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Assessment of Response Reduction Factor for High Rise Irregular Structures

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Abstract* – *The prime purpose of this analysis is to evaluate the value of response reduction factor of RC frames by considering various factors into account. As we are aware about that there is significant difference in the forces which are generated during earthquake than the structure is actually to be designed to withstand against these forces. We cannot design the structures for real values of seismic forces as it is uneconomical from various aspects. There is a necessity to reduce the actual severity of earthquake and to achieve this, rresponse reduction factor is used; it is the factor by which the actual base shear force should be reduced, to obtain the design lateral force during design basic earthquake (DBE) shaking. The response reduction factor (R) is basically depends on Over strength (Rs), Ductility (Rμ), Redundancy (RR). There is no explanation given in (IS:1893-2000) code for various values of response reduction factor used in, so it is difficult to proceed the execution of seismic design without firm basis. Also in terms of various factors such as ductility and over strength, IS code does not separate the component of response reduction factor (R) explicitly. Currently in present work attempt has been made to evaluate the actual value of response reduction factor for RC buildings with plan irregularity, variation in height of building and the effect of various seismic zones on response reduction factor. Also the comparison is made on the basis of importance factor, type of foundation soil and lateral load resisting system by non-linear static pushover analysis using SAP2000 and compare results with values given in IS code 1893(2000). The frames were designed as per specifications of IS 456:2000.The lateral loads acting on the frames were taken from the specifications of IS 1893: 2002 (Part1).

Keywords* – *Vertical irregularity, Plan irregularity, over strength factor, Design base shear, Ductility factor, Zone factor, Response Reduction Factor, Pushover analysis.

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1. INTRODUCTION

An earthquake is the result of a sudden release of stored energy in the Earth's crust that creates seismic waves. The destructive effect of an earthquake can cause adverse effect on infrastructure as well as social and economic life of society. The community related seismology and earthquake has been reassessing its procedures, in the past few years, due to such earthquakes which have caused hazardous damage, loss of life and property. These studies fundamentally consider evaluation of seismic force demands on the structure and then developing design procedures for the structure to withstand the applied actions. Elastic force is the important factor for seismic design in most of the structures.

Now a days many existing structures are designed and to be constructed containing irregularities in their plan as well as in elevation, but some of them are designed and purposefully constructed to be irregular to fulfill various needs and functions such as basements for mercantile purposes created by eliminating central columns. Also, by adjusting the sizes of structural members in the upper story's to fulfill necessary requirements and for other functions like storing heavy machines and equipment's etc. This difference in usage of a particular floor with respect to adjacent floors results in uneven distributions of mass, stiffness and strength along the building dimensions.

Generally nonlinear response of structure is not encompasses in design process but its effect is considered by using a reduction factor called Response Reduction factor (R). There is a variations in the method the response reduction factor (R) is specified in various codes. The value of response reduction factor varies from 3 to 5 in IS code, the present work takes a rational approach in determining R factor for buildings with irregularities and also to analyse the effect of various seismic zone factors on response reduction factors.

1.1 The response reduction factor:-

The response reduction factor, R represents the ratio of the maximum lateral force if structure remains elastic to the lateral force which it has been designed to withstand. Commonly, the response reduction factor is expressed as a function of various parameters of the structural system, such as strength, ductility, damping and redundancy.

$$R=Rs*R\mu*Rr$$

Where 'Rs' is the strength factor, 'Rr' is the redundancy factor, 'Rμ' is the ductility factor.

i) Over strength factor (Rs):-

The extra strength after the design strength is called the over strength. Most of the structures show significant over strength. Subsequentconcurrence of unfavourable zones, Over strength of material, strain hardening, capacity depletion factors are the emergence of Over strength (Rs). Over strength is to be engage to reduce the forces that are used in the design, hence directing to more reasonable structures.. The Over strength, which is specified as member or structural capacity, is usually defined using Over strength factor, which may be defined as the ratio of maximum base shear in actual behavior to first significant yield strength in structure.

$$Rs = Vu/Vd$$

Where,'Vu' is the maximum base shear and 'Vd' is the design base shear.

ii) Ductility factor (Rμ):-

Ductility of a structure, is the capacity to hold up large unyielding deformations without considerable loss of strength and stiffness. Ductile structures functions better than that of the fragile structures. Structures with high ductility can relatively tolerate large distortion and permit the structure to go under high possible strength, in turn, dissolving a substantial amount of energy. The ductility factor (Rμ) is a scale of the universal nonlinear response of the structures in view of its inelastic distortion capacity. It is estimated as the ratio of the base shear considering an elastic response to the ultimate base shear considering an inelastic response.

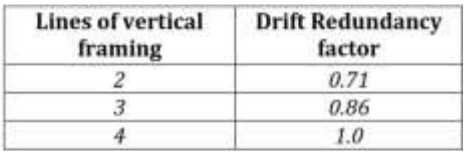
$$R\mu = Ve/Vu$$

Where,'Ve' is the base shear with elastic response and 'Vu' is the base shear with inelastic response.

iii) Redundancy factor (Rr) :-

The redundancy factor is a scale of reiterations in a horizontal load resisting system. The moment resisting frames, shear walls are the mostselected horizontal load resisting systems in reinforced concrete structures. The RC structures with multiple lines of horizontal load resisting frame type is normally considered in the class of redundant type of structures cause the frames are indicated and categorized to convey the seismic inertia loads to the foundation. The horizontal load is retained by various frames depending upon the comparative strength and stiffness property of relevant frames for redundant system of frames. When independent the accuracy of framing system is greater for the structures with multiple lines of frames while it decreases when resisting criteria are accurately correlated. ATC 19 fixed a association between lines of vertical seismic frame and drift redundancy factor as shown in table.

Table 1.1 Redundancy factor (Rr) taken from ATC – 19



Lines of vertical framing	Drift Redundancy factor
2	*0.71*
3	*0.86*
4	*1.0*

1.2 Zone Factor (Z):-

It is a factor to obtain the design spectrum depending on the perceived maximum seismic risk characterized by Maximum Considered Earthquake (MCE) in the zone in which the structure is located. The basic zone factors included in this standard are reasonable estimate of effective peak ground acceleration. From the above table we know that intensity of an earthquake is mainly depends on the seismic zone. As values of zone factors are in fractions and does not have much difference amongst them zone wise but on the front of seismic intensity it may cause huge effect on loss of economic and social life of society.

1.3 Structural Response Factors (S/g):-

It is a factor denoting the acceleration response spectrum of the structure subjected to earthquake ground vibrations, and depends on natural period of vibration and damping of the structure.

1.4 Fundamental Natural Period (Ta):-

Theapproximate fundamental natural period of vibration (T,) in seconds, of a moment-resisting frame building without brick infill panels may be estimated by the empirical expression.

i) Ta = 0.075h^0.75 (for RC MRF building)

ii) Ta = 0.080h^0.75 (for RC-Steel Composite MRF building)

iii) Ta = 0.085h^0.75 (for Steel MRF building)

Where,

h = Height of building, in m. This excludes the basement stores, where basement walls are connected with the ground floor deck or fitted between the building columns.

1.5 Importance factor (I) :-

It is a factor ddepending upon the functional use of the structures, characterized by hazardous consequences of its failure, post-earthquake functional needs, historical value, or economic importance

1.6 Design Seismic Base Shear (VB):-

The total design lateral force or design seismic base shear (VB) along any principal direction shall be determined by the following expression.

VB = Ah*W

Where,

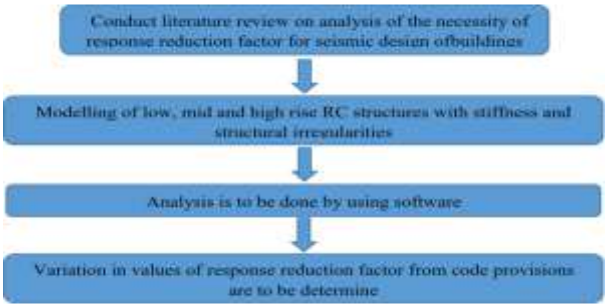
VB= Design horizontal acceleration spectrum value, using the fundamental natural period Ta, in the considered direction of vibration.

W= Seismic weight of the building.

The base shear plays vital role in the estimation of various factors mentioned above such as over strength factor.

The value of ‘R’ factor varies from 3 to 5 in IS code depending on type of resisting frame, but previous studies related this does not provide analysis that on what basis values of Response Reduction Factor are considered. Most of the previous studies in this area have focused on finding the Over strength and ductility components of the response reduction factor. The present work takes a reasonable perspective in determining R factor for irregular high rise RC structures with various irregularities in plan.

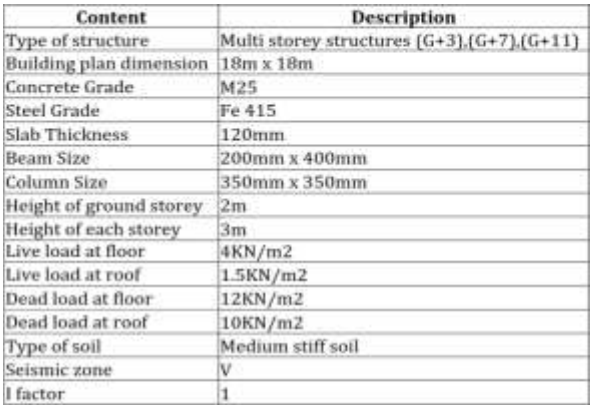
2. METHODOLOGY



3. MODELLING OF BUILDINGS

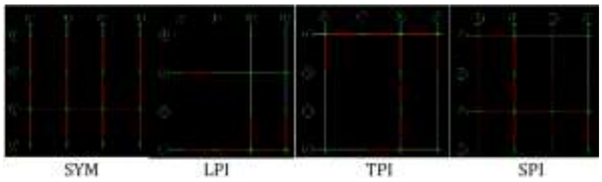
An perfect regular that is symmetric structures having uniform load distribution along each storey individually and three structures having various irregularities were selected for the study. Irregular structures contains an L-shaped, T-shaped and stepped-shaped plan irregularities. The buildings under consideration are 3-storey, 7-storey and 11-storey buildings. All the buildings are having same perimeter of the plot for irregular plan and mass distribution. The seismic evaluation were carried out as per the code IS 1893: 2002. Buildings are to be situated in medium stiff soil are to be considered for analysis. The performance of the buildings are evaluated as per the procedure specified in ATC-19 and IS 1893-2002. The structural analysis of the model is carried out in SAP 2000. The buildings are assumed to be situated in Zone V as per IS 1893 (2000). The concrete floors are designed as rigid. The specifications of the model are to be given in the table below.

Table 3.1 Structural Details

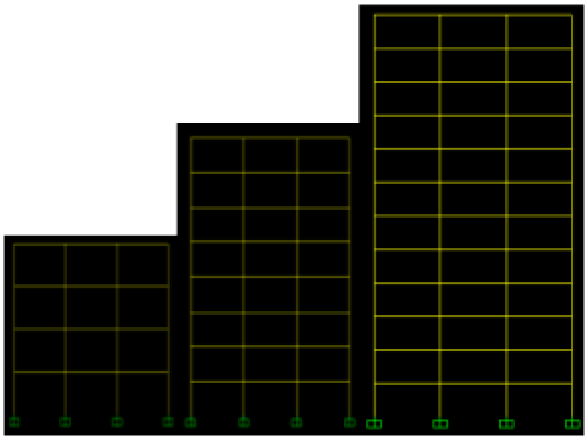


Content	Description
Type of structure	Multi storey structures (G+3),(G+7),(G+11)
Building plan dimension	18m x 18m
Concrete Grade	M25
Steel Grade	Fe 415
Slab Thickness	120mm
Beam Size	200mm x 400mm
Column Size	350mm x 350mm
Height of ground storey	2m
Height of each storey	3m
Live load at floor	4KN/m2
Live load at roof	1.5KN/m2
Dead load at floor	12KN/m2
Dead load at roof	10KN/m2
Type of soil	Medium stiff soil
Seismic zone	V
I factor	1

3.1 Building Plans:-



3.2 Building Elevations:-



In order to differentiate models from each other various abbreviations are used such as,

For Plan Irregularities:

SYM: Symmetric Structure

LI: L-shape Irregularity

TI: T-shape Irregularity

For Vertical Irregularities:

SI: Stepped Irregularity

For Example:

LPI: Model with L-shape plan irregularity.

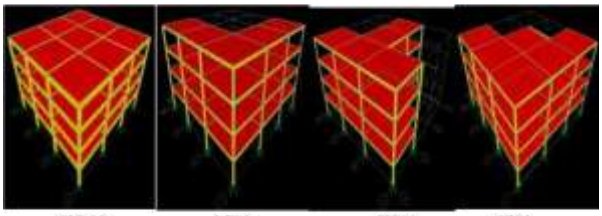
TPI: Model with T-shape plan irregularity.

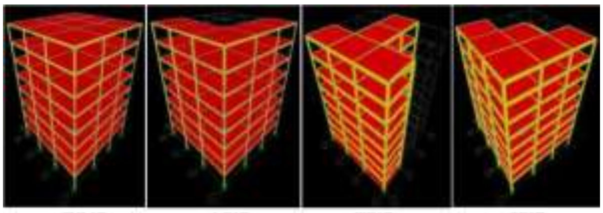
SPI: Model with Stepped-shape irregularity.

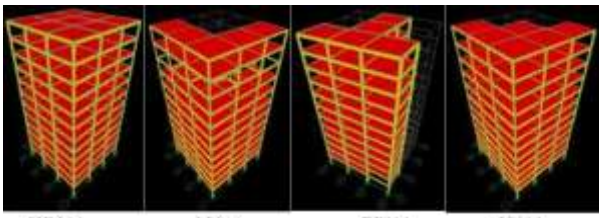
Table 3.2 Model Details

Type	Details
SYM3	3 storey symmetric building
LI3	3 storey L-shaped building
TI3	3 storey T-shaped building
SI3	3 storey stepped building
SYM7	7 storey symmetric building
LI7	7 storey L-shaped building
TI7	7 storey T-shaped building
SI7	7 storey stepped building
TI11	11 storey T-shaped building
SYM11	11 storey symmetric building
SI11	11 storey stepped building
LI11	11 storey L-shaped building

3.3 3-Dimensional models of all above mentioned building types:-


SYM3 LPI3 TPI3 SPI3

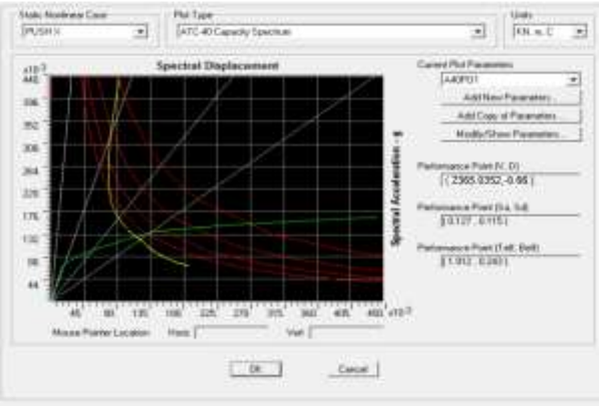

SYM7 LPI7 TPI7 SPI7


SYM11 LPI11 TPI11 SPI11

4. RESULTS AND DISCUSSION

4.1 Estimation of Performance point:-

It is noticed that the capacity curve is to be intersected by the demand curve in the structural performance level, it means significant damage is takes place to the structure, thus it may be possible to lose considerable amount of its actual stiffness. However, a significant margin rests for supplementary horizontal deformation before actual collapse would occur. Such as for3-storey symmetric building, on the above regular building frames the nonlinear static pushover analysis is conducted to evaluate the performance point of the structural frame in terms of base shear and displacement. The different load combinations are also used for this purpose. After the nonlinear pushover analysis the demand curve and capacity curves are obtained to get the performance point of the buildings. The performance point is obtained as per ATC 40 capacity spectrum method. The demand curve and capacity curve for symmetric building is shown in fig below.


Static Nonlinear Case: PUSH X

Plot Type: ATC 40 Capacity Spectrum

Units: KN, m, C

Current Plot Parameters: A40PD1

Performance Point (V, D): (2365.0352, 0.66)

Performance Point (Sa, Sd): (0.127, 0.115)

Performance Point (Teff, Beff): (1.912, 0.241)

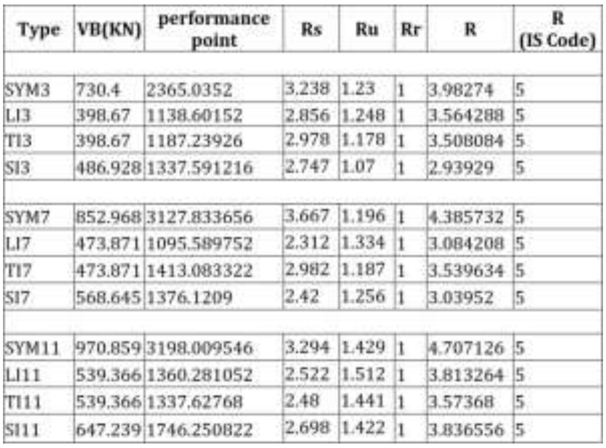
Figure 4.1 ATC 40 Capacity Spectrum

(Graph of Demand curve VS Capacity curve)

Performance point =<u>2365.0352KN.</u>

The pperformance points of all the buildings are obtained and stated in the table below. The table shows the performance points of all the buildings along with their designations and also shows the base shear values of different type of buildings based on which the comparison between the codal values of response reduction factor and estimated values are also specifies.

Table 4.1 Estimated values of response reduction factors

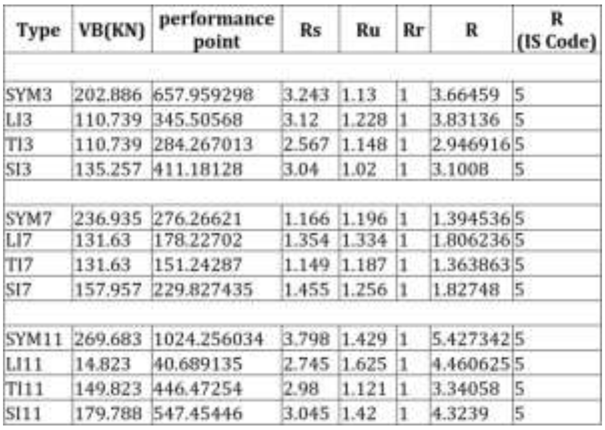


Type	VB(KN)	performance point	Rs	Ru	Rr	R	R (IS Code)
SYM3	730.4	2365.0352	3.238	1.23	1	3.98274	5
LI3	398.67	1138.60152	2.856	1.248	1	3.564288	5
TI3	398.67	1187.23926	2.978	1.178	1	3.508084	5
SI3	486.928	1337.591216	2.747	1.07	1	2.93929	5
SYM7	852.968	3127.833656	3.667	1.196	1	4.385732	5
LI7	473.871	1095.589752	2.312	1.334	1	3.084208	5
TI7	473.871	1413.083322	2.982	1.187	1	3.539634	5
SI7	568.645	1376.1209	2.42	1.256	1	3.03952	5
SYM11	970.859	3198.009546	3.294	1.429	1	4.707126	5
LI11	539.366	1360.281052	2.522	1.512	1	3.813264	5
TI11	539.366	1337.62768	2.48	1.441	1	3.57368	5
SI11	647.239	1746.250822	2.698	1.422	1	3.836556	5

4.2 Comparative results of response reduction factor based on seismic zone:-

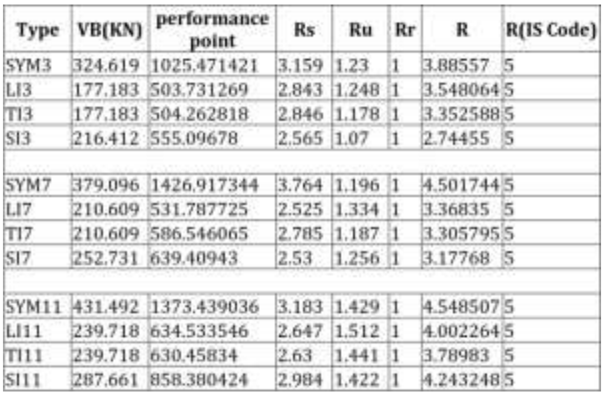
As location of the building changes it may influence the seismic behaviour of the structure in different ways in other words we can say that as the seismic zone of the building where the structure is actually to be situated changes, the zone factor of the respective seismic zone also changes which may turn to effect on the base shear value. We know that the base shear is an estimate of the maximum expected lateral force on the base of the structure due to seismic activity. It is calculated using the seismic zone, soil material, and building code lateral force equations.The table below shows results based on seismic zone II, zone III and zone IV.

Table 4.2 Estimated values of response reduction factors for zone II



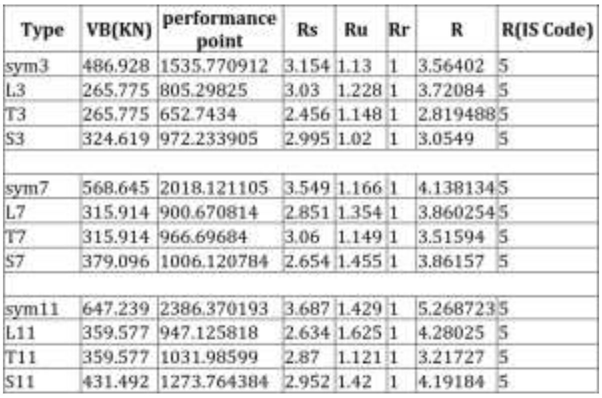
Type	VB(KN)	performance point	Rs	Ru	Rr	R	R (IS Code)
SYM3	202.886	657.959298	3.243	1.13	1	3.66459	5
LI3	110.739	345.50568	3.12	1.228	1	3.83136	5
TI3	110.739	284.267013	2.567	1.148	1	2.946916	5
SI3	135.257	411.18128	3.04	1.02	1	3.1008	5
SYM7	236.935	276.26621	1.166	1.196	1	1.394536	5
LI7	131.63	178.22702	1.354	1.334	1	1.806236	5
TI7	131.63	151.24287	1.149	1.187	1	1.363863	5
SI7	157.957	229.827435	1.455	1.256	1	1.82748	5
SYM11	269.683	1024.256034	3.798	1.429	1	5.427342	5
LI11	14.823	40.689135	2.745	1.625	1	4.460625	5
TI11	149.823	446.47254	2.98	1.121	1	3.34058	5
SI11	179.788	547.45446	3.045	1.42	1	4.3239	5

Table 4.3 Estimated values of response reduction factors for zone III



Type	VB(KN)	performance point	Rs	Ru	Rr	R	R(IS Code)
SYM3	324.619	1025.471421	3.159	1.23	1	3.88557	5
LI3	177.183	503.731269	2.843	1.248	1	3.548064	5
TI3	177.183	504.262818	2.846	1.178	1	3.352588	5
SI3	216.412	555.09678	2.565	1.07	1	2.74455	5
SYM7	379.096	1426.917344	3.764	1.196	1	4.501744	5
LI7	210.609	531.787725	2.525	1.334	1	3.36835	5
TI7	210.609	586.546065	2.785	1.187	1	3.305795	5
SI7	252.731	639.40943	2.53	1.256	1	3.17768	5
SYM11	431.492	1373.439036	3.183	1.429	1	4.548507	5
LI11	239.718	634.533546	2.647	1.512	1	4.002264	5
TI11	239.718	630.45834	2.63	1.441	1	3.78983	5
SI11	287.661	858.380424	2.984	1.422	1	4.243248	5

Table 4.4 Estimated values of response reduction factors for zone IV



Type	VB(KN)	performance point	Rs	Ru	Rr	R	R(IS Code)
sym3	486.928	1535.770912	3.154	1.13	1	3.56402	5
L3	265.775	805.29825	3.03	1.228	1	3.72084	5
T3	265.775	652.7434	2.456	1.148	1	2.819488	5
S3	324.619	972.233905	2.995	1.02	1	3.0549	5
sym7	568.645	2018.121105	3.549	1.166	1	4.138134	5
L7	315.914	900.670814	2.851	1.354	1	3.860254	5
T7	315.914	966.69684	3.06	1.149	1	3.51594	5
S7	379.096	1006.120784	2.654	1.455	1	3.86157	5
sym11	647.239	2386.370193	3.687	1.429	1	5.268723	5
L11	359.577	947.125818	2.634	1.625	1	4.28025	5
T11	359.577	1031.98599	2.87	1.121	1	3.21727	5
S11	431.492	1273.764384	2.952	1.42	1	4.19184	5

5. CONCLUSION

Following are the salient conclusions obtained from the present study:-

1. A persistent value of response reduction factor for any of above case of building are not justified. Precise methodology are essential to estimate the "R" value accounting for strength, ductility and redundancy for specific type of building; present work takes efforts in the same direction.

2. On behalf of results obtained we can conclude that the value of response reduction factories overestimated in IS-1893 (2000), which may leads to the potentially hazardous underestimation of the design base shear.

3. As number of storey that is as height of building goes on increases, the value of response reduction factor goes on increasing.

4. The performance point of T-shaped and L-shaped plan irregularity is almost alike might be due to the same base area.

5. From the obtained results we can conclude that seismic zone may cause considerable effect on values of response reduction factor.

6. There is a necessity to estimate the accurate values of response reduction factor as, many factors causes substantial effect on R-factor. Also there is a need to specify concern values ductility and over strength factors.

7. The obtained results are based on only few considerations and methodology such as we performed our analysis by considering specific seismic zone; specific type of soil etc. and only non-linear static pushover analysis is conducted.

8. If we changes our above specifications and will adopted other modes of analysis such as non-linear dynamic pushover analysis, time history analysis etc., then there may be a possibility to obtain different types of results based on the considerations.

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