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Assessment of Seismic Response Reduction Factor According to Redundancy of RC Buildings

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ABSTRACT

The major task for the present study is to assess the seismic response reduction factor (R factor) of RC frames. Seismic codes combine the nonlinear response of a structure by the regulation of a factor which is called (Response reduction factor) "R". We know that the actual earthquake force or earthquake intensity is incredibly higher than what we design the structures for. The structures cannot be designed for the actual value of earthquake intensity as the cost of the structures will be much high. The actual intensity of earthquake is reduced by a factor called response reduction factor R. Basically the R value is depending on ductility factor, strength factor, structural redundancy and damping. The strength factor depends upon the over strength of material used in construction, where Damping on normal RCC damping. IS Code subsumes ductility in a hazy aspect, for OMRF (not ductile detailed) R factor is 3, for SMRF (Ductile detailed) it is 5.But code is speechless on redundancy of structure. A parametric study is performed to assess the effect of redundancy in ductile reinforced concrete (RC) buildings and the studied variables were the number of bays. Nonlinear static analysis or also called pushover analysis is conducted on the analytical models using SAP 2000 software which is basically a finite element analysis software. The Response reduction factor components are calculated from the results gained from the nonlinear static pushover analysis (pushover curve) and lastly the response reduction factor is computed for all the models. The results obtained from the entire calculations show that for buildings with low redundancy, Seismic response reduction factor 5, given in IS1893-2016 is overblown. As a result it minimizes the earthquake forces on such buildings.

Keywords: Response Reduction Factor Redundancy Ductility Nonlinear Static Pushover analysis, Pushover Curve

I. INTRODUCTION

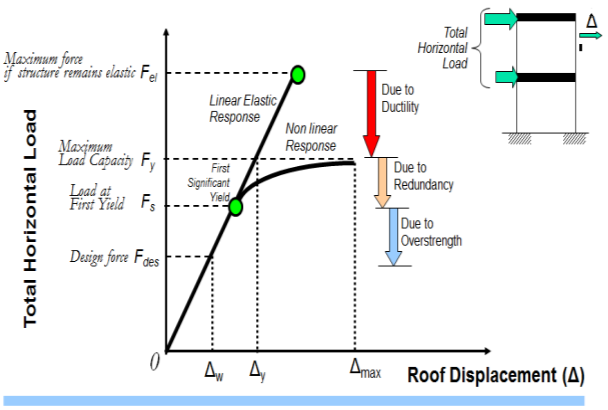
Earthquake are considered to be one of the most unpredictable natural hazards, effecting large economic, property, and population loss. The devastating potential of an earthquake can have major consequences on infrastructures and lifelines. In the past few years, the earthquake engineering community has been reassessing its procedures, in the wake of devastating earthquakes which have caused extensive damage, loss of life and property.

The seismic design in most of the structures is based mainly on elastic force. The nonlinear response of structure is not incorporated in design process but its effect is integrated by using a reduction factor called Response Reduction factor (R). There are differences in the way the response reduction factor (R) is specified in different codes For different kinds of structural systems .The concept of response reduction factor is to reduce the seismic force and incorporate nonlinearity with the help of over strength, redundancy and ductility.

The value of Response reduction factor varies from 3-5 in Indian code as per type of resisting frame, but the existing literature does not provide information on what basis R values are considered Most of the past research efforts in this area have focused on finding the ductility component and overstrength components of the response reduction factor The present work takes a rational approach in determining R factor for RC ductile framed building structures, based on redundancy.

II. RESPONSE REDUCTION FACTOR

During an earthquake, the structures may experience certain inelasticity, the R factor defines the levels of inelasticity. The R factor is allowed to reflect a structures capability of dissipating energy via inelastic behavior. The concept of response reduction factor is to reduce the seismic force and combine nonlinearity with the help of over strength, redundancy and ductility.



$$\text{Response Reduction Factor} = \frac{\text{Maximum Elastic Force } (F_{el})}{\text{Design Force } (F_{des})}$$

Figure 1. Concept of Response Reduction Factor

Generally, the response reduction factor is expressed as a function of different parameters of the structural system, such as strength, ductility, damping and redundancy.

R=Rs Rμ Rξ Rr

Where Rs is the strength factor, Rr is the redundancy factor, Rμ is the ductility factor and Rξ is the damping factor.

1) Redundancy factor:

Redundancy factor *r* can be estimated as ratio of ultimate load to first significant yield load; estimation of this factor requires detailed non-linear analyses Rr=Vu/Vy.

2) Ductility factor

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

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

where m and y 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 medium soil,

$$\emptyset = 1 + \frac{1}{12T-\mu T} - \frac{2}{5T}\exp\left[-2\left(lnT - \frac{1}{5}\right)^2\right]$$

3) Overstrength factor

The overstrength factor is a measure of the additional strength a structure has beyond its design strength. The additional strength exhibited by structures is due to various reasons, including sequential yielding of critical points, factor of safety considered for the materials, load combinations considered for design, member size ductile detailing etc. In the present study Overstrength factor is taken as 1 considering economical design.

4) Damping factor

Damping factor Rξ is used for structures which are provided with additional energy dissipating (viscous damping) devices. The damping factor is assumed as 1 for buildings without such devices. In this study, the damping factor is assumed to be 1.

III. OBJECTIVE OF THE STUDY

a. To assess the effect of redundancy on Response reduction factor for buildings with low redundancy.
b. To compare the computed values with R factor specified in IS 1893:2016.

IV. BUILDING DETAILS

The structural systems that are considered for this study are 5storey buildings with one, two, three, four and five bays in X direction. Bay width is 5m. Height of typical floor is assumed as 3m. The building is considered to be located in Zone V as per IS 1893:2002 with medium soil conditions considered. The building is modelled using the software SAP2000. The dimensions of the beams, columns and slabs also the loads applied are summarized in the Table1.Also the configurations of the 5 building models taken for the study are shown in figure 2.

Table 1. Details and Dimensions of Building Models

Type of structure	Special moment resisting RC frame
Grade of concrete	M25
Grade of steel	Fe 415
Floor height	3 m
Beam size	400 mm X 300 mm
Column size	400 mm X 400mm
Slab thickness	150 mm
Live load on floor and roof	3kN/m2and 1.5kN/m2

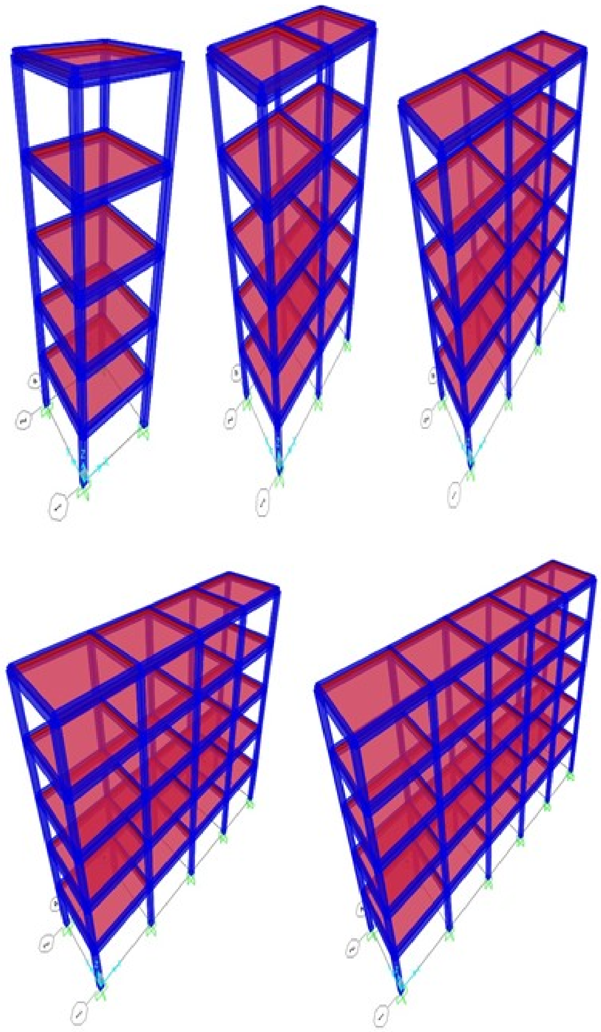


Figure 2. Configurations of selected Buildings

V. ANALYSIS OF THE STRUCTURE

Here in this study two types of analysis procedures have been carried out for determining the different structural parameters of the model. We are mainly concerned with the behavior of the structure under the impact of ground motions and dynamic excitations such as earthquakes and the displacement of the structure in the inelastic range. The analyses performed are as follows:

1) Modal Analysis
2) Pushover Analysis

Modal analysis is carried out for obtaining the natural time periods and other modal parameters of the structure.

Pushover Analysis:

Nonlinear Static Pushover Analysis in the x and y directions of the 5 study frames are conducted to estimate their redundancy and ductility capacity, which are required for calculating R for each frame.

Pushover analysis is a nonlinear static analysis that is done to determine the capacity of structure. In this process a predefined lateral load pattern is distributed along the height of building. Lateral forces are then monotonically increased in constant and continual proportion with a displacement control at the control node of the building until a certain level of deformation is reached. For our analysis we assigned nonlinear plastic hinges to all of the primary elements. Default moment hinges (M3-hinges) have been assigned to beam elements and default axial-moment 2-moment3 hinges (PMM-hinges) have been assigned to column elements.

The result and output of a nonlinear static analysis is generally presented in the form of a 'pushover curve', which is basically the base shear vs. roof displacement plot. The value of the yield base shear and yield displacement is arrived by doing the bilinear approximation.

VI. RESULTS AND DISCUSSIONS:

After analysing the models, redundancy factor and ductility factors are calculated for 5 models from their respective pushover curves in the X- and Y-directions. The time period obtained for the models are shown in the table 2.

Table 2. Fundamental time periods of the study frames

Model	1 bay	2 bay	3 bay	4 bay	5 bay
Time period(s)	0.553	0.572	0.596	0.625	0.716

The sample analysis assessment of R for 1bay frame is shown below:

Sample Analysis:

For 1B5s, the pushover curve obtained from the nonlinear analysis is show in fig-2.Also the yield and ultimate points of the curve is obtained by doing bilinear approximation.

Figure 3. Pushover Curve for 1bay 5 storey

PUSHOVER PARAMETERS

- Vu=310.26 KN
- Vy=288.65 KN
- Δy=28.65mm

Max displacement,

Δm= 0.004H

=60mm

CALCULATION OF R:

Rr=Vu/Vy=1.0748

μ=Δm/Δy=120/59.49=2.094

For t=0.553 (from analysis),ø=0.975 for medium soil

Rμ=(μ-1)/ø +1=2.1214

RS =1

Rξ =1

R=RS Rμ Rξ Rr =2.280267

R=2.28

It is seen that calculated R value is around 54.4% less than the assumed value of R during the design. So it is evident that for less redundant structures R is overestimated in the code which leads to the underestimation of design base shear.

The pushover parameters and the components of R in x and y directions for all other frames are summarized in table 3 and table 4 respectively.

Table 3. Pushover parameters and components of R in x direction

Model	Vu (kN)	Vy (kN)	Rr	Rμ	R
1b5s	310.26	288.65	1.075	2.12	2.28
2b5s	342.26	302.49	1.13	2.19	2.48
3b5s	365.87	311.68	1.17	2.35	2.76
4b5s	398.25	314.76	1.26	2.83	3.58
5b5s	426.32	324.96	1.31	3.56	4.67

Table 4. Pushover parameters and components of R in x direction

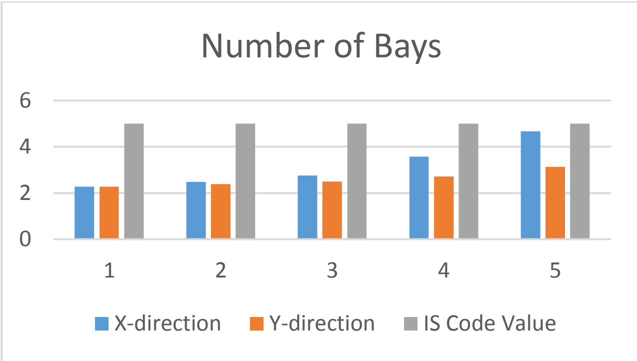
Model	Vu (kN)	Vy (kN)	Rr	Rμ	R
1b5s	310.26	288.65	1.075	2.12	2.28
2b5s	359.62	305.82	1.17	2.03	2.39
3b5s	376.5	312.65	1.20	2.07	2.50
4b5s	385.26	310.24	1.24	2.18	2.71
5b5s	412.28	313.47	1.31	2.38	3.13

Outcomes:

1) The R values range from 2.28 to 4.67 in x-direction and from 2.28 to 3.13 in y-direction for considered frames.

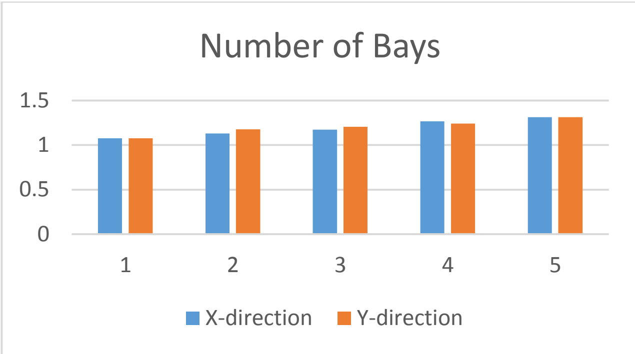
2) All values of R is lesser than the values as mentioned in IS Code for SMRF Buildings.

3) It is seen that R values varies from standard value of 5 by 54.39%,50.32%,44.7%,28.38% and 6.5% respectively in x-direction for considered frames.



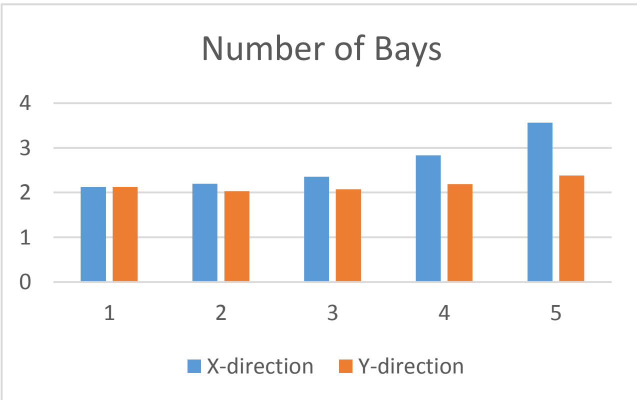
Variation of Response reduction factor with no of bays

4) Redundancy factor is found to increase with number of bays in both directions.



Variation of Redundancy factor with no of bays

5) Ductility factor increases with increase in bays in x direction but it does not show any definite trend in y direction.



Variation of Ductility factor with no of bays

VII. DISCUSSION OF OVERALL CONCLUSIONS

- With increase in the number of bays Redundancy factor is also increases and Response reduction factor shows an increasing trend for all frames. Hence the frames with more number of bays possess higher redundancy.
- With number of bays in x directions ductility factor is increasing but in y direction it looks like there is no flow for that.
- It is revealed that value of Response reduction factor acquired is critical in the direction with less number of bays. Response reduction values should be taken as the least from both directions during design purposes with ductility and redundancy also to be considered.
- The R value achieved from single bay frame was the least among all that is the most critical case. Thus assessed R values are smaller for bays with low redundancy factor compared to the IS code recommended value.
- Generally, the current study shows most of the frames interrogated, failed to achieve the respective target values of response reduction factors recommended by IS 1893 (2016). According to results obtained from nonlinear pushover analysis the Indian standard overestimates the R factor, which is leading to the potentially dangerous underestimation of the design base shear for buildings with low redundancy.

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