Effect of Aspect Ratio on Response Reduction Factor of RC Building

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Abstract

The behaviour of a building during earthquakes depends on its overall size, shape and geometry. The building aspect ratio is the key factor for the efficient structural design. This research emphases on the effect of both plan aspect ratio (L/B ratio i.e. horizontal aspect ratio) and vertical aspect ratio (H/B ratio i.e. slenderness ratio), where L is the length of the building frame, B is the base width & H is the total height of the building frame. Here, height and the base dimension of the building are varied according to the aspect ratio and calculate the actual value of response reduction factor for SMRF frame and comparing these values with the value suggested in IS 1893.

Keywords: *SMRF, Response Reduction Factor, Pushover Analysis, Ductility, Aspect Ratio.*

INTRODUCTION

In the present study, the main objective is to evaluate the response reduction factors for buildings designed and detailed as per IS code. Response reduction factor reduces the elastic forces and calculate the seismic design base shear. Pushover analysis is simplified procedure for calculating the actual response reduction factor and modeling the nonlinearity in the materials. This study comprises static push over analysis of the designed RC frames (SMRF) and the evaluation of R factors.[7]

R factor depends on ductility factor, strength factor, structural redundancy and damping. It is essential to calculate the value of R factor of RC frame building and compare it with codal provision. Based on the elastic spectrum, it would be too costly to design a structure. IS 1893[4] introduces a “response reduction factor” R to reduce the seismic loads. But this reduction can be made, only if adequate ductility in the structure is developed through adequate design and ductile detailing of the RC frame. So in-order to obtain the exact response, it is suggested to perform Non-Linear static pushover analysis.[8]

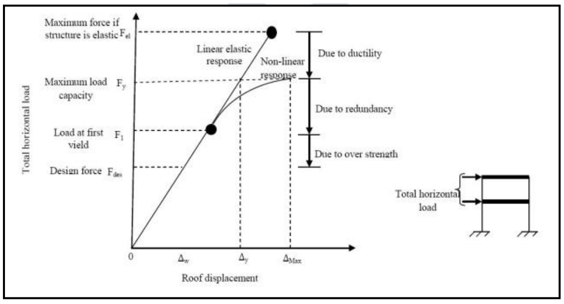

Fig. 1 *Concept of response reduction factor*

PROCEDURE AS PER ATC-19

1. ***Calculation of strength factor (Rs):***

Strength factor r can be estimated as ratio of ultimate load to first significant yield load; estimation of this factor requires detailed non-linear analysis.

$Rs = V_o/V_d$

V_o = maximum base shear in a structure

V_d = design base shear

2. ***Calculation of ductility factor (Rµ):***

According to ATC-19, the global ductility or displacement ductility 'µ' is represented as:

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

Where, Δm and Δy are the maximum drift capacity and yield displacement respectively. In present study equation suggested by Miranda and Bertero is used to evaluate the ductility factor Rµ,

$R\mu = (\mu-1)/\Phi + 1$

Where ø depends on soil conditions and time period

For rock site:

$\Phi=1+(1/(10T-\mu T)-(1e-1.5(\ln T-0.6)^2/2T)$

For alluvium site:

$\Phi=1+(1/(12T-\mu T)-(2e-2(\ln T-0.2)^2/5T)$

For soft soil site:

$\Phi=1+(Tg/3T)-(3Tge-3(\ln(T/Tg)-0.25)^2/4T)$

3. ***Calculation of redundancy factor (Rr):***

As Per ATC 19[1]

Table 1 *Table for drift redundancy factor*

Lines of vertical seismic framing	Drift redundancy factor
2	0.71
3	0.86
4	1.00

Pushover analysis of RC Frame

To analysis the seismic performance of a building, pushover analysis is carried out where the structural model is laterally pushed until a target displacement is achieved or a collapse mechanism has occurred as shown in Fig 2. The loading is increased in increments with a specific predefined pattern such as uniform or inverted triangular pattern. During the analysis, the gravity load is kept as a constant. The structure is pushed until sufficient hinges are formed such that a curve (base shear v/s roof displacement) can be achieved. From this curve, the maximum base shear the structure can resist and its corresponding lateral drift can be found. A typical Pushover curve is shown in Fig 2.

ATC-40[2] and FEMA-273[3] documents, define the acceptance criteria for pushover analysis. As shown in Fig 3, five points labeled A, B,C, D, and E are used to define the force deflection behavior of the hinge and three points labeled IO, LS and CP are used to define the acceptance criteria for the hinge.

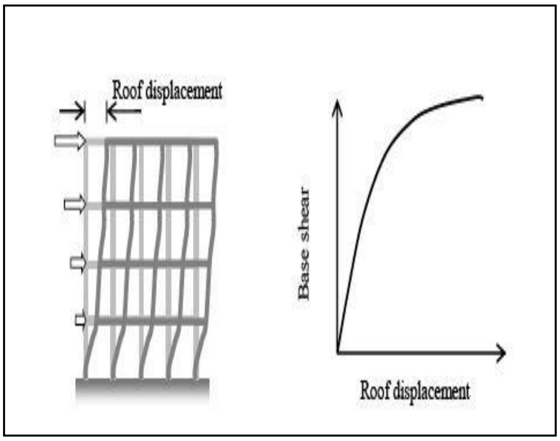

Fig. 2 *Lateral Load Distribution and a Typical Pushover Curve*

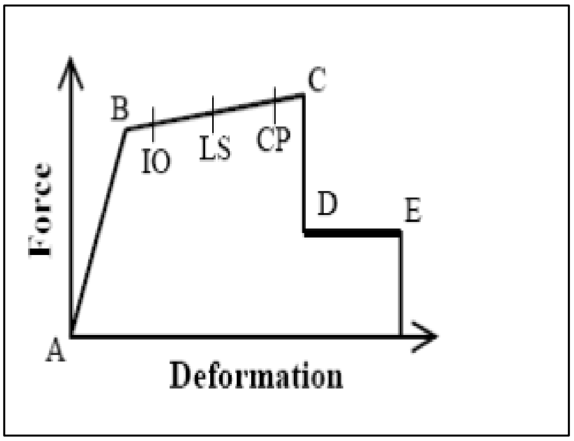

Fig.3 *Force deformation pushover hinge*

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OBJECTIVE

To study effect of both Vertical Aspect Ratio (H/B ratio i.e. Slenderness Ratio) and Horizontal or Plan Aspect Ratio (L/B ratio) on evaluation of response reduction factor for SMRF.

STRUCTURAL SYSTEM CONSIDERED

The buildings are designed for the relevant Indian design codes, employing a linear elastic analysis in SAP 2000 nonlinear software. For this purpose, the beam and column is modeled as 3D frame component with relevant section properties. The design base shear has been calculated by applying mode superposition technique and scaled to the base shear obtained using the relevant empirical formulae for design period, as suggested in IS 1893(Part-I)[4]

In the present study, three building models having different Aspect ratios viz. 1,2,3 ranging from 12 m to 36 m length of different vertical Aspect ratios viz. 1,2,3, ranging from 4 to 12 storeys have been consider. In this way total 9 building models are studied. Dead load on the building is assigned according to IS 875 (Part I) and Floor Finish load and live load are considered as 1 kN/m^2 and 3 kN/m^2 respectively. The buildings are analysed and designed as per IS 1893 (Part I) for seismic zone IV with zone factor 0.24 on soil type II, and IS 456[6] and ductile detailing of RC sections are done as per IS 13920[5] . All supports were assumed to be fixed at base. All other data given in Table 2.

Table 2 *Description of Model*

Type of Structure	Details
Grade of concrete	M25
Grade of steel	Fe 415
Floor height	3.0 m
Typical Bay width	6.0 m
Slab thickness	150 mm
Live Load on floor	3 kN/m^2
Floor Finish Load	1 kN/m^2
Response reduction factor	5
Soil type	Medium
Zone	IV

Table 3 *Formulation of models geometry*

Aspect Ratios	V.A.R. - 1	V.A.R. - 2	V.A.R. - 3
	4 Storey	8 Storey	12 Storey
H.A.R - 1	12x12x12 m M11	12x12x24 m M12	12x12x36 m M13
H.A.R. - 2	24x12x12 m M21	24x12x24 m M22	24x12x36 m M23
H.A.R. - 3	36x12x12 m M31	36x12x24 m M32	36x12x36 m M33

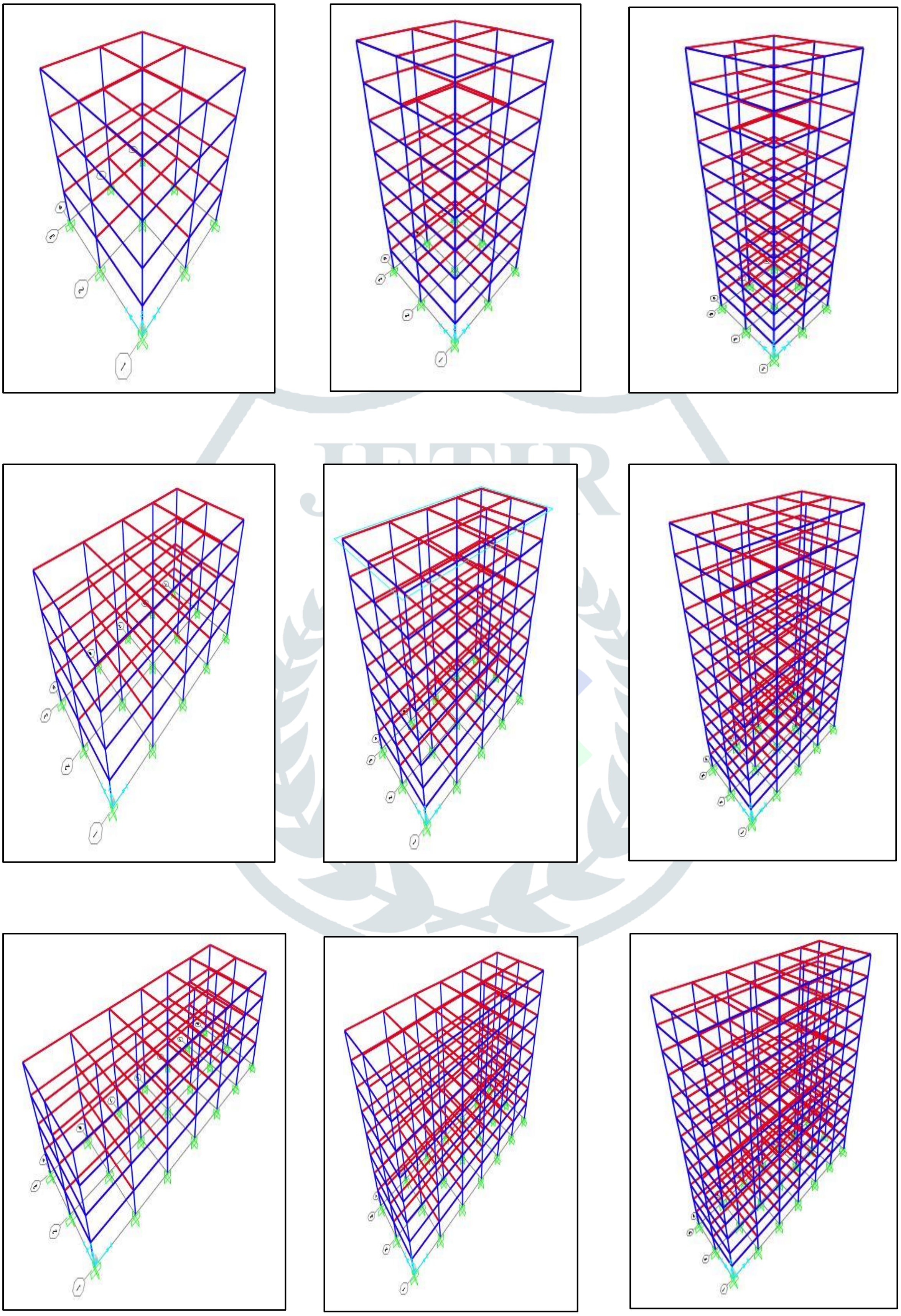

Fig.4 *Models of study RC Frame*

Table 4 *RC section details for the study frame*

Frame Type	Floor	Beam (mm)	Column (mm)	Beam Reinforcement	Column Reinforcement
M11	1-4	300*500	500*500	3-20Φ(top)+ 6-20Φ(bottom)	10-16Φ
M12	1-4	300*550	550*550	3-20Φ(top)+ 7-20Φ(bottom)	12-16Φ
	4-8	300*550	500*500	3-20Φ(top)+ 7-20Φ(bottom)	12-16Φ
M13	1-4	300*600	600*600	3-25Φ(top)+ 6-25Φ(bottom)	10-20Φ
	4-8	300*600	550*550	3-25Φ(top)+ 6-25Φ(bottom)	10-20Φ
	8-12	300*600	500*500	3-25Φ(top)+ 6-25Φ(bottom)	10-20Φ
M21	1-4	300*500	500*500	3-20Φ(top)+ 6-20Φ(bottom)	10-16Φ
M22	1-4	300*550	550*550	3-20Φ(top)+ 7-20Φ(bottom)	12-16Φ
	4-8	300*550	500*500	3-20Φ(top)+ 7-20Φ(bottom)	12-16Φ
M23	1-4	300*600	650*650	3-25Φ(top)+ 6-25Φ(bottom)	10-20Φ
	4-8	300*600	550*550	3-25Φ(top)+ 6-25Φ(bottom)	10-20Φ
	8-12	300*600	500*500	3-25Φ(top)+ 6-25Φ(bottom)	10-20Φ
M31	1-4	300*500	500*500	3-20Φ(top)+ 6-20Φ(bottom)	10-16Φ
M32	1-4	300*550	600*600	3-20Φ(top)+ 7-20Φ(bottom)	12-16Φ
	4-8	300*550	500*500	3-20Φ(top)+ 7-20Φ(bottom)	12-16Φ
M33	1-4	300*600	750*750	3-25Φ(top)+ 6-25Φ(bottom)	10-20Φ
	4-8	300*600	600*600	3-25Φ(top)+ 6-25Φ(bottom)	10-20Φ
	8-12	300*600	500*500	3-25Φ(top)+ 6-25Φ(bottom)	10-20Φ

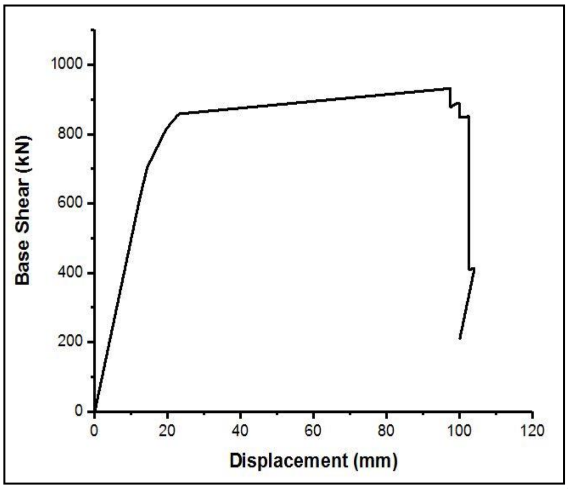

Fig.5 *Pushover curve for M11 Frame (12x12x12 m)*

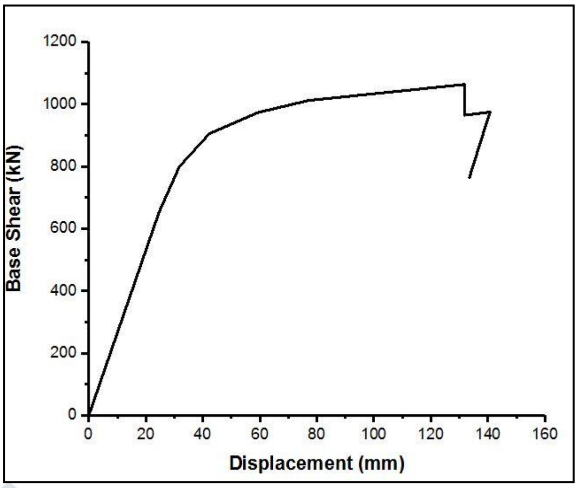

Fig.6 *Pushover curve for M12 Frame (12x12x24 m)*

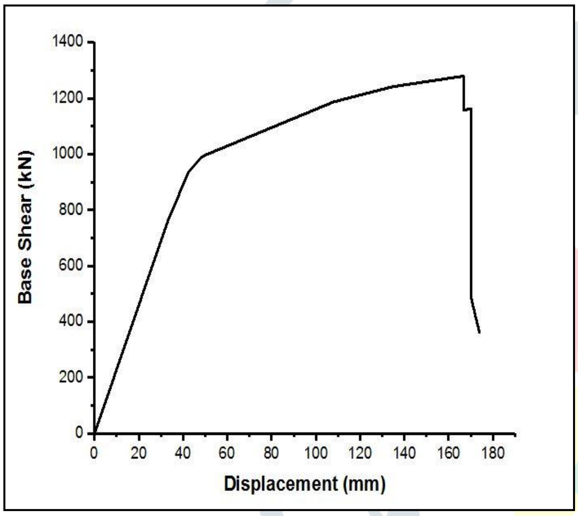

Fig.7 *Pushover curve for M13 Frame (12x12x36 m)*

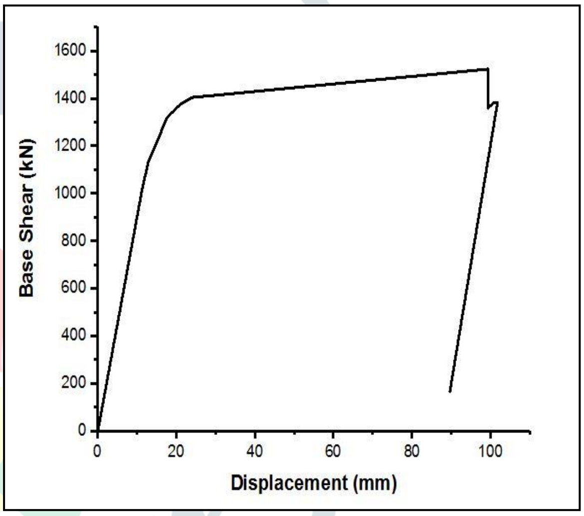

Fig.8 *Pushover curve for M21 Frame (24x12x12 m)*

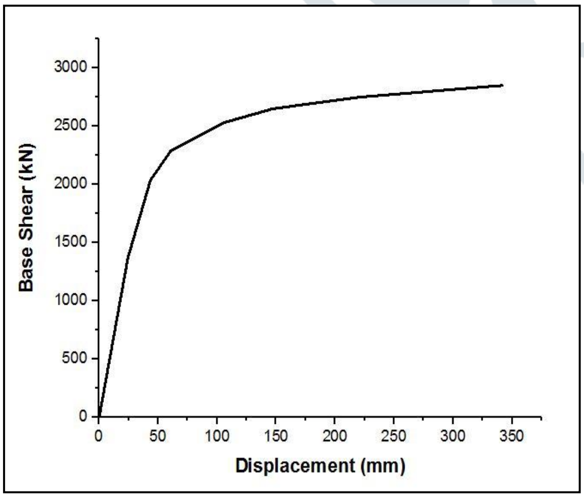

Fig.9 *Pushover curve for M22 Frame (24x12x24 m)*

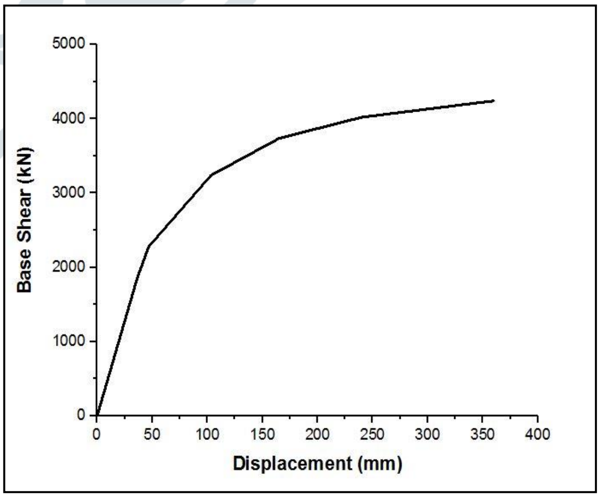

Fig.10 *Pushover curve for M23 Frame (24x12x36 m)*

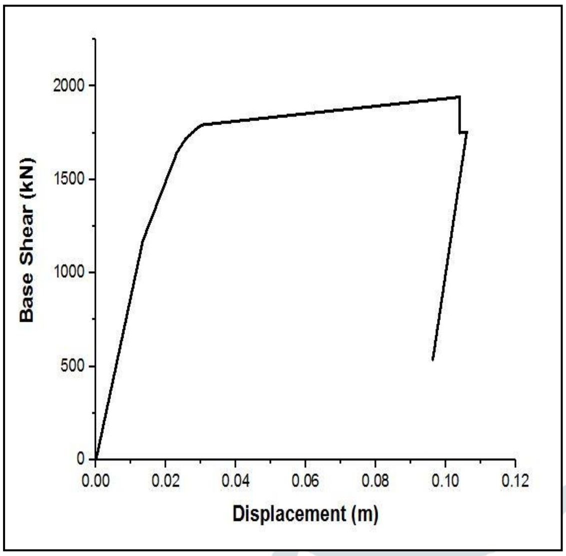

Fig.11 *Pushover curve for M31 Frame (36x12x12 m)*

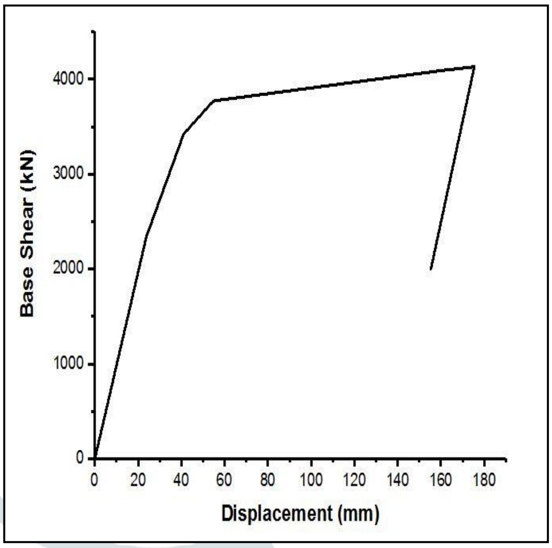

Fig.12 *Pushover curve for M32 Frame (36x12x24 m)*

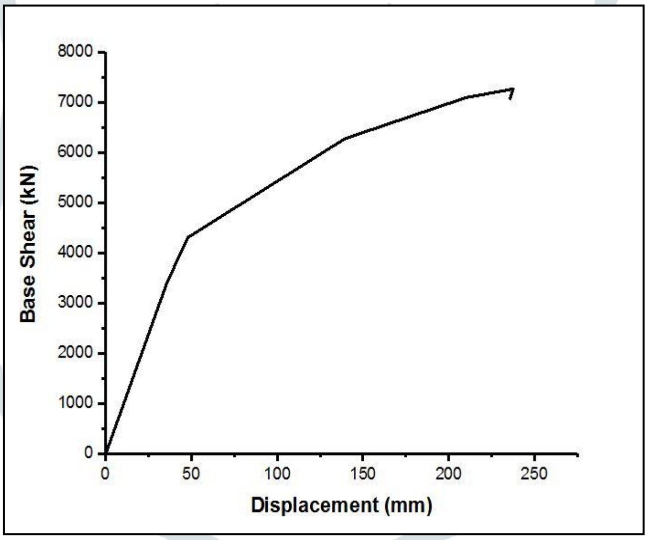

Fig.13 *Pushover curve for M33 Frame (36x12x36 m)*

ESTIMATION OF R-FACTOR & RESULT

For RC Frame M11 12x12x12 m

Calculation of strength factor (R_s):
Max Base Shear (from pushover curve)
V_o=1100.00 KN
Design Base shear (as per EQ calculation)
V_d=451.263 KN

$R_s = V_o/V_d = 2.4376$

Calculation of ductility factor (Rµ):
Max drift capacity Δm=48 mm (0.004H)

Yield drift Δy=20 mm
μ= ductility ratio = Δm / Δy=2.40
Φ can be found out as per formula given in ATC-19
Time period T=0.7395 sec
Φ=0.8136
$R_\mu = \{(\mu - 1 / \Phi) + 1\}$
$R_\mu = 2.73$
Calculation of redundancy factor(Rr):
R_r =0.86 (Redundancy factor from ATC-19)

Calculation of response reduction factor(R):
$R = R_S \times R_r \times R_\mu$ =2.4376X0.86X2.730
R=5.722

Table 5 *Table for calculation of R factor*

Frame	V_0 (kN)	V_d (kN)	R_s	Δy (mm)	Δm (mm)	R_μ	R_r	R
M11	1100.00	451.263	2.437	20	48	2.73	0.86	5.72
M12	1150.00	476.213	2.414	40	96	2.71	0.86	5.62
M13	1410.00	550.518	2.561	61	144	2.46	0.86	5.43
M21	1640.00	672.621	2.438	18	48	2.96	1.00	7.23
M22	2750.00	748.899	3.672	58	96	1.89	1.00	6.92
M23	3400.00	856.832	3.967	90	144	1.71	1.00	6.79
M31	2460.00	913.332	2.693	17	48	2.97	1.00	8.01
M32	4510.00	1152.12	3.914	57	96	1.92	1.00	7.55
M33	5220.00	1361.67	3.833	81	144	1.94	1.00	7.41

COMPARISON OF RESPONSE REDUCTION FACTOR

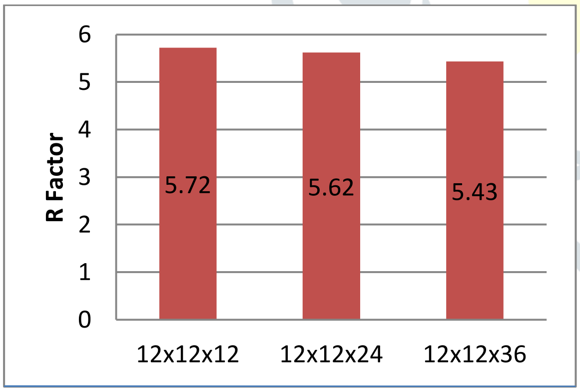

Fig.14 *Comparison of R factor for M11 M12 and M13 frames*

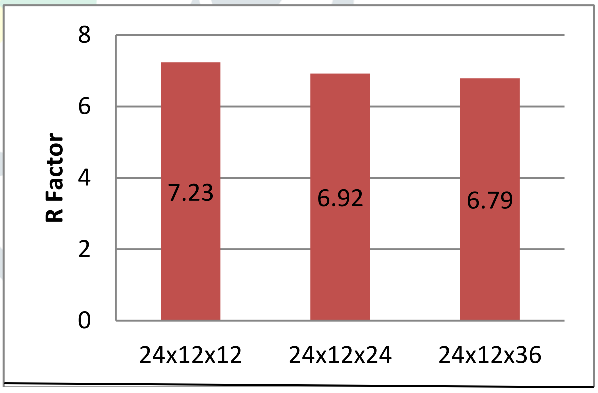

Fig.15 *Comparison of R factor for M21 M22 and M23 frames*

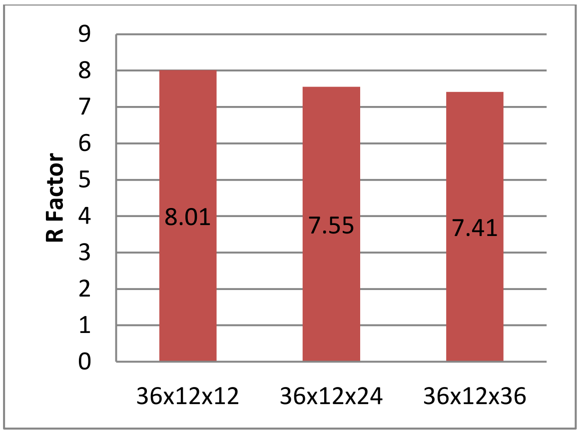

Fig.16 Comparison of R factor for M31 M32 and M33 frames

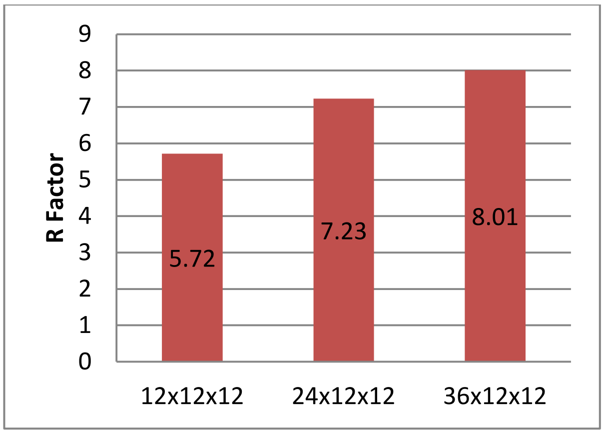

***Fig.17** Comparison of R factor for M11 M21 and M31 frames*

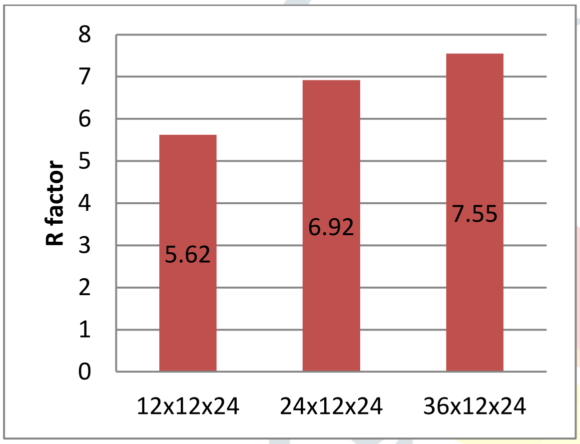

***Fig.18** Comparison of R factor for M12 M22 and M32 frames*

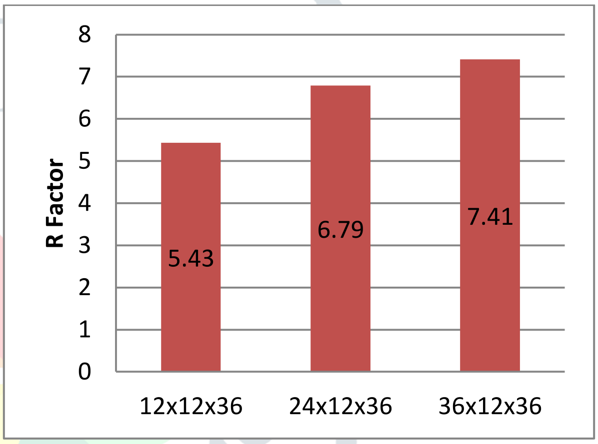

***Fig.19** Comparison of R factor for M13 M23 and M33 frames*

DISCUSSION OF RESULTS

- The response reduction value ranges from 5.43-8.01 for the frames considered.
- All values are higher than the IS specified value of R (=5.0) for SMRF.
- From fig.13 to 18 shows the comparison of response reduction factor for different RC Frames considered. Value of R factor is increases as no of bays increases. It can be seen that values of response reduction factor increases with height of the RC Frame.

CONCLUSION

- In present study, frame 12X12X36 m shows the lowest value of R factor of 5.43 while frame 36x12x12 m shows the highest R factor of 8.01.
- It can be seen that as L/B ratio increase, the response reduction factor also increase. It means as number of bays increases the response reduction factor also increases.
- It also can be seen that as H/B ratio increase, the response reduction factor decrease. It means as number of storeys increases the response reduction factor decreases.

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