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Seismic Analysis of Performance based Design of Reinforced Concrete Building

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***Abstract*—A performance-based design is aimed at controlling the structural damage based on precise estimations of proper response parameters. Performance-based seismic design explicitly evaluates how a building is likely to perform; given the potential hazard it is likely to experience, considering uncertainties inherent in the quantification of potential hazard and uncertainties in assessment of the actual building response. In the present study the performance based seismic design is performed using a simple computer based pushover analysis technique using SAP2000. The proposed method is illustrated by finding the seismic performance point for a four storey reinforced concrete framed building located in Zone-IV, symmetrical in plan (designed according to IS 456:2000).Two performance levels are considered namely:1) Under Design Basis Earthquake (DBE), damage must be limited to Grade 2 (slight structural damage, moderate nonstructural damage) in order to enable Immediate Occupancy after DBE; 2) Under Maximum Considered Earthquake (MCE), damage must be limited to Grade 3 (moderate structural damage, heavy nonstructural damage) in order to ensure Life Safety after MCE.An extensive parametric study is conducted to investigate the effect of many important parameters on the performance point. The parameters include changing reinforcement of columns, size of columns and beams individually and in different combinations. The results of analysis are compared in terms of base shear, spectral acceleration, spectral displacement and storey displacements.**

***Index Terms*— Performance-based design, Pushover analysis, Design Basis Earthquake, Maximum Considered Earthquake.**

I. INTRODUCTION

Amongst the natural hazards, earthquakes have the potential for causing the greatest damages. Since earthquake forces are random in nature & unpredictable, the engineering tools needs to be sharpened for analyzing structures under the action of these forces. Performance based design is gaining a new dimension in the seismic design philosophy wherein the near field ground motion (usually acceleration) is to be considered. Earthquake loads are to be carefully modeled so as to assess the real behavior of structure with a clear understanding that damage is expected but it should be regulated. In this context pushover analysis which is an iterative procedure shall be looked upon as an alternative for the orthodox analysis procedures. This study focuses on pushover analysis of multistory RC framed buildings subjecting them to monotonically increasing lateral forces with an invariant height wise distribution until the preset performance level (target displacement) is reached. The promise of performance-based seismic engineering (PBSE) is to produce structures with predictable seismic performance. To turn this promise into a reality, a comprehensive and

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well-coordinated effort by professionals from several disciplines is required. This study focuses on pushover analysis of multistory RC framed buildings subjecting them to monotonically increasing lateral forces with an invariant height wise distribution until the preset performance level (target displacement) is reached and finally parametric study is carried out to study the effect of performance level of RCC building under earthquake forces.

II. Modeling Approach

The general finite element package SAP 2000 has been used for the analyses. A 3-D dimensional model of structure has been created to undertake the non -linear analysis. Beams and columns are modeled as nonlinear frame elements with lumped plasticity at the start and the end of each element. SAP 2000 provides default-hinge properties and recommends PMM hinges for columns and M3 hinges for beams as described in FEMA-356.

A. Assumptions

1. The material is homogeneous, isotropic and linearly elastic.
2. All columns supports are considered as fixed at the foundation.
3. Tensile strength of concrete is ignored in sections subjected to bending.
4.The super structure is analyzed independently from foundation and soil medium, on the assumptions that foundations are fixed.
5. The floor acts as diaphragms, which are rigid in the horizontal plane.
7.The maximum target displacement of the structure is kept at 2.5% of the height of the building = (2.5/100) x14= 0.35m = 350mm.

III. Numerical Study

To illustrate the PBD procedure for finding the performance point, a four storey concrete frame as shown in Figure1 is taken as an example. The frame is designed according to IS 456: 2000 (with the superimposed vertical loads) using STAAD Pro. The natural frequencies of the concrete frame is given in Table I. It is seen from the table that the natural frequencies of the frame are quite widely spaced. The mass participating factor in the first mode is approximately equal to 78% which means that the dynamic response will be dominated by the first mode so, only first four modes are considered. The frame is subjected to response spectrum as per IS Code 1893: 2002 for 5% damping. The RC buildings (designed according to IS 456: 2000) using Pushover Analysis and redesigning by changing the main reinforcement of various frame elements and again analyzing. The performance based seismic engineering technique known has Non-Linear Static Pushover analysis procedure has been effectively used in this regard. The pushover analysis has been carried out using SAP2000. The description of the various cases is shown in Table-IX.

A. Pushover analysis using SAP2000

Pushover analysis of the four storey RC framed buildings subjecting them to monotonically increasing lateral forces with an invariant height wise distribution is performed using SAP2000. Table II shows the roof displacement and ductility demand for the frame for different performance levels. As is obvious the roof displacement and ductility demand increases as the performance level goes from operational to collapse prevention level.

B. Effect of change of size of the columns (Case B and Case G)

Table III shows the effect of change of reinforcement in columns on the performance point. It is seen that as the reinforcement increases, the base shear increases and the roof displacement decreases and vice versa.

C. Effect of change of size of the Beams (Case H- Case K)

Table 4 shows the effect of change of size of beams on the performance point. It is seen that as the size increases, the base shear increases and the roof displacement decreases and vice versa.

D. Effect of change of size of the Columns (Case L- Case O)

Table V shows the effect of change of size of columns on the performance point. It is seen that as the size increases, the base shear increases and the roof displacement decreases drastically.

E. Effect of change of size of the Columns and Beams simultaneously (Case P- Case S)

Table VI shows the effect of change of size of columns on the performance point. It is seen that as the size increases, the base shear increases and the roof displacement decreases.

F. Effect of change of Response Reduction Factor (R)

Table VII shows that the performance point is slightly affected by variation of Response Reduction Factor (R).

G. Performance Based Design

Table VIII comparison of target roof displacement and actual displacement observed at operational, immediate-occupancy, life-safety and collapse-prevention performance levels Performance based design is obtained by increasing the main reinforcement of various frame elements by hit and trail method, so that the building performance level, (after performing Pushover Analysis) lies in Immediate Occupancy level i.e., roof displacement of building is 0.7% of total height of building (98mm). It is seen that the actual roof displacement is less than the target displacement and so the design is safe.

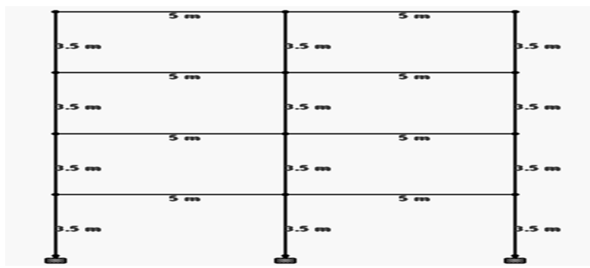

Figure 1: Elevation of four storey two-bay RC frame

TABLE I: NATURAL FREQUENCIES

Mode Shapes	Period(sec)	Frequency (cycle/sec)
1	0.58738	1.7024
2	0.18571	5.3847
3	0.10453	9.5661

TABLE II: ROOF DISPLACEMENT AND DUCTILITY DEMAND

S.No.	Performance Level	Roof Displacement(mm)	Ductility Demand
1	Operational	21.602	1.000
2	Immediate Occupancy	32.971	1.526
3	Life Safety	85.271	3.947
4	Collapse Prevention	165.426	7.657
5	Complete Collapse	∞	∞

TABLE III: EFFECT OF CHANGE OF REINFORCEMENT IN COLUMNS ON PERFORMANCE POINT

S. No.	Case	Base Shear (KN)	% Change in Base Shear	Roof Displacement (mm)	% Change in Roof Displacement
1	A	134.663		71.00	
2	B	134.722	-0.0468	70.60	0.56
3	C	134.795	-0.0980	70.10	1.27
4	D	135.259	-0.4422	69.92	1.52
5	E	134.659	0.0030	71.50	-0.70
6	F	134.646	0.0126	71.90	-1.27
7	G	134.323	0.2525	72.30	-1.83

TABLE IV: EFFECT OF SIZE OF BEAMS OF THE FRAME ON PERFORMANCE POINT

S. No.	Case	Roof Displacement(m)	% Change in roof displacement	Base Shear (KN)	% Change in Base Shear
1	A	0.071		134.664	
2	H	0.069	2.817	147.353	-9.423
3	I	0.066	7.042	159.494	-18.438
5	J	0.074	-4.225	122.194	9.260
6	K	0.08	-12.676	109.857	18.421

TABLE V: EFFECT OF SIZE OF COLUMNS OF THE FRAME ON PERFORMANCE POINT

S. No.	Case	Roof Displacement (m)	% Change in Roof Displacement	Base Shear (KN)	% Change in Base Shear
1	A	0.071		134.664	
2	L	0.058	18.310	141.791	-5.292
3	M	0.057	19.718	148.504	-10.277
4	N	0.075	-5.634	126.317	6.198
5	O	0.083	-16.901	116.944	13.159

TABLE VI: EFFECT OF SIZE OF BEAMS AND COLUMNS OF THE FRAME ON PERFORMANCE POINT

S.No.	Case	Roof Displacement(m)	% Change in Roof Displacement	Base Shear (KN)	% Change in Base Shear
1	A	0.071		134.664	
2	P	0.054	23.944	155.217	-15.262
3	Q	0.051	28.169	177.278	-31.645
4	R	0.086	-21.127	114.459	15.004
5	S	0.092	-29.577	95.163	29.333

TABLE VII: EFFECT ON PERFORMANCE POINT BY CHANGING THE DIFFERENT VALUES OF R

S. No.	Response reduction factor (R)	Spectral Displacement (Sd)	Spectral Acceleration (Sa)	Base Shear (V)	Roof Displacement (Δ)
1	2.0	0.0589	0.224	134.685	0.0692
2	2.5	0.0589	0.224	134.681	0.0695
3	3.0	0.0590	0.225	134.676	0.0699
4	3.5	0.0591	0.225	134.673	0.0704
5	4.0	0.0591	0.225	134.671	0.0708
6	4.5	0.0592	0.226	134.667	0.0709
7	5.0	0.0593	0.226	134.664	0.0710

TABLE VIII: COMPARISON OF TARGET ROOF DISPLACEMENT AND ACTUAL DISPLACEMENT OBSERVED AT VARIOUS PERFORMANCE LEVELS

S.No.	Performance Level	Target Roof Displacement (% of Height)	Actual Displacement (% of Height)
1	Operational	0.37	0.15
2	Immediate Occupancy	0.70	0.23
3	Life Safety	2.50	0.61
4	Collapse Prevention	5.00	1.18

TABLE IX: DESCRIPTION OF VARIOUS CASES

S.No.	Case	Description Of Cases	S.No.	Case	Description Of Cases
1	A	Basic Structure	11	K	20% Decrease In Beams Size
2	B	10% Increase In Columns Reinforcement	12	L	10% Increase In Columns Size
3	C	20% Increase In Columns Reinforcement	13	M	20% Increase In Columns Size
4	D	30% Increase In Columns Reinforcement	14	N	10% Decrease In Columns Size
5	E	10% Decrease In Columns Reinforcement	15	O	20% Decrease In Columns Size
6	F	20% Decrease In Columns Reinforcement	16	P	10% Increase In Columns & Beams Size
7	G	30% Decrease In Columns Reinforcement	17	Q	20% Increase In Columns & Beams Size
8	H	10% Increase In Beams Size	18	R	10% Decrease In Columns & Beams Size
9	I	20% Increase In Beams Size	19	S	20% Decrease In Columns & Beams Size
10	J	10% Decrease In Beams Size			

IV. CONCLUSIONS

Based on the present study, the following conclusions can be drawn:

1. Pushover analysis provides valuable information for the performance based seismic design of building frame.
2. Ductility demand increases as the frame is pushed towards plastic range and ultimately at ∞ demand the structure collapses due to plastic mechanism.
3. The performance point obtained satisfies the acceptance criteria.
4. The increase in reinforcement of columns results in nominal change in base shear and displacement.
5. As the size increases, the roof displacement decreases whereas base shear increases.
6. As the size decreases, the roof displacement increases whereas base shear decreases.
7. Performance point is slightly affected by variation of Response Reduction Factor (R).

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