Planning, Design & Analysis of a Commercial Building with Flat Slab Considering Earthquake Induced Forces Using ETABS.

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Abstract - *Flat-slab building structures possesses major advantages over traditional slab-beam-column structures because of the free design of space, shorter construction time, architectural –functional and economical aspects. Because of the absence of deep beams and shear walls, flat-slab structural system is significantly more flexible for lateral loads then traditional RC frame system and that make the system more vulnerable under seismic events. The critical moment in design of these systems is the slab-column connection, i.e., the shear force in the slab at the connection, which should retain its bearing capacity even at maximal displacements. The behavior of flat slab building during earthquake depends critically on 'Building Configuration'. This fact has resulted in to ensure safety against earthquake forces of tall structures hence, there is need to determine seismic responses of such building for designing earthquake resistant structures. Response Spectrum analysis is one of the important techniques for structural seismic analysis. In the present work dynamic analysis of 25 models of multi-storied RCC Flat slab structure is carried out by response spectrum analysis.*

***Key Words*: Aspect Ratio, Slenderness Ratio, Response Spectrum Analysis, Drift, Displacement, Storey shear, SMRF R.C.C. flat slab structure.**

1. INTRODUCTION

Reinforced concrete (RC) framed structures that feature slabs supported directly by columns, without the use of beams or girders are referred to as slab-column or flat plate framed systems. This type of system offers economic advantages and larger open spaces with reduced storey heights compared to framed systems with beams.

However, the recent and the past failure of flat-slab structures have underlined the need for reviewing the current design and construction practices, especially the design of flat-slab system under seismic action. In general, the shear strength of connection is governed by the more severe of two mechanisms namely beam action or two-way action. Beam-type or one-way shear failure has the critical section for shear 0extending across the entire width of the slab. Punching or two-way shear failure involves potential diagonal tension cracks occurring along a truncated cone or pyramid passing through the critical section [3].

Many flat plate structures have collapsed in the mode of punching failure, especially during earthquakes. In slab-column frames located in regions of high seismic risk, the connections must be capable of transferring gravity loads while the structure undergoes earthquake-induced lateral displacements. These displacements, besides inducing an unbalanced moment, could also translate into large inelastic rotations in the connections, which have the potential to decrease connection punching shear capacity. The detrimental effect of lateral displacements on connection strength may therefore lead to the need for shear reinforcement in slab-column connections that otherwise would be capable of resisting the imposed shear stresses.

Thus, punching failure in flat plate system is a major design concern and effective solutions to avoiding punching failure are of great importance. The weakest point in the -slab systems is their resistance against punching shear in the vicinity of the supporting column.

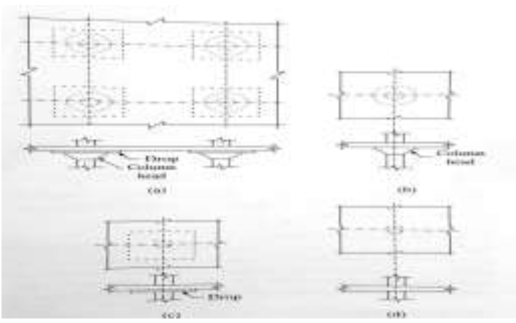

Fig. 1- Flat Slabs & Flat Plates (a) Flat Slab with drop and column head (b) Flab slab with column head (c) Flat slab with drop (d) Flat Plate

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Source-*"Design of Reinforced Concrete Structures",* N.Subramanian

Drop panels play a significant role here as they augment the overall capacity and sturdiness of the flooring system beneath the vertical loads thereby boosting cost effectiveness of the construction. Usually the height of drop panels is about two times the height of slab.

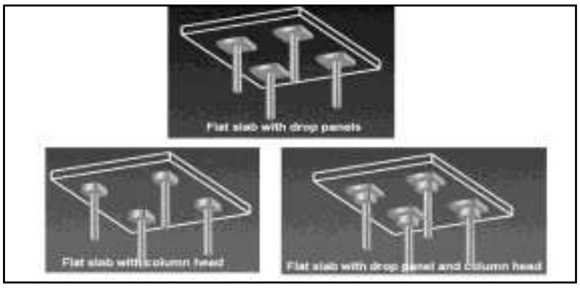


Fig.2 – Types of Flat Slab

Source - www.dailycivil.com/flat-slab-types-uses-advantages-disadvantages/

Flat Slabs are considered suitable for most of the construction and for asymmetrical column layouts like floors with curved shapes and ramps etc. The advantages of applying flat slabs are many like depth solution, flat soffit and flexibility in design layout.

1.1 Benefits of Using Flat Slab Construction Method

1) **Flexibility in Room Layout**

Flat slabs allows Architect to introduce partition walls anywhere required, this allows owner to change the size of room layout. Use of flat slab allows choice of omitting false ceiling and finish soffit of slab with skim coating.

2) **Saving in Building Height**

- Lower storey height will reduce building weight due to lower partitions and cladding to façade
- Approximately saves 10% in vertical members
- Reduced foundation load

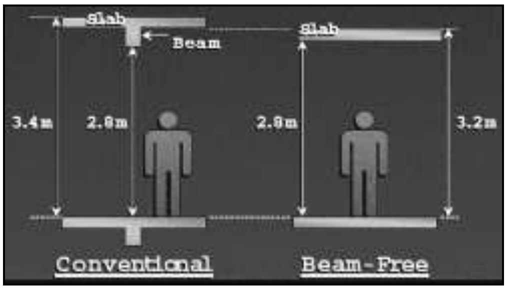


Fig 3 – Building Height

Source - H.S, M., & Kavan, M. (2015). Comparative Study of Flat Slab and Conventional Slab Structure Using ETABS for Different Earthquake Zones of India. *International Research Journal of Engineering and Technology* , 1931-1936.

3) **Shorter Construction Time**

Use of flat slabs requires less time for construction by the use of big table formwork.

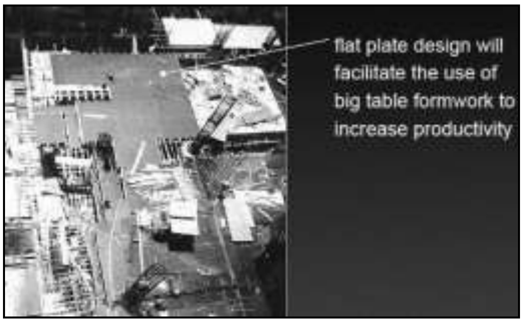


Fig 4 – Formwork of Flat Slab

Source - H.S, M., & Kavan, M. (2015). Comparative Study of Flat Slab and Conventional Slab Structure Using ETABS for Different Earthquake Zones of India. *International Research Journal of Engineering and Technology* , 1931-1936.

4) **Use of Prefabricated Welded Mesh**

Use of prefabricated welded mesh minimizes the installation time of flat slabs. These mesh are available in standard size and provides better quality control in construction of flat slab.

Fig 5 – Welded Mesh

Source-*"Design of Reinforced Concrete Structures",* N.Subramanian

5) **Buildable Score**

This allows standardized structural members and prefabricated sections to be integrated into the design for ease of construction. This process makes the structure more buildable, reduce the number of site workers and increase the productivity at site, thus providing more tendencies to achieve a higher Buildable score.

1.2 Thickness of Flat Slab

All the flat slabs with edge beams have lower slab thickness as compared to flat slabs with perimeter beams.

1.3 Problem Statement

In high seismic regions, slab-column frames are more vulnerable to brittle punching failure and leads to progressive collapse of structure. Flat slab buildings are subjected to large lateral displacements during earthquake ground motion and lose their vertical load carrying capacity under induced moments due to earthquake.

1.4 Objectives

- To calculate design lateral forces on multi-storied R.C.C. Flat slab structure with regular building configuration in plan but different aspect ratio using "Response Spectrum Analysis."
- To calculate and study the response of structure situated in seismic zone III and their comparison.
- To determine limit aspect ratio and slenderness ratio for safe and stable structure.
- To perform analysis using ETABS for static and dynamic analysis.

1.5 Scope of Project Work

i. Present study is strictly restricted to effect of seismic forces on flat slab structure without any lateral force resisting infill elements. To acquire in-depth knowledge about structural behavior we need to study structure with infill element which resist the lateral displacement of structure or which does not resist the movement.
ii. Types of damage occur and points of critical damage are to be studied to save unrepairable damage to lives of animals and human kind and other economic, strategic losses.
iii. Behavior of flat slab structure with different structural bracing elements under lateral loads are to be found out.

2. SITE PLANNING

a) Location

The site is located on the Mumbai – Pune Expressway at Baner. The proposed site as shown in location map is on plot number 35 on the main road.

b) Orientation

The wind direction of this area is from North-West winds. The intensity and the direction sometimes changes form season to season but for most of the year its direction is from NW to NE.

The sun rises for east and sets in west. The sun rays or the light intensity differs for season to season as during rainfall the clouds block the sun rays but throughout the year there is maximum use of the natural light.

The windows and doors are placed in such a way that the 90% of the natural resources are used to the fullest so as to save maximum electricity. As the building is commercial, the working hours may be considered as 8am – 7pm. In this time the windows are placed in such a way that there is maximum use of sunlight from sun rise till sun set.

c) Wind Directions

The placing of the windows and doors is done in such a way that the wind can be channelized through the interiors. This helps in a good working environment for the people working there.

As the wind directions vary from place to place and from time to time, most of the locations have a general major direction from which the wind comes for this site it is North West Winds.

d) Soil Type & Condition

From IS 1893: 2016, Cl.6.4.2.1

Table 1 - The desirable minimum corrected field values of N shall be as specified below:

Seismic Zone	Depth (m) below Ground Level	N Values	Remarks
III, IV & V	≤ 5 ≥ 10	15 25	For values of depths between 5m and 10m linear interpolation is recommended.
II	≤ 5 ≥ 10	10 20	

Hence according to IS 1893 :2016, Table 2,

Type B (Medium or Stiff Soils) is considered for design purpose. As stated in the code, poorly graded sands or poorly graded sands with gravel (SP) with little or no fines having N between 10 and 30. Stiff to medium stiff fine grained soils, like silts of low compressibility (ML) or clays of Low Compressibility (CL) having N between 10 and 30.

The SBC of soil considered for this project is 500kN/m^2.

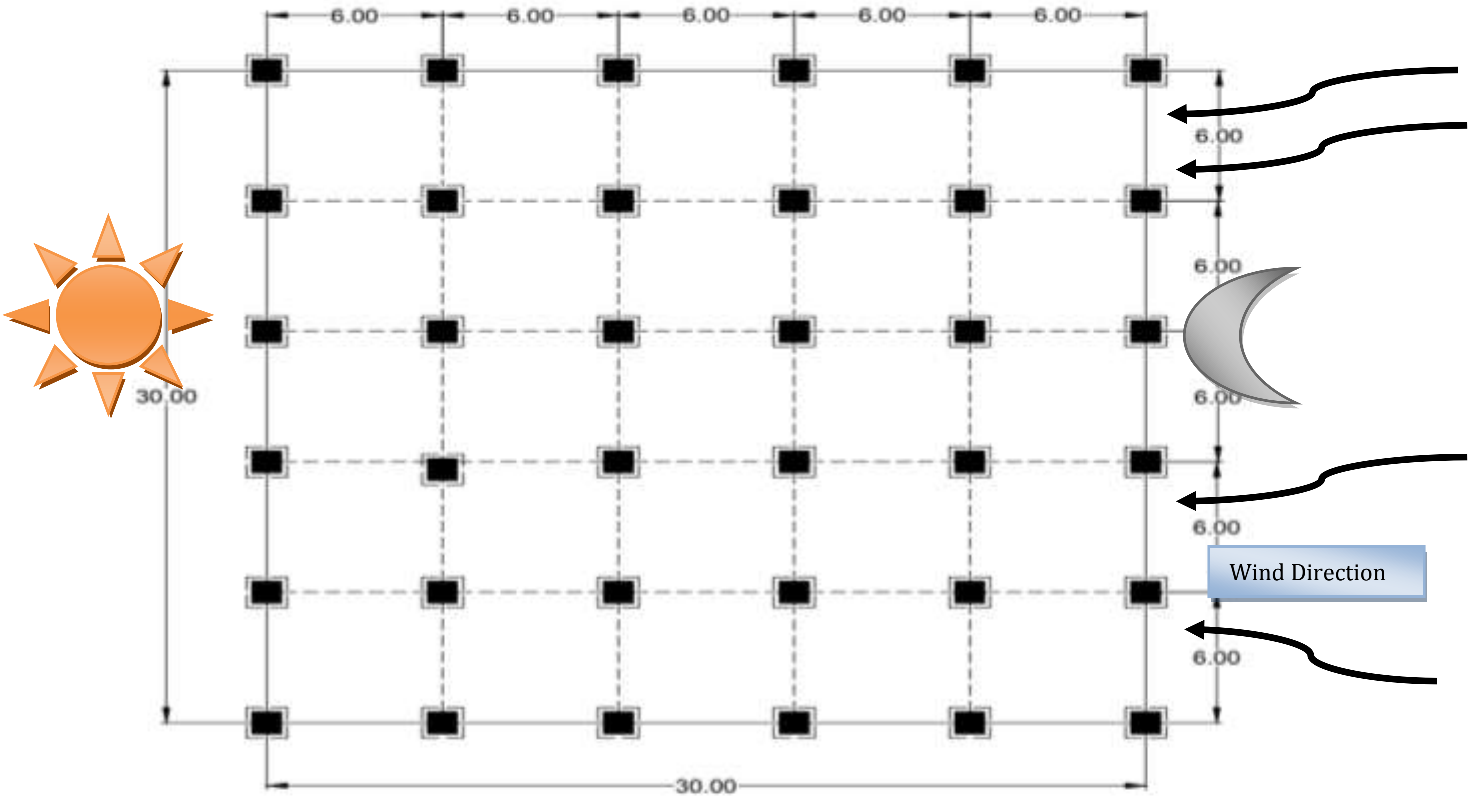


Fig. 6 –Floor Plan

3. STRUCTURAL MODELING DESIGN & ANALYSIS

Modeling a structure involves the modeling and assemblage of its various load-carrying elements. The model must ideally represent the mass distribution, strength, stiffness and deformability. Modeling and analysis is done with the help of ETABS 15 software. All 25 structures are separately modeled and analyzed by RSM. Template available for flat slab with drop are used to create models in ETABS software, proper material properties and joint restrains are assigned and column are assigned fixed support at base. Slabs and drops are assigned as Diaphragms which resist in plane deflection.

Following table represents all 25 models classified in different groups and named accordingly.

Sr No.	Model Group	Model	Aspect Ratio	Length (m)	Width (m)	Column Spacing (m)		No. of storey	Storey Height (m)	Slenderness Ratio
			(L.B)	L	B	X	Z		3.6	(H:B)
1		M11						3	14.4	0.48
2		M12						5	21.6	0.72
3	M1	M13	1	30	30	6	6	7	28.8	0.96
4		M14						9	36	1.2
5		M15						11	43.2	1.44
6		M21						3	14.4	0.69
7		M22						5	21.6	1.03
8	M2	M23	2	41	22	5.85	5.5	7	28.8	1.37
9		M24						9	36	1.71
10		M25						11	43.2	2.06
11		M31						3	14.4	0.85
12	M3	M32	3	50	18	5	6	5	21.6	1.27
13		M33						7	28.8	1.9
14		M34						9	36	2.12

15		M35						11	43.2	2.54
16		M41						3	14.4	0.96
17		M42						5	21.6	1.44
18	M4	M43	4	60	15	6	5	7	28.8	1.92
19		M44						9	36	2.4
20		M45						11	43.2	2.88
21		M51						3	14.4	1.11
22		M52						5	21.6	1.66
23	M5	M53	5	75	12	6.25	6	7	28.8	2.22
24		M54						9	36	2.77
25		M55						11	43.2	3.32

3.1 Material Properties and Design Data

Sr. No.	Design Parameter	Value
1	Unit weight of concrete	25 kN/m3
2	Characteristic strength of concrete	30MPa
3	Characteristic strength of steel	415MPa
4	Modulus of elasticity of steel	2 x 105 MPa
5	Plan area	900 square meters
6	Slab thickness	200mm
7	Drop thickness	300mm
8	Depth of foundation	3.5m
9	Floor height	3.6m

3.2 Seismic Design Data

Sr. No.	Design Parameter	Value
1	Earthquake Load	As Per IS 1893 (Part 1)-2016
2	Type of Foundation	Isolated Column Footing
3	Depth of Foundation	3.5m
4	Type of Soil	Type II, Medium As Per IS 1893-2016
5	Bearing Capacity of Soil	500 kN/m2
6	Siesmic Zone	III
7	Zone Factor (Z)	0.16
8	Response Reduction Factor (R)	5
9	Importance Factor	1
10	Percentage Damping	5%
11	Type of Frame	Special Moment Resisting Frame

3.3 Load Considered For Analysis

Sr.No.	Load Type	Value
1	Self weight of Slab and Column	As Per Dimension and Unit Weight of Concrete
2	Dead Load of Structural Components	As Per IS 875 Part-1
3	Live Load	Al Per IS 875 Part-2
4	Live Load on Roof and Typical Floor	4.0 kN/m2
5	Floor Finish	2.0 kN/m2

3.4 Cross Sectional Dimension for Column

Sr. No.	Type of Structure	Column Size
1	G+3 (5 storey structure)	450 mm X 450 mm
2	G+5 (7 storey structure)	450 mm X 450 mm
3	G+7 (9 storey structure)	450 mm X 450 mm
4	G+9 (11 storey structure)	600 mm X 600 mm
5	G+11 (13 storey structure)	600 mm X 600 mm

3.5 Parameters for Comparative Study

Following parameters are considered for comparative study of analysis results of models.

• Base shear

• Storey drift

• Storey stiffness

• Maximum storey displacement

• Natural time period

Results obtained from software analysis of models were filtered and then arranged to compare it with respective values of other models. For better understanding of results graphs are plotted.

3.6 Method of Seismic Analysis

Response Spectrum method allows determination of maximum modal response of a singly supported structural system or a multiple supported system where all supports receive the same excitation.

In order to perform the seismic analysis and design of a structure to be built at a particular location, the actual time history record is required.

However, it is not possible to have such records at each and every location.

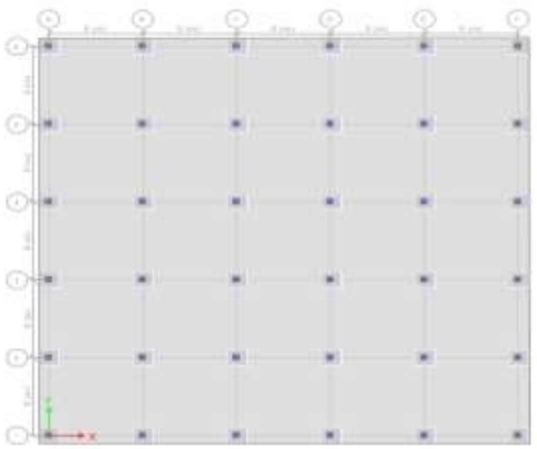
Further, the seismic analysis of structures cannot be carried out simply based on the peak value of the ground acceleration as the response of the structure depend upon the frequency content of ground motion and its own dynamic properties.

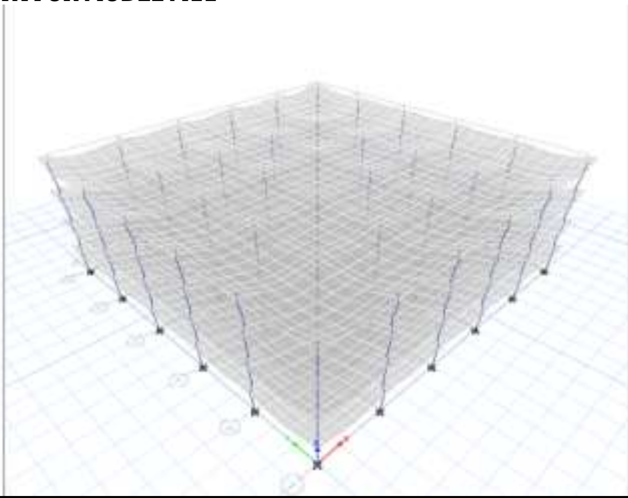
To overcome the above difficulties, earthquake response spectrum is the most popular tool in the seismic analysis of structures.

3.7 Design and Analysis

ASPECT RATIO = 1 : G+3 STRUCTURE : SLENDERNESS RATIO (H/B): 0.48

ANALYSIS DATA FOR MODEL M11

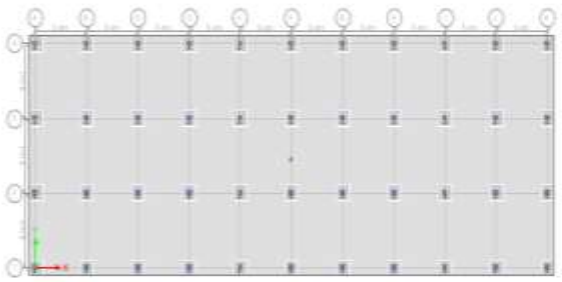


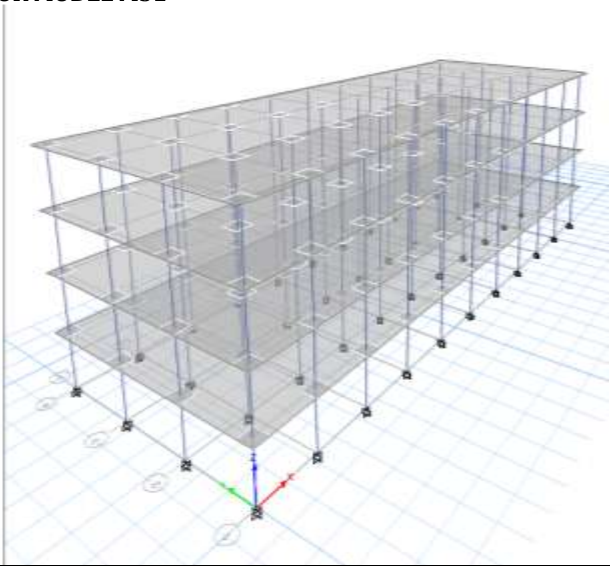


Sr no.	Storey	Shear X	Drift X	Stiffness X	Shear Y	Drift Y	Stiffness Y	Displacement X	Displacement Y
		KN	Mm	KN/m	KN	mm	KN/m	mm	mm

	1	2	3	4	5	6	7	8	9
1	STOREY 4	665.219	2.367	281001	665.342	2.367	281047	0.02	0.02
2	STOREY 3	1205.33	4.065	296547	1205.65	4.065	296613	0.017	0.017
3	STOREY 2	1585.2	5.115	309918	1585.57	5.115	309979	0.011	0.012
4	STOREY 1	1771.89	3.789	467666	1772.12	3.789	467712	0.005	0.005
5	BASE							0	0

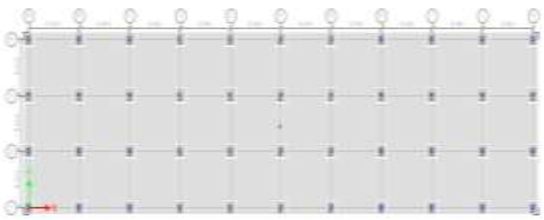
ASPECT RATIO = 3 : G+3 STRUCTURE : SLENDERNESS RATIO (H/B): 0.85
ANALYSIS DATA FOR MODEL M31

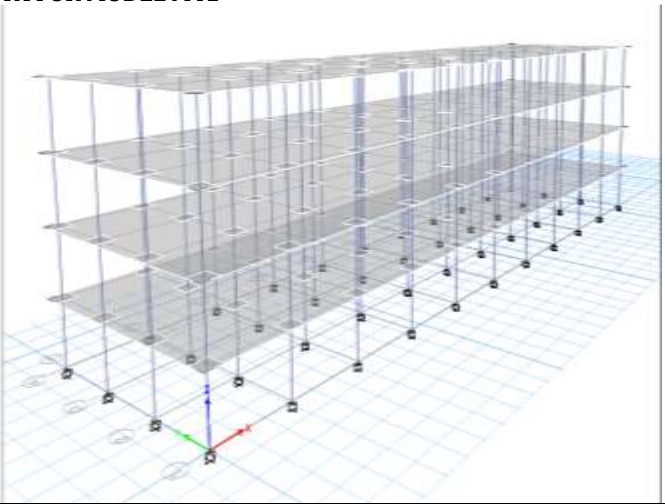




Sr no.	Storey	Shear X	Drift X	Stiffness X	Shear Y	Drift Y	Stiffness Y	Displacement X	Displacement Y
		KN	Mm	KN/m	KN	mm	KN/M	mm	mm
	1	2	3	4	5	6	7	8	9
1	STOREY 4	5030.14	13.512	372281	5074.03	16.595	305762	5.387E-06	0.017
2	STOREY 3	9212.41	23.601	390342	9244.43	28.154	328350	8.727E-06	0.014
3	STOREY 2	12180.6	30.01	405883	12180	35.111	346905	6.244E-06	0.01
4	STOREY 1	13645.8	22.796	598606	13599.9	25.232	538983	0.00001446	0.004
5	BASE							0	0

ASPECT RATIO = 4 : G+3 STRUCTURE : SLENDERNESS RATIO (H/B): 0.96
ANALYSIS DATA FOR MODEL M41



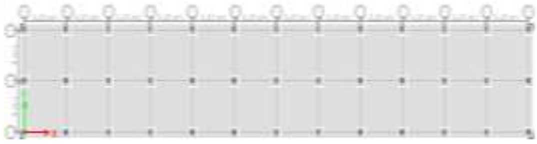


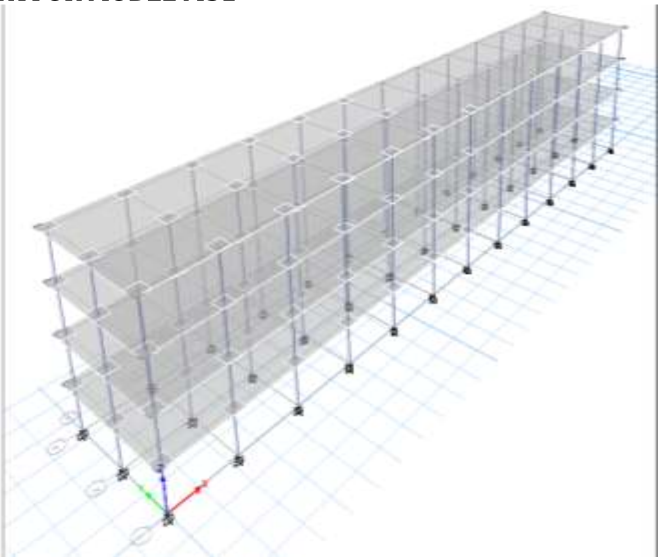
Sr no.	Storey	Shear X	Drift X	Stiffness X	Shear Y	Drift Y	Stiffness Y	Displacement X	Displacement Y
		KN	Mm	KN/m	KN	mm	KN/M	mm	mm
	1	2	3	4	5	6	7	8	9
1	STOREY 4	447.706	3.393	131944	449.84	3.371	133427	0.03	1.17E-06

2	STOREY 3	731.328	4.858	150549	736.196	4.828	152494	0.024	3.24E-06
3	STOREY 2	934.492	5.395	173215	941.008	5.366	175364	0.015	1.54E-06
4	STOREY 1	1051.69	3.179	330804	1058.68	3.169	334044	0.006	2.86E-06
5	BASE							0	0

ASPECT RATIO = 5 : G+3 STRUCTURE : SLENDERNESS RATIO (H/B): 1.11

ANALYSIS DATA FOR MODEL M51





Sr No.	Storey	Shear X	Drift X	Stiffness X	Shear Y	Drift Y	Stiffness Y	Displacement X	Displacement Y
		KN	Mm	KN/m	KN	mm	KN/M	mm	mm
	1	2	3	4	5	6	7	8	9
1	STOREY 4	577.978	2.035	284019	563.575	2.139	263492	3.19E-05	0.028
2	STOREY 3	1023.95	3.438	297821	990.59	3.53	280604	4.07E-05	0.024
3	STOREY 2	1338.69	4.284	312490	1291.63	4.352	296773	3.7E-05	0.016
4	STOREY 1	1501.14	3.104	483556	1448.49	3.093	468348	4.5E-05	0.007
5	BASE							0	0

Variation in period and frequency

SrNO.	Mode	Period	Frequency	Period	Frequency	Period	Frequency	Period	Frequency	Period	Frequency
		sec	cyc/sec	sec	cyc/sec	sec	cyc/sec	sec	cyc/sec	sec	cyc/sec
		M11		M21		M31		M41		M51	
1	1	1.561	0.641	1.488	0.672	1.492	0.67	1.523	0.657	1.523	0.657
2	2	1.551	0.645	1.459	0.685	1.462	0.684	1.434	0.697	1.434	0.697
3	3	1.438	0.695	1.374	0.728	1.42	0.704	1.384	0.722	1.384	0.722
4	4	0.495	2.02	0.473	2.116	0.474	2.111	0.482	2.073	0.482	2.073
5	5	0.493	2.03	0.465	2.152	0.466	2.146	0.458	2.183	0.458	2.183
6	6	0.453	2.209	0.434	2.303	0.449	2.229	0.44	2.275	0.44	2.275
7	7	0.276	3.622	0.264	3.788	0.265	3.779	0.269	3.724	0.269	3.724
8	8	0.275	3.634	0.261	3.837	0.262	3.816	0.258	3.87	0.258	3.87
9	9	0.249	4.011	0.241	4.158	0.248	4.027	0.245	4.077	0.245	4.077
10	10	0.187	5.335	0.179	5.572	0.18	5.547	0.182	5.503	0.182	5.503
11	11	0.187	5.344	0.178	5.607	0.179	5.574	0.178	5.607	0.178	5.607
12	12	0.167	5.999	0.162	6.175	0.167	5.98	0.167	5.989	0.167	5.989

3.8 Result Chart

3.7.1 Maximum Deflection

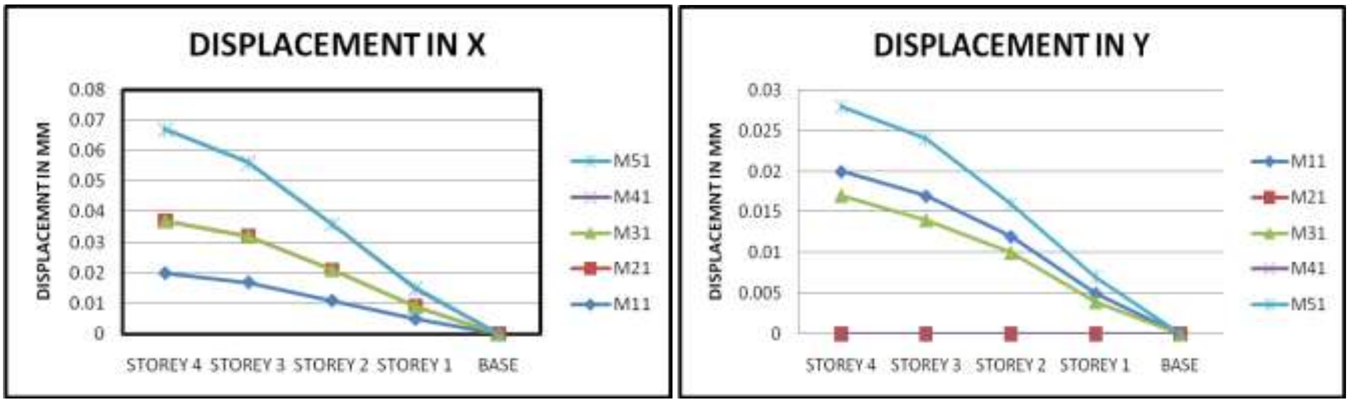


Chart-1&2: For G+3 Storey

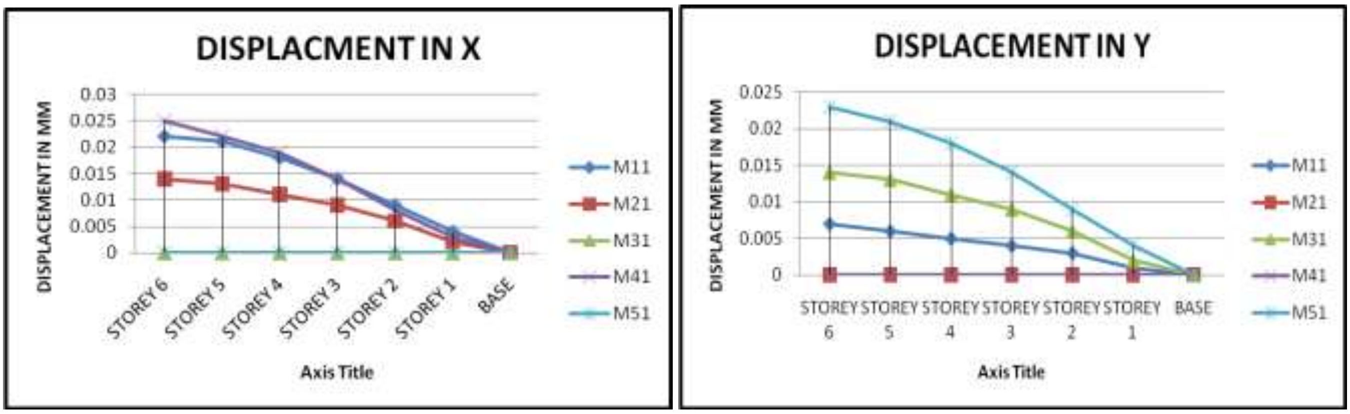


Chart-3&4: For G+5 Storey

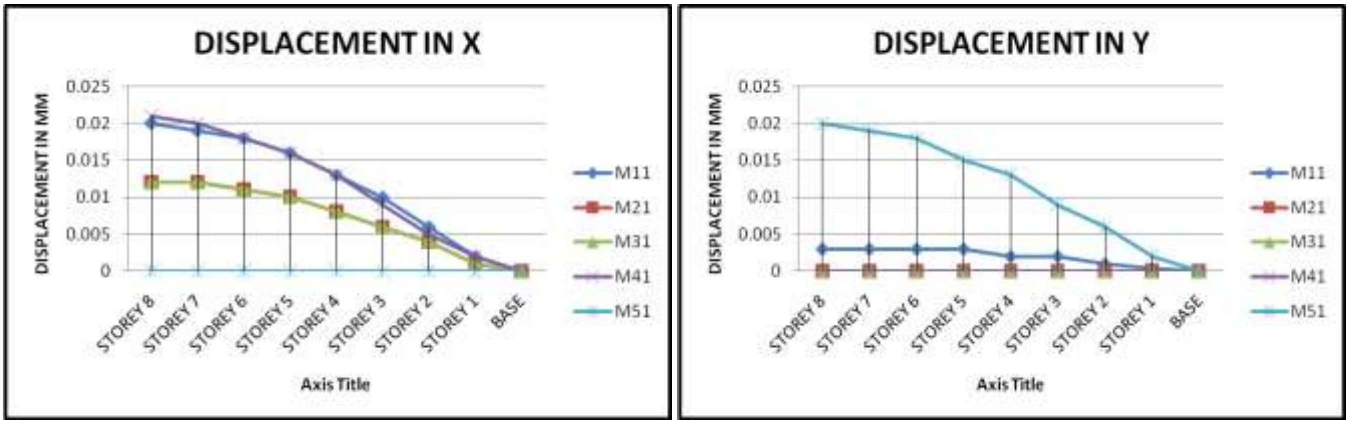


Chart-5&6: For G+7 Storey

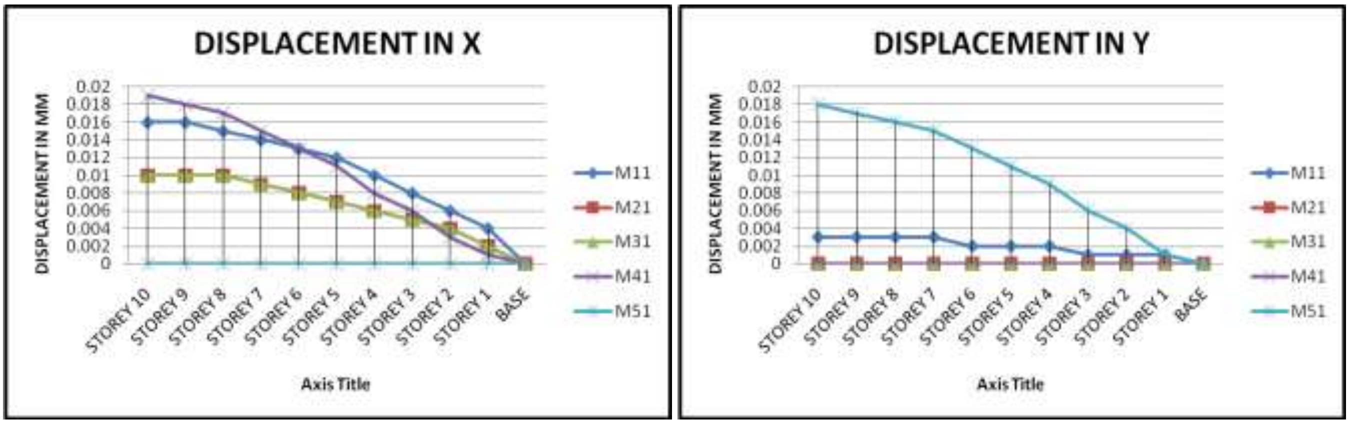


Chart-7&8: For G+9 Storey

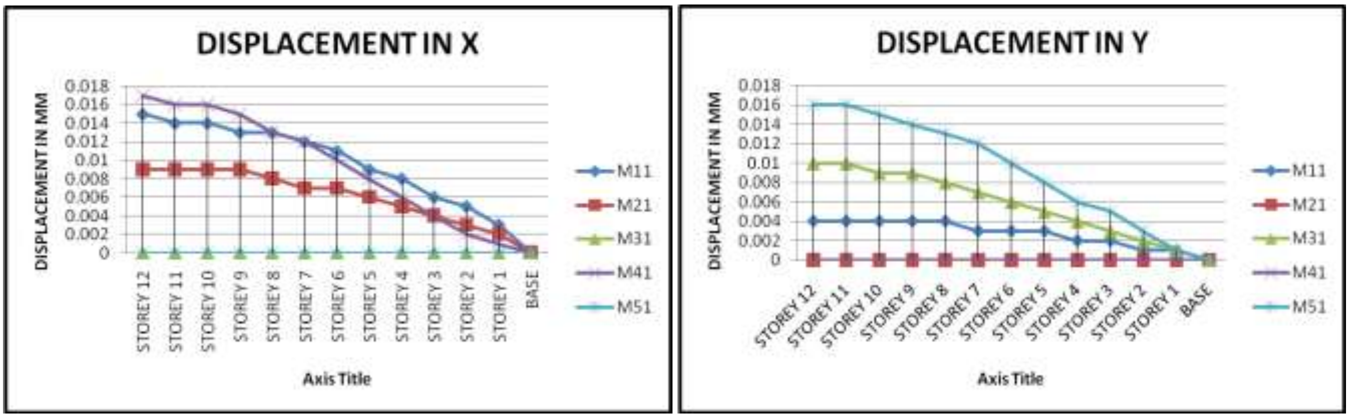


Chart-9&10: For G+11 Storey

From above graphs points observed are as following:

- Displacement for aspect ratio L/B = 5 is maximum.
- For first mode displacement in x direction is greater than y direction up to G+9 models.
- Displacement decreases with increase in aspect ratio up to L/B = 3.

3.7.2 Maximum Storey Drift

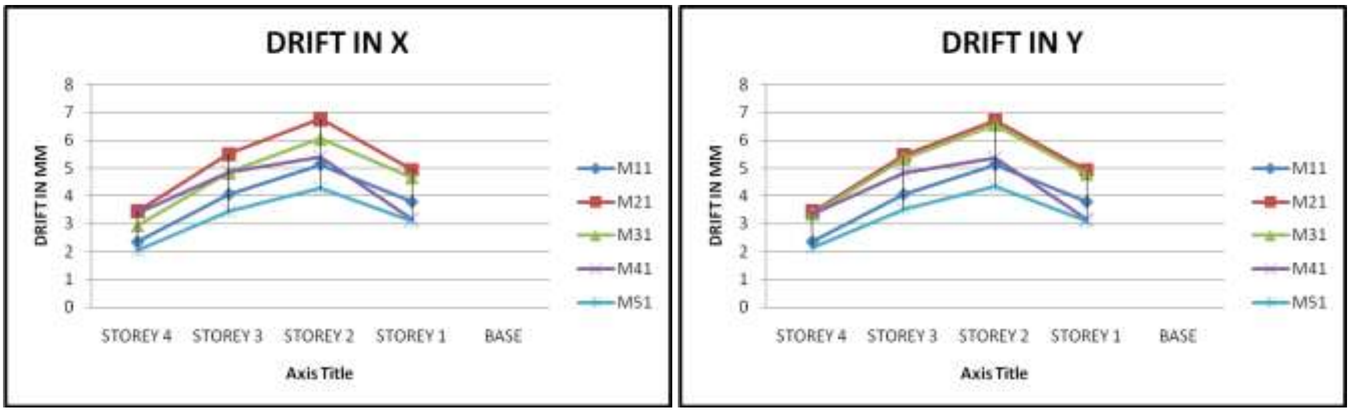


Chart 11&12: For G+3

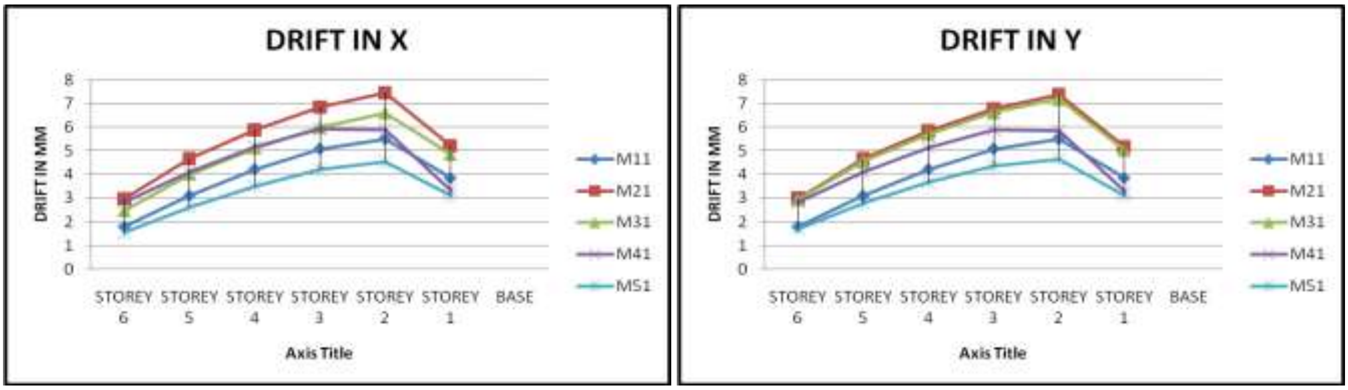


Chart 13 & 14: For G+5

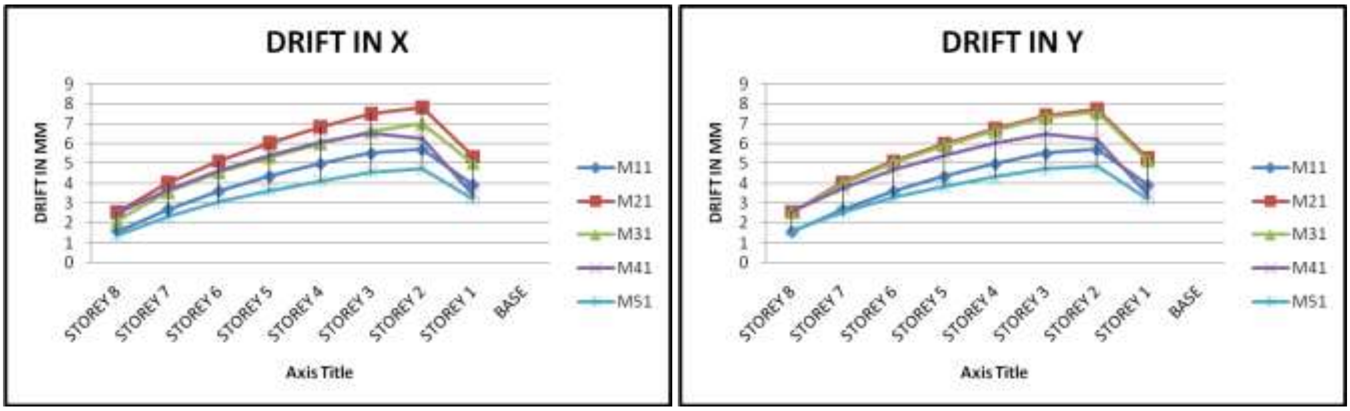


Chart 15 & 16: For G+7

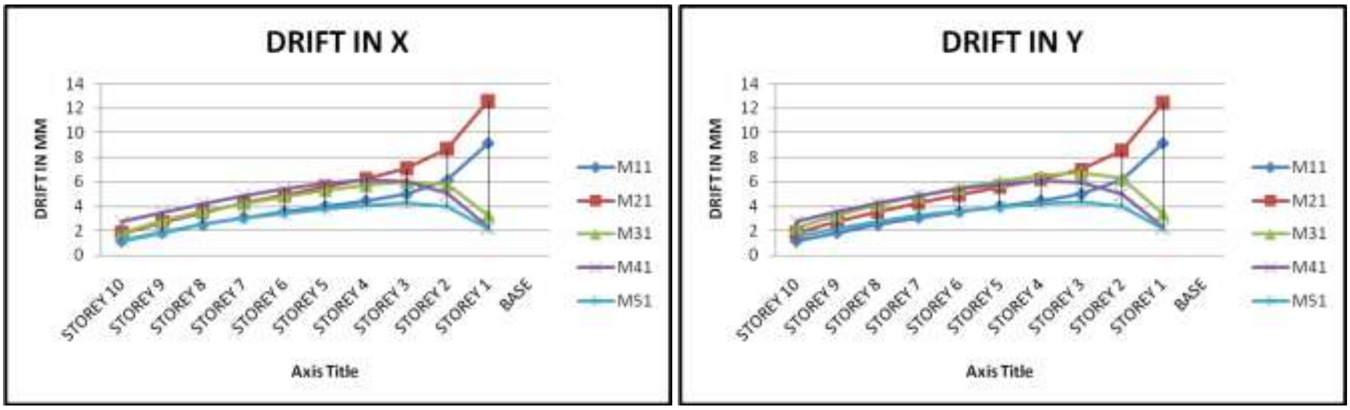


Chart 17&18 : For G+9

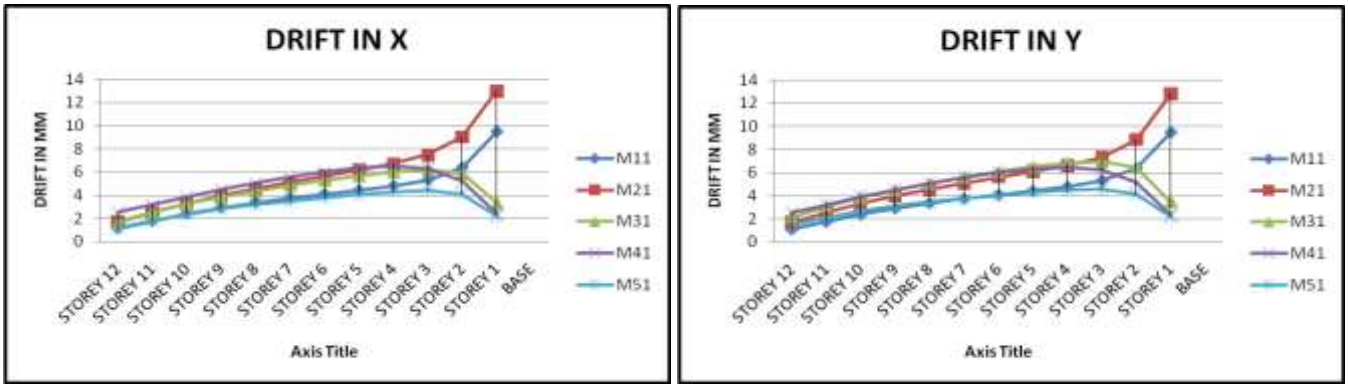


Chart 19 & 20: For G+11

From above graphs points observed are as following

- In case of flat slab structure Storey drift in x direction is more as compared to Storey drift in y direction for same slenderness ratio.

- Maximum value of Storey drift was found out to be at second storey level in case of G+3, G+5, G+7 structures where as in case of G+9 and G+11 storey structure the maximum Storey drift was found on third storey level

- As per limitation laid by IS 1893 (Part 1) 2002, the maximum drift should not be more than 0.004 times storey height which is 0.0144 m. This drift limit is exceeds in aspect ratio L/B= 5 and slenderness ratio 3.32

3.7.3 Maximum Storey Stiffness

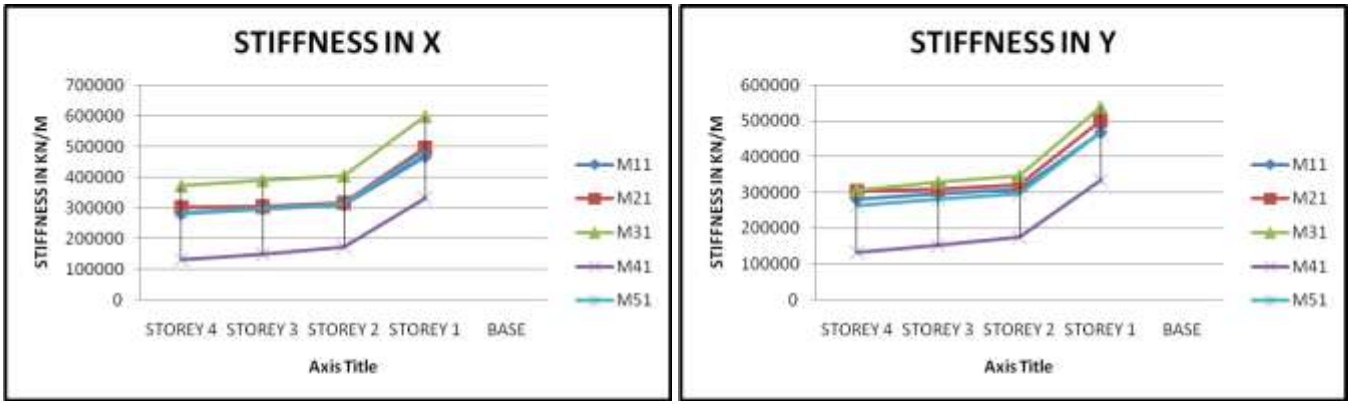


Chart 21 & 22: For G+3

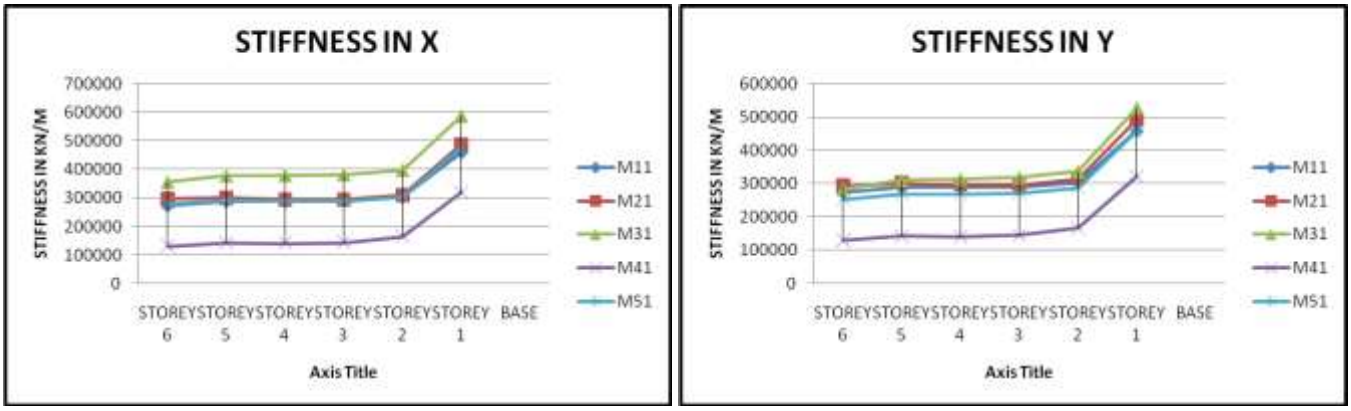


Chart 23 & 24: For G+5

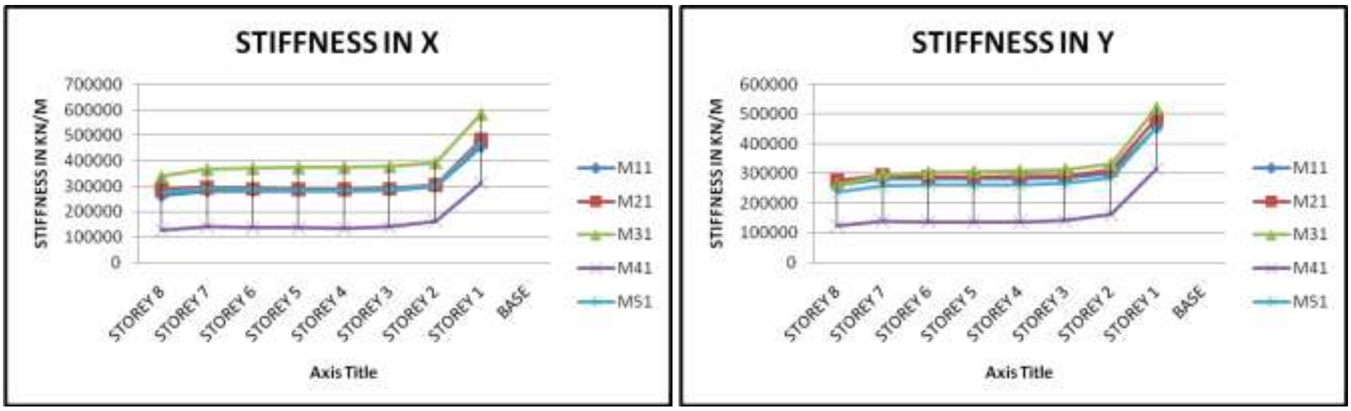
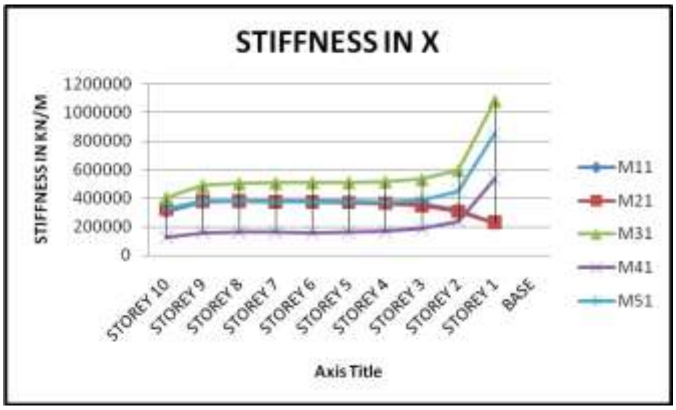


Chart 25 & 26: For G+7



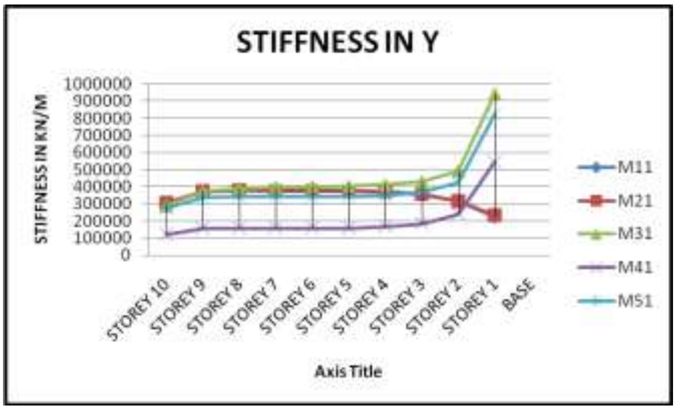
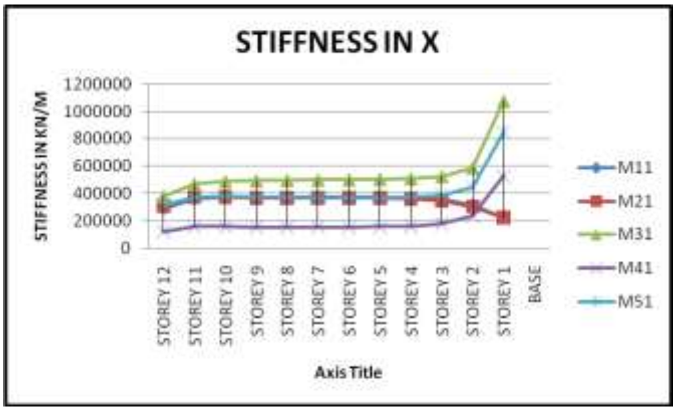


Chart 27 & 28: For G+9



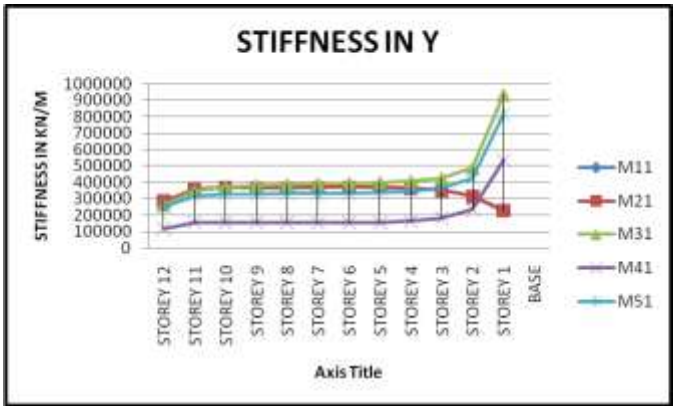
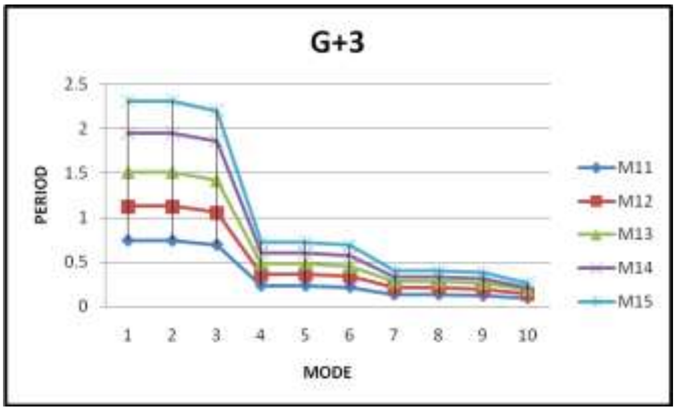


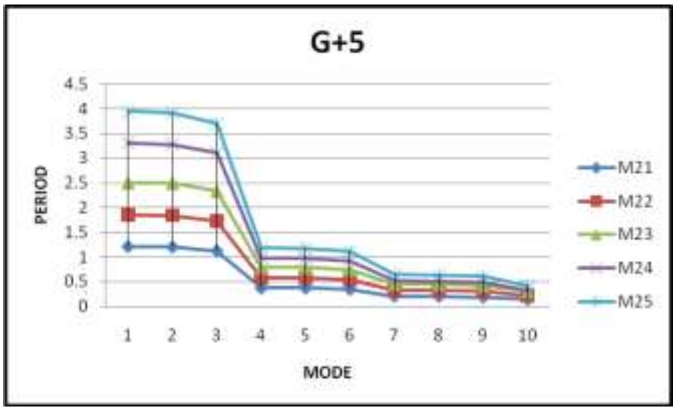
Chart 29 & 30: For G+11

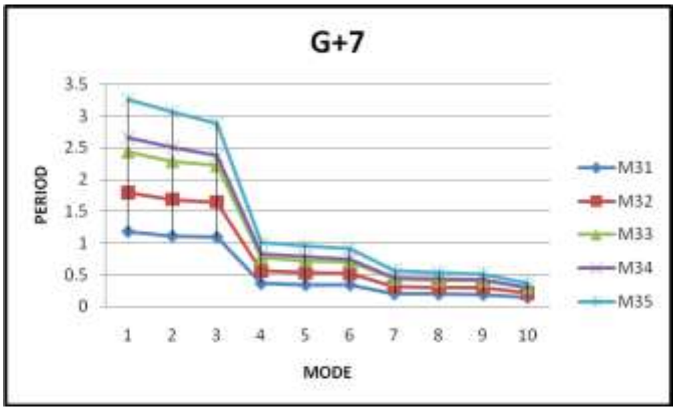
From above graphs points observed are as following

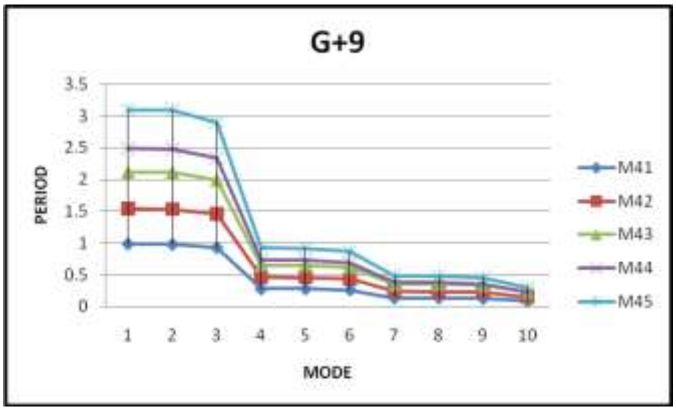
- Storey stiffness increases with size of column
- For same size of column stiffness increases with no of column in respective direction.

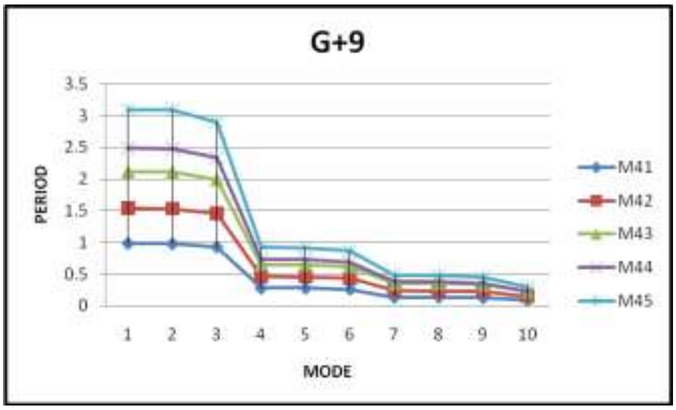
3.7.4 Time Period

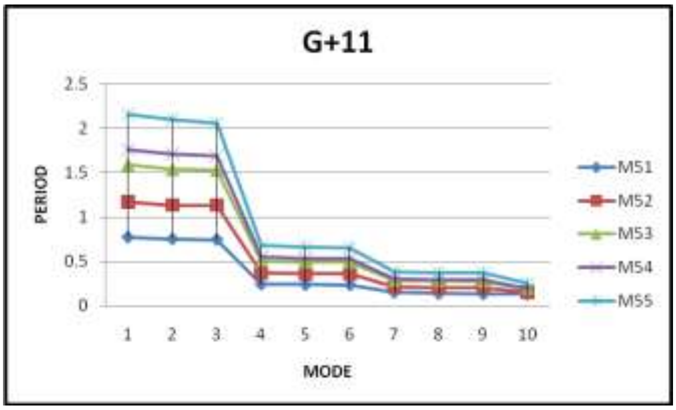












From above graphs points observed are as following

- For first 3 modes value of time period is maximum.
- With increase in no of storey time period increases.
- Sudden increase in time period for model M55 is noted.

3.8 RESULTS

3.8.1 BASE SHEAR

- From tables of results the value of the base shear is found out to be increasing with increase in slenderness ratio & aspect ratio.
- The percentage increase in base shear for aspect ratio 4 & 5 is more as compared to other ratio, as the column size increases seismic weight increases.
- In case of same number of storey base shear does not increases linearly with linear increase in aspect ratio.

3.8.2 STOREY DRIFT

- Building with aspect ratio 1 have same drift in both the direction
- Increase in slenderness ratio Results in increasing maximum storey drift
- In case of flat slab structure Storey drift in x direction is more as compared to Storey drift in y direction for same slenderness ratio
- Maximum value of Storey drift was found out to be at second storey level in case of G+3, G+5, G+7 structures where as in case of G+9 and G+11 storey structure the maximum Storey drift was found on third storey level.

- Value of maximum storey drift is exceeded in model M55 is 20.1 mm which is more than limiting value 14.4 mm for storey height 3600 mm.

- Increasing lateral stiffness of structure by increasing size of column results in increasing storey level of maximum storey drift.

- As per limitation laid by IS 1893 (Part 1) 2002, the maximum drift should not be more than 0.004 times storey height which is 0.0144 m. This drift limit is exceeds in aspect ratio L/B= 5 and slenderness ratio 3.32.

3.8.3 STIFFNESS

- With increase in lateral storey Stiffness fundamental time period decreases.

- Increase in lateral storey stiffness Results in decreases Storey drift and maximum storey displacement.

- In same aspect ratio size of column are not fixed so stiffness changes with change in column size. Results in change of behaviour of structure for lateral loading.

- Increasing lateral stiffness of structure by increasing size of column results in increasing storey level of maximum storey drift.

3.8.4 NATURAL TIME PERIOD

- The value of time period increases with increase in slenderness ratio

- The numerical value for modal period and frequency shows that value of period increases linearly with linear increase in slenderness ratio but not in the case of change in aspect ratio.

- First three modes of displacement govern the response of structure for lateral loads. In first three modes natural time period is more frequency is less hence for lower values of excitation gives maximum lateral deflection.

4. CONCLUSIONS

Based on the work done in this dissertation following conclusions are drawn:

- Limiting plan aspect ratio is L/B =5 and slenderness ratio is 3.32.

- Structure with aspect ratio more than 3 has higher magnitude of design base shear along both X and Y direction though their seismic weight is lesser than structure with aspect ratio 3.

- Curtailment in column size reduces the seismic weight of structure, hence less seismic weigh and less base shear.

- Buildings having square plan shape i.e. aspect ratio 1, is safest because:

  - Lower and equal amount of base shear is acting along both X and Y direction.

  - Fundamental time period for square plan structure is comparatively lesser than rectangular plan building. Hence it will perform well during earthquake with higher frequencies.

  - Lateral deformation (i.e. lateral displacement and storey drift) for all the storey level is same along both X and Y direction.

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