Push over Analysis on Existing Bridge

Abdul raheem[1] Amaresh S patil[2]
[1,2]Department of Civil Engineering
[1]M Tech Student [2]Associate Professor
[1,2]H.K.E. Society's P.D.A. College Of Engineering, Gulbarga

Abstract— The aim of the project is to carry out a seismic evaluation case study for an existing RC bridge using nonlinear static (pushover) analysis and study the loads and load combination. An existing reinforced cement concrete T-beam bridge was evaluated using inelastic analysis procedures namely modal pushover procedure (MPA). MPA was performed in both the transverse and longitudinal directions of the bridge structure independently. The capacity curves that represent the response of the bridge in transverse and longitudinal directions for the particular modes of the vibration are generated using MPA. In present study a 20 span RC T Beam Bridge situated at SH-10 in Karnataka is taken as case study. The bridge is modeled in SAP 2000 software by defining FEMA 356 Auto hinges and conducted Nonlinear Static (Pushover) Analysis using ATC 40 Capacity Spectrum Method.

***Key words*: Bridge, Pushover Analysis, SAP 2000, FEMA 356, ATC 40, Non-Linear Analysis.**

I. Introduction

India had a number of the world's greatest earthquakes in the last century. The north-eastern region of the country as well as the entire Himalayan belt is susceptible to great earthquakes of magnitude more than 8.0. After 2001 Gujarat Earthquake and 2005 Kashmir Earthquake, there is a nation-wide attention to the seismic vulnerability assessment of existing buildings. The seismic building design code in India (IS 1893, Part-I) is also revised in 2002. The magnitudes of the design seismic forces have been considerably enhanced in general, and the seismic zone of some regions has also been upgraded.

There are many literatures available that presents step-by-step procedures to evaluate multi-storied buildings. This procedure follows nonlinear static (pushover) analysis. The attention for existing bridges is comparatively less. However, bridges are very important components of transportation network in any country. The bridge design codes, in India, have no seismic design provision at present. A large number of bridges are designed and constructed without considering seismic forces. Therefore, it is very important to evaluate the capacity of existing bridges against seismic force demand.

There are presently no Comprehensive guidelines to assist the practicing structural engineer to evaluate existing bridges and suggest design and retrofit schemes. In order to address this problem, the present work carried out seismic evaluation for an existing RC bridge using Nonlinear static (pushover) analysis as per ATC 40 is used to verify the result.

II. NONLINEAR STATIC (PUSHOVER) ANALYSIS

The use of the nonlinear static analysis came in to practice in 1970‟s but the potential of the pushover analysis has been recognized for last 10-15 years . This procedure is mainly used to estimate the strength and drift capacity of existing structure and the seismic demand for this structure subjected to selected earthquake. This procedure can be used for checking the adequacy of new structural design as well. Pushover analysis is defined as an analysis wherein a mathematical model directly incorporating the nonlinear load-deformation characteristics of individual components and elements of the structure shall be subjected to monotonically increasing lateral loads representing inertia forces in an earthquake until a „target displacement‟ is exceeded. Target displacement is the maximum displacement (elastic plus inelastic) of the structure at top expected under selected earthquake ground motion. Pushover analysis assesses the structural performance by estimating the force and deformation capacity and seismic demand using a nonlinear static analysis algorithm. The seismic demand parameters are global displacements (at roof or any other reference point), storey drifts, storey forces, and component deformation and component forces. The analysis accounts for geometrical nonlinearity, material inelasticity and the redistribution of internal forces. Response characteristics that can be obtained from the pushover analysis are summarized as follows:

1) Estimates of force and displacement capacities of the structure, Sequence of the member yielding and the progress of the overall capacity curve.
2) Estimates of force (axial, shear and moment) demands on potentially brittle elements and deformation demands on ductile elements.
3) Estimates of global displacement demand, corresponding inter-storey drifts and damages on structural and non-structural elements expected under the earthquake ground motion considered.
4) Sequences of the failure of elements and the consequent effect on the overall structural stability.
5) Identification of the critical regions, where the inelastic deformations are expected to be high and identification of strength irregularities (in plan or in elevation) of the building.

III. Pushover analysis procedure

Pushover analysis is a static nonlinear procedure in which the magnitude of the lateral load is increased monotonically maintaining a predefined distribution pattern along the height of the Structure. Structure is displaced till the „control node‟ reaches „target displacement‟ or structure collapses. The sequence of cracking, plastic hinging and failure of the structural components throughout the procedure is observed. The relation between base shear and control node displacement is plotted for all the pushover analysis. Generation of base shear – control node displacement curve is single most important part of pushover analysis. This curve is conventionally called as pushover curve or capacity curve. The capacity curve is the basis of „target displacement‟ estimation. The seismic demands for the selected earthquake are calculated at the target displacement level. The seismic demand is then compared with the corresponding structural capacity or predefined performance limit state to know what performance the structure will exhibit .

IV. LITERATURE SURVEY

The use of the nonlinear static analysis came in to practice in 1970's but the potential of the pushover analysis has been recognized for last 10-15 years. This procedure is mainly used to estimate the strength and drift capacity of existing structure and the seismic demand for this structure subjected to selected earthquake. This procedure can be used for checking the adequacy of new structural design as well.

Pushover analysis is defined as an analysis wherein a mathematical model directly incorporating the nonlinear load-deformation characteristics of individual components and elements of the structure shall be subjected to monotonically increasing lateral loads representing inertia forces in an earthquake until a 'target displacement' is exceeded. Target displacement is the maximum displacement (elastic plus inelastic) of the structure at top expected under selected earthquake ground motion. Pushover analysis assesses the structural performance by estimating the force and deformation capacity and seismic demand using a nonlinear static analysis algorithm. The seismic demand parameters are global displacements (at roof or any other reference point), storey drifts, storey forces, and component deformation and component forces. The analysis accounts for geometrical nonlinearity, material inelasticity and the redistribution of internal forces.

The following are some of the review of journal papers based on Pushover Analysis on Existing Bridges:

R.E.T. Amaladosson & U. Gunasekaran have evaluated an existing reinforced cement concrete T-beam bridge using inelastic analysis procedures namely capacity spectrum method (CSM) and modal pushover procedure (MPA). Modal pushover procedure (MPA) was performed in both the transverse and longitudinal directions of the bridge structure independently. The response of the bridge structure to El Centro and Kobe earthquake ground motions was evaluated by the capacity spectrum method (CSM). The capacity curves that represent the response of the bridge in transverse and longitudinal directions for the particular modes of the vibration are generated using MPA. The capacity-demand spectra for mode#1, mode#8 (transverse direction) and mode#2 (longitudinal direction) were obtained using SAP2000 analysis software.

When the bridge was subjected to an earthquake similar to the El Centro Earthquake in transverse and longitudinal directions, the bridge capacity spectrum curve extended through the envelope of the demand curves, indicating that the bridge would survive in both the directions. Whereas for an earthquake similar to the Kobe one, the demand was much greater than the capacity and the bridge failed to survive. In the transverse modes, the structure indicates large energy absorption capacities in the inelastic range, without a significant loss of strength and stiffness. The bridge has more displacement ductility in the transverse direction than in the longitudinal direction. Hence, retrofitting applications to the multi-column bents are suggested, to enhance the global stability.

Ahmed Abdel-Mohti and Gokhan Pekcan have developed three-dimensional improved beam-stick models of two-span highway bridges with skew angles varying from 0° to 60° to investigate the seismic response characteristics of skew box girder bridges. He found that, larger response quantities (i.e., displacements, forces) were observed with larger levels of ground motions. Relatively stiff soil conditions (soil type B) versus soft soil (soil type D) lead to smaller response for the comparable levels of excitations, regardless the skew angle. It was found in general that shear keys have a predominant effect on the overall seismic response of the bridges studied

Sreeraja Sreevilasan K and Dr. M.A. Chakrabarti has selected a model of pre stressed bridge with continuous span. Subsequently, the Capacity Spectrum Analysis (a nonlinear static procedure), has been used to evaluate the seismic performance of the bridge model based on displacement control. The demand spectrum of IS 1893 is used to determine the performance level for this bridge model. This also helps to study the progressive collapse of the bridge during an earthquake. He concluded that, Capacity Spectrum Analysis of the existing bridges shows that the bridges has a performance level A-B, that is the structure does not cross the yield point and hence the bridges are safe for the response spectra IS 1983. Capacity spectrum method gives progressive collapse of the bridge structure for a given Earthquake ground motion, for response spectra IS 1893.

Sachin Kulkarni & U.N.Karadi had carried out a seismic evaluation case study for an existing RC bridge using nonlinear static (pushover) analysis. A 4 Span RC Slab Bridge existed in SH-12 in Karnataka, was selected and by defining FEMA 356 Auto hinges conducted Nonlinear Static (Pushover) Analysis using Capacity Spectrum Method and software SAP2000 was used to analyze the Bridge. The evaluation result shows that the selected bridge does not have the capacity to meet the desired performance level and it requires retrofitting. From the Analysis it is evident that Spectral Displacement Demand is more than the Spectral Displacement Capacity in the analyzed Bridge. So the analyzed bridge requires retrofitting.

Parimal A. Godse (2013) explained, the structure remains within elastic range employing linear method and resulting forces and the displacement are quite high. By introducing ductility in bridges, the load carrying capacity can be enhanced thus bridge is to be designed for lesser forces than obtained in elastic range. This requires to employ non-linear analysis (in-elastic range). Static non-linear analysis is an effective tool to evaluate the expected non-linear behavior and consequent failure pattern in different components of the bridge.

Gokhan Pekcan and Ahmed Abdel-Mohti examines the seismic performance of a three-span continuous concrete box girder bridge with skew angles from 0 to 60 degrees, analytically. The bridge was modelled using finite element (FE) and simplified beam-stick (BS) using SAP2000. Different types of analysis were considered on both models such as: nonlinear static pushover and linear and nonlinear time history analyses. They have concluded that, Bridges with larger skew angles (> 30 degrees) experienced larger deformations, which in turn, resulted in larger ductility demands; however, forces in the substructure elements remained relatively unaffected with exception to the torsional response of the columns that are on the diagonal with respect to the acute corners of the bridges. The direction of the two horizontal components of the strong motions relative to the longitudinal and transverse directions did not have any significant effect on the overall response. For larger skew angles, the results from the nonlinear time history analyses agree with the observed yield mechanism in the columns from the pushover analyses.

V. PROBLEM DEFINITION

A 20 Span RC T Beam Bridge existed at State Highway (SH-10) from Gulbarga to Sedam Road across Kagina River is taken as a case study. The loads and load combinations on the bridge will be studied and the same bridge is modelled in SAP 2000. The FEMA 356 Hinges will be defined in the model and conducted Nonlinear Static (Pushover) Analysis using ATC-40 to calculate Base Shear vs. Displacements, Effective time, Spectral Displacement Capacity & Spectral Displacement Demand and to find out Performance points of Bridge.

VI. BRIDGE DETAILS CONSIDERED FOR ANALYSIS

Bridge Details		
Sl.No	**Description**	
1	Number of Span	20nos
2	Centre to Centre Length of each Span of Bridge	10m
3	Width of Bridge	6.75 m
4	Number of Main Girders	3 No's
5	Total depth	1.12m
6	Slab thickness (average)	0.22m
7	Thickness of Wearing Coat	100mm
8	Longitudinal Girder Size	0.45m X 0.90m
9	Type of Loading	IRC class A Train
10	Loads	DL+LL+IL+EQ
11	Compressive Strength of Concrete (fck) (M30)	30000 KN/m²
12	Modulus of Elasticity $E=5000\sqrt{fck}$ $E=5000\sqrt{30} = 30000$ N/mm²	27386128 KN/m²
13	Poisson's Ratio of Concrete	0.18
14	Type of Analysis	Linear and Nonlinear

Table. 1: Bridge details

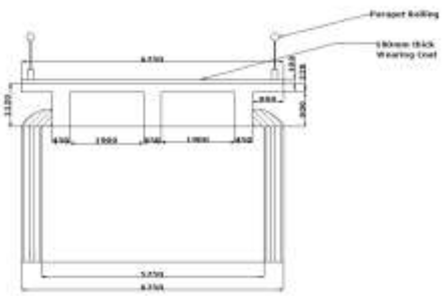


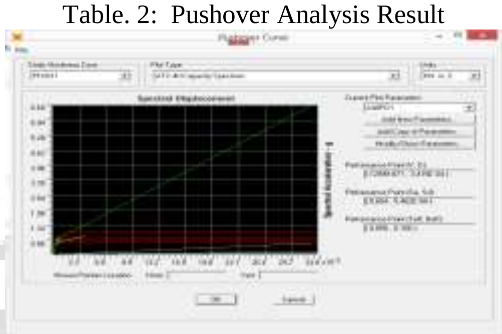
Fig. 1: Cross Section of the Bridge

Fig. 2: Bridge Model in SAP

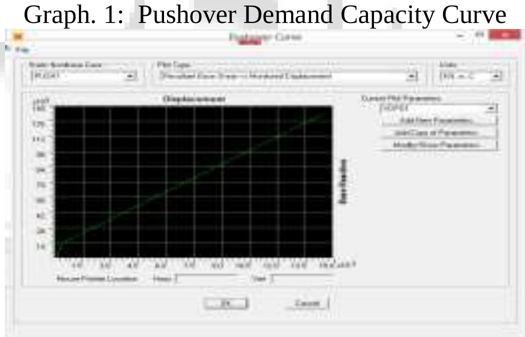
VII. PUSHOVER ANALYSIS RESULTS

Step	Teff	Sd Capacity	Sd Demand
		m	m
0	0.054022	0	0.000584
1	0.054022	0.000439	0.000584
2	0.057268	0.000528	0.000544
3	0.06359	0.000712	0.00057
4	0.140106	0.032136	0.004006

Table. 2: Pushover Analysis Result



Graph. 1: Pushover Demand Capacity Curve



Graph. 2: Base Shear vs. Displacement

Step	Displacement	BaseForce
	m	KN
0	0.000067	0
1	0.000306	12147.419
2	0.000335	12891.276
3	0.0004	13981.995
4	0.014538	133476.03

Table. 3: Base Shear vs. Displacement

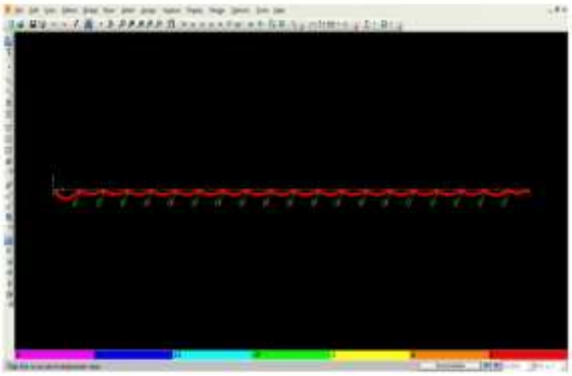


Fig. 3: Pushover Step 1

Fig. 4: Pushover Step 2

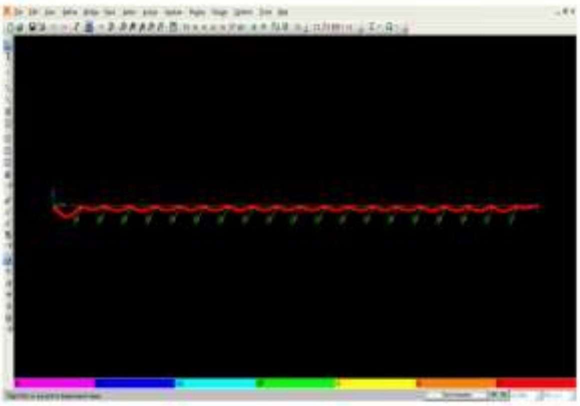


Fig. 5: Pushover Step 3

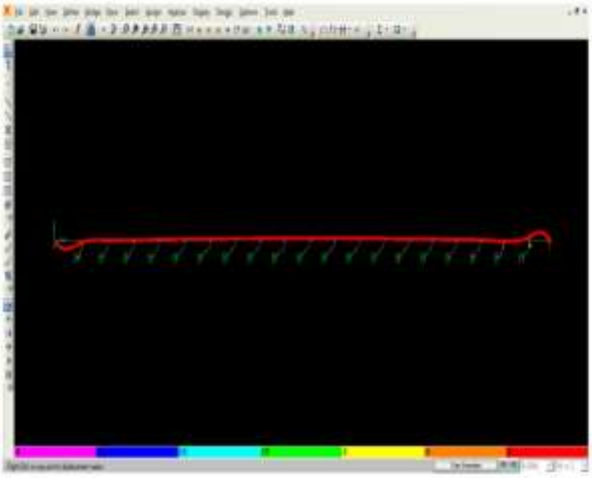
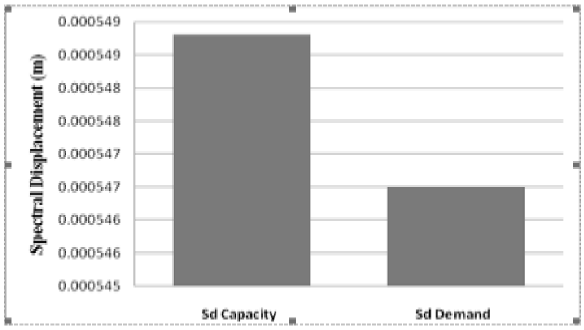


Fig. 6: Pushover Step 4

The effective time is 0.058; it is in between pushover step 2 and step 3. At effective time the Spectral Displacement Capacity (m) and Spectral Displacement Demand (m) is calculated by interpolating values in the Table 6.5. The table 6.6 shows the Spectral Displacement Capacity and Spectral Displacement Demand values according to Capacity Spectrum Method ATC 40 at effective time 0.058 sec's

Step	**Teff**	**SdCapacity**	**SdDemand**
		m	m
Between Step 2 & 3	0.058	0.0005493	0.00054701

Table. 4: Comparison between Capacity & Demand (ATC 40)



Graph 3 Comparisons between S_d Capacity & S_d Demand

VIII. CONCLUSION

1) From the Analysis, Spectral Displacement Capacity is more than the Spectral Displacement Demand in the analysed Bridge. So the analysed bridge is safe.
2) The performance levels of all the hinges in all the bents were at safe performance levels.
3) The performance level of the structure is in between A to B and B to IO.
4) Hence, Retrofitting application does not require.

REFERENCES

[1] Y.Chen "An Effective and Efficient Approach for Nonlinear Seismic Analysis of Bridges" , June 1993

[2] Dr. Cosmin G. Chiorean, "Application of pushover analysis on reinforced concrete bridge model" Research Report No. POCTI/36019/99 July 2003.

[3] Nicknam, A. Mosleh and H. Hamidi Jamnani , "Seismic Performance Evaluation of Urban Bridge using Static Nonlinear Procedure, Case Study: Hafez Bridge" The twelfth East Asia Pacific Conference on Structural Engineering and Construction.

[4] R.E.T. Amaladosson & U. Gunasekaran, Analysis of T beam bridge for seismic Characterisation", 2014 NZSEE Conference, Paper Number P11

[5] Ahmed Abdel-Mohti and Gokhan Pekcan "Assessment of seismic performance of skew reinforced concrete box girder bridges" International Journal of Advanced Structural Engineering 2013, 5:1

[6] Sreeraja Sreevilasan K and Dr. M.A. Chakrabarti "Capacity Spectrum Analysis For Prestressed Concrete Bridges", full paper *Proc. of Int. Conf. on Advances in Design and Construction of Structures 2012*

[7] Sachin Kulkarni & U.N.Karadi "Case Study of RC Slab Bridge using Nonlinear Analysis", International Journal of Engineering and Innovative Technology (IJEIT) Volume 3, Issue 12, June 2014

[8] Parimal A. Godse, "Seismic Performance Study of Urban Bridges Using Non-Linear Static Analysis",

International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 6, June 2013

[9] Gokhan Pekcan and Ahmed Abdel-Mohti, "Seismic Response of Skewed RC Box-Girder Bridges" The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China

[10] IRC 6-2010, "Standard Specifications and Code of Practice for Road Bridges", Section II, loads and stresses, The Indian Roads Congress, New Delhi, India, 2010.

[11] IS 1893-Part 3 "Criteria for earthquake resistant design of structures -Bridges and Retaining walls"

