Evaluation of Response Reduction Factor of RCC Framed Structure having an Arched Beam

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Abstract**:** ***In Civil Engineering, the requirement of large span frame structures is in demand which provide more clear space without any obstacles. The seismic design of these types of structures is more complicated than regular framed structures. In this study, Response Reduction Factor (R) is evaluated for RCC frame having different type of arched beams using the software SAP2000. The value of R is investigated for realistic RCC frame having straight beam, segmental arch, semi-circular arch and parabolic arch for different earthquake zones. Non-linear static pushover analysis is conducted to measure the R factor which is very important for economic design and safe structure. Design & detailing of a structure is done as per the provisions of Indian standards. The results show that the value of R drastically changes with different earthquake zones, which is not specified in Indian standards. Other significant conclusions are also provided in this study.***

Keywords**: Large span reinforced concrete arched frames, Non-linear Static analysis, Response reduction factor (*R*), SAP2000.**

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I. INTRODUCTION

Today, the seismic forces are one of the most important forces to be considered in the analysis and design of any structure. Bureau of Indian standards has divided Indian region in four different earthquake zones based on technical data regarding earthquakes occurred in past few years, seismicity and tectonic structure of the region. In Zone II to V, the Zone V is seismically most active Zone, whereas the Zone II is least active Zone. Seismic analysis can be done by two analytical methods namely nonlinear static analysis method and dynamic analysis method. The nonlinear static analysis method considered where the relation between applied force and displacement is nonlinear. This research focuses on the study of Response Reduction Factor (*R*) which is measured by pushover analysis. The factor R was firstly introduced in ATC-3-06 (ATC, 1978), and then *R* factor was continuously developed. This factor is used to reduce the actual base shear of a structure to get design horizontal forces through Design Basis Earthquake.

During an earthquake event, forces are generated along all axes resulting in lateral forces, moments, shear forces in the structure. For the cost of the structure to be economically viable, the structure needs to design for forces, less than the actual forces generated in an extreme event but still ensuring safety through a combination of strength, ductility and redundancy. Indian standards IS 1893 [1] suggested the value of *R* for Special Moment Resisting Frame (SMRF) is 5 and for Ordinary Moment Resisting Frame (OMRF) is 3. For reinforced concrete structure, SMRF is designed and detailed according to IS 13920 [2]. ATC – 19 [3] suggests that value R factor should be a product of Ductility factor (R_μ), Over-Strength factor (R_S), Redundancy factor (R_r) as followed by the Equation (1).

$$R = R_s \times R_\mu \times R_r \tag{1}$$

Over strength factor (R_s) is a ratio of maximum base shear (V_u) of a structure to the design base shear (V_d) of a structure. V_u is obtained by the pushover curve whereas V_d is calculated as per IS 1893 [1]. The R_s is obtained by using Equations (2) - (4)

$$R_s = V_u / V_d \tag{2}$$

$$V_d = A_h \times W \tag{3}$$

$$A_h = Z/2 \times I/R \times S_a/g \quad (4)$$

where

A_h = Design horizontal seismic coefficient
Z = Seismic Zone factor
W = Seismic weight of the structure
I = Importance factor
S_a/g = Design acceleration coefficient

The value of S_a/g for different soil type corresponding to natural time period (T) of structure which is obtained by the Response Spectrum graph as per IS: 1893 [1]. Response Spectrum Analysis calculates modal responses using the natural periods of the structure which is obtained by the Equation (5).

$$T = (0.09h) / \sqrt{d} \quad (5)$$

h = height of Structure
d = base dimension of the structure along the considered direction of earthquake shaking

Newmark and Hall gives R_μ-μ-T relationship which is used to measure the ductility factor as per ATC-19 [3].This relationship is based on the displacement ductility ratio (μ) and time period (T). Ductility ratio is obtained through the ratio of maximum displacement to yield displacement of the structure which is measured from pushover curve. Equations (6)-(8) show the value of ductility factor according to different range of time period (T). Fig. 1 shows the graph of R_μ-μ-T relationship given in ATC-19 [3].

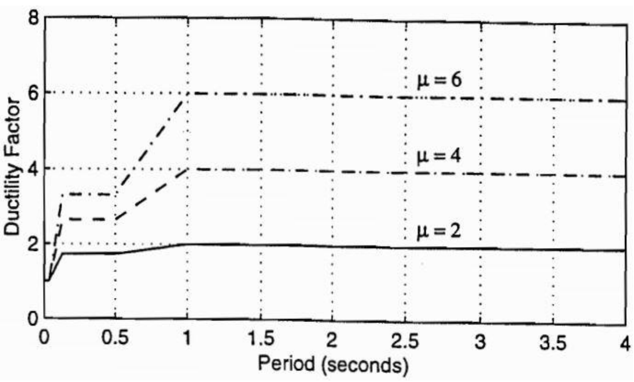

Fig. 1. Newmark and Hall R_μ-μ-T relationship *[3]*

Time period below 0.03 second : $R_\mu = 1.0$ (6)

Time period between 0.12 to 0.5 second: $R_\mu = \sqrt{(2\mu-1)}$ (7)

Time period exceeding 1.0 second : $R_\mu = \mu$ (8)

where
$\mu = \Delta_m/\Delta_y$ (Δ_m= Maximum Displacement, Δ_y = Yield Displacement)

The values shown in Table 1 are not proposed for implementation in seismic codes or guidelines. It is only inspiration for discussion of researchers and design professionals and to promote research and study. The draft values shown in Table 1 have no technical basis.

TABLE 1. Redundancy Factor as per ATC-19 *[3]*

Number of Vertical Seismic Frame	Redundancy Factor
4	1.00
3	0.86
2	0.71

II. LITERATURE SURVEY

Mondal et al. [4] obtained the actual values of R at two performance levels for 2, 4, 8 & 12 story reinforced concrete moment framed building, which was located in zone IV with time periods covering a large spectrum. They concluded that the Indian Standards endorses more value than actual value of R which is unsafe.

Chaulagain et al. [5] estimated value of R in Kathmandu valley for engineered designed construction of RCC framed buildings. They selected 12 different typical irregular engineered buildings located in Kathmandu valley. They measured actual value of R and compared with the standard values provided in design procedure. As per study, they found that in rigid frames, the value of R is higher due to structural and geometrical configuration.

Tamboli and Amin [6] measured R and lateral strength of 4-story RCC framed building with provisions of bracing or shear wall at centre or alternative bay and gave comparative study of RCC bare frame. They concluded that the R factor of this structure was noticeably changed by the arrangements and types of bracing system. Due to provision of bracing system or shear wall in alternate bays, the values of R nearly are increased from1.88 to 2.2 and 3.75 to 3.9 times, respectively.

Khatavkar et al. [7] focused on the comparison of response reduction factor between 8-storey of RCC frame and steel frame. According to results, they noticed that the value of R given in IS codes are not realistic.

Mohod [8] created 9 models with different plane irregularities of RCC framed building and carried out nonlinear static analysis to get Response reduction factor R and observed that complex plan geometries attract more forces which make them weak under the effect of seismic action and concluded that the Complex geometries can be fixed into simple shapes by provision of seismic gap as per the requirements.

III. STRUCTURAL ANALYSIS

The structure shown in Fig. 2 is a Reinforce concrete frame having a segmental arched beam, this frame is actually an entrance gate of VADTAL town in KHEDA district, GUJARAT, INDIA, which is located in Earthquake Zone-III. This reinforced concrete frame has an arched beam with a clear span of 261 inches, Height of the structure is 328 inches at the ground level. In this study, Modelling of this structure is done in SAP-2000 software to obtain the actual value of R. Design and detailing of structure is carried out as per IS 456 [9], IS 1893 [1] and IS 13920 [2].

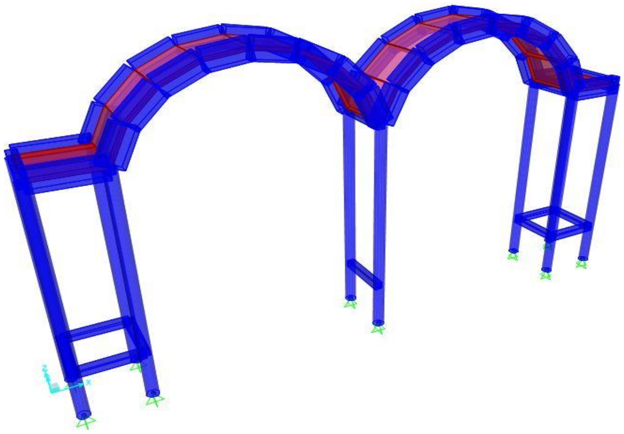

Fig. 2. Structure Modelled in SAP-2000

TABLE 2. Structural Details

Frame Type	Reinforce concrete
Height of Structure	328 inch
Length & Width	654 & 66 inch
Depth of Foundation	60 inch
Grade of Concrete	M20
Type of Reinforcement	HYSD415
Analysis Software	SAP-2000

TABLE 3. Detailed Parameters of the structure

Section Name	Dimensions (Inch)	Grade of Concrete & Steel	Reinforcement Details
Beam 1	9”× 17”	M20 & HYSD415	[2-12Ø] (top) + [3-12Ø] (bottom)
Beam 2	12”× 24”	M20 & HYSD415	[2-16Ø] (top) + [5-20Ø] (bottom)
Ground Beam	9”× 9”	M20 & HYSD415	[3-12Ø] (top) + [3-12Ø] (bottom)
Column 1	13” Ø	M20 & HYSD415	[6-14Ø] Main + 8 Ø Ring @ 8”
Column 2	13” Ø	M20 & HYSD415	[6-16Ø] Main + 8 Ø Ring @ 8”

In this case study, a conventional reinforced concrete structure with a various arches such as segmental arch, semi-circular arch and parabolic arch is considered and compared values of R_μ, R_s, R_r and R of all cases for all four seismic zones. In this study, 5% damping ratio is taken for all structures.

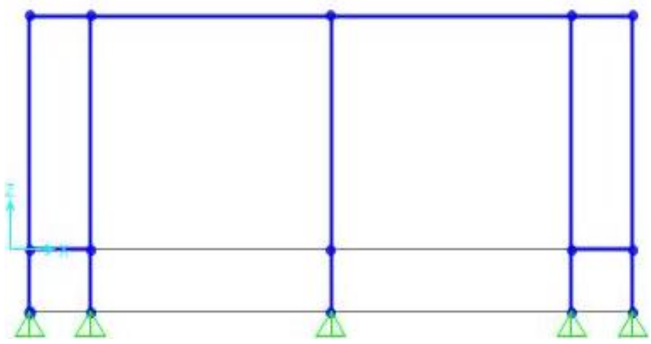

Fig. 3. Conventional RC Frame

Fig. 3 shows Conventional RCC frame.

Seismic weight of the structure (W) = 539.831 kN
Height of the structure (H) = 5.778 meter
Fundamental time period of the structure (T) = 0.402 sec
Type of soil = medium soil
Value of S_a/g = 2.5

Table 4 shows values of R_μ, R_s, R_r and R of Conventional RCC Frame for all four seismic zones.

TABLE 4. Calculation of R factor for conventional RCC frame.

Seismic Zone	R_s		R_μ		R_r		R	
	x	***y***	***x***	***y***	***x***	***y***	***x***	***y***
II	5.043	5.532	2.207	2.086	0.71	0.71	7.903	8.194
III	3.152	3.458	2.664	2.711	0.71	0.71	5.961	6.656
IV	2.101	2.305	2.950	3.034	0.71	0.71	4.401	4.965
V	1.401	1.537	3.195	3.348	0.71	0.71	3.178	3.653

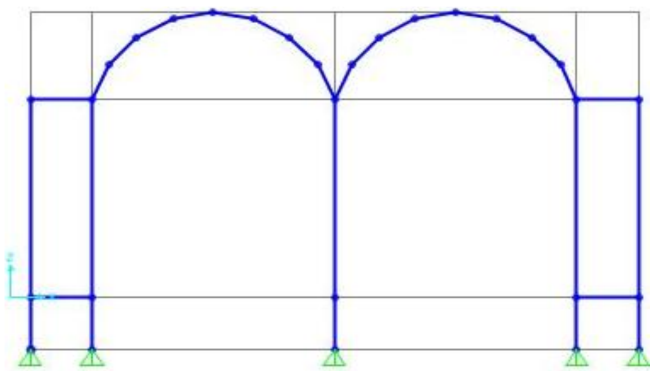

Fig.4. Segmental Arched Frame.

Fig. 4 shows Segmental arched frame.

Seismic weight of the structure (W) = 603.572 kN

Height of the structure (H) = 8.331 meter

Fundamental time period of the structure (T) = 0.579 sec

Type of soil = medium soil

Value of S_a/g = 2.348.

TABLE 5. Calculation of R factor for Segmental Arched RCC Frame.

Seismic Zone	R_s		R_μ		R_r		R	
	x	***y***	***x***	***y***	***x***	***y***	***x***	***y***
II	4.688	5.104	2.562	2.129	0.71	0.71	8.527	7.715
III	2.930	3.190	3.044	2.850	0.71	0.71	6.332	6.455
IV	1.953	2.127	3.394	3.160	0.71	0.71	4.707	4.771
V	1.302	1.418	3.622	3.549	0.71	0.71	3.348	3.573

Table 5 shows values of R_μ, R_s, R_r and R of segmental arched RCC frame for all four seismic zones.

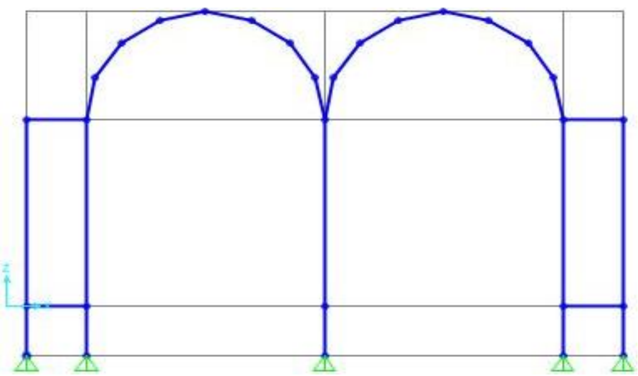

Fig. 5. Semi-circular Arched Frame

Fig. 5 shows Semi-circular arched frame.

Seismic weight of the structure (W) = 653.368 kN
Height of the structure (H) = 9.093 meter
Fundamental time period of the structure (T) = 0.632 sec
Type of soil = medium soil
Value of S_a/g = 2.152

TABLE.6. Calculation of R factor for semi-circular arched RCC frame

Seismic Zone	R_s		R_μ		R_r		R	
	x	***y***	***x***	***y***	***x***	***y***	***x***	***y***
II	4.628	5.338	2.972	2.097	0.71	0.71	9.765	7.948
III	2.892	3.336	3.331	2.844	0.71	0.71	6.840	6.737
IV	1.928	2.224	3.691	3.145	0.71	0.71	5.053	4.967
V	1.285	1.483	3.899	3.519	0.71	0.71	3.558	3.705

Table 6 shows values of R_μ, R_s, R_r and R of semi-circular arched RCC frame for all four seismic zones.

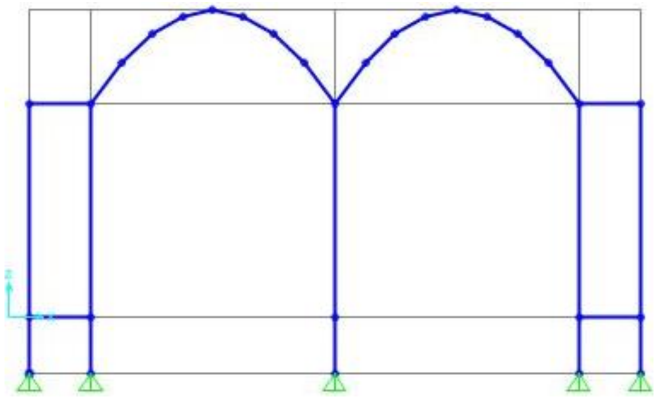

Fig. 6. Parabolic Arched Frame

Fig. 6 shows parabolic arched frame.

Seismic weight of the structure (W) = 584.011 kN
Height of the structure (H) = 8.331 meter
Fundamental time period of the structure (T) = 0.579 sec
Type of soil = medium soil
Value of S_a/g = 2.348

TABLE 7. Calculation of R factor for Parabolic Arched RCC Frame

Seismic Zone	R_s		R_μ		R_r		R	
	x	***y***	***x***	***y***	***x***	***y***	***x***	***y***
II	4.878	5.055	2.510	2.211	0.71	0.71	8.694	7.936
III	3.049	3.160	3.024	2.955	0.71	0.71	6.546	6.629
IV	2.033	2.106	3.359	3.240	0.71	0.71	4.848	4.846
V	1.355	1.404	3.649	3.629	0.71	0.71	3.511	3.618

Table 7 shows values of R_μ, R_s, R_r and R of parabolic arched RCC frame for all four seismic zones

IV. COMPARATIVE RESULTS OF THE ANALYTICAL STUDY

Figs. 7 & 8 show comparison of R_μ, R_s, R_r and R of all cases for all four seismic zones. Comparison between RCC frame with straight beam and RCC frame with various arches is also shown in Fig. 7. Decrease in values of R_μ, R_s, R_r and R is observed when moved from Zone 2 to 5.

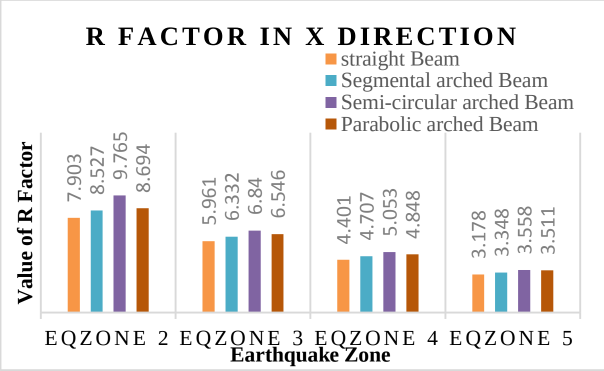

Fig.7.Comparative Graph of *R* factor in *x*-direction.

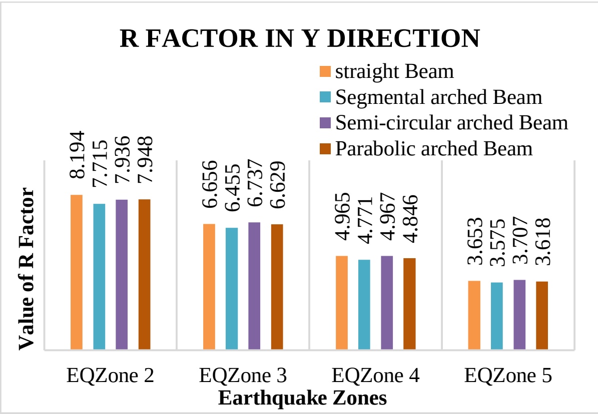

Fig. 8. Comparative Graph of *R* factor in *y*-direction.

V. CONCLUSIONS

In this case study, pushover analysis has been conducted on reinforced concrete framed structure to obtain values of R factor for different arches and straight beam. The focus of this study to measure the R factor for different earthquake Zones and compare the values of R with values recommended in IS 1893 for OMRF structure. The major conclusions of this research are as follows:

- Response Reduction Factor varies with different Earthquake Zones. Indian Standard does not Provide *R* for Different Earthquake Zones.
- Response Reduction Factor decreases in higher earthquake zones which mean actual response increases with increasing earthquake zone. As a result, design base shear of the structure also increases.
- The comparative study shows that provisions of different arched beams are not showing much difference in the *R* factor

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