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Performance Based Design of Irregular High-Rise Buildings and Optimization of Story Levels for Seismic Zones

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Abstract: Performance-based design in civil engineering entails a dynamic and forward-thinking approach to conceptualizing and constructing high-rise structures. This methodology prioritizes achieving specified performance criteria levels to ensure the safety, functionality, and resilience of these towering edifices. By integrating advanced analysis techniques and simulations, designers can optimize structural systems, materials, and configurations to meet rigorous demands. Performance criteria levels within the context of high-rise structures encompass a spectrum of factors including structural stability, wind and seismic resistance, occupant comfort, and sustainability. Striking a balance between innovative design and stringent performance targets, this approach not only fosters the creation of iconic and efficient skyscrapers but also enhances our understanding of complex interactions in urban environments. In this study structures are modelled and their performance criteria levels are evaluated based on seismic analysis using push over method. The synergy between performance-based design and well-defined performance criteria levels paves the way for safer, smarter, and more sustainable high-rise construction in the modern era of civil engineering.

Index Terms **– Etabs, Seismic analysis, L shaped unsymmetrical Building, Push over analysis.**

I. INTRODUCTION

The Earth's surface continues to change slowly. the movements of enormous, unyielding plates at the Earth's surface, or plate tectonics. The earth's surface is covered in the plates. The San Andreas Fault in the United States is one example of how they move and rub against one another. Other examples include the Peru-Chile Trench across the west coast of South America and the Mid-Atlantic Ridge, which separates them from one another. In some locations, movement is restricted because the edges of the plates are locked together while the remainder of them are still moving. As a result, the rocks along the edges are warped. The rock can only bend so far before the strain becomes too great for it to continue.

Pushover analysis is a seismic assessment method in structural engineering. It evaluates a building's response to incremental lateral loads, simulating the progressive collapse behavior during earthquakes. By plotting the structure's capacity curve against its demand curve, engineers can identify potential weaknesses and optimize designs for enhanced seismic performance. In this study L shaped building with different story levels been created with auto hinges and assigned with lateral loads, analyzed its performance criteria levels in various seismic zones. After analysis its optimization has done by changing the plan areas.

The structural performance level of a building shall be selected from four discrete level and two intermediate ranges. The discrete structural performance levels are:

1) Immediate Occupancy (S-1)
2) Life Safety (S-3)
3) Collapse Prevention (S-5)
4) Not considered (S-6)

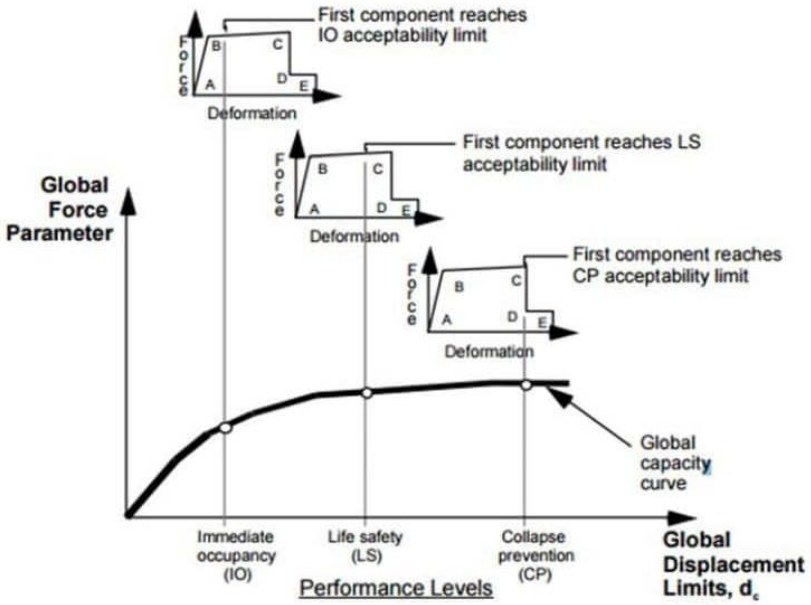

Fig -1: Performance levels in structure

II. MODELLING OF THE L SHAPED BUILDING:

Models in Etabs: An L shaped building has modelled with the following input parameters and applied loads i.e., dead load, Live load, seismic loads in the directions of x and y, Push over loads. Auto Hinges are assigned to the columns and beams respectively, after the analysis interpreted the results due to seismic loads in x and y directions.

The design parameters considered for an L shaped unsymmetrical floor plan building has shown in the below table.

S. No.	Parameter	Value
1	Column Size	0.30 mm x 0.30 mm
2	Beam Size	0.23 mm X 0.30 mm
3	Slab Thickness	150 mm
4	Span of Beams	4 m
5	Height of each storey	3 m
6	Grade of concrete	M30
7	Grade of Rebar	Hysd415

Table-1: Design parameters of L shaped floor plan building

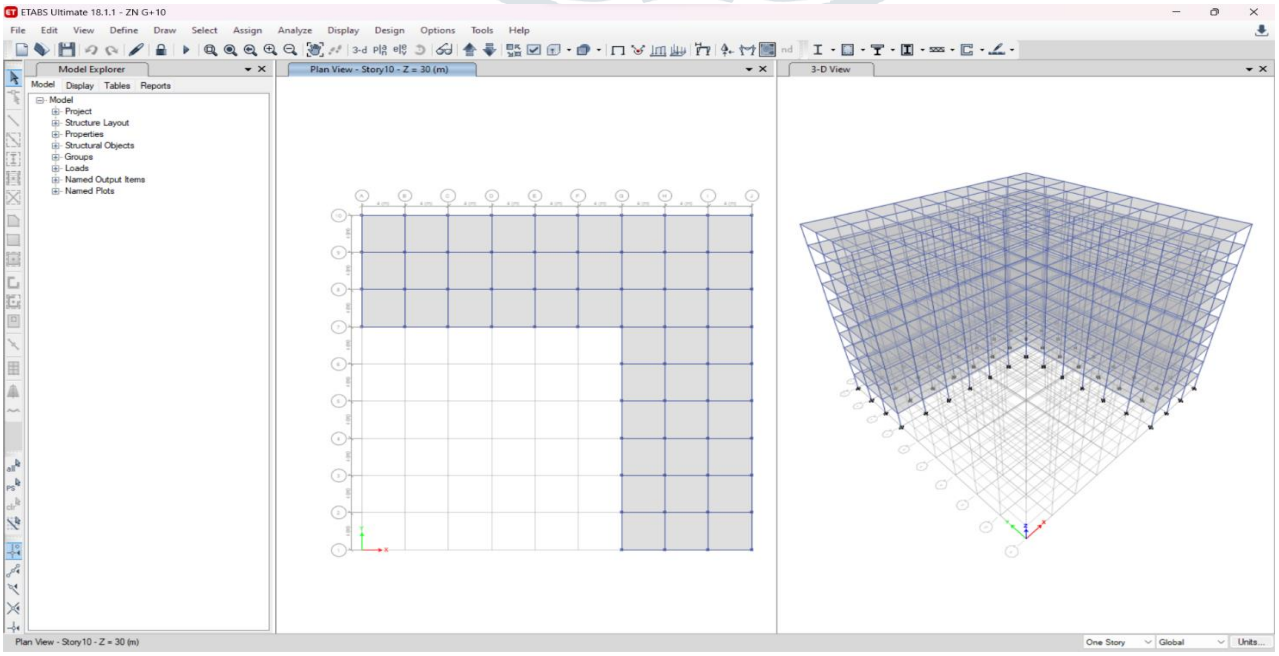

Fig-2: L shaped building floor plan and 3d view

Assigning the Loads:

1. **Dead Load:**
   Due to beams = 0.23x0.3x25 = 1.725 kN/m
   Due to columns = 0.3x0.3x25 = 2.25 kN/m
   Due to Slab = 0.15x 25 = 3.75 kN/m2

2. Live Load = 2.5 kN/m2

3. **Earth Quake Load:**
   In the direction of X, Seismic Coefficients:
   EQ X = 1.25 kN/m (Global-x direction)
   Seismic Code factor Z, Per code values = 0.36 (zone -5)
   Seismic Code factor Z, Per code values = 0.24 (zone –4)
   Seismic Code factor Z, Per code values = 0.16 (zone –3)
   Seismic Code factor Z, Per code values = 0.10 (zone –2)
   Soil Type = II, Importance Factor I = 1
   Response Reduction Factor R = 5

   In the direction of Y, Seismic Coefficients:
   EQ Y = 1.25 kN/m (Global-y direction)
   Seismic Code factor Z, Per code values = 0.36 (zone -5)
   Seismic Code factor Z, Per code values = 0.24 (zone –4)
   Seismic Code factor Z, Per code values = 0.16 (zone –3)
   Seismic Code factor Z, Per code values = 0.10 (zone –2)
   Soil Type = II , Importance Factor I = 1

4. Push X and Push Y (Static non-linear analysis) – due to ground acceleration in U_x and U_y direction respectively.

S. No.	Structural Member	Size
1	Dead Load	
	Due to beams	1.725 kN/m
	Due to columns	2.25 kN/m
	Due to Slab	3.75 kN/m2
	Total Dead Load	7.725 kN/m2
2	Live Load	2.5 kN/m2
3	Earth Quake Load	
	EQ X (Global-x direction)	1.25 kN/m
	EQ Y (Global-y direction)	1.25 kN/m
4	Push Over Force	
	PUSH X	X direction
	PUSH Y	Y direction

Table-2: Assigning the loads

Assign Hinges: Assigning hinges to all beams and columns in frame at a distance of 5% and 95% distances from joint i.e., (0.05 and 0.95). Hinges assigned are auto hinges, beams moment Auto M3 and for columns Auto P-M2-M3 are applied using the loads considered as PUSH X and PUSH Y respectively.

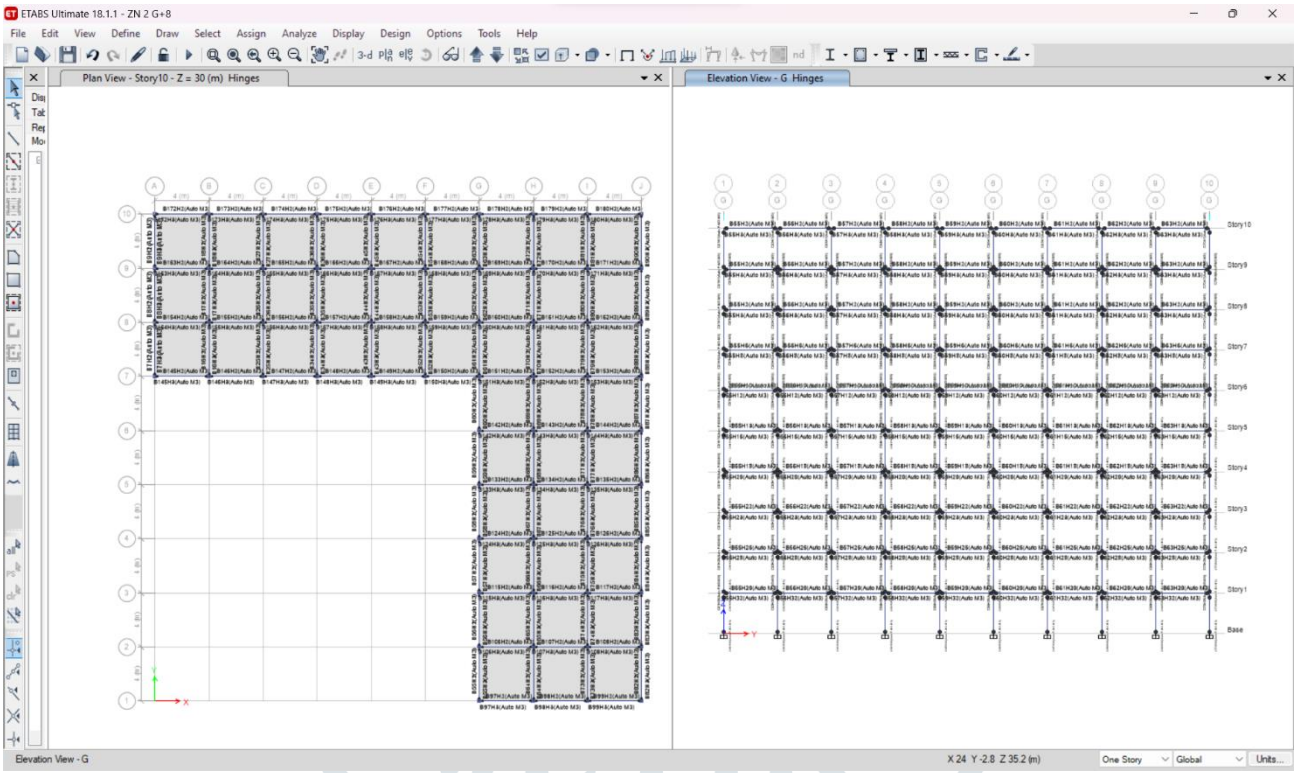

Fig-3: Assigned hinges in beams and columns in plan and side view respectively

Story	Frame	Output Case	Hinge	Generated Hinge	Rel Dist	Abs Dist	P	R2 Plastic	R3 Plastic	Hinge State	Hinge Status
Story1	C7	EQ X	Auto P-M2-M3	C7H37	0.05	0.135	127.1265	-0.000019	0.008	B to C	>CP
Story1	C7	EQ X	Auto P-M2-M3	C7H38	0.05	0.135	127.1265	-0.000019	0.008	B to C	>CP
Story1	C8	EQ X	Auto P-M2-M3	C8H37	0.05	0.135	137.5258	0.000207	0.008	B to C	>CP
Story1	C8	EQ X	Auto P-M2-M3	C8H38	0.05	0.135	137.5258	0.000207	0.008	B to C	>CP
Story1	C9	EQ X	Auto P-M2-M3	C9H37	0.05	0.135	137.6861	0.000061	0.008	B to C	>CP
Story1	C9	EQ X	Auto P-M2-M3	C9H38	0.05	0.135	137.6861	0.000061	0.008	B to C	>CP
Story1	C61	EQ X	Auto P-M2-M3	C61H37	0.05	0.135	140.0763	-0.000050	0.008	B to C	>CP
Story1	C61	EQ X	Auto P-M2-M3	C61H38	0.05	0.135	140.0763	-0.000050	0.008	B to C	>CP
Story1	C62	EQ X	Auto P-M2-M3	C62H37	0.05	0.135	139.1091	-0.000031	0.008	B to C	>CP
Story1	C62	EQ X	Auto P-M2-M3	C62H38	0.05	0.135	139.1091	-0.000031	0.008	B to C	>CP
Story1	C63	EQ X	Auto P-M2-M3	C63H37	0.05	0.135	138.9662	-0.000018	0.008	B to C	>CP
Story1	C63	EQ X	Auto P-M2-M3	C63H38	0.05	0.135	138.9662	-0.000018	0.008	B to C	>CP
Story1	C64	EQ X	Auto P-M2-M3	C64H37	0.05	0.135	138.6481	-0.000008	0.008	B to C	>CP
Story1	C64	EQ X	Auto P-M2-M3	C64H38	0.05	0.135	138.6481	-0.000008	0.008	B to C	>CP
Story1	C65	EQ X	Auto P-M2-M3	C65H37	0.05	0.135	138.3137	0.000000	0.008	B to C	>CP
Story1	C65	EQ X	Auto P-M2-M3	C65H38	0.05	0.135	138.3137	0.000000	0.008	B to C	>CP
Story1	C66	EQ X	Auto P-M2-M3	C66H37	0.05	0.135	127.6668	0.000017	0.008	B to C	>CP
Story1	C66	EQ X	Auto P-M2-M3	C66H38	0.05	0.135	127.6668	0.000017	0.008	B to C	>CP

Table-3: Hinge state results of G+10 story frames performing >CP level in Seismic Zone-5

III. RESULTS AND DISCUSSION:

RESULTS OF G+10 story building

An L shaped unsymmetrical building is modelled and verified that all members in frames along with footings are passed under normal loading conditions. After applying the seismic load and push over using ground acceleration, the analysis results obtained using hinge displacement values. The results such as hinge states, story drift, displacement (sway) of the hinges in frames, load and hinge state in frames showing the performance level >CP is shown below.

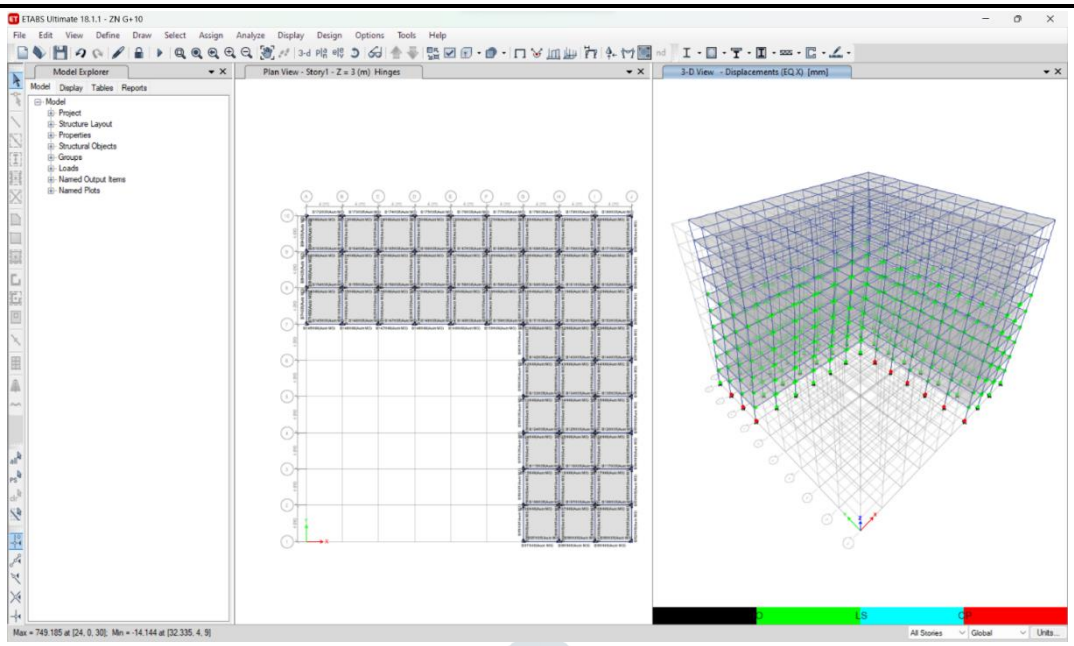

Fig-4: Performance criteria levels of G+10 story building due earthquake load in X direction

RESULTS OF G+9 story building:

An L shaped unsymmetrical building is modelled with same design parameters shown in the G+10 story structure and verified that all members in frames along with footings are passed under normal loading conditions. After applying the seismic load and push over using ground acceleration, the analysis results obtained using hinge displacement values. The results such as hinge states, story drift, displacement (sway) of the hinges in frames, load and hinge state in frames showing the performance level >CP is shown below.

Story	Frame	Output Case	Hinge	Generated Hinge	Rel Dist	Abs Dist	P	R2 Plastic	R3 Plastic	Hinge State	Hinge Status
Story1	C10	EQ X	Auto P-M2-M3	C10H33	0.05	0.135	139.3	0.000017	0.00918	B to C	>CP
Story1	C10	EQ X	Auto P-M2-M3	C10H34	0.05	0.135	139.3	0.000017	0.00918	B to C	>CP

Table-4: Hinge state results of G+9 story frames performing >CP level in Seismic Zone-5

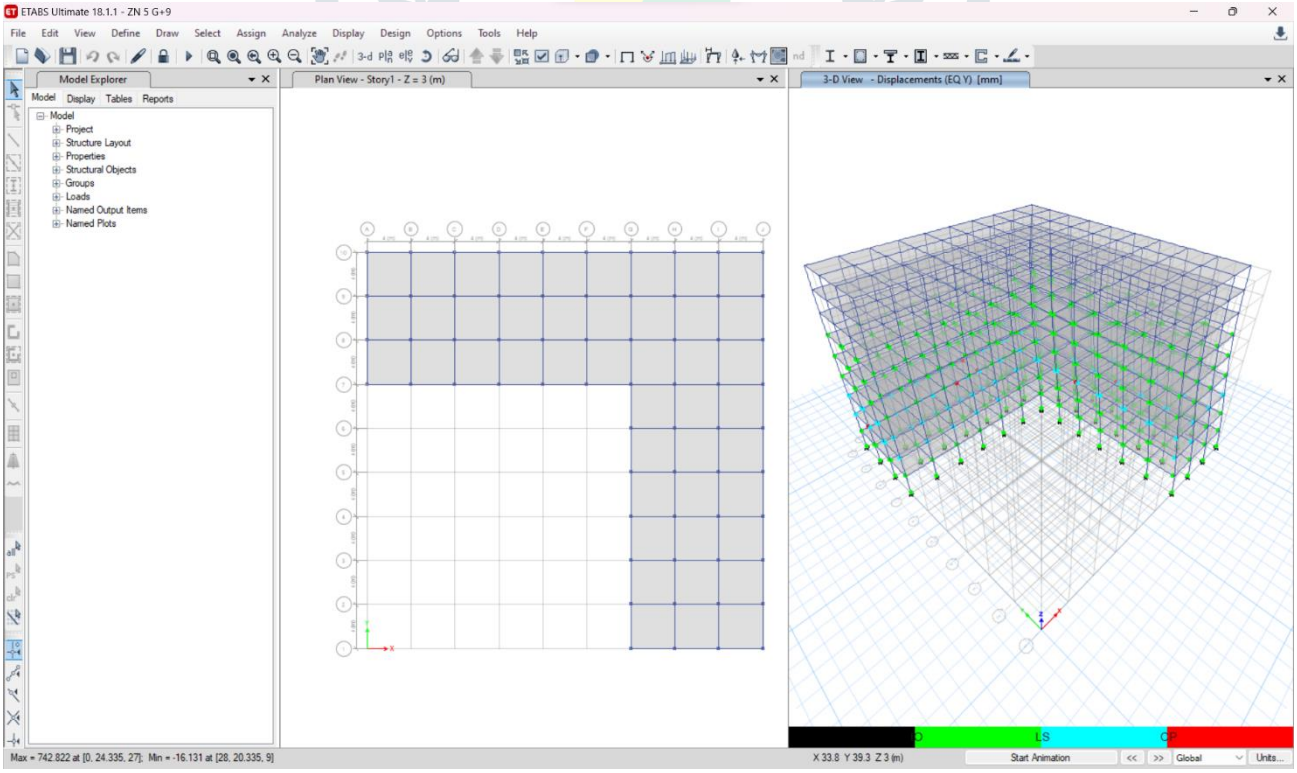

Fig-5: Performance criteria levels of G+9 story building due earthquake load in X direction

RESULTS OF G+8 story building:

An L shaped unsymmetrical building is modelled and verified that all members in frames along with footings are passed under normal loading conditions. After applying the seismic load and push over using ground acceleration, the analysis results obtained using hinge displacement values. The results such as hinge states, story drift, displacement (sway) of the hinges in frames, load and hinge state in frames showing the performance level >CP is shown below.

Results for G+8 for seismic Zone-5: **Hinge state >CP** (collapse Prevention) – **NIL**
but observed between **CP to LS** and **LS to Io** performance levels

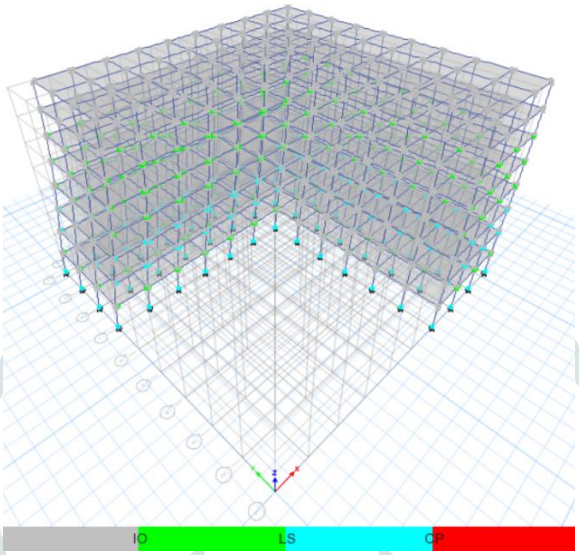

Fig-6: Performance criteria levels of G+8 story building due earthquake load in X direction

Results of Increasing Floor Plan area for G+8: A change in floor plan area of same L shaped building from 720 sqm to 1280 sqm i.e., an increase of 77% floor plan area is modelled with same design parameters, verified that all members in frames along with footings are passed under normal loading conditions. After applying the seismic load and push over using ground acceleration, the analysis results obtained using hinge displacement values. The results such as hinge states, story drift, displacement (sway) of the hinges in frames, load and hinge state in frames showing the performance level >CP is shown below.

Story	Frame	Output Case	Case Type	Hinge	Generated Hinge	P	R2 Plastic	R3 Plastic	Hinge State	Hinge Status
Story1	C10	EQ X	Non-Static	Auto P-M2-M3	C10H29	111.7651	0.000332	0.01023	B to C	>CP
Story1	C10	EQ X	Non-Static	Auto P-M2-M3	C10H30	111.7651	0.000332	0.01023	B to C	>CP
Story1	C11	EQ X	Non-Static	Auto P-M2-M3	C11H29	118.8507	0.000348	0.010252	B to C	>CP
Story1	C11	EQ X	Non-Static	Auto P-M2-M3	C11H30	118.8507	0.000348	0.010252	B to C	>CP
Story1	C12	EQ X	Non-Static	Auto P-M2-M3	C12H29	118.6906	0.000356	0.010263	B to C	>CP
Story1	C12	EQ X	Non-Static	Auto P-M2-M3	C12H30	118.6906	0.000356	0.010263	B to C	>CP
Story1	C13	EQ X	Non-Static	Auto P-M2-M3	C13H29	118.6452	0.000363	0.010275	B to C	>CP
Story1	C13	EQ X	Non-Static	Auto P-M2-M3	C13H30	118.6452	0.000363	0.010275	B to C	>CP
Story1	C14	EQ X	Non-Static	Auto P-M2-M3	C14H29	125.1147	0.000019	0.010183	B to C	>CP
Story1	C14	EQ X	Non-Static	Auto P-M2-M3	C14H30	125.1147	0.00002	0.010183	B to C	>CP

Table-5: Hinge state results of G+8 story *with increased area*, frames performing >CP level in Seismic Zone-5

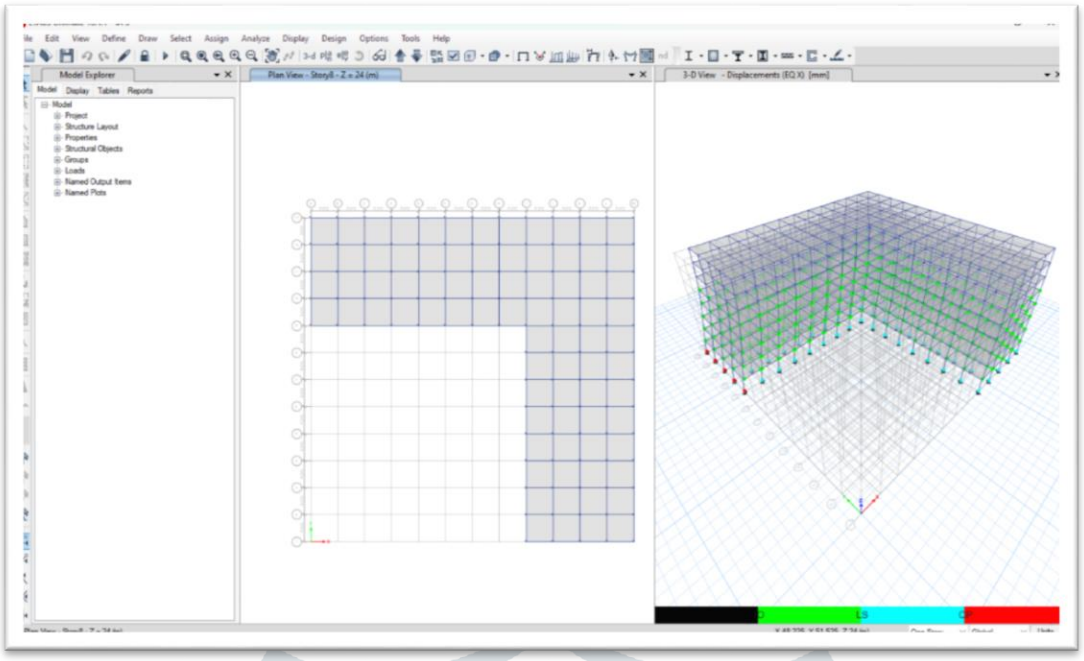

Fig-7: Performance criteria levels of G+8 story *with increased floor plan area* due to earthquake load in X-direction.

Results of Increased Plan area for G+7: With an increase of floor plan area from 720 sqm to 1280 sqm for G+7 story building by keeping the remaining design parameters constant, the following are the results obtained as shown below.

Results for G+7 for seismic Zone-5: **Hinge state >CP** (collapse Prevention) – **NIL**
but observed between **CP to LS** and **LS to Io** performance levels

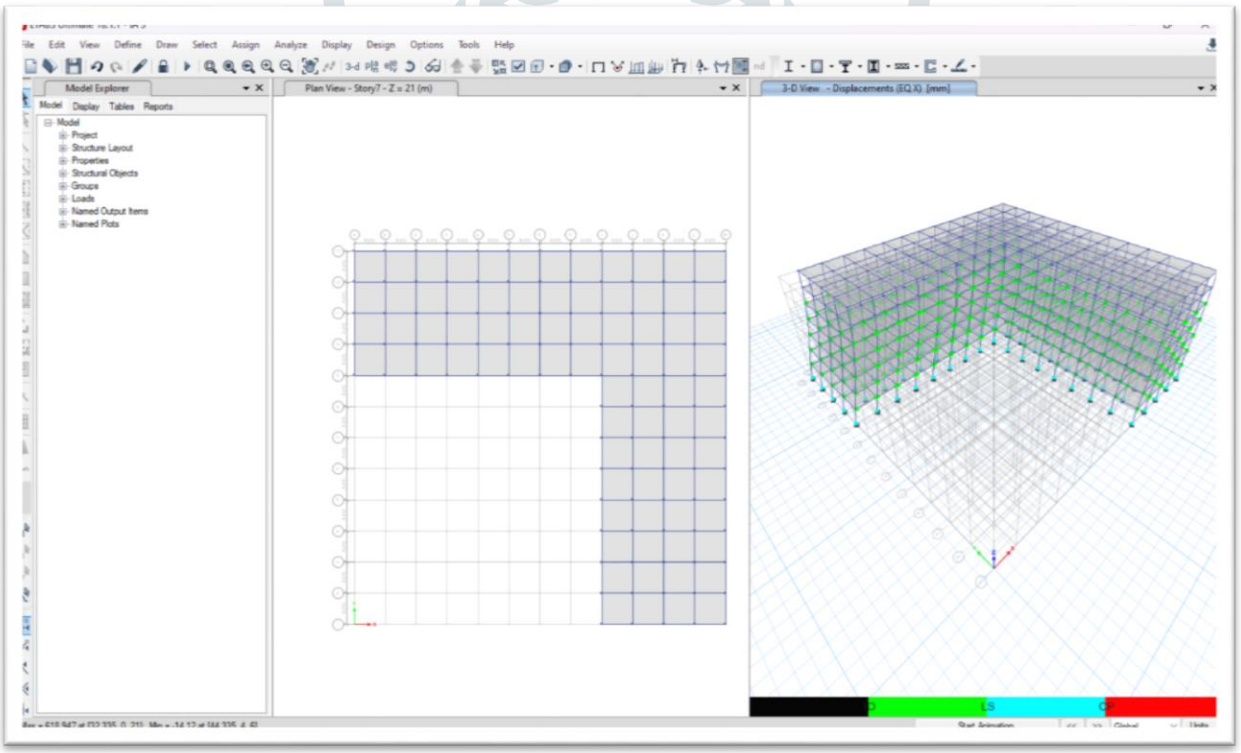

Fig-8: Performance criteria levels of G+7 story *with increased floor plan area* due to earthquake load in X-direction.

Results of Decreased Floor Plan area for G+8: A change in floor plan area of same L shaped building from 720 sqm to 448 sqm i.e., a decrease of 38% floor plan area is modelled with same design parameters, verified that all members in frames along with footings are passed under normal loading conditions. After applying the seismic load and push over using ground acceleration, the analysis results obtained using hinge displacement values. The results such as hinge states, story drift, displacement (sway) of the hinges in frames, load and hinge state in frames showing the performance level >CP is shown below.

Results for G+7 for seismic Zone-5: Hinge state >CP (collapse Prevention) – NIL
CP to LS – NIL
LS to IO – Observed

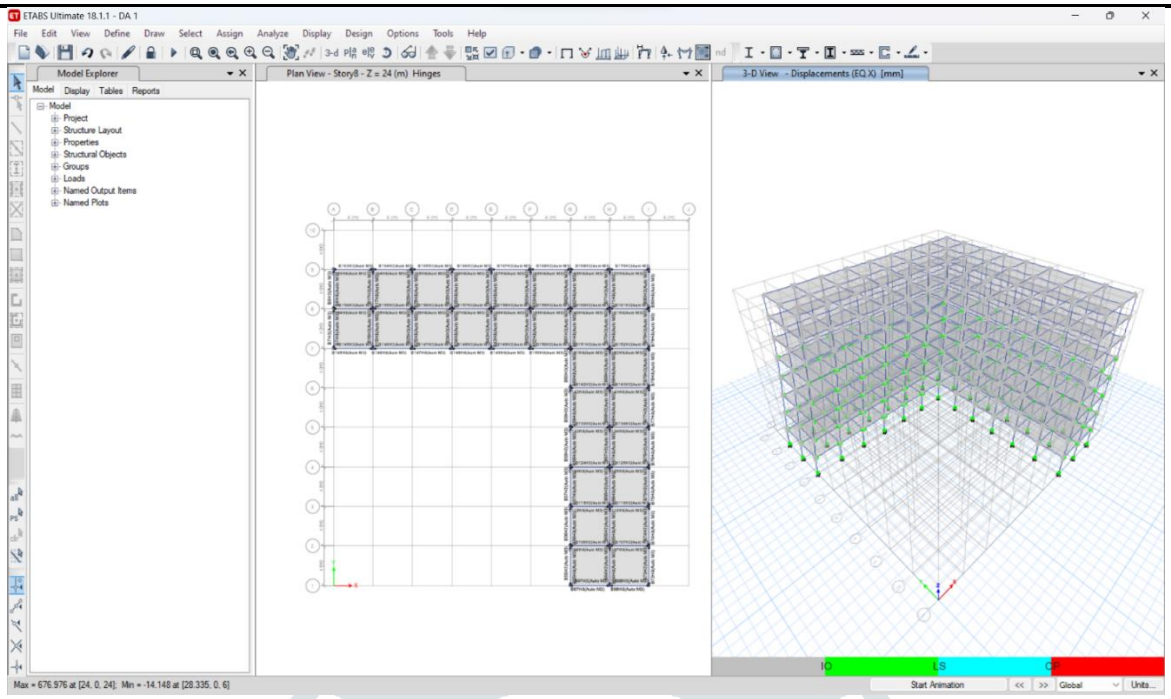

Fig-9: Performance criteria levels of G+8 story *with decreased floor plan area* due to earthquake load in X-direction

Results of Decreased Floor Plan area for G+10: With the decrease of floor plan area from 720 sqm to 448 sqm for G+10 story building by keeping the remaining design parameters constant, the following are the results obtained as shown below.

Story	Frame	Output Case	Hinge	Generated Hinge	M2	M3	R2 Plastic	R3 Plastic	Hinge State	Hing Statu
Story1	C7	EQ X	Auto P-M2-M3	C7H29	-1.0445	148.1818	0.000025	0.007938	B to C	>CP
Story1	C7	EQ X	Auto P-M2-M3	C7H30	-1.0445	148.1818	0.000025	0.007938	B to C	>CP
Story1	C61	EQ X	Auto P-M2-M3	C61H29	-1.4327	146.883	0.000032	0.007987	B to C	>CP
Story1	C61	EQ X	Auto P-M2-M3	C61H30	-1.4327	146.883	0.000032	0.007987	B to C	>CP
Story1	C62	EQ X	Auto P-M2-M3	C62H29	-0.1512	147.4248	-0.000002	0.007973	B to C	>CP
Story1	C62	EQ X	Auto P-M2-M3	C62H30	-0.1512	147.4248	-0.000002	0.007973	B to C	>CP
Story1	C63	EQ X	Auto P-M2-M3	C63H29	0.2519	147.4447	-0.000012	0.007975	B to C	>CP
Story1	C63	EQ X	Auto P-M2-M3	C63H30	0.2519	147.4447	-0.000012	0.007975	B to C	>CP
Story1	C64	EQ X	Auto P-M2-M3	C64H29	0.1774	147.459	-0.00001	0.007971	B to C	>CP
Story1	C64	EQ X	Auto P-M2-M3	C64H30	0.1774	147.459	-0.00001	0.007971	B to C	>CP
Story1	C65	EQ X	Auto P-M2-M3	C65H29	0.368	147.4637	-0.000014	0.007972	B to C	>CP
Story1	C65	EQ X	Auto P-M2-M3	C65H30	0.368	147.4637	-0.000014	0.007972	B to C	>CP
Story1	C66	EQ X	Auto P-M2-M3	C66H29	7.6812	145.1428	-0.000202	0.008032	B to C	>CP
Story1	C66	EQ X	Auto P-M2-M3	C66H30	7.6812	145.1428	-0.000202	0.008032	B to C	>CP

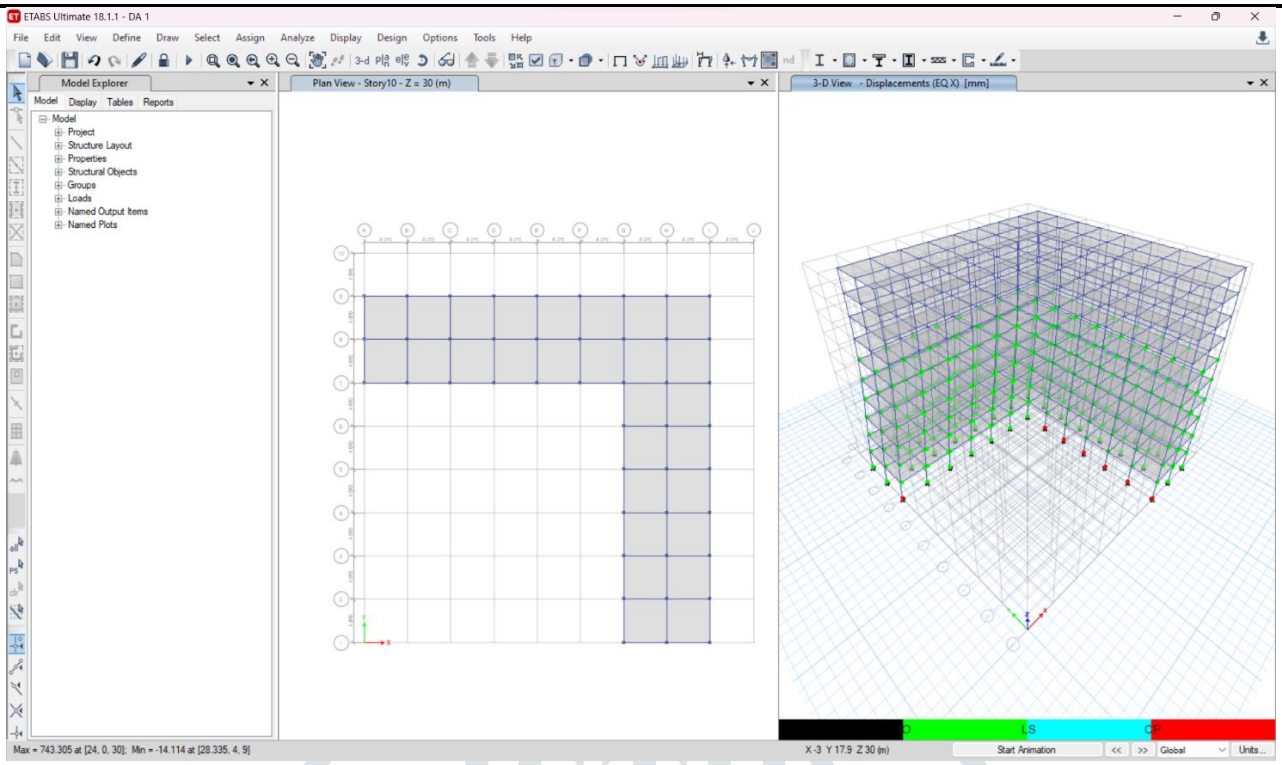

Fig-10: Performance criteria levels of G+10 story *with decreased floor plan area* due to earthquake load in X-direction

IV. CONCLUSION

During the current analytical study, the L shaped building was analyzed by applying seismic and push over load cases using the Etabs Software in various seismic zones. The results were recorded and represented in the previous chapter and final conclusions of the study were drawn. These conclusions are mentioned below:

Conclusions for G+10 Story Building

- After the application of dead load, live load, seismic loads in both directions and push over loads which are set to run, some of the deformed hinges under seismic loads in zone-**V** are formed above the performance criteria > **CP** level.
- After the application of dead load, live load, seismic loads in both directions and push over loads which are set to run, some of the deformed hinges under seismic loads in zone-**IV** are formed above the performance criteria > **CP** level.
- After the application of dead load, live load, seismic loads in both directions and push over loads which are set to run, some of the deformed hinges under seismic loads in zone-**III** are formed above the performance criteria > **CP** level.
- After the application of dead load, live load, seismic loads in both directions and push over loads which are set to run, some of the deformed hinges under seismic loads in zone-**II** are formed above the performance criteria > **CP** level.
- Maximum story drift was observed at story 3.

Conclusions for G+9 story Building:

- After the application of dead load, live load, seismic loads in both directions and push over loads which are set to run, some of the deformed hinges under seismic loads in zone-**V** are formed above the performance criteria > **CP** level.
- After the application of dead load, live load, seismic loads in both directions and push over loads which are set to run, some of the deformed hinges under seismic loads in zone-**IV** are formed above the performance criteria > **CP** level.
- After the application of dead load, live load, seismic loads in both directions and push over loads which are set to run, some of the deformed hinges under seismic loads in zone-**III** are formed above the performance criteria > **CP** level.
- After the application of dead load, live load, seismic loads in both directions and push over loads which are set to run, some of the deformed hinges under seismic loads in zone-**II** are formed above the performance criteria > **CP** level.
- Maximum story drift was observed at story 3.

Conclusions for G+8 story Building:

- After the application of dead load, live load, seismic loads in both directions and push over loads which are set to run, some of the deformed hinges under seismic loads in zone-**V** are observed in between the performance criteria levels of **LS to CP and IO to LS.**
- After the application of dead load, live load, seismic loads in both directions and push over loads which are set to run, some of the deformed hinges under seismic loads in zone-**IV** are observed in between the performance criteria levels of **LS to CP and IO to LS.**
- After the application of dead load, live load, seismic loads in both directions and push over loads which are set to run, some of the deformed hinges under seismic loads in zone-**III** are observed in between the performance criteria levels of **LS to CP and IO to LS.**
- After the application of dead load, live load, seismic loads in both directions and push over loads which are set to run, all the deformed hinges under seismic loads in zone-**II** are observed in between the performance criteria of **IO to LS**.
- Maximum story drift was observed at story 3.

Conclusions for Increased plan area i.e., from 720 sqm to 1280 sqm, 77% increased:

- After the application of dead load, live load, seismic loads in both directions and push over loads for **G+8 story**, some of the deformed hinges under seismic loads in zone-**V** are observed in are formed above the performance criteria > **CP** level
- After the application of dead load, live load, seismic loads in both directions and push over loads for **G+7 story**, some of the deformed hinges under seismic loads in zone-**V** are observed in between the performance criteria levels of **LS to CP and IO to LS.**

Conclusions for Decreased plan area i.e., from 720 sqm to 448 sqm, 38% reduction:

- After the application of dead load, live load, seismic loads in both directions and push over loads for **G+8 story**, all the deformed hinges under seismic loads in zone-**V** are observed in between the performance criteria of **IO to LS**.
- After the application of dead load, live load, seismic loads in both directions and push over loads for **G+10 story**, all the deformed hinges under seismic loads in zone-**V** are observed in are formed above the performance criteria > **CP** level

Story Height	Seismic Zones	Performance criteria levels
G+8	II	IO to LS
	III	LS to CP and IO to LS
	IV	LS to CP and IO to LS
	V	LS to CP and IO to LS
G+9	II	> CP level
	III	> CP level
	IV	> CP level
	V	> CP level

Table-6: Performance criteria levels for 720 sqm floor plan area L shaped building

Plan Area (sqm)	Story Height	Seismic Zones	Performance criteria levels
720 sqm	G+8	II	IO to LS
		III	LS to CP and IO to LS
		IV	LS to CP and IO to LS
		V	LS to CP and IO to LS
	G+9	II	> CP level
		III	> CP level
		IV	> CP level
		V	> CP level
1280 sqm	G+8	V	> CP level
	G+7	V	LS to CP and IO to LS
448 sqm	G+8	V	IO to LS
	G+10	V	> CP level

Table-7: Performance criteria levels with varying plan areas

Floor Plan Area	Story	Seismic Zone	Frame	Generated Hinge
720 sqm	G+9	zone -5	C10	C10H33
			C10	C10H34
1280 sqm	G+8	zone -5	C10	C10H29
			C10	C10H30
			C11	C11H29
			C11	C11H30
			C12	C12H29
			C12	C12H30
			C13	C13H29
			C13	C13H30
			C14	C14H29
			C14	C14H30
448 sqm	G+10	zone -5	C7	C7H29
			C7	C7H30
			C61	C61H29
			C61	C61H30
			C62	C62H29
			C62	C62H30
			C63	C63H29
			C63	C63H30
			C64	C64H29
			C64	C64H30
			C65	C65H29
			C65	C65H30
			C66	C66H29

			C66	C66H30

Table-8: Generated hinges performed **>CP** Level with varying story levels with floor plan area.

Therefore, as per the research study undertaken for the different models it was concluded that –

- The building having **G+10** story height has allowed hinges that are in performance criteria **>CP** level in all the seismic zones i.e., Zone-V, IV, III, II.
- The building having **G+9** story height has allowed hinges that are in performance criteria **>CP** level in all the seismic zones i.e., Zone- V, IV, III, II.
- The building having **G+8** story height has allowed hinges that are in performance criteria between **LS to CP** and **IO to LS** levels in the seismic Zone-III, IV, V only, where as in Zone-II Hinges are observed in performance criteria **IO to LS** level.
- If the number of story's increased from **8 to 9**, hinges are observed in the performance criteria **>CP level**.
- If the plan area increased from 720 sqm to 1280 sqm i.e., by 77% increased for G+8 story, hinges are observed in the performance criteria **>CP level** in zone-5
- If the plan area increased from 720 sqm to 1280 sqm i.e., by 77% increased for G+7 story, hinges are in performance criteria between **LS to CP** and **IO to LS** levels.
- If the plan area decreased from 720 sqm to 448 sqm i.e., by 38% for G+10 story, hinges are observed in the performance criteria **>CP level** in zone-5

V. FUTURE SCOPE

The current analytical study has few limitations which can be covered in further studies. The future scope of the study is as under the following conditions:

a) The design, height, and other loads can be considered and analysed in the further study.
b) In this study auto hinges are assigned for a concrete framed structure, hinges and material can differ the results and effective story with respect to performance criteria levels.
c) L shaped unsymmetrical building has considered for this study, change in plan obtains different results.
d) Seismic zone wise hinge evaluation can be analysed in detail with respect to individual members.

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