International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 01, January-2019

Seismic Response Reduction Factor Evaluation for Irregular RC Structures

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***Abstract*- Response reduction factor is invariably used by most seismic design codes to include the non-linear response of structure. The non-linear behaviour of the structure is taken into account due to this factor which permits the designer to use a linear elastic force-based design. It is a combined effect of over strength, ductility and redundancy. Response modification factors play a key, but controversial role in the seismic design process. No other parameter in the design base shear equation impacts the design actions in a seismic framing system as does the value assigned to R. Despite the profound influence of R on the seismic design process and ultimately on the seismic performance of buildings in India. No scientific basis exists for the values of R adopted in seismic design codes in India. Without such a basis, it will be difficult to advance the practice of force-based seismic design in its current form. In present work efforts has been made in estimating the actual value of response reduction factor (R) for reinforced concrete buildings having irregularity in plan by non-linear static pushover analysis using SAP2000 and compare results with codal values. The frames were designed as per guidelines of IS 456:2000.The lateral loads acting on the frames were obtained from the guidelines of IS 1893: 2002 (Part1).**

I. INTRODUCTION

The devastating effect of an earthquake can have major consequences on infrastructures and service life. 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 effects.

The value of Response reduction factor varies from 3 to 5 in Indian code as per type of resisting frame, but previous studies 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 irregular RC structures.

Fig 1. Examples of Irregular structures

II. METHODOLOGY

- Conduct literature review on response reduction factor of structures and effect of various parameters of response reduction factor on buildings.
- Modelling of low, mid and high rise RC structures with stiffness irregularities.
- Analysis to be done using SAP 2000 software.
- Percentage variation in R value from code provisions are to be determine.

III. MODELLING OF BUILDINGS

An ideal symmetric structures having the distribution of loads is uniform along each storey and three asymmetric structures were chosen for the study. Asymmetric structures includes an L shape, step shape and T shape floor. The buildings under consideration are low, mid and high rise buildings. All the structure had got the same perimeter for the plot they are compared for their irregular plan and mass distribution. The seismic analysis were carried out as per the code IS 1893: 2002. Zone IV and soil type II are considered for analysis. The performance of the structures are assessed as per the procedure prescribed in ATC-19, IS 1893-2002 and

FEMA-356. The analysis of the structural model is done in SAP 2000.

Three, seven and eleven storied RC structures which are symmetric and asymmetric in plan have been considered for the study. The building is assumed to be situated in Zone III as per IS 1893 (2000). The concrete floors are modelled as rigid. The details of the model is given in the table 1. The structures are assumed to be constructed on medium soil as per IS 1893. The design dead loads and live loads are calculated from IS 875 (Part 1) and IS 875 (Part 2) respectively.

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Table 1: Structural details

Contents	Description
Type of structure	Multi storey structures (G+3, G+7 and G+11)
Building plan dimension	15m x 15m
Concrete Grade	M_{30}
Steel Grade	Fe 415
Slab Thickness	120mm
Height of each storey	3.5m
Height of ground storey	2m
Live load at floor & roof level	2 kN/m² & 0.75 kN/m²
Type of soil	Medium soil
Seismic zone	IV

Table 2 gives the further details regarding the planar frames. The seismic weight calculation is done as per IS 1893. Based on the common practice of the engineers the models for the study have been selected. Same beam sections have been used throughout the structure whereas the column section have been varied as per the height of the buildings as is done in common practice. The RC design is based on IS-456 (2000) and the ductile designing is based on IS 13920 (2003). The reinforcement details of all the sections are not same in the three models.

Table 2: Details of the RC frames considered for the study

Number of storey	Height (m)	Time period (s)	Weight (kN)	Design base shear (kN)
3	12.5	0.452	9654.50	387
7	26.5	0.816	21682.54	543
11	40.5	1.1106	35830.94	645

b. Variation in plan shape

It contains G+3, G+7 and G+11 structures with variation in plan shapes. Different plan shapes are L shape, T shape and stepp shape. All these structures have same base area. Fig 4 shows the different plan irregularities used for the thesis work

a. Variation of height

It contains rectangular plan shaped structure with variation in height. ie, G+3, G+7 and G+11 structures. The plan layout of the structures shown in the fig 2. Fig 3 shows the typical elevations for these structures.

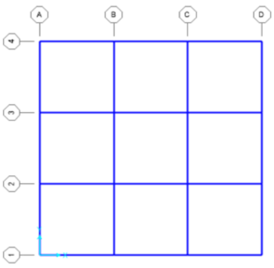


Fig 2. Plan of building

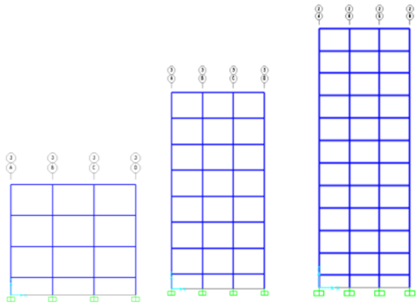
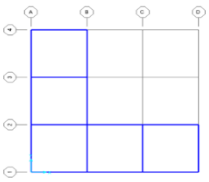
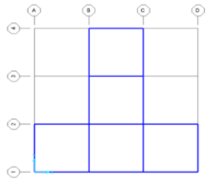


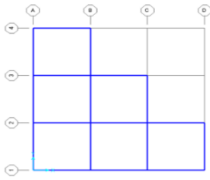
Fig 3. Elevations of the structures



(a) L shape



(b) T shape



(C) stepp shape

Fig 4. Plan irregularity

c. *Model Geometry*

In order to differentiate models from each other various abbreviations are used. For example, PL3: Model number 1 with 3 storey L shaped plan irregularity. Table 3 given below shows the model details of the thesis work. Fig 5 to 7 shows the three dimensional view of models used for the study.

Table 3: Model details

Designation	Details
R3	3 storey regular structure
PL3	3 storey L shaped plan irregular structure
PS3	3 storey step shaped plan irregular structure
PT3	3 storey T shaped plan irregular structure
R7	7 storey regular structure
PL7	7 storey L shaped plan irregular structure
PS7	7 storey step shaped plan irregular structure
PT7	7 storey T shaped plan irregular structure
R11	11 storey regular structure
PL11	11 storey L shaped plan irregular structure
PS11	11 storey step shaped plan irregular structure
PT11	11 storey T shaped plan irregular structure

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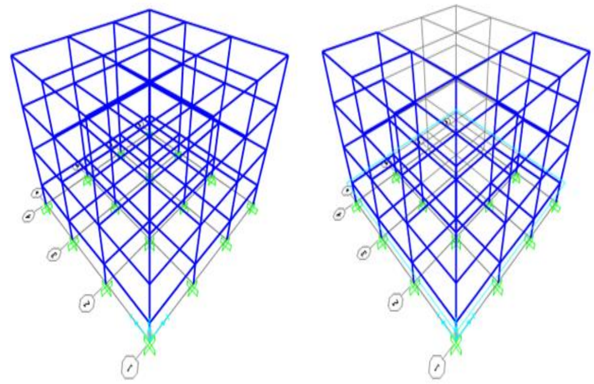
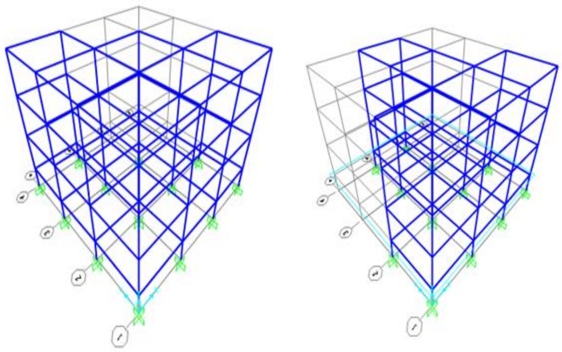
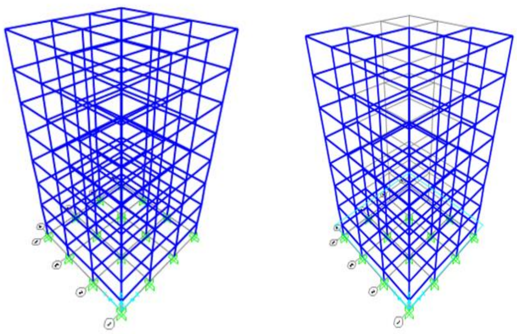


(a) R3 (b) PL3

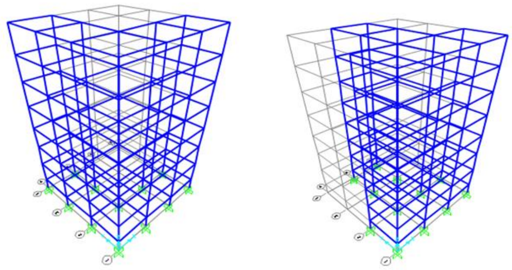


(b) PS3 (d) PT3

Fig 5. Three dimensional view of 3 storey building

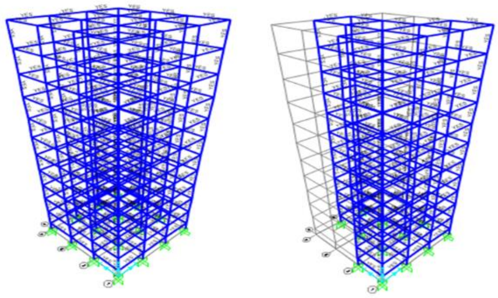


(a) R7 (b) PS7



(c) PL7 (d) PT7

Fig 6. Three dimensional view of 7 storey building



(a) R11 (b) PT11

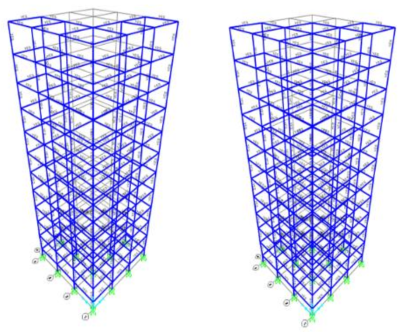


Fig 7. Three dimensional view of 11 storey building

IV. ANALYSIS

Pushover Analysis

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 control 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.

V. RESULTS AND DISCUSSIONS

i. Comparison of Pushover curve

Comparison of pushover curve having irregularity in plan is shown in fig 8 to fig 10. The figure describes the pushover curves of different models of rectangular shape, L shape, T shape and step shape. This shows that as percentage of irregularity goes on increasing push over curve drops down to the lower values. As we can clearly observe that graph of R3 is on lower value than PL3, PT3 and PS3. In case of mid and high rise structures, the base shear versus displacement graphs are almost similar.

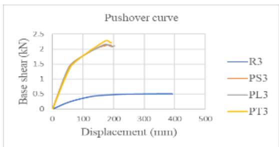


Fig 8. Comparison of pushover curve of 3 storey irregular structures

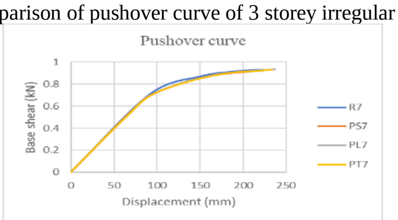


Fig 9. Comparison of pushover curve of 7 storey irregular structures

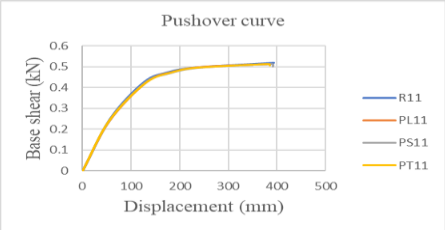


Fig 10. Comparison of pushover curve of 11 storey irregular structures

ii. Estimation of Performance point

It is observed that the demand curve tend to intersect the capacity curve in the building performance level of Life Safety Level, which means substantial damage as occurred to the structure, thus it may lose a significant amount of its original stiffness. However, a substantial margin remains for additional lateral deformation before collapse would occur.

E.g. For 3 storey regular building, on the above regular building frames the nonlinear static pushover analysis is performed to investigate the performance point of the building frame in terms of base shear and displacement. The various load combinations are also used for this purpose. After pushover analysis the demand curve and capacity curves are obtained to get the performance point of the structure. The performance point is obtained as per ATC 40 capacity spectrum method. The demand curve and capacity curve for regular building is shown in fig 11 - (ATC 40 Capacity Spectrum).

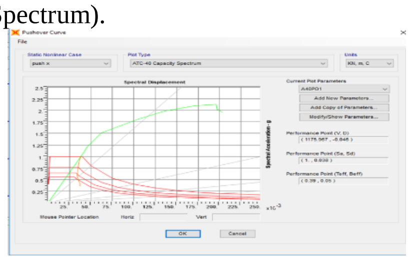


Fig 11. ATC 40 Capacity Spectrum

Performance point = 1175.967 kN

The Performance points of all the buildings are obtained and stated in the table 4. The table specifies the performance points of all the buildings along with their designation.

Table 4. Performance points for modelled buildings from capacity spectrum method

Sl no	Designation	Performance point
1	R3	1175.967
2	PL3	810.17
3	PS3	905.214
4	PT3	806.689
5	R7	1868.91
6	PL7	1265.603
7	PS7	1429.085
8	PT7	1266.205
9	R11	2030.085
10	PL11	1362.236
11	PS11	1547.119
12	PT11	1364.118

iii. Estimation and Comparison of Response reduction factor

Variation of Response reduction factor with respect to irregularities in plan is shown in the table 5.

Table 5. Response reduction factor for modelled buildings

Sl no	Designation	Rs	Rμ	Rr	R	Codal value
1	R3	3.03	1.09	1	3.302	5
2	PL3	2.264	1.127	1	2.553	5
3	PS3	2.503	1.114	1	2.788	5
4	PT3	2.223	1.04	1	2.31	5
5	R7	3.44	1.163	1	4.002	5
6	PL7	2.451	1.232	1	3.021	5
7	PS7	2.881	1.198	1	3.452	5
8	PT7	2.585	1.23	1	3.18	5
9	R11	3.147	1.32	1	4.154	5
10	PL11	2.261	1.347	1	3.046	5
11	PT11	2.24	1.34	1	3.021	5
12	PS11	2.583	1.312	1	3.389	5

VI. CONCLUSIONS

On the above building frames the nonlinear static pushover analysis is performed to investigate the performance point of the building frame in terms of base shear and displacement. The various load combinations are also used for this purpose. After pushover analysis the demand curve and capacity curves are obtained to get the performance point of the structure. The performance point is obtained as per ATC 40 capacity spectrum method. From the above study followings conclusions were drawn.

- The evaluated value of "R" in the present work were obtained by nonlinear static (pushover) analysis of structures with plan irregularities are found to be less than as those specified in the IS 1893.
- As number of storey increases, the value of response reduction factor goes on increasing.
- The performance point of T shape and L shape plan irregularity is almost nearer to each other. It may due to same base area.

- The performance point of step shape irregular structure is higher than that of other irregular structures. It may due to increased base area.

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