EVALUATION OF RESPONSE REDUCTION FACTOR BASED ON REDUNDANCY FOR HIGH RISE BUILDINGS

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Abstract - *Seismic codes incorporate the nonlinear response of a structure by the provision of a factor called Response reduction factor 'R' so that a linear elastic force based approach can be used for design. The concept of R factor is based on the observations that well detailed seismic framing systems can sustain large inelastic deformation without collapse and have excess of lateral strength over design strength. The value of R depends on ductility factor, strength factor, structural redundancy and damping. The strength factor depends upon the over strength of material used in construction, whereas Damping on normal RCC damping. IS Code incorporates ductility in a vague manner, for OMRF(not ductile detailed) response reduction factor is 3, for SMRF(Ductile detailed) it is 5.But code is silent on redundancy of structure. A parametric study is conducted to assess the impact of redundancy in ductile reinforced concrete (RC) moment framed buildings and the studied variables were the number of bays. Nonlinear static pushover analysis is carried out on the analytical models using finite element analysis software SAP 2000. The R factor components are computed from the results obtained from the nonlinear static pushover analysis and finally the response reduction factor is calculated for all the models. The results show that for buildings with low redundancy, Response reduction factor 5,applied by IS1893 is overestimated. Thereby it underestimates the earthquake forces on such buildings.*

***Key Words*: Ductility, Redundancy, Response reduction factor, Pushover curve, Yield displacement, Yield base shear**

1. INTRODUCTION

The devastating effect of an earthquake can have major consequences on infrastructures and lifelines. The earthquake engineering community has been reassessing its procedures, in the past few years, due to such earthquakes which have caused extensive damage, loss of life and property. These procedures mainly consider assessment of seismic force demands on the structure and then developing design procedures for the structure to withstand the applied actions.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.

1.1 Response reduction factor

The response reduction factor, R, represents the ratio of the maximum lateral force if structure remains elastic(Ve), to the lateral force(Vd), which it has been designed to withstand[13]. Response reduction (R) factors are essential seismic design tools, which are typically used to describe the level of inelasticity expected in lateral structural systems during an earthquake. Commonly, the response reduction factor is expressed as a function of various parameters of the structural system, such as strength, ductility, damping and redundancy.

$$R = R_s\, R_\mu\, R_\xi\, R_r$$

Where R_s is the strength factor, R_r is the redundancy factor, R_μ is the ductility factor and R_ξ 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
$R_r = V_u/V_y$

2) Ductility factor
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 R_μ,
$R_\mu = (\mu-1)/\Phi + 1$
Where ø depends on soil conditions and timeperiod.For alluvial 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

2. RESEARCH SIGNIFICANCE

Due to economic pressures, less redundant special moment frames with few bays of moment resisting framing supporting large floor and roof areas are being constructed nowadays. Buildings where one-bay frames are used in the slender direction have had poor performances during past earthquakes Response reduction factors (R) were originally developed assuming that structures possess sufficient level of redundancy[8]. However less redundant structures are to be designed for more base shear as they are prone to earthquakes. Bur for design purposes, we always use the code specified value of 5 for such frames. Therefore R is over estimated as per code for buildings with low redundancy. Hence it is essential to calculate the actual response reduction factor based on redundancy.

3. OBJECTIVES OF PRESENT STUDY

- To evaluate the effect of redundancy on Response reduction factor for buildings with low redundancy
- To compare these values with Response reduction factor specified in IS 1893

4. BUILDING DETAILS

The structural systems considered for this study are (G+9) storey buildings with 1,2,3,4 and 5 bays in x direction. Typical bay width is 4m. Height of typical floor is taken as 3m. The building is considered to be located in Zone V as per IS 1893:2002 with medium soil conditions.. The building is modeled using the softwareSAP2000. 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 fig 1.

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	300 mm X 300mm
Slab thickness	150 mm
Live load on floor and roof	3kN/m²and 1.5kN/m²

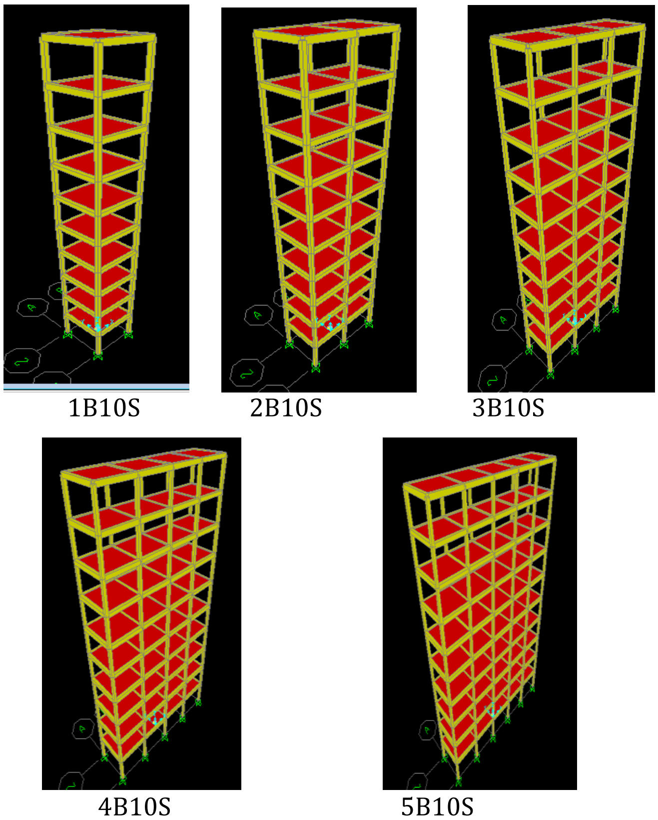

Fig-1. Configurations of buildings chosen

5. ANALYSIS OF THE STRUCTURE

Two types of analysis procedures have been carried out for determining the various structural parameters of the model. Here we are mainly concerned with the behavior of the structure under the effect of ground motion and dynamic excitations such as earthquakes and the displacement of the structure in the inelastic range. The analyses carried out are as follows:

1)Modal analysis

2)Pushover Analysis

Modal analysis is carried out for obtaining the natural timeperiods and other modal parameters of the structure

5.1. Pushover Analysis

Nonlinear static pushover analyses (NSPA) n the x and y directions of the 5 study frames are performed to estimate their redundancy and ductility capacity, which are required for computing R for each frame.

Pushover analysis is Non Linear Static Analysis done to determine the capacity of structure. In this procedure a predefined lateral load pattern is distributed along the building height. The lateral forces are then monotonically increased in constant proportion with a displacement con-trol at the control node of the building until a certain level of deformation is reached. For this analysis nonlinear plastic hinges have been assigned 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 output of a nonlinear static analysis is generally presented in the form of a 'pushover curve', which is typically the base shear vs. roof displacement plot. The value of the yield base shear and yield displacement is arrived by plotting the curve in Autocad 2016

6. 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	1B10S	2B10S	3B10S	4B10S	5B10S
Time period(s)	1.468	1.6227	1.6946	1.7363	1.7635

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

Sample analysis evaluation:

For 1B10s, the pushover curve obtained from the non linear analysis is show in fig-2.Also the yield and ultimate points of the curve is obtained by plotting the same in Autocad2016 and is shown in fig-3

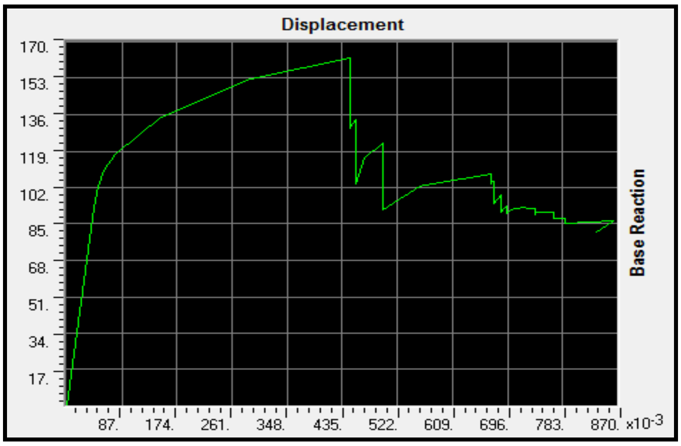

Fig-2 :Pushover curve for 1B10S

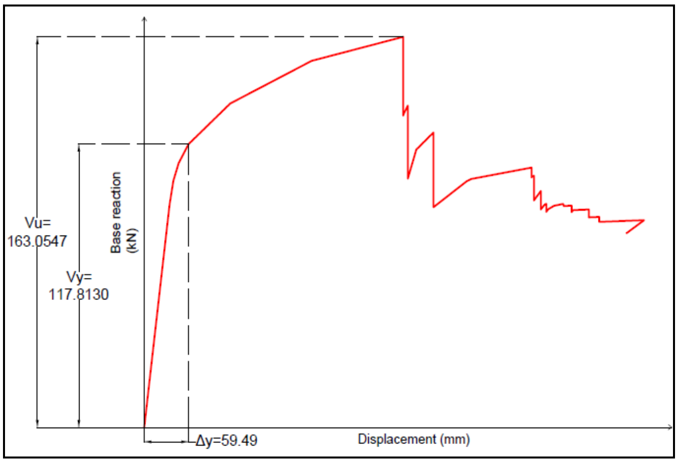

Fig-3:Yield and ultimate points for 1B10S

PUSHOVER PARAMETERS

- Vu=163.0547
- Vy=117.813
- Δy=59.49

Max displacement,
Δm= 0.004H
=120mm

CALCULATION OF R:

Rr=Vu/Vy=1.38
μ=Δm/Δy=120/59.49=2.02
For t=1.468s,ø=0.82
Rμ=(μ-1)/ø +1=2.24
RS =1
Rξ =1
R=RS Rμ Rξ Rr =3.09
R=3.09

It is seen that calculated R is about 40% 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	Δm (mm)	Rμ	R
1b10s	163.0547	117.813	1.38	120	2.24	3.09
2b10s	295.215	201.8	1.47	120	2.14	3.14
3b10s	423.113	265.445	1.59	120	2.78	4.42
4b10s	556.576	345.86	1.61	120	2.76	4.45
5b10s	676.402	387.539	1.74	120	3.13	5.44

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

Model	Vu (kN)	Vy (kN)	Rr	Δm (mm)	Rμ	R
1b10s	163.0547	117.813	1.38	120	2.24	3.09
2b10s	295.215	201.8	1.47	120	2.14	3.14
3b10s	423.113	265.445	1.59	120	2.78	4.42
4b10s	556.576	345.86	1.61	120	2.76	4.45
5b10s	676.402	387.539	1.74	120	3.13	5.44

6.1. Inferences

1) The R values range from 3.09-5.44 and 3.09-3.4 in x and y directions respectively for the frames considered ,
2) All values are lesser than the IS specified value of R (= 5.0) except for 5 bay frames.
3) It is seen that R value varies from standard value of 5 by 38.2%,37.2%,11.6% and 11% for 1,2 ,3 and 4 bays respectively in x direction and it exceeded the code recommended value of 5 by 8.8% for 5 bay frames in x direction

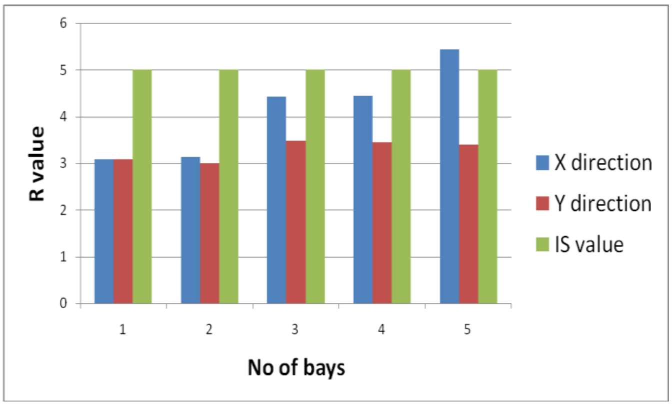

Chart-1: Variation of Response reduction factors with number of bays

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

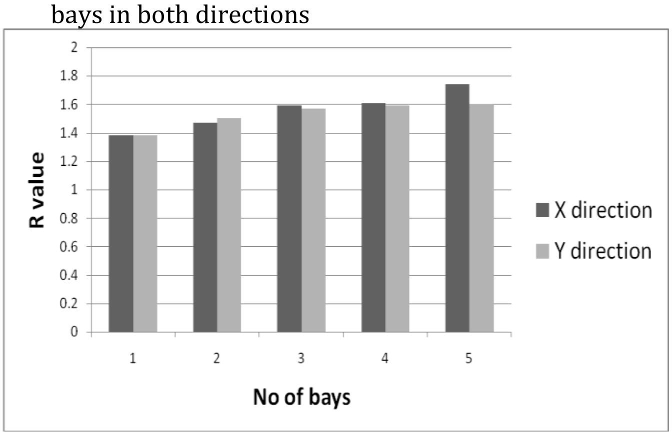

Chart -2: Variation of redundancy factors with number of bays

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

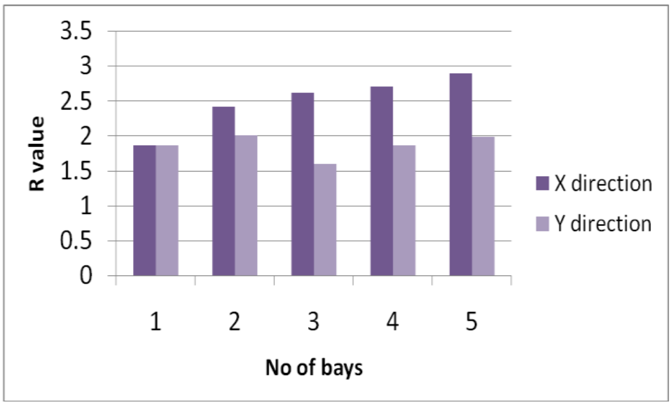

Chart -3: Variation of ductility factors with number of bays

6) In x direction,beyond four bays the increase of redundancy, resulting by adding more bays, becomes insignificant since the calculated value coincides with the recommendation of IS 1893.

7. CONCLUSIONS

- As the number of bays increases the redundancy factor, *R*r shows an increasing trend for all the frames. Thus the frames with more bays possess higher redundancy.
- Ductility factor increases with number of bays in x directions. In y direction it looks like there is no definite trend for ductility factor
- It is found out that value of R obtained is critical in the direction with less number of bays. R values must be taken as the least from both directions during design purposes considering ductility and redundancy
- The R value obtained for single bay structure was found to be least, which is the most critical case. Therefore estimated R values are smaller for bays with low redundancy factor compared to the IS recommended value.
- In general, the present study shows most of the frames investigated, failed to achieve the respective target values of response reduction factors recommended by IS 1893 (2002). Based on the results obtained from non linear pushover analysis the Indian standard overestimates the R factor, which leads to the potentially dangerous underestimation of the design base shear for buildings with low redundancy.

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