International Journal For Technological Research In Engineering
Volume 5, Issue 12, August-2018 *ISSN (Online): 2347 - 4718*

EVALUATION AND APPLICATION OF RCC BRIDGE BY USING PUSHOVER ANALYSIS

Er. Suhaib Alam Bhat

ABSTRACT

Keywords: pushover analysis, RC Bridge, plastic hinge, target displacement, capacity curve

Pushover Analysis

This is one of the procedures under the heading of non linear static analysis and considers the structure to be monotonically expanding based on the lateral loads and the inertial forces that will be generated during an earthquake. This methods involves determining the most susceptible member to danger, due to the application of incremental loads the components of the structure yields. Thus the strucrure will be under great danger at every point of the load cycle. Thus a non linear force-displacement plot will be determined.This method can clearly help in understanding the basic nature of the seismic loads and the corresponding response of the structure. It includes determining shear-displacement plots, called capacity curve, and gives information of the quality and ductility of the structure. After 2001 Gujarat Earthquake and 2005 Kashmir Earthquake, there is a nation-wide attention to the seismic vulnerability assessment of existing buildings. There are many literatures available on the seismic evaluation procedures of multi-storeyed buildings using nonlinear static (pushover) analysis. There is no much effort available in literature for seismic evaluation of existing bridges although bridge is a very important structure in any country. 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 aims of the present project was to carry out a seismic evaluation case study for an existing RC bridge using nonlinear static (pushover) analysis. Bridges extends horizontally with its two ends restrained and that makes the dynamic characteristics of bridges different from building. 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. A 12-span existing RC bridge was selected for the case study. Standard pushover analysis using FEMA 356 (2000) displacement coefficient method and an improved upper bound pushover analysis method were used to analyse the building. Some of the analysis parameters were suitably modified to use in a bridge structure. The evaluation results presented here shows that the selected bridge does not have the capacity to meet any of the desired performance level.

I. INTRODUCTION

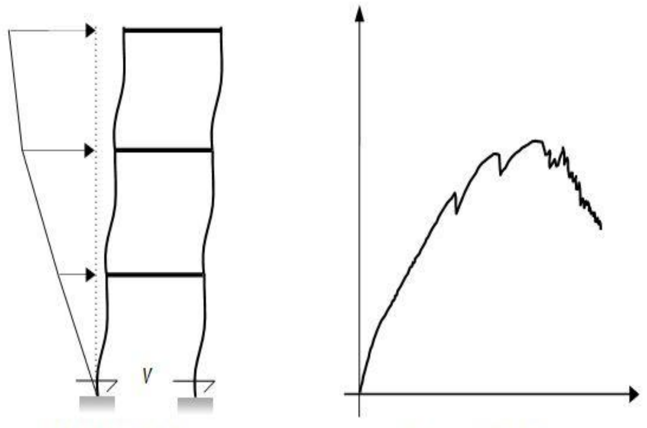
India has had a number of the world’s greatest earthquakes in the last century. In fact, more than fifty percent area in the country is considered prone to damaging earthquakes. The northeastern region of the country as well as the entire Himalayan belt is susceptible to great earthquakes of magnitude 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. Also, a lot of efforts were focused on the need for enforcing legislation and making structural engineers and builders accountable for the safety of the structures under seismic loading. 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 zonation of some regions has also been upgraded. There are many literature (e.g., IITM-SERC Manual, 2005) available that presents step-by-step procedures to evaluate multi-storeyed buildings. This procedure follows nonlinear static (pushover) analysis as per FEMA 356. 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 aims to carry out a seismic evaluation case study for an existing RC bridge using nonlinear static (pushover) analysis. Nonlinear static (pushover) analysis as per FEMA 356 is not compatible for bridge structures. Bridges are structurally very different from a multi-storeyed building. So, in the present study an improved pushover analysis is also used to verify the results.

II. PUSHOVER ANALYSIS

The use of the nonlinear static analysis (pushover analysis) came in to practice in 1970’s but the potential of the pushover analysis has been recognised 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. The effectiveness of pushover analysis and its computational simplicity brought this procedure in to several seismic guidelines (ATC 40 and FEMA 356) and design codes (Eurocode 8 and PCM 3274) in last few years. 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 building 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 building at roof 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, 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 summarised as follows:

a) Estimates of force and displacement capacities of the structure. Sequence of the member yielding and the progress of the overall capacity curve.
b) Estimates of force (axial, shear and moment) demands on potentially brittle elements and deformation demands on ductile elements.
c) Estimates of global displacement demand, corresponding inter-storey drifts and damages on structural and non-structural elements expected under the earthquake ground motion considered.
d) Sequences of the failure of elements and the consequent effect on the overall structural stability.
e) 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.

Pushover analysis delivers all these benefits for an additional computational effort (modeling nonlinearity and change in analysis algorithm) over the linear static analysis.



a) Buildingmodel b) Pushovercurve

III. OBJECTIVES

Following are the main objectives of the present study:
a) To understand the standard pushover analysis procedures and other improved pushover analysis procedures available in literature. b) To carry out a detailed case study of pushover analysis of a reinforced concrete bridge using standard pushover analysis and other improved pushover analyses.

IV. METHODOLOGY

a) A thorough literature review to understand the seismic evaluation of building structures and application of pushover analysis.
b) Select an existing RC bridge with geometrical and structural details
c) Model the selected bridge in computer software SAP2000.
d) Carry out modal analysis to obtain the dynamic properties of the bridges and generate input parameters for pushover analysis from the modal properties of the bridge.
e) Carry out pushover analysis of the bridge model and arrive at a conclusion.

Lateral LoadPatterns

Inpushoveranalysisthebuildingispushedwithaspecificloaddistributionpatternalongthe height of the building. The magnitude of the total force is increased but the pattern of the loading remains same till the end of the process. Pushover analysis results (*i.e.*, pushover curve, sequence of member yielding, building capacity and seismic demand) are very sensitive to the load pattern. The lateral load patterns should approximate the inertial forces expected in the building during an earthquake. The distribution of lateral inertial forces determines relative magnitudes of shears, moments, and deformations within the structure. The distribution of these forces will vary continuously during earthquake response as the membersyieldandstiffnesscharacteristicschange.Italsodependsonthetypeandmagnitude of earthquake ground motion. Although the inertia force distributions vary with the severity of the earthquake and with time, FEMA 356 recommends primarily invariant load pattern for pushover analysis of framed buildings.

Several investigations (Mwafy and Elnashai, 2000; Gupta and Kunnath, 2000) have found that a triangular or trapezoidal shape of lateral load provide a better fit to dynamic analysis results at the elastic range but at large deformations the dynamic envelopes are closer to the uniformly distributed force pattern. Since the constant distribution methods are incapable of capturing such variations in characteristics of the structural behaviour under earthquake loading, FEMA 356 suggests the use of at least two different patterns for all pushover analysis.Useoftwolateralloadpatternsisintendedtobindtherangethatmayoccurduringactualdynamicresponse.FEMA356 recommendsselectingoneloadpatternfromeachofthe following two groups:

Group – I:

Code-basedverticaldistributionoflateralforcesusedinequivalentstaticanalysis (permitted only when more than 75% of the total mass participates in the fundamental mode in the direction underconsideration).

A vertical distribution proportional to the shape of the fundamental mode in the direction under consideration (permitted only when more than 75% of the total mass participates in thismode).

A vertical distribution proportional to the story shear distribution calculated by combining modal responses from a response spectrum analysis of the building (sufficient number of modes to capture at least 90% of the total building mass required to be considered). This distribution shall be used when the period of the fundamental mode exceeds 1.0second.

Group – II:
Auniformdistributionconsistingoflateralforcesateachlevelproportionaltothe total mass at eachlevel. An adaptive load distribution that changes as the structure is displaced. The adaptive load distribution shall be modified from the original load distribution using a procedure that considers the properties of the yielded structure.
Insteadofusingtheuniformdistributiontobindthesolution,FEMA356alsoallowsadaptive lateral load patterns to be used but it does not elaborate the procedure. Although adaptive procedure may yield results that are more consistent with the characteristics of the building under consideration it requiresconsiderablymoreanalysiseffort.Fig.2.2showsthecommon lateral load pattern

STRUCTURAL MODELLING
The study in this thesis is based on nonlinear analysis of RC bridge models. This chapter presents a summary of various parameters defining the computational models, the basic assumptions and the bridge geometry considered for this study. Accurate modelling of the nonlinear properties of various structural elements is very important in nonlinear analysis. In the present study, piers were modelled with inelastic flexural deformations using point plastic model. This chapter also presents the properties of the point plastic hinges.

COMPUTATIONALMODEL
Modelling a building involves the modelling and assemblage of its various load-carrying elements. The model must ideally represent the mass distribution, strength, stiffness and deformability. Modelling of the material properties and structural elementsused in the present study is discussed below.

Structural Elements
Piersandgirderssupportingdeckaremodelledby3Dframeelements.Thegirder-pierjoints are modeled by giving end-off sets totheframeelements,toobtainthebendingmoments and forces at the beam and column faces. The girder-pier joints are assumed to be rigid(Fig.3.1). The pier end at foundation was considered as fixed. All the pier elements are modelled with nonlinear properties at the possible yield locations. Deck is not modelled physically. However, the weight of the deck is applied on the beam as Dead Load. Also, mass of the deck is considered for modalanalysis.

MODELLING OF FLEXURAL PLASTICHINGES
In the implementation of pushover analysis, the model must account for the nonlinear behaviour of the structural elements. In the present study, a point-plasticity approach is considered for modelling nonlinearity, wherein the plastic hinge is assumed to be concentratedataspecificpointintheframememberunderconsideration.Piersinthisstudy were modelled with flexure (P-M2-M3) hinges at possible plastic regions under lateralload
(i.e., both ends of the beams and columns). Properties of flexure hinges must simulate the actual response of reinforced concrete components subjected tolateral load.

Stress-Strain Characteristics forConcrete
The stress-strain curve of concrete in compression forms the basis for analysis of any reinforced concrete section. The characteristic and design stress-strain curves specified in most of design codes (IS 456: 2000, BS 8110) do not truly reflect the actual stress-strain behaviour in the post-peak region, as (for convenience in calculations) it assumes aconstant stress in this region (strains between 0.002 and 0.0035). In reality, as evidenced by experimentaltesting,thepost-peakbehaviourischaracterisedbyadescendingbranch,which is attributed to 'softening' and micro-cracking in the concrete. Also, models as per these codes do not account for strength enhancement and ductility due to confinement. However, the stress-strain relation specified in ACI 318M-02 consider some of the important features fromactualbehaviour.Apreviousstudy(Chugh,2004)onstress-strainrelationofreinforced

The advantage of using this model can be summarized as follows:
A single equation defines the stress-strain curve (both the ascending and descending branches) in this model.
Thesameequationcanbeusedforconfinedaswellasunconfinedconcretesections.

The model can be applied to any shape of concrete member section confined by any kind of transversereinforcement(spirals,crossties,circularorrectangularhoops).
The validation of this model is established in many literatures (*e.g*., Pam and Ho, 2001).
Moment-RotationParameters

Moment-rotation parameters are the actual input for modelling the hinge properties and this can be calculated from the moment-curvature relation. The moment-rotation curve can be idealised as shown in Fig. 3.9, and can be derived from the moment-curvature relation. The main points in the moment-rotation curve shown in the figure can be defined as follows:
The point 'A' corresponds to the unloadedcondition.
The point 'B' corresponds to the nominal yield strength and yield rotationθ_y.

The point 'C' corresponds to the ultimate strength and ultimate rotationθ_u , following which failure takes place.
Thepoint'D'correspondstotheresidualstrength,ifany,inthe member.Itisusually limited to 20% of the yield strength, and ultimate rotation,θ_u can be taken with that.
The point 'E' defines the maximum deformation capacity

and is taken as $15\theta_y$ or θ_u , whichever isgreater.

V. RESULTS AND DISCUSSIONS

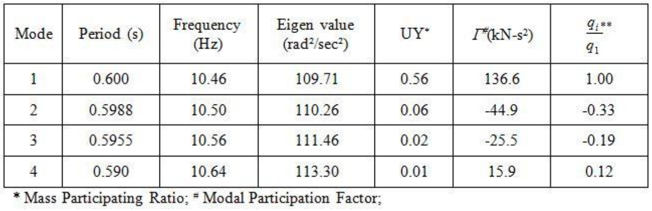
The selected bridge model is analysed using upper bound pushover analysis. This chapter presents elastic modal properties of the bridge, pushover analysis results and discussions. Pushover analysis was performed first in a load control manner to apply all gravity loads on to the structure (gravity push). Then a lateral pushover analysis in transverse direction was performed in a displacement control manner starting at the end of gravity push. The results obtained from these analyses are checked against the seismic demand corresponds to the Zone V (PGA = 0.36g) of India.

MODALPROPERTIES

Modal properties of the bridge model were obtained from the linear dynamic modal analysis. Table 4.1 shows the details of the important modes of the bridge in transverse direction (Y direction). The table shows that participating mass ratio in the first mode is only 56% cumulative mass participating ratio for first four modes is 65%. Therefore, unlike regular buildings the higher mode participation in the response of bridge is significant. Figs.4.1 and 4.2 present the first four mode shapes in the transverse direction.

Oneofthemainassumptionsforthestandardpushoveranalysis(FEMA356)ishundredpercent fundamental mode contributions in the structural response which is not true for the bridges. Therefore,standardpushoveranalysisasperFEMA356isnotsuitableforthebridges.

Table 4.1: Elastic Dynamic Properties of the Bridge for Lateral vibration (Y- direction)



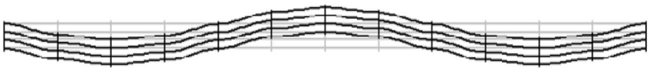
Mode	Period (s)	Frequency (Hz)	Eigen value (rad²/sec²)	UY*	$\Gamma^{\#}$(kN-s²)	$\frac{q_i}{q_1}$**
1	0.600	10.46	109.71	0.56	136.6	1.00
2	0.5988	10.50	110.26	0.06	-44.9	-0.33
3	0.5955	10.56	111.46	0.02	-25.5	-0.19
4	0.590	10.64	113.30	0.01	15.9	0.12

* Mass Participating Ratio; # Modal Participation Factor;

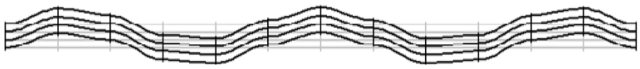
PUSHOVERANALYSIS

Pushover analyses carried out using FEMA 356 displacement coefficient method as well as upper bound pushover analysis (UBPA) method. A triangular load pattern was used for standard pushover analysis (FEMA 356). Fig. 4.3 shows the load pattern used for standard pushover analysis.

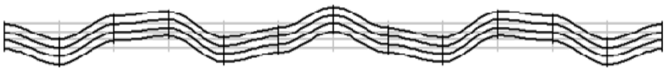
Firstmode



Secondmode



Thirdmode



Fourthmode

Fig. : First four modes of the bridge (plan view)

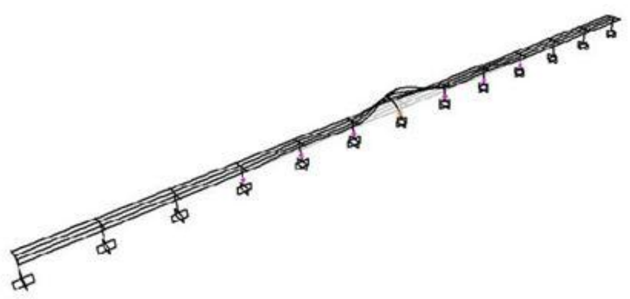
For UBPA, the load pattern for the analysis was calculated from the modal properties as discussed in Section 2.4.1. Sample calculation for determining the load profile for UBPA is presentedin Table.Fig shows the load pattern for UBPA graphically and comparesit with the triangular load pattern.

Table: Target displacements for different performance levels

Performance Level	IO	LS	CP
FEMA -356	80 mm	88 mm	96 mm
UBPA	106 mm	117 mm	128 mm

IO = Immediate Occupancy; LS = Life Safety; CP = Collapse Prevention

TheresultsobtainedfromPushoverAnalysis(bothforFEMA-356andUBPA)showsthatthe bridge collapses before reaching the Target Displacement. For FEMA-356, the failure is concentratedatthemiddleofthebridgewhereas,forUBPA,thefailureisdistributedoverthe length of the bridges. Figs. 4.6 and 4.7 present the distribution of the plastic hinges in the bridge at collapse for the two push over analyses.



VI. CONCLUSION

After 2001 Gujarat Earthquake and 2005 Kashmir Earthquake, there is a nation-wide attention to the seismic vulnerability assessment of existing buildings. There are many literatures available on the seismic evaluation procedures of multi-storeyed buildings using nonlinearstatic(pushover)analysis.Thereisnomucheffortavailableinliteratureforseismic evaluation of existing bridges although bridge is a very important structure in any country. Therearepresentlynocomprehensiveguidelinestoassistthepracticingstructuralengineerto evaluate existing bridges and suggest design and retrofit schemes. In order to address this problem, the aims of the present project was to carry out a seismic evaluation case study for an existingRCbridgeusingnonlinearstatic(pushover)analysis.

To achieve this, a multi-span RC bridge is selected from literature. The bridge was modelled using SAP2000 for nonlinear analysis. Nonlinear hinge properties were generated using improved stress-strain curve of concrete and reinforcing steel. The bridge is analysedusing pushover analysis procedure as per FEMA 356 and Upper Bound Pushover Analysis procedure. Both of these two procedures are developed for multi-storeyed building. These procedures were suitably modified to use for multi-span bridges.

CONCLUSIONS

Bridges extends horizontally with its two ends restrained and that makes the dynamic characteristics of bridges different from buildings. By analysing the structure using 'Upper Bound Pushover Analysis' (UBPA) and FEMA-356 (TLP) pushover analysis, it was

concluded that:

Here the performance of the bridge, according to FEMA-356 and UBPA, is not acceptable. Therefore it requires retrofitting. The distributions of the hinges are different for the two pushover analyses carried out in this study. For FEMA-356 loading hinges are concentrated at the middle of thebridges.

ForUBPAloading,hingesaredistributedovertheentirelengthofthebridge.

However, the formation of hinges initiated from Pier# 5 and Pier# 10.

Modalanalysisofa3Dbridgemodelrevealsthatithasmanyclosely-spacedmodes.

Participating mass ratio for the fundamental mode is only 56%. Therefore, the contribution from the higher modes is very high(44%).

Furtherinvestigationisrequiredinordertomakeageneralisedevaluationprocedure for bridge structures with different configurations.

REFERENCES

[1] ATC40(1996),"SeismicEvaluationandRetrofitofConcreteBuildings":Vol.1, *Applied Technology Council, USA*.

[2] Aschheim, M.A., Maffei, J., and Black, E.F. (1998). "Nonlinear static procedures and earthquake displacement demands". *Proceedings of 6th U.S. National Conference on Earthquake Engineering, Seattle*, Paper167.

[3] Au, FTK, Chengand, YS and Cheung, YK (2001) "Vibration analysis of bridges undermovingvehiclesandtrains",*EngineeringStructures*,vol.30,pp.54-66.

[4] BS 8110 Part 1 and 2 (1997) "Structural Use of Concrete, Code of Practice for Design and Construction", *British Standards Institute Chugh*,2004

[5] Chopra, A.K., and Goel, R.K. (1999). "Capacity-demand-diagram methods for estimating seismic deformation of inelastic structures: SDF systems". Report No. PEER-1999/02, *Pacific Earthquake Engineering Research Center, University of California, Berkeley,California.*

[6] Chopra AK, Goel RK. (2000) "Evaluation of NSP to estimate seismicdeformation: SDF systems". *J StructEngg.* 2000;126(4):482–90.

[7] Chopra, A.K., and Chintanapakdee, C. (2001). "Comparing response of SDF systems to near-fault and far-fault earthquake motions in the context of spectral regions". *EarthquakeEngineeringandStructuralDynamics*,30(10),375–388.

[8] Chopra, A.K. and Goel, R.K. (2002). "A modal pushover analysis procedure for estimating seismic demands for buildings". *Earthquake Engineering and Structural Dynamics,* 31,561-582.

[9] Chiorean, CG (2003) "Application of pushover analysis on reinforced concrete bridge model", *4th European Workshop on the Seismic Behaviour of Irregular and Complex Structures,* Thessaloniki,Greece.

[10] Chopra, A. K., Goel, R. K., and Chintanapakdee, C. (2003). "Statistics ofSingle- Degree-of-Freedom Estimate of Displacement for Pushover Analysis of Buildings". *Journal of Structural Engineering ASCE,* 129(4),449-469;