RESPONSE REDUCTION FACTOR AND PUSH OVER ANALYSIS OF EXISTING HIGH RISE BUILDING

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Abstract -The basic concept of performance based seismic design is to provide engineers with the capability to design buildings that have a predictable and reliable performance in earthquakes. The performance based seismic design is a process that permits design of new buildings or upgrade of existing buildings with a realistic understanding of risk of life, occupancy and economic loss that may occur as a result of future earthquake. Pushover analysis is a simplest method for performance based seismic analysis. This paper represents, the performance point of the RCC structure, a non linear static pushover analysis has been conducted by using SAP2000v 19. To achieve this objective two existing high-rise buildings of 21, 30 storey existing buildings are analyzed with zone factor of 0.16 i.e. zone III as per IS 1893-2002 and also found the Capacity curve and Response reduction factor.

Key Words: Pushover analysis; Non linear static analysis; Performance point; Response reduction factor; SAP2000 v19.

1 INTRODUCTION

Earthquake in the simplest terms can be defined as Shaking and vibration at the surface of the earth resulting from underground movement along a fault plane. The vibrations produced by the earthquakes are due to seismic waves. Of all the factors accounted for, in any building design, seismic waves are the most disastrous one. Conventional seismic design in codes of practice is entirely force-based, with a final check on structural displacements. Seismic design follows the same procedure, except for the fact that inelastic deformations may be utilized to absorb certain levels of energy leading to reduction in the forces for which structures are designed. This leads to the creation of the Response Reduction Factor (R factor); the important parameter that accounts for over-strength, energy absorption and dissipation as well as structural capacity to redistribute forces from inelastic highly stressed regions to other less stressed locations in the structure.

1.1 NEED FOR STUDY

IS 1893 (Part 1):2002 gives the value of Response Reduction Factor (R), for lateral load resisting system. IS 13920-1993 gives the ductility requirement for earthquake resistant design. For special moment resisting RC frame structures (SMRF) R value is given as 5. While designing the RC structure R value is taken as 5 in all situations and with expectation of very high ductility. Code does not explain all necessary circumstances of SMRF. Thus it is essential to study the real behaviors of RC buildings in through non-linear analysis and suggest the circumstance which affects the response of the structure.

This factor is unique and different for different type of structures and materials used. Hence classification of Response modification factor for various structural systems is extremely important in order to do evaluation based on demand (earthquake ground motion) and capacity of the structure.

1.2 RESPONSE REDUCTION FACTOR:

Response reduction is used to scale down the elastic response of the structure. This factor is unique and different for different type of structures and materials used. The structure is allowed to be damaged in case of severe shaking. Hence, structure is designed for seismic force much less than what is expected under strong shaking if the structure were to remain linearly elastic.

As stated earlier, Response reduction factor is the most important factor for seismic design of structure. Response reduction factor takes into account the nonlinearity of structure and reduces the elastic response of structure. As per global standard codes such as ATC-40, FEMA 273 this factor has been defined as function of ductility factor, Strength factor, redundancy factor and damping factor.

$$R = R_S * R_\mu * R_\xi * R_R \qquad \text{………….. (1.1)}$$

Where,

R_S is strength factor,

R_μ is ductility factor,

R_ξ is damping factor and

R_R is Redundancy Factor.

1.2.1 STRENGTH FACTOR (R_S):

The maximum lateral strength of building (V_u) will generally exceed the design lateral strength (V_d) of building because the members or elements are designed with capacities substantially greater than design actions and material strength also exceed specified nominal strengths. Thus the strength factor or over-strength factor is defined as ratio of ultimate base shear to design base shear.

$$Rs = \frac{Vu}{Vd} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1.2)$$

1.2.2 DUCTILITY FACTOR (Rμ):

The ductility factor is a measure of global Nonlinear (whole structure) response of framing system and not the component of that system. It is measured as ratio of ultimate or maximum base shear to base shear corresponding to yield (Ve). Ductility factor shows response of structure in terms of its plastic deformation capacity. It depends upon ductility level (μ) and time period of system. In this study, the formulation proposed by T. Paulay and M. J. N. Priestley is used that divides the time period of the structure for calculating ductility reduction factor.

$R\mu = 1.0$ for zero-period structures

$R\mu = 2\mu - 1$ for short-period structure (1.3)

$R\mu = \mu$ for long period structure

$R\mu = 1 + (\mu - 1)\, T/0.70$ $(0.70\ s < T < 0.3)$

Where, 'μ' is given by $\mu = \Delta u / \Delta y$, where Δu is ultimate deformation and Δy is yield deformation.

1.2.3 DAMPING FACTOR (Rξ):

The damping factor (Rξ) accounts for the effect of 'added' viscous damping and is primarily applicable for structures provided with supplemental energy dissipating devices. Without such devices, the damping factor is generally assigned a value equal to 1.0 and is excluded from the explicit components of response reduction factor used in force-based design procedures.

1.2.4 REDUNDANCY FACTOR (R_R):

The redundancy factor R_R is measure of redundancy in a lateral load resisting system. In RC structures, the moment resisting frames, shear walls or their combinations are the most preferred lateral load resisting systems. Sometimes, the central frames are only designed for gravity loads and the perimeter frames are designed as the lateral load resisting systems. Thus the redundancy in lateral load resisting systems depends on the structural system adopted. It is obvious that a less redundant structural system is to be designed for a higher seismic force demand. ASCE 7 recommends a redundancy factor R_R= 1.0 for systems with parallel frames and the same is adopted for this work as the case study structures fall in this category.

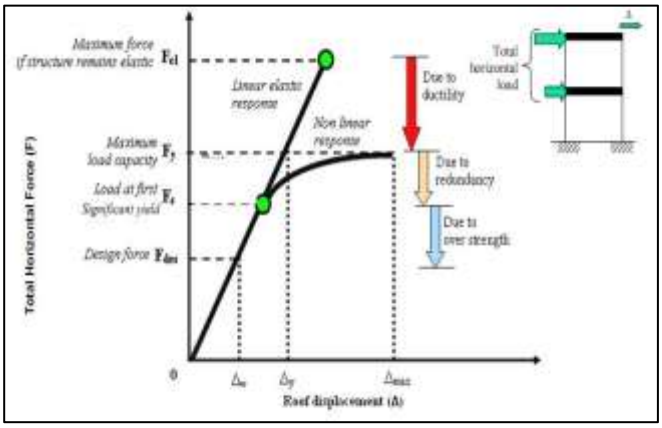

Fig -1: Concept of Response Reduction Factor

1.2.5 RESPONSE REDUCTION FACTOR ACCORDING TO DIFFERENT SEISMIC CODE:

Table -1: Values of R for RC framed structures as per IS 1893 part 2002

Structural systems	R
Ordinary moment resisting frame (OMRF)	3.0
Special moment resisting frames (SMRF)	5.0
Ductility shear wall with SMRF	5.0

Table -2: Values of R for RC framed structures, as per ASCE7 (2005)

Structural systems	Response modification coefficient, (R)	System over strength factor (Ω_0)
Ordinary moment resisting frame	3.0	3.0
Intermediate moment frame	5.0	3.0
Special moment frame	8.0	3.0

Table -3: Values of behaviour factor for RC framed structures as per EC 8 (1998)

Structural systems	Behaviour factor (Q)
Medium ductile class(DCM)	3.90
High ductile class (DCH)	5.85

Table -4: Values of RC framed structures, as per Japan (2001) and Mexico code (2003)

Response Modification Factor Comparison			
Structural system	Period	Japan	Mexico
RC moment resisting frame	T = 0.1 sec	3.3	2.5
	T = 1.0 sec	4	4

Table -5: Values of R for RC framed structures, as per Australian and Newzealand code (2007)

Structural system	R
Ordinary moment resisting frame (OMRF)	2.6
Intermediate moment resisting frames (IMRF)	4.5
Special moment resisting frame (SMRF)	6.0

Table -6: Values of R for RC framed structures, as per Korean code (2009)

Structural system	**Response modification coefficient, (R)**	**System over-strength factor (Ω_0)**
Special reinforced concrete moment frame	8.0	3.0
Intermediate reinforced concrete moment frame	5.0	3.0
Ordinary reinforced concrete moment frame	3.0	3.0

Table -7: Values of R for RC framed structures, as per Egypt code (1988)

R factor in Egypt code		
Structural system	Ductility	R
RC moment resisting frame	Sufficient	7
	Not sufficient	5

1.3 PUSH OVER ANALYSIS:

A Pushover analysis is non-linear static analysis procedure in which a lateral load profile is applied to structure and then incrementally increased by scaling factor until the displacement at the same point on structure reaches a specified target displacement. Pushover analysis monitors the progressive stiffness degradation of structure as it is loaded into post elastic range of behavior.

Pushover analysis can be performed as either force-controlled or displacement controlled depending on the physical nature of the load and the behavior expected from the structure. Force-controlled option is useful when the load is known (such as gravity loading) and the structure is expected to be able to support the load. Displacement controlled procedure should be used when specified drifts are sought, where the magnitude of the applied load is not known in advance, or where the structure can be expected to lose strength or become unstable.

2. PROBLEM DEFINATION:

In the present study, seismic performance of (G+21) and (G+30) storeys existing high rise buildings designed with different plan as shown in figures are considered. Details of building geometry, material properties and load configurations are shown. Salient features of buildings considered for paper work given in table below.

Table -8: Loads applied on buildings

Description	**Salient features**	
	Building no 1	**Building no 2**
Floor	G+21	G+30
Typical floor	21	30
Dead load(KN/M^2)		
Self Weight		
Floor finish	1.5	1.5

Internal wall 150mm thick	3	3
External wall 230mm thick	4	4
Live load(KN/M²)		
Residential floor	3	3
Seismic load data		
Seismic Zone	III	III
Zone factor (Z)	0.16	0.16

From the above details SAP 2000 auto calculated earthquake load and assign in to the model.

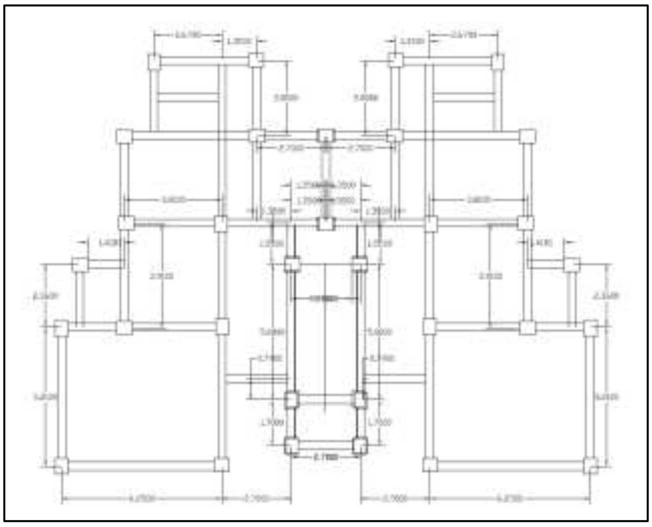

Fig -2: G+21 storey building

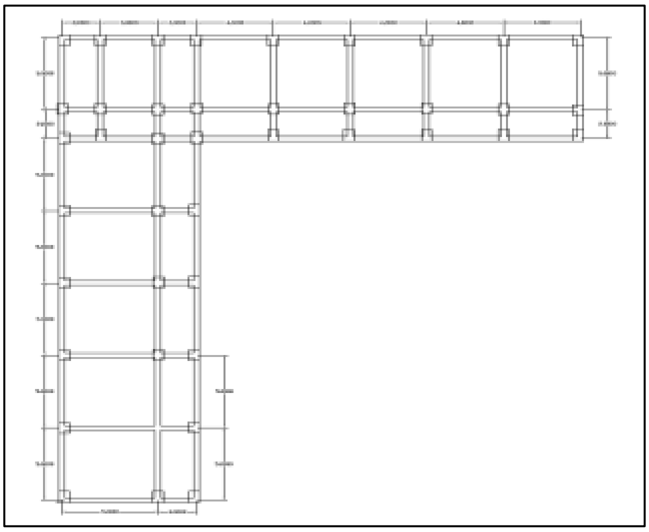

Fig -3: G+30 storey building

2.1 REINFORCEMENT DETAILS OF EACH BUILDING GIVEN BELOW:

Table -9: Salient features of buildings

(G+21) BUILDING			
MATERIALS	**SECTION**	**TOP RNFT**	**BOTTOM RNFT**
Concrete grade M30 $ Fe500	Beam 300x500	3-12Φ	3-12Φ
	Beam 300x500	2-Φ+1-10Φ	2-12Φ+1-10Φ
	Column 350x450	4-16Φ+6-12Φ	
	Column 350x400	4-16Φ+6-12Φ	
	Column 350x400	4-16Φ+6-10Φ	
(G+30) BUILDING			
Concrete grade M30 $ Fe500	Beam 550x650	5-16Φ	5-16Φ
	Beam 500x600	5-16Φ	5-16Φ
	Beam 400x550	4-12Φ	4-16Φ
	Column 550x750	18-16Φ	
	Column 50x650	16-16Φ	

3. RESULT & DISCUSSION:

3.1 G+21 BUILDING:

G+21 storey building is modeled in SAP 2000v19 and above mentioned loads applied. After performing non-linear pushover analysis, results obtained are given below

3.1.1 DRIFT:

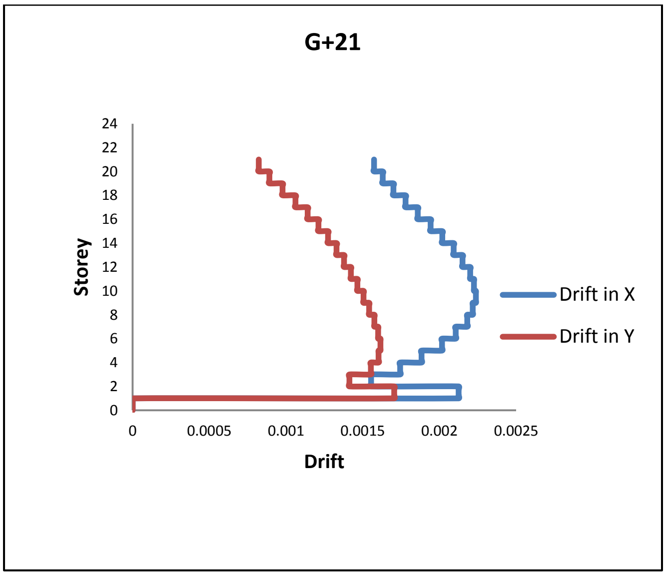

Chart -1: Storey drift

Above graph shows the comparison for the variation of interstorey drift for G+21 floor building with respect to storey number for earthquake case in X and Y direction respectively. In both direction interstorey drift is less than 0.4% of building height.

3.1.2 CAPACITY CURVE:

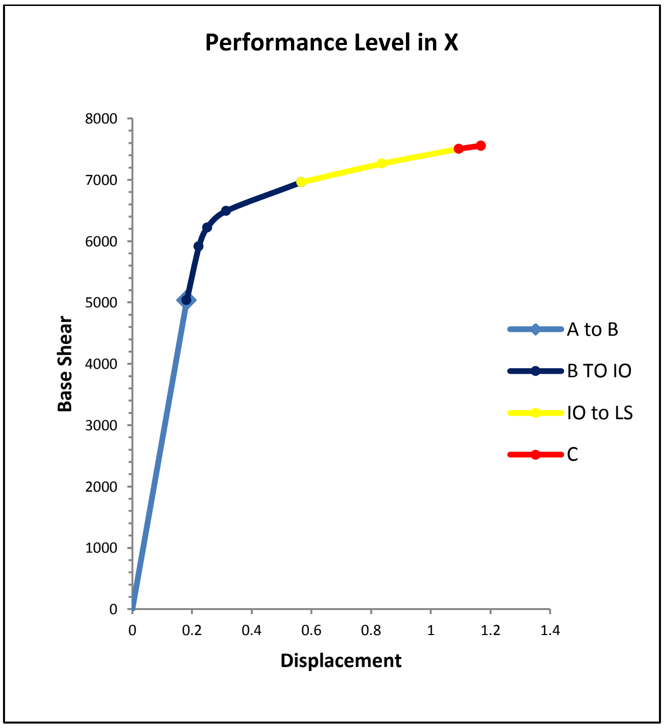

Chart -2: Capacity Curve in X direction

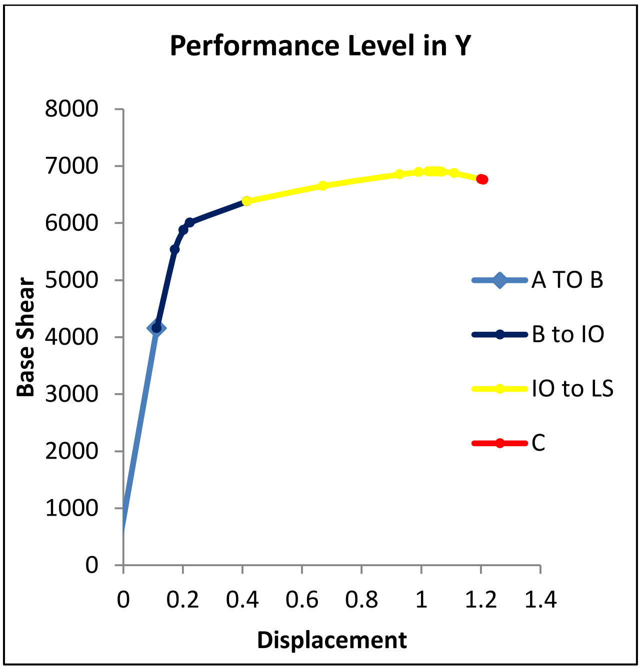

Chart -3: Capacity Curve in Y direction

Above graph shows the capacity curve or pushover curve i.e. variation of displacement of building with respect to base shear. Result shows four stages of performance i.e. Operational, Immediate Occupancy, Life Safety and Collapse Stage.

3.1.3 PERFORMANECE POINT:

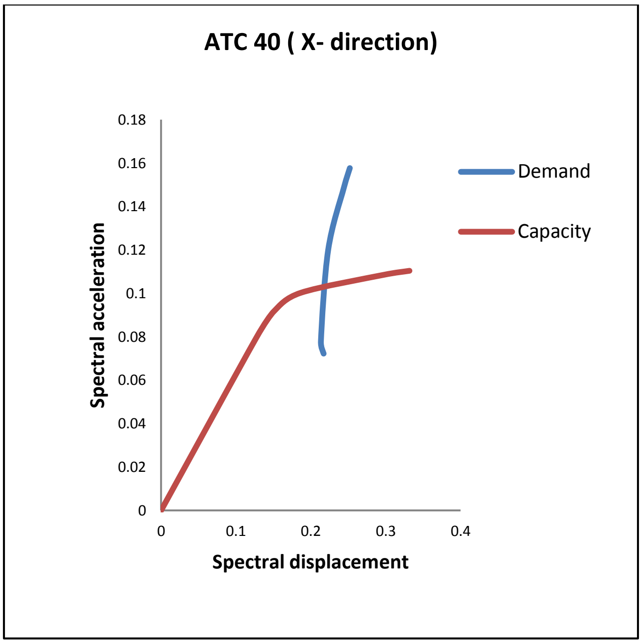

Chart -4: Performance Point in X direction

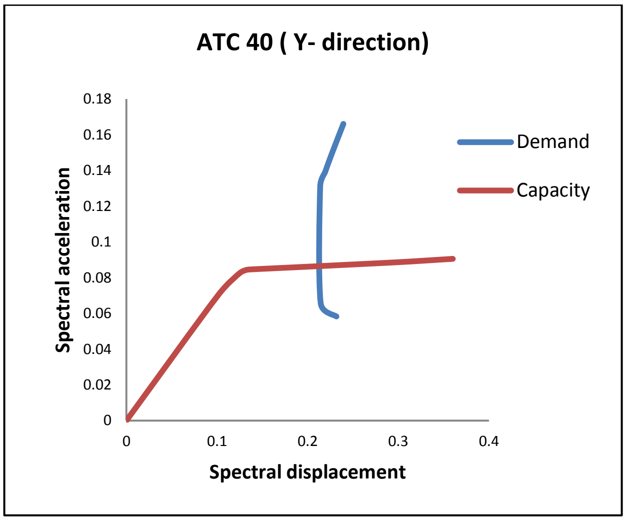

Chart -5: Performance Point in Y direction

Above graph shows the variation of spectral displacement with respect to spectral acceleration, also showing the performance point i.e. intersection of demand curve and capacity curve. Performance point is (0.125, 0.236) in X-direction and (0.0883, 0.219) in Y-direction.

3.2 G+30 BUILDING:

G+30 storey building is modeled in SAP 2000v19 and above mentioned loads applied. After performing non-linear pushover analysis, results obtained are given below.

3.2.1 DRIFT:

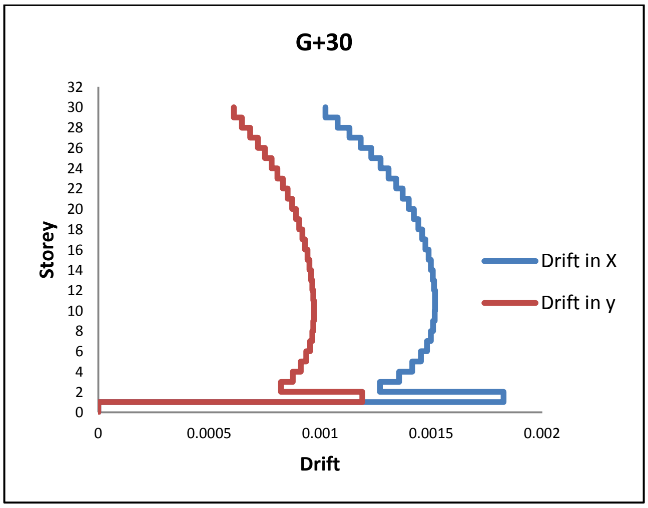

Chart -6: Storey drift

Above graph shows the comparison for the variation of interstorey drift for G+30 floor building with respect to storey number for earthquake case in X and Y direction respectively. In both direction interstorey drift is less than 0.4% of building height.

3.2.2 CAPACITY CURVE:

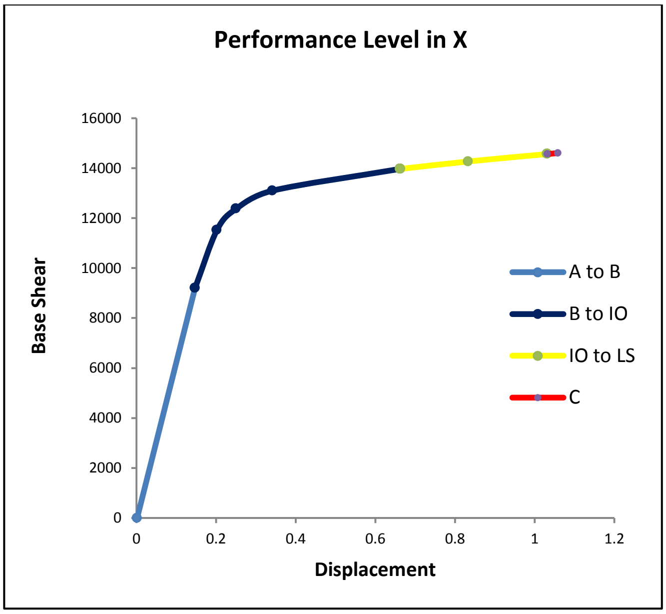

Chart -7: Capacity Curve in X direction

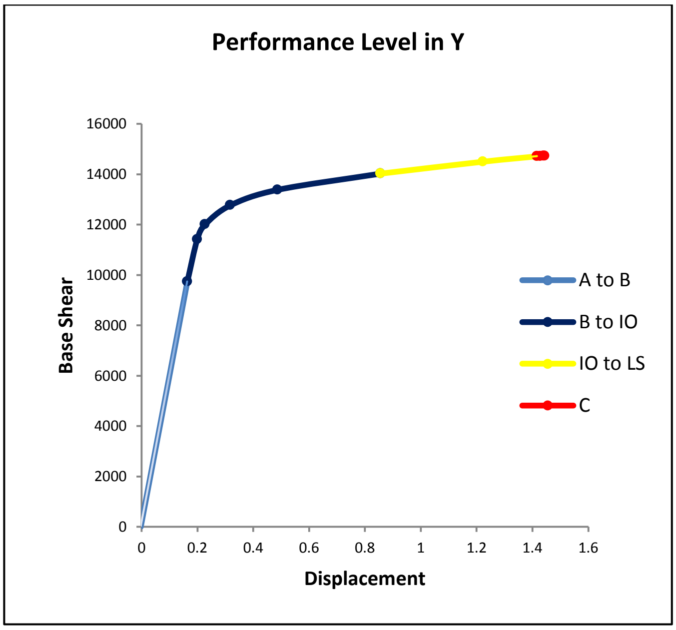

Chart -8: Capacity Curve in Y direction

Above graph shows the capacity curve or pushover curve i.e. variation of displacement of building with respect to base shear. Result shows four stages of performance i.e. Operational, Immediate Occupancy, Life Safety and Collapse Stage.

3.2.3 PERFORMANECE POINT:

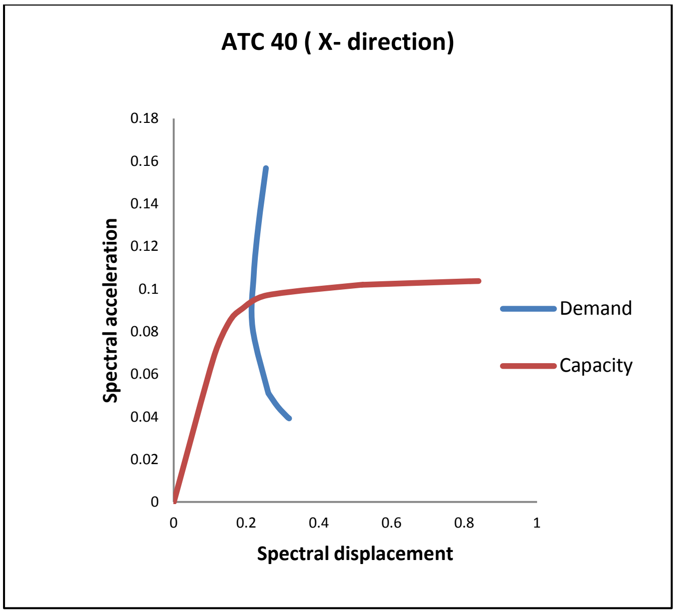

Chart -9: Performance Point in X direction

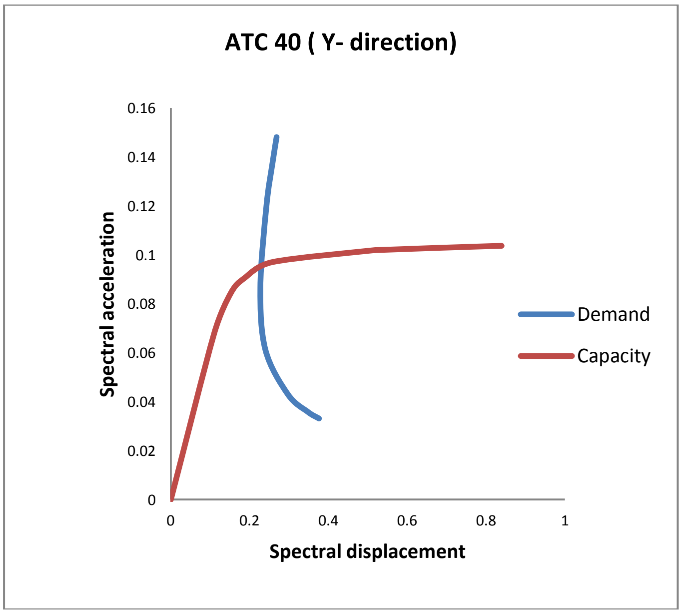

Chart -10: Performance Point in Y direction

Above graph shows the variation of spectral displacement with respect to spectral acceleration, also showing the performance point i.e. intersection of demand curve and capacity curve. Performance point is (0.0963, 0.215) in X-direction and (0.0949, 0.283).

3.3 COMPARISION OF RESPONSE REDUCTION FACTOR & ITS COMPONENTS:

Floors	G + 21	G + 30
Time period (T) sec	1.182	1.5588
S_a/g	1.1505	0.8725
R_s	1.655412	1.266612
R□	3.298429	5.96.265
R_R	1	1
R□	1	1
R	5.460259	7.549341

4. CONCLUSIONS:

Followings are the conclusion made in this study of TWO existing high-rise buildings

- First two modes are not in z-direction; i.e. first two modes are not in torsion in respect of the four existing high-rise buildings.
- Modal mass participation factor in X direction and in Y direction is greater than 90% in all four existing building, hence IS1893 part 1- 2002 clause no.7.8.4.2 is satisfied in respect of all four existing high-rise buildings.
- There are different methods to perform non linear analysis, but pushover analysis is a simple way to explore the non linear behavior of building.
- After performing the analysis the base shear at performance point is found to be greater than design base shear in respect of all four existing high-rise buildings. Since at the performance point base shear is greater than the design base shear hence the building structure is safe under the earthquake loading.
- After performing the pushover analysis, performance stages are obtained in all four existing high-rise buildings. i.e. immediate occupancy (IO), life safety (LS), collapse (C) performance stages are obtained.
- If performance of building is not safe under earthquake loading then retrofitting to the beam and

column is necessary between life safety and collapse stages of performance.

• Performance of the building decreases when the sectional sizes of the beams and columns are reduced while keeping same reinforcement.

• After performing pushover analysis if performance point is not obtained then there are three way to get that

• Increase strength or stiffness of the structure or combination theory.

• Increase ductility of the structure.

• Reduce seismic demand by using damping or isolation.

• There is no mathematical basis for the response reduction factor tabulated in Indian standard design code.

• The values for the roof displacement and base shear capacity of the structure at the yield and ultimate levels are obtained and the various components of the 'R' factor calculated.

• The response reduction factor is different for all this four existing high-rise buildings because of variation in geometry of the plan and elevation of buildings, different material properties, variation in strength and ductility of the building etc.

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