

Evaluation of Response Reduction Factor for RC Framed Structure

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ABSTRACT: Earthquake resistant structures are designed to withstand large base shear force induced during the occurrence of seismic wave due to earthquake. When the structure behaves linearly elastic, the seismic force generated during strong earthquake shaking is much higher than the actual design force. Earthquake is a phenomenon which occurs occasionally and designing the structure for full expected seismic load is uneconomical. Hence this response reduction factor comes into a picture, in order to maintain economy as well as strength to resist seismic force effectively. The present study investigates the formulation of Response reduction factor for different OMRF structures for varying height of the structure. The analysis include all the factors which are responsible for R values such as over-strength factor, ductility factors, redundancy factors that affects the actual value of response modification factor and therefore they must be taken into consideration while determining the appropriate response modification to be used during the seismic design process. The evaluation of response modification factor is done using static nonlinear pushover analysis. Pushover analysis is an advanced tool to carry out static nonlinear analysis of framed structures. It is used to evaluate non-linear behavior and gives the sequence and mechanism of plastic hinge formation. The R values specified in Indian Standard IS 1893:2002 Part I for Ordinary Moment Resisting Frames and Special Moment Resisting Frames are 3 and 5 respectively. The basis on which these R values considered for different type of frames are not explained in IS code. R values specified in different international standards varies depending on the geometry of the structural system, material properties, confinement effect, ductility factor and sub soil strata of the structure under consideration. Providing single R value to a typical building may not ensure the desired performance during seismic resistance design of structures. R value is complex in nature and cannot be determined by simple equations for many conditions. There are many interconnected parameters which are to be studied independently for their influence in R value. An attempt was made in this study to estimate the value of R, considering the geometrical and material properties of RCC beam and column members and for a framed structural system. The seismic response reduction factor of RCC framed structure is the only factor which relates the type of structure, grade of materials used, configuration and factor of safety to resist seismic forces. The process of estimation of response reduction factor involves the study of individual RCC member (beam and column) and for a system (framed structure) with various parameters. A parametric study was carried out for RCC members on effect of material properties such as stress – strain behavior, confinement effect, moment - curvature relationship, ductility factor of RCC members by considering typical beam size and analysis on E-tabs.

KEYWORDS: Response Reduction Factor, Seismic, Push over Analysis, Base shear.

I. INTRODUCTION

Seismic resistant structures are designed to withstand large base shear force induced during an earthquake. When the structure behaves linearly elastic, the seismic force generated during strong earthquake shaking is much higher than the actual design force. Earthquake occurs occasionally and designing the structure for full expected seismic load is uneconomical. In seismic design philosophy, the structure is allowed to sustain damages in the event of severe shaking with no loss of life.

Response reduction factor value (R) is used to describe the level of inelasticity expected in lateral load and reflects the capacity of structure to dissipate energy through inelastic behavior. Seismic design code introduced appropriate R value for Reinforced Cement Concrete (RCC) framed structures and non-linear response of the structure is indirectly incorporated in the base shear calculation. Accordingly, the design lateral force is reduced from the actual base shear force which is generated during an earthquake and building is designed economically.

The strength factor depends upon the over strength of material used in construction. Moment resisting frames are commonly used as the dominant mode of lateral resisting system in seismic regions for a long time. Damping factor depends upon the type of damping used in structure such as base isolation, kinematic isolation etc. Redundancy factor depends on the indeterminacy of the structure which further depends upon the degree of fixity. Ductility factor depends upon ductility of materials, type of resisting frame, configurations of elements, connections, section of element and



others. Ductile detailing is done in structure to increase the ductility and to reduce the amount of damage compared to non-ductile detailed structure. The response reduction factor of 5 in SMRF reduces the design base shear and in such a case these building rely greatly on their ductile performance. To ensure ductile performance, the design seismic forces are reduced drastically by using higher values of R and incorporating higher ductility.

II. OBJECTIVE

- To estimate the response reduction factor for RCC structure based on stress – strain behaviour, moment - curvature relationship, ductility of RCC members.
- To compare the estimated R values with specified R values in IS code or any other code necessary.
- To estimate R for RCC moment resisting frames using different structural configurations by pushover analysis.

III. BUILDING DESCRIPTION

Two types of RCC framed structures G+3 and G+5 residential building configurations were considered for nonlinear pushover analysis. These buildings considered were three-dimensional space frame structures in both orthogonal directions. Each structure was 13.3m in length and 13.9m width having three/four bays in both direction. The building was unsymmetrical about both axes, and floor to floor heights were 3.0m. The frames were designed according to the Indian seismic code of practice for seismic zones III. The foundation systems considered was on medium soil. A typical framing plan and 3D elevations, beams and column sizes used for analysis of G+3 configurations were shown in Table no 1.

Slab thicknesses were kept as constant throughout the height of the structure as 135 mm. Material properties considered were M20, M25, M30 grades of concrete and Fe415 grades of steel for both longitudinal and lateral reinforcements. All the models were designed as per IS 1893: 2002 code and IS 456: 2000.

Table no. 1 – Schedule of Beam

| | |
|-------------|-----------------------------|
| Size | 230x510 mm ² |
| Top bars | 2- 20mm diameter bars |
| Bottom bars | 2- 20mm diameter bars |
| Stirrups | 2-legged 8mm dia @300mm c/c |

Table no. 2 – Schedule of Column

| | |
|-------------------|--------------------------|
| Size | 450x600 mm ² |
| Longitudinal bars | 16- 16mm dia bars |
| Lateral ties | 6mm dia bars @ 230mm c/c |

Table no. 3 – Structural Data

| | |
|-------------------|--------------------------------|
| Live load | 3 KN/m ² |
| Floor finishing | 1.5 KN/m ² |
| Wall load | 13.8 KN/m |
| Water proofing | 1 KN/m ² |
| Zone type | III |
| Zone factor | 0.16 |
| Floor height | 3m |
| Type of soil | Medium type soil/Alluvium soil |
| Importance factor | 1.0 |



Table no. 4 – Storey Data

| Story | Elevation (m) | Master storey | Similar to | Splice storey |
|-----------------------|---------------|---------------|------------------------|---------------|
| 5 th Floor | 18 | NO | None | NO |
| 4 th Floor | 15 | NO | 5 th Storey | NO |
| 3 rd Floor | 12 | NO | 5 th Storey | NO |
| 2 nd Floor | 9 | NO | 5 th Storey | NO |
| 1 st Floor | 6 | NO | 5 th Storey | NO |
| GF | 3 | NO | 5 th Storey | NO |
| Base | 0 | NO | None | NO |

Table no. 5 – Load Patterns

| Name | Type | Self Weight Multiplier | Auto load |
|-----------|--------------|------------------------|--------------|
| Dead Load | Dead | 1 | - |
| Live Load | Live | 0 | - |
| Eq-X | Seismic | 0 | IS 1893-2002 |
| Eq-Y | Seismic | 0 | IS 1893-2002 |
| Push-X | Acceleration | 0 | IS 1893-2002 |
| Push- Y | Acceleration | 0 | IS 1893-2002 |
| Wind – X | Wind | 0 | IS 875-1987 |
| Wind- Y | Wind | 0 | IS 875-1987 |

IV.MODELLING OF STRUCTURE

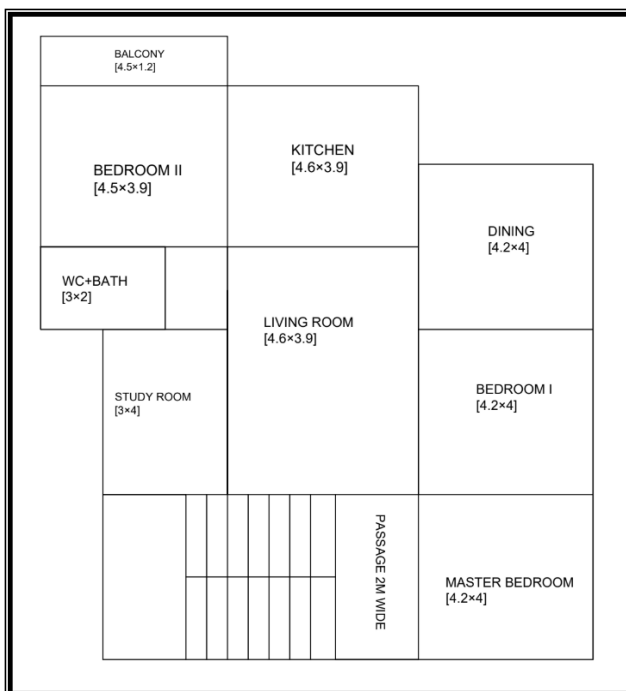


Figure no. 1:Architectural Plan

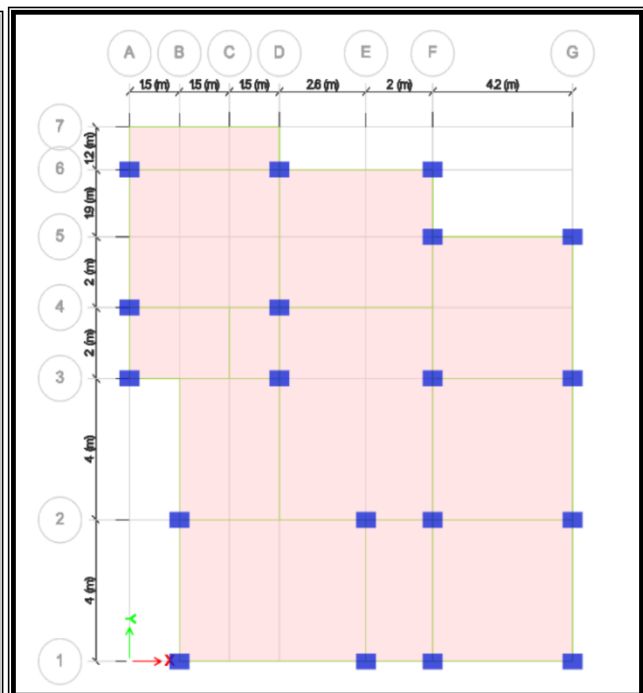


Figure no.2: Structural Plan

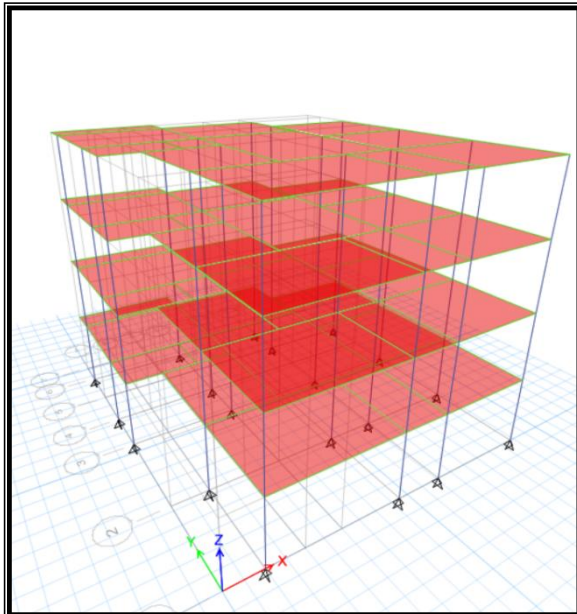


Figure no. 3(a): 3D Modal (G+3)

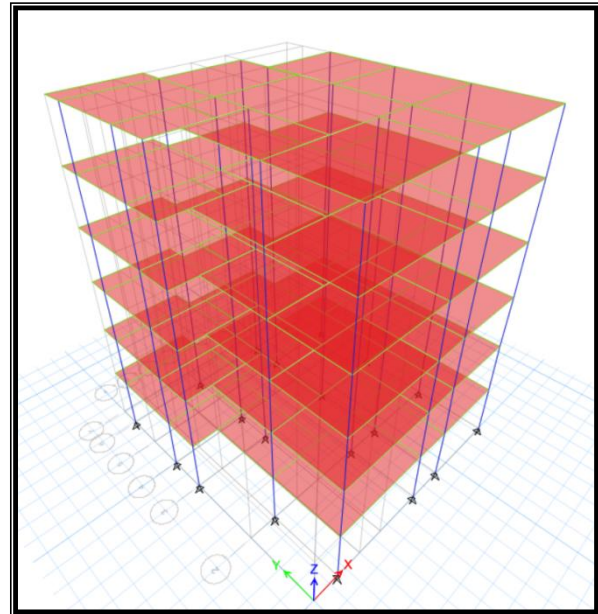


Figure no. 3(b): 3D Modal (G+5)

V. ANALYSIS

PUSHOVER ANALYSIS

The use of the nonlinear static analysis pushover analysis came into practice in 1970's but the potential of pushover analysis has been recognized for last 10 to 15 years. This procedure is mainly used to estimate the strength and drift capacity of existing structure and the seismic demand for this structure subjected to selected earthquake this procedure can be used for checking the adequacy of new structural design as well pushover analysis is defined as an analysis wearing a mathematical model directly incorporating the normal load deformation characteristics of individual components and elements of the building shall be subjected to monotonically increasing lateral loads representing inertia forces in an earthquake until a target displacement is reached. The maximum displacement elastic plus inelastic of the building address expected under selected earthquake ground motion pushover analysis assesses the structural performance by estimating the force and deformation capacity and seismic demand using a nonlinear static analysis algorithm the seismic demand parameters are global displacement at roof or any other reference point story drift story forces component deformation and component forces the analysis accounts for geometrical nonlinearity, material inelasticity and the redistribution of internal forces.

Pushover analysis can be performed as either force control or displacement controlled depending on the physical nature of the Lateral load and behavior expected from the structure force. Controlled procedure is useful when the load is known such as gravity loading and the structure is expected to be able to support the load. Displacement controlled procedure should be used when a specified source such as in seismic loading where the magnitude of the applied load is not known in advance or when the structure can be expected to lose strength or become unstable. The nonlinear pushover analysis of a structure is an iterative procedure. It depends on the final displacement as the effective damping depends on the hysteretic energy loss due to inelastic deformation which in turn depends on the final displacement. This makes the analysis procedure iterative. Difficulty in the solution is faced near the ultimate load as the stiffness Matrix at this point becomes negative, definite due to instability of the structure becoming a mechanism.

THE ANALYSIS OF ETABS:

1. Modeling
2. Static analysis
3. Design
4. Pushover analysis

STEPS FOR PUSHOVER ANALYSIS IN E-TABS:

1. The ETABS has inbuilt default ACI 318 material proportions ATC 40 and FEMA 273 hinge properties also it has capability for inputting any material or Hinges property ETABS deals with the buildings only where uncoupled moment M2 and M3, Torsion T, axial force p and V2 and V3 force displacement relations can be defined and the column axial load changes under lateral loading there is also a coupled P-M2-M3(PMM) hinge which yields based on the interaction of axial force and bending moment At The hinge location in a location also more than one type of hinge can be assigned at the same location of a frame element following are the steps in performing pushover analysis for a 3D frame building one creating the basic model without the pushover data in the usual manner.
2. Defining properties and acceptance criteria for the pushover hinges the program includes several built-in default hinge properties that are based on average values from ATC 40 for concrete members and average values from FEMA 273 for steel members these built-in properties can be useful for preliminary analysis but user defined properties are recommended for final analysis.
3. Locate the pushover Hinges on the model by selecting one or more frame members and assigning them one or more hinge properties and its locations.
4. Defining the pushover analysis load cases inner tabs more than one pushover load can be run in the same analysis also a pushover load case can start from the file and conditions of another pushover Loads that was previously run in the same analysis typically a gravity load pushover is force control and lateral pushover displacement controlled.
5. Run the basic static analysis and if desired dynamic analysis then run the static nonlinear pushover analysis.
6. Display the pushover curve.
7. Review a pushover displaced shape and sequence of hinge formation on a step-by-step basis.

Finally, using display show table command in SAP program, the designed results were obtained. The design base shear for a building was derived as,

$$V_d = (Z * I * S_a) / (2 * R * g) * W.$$

The maximum base shear was obtained corresponding to the max roof displacement from pushover curve.

OUTCOME OF PUSHOVER ANALYSIS OF RCC FRAMEDSTRUCTURES:

Non linear pushover analysis using SAP 2000 was performed for G+3 and G+5 framed structures. The parameters considered were M20, M25, M30, grades of concrete, Fe415, grades of steel and lateral reinforcement spacing of 75mm, 100mm, 125mm, 150mm, 175mm and 200mm. Typical hinge formation and lateral load vs. base reaction of pushover curve for G+5 structure in Zone III load for M30 grade of concrete, Fe415 steel and lateral spacing of 150mm.

EXAMPLE OF PUSOVER ANALYSIS OF G+ 5 STRUCTURES ARE SHOWN BELOW:

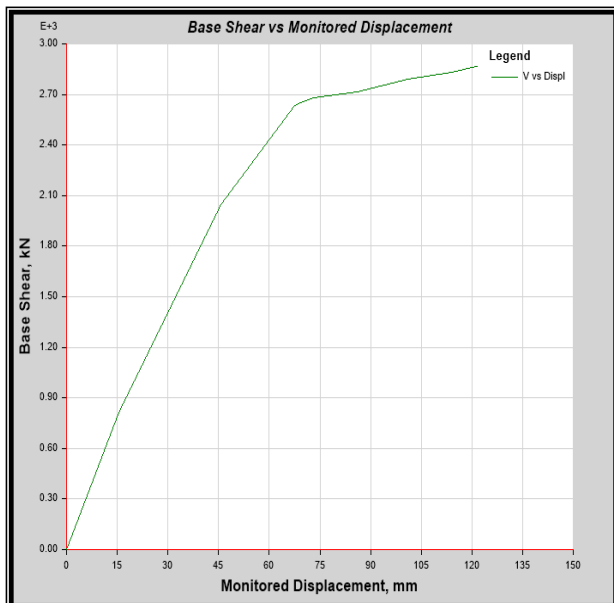


Figure no. 4(a): Typical Pushover Curve for G+5 Structure for Zone III

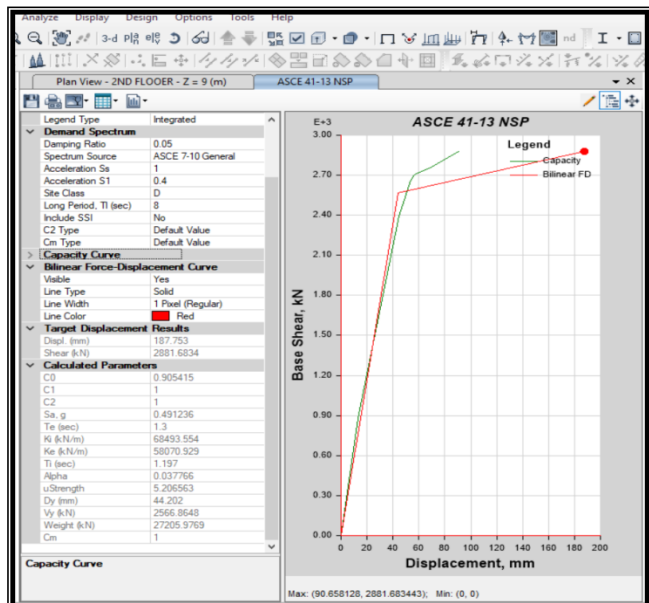


Figure no. 4(b): Typical Bilinear Approximation Pushover Curve for G+5

Seismic Loads

Structure for Zone III Seismic Loads

Table no. 5 - The lateral displacement and base reaction values at ultimate point for G+5 Configuration for Zone III loads

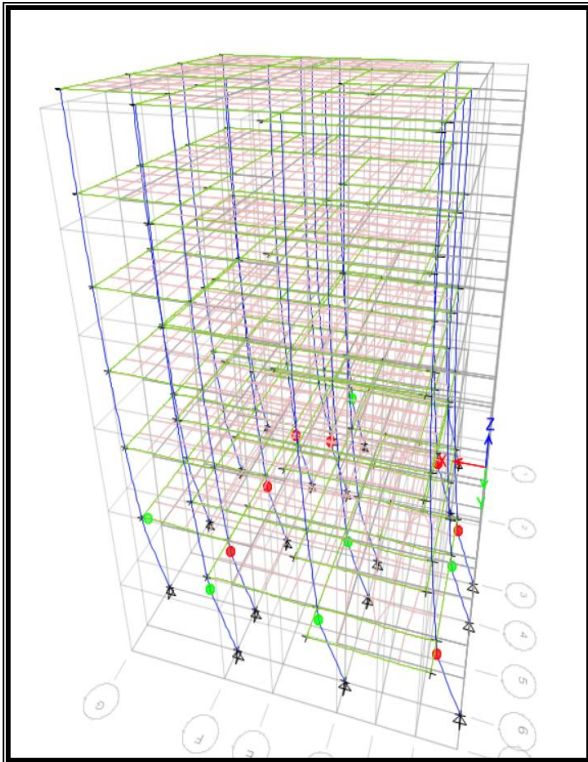


Figure no. 5- Typical Hinge Formation in G+ 5 Structures for Zone III Seismic Loads

| Monitored Displacement (mm) | Base Force (kN) |
|-----------------------------|-----------------|
| 0 | 0 |
| -12.848 | 880.0354 |
| -44.704 | 2394.1986 |
| -53.77 | 2658.4604 |
| -55.841 | 2693.4113 |
| -57.178 | 2706.5018 |
| -59.012 | 2717.5986 |
| -59.055 | 2717.7589 |
| -68 | 2755.1492 |
| -90.651 | 2881.6757 |
| -90.658 | 2881.6834 |

Table no. 6: CALCULATED DATA OF G+5:

| | | | |
|----------------|----------------|-----------------------------------|---------------|
| T _a | 0.444 sec | V _{max} / V _u | 2881.6834 kN |
| T _i | 1.197 sec | D _y | 44.202 mm |
| T _e | 1.3 sec | V _y | 2566.8648 kN |
| K _i | 68493.554 kN/m | Weight | 27205.9769 kN |
| K _e | 58070.929 kN/m | | |

V. RESULTS AND DISCUSSIONS

Table no. 7: Parameters of pushover analysis

| Storey | Δ_m (mm) =0.004xH | Δ_v (mm) (FROM CURVE) | V _u (KN) | V _d (KN) | $\mu = \Delta_m / \Delta_y$ | R _S =V _u /V _d |
|--------|-----------------------------|---------------------------------|---------------------|---------------------|-----------------------------|--|
| G+3 | 48 | 25.825 | 2026.438 | 725.493 | 1.858 | 2.793 |
| G+5 | 72 | 44.202 | 2881.683 | 980.2313 | 1.629 | 2.94 |

Table no. 8: Response reduction factors and the components

| Storey | R _S | R _μ | R _R | R |
|--------|----------------|----------------|----------------|--------|
| G+3 | 2.793 | 2.09 | 1.0 | 5.837 |
| G+5 | 2.94 | 1.711 | 1.0 | 5.0303 |



In the present study, the response reduction factor for RCC framed structures with different configurations were analytically estimated and the results were compared with Indian seismic code IS 1893 and with R values specified in other countries seismic code. From the study, it was observed that R factor is sensitive to both geometric configuration and material properties.

Parametric study performed in this work reveals that R values has an increasing tendency due to decrease in number of storey. It was also observed that R value was higher in shorter buildings than in taller buildings.

Based on the objective, the parameters contributing response reduction factor for RCC framed structure were studied. Subsequently, non linear pushover analysis of RCC framed structure without shear wall was performed and R values were estimated. The study was performed in the following areas:

- Pushover analysis for two different storey buildings i.e. G+3 and G+5 of RCC framed structures were performed for M30 grades of concrete and Fe415 steel. The maximum roof displacement corresponding base reaction (pushover curve) for all these parameters was obtained.
- R values were estimated from the nonlinear pushover curve by calculating strength factor and ductility factor by keeping redundancy and damping factor as constant value of 1.0. R values were estimated for G+3 and G+5 structures. The parameters considered were alluvium/medium soil and seismic zone III loads.

RESULTS FROM VARIOUS PARAMETRIC STUDIES:

For the variation over the number of floors:

- Effect of base reaction in framed structures. The performance of multi-storeyed building in terms of resisting base reaction had increased up to the range of 29.7% due to increase of number of storey from 4 to 6.
- Effect of R values in framed structures. The R value had increased up to 13.82% when number of stories increased.
- R values have an increasing tendency due to decrease in number of storey. It was also observed that R value was higher in shorter buildings than in taller buildings.

COMPARISON OF THE ESTIMATED R VALUES WITH OTHER COUNTRIES R VALUES SPECIFIED IN THEIR SEISMIC CODES:

The use of response reduction factors was not limited to the seismic design of buildings in India alone but is used in a number of countries for seismic design. The different values of R factor were considered based on the ductility classes of various buildings. The numerical values of response reduction factors R used in USA, Europe codes were compared with Indian code and our estimated value. The investigation shows that larger value of R was considered in the United States than in Europe and Mexico. As the seismic performance objectives were similar in all cases, the conclusion drawn from the study was that the values of R in the United States seismic codes may not be conservative.

| CATEGORY | ASCE 7 (US) | IS 1893 (INDIAN) | OUR ESTIMATED VALUE |
|----------|-------------|------------------|---------------------|
| SMRF | 8 | 5 | 5.837 to 5.0303 |
| IMRF | 5 | -- | -- |
| OMRF | 3 | 3 | -- |

COMPARISON CHARTS:

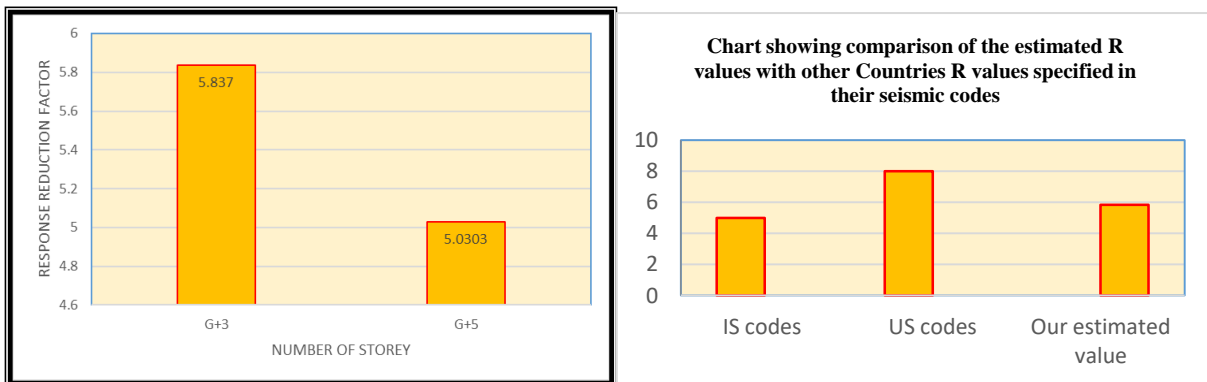


Figure no. 6: Chart showing comparison of R values for G+3 and G+ 5 structures

VI.CONCLUSION

In the above structural models, R value is complex in nature and needs to be determined by mathematical equations for various types of buildings by considering different material and geometrical properties. R values given in IS 1893: 2002 code needs to be varied for types of buildings, building height, plan geometry and framing layout, geometry of the structural system, material properties, and sub soil strata of the structure to ensure the desired performance during seismic resistance design of structures. Different R value for each seismic zone and soil type also to be introduced. Results from various parametric studies such as pushover analysis and estimation of R value for different number of floors have been summarized and concluded in this chapter. From the limited study carried out, the following conclusions are made:

- The R value will depend on both the fundamental period of the building and the soil type.
- The R value estimated based on various parameters will vary for different seismic zones.
- It is observed that as the number of storeys increases the R factor tends to decrease. Hence we can conclude that the 'R' factors exhibits a decreasing trend as the number of stories increases. The shorter frames show higher 'R' value compared to taller frames.
- Form the above comparison of the results it is found that US codes provide higher value of RRF than the IS codes.
- As the value of R increases the magnitude of base shear decreases there by it makes the design more economical than that of structures with lesser R value. Though, the use of lesser R value will be safer against the high shear.

REFERENCES

- [1] Alam, Md. I. and Dookie Kim (2012) Effect of Constitutive Material Models on Seismic Response of Two-Story Reinforced Concrete Frame. International Journal of Concrete Structures and Materials, Vol.6, No.2, pp.101–110.
- [2] ASCE 7 (2005) Minimum Design Loads for Buildings and Other Structures. American Society of Civil Engineers. USA.
- [3] Asgarian, B. and Shokrgozar, H.R. (2009) BRBF response modification factor, Journal of Constructional Steel Research 65, 290_298.
- [4] Bansal, R. (2011) Pushover analysis of reinforced concrete frame. M.Tech project report. Department of Civil engineering, Thapar University.
- [5] Estimation Of Response Reduction Factor For Reinforced Cement Concrete Framed Structures - Nallathambi P.
- [6] Evaluation Of Response Reduction Factor Based On Redundancy For High Rise Buildings – Keerthi S & Vivek Philip.
- [7] Evaluation Of Response Reduction Factor And Ductility Factor Of RC Braced Frame - Kruti Tamboli, J. A. Amin. Rationalizing Response Reduction Factor R for better Performance of Reinforced Concrete Framed Buildings. - Swajit Singh Goud, Pradeep Kumar Ramancharla.
- [8] Evaluation of Response Reduction Factors for Moment Resisting RC Frames - Minnu M M.
- [9] Indian Standard Criteria for Earthquake Resistant Design of Structures Part I: General Provisions and Buildings, IS 1893:2002. New Delhi: Bureau of Indian Standards.
- [10] Applied Technology council (ATC), "Structural response modification factors" (ATC- 19), Redwood city, California, 1995.
- [11] "Ductile Detailing and Design of Reinforced concrete structure" IS 19320: 2016. New Delhi: Bureau of Indian Standards.
- [12] www.youtube.com/TPst1wiAQLc