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Effect of 'X' Type Bracing on Response Modification Factor for R.C. Building with Special Shaped Column Cross Sections

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Abstract: Earthquake is the most destructive natural hazard in the world. While designing any earthquake resistant structure, actual forces developed are much higher than designed forces. Therefore, to get design lateral force, the actual base shear force should be reduced by the factor known as response modification factor(R). Response modification factor plays vital role in seismic design of structures. Components of response modification factor (R) are ductility factor, over strength factor, redundancy factor and damping factor. Generally, value of response modification factor is adopted from seismic design codes of developed countries such as Europe, United States and India. Column is important part of Reinforced concrete building as overall load is transferred through column. Not only from aesthetical point of view, but also from structural aspect special shaped columns performs better than rectangular columns. So this study aims at calculating components of response modification factor(R) for column cross section with special shapes (L, T, +) for 'X' type bracing. In this study total 16 models of different number of storeys i.e. 5,10 are analysed using Pushover analysis for different seismic zones. The study also involves comparison of response modification factor (R) for structures designed with Indian code IS1893:2016(Part1) and American code ASCE 7-16.
Keywords: Response modification factor, Special shaped column, Braced column, Ductility factor, Pushover analysis.

I. INTRODUCTION

Response modification factor plays important role in seismic design of any structure. R indicates the ability of structure to dissipate energy through inelastic behaviour as given in recent building codes. R helps in determining the non linear performance of building structures during strong earthquakes. Ductility, Overstrength, Redundancy & Damping are the component parts of response modification factor. These factors are taken into consideration because of the impact they produce on various aspects of the structural energy absorption and dissipation ,internal forces redistribution in the elastic range.

$R=Rs*R\mu *R\xi *Rr$

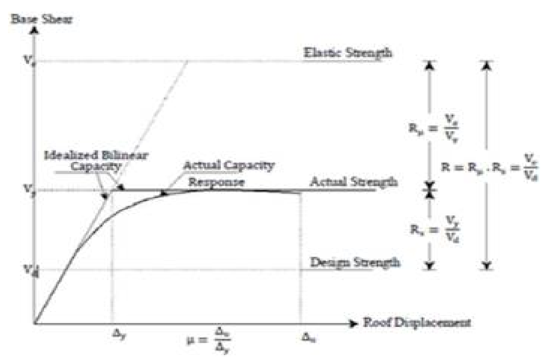

Figure 1 : Components of Response Modification (reduction) Factor [16]

1) *Ductility Factor:* The energy dissipation capacity of a structural system is mainly dependent on the ductility of the structure. According to ATC-19 ductility is represented as:

$\mu = (\Delta m) /(\Delta y)$

Where:

Δm- Maximum drift capacity

Δy-Yield displacement

Short period T < 0.2 seconds	$R\mu = 1$
Intermediate period 0.2 < T < 0.5 seconds	$R\mu= \sqrt{2\mu - 1}$
Long period T > 0.5 seconds	$R\mu = \mu$

2) *Overstrength Factor:* The overstrength factor measures additional strength of any structure has beyond its design strength.It helps in preventing collapse of the buildings. The overstrength factor can be defined as the ratio of actual lateral strength to the design lateral strength.

R = Vy/Vd or Rs = Vmax/Vd

Where:

Vy (Vmax) - Base shear coefficient corresponding to the actual yielding of the structure

Vd -Code prescribed unfactored design base shear coefficient

3) *Redundancy Factor:* Redundancy factor Rr can be calculated as the ratio of ultimate load to the first significant yield load; estimation of this factor requires detailed non-linear analysis.

R = Vu Vy

4) *Damping Factor:* Damping factor is used for the structures in which additional energy dissipating(Viscous damping) devices are provided. The damping factor is taken as 1 for the buildings in which no such devices are used.

II. LITERATURE REVIEW

An detailed literature review was carried out prior to the project. This literature survey includes SMRF and OMRF, Response reduction factor, ductility, pushover analysis ,braced columns, shape of columns.

According to 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) RC frame buildings are classified in two classes, Ordinary Moment Resisting Frames (OMRF) and Special Moment Resisting Frames (SMRF) having response modification factors 3 and 5 respectively, whereas for braced frames response modification factor is 4.5. 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 response modification factors are 3, 5 and 8, respectively, whereas for braced SMRF & OMRF response modification factors are 6 and 5.5 respectively. Sadjadi et.al. [8] assessed seismic performance of RC frames of 5-story frame designed as ductile, nominally ductile and Gravity Load Designed (GLD) and concluded that the nominally ductile frames behaved very well under the considered earthquake. V.

Gioncu [10]observed that factors regarding seismic actions ie. Velocity and cyclic loading reduces available ductility. Whittaker et.al. [11] identified formulation for response modification factor. 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 through a response modification factor (R) and observed that Indian standard recommends higher value than the actual value of R. Swajit Singh Goud et. al. [15] studied the seismic resistant design philosophy.

The value of R is directly related to the ductility level provided in the structure. Jianguo et al. [16] investigated the seismic behaviour of concrete-filled rectangular steel tube structures and concluded that in push-over analysis different types of plastic hinges should be applied for the beam elements and the column elements separately. B. Shah and Pradeep Patel [17] studied a 7 storey RC space frame model with two 3m x 3m panels in each plan direction and two 3m x 4.5m panels in each principal plan direction and stated that 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. [18] 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.

Abdel-Rahman Sobhy et al. [19] tudied 2D braced and un-braced reinforced concrete moment resisting frames to study the effect of position, number of bracing and concluded that increasing in number of X-bracing lead to increase the value of R factor and therefore it leads to improve the behavior of the structure during earthquake

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III. BUILDING DETAILS

The structural models considered in this study are 5 & 10 storeyed buildings symmetrical about both axis with 3 bays. Width of bay is 4m.Typical height floor is 3m. Modelling is done using the software ETABS.

Table 1: Details and dimensions of building models

Sr. No.	Parameters	Values
1	Type of structure	Special moment resisting RC frame
2	Grade of concrete	M50
3	Grade of steel	Fe 415
4	Floor height	3 m
5	Beam size	350 mm X 400 mm
6	Column size	400 mm X 400 mm
7	Slab thickness	150 mm
8	Live and dead load on floor	2 KN/m^2
9	Live load on roof	1.5 KN/m^2

Table 2: Seismic Properties (IS 1893:2016)

Sr. No.	Parameters	Values
1	Seismic zone	V (Z=0.36)
2	Importance Factor	1.2
3	Damping	5%
4	Site Class	Type II (Medium soil)
5	RMF (Braced frames)	4.5
6	RMF (Unbraced frames)	5

Table 3: Seismic Properties (ASCE 7-16)

Sr. No.	Parameters	Values
1	Seismic zone	IV (Z=0.4)
2	Importance Factor	1
3	Damping	5%
4	Site Class	D (Stiff soil)
5	RMF (Braced frames)	6
6	RMF (Unbraced frames)	8

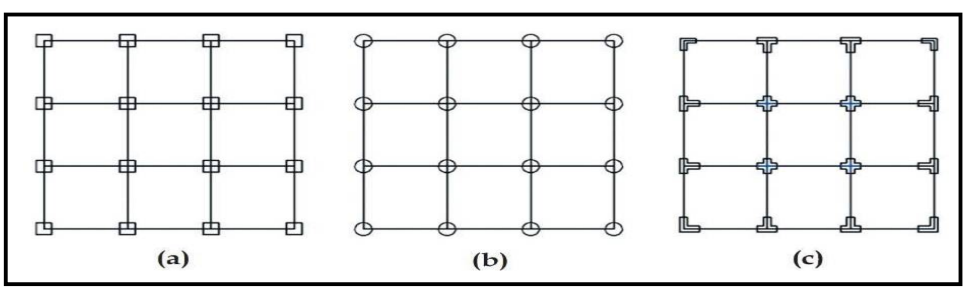

Figure 2: Plans having column cross sections (a) Plan with square columns, (b) Plan with circular columns, (c) Plan with plus, L and T-shaped columns [23]

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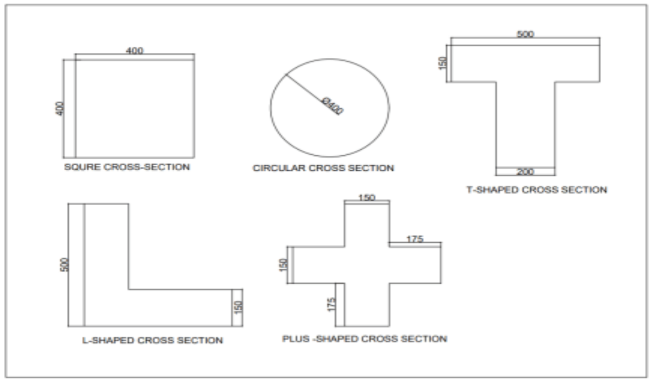

Figure 3 : Cross sections of different shapes of column

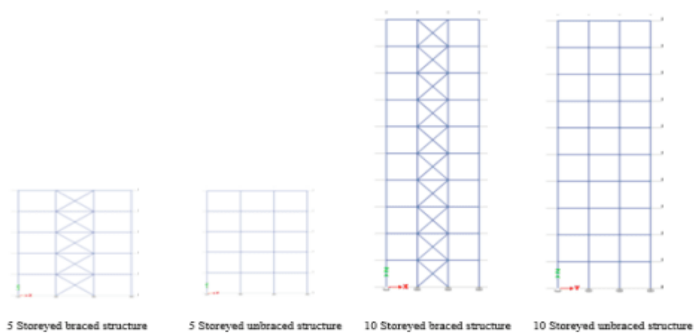

Figure 4: Cases for multi-storeyed structures

IV. ANALYSIS

Analysis of the frames has been done using ETABS17.0.1, which is structural analysis software used for static and dynamic analysis. Pushover analysis is performed using ETABS nonlinear version 17.0.1 Capacity curve is obtained from the graph of base shear versus displacement. Displacement control strategy is used for nonlinear static analysis.

V. RESULT AND DISCUSSION

16 models were developed and analysed and on that basis pushover curve was obtained. The response modification factors are calculated in table 5.

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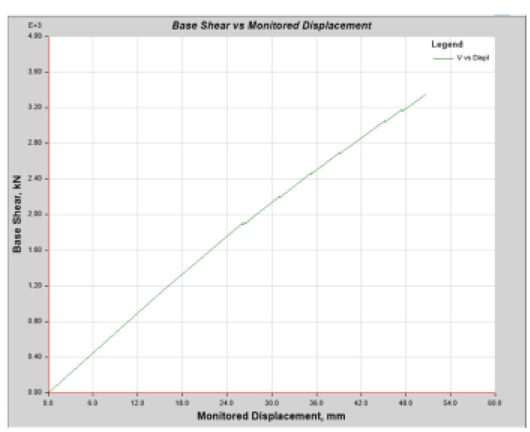

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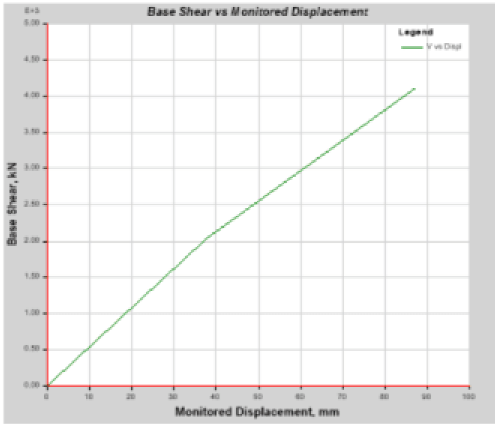

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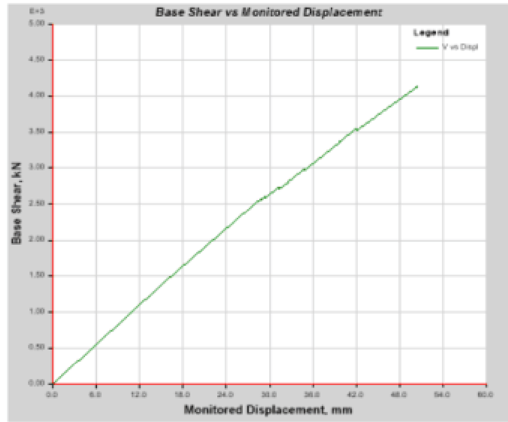

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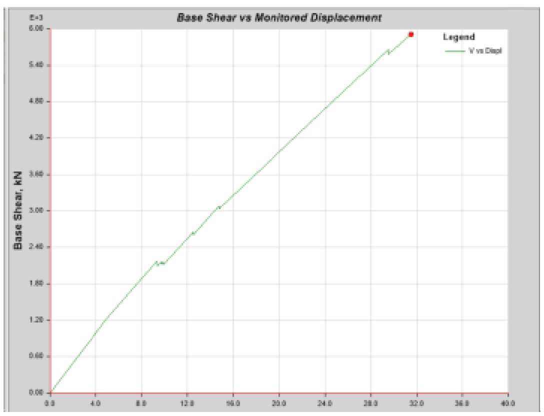

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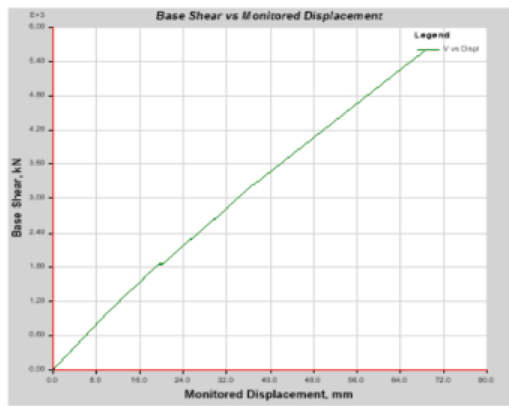

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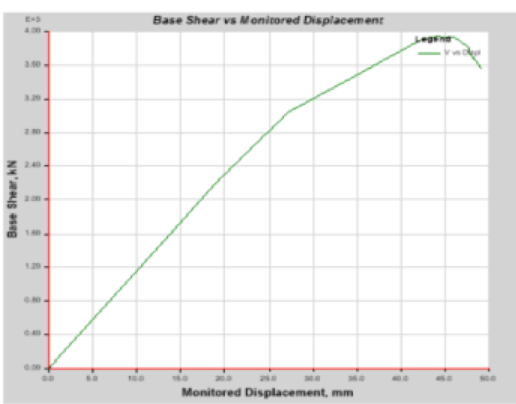

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Fig 5 :Static pushover curves obtained by using Indian standard code IS 1893:2016

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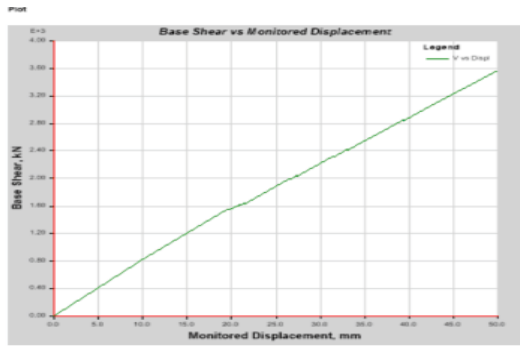

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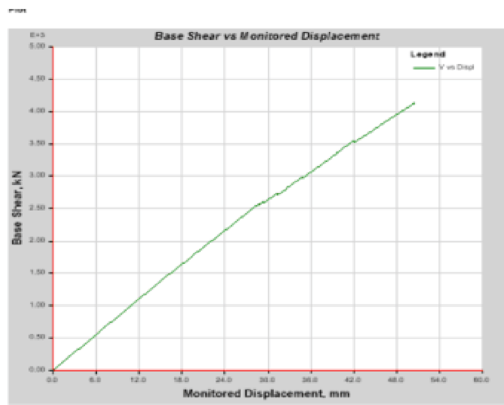

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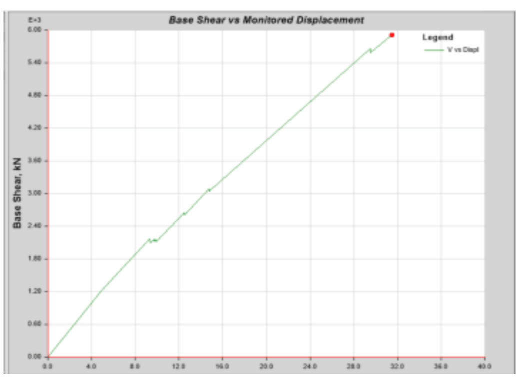

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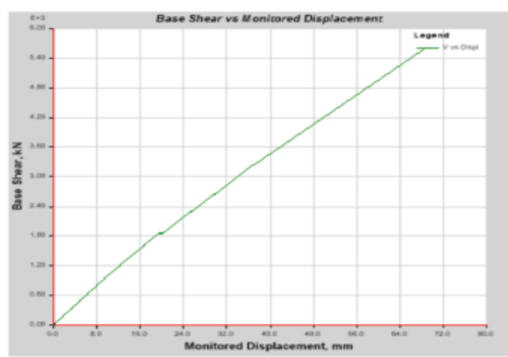

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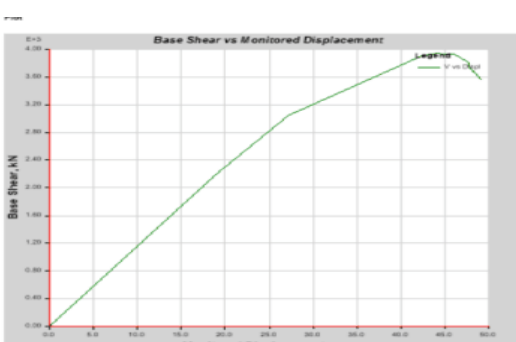

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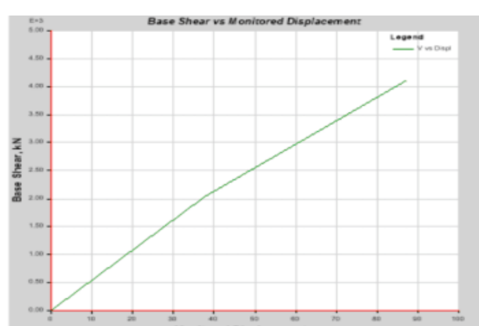

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Fig 6: Static pushover curves obtained by using American standard code ASCE 7-16

Table 5: Determination of R factor from static pushover curves

Code	Shape of column	Storey	Notations	Vu (kN)	Vd (kN)	Δu (mm)	Δy (mm)	Rs	Rμ	R
IS 1893:2016	Square	5	I5SX	3520.17	1485.30	27.15	13.30	2.37	2.04	4.84
		10	I10SX	4130.61	1716.86	50.45	24.14	2.42	2.09	5.03
	Circle	5	I5CX	2997.47	1476.58	16.7	7.26	2.03	2.30	4.68
		10	I10CX	3343.12	1714.42	50.62	20.10	1.95	2.51	4.91
	Mix	5	I5MX	5912.7	2104.16	14.78	7.17	2.81	2.06	5.79
		10	I10MX	5668.47	1934.63	67.10	33.05	2.93	2.03	5.97
	Unbraced	5	I5UX	4256.78	1570.76	62.16	31.71	2.71	1.96	5.30
		10	I10UX	4376.14	1568.56	103	51.24	2.79	2.01	5.62
ASCE 7-16	Square	5	A5SX	3478.46	1220.51	28.26	12.67	2.85	2.23	6.34
		10	A10SX	4215.94	1511.09	51.07	21.73	2.79	2.35	6.57
	Circle	5	A5CX	2987.32	1176.11	17.45	7.15	2.54	2.44	6.21
		10	A10CX	3554.21	1377.60	51.78	20.96	2.58	2.47	6.39
	Mix	5	A5MX	5585.41	1912.81	29.03	11.04	2.92	2.63	7.68
		10	A10MX	5603.38	1843.21	64.08	24.93	3.04	2.57	7.82
	Unbraced	5	A5UX	3940.77	1422.66	49.61	15.95	2.77	3.11	8.64
		10	A10UX	4107.87	1493.77	87.12	26.81	2.75	3.25	8.93

VI. CONCLUSION

The seismic assessment of braced reinforced concrete frames having different number of stories viz.5 storey &10 storey and special shaped viz. circular, square, T shaped, plus shaped &L shaped column cross section is presented in this paper. These models are developed and pushover analysis is carried out in ETABS. From the static pushover curve values of response modification factors are calculated.

Concluding remarks drawn from the analysis are as follows:

A. From the analysis it is observed that values of response reduction factor for the structures designed as per ASCE 7-16 is on higher side than that of structures designed with IS1893:2016
B. The values of response reduction factor computed from static pushover analysis is strongly affected by changing number of stories, geometric properties and by providing bracing.
C. The value of response reduction factor given in design codes often do not match the true values.
D. From the analysis results it is observed that response reduction factor for structures using special shaped column cross section is higher than that of structures of regular shaped column cross sections.

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