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Pushover and Time History Analyses of Irregular RCC Building Frames

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Abstract—*The purpose of the study is to evaluate the linear and nonlinear static and dynamic responses of ten storied RCC building frame. In this study, five building models with different irregularities in mass and stiffness are created including a regular model with no mass and stiffness irregularity. The models are created using finite element software SAP 2000. Dynamic analysis is carried out for all the building models using linear time history analysis and nonlinear time history analysis. Time history analysis using IS 1893:2002 compatible response spectrum for hard soil is taken to study response of all the structures. Nonlinear static analysis using pushover analysis is also performed for all the models and performance points are compared. The analyses are performed for Zone IV. Behavior of structures will be found by comparing responses in the terms of storey displacement and base shear for regular and irregular structures. The nonlinear behaviour of structural elements can be idealized by plastic hinges set in pre-selected locations. The location of plastic hinge development and their colour is noted for all the different building models.*

1. INTRODUCTION

The modern world demands the construction of multi-storey buildings due to fast growing population and increasing urbanization. Earthquakes have a potential of causing major damages to such tall structures. Reinforced concrete multi-storey buildings are modeled using finite beam elements as two dimensional or three dimensional frames. We know that earthquake forces are unpredictable and random in nature and therefore, for doing the analysis of structures, engineering tools should be sharpened. The real behaviour of a structure can be assessed by modeling the earthquake loads and keeping in mind that the damage is expected and it has to be regulated.

Load carrying capacity, mass, stiffness, ductility and damping are the main parameters as far as seismic analysis is concerned. Firstly we perform linear analysis and structure's functionality is ensured after minor earthquakes and then we control the behaviour of structure during strong earthquakes by the help of nonlinear methods.

2. STRUCTURAL MODELING AND ANALYSIS

The present study adopts building models with different type, magnitude and location of irregularity. The seismic responses of these building models have been compared with that of the regular building model. In the present study, 5 buildings models of 10 storeys each are taken and results of linear and nonlinear time history analysis and pushover analysis are compared with the one of the regular model. The analysis is done for zone IV. Following 5 models of buildings are considered:

MODEL A: Regular Model

MODEL B: Model with Stiffness Irregularity at ground floor (Fig. 2)

MODEL C: Model with Mass Irregularity **MODEL D:** Model with Stiffness Irregularity at top floor (Fig. 3)

MODEL E: Model with Stiffness and Mass Irregularity both (Fig. 4)

Building models without any irregularity in mass, stiffness and strength distribution are regular buildings. The stiffness irregularity in the building is obtained by increasing the height of a particular floor. For mass irregularity, the masses at 4th and 8th floor have been increased by the provision of swimming pools on those floors.

The structures analyzed are ten-storied, with bays along X-direction Y-directions (Fig. 1). The concrete floors are modelled as rigid.

The details of the model are given as:

Type of frame: Special RC moment resisting frame

Number of stories = 10

Number of bays along X-direction = 4

Number of bays along Y-direction = 3

Bay width along X-direction = 5.0 m

Bay width along Y-direction = 4.0 m

Column dimensions (mm): 450 x 650 and

450 x 750 (ground floor)

Beam dimensions (mm): 300 x 450

Thickness of slab: 150mm

Seismic zone: Zone IV

Type of soil: Hard Soil (type I)

Importance Factor: 1

Response reduction factor: 5

Response spectra: As per IS 1893

(Part-1):2002

Damping of structure: 5 percent

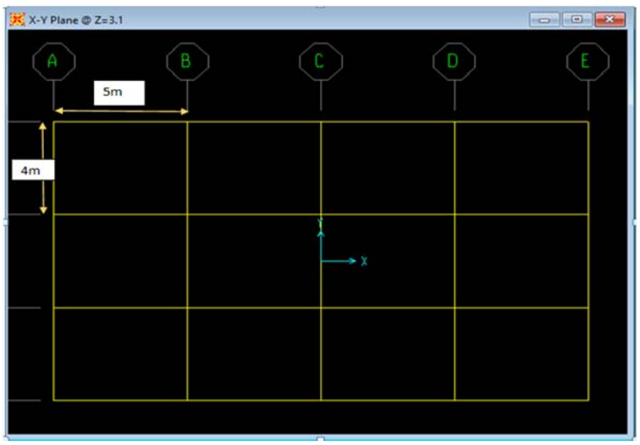


Fig. 1: Plan of all the building models

Description of model A:

In model A, regular masses and stiffness in horizontal and vertical direction are there.

Model B is shown below:

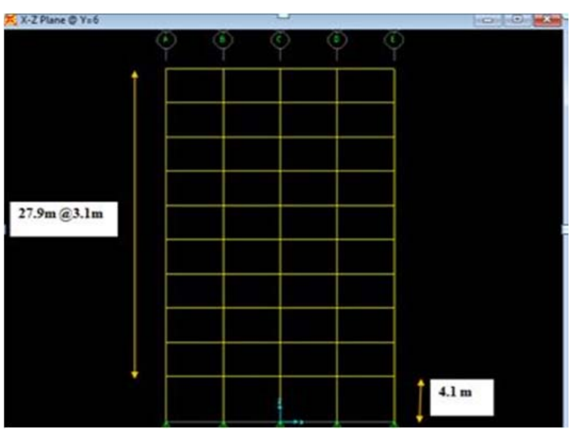


Fig. 2: Elevation of Stiffness irregularity at ground floor (MODEL B)

In case of Model C, masses on 4th and 8th floors have been significantly increased.

Model D is shown below:

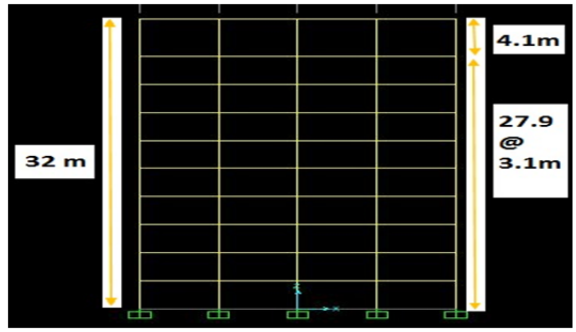


Fig. 3: Stiffness Irregularity at top floor (MODEL D)

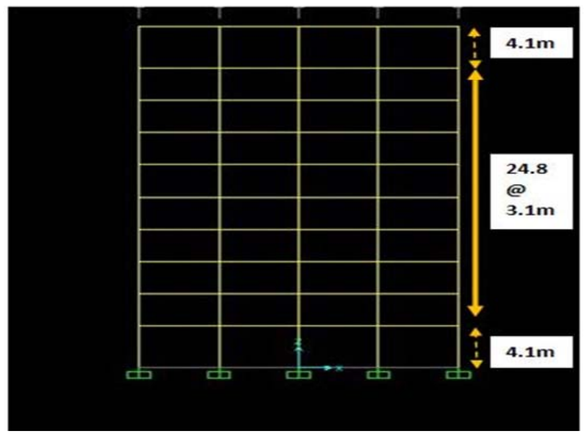


Fig. 4: Stiffness and mass irregularity both (MODEL E)

3. RESULTS AND DISCUSSION

All 5 models are analyzed with linear and nonlinear time history analysis and pushover analysis and the comparison of base shear and storey displacement is made among all the models with respect to one of the regular model.

LINEAR TIME HISTORY ANALYSIS:

Results from linear time history are analyzed in this section. The base shear and roof displacement from the analysis has been tabulated here (Table 1) below:

Table 1: Base shear and roof displacements after linear TH

MODEL	BASE SHEAR IN X-DIR (kN)	BASE SHEAR IN Y-DIR (kN)	ROOF DISPLACEMENT (mm)
MODEL A	1936.10	1840.54	38.39
MODEL B	1907.70	1804.12	42.56
MODEL C	1973.81	1880.88	43.04
MODEL D	1901.22	1812.92	40.42
MODEL E	2003.56	1917.62	44.81

The variation of base shear in x-direction for different building models is shown below (Fig. 5):

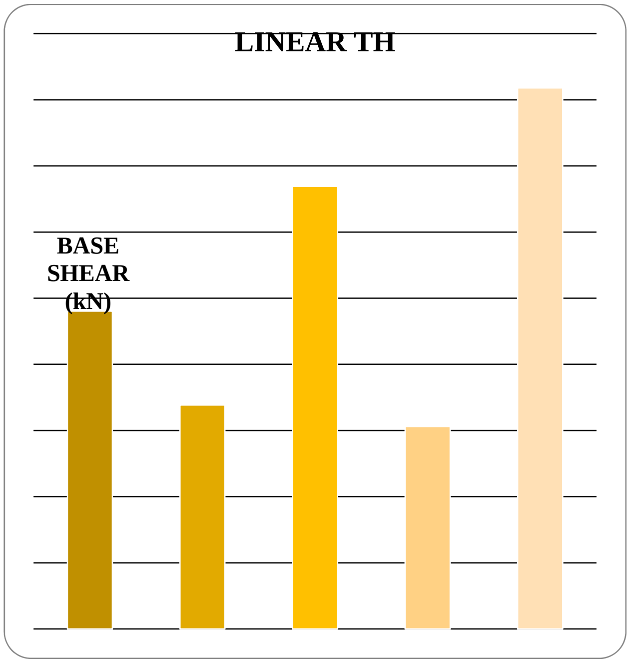


Fig. 5: Variation of base shear in x-direction for all the different models (linear TH)

For models with stiffness irregularity, the stiffness is reducing as compared to regular structure and hence the modal time period is increasing and therefore decreasing the base shear.

Mass irregular structures with heavy masses on two floors have greater base shear as compared to regular structure. The storey displacement at different storey levels for all the models has been tabulated in Table 2 and time period has been tabulated in Table 3.

Table 2: Storey displacement (mm) in x-direction for different building models (linear analysis)

Floor	Model A	Model B	Model C	Model D	Model E
1st	2.31	3.52	2.55	4.29	5.53
2nd	7.63	8.59	8.07	13.60	11.60
3rd	13.87	14.14	14.42	17.86	19.15
4th	17.01	19.57	20.62	20.06	24.56
5th	23.58	24.88	26.27	25.74	28.86
6th	26.34	29.98	31.13	28.70	32.91
7th	30.32	34.53	35.09	32.00	37.56
8th	32.66	38.28	39.03	34.14	40.29
9th	35.47	41.04	42.09	37.39	42.05
10th (roof)	38.39	42.56	44.04	40.42	45.81

The storey displacement for various models using linear time history analysis depicts as follows (Fig. 6):

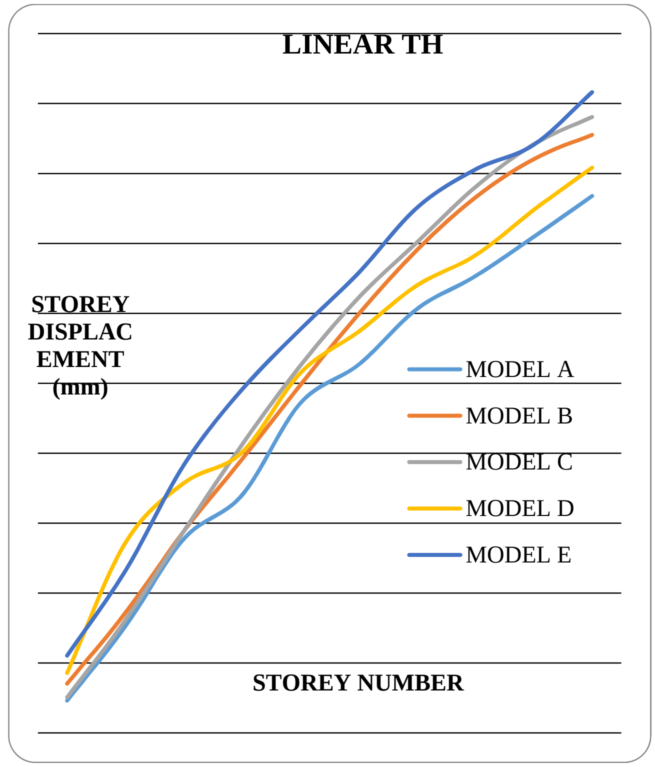


Fig. 6: Variation of storey displacement with storey for linear TH

Table 3: Time period (sec) for different models in different modes

MODE	MODELA	MODEL B	MODEL C	MODEL D	MODEL E
MODE 1	1.0569	1.0740	1.0648	1.0687	1.0523
MODE 2	1.0086	0.9975	1.0160	1.0201	0.9926
MODE 3	0.9511	0.9529	0.9576	0.9626	0.9424
MODE 4	0.3440	0.3515	0.3464	0.3537	0.3498
MODE 5	0.3210	0.3201	0.3233	0.3307	0.3240
MODE 6	0.3080	0.3104	0.3101	0.3167	0.3115
MODE 7	0.1957	0.2001	0.1971	0.2072	0.2052
MODE 8	0.1773	0.1787	0.1786	0.1881	0.1859
MODE 9	0.1751	0.1777	0.1763	0.1853	0.1834
MODE 10	0.1336	0.1373	0.1346	0.1447	0.1445
MODE 11	0.1176	0.1204	0.1184	0.1272	0.1273
MODE 12	0.1156	0.1179	0.1165	0.1248	0.1253

NONLINEAR TIME HISTORY ANALYSIS:

The results obtained from nonlinear time history analysis have been discussed in this section. The base shear in X and Y direction and roof displacement has been given in the following table (table 4) and storey displacement is given in Table 5.

Table 4: Base shear and roof displacements after nonlinear TH

MODEL	BASE SHEAR IN X-DIR (kN)	BASE SHEAR IN Y-DIR (kN)	ROOF DISPLACEMENT (mm)
MODEL A	1934.83	1720.29	40.72
MODEL B	1902.70	1447.38	42.75
MODEL C	1968.64	1845.96	45.95
MODEL D	1897.44	1840.92	47.14
MODEL E	1972.82	1873.52	45.71

The variation of base shear in x-direction for different building models is shown below (Fig. 7).

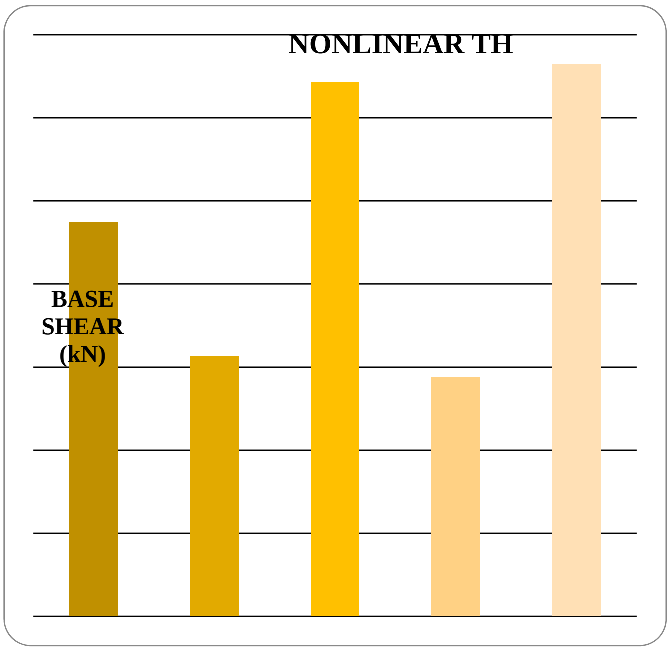


Fig. 7: Variation of base shear in x-direction for all the different models (nonlinear TH)

Similarly, for models with stiffness irregularity, the stiffness is reducing as compared to regular structure and hence the modal time period is increasing and therefore decreasing the base shear.

Mass irregular structures with heavy masses on two floors have greater base shear as compared to regular structure.

Table 5: Storey displacement (mm) in x-direction for different building models (nonlinear analysis)

Floor	Model A	Model B	Model C	Model D	Model E
1st	3.23	3.66	2.49	2.22	3.76
2nd	6.73	8.96	6.95	7.43	9.20
3rd	10.1	14.66	12.27	13.61	15.10
4th	15.36	20.1	20.46	19.73	20.75
5th	21.05	24.93	24.10	25.35	25.86
6th	26.95	29.65	31.19	30.83	30.21
7th	31.40	34.16	35.42	36.07	36.78
8th	36.66	37.86	39.69	40.41	38.85
9th	38.76	40.55	42.82	43.81	42.55
10th (roof)	40.72	42.75	45.95	47.14	45.71

Due to lesser stiffness of stories in stiffness irregular building models, the floor displacement is more in stiffness irregular structure than regular structure. Mass irregular structure has swimming pool in 4th and 8th. With increase in mass of stories, there is increase in inertia force generated in those stories and the moment of the inertial force is more leading to larger displacements as compared to regular structure.

Here, the maximum storey displacement is observed for the model with stiffness irregularity at top floor followed by mass irregularity model, stiffness and mass irregularity both model, stiffness irregularity at ground floor and regular model. The variation of storey displacement with the storey number for nonlinear TH analysis is shown below (Fig. 8).

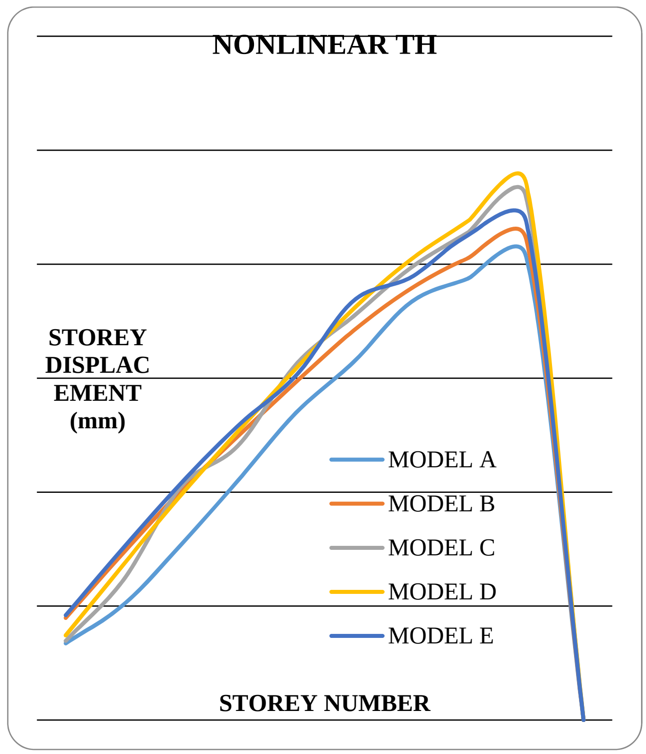


Fig. 8: Variation of storey displacement with storey for nonlinear TH

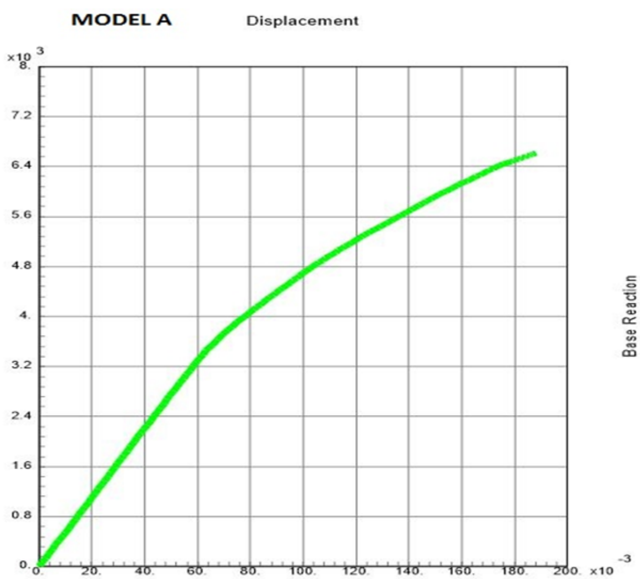
The comparison of roof displacements obtained after linear and nonlinear time history analysis is made in the following table (Table 6).

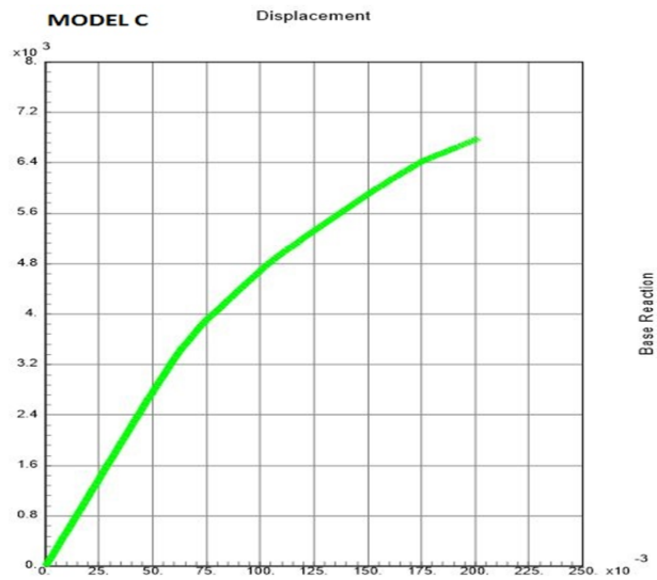
Table 6: Comparison of maximum roof displacements after linear and nonlinear time history analysis

MODEL	LINEAR TH DISPLACEMENT	NONLINEAR TH DISPLACEMENT	% CHANGE
MODEL A	38.39	40.72	6
MODEL B	42.56	42.75	0.45
MODEL C	43.04	45.95	4.33
MODEL D	40.42	47.14	16.61
MODEL E	44.81	45.71	2.01

4. RESULTS OF PUSHOVER ANALYSIS:

The pushover curves for the various building models are shown below (Fig. 9) and performance points for different models are given in Table 7.





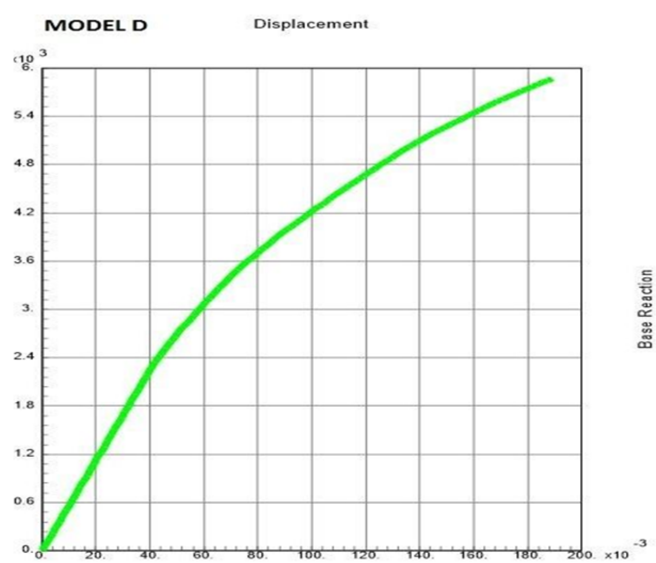


Fig. 9- pushover curves

Table 7: Comparison of performance points

MODEL	Target Displacement (m)
MODEL A	0.031
MODEL B	0.034
MODEL C	0.039
MODEL D	0.035
MODEL E	0.036

Development of plastic hinges for some models by pushover analysis has been shown below (Fig. 10):

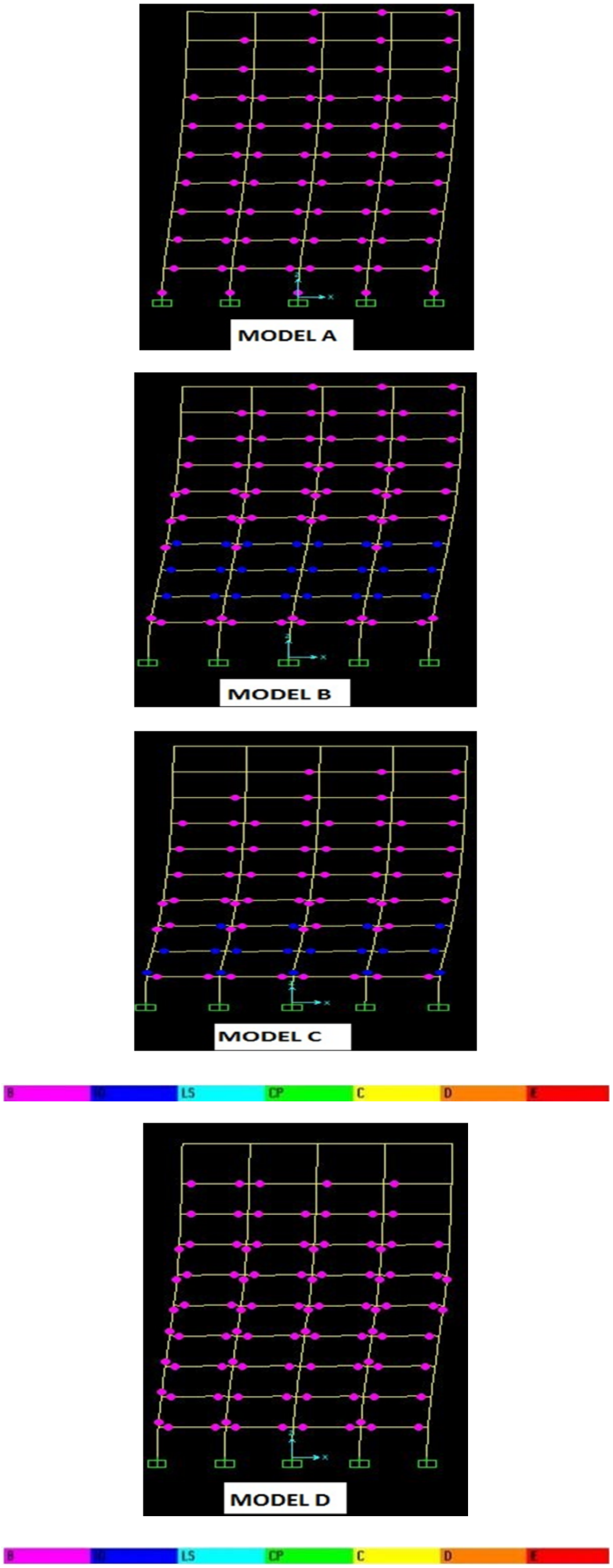


Fig. 10: Development of plastic hinges for different models

5. CONCLUSION

Due to lesser stiffness of stories in stiffness irregular building models, the floor displacement is more in stiffness irregular structure than regular structure. Mass irregular structure has swimming pool in 4th and 8th. With increase in mass of stories, there is increase in inertia force generated in those stories and the moment of the inertial force is more leading to larger displacements as compared to regular structure.For models with stiffness irregularity, the stiffness is reducing as compared to regular structure and hence the modal time period is increasing and therefore decreasing the base shear. Mass irregular structures with heavy masses on two floors have greater base shear as compared to regular structure.

The performance point for all the building models is determined using ATC 40 capacity spectrum.

Pink and blue colors for hinges correspond to immediate occupancy and life safety performance levels, respectively. When the total number of plastic hinges is considered, it yields that structural system of most of the building satisfies life-safety performance level.

Irregularities are found to be harmful for the structures and therefore it is advisable to have simple and regular configurations and moreover uniform distribution of mass over the building. If irregularities have to be provided, the building must be carefully designed as per building codes.

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