The Seismic Performance of Multi-Storied R.C. Building with Mass Irregularity

(Horizontal Plan Regular & Irregular Structure)

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Abstract –
The thesis involves analysis of buildings with vertical mass irregularity in horizontal plan regular and irregular configuration, to evaluate performance of the building during earthquake forces. In this project an attempt will be made to see variation in design forces due to different mass distributions along the height of the multi-storeyed structures. All seismic codes give different limits of irregularities. IS 1893:2002, prescribe a single storey of building should be mass irregular, if its mass exceeds 200 % more than adjacent storey. When a single storey considered and its stiffness is less than its adjacent by 70% or less than 80 % average lateral stiffness of three storeys' above, then the storey is known as "soft storey".
In Seismic analysis and design, calculation of fundamental time period of vibration is a critical, because its gives global seismic demands of the structure. The period of structure depends upon properties as stiffness, mass, seismic forces, cracking, height and no of storey.
Basically the structure has always forms structural irregular and cracks which leads to change in stiffness and strength of structure. These things has been ignored in code while calculation of empirical expressions of fundamental time period of structure. Due to this, calculated expressions are not suitable for calculation of actual seismic demands of structure. So, there is a need to change codal fundamental time period. Previously Eigen value analysis used for calculating fundamental time period. This research work proposed modified equations of fundamental time period calculation to overcome on codal limitations in terms of mass irregularity in vertical and horizontal plan regular and irregular configuration. Analysis of building carried out using computer program ETABS Software.

***Key Words*:** Mass irregularity, Multi-story building, Seismic responses, Seismic demand, ETAB

1. INTRODUCTION

Seismic effect should be taken into account due to rapid development of infrastructure and increasing number of the multi-storied buildings. The structural performance under seismic condition depends upon many factors, which include mass, stiffness, strength, ductility, lateral strength and regular configuration. The structure with above mentioned factors is less vulnerable to earthquake as compare to the Irregular structures. Irregular buildings are divided in two categories of irregularities namely Plan irregularities and Vertical irregularities as per the IS- 1893 - 2002 (Part 1)

In Multi-storied structures mass irregularity is an important factor. Irregular structures are major constituent in the modern urban infrastructure. Irregular structure includes all types of buildings which are irregular in shape as well as mass, stiffness, strength and ductility. The components of building resisting earthquake forces are known as the Lateral Force Resisting System (LFRS). The different lateral force resisting systems are as Shear walls, Special Moment resisting frame, and dual Frame system. The damage in a structure generally initiates at the location of structural weak planes present in the building system. A Mass irregular structure can be defined as a structure in which the storey mass of single storey exceeds 200% more than that of the adjacent storey as per IS-1893-2002 (Part 1). Vertical irregularities classified in NEHRP code (BSSC, 2003).In this code, a structure is defined as irregular, if the ratio of one of the quantities such as mass, stiffness / strength between adjacent stories exceeds 70-80 % for soft story, 150% for set-back structures and 80% for weak story. Various building codes suggest using dynamic analysis such as elastic time history analysis or elastic response spectrum analysis for calculation of design lateral force in irregular structures except equivalent lateral force method.

1.1 Objective

The objective can be summarized as follows-

1) Modeling of multi-storied R.C. building with mass irregularity in both plan horizontal regular and irregular shape structure. Calculation of the mass irregular index in structure.
2) Analysis of multi-storied irregular RC building using linear static and linear dynamic analysis as per IS 1893- 2002 (Part 1) code using modal analysis techniques.
3) Proposing design guidelines for calculation of modified fundamental time period with same vertical mass irregularity. This vertical mass irregular structure studied in both horizontal plan regular and irregular structure.

1.2 Project Methodology

Seismic analysis methods are classified as linear static, linear dynamic, Non-linear static and Non-linear dynamic analysis methods.1st and 2nd methods are suitable for structural's having small loads and these loads never reach to collapse load. The 3rd and 4th methods are the improved methods over linear approach. In earthquake loads the structural loading will reach to collapse load and the material stresses will be above yield stresses. So in that case material non-linearity and geometrical non-linearity should be incorporated into the analysis to get better results.

1.2.1 Response Spectrum Analysis in ETABS software

All models are analyzed in ETAB 2016 software, by using linear dynamic analysis i.e. Response Spectrum Analysis method.

1.2.2 The Load calculations for the model are as described below:-

A. The weight of slab, beams and columns as assigned in ETAB software with Self-weight command as dead Load.

B. Dead load- Floor load, Wall load and parapet wall load considered as per IS-875-Part1.

1) Wall load: Brick masonry unit weight unit x Wall thickness x Wall height

= (0.15 x 20 KN / m3 + 0.12 x 2 x 20 KN / m3) = 3.48 KN/m3 ~ 3.75 KN/m3

UDL Wall Load applied on beam = 3.75 x 3.0 = 11.25 KN/m

2) Parapet wall load (At podium parking and Roof floor level): Brick masonry unit weight x Wall Thickness x Wall height

= 3.75 KN / m2 * 1.20 m = 4.50 KN / m.

C. Live load: Floor live load considered as 2.5 KN/m2 and roof live load as 1.5 KN/m2, as per IS-875-Part 2.

D. Seismic Load: The seismic parameters are taken as per IS 1893- 2002(Part I).

Table -1

Soil type	Medium (II)
Seismic zone	IV (Z = 0.24)
Importance factor	1
Response reduction factor	5
Damping	5%

2 Modeling & Analysis of Structure used ETAB Software, with vertical Mass Irregularity.

2.1With Horizontal Regular Plan

Model 4.1 – G+18 R.C. structure with mass irregularity at 1st and 2nd Storey level in form of Podium parking (L.L = 5 kN /sqm).

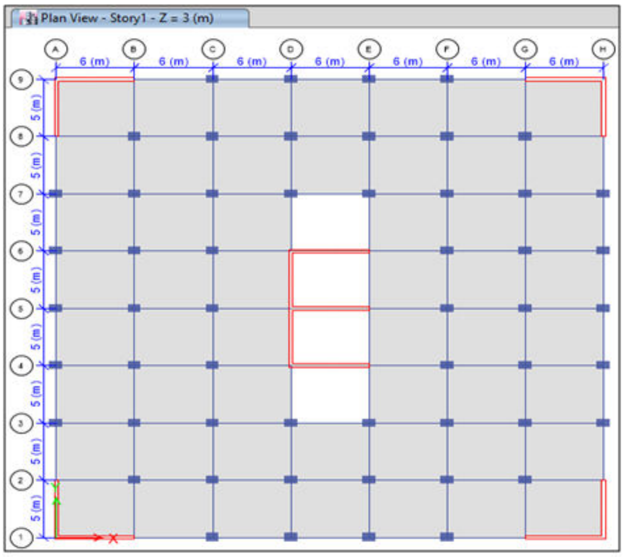
Model 4.2 – G+18 R.C. structure with Mass irregularity at 12th storey level in form of Gymnasium (L.L = 6.5 kN/sqm).

Model 4.3 – G+18 R.C. structure with Mass irregularity at 17th storey level in form of Club centre (L.L = 7.5 kN/sqm).

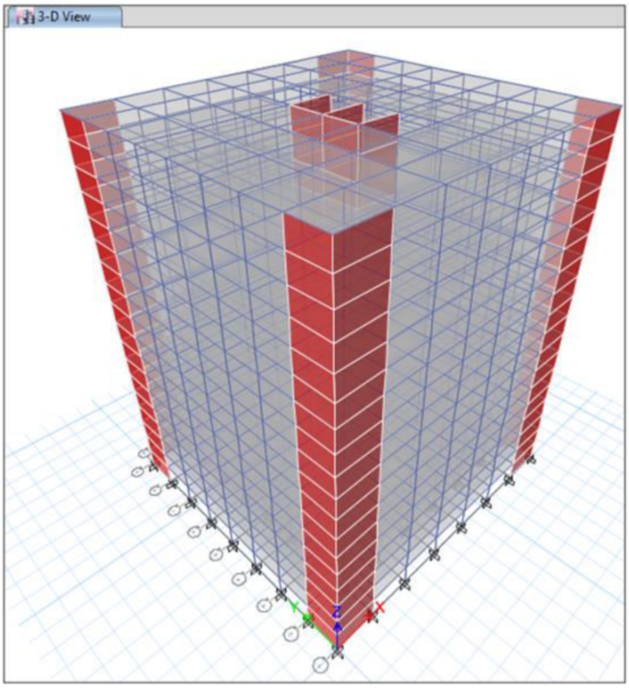
Model 4.4 - G+18 R.C. structure with same Mass on all storey. (L.L = 2.5 kN/sqm).

Modeling of G + 18 storey residential building (Model 4.1 & Model 4.4)

The G+18 structure is modeled and analyzed in ETAB version 16 software and the results and different type of responses are studied. The structure has horizontal length in X-direction is 42m & 40m in Y-direction. The columns are spaced at 6m c/c in X-direction and 5.0 m c/c in Y-direction. The storey height considered as 3 m throughout the model. The Model consists of eighteen storey building. The thickness of slab assumed 0.20 m. Model consists of two lift cabin modeled using Shear wall having thickness 0.300 m.



Plan of Building (TYP)



3D View Building

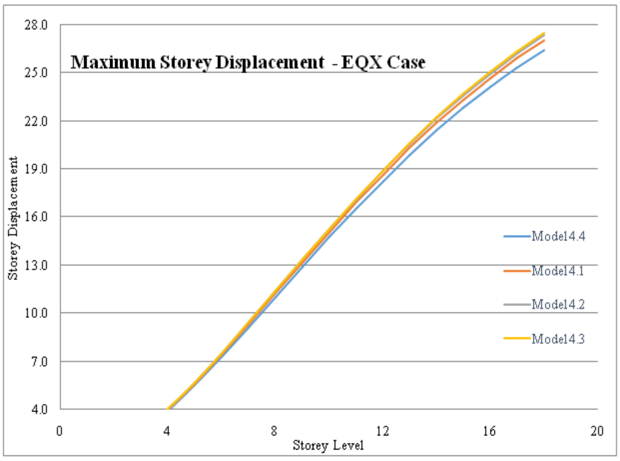
2.2 Comparison of Parameters for all models in EQX, EQY and SPECX, SPECY case

2.2.1 Maximum Storey Displacement

Table 2- Max. Storey displacement (EQX & EQY case).

Storey level	Model 4.4		Model 4.1		Model 4.2		Model 4.3	
	EQX (mm)	EQY (mm)	EQX (mm)	EQY (mm)	EQX (mm)	EQY (mm)	EQX (mm)	EQY (mm)
1	0.41	0.50	0.42	0.51	0.42	0.51	0.42	0.51
2	1.27	1.41	1.30	1.44	1.32	1.46	1.32	1.46
3	2.46	2.58	2.51	2.65	2.54	2.68	2.54	2.68
4	3.90	3.93	3.98	4.05	4.03	4.09	4.03	4.09
5	5.53	5.43	5.65	5.59	5.71	5.65	5.72	5.65
6	7.30	7.01	7.45	7.23	7.54	7.31	7.54	7.31
7	9.15	8.66	9.34	8.93	9.45	9.03	9.45	9.04
8	11.04	10.33	11.27	10.66	11.40	10.78	11.42	10.79
9	12.93	12.00	13.21	12.39	13.36	12.53	13.38	12.55
10	14.79	13.65	15.11	14.09	15.29	14.25	15.31	14.27
11	16.57	15.22	16.94	15.72	17.13	15.90	17.17	15.94
12	18.28	16.73	18.69	17.29	18.90	17.49	18.95	17.53
13	19.90	18.16	20.34	18.77	20.58	18.99	20.64	19.04
14	21.41	19.50	21.90	20.16	22.15	20.39	22.23	20.46
15	22.82	20.73	23.34	21.44	23.62	21.69	23.71	21.78
16	24.13	21.85	24.68	22.61	24.97	22.88	25.08	22.98
17	25.33	22.88	25.92	23.68	26.23	23.96	26.36	24.08
18	**26.44**	**23.78**	**27.06**	**24.63**	**27.38**	**24.92**	**27.53**	**25.05**

Graph 1-Max. Storey displacement (EQX case)



Graph 2- Max. Storey displacement (EQY case)

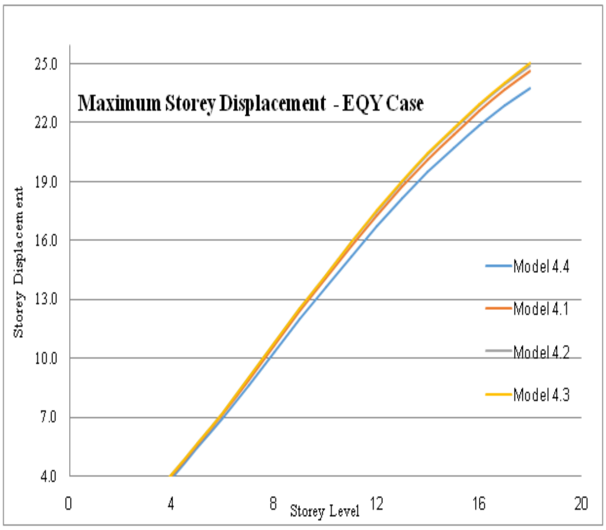
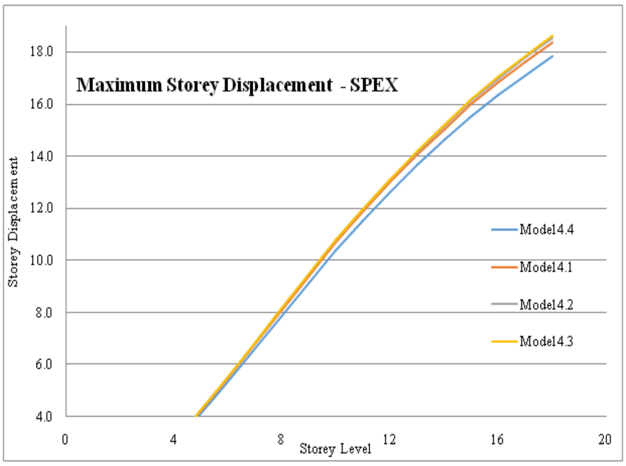


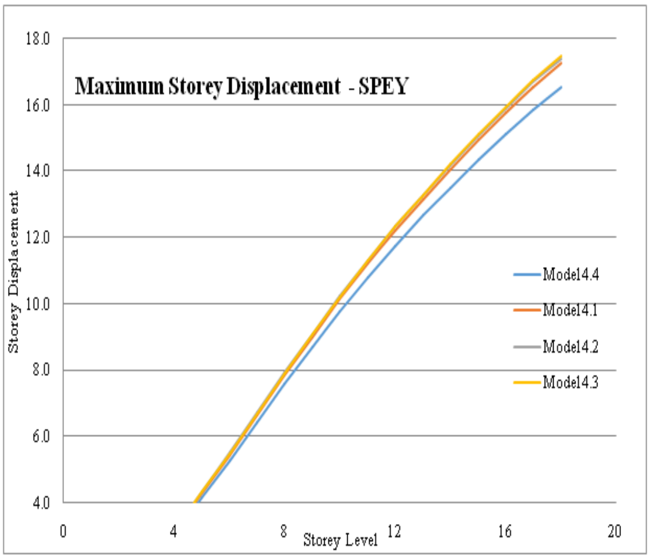
Table 3- Max. Storey displacement SPEX & SPEY case

Storey level	Model 4.4		Model 4.1		Model 4.2		Model 4.3	
	SPECX (mm)	SPECY (mm)	SPECX (mm)	SPECY (mm)	SPECX (mm)	SPECY (mm)	SPECX (mm)	SPECY (mm)
1	0.32	0.41	0.33	0.42	0.34	0.42	0.34	0.42
2	0.99	1.13	1.01	1.16	1.02	1.17	1.02	1.17
3	1.88	2.03	1.93	2.09	1.95	2.12	1.95	2.11
4	2.94	3.06	3.01	3.15	3.04	3.18	3.04	3.18
5	4.11	4.15	4.22	4.29	4.26	4.33	4.25	4.32
6	5.36	5.29	5.49	5.47	5.54	5.52	5.54	5.51
7	6.63	6.44	6.81	6.66	6.87	6.72	6.87	6.71
8	7.92	7.58	8.13	7.85	8.20	7.92	8.20	7.91
9	9.18	8.70	9.42	9.02	9.50	9.10	9.51	9.09
10	10.40	9.78	10.68	10.15	10.77	10.23	10.78	10.23
11	11.55	10.80	11.87	11.22	11.97	11.31	11.99	11.31
12	12.64	11.77	13.00	12.23	13.11	12.33	13.13	12.33
13	13.67	12.68	14.06	13.18	14.18	13.29	14.21	13.30
14	14.63	13.52	15.06	14.07	15.18	14.19	15.22	14.21
15	15.52	14.36	15.98	14.95	16.12	15.08	16.17	15.12
16	16.35	15.15	16.84	15.78	16.98	15.92	17.04	15.96
17	17.12	15.88	17.64	16.55	17.79	16.70	17.86	16.75
18	**17.83**	**16.55**	**18.37**	**17.25**	**18.53**	**17.41**	**18.61**	**17.47**

Graph 3-Max. Storey displacement (SPEX case)



Graph 4- Max. Storey displacement (SPEY case)

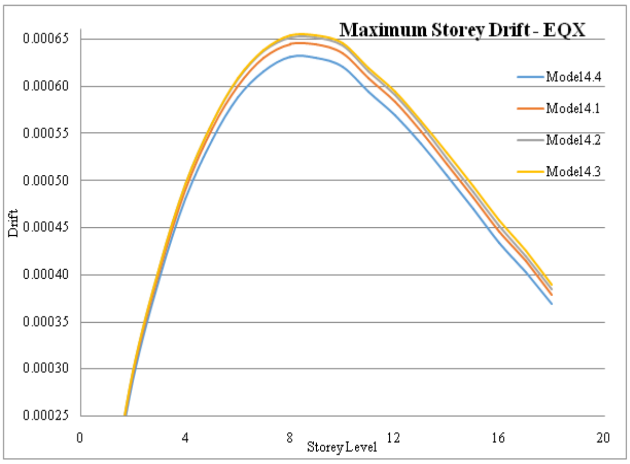


2.2.2 Maximum Storey Drifts

Table 4- Max. Storey drifts (EQX & EQY case).

Storey level	Model 4.4		Model 4.1		Model 4.2		Model 4.3	
	EQX	EQY	EQX	EQY	EQX	EQY	EQX	EQY
1	0.000136	0.000165	0.000139	0.000169	0.000141	0.000171	0.000141	0.000171
2	0.000288	0.000304	0.000294	0.000312	0.000297	0.000315	0.000297	0.000315
3	0.000396	0.000390	0.000404	0.000401	0.000409	0.000406	0.000409	0.000406
4	0.000480	0.000453	0.000490	0.000467	0.000496	0.000472	0.000496	0.000472
5	0.000543	0.000498	0.000555	0.000514	0.000561	0.000520	0.000561	0.000520
6	0.000588	0.000529	0.000600	0.000547	0.000607	0.000553	0.000608	0.000553
7	0.000616	0.000549	0.000630	0.000567	0.000637	0.000574	0.000638	0.000575
8	0.000631	0.000558	0.000645	0.000577	0.000652	0.000584	0.000654	0.000585
9	**0.000630**	**0.000557**	**0.000644**	**0.000576**	**0.000652**	**0.000583**	**0.000654**	**0.000585**
10	0.000621	0.000548	0.000635	0.000567	0.000643	0.000574	0.000646	0.000576
11	0.000594	0.000525	0.000608	0.000544	0.000616	0.000551	0.000619	0.000554
12	0.000569	0.000503	0.000583	0.000522	0.000590	0.000528	0.000594	0.000532
13	0.000539	0.000476	0.000552	0.000494	0.000559	0.000500	0.000563	0.000504
14	0.000505	0.000445	0.000518	0.000462	0.000524	0.000468	0.000530	0.000473
15	0.000470	0.000411	0.000482	0.000427	0.000488	0.000433	0.000494	0.000438
16	0.000434	0.000375	0.000446	0.000391	0.000452	0.000395	0.000458	0.000402
17	0.000402	0.000340	0.000414	0.000355	0.000419	0.000360	0.000425	0.000366
18	0.000369	0.000303	0.000379	0.000316	0.000384	0.000320	0.000389	0.000324

Graph 5- Max. Storey drifts (EQX case)



Graph 6- Max. Storey displacement (EQY case)

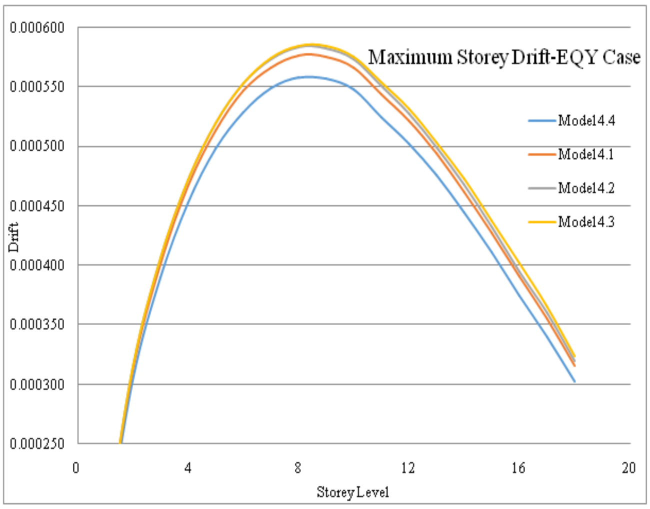
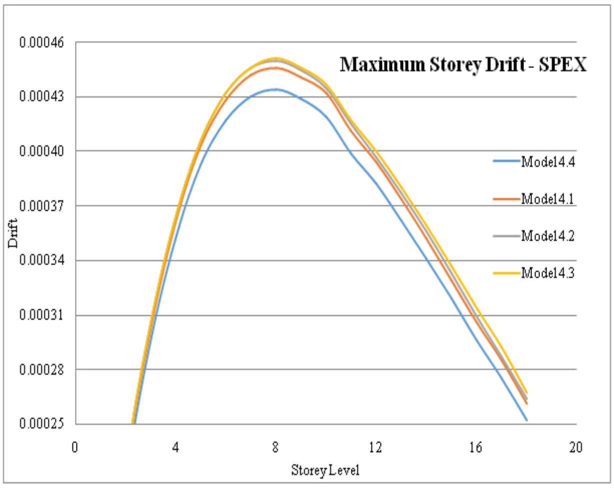


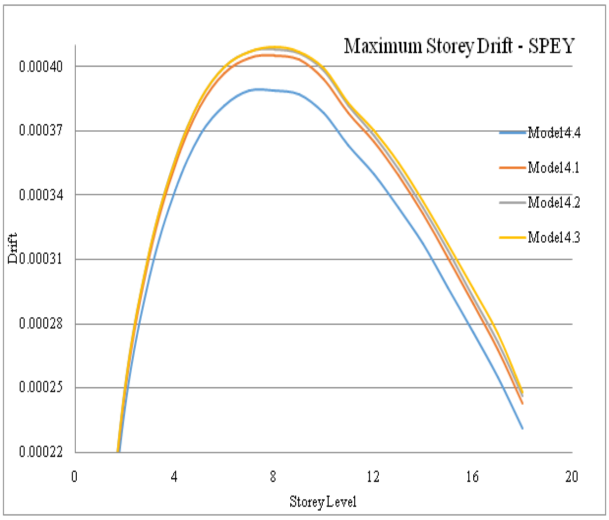
Table 5- Max. Storey drifts SPEX & SPEY case

orey level	Model 4.4		Model 4.1		Model 4.2		Model 4.3	
	SPECX	SPECY	SPECX	SPECY	SPECX	SPECY	SPECX	SPECY
1	0.000108	0.000135	0.000111	0.000138	0.000112	0.000140	0.000112	0.000140
2	0.000221	0.000241	0.000227	0.000248	0.000229	0.000251	0.000229	0.000250
3	0.000298	0.000302	0.000305	0.000312	0.000308	0.000314	0.000308	0.000314
4	0.000354	0.000342	0.000363	0.000354	0.000366	0.000357	0.000366	0.000356
5	0.000393	0.000368	0.000403	0.000381	0.000406	0.000384	0.000406	0.000384
6	0.000417	0.000382	0.000428	0.000397	0.000432	0.000400	0.000432	0.000400
7	0.000430	0.000389	0.000442	0.000404	0.000446	0.000407	0.000446	0.000407
8	**0.000434**	**0.000389**	**0.000446**	**0.000405**	**0.000450**	**0.000408**	**0.000451**	**0.000409**
9	0.000429	0.000387	0.000441	0.000403	0.000445	0.000406	0.000446	0.000407
10	0.000419	0.000378	0.000432	0.000394	0.000435	0.000398	0.000437	0.000399
11	0.000399	0.000363	0.000411	0.000378	0.000415	0.000382	0.000417	0.000383
12	0.000382	0.000350	0.000394	0.000365	0.000397	0.000368	0.000400	0.000370
13	0.000362	0.000334	0.000374	0.000349	0.000377	0.000352	0.000380	0.000355
14	0.000341	0.000317	0.000352	0.000331	0.000356	0.000334	0.000359	0.000337
15	0.000319	0.000297	0.000329	0.000311	0.000333	0.000314	0.000337	0.000317
16	0.000296	0.000276	0.000306	0.000289	0.000309	0.000292	0.000314	0.000296
17	0.000275	0.000255	0.000285	0.000268	0.000287	0.000271	0.000292	0.000275
18	0.000252	0.000231	0.000261	0.000243	0.000264	0.000246	0.000267	0.000248

Graph 7- Max. Storey drifts (SPEX case)



Graph 8- Max. Storey displacement (SPEY case)



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2.3 With Horizontal Irregular Plan

Model 4.5 – G+18 R.C. structure with mass irregularity at 1st and 2nd Storey level in form of Podium parking (L.L = 5 kN /sqm).

Model 4.6 – G+18 R.C. structure with Mass irregularity at 12th storey level in form of Gymnasium (L.L = 6.5 kN/sqm).

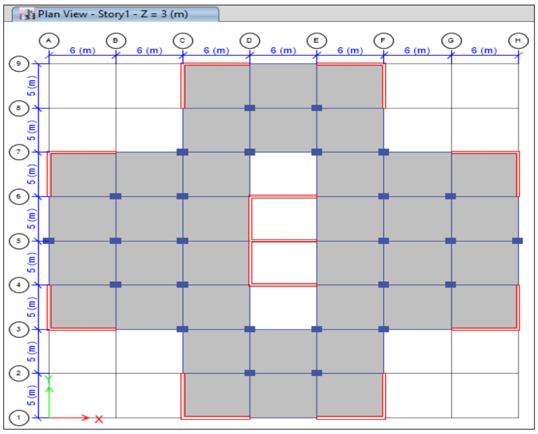
Model 4.7 – G+18 R.C. structure with Mass irregularity at 17th storey level in form of Club centre (L.L = 7.5 kN/sqm).

Model 4.8- G+18 R.C. structure with same Mass on all storeys. (L.L = 2.5 kN/sqm).

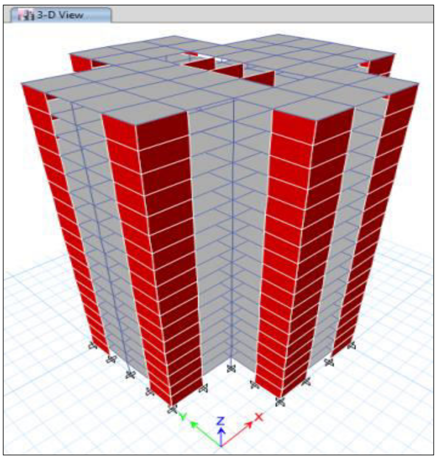
Modeling of G + 18 storey residential building (Model 4.5 & Model 4.8)

The G+18 structure is modeled and analyzed in ETAB version 16 software and the results and different type of responses are studied. The structure has horizontal length in X-direction is 42m & 40m in Y-direction. The columns are spaced at 6m c/c in X-direction and 5.0 m c/c in Y-direction. The storey height considered as 3 m throughout the model. The Model consists of eighteen storey building. The thickness of slab assumed 0.20 m. Model consists of two lift cabin modeled using Shear wall having thickness 0.300 m.

The Material property, Geometry and loads considered on all the models considering different mass irregularities are same described in horizontal plan regular structure i.e. model 4.1 to 4.4



Plan of Building (TYP)



3D View Building

2.4 Comparison of Parameters for all models in EQX, EQY and SPECX, SPECY case

2.4.1 Maximum Storey Displacement

Table 6- Max. Storey displacement (EQX & EQY case).

Storey level	_Model 4.8		_Model 4.5		_Model 4.6		_Model 4.7	
	EQX (mm)	EQY (mm)	EQX (mm)	EQY (mm)	EQX (mm)	EQY (mm)	EQX (mm)	EQY (mm)
1	0.30	0.35	0.30	0.36	0.32	0.38	0.35	0.41
2	0.93	1.03	0.95	1.06	0.97	1.09	1.04	1.15
3	1.82	1.94	1.88	2.01	1.91	2.04	2.01	2.14
4	2.93	3.03	3.02	3.14	3.06	3.18	3.21	3.31
5	4.21	4.26	4.33	4.41	4.38	4.47	4.58	4.63
6	5.61	5.58	5.77	5.79	5.84	5.86	6.08	6.05
7	7.11	6.98	7.31	7.23	7.40	7.32	7.68	7.53
8	8.67	8.41	8.92	8.72	9.02	8.82	9.34	9.06
9	10.25	9.86	10.54	10.23	10.66	10.34	11.02	10.60
10	11.83	11.30	12.17	11.72	12.31	11.85	12.71	12.13
11	13.39	12.70	13.77	13.18	13.92	13.33	14.37	13.62
12	14.91	14.06	15.34	14.60	15.50	14.76	15.99	15.07
13	16.37	15.37	16.85	15.96	17.03	16.14	17.56	16.46
14	17.78	16.61	18.30	17.26	18.49	17.44	19.06	17.77
15	19.12	17.78	19.68	18.47	19.89	18.67	20.49	19.01
16	20.40	18.87	21.00	19.61	21.22	19.82	21.85	20.16
17	21.61	19.88	22.25	20.67	22.48	20.90	23.13	21.23
18	**22.77**	**20.83**	**23.44**	**21.66**	**23.68**	**21.90**	**24.34**	**22.21**

Graph 7-Max. Storey displacement (EQX case)

Graph 10- Max. Storey displacement (EQY case)

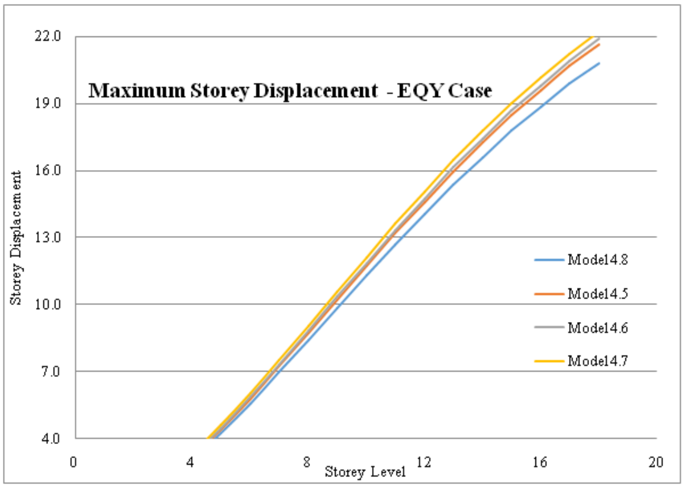


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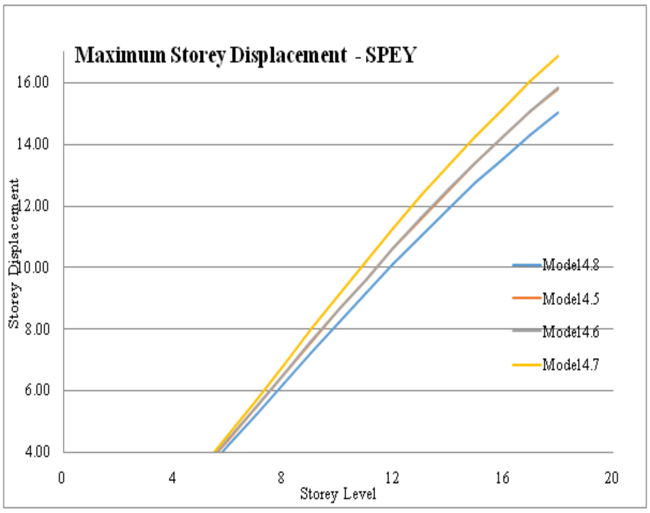
Table 8- Max. Storey displacement SPEX & SPEY case

Storey level	_Model 4.8		_Model 4.5		_Model 4.6		_Model 4.7	
	SPECX (mm)	SPECY (mm)	SPECX (mm)	SPECY (mm)	SPECX (mm)	SPECY (mm)	SPECX (mm)	SPECY (mm)
1	0.23	0.28	0.24	0.29	0.25	0.31	0.30	0.33
2	0.72	0.82	0.74	0.85	0.75	0.86	0.88	0.91
3	1.39	1.52	1.44	1.59	1.46	1.60	1.67	1.66
4	2.21	2.35	2.29	2.45	2.31	2.47	2.63	2.54
5	3.14	3.26	3.25	3.40	3.28	3.42	3.71	3.52
6	4.14	4.22	4.30	4.42	4.33	4.43	4.87	4.58
7	5.20	5.22	5.39	5.46	5.43	5.48	6.10	5.69
8	6.29	6.23	6.52	6.52	6.56	6.54	7.35	6.83
9	7.38	7.23	7.65	7.57	7.69	7.59	8.60	7.97
10	8.46	8.21	8.77	8.61	8.82	8.62	9.84	9.10
11	9.51	9.16	9.86	9.60	9.91	9.62	11.05	10.20
12	10.52	10.11	10.92	10.61	10.97	10.62	12.22	11.27
13	11.50	11.03	11.93	11.58	11.99	11.59	13.35	12.31
14	12.43	11.91	12.91	12.52	12.97	12.53	14.42	13.31
15	13.32	12.75	13.83	13.40	13.90	13.41	15.45	14.26
16	14.17	13.54	14.71	14.24	14.78	14.25	16.43	15.16
17	14.98	14.30	15.56	15.04	15.63	15.05	17.36	16.02
18	**15.75**	**15.01**	**16.36**	**15.80**	**16.44**	**15.81**	**18.23**	**16.84**

Graph 11 - Max. Storey displacement (SPEX case)

Graph 12- Max. Storey displacement (SPEY case)

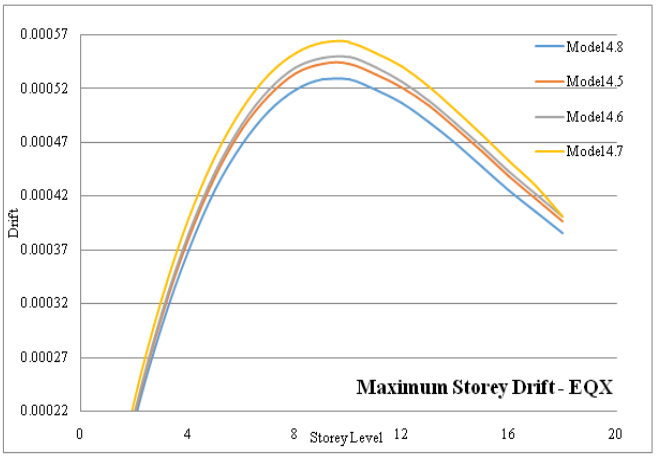


2.2.1 Maximum Storey Drifts

Table 9- Max. Storey drifts (EQX & EQY case).

Storey level	_Model 4.8		_Model 4.5		_Model 4.6		_Model 4.7	
	EQX	EQY	EQX	EQY	EQX	EQY	EQX	EQY
1	0.000098	0.000116	0.000101	0.000120	0.000106	0.000126	0.000115	0.000135
2	0.000211	0.000226	0.000217	0.000234	0.000219	0.000236	0.000231	0.000247
3	0.000298	0.000304	0.000307	0.000315	0.000310	0.000318	0.000324	0.000330
4	0.000369	0.000364	0.000380	0.000377	0.000384	0.000381	0.000398	0.000392
5	0.000426	0.000409	0.000438	0.000424	0.000442	0.000428	0.000457	0.000439
6	0.000468	0.000442	0.000482	0.000459	0.000487	0.000463	0.000501	0.000472
7	0.000499	0.000464	0.000513	0.000482	0.000519	0.000487	0.000533	0.000495
8	0.000519	0.000478	0.000534	0.000496	0.000539	0.000501	0.000553	0.000509
9	**0.000528**	**0.000482**	**0.000543**	**0.000502**	**0.000548**	**0.000506**	**0.000562**	**0.000513**
10	0.000528	0.000480	0.000543	0.000499	0.000549	0.000504	0.000563	0.000510
11	0.000518	0.000468	0.000533	0.000487	0.000539	0.000492	0.000553	0.000498
12	0.000506	0.000454	0.000521	0.000473	0.000526	0.000478	0.000540	0.000482
13	0.000489	0.000436	0.000504	0.000454	0.000509	0.000458	0.000522	0.000462
14	0.000469	0.000413	0.000483	0.000431	0.000488	0.000435	0.000500	0.000438
15	0.000447	0.000389	0.000461	0.000406	0.000466	0.000410	0.000477	0.000412
16	0.000425	0.000363	0.000438	0.000379	0.000443	0.000383	0.000452	0.000384
17	0.000405	0.000339	0.000417	0.000354	0.000422	0.000358	0.000429	0.000357
18	0.000385	0.000315	0.000396	0.000329	0.000401	0.000333	0.000401	0.000328

Graph 13- Max. Storey drifts (EQX case)



Graph 14-Max. Storey displacement (EQY case)

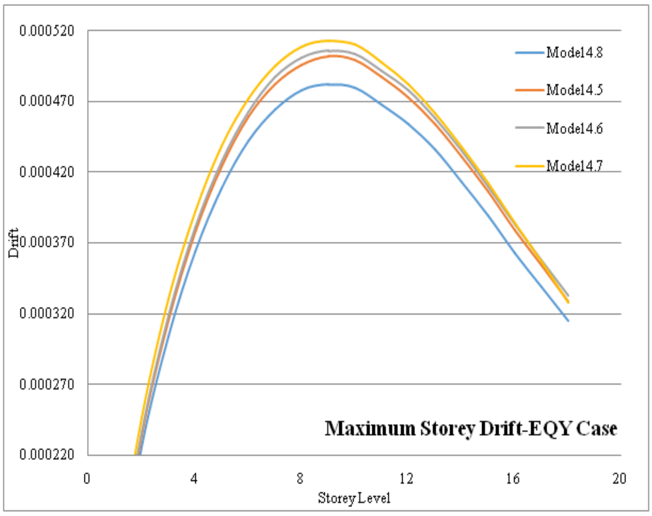
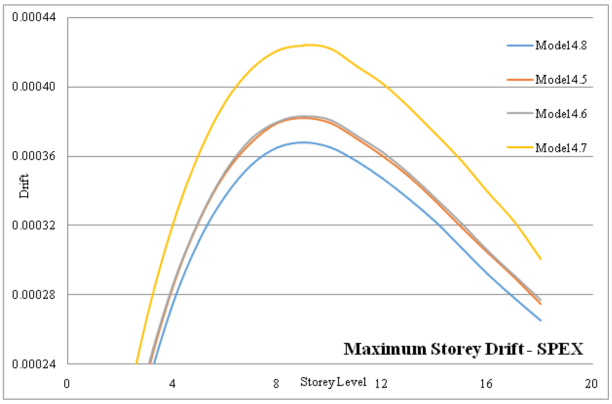


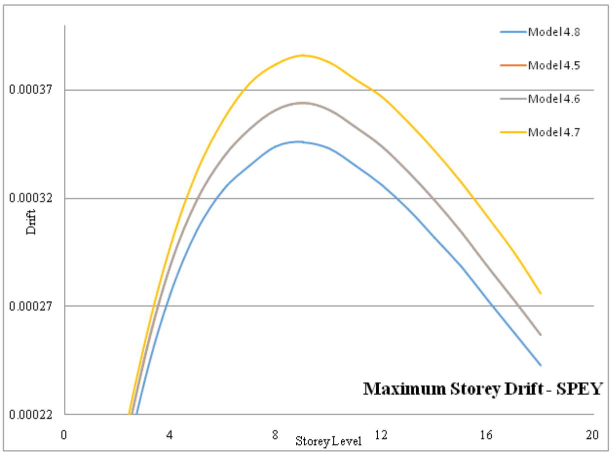
Table 10- Max. Storey drifts SPEX & SPEY case

Storey level	Model 4.8		Model 4.5		Model 4.6		Model 4.7	
	SPECX	SPECY	SPECX	SPECY	SPECX	SPECY	SPECX	SPECY
1	0.000077	0.000094	0.000080	0.000098	0.000084	0.000102	0.000099	0.000109
2	0.000161	0.000178	0.000167	0.000186	0.000168	0.000186	0.000193	0.000193
3	0.000224	0.000235	0.000232	0.000245	0.000234	0.000246	0.000265	0.000252
4	0.000274	0.000276	0.000284	0.000289	0.000285	0.000289	0.000320	0.000298
5	0.000311	0.000305	0.000322	0.000319	0.000323	0.000319	0.000361	0.000332
6	0.000337	0.000324	0.000350	0.000339	0.000351	0.000339	0.000391	0.000356
7	0.000355	0.000335	0.000368	0.000352	0.000370	0.000352	0.000410	0.000373
8	0.000365	0.000344	0.000379	0.000361	0.000380	0.000361	0.000421	0.000382
9	**0.000368**	**0.000346**	**0.000382**	**0.000364**	**0.000383**	**0.000364**	**0.000424**	**0.000386**
10	0.000365	0.000343	0.000379	0.000361	0.000381	0.000361	0.000422	0.000383
11	0.000357	0.000335	0.000370	0.000353	0.000372	0.000353	0.000412	0.000375
12	0.000347	0.000326	0.000360	0.000344	0.000362	0.000344	0.000402	0.000367
13	0.000335	0.000315	0.000348	0.000332	0.000350	0.000332	0.000388	0.000355
14	0.000322	0.000302	0.000334	0.000319	0.000336	0.000319	0.000373	0.000342
15	0.000307	0.000288	0.000319	0.000304	0.000321	0.000304	0.000357	0.000327
16	0.000292	0.000273	0.000304	0.000288	0.000305	0.000288	0.000339	0.000311
17	0.000278	0.000258	0.000290	0.000273	0.000291	0.000273	0.000322	0.000295
18	0.000265	0.000243	0.000275	0.000257	0.000277	0.000257	0.000301	0.000276

Graph 15- Max. Storey drifts (SPEX case)



Graph 16- Max. Storey displacement (SPEY case)



2.4 Mass Irregular Index Calculation of Irregular models.

Mass irregular three models are considered for the study at different storey level. Model 4.5 has mass irregularity at 1st & 2nd storey level. Model 4.6 has mass irregularity at 12th storey and model 4.7 at 17th storey level. Model 4.8 has same mass on all floor level is considered for comparison with mass irregular model. All models are analyzed in ETAB software. The interpretation of results shows that some changes in the design forces as well as parameters like Maximum storey displacement, Storey shear, Maximum storey drift, Storey stiffness. The Comparison tables show the values of all the above parameters.

The Mass irregular index for all models is calculated, which is dependent on a number of parameters of the structure. These parameters are identified and used to calculate the Mass index ηm of models and calculated the ratio of Time period of irregular and regular structure (Ti/Tr).The definition of the mass index quoted by the researcher as studied in the literature review, it is given in following equation,

$$\eta_m = \frac{hi}{h}\frac{Mi}{M}\frac{b}{L}b$$

b = plan width in seismic force direction

L = Plan width transverse to direction seismic force

hi = Height of mass irregular floor from base of structure.

H = Total height of structure.

Mi = Mass of ith floor with irregularity.

M = Total mass of structure.

The Mass Irregularity index calculation for the Mass irregular models were calculated as shown below:

1.0) Model 4.5 (Irregularity at 1st and 2nd storey level)

The Model 4.5 has mass irregularity at 1st and 2nd storey levels. Mass irregularity index calculation parameters are as below:

Plan dimension – 42.0 m x 40.0 m

Model 4.5 has Mass irregularity at 1st and 2nd storey level

a.) For 1st storey level

b.) b = 40.0 m, L = 42.0 m, h1 = 3 m, h = 54.0 m, M1 = 18784.30 kN and

M = 367235.63 kN

$$\eta m = \frac{40}{42} * 40.0 * \frac{3}{54} * \frac{18784.30}{367235.63} = 0.1083$$

For 2nd storey level

b = 40.0 m, L = 42.0 m, h1 = 6 m, h = 54.0 m, M2 = 18784.30 kN and

M = 367235.63 kN

$$\eta m = \frac{40}{42} * 40 * \frac{6}{54} * \frac{18784.30}{367235.63} = 0.2165$$

2.) Model 4.6 (Irregularity at 12th storey level)

The Model 4.6 has mass irregularity at 12th storey level. Mass irregularity index calculation parameters are as below:

Plan dimension – 40.0 m * 42.0 m

Dimension as per model for Mass irregularity at 12th storey level

For 12th storey level

b = 40.0 m, L = 42.0 m, h1 = 36.0 m, h = 54.0 m, M12 = 20593.13 kN and

M = 370743.99 kN

$$\eta m = \frac{40.0}{42.0} * 40 * \frac{36.0}{54.0} * \frac{20593.13}{370743.99} = 1.411$$

3.) Model 4.3 (Irregularity at 17th storey level)

The Model 4.3 has mass irregularity at 17th storey level. Mass irregularity index calculation parameters are as below:

Plan dimension – 40.0 m * 42.0 m

Dimension as per model for Mass irregularity at 17th storey level

c.) For 17th storey level

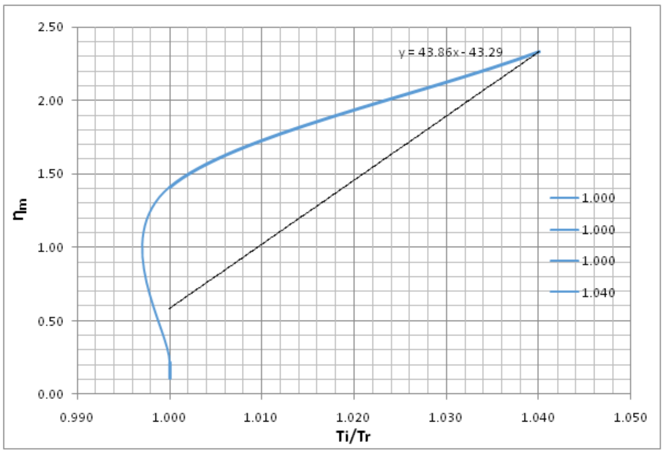
b = 40.0 m, L = 42.0 m, h17 = 51 m, h = 54.0 m, M17 = 24325.95 kN and

M = 375114.21 kN

$$\eta m = \frac{40.0}{42.0} * 40.0 * \frac{51.0}{54.0} * \frac{24325.95}{375114.21} = 2.333$$

2.4.1 Graph showing variation of Mass irregularity index with ratio of Irregular & Regular time period for all the irregular models considered.

Graph 17 -Variation of ηm to Ti/Tr Ratio



2.4.2 Mass Irregularity index ηm & Ti/Tr ratio variation table

As shown in this table, the variation in value of Mass irregular index has been explained as calculated for all the models. Also the Percentage increase of mass index for the models has been explained.

Table 11: Table of Mass Irregularity index with Ratio of Time period

Floor	T_r (seconds)	T_i (seconds)	N_m	T_i/T_r	Percentage Increase in the Mass Irregularity Index
1	1.193	1.193	0.1083	1.000	
2	1.193	1.193	0.2165	1.000	50.000
12	1.193	1.193	1.4107	1.000	84.652
17	1.193	1.247	2.3332	1.040	39.539

3. CONCLUSIONS

1.) The value of the Mass irregularity index suddenly increases as the mass irregularity increases according to the height. When irregular mass present at bottom level mass irregularity index was less. These results also can be seen on graph and results incorporated. This is concluded that mass irregularity index is directly proportional to mass irregularity along the height of building.

2.) In models 4.5 to 4.8 i.e. mass irregular structure and with horizontal plan irregular structure 50.0 % increase in mass irregularity index from 1st to 2nd floor. There is a difference in the mass irregularity index on the higher floors 12th and 17th floor is 45.12 %. This shows that, there is consistency in mass irregularity index in geometrical plan regular and irregular structure.

3.) The ratio of Time period in models 4.1 to 4.5 (mass irregular, but without horizontal plan irregular) increase along height of building. Time period Tr of regular structure and Ti irregular structure was calculated separately.

4.) It is observed that ratio of Ti/ Tr ratio increases with the position of mass irregular floor on top floor. It is also seen that in plan regular structure the value decreases at 12th floor, which means the ratio Ti/ Tr not only depends on mass irregularity but also depends on other building factors.

5.) Different models are observed with geometrical plan regular and irregular structure with same mass irregularity. Its shows that mass irregularity increase from bottom storey to top storey. Time period of mass irregular structure at 1st and 2nd storey remains same as mass regular structure.

6.) It is observed that time period of horizontal plan irregular structure is less than plan regular structure with mass irregular structure

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