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"PERFORMANCE EVALUATION OF RC FRAME STRUCTURE AT VARIOUS SEISMIC CONDITIONS"

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Abstract:
Seismic design studies have gained significant importance globally due to the increasing structural damage observed in earthquake-prone areas. To meet safety objectives, it is essential to thoroughly understand how structures behave during seismic events. In India, after major earthquakes, it has become standard practice to assess the seismic capacity and potential damage of structures.
Structures in seismic regions are highly vulnerable to collapse during strong ground motions. This vulnerability is often due to inadequacies in seismic design guidelines, particularly in the selection of appropriate structural systems. The commonly used equivalent static analysis in seismic design may not fully account for the structure's strength and stiffness. Consequently, ground storey columns may become overly reinforced, which can decrease ductility and negatively impact performance.
This study explores a parametric analysis of RC frame structures designed for various seismic zones. Finite element software was utilized to model the structures and evaluate their performance levels. Pushover analysis was performed to assess the seismic capacity and behavior of the structures across different seismic conditions. The study also examined the impact of varying demand on RC frames to understand their behavior in different seismic regions of the country.

Keywords:
Pushover Analysis, RC Frame Structure, Seismic conditions, seismic capacity

1.0 Introduction:

Earthquake engineering has undergone substantial evolution, continuously advancing with each seismic event. The Bhuj Earthquake highlighted the necessity for structures that prioritize more than just life safety. Traditionally, the emphasis was on ensuring buildings could withstand earthquakes with minimal loss of life. However, the aftermath of such events has shown the significant costs associated with maintaining structures that are life-safe but heavily damaged. Building owners often face operational disruptions, relocation expenses, and the challenges of a competitive reconstruction market. In contrast, investing slightly more in higher-quality designs tailored to specific needs can ensure buildings remain functional even after minor earthquakes while still providing safety during rare, destructive seismic events.
A substantial fraction of India's population lives in high seismic danger zones, and the proportion is growing as cities expand into these areas. The 2001 Bhuj earthquake demonstrated the terrible impact on both lives and the economy when structures fall. There is an urgent demand for structures that can survive the greatest expected earthquakes without collapsing and sustain little to no damage from more frequent seismic occurrences. Designing for seismic activity often considers the earthquake return period, which may differ from the greatest probable event at a given location. Reinforced concrete (RC) structures, constructed according to contemporary building regulations as moment-resisting space frames, shear walls, or combinations thereof, are intended to withstand large earthquake stresses by flexibly deforming into the inelastic region and releasing energy via stable hysteretic behavior. Given that inelastic deformations tend to concentrate in certain important parts of the structure, forecasting its mechanical response during earthquakes requires trustworthy analytical models and a variety of analysis approaches. Accurate analytical methodologies are essential for understanding the structure's behavior.

1.1 METHODS OF ANALYSIS:

There are mainly elastic and inelastic method used for the analysis of RC frame structures. Several elastic analytic techniques are used to assess the force demand on structural elements with respect to their capabilities during earthquakes (Albanesi et al., 2000; Ou et al., 2024). These techniques include the code static lateral force process, code dynamic procedure, and demand/capacity ratio (DCR) procedure. These techniques, together known as force-based processes, operate on the assumption that the structure would respond elastically. Scaled-down lateral forces obtained from elastic response spectra are applied to structures in the code static lateral force technique, assuming larger real strength than design strength. Either response spectrum or time history analysis is included into the code dynamic technique, which employs elastic dynamic analysis (Alimoradi, 2005; Mukherjee and Gupta 2016; Zhou et al., 2023). The DCR process weighs the effects of gravity in addition to comparing force actions to capabilities. Although elastic approaches can estimate structural capacity, they may fail to take force redistribution into account and ignore shortcomings. As a result, displacement-based methods have been created to more precisely evaluate seismic performance by considering seismic demands and capacity. These methods emphasize inelastic deformations and nonlinear analysis (Chintanapakdee and Chopra, 2003; Kalkan and Chopra 2010; Kunnath et al., 1996).

Strong earthquakes cause considerable inelastic deformation in structures, necessitating the use of inelastic analytical tools to accurately estimate performance. To find failure modes and possible progressive collapse, these techniques—such as inelastic time history analysis and inelastic static analysis, or pushover analysis—are crucial (Antoniou et al., 2016; Bracci et al., 1997; Clough and Johsnton 1996; Goel and Chopra 2004; Gupta 2001; Habibulla A. and Pyle S., 1998; Jain et al., 1994). The most accurate technique is inelastic time history analysis, but it depends on the ground motion characteristics and modeling accuracy, thus it requires a variety of ground motion recordings and a correct representation of cyclic load deformation. However, its high computational demands often make it impractical for seismic performance evaluation. Conversely, inelastic static analysis, such as pushover analysis, is favoured for its simplicity and ability to directly incorporate nonlinear material behavior. Techniques like the Capacity Spectrum Method, Displacement Coefficient Method, and Secant Method are commonly employed in these inelastic static analysis procedures (Fajfar and Fischinger, 1989).

In the present study, an attempt has been made to evaluate structural performance through systematic pushover analysis implementation. Further, capacity curve, representing the relationship between base shear and roof displacement has been also determined. Based on the analysis results, critical points on the capacity curve, such as yield point, ultimate strength, and maximum displacement has been identified for the eight-story reinforced concrete (RC) frame structure.

In this study, eight-story reinforced concrete (RC) frame structure was modelled covering aspects such as fundamental assumptions, and building geometry. When modeling a structure, it involves assembling its load-bearing components to accurately capture mass distribution, strength, stiffness, and deformability. Ensuring the model aligns with the material properties and structural elements under scrutiny is paramount for a comprehensive analysis. The ongoing study emphasizes the meticulous modeling of material properties and structural elements, reflecting careful consideration of attributes such as material strength, stiffness, and deformability. This approach aims to create a robust and reliable representation of the structure for analysis purposes. All frame models utilized in this study are made of concrete grade M-30 and reinforcing steel grade Fe-415. These materials' elastic material characteristics are calculated using the Indian Standard IS 456 (2000).

2.1 Structure Geometry:

The study examines plane and orthogonal frames with consistent storey heights and bay widths. The RC frame structure comprises four bays in both directions, with each storey having a height of 3 meters. As illustrated in Figure 3.3, the regular frame is analyzed using SAP-2000 software. The gravity loads on the floor are assumed to be 8 kN/m² (including dead and live loads). The column sections are designed to meet both strength and stiffness requirements. Diaphragms are provided at all floor levels to account for slab action. The structure models are bare frames with specified loadings to simplify the analysis. All selected models use concrete with a 28-day characteristic compressive strength of 30 N/mm² and reinforcement bars with a yielding strength of 415 N/mm², according to

Indian Standards. The structures are designed for four seismic zones per IS-1893: 2016, with each zone assigned a seismic zone factor indicating the maximum peak ground acceleration during the maximum considered earthquake (MCE). All buildings are assumed to be founded on competent soil type B (medium dense sand or stiff clays). The structural characteristics of the assessment sample are varied to represent common types of RC frame structures.

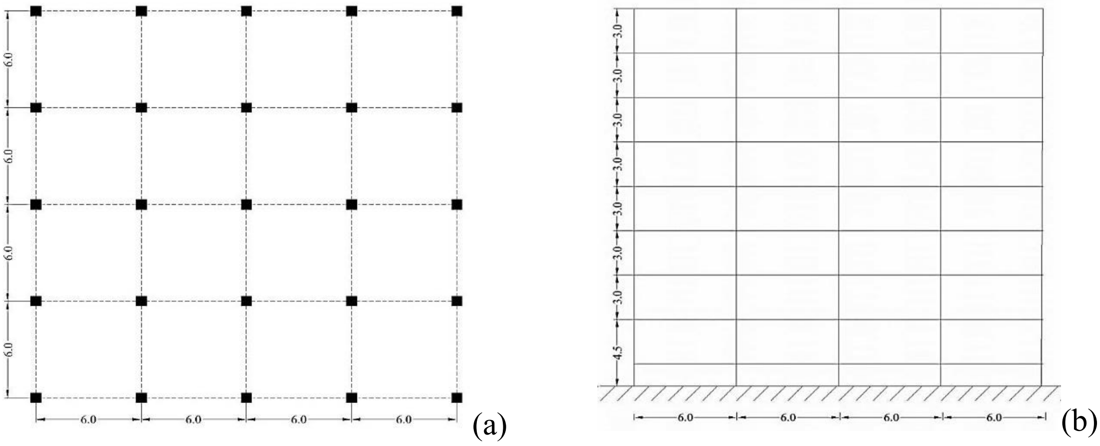

Fig. 1 Plan and elevation of the modelled structure

The plan and elevation of the structures are illustrated in Fig. 1. The cross-sectional dimensions of the beam and column elements for the various structures are detailed in Table 1.

Table 1: ***Sectional details of eight storey RC frame structure at different zones***

Levels	***8S-Z2 & 8S-Z3***			***8S-Z4***		
	EXTERIOR COLUMN (mm × mm)	INTERIOR COLUMN (mm × mm)	BEAMS (mm × mm)	EXTERIOR COLUMN (mm × mm)	INTERIOR COLUMN (mm × mm)	BEAMS (mm × mm)
8	300 × 300	300 × 300	400 × 300	350 × 350	350 × 350	450 × 300
7	350 × 350	350 × 350	400 × 300	400 × 400	400 × 400	450 × 300
6	350 × 350	350 × 350	400 × 300	400 × 400	400 × 400	450 × 300
5	350 × 350	350 × 350	400 × 300	400 × 400	400 × 400	450 × 300
4	450 × 450	450 × 450	400 × 300	450 × 450	450 × 450	450 × 300
3	450 × 450	450 × 450	400 × 300	450 × 450	450 × 450	450 × 300
2	500 × 500	500 × 500	400 × 300	550 × 550	550 × 550	450 × 300
1*	500 × 500	500 × 500	400 × 300	550 × 550	550 × 550	450 × 300

for zone 5 (8S-Z5), the exterior column, interior column, and beam size is considered as 600 × 600, 600 × 600, and 450 × 300 respectively for level 2 and 1.

2.2 Theory and Modelling used in SAP 2000

For performing structural analyses and assessments, computer modeling has emerged as a dependable and efficient technique. Numerical modeling is a popular substitute for expensive laboratory tests in structural research, providing an affordable option. SAP2000, a nonlinear structural analysis program, will be utilized for this study. The research community's non-commercial tool, SAP2000, is essential to the advancement of diaphragm analysis and design techniques. The basic ideas of SAP2000 are highlighted in this paper, along with its importance. Enhancing SAP2000 to capture the nonlinear features of elements—which enable the definition of diaphragm characteristics—will be a crucial component of the project. The significance of SAP2000 in this study is highlighted by its well-established efficacy in the nonlinear seismic analysis of RC frame structures.

2.3 Modeling of Non-linear Plastic Hinges

The nonlinear curve can be roughly represented as a set of linear segments in order to guarantee numerical efficiency and simplify the definition of a monotonic force-displacement (F-D) relationship. A force-displacement (moment-rotation) curve is created for each degree of freedom in order to provide the yield value and the plastic deformation after the yield. Figure 2 shows the five points that define this curve, which is symmetric in both positive and negative directions. The points are A, B, C, D, and E. The curve may be described as follows:

- Point B is the effective yield point, below which the hinge experiences no deformation.
- Point A is the unloaded condition and the curve's origin. Plastic deformation only happens after Point B.
- The strain hardening zone, which is between Points B and C, is distinguished by a slope that represents a little portion (0–10%) of the elastic slope.
- The component's maximum strength is shown at point C, after which strength decline starts.
- The residual strength is represented by point D.
- Point E denotes the component's failure.

2.4 Performance Level and Acceptance Criteria

The structural performance level of a structure should be selected from four discrete levels and two intermediate ranges as defined in FEMA-356 (2000). The discrete performance levels are Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP). The intermediate performance ranges are the Damage Control Range and Limited Safety Range. Acceptance criteria for performance within the Damage Control Range are determined by interpolating the criteria provided for Immediate Occupancy and Life Safety Performance Levels. The descriptions of these Structural Performance Levels, as outlined in FEMA-356 (2000), are detailed in Table 2.

Operational (up to B)
(Negligible Damage) *Very likely*

Immediate Occupancy (IO)
(Light Damage) *Likely*

Life Safety (LS)
(Moderate Damage) *Limited*

Collapse Prevention (CP)
(Severe Damage) *Not practical*

Collapse
(Complete Damage)

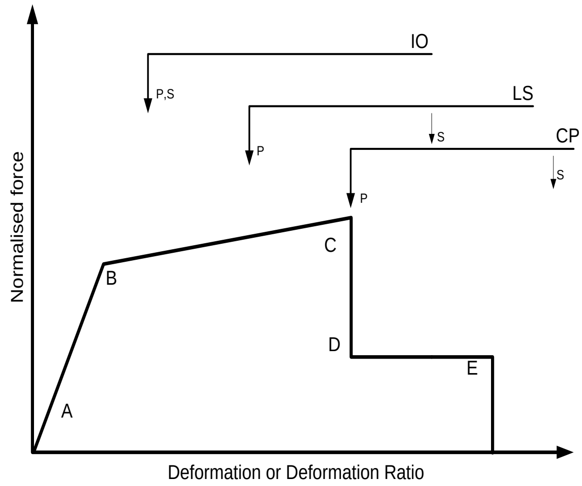

Figure 2. Normalized Force-Deformation Relationships for Modeling and Acceptance Criteria

Table 2. Performance level description of RC structure as per FEMA-356(2000)

Performance Levels	*Element Type*	*Description*
Immediate Occupancy Level (IO)	Primary	Minor hairline cracking. Limited yielding possible at a few locations. No crushing (strains below 0.003).
	Secondary	Minor spalling in a few places in ductile columns and beams. Flexural cracking in beams and columns. Shear cracking in joints < 1/16" width.
	Drift	1% transient; negligible permanent
Life Safety Level (LS)	Primary	Extensive damage to beams. Spalling of cover and shear cracking (< 1/8" width) for ductile columns. Minor spalling in nonductile columns. Joint cracks < 1/8" wide.
	Secondary	Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some nonductile columns. Severe damage in short columns.
	Drift	2% transient; 1% permanent
Collapse Prevention Level (CP)	Primary	Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some nonductile columns. Severe damage in short columns
	Secondary	Extensive spalling in columns (limited shortening) and beams. Severe joint damage. Some reinforcing buckled

	Drift	4% transient or permanent

3. Results And Discussions:

Pushover analysis was used to examine the RC frames, and the procedure was thorough and informative. Plotting data, comparing inter-storey drifts, comprehending how hinges develop within the buildings, and creating capacity curves to show structural behavior under seismic stresses were all part of the extensive analysis that was involved in this project. Together, these evaluations provided important insights into the seismic resilience and performance levels of the structures by highlighting significant variations in how they behaved in different seismic zones.

3.1 Capacity Curve

When post-processing a nonlinear structural study, achieving the capacity curve—basis shear against top displacement—is one of the most crucial tasks. ATC-40 (1996) states that the capacity curve is a plot of the structure's total base shear versus the roof's lateral deflection. Pushover curve is another term for it. Important structural reaction characteristics, such as yield displacement, overall strength, and the structure's initial stiffness estimate, may be seen in the capacity curve. This curve, which is independent of seismic demand, uniquely illustrates the structure's capability. This curve represents the reaction of the structure to lateral displacement caused by earthquakes. The precise level of structural damage is shown by a point on a curve. Various models' capacity curves have been described below.

In capacity curves several performance levels have been shown. The description of the performance levels are as follows:

P – Represents the performance point of the structure under given seismic demand.

A – Represents the Immediate Occupancy Level (IO) of the structure.

B – Represents the Life Safety Level (LS) of the structure.

C – Represents the Collapse Prevention Level (CP) of the structure.

Figure 3 shows the capacity curve of the eight storey RC frame structures along with the variation in the performance for the low seismic demand i.e. for zone-II seismic demand. The capacity curves of different eight storey structures have been plotted and displacement demand and base shear capacity have been marked on capacity curve of structures for seismicity of zone-II. Figure also shows the attainment of the different performance levels of the eight storey structures.

Table 3. Comparison of the performance point of the structure for different seismicity

Structure Model	Performance point for different seismic demands			
	Zone-II (m)	Zone-III (m)	Zone-IV (m)	Zone-V (m)
8S-Z5	0.079	0.127	0.189	0.311
8S-Z4	0.084	0.135	0.200	-
8S-Z3	0.095	0.152	-	-
8S-Z2	0.178	-	-	-

Comparison between all the zones is presented in Table 3. Table 3 shows the displacement demand of the four storey and eight storey structures designed for different seismic zones. The lateral displacement demands of the structures have been shown for different seismic zones. The comparison has been made to show the variation in displacement demand of the structures for different seismicity.

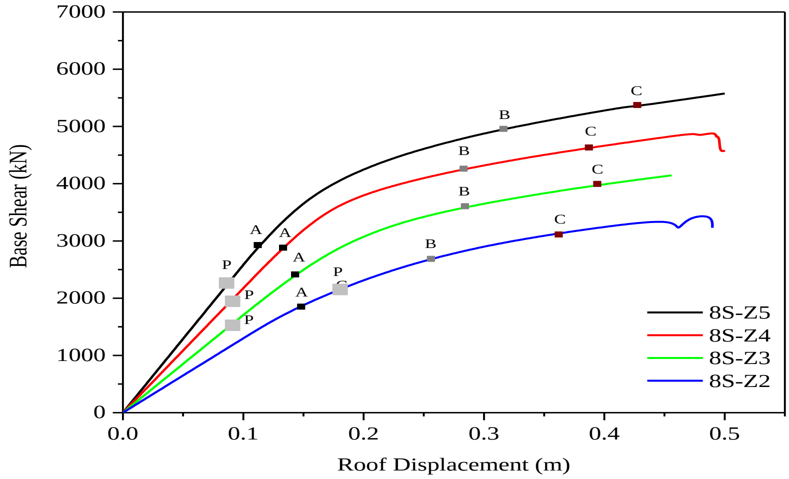

Figure 3. Performance Point Variation in Eight-Storey RC Frame Structures under different zones

3.2 Inter Storey Drift:

The estimation and analysis of the inter-story drift ratio, along with its distribution throughout a building's height, are crucial for evaluating seismic performance. The inter-story drift ratio measures the relative displacement between floors during seismic events and directly correlates with structural damage. Understanding this ratio's distribution provides insights into a building's seismic behavior, identifying vulnerabilities and areas of strength.

Figure 4 shows the inter-storey drifts of the structures compared at the performance point of the structures for zone-II seismic demand. The eight storey structures have been designed for higher zones are checked for demand of zone-II. All eight storey structures are analyzed for Zone-II seismic demand and at the roof displacement demand of the structures for zone-II seismicity the storey drifts have been plotted.

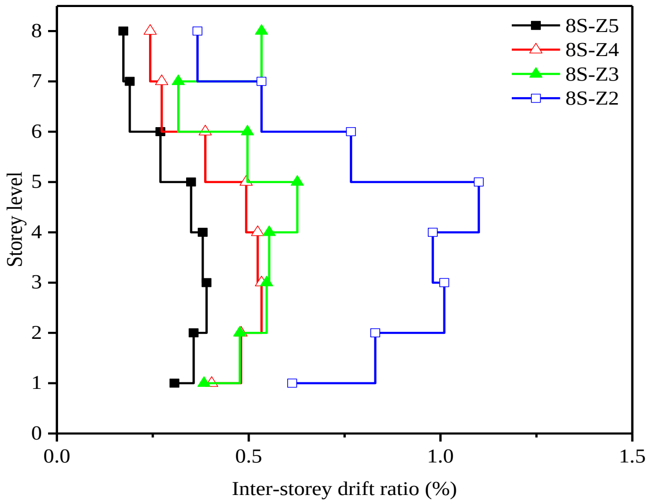

Figure 4. Inter-storey drift ratio of eight storey RC structure at performance point of Zone-II demand

The structures designed for low seismic demand achieves highest inter-storey drift ratio for zone-II seismic region. Structure model 8S-Z2 has highest inter-storey drift for zone-II seismic demand. It is also observed that the highest inter-storey drift is occurring at storey level five.

Figure 5 shows the inter-storey drift of the structures in zone-III seismic region. The storey drifts of structures 8S-Z5, 8S-Z4 and 8S-Z3 are analysed for zone-III seismic region. The inter-storey drifts have been plotted at the roof displacement demand of the structures for seismic zone III. The performance of the different RC frame structures is checked for seismic demand of zone-III by plotting inter-storey drifts of the structures. The comparison of the stability of the structures for zone-III seismicity has been made by comparing inter-storey drifts of the structures for seismic demand of zone-III.

From graph, 8S-Z3 is more critical structure in zone-III seismic region. The inter-storey drift of the structure 8S-Z3 is highest. Floor level three and four are the critical floor level for zone-III demand. Structure models 8S-Z4 and 8S-Z5 have lesser inter-storey drifts in zone-III seismic region.

Inter-storey drift of the structures has been plotted in Figure 6 for the seismic demand of zone-IV. Inter-storey drifts of structure 8S-Z5 and 8S-Z4 have been plotted for the roof displacement at the performance point of the structures for seismic zone-IV. The performance of the different RC frame structures is checked for seismic demand of zone-IV by plotting inter-storey drifts of the structures. The comparison of the stability of the structures for zone-IV seismicity has been made by comparing inter-storey drifts of the structures for seismic demand of zone-IV.

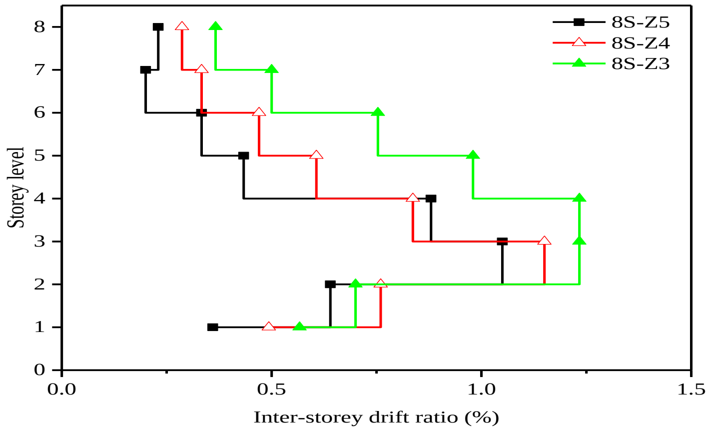

Figure 5 Inter-storey drift ratio of eight storey RC structure at performance point of Zone-III demand

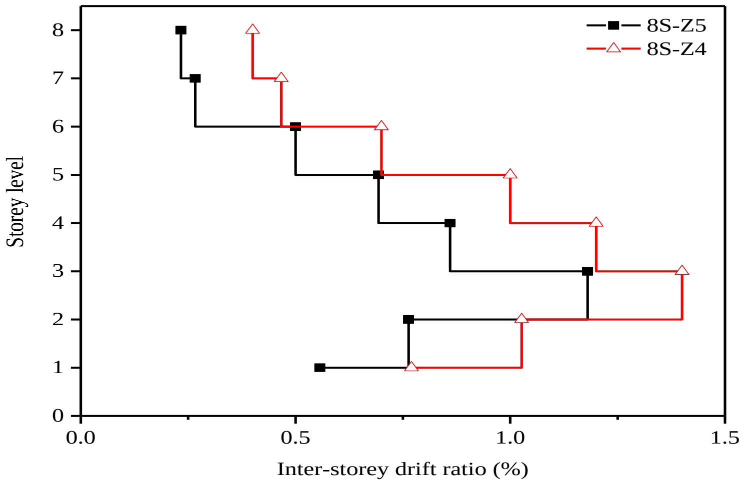

Figure 6. Inter-storey drift ratio of eight storey RC structure at performance point of Zone-IV demand

For Zone-IV seismic demand, the drift values are greater than 1%. Hence, all structures will have damages. The structure designed for the Zone-V shows higher stability and the structures will not have less damage for zone IV seismic region as compared to structure 8S-Z4. Higher drifts can be seen in storey level three for all the structures. The inter-storey drifts of 8S-Z4 are higher than any other structure. Thus 8S-Z4 will be more susceptible to damages.

Table 4 shows the comparison of the maximum inter-storey drift ratio of the different RC frame structures subjected to different seismic demands. Maximum inter-storey drifts for the structures at the lateral displacement demand of the structures in different seismicity have been discussed below. The RC frame structures have been analyzed for different seismic demands and the response of the structures for different seismic demand have been described here in terms of inter-storey drift.

Table 4.Comparisons of the Inter-story drift of different structure at performance point

Structure Model	Inter-storey drift ratio at performance point for different seismic zones		
	Zone-II	Zone-III	Zone-IV
8S-Z5	0.35%	1.05%	1.19%
8S-Z4	0.55%	1.15%	1.4%

8S-Z3	0.55%	1.35%	-
8S-Z2	1.2%	-	-

3.3 Capacity Spectrum

The capacity curve transformed from shear force vs. roof displacement (*V* vs. *d*) co-ordinates into spectral acceleration vs. spectral displacement (S_a *vs.* S_d) co-ordinates is called the capacity spectrum. The intersection is the performance point, and the displacement coordinate, the performance point is the estimated displacement demand on the structure for the specified level of seismic hazard. The detailed procedure of plotting the ADRS curve or Capacity spectrum is defined in ATC-40 (1996).

The comparison of the capacity of the structures has been made by plotting the capacity spectrum of the structure for demand of seismic zone-II. Figure 7 shows the capacity spectrum of the structure and response spectrum of Zone-II demand. The spectral acceleration versus spectral displacement graph has been plotted for eight storey RC frame structure designed for different seismic zones. The demand is taken as the response spectrum of seismic zone II. The seismic demand of the structures is graphically represented by intersection of capacity spectrum of structure with the demand spectrum.

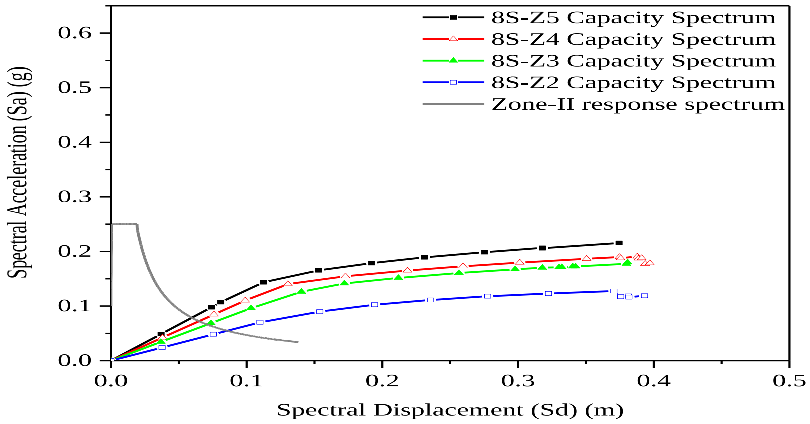

Figure 7. Capacity spectrum of eight storey RC frame structures for Zone-II seismic demand

Results show that the structure 8S-Z5 and 8S-Z4 and 8S-Z3 are over estimated for the given seismic demand. Demand spectrum is intersecting the capacity spectrum at the higher spectral displacement for 8S-Z2. Thus, the performance of the structure is will be poor for zone-II seismic demand. 8S-Z3 will perform well and resist the ground shaking of zone-II efficiently.

The comparison of the capacity of the structures has been made by plotting the capacity spectrum of the structure for demand of seismic zone-III. Figure 8 shows the capacity spectrum of the structure and response spectrum of Zone-III demand. The spectral acceleration versus spectral displacement graph has been plotted for eight storey RC frame structure designed for different seismic zones. The demand is taken as the response spectrum of seismic zone III. The seismic demand of the structures is graphically represented by intersection of capacity spectrum of structure with the demand spectrum.

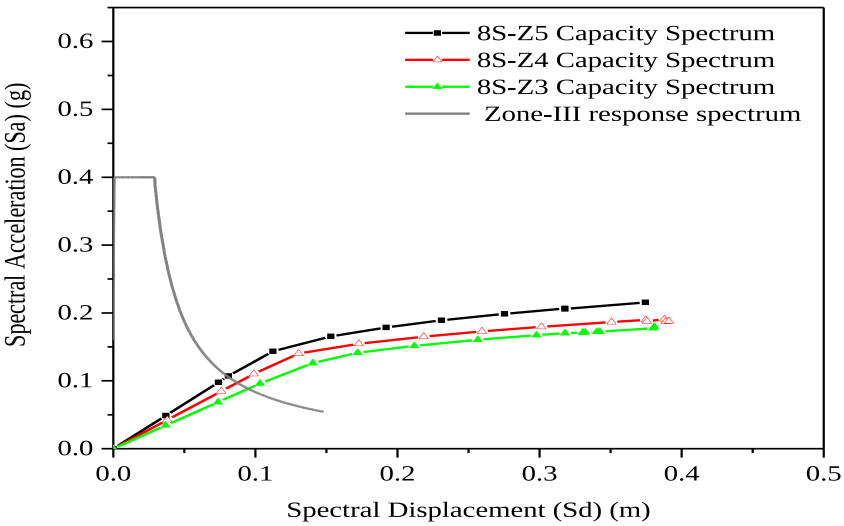

Figure 8. Capacity spectrum of eight storey RC frame structures for Zone-III seismic demand

Results show that the structure 8S-Z5 and 8S-Z4 are over estimated for the given seismic demand. Demand spectrum is intersecting the capacity spectrum at the higher spectral displacement for 8S-Z3.

Thus, the performance of the structure is will be poor for zone-II seismic demand. 8S-Z4 will perform well and resist the ground shaking of zone-III efficiently.

The comparison of the capacity of the structures has been made by plotting the capacity spectrum of the structure for demand of seismic zone-IV. Figure 9 shows the capacity spectrum of the structure and response spectrum of Zone-IV demand. The spectral acceleration versus spectral displacement graph has been plotted for eight storey RC frame structure designed for different seismic zones. The demand is taken as the response spectrum of seismic zone IV. The seismic demand of the structures is graphically represented by intersection of capacity spectrum of structure with the demand spectrum.

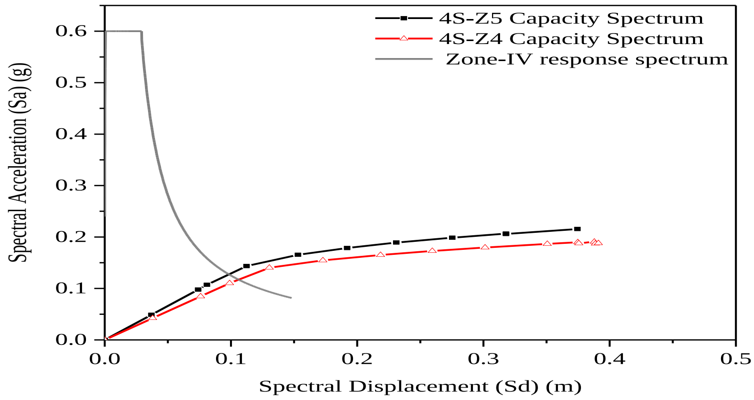

Figure 9. Capacity spectrum of eight storey RC frame structures for Zone-IV seismic demand

Demand spectrum is intersecting the capacity spectrum at the higher spectral displacement for 8S-Z4. Thus the performance of the structure is will be poor for zone-IV seismic demand. 8S-Z5 will perform well and resist the ground shaking of zone-IV efficiently.

The comparison of the performance points of the different structure for different seismic region has been described in Table 5 shows the values of spectral acceleration and spectral displacement at the performance point of the structure when subjected to different seismic demand.

Table 5. Comparison of the performance points of RC frame structures

Structural Models	Performance Point in different seismic demands							
	Zone-II		Zone-III		Zone-IV		Zone-V	
	S_a (g)	S_d (m)	S_a (g)	S_d (m)	S_a (g)	S_d (m)	S_a (g)	S_d (m)
8S-Z5	0.078	0.059	0.123	0.95	0.157	0.137	0.180	0.196
8S-Z4	0.074	0.064	0.114	0.103	0.147	0.159	-	-
8S-Z3	0.066	0.071	0.104	0.113	-	-	-	
8S-Z2	0.054	0.085	-	-	-	-	-	-

S_a – Spectral Acceleration of the structure at performance point in terms of g.

S_d – Spectral Displacement of the structure at performance point in meter.

3.4 Hinge Formation Mechanism

Plastic hinges occur in the sections that have bending moments that exceed the nominal bending moment associated with yielding of the section. Pushover analysis gives the hinge formation mechanism of the structure which will provide the information about the critical section of the structure. One frame of the structure has been shown for illustrating the hinge formation pattern of the RC structures at the collapse. The figures also show the different performance levels of the elements of structures.

The middle frame has been chosen for illustrating the hinge formation pattern of eight storey structures Figure 4.10 to Figure 4.11 show the hinge formation pattern of eight storey structures. Hinge formation pattern has been shown at 0.50m of lateral deflection for all eight storey structures.

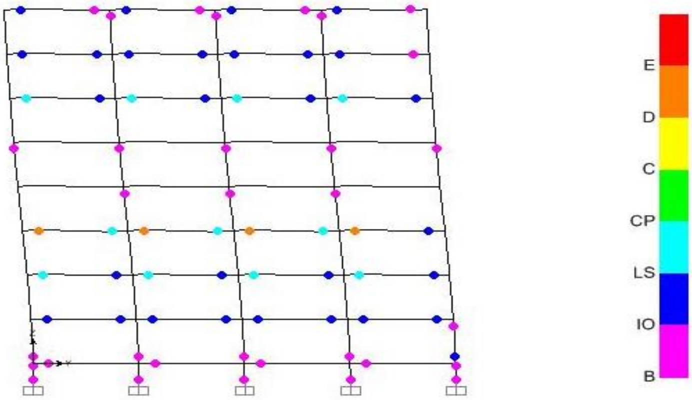

Figure 4.10. Hinge formation of eight storey RC structure model 8S-Z2

The above figure shows the hinge formation mechanism of the 8S-Z2. Second and third storey levels are critical and most of the beams on these storey levels are attaining the life safety performance level.

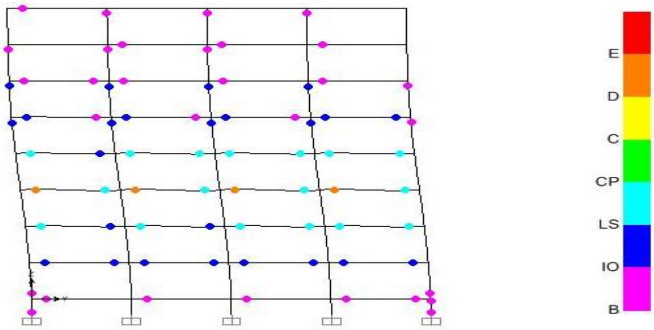

Figure 4.11. Hinge formation of eight storey RC structure model 8S-Z3

The hinge formation mechanism of 8S-Z3 shows that beams of the storey level two, three and four will attain the life safety performance level and fail earlier than other floor levels.

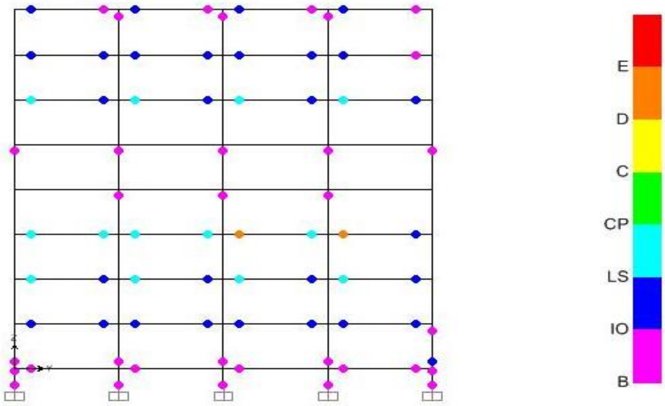

Figure 4.12. Hinge formation of eight storey RC structure model 8S-Z4

Above figure shows that third storey level is critical and fails. Most of the beams are attaining the life safety performance level. The beams in third storey crossed the collapse prevention level.

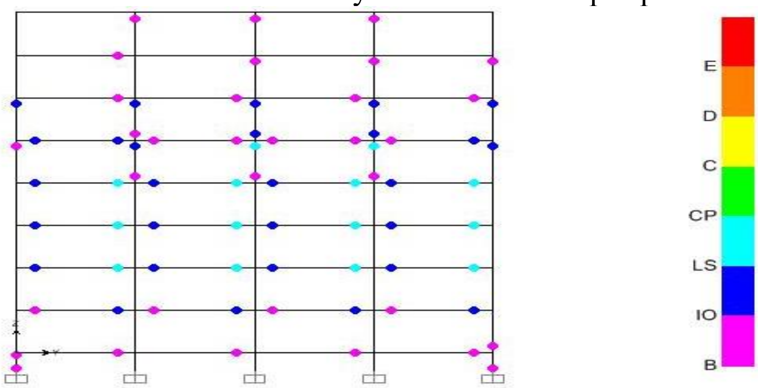

Figure 4.15. Hinge formation of eight storey RC structure model 8S-Z5

Hinge formation of the structure 8S-Z5 has been shown in above figure. It shows that storey level two, three and four are more critical. The beams of these storey levels will fail earlier than other element. From Table 6 to Table 8 the sequence of the hinge formation to different performance levels have been described for four storey structures. The Table describes numbers of elements which are undergoing to different levels at increment of the lateral displacement.

Table 5. Hinge pattern formation in 8S-Z2

Step	Displacement (m)	A to B	B to IO	IO to LS	LS to CP	Total
1	0	1170	0	0	0	1170
2	0.05	1170	0	0	0	1170
3	0.10	1170	0	0	0	1170
4	0.15	1167	3	0	0	1170
5	0.20	1091	79	0	0	1170
6	0.25	1055	100	15	0	1170
7	0.30	1007	132	55	0	1170
8	0.35	954	150	73	11	1170
9	0.40	919	134	49	52	1170
10	0.45	834	139	133	62	1170
11	0.50	817	152	103	78	1170

Table 6. Hinge pattern formation in 8S-Z3

Step	Displacement (m)	A to B	B to IO	IO to LS	LS to CP	Total
1	0	1170	0	0	0	1170
2	0.05	1170	0	0	0	1170
3	0.10	1170	0	0	0	1170
4	0.15	1167	3	0	0	1170
5	0.20	1095	75	0	0	1170
6	0.25	1004	166	0	0	1170
7	0.30	953	201	16	0	1170
8	0.35	905	190	75	0	1170
9	0.40	840	178	143	8	1170
10	0.45	834	149	143	42	1170
11	0.50	807	122	103	58	1170

Table 7. Hinge pattern formation in 8S-Z4

Step	Displacement (m)	A to B	B to IO	IO to LS	LS to CP	Total
1	0	1170	0	0	0	1170
2	0.05	1170	0	0	0	1170
3	0.10	1170	0	0	0	1170
4	0.15	1166	4	0	0	1170
5	0.20	1075	95	0	0	1170
6	0.25	984	186	0	0	1170
7	0.30	930	206	34	0	1170
8	0.35	890	191	89	0	1170
9	0.40	862	166	134	8	1170
10	0.45	844	139	143	42	1170
11	0.50	847	162	103	38	1170

Table 4.8. Hinge pattern formation in 8S-Z5

Step	Displacement (m)	A to B	B to IO	IO to LS	LS to CP	Total

1	0	1170	0	0	0	1170
2	0.05	1170	0	0	0	1170
3	0.10	1170	0	0	0	1170
4	0.15	1168	2	0	0	1170
5	0.20	1076	94	0	0	1170
6	0.25	969	201	0	0	1170
7	0.30	913	243	14	0	1170
8	0.35	859	257	54	0	1170
9	0.40	833	205	132	0	1170
10	0.45	800	189	151	30	1170
11	0.50	813	161	162	34	1170

It has been seen that the structures designed for higher demands will perform well for lower demands and damages will be less. The structures designed for higher demand will be more stable and will have more resistance to damage for lower seismic demands.

4. CONCLUSIONS

The most important conclusion drawn from the study by pushover analysis of RC frame structures designed for different seismic zones is as follows:

- Overestimation of RC Frame Structures: The eight-storey RC frame structures designed for seismic zones V and IV exhibit an overestimation when applied to zone-II seismic conditions. Surprisingly, these structures demonstrate very high-performance levels in zone-II compared to those designed specifically for zones III and II. This suggests that the design specifications intended for higher seismic zones may result in structures that are overly robust for lower seismic demands. Despite this overestimation, these structures perform relatively well in zone-II, outperforming those designed for less severe seismic conditions.
- Need for Optimized Design: To achieve desired performance levels, an optimized design approach is essential. Designing structures that are appropriately tailored to the specific seismic demands of a given region is crucial for achieving optimal performance and ensuring structural integrity during earthquakes.
- Higher Capacity for Better Performance: Structures with higher capacity exhibit better performance under the given seismic demand. This highlights the importance of designing structures with sufficient strength and resilience to withstand the forces exerted by seismic events. Higher capacity enables these structures to better withstand seismic forces and minimize potential damage.
- Impact of Seismic Capacity on Structural Performance: Structures designed for lower seismic capacity are prone to early collapse and demonstrate poor performance under the corresponding seismic demand. This underscores the critical role of seismic design in ensuring structural safety and resilience. Structures inadequately designed for the expected seismic forces are at greater risk of failure, leading to potentially catastrophic consequences during earthquakes.

Therefore, the study concludes that for better performance of the structures in respective seismic zones the structures should be designed for higher demands.

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