International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 10, October 2016)

# Effect of Aspect Ratio on Seismic Performance of Reinforced Concrete Building Using Pushover Analysis

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***Abstract*—During recent earthquakes, it was observed that urban areas are more prone to seismic risk and the infrastructure facility is far from acceptable levels. There is a need to look into this situation and it is believed that one of the most effective ways of doing this is through the Performance Based Earthquake Engineering (PBEE) in which the structures are designed based on the predicted performance of the structure during an earthquake. It is a limit-state design extended to cover complex range of issues faced by earthquake engineers. This paper emphasizes on pushover analysis on reinforced concrete structure. In which G+4 RC building was subjected to push in X and push in Y-direction for different aspect ratio. Analysis was done in ETABS. Based on performance point obtain from the analysis we get to know whether thestructure will perform well or not during seismic activity. The graph of pushover curve has been plotted in terms of base shear – roof displacement for different aspect ratio. In addition, number of hinges formed and maximum story drift are also analyzed in X as well as Y-direction for different aspect ratio.**

***Keywords*—Static pushover analysis, Performance based design, E-tabs, Aspect ratio, Story drift, Base shear, Performance point etc.**

## I. Introduction

Earthquake is a very important aspect to be considered while designing structures, as it causes devastation as well as huge loss of life as well as property. Buildings are the complex systems and multiple items have to be considered in its designing. The behaviour of a building during earthquakes depends on its configuration i.e. overall shape, size and geometry, in addition to how the earthquake forces are carried to the ground. Hence, at the planning stage itself, architects and structural engineers must work together to ensure that the unfavorable features are avoided and a good building configuration is chosen. The size of the building affects the seismic performance of the building. The figure and the table below show how they affect the seismic performance.

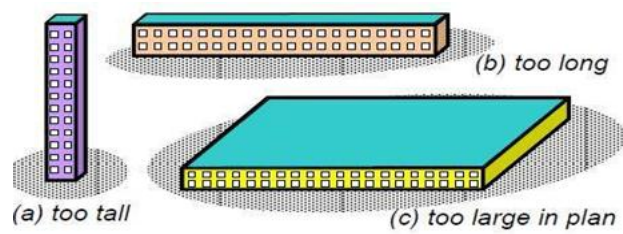


**Fig.1 Various Size of Building**

**Table I.**
**Description of the size of building and problems faced by the building**

| Size of the building | Problem Faced by the building |
|---|---|
| Too Tall (Extreme height to depth ratio) | High overturning forces, Large drift causing Non-structural damage |
| Too Long (Extreme length to depth ratio) | Large Lateral forces acting on the perimeter, Big difference in resistance along both the axes |
| Too Large in plan | Large Diaphragm forces act |

In recent years, the term Performance Based Design is arecent trend in the field of earthquake engineering, with the structural engineer taking keen interest in its concepts due to its potential benefits in assessment, design and better understanding of structural behaviour during Earthquake. The basic idea of Performance Based Design is to conceive structures that perform desirably during various loading scenarios.

The Performance Based Earthquake Engineering (PBEE) also known as the Performance Based Seismic Engineering (PBSE) is a rapidly growing idea that is present in all guidelines that were recently published: Vision 2000 (SEAOC, 1995), ATC40 (ATC, 1996), FEMA273 (FEMA, 1997), and SAC/FEMA350 (FEMA, 2000a).

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A performance based design is aimed at controlling the structural damage under the action of earthquake forces, based on precise estimation of proper response parameters. Performance based design using nonlinear pushover analysis involves tedious and intensive computational effort is a highly iterative process needed to meet designer specified and code requirements. Performance based seismic design evaluates performance of building considering uncertainties in the quantification of potential hazard and assessment of the actual building response.

The main objective of performance based seismic design of buildings is to avoid total catastrophic damage and to restrict the structural damages caused, to the performance limit of the building.

## II. METHODOLOGY

The performance-based seismic engineering`s (PBSE) promise is to design structures with its predictable seismic performance. In Performance based design non-linear static analysis procedure become important. Static pushover analysis is a simplified nonlinear procedure wherein the pattern of earthquake is applied incrementally to the structural frame until a plastic collapse mechanism is formed and the pattern of applying load is controlled by its fundamental mode shape.

Two types of pushover analysis are force controlled and displacementcontrolled. In the formal one - force controlled, the structure is subjected to an incrementallateral load pattern and corresponding displacements are calculated. In the later one - displacement control, the displacement of the top storey of the structure is incremented step by step, such that the required horizontal force pushes the structure laterally. The analysis could be carried out up to the desired level of the displacement so displacement controlled pushover analysis is generally preferred.

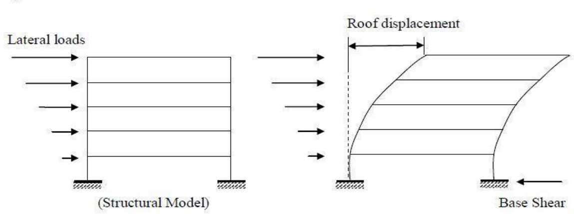


**Fig. 2 Static Approximation in Pushover Analysis**

In Pushover analysis, a static horizontal force pattern, usually proportional to the design force pattern specified in the codes and it is applied to the structure.

The force profile is then incremented in small steps and the structure is analyzed at each step. As the loads are increased, the building undergoes yielding at a few locations. The analysis is continued till the structure reaches its capacity to deform or the building reaches certain level of lateral displacement. It provides a load versus deflection curve 16 of the structure starting from the state of rest to the ultimate failure of the structure (refer Figure 3).The load is representative of the equivalent static load of the fundamental mode of the structure. It is generally taken as the total base shear of the structure and the deflection is selected as the top-storey deflection.

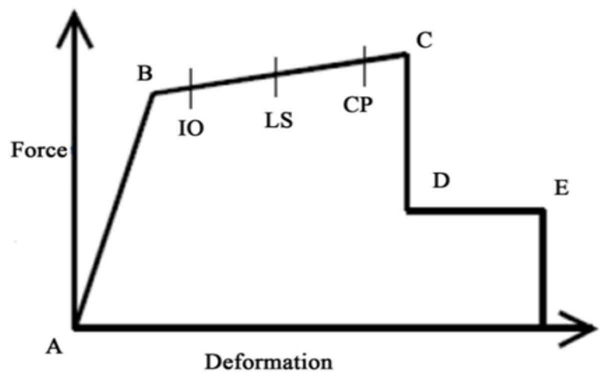


**Fig. 3 Load Deformation Curve**

The structure is modelled as a MDOF systemMulti degree of freedom system (MDOF) is converted to an equivalent single degree of freedom (ESDOF) with properties predicted by a nonlinear static analysis of the MDOF system. The displacement demand for the SDOF model Sd is transformed into the maximum top displacement Dt of the MDOF system. The local seismic response (e.g. storey drifts, joint rotations) can be determined by pushover analysis. Under increasing lateral loads with a fixed pattern the structure is pushed to a target displacement Dt. Consequently it is appropriate the likely performance of building under push load up to target displacement. The expected performance can be assessed by comparing seismic demands with the capacities for the relevant performance level.

The seismic performance of a building can be evaluated with respect to capacity curve, performance point, displacement, plastic hinge formation etc. The base shear vs. roof displacement curve (Figure 4) is obtained from the pushover analysis. This capacity curve and demand or response spectrum is also generated. When demand curve meets the capacity spectrum curve, we get the performance point for the structure.

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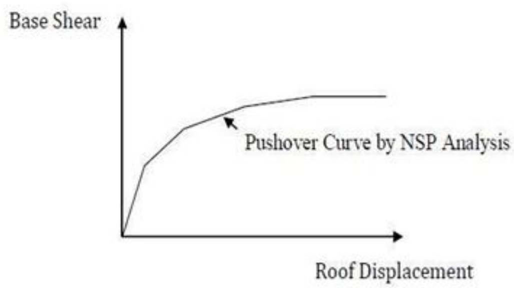


**Fig. 4 Base shear Vs. Displacement curve**

The Performance Point so obtained from pushover analysis can be used to check whether the structure reaches target displacement.

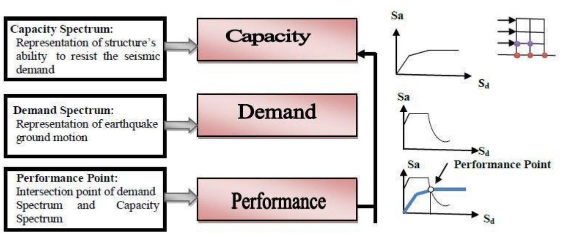


**Fig. 5 Capacity Curve, Demand Curve and Performance Point**

*A. Capacity Spectrum*

The capacity curve is transformed into capacity spectrum curve as per ATC-40, Volume-1, p-8.9. A typical capacity spectrum is as shown in Fig. 6

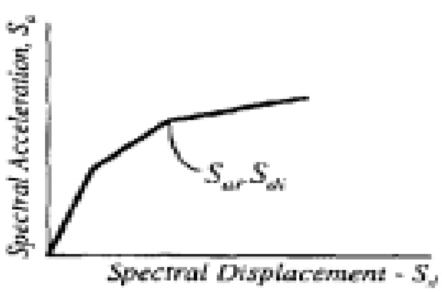


**Fig. 6 Capacity Spectrum**

*B. Demand Curve*

It is very impractical to track ground motion at each and every time interval during earthquakes, so in lieu of this displacement demands are estimated for the building response. So the Demand curve generated is a mere representation of the earthquake on a time scale.. It is given by spectral acceleration (Sa) Vs. Time period (T) as shown in Fig 7.

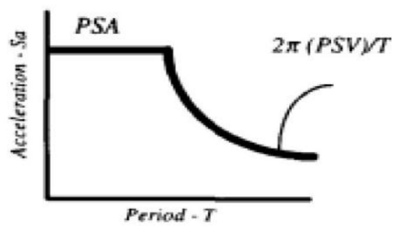


**Fig. 7 Demand curve (Traditional spectrum)**

Fig. 8 illustrates the construction of an elastic response spectrum (Demand curve) given by ATC-40, Volume-1, p-4-12.

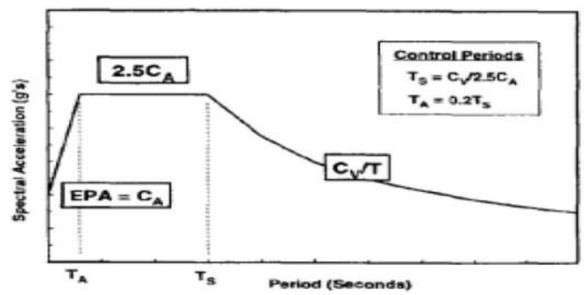


**Fig. 8 Construction of a 5% damped elastic response spectrum**

As per provisions and commentary on Indian seismic code IS 1893(part-1), equivalent seismic coefficient Ca is given by,

Ca = Z*g*Sa/g
Cv = 2.5*Ca*Ts

*C. Demand Spectrum*

Demand curve (traditional spectrum-Sa Vs T format) is converted into demand spectrum (acceleration displacement response spectrum-Sa Vs Sd format). Using ATC-40, Volume-1, p-8-10.

*D. Performance Point*

Performance point can be obtained by superimposing capacity spectrum and demand spectrum and the intersection point of these two curves is Performance Point. Fig.6. shows superimposing demand spectrum and capacity spectrum.

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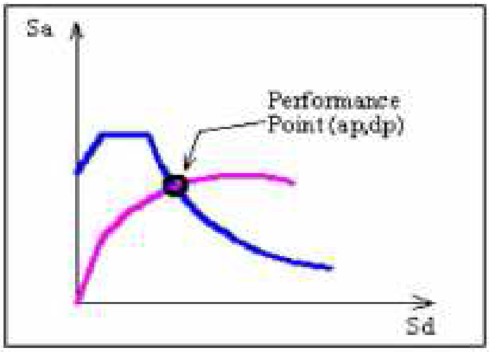


**Fig. 9 Performance Point**

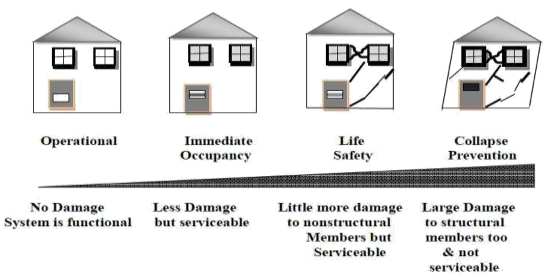


**Fig. 10 Performance level and Damage Function**

Performance level of the structure and plastic hinge formation is checked at performance point. At this point theresulting capacity response of the structure meets the seismic demands of the ground motions.

There are two different approaches to Pushover Analysis.

(1) **DCM** (Displacement Coefficient Method)
(2)**CSM**(Capacity Spectrum Method)

Building performance has been classified into 5 levels, viz. (i) Operational (OP), (ii) Immediate Occupancy (IO), (iii) Damage Control (DC), (iv) Life Safety (LS) and (v) Collapse Prevention (CP).

## III. PROCEDURE OF PUSHOVER ANALYSIS

The ATC 40 [1] provides detailed guidelines about how to perform a nonlinear static pushover analysis. The following are steps based on the ATC 40 procedure.

[1] Create 3D models and define loads including dead, live and lateral loads
[2] Define response spectrum and time history function
[3] Define load case for response spectrum and time history
[4] Analyse the 3D model and perform design check
[5] Define hinge properties
Beam- Default M3
Column- PM2M3
[6] Assign hinge properties as well as hinge overwrite
[7] Define static pushover load case ( Lateral load at centre of mass )
[8] Run static pushover analysis
[9] Establish capacity curve and performance point.

## IV. MODELLING

### *A. Assumption*

Following assumptions are made while analyzing a structure in ETABS:-

(i) The material is homogeneous, isotropic (ii) Ground Columns are assumed to have fixed supports. (iii) Tensile strength of concrete is ignored in sections subjected to bending, (iv) The super structure is analyzed independently from foundation and soil medium, based on the assumptions that ground columns are fixed to the foundation (v) Pushover hinges are assigned to all the member ends. In case of Columns PM2M3 hinges (i.e. Axial Force and Biaxial Moment Hinge) are provided while in case of beams M3 hinges (i.e. Flexural hinge) are provided, (vi) the maximum target displacement of the structure is calculated in accordance with the guidelines given by FEMA 356 for maximum roof level lateral drift.

### *B. Model Parameters*

Here the four models of residential building having different aspect ratio but same plan area and height are modeled in ETABS.

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| | |
|---|---|
| Grade of Concrete | M25 |
| Grade of Steel | HYSD415 |
| Plan Area | 400 sqm |
| No. of stories | 5 |
| Storey height | 3.04 m |
| Beam dimensions | 300x500mm |
| Column dimensions | 500x300mm |
| Slab Thickness | 140mm |
| Live Load(On Floor) | 3 $kN/m^2$ |
| Live Load(On Roof) | 1 $kN/m^2$ |
| Water Proofing Load | 2.5 $kN/m^2$ |
| Floor finish load | 1 $kN/m^2$ |
| Partitions | 3 $kN/m^2$ |
| Seismic Zone | III |
| Importance factor(I) | 1 |
| Response Reduction factor(R) | 5 |
| Soil Type | Medium Soil |
| Frame Type | Moment Resisting RC Frame |

*C. Used Formulas as per IS-1983*

Total base shear as per IS-1893 (part-1) along any principal direction can be calculated by the following formula.

$$V_b = \frac{ZISa}{2Rg} . W$$

The approximate fundamental period (T) of structure is calculated from the following equation:

$$T= 0.075\, h^{0.75}$$

where,
$V_b$ = Total Base shear (in kN)
Z = Zone Factor
I = Importance Factor
R = Response Reduction Factor
Sa/g = Average Response Acceleration Coefficient
W = Total Seismic Weight of the building.
h = Height of the building (in m)

The base shear shall be distributed over each story height of the structure, including Storey *n*, according to the following formula:

$$Q_i = Vb.\frac{Wi\ hi^2}{\sum_{i=1}^{n} Wi\ \ hi^2}$$

where,
Qi = Design lateral force at floor i
Wi = Seismic weight of floor i
hi = Height of floor I measured from base
n = Number of stories in the building is the number of levels at which the masses are located.

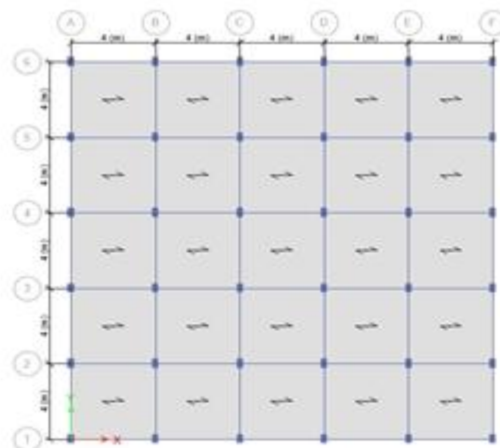

**Fig. 11 Case 1 plan of building with aspect ratio 1**

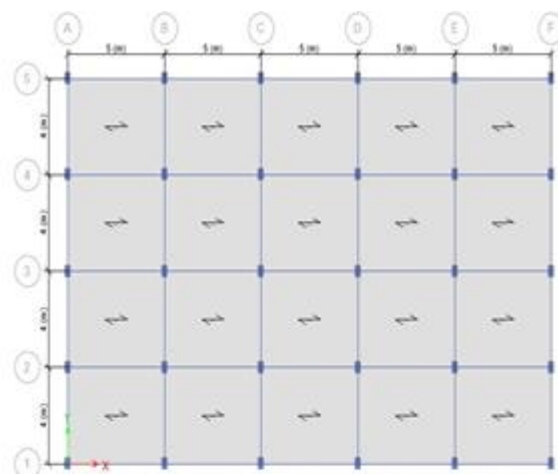

**Fig. 12 (Case 2) Plan of building with aspect ratio 1.5**

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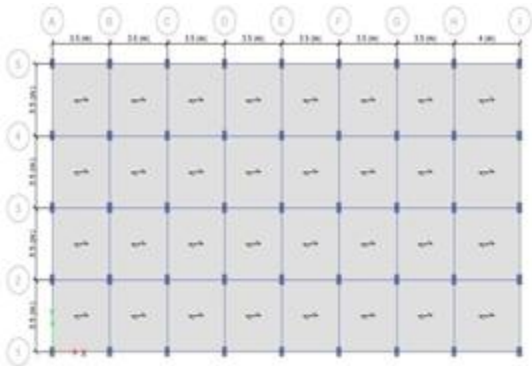

**Fig. 13 (Case 3) Plane of building with aspect ratio 2**

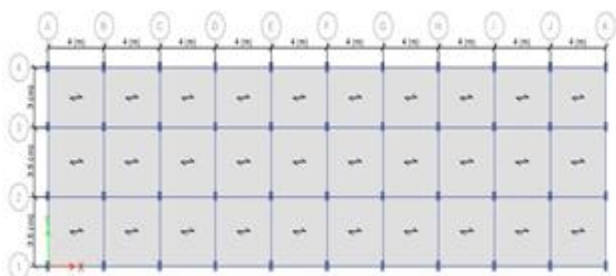

**Fig. 14 (Case 4) Plane of building with aspect ratio 4**

## V. Result And Discussions

### *A. Base shear vs Top displacement*

All four buildings were analyzed in both X and Y directions for static nonlinear (pushover) analysis using ETABS. The Base shear versus roof displacement graphs have been plotted and compared for all models as shown in Figure 15 and Figure 16.

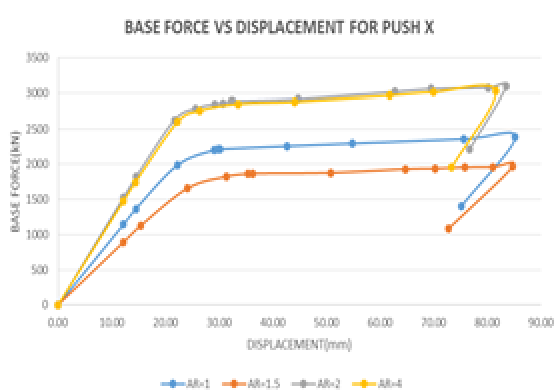


**Fig. 15 Comparison of Base force vs. displacement in x-direction**

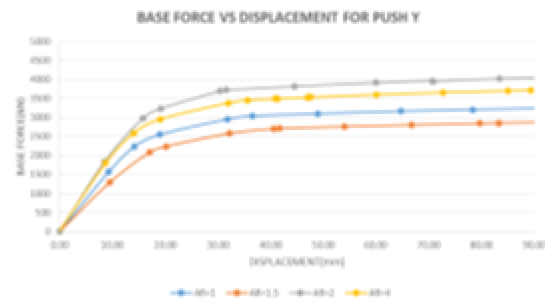


**Fig. 16 Comparison of Base force vs. displacement in y-direction**

Here the values of base shear have been compared for all models. However, Case 2 shows the least values of base shear in both directions. Moreover the displacement values have been same in all the cases for x direction. In addition to all four models show ductile behaviour in y direction.

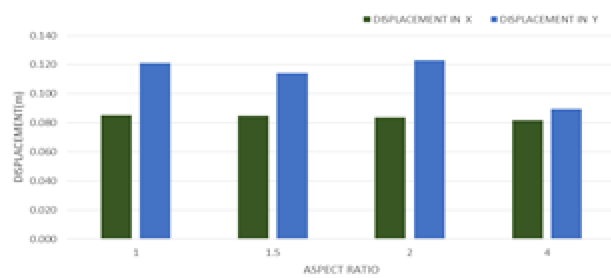


**Fig. 17 Comparison of Displacement in X and Y direction**

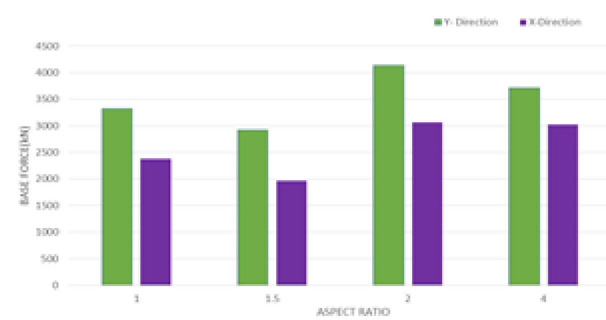


**Fig. 18 Comparison of Base force in X and Y direction**

### *B. Performance Point*

Performance Point is a point where the Capacity curve crosses the Demand curve. Figures 19-20 shows the performance point in both directions for all push over curves,. The intersection of the red line (demand) and the green curve (capacity) is the performance point.

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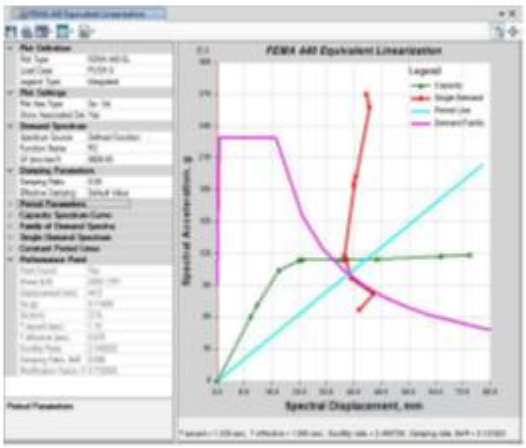
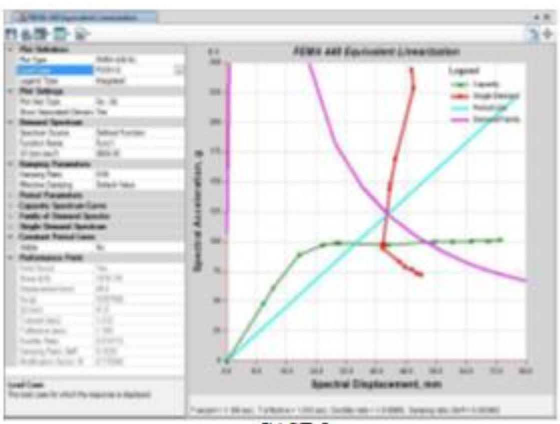
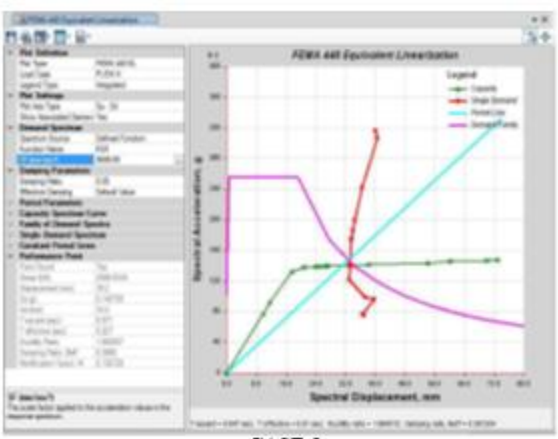


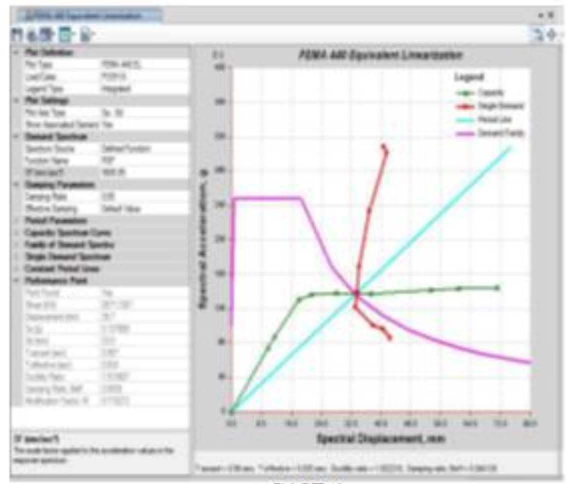
CASE 1



CASE 2

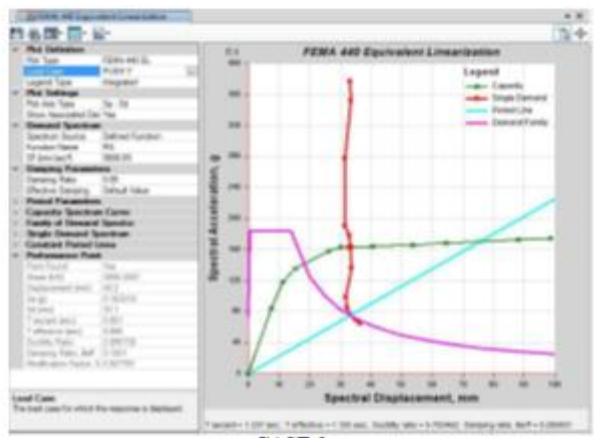


CASE 3

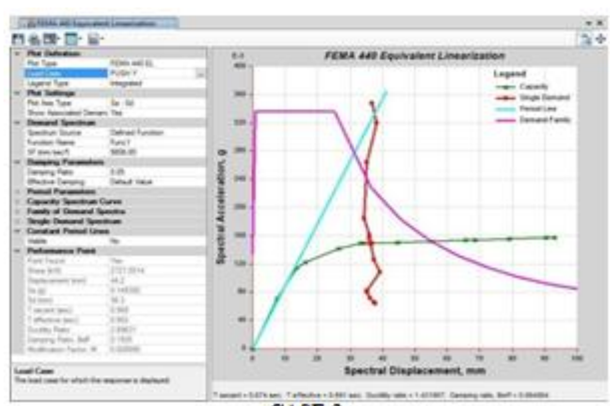


CASE 4

**Fig. 19[Case 1 to Case 4] Push over Capacity curve and Performance point(X direction)**



CASE 1



CASE 2

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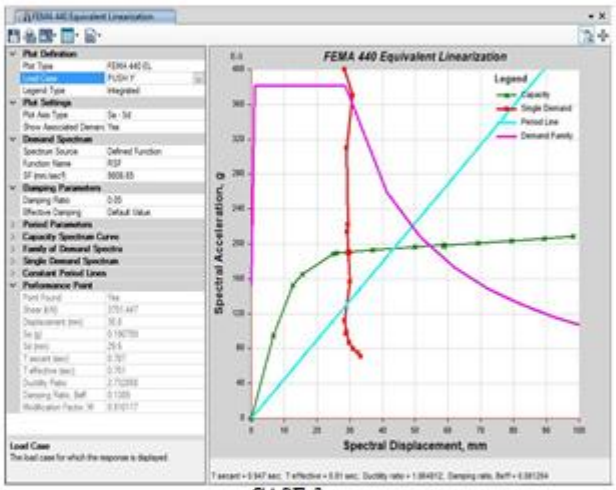
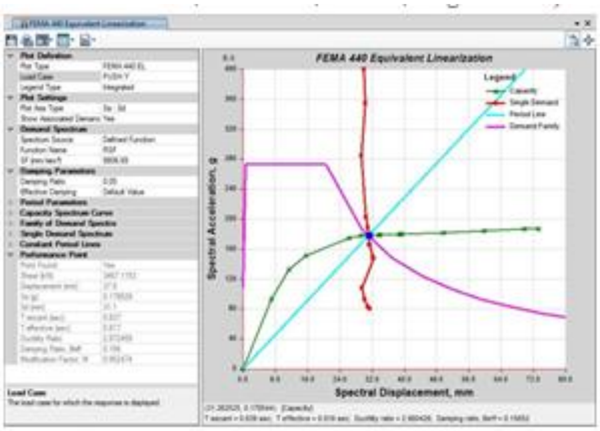


CASE 3




CASE 4

**Fig. 20 [Case 1 to Case 4] Push over Capacity curve and Performance point(Y direction)**

*B. Yielding (Plastic Hinge) Pattern of the Structure*

The graph of total hinges formed in each of the models is plotted and Case 2 shows the least number of hinges formed in both the directions as shown in figure 21.

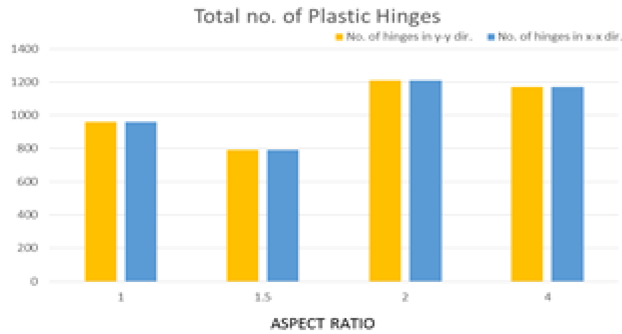
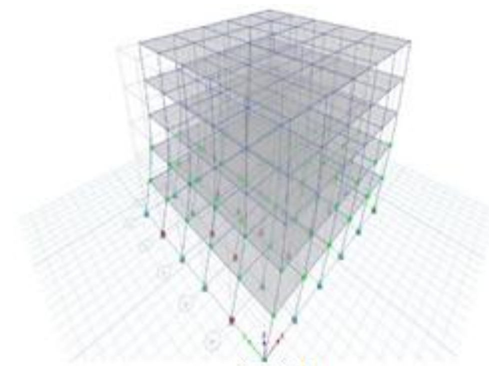
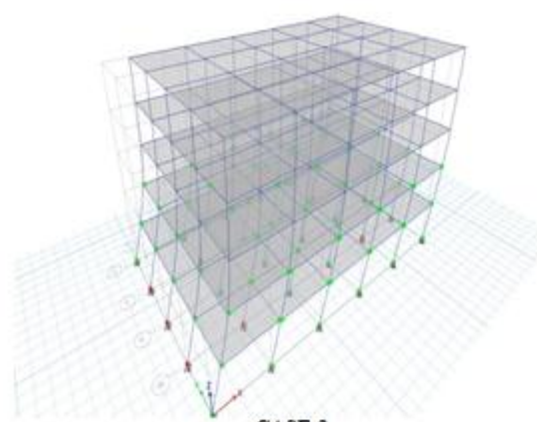
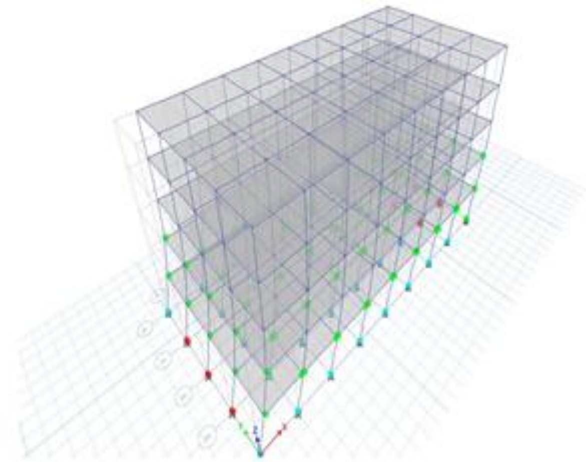


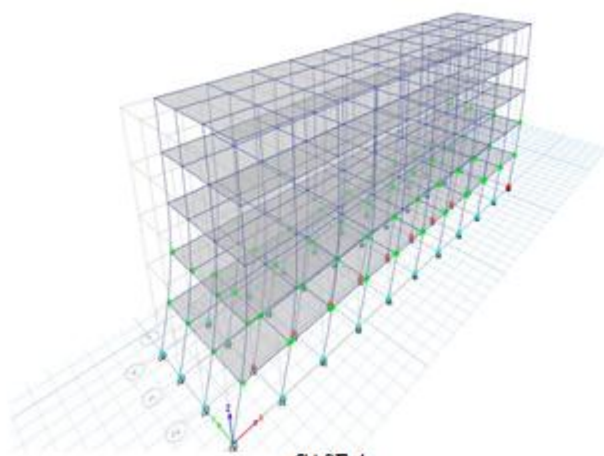

**Fig. 21 Total no. of plastic hinges form in x and y direction**


CASE 1


CASE 2

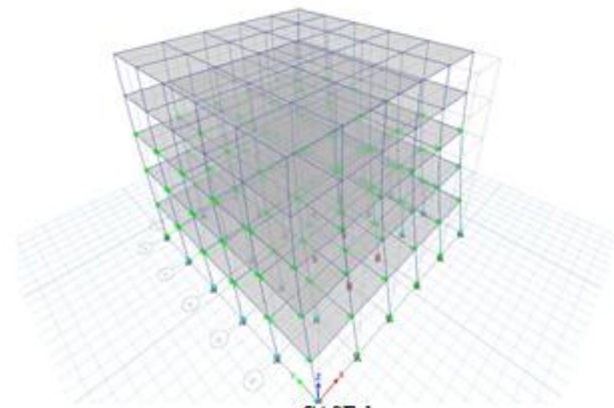


CASE 3

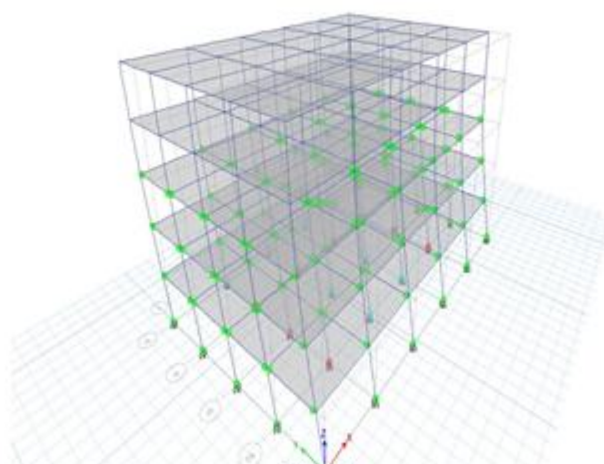


CASE 4

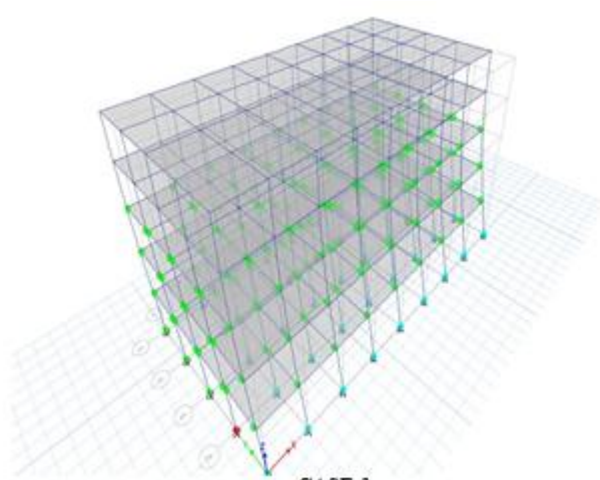
**Fig. 22 Plastic hinge formations in X direction**



CASE 1



CASE 2



CASE 3

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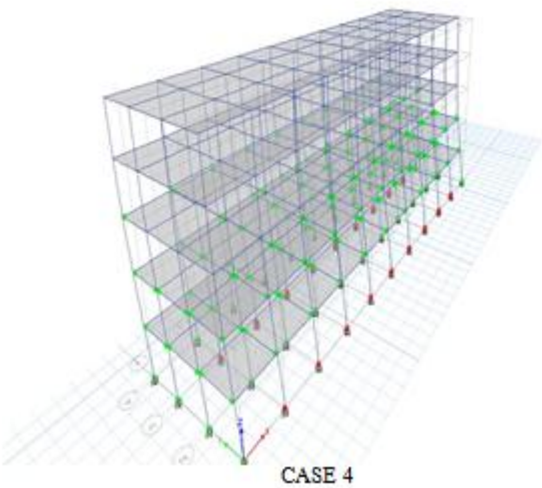


**Fig. 23 Plastic hinge formation in y direction**

Comparison of these figures shows hinge pattern. Plastic hinge formation starts with the yielding of structural members of ground stories and then travels to upper stories with yielding of columns. Case 2 turns out to be better in both directions with least number of hinges formed.

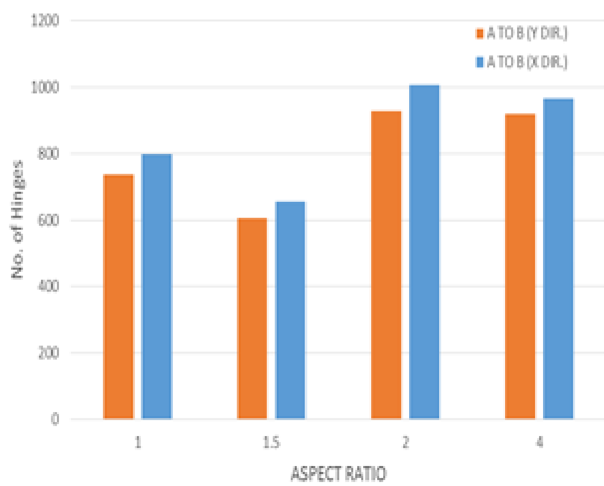


**Fig. 24 No. of Plastic Hinges from A to B in x and y direction**

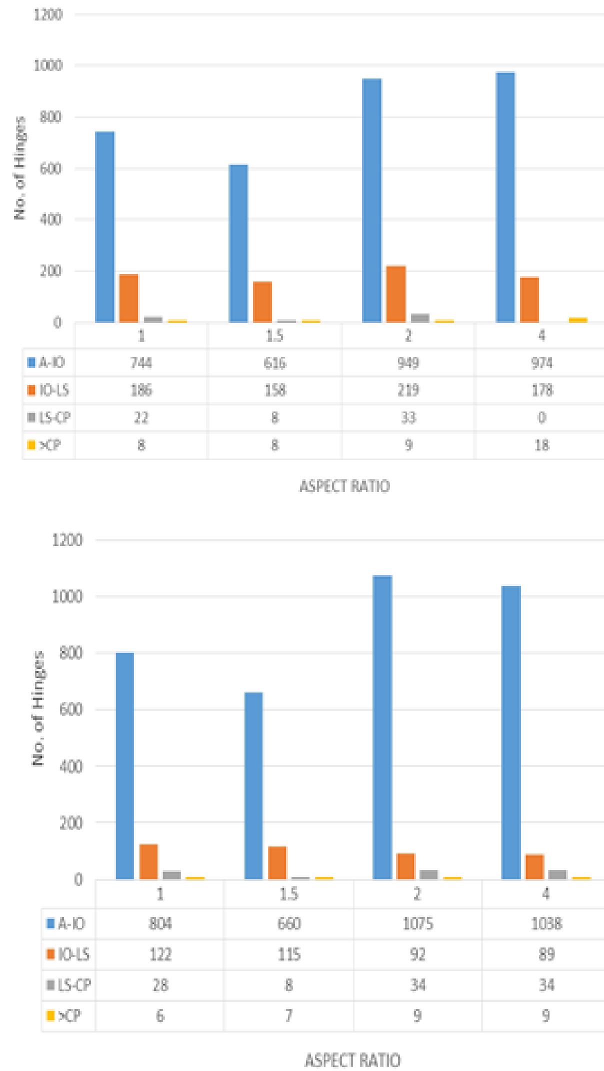


**Fig. 25 No. of hinges formed at various levels in x and y direction**

Figures 25 shows the number of plastic hinges formed due to yielding of members, at different performance level in X and Y directions.

### *C. Inter Storey Drift Ratio*

The inter storey drift ratios have been compared for all the four models in both x and y direction. However for case 2 with aspect ratio of 1.5 shows the least value among all the four models. Figure 27 and Figure 28 show the inter storey drift ratios for all the four models in x and y direction.

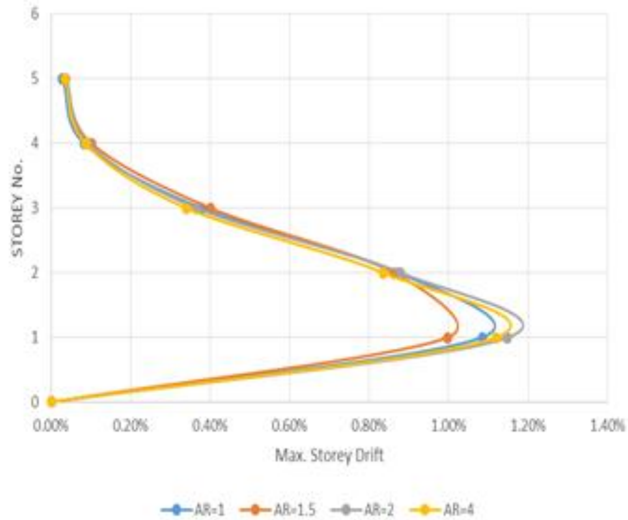


**Fig. 26 Inter storey drift ratio in x direction**

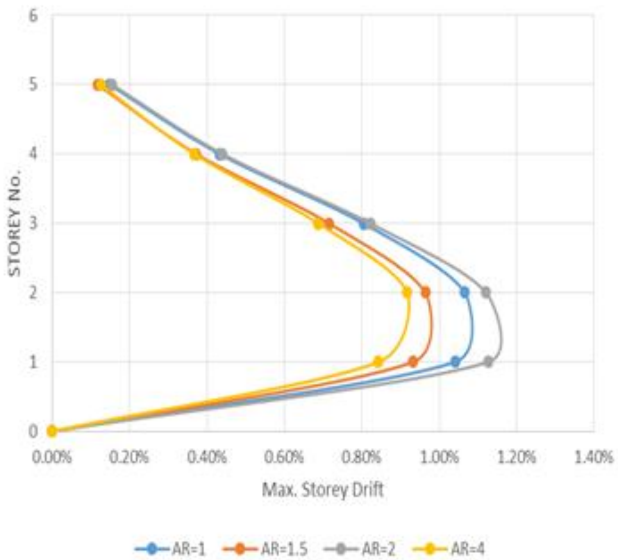


**Fig. 27 Inter storey drift ratio in y direction**

## VI. CONCLUSIONS

Static pushover analysis is an attempt by the structural engineers to evaluate the capacity of the structure. Four residential buildings with different plan aspect ratio have been analyzed by this method and results have been compared in terms of base shear, displacement and, plastic hinge pattern.

*X direction.*

| **Parameter** | **Aspect Ratio 1** | **Aspect Ratio 1.5** | **Aspect Ratio 2** | **Aspect Ratio 4** |
|---|---|---|---|---|
| Base Shear | 2377.46 kN | 1968.38 kN | 3067.63 kN | 3024.55 kN |
| Displacement | 0.085 m | 0.085 m | 0.084 m | 0.082 m |
| No.of Hinges | 960 | 790 | 1210 | 1170 |
| Damping Ratio | 0.098 | 0.103 | 0.086 | 0.084 |
| Time Period | 0.975 s | 1.109 s | 0.827 s | 0.834 s |

*Y direction.*

| **Parameter** | **Aspect Ratio 1** | **Aspect Ratio 1.5** | **Aspect Ratio 2** | **Aspect Ratio 4** |
|---|---|---|---|---|
| Base Shear | 3319.34 kN | 2919.25 kN | 4136.82 kN | 3714.37 kN |
| Displacement | 0.121 m | 0.114 m | 0.123 m | 0.089 m |
| No. of Hinges | 960 | 790 | 1210 | 1170 |
| Damping Ratio | 0.15 | 0.151 | 0.139 | 0.156 |
| Time Period | 0.868 s | 0.952 s | 0.751 s | 0.817 s |

[1] Pushover analysis has been found relatively simple and evaluates the performance of the building close to more realistic behaviour.

[2] The aspect ratio significantly influences the seismic behaviour of the buildings.

[3] The building with plan aspect ratio 1.5 shows the least base shear in both directions, thereafter base shear significantly increases with increase in plan aspect ratio.

[4] The inter storey drift is relative displacement of one storey relative to storey below. Case 3 shows maximum storey drift in both x and y directions.

[5] Ductility is one of the most important factors affecting the building performance. Thus, earthquake resistant design strives to determine the plan dimensions to ensure ductile behaviour of the building.

[6] Therefore, it can be concluded that a building having an aspect ratio 1.5 will perform better during strong ground motion.

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