Comparative Analysis of Tall Building Structures with a Hexa-Grid System

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Abstract: *These days the designers working in structure fields are facing new issues as compared to the present trends of design especially for buildings that are tall and will have acceptable stiffness and high strength. It is a well-known fact that honeycombs structure is appropriate rigid so the seismic loading effect on the structure is greatly reduced; also this type structure uses natural energy as compared to conventional structures and theses are constructed by means of heavy materials. One of the main and important issue in the layout of high-rise buildings is lateral load system which therefore, the variable of selecting the structural system is sufficient resistance, stiffness, and ductility which depends on legitimate policy and are stated as the most important factors to be noted about high buildings, which are built on the parametric factors of sufficient resistance, stiffness, and ductility which is also changed with exceptionally large changes in that structure of lateral load. Therefore, on this look at, a new structural system has been prolonged that nominated new hexagrid. A structural building in diagrid shape having a tubular geometry is now used as an efficient option in addition to being a comparatively pleasing building system used for high-rise structures. A hexagrid type of structure is formed by the intersection of horizontal and diagonal elements. The STAAD pro program is used to model the structure of hexagrid systems using the vertical and diagonal members. The research parameter here adopted is the size and pattern of a hexagrid. For determining the structural behaviour of high and tall structures using hexagrid, a 15-storey, 45m high structures were constructed. Some of the dynamic and static outcomes of every model in the terms of inter storey time and drift period and displacement of storeys is discussed in this study. The research is concluded by observing an increase in carrying the lateral load with every module size increase of vertical hexagrids, in static analysis, the vertical hexagrids show better performance in higher module size. It was estimated that the value of drift in case of HP6 is high in value as compared with HP1, HP2, HP3, HP4 and HP5. In vertical hexagrids with the rising size of a module, the drift is also increased. Hence it becomes preferable to use large size vertical hexagrids modules.*

***Index Terms* – Hexagrids, Tall Building Structures, Beehive structure.**

I. INTRODUCTION

These days the designers working in structure fields are facing new issues as compared to the present trends of design especially for buildings that are tall and will have acceptable stiffness and high strength and etc. The daily rising sustainability, awareness about the limites resources of materials, requirements of the economy coupled with robustness, shape complexity, and higher heights are all ever increasing issues to be solved using strategies, of open minds and systems of structural systems.

Structural configurations nice addressing the conventional necessities of strength and stiffness for tall buildings are the ones using the tube concept, whose performance is precisely associated with the concerned shear resisting mechanism, and actually the ancient evolution of the tube concept has been marked by the tries of lowering the incidence of performance loss due to shear deformations. In this thesis the structural behaviour of modern structural solutions for tube structure is mentioned, studying the ordinary behaviour of every analyzed geometry, offering new layout techniques and comparing the related structural performance.”

Tall building structure system and its classification

As per a study conducted by Khan in the year 1969, the categorization of structural systems according to their efficiency and height can be done using a diagram for the structure of tall buildings. Although, this assembly was studied for both concrete as well as the steel structures. As it is known that the structure of a tall building is divided into sections: Exterior and the Interior of the structure. Such a layout is established on the distribution of the main components resisting opposing to the horizontal force present across a building.

The “interior or “exterior structure” are defined on the basis of the resisting system against the lateral forces are placed outside or inside the building. Although, the “interior system” might have some secondary element to resist the system in opposed to the lateral forces of a structure and it can be said that there might exist the secondary elements of the resisting assembly in every exterior of the building opposed to the forces present inside the structure.

Alternative structural patterns

As the name suggests it means it was inspired by nature. These type of design presents great structural importance for its aesthetical as well as the structural qualities. Natural patterns, like that geometrical type of patterns, exist in our nature and are successful and virtually limitless motivational sources to make impactful man-made buildings, irrespective of the size and level of scale from tallest of the structures to tiny ones. In nature, we have a large number of examples available with regard to heterogeneous materials such as formed from varying components, fibers, or cells having a different arrangement of forming a strong network of structures that promise efficient outcomes. Such types of effective structural assembly are witnessed as “natural cellular solids as shown below.

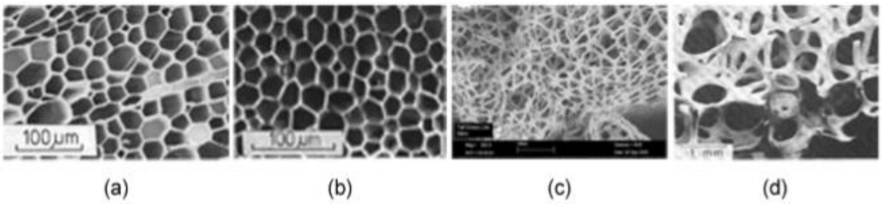


Fig. 1.1: The usable structure of natural cellular solid: (a) Balsa; (b) Cork; (c) Internal core of the stem of the plants; (d) Trabecular bone

Beehive structure

Bees have an attractive, particular strategy of establishing their homes, which are termed as beehives and provides to their safety and a place to provide life source for them. This does not mean that everything has been built already but that the principle behind the design already exists. Recently various structural engineers studied various structures exist in nature and they see where the principle exist or not and analyze how we can integrate these principles in structures today. However, we have also noticed that when we compare natural and manmade structures, natural structural always use sources present in nature whereas humans make use of artificial materials and both of these doesn't continuously show similar properties.

Honeycomb is defined as an internal part and it is a matrix packed densely with hexagonally shaped cells. Bees use these hexagonal shaped cells for storing food and also to keep its' "brood". Also, we know that the hexagonal shape seamlessly allocates and disbands the environmental or the outer human forces and also protects its interiors. It also provides an easy expandability feature with considering the hexagonal shaped segments with the parameter of a honeycomb. The simple features of a hexagon shape form a smart and extremely strong pattern that offer high security and stability to the bees.

Fig. 1.2: Natural forms and structures

Hexagrid structural system

This kind of structure is used rarely and also has evolved recently which was inspired by houses of bees called the "beehives" which are termed as the most stable assembly presented by nature. Such a Hexagrid type of structure is formed by assembling different hexagonal shapes with similar story height connected in a similar manner as it is connected in a beehive.

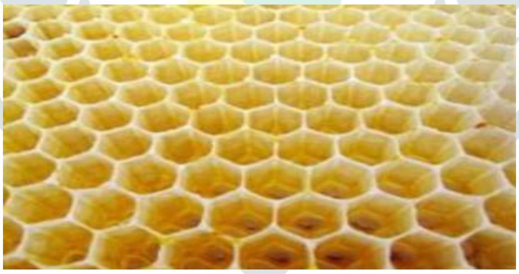


Fig. 1.3: Hexagrid System

The structure of hexagrid is set up on a polygonal shaped matrix having a total of six main components. This particular structure has a benefit of equal stress distribution of itself because of a constant 120° angle in any of the components, but also has a limitation of low stiffness.

Hexagrid: Architecture

From a literature survey, we found an example of the excellent construction project called Beehive Towers at London, which was designed by Rory Newel & Lucy Richardson. The height of the Beehive Towers is 220 m. This design was truly inspired by the hexagonal forms of the honeycomb in Heron Quay, London. It has 8 stories and contains 8 duplex apartments. The cavities which were formed by a number of the hex shapes are devoted to gardening and faces of each shape well receive sun rays from different directions. Another interesting feature of this structure is having a number of sustainable systems such as wind turbines at the top roof and a rainwater collection system for cropping purposes.

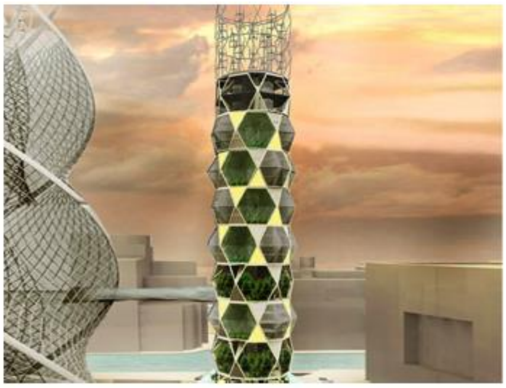


Fig. 1.4: 3D Model of Beehive Tower, London

Hexagrid: Structural system

- It can temporarily ignore the box shape; hence we can see the structure into a sequence of hexagons which can be connected at called nodes and rings and the members intersect at the nodes. Hence it is a hexagonated, ring perimeter framed system i.e. Hexa Grid.
- From the above image, we noticed that Hexagrid is rendered in different colours because of different young modulus and section for the structural components.
- These hexagons along with the rings were constructed using the sections of wide rolls (flanged) which are bolted or welded with each other hence it can offer full restraint.

Advantages of Hexagrid system

The Hexagrid system offers the following advantages.

- It offers the benefits of a combination of the tube (hollow) with its chords and the truss.
- The ultimate advantage is that with the angled arrangement of a column part, it allows for a natural stream the forces about the assembly. Hence it can transfer effectively the lateral load and gravity loads to the ground.
- However, loads always follow the hexagons throughout the structure because naturally it can resist vectors of forces through its hexagonal shapes.
- Loading paths are uninterrupted as well as continuous.
- Loads of vertical gravity are dependent on the tube structure from top-base using the members of hexagonal structures.
- Commonly material used with Hexa Grid is Steel, Wood, and Composite (Concrete & Steel). But Steel is one of the number one choice because it has higher resisting abilities of both compressive and tensile forces.
- From an economy point of view, it offers less steel take off in the range of 10 % to 15 %.

Disadvantages

- Construction crews can be an issue, having no or less experience of constructing a hexagrid.
- To form a regular view from floor-to-floor it offers difficulty into design windows.
- As we all know that hexagrid is handed heavily if it is not implemented correctly.

Objectives of the study

It is a well-known fact that honeycombs structure is appropriate rigid so the seismic loading effect on the structure is greatly reduced; also, this type structure uses natural energy as compared to conventional structures and theses are constructed by means of heavy materials. Recently tall buildings grasp a great interest towards construction and look wise in the world today and also it creates the exposures with the promptly emergent tall structures. As we all know that the structure has mostly exposed to natural disasters and suddenly, they collapse and damage hence by implementing these types of structures or new techniques we can construct it easily and also it will minimize the failure of tall structures.

1. To analyse the "Hexagrid Structural System" with respect to the high rising building.
2. To study the seismic loading and its effect on the structure so that the failure of structure can be minimized.
3. To investigate the time period of the structure, axial forces of the columns, shear forces, the bending moment of the structure is also covered.
4. To analyse different structure models with different module size and also to find out which structure has greater resistance to lateral.
5. To analyse different models with various size and pattern of hexagrid modules under seismic loading.
6. At last, we will present the outcomes for max story displacement and Max story drift.

II. LITERATURE REVIEW

Mathew Thomas [1] had done the seismic examination of the building with hexagrid having a vertical and horizontal orientation. The scale of the hexagrids was changed for attaining a highest size of module for both orientations. An analysis is carried out using 60-storey building of steel having a symmetric ground plan with the aid of the use of same the extent of steel. Equal static evaluation of the building is carried out in sap 2000 software to obtain the best module length. Objectives: Evaluation of seismic analysis of a structure having horizontal as well as a vertical module of hexagrid orientation. Methodology: In their research work hexagrids structure size was changed to attain the highest size of the module for both orientations. This analysis was conducted for a 60-storey building of steel having a symmetric ground plan with the aid of the use of the same the extent of steel. Equal static evaluation of the building is carried out in sap 2000 software to obtain the best module length. Conclusion: He noticed that by increasing the size of the module, the drift and displacement value of vertical hexagrid structures are reduced. Then he suggested that with large size of the module the buildings with higher stability is achieved using hexagrid structures. The capacity to carry lateral load is raised with rising modular vertical hexagrids size, and similarly in Horizontal hexagrids as well.

Han-Ul Lee and Young Chan Kim [2] investigated tall hexagrid tubular buildings, with the variation of the size and pattern of the hexagrid modules, and suggested a formula for calculating the size which was based on stiffness- design criteria of members in the preliminary design stage. In this study comparison of size and pattern of hexagrid modules under seismic forces is presented. Objectives: One of the primary factors used in the research is hexagrid module shape and size. Horizontal and vertical pattern of a hexagrid is used. 60 storey buildings have been designed. Methodology: Pin connections between interior beams and the perimeter structure were introduced and the rigid diaphragm action of the floor was included in the analysis. The design dead load was 4KN/m^2 and live load was 2.5 KN/m^2. A wind speed of 40 m/s was used for wind loading and earthquake loads were applied according to Korean code 2009. Conclusion: The Horizontal hexagrid structure has low stiffness level than the vertical hexagrid structure. The member size grouping for cells shows few effects on the performance of the structure.

Saeed Kia Darbandsari [3] assessed the seismic behaviour of vertical and the horizontal hexagrid, diagrid and tubular structures. They studied the behaviour on 50 and 30 storey structures by making use of ETABS, the non-linear and pushover dynamic analysis is done on the structures with software named PERFORM 3D. Objectives: To assessed seismic behaviour of horizontal and vertical hexagrid, tubular and diagrid structural systems and make comparison among these. Methodology: They studied the behaviour on 50 and 30 storey structures by making use of ETABS, the non-linear and pushover dynamic analysis is done on the structures with software named PERFORM 3D. Conclusion: The outcomes suggest that using non-linear dynamic evaluation, the horizontal hexagrid system shows the lowest roof displacement with reference to the capacity curve of the building it suggests that the furthermost effective system is horizontal hexagrid because it shows the least displacement in the roof, with higher strength dissipation.

Divya M. S. [4] analyzed forty-eight storey structure of steel having hexagrid and diagrid systems using ETABS. Seismic data, load combinations along with Load definition are used according to IS 1893:2002 and IS 875:1987 resp. The result comparison as per the conventional system was performed using story shear and storey displacement. Objectives: To carry out an analysis of forty-eight storey structure of steel having a hexagrid and diagrid systems. Methodology: She adopted simple steps to complete her research work like from modelling of building, selection of site and seismic zone associated with it and finally she makes a comparison of results. Conclusion: She observed that the top storey displacement with respect to the conventional system is minimum in diagrid and hexagrid it is due to the fact that diagonal columns are well able to resist the lateral load of the structure.

Zeba J. Sayyed [5] proposed an innovative and effective technique which was implemented on normal conventional structure and effect of seismic forces on the structure. The analysis was executed under live, dead and earthquake load. Finally, he makes a comparison of results. Objectives: The only objective of its study was to find the impacts of seismic forces on a structure. The analysis was executed under live, dead and earthquake load. The time period of the structure, shear forces, bending moment of the structure was also a part of objectives. Methodology: It encompasses the analysis of G+12 building. Rectangular plan of the building is selected. Conclusion: Authors concluded that dead load with reference to honeycomb structure is found to be minimum than conventional structure by 16% and subsequently after optimization, it is found to be minimum by 38%. Also, the time period obtained was reduced by 49% in the honeycomb structure.

Kiran. T [6] carried out linear dynamic response spectrum analysis on a multi-storied RC building with the bare frame, Shear wall and Hexagrid system of bracings. Objectives: To carry out linear dynamic response spectrum analysis on a multi-storied RC building with the bare frame, Shear wall and Hexagrid system of bracings. Methodology: For this purpose, the RC frame is designed using ETABS V.13. The behavior of the structure is studied based on the maximum displacement, maximum drift, maximum storey shear and maximum overturning moment. Conclusion: The outcomes suggest that using non-linear dynamic evaluation, the horizontal hexagrid system shows the lowest roof displacement with reference to the capacity curve of the building it suggests that the furthermost effective system is horizontal hexagrid because it shows the least displacement in the roof, with higher strength dissipation.

III. Research Methodology

Here the comparison is performed with respect to the size and pattern of hexagrid modules working under seismic forces. A fifteen storey structure is considered here and to check the comparison and behaviour of a building, the same live and dead load is applied Han-Ul Lee and Young Chan Kim (2017). As we all know that buildings are always experiencing some sort of vibrations due to any natural reasons like the earthquake and hence is it important to use seismic methods for the high structures. So in our work, we also conduct vibration analysis of all the buildings along with storey drift in seismic zone IV are determined using the STAAD PRO program. The performance evaluation is then done for the building frames to specify every outcome.

Analysis steps

The foremost performance factors for this research work on different hexagrid modules size and shape of a hexagrid. However, in this investigation, only vertical hexagrids in orientations are used. 15 storey buildings have been designed using STAAD Pro. These are the steps that are used for the study:

Step 1: Selection of floor plan and Seismic zone. As in previous discussions we have designed our models for Zone IV as per IS code 1893 (Part 1): 2002 for which zone factor (Z) taken is 0.24. According to our assumptions, we modelled 15 storey building with different module size and pattern of hexagrid is taken. Floor to floor height is 3m.

Step 2: Modelling of buildings using STADD. Pro software

Step 3: Investigation of all the building frames was done under seismic zone IV

Step 4: Presentation of results with regard to maximum moments in columns and beams, storey displacement, shear force, axial force and drift.

Models of the structure

A square floor plan of 20 m×20 m is used in all the models. Height of the storey taken was 3m. The live and dead load obtained from the study of Han-Ul Lee and Young Chan Kim (2017) are 2.5 and 4 KN/m^2 respectively. Every model is investigated for seismic zone-IV only. Seismic parameters definitions are adopted from Indian code IS 1893 (Part 1): 2002.

Table 3.1: Geometry and load consideration

Type of structure	Residential building
Beam size	400 x 400 mm
Column size	400 x 300 mm
Dead load (4 KN/m^2)	875- part 1
Diagrid section	Steel section
Height of each storey	3 m
Live load (2.5 KN/m^2)	875- part 2
Plan dimension	20 x 20 m
Seismic load (as per IS code 1893 part-1)	Zone IV
Thickness of slab	150 mm
Total height of the building	45 m

Table 3.2: Material properties considered in the modelling

Description	Value
Elongation at Break Steel	70%
Modulus of Elasticity Steel	193-200 GPa
Poisson ratio	0.17
Steel table	Standard section (l100012B50016)
Tensile Strength, Ultimate Steel	505 MPa
Tensile Strength, Yield Steel	215 MPa
Young's modulus of steel, Es	2.17x104 N/mm^2

Module and building configuration

The STAAD pro program is used to model the structure of hexagrid systems using the vertical and diagonal members. The research parameter here adopted is the size and pattern of a hexagrid. For determining the structural behaviour of high and tall structures using hexagrid, a 15-storey, 45m high structures were constructed.

Table 3.3: Building configurations

Model name	Module no. of storeys
HP1	3
HP2	3
HP3	1
HP4	1
HP5	2
HP6	4

Supports: In STAAD pro we have a different support like FIXED, PINNED, and various releases of FIXED like the FIXED BUTT. The FIXED support limited among all directional movements. Where Rotational and Transitional springs are also mentioned. Whereas the PINNED support limits all of the rotational and transitional movements. Hence, it can also be said that such support can react to every kind of force but does not resist any of the moments. The Rotational and Transitional springs are differentiated according to the spring constants. Though the spring constant of translational movements is explained as a force to relocate joint support of 1 length unit in any mentioned direction.

Loads: A structure load is differentiated as temperature load, member load, or joint load, etc. It is already known that the STAAD pro can also produce some self-weight for construction and can also utilize it in the form of member load (allotted uniformly) in simulation. Any part out of this produced self-weight could be applied in any direction desired.

Dead Loads: It encompasses a permanent structural loads material such as roof, or floor, etc. together with cladding, fixes and finished the equipment. Dead load is defined as the complete amount of load used in all building components which commonly does not undergo any modification throughout the years, along with, roofing material, bricks, concrete floors, steel columns and so forth. Usung the STAAD pro the dead load challenge is routinely done by means of providing features or the parameters of any member. The STAAD pro feature of load case modules presents with a choice of self-weight and it automatically determines the beam, slab and column weights utilizing the assigned material parameters.

IV. RESULTS

This part of the paper presents some of the dynamic and static outcomes of every model in the terms of inter storey time and drift period and displacement of storeys.

Vibration effect on different models

In this particular investigation, we study the effect of "Damping Ratio". In such a case, the ratio is assumed at 5%. The values of vibration frequency and six "mode shape of the system" are shown below. The deformed shapes due to various vibration modes are shown in figures below:

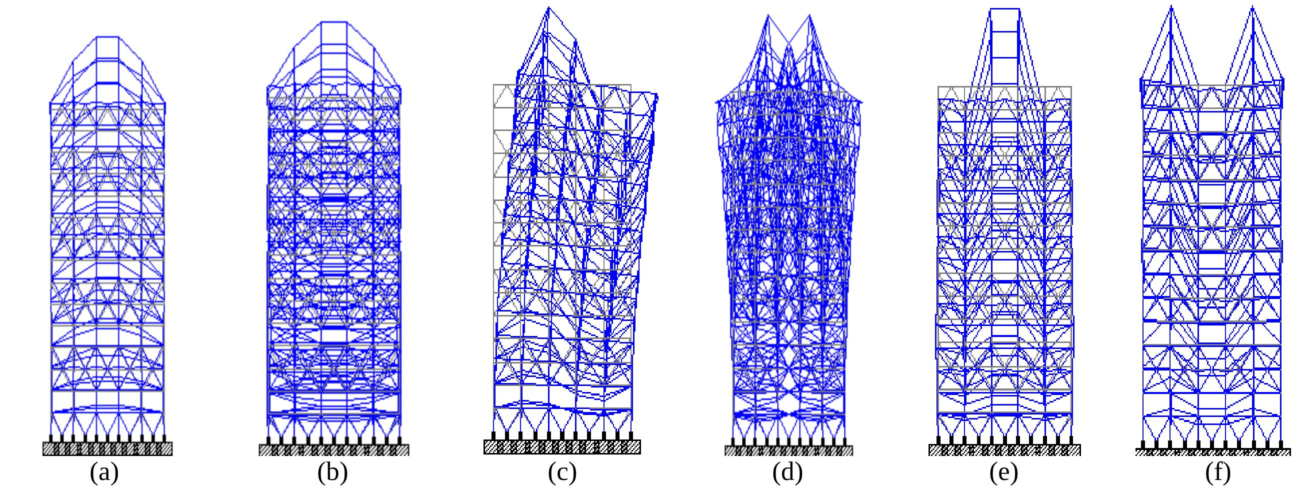


Fig. 4.1. Mode shape of HP1

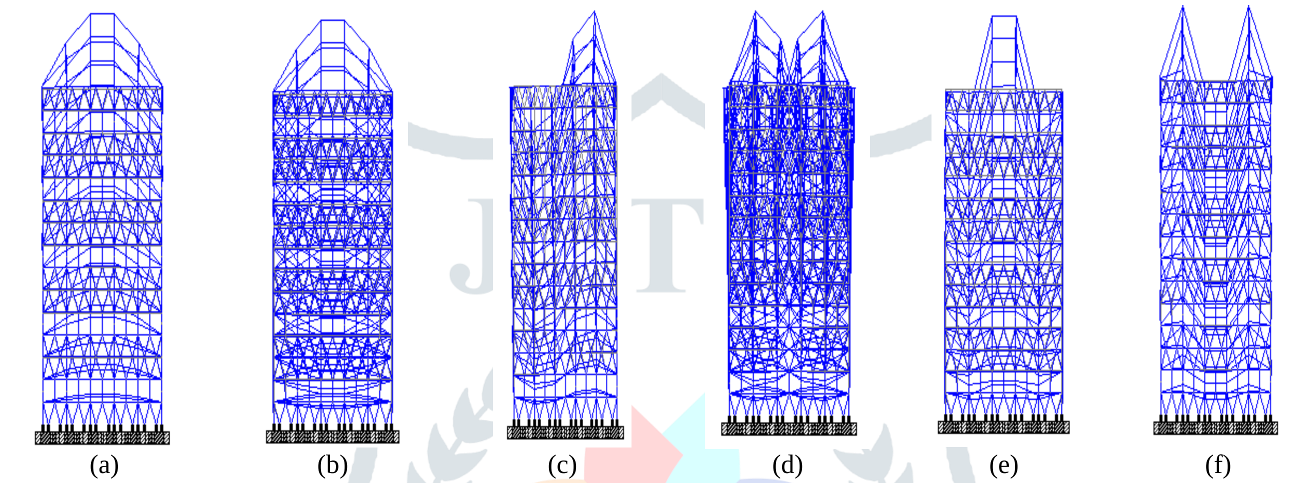


Fig. 4.2. Mode shape HP2

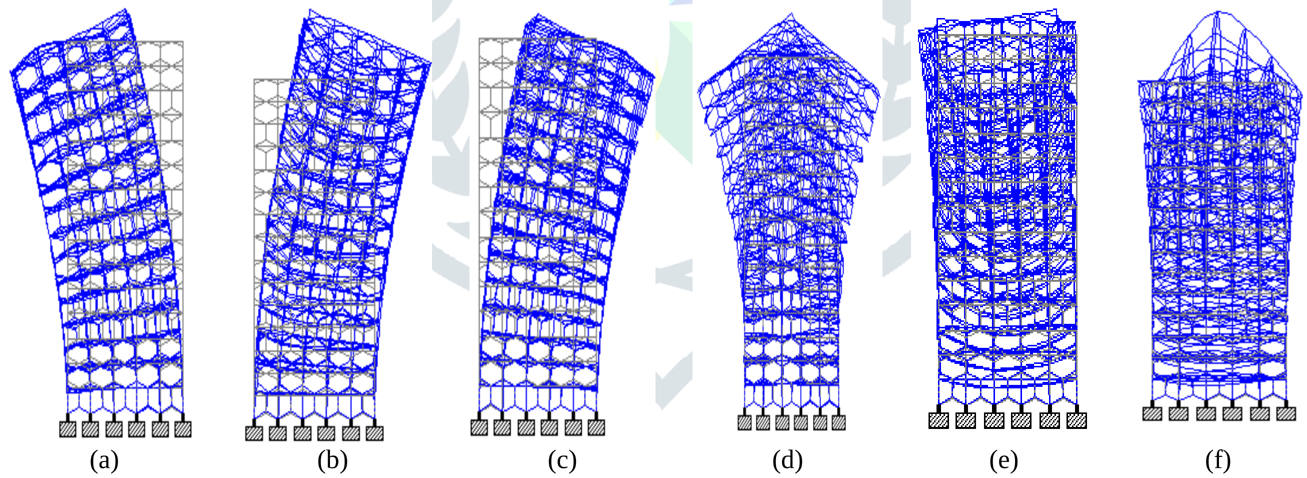


Fig. 4.3. Mode shape HP3

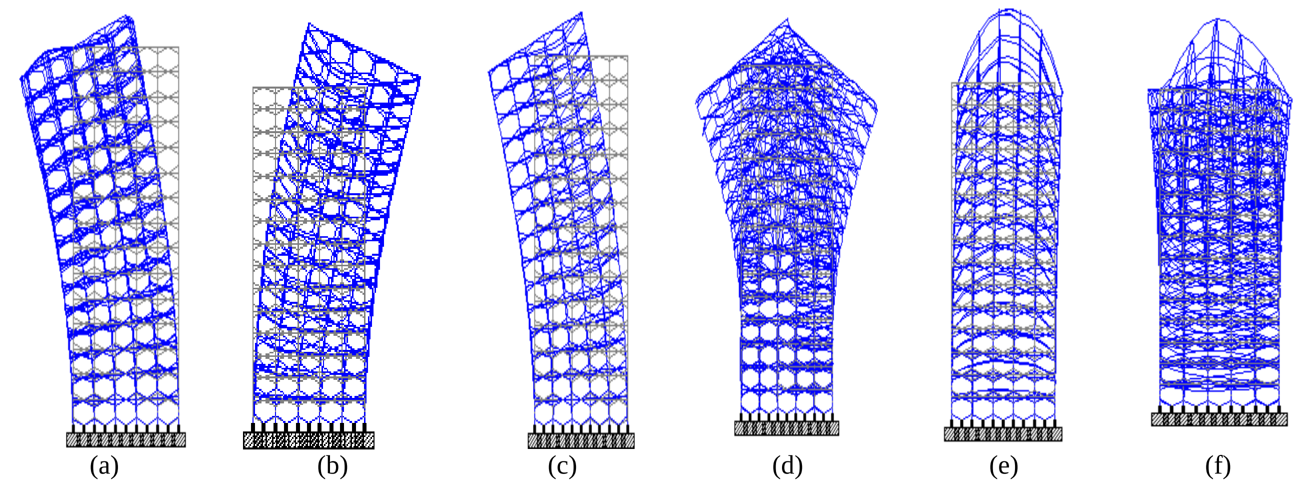
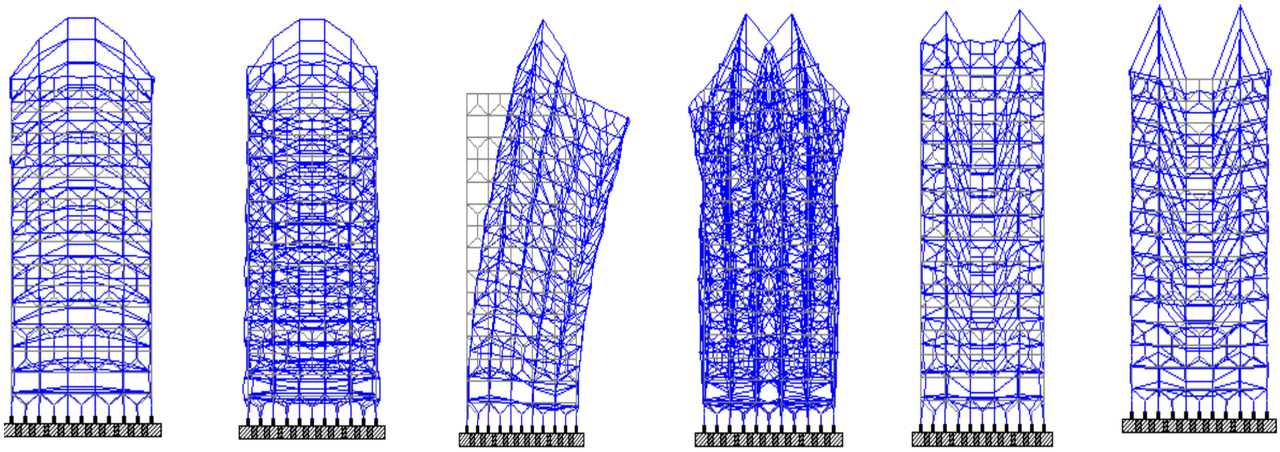
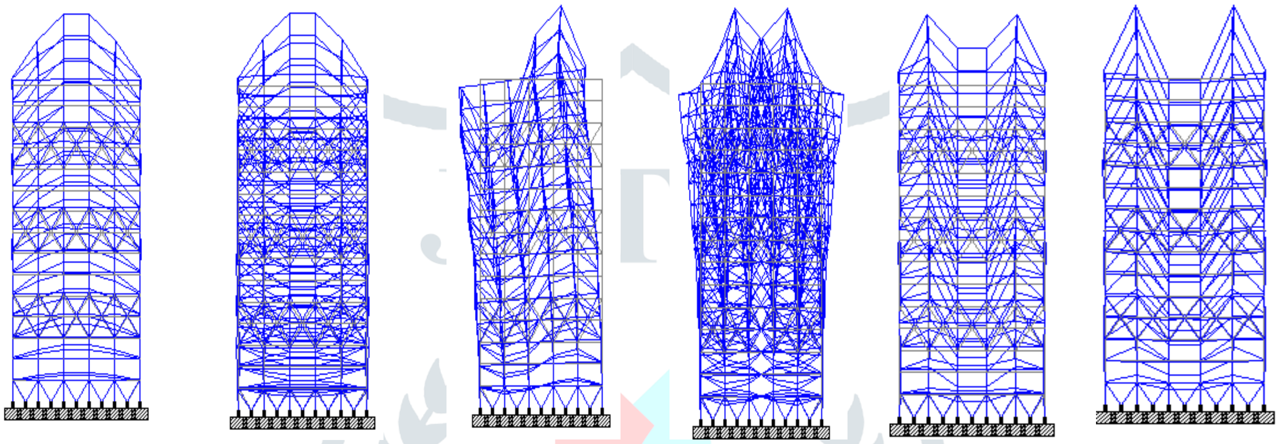


Fig. 4.4. Mode shape HP4



(a) (b) (c) (d) (e) (f)

Fig. 4.5. Mode shape HP5



(a) (b) (c) (d) (e) (f)

Fig. 4.6. Mode shape HP6

Table 4.1: Frequency of different model

Mode	HP1	HP2	HP3	HP4	HP5	HP6
	Frequency (cycles/sec)					
1	6.123	6.197	3.645	3.222	6.046	6.157
2	6.969	7.118	4.004	3.506	6.766	7.031
3	6.971	7.122	4.425	4.023	6.769	7.040
4	7.825	7.962	5.644	5.535	7.688	7.902
5	8.181	8.365	5.930	5.867	7.888	8.243
6	8.317	8.389	6.217	6.159	8.237	8.364

The vibration analysis of a structure suggested a lot of implication in its designing and performance over a period of time. The 1^{st} mode frequency was the lowest. With every subsequent vibration mode, the frequency is increased and is also increases with hexagrid module size.

Support reaction

The support reaction magnitude in different models are plotted in figure 4.8 below, it is also calculated that in the comparison report, the lowest support reaction value is in HP and HP4 shows the highest-support-reaction.

Table 4.2: Support reaction

Support Reaction, KN	HP1	HP2	HP3	HP4	HP5	HP6
	28143	62841	83137	84963	57437	57054

Shear force

The shear force magnitude in different models is plotted in the figure 5.9, results suggest that the lowest shear force is in HP2. HP4 depicts higher shear force values with little consequences in the balanced construction. Here the shear force is maximum in HP4 than other structures.

Table 4.3: Maximum shear force

Shear Force, KN	HP1	HP2	HP3	HP4	HP5	HP6
	1408.565	1385.881	2132.347	2208.534	1683.161	1474.57

Bending moment

Magnitude of bending moment for various models has been plotted in figure number 5.10, it is determined that in this comparative study maximum bending moment is in HP4 whereas HP2 shows minimum bending moment value which results in balanced section. Here outcomes here depict that HP2 structure shows low bending moments, which simply depicts a low requirement for reinforcements.

Table 4.4 Maximum bending moment

Bending moment, KNm	**HP1**	**HP2**	**HP3**	**HP4**	**HP5**	**HP6**
	795.987	447.897	1450	1585.994	912.789	1336.602

Displacement

The high displacement magnitude for different models are presented in the graph given in figure 5.11, and it can be stated that HP2 has minimum deflection and HP3 has maximum deflection, which means that more support is required in the HP3 when compared with other structures. There is an increase in vertical hexagrid displacement with an increase in the size of a module.

Table 4.5: Maximum displacement

Displacement, mm	**HP1**	**HP2**	**HP3**	**HP4**	**HP5**	**HP6**
	79.546	68.191	173.591	150.651	113.653	133.985

Lateral displacement

It represents complete floor displacement with respect to the ground. The lateral forces (seismic/wind) present in a structure are the main reason for it. According to the code IS: 800:2007, for a building of height = H, the highest displacement in the top storey because of the presence of lateral load must not be higher than H/500. The displacement outcomes of this analysis used in every model are under a possible and acceptable limit. In figure 5.12, Y axis represent the value of storey displacement and X axis represent a number of floors. The construction faces higher displacement on the top most storey in case of HP6. The maximum displacement in HP1, HP2, HP3, HP4, HP5 and HP6 is 3.9372 mm, 2.2436 mm, 1.4372 mm, 1.3140 mm, 1.3429 mm and 5.5382 mm respectively. The vertical hexagrid displacement is increased with the size of the module. Also, the hexagrid structure whose module size is small it offers higher stiffness level for the system that shows a lower displacement in the top storey,

Table 4.6: Lateral displacement (cm)

Floor	**HP1**	**HP2**	**HP3**	**HP4**	**HP5**	**HP6**
1st floor	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2nd floor	0.1264	0.0968	0.0279	0.0364	0.0463	0.1972
3rd floor	0.3911	0.1938	0.1123	0.1106	0.0956	0.6355
4th floor	0.5904	0.2997	0.2057	0.1884	0.1323	1.0854
5th floor	0.8627	0.4728	0.3010	0.2564	0.2840	1.3982
6th floor	1.1882	0.6964	0.3793	0.3172	0.4481	1.8013
7th floor	1.4022	0.7923	0.4898	0.4230	0.4542	2.3012
8th floor	1.7642	0.9581	0.6007	0.5300	0.5614	2.8007
9th floor	2.1244	1.1560	0.6871	0.6159	0.7844	3.1013
10th floor	2.3212	1.4381	0.7772	0.7060	0.9439	3.5965
11th floor	2.7581	1.5031	0.9049	0.8306	0.8808	4.0735
12th floor	3.1086	1.7244	1.0338	0.9562	1.1524	4.5354
13th floor	3.2313	1.9109	1.2280	1.1302	1.1179	4.7247
14th floor	3.6821	2.2370	1.2868	1.1711	1.5486	5.2202
15th floor	3.9372	2.2436	1.4372	1.3140	1.3429	5.5382

Storey drift

According to IS: 1893-2002, the storey drift in any storey should not exceed 0.004 times storey height. The storey drift values obtained in our analysis is within the permissible limit. Above graph given in figure 5.13 shows the variation of drift in all structural systems. With reference to lateral load resisting system drift is of interest. Now X axis characterizes a number of floor and Y axis signifies Storey drift. We noticed that drift for HP6 is higher compared to HP1, HP2, HP3, HP4 and HP5. We also observed that drift increases with an increase in module size. So it is desirable to have vertical hexagrids with greater module size.

Table 4.7: Storey drift values

Floor	**HP1**	**HP2**	**HP3**	**HP4**	**HP5**	**HP6**
1st floor	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2nd floor	0.1264	0.0968	0.0279	0.0364	0.0463	0.1972
3rd floor	0.2647	0.0970	0.0844	0.0742	0.0494	0.4383
4th floor	0.1993	0.1058	0.0933	0.0777	0.0367	0.4499
5th floor	0.2723	0.1732	0.0954	0.0680	0.1517	0.3128
6th floor	0.3255	0.2235	0.0782	0.0608	0.1641	0.4031
7th floor	0.2141	0.0960	0.1105	0.1058	0.0061	0.4999
8th floor	0.3620	0.1658	0.1109	0.1070	0.1072	0.4995
9th floor	0.3602	0.1978	0.0864	0.0859	0.2230	0.3007
10th floor	0.1968	0.2822	0.0901	0.0900	0.1595	0.4952
11th floor	0.4369	0.0650	0.1277	0.1247	0.0630	0.4770
12th floor	0.3506	0.2213	0.1289	0.1256	0.2715	0.4620
13th floor	0.1227	0.1865	0.1942	0.1740	0.0345	0.1893
14th floor	0.4508	0.3261	0.0588	0.0410	0.4307	0.4955
15th floor	0.2551	0.0066	0.1504	0.1428	0.2057	0.3179

Time period

In order to perform dynamic analysis, the total time is calculated by using six mode shapes for every model type. It is already known that time is dependent on the stiffness and mass of a structure. The building will have lower stiffness and higher modal mass is the time period if high and vice versa. It is also noted that HP4 has a lesser time period, hence resulting in higher stiffness when associated with other models. Also, in case of HP1, the structural mass is lower because of the lower time period and hence stiffness is also higher. The calculated time for different models is shown in the graph given in figure 5.14. The 1st mode time period of HP1 is 0.16331s whereas for HP2 is 0.16137 seconds, HP3 is 0.27432 seconds, HP4 is 0.31036 seconds, HP5 is 0.16539 seconds and for HP6 is 0.16243 seconds respectively. The time period of HP1 structure is the least suggesting that it has a high stiffness level compared to other structures

Table 4.8: Time period of different model

Mode	HP1	HP2	HP3	HP4	HP5	HP6
	Time period (sec)					
1	0.16331	0.16137	0.27432	0.31036	0.16539	0.16243
2	0.14349	0.14050	0.24975	0.28521	0.14780	0.14223
3	0.14345	0.14050	0.22598	0.24858	0.14774	0.14204
4	0.12780	0.12559	0.17717	0.18067	0.13007	0.12655
5	0.12223	0.11955	0.16864	0.17045	0.12677	0.12132
6	0.12024	0.11920	0.16085	0.16237	0.12140	0.11956

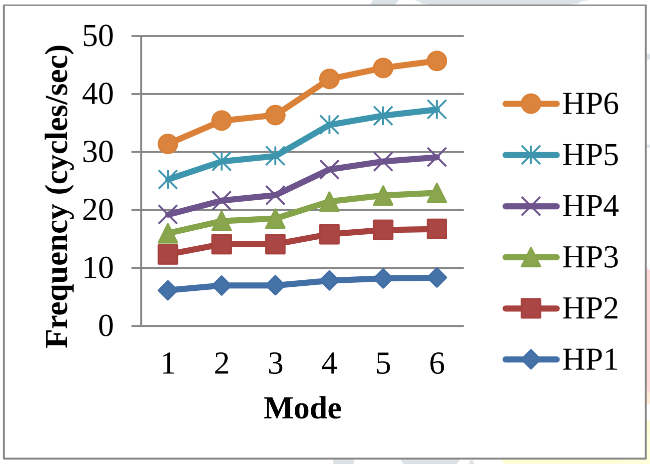


Fig. 4.7: Variation of the frequency with different shape

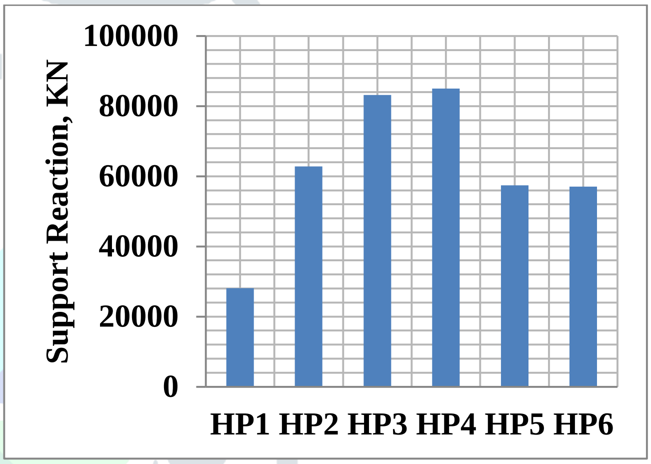


Fig. 4.8: Support reaction

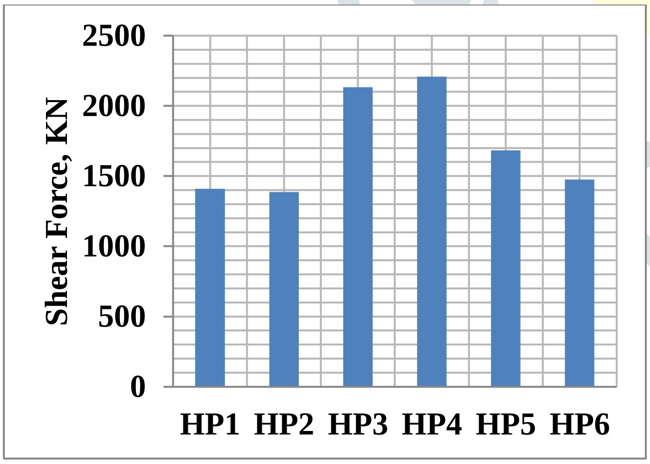


Fig. 5.9. Maximum shear force

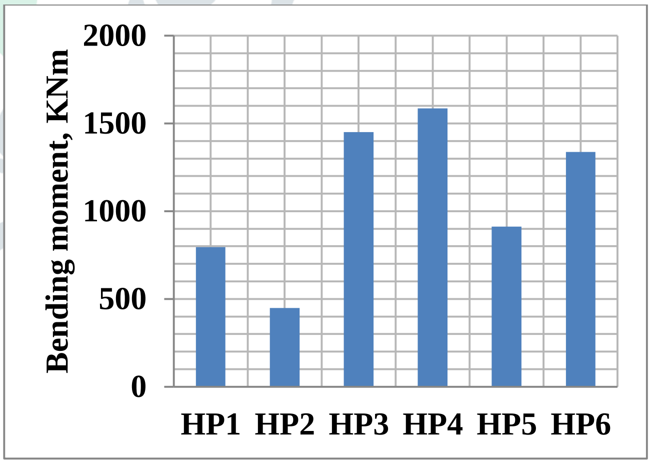


Fig. 5.10. Maximum bending moment

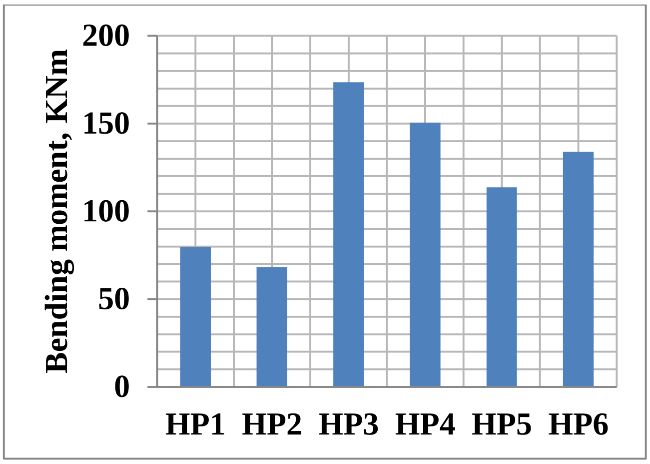


Fig. 5.11. Displacement comparison

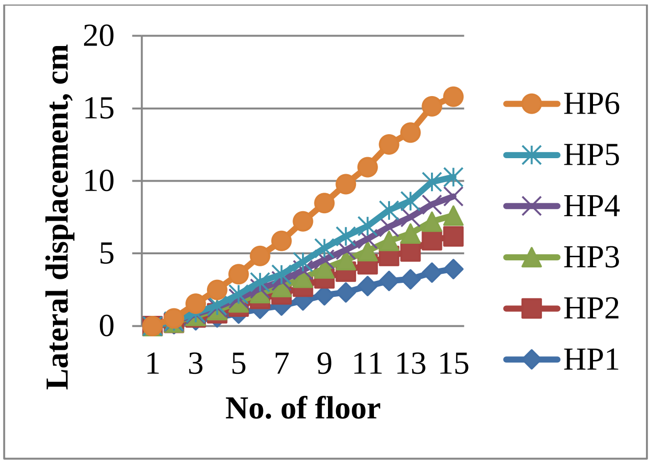


Fig. 5.12. Lateral displacement of models

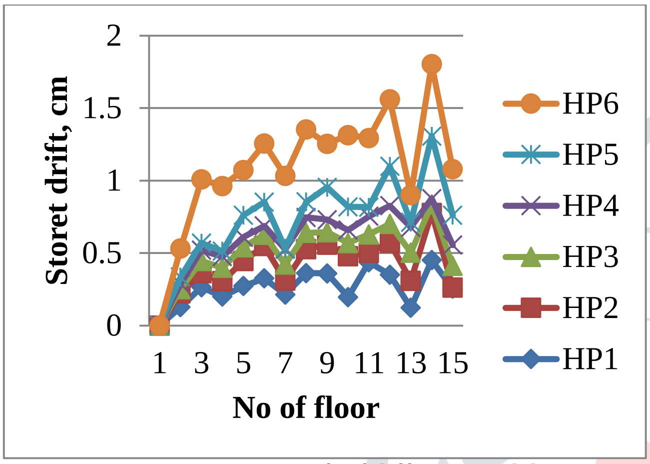


Fig. 5.13. Storey Drift of different models

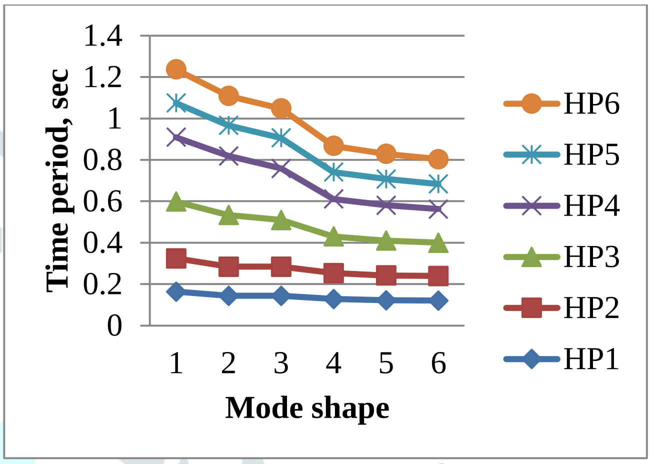


Fig. 5.14. Time period

V. CONCLUSION

The research presented here calculated the performance of a building structure when making use of hexagrid structure, where the study was performed on a fifteen storey structure. Following are the primary conclusions resulted after analyzing the frames of the building:

- There is an increase in carrying the lateral load with every module size increase of vertical hexagrids, in static analysis, the vertical hexagrids show better performance in higher module size.
- With the rise in vertical hexagrids module size, the capacity of carrying lateral load is also increased.
- We noticed that vertical hexagrid displacement increases with increase in module size also the hexagrid structure whose module size is small it offers higher stiffness level to a structure that shows a lower level of displacement in the top most storey.
- We observed that minimum time is required for HP1, hence providing more stiffness as associated with other cases considered here. Also in case of HP1 there is more stiffness because of lower structural mass and lower time required.
- The time required for different models suggests that the 1st time period mode for HP1 is 0.16331s, for HP2 is 0.16137 seconds, HP3 is 0.27432 seconds, HP4 is 0.31036 seconds, HP5 is 0.16539 seconds and for HP6 is 0.16243 seconds respectively. The vibration analysis of a structure embraces a lot of impact in its designing and performance over a period of time. The minimum frequency was in the first mode, after every subsequent vibration mode the frequency is increased and also increases with hexagrid module size.
- In the above comparison, the minimum support value of reaction is showed in HP1, and in HP4 it is maximum.
- Here performance shows that HP2 structure has a low bending moment which results in the minimum requirement of reinforcement.
- It was estimated that the value of drift in case of HP6 is high in value as compared with HP1, HP2, HP3, HP4 and HP5. In vertical hexagrids with the rising size of a module, the drift is also increased. Hence it becomes preferable to use large size vertical hexagrids modules. Therefore, HP1 is best with respect to its performance.

VI. FUTURE SCOPE

The research depicts the performance of different pattern of the hexagrid system. We can work also with regards to hexagrid angle and it is useful to find out the optimum angle of hexagrid. Since the angle is an important parameter for hexagrid because variation in hexagrid angle can make variations in dimensions of the entire structure without any change in the quantity of material utilised. The research was worked on the performance of hexagrid structure only. A compressive evaluation can be done to identify other problems like the number of connections among different modules and its size aesthetics, in parallel with a structure's functioning.

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