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Pushover analysis of RC frame structure using ETABS 9.7.1

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Abstract: *Pushover analysis is a non linear static analysis used to determine the force-displacement relationship, or capacity curve, for a structural element. To evaluate the performance of RC frame structure, a non linear static pushover analysis has been conducted by using ETABS 9.7.1. To achieve this objective, three RC bare frame structures with 5, 10, 15 stories respectively were analyzed. And also compared the base force and displacement of RC bare frame structure with 5, 10, 15 stories.*
Keywords: *ETABS 9.7.1, Hinge properties, Non linear static analysis, Pushover analysis, RC bare frame.*

I. Introduction

Pushover analysis is non linear static analysis in which provide 'capacity curve' of the structure, it is a plot of total base force vs. roof displacement. The analysis is carried out up to failure, it helps determination of collapse load and ductility capacity of the structure.The pushover analysis is a method to observe the successive damage state of the building. In Pushover analysis structure is subjected to monotonically increasing lateral load until the peak response of the structure is obtained as shown in figure

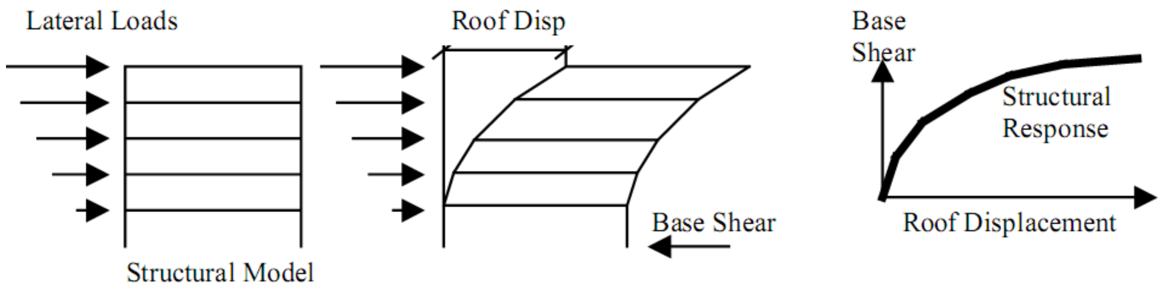


Fig A. Static approximation used in the pushover analysis.

1. FORCE DEFORMATION BEHAVIOR OF HINGES

- Point A corresponds to unloaded condition.
- Point B represents yielding of the element.
- The ordinate at C corresponds to nominal strength and abscissa at C corresponds to the deformation at which significant strengthdegradation begins.
- The drop from C to D represents the initialfailure of the element and resistance tolateral loads beyond point C is usuallyunreliable.
- The residual resistance from D to E allows the frame elements to sustain gravity loads.

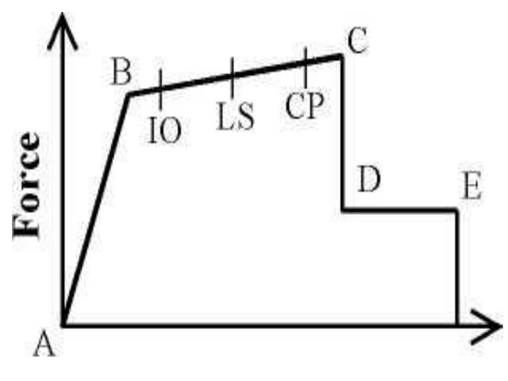


Fig B. Graph shows the curve Force Vs Deformation

- Beyond point E, the maximum deformationcapacity, gravity load can no longer besustained.

2. PERFORMANCE LEVELS AND RANGES

The building performance level is a function of the post event conditions of the structural and non-structural components of the structure. The performance levels are as follows:

- Immediate Occupancy
- Life Safety
- Collapse Prevent

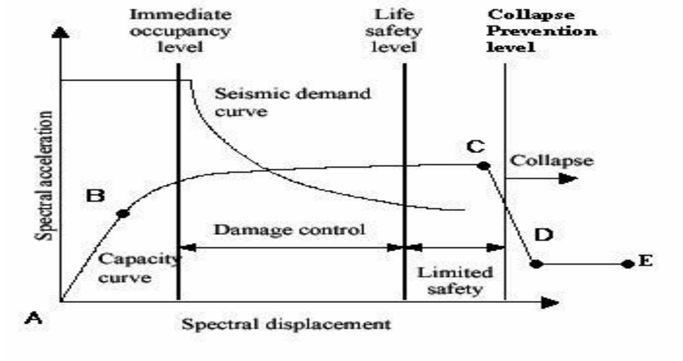


Fig C. Performance levels and ranges

2.1) Immediate Occupancy Performance Level (S-1)

Immediate Occupancy is the post-earthquake damage state in which only very limited structural damage has occurred. In the primary concrete frames, there will be hairline cracking.

2.2) Damage Control Performance Range (S-2)

Structural Performance Range S-2, Damage Control, is the continuous range of damage states that less damage than that defined for the Life Safety level, but more than that defined for the Immediate Occupancy level.

2.3) Life Safety Performance Level (S-3)

Structural Performance Level S-3, Life Safety, is the post-earthquake damage state in which significant damage to the structure has occurred, but some margin against either partial or total structural collapse remains. In the primary concrete frames, there will be extensive damage in the beams. There will be spalling of concrete cover and shear cracking in the ductile columns

2.4) Limited Safety Performance Range (S-4)

Structural Performance Range S-4, Limited Safety is the continuous range of damage states between the Life Safety and Collapse Prevention levels

2.5) Collapse Prevention Performance Level (S-5)

Structural Performance Level S-5, Collapse Prevention, is the building is on the verge of experiencing partial or total collapse. In the primary concrete frames, there will be extensive cracking and formation of hinges in the ductile elements

Performance point – The performance point is the point where capacity curve crosses demand curve.

II. Data To Be Used

1.Material properties

Modulus of elasticity of concrete, E_c= 22360 N/mm^2 .
Grade of concrete = M20
Grade of steel = Fe-415
Poissons ratio of concrete = 0.2

2. Description of frame structure

The RC frame structure 5, 10, 15 stories is considered in this study.In themodal,in X- direction and Y-direction, each of 5m in length and the support condition was assumed to be fixed and soil condition was assumed as medium soil. The seismic zone assumed as zone IV.All slabs were assumed as Membrane element of 120 mm thickness. The typical floor height is 3m.The details of beams and columns are shown in table 1.Live load on slab is 3KN/m^2 .

Table 1 Specification

Beams	*Columns*
230X450mm	*300X600mm*

3. Plan of Structure

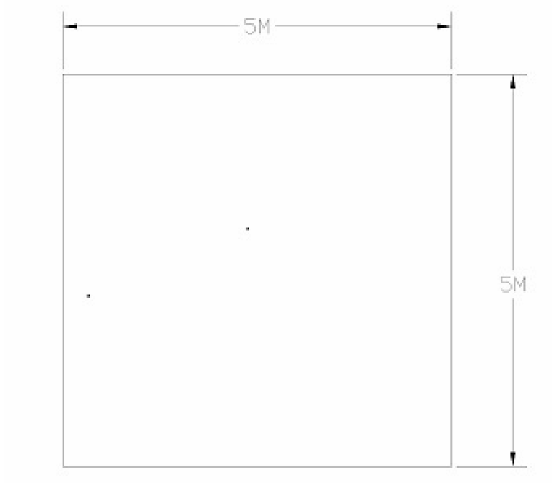


Fig D: plan of structure

III.Static Analysis Of Buildings Using Is 1893 (Part 1)-2002

1) Design Seismic Base Shear- The total design lateral force or design seismic base shear (Vb) along any principal direction of the building shall be determined by the following expression

$$VB = Ah\ W$$

Where Ah = Design horizontal seismic coefficient.
W = Seismic weight of the building

2) Seismic Weight of Building:

The seismic weight of each floor is its full dead load plus appropriate amount of imposed load. While computing the seismic weight of each floor, the weight of columns and walls in any storey shall be equally distributed to the floors above and below the storey. The seismic weight of the whole building is the sum of the seismic weights of all the floors. Any weight supported in between the storey shall be distributed to the floors above and below in inverse proportion to its distance from the floors.

3) Fundamental Natural Time Period:

The fundamental natural time period (Ta) calculates from the expression

$Ta = 0.075h^{0.75}$ for RC frame building

For 5 storey, $Ta = 0.075x15^{0.75} = 0.57$ sec where h=15m

For 10 storey, $Ta = 0.075x30^{0.75} = 0.96$ sec where h=30m

For 15 storey, $Ta = 0.075x45^{0.75} = 1.30$ sec where h=45m

4) Distribution of Design Force-

The design base shear, VB computed above shall be distributed along the height of the building as per the following expression

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2}$$

IV. Pushover Analysis

After assigning all properties of the models, thedisplacement –controlled pushover analysis of the modelsare carried out. The models are pushed in monotonicallyincreasing order until target displacement is reached orstructure loses equilibrium.The program includes several built-indefault hinge properties that are based onaverage values from ATC-40 for concretemembers and average values from FEMA-273 for steel members.

- Locate the pushover hinges on model. ETABS provides hinge properties and recommends PMM hinges for columns and M3 hinges for beam as described in FEMA-356.
- Define pushover load cases. IN ETABS more than one pushover load case can be run in the same analysis

V. Results and Graphs

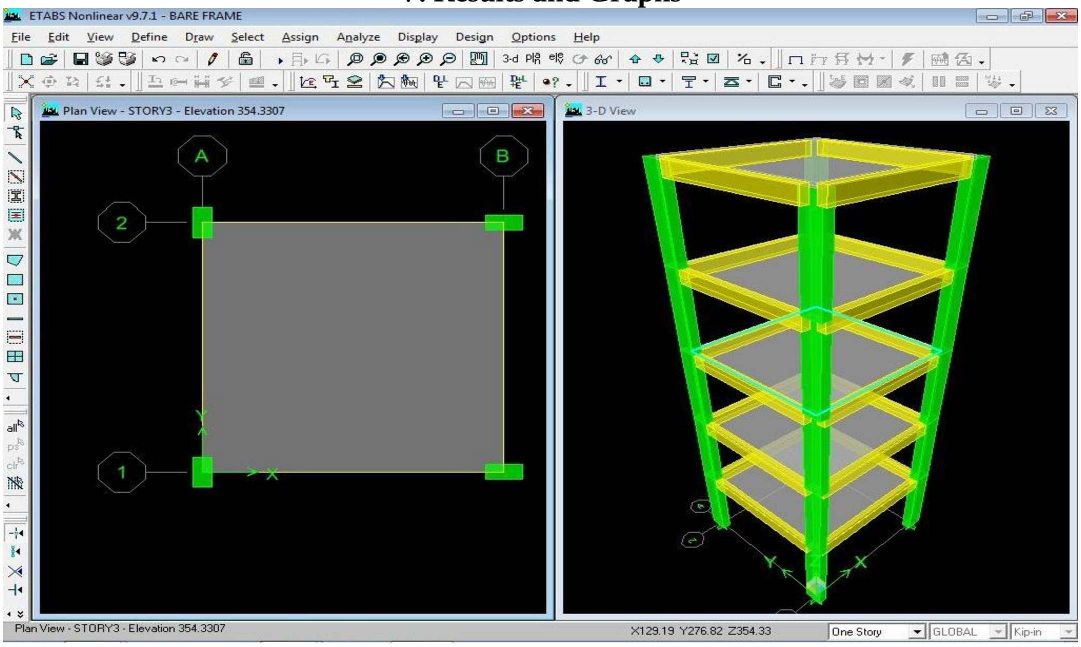


Fig E. Modeling of the structure – 5 storey

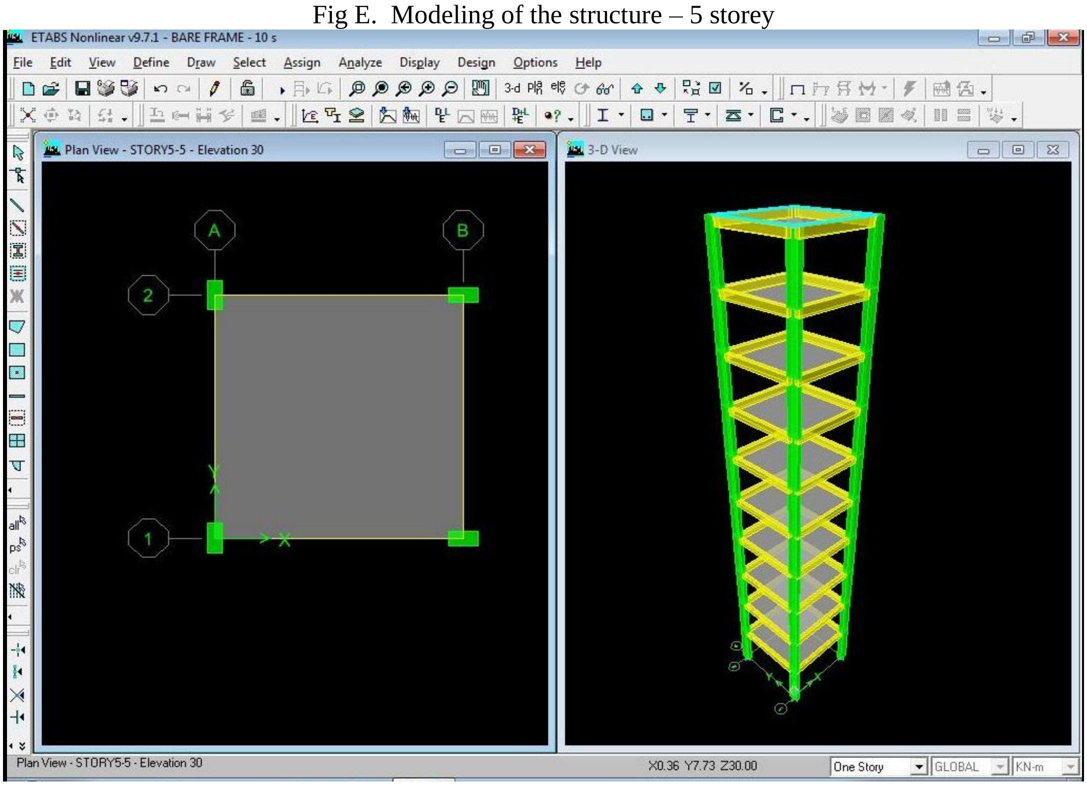


Fig F. Modeling of the structure – 10 storey

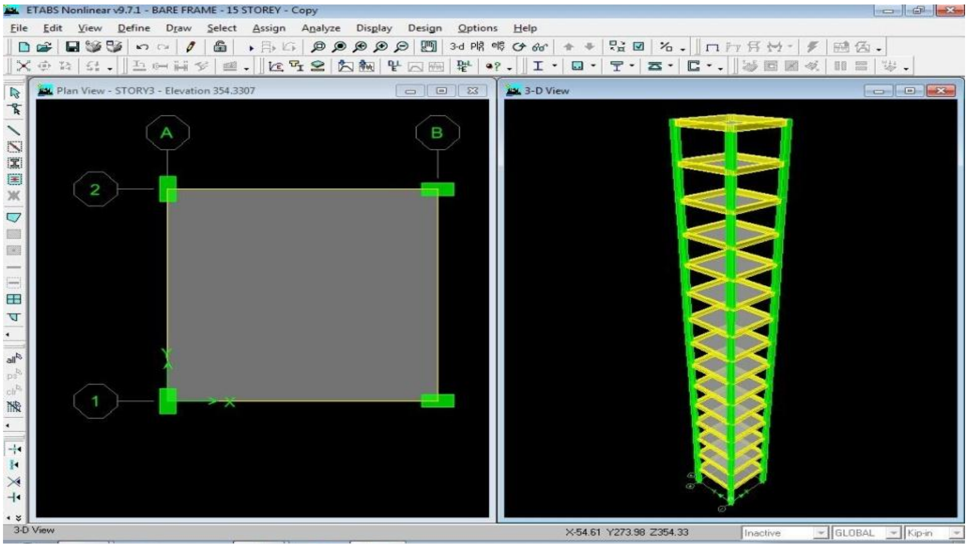


Fig G. Modeling of the structure – 15 storey

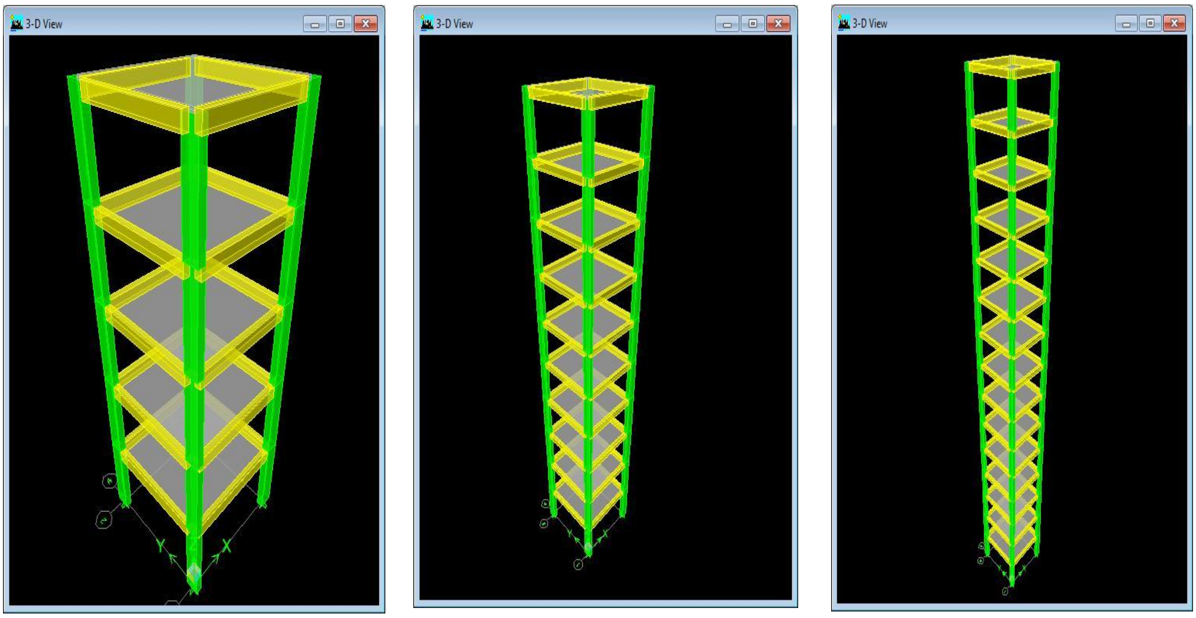


Fig H. Modeling of the structure – 5, 10 and 15 storey

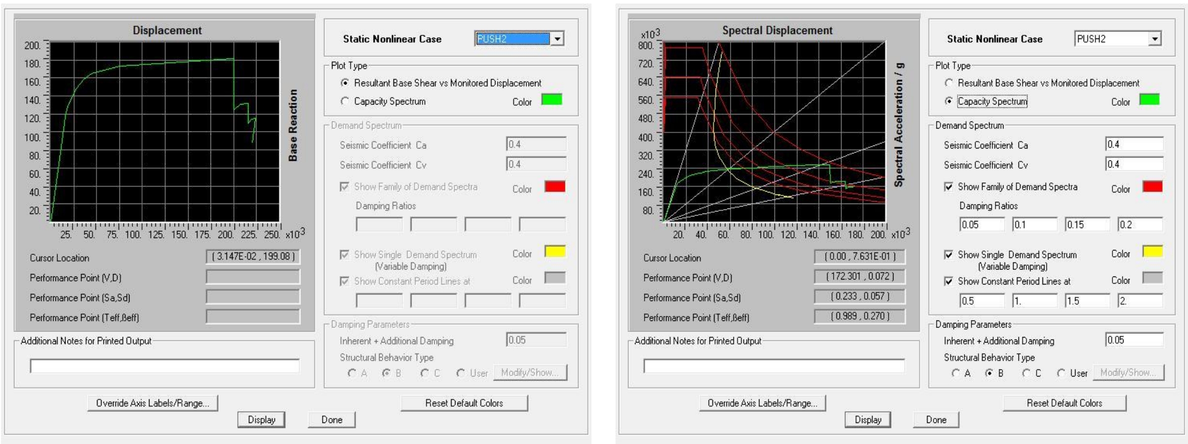


Fig I. Pushover curve and capacity spectrum curve of 5 storey frame structure

Table 2. Data of pushover curve – 5 storey

Steps	Displacement (m)	Base Force (KN)	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
0	0.0000	0.0000	78	2	0	0	0	0	0	0	80
1	0.0136	103.3671	74	6	0	0	0	0	0	0	80
2	0.0156	116.6227	72	8	0	0	0	0	0	0	80
3	0.0187	128.0727	68	12	0	0	0	0	0	0	80
4	0.0276	148.0758	64	14	2	0	0	0	0	0	80
5	0.0356	158.2161	60	16	4	0	0	0	0	0	80
6	0.0446	165.1577	58	18	4	0	0	0	0	0	80
7	0.0468	166.0575	54	16	10	0	0	0	0	0	80
8	0.0761	173.3783	54	12	10	4	0	0	0	0	80
9	0.1031	175.1543	54	4	14	8	0	0	0	0	80
10	0.1301	176.9303	54	2	14	10	0	0	0	0	80
11	0.1571	178.7063	54	2	10	14	0	0	0	0	80
12	0.1841	180.4822	54	2	2	20	0	2	0	0	80
13	0.2004	181.5562	52	4	2	18	0	0	4	0	80
14	0.2004	124.1375	50	6	2	18	0	0	4	0	80
15	0.2069	130.9482	50	4	4	16	0	2	4	0	80
16	0.2158	132.0359	48	6	4	16	0	0	6	0	80
17	0.2158	109.3345	48	6	4	16	0	0	6	0	80
18	0.2191	114.3603	48	4	6	16	0	0	4	2	80
19	0.2239	114.8572	48	4	6	16	0	0	4	2	80
20	0.2203	87.6012	80	0	0	0	0	0	0	0	80

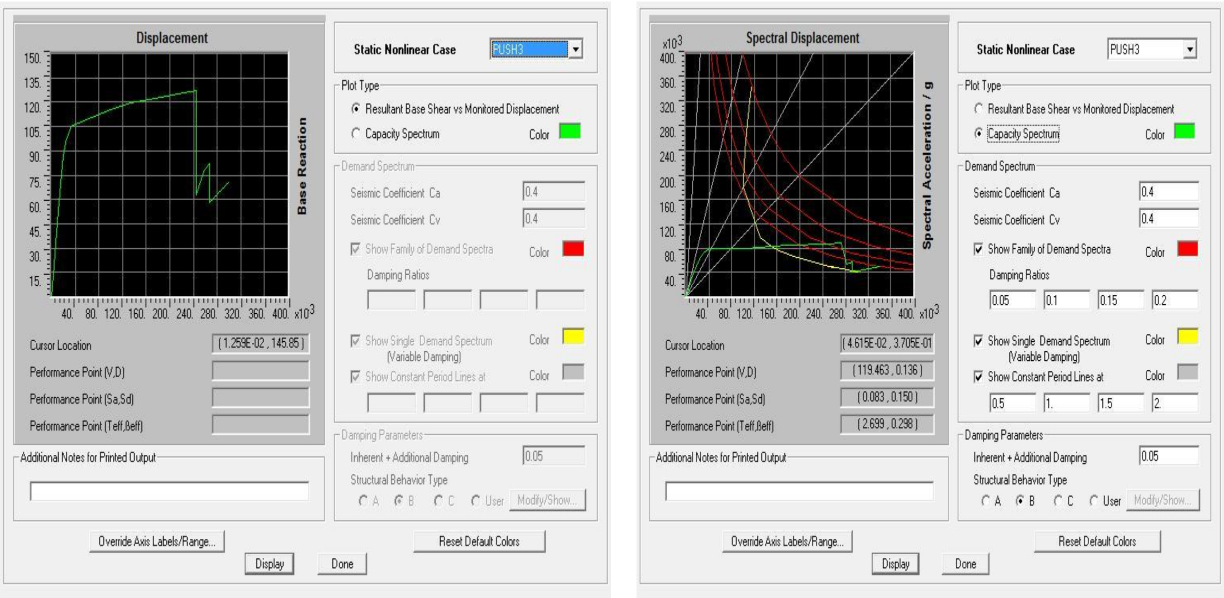


Fig J. Pushover curve and capacity spectrum curve of 10 storey frame structure

Table 3. Data of pushover curve – 10 storey

Step	Displacement (m)	Base Force (KN)	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
0	0.0000	0.0000	158	2	0	0	0	0	0	0	160
1	0.0105	52.1994	148	12	0	0	0	0	0	0	160
2	0.0199	87.1962	142	18	0	0	0	0	0	0	160
3	0.0255	97.3409	130	30	0	0	0	0	0	0	160
4	0.0340	104.9231	128	32	0	0	0	0	0	0	160
5	0.0364	105.9282	126	12	22	0	0	0	0	0	160
6	0.0955	114.4206	118	16	26	0	0	0	0	0	160
7	0.1348	119.3922	118	14	10	18	0	0	0	0	160
8	0.1648	121.7376	114	16	4	26	0	0	0	0	160
9	0.2243	126.0053	112	18	4	22	0	4	0	0	160
10	0.2449	127.4227	112	18	4	22	0	0	4	0	160
11	0.2449	63.0684	112	18	4	22	0	0	4	0	160
12	0.2576	77.3997	112	18	4	20	0	2	4	0	160
13	0.2664	82.5136	110	20	4	20	0	0	6	0	160
14	0.2664	58.3872	110	20	4	20	0	0	6	0	160
15	0.3000	71.3378	160	0	0	0	0	0	0	0	160

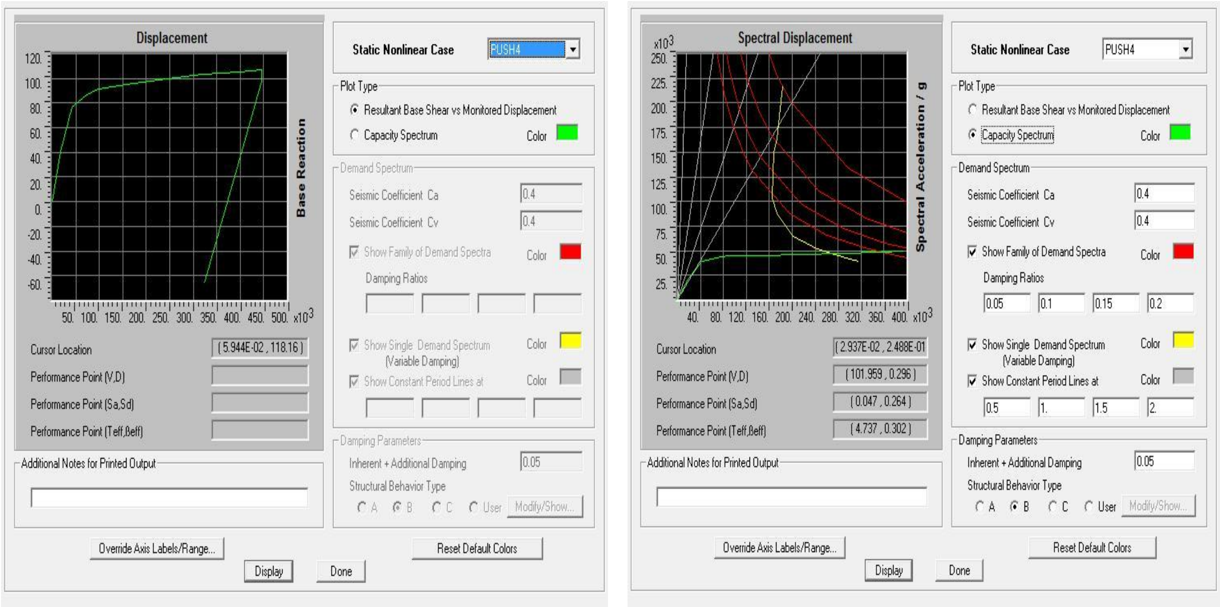


Fig K. Pushover curve and capacity spectrum curve of 15 storey frame structure

Table4. Data of pushover curve – 15 storey

Step	Displacement (m)	Base Force (KN)	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	> E	TOTAL
0	0.0000	0.0000	238	2	0	0	0	0	0	0	240
1	0.0177	40.5246	218	22	0	0	0	0	0	0	240
2	0.0427	76.2900	212	28	0	0	0	0	0	0	240
3	0.0470	78.8367	202	38	0	0	0	0	0	0	240
4	0.0734	87.1870	196	44	0	0	0	0	0	0	240
5	0.0975	91.6756	194	24	22	0	0	0	0	0	240
6	0.1565	95.1070	188	18	30	4	0	0	0	0	240
7	0.2449	99.6026	182	20	8	30	0	0	0	0	240
8	0.3203	103.1052	178	22	6	34	0	0	0	0	240
9	0.3978	105.6151	178	20	8	30	0	4	0	0	240
10	0.4451	107.0373	178	20	8	28	0	2	4	0	240
11	0.4451	97.4755	172	26	8	28	0	2	4	0	240
12	0.3238	-66.4159	240	0	0	0	0	0	0	0	240

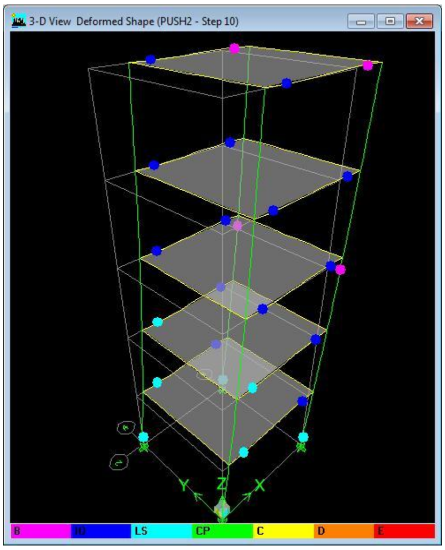


Fig L. Formation of Plastic hinges at step 10

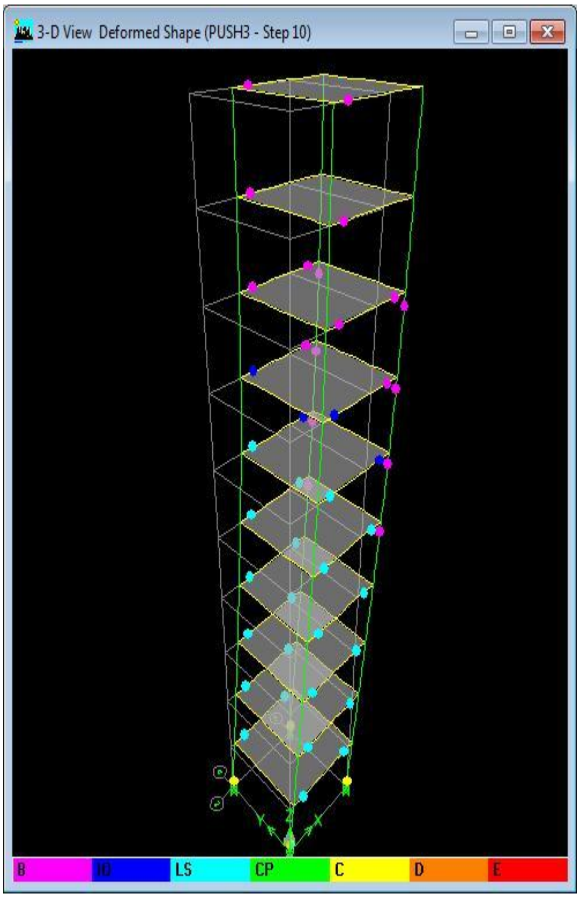


Fig M. Formation of Plastic hinges at step 10

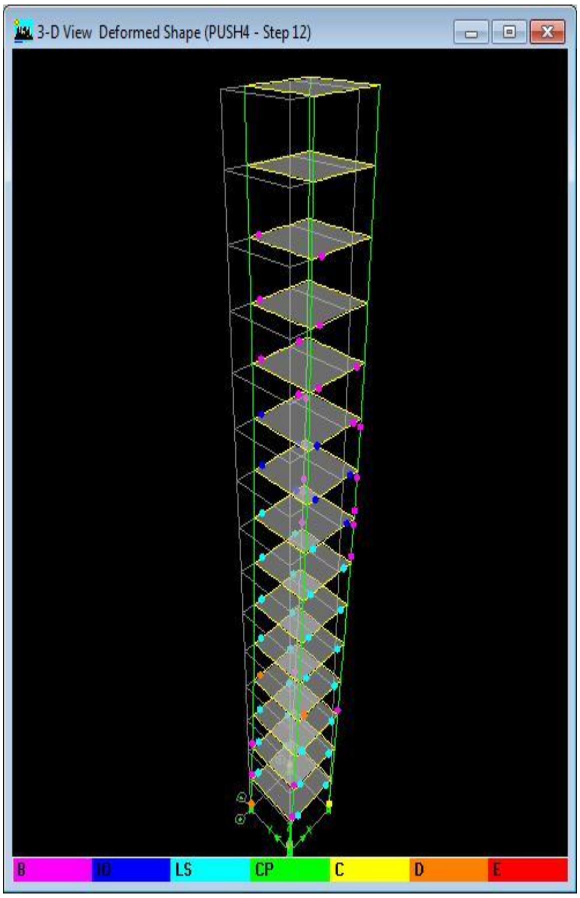
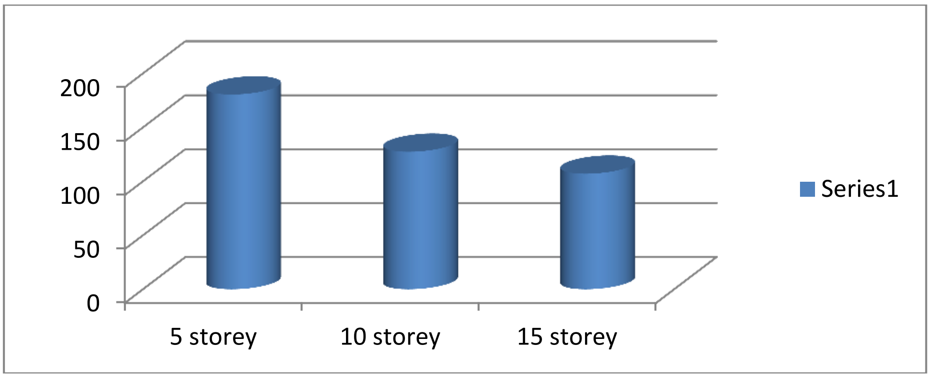


Fig N. Formation of Plastic hinges at step 12

V1. Comparison Of Maximum Base Force And Displacement Of 5,10,15Storeys

Table5. Maximum base force of 5,10,15 storey

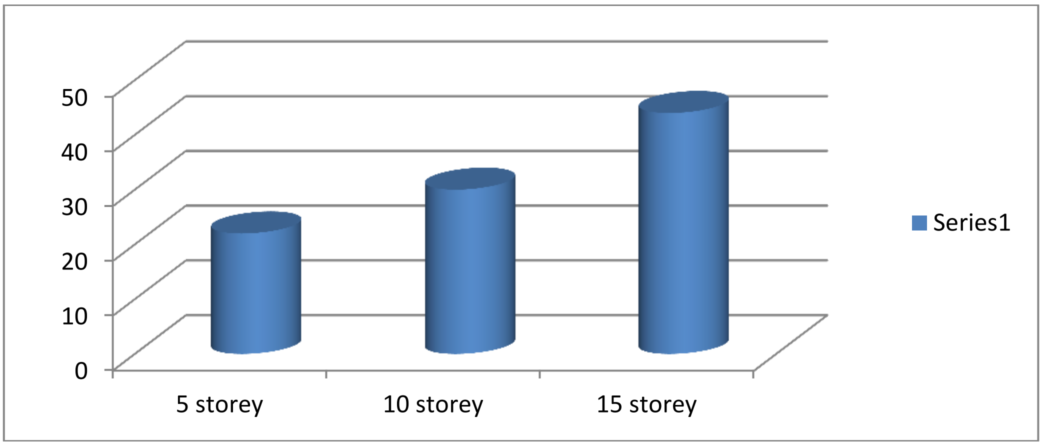
STOREYS	MAXIMUM BASE FORCE (KN)
5 Storey	181
10 Storey	127
15 Storey	107



Graph 1. Comparison of maximum base force of 5, 10, 15 storey

Table 6.Maximum displacement of 5, 10, 15 storey

STOREYS	MAXIMUM DISPLACEMENT (mm)
5 Storey	22
10 Storey	30
15 Storey	44



Graph 2. Comparison of maximum displacement of 5, 10, 15 storey

VII. Conclusions

The performance of reinforced concrete frame was investigated using pushover analysis. These are the conclusions drawn from the analysis:

- The pushover analysis is a simple way to explore the non linear behavior of building.
- In 5 storey frame structure pushover analysis was including 20 steps. It has been observed that, on subsequent push to building, hinges started forming in beams first. Initially hinges were in B-IO stage and subsequently proceeding to IO-LS and LS-CP stage. At performance point, where the capacity and demand meets, out of 80 assigned hinges 54 were in A-B stage, 12,10, and 4 hinges are in BIO, IO-LS and LS-CP stages respectively. As at performance point, hinges were in LS-CP range, overall performance of building is said to be Life safety to Collapse prevention level.
- In 10 storey frame structure pushover analysis was including 15 steps. At performance point, where the capacity and demand meets, out of 160 assigned hinges 118 were in A-B stage, 14,10, and 18 hinges are in BIO, IO-LS and LS-CP stages respectively. As at performance point, hinges were in LS-CP range, overall performance of building is said to be Life safety to Collapse prevention level.
- In 15 storey frame structure pushover analysis was including 12 steps. At performance point, where the capacity and demand meets, out of 240 assigned hinges 182 were in A-B stage, 20,8and 30 hinges are in BIO, IO-LS and LS-CP stages respectively. As at performance point, hinges were in LS-CP range, overall performance of building is said to be Life safety to Collapse prevention level.
- The RC bare frame which is analyzed for the static non linear pushover cases, 5 storey frame can carryhigher base force and at lower displacement it fails
- The RC bare frame which is analyzed for the static non linear pushover cases, 15 storey frame can carry lower base force and at higher displacement it fails.

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