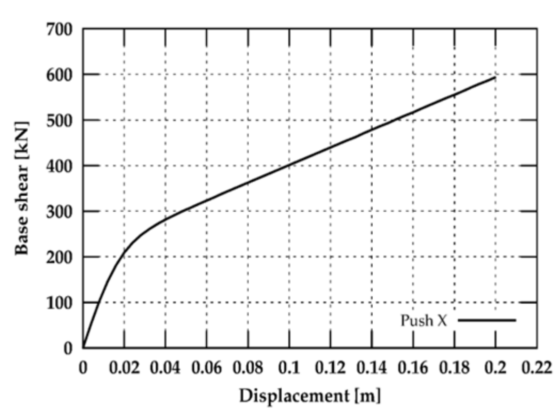

Fig. 6.1. Pushover curves of the considered existing railway bridge in longitudinal direction

Pushover curve in transverse direction:

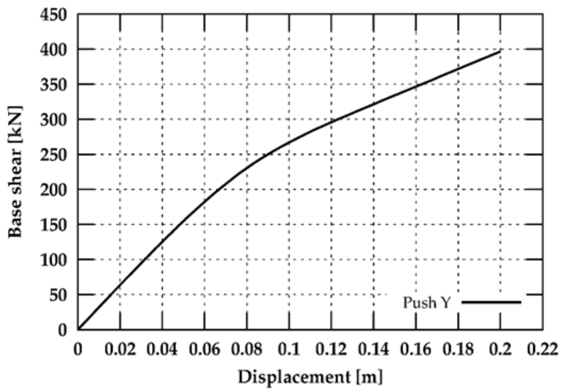

Fig. 6.2 Pushover curve of the considered existing railway bridge in transverse direction.

The seismic performance of the existing bridge is also computed as per Displacement Modification Method (DMM) methodology of ASCE-41, 2007. The study shows that maximum peak ground acceleration (PGA) sustained by existing bridge was 0.37g and 0.34g in longitudinal and transverse directions which is safe as the bridge under study is lies in seismic zone III which produces maximum PGA of 0.16g.

The discrete comparison has also been made on the basis of Damage Probability Matrices (DPMs) as shown in Figures 6.3 and 6.4 in longitudinal and transverse direction considering the PGA in active seismic zone (0.34g). This comparison shows probabilities of different grades of damage in existing bridge in x and y directions.

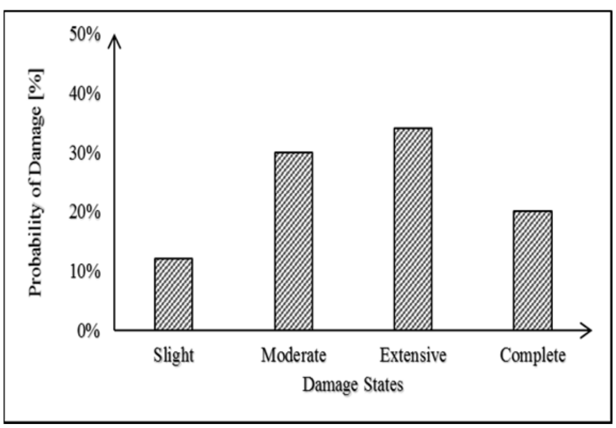

Fig. 6.3 Damage Probability Matrices (DPMs) for existing railway bridge in longitudinal (x) direction.

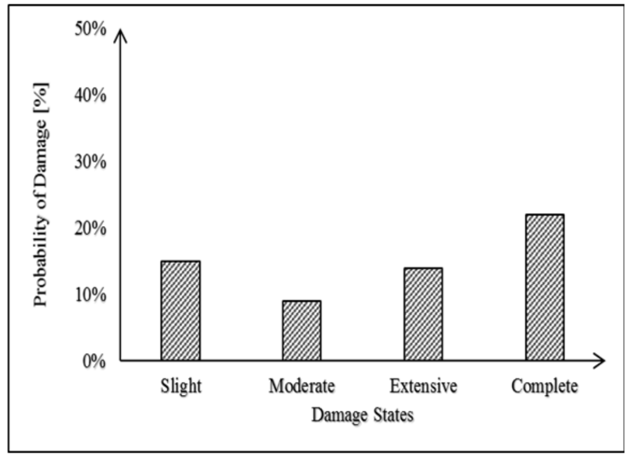

Fig. 6.4 Damage Probability Matrices (DPMs) for existing railway bridge in transverse (y) direction.

Fig. 6.3 shows DPMs in x direction in which it is clear that the probability of damage by considering different damage states as per HAZUS are 12%, 30%, 34% and 20% in Slight, Moderate, Extensive and Collapse damage states. Further these values in y direction are 17%, 10%, 15% and 23% in Slight, Moderate, Extensive and Collapse damage states as shown in Fig. 6.4.

7. CONCLUSION:

From the above results it is observed that for the given condition the existing bridge doesn't require any retrofitting and sustained maximum peak ground acceleration of 0.37g and 0.34g in longitudinal and transverse directions which is safe as the bridge under study is lies in seismic zone III which produces maximum PGA of 0.16g. It is also concluded from DPMs that for severe seismic zone the bridge has moderate and extensive probability of damages in x direction while it has equal probability of damages in y direction.

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