RESEARCH ARTICLE OPEN ACCESS

Performance-based Evaluation of Gravity based Design Moment Resisting Frames using Nonlinear Static Analysis

Syed Moin Syed Hassan*, Mohd. Zameeruddin**
**(PG Student, Department of Civil Engineering, MGM's College of Engineering Nanded, Maharashtra, India., Contact 9890982283)*
*** (Associate Professor, Department of Civil Engineering, MGM's college of Engineering, Nanded Maharashtra, India.*

ABSTRACT
Present seismic codes provide earthquake-resistant designs that are gravity-based and apply the response reduction/modification factor (R) to address nonlinear behavior and deformation limits. The intention of the current study is to have a parametric study of RC moment-resisting bare frames that are designed in accordance with IS 1893. The example MRFs are modeled with different "R" values, having the same sizes of structural components. Nonlinear static analysis is employed using incremental lateral loads with uniform distribution over the height of the frame. Performance-evaluation procedures used include the capacity spectrum method and the displacement coefficient method. The nonlinear values obtained at the performance point resulting from these performance evaluations are used to predict loss in ductility, strength, and stiffness. The procedure illustrated is a quick and rational approach to performance evaluation.
***Keywords*–**Moment Resisting Frames, Performance-evaluation Procedures**,** Parametric Studies

Date of Submission: 05-11-2025 Date of acceptance: 16-11-2025

I. INTRODUCTION

The IS 1893 and IS13920 codes' recommended earthquake-resistant design aims to set minimum standards for both damage control (serviceability drift limits) and life safety (strength and ductility) from natural hazards.This is made possible by the force-based criteria for design, which state that displacements and forces must fall within elastic limits. When subjected to seismic loads, these buildings exhibit inelastic behavior, which has been addressed by applying a response reduction factor to forces and displacements. This adds to the limitation of design approach [3].

As an alternative the design approaches have shifted to predictive methods of evaluating possible seismic performance in order to communicate safety-related decisions.These methods are documented in Performance-based Seismic Design [PBSD] framework. The evaluation techniques are named as Capacity Spectrum Method (CSM) and Displacement Coefficient Method (DCM).

In CSM, PoA is applied to obtain the capacity curve of a structure. The performance of the structure is approximated by the responses resulting at the performance point, which is the graphical intersection of the capacity spectrum and demand spectrum. In CSM a reasonable level of performance is attained theoretically, but the results were found to be inconsistent, and their physical interpretation was questionable. Theoretically, CSM produces an acceptable level of performance, but the physical interpretation of information was doubtful, and the results were found to be inconsistent[6]. Figure 1 describes the CSM.

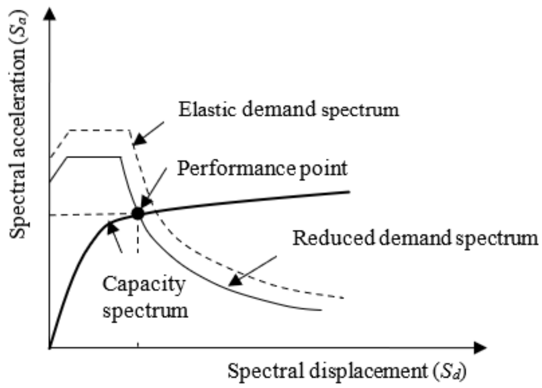


Fig. 2. Construction of capacity curve as per CSM

DCM is a simple technique that uses ductility to estimate the target displacement. An idealized bilinear relation replaces position of the nonlinear base shear-displacement relationship. Coefficients calibrated against numerous dynamic analyses are utilized to derive the responses of the structural elastic linear system [6]. Figure 2 illustrates DCM approach.

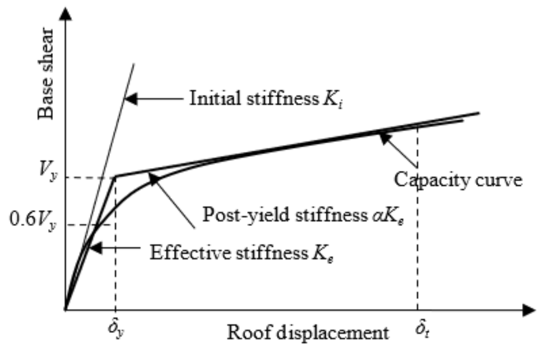


Fig. 2: Construction of capacity curve as per DCM

II. EXAMPLE MRFS

The example MRFS considered for this study is Reinforced Concrete (RC) frame of 3 bays, 12 storey representing medium rise structure, located in seismic zone IV as per IS 1893 [3].The width of each bay is 3 m andheight of each storey is 3 m. Figure 3, describes the geometry of the building and member designation.Thestructural system supports gravity loads of magnitude 7 kN/m^2 (dead load) and 3 kN/m^2 (live load). The RC design of the building was based on IS 456 [4]. The seismic demands on building are calculated following IS 1893 [3].

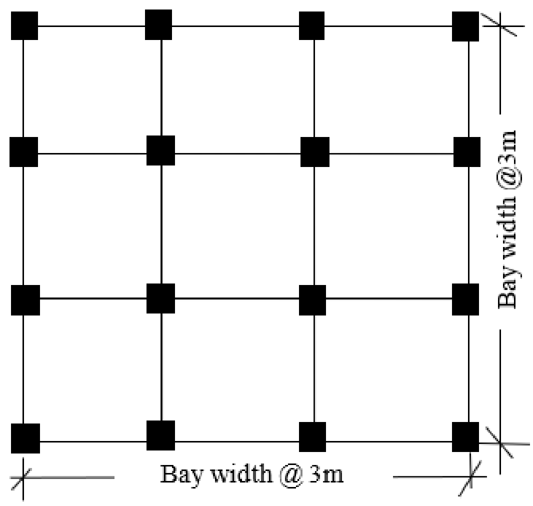


Fig. 3: Typical Plan of example MRFs

The frame is designed with M 30 grade of concrete (having 28 days compressive strength of 30 MPa) [4] and Fe 550 gradereinforcement (having characteristic yield strength of415 MPa) [1].Table 1 showsother details of materials used in design. The structural design details are provided in Table 2.The adopted cross-section size is mapped with general trend of practice in India. The example MRFs are nomenclated asS12B3R1, S12B3R2, S12B3R3, S12B3R4 and S12B3R5. Where S represents number of storey, B states number of bay and R shows response reduction factor used in design.Value of R is varied from 1 to 5, with an intention to evaluate the effects of R value variation on design of structural components and nonlinear evaluation. Seismic design and lateral loads at each storey along the height of example MRFs is stated in Table 3 and Table 4.

Table 1: Design material strength and other parameters used for gravity design

S. No.	Description	Value
1	Type of structure	MRF
2	Materials	
	Concrete M 30	30 kN/m²
	Reinforcement- Fe 550	550 kN/m²
3	Specific weight of RCC	25 kN/m³
4	Type of soil	Medium soil
5	Imposed load	3 kN/m²
6	Important factor	1.0
7	Zone factor	0.36
8	Response reduction factor R-value	1-5

Table 2: Adopted cross-sectional details for design

S. No.	Structure member	Size (mm)
1	**Beams**	
	9th to 12th floor	450x450
	6th to 9th floor	450x650
	3rd to 6th floor	450x750
	base to 3rd floor	450x750
2	**Columns**	
	C1	525 x 525
	C2	600 x 600
	C3	675 x 675

	C4	750 x 750

III. PUSHOVER ANALYSIS

For evaluation of nonlinear responses, the example bare frames were subjected to lateral loads distribution as described in IS 1893 applied in incremental steps till target displacements values are obtained, this procedure is called as Pushover Analysis (PoA). The PoA was carried out in two steps. In first step, push gravity is applied, wherein the structure is subjected to gravity loads, in force-controlled mode.

Table 3: Seismic design results as per 1893:2002

Model	T (sec)	W (kN)	Base shear Coefficient (A_h)	V (kN)
S12B3R1	0.997	18852	0.196	3698.76
S12B3R2	0.997	18852	0.112	2312.57
S12B3R3	0.997	18852	0.0817	1541.71
S12B3R4	0.997	18852	0.0613	1156.28
S12B3R5	0.997	18852	0.049	925.03

Table 4: Lateral Load applied on example MRFs

Storey Height (m)	Lateral Loads [10^5 N]				
	S12B3 R1	S12B3 R2	S12B3 R3	S12B3 R4	S12B3 R5
36	7.16	3.58	2.38	1.79	2.38
33	8.11	4.05	2.70	2.02	2.70
30	6.66	3.33	2.22	1.66	2.22
27	5.71	2.85	1.90	1.42	1.90
24	5.66	2.83	1.88	1.41	1.88
21	4.28	2.14	1.42	1.07	1.42
18	3.48	1.74	1.16	0.87	1.16
15	2.50	1.25	0.83	0.62	0.83
12	1.54	0.77	0.51	0.38	0.51
9	0.85	0.42	0.28	0.21	0.28
6	0.25	0.17	0.11	0.08	0.11
3	0.05	0.02	0.01	0.01	0.01
Base	7.16	3.58	2.38	1.79	2.38

In second step the damage state of example MRF is recalled and then subjected to the lateral load till target displacement is attained [in displacement-controlled mode]. The PoA was carried out in ETABSV 9.7 [2]. PoA was performed on 3D model of example MRF with Diaphragm [Lumped masses] along with beams and columns assigned with plastic hinges as per recommendation of ASCE 41-17. Idealized inelastic force - deformation relationship for nonlinear displacement control action under flexure recommended in ASCE 41-17 as represented in figure 4, were used.

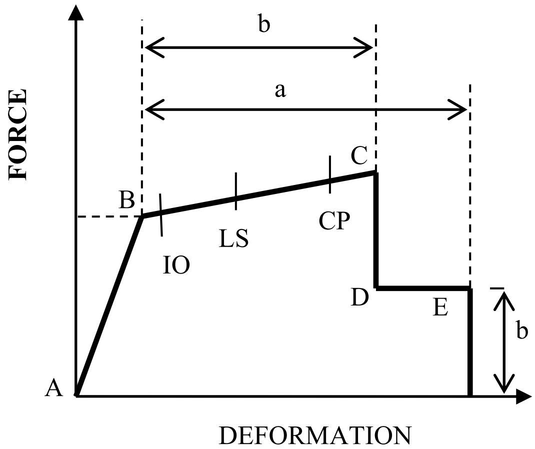


Fig. 4: Idealized inelastic force-deformation relationship [Displacement-Controlled]

Points labelled A, B, C, D, E represents various performance levels expressed directly in terms of strain, curvature, rotation, or elongation. The parameters (a, b) represent the portion after plastic deformation (yield). Parameter (c) represents reduced
resistance after sudden reduction from C to D.

Acceptance criteria or performance levels for the plastic hinge formed near the both ends at relative distance of 10 % of the span of columns and beams are represented by IO (Immediate-Occupancy), LS (Life Safety), and CP (Collapse Prevention).

IV. RESULT AND DISCUSSION

Figure 5, represents the POA curve of all example MRFs. Table 5, represents values of base shear and displacements at performance point for different performance evaluation methods described in PBSD [6,7]. Table 6 shows the stiffness values of example MRFs for different performance evaluation Methods. Table 6 gives the storey displacement for example MRFs. Figure 5 provides the inter-storey drift of all example MRFs. Figure 6 illustrates the collapse mechanism of example MRFs. The loss in stiffness describes the damages to structural and non-structural components. It is observed that these damages vary with the adopted values of response modification factor. It shows that strength factor is important component in the computation of R values. The flow of drift and inter-storey drift along the height of building depends on ductility of the structure that directly depends on adopted value of R value. The collapse mechanism describes the inelastic behaviorof a structure which describes the redundancy of the structure and depends on joint restraints and material characteristics which adds to the value of R. The design base shear and storey shear includes the effects of importance factor, soil type, time period of structure and damping characteristic of materials hence contributes towards damping factor for R. The present parametric study illustrates rational approach of analysis the structure with less iteration procedure compare to nonlinear dynamic analysis or time history analysis.

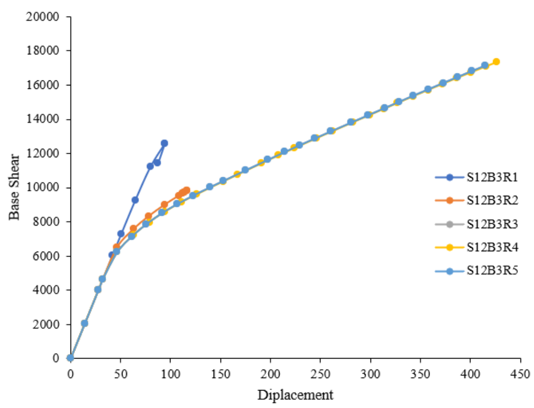


Fig. 5. Capacity Curve of all Example MRFs

Table 5: Nonlinear responses of all example MRFs

Example MRFs	FEMA 440 EL		EC 8 2004		NTC 2008		ASCE	
	V_p	d_P	V_p	d_P	V_p	d_P	V_p	d_P
S12B3R1	8056.47	55.99	4393.52	30.45	4234.63	29.35	8571.82	59.66
S12B3R2	7144.84	56.34	4393.52	30.45	4234.63	29.35	7373.71	59.89
S12B3R3	6896.57	57.26	4393.52	30.45	4234.63	29.35	7118.06	60.77
S12B3R4	6896.98	57.53	4393.52	30.45	4234.63	29.35	7097.21	60.79
S12B3R5	6896.57	57.26	4393.52	30.45	4234.63	29.35	7118.06	60.77

V. CONCLUSION

PoA is used to evaluate the nonlinear response of a structure subjected to a given seismic load. The present available seismic code does not provide specific criteria to address the inelastic incursion, but provided response reduction factor R to indirectly address it.

Table 3: Stiffness values of all example MRFs

Example MRFs	FEMA 440 EL	EL 8 2004	NTC 2008	ASCE
S12B3R1	143.89	144.29	144.28	143.68
S12B3R2	126.82	144.29	144.28	123.12
S12B3R3	120.44	144.29	144.28	117.13
S12B3R4	119.88	144.29	144.28	116.75
S12B3R5	120.44	144.29	144.28	117.13

Table 4: Storey Drift of all example MRFS

Storey Height (m)	Storey Displacements (mm)				
	S12B3 R1	S12B3 R2	S12B3 R3	S12B3 R4	S12B3 R5
36	86.61	115.9	412.6	423.9	412.6
33	81.84	111.6	398.1	407.8	398.1
30	75.16	105.7	372.4	380.4	372.4
27	67.20	98.24	338.8	345.5	338.8
24	59.66	90.25	302.9	308.6	302.9
21	52.32	81.18	267.6	272.4	267.6
18	44.63	70.16	229.8	233.9	229.8
15	36.87	57.75	191.6	195.0	191.6
12	27.49	42.8	147.8	150.5	147.8

ISSN: 2248-9622, Vol. 15, Issue 11, November 2025, pp 100-106

9	18.00	27.05	97.67	99.42	97.67
6	8.82	12.32	49.13	50.12	49.13
3	1.19	1.84	6.47	6.58	6.47
Base	0.03	0.05	0.02	0.00	0.00

In present state-of-practice of structural components uses R values to design for ductility. IS 1893 recommends R = 3 for ordinary moment resisting frame and R =5 for special moment resisting frames. There is a gray area between these values to design for other ductility demands. In present study, this gray area is explored performing PoA of MRFs designed for varying values of R between 1 to 5. were design for gravity loads with varying values of R. The parametric study was done on engineering demand parameter which includes base shear, storey displacement, inter-storey drift and stiffness. The study reveals that;

- For lower values of R, the structural design obtained is uneconomical in term of structural cross-section and reinforcements.
- With the increase in R values, nonlinear responses show lower yield values
- The collapse mechanism reveals that damages to structural components depends on plastic hinges and their nonlinear characteristics which depends on materials, adopting gravity design leads towards constraints over the use of material reserve strength

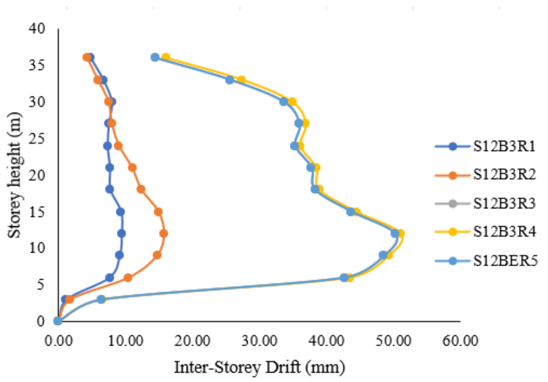
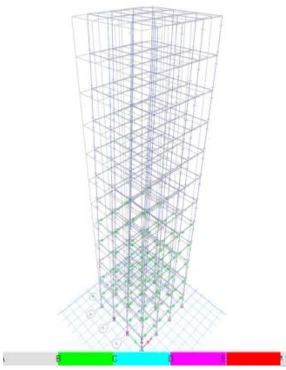


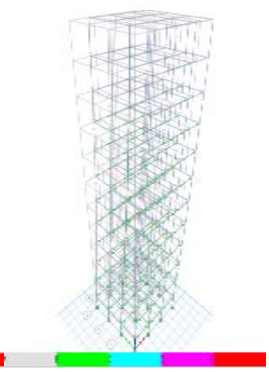
Figure 5. Inter-storey drifts of all example MRFs

Figure 6: Collapse mechanism of all example MRFs

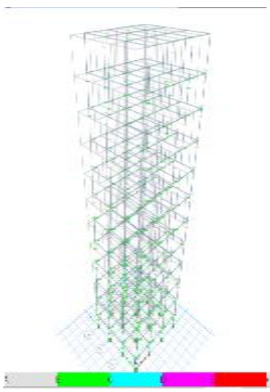
Present study is limited to parametric study, but there is a scope to involve the computation of R values which relates with ductility, strength, redundancy and damping of materials to reach accurate and reasonable design.



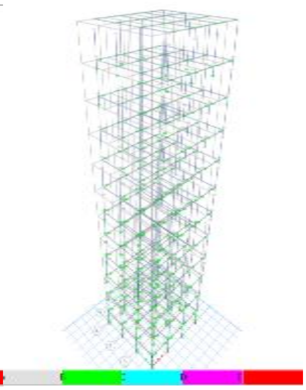
S12B3R1



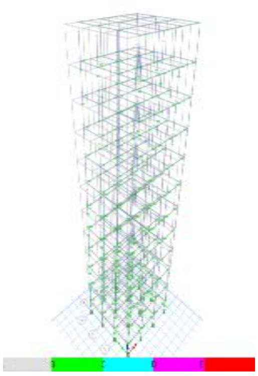
S12B3R2



S12B3R3



S12B3R4



S12B3R5

Acknowledgements

The authors acknowledge the research contribution of all citations under reference and support from MGM's College of Engineering, Nanded,Maharashtra, India.

ISSN: 2248-9622, Vol. 15, Issue 11, November 2025, pp 100-106

REFERENCES

[1]. ASCE SEI/ASCE 7-05. Minimum design loads for buildings and other structures. Reston (USA): American Society of Civil Engineers; 2005.

[2]. CEN Eurocode 8. Design Provisions for earthquake resistance of structures (European Pre-standard ENV 1998). Brussels (Belgium): Comité Européen de Normalisation; 2004.

[3]. BIS IS 1893: Criteria for earthquake resistant design of structures, Part 1. New Delhi (India): Bureau of Indian Standards; 2002.

[4]. BIS IS 456: Plain and reinforced concrete-code of practice. New Delhi (India): Bureau of Indian Standards; 2000.

[5]. BIS IS 13920: Ductile detailing of reinforced concrete structures subjected to seismic forces-code of practice. New Delhi (India): Bureau of Indian Standards; 1993.

[6]. ACT-40 Seismic evaluation and retrofit of concrete building vol. 1. Applied Technical Council Redwood City (USA). 1996.

[7]. FEMA 356 Pre-standard and commentary for seismic rehabilitation of building, Federal Emergency Management Authority, Washington (USA) 2000.

[8]. Apurba Mondal, Siddhartha Ghosh, G.R Reddy 2013 "Performance-based evaluation of the response reduction factor for ductile RC frames" Engineering Structure, 56(2013) 1808-1819.

[9]. Mohd. Zameeruddin Mohd. Saleemuddin, Jyotsna M 2015 "Some Studies on Effects of Reduction Factor (R) – Value on Seismic Behavior of RCC Building" International Journal of Earth Sciences and Engineering (ISSN 0974-5904), Vol. 08, No. 01 Issue Feb. 2015.

[10]. Krawinkler H, Nassar A. Seismic design based on ductility and cumulative damage demands and capacities. In: Nonlinear seismic analysis of reinforced concrete buildings, New York, USA; 1992. p. 27–47.

[11]. Mohd. Zameeruddin Mohd. Saleemuddin, Keshav K Sangle, "Some Studies on Seismic Performance Evaluation of 2D-Reinforcement Concrete Frame based on Seismic Indices Proceedings of 3rd ICRTRT 2014, pp 724-732.

[12]. Sharma A, Reddy G, Vaze K, Ghosh A, Kushwaha H. Experimental investigations and evaluation of strength and deflections of reinforced concrete beam column joints using nonlinaer static analysis. Technical report; Bhabha Atomic Research Centre; Mumbai, India; 2009.

[13]. Priestley M. Displacement-based seismic assessment of reinforced concrete buildings. J Earthq Eng 1997;1(1):157–92. [26] Park R, Paulay T. Reinforced concrete structures. New York (USA): John Wiley & Sons; 1975.

[14]. Prakash V, Powell GH, Campbell S. DRAIN-2DX, base program description and user guide: version 1.10. Report no. UCB/SEMM-93/17; University of California, Berkeley, USA; 1993. [28] Prasanth T, Ghosh S, Collins KR. Estimation of hysteretic energy demand using concepts of modal pushover analysis. Earthq Eng Struct Dynam 2008;37(6): 975–90.

[15]. Ghosh S, Datta D, Katakdhond AA. Estimation of the Park–Ang damage index for planar multi-storey frames using equivalent single-degree systems. Eng Struct 2011;33(9):2509–24.

[16]. Chryssanthopoulos MK, Dymiotis C, Kappos AJ. Probabilistic evaluation of behaviour factors in EC8-designed R/C frames. Eng Struct 2000;22(8): 1028–41ATC. (2009). Quantification of building seismic performance factors. Fema P695, June, 421.

[17]. Azam, S. K. M., & Hosur, V. (2013). Seismic Performance Evaluation of Multistoried RC framed buildings with Shear wall. International Journal of Scientific & Engineering Research, 4(1), 1. Constantin, R. (2016). Seismic behaviour and analysis of U-shaped RC walls. 7133.

[18]. El-Tawil, S., Fortney, P., Harries, K., Shahrooz, B., Kurama, Y., Hassan, M., & Tong, X. (2009). Recommendations for seismic design of hybrid coupled wall systems. In Recommendations for Seismic Design of Hybrid Coupled Wall Systems. https://doi.org/10.1061/9780784410608

[19]. Harries, K. A. (2001). Ductility and deformability of coupling beams in reinforced concrete coupled walls. In Earthquake Spectra (Vol. 17, Issue 3, pp. 457–478). https://doi.org/10.1193/1.1586184

[20]. Huret, R. (2017). 5. Federal Emergency Management Agency. Katrina, 2005, November, 163–189. https://doi.org/10.4000/books.editionsehess.939

[21]. Khalid Mosalam, Amarnath Kasalanati, Grace Kang, C. B.-A. (2011). Pacific Earthquake Engineering Research Center.

[22]. Lu, X., Tian, Y., Cen, S., Guan, H., Xie, L., & Wang, L. (2018). A high-performance quadrilateral flat shell element for seismic collapse simulation of tall buildings and its

implementation in OpenSees. Journal of Earthquake Engineering, 22(9), 1662–1682.
[23]. Lu, X., Xie, L., Guan, H., Huang, Y., & Lu, X. (2015). A shear wall element for nonlinear seismic analysis of super-tall buildings using OpenSees. Finite Elements in Analysis and Design, 98, 14–25. https://doi.org/10.1016/j.finel.2015.01.00