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Seismic Performance of Combined Grid System on Tall Structures with Irregularity Condition

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Abstract
Advancement in materials, construction technology accelerated the development of tall structures. Multi-storied structures need proper evaluation of loads for safe and economical design. The widely used internal lateral load resisting structural systems include rigid frame, braced frame, shear wall and outrigger structure whereas the exterior systems constitute tubular, diagrid, pentagrid, hexagrid and octagrid structures. The employment of grid structural systems in a building give rise to numerous advantages like reduction of interior columns giving large column free spaces that can be used as indoor sports auditoriums, exhibition halls etc. The inclined columns take up gravity as well as lateral loads unlike the conventional vertical columns. There are various studies regarding the seismic performance of grid system on tall structures with regular condition. The objective of this paper is to study the seismic performance of combined grid system on tall structures with irregular condition. Stiffness irregularity and geometric irregularity is introduced to the regular building and its performance is studied. A comparison of parameters Storey Shear, Storey drift, Storey displacement, Time period and Structural weight is done to determine the efficient and cost effective structure. ETABS V15 software is used for modelling and analysis of structural members.
Keywords: *Diagrid, Hexagrid, stiffness irregularity, Geometric irregularity, Seismic performance*

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I. INTRODUCTION

Advancement in materials, construction technology accelerated the development of tall structures. Loading on tall buildings is different from that of low-rise buildings in many ways such as large accumulation of gravity loads on the bottom floor is more than top floors. Thus, multi-storied structures need proper evaluation of loads for safe and economical design. Except dead loads, the evaluation of loads cannot be done accurately. Live loads can be predicted approximately from a combination of experience and the previous field observations. Wind loads and earthquake loads are random in nature and it is difficult to predict them. They are evaluated based on a probabilistic approach.

The widely used internal lateral load resisting structural systems include rigid frame, braced frame, shear wall and outrigger structure whereas the exterior systems constitute tubular, diagrid, pentagrid, hexagrid and octagrid structures. Lately, diagrid structural systems are adopted in tall buildings, owing to its structural efficiency and aesthetic potential.

Figure1: Examples for diagrid structure

Some examples for diagrid structural system is shown in Fig 1. It is widely used for recent tall buildings due to the structural efficiency and aesthetic potential. Hexagrid structural system can be used to challenge the limit to building height in diagrid. The employment of Diagrid and Hexagrid systems in a building lead to reduction of interior columns giving large column free spaces that can be used as indoor sports auditoriums, exhibition halls etc. The inclined columns take up gravity as well as lateral loads unlike the conventional vertical columns. Also, these systems lead to huge savings in terms of material cost.

The hexagrid structure consists of multiple hexagonal grids at the exterior perimeter surfaces of building. The hexagrid system is a particular form of belt trusses mixed tubular system and resists lateral loads acting in tension or compression. Module density of a hexagrid denotes the number of hexagon around the periphery. If more number of modules can be incorporated around the periphery, the building is said to be of high module density and vice-versa.

In this paper, a combined grid structure with irregularity condition is modeled and compared with regular structure. Combined grid structure is made by combining hexagrid and diagrid structural members. A regular floor plan of 36 m × 36 m size is considered. ETABS software is used for modeling and analysis of structural members. All structural members are designed as per IS 800:2007 considering all load combinations.

II. ANALYSIS AND DESIGN OF COMBINED GRID SYSTEM FOR REGULAR BUILDINGS

2.1 Building configuration

The 36 storey tall building is having 36 m × 36 m plan dimension. The storey height is 3.6 m. The structural elements like columns, beams and diagrids are assigned structural steel properties while the slabs are considered of RCC. For the design of diagrids and columns, built-up box sections are used and for the design of beams, Indian Standard I-Sections are used. The typical plan and elevation are shown in Fig 2. In diagrid structures, pair of braces is located on the periphery of the building. The inclined columns are provided at six meter spacing along the perimeter. The interior frame of diagrid structures is designed only for gravity load. The design dead load and live loads on floor slab are 3.75 kN/m2 and 2.5 kN/m2 respectively. The dynamic along wind loading is computed based on the basic wind speed of 30 m/sec and terrain category III as per IS:875 (III)-1987. The design earthquake load is computed based on the zone factor of 0.16, medium soil, importance factor of 1 and response reduction factor of 5 . Modeling, analysis and design of diagrid structure are carried out using ETABS software. For linear static and dynamic analysis the beams and columns is modeled by beam elements and braces are modeled by truss elements. The support conditions are assumed as hinged. All structural members are designed using IS 800:2000. Secondary effect like temperature variation is not considered in the design, assuming small variation in inside and outside temperature.

Beam sections are taken as same for all the storey. Each storey contains three types of beams- B1(ISMB 550) ,B2(ISWB 600) and B 3(ISB 550). B3 is provided for exterior beams and B1 and B2 for interior beams. For these three structural systems, there are no vertical columns in the exterior of the structure and also, only internal columns are there. The size of the interior vertical column is taken as 1500 x 1500 mm throughout the structure. 450 mm Pipe sections with 25 mm thickness column section is used from 1st to 18th floor. 375 mm Pipe sections with12 mm thickness is used in 18th to 36th floor.

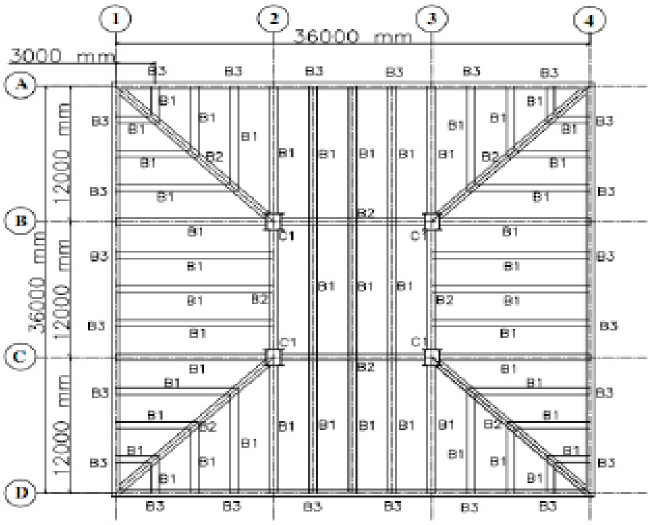

Figure 2 : Typical floor plan

2.2 Modeling

Modeling, analysis and design of the structure are carried out using ETABS software. For linear static and dynamic analysis the beams and columns is modeled by beam elements and braces are modeled by truss elements. The support conditions are assumed as hinged. All structural members are designed using IS 800:2007. The elevation of diagrid and hexagrid structures are shown in figure 5. Diagrid is formed by intersecting the diagonal and horizontal components and the hexagrid structure consists of multiple hexagonal grids at the exterior perimeter surfaces of building.

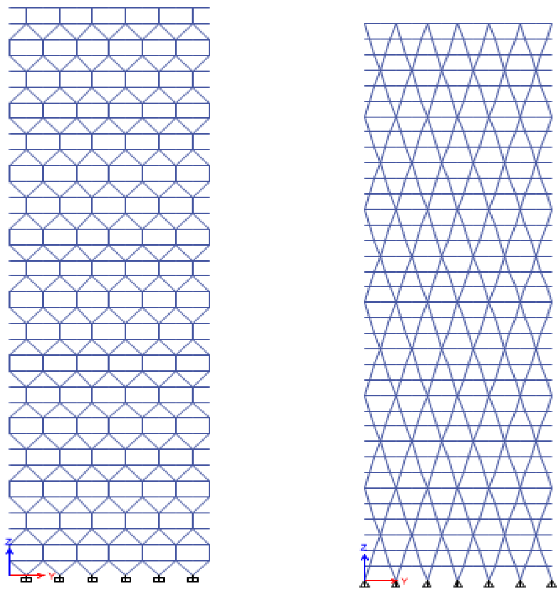

Figure 3: Elevation view of hexagrid and diagrid structure

The combined grid structure is made by combining the hexagrid and diagrid members. In this paper the diagrid and hexagrid structures are combined in three different ways, and hence three models are made. The three models are analysed and compared to obtain the most effective model. Figure 4 shows the elevation of three models made by combining diagrid and hexagrid.

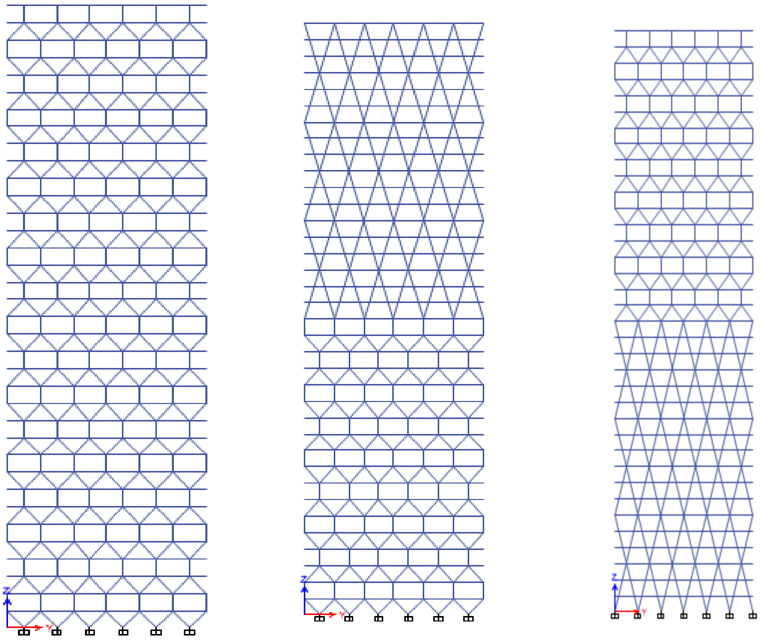

Figure 4: Elevation view of combined grid structure

2.3 Analysis results

The analysis results in terms of Time period, Storey shear, Displacement, Inter-storey Drift are presented in this section. The deformed shape of the structure after analysis is shown in Fig 5. The base shear along the x direction for diagrid structure are shown in figure 6. Similarly the variation of storey displacement along each floor is shown in figure 7.

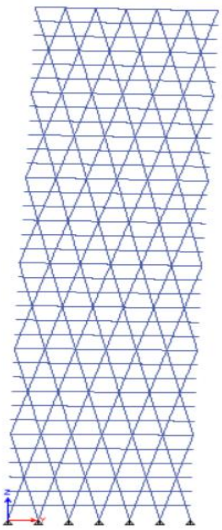

Figure 5: deformed shape

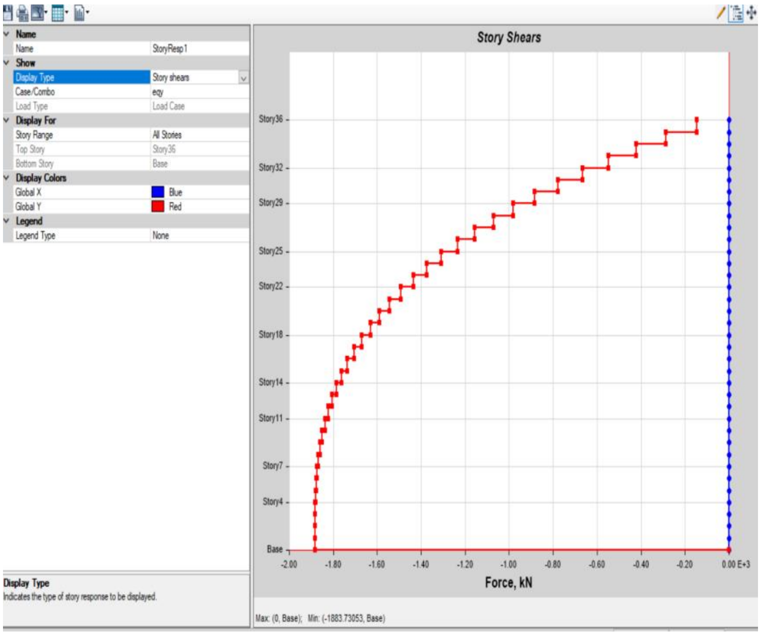

Figure 6 : Story shear in x direction

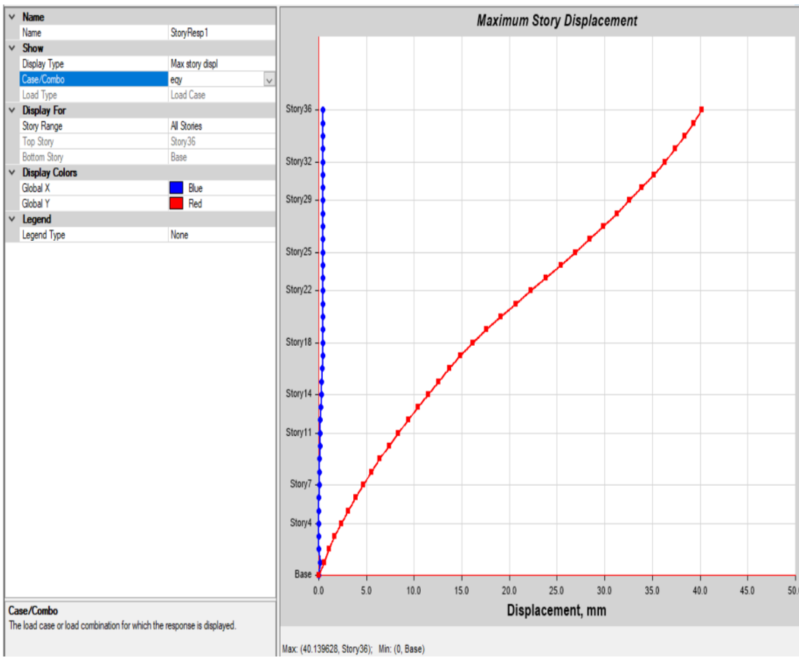

Fig 7: Story displacement in x direction

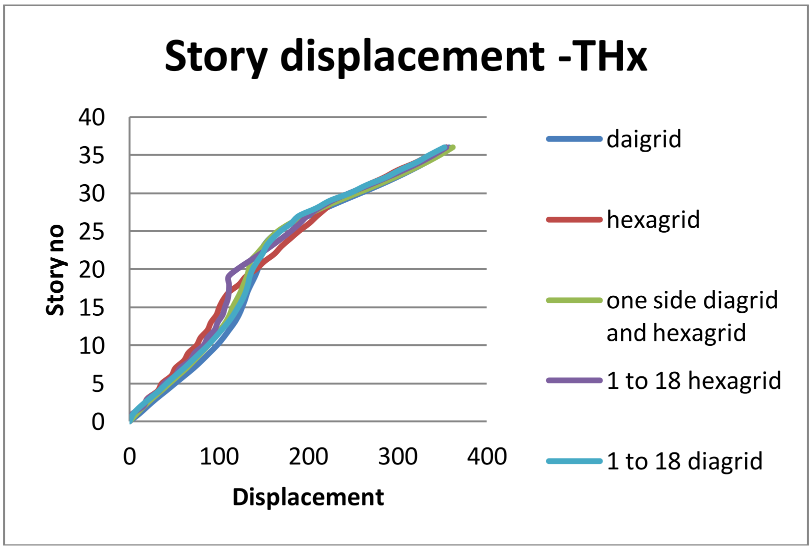

Fig 8: performance of Story displacement with story height for each model

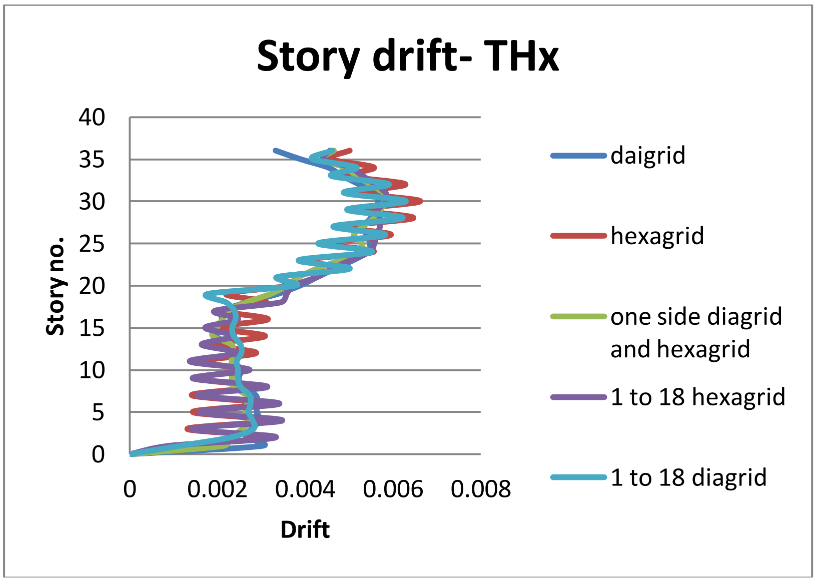

Fig 9: performance of Story drift with story height for each model

After analysing and designing all the structures, the comparison of different parameters for all the models are tabulated in the Table 1.

Table 1: comparison of models

Model	Time period (s)		Storey displacement(mm)		Storey drift (mm)		Base shear(kN)		Weight (kN)
	x	y	x	y	x	y	x	y	
Diagrid	3.04	3.1	357.1	362.41	.05654	.005666	34915	35767	443729
Hexagrid	3.168	3.187	354.738	354.099	.0662	0.006511	31883	31556	442464
One side dia and hexa	2.95	3.24	361.95	347.81	0.00583	0.00603	13199	33235	443310
B- diagrid	2.87	2.88	352.82	351.51	0.0063	0.0062	22095	22458	443705
B- hexagrid	3.31	3.34	354.65	354.14	0.005855	0.00582	32984	34190	442693

2.4 Comparison of analysis results

a) Time period

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. Figure 10 represents the comparison of the time period for the five models. It is observed from the figure that for individual diagrid and hexagrid structure, time period is more. For combined structure with diagrid at bottom, structure becomes stiffer & it has less time-period. But in combined structure having hexagrid at bottom, time period is higher than that of individual structure. Thus it is observed that the building with diagrid at bottom is stiffer among the five models.

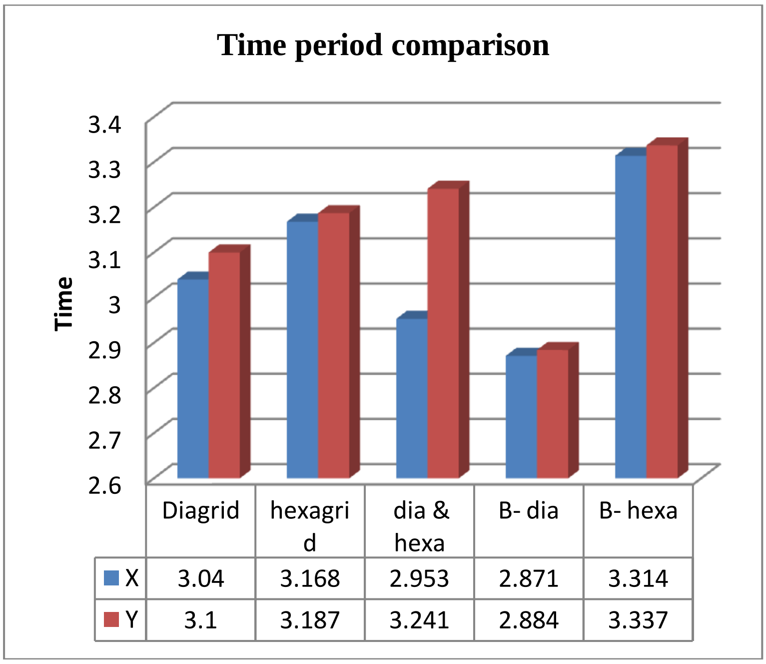

Fig 10: Comparison of time period

b) Story drift

Story-Drift is the relative story displacement due to acting of total lateral load. It is defined as a Drift of one level of multi-story relative to level belo. Story drift comparison for horizontal & vertical structural patterns is plotted in the graphical form for different models as shown in figure 11.

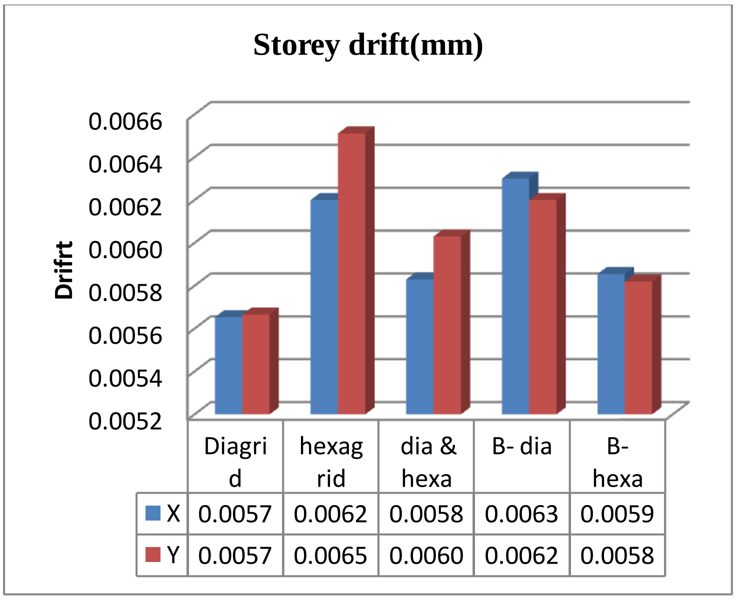

Fig 11: Comparison of storey drift

c) Story displacement

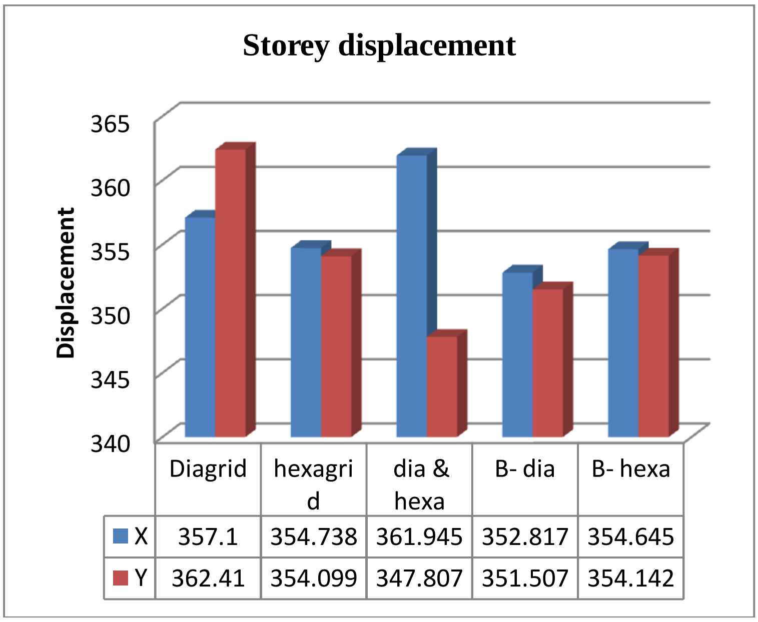

Fig 12: Comparison of displacement

Figure 12 represent the comparison of the maximum top storey displacements for the systems. The storey displacement of structure with diagrid at bottom has the least displacement of all the models and the model. The individual diagrid structure is having the highest story displacement.

d) Base shear

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 the five structural grids is plotted in the bar chart form as shown in figure 13. When the building is symmetric, the base shear will be the same in both the directions. The highest storey shear value is possessed by the structure with diagrid at bottom. The individual diagrid structure has minimum storey shear value.

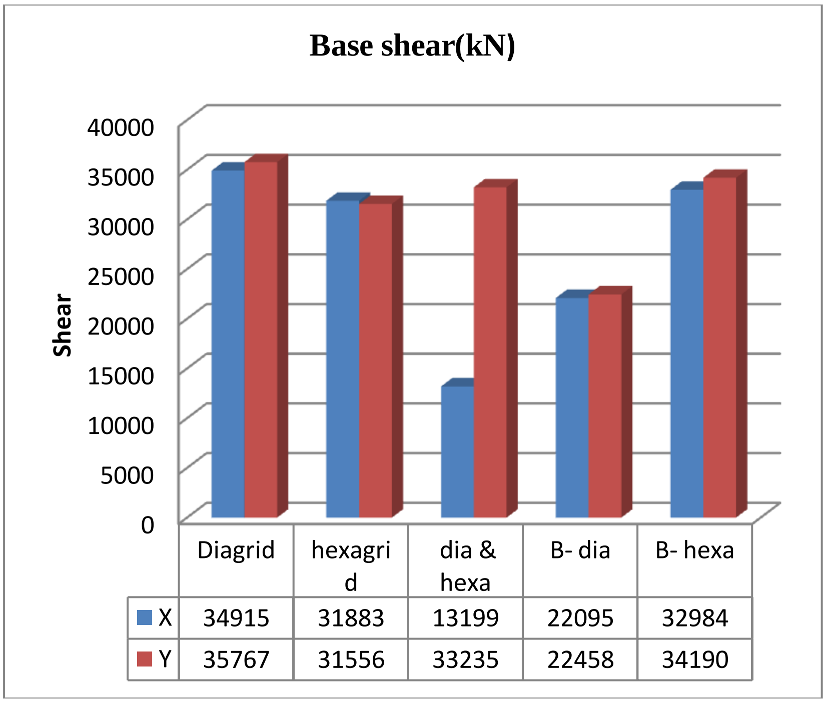

Fig 13: Comparison of base shear

III. ANALYSIS AND DESIGN OF COMBINED GRID SYSTEM FOR IRREGULAR BUILDINGS

Irregular buildings constitute a large portion of the modern urban infrastructure. Structures are never perfectly regular and hence the designers routinely need to evaluate the likely degree of irregularity and the effect of this irregularity on a structure during an earthquake. When such buildings are located in a high seismic zone, it becomes more than a concern. Uncertainties involved and behaviour studies are vital for all civil engineering structures. In this section, response of combined grid structure subjected to lateral loads is studied for stiffness and geometric irregularities.

3.1 Analysis of irregular structure- stiffness irregularity

Mass eccentricity of 5%, 10%, 15%, 20% and 25% is introduced to the regular building with combined grid structure. Torsional performance is checked by finding Max.displacement(Δmax) and Avrg. displacement(Δav).

After analysing and designing all the structures, the comparison of different parameters for all the models are tabulated in the Table 2.

Table 2: Comparison of model for stiffness irregularity

Model	Time period (s)		Storey displacement(mm)		Storey drift (mm)		Base shear(kN)		Weight (kN)
	x	y	x	y	x	y	x	y	
Diagrid	2.87	2.88	352.82	351.51	0.0063	0.0062	22095	22458	443705
5% e	2.88	2.90	372.08	371.86	0.00698	0.006939	21585	21936	443705
10% e	2.88	2.94	379.63	378.96	0.00742	0.0074	20686	20844	443705
15%e	2.88	3.02	381.19	378.73	0.00741	0.0073	18638	18899	443705
20%e	2.88	3.12	362.55	362.37	0.00673	0.0067	16239	16676	443705
25% e	2.88	3.24	338.21	339.09	0.00607	0.00607	15791	15776	443705

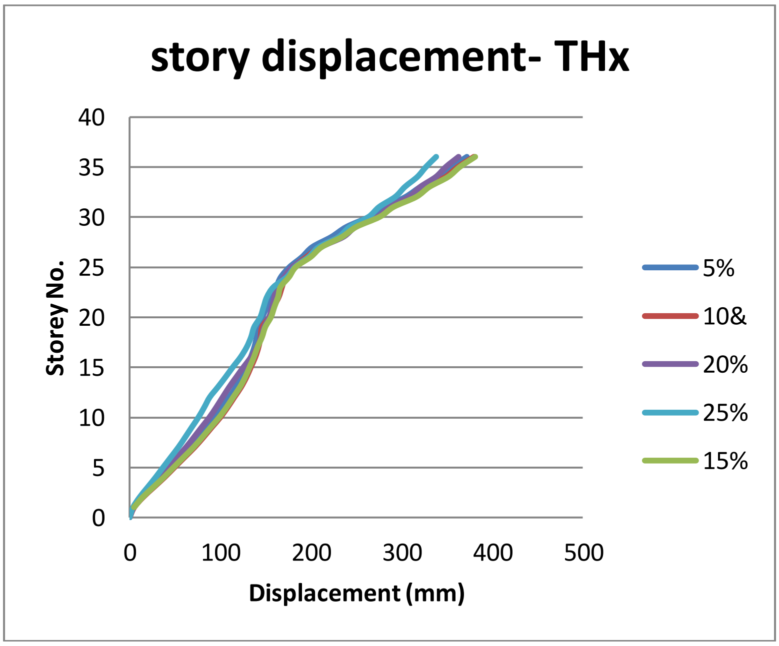

Fig 14: performance of Story displacement with story height for stiffness irregularity

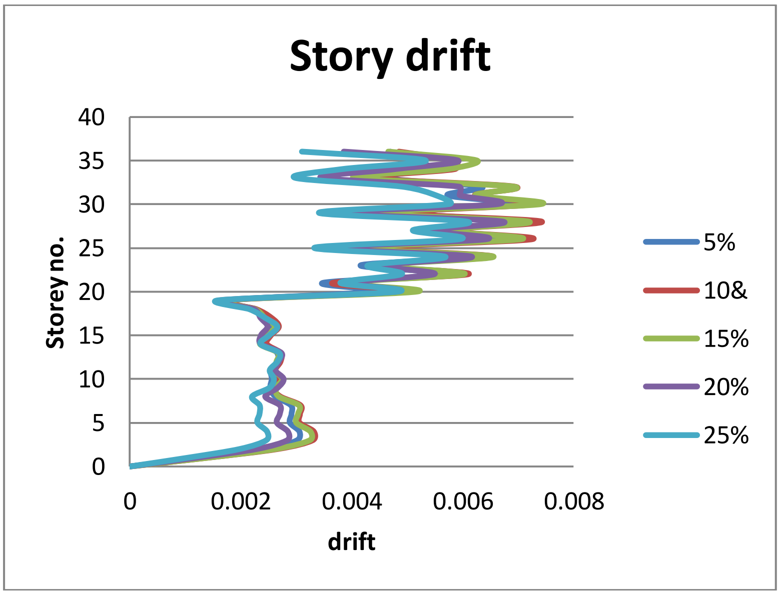

Fig 15: performance of Story displacement with story height for stiffness irregularity

Comparison of analysis results

a) Time period

Figure 16 represents the comparison of the time period for the models with varying eccentricity values. It is observed from the figure that as eccentricity increases time period also increases.

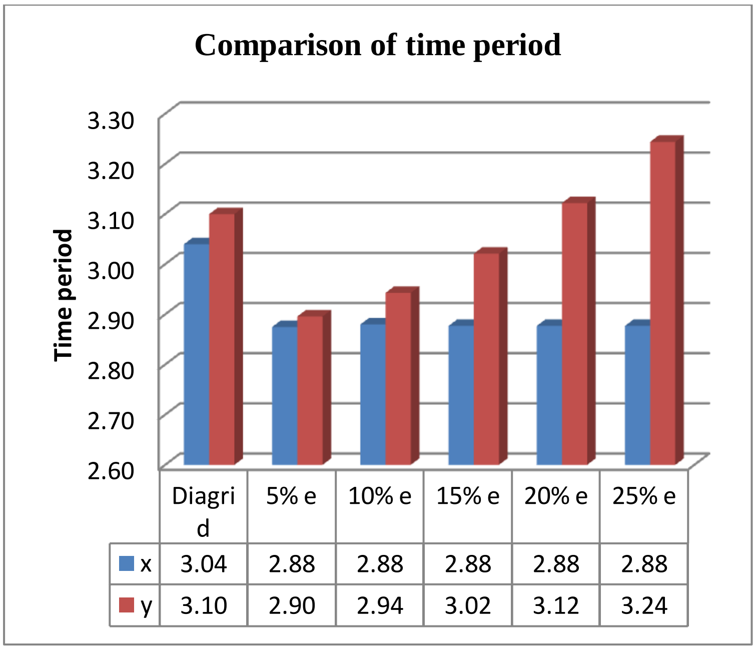

Fig 16: Comparison of time period

b) Story drift

Figure 17 represents the comparison of the story drift for the models with varying eccentricity values. It is observed from the figure that as eccentricity increases story drift value dcreases..

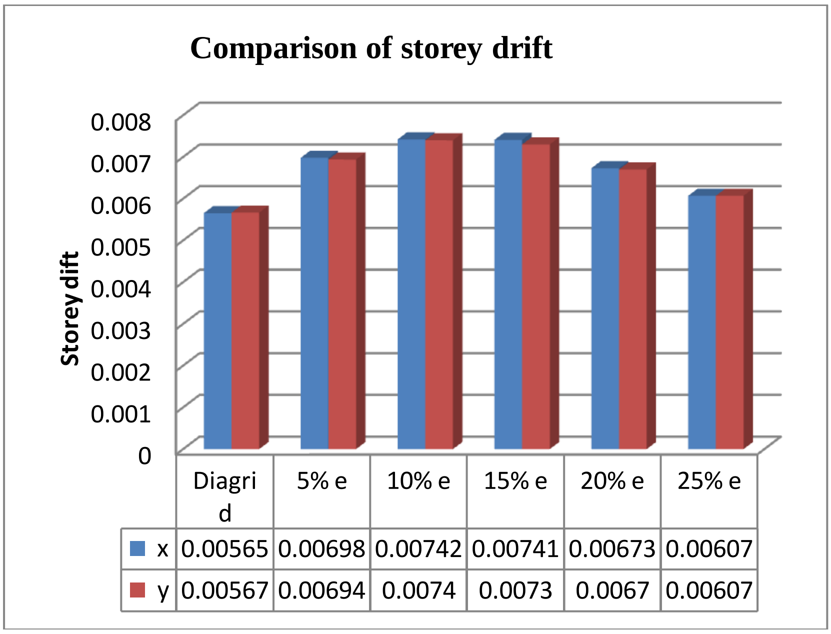

Fig 17: Comparison of storey drift

c) Story displacement

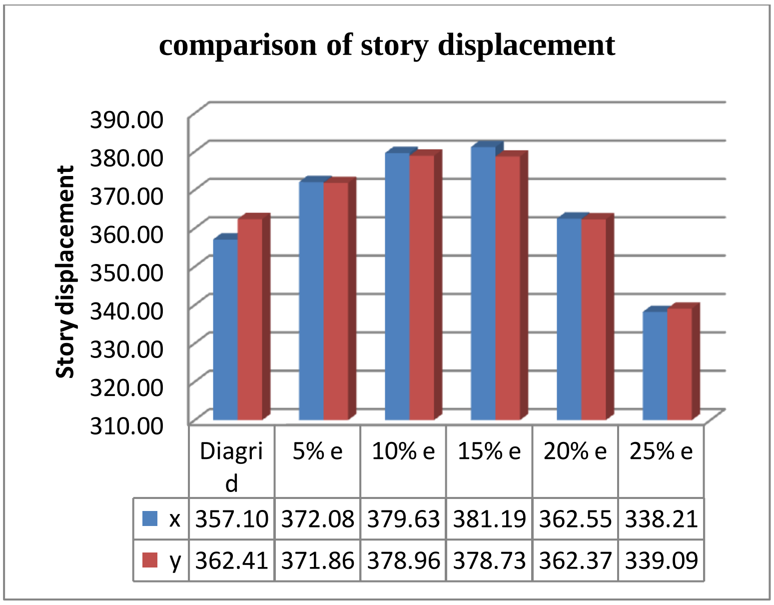

Fig 18: Comparison of displacement

Figure 18 represents the comparison of the story displacement for the models with varying eccentricity values. It is observed from the figure that as eccentricity increases story displacement value decreases.

d) Base shear

Figure 17 represents the comparison of the base shear for the models with varying eccentricity values. It is observed from the figure that as eccentricity increases shear value decreases.

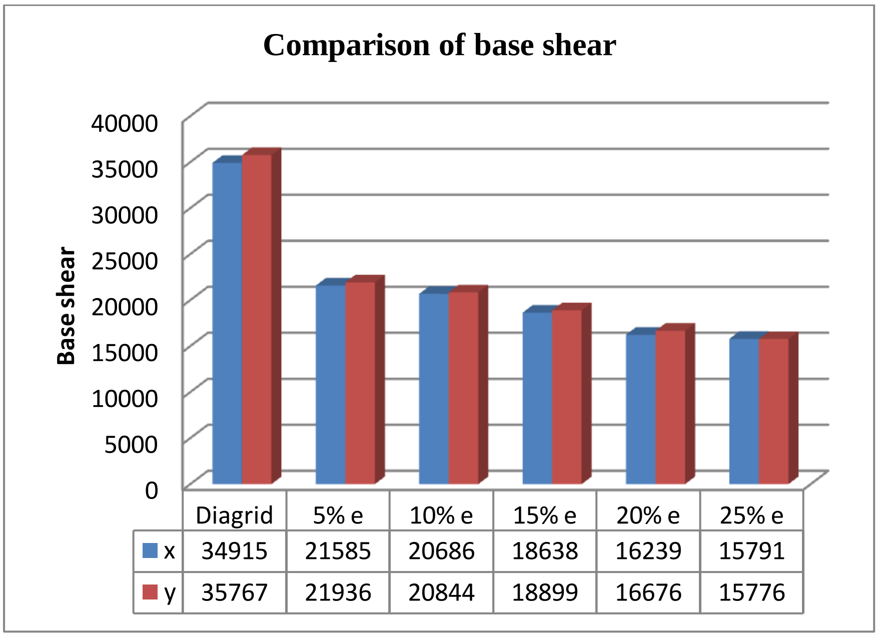

Fig 19: Comparison of base shear

3.2 Analysis and design of irregular structure- geometric irregularity

In this section, combined grid structure is analysed for different plan shapes. For this purpose, three models are created with different plan shapes- L shaped, T shaped and I shaped

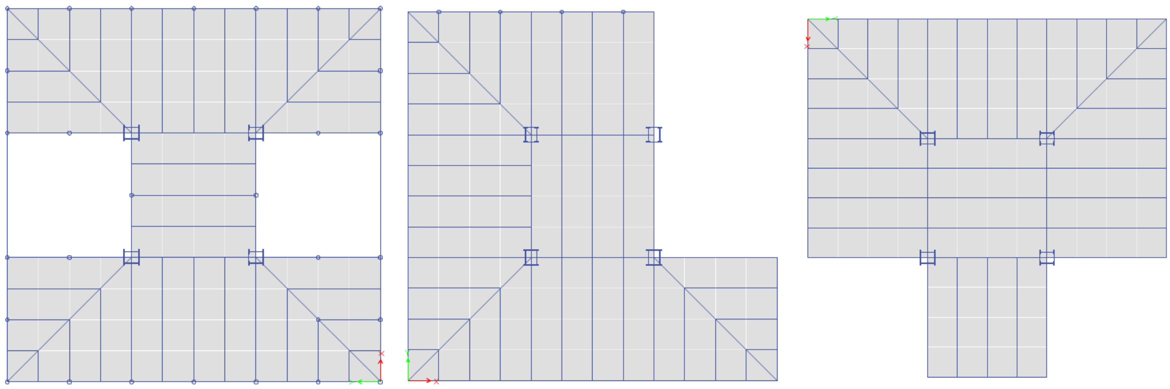

Fig 20: different plan shapes

After analysing and designing all the structures, the comparison of different parameters for all the models are tabulated in the Table 3

Table 3: comparison of buildings with different plan shapes

Model	Time period (s)		Storey displacement(mm)		Storey drift (mm)		Base shear(kN)		Weight (kN)
	x	y	x	y	x	y	x	y	
Regular	2.87	2.88	352.82	351.51	0.0063	0.0062	22095	22458	443705
L shape	2.68	3.08	371.14	323.79	0.0092	0.00623	16207	18864.36	350176
Tshape	2.84	2.85	348.05	347.47	0.0061	0.00614	18981	18816	349982
I shape	2.51	2.59	315.89	349.26	0.00488	0.0054	20293	22697	356703

Comparison of analysis results

a) Time period

Figure 14 represents the comparison of the time period for the geometric irregularity models. It is observed from the figure that time period is more for the L shaped structure and it is less for I shaped structure.

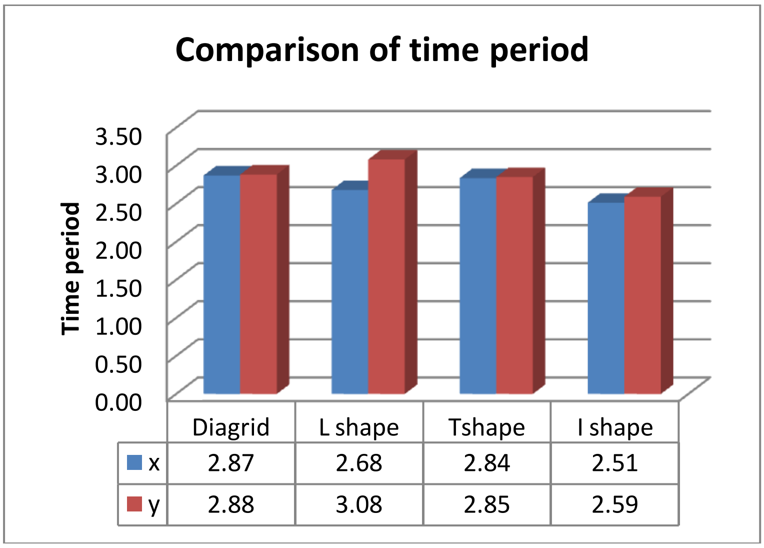

Fig 21: Comparison of time period

b) Story drift

Story-Drift is the relative story displacement due to acting of total lateral load. It is defined as a Drift of one level of multi-story relative to level below. Story drift comparison is plotted in the graphical form for different models as shown in figure 22. Story drift value is minimum for the I shaped structure.

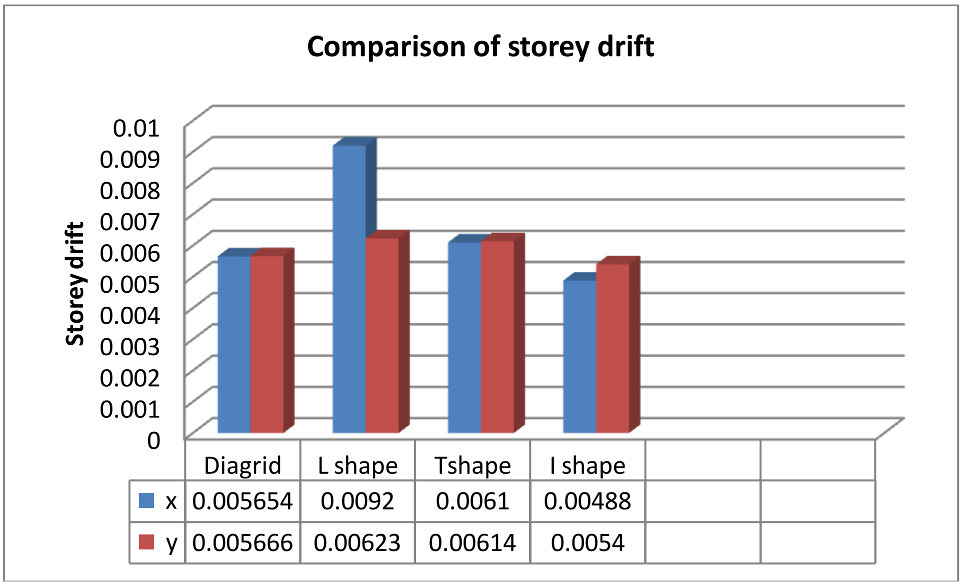

Fig 22: Comparison of storey drift

c) Story displacement

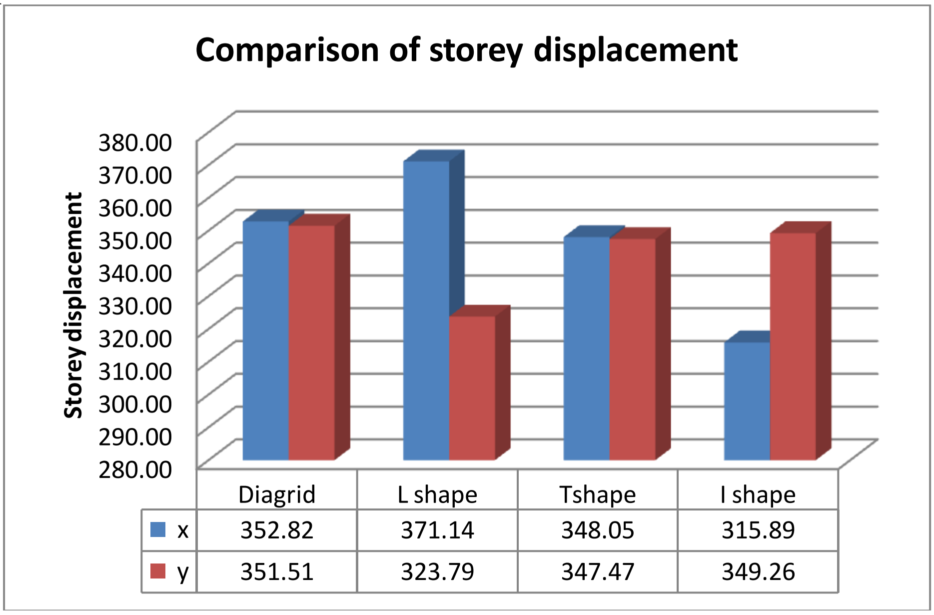

Fig 23: Comparison of displacement

Figure 23 represent the comparison of the maximum top storey displacements for the systems. The storey displacement of the T shaped structure is less compared to regular structures..

d) Base shear

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 the geometric irregular models are plotted in the bar chart form as shown in figure 24. Compared to regular structure, base shear value is minimum for irregular structures.

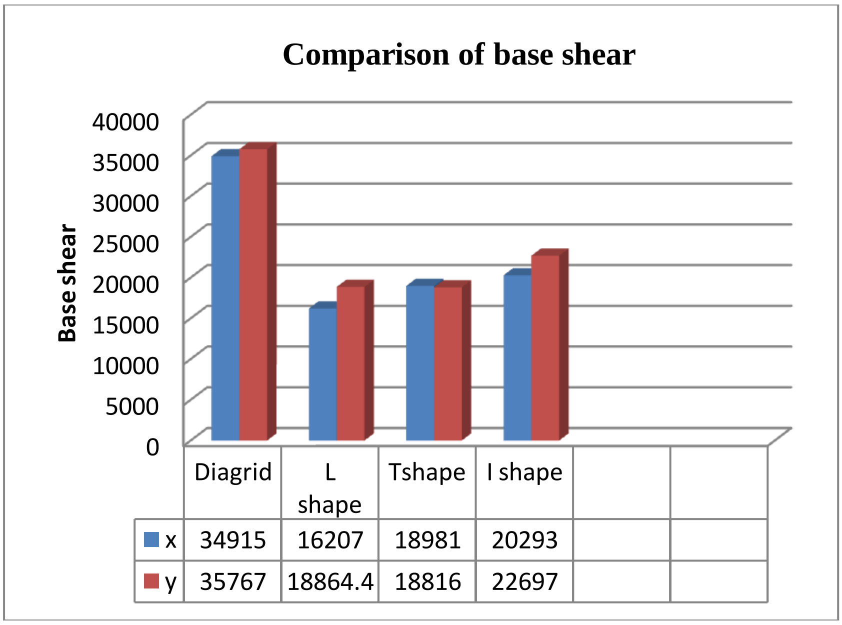

Fig 24: Comparison of base shear

IV. CONCLUSION

In this paper, analysis and design of 36 storey diagrid steel building is presented in detail. A regular floor plan of 36 m ×36 m size is considered. ETABS software is used for modeling and analysis of structure. All structural members aredesigned using IS 800:2007 considering all load combinations. Load distribution in diagrid system is also studied for 36 storey building.

- Diagrid is having less time period and low drift value compared to hexagrid structure
- Hexagrid is having low storey displacement and base shear than diagrid structure.
- When compared to diagrid, hexagrid is more effective since it is having low storey displacement and base shear and low weight.
- Among the combined structures, structure with diagrid at bottom half and hexagrid at top is found to be more effective. It has more stiffness. It is also having lower displacement and base shear values. Hence the stability of structure is increased.
- Stiffness irregularity is given to the building by giving mass eccentricity of 5%,10%,15%,20% and 25% and torsion limit is checked.
- Upto 25% the value of $\Delta max/\Delta av$ is within the limit 1.5 So upto an eccentricity of 25% the building is safe.
- Compared to individual structure, I shaped building is having lower drift value and time period.
- For L shaped building, there is significant decrease in base shear value.
- Base shear value is less for one side set back building compared to two side set back building

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