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Evaluation of Effect of Special Shaped Column Cross Section on Response Modification Factor of Reinforced Concrete Building

Shruti R. Sarage[1], Dr. S. K. Hirde[2]

[1]*Post Graduate Student, Applied Mechanics Department, Government College of Engineering, Amravati.*
[2]*Professor, Applied Mechanics Department, Government College of Engineering, Amravati.*

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Abstract - *During earthquake, due to vibration of the building earthquake forces are developed. In earthquake resistant design, the building is designed for the force which is much lower than actual earthquake force which is developed during the earthquake. Therefore the actual base shear force should be reduced in order to get the design lateral force by the factor which is known as response modification factor (R). Component of the response modification factor depend on strength factor, ductility factor, structural redundancy and damping. Many developing countries adopts the response modification factor (R) from the seismic design codes of developed countries such as United States and Europe. The value of response modification factor is directly given in codes without its components. So in this study the efforts are made to calculate these component of response modification factor by considering various shapes of column so as to check the effect of shape of cross section of column on response modification factor. In this study three models of different number of storeys i.e. 4 storey, 8 storey and 12 storey are analysed by Pushover analysis, first model with square columns, second with circular columns and third model with combination of column cross sections such as L, T and plus (+) shaped. The study also compares response modification factors for structures designed with Indian code IS 1893: 2002 (Part1), IS 1893:2016 (Part1) and American code ASCE 7-10.*

Key Words: **Response modification factors, Special Shaped Column, Over Strength, Ductility, Redundancy.**

1. INTRODUCTION

Seismic design of structures is based on elastic force. The nonlinear response of structure is not included in design philosophy, but its effect is subsume by using response modification factor (R). The concept of response modification factor is to reduce the seismic force and include nonlinearity with the support of structure's ductility, over strength, redundancy and damping.[18]

The response modification factor (R) indicate the capacity of structure to dissipate energy through inelastic behaviour. Over strength, ductility, damping and redundancy these are different parameters of the structural system which affects the response modification factor.

R=Rs*Rμ *Rξ *Rr (1)

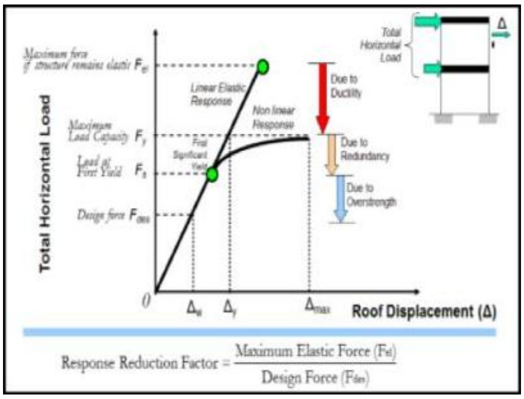

Fig -1: Components of Response Modification Factor [15]

1.1 Ductility Factor (Rμ)

The ductility reduction factor (Rμ) is a factor which reduces the elastic force to idealized yield strength level of the structure. It can be calculated using ductility (μ) of the structure which is the ratio between the maximum roof displacement and yield roof displacement. Ductility factor was developed by Newmark and Hall as follows. [11]

$$\mu = \frac{(\Delta m)}{(\Delta y)} \quad (2)$$

T < 0.2 seconds $R_\mu = 1$ (3)

0.2 < T < 0.5 seconds $R_\mu = \sqrt{2\mu - 1}$ (4)

T > 0.5 seconds $R_\mu = \mu$ (5)

1.2 Overstrength Factor (Rs)

Structural overstrength plays an important role in collapse prevention of the buildings. The overstrength factor (Rs) may be defined as the ratio of actual to the design lateral strength:

$$R_s = \frac{Vy}{Vd} \quad \text{or} \quad R_s = \frac{Vmax}{Vd} \qquad (6)$$

Where Vy (Vmax) is the base shear coefficient corresponding to the actual yielding of the structure ,Vd is the code prescribed unfactored design base shear coefficient.

1.3 Redundancy Factor (Rr)

A redundant seismic framing system ought to be composed of multiple vertical lines of framing, each designed and detailed to transfer seismic induced inertia forces to the foundation. The lateral load is shared by different frames depending on the relative (lateral) stiffness and strength characteristics of each frame using such systems. Redundancy factor Rr can be estimated as ratio of ultimate load to first significant yield load; estimation of this factor requires detailed non-linear analysis.

$$R_r = \frac{Vu}{Vy} \qquad (7)$$

1.4 Damping factor (Rξ)

Damping factor accounts for the effect of added viscous damping and is primarily applicable for structures provided with supplemental energy dissipating devices. If such devices are not used, the damping factor is usually assigned a value equal to 1.0.

2. LITERATURE REVIEW

An extensive literature review was carried out prior to the project. The survey of literature includes SMRF and OMRF, ductility, response reduction factor, and pushover analysis, shape of columns.

IS 1893: 2002 (Part1) [2] and IS 1893:2016 (Part1) [3] Criteria for earthquake resistant design of structures Part 1 General provisions and buildings, Bureau of Indian Standards (BIS) classifies RC frame buildings into two classes, Ordinary Moment Resisting Frames (OMRF) and Special Moment Resisting Frames (SMRF) with response reduction factors 3 and 5 respectively. ACI 318: [6] Building code requirements for reinforced concrete and commentary, published by American Concrete Institute. ASCE 7 [5] classifies RC frame buildings into three ductility classes: Ordinary Moment Resisting Frame (OMRF), Intermediate Moment Resisting Frames (IMRF) and Special Moment Resisting Frames (SMRF) and corresponding reduction factors are 3, 5 and 8, respectively. Sadjadi et.al. [8] conducted an analytical study for assessing the seismic performance of RC frames of 5-story frame designed as ductile, nominally ductile and Gravity Load Designed (GLD) and observed that the nominally ductile frames behaved very well under the considered earthquake. Khose et. al. [9] performed an overview of ductile detailing requirements for RC frame buildings in different seismic design codes. V. Gioncu [10] performed the review for ductility related to seismic response of framed structures. Newmark and Hall [11] made the first attempt to relate R with for a single degree-of- freedom (SDOF) system with elasto-perfectly plastic (EPP) resistance curve. Anagnostopoulous and Nikolaou [12] investigated the relationship between the ductility reduction factor and ductility demand depending on a natural period of the structure for SDOF systems and for frames designed in accordance with the Uniform Building Code (UBC) provisions. Asgarian and Shokrgozar [13] evaluated over- strength, ductility and response modification factor of buckling restrained braced frames and it was perceived that the response modification factor drops as the height of building increases. Mondal et. al. [14] studied the nonlinear response of a structure implicitly through a response reduction/modification factor (R). Swajit Singh Goud et. al. [15] studied the seismic resistant design philosophy which incorporates the non linear response of the structure by using appropriate response reduction factor (R). Sadjadi et. al.[8] proposed a nonlinear static analysis, also acknowledged as a push-over analysis, which involves laterally pushing of the structure in one direction with a certain lateral force or displacement distribution until either a specified drift is attained or a numerical instability has occurred. B. Shah and P. Patel [16] made comparison between the model having the rectangular cross section of columns and the equivalent square cross section and concluded that the square shape of the column cross section improves the seismic response of a structure as compared to the rectangular shape of an equivalent area. A. Rahaman et.al. [17] evaluated the comparative lateral load resistance capacity of buildings with rectangular columns and buildings with specially shaped columns and concluded that the buildings with specially shaped columns perform better under lateral load conditions than the buildings with conventional rectangular columns under the same loadings. Shivam Mishra et. al. [18] studied different shapes of column cross sections like square, circular, plus, L, and T shaped with same cross sectional area and reinforcement and found the response modification factor for different buildings by comparing Indian and American code provisions.

3. BUILDING DETAILS

The structural systems that are considered for this study are 4, 8 and 12 storeyed buildings with 3 bay symmetrical about both axes reinforced concrete frame slab building (Fig 2 and 4). Bay width is 4 m. Height of typical floor is 3m. The building is modelled using the software ETABS. Column cross sections such as square cross section, circular cross section, L-shaped cross section, plus shaped cross section, T-shaped cross section are given Fig 3.

Table -1: Details And Dimensions of Building Model[1]

Sr. No.	Parameters	Values
1	Type of structure	Special moment resisting RC frame
2	Grade of concrete	M50 (fc=50 MPa)
3	Grade of steel	Fe 415 (fy= 415 MPa)
4	Floor height	3 m
5	Beam size	450 mm X 550 mm
6	Column size	550 mm X 550mm
7	Slab thickness	150 mm
8	Live and dead load on floor	2 kN/m²
9	Live load on roof	1.5 KN/m²
10	Internal wall load	5.635 KN/m
11	External wall load	11.27 KN/m

Table -2: Seismic Properties (IS 1893:2002)[2]

Sr. No.	Parameters	Values
1	Seismic zone	V (Z=0.36)
2	Response Modification Factor	5
3	Importance Factor	1
4	Damping	5%
5	Site Class	Type II (Medium soil)

Table -3: Seismic Properties (IS 1893:2016)[3]

Sr. No.	Parameters	Values
1	Seismic zone	V (Z=0.36)
2	Response Modification Factor	5
3	Importance Factor	1.2
4	Damping	5%
5	Site Class	Type II (Medium soil)

Table -4: Seismic Properties (ASCE 7-10)[5]

Sr. No.	Parameters	Values
1	Seismic zone	IV (Z=0.4)
2	Response Modification Factor	8
3	Importance Factor	1
4	Damping	5%
5	Site Class	Site class D (Stiff soil)

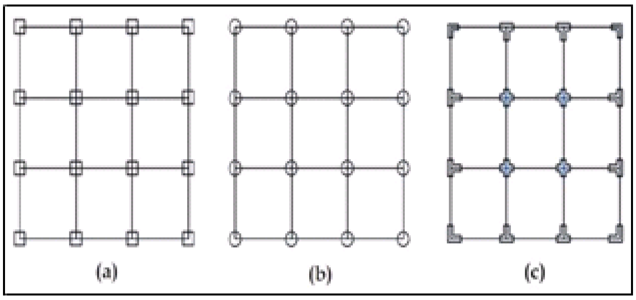

Fig -2: Plans with different column cross sections (a) Plan with square columns, (b) Plan with circular columns, (c) Plan with plus, L and T- shaped columns [18]

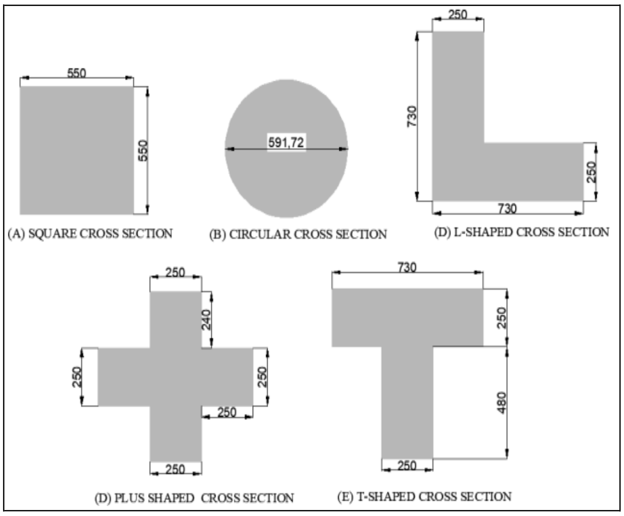

Fig -3: Cross sections of different shapes of column [1]

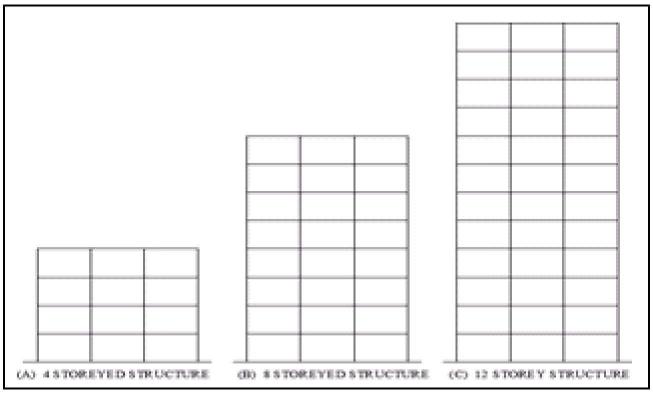

Fig -4: Cases for multi-storeyed structures [18]

4. ANALYSIS OF STRUCTURE

Analysis of frame has been done by using ETABS 17.0.1, which is a structural analysis program for static and dynamic analysis of structure. ETABS nonlinear version 17.0.1 is used to perform pushover analysis. Capacity curve is obtained from analysis i.e. graph between base shear versus displacement. For nonlinear static analysis, displacement control strategy is used.

5. RESULT AND DISCUSSION

Total 27 numbers of models were developed, analysed and results were obtained from the pushover analysis as shown in Fig. 5-7. The response modification factor are calculated and shown in table 5. The comparisons of these results were done with same type of building having different cross section of the column, different number of storey and different codal provisions.

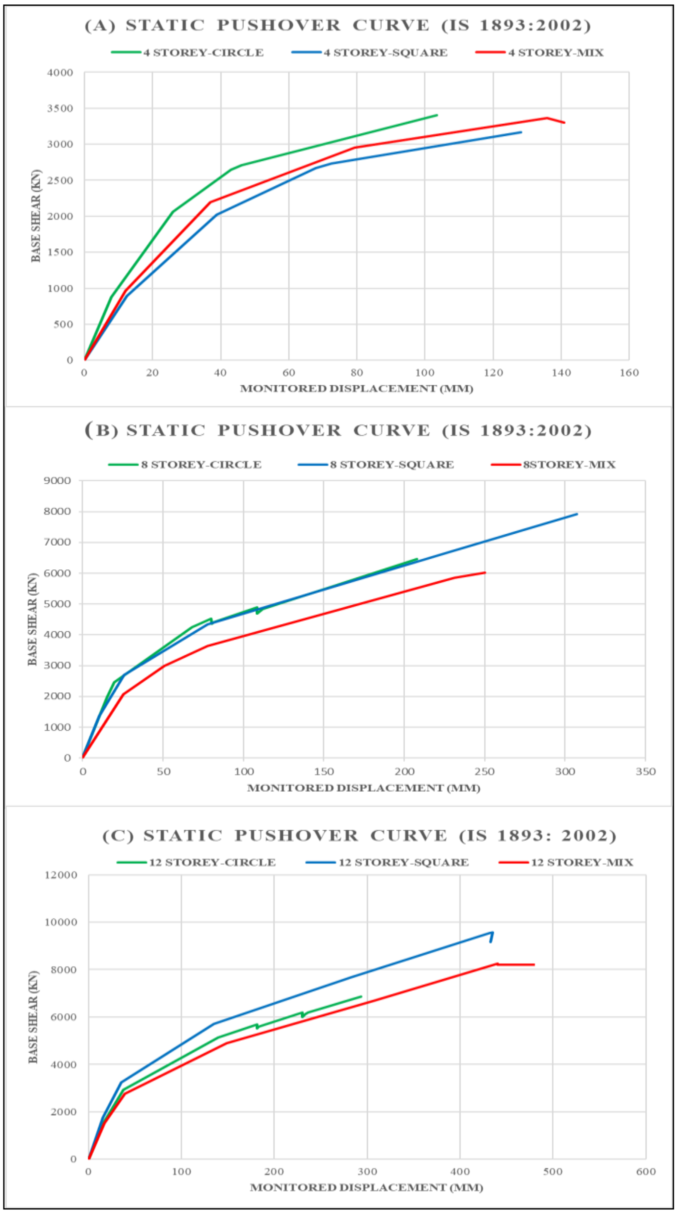

Fig -5: Combined graph of static pushover curve for 4, 8 and 12 storeyed structure designed with IS 1893:2002. [2]

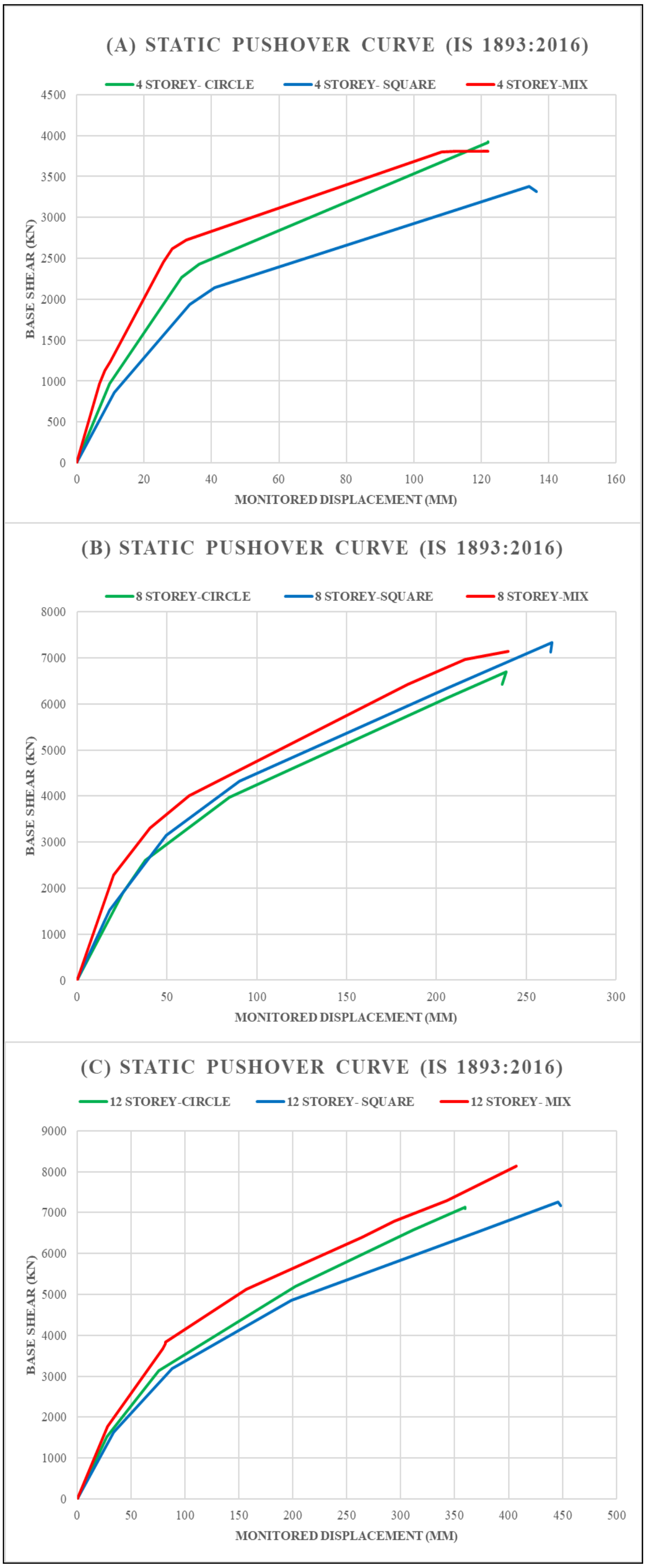

Fig -6: Combined graph of static pushover curve for 4, 8 and 12 storeyed structure designed with IS 1893:2016. [3]

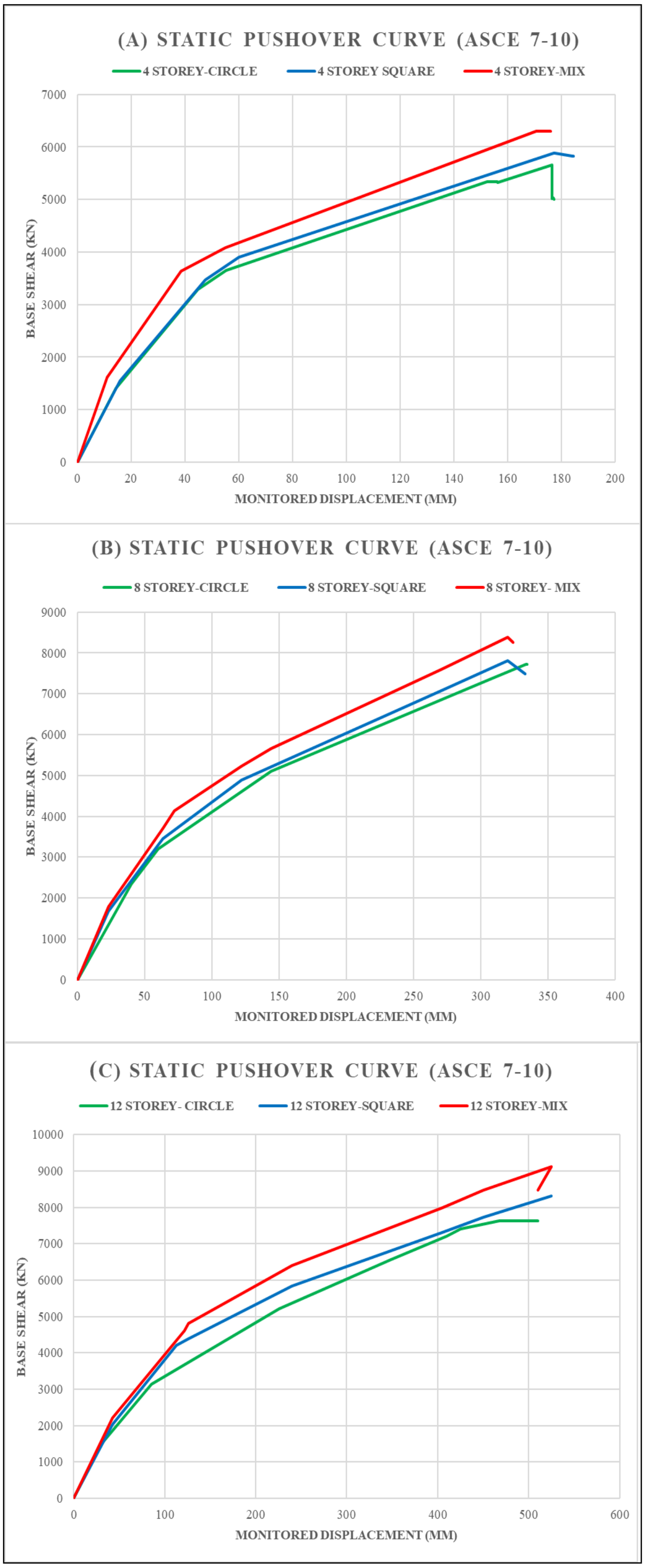

Fig -7: Combined graph of static pushover curve for 4, 8 and 12 storeyed structure designed with ASCE7-10. [5]

Static pushover curves have been plotted. From these curves values required for calculating R factor and its parameters are obtained. Parameters of R factor are evaluated using eqn. 2 and 6 and finally value of R factor evaluated using eqn. 1 for system which has been shown in the table 5.

Table -5: Determination of Response Modification Factor From Static Pushover Curve

Code	Shape of column	Storey	Vu (kN)	Vd (kN)	Δu (mm)	Δy (mm)	Rs	Rμ	R
IS 1893:2002	Square	4	5277.1	3127.2	51.26	18.48	1.68	2.77	4.65
		8	7911.4	4462.2	306.1	101.3	1.77	3.02	5.34
		12	6838.3	3542.7	435.3	130.6	1.93	3.33	6.42
	Circle	4	3361.2	2103.2	106.2	38.16	1.59	2.78	4.42
		8	6459.2	3601.6	200.1	68.18	1.79	2.93	5.24
		12	6821.2	3443.8	280.5	84.08	1.98	3.33	6.59
	Mix	4	3530.6	1353.8	118.7	46.65	2.6	2.54	6.61
		8	6011.4	2205.6	250	105.2	2.72	2.37	6.44
		12	8208.5	3400.8	458.1	145.3	2.41	3.15	7.59
IS 1893:2016	Square	4	3806.2	1889.4	122.5	48.46	2.01	2.52	5.06
		8	6834.9	3332.8	234.5	79.95	2.05	2.93	6.01
		12	7137	3713.6	359.2	100.2	1.92	3.58	6.87
	Circle	4	3432.9	1787	132.9	51.36	1.92	2.58	4.95
		8	7208.2	3015.7	262.3	103.2	2.39	2.54	6.07
		12	7231	4026.7	446.4	123.4	1.79	3.61	6.46
	Mix	4	3806.2	1303.7	121.4	52.01	2.91	2.33	6.78
		8	7238.3	2379.5	243.7	108.1	3.04	2.25	6.84
		12	8228	3221.2	401.8	131.2	2.55	3.06	7.803
ASCE 7-10	Square	4	5831.1	2102.7	176.3	61.89	2.77	2.84	7.86
		8	7479	2879.7	332.5	102.2	2.59	3.25	8.41
		12	8487.6	4001.4	525.7	109.3	2.12	4.81	10.19
	Circle	4	5332.3	1987.3	173.3	59.26	2.68	2.92	7.82
		8	7712.1	2204.7	334.3	142.3	3.49	2.34	8.16
		12	7586.9	3487	522.2	112.6	2.17	4.63	10.04
	Mix	4	6307.1	2101.3	178.5	62.01	3	2.87	8.61
		8	8254.3	2429.5	316.3	118.8	3.39	2.66	9.01
		12	9268.5	3223.1	532.7	138.7	2.87	3.84	11.02

Response modification factors are calculated and given in the table 5.

Comparison of response modification factor with different cross section and codes for same models are plotted and shown in Fig. 8.

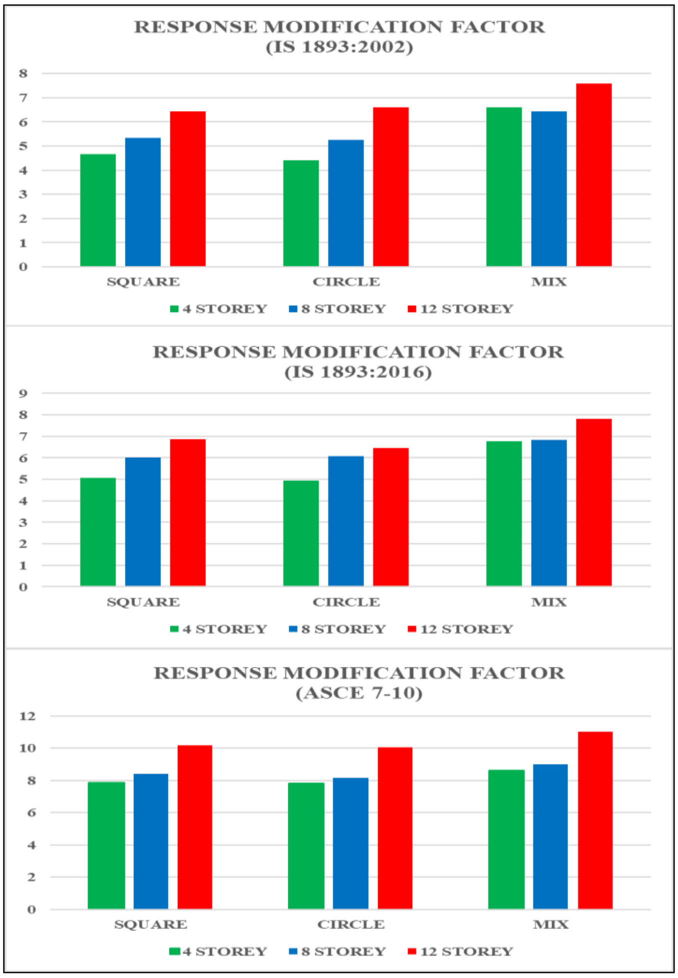

Fig -8: Variation of response modification factor with different cross section and codes.

6. CONCLUSIONS

The seismic assessment of RC frames with different storey heights and different cross section of column systems is presented in this study. Three buildings with different heights, viz. 4 storey, 8 storey ,12 storey, and different column cross sections of building systems, viz. square, circular , plus shaped, T shaped, L shaped are modelled in ETABS and pushover (nonlinear static) analysis has been carried out. From the static pushover curves, values of response modification factors are calculated.

Concluding remarks that have been drawn from the results of static pushover curves are summarized as follows:

1. Data shown in table 5 represents the trend of higher response modification factor for structures using combination of plus, L and T shaped columns using Indian standards IS 1893:2002,IS 1893:2016 and American standard ASCE 7-10.
2. From the analysis results it is observed that values of response modification factor for structures designed as per IS 1893: 2016 is on higher side as compared to those designed with IS 1893: 2002.
3. From the analysis results it is observed that values of response modification factor for structures designed as per ASCE 7-10 is on higher side as compared to those designed with IS 1893: 2002 and IS 1893:2016.
4. The results obtained from pushover analysis also indicate that structures designed by Indian standards have comparatively lower reserved strength and dissipation capacity than American standards.
5. It is observed that for structures designed according to Indian standards (IS 1893:2002 and IS 1893:2016) response modification factor increases as height of building increases. Similar observations are valid for structures designed and analysed by American code provisions.

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