Performance Evaluation of Reinforced Concrete Building for Seismic Loading

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***Abstract*:- Many buildings are constructed before new requirements of seismic demands and some buildings are not designed for seismic demands. Therefore, performance evaluation of existing reinforced concrete building becomes important to ensure safety of the building. The present study is to evaluate the performance of existing reinforced concrete building during seismic events. A four storyed building earlier designed for zone-2 of IS1893 and requirement of same is changed to zone 3 of IS 1893 is considered for the analysis and software used for analysis is SAP 2000. Non-linear static analysis (Pushover analysis) is carried out to evaluate the performance characteristics of the building. The output of the analysis is roof displacement vs Base shear and Demand spectrum vs capacity spectrum. Demand spectrum and capacity spectrum are compared and found Capacity is more than the Demand. The performance of four storyed building is evaluated for the seismic demand corresponding to Zone-3 of IS 1893 and found that the building meets the performance requirements.**

Keywords: Performance evaluation, Non-linear Static analysis, Pushover analysis, SAP2000.

I. INTRODUCTION

Seismic zoning map of India depends on the geology and the seismic activity in the country. Therefore, it is subjected to change based on the seismic activity and more understanding on geology. Buildings that are designed with old seismic requirements (based on old seismic zones) need to be evaluated for the new requirements. In this study performance evaluation of the building is carried out using Capacity spectrum method (CSM) prescribed in ATC-40 by using nonlinear static analysis. Displacement controlled Nonlinear static analysis is used to evaluate the performance of the building. Analysis is carried out using SAP 2000 software. A G+3 storey building with plan dimension of 36m x 16m and 12m height is considered for the analysis. First the building design is carried out using Response spectrum corresponding to zone-II of IS1893 and arrived at the reinforcement and cross-sectional details. Then, performance evaluation is carried out for zone-III of IS1893. In this study, performance evaluation of the existing building is studied by the nonlinear static analysis and compared with the performance objectives laid out in ATC-40 and ASCE 41-17.

II. LITERATURE REVIEW

Mohd.Zameeruddin [5] (2020) published a paper in which performance based seismic assessment of reinforced concrete moment resisting is carried out. Fifteen moment resisting frames of different configuration designed following Indian seismic guidelines were subjected to different load patterns. Displacement controlled nonlinear static pushover analysis is performed on moment resisting frames by using SAP 2000 V17.0 software. Beam and column elements were modelled as nonlinear frame elements by assigning M3 and P-M3 plastic hinges respectively. The result of pushover analysis is presented in the form of capacity cure. The study attempted to assess seismic performance of moment resisting frames subjected to different lateral load patterns using pushover analysis.

MAP Handna [6] (2018) published a paper in which performance evaluation of existing building is carried out using pushover analysis. The author conducted a study of seismic building performance evaluation with a pushover analysis using SAP2000. In this study, Wari Medan 3 storey building becomes research object of the writer. The intent of the study is structure is still safe or insecure against workloads and performance of the building when earthquake occurs. The performance of the building is expressed in the form of plan displacement calculated based on guidance of FEMA 356 and Performance point calculated based on ATC-40 guideline. Result indicates that the building under review meets the performance limit of immediate occupancy (IO), then in the case of earthquake the building does not suffer structural and non-structural damage.

Mayank Desai [7] (2015) published a paper in which nonlinear static pushover procedure to the displacement-based approach of seismic analysis of G+10 storey building structure for Indian terrain is studied. The model used is G+10 storey symmetric RCC frame with plan dimension of 7.5m x 7.5m and software used for modeling and analysis is SAP2000. Various loads as per IS code have been applied and linear static push loads have been applied in x and y direction. The capacity curve from model is exported to excel sheet and converted into

acceleration deformation response spectrum (ADRS) and demand curve as per specification is also converted into ADRS format. Both Capacity and demand curve are superimposed to obtain performance point. The point where capacity and demand curves intersect is known as performance point. The plastic hinges formed at the performance point were obtained and the building was found to be safe.

III. OBJECTIVE

The main objective of this project is

1. To perform nonlinear static analysis (Pushover Analysis) on existing building using SAP2000 software
2. To access whether the existing building meets the performance criteria.

IV. METHODOLOGY

For this study, an existing building having G+3 stories with plan dimension 36m x 16m and height 15m above ground level. To replicate the existing building in zone-II, the building is first modelled, analysed and designed for dead load, Live load and Response spectrum corresponding to zone-II and arrived at the cross section and reinforcement. Mander confined model was used for concrete models to obtain moment curvature relationship. In Load application control for nonlinear static Analysis, displacement control is selected and Hinges are assigned to the beam and column elements. Demand spectra (corresponding to zone-III) is converted into acceleration displacement response spectrum (ADRS) and nonlinear static analysis is performed. Capacity Spectrum Method (CSM) as per ATC-40 is considered for performance evaluation. The capacity spectrum is overlapped on demand spectrum to determine the performance point. Finally, the performance evaluation of the structure is carried out to access whether the building meets the performance requirements.

V. MODELLING AND ANALYSIS

Building with G+3 stories with plan dimension 36m x 16m, height 15m above ground and 3m below ground is modelled using SAP2000 software. The center-to-center distance of column along x-direction is 6m and along y direction is 4m. Floor to floor height is considered as 3m. At foundation level (bottom of column) boundary condition is considered as all degrees of freedom restrained (Fixed).

5.1 Basic details of existing structure

Table 1 - Basic details of existing structure

S.No	PARAMETERS	SPECIFICATION
1	Plan dimension	36m x 16m
2	Height of Building	15m
3	Height of each storey	3m
4	Grade of Concrete	M30
5	Grade of Reinforcement	FE500
6	Column dimension	0.475m x 0.475m
7	Beam dimension	0.3m x 0.6m
8	Slab Thickness	0.25m

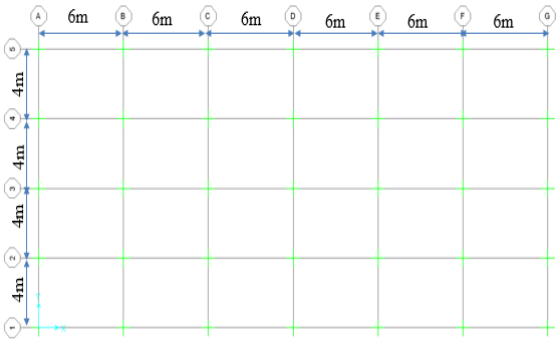

Fig.1. Plan

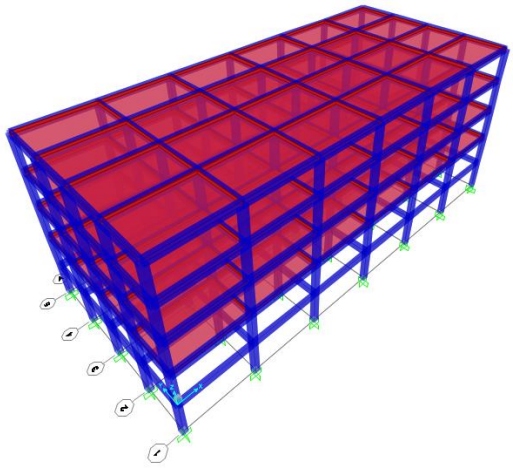

Fig.2. 3D Model

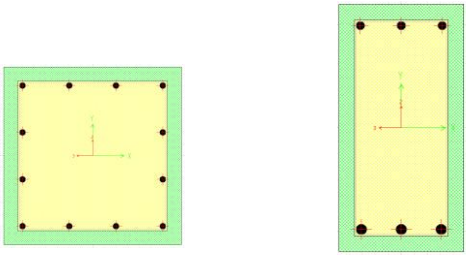

Fig.3. Column and Beam details

5.2 Load cases

Table 2 – Load Cases

S.No	PARAMETERS	SPECIFICATION
1	Dead load (DL)	Self-weight + Floor finish 50mm
2	Live Load (LL)	1.5 kN/m^2
3	Eqx	Horizontal along x
4	Eqy	Horizontal along y
5	Eqz	Vertical along z (2/3rd of Horizontal)

Earthquake loads Eqx, Eqy and Eqz Response spectrum corresponding to zone-II with medium soil site. Importance factor and response reduction factor is considered as 1.5 and 5 respectively.

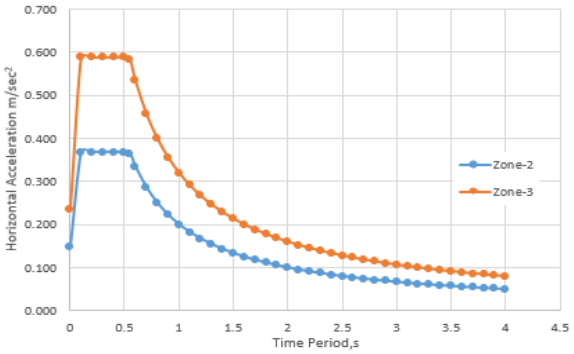

Fig.4. Horizontal Response spectrum

5.3 Free Vibration Analysis

Free vibration analysis is carried out to determine the dynamic characteristics in the form of natural frequencies and mode shape. The mass source for free vibration analysis is considered as dead load plus 0.25 times the live load (live load less than 3 kN/m2).

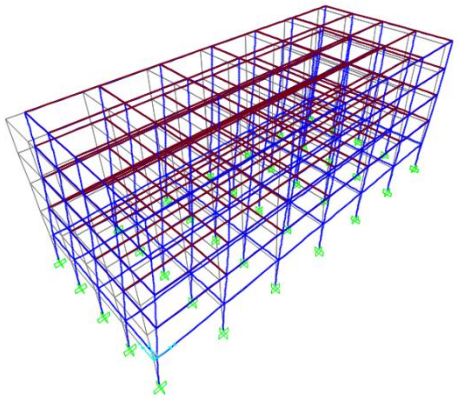

Fig.5. First Mode Shape

5.4 Response spectrum Analysis

Response spectrum analysis is performed to estimate the structural response. Each modal response is combined by Complete Quadratic Combination (CQC) method. Missing mass correction is carried out to account the non-participated mass and same is combined by Square Root of Sum of Squares (SRSS) method.

5.5 Load Combinations

Table 3 – Load Combinations

S.No	LOAD COMBINATIONS
1	1.5 DL + 1.5 LL
2	1.2 [DL + LL ± (Eqx ± 0.3Eqy ± 0.3 Eqz)]
3	1.2 [DL + LL ± (Eqy ± 0.3Eqx ± 0.3 Eqz)]
4	1.2 [DL + LL ± (Eqz ± 0.3Eqx ± 0.3 Eqy)]
5	1.5 [DL ± (Eqx ± 0.3Eqy ± 0.3 Eqz)]
6	1.5 [DL ± (Eqy ± 0.3Eqx ± 0.3 Eqz)]
7	1.5 [DL ± (Eqz ± 0.3Eqx ± 0.3 Eqy)]
8	0.9 DL ± 1.5(Eqx ± 0.3Eqy ± 0.3 Eqz)
9	0.9 DL ± 1.5(Eqy ± 0.3Eqx ± 0.3 Eqz)
10	0.9 DL ± 1.5(Eqz ± 0.3Eqx ± 0.3 Eqy)

VI. DESIGN

After analysis and load combination, design is carried out as per IS 456-2000 using SAP2000 software. Assumed sections are checked and if does not meet the design requirements sections and reinforcement are revised. If the section provided is more then, the section and reinforcement is optimized.

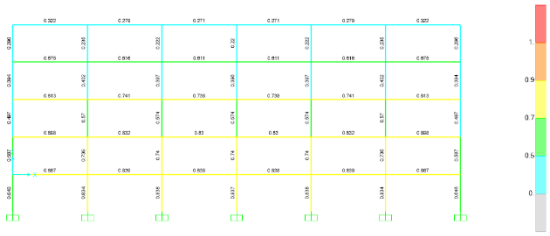

Fig.6. P-M interaction results

VII. PERFORMANCE EVALUATION

7.1 Pushover load definition

After the design is completed, model is unlocked and in load case pushover load case is defined in x and y direction. Dead load case is modified as nonlinear and set to run as initial condition for nonlinear analysis. Push-x and push-y is continued from state of end of nonlinear dead load case. Scale factor is set as -1 to get displacement values in positive in displacement vs Base shear curve. Load application control is selected as Displacement control and top corner node of the building is set as monitored displacement point.

7.2 Assigning Plastic Hinge

Various options are available in SAP2000 software for defining and assigning hinges. In this study default hinges is used and hinge type is considered as ASCE 41-13. Relative distance for hinges along the span was specified as 0.05 and 0,95. For beam element M3 hinges are applied and for column element P-M2-M3 hinges are applied.

For analyzing and optimizing the results the following interpretations were considered: i) Main effects plot and response table, ii) Analysis of Variance (ANOVA table), iii) Regression equation. Statistical software used is MINITAB 16 which was widely used by many researchers.

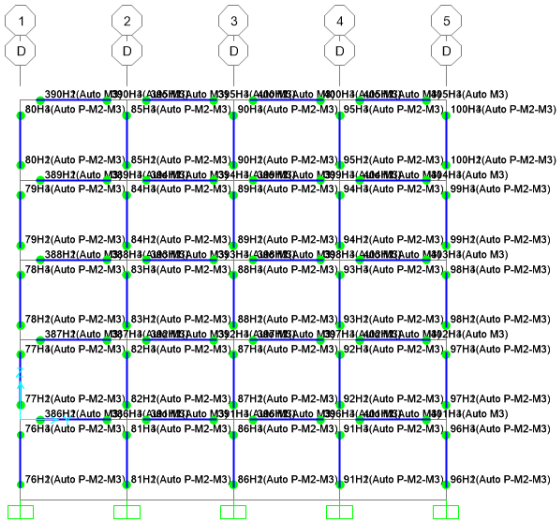

Fig.7. Model Hinge details

7.2 Demand Spectrum

Demand spectrum for this study is Response spectrum corresponding to zone-III of IS1893. Capacity spectrum will be in ADRS format as specified in ATC-40. IS1893 and ATC-40 response spectrum is compared to obtain the demand ADRS plot.

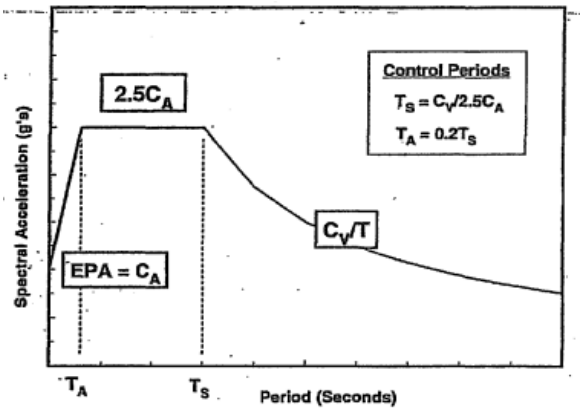

Fig.8. ATC-40 Response spectrum

By comparing IS1893 (Part-I):2016 Response spectrum and ATC-40 spectrum we get (8)

Ca = z/2
Cv = 1.36*(z/2)

Demand curve in ADRS format can be obtained by inputting Ca and Cv coefficients in SAP2000 software or ADRS format demand curve can be obtained by following relation

Sd = (T2/4π2) *Sag
Where,
Sd = Spectral displacement (m)
Sa = Spectral acceleration (g)
T = Time period (s)

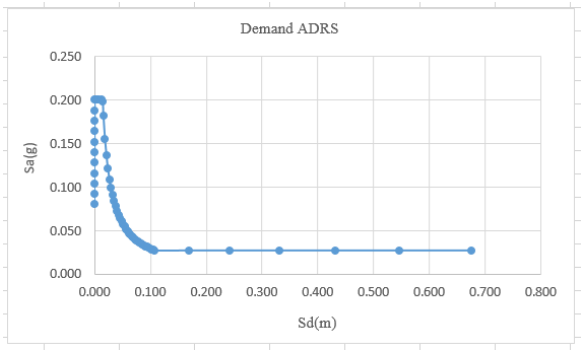

Fig.9. Demand ADRS

VIII. RESULT AND DISCUSSION

After assigning all parameters nonlinear static analysis (pushover analysis) is carried out. Base shear vs monitored displacement is the output of the analysis. Below figures shows the pushover curves obtained for push-x and y.

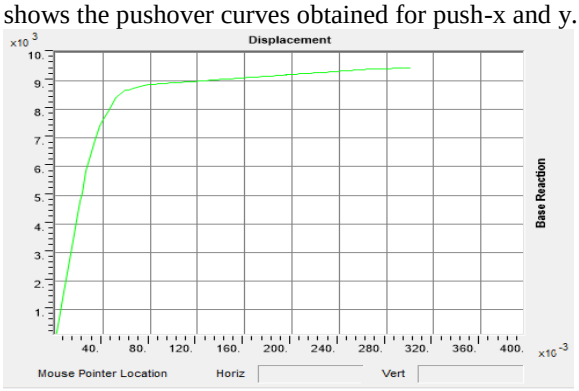

Fig.10. Pushover curve for Push-x

Unit of displacement is m and base shear is kN. For Push-x maximum displacement and Base shear observed is 0.3m and 9444.57kN respectively. For Push-y maximum displacement and Base shear observed is 0.3m and 9104.15kN respectively.

Capacity ADRS curves are obtained from SAP2000 software. Below figures shows capacity ADRS for push-x and y.

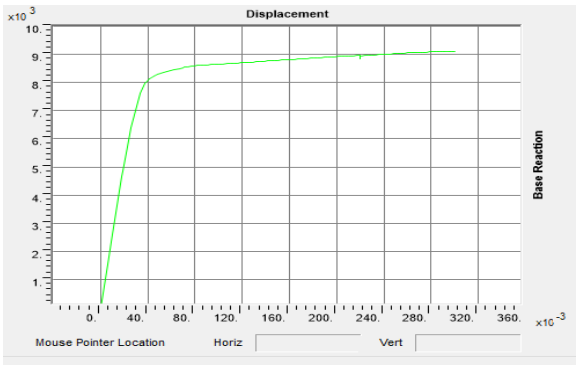

Fig.11. Pushover curve for Push-y

Unit of displacement is m and base shear is kN. For Push-x maximum displacement and Base shear observed is 0.3m and 9444.57kN respectively. For Push-y maximum displacement and Base shear observed is 0.3m and 9104.15kN respectively.

Capacity ADRS curves are obtained from SAP2000 software. Below figures shows capacity ADRS for push-x and y.

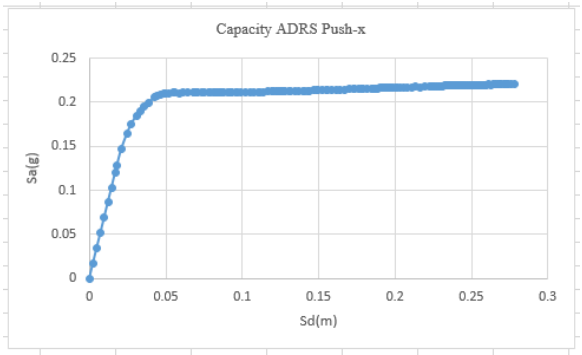

Fig.12. Capacity ADRS for Push-x

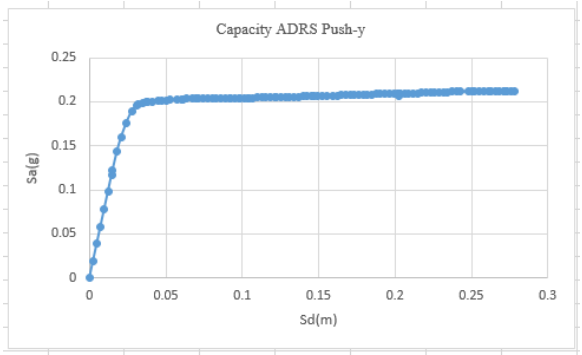

Fig.13. Capacity ADRS for Push-y

Once the capacity and demand ADRS curves are available, both the curves are superimposed to find the performance point. Below figures shows the comparison of ADRS plot for Push-x and y.

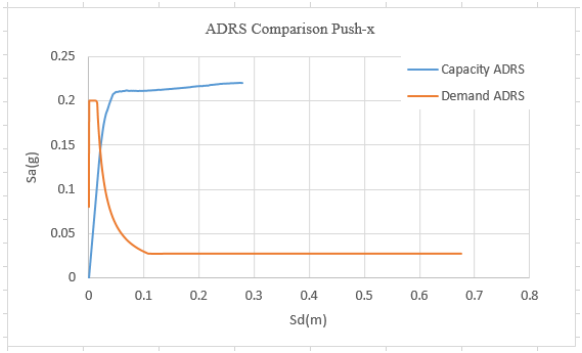

Fig.14. ADRS Comparison Push-x

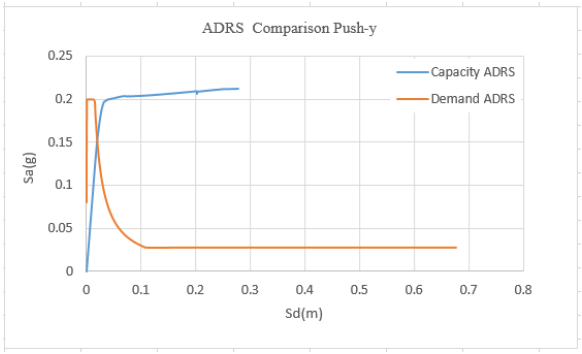

Fig.15. ADRS Comparison Push-Y

From the ADRS comparison it has been observed that the demand curve intersects the capacity curve and thus capacity of structure meets the seismic demand. Intersection point is known as performance point.

At performance point level for push-x acceleration Sa= 0.022m and Sd = 0.136g and similarly for push-y Sa= 0.019m and Sd = 0.155g. The displacement observed in push-x and y at performance point is 0.022m and 0.019m and maximum ratio displacement to height of building is 0.001 which is less than the immediate occupancy limit as per ATC-40.

The below figures shows the hinge states at the final steps of push-x and y

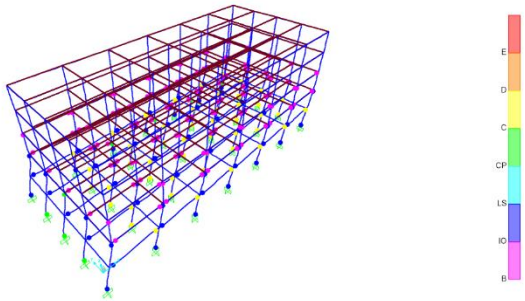

Fig.16. Final state results for Push-x

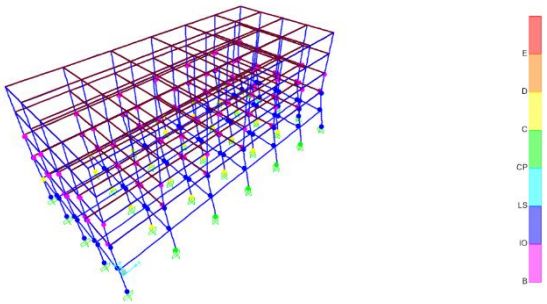

Fig.17. Final state results for Push-y

From the hinge results of push-x and y it is observed that most of the hinges are within the life safety

level and some the hinges are greater than collapse prevention and in the range of C to D indicating that the structure performs overall and distress observed in some of the elements.

IX. SUMMARY AND CONCLUSION

Performance evaluation is carried out for the existing structure designed for zone-II of IS1893 for the demand of zone-III of IS1893 using nonlinear static analysis in SAP2000 software. The observations are presented below

1. From the ADRS comparison it is observed that the capacity of the structure meets the seismic demand.
2. Inter storey drift limit of the building is well within the immediate occupancy limit specified in ATC-40.
3. Hinge results shows that, some of the hinges exceeds the collapse prevention limit and in the range of B and C indicating some of the elements are in distress but globally structure performs.
4. Performance of Elements with distress can be improved by suitable retrofitting techniques.

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