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Evaluation Of Response Modification Factor For Moment Resisting Frames

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Abstract

Conventional seismic analysis of structure incorporates only elastic response of the structure. To understand nonlinear response of the structure, Performance Based Design (PBD) approach is widely used. PBD includes Pushover analysis i.e. nonlinear static analysis, which shows the post-elastic behaviour of the structure. IS 1893-2002 incorporates the nonlinear response of a structure considering response reduction factor (R) so that a linear elastic force based approach can be used for design. The response modification factor plays a key role in the seismic design of new buildings. However, the Indian code does not provide information on the components of R factor. The values assigned to this factor is based on engineering judgment. The study includes the calculation of value R based on different components as per ATC-19 and compares values of R for Special Moment resisting frame (SMRF) and Ordinary Moment resisting frames (OMRF) for two different seismic zones. An improvement in the reliability of modern earthquake-resistant buildings will require the systematic evaluation of the building response characteristics, which mostly affects the values assigned to the factor.
Keywords- Pushover analysis, response reduction factor, Ductility, Overstrength factor

1. Introduction

An actual earthquake force experienced by the structures is much greater than designed earthquake forces. It is impossible to design an earthquake-proof building, so engineers rather design earthquake resistant structures. Here Response Reduction factor (R) plays a major role. R indirectly accounts for the inelastic behaviour of structures in the standards on seismic analysis and design. IS: 1893-2002 [8] suggest R factors 3 and 5 for Ordinary Moment resisting frames (OMRF) and Special Moment resisting frame (SMRF) for RC structures. The basic discrepancy between OMRF and SMRF are RC frames with ductile behaviour and non-ductile behaviour respectively.

The basic conception of R factor is that, if R=5 used to design RC Moment resisting frames, to facilitate frames can take the only $1/5^{th}$ of the actual seismic forces. Such frame designed for $1/5^{th}$ of the actual seismic forces taken by linear stage. Additional forces or deflection can be taken care by the ductile capacity of frames. In the conventional analysis, structures are never designed for the ductile part but only follows ductile detailing guidelines as per IS: 13920-1993 [8]. IS 1893-2002 [9] does not provide information to calculate factor R as well as components of R. In order to determine its components, the Non-linear static analysis should be carried out.

Conventional seismic analysis of structure incorporates only its elastic response. To understand the non-linear response of structure Performance Based Design (PBD) approach is frequently extensively used nowadays. PBD includes pushover analysis i.e. nonlinear static analysis which shows the post-elastic behaviour of the structure.

2. Components of R factor

R factors are essential seismic design tools, which defines the level of inelasticity in structural systems during an earthquake. As per National Earthquake Hazard Reduction Program (NEHRP) definition of R factor is "factor intended to account for both damping and ductility inherent in structural systems at the displacements great enough to approach the maximum displacement of the systems." This definition provides some insight into the understanding of the seismic response of buildings and the expected behaviour of a code-compliant building in the design earthquake. During Inelastic behaviour of structure, factor R shows the capability of structure to dissipate energy. R factor is used to reduce the design forces in earthquake resistant design and accounts for damping, energy dissipation capacity and for over-strength of the structure.

The conventional concept of reducing seismic forces by a single reduction factor, to get design force level, is still far and wide applicable. Seismic codes rely on reserve strength and ductility, which improves the capability of the structure to absorb and dissipate energy. According to codes, the role of force reduction factor is essential elements of seismic design.

As per US codes (FEMA, 1997; UBC, 1997), the values of response modification factor are based on reserve strength and ductility. In this study, redundancy is considered as parameter contributing to over strength, contrary to the proposal of ATC-19 [7] (ATC, 1995), splitting R into three factors: strength, ductility and redundancy. [1]

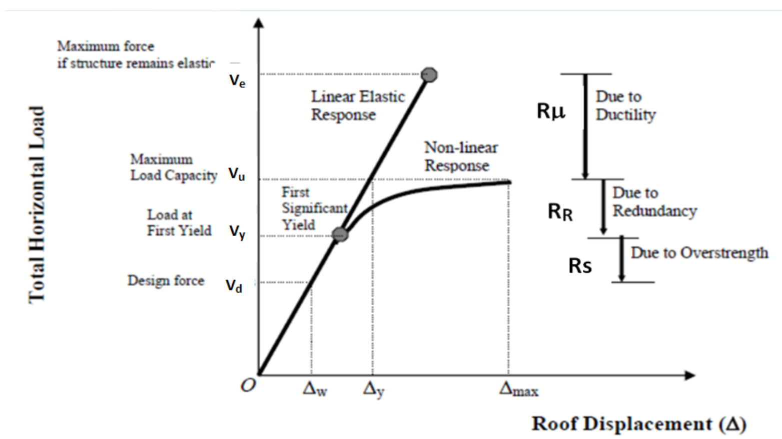

Figure1: Components of R factor

Consistent with this philosophy of Earthquake Resistant Design the structure is designed for much less base shear forces than would be required if the building is to remain elastic during severe shaking at a site.

$$R = R_S\, R_\mu\, R_\xi\, R_R$$

Such large reductions are mainly due to two factors: (i) the ductility reduction factor (R_μ), which reduces the elastic demand force to the level of the maximum yield strength of the structure, and (ii) the overstrength factor (R_s), which accounts for the over strength introduced in code-designed structures.

2.1 Ductility Reduction factor (Rμ)

The ductility reduction factor (R_μ) is a factor which reduces the elastic force to idealised 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. The relationship linking displacement ductility and ductility-dependent R factor have been the subject of considerable research. There are various methods to calculate ductility factor. i.e. Newmark and Hall (1982), Krawinkler and Nassar (1992), Miranda and Bertero (1994) [5]. In this study ductility factor is considered using Newmark and Hall (1982) method.

R_μ to be determined is a function of ductility. It was observed that in the long period range, elastic and ductile systems with the same initial stiffness reaches almost the same displacement. As an output, R_μ can be considered equal to μ. For intermediate period structures, μ is higher than R_μ and the 'equal energy' approach may be adopted to calculate force reduction. The relationship derived for R_μ as a function of μ, for short, intermediate and long period structures is presented below.

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

2.2 Over strength factor (R_S)

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

$R_s = V_y / V_d$ or $R_s = V_{max} / V_d$

Where V_y (V_{max}) is the base shear coefficient corresponding to the actual yielding of the structure; V_d is the code-prescribed unfactored design base shear coefficient. Over-strength is a parameter used to quantify the discrepancy between the required and the actual strength of material, a component or a structural system.

2.3 Redundancy Factor (R_R)

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.

Lines of vertical seismic framing	**Draft redundancy factor**
2	0.76
3	0.86
4	1.00

Table 1: Redundancy factors [10]

2.4 Damping factor (R_ξ)

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.

3. Pushover Analysis

Pushover analysis is a tool to perform non-linear static analysis of structure. It derives capacity curve i.e. base shear v/s displacement and evaluates the mechanism of plastic hinge formation at every stage in the post-elastic region.

In the analysis considered, the increasing forcing function is in terms of either horizontal forces or displacements imposed on mathematical model of a building. The analysis is terminated when the target displacement or critical state is reached. The target displacement or drift represents a maximum building displacement or drift during earthquake shaking.

For building design, IS 456-2000[11] is considered. Non-linear Static Analysis was performed using software, ETABS. Non-linear static analysis requires the knowledge of material property, stress-strain model, plastic hinge property, types of hinges, hinge location, hinge length and moment-curvature relationship.

ETABS defines plastic hinge properties as per FEMA-356 [4]. Hinge property defined is a form of force–deformation curve with five points labelled A, B, C, D, and E as shown in Fig-2. The value of these points obtained from the moment-curvature relationship of an element depends on the type of geometry, material property, longitudinal reinforcement, shear reinforcement and loads subjected to a particular member.

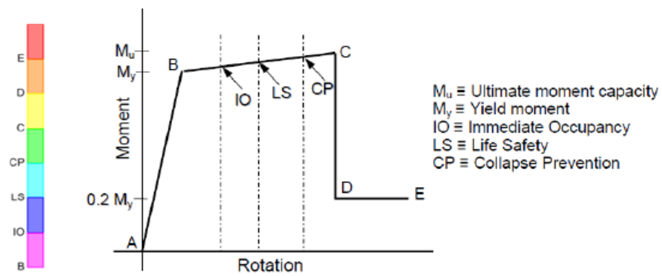

Figure.2: A-B-C-D-E curve for moment vs. rotation

4. Parametric Study

The RC frame structure considered as a part of study have the same plan arrangement with four numbers of bays 5.0 m each in both directions considering M20 and Fe 415. The floor-to-floor height is 3.0 m for the entire building. As per importance of the structure, considering R factor 3 for OMRF and 5 for SMRF. The total height of the building is 15 meters and the Live load is taken 2 kN/m². Other Building data are as following:
Importance factor (I)- 1.5, Soil type- Medium(II), Slab thickness- 150mm,
Size of beam- 230 mm x 450 mm, Size of Column- 450 x 450mm.
Four different models are being considered.
Model I & II: Designed for Gravity and Seismic Loads of Zone V (SMRF) & (OMRF) respectively
Model III & IV: Designed for Gravity and Seismic Loads of Zone III (SMRF) & (OMRF) respectively

All considered models are designed as per IS design codes. From the graphical representation shown in Figure 3 to Figure 5, there is no such change of observable fact due to the deviation of the zone and it shows a reliable pattern only, considering linear static analysis. Equivalent loads from the third dimension were applied on considered frame. For pushover analysis, 100% dead load and 25% of live loads were considered as an initial load. Reinforcement in the members was defined using Auto hinges with hinge type P-M3 and M3 hinges were assigned to columns and beams, respectively. Pushover curves are shown in Figure 6 to Figure 9.

5. Response reduction factor calculation

The value of response reduction factor, R depends on the performance limit considered for the structure. As the performance limit, corresponding to R has not provided in IS 1893-2002[8], they are considered which are defined differently in PBD guidelines, like ATC-40 [8] and FEMA-356 [4]. There is slight variation in definitions of performance limits of these codes.

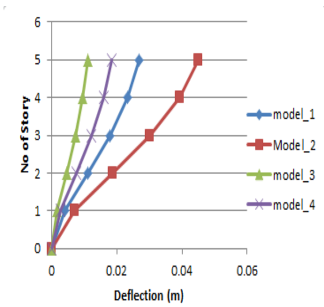

Figure3: Graphical representation of Deflection

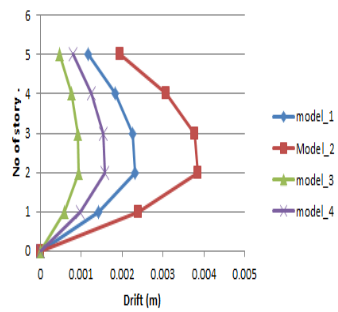

Figure 4: Graphical representation of Drift

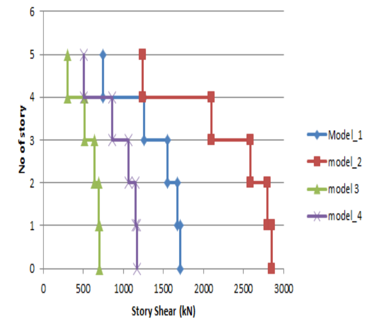

Figure5: Graphical representation of Story shear

Model	R	Z	Max. Base Shear V_{max} (performance)	Design Base Shear V_d	Max. Displ. Δ_{max}	Yield. Displ. ΔY (performance point)	μ	R_μ	$R_s = (V_{max}/V_d)$	R_R	R
			(kN)	(kN)	(m)	(m)					
1	5	0.36	2909	1711	0.239	0.0405	5.901	3.29	1.70	1	5.6
2	3	0.36	2236	2694	0.225	0.0307	6.436	3.45	0.83	1	3.1
3	5	0.16	2094	703.18	0.224	0.0325	6.902	3.58	2.98	1	10.7
4	3	0.16	2133.8	1171	0.21	0.0400	5.258	3.08	1.82	1	5.6

Table 2: Calculation for components of factor R

6 Results And Discussions

- Ductility reduction factor varies only 1% to 4% in view of IS 456-2000 [11] (Normal Detailing) while varies 6% to 10% in view of IS 13920 -1993 [12] (Ductile detailing).
- It was observed from table 2 that response reduction varies from 3.1 to 5.6 in seismic zone V and from 5.6 to 10.7 in seismic zone III.
- The lateral load distribution based on IS 1893-2002[9] and the ASCE7[10], give R almost in the same range. Nevertheless, a load distribution based on the fundamental mode shape computes R in a range of upper values.

7 Conclusions

- The response reduction factor is noticeably affected by the seismic zone.
- As zone increases, 'R' factor decreases.
- The dependency of over strength factor is most significant with respect to seismic zone.
- The seismic zoning has a trivial effect on the ductility reduction factor (Rμ) for the studied frame.
- Response reduction factor provided in IS: 1893-2002 [9] should be provided with the corresponding ductility and over strength factor for checking the safety of structure based on performance-based design.
- Based on the assumed performance limits the IS-1893-2002[9] recommendation of R is on the conservative side.
- Performance limit corresponding to the R should be provided in IS-1893-2002 [9] as ductility factor is dependent on the performance limit, which ultimately changes the calculated R.
- Evaluation of Response reduction factor with precise analysis will help in an economical design.

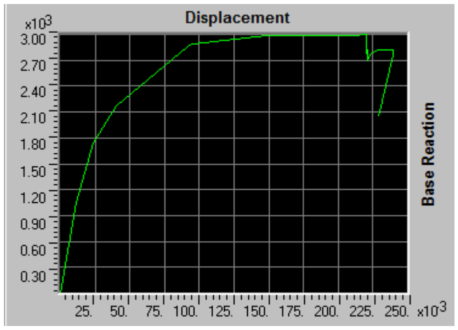

Figure 6: Pushover curve for Model 1

Figure 7: Pushover curve for Model 2

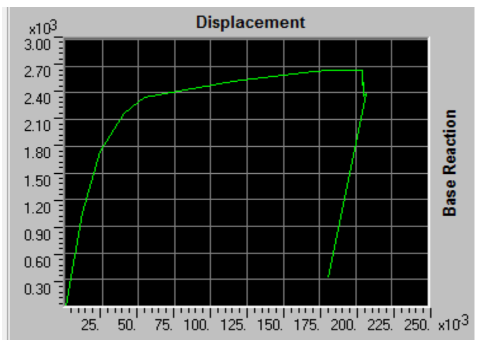

Figure 8: Pushover curve for Model 3

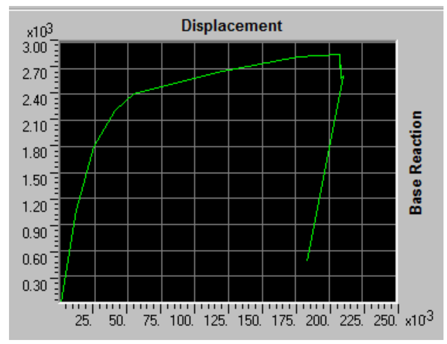

Figure 9 : Pushover curve for Model 4

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