Seismic Vulnerability Assessment of a Reinforced Concrete Building Located in India

Prasanth S, Goutam Ghosh

Abstract— Over the recent years the natural disaster especially due to the earthquake effect on buildings increases which causes loss of life and property in many places all over the world. The latest development leads to finding the direct losses and damage states of the buildings for various intensities of earthquake ground motions. In the present study, seismic vulnerability assessment was done for a medium rise building (G+5). The design peak ground acceleration of 0.16g and 0.36g were considered for the risk assessment. The nonlinear static pushover analysis was done to fine the performance point, spectral acceleration and corresponding spectral acceleration by Equivalent Linearization (EL) method given by Federal Emergency Management Agency (FEMA-440). The four damage states such as slight, moderate, extreme and collapse has been considered as per HAZUS-MR4. The seismic vulnerability in terms of fragility curves was developed to evaluate the damage probabilities based on HAZUS methodology. The discrete and cumulative damage probability was found for all the damage states of the building which shows the building at 0.16g experience slight damage whereas at 0.36g the moderate damage state equally becomes predominant.

Keywords: Capacity curves, Ductility, Fragility curves, Performance point.

I. INTRODUCTION

In recent century, India has experienced many earthquakes including that in Assam on August 15th, 1950 (M8.7); Koyna, Maharashtra on December 11th, 1967 (M6.3); Kinnaur, Himachal Pradesh on January 19th , 1975 (M6.8); Assam on August 6th, 1988 (M7.0); Uttarkashi, Uttranchal on October 18th, 1991 (M7.5); Killari, Maharashtra on September 30th, 1993 (M6.3); Jabalpur earthquake on 22nd May 1997 (M6.8); Bhuj, Gujarat on January 26th, 2001 (M 7.9); Sumatra earthquake on 26th December 2005 (M9.3) and Jammu Kashmir - Kohistan earthquake on October 8th, 2005 (M7.6), etc. Peninsular India (PI), which was considered to be more stable than the extra-peninsular, was known to have experienced several earthquakes with a magnitude of more than 5 in historical times. Mainly earthquake occurred at Latur with a moment magnitude of (Mw) 6.1 on 30th September 1993, Jabalpur earthquake occurred on 22nd May 1997 with a moment magnitude of (Mw) 5.8 and earthquake occurred at Bhuj on 26th January 2001, with a moment magnitude of (Mw) 7.7, shows the need of the study for Indian cities. Many researches regarding the vulnerability assessment were done all over the world. Andreas J. Kappos et al [1] has developed the fragility curves based on peak ground acceleration for the Greece city. They made use of a hybrid approach which leads to more efficient way of finding the fragility curves. Iman Mansouri et al [5] has plotted fragility curves for steel and RC moment resisting frame for the damage assessments in terms of PGA based on HAZUS. Recent studies did by few researchers F. Ibarra et al [4], C. B. Haselton [3], A. B. Liel [6], F. Zareian [8] found that the log-normal distribution to provide good results for illustrating the collapse capacity data. G. M. Calvi et al [2] suggested several methods for the fragility analysis of structures: empirical, analytical, and hybrid methods. Rossetto and Elnashai [7] made use of the empirical method by using data gathered on structures damaged during past earthquakes. ATC-63 project [10] has reported extensive literature reviews of analytical methods available to evaluate the capacity of structures to withstand seismic collapse. Since very few works has been done in India, there is a need for this study. This paper shows for Indian standard conditions how the performance and damage stage of the structure has been found by the non-linear static pushover analysis using SAP2000 and the seismic vulnerability was assessed by developing the fragility curves using HAZUS [13] methodology which was proposed by FEMA.

II. TYPE OF BUILDING

The building considered for the study was categorized as mid-rise building (G+ 5 storey). The plan area of the building was 18 X 18 m (fig 1). The building was designed based on IS: 456-2000. The seismic parameters such as the fundamental time period (T_a), importance factor (I) of 1.5, response reduction factor (R) of 5 and seismic zone factor (R) of 0.16g and 0.36g were considered based on IS: 1893-2016. The demand response spectrum curve considered for the study was based on the fundamental time period (T_a = 0.075*h^0.75) and the soil condition. Medium soil (Type-B) condition was used for the above calculation.

The story height of the building was 4.00 m . The size of beams of 400 x 600 mm and columns of 500 x 500 mm were used for the analysis. The slab thickness was taken as 120mm, along with wall load on the outer periphery of the building. Live load of 2 kN/m^2, roof live load of 1.5 kN/m^2, floor finish of 1.5 kN/m^2 and water proof load at the roof of 1 kN/m^2 were considered. The ground support condition was assigned as rigid/fixed condition. The reinforcement details of beams and columns were shown in fig 2.

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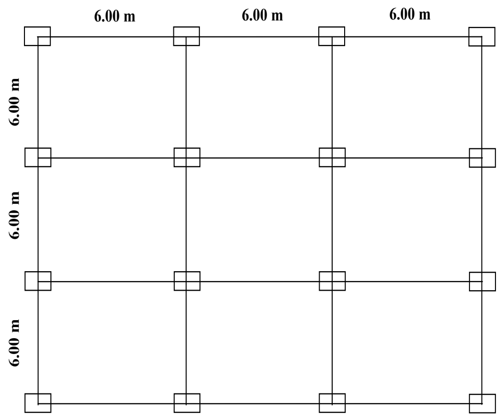

Fig. 1. Typical plan view

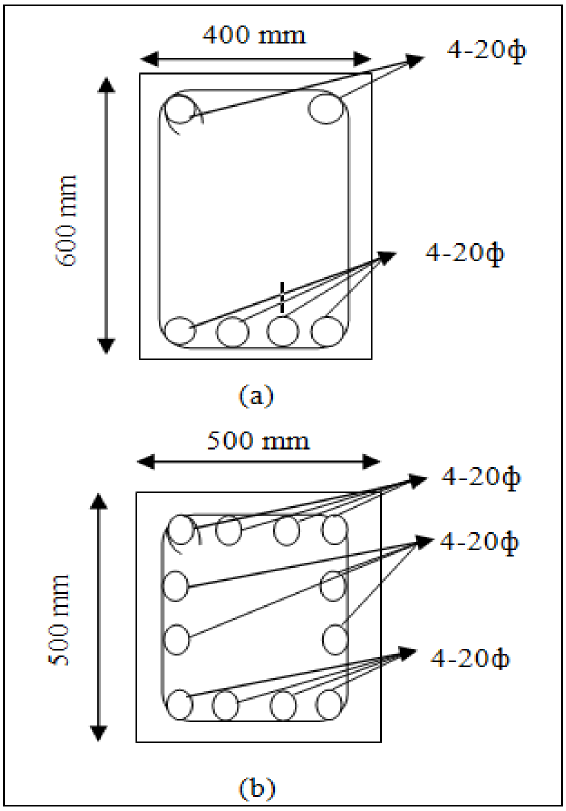

Fig. 2. Reinforcement details of (a) beam and (b) column

III. ASSESSMENT OF DAMAGE STAGE USING PUSHOVER ANALYSIS

A. Modelling and Analysis using SAP2000

The static pushover analysis was done using the SAP2000. The RC frame structure was modelled without infill walls. Initially the linear static analysis was done with dead and live to find the initial stiffness of the structure that was used later in non-linear analysis. The modal participation factor was found to check the ratio of mass participation. In order to proceed for inelastic analysis, the non-linearity of the structure was created by assigning the hinges based on the FEMA-356/ ASCE 41-13. The beam elements were assigned to M2 & M3 hinges, whereas for columns it was P-M2-M3 hinges. The plastic rotation limit for beams and columns for the three performance limits like Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) under flexure were taken from ATC-40 & ASCE 41-13 for nonlinear analysis.

B. Capacity curve, Performance point and Spectral displacement

The linear elastic response spectrum curve based on IS:1893-2016 was used to find the capacity of the structure. Initially as per zone factor the maximum peak ground acceleration of 0.16g was taken for the analysis. Henry V Burton et al (2017) considered the median spectral acceleration of 0.36g and 0.79g for the magnitude intensity of 6 and 7 earthquakes respectively for Noida region. Hence for the performance evaluation of the building the analysis was done for 0.36g. The demand response spectrum for the analysis was taken from IS:1893-2016 based on soil and time period of the structure. FEMA 440 is the improved version of static non-linear analysis provided by ATC-55. FEMA-440 has two methods namely Displacement Modification (DM) method and Equivalent Linearization (EL) method which are based on the displacement method and capacity spectrum method respectively. In this study FEMA-440 EL method has been used, which has a target displacement that can be fixed in the analysis to check the performance of the structure. In this study the maximum roof displacement of 4 percent (based on IS:1893-2016) of the storey height.

The site coefficient factors Ca & Cv were found based on ATC-40. The soil profile type was S_D (medium/stiff soil as per IS:1893-2016 type B). The shaking intensity considered was 0.16g & 0.36g which shows medium and high seismicity. The Ca & Cv values shown in table-I.

Table- I: Ca & Cv values used for demand spectrum

Site coefficient parameters	**PGA=0.16g**	**PGA=0.36 g**
Ca	**0.22**	**0.36**
Cv	**0.32**	**0.54**

The pushover curve was plotted between the base shear and the roof displacement for 0.16g and 0.36g (fig 3). The capacity and the demand curve of the building was plotted separately and the intersection point of both the curves gives the performance point of the building (fig 4). The corresponding spectral displacement at that point was noted.. The ductility capacity (μ_c) ratio of 6.11, the yield displacement (ΔY) of 56mm and ultimate displacement (Δu) 342.656 & 334.652 mm for 0.36g & 0.16g respectively, which were found from the bilinear curve which was plotted by equal area method given by ATC-40. FEMA-356 and ATC-40 provide guidance on the performance of the structures such as Immediate Occupancy (IO), Life Safety (LS) and Collapsed Prevention (CP) which were based on the formation of hinges at the performance point. For each building the performance level was found, which was shown in fig 4.

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Table- II: Modal properties

Mode	Time period (sec)	Modal mass participation ratio (%)
1st	1.211	73.330
2nd	1.200	9.815

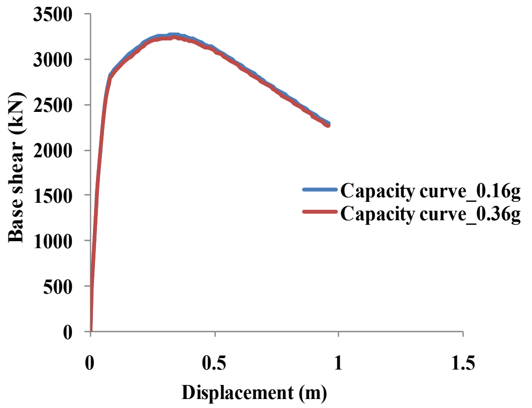
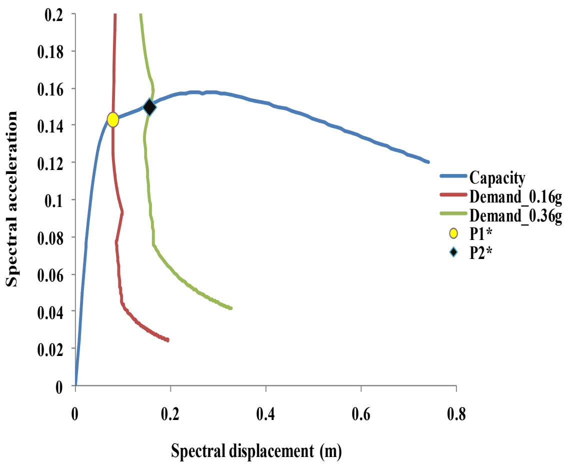


Fig. 3. Pushover capacity curve



*** Performance point at 0.16g & 0.36g respectively**

Fig. 4. Performance point by FEMA-440 EL method

Table- III: Pushover parameters of medium rise building (G+5) based on FEMA-440

S. No	Parameter	PGA=0.16g	PGA=0.36g
		EL method	*EL method*
1	Performance point (kN)	2882.685	3080.832
2	Roof displacement (mm)	95.806	184.563
3	Spectral acceleration (g)	0.143	0.150
4	Spectral displacement (mm)	79.397	156.113
5	Demand ductility	2.152	3.891

IV. DEVELOPMENT OF FRAGILITY CURVES & RESULTS

A. HAZUS methodology

HAZUS is one of the technical tools that provide the basic methodology to find the vulnerability by developing the fragility curves based on Peak Ground Acceleration (PGA), Spectral Displacement (S_d) and Peak Gorund Deformation (PGD). In this study, the fragility curve was found in terms of S_d, which was calculated by pushover analysis. The building was classified based on the height and the type of structure such as a steel moment frame, concrete moment frame etc (ref: Hazus-MR4 technical manual*)* and the label was given. For this study the concrete moment frame was considered and the Hazus indicates the label of medium rise as C1M. There are different level of seismic code design level such as low code, moderate code, high code and pre code. Each code can be selected based on the structure considered for the study. In this study moderate seismic design level code was considered.

$$P(d_s / S_d) = \phi\left(\frac{1}{\beta d_s} \ln\left({S_d}/{S_{d,ds}} \right)\right) \qquad (1)$$

Where,

S_d - the spectral displacement defining the threshold of a particular damage state.

$S_{d,ds}$ - median value of spectral displacement at which the building reaches the threshold of damage states, can be calculated by various damage state models.

βds - standard deviation of natural logarithm of spectral displacement for damage state (ds).

ϕ - standard normal cumulative distribution function.

The damage state of the building as per HAZUS has been classified as slight, moderate, extensive and complete. The fragility curves indicates the probability of exceedance of the different damage state for the considered PGA in terms of S_d. The discrete and cumulative probability exceedance was found that shows the extent of the damage state (Table-VI & VII).

B. Parameters evaluation for fragility curves

The total variability of each damage state was given by standard deviation (βds) which can be found by the CONV process of demand spectrum (β_d) and capacity spectrum variability (β_C). The corresponding values of β_d, β_C and β_{Tds} were taken from the tables provided in HAZUS- MH MR4 technical manual.

$$\beta d_s = \sqrt{CONV(\beta_c, \beta_d)^2 + (\beta_{Tds})^2} \qquad (2)$$

In other way, the βds values can be taken directly from the tables given in HAZUS-MR4 technical manual based on the respective design level and type of building. Here for moderate code seismic design level was considered and the β_{ds} value was found (table-IV).

Table- IV: Total variability of damage state (β_{ds}) for moderate code seismic design level

Type of building	Damage state			
	Slight	*Medium*	*Extreme*	*Collpase*
Medium rise (C1M)	0.70	0.70	0.70	0.89

The median value of spectral displacement ($S_{d,ds}$) can be found using three methods proposed by various authors

Giovinazzi et al (2005), Barbat et al (2006) and Kappos et al (2006). In this study the method proposed by Barbat et al (2006) was used (table-V). The yield displacement (S_{dy}) and ultimate displacement (S_{du}) was found from the bilinear curve.

Table- V: Median threshold value of spectral displacement ($S_{d,ds}$)

Damage state	Threshold value of spectral displacement
Slight	0.7 S_{dy}
Moderate	1.0 S_{dy}
Extreme	S_{dy} + 0.25 (S_{du} - S_{dy})
Complete	S_{du}

The graphical representation of discrete damage probability for 0.16g and 0.36g were shown in fig 5 & 6. The probability of exceedance of different damage state was found (table-VI), by substituting the spectral displacement value (S_d) which was found by pushover analysis (Table-III) in equation (1). The fragility curve was plotted between cumulative damage probabilities and spectral displacement (fig 7).

Table- VI: Cumulative damage probability of exceedance

Damage state	Probability of exceedance of damage state (%)	
	PGA=0.16g	*PGA=0.36g*
Slight	84.35	97.85
Moderate	69.11	92.86
Extreme	24.88	61.31
Collapse	5.02	18.85

Table- VII: Discrete damage **probability**

PGA	Slight	Moderate	Extreme	Collapse
0.16g	0.152	0.435	0.203	0.053
0.36g	0.047	0.315	0.425	0.189

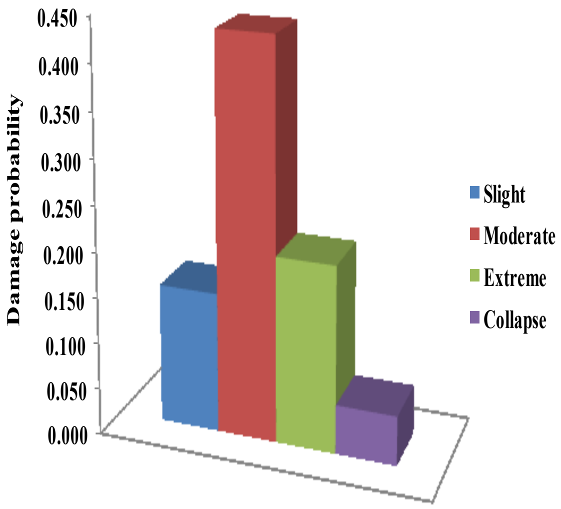


Fig. 5. Discrete damage probability at 0.16g

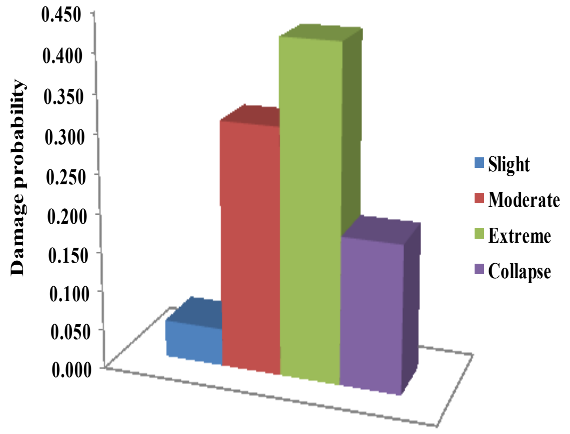


Fig. 6. Discrete damage probability at 0.36g

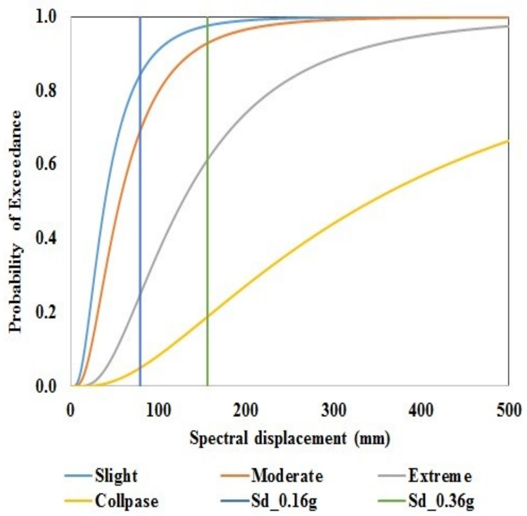


Fig. 7. Fragility curve based on S_d

V. CONCLUSION

The improved version of static non-linear analysis was used to find the performance of the structure in terms of spectral displacement and hinge formation level. For vulnerability assessment, the discrete and cumulative probability of exceedance of each damage state was evaluated using HAZUS methodology.

1) At the performance point, the hinging pattern at 0.16g and 0.36g are quite similar, where the yielding initially starts at the beams of lower storey and slowly it reaches the upper storey with significant yielding at the intermediate levels. The beams at the top floor remains in the IO level, where as the lower stories starts to reach LS level and hence it shows it has adequate ductility as it is in the can bring back to the operational level.

2) From the discrete damage probability at 0.16g the building has most vulnerability towards the moderate damage state, where as at 0.36g the moderate and extreme damage states are very close together.

3) For the spectral displacement values at 0.16g and 0.36g the expected probability of complete damage from the fragility was 24.88% and 61.31%, where as the extreme

4) damage was of 5% and 18.85%. It shows that structure has been prevented against complete damage.

The replacement of the building can be identified using the failure criteria of the RC members in the structures. If 50% of the column has hinge formation more than IO level the failure was assumed to be occurred. Hence based on the occupancy level and damage state found by hinge formation mechanism, the design engineer can decide whether the building can be repaired by retrofitting.

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