Seismic Assessment of Reinforced Concrete Framed Structures

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***Abstract*—** The design and construction of earthquake resistant structures can counter the aspect of the earthquake hazard with effective application of engineering knowledge. Most seismic design codes today include the nonlinear response of a structure implicitly through 'Response reduction factor'(R) by IS 1893 (Part I):2002.This factor allows a designer to use a linear elastic force-based design while accounting for non-linear behavior and deformation limits. Performance based seismic design method which is recent path of seismic assessment, both efficient and effective to avoid future earthquake losses.

In this work, performance based seismic design of buildings by pushover analysis method in four different seismic zones II, III, IV and V studied. For analysis building models of G+12, G+16 and G+20 stories, plan rectangular shaped generated by a computer program SAP 2000(version 19).In this present work attempt is made to study and obtained Response Reduction Factor in different zones II, III, IV and V. Also different parameters like displacement, drift, pushover curves, performance point and plastic hinge mechanism studied.

Keywords*-Static analysis, Moment curvature relationship, Pushover analysis, Response reduction factor (R).*

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I. INTRODUCTION

Earthquake engineering is a sector of civil engineering that deals with the mitigation of earthquake-induced damage on structures and the minimization of loss of life ". During the last forty years this sector has advanced considerably due to the rapid developments of computers and computing, the improved experimental facilities, and the development of new methods of seismic design and assessment of structures. This advancement though has not been enough to resist the catastrophic consequences that earthquakes impose. However, it has led to some improvement of design and assessment procedures with a shift from traditional force-based procedures to displacement-based procedures (Antoniou 2002), as inelastic displacements have been deemed to be more representative of different structural performance levels. The characterization of the various performance levels has led to performance-based earthquake engineering, the most recent path of seismic design and assessment.

This chapter provides a short description of the nature of performance-based earthquake engineering and its goals in seismic assessment. The procedures that are recommended for seismic assessment purposes are briefly described and the theoretical background of the non-linear static pushover analysis method is described.

II. PERFORMANCE- BASED EARTHQUAKE ENGINEERING

It was suggested that performance goals should be defined in order to account for all the three factors, structural damage, loss of life and economic losses. An attempt to define in a clear manner the performance objectives. Structural Engineers Association of California, SEAOC Vision 2000 (1995) and the US National Earthquake Hazard Reduction Program Guidelines NEHRP (1997) recommended a different approach.

Immediate Occupancy: No significant damage has occurred to structure, building may be used for intended purpose, and Nonstructural elements are secure.

Life Safety: Significant damage to structural elements with substantial reduction in stiffness, Nonstructural elements are secured but may not function. Occupancy may be prevented until repairs can be instituted.

Collapse Prevention: Substantial structural and nonstructural damage. Stiffness substantially little margin against collapse. Some falling debris hazards may have occurred.

The NSP procedure normally called Pushover Analysis, POA, is a technique of performance based methodology tool for assessment and design in which a computer model of a structure is subjected to a predetermined lateral load pattern, which approximately represents the relative inertia forces generated at locations of substantial mass. The intensity of the load is increased, i.e. the structure is 'pushed', and the sequence of cracks, yielding, plastic hinge formations, and the load at which failure of the This incremental various structural components occurs is recorded as function of the increasing lateral load. Process continues until a predetermined displacement limit.

Terms involved in pushover analysis

- Capacity - The capacity usually refers to the strength at the yield point of the element on the structure's capacity curve.
- Capacity curve – It is the plot of the total lateral force V, on a structure, against the lateral deflection d, of the roof of the structure. This is often referred to as pushover curve.
- Capacity spectrum – The capacity curve transformed from shear force vs roof displacement (V vs d) co-ordinates into special acceleration vs spectral displacement (Sa vs Sd) co-ordinates called capacity spectrum.
- Demand – It is a representation of the earthquake ground motion or shaking that the building is subjected to. In nonlinear static analysis procedures, demand is represented by an estimation of the displacements or deformations that the structure is expected to undergo
- Performance point – The intersection of capacity spectrum with the appropriate demand spectrum in the capacity method
- Ductility - It is the ability of a structural component, element, or system to undergo both large deformations or several cycles of deformation beyond its yield point or elastic limit and maintain its strength without significant degradation or abrupt failure.
- Ductility demand - It refers to the extent of deformation beyond the elastic limit.

A. Seismic Zones of India

Based on the levels of intensities sustained during damaging past earthquakes, the seismic zone map is revised with only four zones, instead of five. Erstwhile Zone I has been merged to Zone II. Hence, Zone I does not appear in the new zoning; only Zones II, III, IV and V.

B. Response Reduction Factor(R)

Response reduction factor reflecting the capability of the structure to dissipate energy through inelastic behavior. This factor is unique and different for different type of structures and materials used. It is given as

$$R = R_s \times R_\mu \times R_\xi \times R_R$$

Components of Response reduction factors are Strength factor (Rs) is obtained by dividing the maximum / ultimate base shear (Vu) by the design base shear (Vd).

Ductility factor (Rμ) is a measured as ratio of ultimate or maximum base shear to base shear corresponding to yield. It is the capacity to undergo large inelastic deformation without significant loss of strength or stiffness, Rμ depends on time period. $R_\mu = 1$ for zero-period structure, $R_\mu = \sqrt{(2\mu - 1)}$ for short period structure, $R_\mu = \mu$,for long period structure, $R_\mu = 1 + (\mu - 1)$ T/0.7 $(0.7 < T < 0.3)$ .Where $\mu = \Delta u / \Delta y$. i.e the ratio of ultimate displacement and yield displacement.(Paulay and Priestley equation Rμ depends on time period).

Damping factor (Rξ) accounts for the effect of 'added' viscous damping, without devices, the damping factor is generally assigned a value equal to 1.0. Redundancy factor (RR) is measure of redundancy in a lateral load resisting system, depends on the structural system adopted. It is ASCE 7 recommends a redundancy factor RR=1.0

C. Moment Curvature Relationship (M-ϕ) in Pushover Analysis

Moment curvature relationships are very important to find out ductility of the structure and the amount of possible redistribution of stresses.In pushover analysis status of damage is indicated by hinges formed in the frame elements. In order to define hinges, moment curvature relationship is used.Mander et al. (1988) have proposed a unified stress-strain approach for confined concrete that is applicable to both circular and rectilinear transverse reinforcement. The stress-strain curve is based on the equation proposed by Popovics (1973), in which the shape of the descending part of the curve depends upon the secant modulus at the peak point.

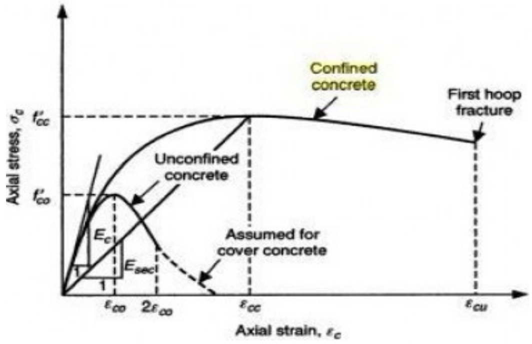

Fig1:stress-strain model for confined and unconfined concrete – Manders (1988) model.

III. OBJECTIVE OF STUDY

1. To verify the designed R factor of most common engineer designed RC buildings and to obtain performance point of the buildings by comparing the assumed R factor during design to actual R factor obtained from non-linear analysis.
2. To calculate strength factor, ductility factor, damping factor, redundancy factor for considered frame in all zones.
3. To find out drift, displacement and base shear results of considered frame in all zones.
4. To compare various analysis results of building under zone II,III,IV and V
5. To obtain capacity curve for each building in both X and Y direction uses capacity spectrum method.
6. To obtain performance point for each building.

IV. PROBLEM STATEMENT

In the present study for seismic performance of 12, 16 and 20 storey reinforced concrete frames with the height 41.5m, 53.9m and 66.3m respectively are designed. In plan, horizontally four bays are at 3.2m and vertically three bays are at 4.8m.and in elevation floor height 3.1m and plinth 1.2m considered shown in Fig 2

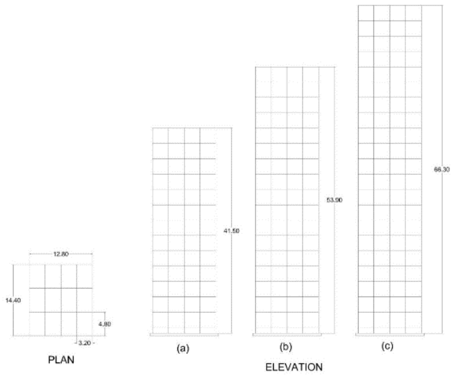

Fig2:Elevation of frames considered

Details of building geometry, material properties and load configurations

Table 1: Building Details

Description	Salient Features			
Parameter	ZONE II	ZONE III	ZONE IV	ZONE V
Seismic zone factor	0.10	0.16	0.24	0.36
Building Shape	Rectangle (plan 12.8 m X 14.4 m)			
Dead load(KN/M2)				
Floor Finish	1.5	1.5	1.5	1.5
Internal wall 150mm thick brick wall	3	3	3	3
External wall 230mm thick brick wall	4	4	4	4
Response reduction factor	5	5	5	5
Importance factor	1	1	1	1
Soil condition	Medium	Medium	Medium	Medium
Live load(KN/M2)				
Residential floor	3	3	3	3
Grade of concrete	M25	M25	M25	M25
Grade of Steel	Fe415	Fe415	Fe415	Fe415

Table 2: Details of beams and columns of buildings

Zone II	Frame	Members	Floors	Width	Depth
0.1	12 Storey	Beam	1-12	250	400
		Column	1-8	250	600
		Column	9-12	250	500
	16 Storey	Beam	1-16	250	400
		Column	1-10	250	700
		Column	11-16	250	600
	20 Storey	Beam	1-20	250	400
		Column	1-5	250	900
		Column	6-12	250	700
		Column	13-20	250	500
Zone III	Frame	Members	Floors	Width	Depth
0.16	12 Storey	Beam	1-12	300	450
		Column	1-8	300	700
		Column	9-12	300	500
	16 Storey	Beam	1-16	300	450
		Column	1-10	300	800
		Column	11-16	300	600
	20 Storey	Beam	1-20	300	450
		Column	1-5	300	1000
		Column	6-12	300	800
		Column	13-20	300	600
Zone IV	Frame	Members	Floors	Width	Depth
0.24	12 Storey	Beam	1-12	300	450
		Column	1-8	300	700
		Column	9-12	300	500
	16 Storey	Beam	1-16	300	450
		Column	1-10	300	800
		Column	11-16	300	600
	20 Storey	Beam	1-20	300	450
		Column	1-5	300	1000
		Column	6-12	300	800
		Column	13-20	300	600
Zone V	Frame	Members	Floors	Width	Depth
0.36	12 Storey	Beam	1-12	350	550
		Column	1-8	350	800
		Column	9-12	350	700
	16 Storey	Beam	1-16	400	550
		Column	1-10	400	1000
		Column	11-16	400	800
	20 Storey	Beam	1-20	400	550
		Column	1-5	400	1200
		Column	6-12	400	1000
		Column	13-20	400	800

V. PROCEDURE USED FOR NONLINEAR ANALYSIS IN SAP 2000(V.19)

1. Created model of considered RC framed 12, 16 and 20 storey in computer program SAP2000 version 19.
2. Define the static load cases, if any, that are needed for use in the static nonlinear analysis.
3. Define hinge properties, if any (Define > Frame Nonlinear Hinge Properties command).
4. Assign hinge properties, if any, to frame/line elements (Assign > Frame/Line > Frame Nonlinear Hinges command).
5. Run the model for basic linear and dynamic analyses. (Analyze > Run Static Nonlinear Analysis command).
6. Define the static nonlinear load cases (Define > Static Nonlinear/Pushover Cases command).
7. Run the static nonlinear analysis (Analyze > Run Static Nonlinear Analysis command).
8. Review the static nonlinear results (Display > Show Static Pushover Curve command), (Display > Show Deformed Shape command), (Display > Show Member Forces/Stress Diagram command), and (File > Print Tables > Analysis Output command).
9. Perform any design checks that utilize static nonlinear cases.
10. Revise the model as necessary and repeat.

VI. RESULT

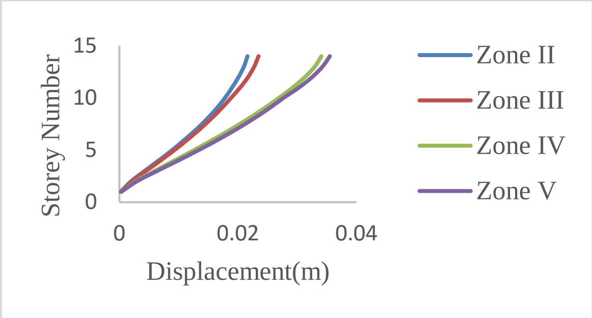

Fig3: EQ-X Displacement graph for 12 storey

Fig 3 shows the variation of displacement with respect to storey number for earthquake case in X direction at roof level of the building. Maximum values of displacement are 0.0216 m, 0.0236 m, 0.0346 m, and 0.03549 m in Zone II, Zone III, Zone IV and Zone V respectively.

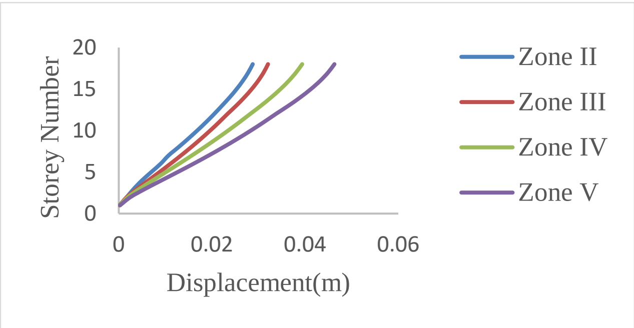

Fig4: EQ-X Displacement graph for 16 storey

Fig4 shows the variation of displacement with respect to storey number for earthquake case in X direction at roof level of the building. Maximum values of displacement are 0.0287 m, 0.0320 m, 0.0393 m and 0.0380 m in Zone II, Zone III, Zone IV and Zone V respectively.

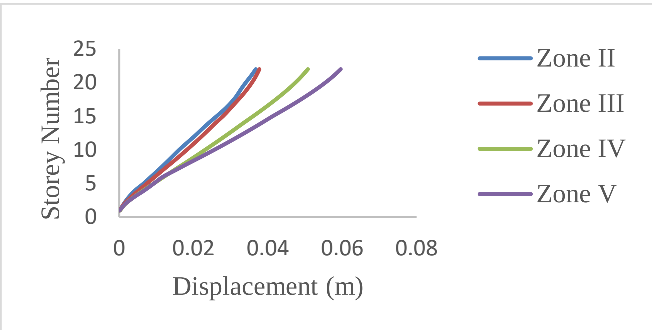

Fig5: EQ-X Displacement graph for 20 storey

Fig 5 shows the variation of displacement with respect to storey number for earthquake case in X direction at roof level of the building. Maximum values of displacement are 0.0367 m, 0.0376 m, 0.050 m and 0.059 in Zone II, Zone III, Zone IV and Zone V respectively

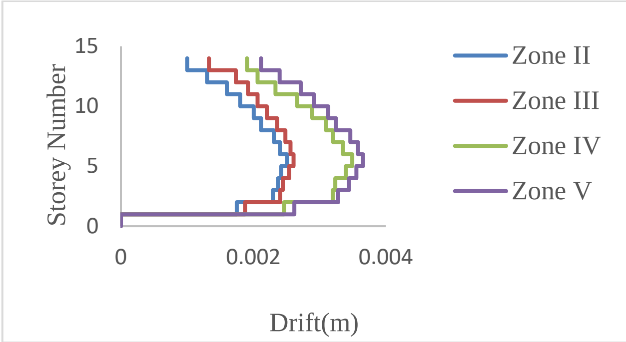

Fig6: EQ-X Drift graph for 12 storey

Fig 6 shows inter storey drift is higher at 5th storey and then decrease till terrace floor. Drift increases Zone II to Zone V.

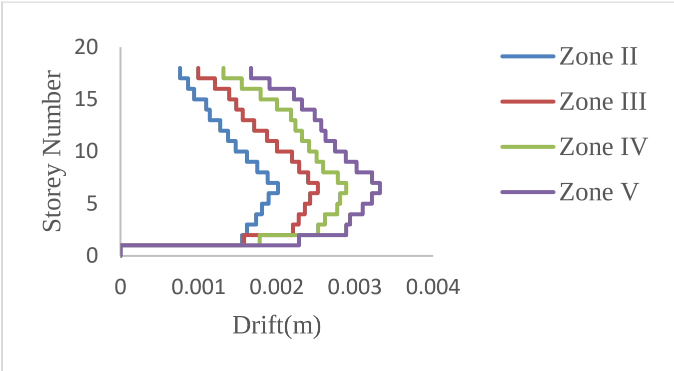

Fig7: EQ-X Drift graph for 16 storey

Fig 7 shows inter storey drift is higher at 6th storey and then decrease till terrace floor. Drift increases Zone II to Zone V.

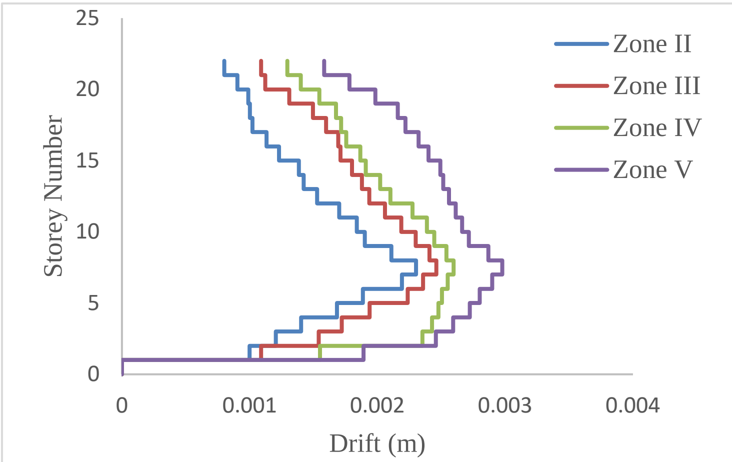

Fig8: EQ-X Drift graph for 20 storey

Fig 8 shows inter storey drift is higher at 7th storey and then decrease till terrace floor. Drift increases Zone II to Zone V.

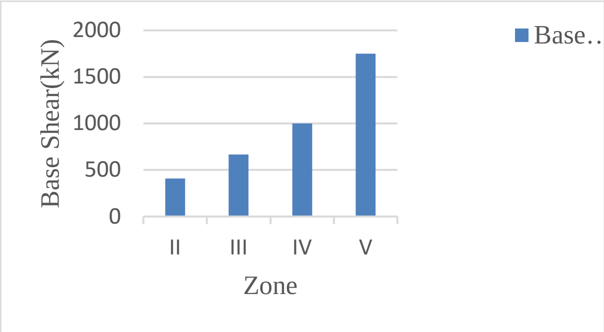

Fig9:Variations of Base Shear Values for different Zones

Fig 9: shows the variation of base shear of G+12 building in Zone II, Zone III, Zone IV and Zone V.

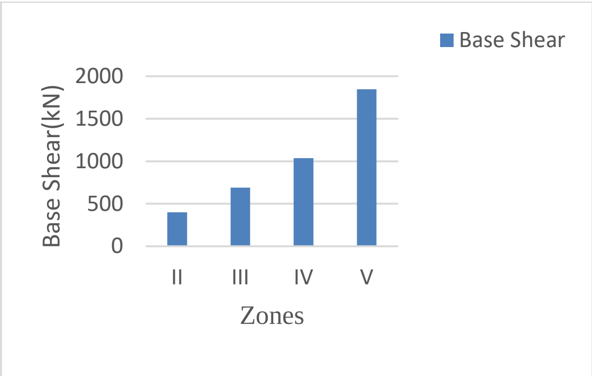

Fig10:Variations of Base Shear Values for different Zones

Fig 10: shows the variation of base shear of G+16 building in Zone II, Zone III, Zone IV and Zone V.

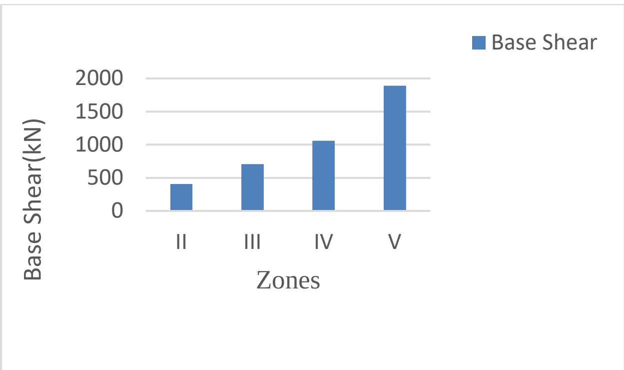

Fig11:Variations of Base Shear Values for different Zones

Fig 11: shows the variation of base shear of G+20 building in Zone II, Zone III, Zone IV and Zone V.

Calculated values of response reduction factor and it's all components for buildings shown in following tables.

Table3 - Results of response reduction factor for 12 storey

12 Storey building	Zone II	Zone III	Zone IV	Zone V
Time period (T) sec	1.043	1.043	1.043	1.043
Sa/g	1.303	1.303	1.303	1.303
Rs	2.624	2.012	2.649	1.039
Rμ	2.86	3.772	3.12	4.882
R_R	1	1	1	1
Rξ	1	1	1	1
R	7.51	7.58	8.26	5.07

Table4 - Results of response reduction factor for 16 storey

16 Storey building	Zone II	Zone III	Zone IV	Zone V
Time period (T) sec	1.355	1.355	1.355	1.355
Sa/g	1.003	1.003	1.003	1.003
Rs	3.18	2.73	2.33	1.10
Rμ	2.83	3.08	3.64	4.92
R_R	1	1	1	1
Rξ	1	1	1	1
R	8.99	8.40	8.49	5.41

Table5 - Results of response reduction factor for 20 storey

20 Storey building	Zone II	Zone III	Zone IV	Zone V
Time period (T) sec	1.67	1.67	1.67	1.67
Sa/g	0.814	0.814	0.814	0.814
Rs	3.87	2.03	2.4	1.07
Rμ	2.73	3.25	3.06	4.68
R_R	1	1	1	1
Rξ	1	1	1	1
R	8.79	6.59	7.34	5.02

VII. CONCLUSION

1. The base shear of structure increases as we go to higher seismic zones. For 12 storey building the base shear of Zone II is 409.9 kN and Zone V is 1749.94 kN. For 16 storey building the base shear of Zone II is 401.14 kN and Zone V is 1846.133 kN and for 20 storey building the base shear of Zone II is 408.91 and Zone V is 1891.54 kN. This means base shear increases by more than 430% if seismic Zone changes from II to V.
2. The Displacement is very high at roof and very low at the base. For 12 storey building the displacement occur at the Zone II is 0.0216m and Zone V is 0.0354 m.For16 storey building the displacement occur at Zone II is 0.0287 and Zone V is 0.0380 and for 20 storey building displacement at Zone II is 0.0367 and Zone V is 0.059.This means displacement of building models increases with the increasing of seismic Zones.
3. The storey drift is mainly occurred at the middle of the building structure. The maximum storey drift is available at 5th, 6th and 7th floor for 12, 16 and 20

storey building respectively. As per result shown in 6.1, 6.2 and 6.3 comparison graph for inter-storey drift in X and Y direction. The drift is increases by more than 40% when compare to Zone II to Zone V, it is concluded that the storey drift increases with the increasing of seismic Zone factor. The maximum storey drift for all buildings is less than 0.4% of the building height, therefore IS 1893 part1-2002 clause no.7.11.1 is satisfied.

4. As the height of the building increases, the time period of the building also increases. For 12 storey building, time period is less than 16 storey and 20 storey buildings. (As per Result shown in Table 3, Table 4 and Table 5).
5. In pushover analysis, the values for the roof displacement and base shear capacity of the structure at the yield and ultimate levels are obtained and various components of the 'R' factor calculated, for estimating base shear, over strength factor, ductility factor and response reduction factor respectively.
6. The response reduction factor is different for all buildings because of variation in, elevation of buildings, different materials properties, variation in strength and ductility of the building etc. (Table 3, Table 4 and Table 5).
7. After performing pushover analysis if performance point is not obtained then to get that by using dampers or isolation, increasing strength or stiffness of the structure.
8. Structure has significant impact of zones on the seismic response of structure in terms of displacement, storey drift, base shear and response reduction factor.

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