Performance Based Evaluation of Reinforced Concrete Regular Structures

Karanpal Singh H. [1*], Arshad K. Hashmi[2], Patil L. G.[3]
[1]Karanpal Singh H.,
Doctoral Candidate, SGGSIE&T, Nanded
karansingh3050@gmail.com

[2]Arshad k. Hashmi,
Assosicate Professor,M.G.M's COE,
hashmi_arshad@mgmcen.ac.in

[3]L.G. Patil
Professor, SGGSIE&T, Nanded,
lgpatil@sggs.ac.in

Abstract: ***The response reduction factor is crucial in the seismic analysis and design of new structures. IS 1893:2002,2016 provides certain response reduction factor values for typical buildings based on the kind of moment resistant frame building. This research aims at how to obtain the real value of the response reduction factor for regular frames with varied numbers of stories and to establish a comparative relationship for the response reduction factor between real and IS 1893 values. SAP2000 is used in an analytical method to examine the behavior of five distinct storeyed frames. The results reveal that the values proposed by the Indian code are on the safer side, however the response reduction factor varies as the number of stories changes.***

Keywords**: Performance-based design, Response reduction factor, Pushover analysis, Overstrength factor, Ductility reduction factor.**

(Article history: Received: 28th October 2021 and accepted 21st December 2021)

1. Introduction

Various standards in the field of Earthquake Engineering have changed during the last few decades. IS 1893[1,2] for the Indian scenario has been changed twice in the last two decades due to changes in seismic activity. Earthquake analysis is divided into two categories: static and dynamic, which are further subdivided into linear and nonlinear. The Equivalent static technique, commonly known as the Code method, is the most extensively utilized seismic analysis approach today. This study focuses on the lateral forces and base shear of a structure, which are determined by the formula.

$$V_B = \frac{ZIS_a}{2Rg}W \quad (1)$$

Where V_B represents the base shear, I represent the importance factor, Sa/g is spectral acceleration which is dependent on time period of structure and soil condition of the site, and R represents the response reduction factor which depends on type of moment resisting frame. whereas response reduction factor is having different nomenclature for ASCE7[3] and Eurocode 8 (EC8) [4] i.e. "response modification factor" and "behavior factor" respectively. The reduction factor value changes from code to code based on the kind of structural system.

Because the Indian code has been altered twice, the parameters that have been revised include zone factor, importance factor, and a few modifications in spectral acceleration, but the response reduction has remained consistent throughout these revisions. It was found [5][6][7][8] with the variation of shape , size, and geometry there is a possibility that the value of response reduction may change. So, this study focusses on evaluation of "R" for regular frames with varying number of stories.

2. Response reduction factor (R)

The response reduction factor is a force reduction factor that is used to reduce the elastic response to inelastic response and it is dependent on four parameters that is strength, ductility, redundancy, and damping.[9,10]

$$R = R_S R_\mu R_R R_\xi \quad (2)$$

Where R_S is strength factor, which is the fraction of maximum base shear (V_u) to design base shear (V_d). The strength factor is governed by factor like safety margins or partial safety factors and design sections adopted.

$$R_S = \frac{V_u}{V_d} \quad (3)$$

R_μ is known as the ductility factor, basically dependent on displacement ductility (μ) and the natural time period of the structure. It is a measure of the structural system's global nonlinear response in terms of plastic deformation capacity [7]. It is defined as the fraction of elastic base shear to maximum base shear. Fig. 1 shows the relationship between base shear, strength, and ductility factor. Significant effort has been done in the last several decades to establish the ductility factor using SDOF systems exposed to various forms of ground movements. Newmark and Riddell [11], Krawinkler and Nassar [12], Newmark and Hall [13], Miranda and Bertero [14]. In this research, a relationship established by Newmark and Hall [13,15] between displacement ductility and natural time period has been used. A relationship has been established between ductility reduction factor and displacement ductility for a varying range of natural time period as shown in Fig. 2.

- Short period(T<0.2sec), $R_\mu = \mu = 1$ (4)
- Intermediate period(0.2<T<0.5sec), $R_\mu = \sqrt{2\mu - 1}$ (5)
- Long period(T>0.5sec), $R_\mu = \mu$ (6)

Where $\mu = \Delta u / \Delta y$

Displacement ductility (μ) can be achieved with the help of the above equations provided by Newmark and Hall [12,14] and there are four methods which are provided by R. Park [16] shown in Fig 3, out of which reduced stiffness based on equivalent elastoplastic yield was adopted. It helps us estimate the yield displacement and ultimate displacement can be obtained from the bilinear pushover curve of the study frames. Structure with more vertical members falls in the group of redundant structural buildings. According to the ASCE7 redundancy factor (R_R) is treated as a unity. The damping factor (R_ξ) varies depending on the dampers provided, if no additional dampers are provided, it is treated as a unity. For this study, the redundancy and damping factor are treated as 1.

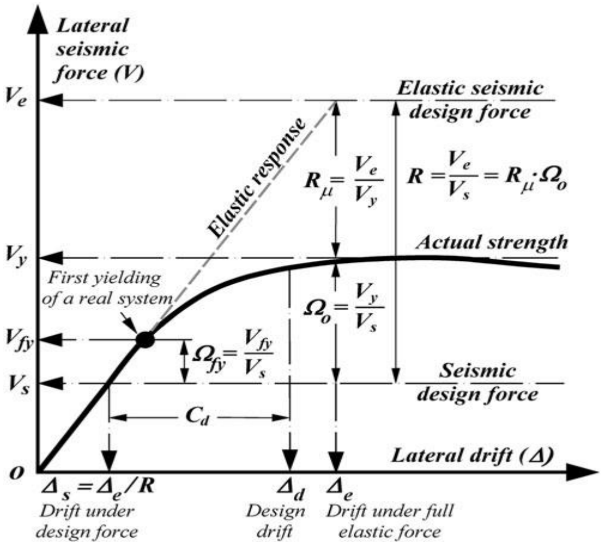


Fig.1. Relationship between Response reduction factor, over-strength factor, and ductility reduction factor.

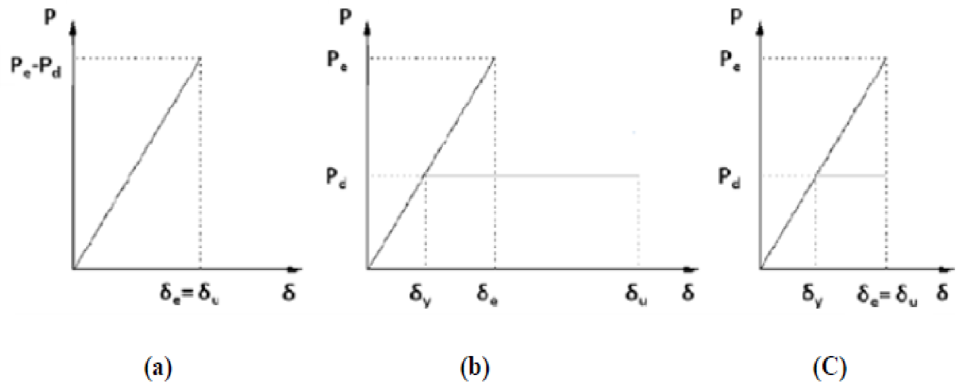


Fig.2. The relation between elastic and inelastic forces for (a) short period (b) Intermediate period (c) long period structures[13]

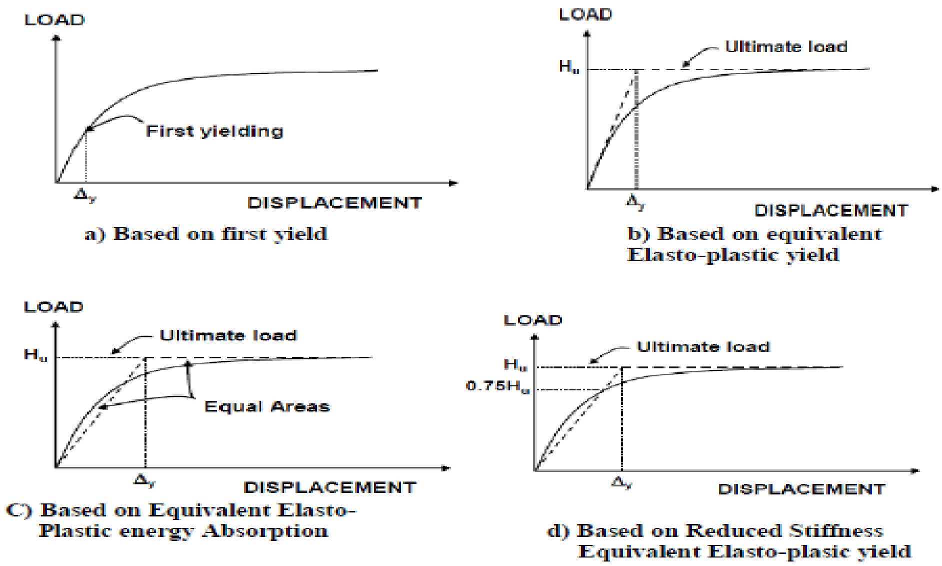


Fig.3. Alternative Definitions for Yield Displacement of Reinforced Concrete Elements [16]

The response reduction factor values vary for different international codal provisions, depending on the kind of structural system and ductility degree. Tables 1 show the value of the response reduction factor defined in IS 1893(part 1), Eurocode 8, and ASCE7 for regular frames [2,4,17,18]. IS 1893 (part 1) and ASCE 7 has classified the response reduction factor based on the type of moment resisting frame whereas EC8 has restricted it to the type of ductility class. The IS code 'R' factor ranges from 3 to 5, EC8 'R' factor ranges from 3.9 to 5.85, and ASCE7 'R' factor ranges from 3 to 8.

Table.1. Comparative study of Response Reduction Factor as per different Seismic Codes

Seismic Code	Type of Fame	Nomenclature of Response Reduction Factor, R	Suggested Value of R,
IS 1893	Ordinary Moment resisting Frame (OMRF)	Response Reduction Factor, R	3
	Special Moment Resisting Frame (SMRF)		5
EC 8	Medium Ductility Class (DCM)	Behavior Factor, R	3.9
	High Ductility Class (DCH)		5.85
ASCE 7	Ordinary Moment Frame	Response Modification Coefficient, R (Excluding the effect of overstrength and redundancy)	3
	Intermediate Moment Frame		5
	Special Moment Frame		8

3. Structural Description

The purpose of this research is to estimate the realistic value of the response reduction factor for five study frames with varying storey heights: two, four, six, eight, and twelve storeys. The typical layout and elevation of the five study frames are depicted in Figs. 4 and 5. The frames are considered as residential buildings, the bay width and floor to floor height are 3m and 3.35m, respectively. The frames are assumed to be bare frames located in Zone V and at hard rock soil strata. Zone V is considered to be the most critical earthquake zone in the India scenario. The RC design of the structure is carried out using IS 456[19], the seismic demand is determined to utilize IS 1893[2] and the ductile detailing is carried out with the help of IS 13920[20]. The base shear of the structure can be calculated as follows.

$$V_B = \frac{ZIS_a}{2Rg}W \qquad (1)$$

Where Z is the zone factor (Zone V= 0.36), I is the importance factor (for residential building= 1.0), R is the response reduction factor (for special moment-resisting frame= 5.0), Sa/g is the design spectral acceleration which is dependent on soil strata and fundamental time period of the structure, W is the seismic weight of the structure. Short, medium and long period moment resisting frames are chosen, Table 2 shows structural information such as total height (from the foundation level), fundamental time period, seismic weight, and design base shear. The fundamental periods in Table 2 are calculated using the empirical formula proposed by IS 1893 for bare frames. M25 grade concrte and Fe415 grade steel is used in the design of the RC frames. The demand achieved can vary depending on the structural configuration, but the design technique is identical to the conventional practice followed by design engineers. To maintain basic workmanship, the column size in a frame, for example, remains the same for 2-3 storeys while the beam size remains the same for the whole frame. The concepts of a strong column and a weak beam are considered. Table 3 shows the RC section details of columns and beams for study frames designed pursuant to the specifications specified by Indian standard codes.

Table.2. Details of study frames

Frame	Height	T(sec)	W(kN)	$A_h = \frac{ZIS_a}{2Rg}$	V_d(kN)
G+2	10.3	0.43	2159	0.085	183.6
G+4	16.75	0.62	3655	0.058	211.89
G+6	23.45	0.8	5151	0.045	232.02
G+8	30.15	0.96	7097	0.037	264.76
G+12	43.55	1.27	10389	0.028	294.15

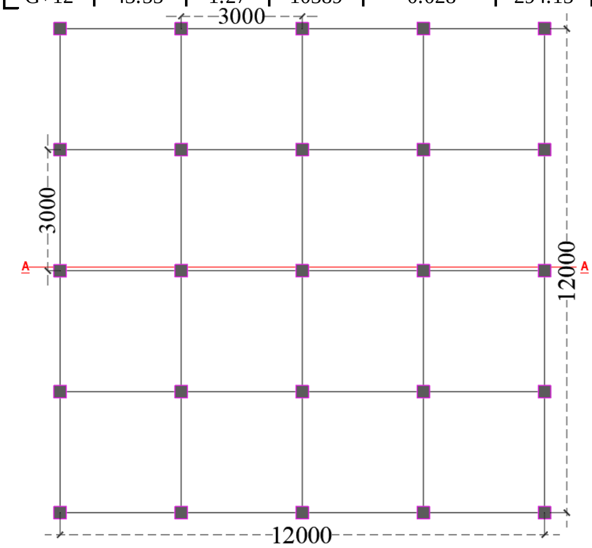


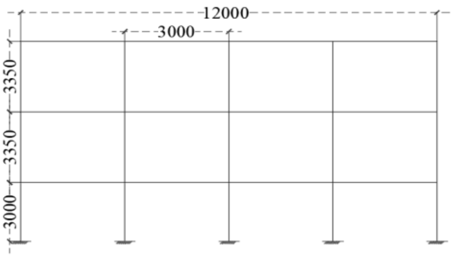
Fig.4. Typical floor plan for study frame.

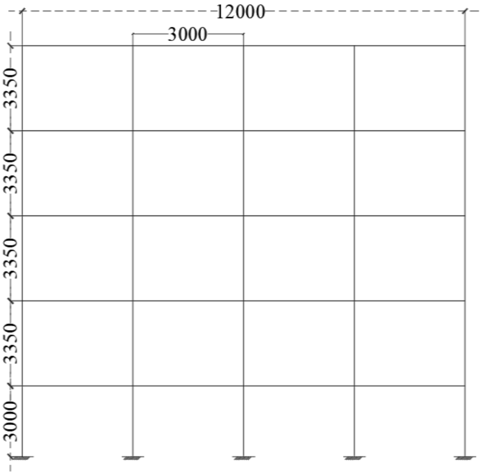
4. Modeling Approach

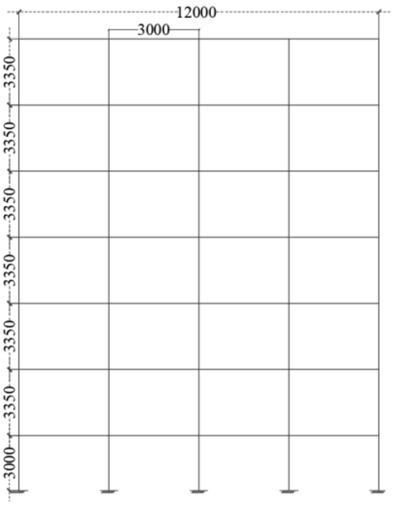
The study was performed utilizing SAP2000 version 20, a structural analysis programme used for static and dynamic structural analysis. The nonlinear behavior of the study frames will help us predict the exact value of the response reduction factor. The 'R' factor can be estimated with the help of nonlinear static analysis (pushover analysis), so the study frames need to be modeled by satisfying a few criteria. The reinforced frame's nonlinear behavior is determined by the plastic hinge's moment-curvature properties and plastic hinge length.

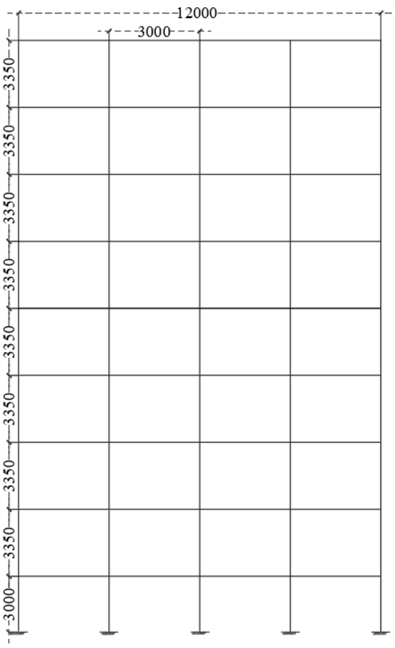
Some studies have been carried out on moment-curvature characteristics of RC members, As IS 13920 is used for carrying out ductile detailing of RC frames, the concrete is confined by transverse reinforcement of columns and beams as they are closely spaced hence concrete can be bifurcated into core concrete and cover concrete. Various analytical models were proposed by Mander et al. [21], Sheikh and Uzumeri [22], Saatcioglu, Razvi [23], and Kent and Park model [24]. For the current study, the model proposed by Mandar et.al [24] is used. In this research, the ultimate concrete strain (in compression) for unconfined concrete recommended by Priestley [25] is εcu = 0.005 is used. To establish the M–φ characteristics of plastic hinge sections, the ultimate compressive strain of concrete restricted by transverse reinforcements (εcc) as specified in ATC-40 is preferred:

$$\varepsilon_{cc} = 0.005 + 0.1\frac{\rho_s f_y}{f'_c} \leq 0.02 \qquad (7)$$









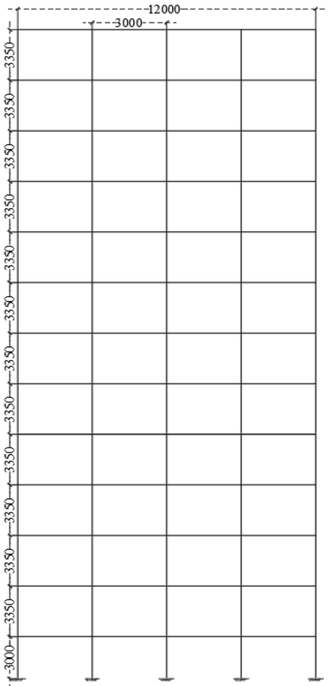


Fig.5. Elevation for five study frames (G+2, G+4, G+6, G+8, G+12)

Table.3. Structural details of the RC section for the study frames

Structure	Elements	Levels	Size(mm)	Reinforcement
G+2	Column	0-2	300x600	6-16mmφ+6-12mmφ
	Beam	1-2	230x525	Top- 2-16mmφ(T)+3-16mmφ(C), Bottom- 3-16mmφ(T)
G+4	Column	0-4	300x600	10-16mmφ
	Beam	1-4	230x600	Top- 2-16mmφ(T)+3-16mmφ(C), Bottom- 4-16mmφ(T)
G+6	Column	0-3	300x600	4-20mmφ+6-16mmφ
	Beam	1-3	230x600	Top- 2-20mmφ(T)+3-16mmφ(C), Bottom- 4-16mmφ(T)
	Column	4-6	230x600	10-16mmφ
	Beam	3-6	230x600	Top- 2-16mmφ(T)+3-16mmφ(C), Bottom- 4-16mmφ(T)
G+8	Column	0-4	300x750	6-20mmφ+6-16mmφ
	Beam	1-4	230x600	Top- 2-20mmφ(T)+4-16mmφ(C), Bottom- 3-20mmφ(T)
	Column	5-8	230x600	10-16mmφ
	Beam	5-8	230x600	Top- 2-16mmφ(T)+3-16mmφ(C), Bottom- 4-16mmφ(T)
G+12	Column	0-4	450x600	8-25mmφ+6-16mmφ
	Beam	1-4	300x600	Top- 3-20mmφ(T)+3-20mmφ(C), Bottom- 4-20mmφ(T)
	Column	5-8	300x600	12-16mmφ
	Beam	5-8	230x600	Top- 2-20mmφ(T)+4-16mmφ(C), Bottom- 3-20mmφ(T)
	Column	9-12	230x600	10-16mmφ
	Beam	9-12	230x600	Top- 2-16mmφ(T)+3-16mmφ(C), Bottom- 4-16mmφ(T)

The limiting value of εcc is confined to 0.02 to prevent longitudinal reinforcement bars from buckling in between two successive transverse reinforcement hoops. Similar formulas for the ultimate compressive strain of confined concrete were provided by Priestley [25]. As previously defined, the plastic rotation characteristics of the member are determined by the member's ultimate, yield curvature and the length of the plastic hinge(L_p). The ultimate and yield curvature can be determined from SAP2000 and the L_p can be obtained from the simplest equation provided by Park and Paulay [26] is 0.5H. Another equation was proposed by Priestley [25] is given below.

$$L_p = 0.5H \quad (8)$$

$$L_p = 0.08L + 0.22 f_{ye} d_{dl} \quad (9)$$

Where H is the depth of beam or column, L is a distance of critical section from point of contra flexure, f_{ye} and d_{dl} are the yield strength of reinforcement and its diameter. M. Inel and H. Ozmen [27] have used both the expression for calculating the length of the plastic hinge for a four and seven storey RC frame. There are various expressions derived for calculation of the length of the plastic hinge but X. Zhao [28] has proved both equation 8, 9 gives similar and accurate results when compared to other expressions. PMM and M3 are the default hinges that are assigned to columns and beams in SAP2000 with the calculated plastic hinge length from equation 8,9. The force-deformation relationship for a typical plastic hinge is given in Fig.6 specifies different acceptance criteria for a structure. Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) are the three performance levels of the structure that define the behavior of the structure when subjected to lateral loads.

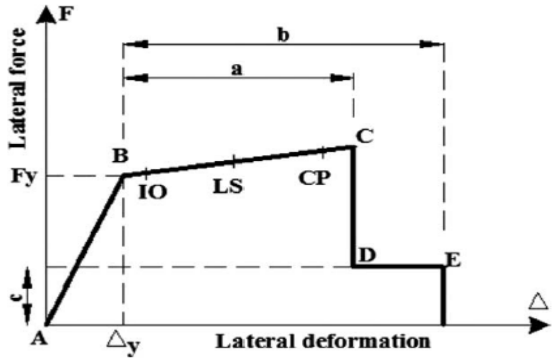


Fig.6. Force-Deformation relationship for a typical plastic hinge.

5. Pushover Analysis and Response Reduction factor.

Pushover analysis is a non-linear static analysis that assesses the capacity of a structure. Pushover analysis is divided into two types: force-based and displacement-based. For this research, the five study frames were subjected to displacement-based pushover analysis. So, while the primary purpose of the study is to find the real value of the response reduction factor, pushover analysis supports us in establishing the structure's over strength and global ductility. Because the study frames are rigid and symmetrical in both directions, all five frames are subjected to a two dimensional pushover analysis considering a single frame for whole structure.

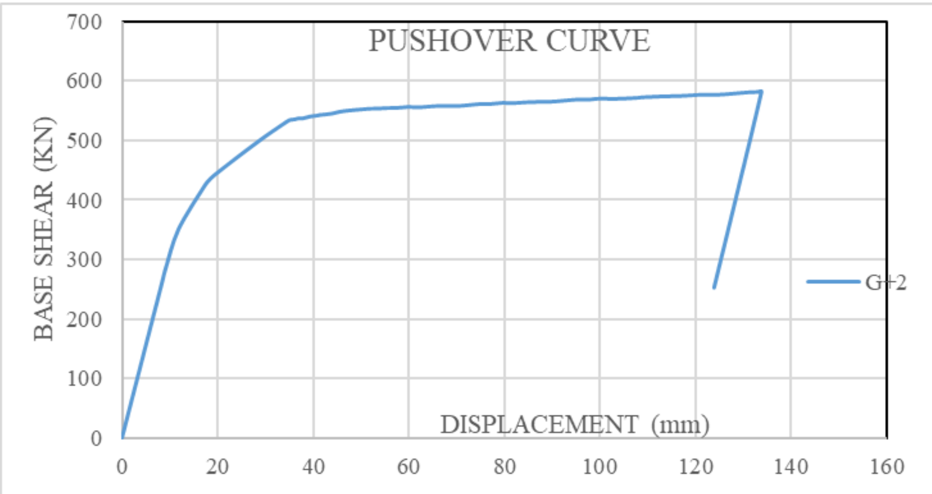


Fig.7. Pushover curve for the G+2 storey frames.

Dead and live loads were applied according to IS 875 part 1,2 [29,30] in the form of wall load and floor load, with the help of the concept of yield line theory the loads were transferred to the single frame which is considered for analysis and design. The frames were firstly analyzed and designed according to IS 456 [19], IS 1893 [2], and detailing was done according to IS 13920[20] . The plastic hinges were assigned to the columns and beams, at specific locations obtained with the help of equation 9. The NSPA was carried out for the critical load combination provided in IS 1893 for residential buildings, the displacement-based approach was adopted and the structure was pushed to a certain amount of displacement, and the plot of force versus displacement was recorded for five study frames. As discussed earlier the overstrength factor and ductility factor are calculated by methods proposed by R. Park [16] and Newmark and Hall [12,14] were adopted. Fig. 7,8,9,10,11 shows the pushover curve for the five study frames.

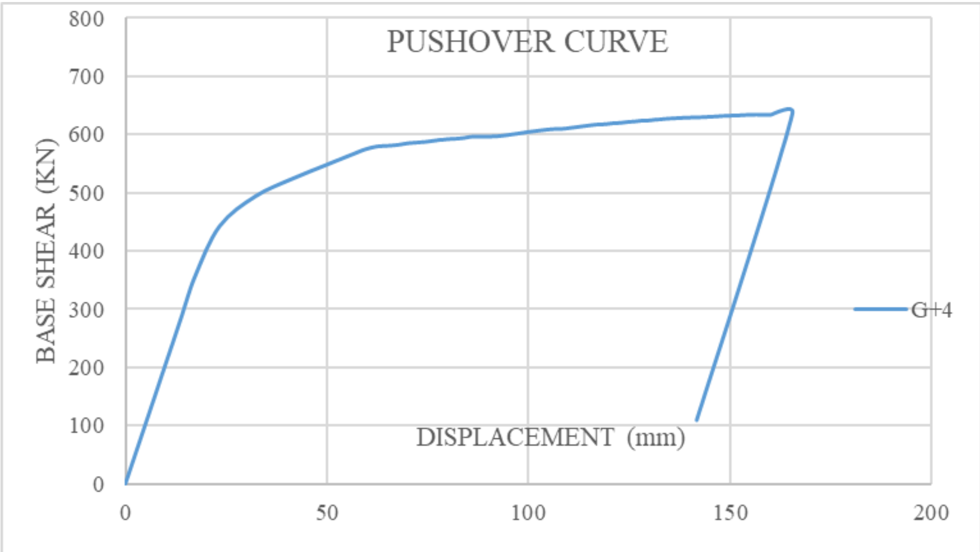


Fig.8. Pushover curve for the G+4 storey frames.

As previously discussed, the reduction factor is primarily determined by two factors: overstrength and ductility factor, which are in turn determined by various factors such as ultimate and design base shear, roof displacement, and yield displacement of the building, all of which are determined using pushover analysis. A similar method was used by S. Goud et.al, Mondal et.al, Yong Lu et.al, and R. Park [7,8,16,34] to bilinearize the force vs displacement curve by assuming equal area under the real and approximating curves.

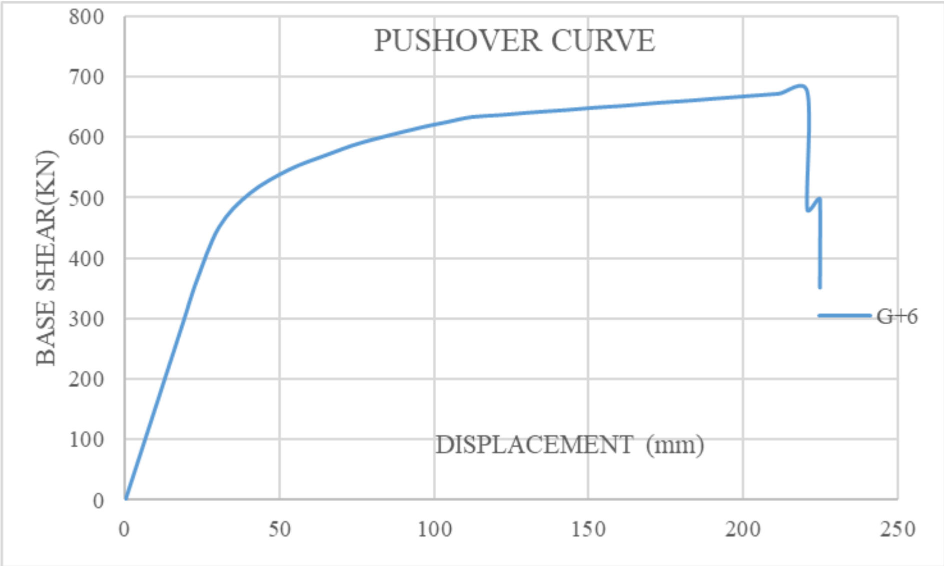


Fig.9. Pushover curve for the G+6 storey frame.

Table.4 shows the R values obtained for the five study frames, which vary from 9.05 to 11.94. As the value suggested by the Indian standard code for response reduction factor is 5, the obtained values are significantly greater than the value suggested by the Indian code, indicating steady behavior. However, as the number of stories rises, the value of the response reduction factor decreases.When we focus on overstrength and global ductility, we find that overstrength decreases as the number of stories increases, but global ductility varies (increases and slightly decreses) as the number of stories increases.

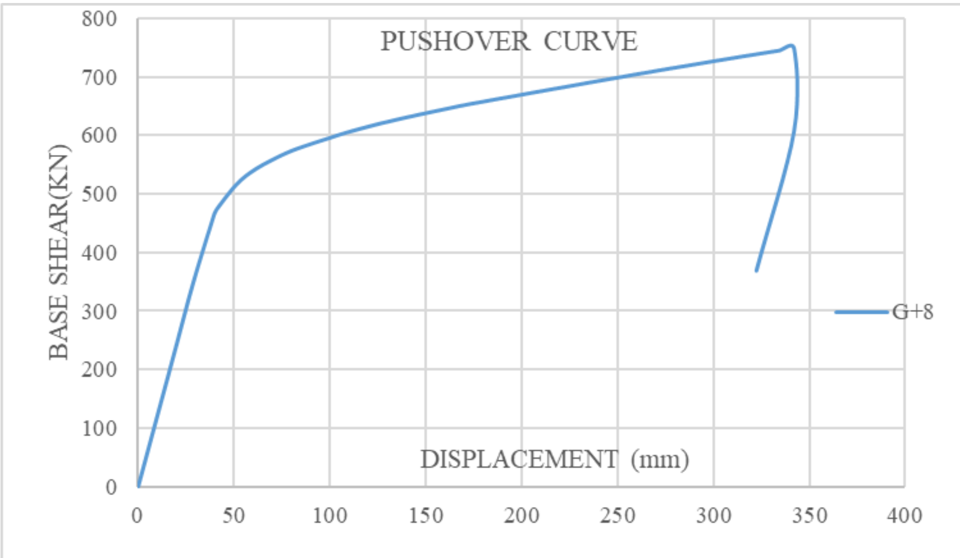


Fig.10. Pushover curve for the G+8 storey frames.

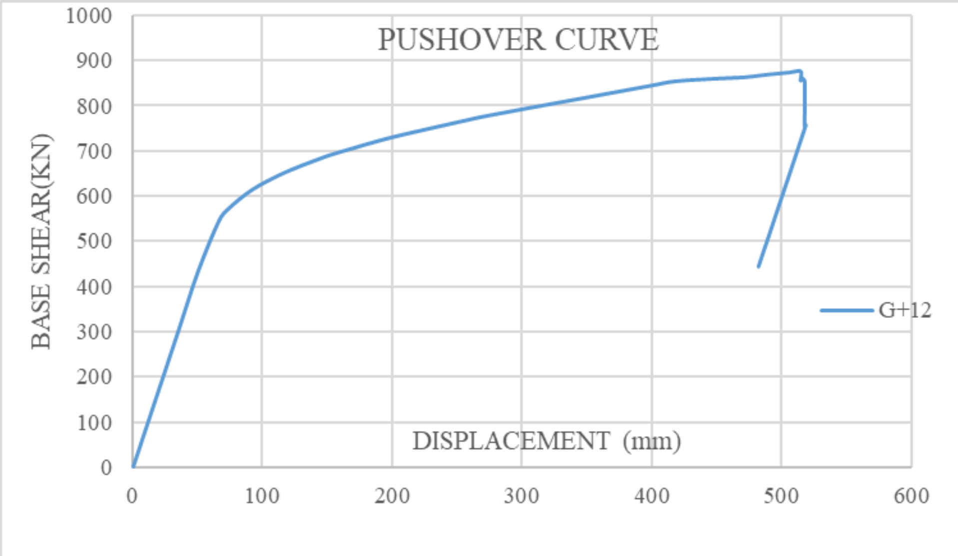


Fig.11. Pushover curve for the G+12 storey frames.

If we look at the pushover curves for all of the frames, we can see one consistent behaviour: the frames have significant ductility, but the sudden drop in the curve represents the brittle failure of the structure; the plastic hinges for the frames showed the beam mechanism, but the final failure is due to the formation of a plastic hinge in the column. Fig. 12 depicts the formation of plastic hinges for G+8 and G+12 storey structures, and hence the progression of plastic hinges from life safety to collapse prevention. When the plastic hinge passes through the collapse prevention stage, the structure fails.

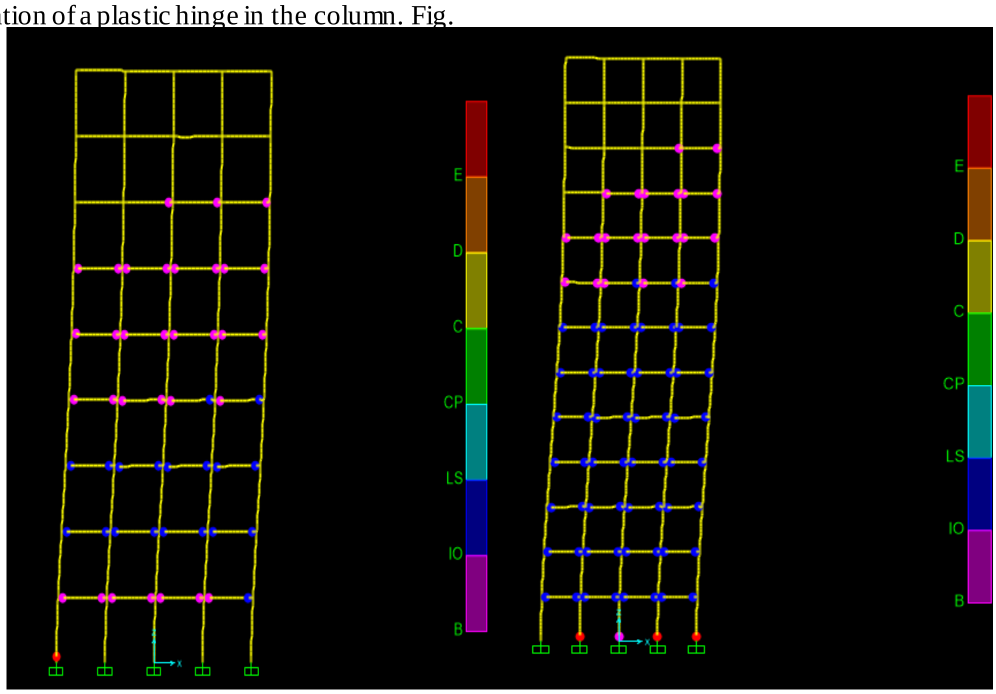


Fig.12. Plastic Hinge formation for G+8, G+12 storey Structure.

Table.4. Response reduction factor for study frames

Structure	Vu	Vb	Δmax	Δy	Rs	Rμ	R
G+2	581.49	183.60	133.69	24.75	3.17	3.13	9.91
G+4	635.62	211.89	165.62	41.62	3.00	3.98	11.94
G+6	676.75	232.02	220.89	54.63	2.92	4.04	11.79
G+8	748.93	264.76	341.99	96.59	2.83	3.54	10.02
G+12	875.14	294.15	514.18	168.98	2.97	3.04	9.03

6. Conclusion

The present study briefly explores different components of Response reduction Factor. The study also explores the definition of Regular frames. The study's findings may be summarised as follows:

- Based on the performance based design carried out, the value of response reduction obtained are on the saferside compared to Indian Code values
- There is a continues reduction in R values, as the number of floors increases.
- The basic reason for continuous reduction of R values was observed to be the overstrength factor.
- G+12 storeyed building showed the critical behaviour compared to other structures in the present study, but still on the safer side.
- For all the study frames, the ultimate failure is in the brittle manner, which is very hazardous. So there is a need to improve the ductility of structure, so that it may fail in ductile manner.
- Differernt performance levels may be plotted to insure the ductile failure.

REFERENCES

[1] BIS. IS 1893 (Part 1) : 2002, Criteria For Earthquake Resistant Design Of Structures:Part 1 General Provisions And Buildings, 5th Revision. Bur Indian Stand Fifth Revis New Delhi, India 2002;1893.

[2] Bureau of Indian Standard(BIS). IS 1893 - Indian Standard Criteria for Earthquake Resistant Design of Structures , Part 1 - General Provisions and Buildings. vol. 1893. 2016.

[3] Chintanapakdee C, Chopra AK, "Seismic response of vertically Irregular frames: Response history and modal pushover analyses," J Struct Eng 2004;130:1177–85. https://doi.org/10.1061/(ASCE)07339445(2004)130:8(1177).

[4] EUROPEAN COMMITTEE. Eurocode 8: Design of structures for earthquake resistance. vol. 1. 2004.

[5] Kruti Tamboli;J. A. Amin, "Evaluation of response reduction factor and ductility factorfor RC braced frame," J Mater Eng Struct « JMES » 2015;2:120–9.

[6] Brahmavrathan D, Arunkumar C, "Evaluation of response reduction factor of irregular reinforced concrete framed structures," Indian J Sci Technol 2016;9:1–8. https://doi.org/10.17485/ijst/2016/v9i23/95981.

[7] Mondal A, Ghosh S, Reddy GR, "Performance-based evaluation of the response reduction factor for ductile RC frames," Eng Struct 2013;56:1808–19. https://doi.org/10.1016/j.engstruct.2013.07.038.

[8] Goud SS, Kumar RP, "Rationalizing response reduction factor R for better performance of reinforced concrete framed buildings," Two Day National Conference on Rationalizing Response Reduction Factor (R) for better Performance of Reinforced Concrete Framed Buildings 2014.

[9] Whittaker A, Hart G, Rojahn C, "Seismic response modification factors," J Struct Eng, 1999;125:438–44.

[10] Kappos AJ, "Evaluation of behaviour factors on the basis of ductility and overstrength studies," Eng Struct 1999;21:823–35. https://doi.org/10.1016/S01410296(98)00050-9.

[11] Riddell R NN, "Statistical analysis of the response of nonlinear systems subjected to earthquakes," Struct Res Ser No 468 1979.

[12] Krawinkler, H, Nassar A, "Seismic design based on ductility and cumulative damage demands and capacities," Nonlinear Seism Anal Reinf Concr Build New York, USA 1992:27–47.

[13] NEWMARK, M. N, "Earthquake Spectra and Design," Earthq. Eng.Research Institute, Berkeley, CA, 1982, p. 108.

[14] Miranda E, Bertero V V, "Evaluation of strength reduction factors for earthquake-resistant design. EarthqSpectra1994;10:357–79. https://doi.org/10.1193/1.1585778.

[15] Paulay T, Priestley MJN, "Seismic design of reinforced concrete and masonry buildings," 2009. https://doi.org/10.1002/9780470172841.fmatter.

[16] R. Park. State of the Art Report Ductility Evaluation from Laboratory and Analytical Testing. Proceeding Ninth World Conf Earthq Eng 1988;8:605–16.

[17] Society of Civil Engineers A. ASCE American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures This document uses both the International System of Units (SI) and customary units 2006.

[18] EN 1998-1. Eurocode 8 - Design of structures for earthquake resistance - Part 1. Buildings 2004:229.

[19] BIS IS 456: Plain and reinforced concrete-code of

practice. New Delhi (India):Bureau of Indian Standards; 2000

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

[21] Mander JB, Priestley MJN, Park R, "Theoretical stress-strain model for confined concrete," J Struct Eng 1988;114:1804–26.

[22] Sheikh SA, Uzumeri SM, "Strength and ductility of tied concrete columns," ASCE J Struct Div 1980;106:1079–102.

[23] Saatcioglu M, Razvi SR, "Strength and ductility of confined concrete," J Struct Eng (United States) 1993;119:3109–10.https://doi.org/10.1061/(ASCE)07339445(1993)119:0(3109).

[24] Kent DC, Park R, "Flexural members with confined concrete," J Struct Div 1971:97.

[25] Priestly MJN, "Diplacement based seismic assessment RC buildings," J Earthq Eng 1997;1(1):157-92.

[26] R. Park T.Paulay, "Reinforced concrete structures," Newyork(USA): John Wiley & Sons; 1975.

[27] Inel M, Ozmen HB, "Effects of plastic hinge properties in nonlinear analysis of reinforced concrete buildings,"EngStruct2006;28:1494–502. https://doi.org/10.1016/j.engstruct.2006.01.017.

[28] Zhao X, Wu YF, Leung AY, Lam HF, "Plastic hinge length in reinforced concrete flexural members," ProcediaEng2011;14:1266–74. https://doi.org/10.1016/j.proeng.2011.07.159.

[29] Bureau of Indian Standards (BIS). IS 875 (Part 1): 1987 (Reaffirmed 2003) Code of Practice For Design Loads (Other Than Earthquake) For Buildings And Structures, Dead Loads 2003:37.

[30] IS 875 : 1987. Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures, Part 2: Imposed Loads. Bur Indian Stand New Delhi 1987:18.

[31] MadanA.andHashmiA.,"Seismic performance of masonry infilled reinforced concrete frames subjected to near-field earthquakes," Journal of Structural Engineering, ASCE, 134(9); 2008, 1569-1581.

[32] HashmiA.,"Preliminary design and analys is of masonry reinforced concrete frame based on storey drift limitations under lateral loads," Journal of Structural Engineer,SERC,CSIR,41(5);2014;509-523

[33] HashmiA.,"Seismic evaluation and preliminary design of regular setback masonry infilled open ground storey frames," Journal of Institute of Engineers (India): SeriesA,97(2), 2016, 121-131.

[34] Lu Y, Hao H, Carydis PG, Mouzakis H. Seismic performance of RC frames designed for three different ductility levels. Eng Struct 2001;23:537–47. https://doi.org/10.1016/S0141-0296(00)00058-4.

Karanpal Singh Hazuria
Doctoral Candidate,
Dept. of civil Engineering
SGGSIE&T,
Nanded, 431606 (Maharashtra, India.).

Arshad K. Hashmi
Associate Professor,
Dept. of civil Engineering
MGM's College of Engineering,
Nanded, 431605 (Maharashtra, India.).

L.G. Patil
Professor,
Dept. of civil Engineering,
SGGSIE&T,
Nanded, 431606 (Maharashtra, India.).