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Performance Based Seismic Analysis of RCC Framed Hospital Buildings In India

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Abstract: Hospital buildings have immense post-earthquake importance. Post-earthquake both structural and non-structural components of building should remain functional. Performance-Based Design is a powerful approach to structural engineering evolved from ongoing efforts to resolve the differences between the actual observed performance and the expected performance of structures. In this article non-linear static analysis (pushover analysis) has been done to understand the behavior of G+10 multistorey Hospital building located in different seismic zones (III, IV, V) of India having similar geometrical properties using SAP2000. The behavior of multistoried building has been investigated considering Immediate occupancy as performance objective in terms of force-displacement relationships, inelastic behavior of structure and sequential hinge formations etc. From the analysis results, it was observed that, when the zone varies from III to V, base shear, displacement and time period has been increased gradually, indicating the severity of seismic activity. Plastic hinge formation which determines the behavior of the structure was studied.

***Index Terms* – Performance Based, Pushover Analysis, Immediate Occupancy.**

I. INTRODUCTION

The concept of safe hospitals does not just refer to the physical and functional integrity of healthcare facilities but also the preparation to function at full capacity and cater to the needs of the affected community immediately after disaster strikes. Therefore, special attention must be given to ensure that hospitals are structurally safe even after natural hazard. Performance-Based Design is an effective approach to structural engineering. It differs from current codes such that it focuses on a building's individual performance and allows design professionals, owners and other stakeholders to learn more about a building's performance in different earthquakes, and implement a design that optimizes design and construction costs with respect to life-cycle performance as shown in flow chart.

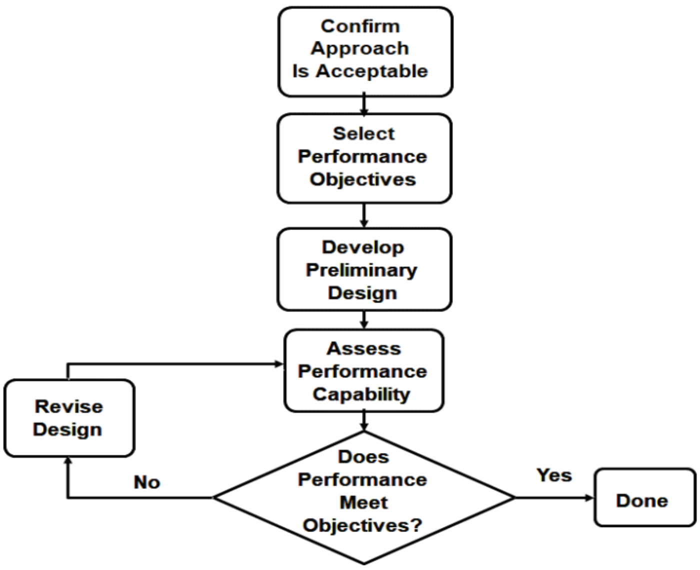

Figure1.1 Flow chart for performance-based design

Performance objectives relate to expectations regarding the amount of damage a building may experience in response to earthquake shaking and the consequences of that damage. Performance objectives are Operational (O)- Buildings meeting this performance level are expected to sustain minimum or no damage to their structural elements and only minor damage to their non-structural components, Immediate Occupancy (IO)- Building is safe to occupy but possibly not useful until clean up and repair has done, Life Safety (LS)- Buildings meeting this level may experience extensive damage to structural and non-structural components. Repairs may be required before re-occupancy of the building, and repair may be deemed economically impractical Collapse Prevention (CP)- Buildings meeting this performance level may pose a significant hazard to life safety resulting from failure of non-structural components. However, because the building itself does not collapse, gross loss of life should be avoided.

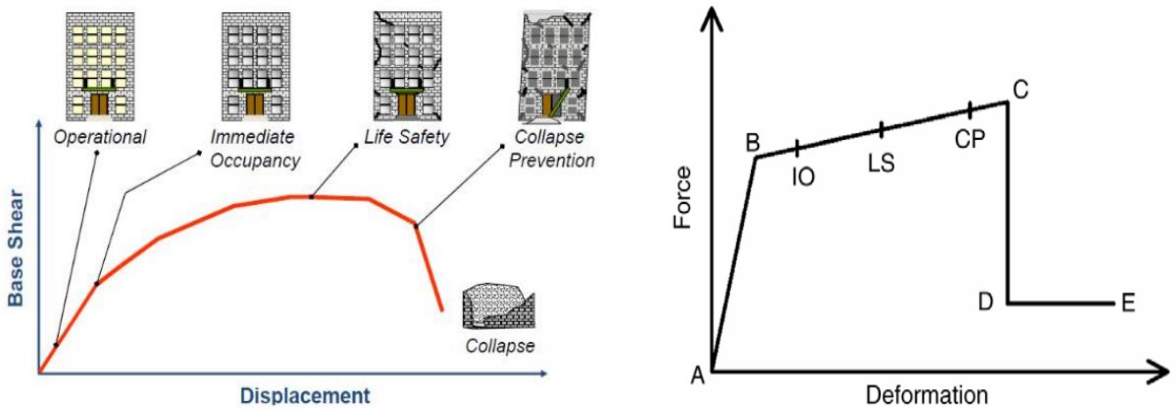

Figure1.2 Structural Performance Levels

For hospital building structural components it has to satisfy the Immediate Occupancy (IO) performance level and Operational level performance for non-structural components or functional components. With the improvements in the capability of relevant analytical tools and computing technology, structural engineers are increasingly using PBD for new design and for evaluation or retrofit of existing structures to predict better building performance, provide more economical designs, or address when the prescriptive provisions of the building code just do not apply.

II. PROBLEM STATEMENT

A G+10 reinforced concrete building is modelled, analysed and studied. The study is carried out in all the seismic zones of India and conclusions are drawn. The input data required for the design of building are presented in the tables below. The plan and elevation of the building frame is shown in Fig 2.1.All dimensions are shown in mm. For the purpose of analysis, modelling has been done using 'SAP-2000' software of Computers and Structures Inc.

No of Storey	10
Bay spacing in X direction	6m
Bay spacing in Y direction	5m
Length in X Direction	18m
Length in Y Direction	25m
Typical storey height	3.5m
Total building height	38.5m
Grade of concrete	M25
Grade of concrete	Fe415

Table2.1 Basic parameters for analysis

Zones	III, IV, V
Importance Factor	1.5
Reduction Factor	5 (SMRF)
Damping	5%
Soil Type	Type II (Medium)

Table2.2 Basic seismic parameters

	ZONE III	ZONE IV	ZONE V
Beam dimension	230mm x 600mm	230mm x 600mm	230mm x 600mm
Slab dimension	150mm	150mm	150mm
Column dimension			
Ground Level	400x750mm	400x750mm	450x850mm
1st to 4th Level	350x750mm	350x750mm	400x850mm
5th to 7th Level	350x650mm	350x650mm	400x750mm
8th to 10th Level	350x550mm	350x550mm	400x650mm

Table2.3 Member sizes considered for analysis

Floor Finish load on slab	1.5kN/m2
Live load on slab	3.0 kN/m2
Wall loads on beam	5 kN/m2

Table2.4 Loading data considered for analysis

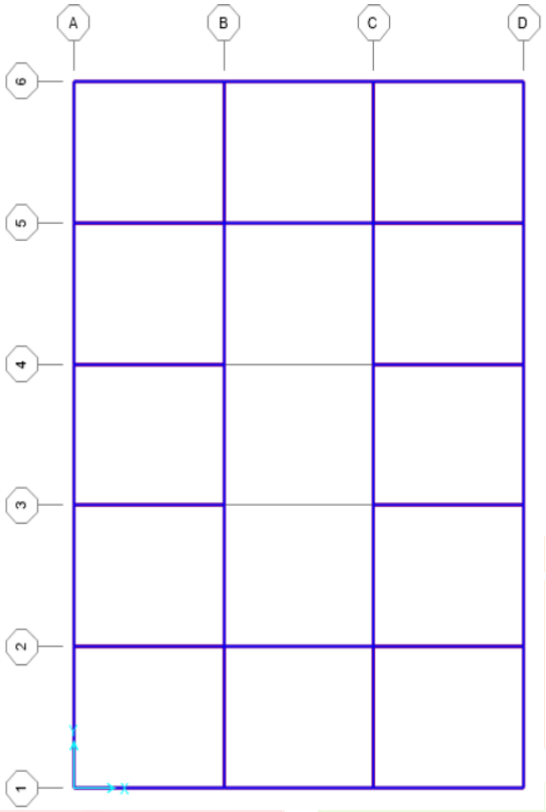

Figure 2.1 Plan considered for analysis

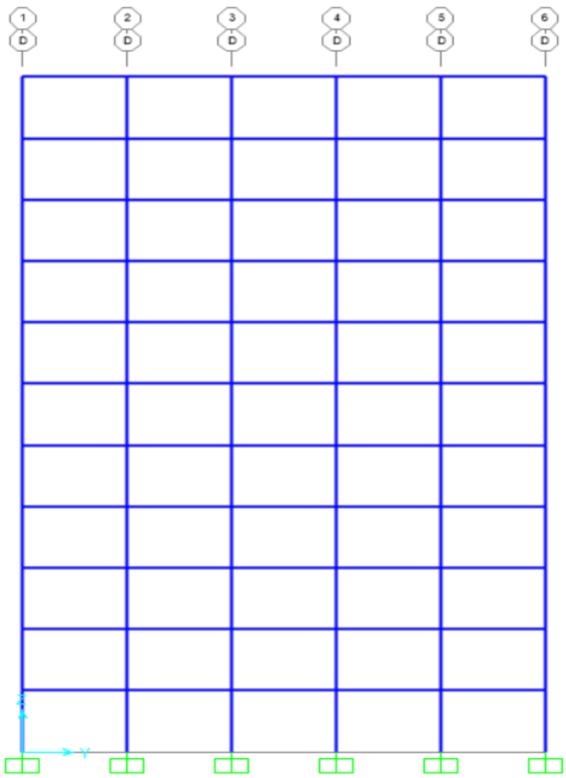

Figure 2.2 Elevation

III. NON LINEAR ANALYSIS

Non linear static analysis is an efficient way to analyse the behaviour of the structure, highlighting the sequence of member cracking and yielding as the base shear value increases. In this a lateral load is applied on the created model and analysed. The Building is pushed in one horizontal direction and the behaviour of the building is studied in the form of top deflection. The lateral load intensity is gradually increased in a controlled manner such that plastic hinges formation and failures in structural elements are observed. Proportion of applied force on each floor is constant, only its magnitude is increased gradually. Under pushover load or incrementally increased lateral loads, gradual yielding of structural elements would occur. Yield in structural elements experience a change in stiffness of structure. Plastic hinge (yielding) formation sequence in the structural elements can be studied by this force deflection curve.

3.1 Performance Point:

The Performance Point represents the state of maximum inelastic capacity of the structure and is found through intersection of the Capacity Spectrum and Demand Spectrum for a given damping ratio. The base shear Vs. roof displacement curve is obtained from the pushover analysis from which the maximum base shear capacity of structure can be obtained. This is illustrated in Figure 3.1.

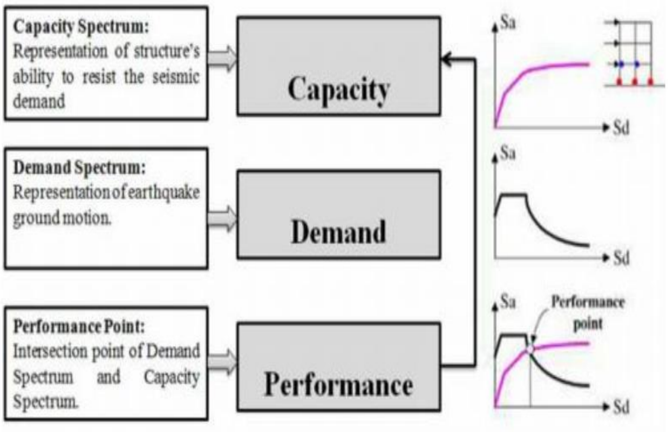

Figure 3.1 ATC40 -Determination of Performance point

3.2 Inter-storey drifts:

Inter-storey drift is also one of the most important design parameters in all the seismic design codes as the performance of structural as well as non-structural components of a building is controlled by inter-storey drift. It is defined as the ratio of relative horizontal displacement of two adjacent floors and corresponding storey height.

Structural system	IO	LS	CP
Other than Masonry shear wall system	0.01	0.02	0.025

Table 3.1 FEMA – 356 Inter-storey drift ratio (IDR) allowable limits

3.3 Displacement Ductility:

The ability of a structure or member to undergo inelastic deformations beyond the initial yield deformation with no decrease in the load resistance is ductility. The displacement ductility demand for a given earthquake load is obtained from the pushover curve and is calculated by the following equation,

$$\mu = \frac{\Delta m}{\Delta y}$$

Where Δm = maximum displacement

Δy = yield deformation

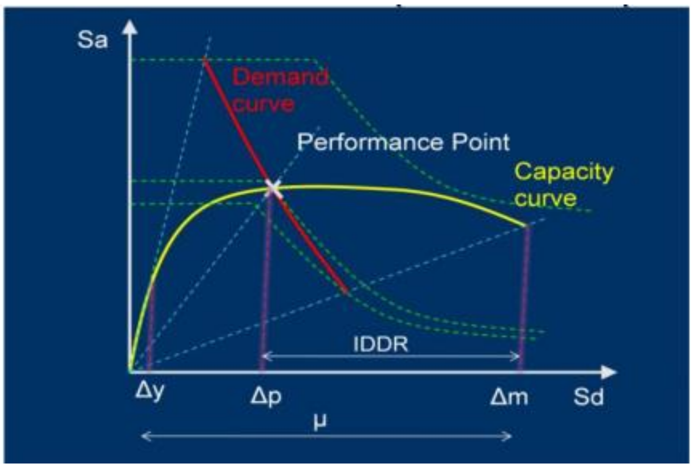

Figure 3.2 Determination of Displacement Ductility

3.4 Plastic Rotations

The sequence of plastic hinge formation and state of hinge at various levels of building performance can be obtained that gives the information about the weakest member

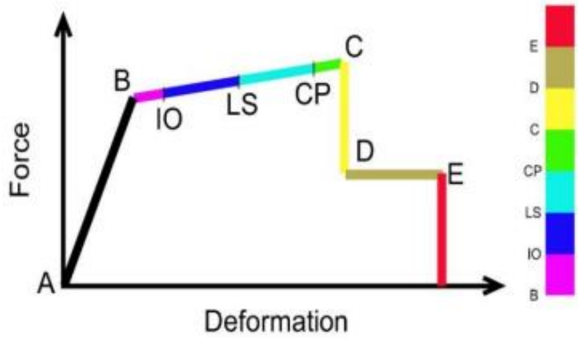

Figure 3.3 Typical curve for hinge formation

Structural system	IO	LS	CP
Beams	0.005	0.02	0.025
Columns	0.005	0.01	0.02

Table 3.2 FEMA – 273Plastic rotation allowable limits

3.5 Response reduction factor

The response reduction factor reflects the capacity of structure to dissipate energy through inelastic behaviour. It is a combined effect of over strength, ductility and redundancy represented as:

$R = R_S \times R_R \times R_u$

where,

R_S = Over strength factor

R_R = Redundancy factor

R_u = Ductility reduction factor

IV. RESULTS AND DISCUSSION

Following are the results for Maximum Considered Earthquake condition for the building in different seismic zone

4.1 Performance Point

ZONE III

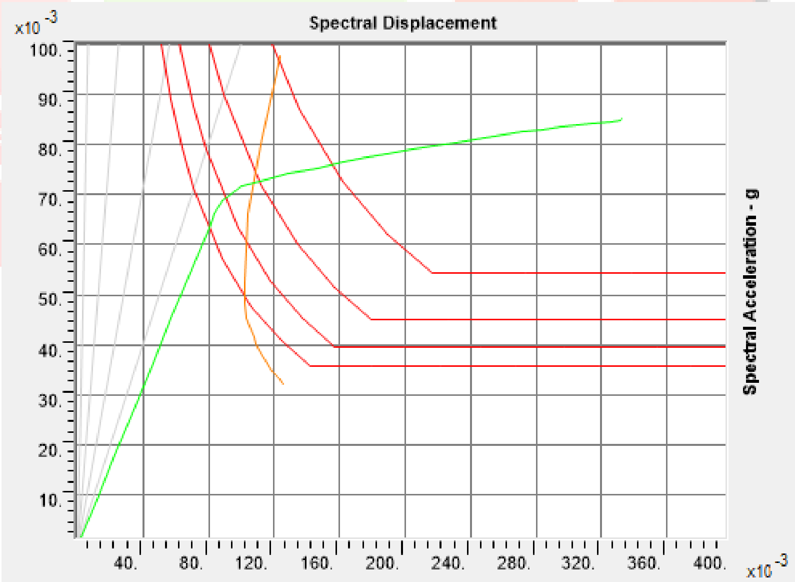

Figure 4.1 Performance Point plot for seismic zone III

In Fig 4.1 the graph shows Capacity curve in green, demand curves in red, and intersection of Performance Point in orange. The lateral load was applied in pattern of that first mode shape in the transverse direction of the building, with an intensity for MCE as per IS:1893-2016, corresponding to zone-III in medium soil. It shows the ADRS plot in which the Sa and Sd at Performance Point are 0.072g and 0.108m. The corresponding Base shear and roof displacement at top are 2607.072 kN and 0.143m respectively. The value of effective T is 2.445s and the effective β at that level of the demand curve which met the Performance Point is 10.09%.

ZONE IV

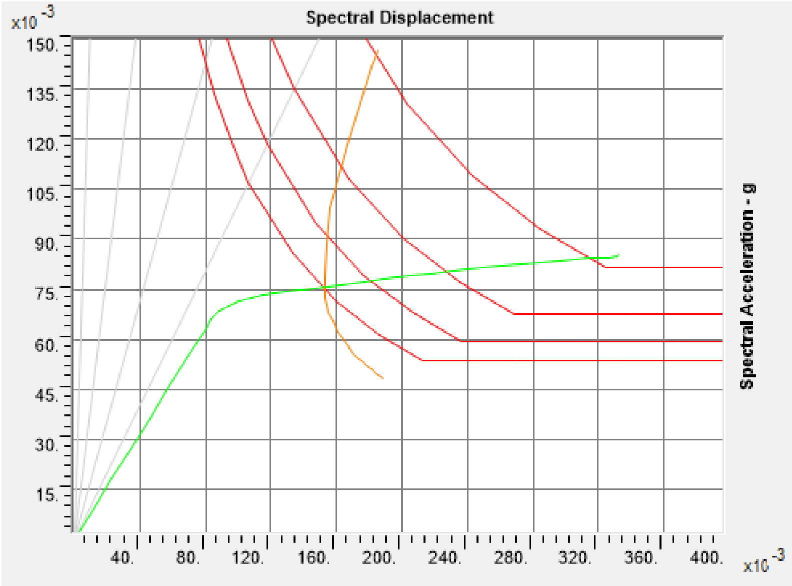

Figure 4.2 Performance Point plot for seismic zone IV

In Fig 4.2 the graph shows Capacity curve in green, demand curves in red, and intersection of Performance Point in orange. The lateral load was applied in pattern of that first mode shape in the transverse direction of the building, with an intensity for MCE as per IS:1893-2016, corresponding to zone-IV in medium soil. It shows the ADRS plot in which the Sa and Sd at Performance Point are 0.076g and 0.153m. The corresponding Base shear and roof displacement at top are 2693.326kN and 0.201m respectively. The value of effective T is 2.85s and the effective β at that level of the demand curve which met the Performance Point is 19.8%.

ZONE V

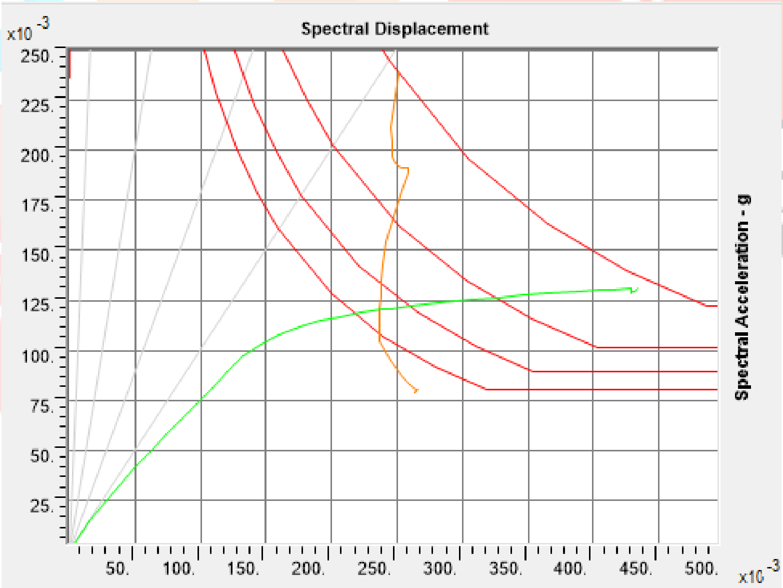

Figure 4.3 Performance Point plot for seismic zone V

In Fig 4.3 the graph shows Capacity curve in green, demand curves in red, and intersection of Performance Point in orange. The lateral load was applied in pattern of that first mode shape in the transverse direction of the building, with an intensity for MCE as per IS:1893-2016, corresponding to zone-V in medium soil. It shows the ADRS plot in which the Sa and Sd at Performance Point are 0.12g and 0.237m. The corresponding Base shear and roof displacement at top are 4556.66kN and 0.297m respectively. The value of effective T is 2.814s and the effective β at that level of the demand curve which met the Performance Point is 17.7%.

4.2 INTERSTOREY DRIFT

ZONE III

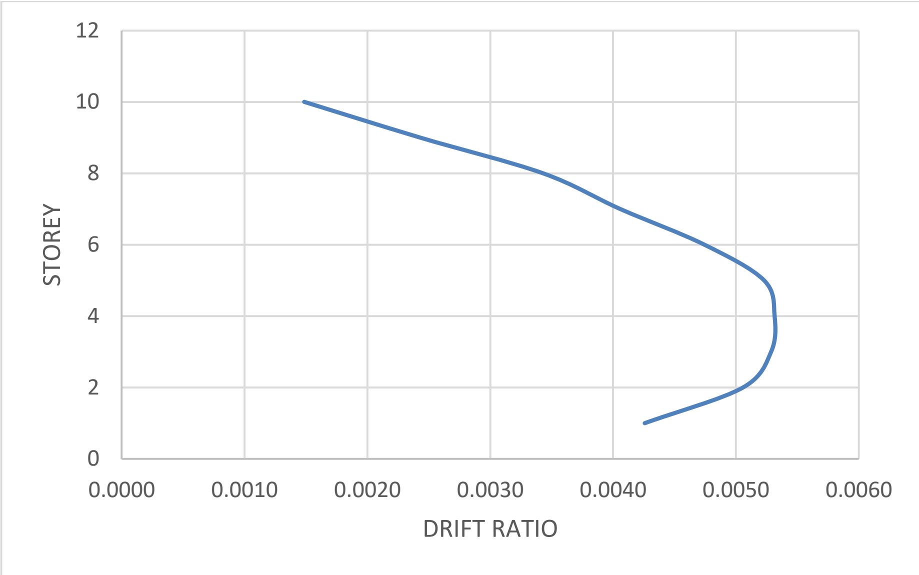

Figure 4.4 Interstorey drift graph for seismic zone III

It is observed that in seismic zone III the structure is within the 1% drift limit at performance point indicating that the structure lies within immediate occupancy performance level as per FEMA 356 limits.

ZONE IV

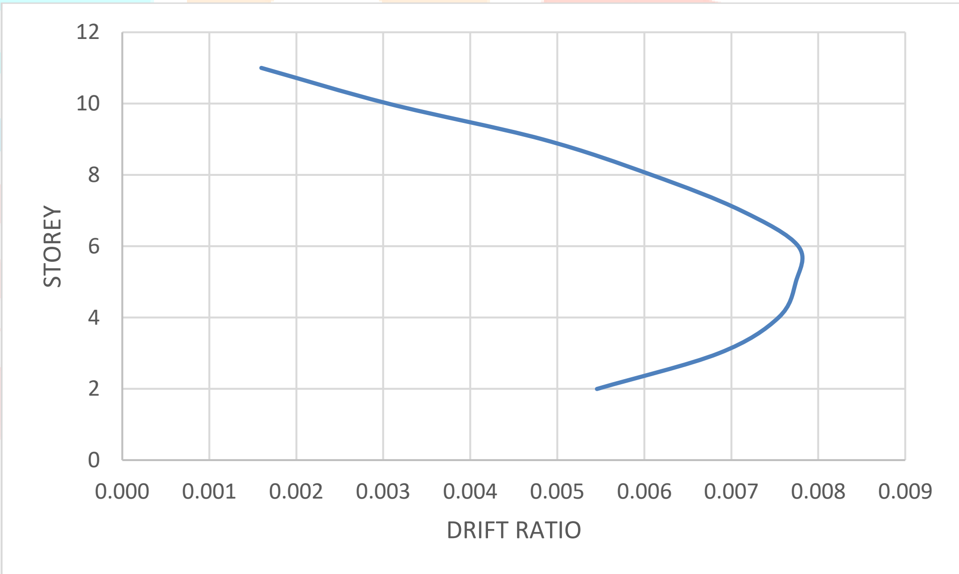

Figure 4.5 Interstorey drift graph for seismic zone IV

It is observed that in seismic zone IV the structure is within the 1% drift limit at performance point indicating that the structure lies within immediate occupancy performance level as per FEMA 356 limits.

ZONE V

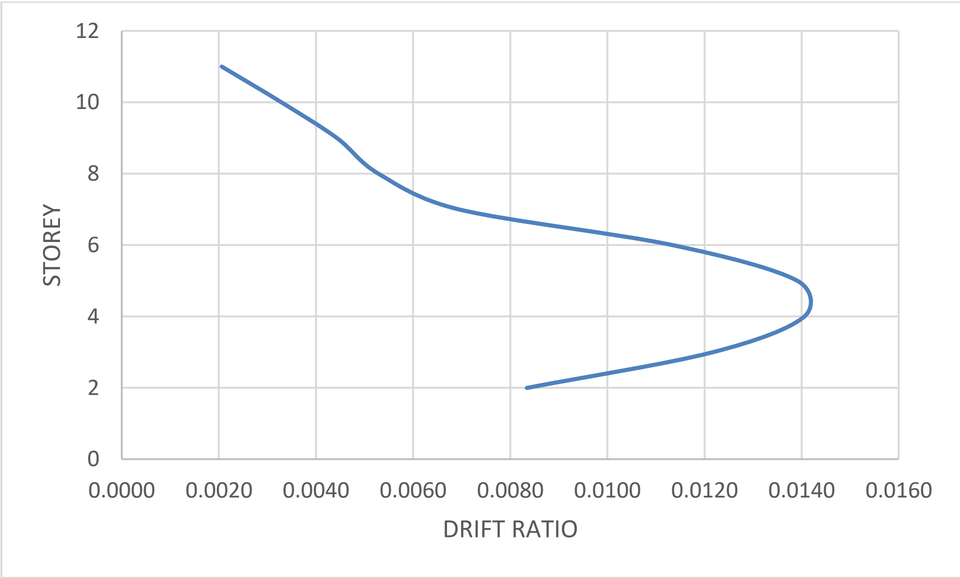

Figure 4.6 Interstorey drift graph for seismic zone V

It is observed that in seismic zone V the structure is within the 1% drift limit but storey level 3 to 6 has crossed 1% at performance point indicating that the structure lies within immediate occupancy to Life safety performance level as per FEMA 356 limits.

4.3HINGE RESULTS

The sequence of plastic hinge formation and state of hinge at various levels of building performance can be obtained from SAP output. This gives the information about the weakest member and so the one which is to be strengthened in case of a building need to be retrofitted. Accordingly, the detailing of the member can be done in order to achieve the desired pattern of failure of members in case of severe earthquakes. From the following figures the formation of hinges for immediate occupancy level at performance point are observed.

ZONE III

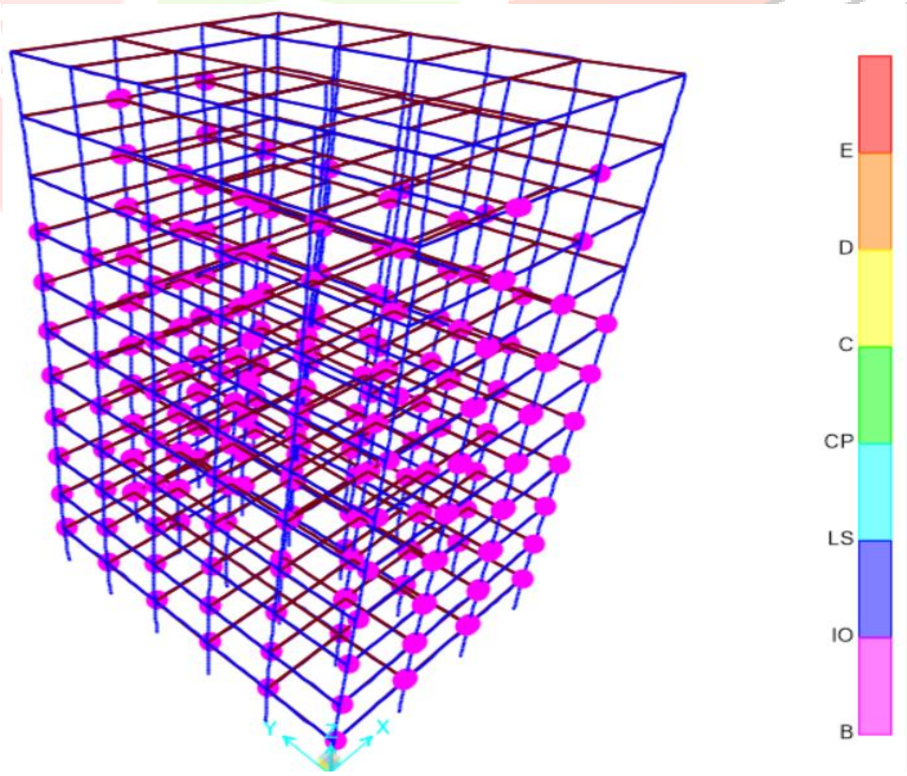

Figure 4.7 Hinges at Performance Point in zone III

From the above figure, it has been observed that for the Performance Point taken as step 11, total 1320 number of hinges were formed out of which 80% hinges were formed in elastic range i.e. A-B range and 20% were formed in Immediate occupancy range i.e. B-IO range.

ZONE IV

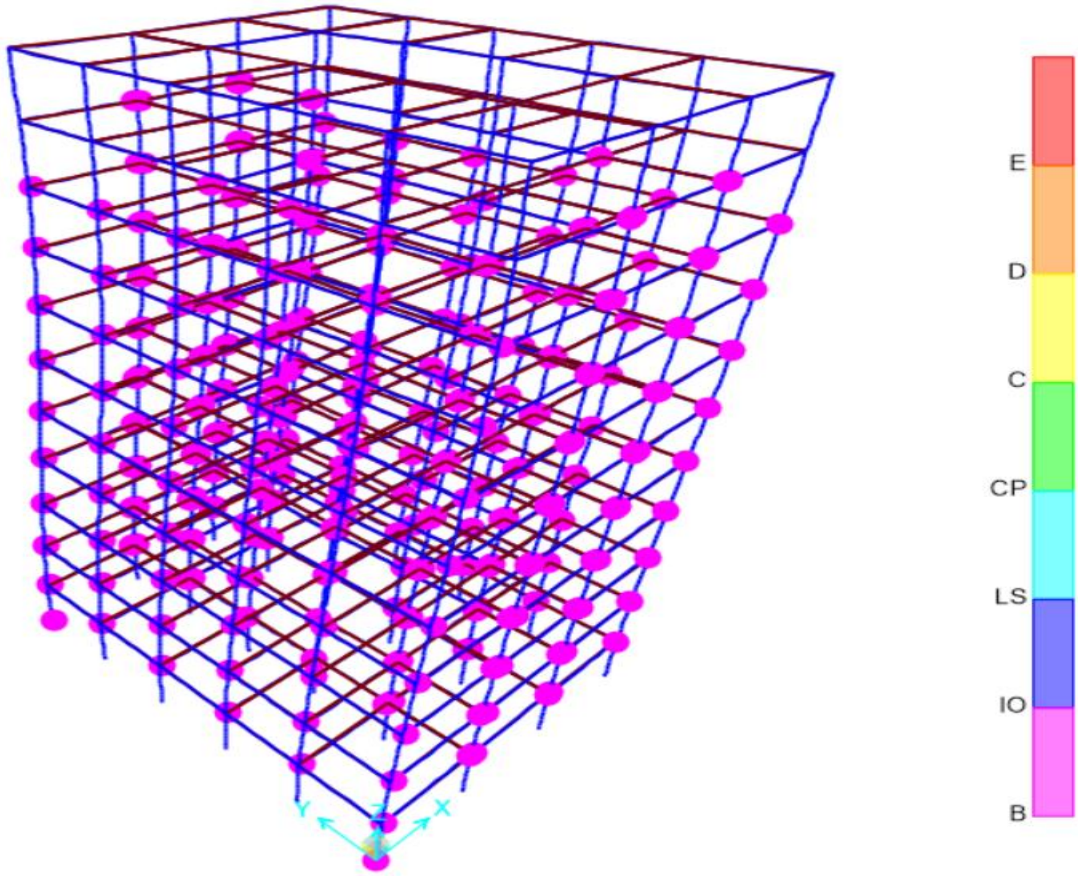

Figure 4.8 Hinges at Performance Point in zone IV

From the above figure, it has been observed that for the Performance Point taken as step 14, total 1320 number of hinges were formed out of which 78% hinges were formed in elastic range i.e. A-B range and 22% were formed in Immediate occupancy range i.e. B-IO range.

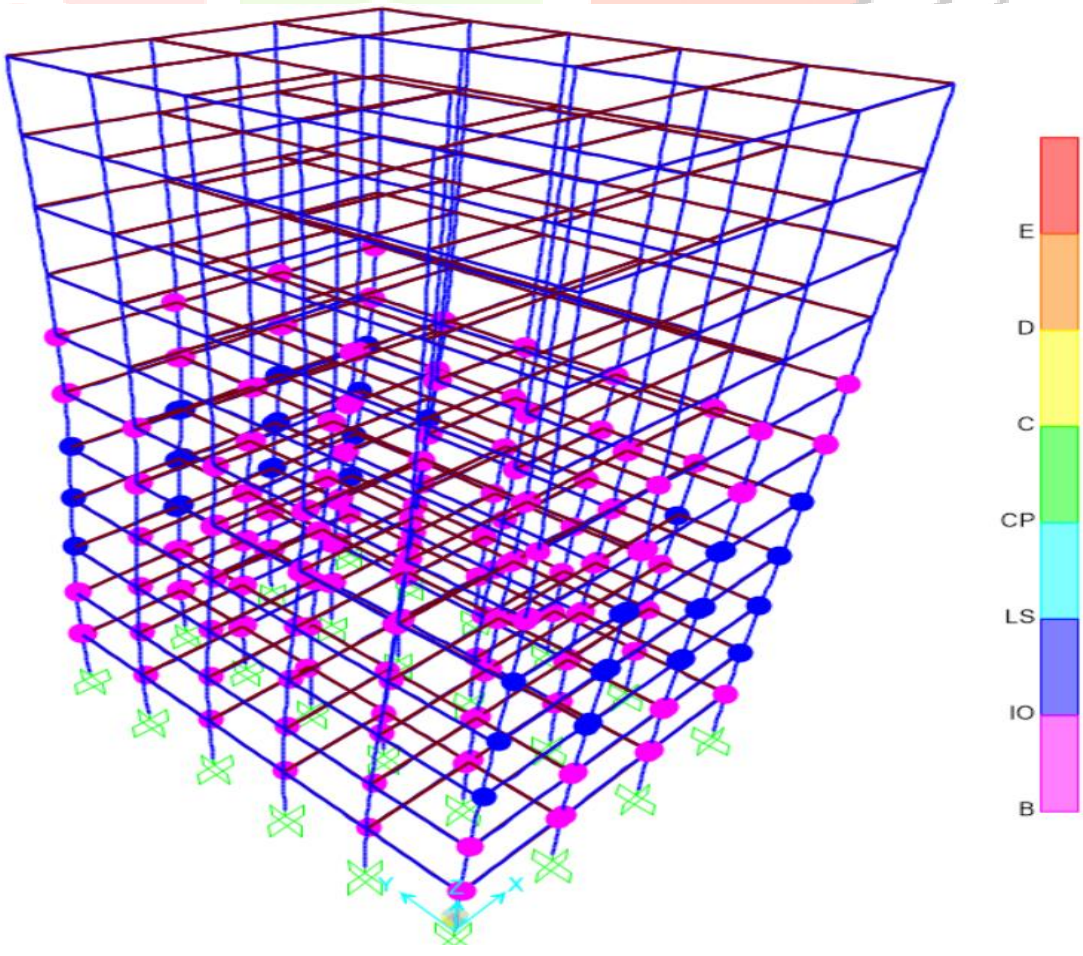

Figure 4.9 Hinges at Performance Point in zone V

From the above figure, it has been observed that for the Performance Point taken as step 18, total 1320 number of hinges were formed out of which 82% hinges were formed in elastic range i.e. A-B range and 14% were formed in Immediate occupancy range i.e. B-IO range and 4% in IO-LS range.

Based on the analysis performed for three different seismic zones, the comparative results are presented:

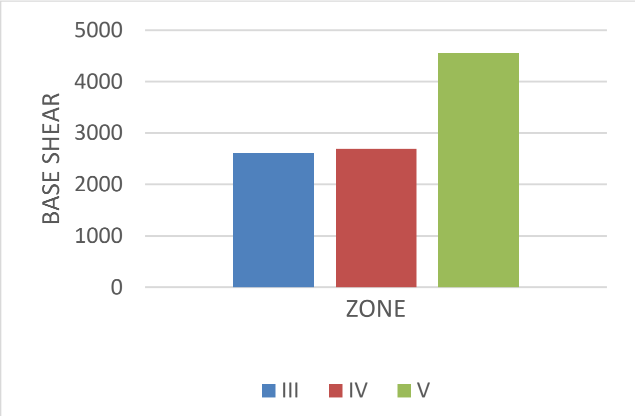

Figure 4.10 Base shear(kN) at Performance point in each zone

Base shear is the function of the weight and the acceleration of the structure. From figure it is observed that the base shear of zone V is more than zone III and IV. This is because of the increase in weight and seismic zone of the structures.

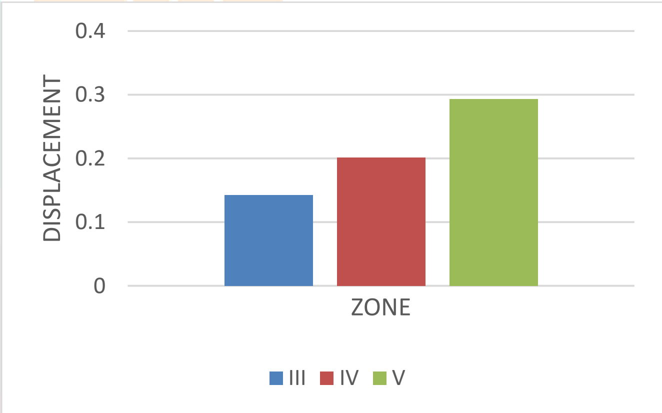

Figure 4.11 Displacement (m) at Performance point in each zone

From figure it is observed that the roof displacement increases gradually with increse in seismic zone for medium soil condition.

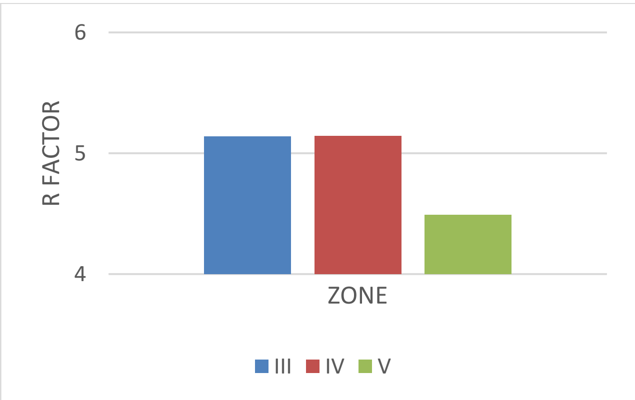

Figure 4.12 Response Reduction in each zone

From the figure it can be observed that the reponse reduction factor for zone III and IV crosses the value of 5 which is recommended by the IS 1893:2016 code while for zone V it is failed to achieve the recommended value using performance based analysis for the design of the structure.

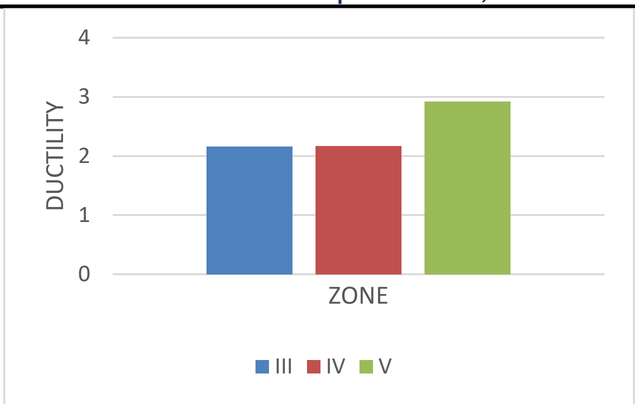

Figure 4.13 Ductility in each zone

From the figure it can be observed that the duclility remians steady for zone IV and V but slightly increases for zone V.

Based on the analysis performed for three different seismic zones, the comparative results are presented in the table:

For Immediate Occupancy	ZONE III	ZONE IV	ZONE V
Base Shear	2607.072kN	2693.326kN	4556.66kN
Roof displacement	0.143m	0.201m	0.297m
Spectral acceleration	0.072g	0.076g	0.12g
Spectral Displacement	0.108m	0.153m	0.237m
Time Period	2.445sec	2.85sec	2.814sec
Ductility	2.162	2.162	2.919
R Factor	5.1395	5.1432	4.49
Plastic Rotation allowable for column	0.005radian	0.005 radian	0.005 radian
Plastic Rotation	0.0017radian	0.0025 radian	0.0039 radian

Table 4.1 Comparison results in each seismic zone

V. CONCLUSION

In this work, Performance based seismic design of a G+10 storey building with opening in diaphragm has been done by evaluating their performance using pushover analysis to achieve performance objective as immediate occupancy. By varying member (Beam, Column) size in different combinations we can easily achieve preestablished performance objectives for PBSD of Buildings.

- The nonlinear hinges were observed to be in immediate occupancy for zone III and IV and in Immediate occupancy to Life safety for zone V. Maximum number of the hinges are produced in the beams then the columns following the weak beam strong column concept. The determination of plastic rotations and the type of hinge formation for Immediate occupancy performance level and their potential locations provides an useful input for providing special confining reinforcement in the structural members.

- The performance point has maximum displacement of 0.143m, 0.201m,0.297m for seismic zone III, IV and V for 10 storey RCC frame structure which is less than 1%H which is 0.385m, hence the building is well within elastic limits and comes under operational performance level criteria.
- The yield base shear and displacement increase with increase of seismic zone indicating the severity of seismic activity.

- For 10 storey buildings the ductility demand arising from the member performance level dominates the design procedure. The ductility of the structure seems to be has major contribution to response reduction factor for the structure indicating the importance of critical consideration of structural ductility in the seismic analysis process.

- The response reduction factor for the required performance level has been computed with time period associated with respective performance point. This overcomes the deficiency of adopting a constant reduction factor for all design periods.

- The evaluation factors like displacement ductility justify the ductile detailing of the structure as every parameter associated with it is critically evaluated for the seismic behaviour at each performance level.

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