A Study on Seismic Behavior of Hexagrid Type Structural System

Ronak S. Vagadiya[1], Prof. Deepak K. Jivani[2], Dr. R.G. Dhamsaniya[3], Prof. M. V. Sanghani[4]

[1]*P.G.Student, Department of Civil Engineering, DIET-Rajkot, Gujarat, India*

[2]*Assistant Professor, Department of Civil Engineering, DIET-Rajkot, Gujarat, India*

[3] *Professor & principal, Civil Engineering, DIET-Rajkot, Gujarat, India*

[4] *Professor, Department of Civil Engineering, DIET-Rajkot, Gujarat, India*

ABSTRACT

There are a number of high-rise structures constructed all over the world and are being continue to construct. The analysis and design of high-rise structures is quite different from that of low rise structures because of lateral forces due to wind and earthquake. In high-rise structures the resistance to lateral loading becomes dominant criteria that have to be considered in the analysis and design and an efficient lateral load resisting system will define the efficiency of tall structures. In order to improve the efficiency of tube-type structures in tall buildings, a new structural system, called "Hexagrid", is introduced in this study. It consists of multiple hexagonal grids on the facade of the building. In Hexagrid structural system almost all the conventional columns are eliminated. In this study an attempt has been made to study the Hexagrid structural patterns namely Horizontal hexagrid structural pattern and Vertical Hexagrid structural patterns under the seismic behavior & identify which structural pattern is efficient. The hexagrid resist both gravity & lateral load by the axial action of the diagonal members so, they simply act in tension or compression with no bending, depending upon the direction of the loading. A regular floor plan 36m x 36m is considered, all structural members are designed as per IS 456:2000. Earthquake parameters are considered from 1893-2002. Dead & live loads are considered as per Indian Standards. Here, analysis of hexagrid system will be conducted by using analysis & design software sap (2000). In this research, a set of structures using Hexagrid system having three various diagonal angles 40,50,60, degrees were designed based on plan configuration by computer program sap (2000), for G+30, Story buildings for two different structural patterns namely horizontal hexagrid structural patterns & vertical hexagrid structural patterns. Finally, seismic behaviors of different hexagrid models based on hexagrid structural patterns is compared in terms of story drift, story displacement, time period, Distribution of load (Total gravity load & EQ as a lateral load), Base reactions, for static analysis & dynamic analysis in the form of response spectrum.

Keyword: - *Hexagrid (Beehive-structure), new innovated structural system, Hexagrid structural patterns, Seismic Behavior, Angle performance of Hexagrid, Braced-frame tube, Story-Drift (Drift-Ratio), Response Spectrum.*

I. INTRODUCTION

Due to heavy urbanization and population growth, the cost of land is increasing rapidly and the land availability has become a constraint for developers & builders. This creates a picture of vertical growth as natural process. The control of lateral responses keeping an eye on constructability & cost become order of the day for the structural engineers. The increased wind pressure due to large exposed area of the building, high intensity of the wind at higher elevations and the earthquake loads add to the bulk of the structural forces & minimizing their effects on life of tall structure. Major point of this design approach is to introduce a new innovated structural system for tall buildings as a hexagrid structural system. Hexagrid consist of intersecting the diagonal & horizontal structural components. In hexagrid structural system almost all the conventional columns are eliminated. The topology of the hexagrid system is an important design variables since the degree of an angle between the diagonal members consisting of hexagrid determines stress distribution resisting internal forces.

Control of lateral responses keeping an eye on constructability & cost become order of the day for structural engineers. The increased wind pressure due to the large exposed area of the building, high intensity of the wind at higher elevations and the earthquake loads add to the bulk of structural forces. The present study is based on such bulk lateral forces in the form of seismic force & minimizing their effects on life of tall structure. Here it is attempted to derive at a stability optimised structural system – i.e. hexagrid structural system.

II. METHODOLOGY

In this paper comparison of Hexagrid structural patterns for different varying angles under total gravity load & under lateral load in the form of EQ is carried out for both static & dynamic analysis in the form of Response Spectrum method.

For the hexagrid analysis a suitable square plan of square shape 36mt X 36mt is considered (G+30 building) for study purpose & designed as per IS 456:2000. Dead & Live loads are considered as per the Indian Standards. Seismic parameters may be taken as IS 1893:2002. For hexagrid structural modal we considered both structural patterns according to the plan dimensions i.e. Horizontal & vertical hexagrid structural patterns and then both the systems may be compared for different angles varying from 40˚ to 65˚ for static & Dynamic analysis in the form of response spectrum.

Finally, both the structural patterns is compared for different parameters such as modal analysis (Mode-shapes) in the form of Time-period, static & Response spectrum method for displacement, Story-drift (Drift-ratio), distribution of load, base-shear, etc.

III. RESPONSE SPECTRUM METHOD

"The presentation of the maximum response of idealized single degree of freedom systems having certain period and damping during earthquake ground motion is referred as **Response spectrum**". Response Spectrum analysis should be performed to obtain the design seismic force, & its distribution to different levels along the height of the building and various lateral load resisting elements. 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 can't 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. There are computational advantages in using the response spectrum method of seismic analysis for prediction of displacements and member forces in structural systems. The method involves the calculation of only the maximum values of the displacements and member forces in each mode of vibration using smooth design spectra that are the average of some earthquake motions.

IV. PROBLEM STATEMENT

A regular symmetrical floor plan of 36mt X 36mt is considered, all structural members are designed as per the IS 456:2000. After designing the one hexagrid model all the parameters such as beam, column & grid dimensions as well seismic parameters & story height should be kept constant for all different hexagrid models for both different hexagrid structural patterns such as horizontal hexagrid & vertical hexagrid structural patterns.

For hexagrid structural modal we considered both structural patterns according to the plan dimensions i.e. Horizontal hexagrid structural patterns & vertical hexagrid structural patterns and then both the systems may be compared for different angles varying from 40˚ to 65˚ for static analysis & dynamic analysis in the form of response spectrum. In hexagrid structural patterns story height should be kept constant equal to 3mt for every model.

Table 1. Building parameters

Plan	36mt
Height of building	93 mt
Floor to floor height	3 mt
Depth of slab	120 mm
Number of stories	G+30
Floor finish	1 KN/m^2
Live load	2 KN/m^2
Characteristics strength of concrete	30 N/mm^2
Characteristics strength of steel	415 N/mm^2

Table 2. Beam, Column & Grid Dimensions

B2	400mm X 600mm
C1	1650mm X 1650mm
D1	800mm X 800mm

Table 3. Seismic parameters

Zone factor	0.36
Importance factor	1
Type of soil	Medium
Response reduction factor	5
Damping ratio	5%

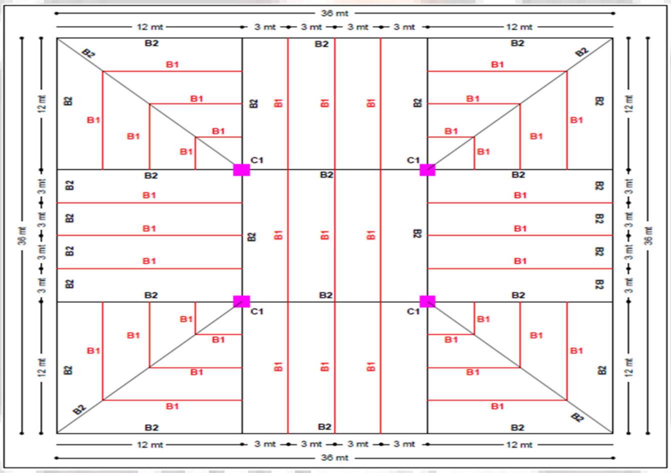
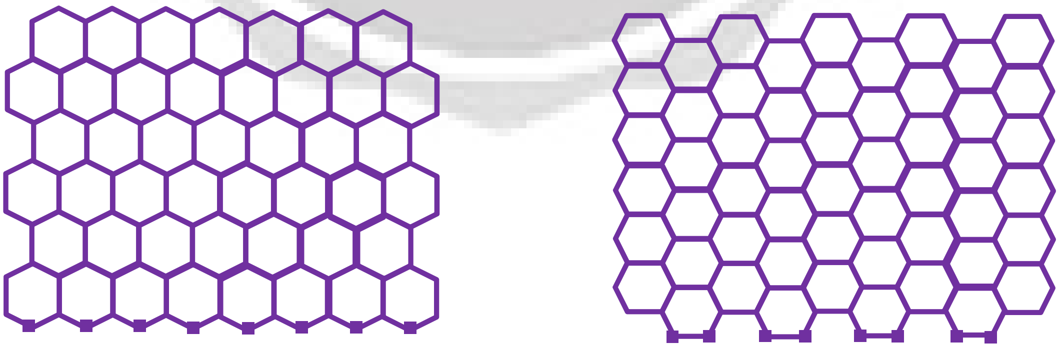


Figure 1. Plan of the study



(a). Elevation of Vertical hexagrid patterns *(b). Elevation of Horizontal hexagrid patterns*

Figure 2. Elevation of hexagrid patterns

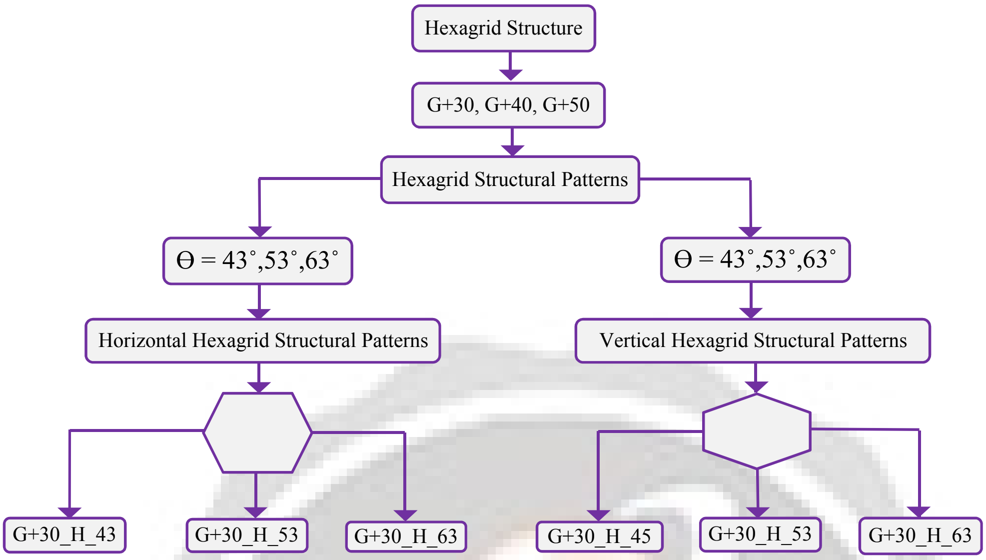
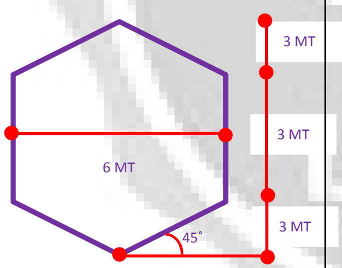
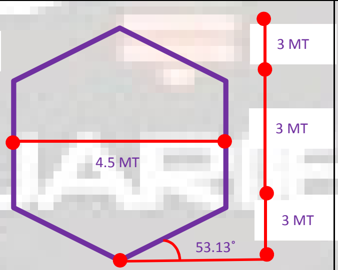
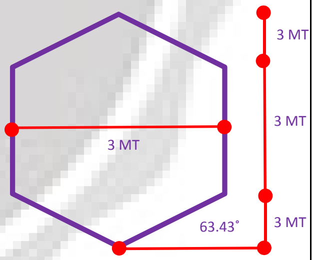
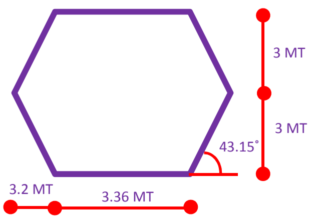
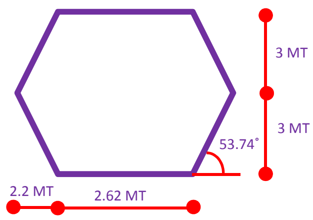
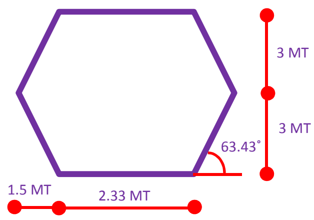


Figure 3. Flow chart of the study

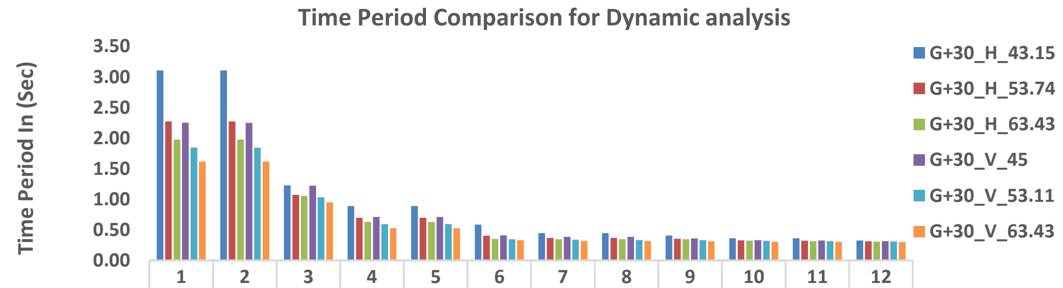
Table 4. Horizontal & Vertical structural patterns based in angle variation

G+30_V_45	G+30_V_53.13	G+30_V_63.43
No of Hexagons = 6	No of Hexagons = 8	No of Hexagons = 8
		
G+30_H_43	G+30_H_53	G+30_H_63.43
No of Hexagrid = 5	No of Hexagrid = 7	No of Hexagrid = 9
		

IV. RESULTS AND DISCUSSION

Here, for the comparison purpose of Horizontal & Vertical Hexagrid structural patterns both structural patterns are analysed for linear static analysis & Dynamic analysis in the form of Response spectrum method and finally it will be compared in terms modal analysis (Time-period), story-displacement, story-drift, distribution of total gravity & EQ load, base-shear comparison, etc.

Time period is a property of system, when it allows to vibrate freely without any external force and it depends on mass and stiffness of the structure. Fundamental time period is inversely proportional to the frequency of the structure. With increase in angle of inclination no of hexagons are increased and structure becomes stiffer & it has less time-period for both the structural grids as shown in figure 5 & it will be same for both methods linear static & response spectrum method.



	1	2	3	4	5	6	7	8	9	10	11	12
G+30_H_43.15	3.11	3.10	1.23	0.89	0.89	0.59	0.45	0.45	0.41	0.37	0.36	0.33
G+30_H_53.74	2.27	2.27	1.07	0.70	0.70	0.41	0.37	0.37	0.36	0.33	0.33	0.31
G+30_H_63.43	1.98	1.98	1.06	0.63	0.63	0.35	0.35	0.35	0.35	0.32	0.32	0.31
G+30_V_45	2.25	2.25	1.22	0.71	0.71	0.41	0.39	0.39	0.36	0.33	0.33	0.32
G+30_V_53.11	1.85	1.85	1.03	0.59	0.59	0.35	0.34	0.33	0.33	0.32	0.32	0.31
G+30_V_63.43	1.62	1.62	0.95	0.53	0.53	0.33	0.32	0.32	0.31	0.31	0.30	0.30

No Of Modes

Figure 4. Time-period comparison for both structural grids

Displacement comparison for horizontal & vertical hexagrid structural patterns is plotted in the graphical form for different hexagrid models as shown in figure 6 & figure 7 for linear static & response spectrum method respectively. With increase in angle of inclination no of hexagon is increased and structure becomes stiffer & displacement is gradually decreased for both the structural patterns as plotted in the graphical form for both horizontal & vertical hexagrid structural patterns.

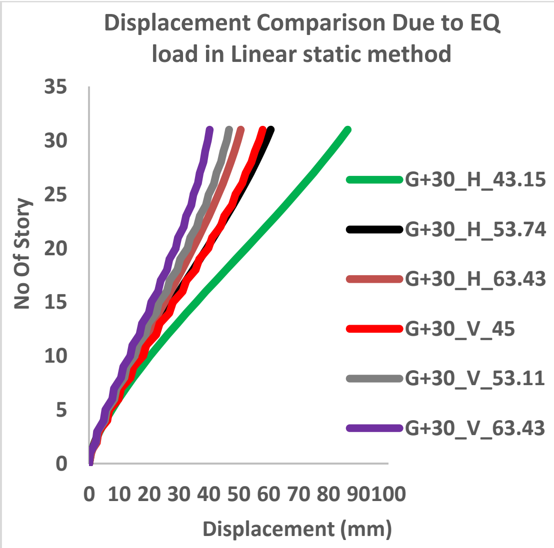


Fig 5. Displacement comparison for both structural grids in linear static method

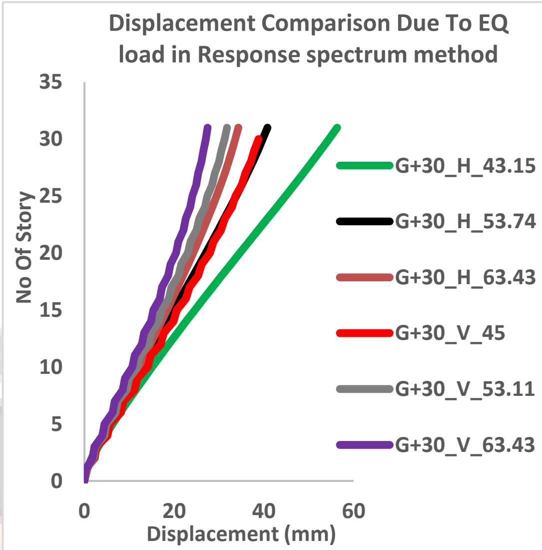


Fig 6. Displacement comparison for both structural grids in response spectrum method

Story-Drift is the relative story displacement due to acting of total lateral load. Story-drift is defined as a "Drift of one level of multi-story relative to level below". Story drift comparison for horizontal & vertical hexagrid structural patterns is plotted in the graphical form for different hexagrid models as shown in figure 8 & figure 9 for linear static & response spectrum method respectively. With increase in angle of inclination no of hexagon is increased and structure becomes stiffer & same comparison is obtained as displacement as plotted in the graphical form in figure 8 & figure 9 for linear static & Response spectrum method respectively.

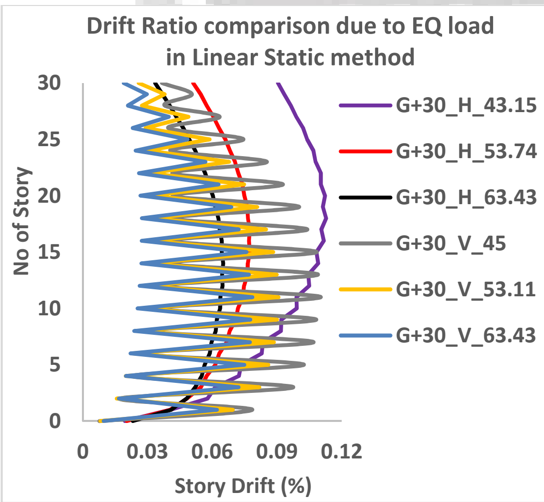


Fig 7. Story-drift comparison for both structural grids in linear static method

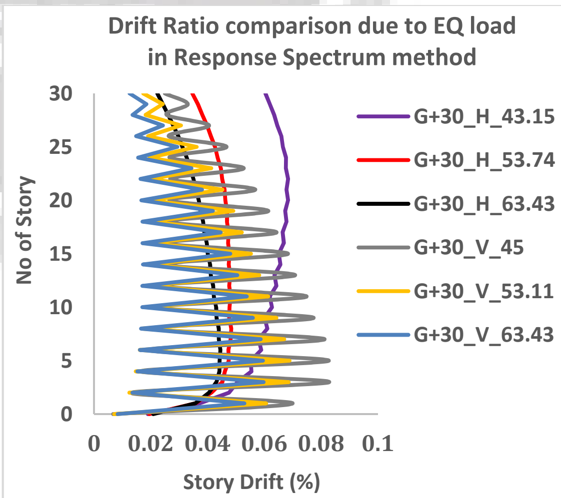


Fig 8. Story-drift comparison for both structural grids in response spectrum method

Distribution of total gravity load & EQ load is plotted for horizontal & vertical hexagrid structural patterns in the graphical form for different hexagrid models as shown in figure & also in tabular form as shown in below table for linear static & response spectrum method respectively.

Load transferred mechanism is directly proportional to the area covered by elements at facade in the form of grids or centrally column. In our study grids at the facade can cover more area as compared to the centrally column area so grids can transferred more loads either lateral load in the form of earthquake load and total gravitational load.

Table 5. Distribution of load in G+30_V_45˚

	Distribution of load (KN) in Hexagrid	Distribution of load (KN) in Column	Total Distribution of load on hexagrid system	% Distribution in Hexagrid	% Distribution in Column
D.L+L.L+F.F	255360.67	187365.26	442725.93	57.68%	42.32%
EQx	6340.42	2003.21	8343.63	75.99%	24.01%
RSPx	6157.05	1552.55	7709.60	79.86%	20.14%

Table 6. Distribution of load in G+30_V_53.11˚

	Distribution of load (KN) in Hexagrid	Distribution of load (KN) in Column	Total Distribution of load on hexagrid system	% Distribution in Hexagrid	% Distribution in Column
D.L+L.L+F.F	283561.50	185120.80	468682.30	60.50%	39.50%
EQx	9164.30	1696.60	10860.90	84.38%	15.62%
RSPx	8356.83	1324.09	9680.92	86.32%	13.68%

Table 7. Distribution of load in G+30_V_63.43˚

	Distribution of load (KN) in Hexagrid	Distribution of load (KN) in Column	Total Distribution of load on hexagrid system	% Distribution in Hexagrid	% Distribution in Column
D.L+L.L+F.F	325729.00	179654.50	505383.50	64.45%	35.55%
EQx	12124.50	1379.77	13504.27	89.78%	10.22%
RSPx	10523.44	1114.78	11638.22	90.42%	9.58%

Table 8. Distribution of load in G+30_H_43.15˚

	Distribution of load (KN) in Hexagrid	Distribution of load (KN) in Column	Total Distribution of load on hexagrid system	% Distribution in Hexagrid	% Distribution in Column
D.L+L.L+F.F	241084.90	210594.20	451679.10	53%	47%
EQx	2819.50	3368.51	6188.01	45.56%	54.44%
RSPx	6543.87	2601.77	9145.63	71.55%	28.45%

Table 9. Distribution of load in G+30_H_53.746˚

	Distribution of load (KN) in Hexagrid	Distribution of load (KN) in Column	Total Distribution of load on hexagrid system	% Distribution in Hexagrid	% Distribution in Column
D.L+L.L+F.F	269044.00	192197.50	461241.50	58.33%	41.67%
EQx	5594.35	3062.25	8656.60	64.63%	35.37%
RSPx	8088.46	2452.78	10541.25	76.73%	23.27%

Table 10. Distribution of load in G+30_H_63.43˚

	Distribution of load (KN) in Hexagrid	Distribution of load (KN) in Column	Total Distribution of load on hexagrid system	% Distribution in Hexagrid	% Distribution in Column
D.L+L.L+F.F	286539.10	186172.80	472711.90	60.62%	39.38%
EQx	7515.90	2720.93	10236.83	73.42%	26.58%
RSPx	8505.27	2228.45	10733.72	79.24%	20.76%

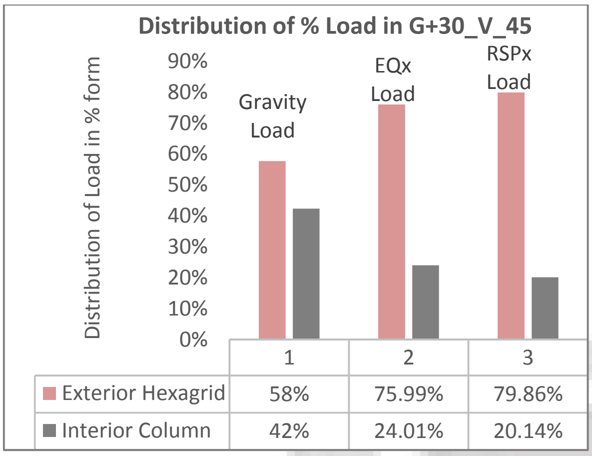


Figure 9. Distribution of % load in G+30_V_45˚

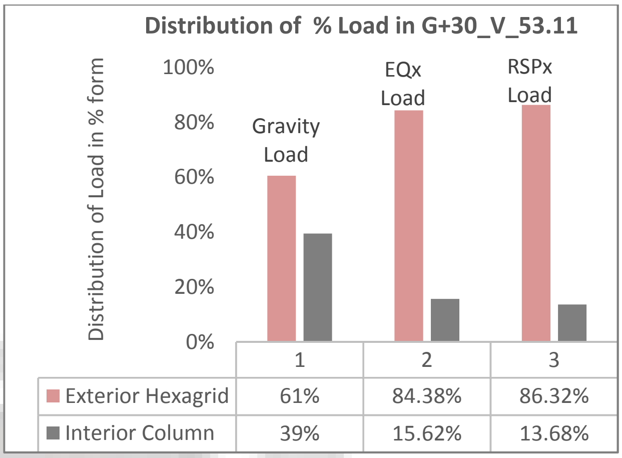


Figure 10. Distribution of % load in G+30_V_53.11˚

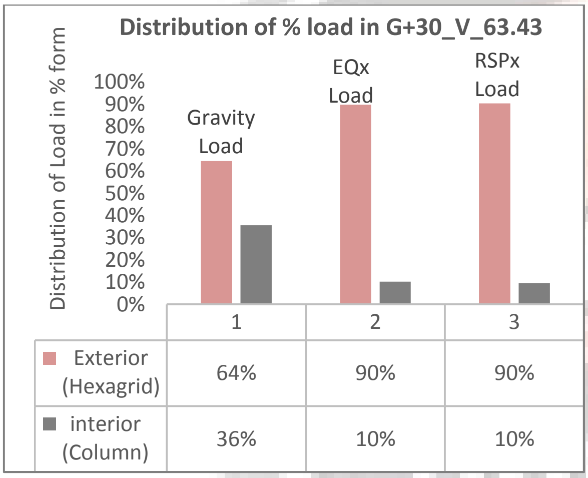


Figure 11. Distribution of % load in G+30_V_63.43˚

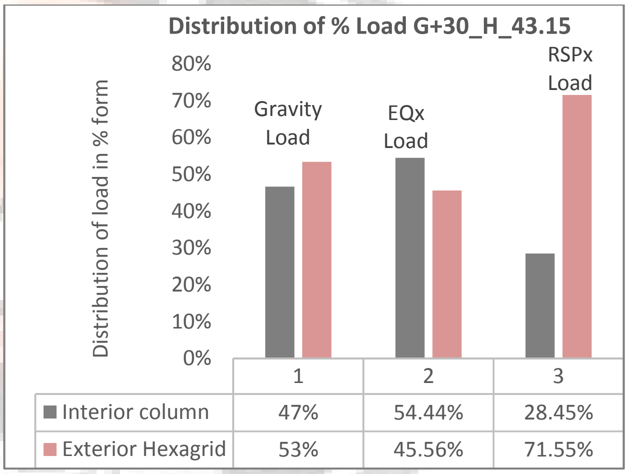


Figure 12. Distribution of % load in G+30_H_43.15˚

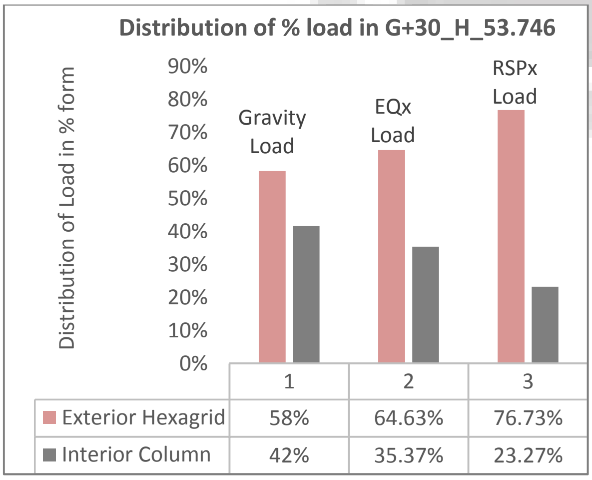


Figure 13. Distribution of % load in G+30_H_53.746˚

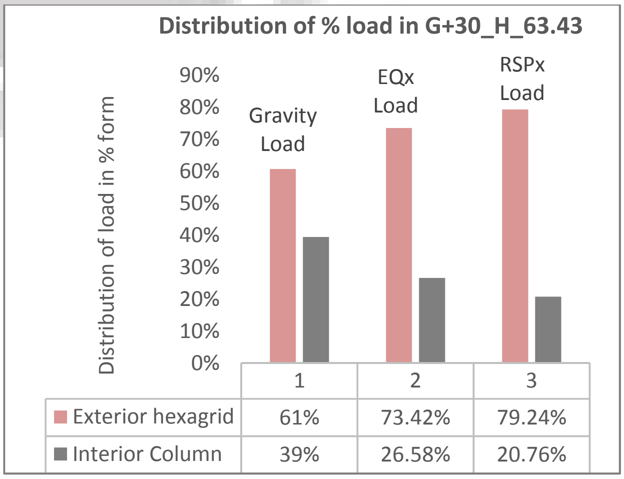


Figure 14. Distribution of % load in G+30_H_63.43˚

Base shear is is the approximate maximum expected reactions that would be generated due to seismic ground of motion at the base of the structure. Base shear for both the structural grids is plotted in the bar chart form for both the different structural patterns for both methods linear static & response spectrum method as shown in figure 1. With increase in angle of inclination structure becomes stiffer & due to that it will carry more load so base shear is gradually increased with increased in angle of inclination for both the hexagrid structural patterns.

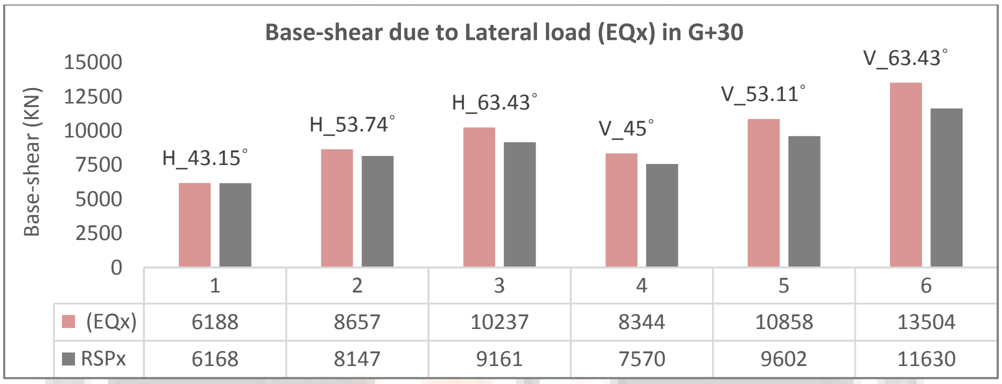


Figure 15. Base-shear comparison due to EQ load for both structural patterns

V. CONCLUSION

On the basis of the above results obtained of different hexagrid structural patterns with linear static analysis & Response spectrum analysis following conclusion can be obtain.

- Time period, Displacement, Story-Drift & base-shear of hexagrid is decrease with increase in angle of inclination
- Horizontal pattern has more Time-period, displacement, & drift as compared to vertical pattern, while vertical pattern has more Base-shear as compared to Horizontal pattern.
- Hexagrid at perimeter can carry more load as compared to centrally column.
- With increase in angle of inclination load distribution is increased in hexagrid & decreased in centrally column.

VI. REFRENCES

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