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PARAMETRIC STUDY OF DIAGRID, PENTAGRID AND HEXAGRID STRUCTURAL SYSTEM

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ABSTRACT

Tall building or High rise structures construction are more in this era; due to increase in population, economic prosperity and also due to the scarcity of lands high-rise structures are preferred. Height is main criteria in this kind of buildings, demand for tall buildings has increased because of increase in demand for business and residential space, advances in constructions, high strength structural elements, materials and also various software like Etabs, Staad pro etc these are analysis and design software's have provided growth of high rise structures.

Due to the heavy urbanization and population growth, the cost of land is increasing rapidly and the land availability has become a constraint for developers & builders. And this creates a picture of vertical growth as natural process. 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. Recent design trends in tall buildings pose new challenges to structural designers, in addition to the traditional requirements for strength, stiffness, ductility and system efficiency.

INTRODUCTION

The structural system of ahigh-risebuilding is designed to cope with the vertical gravity loads andlateral loadscaused by wind or seismic activity. The structural system consists only of the members designed to carry the loads, all other members are referred to as non-structural. The term structural system or structural frame in structural engineering refers to load-resisting sub-system of a structure. The structural system transfers loads through interconnected structural components or members.
Due to the heavy urbanization and population growth, the cost of land is increasing rapidly and the land availability has become a constraint for developers & builders. And this creates a picture of vertical growth as natural process. 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.Recent design trends in tall buildings pose new challenges to structural designers, in addition to the traditional requirements for strength, stiffness, ductility and system efficiency. Structural configurations best addressing the traditional requirements of strength and stiffness for tall buildings are the ones employing the tube concept, whose efficiency is strictly related to the involved shear resisting mechanism, and in fact the historical evolution of the tube concept has been marked by the attempts of reducing the occurrence of efficiency loss due to shear deformations.

Tall building or high rise structures construction are more in this era; due to increase in population, economic prosperity and also due to the scarcity of lands high-rise structures are preferred. Height is main criteria in this kind of buildings, demand for tall buildings has increased because of increase in demand for business and residential space, advances in constructions, high strength structural elements, materials and also various software like Etabs, Staad pro etc these are analysis and design software's have provided growth of high rise structures..

1.1 Types of structural systems

Construction of tall buildings are not easy as that of normal conventional buildings due to the action of lateral loads, lateral displacement will induces bending and shear lag effects will be more so that in order to resist lateral loads new systems were invented known as lateral load resisting systems some of them are

a) Interior structures
  - Rigid frame
  - Shear wall structure
  - Outrigger structure

b) Exterior structures
  - Tube system
  - Diagrid system, Pentagrid system & Hexagrid system
  - Space truss
  - Exoskeleton structure
  - Super frame structure.

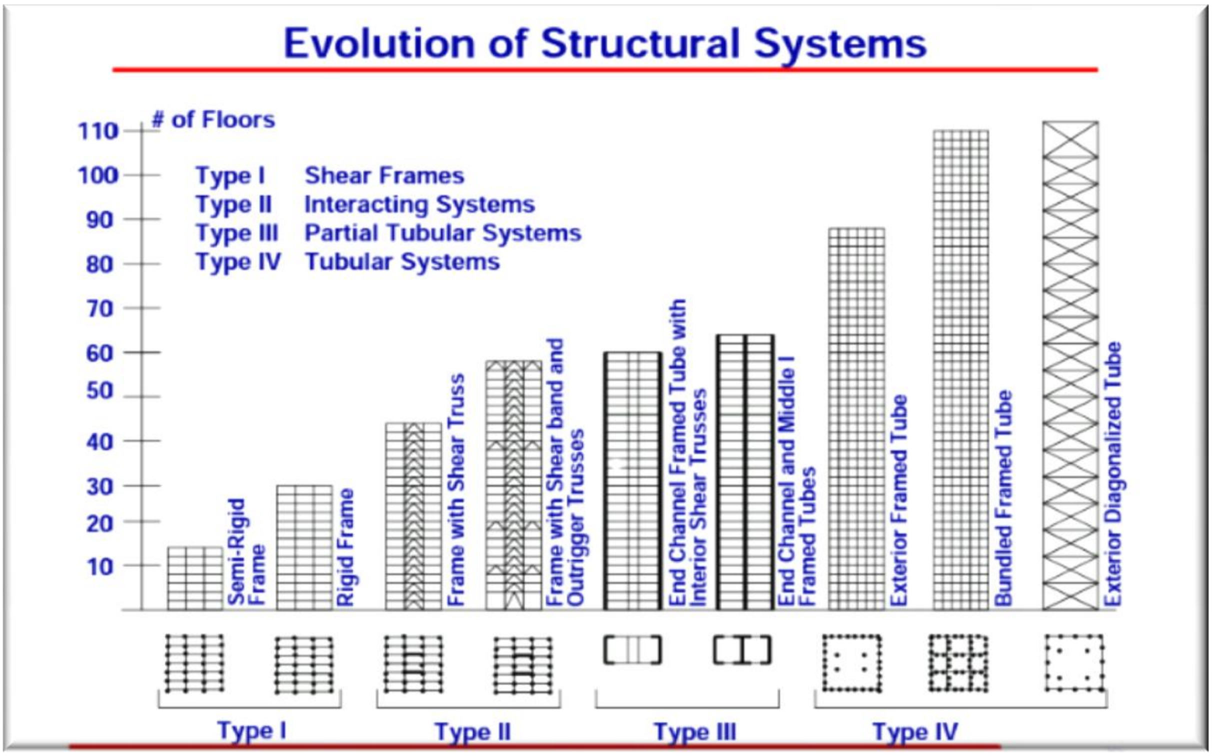


Figure 1 Evolution of structural systems

1.2 Diagrid Structural systems

Diagrid is a particular form of space truss. It consists of perimeter grid made up of a series of triangulated truss system. Diagrid is formed by intersecting the diagonal and horizontal components.Diagrid has good appearance and it is easily recognized. The configuration and efficiency of a diagrid system reduce the number of structural element required on the façade of the buildings, therefore less obstruction to the outside view. The structural efficiency of diagrid system also helps in avoiding interior and corner columns, therefore allowing significant flexibility with the floor plan. Perimeter "diagrid" system saves approximately 20 percent of the structural steel weight when compared to a conventional moment-frame structure. The diagonal members in diagrid structural systems can carry gravity loads as well as lateral forces due to their triangulated configuration. Diagrid structures are more effective in minimizing shear deformation because they carry lateral shear by axial action of diagonal members. Diagrid structures generally do not need high shear rigidity cores because lateral shear can be carried by the diagonal members located on the periphery.

Figure 2 Diagrid Structural system (swiss re buildind in London)

1.3 Pentagrid Structural system

The pentagrid structural system is derived by smartly arranging several technically developed irregular pentagons - alternatively inverted both in horizontal as well as vertical directions. This structural system is developed by using multiangle concept by which all the elements share both gravity as well as lateral loads partially. Unlike most of other structural systems this structural system is non nature inspired but it is technically devised by applying mathematics so that it can resists both shear force as well as bending moment developed in the structure due to gravity as well as lateral loads.

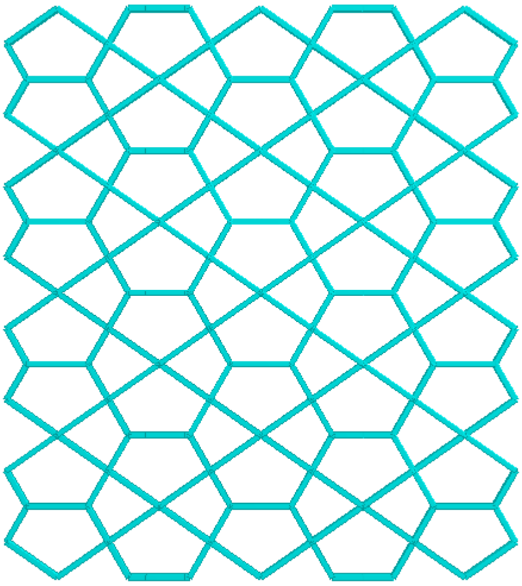


Figure 3 Pentagrid structural system

1.4 Hexagrid Structural system

In the hexagrid structure system, almost all the conventional vertical columns are eliminated. Hexagrid structural system consists of Hexagrid perimeter which is made up of a network of multi-storey tall hex-angulated truss system. Hexagrid is formed by intersecting the diagonal and horizontal components. The project is focused to horizontal hexagrid pattern which aims to investigate the optimal angle and a topology of diagonal members in a hexagrid frame using finite element analysis and to study the structural properties of hexagonal structures so as to compare their potential efficiency with the conventional systems.

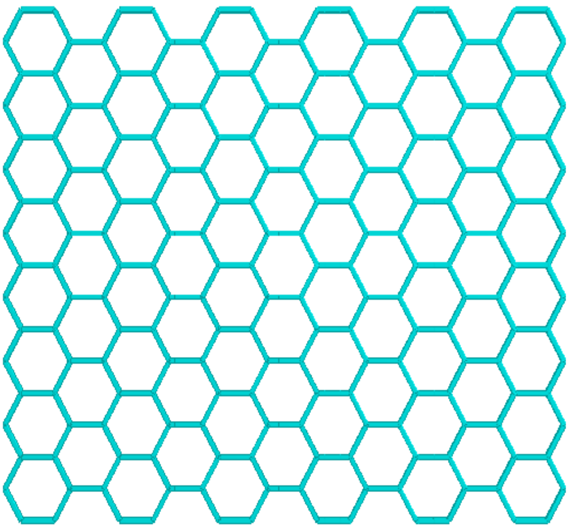


Figure 4 Hexagrid Structural system

LITERATURE REVIEW

Khushbu Jani et al (2013) Advances in construction technology, materials, structural systems and analytical methods for analysis and design facilitated the growth of high rise buildings. Structural design of high rise buildings is governed by lateral loads due to wind or earthquake. Lateral load resistance of structure is provided by interior structural system or exterior structural system. Usually shear wall core, braced frame and their combination with frames are interior system, where lateral load is resisted by centrally located elements. While framed tube, braced tube structural system resist lateral loads by elements provided on periphery of structure. It is very important that the selected structural system is such that the structural elements are utilized effectively while satisfying design requirements. Recently diagrid structural system is adopted in tall buildings due to its structural efficiency and flexibility in architectural planning. Compared to closely spaced vertical columns in framed tube, diagrid structure consists of inclined columns on the exterior surface of building. Due to inclined columns lateral loads are resisted by axial action of the diagonal compared to bending of vertical columns in framed tube structure. Diagrid structures generally do not require core because lateral shear can be carried by the diagonals on the periphery of building. Analysis and design of 36 storey diagrid steel building is presented. 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. Dynamic along wind and across wind are considered for analysis and design of the structure. Load distribution in diagrid system is also studied for 36 storey building. Similarly, analysis and design of 50, 60, 70 and 80 storey diagrid structures is carried out. Comparison of analysis results in terms of time period, top storey displacement and inter-storey drift is presented in this paper.

Taranath S. D. et al (2014) Due to heavy urbanization and population growth, vertical growth has become challenging thing in the building industry. This challenge is handled by using material of high strength and light weight. In addition to imposition of advanced efficient structural forms for gravity and lateral loads, there is continuous development to control structural distortions, in this regard bracing systems have the responsibility of controlling lateral responses. The present investigation involves the study of efficiency of peripheral pentagrid and hexagrid bracing systems compared with the basic model (without bracings) at standard loading conditions. Three tall buildings of 40, 50 and 60 stories with structural forms of rigid frame-slab, shear walls with flat slabs, flat slabs with columns are considered for comparison. Lateral bracings of pentagrid & hexagrid shape with rigid connections are made to these models by using RC members of 200 x 200 mm. The lateral response of these models are compared for least displacements.

Mohsen Rostami, et al (2016) The most important issue in the design of high-rise buildings is the lateral load system that accordingly, the selection of a structural systems that can ductility, stiffness, and sufficient resistance based on valid regulations provide is the most important principle in the field of high-rise building because the parameters of stiffness, ductility and structural resistance system will change with variation the type of lateral load systems a relatively large amount. therefore, in this study, new structural system have been extended that nominated new Hexagrid, three structural systems tube and diagrid and new Hexagrid in similar structures (in plan, height, loading, etc) with 30 floors has been modelled in software ABAQUS and SAP2000 and after the calculation of earthquake factors on structures mentioned by program written in MATLAB based on 2800 regulation. Analysis of static and liner dynamic and nonlinear static (pushover), respectively is done on structures 30 floors of the diagrid and tube and new hexagrid, finally after analysing of 3 structure studied, the advantages and disadvantages and relative superiority of the three systems lateral load in structures mentioned based on stiffness parameters, relative displacement, ductility and resistance compared with each other. the importance of this comparison is that based on its finding can be determined the system suitable lateral load based on the seismic hazard at the site of construction. The results of the above analysis show that the new Hexagrid structures, have stiffness higher than the tube and Diagrid structures but its plasticity is lower than that other system.

Deepika R. et al (2016) Advances in technology, change in life style of people, requirements of present population has increased the growth of tall buildings. Load action on tall building are very much different than the low rise building, lateral loads due to wind and earthquake would produce more effect on high rise buildings. There are many lateral load resisting systems mainly classified into interior structures and exterior structures since diagrid and hexagrid systems are provided at outer periphery of buildings it comes under exterior structures. Normal bracing systems will be uneconomical, if number of stories are more than 25 hence, a new grid system has been developed i.e. diagrid system. As compared to other systems diagrid are aesthetically more pleasing and gives better stiffness to structures. Here, analysis of normal framing system without any load resisting system, diagrid with varied diagonal angles and hexagrid system will be conducted by using analysis and design software extended three dimensional analyses of building systems (ETABS V15.2). A regular floor plan of square shape of 30mx30m is considered, all structural members are designed as per IS 456-2000. Wind and earthquake parameters are considered from IS875-1987 (part III) and IS1893-2002 respectively. Analysis results are compared in terms of storey drift, storey displacement, time period and overturning moment.

Ravi Sorathiya et al (2017) Construction of multi-storey building is rapidly increasing throughout the world. . Recently the diagrid structural system has been widely used for tall buildings due to the structural efficiency and aesthetic potential provided by the unique geometric configuration of the system.These days the latest trend of technology in diagrid structures is evolving. The diagrid structures are buildings with diagonal grids in the periphery at a particular angle and in modules across the height of the building. Diagrid structure uses triangulated grids which are in place of vertical columns in the periphery. Thus, systems that are more efficient in achieving stiffness against lateral loads are considered better options in designing tall buildings. This paper presents a stiffness-based design methodology for determining preliminary member sizes of r.c.cdiagrid structures for tall buildings. A G+24, G+36,G+48,G+60 storey RCC building with plan size 18 m × 18 m located in surat wind and seismic is considered for analysis. STAAD.Pro software is used for modeling and analysis of structural members. All structural members are designed as per IS 456:2000 and load combinations of seismic forces are considered as per IS 1893(Part 1): 2002. Comparison of analysis results in terms of beam displacement, Storey Drift, Bending Moment. This cause economical design of diagrid structure compared to conventional structure.

METHODOLOGY

In this study comparison of diagrid, pentagridand hexagrid system is compared with conventional system in terms of storeydisplacement, storey drift, base shear and modal time period.

Following steps are adopted in this study.

Step 1: Selection of building geometry and modeling of diagrid,pentagrid,hexagrid and conventional structural system using ETABS 2016 software for the same plan.

Step 2: Selection of site condition and seismic zone.

Step 3: Application of loads and load combination to the structural model according to the standard codes.

Step 4: Analysis of each building frame models.

Step 5: Comparative study of results in terms of storey displacement, storey drift, base shear and time period. By considering different storeysi. e. 13 storey, 37 storey, and 47 storeys.

Step 6: Effect of shear wall on above mentioned parameters for different storeys

Step 7: Above structures are analyzed by static method as well as dynamic method by response spectrum method and the results have to be compared.

MODELING & ANALYSIS

In this chapter comparative study has been carried out on simple frame building, diagrid structural system building, pentagrid structural system building and hexagrid structural system building.

Modeling data:

Plan dimension	(36 X 36) m
Number of storey	13
Floor to floor height	3.5m
Structure utility	Commercial
Seismic zone	3
Seismic coefficient	0.16
Response reduction factor	5
Importance factor	1
Wind speed	44 m/s
Structure type	C
Analysis method	• Static method • Dynamic analysis(RSM)
Codes used	• IS 456-2000, • IS 800-2007. • IS 875-2015. • IS1893 Part 1-2015

Load cases:

1)1.5DL	14)0.9DL-1.5WINDY	27)1.5(DL+EQY)
2)1.5(DL+LL)	15)1.2(DL+LL+EQX)	28)1.5(DL-EQY)
3)1.2(DL+LL+WIND X)	1601.2(DL+LL-EQX)	29)1.5(DL+EQY-)
4)1.2(DL+LL-WIND X)	17)1.2(DL+LL+EQX-)	30)1.5(DL-EQY-)
5)1.2(DL+LL+WIND Y)	18)1.2(DL+LL-EQX-)	31)0.9DL+1.5EQX
6)1.2(DL+LL-WIND Y)	19)1.2(DL+LL+EQY)	32)0.9DL-1.5EQX
7)1.5(DL+LL+WIND X)	20)1.2(DL+LL-EQY)	33)0.9DL+1.5EQX-
8)1.5(DL+LL-WIND X)	21)1.2(DL+LL+EQY-)	34)0.9DL-1.5EQX-
9)1.5(DL+LL+WIND Y)	22)1.2(DL+LL-EQY-)	35)0.9DL+1.5EQY
10)1.5(DL+LL-WIND Y)	23)1.5(DL+EQX)	36)0.9DL-1.5EQY
11)0.9DL+1.5WINDX	24)1.5(DL-EQX)	37)0.9DL+1.5EQY-
12)0.9DL-1.5WINDX	25)1.5(DL+EQX-)	38)0.9DL-1.5EQY-
13)0.9DL+1.5WINDY	26)1.5(DL-EQX-)	

The design data as follow:

1. For all the types of buildings 450x900 mm concrete sections have been used as beam sections.
2. For all the four types of buildings 700x700 mm concrete section have been used as column sections for interior as well as exterior.
3. For diagrid, pentagridhexagrid structural systems the grids are provided as pipe section of 400 mm diameter and 10 mm thickness.
4. Floor finish of 1.5 kN/m^2 is applied on all the storeys.
5. Live load of 3 kN/m^2 and 2kN/m^2 is applied on all storeys except terrace level and terrace level respectively.
6. Wall load of 12kN/m and 7kN/m as parapet wall load is applied on the storeys.

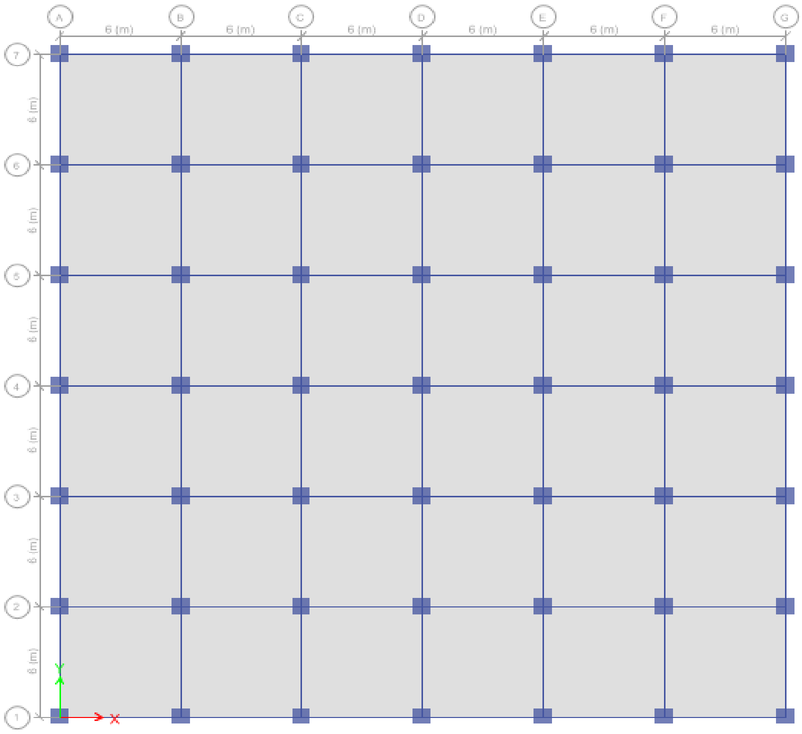


Figure 5 Floor plan of regular building

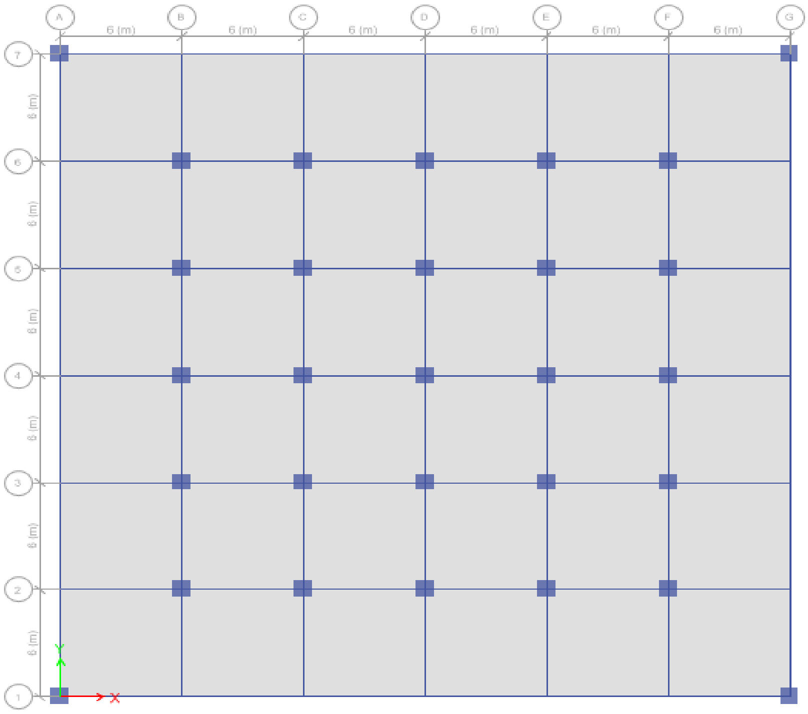
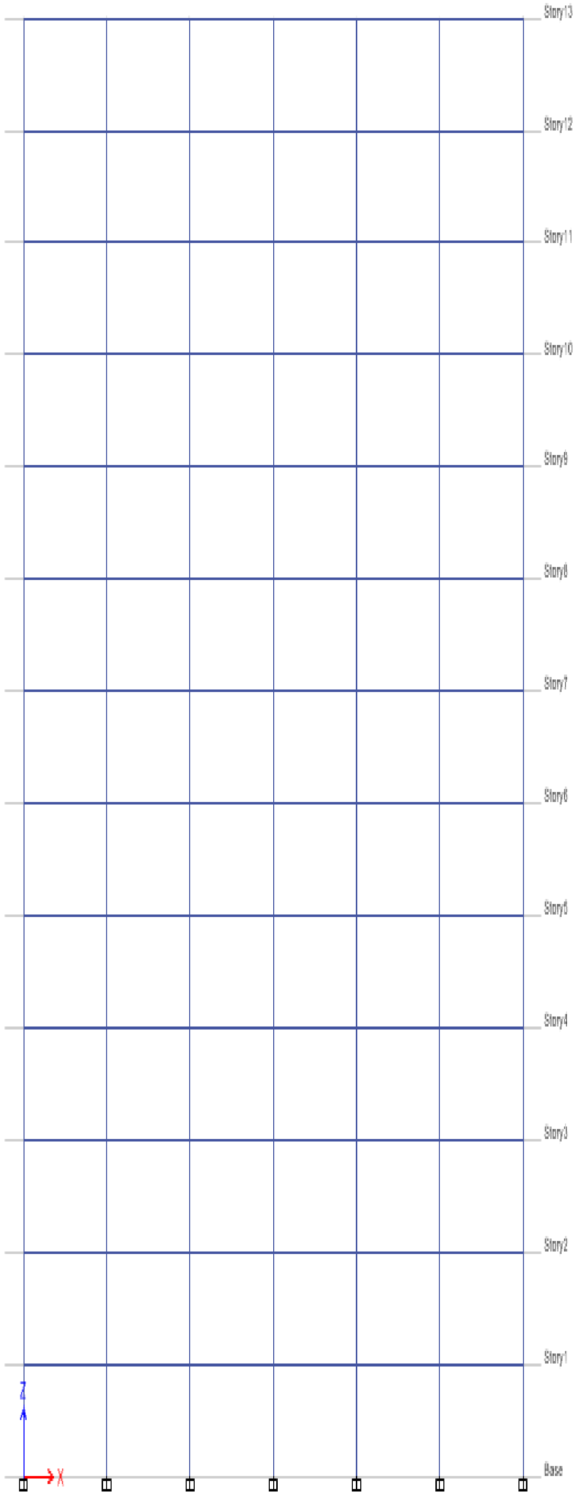


Figure 6 Floor plan of Diagrid, pentagrid and hexagrid structural system building



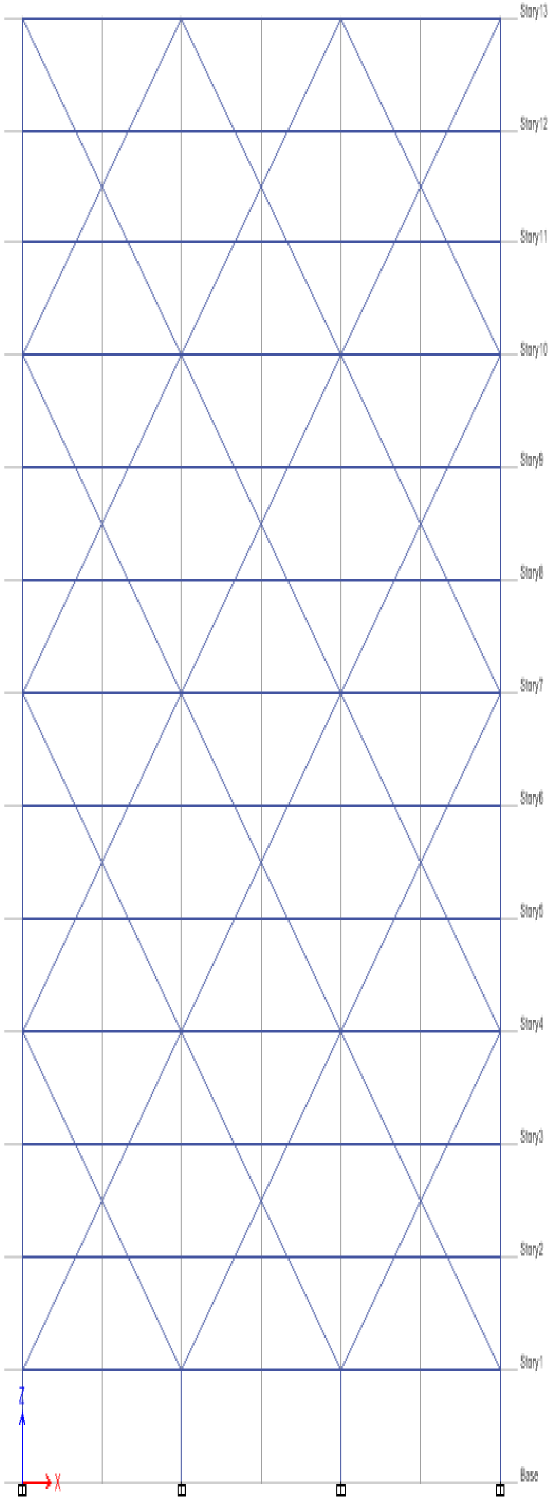


Figure 7 Elevation of Regular building

Figure 8 Elevation of Diagrid building

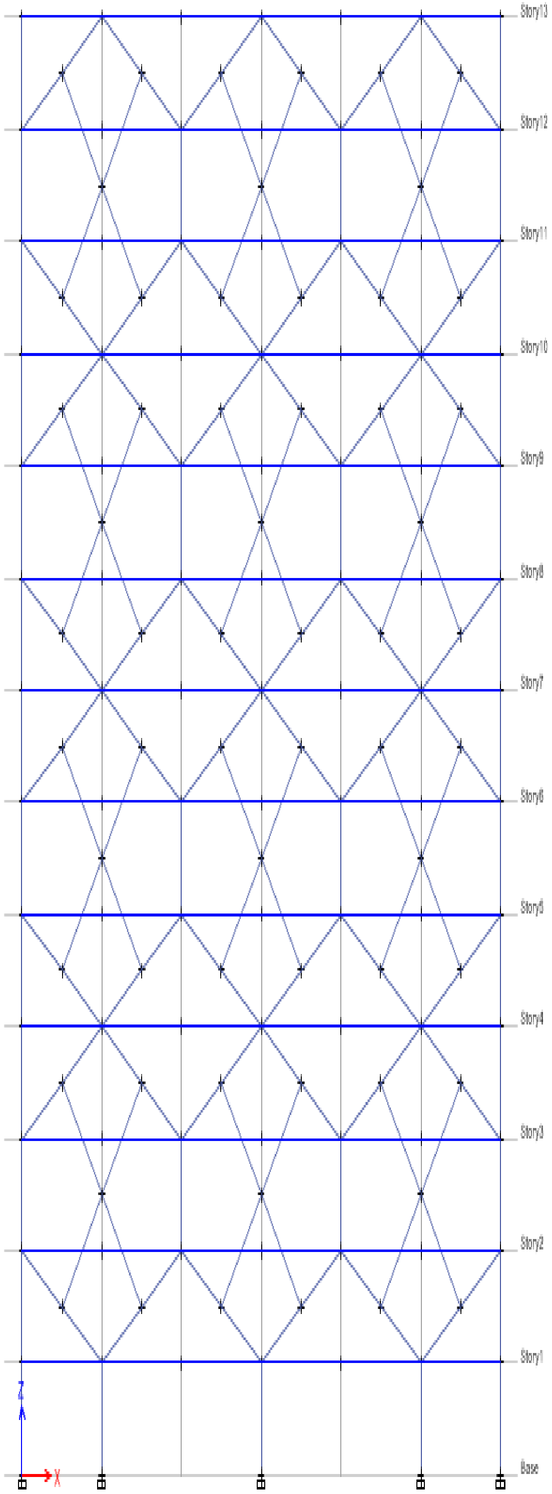


Figure 9 Elevation of Pentagrid building

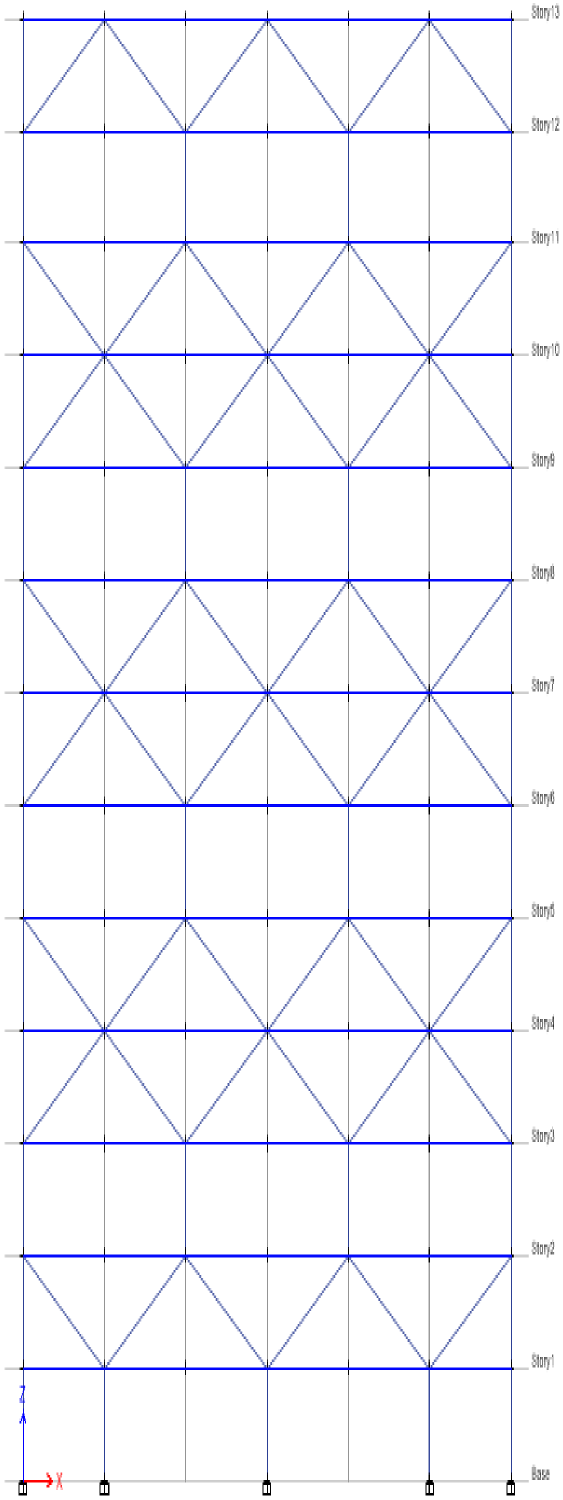


Figure 6 Elevation of Hexagrid building

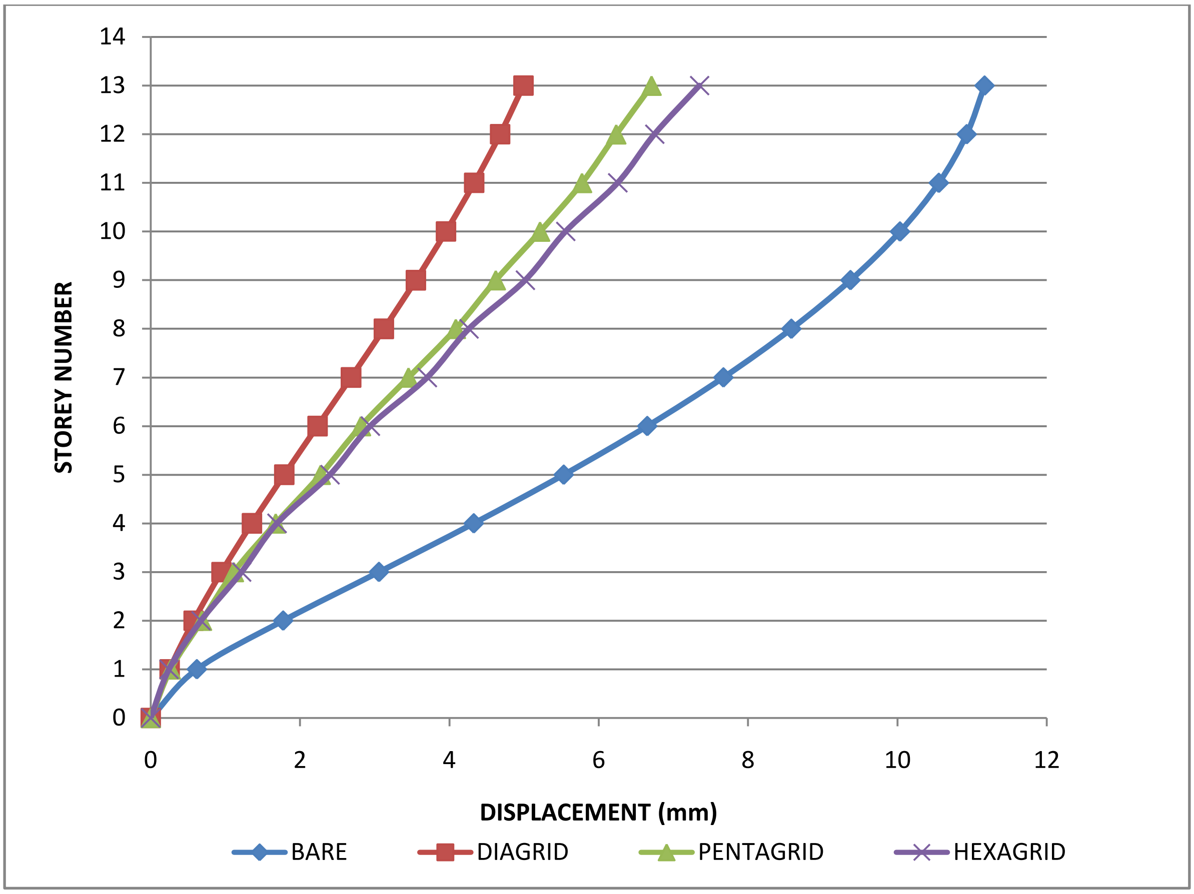


Figure 7 Combined Storey Displacement (RSM) 13 storey for 2 floor grid with Shear wall

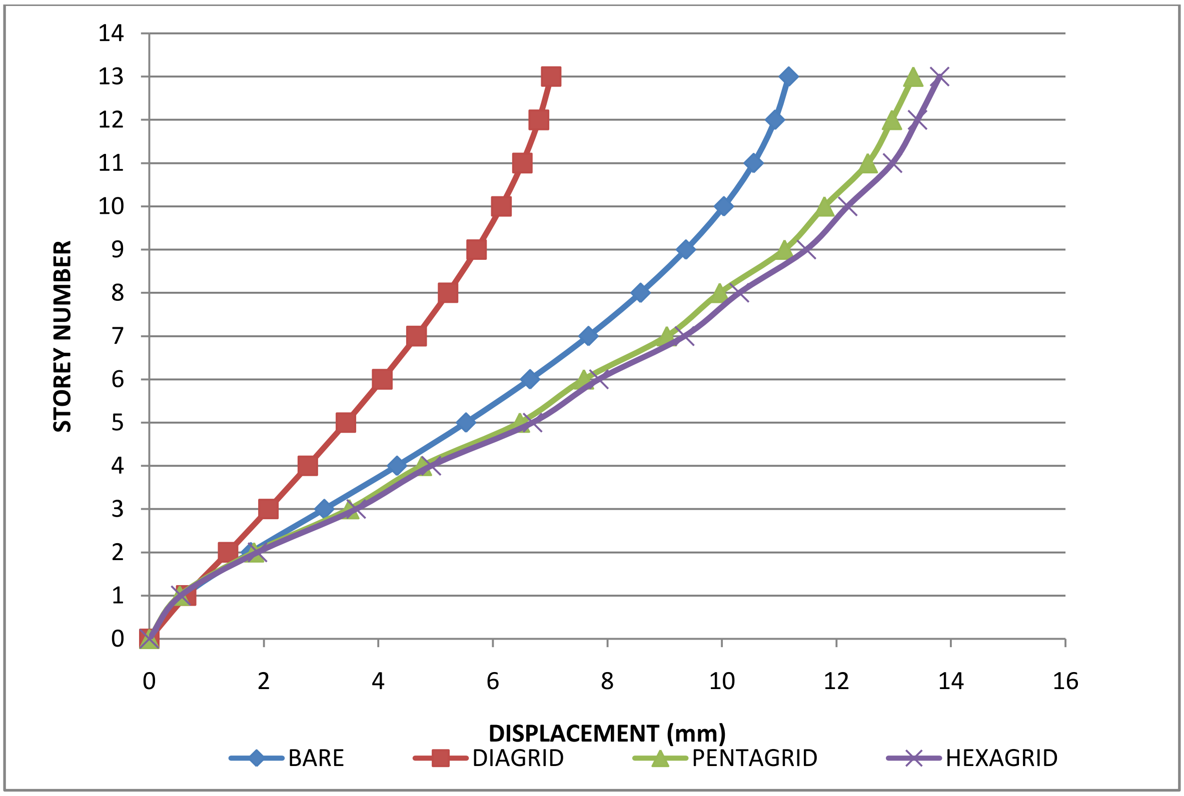


Figure 8 Combined Storey Displacement (RSM) 13 storey for 2 floor grid with no Shear

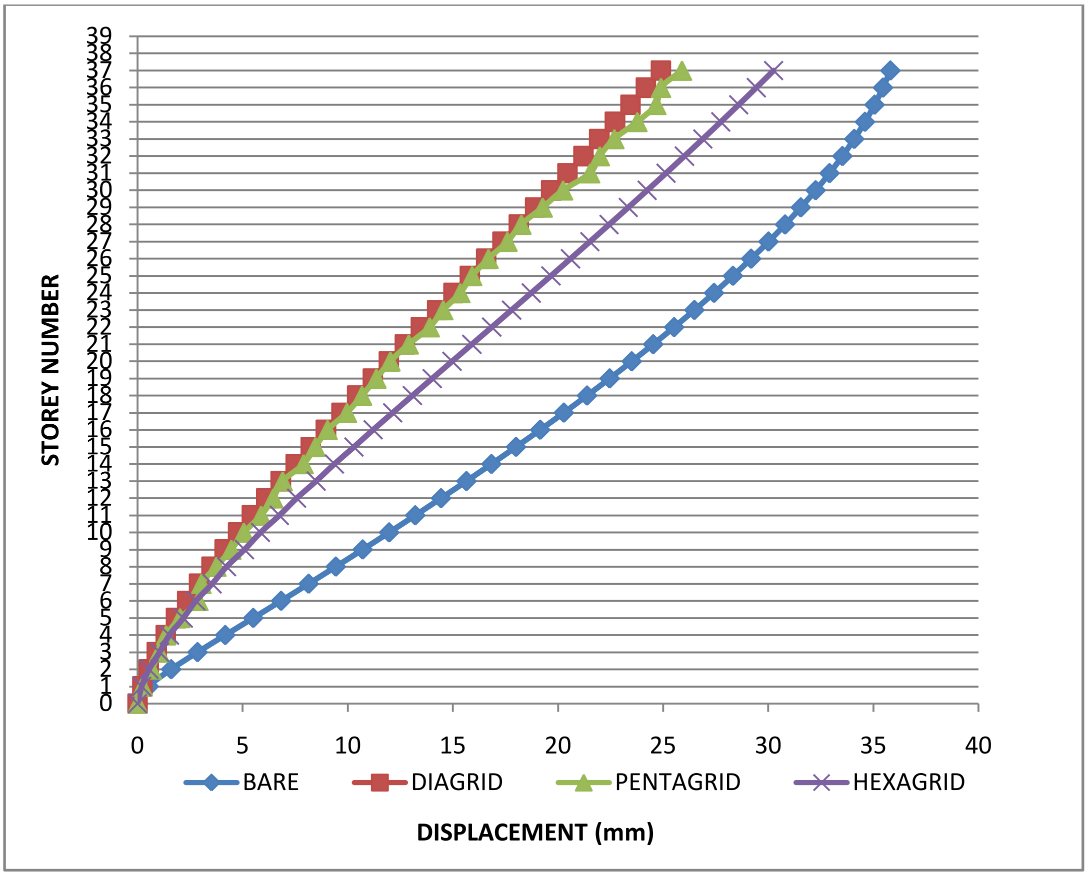


Figure 9 Combined Storey Displacement (RSM) 37 storey for 2 floor grid with Shear

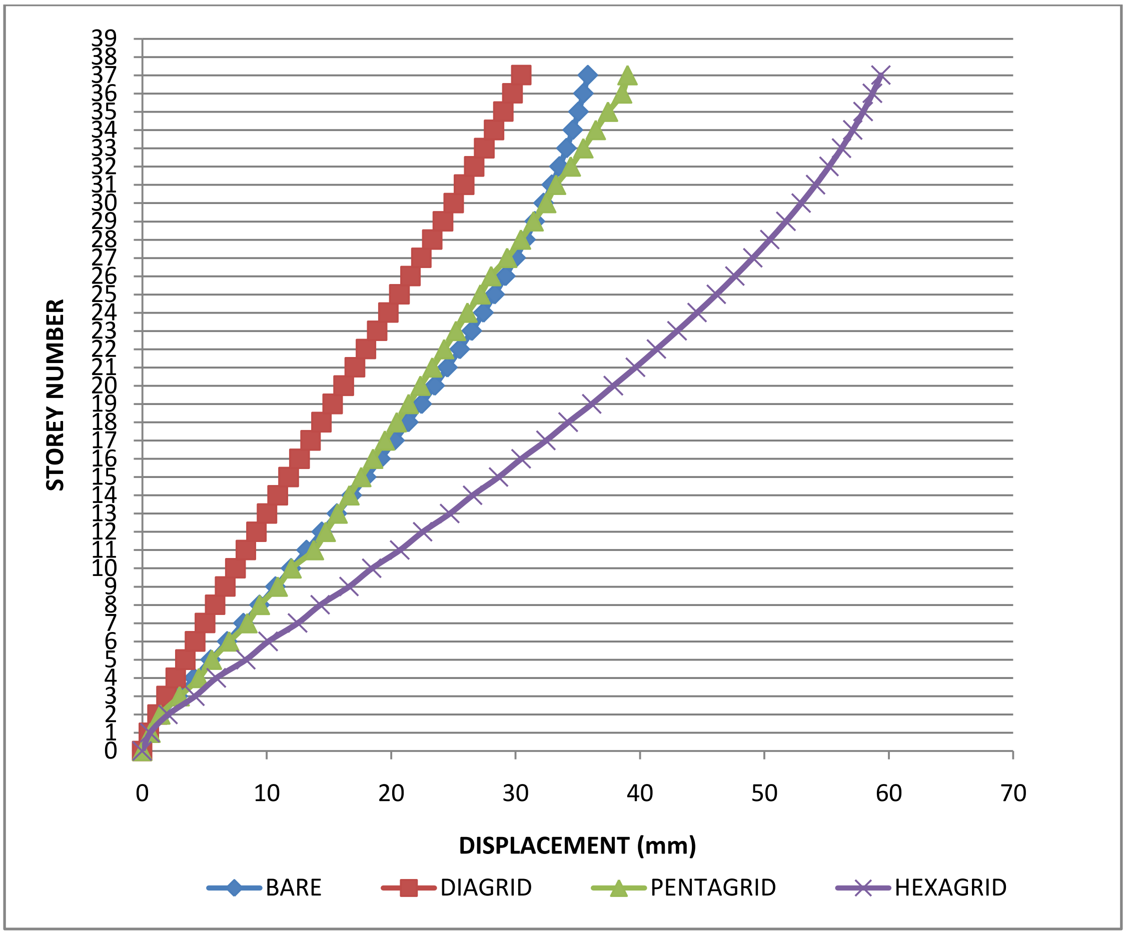


Figure 10 Combined Storey Displacement (RSM) 37 storey for 2 floor grid with no Shear

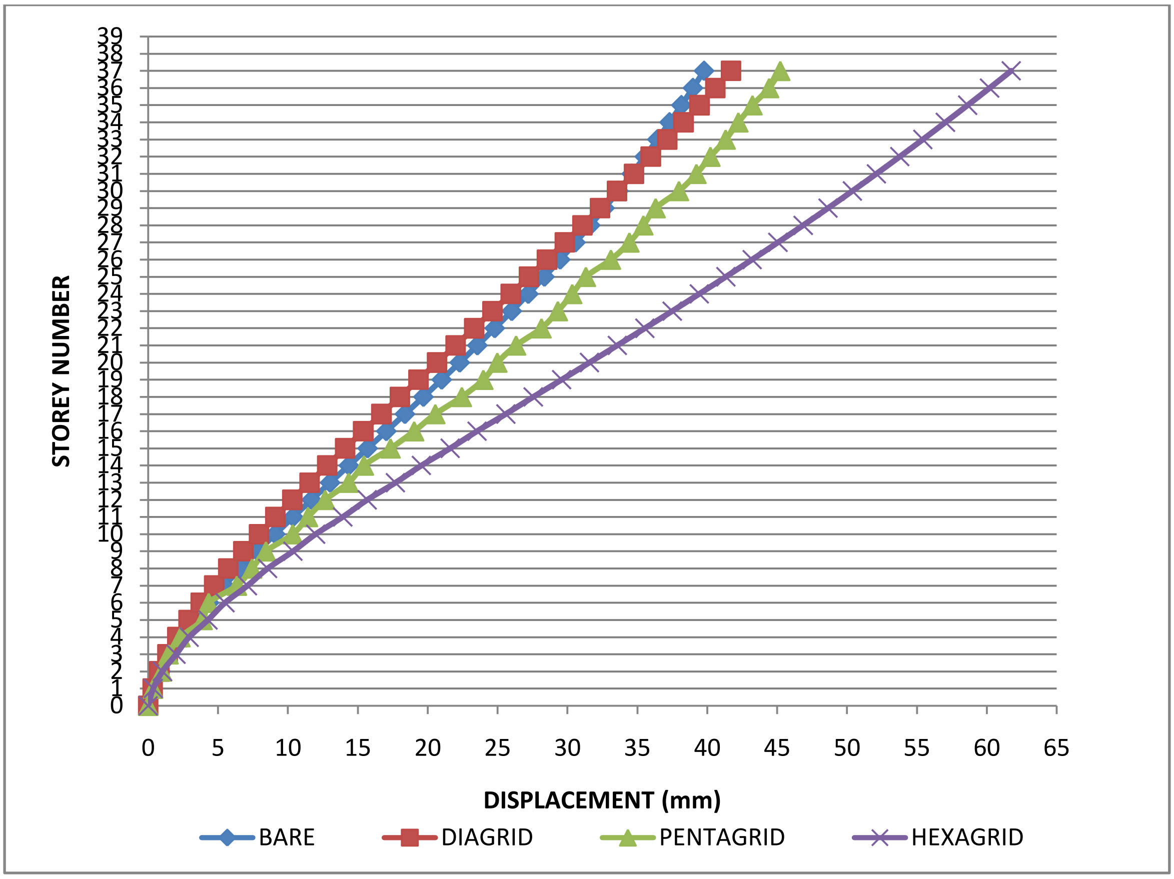


Figure 11 Combined Storey Displacement (Wind dynamic analysis) 37 storey for 2 floor grid with Shear Wall

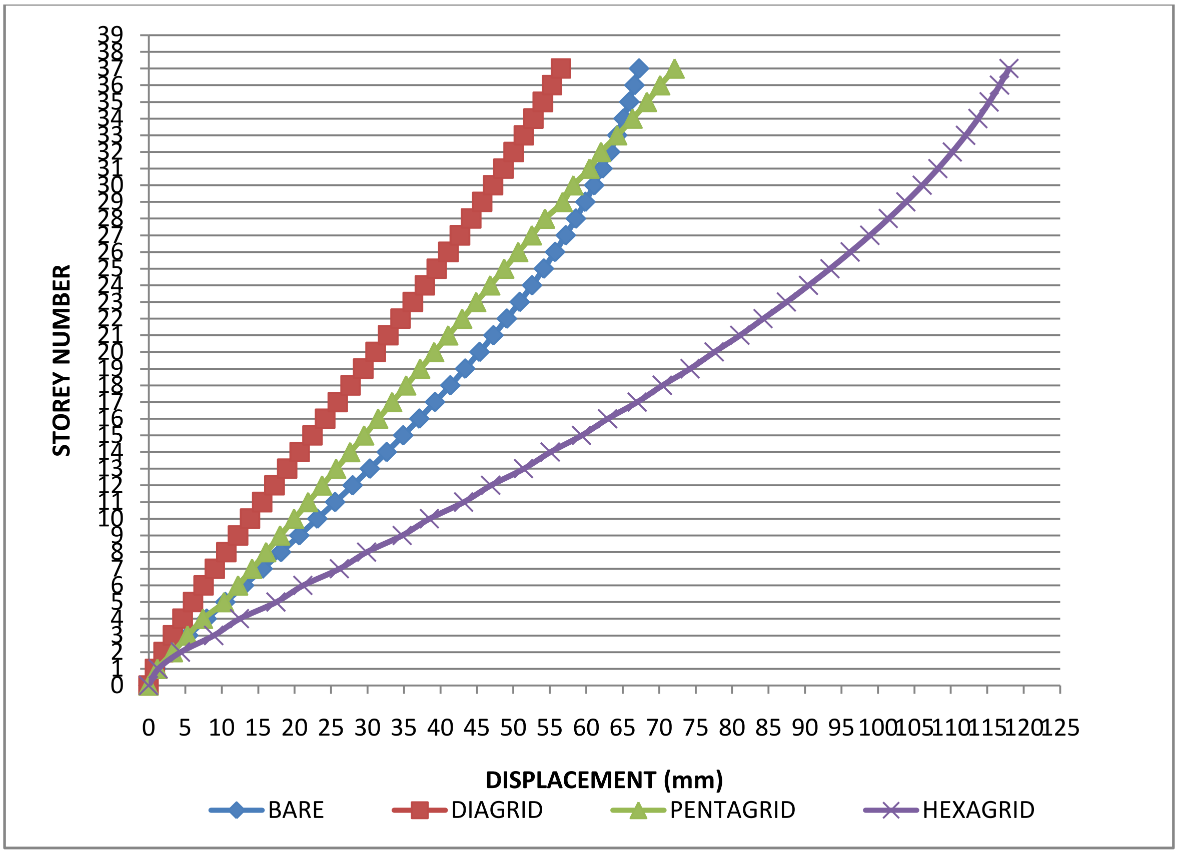


Figure 12 Combined Storey Displacement (Wind dynamic analysis) 37 storey for 2 floor grid with no Shear

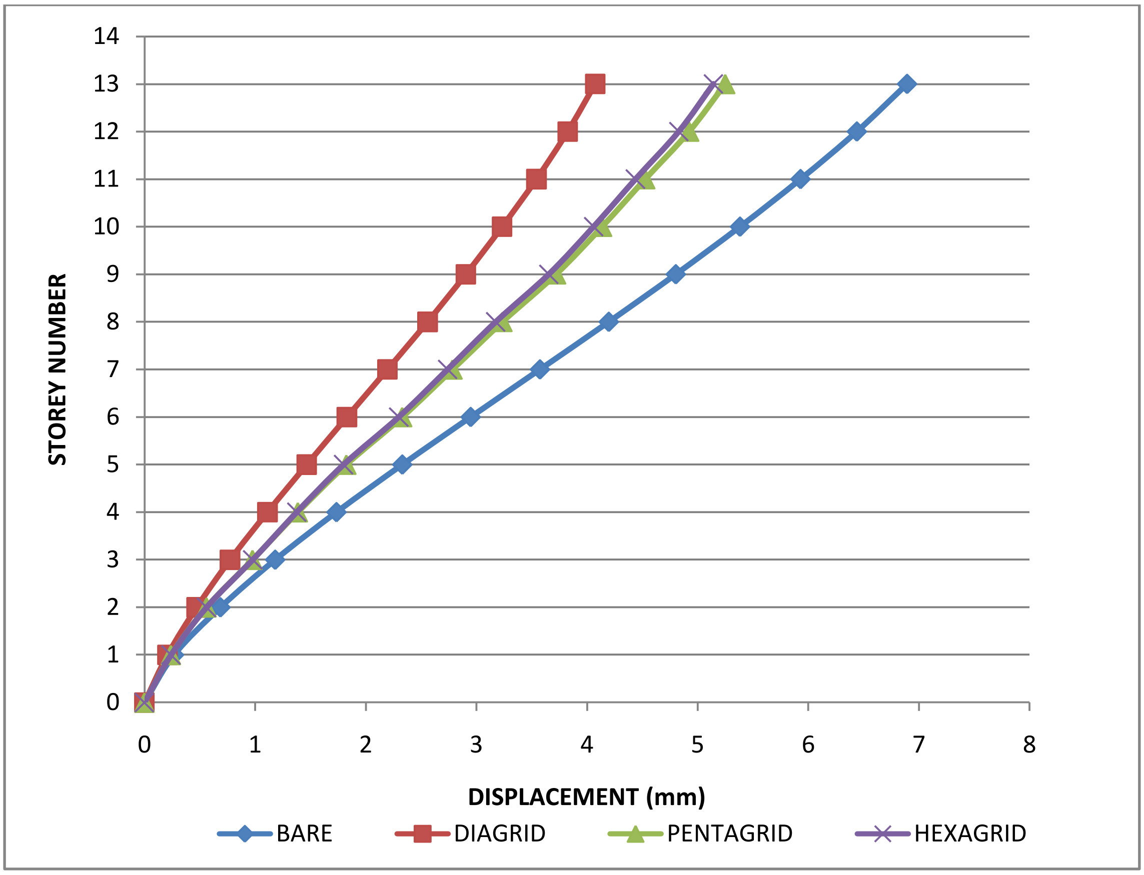


Figure 13 Combined Storey Displacement (RSM) 13 storey for 3 floor grid with Shear

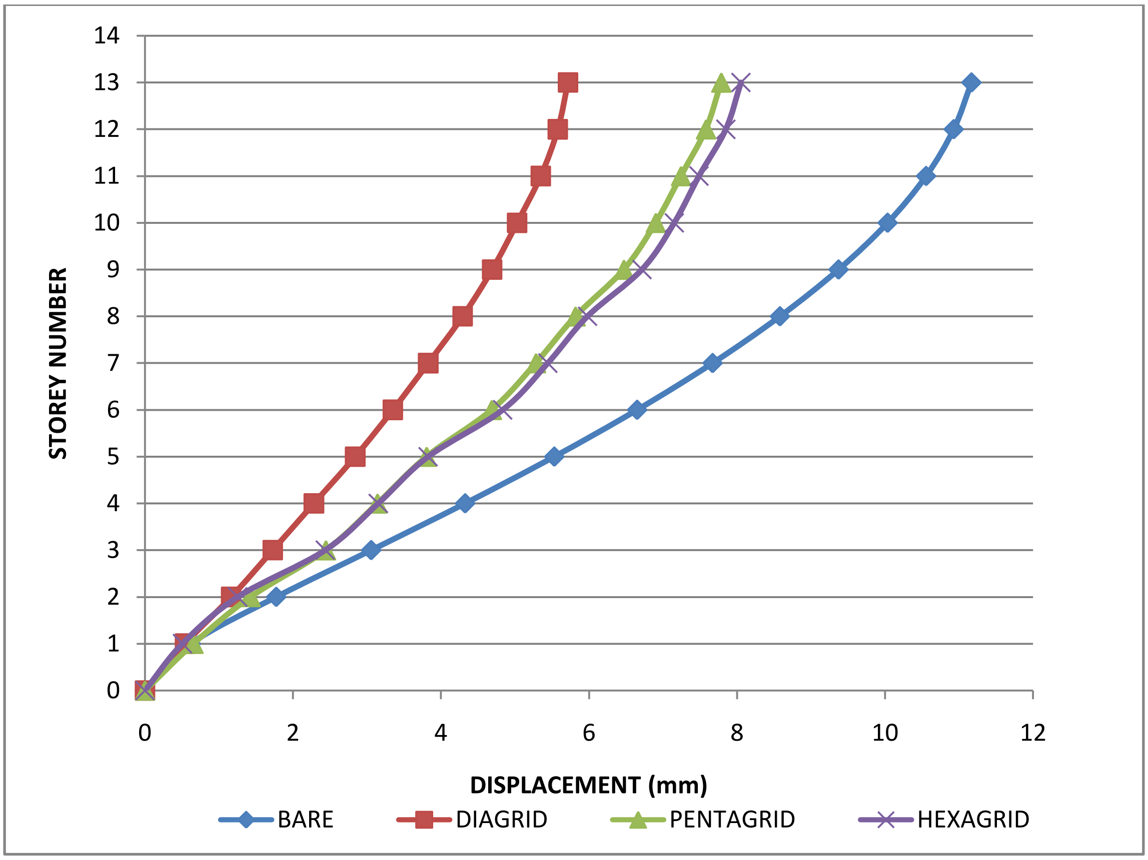


Figure 14 Combined Storey Displacement (RSM) 13 storey for 3 floor grid with no Shear

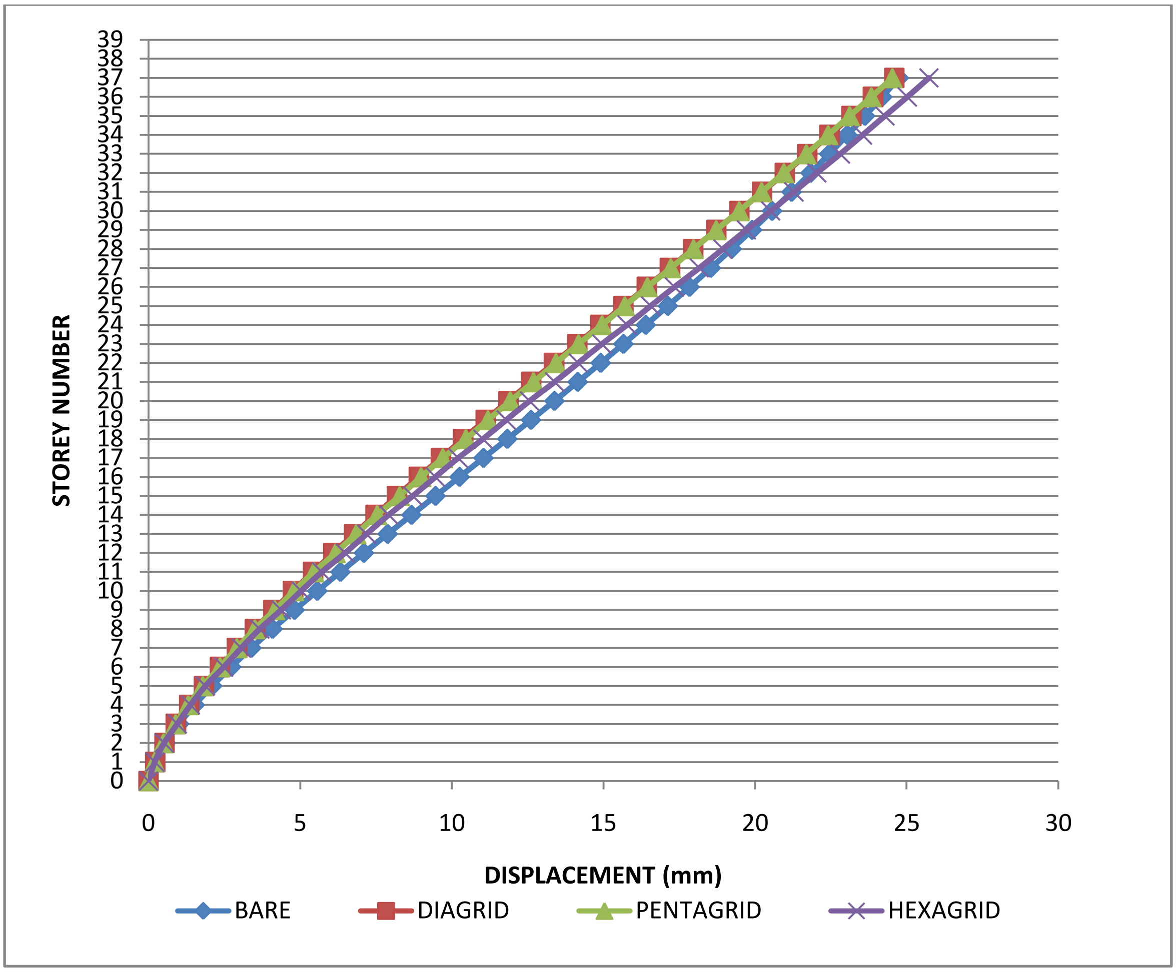


Figure 15 Combined Storey Displacement (RSM) 37 storey for 3 floor grid with Shear

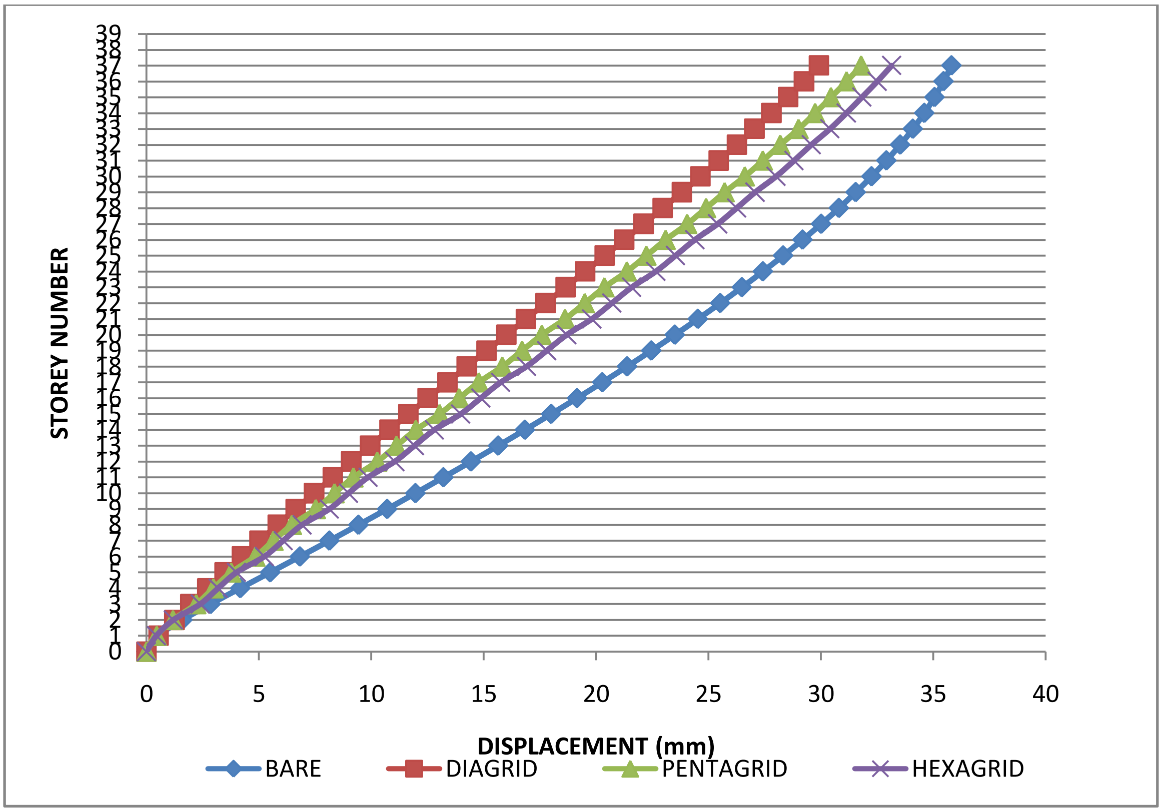


Figure 16 Combined Storey Displacement (RSM) 37 storey for 3 floor grid with no Shear

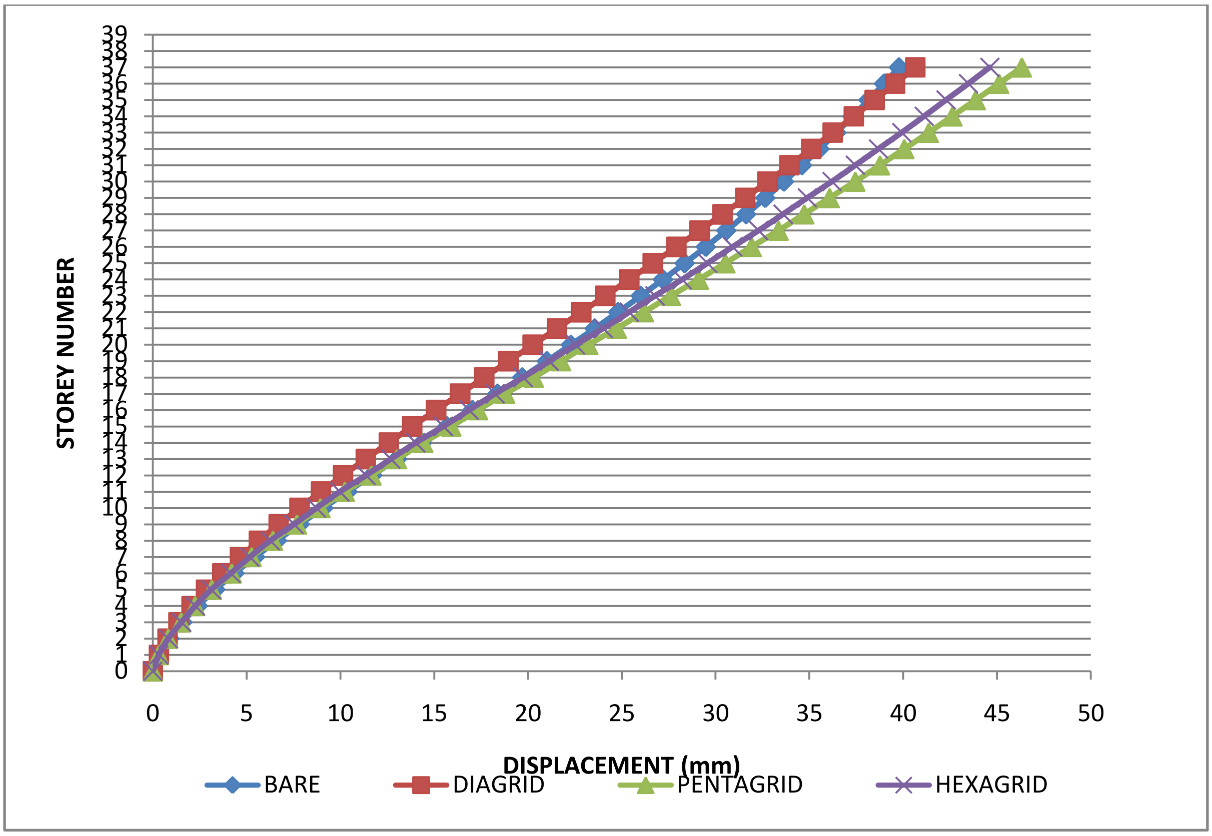


Figure 17 Combined Storey Displacement (Wind dynamic analysis) 37 storey for 3 floor grid with Shear

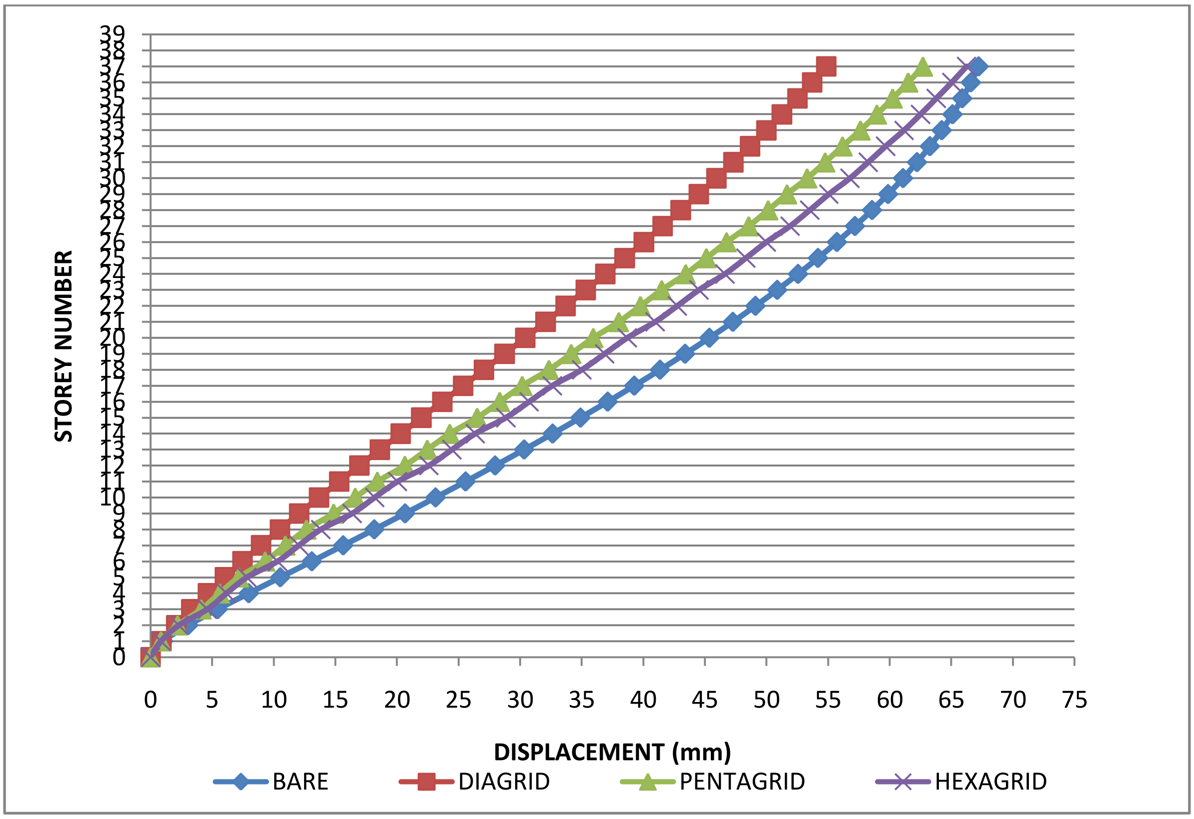


Figure 18 Combined Storey Displacement (Wind dynamic analysis) 37 storey for 3 floor grid with no Shear

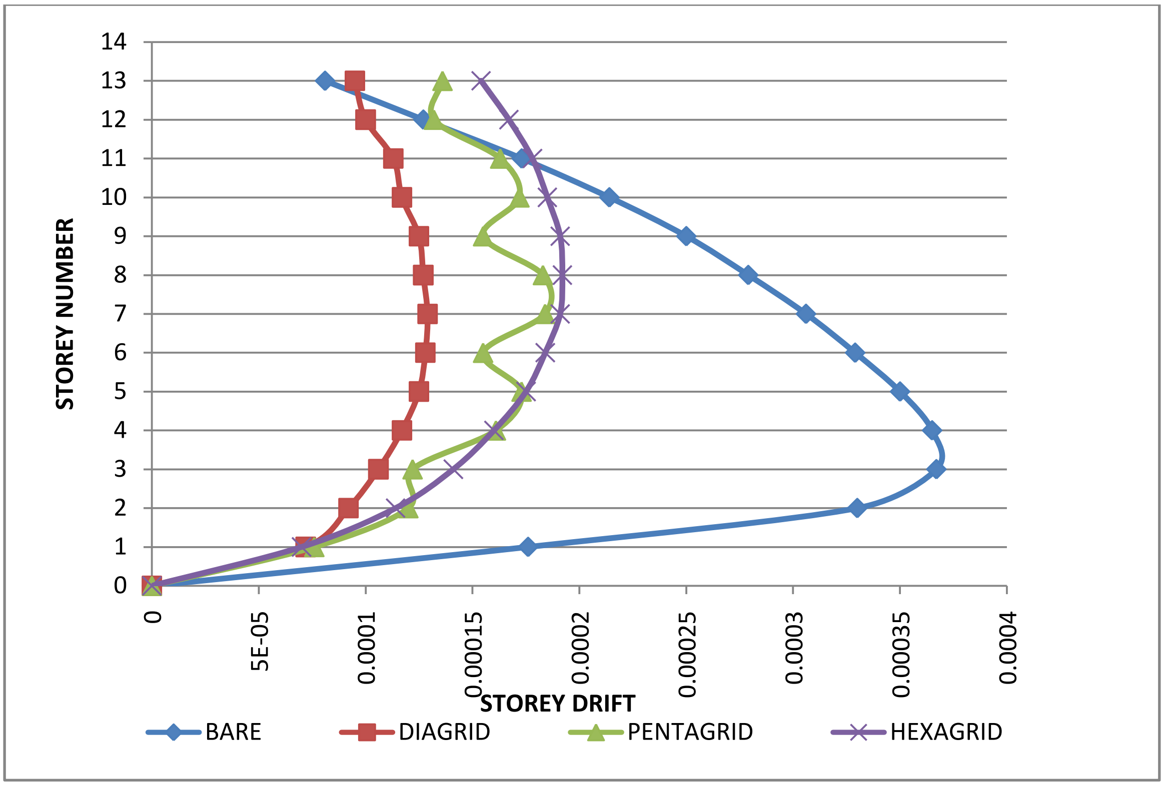


Figure 19 Combined StoreyDrift (RsM Analysis) for 13 STOREY structure with 2 floor grid with shear

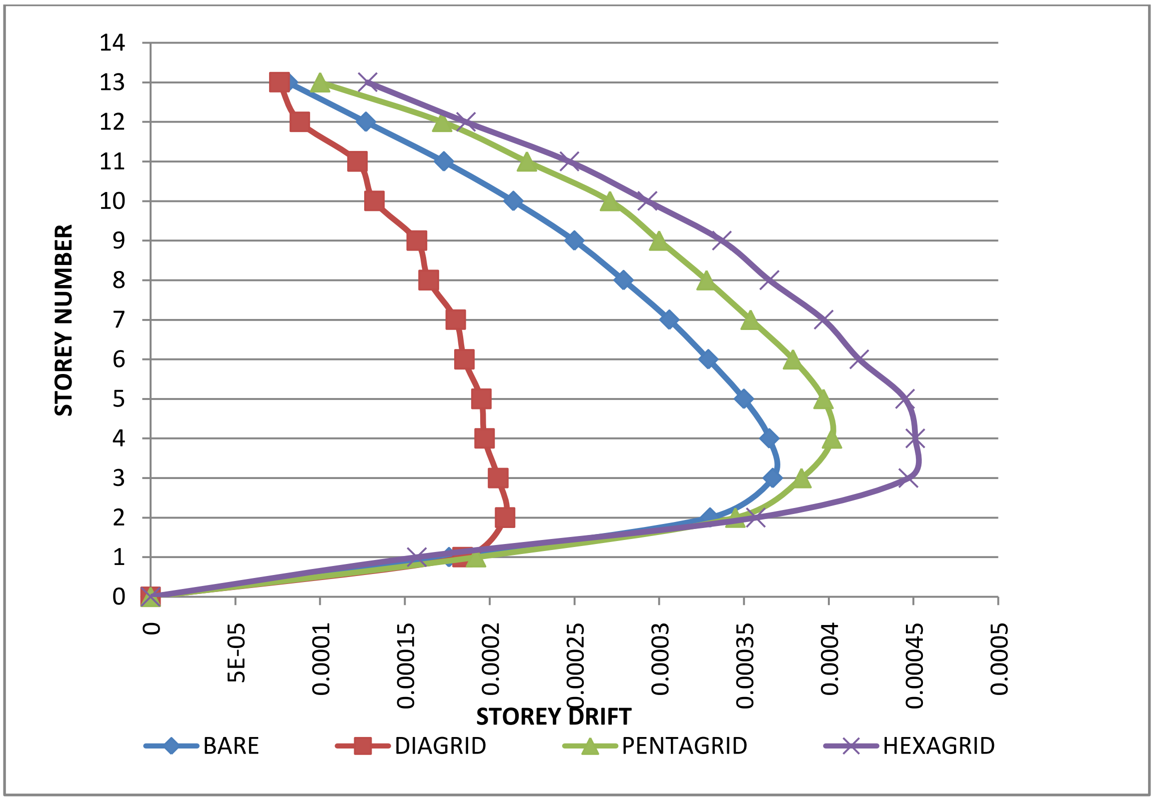


Figure 20 CombinedStoreyDrift (RsM Analysis) for 13 STOREY structure with 2 floor grid with no shear

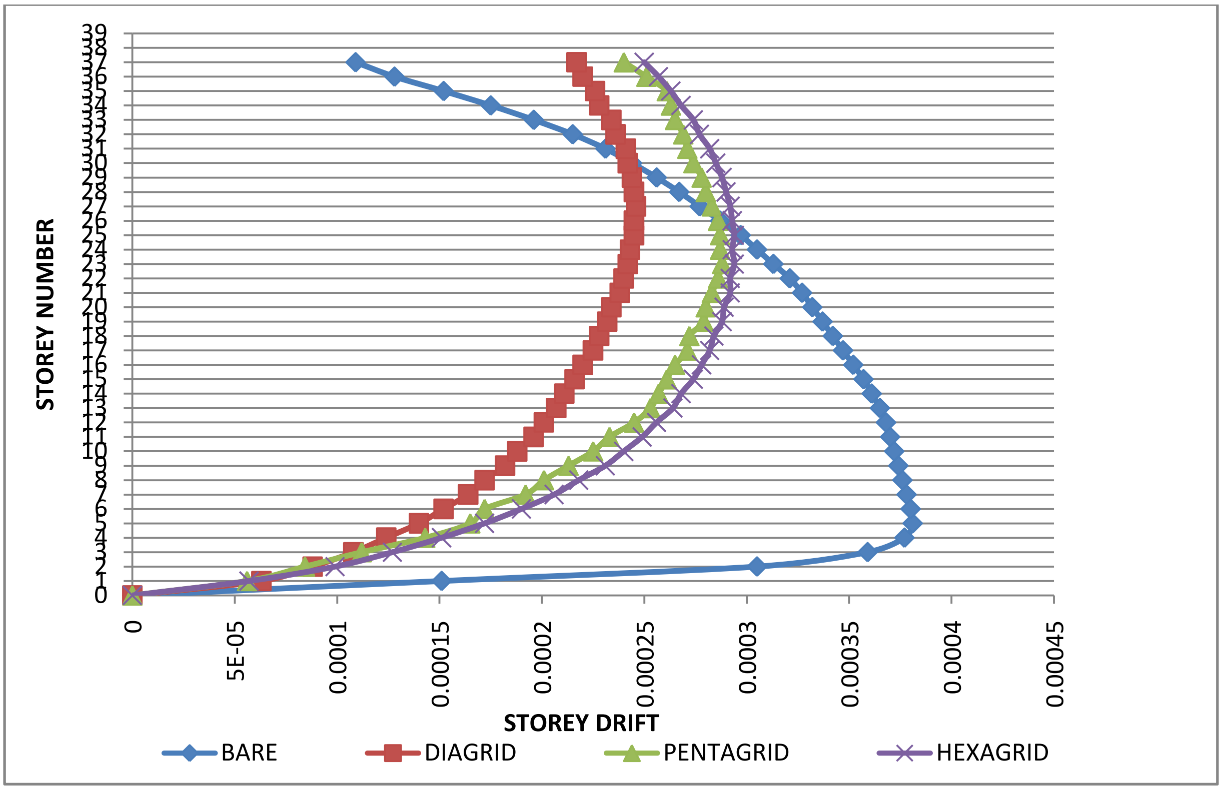


Figure 21 Combined StoreyDrift (RsM Analysis) for 37 STOREY structure with 2 floor grid with shear

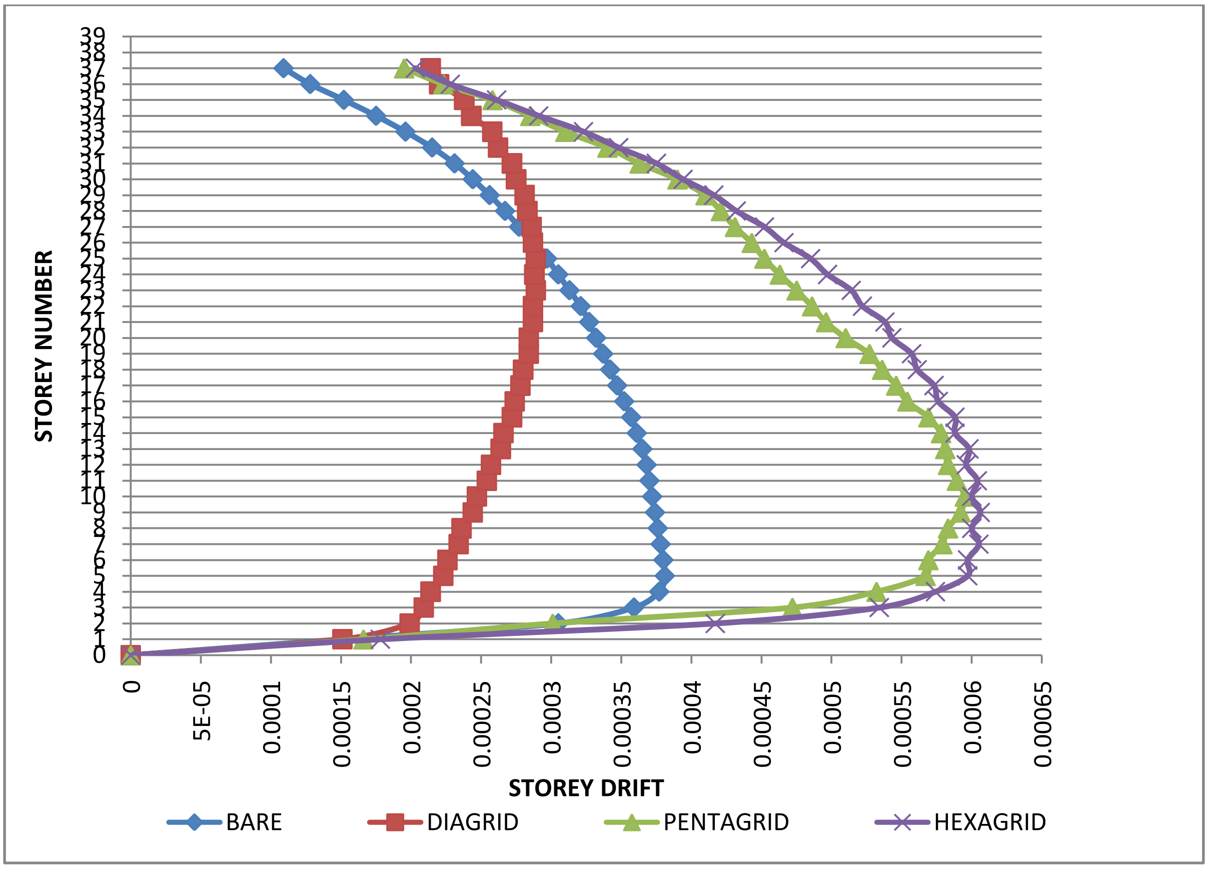


Figure 22 Combined StoreyDrift (RsM Analysis) for 37 STOREY structure with 2 floor grid with no shear

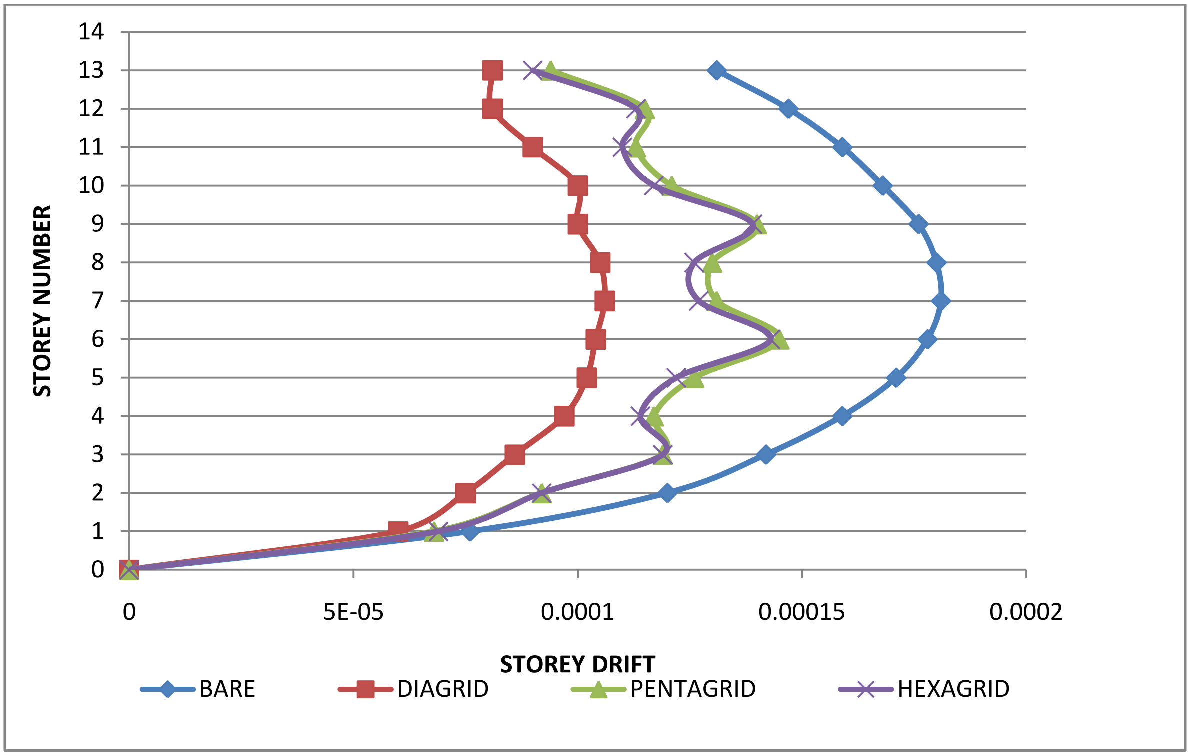


Figure 23 Combined StoreyDrift (RsM Analysis) for 13 STOREY structure with 3 floor grid with shear

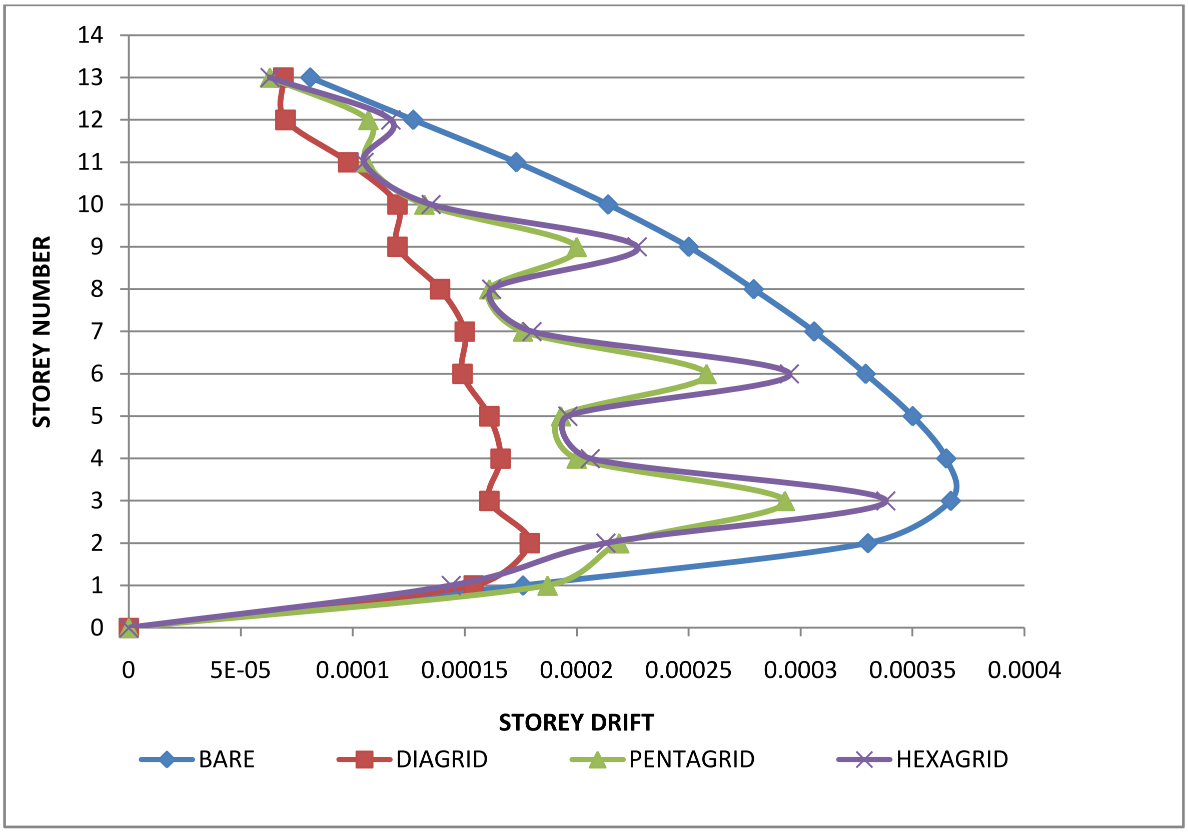


Figure 24 Combined StoreyDrift (RsM Analysis) for 13 STOREY structure with 3 floor grid with no shear

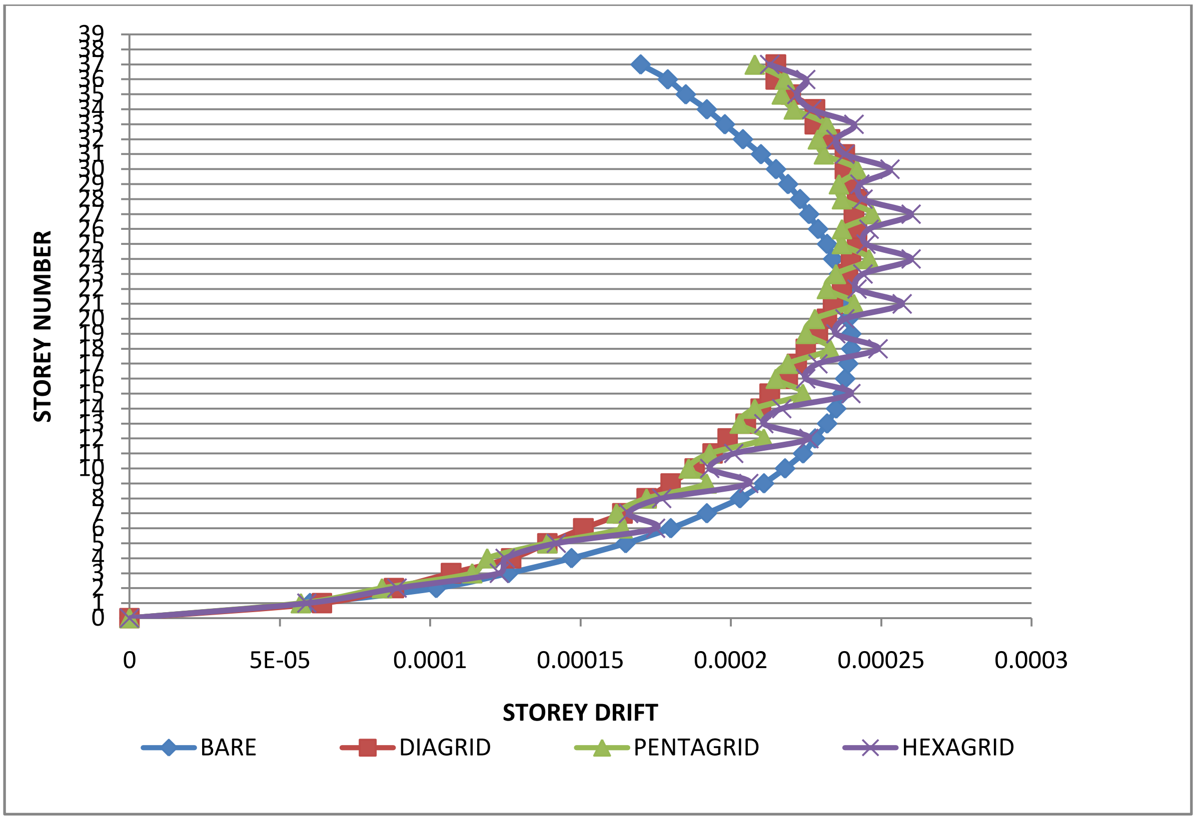


Figure 25 Combined StoreyDrift (RsM Analysis) for 37 STOREY structure with 3 floor grid with shear

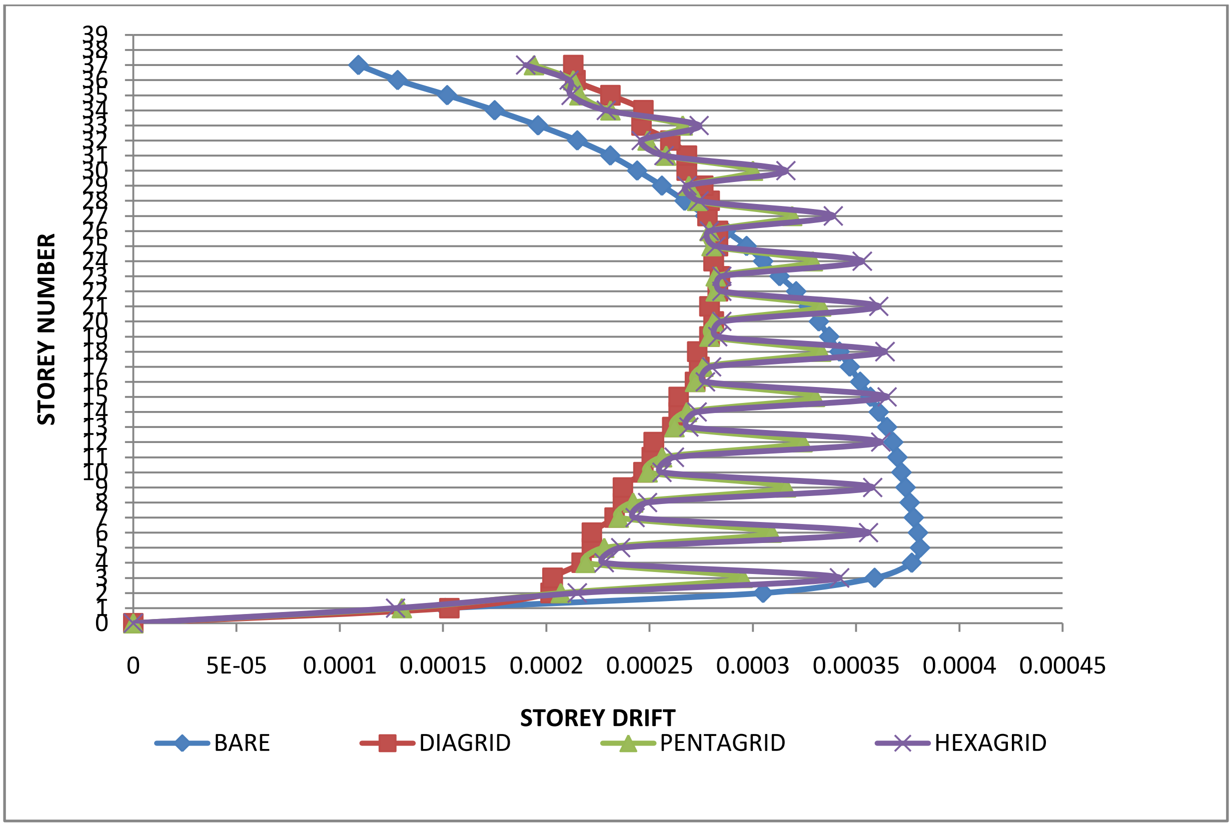


Figure 26 Combined StoreyDrift (RsM Analysis) for 37 STOREY structure with 3 floor grid with no shear

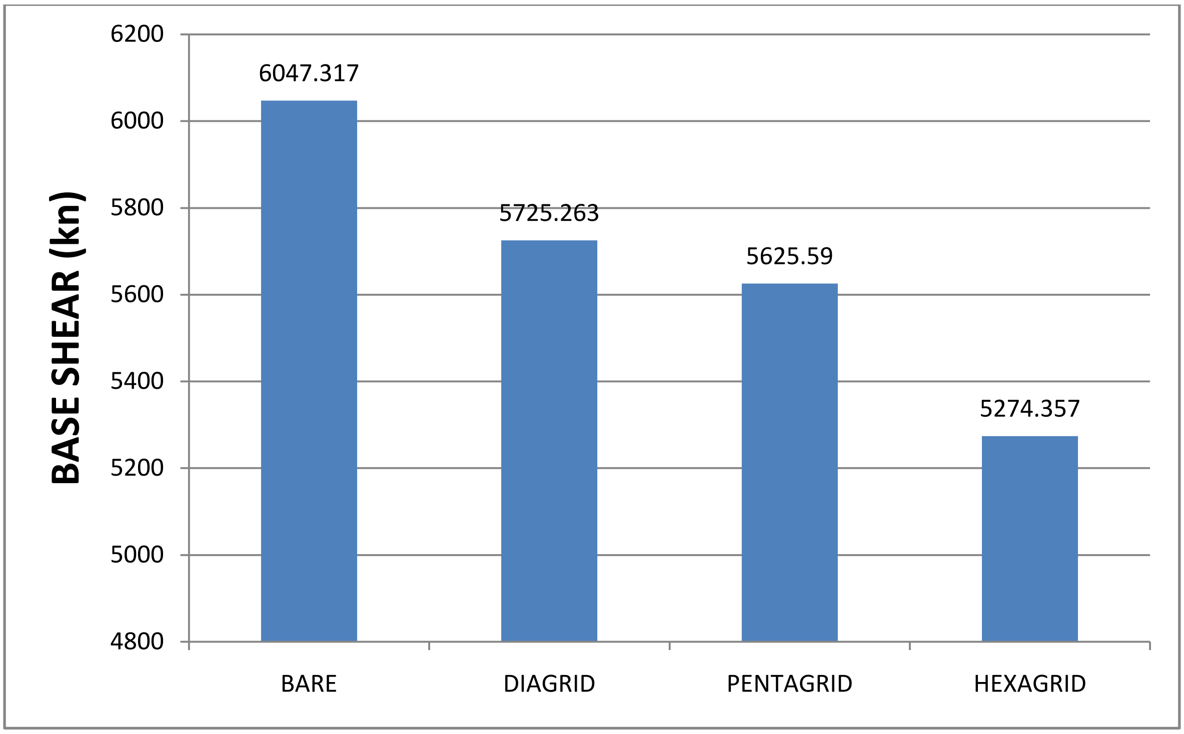


Figure 27: Base shear for 13 STOREY structure with 2 Grid with shear

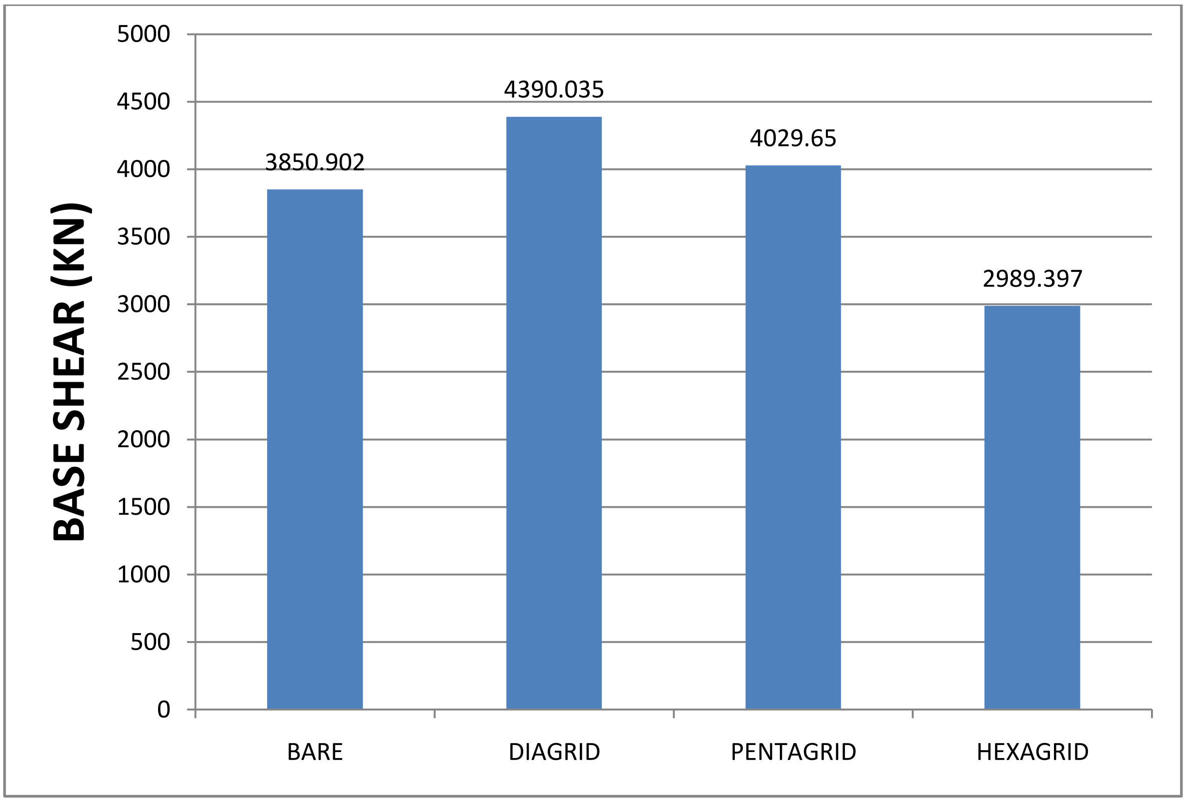


Figure 28: Base shear for 13 STOREY structure with 2 Grid with no shear

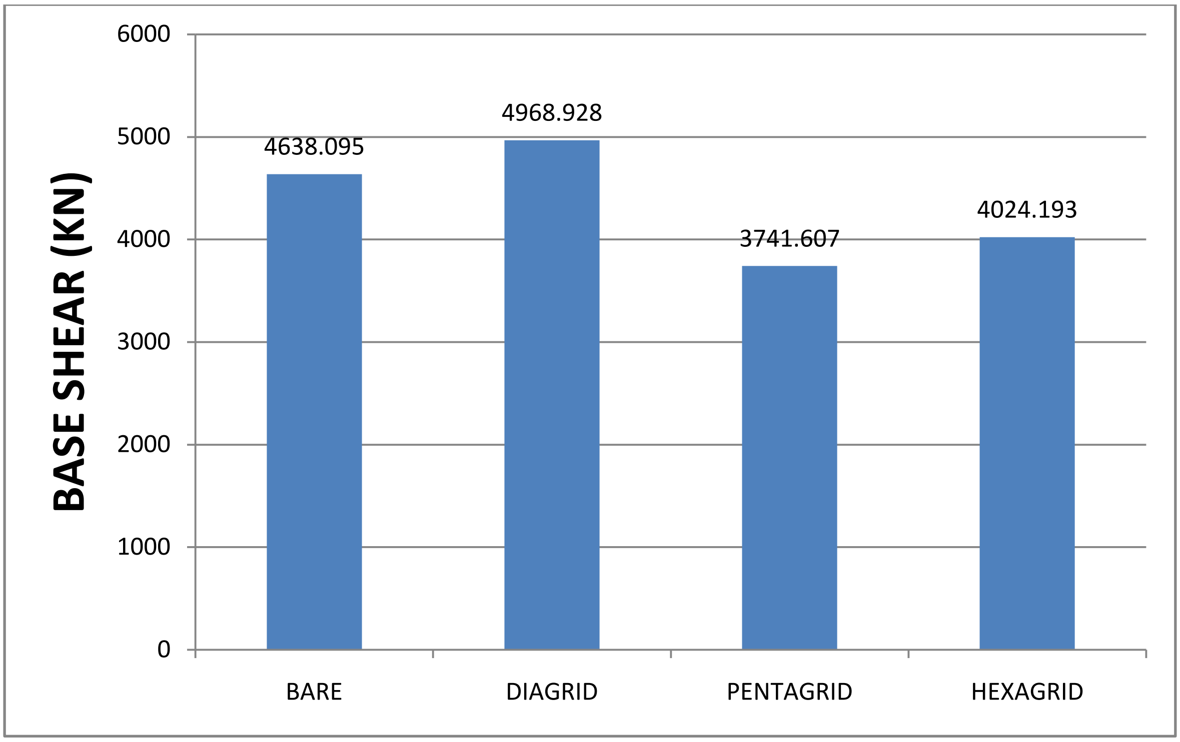


Figure 29: Base shear 2for 37 STOREY structure with 2 Grid with shear

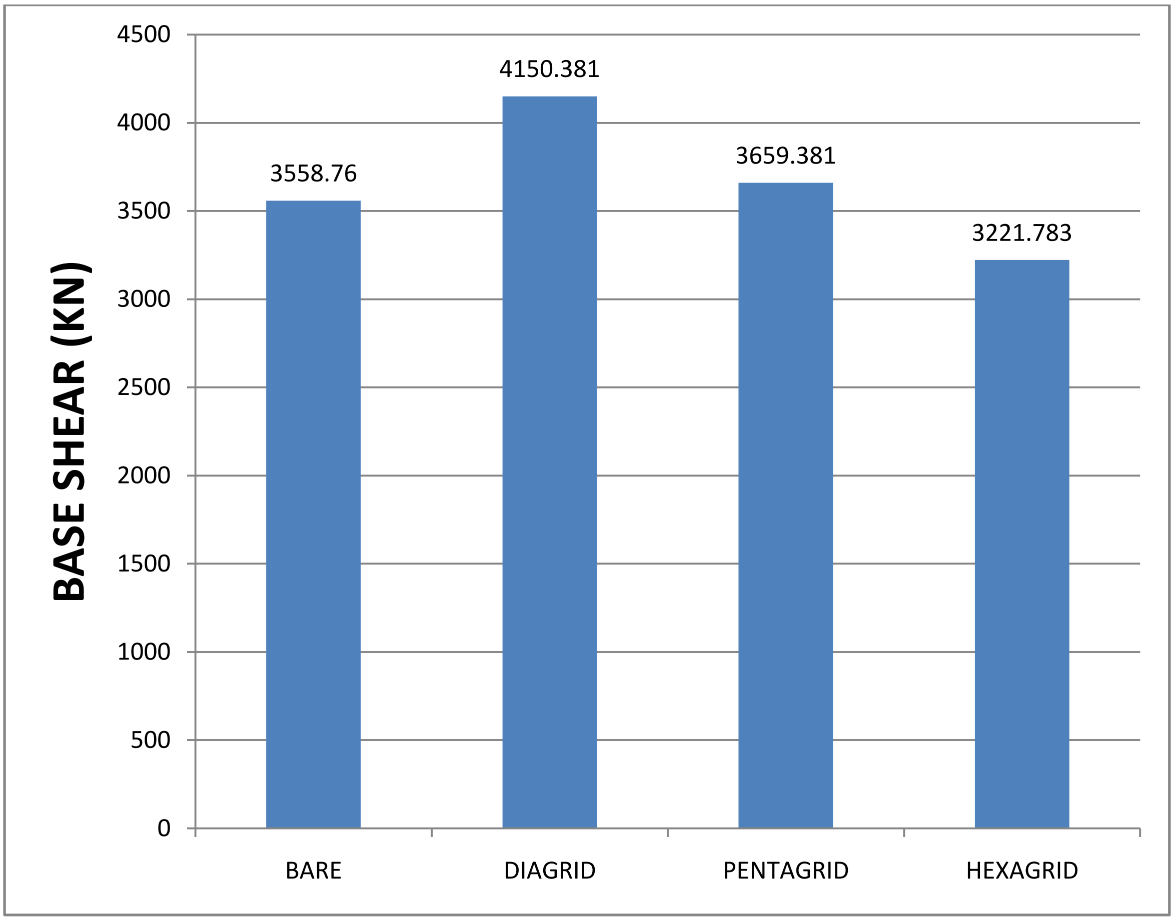


Figure 30: Base shear for 37 STOREY structure with 2 Grid with no shear

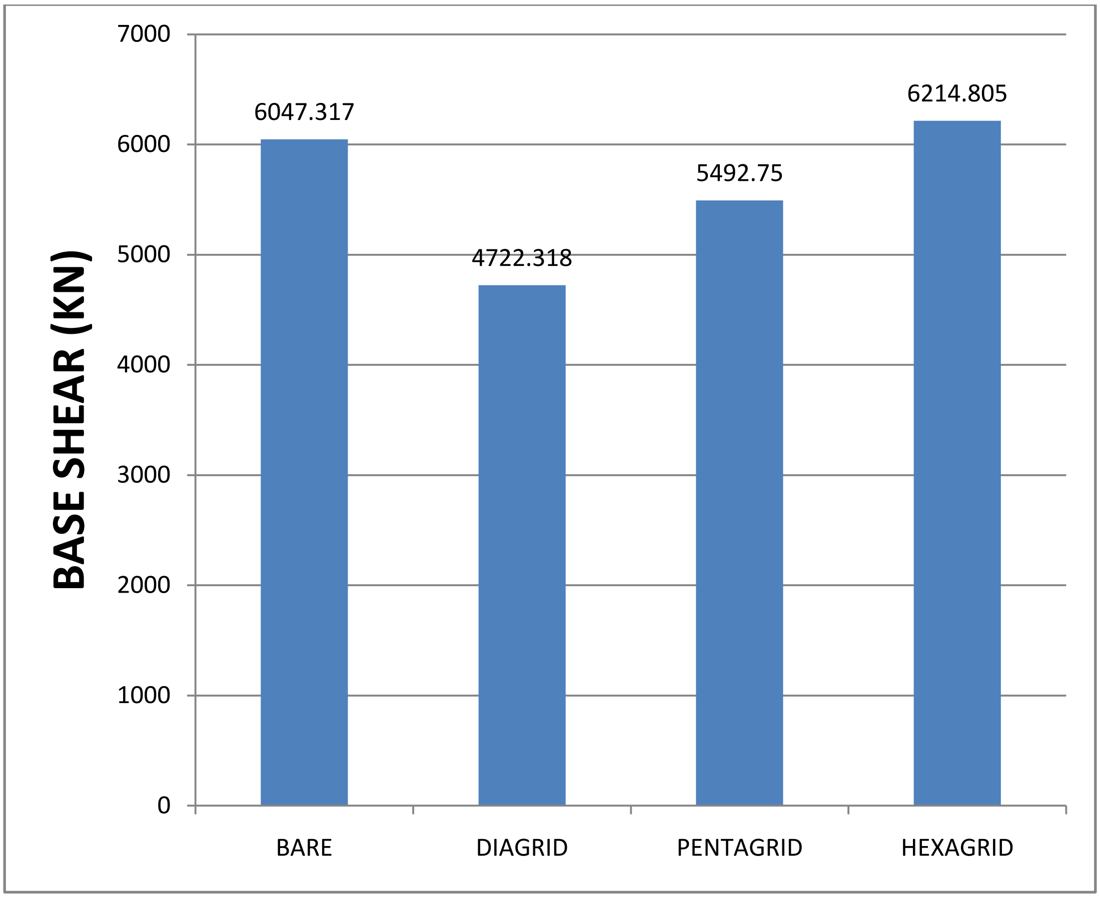


Figure 31: Base shear for 13 STOREY structure with 3 Grid with shear

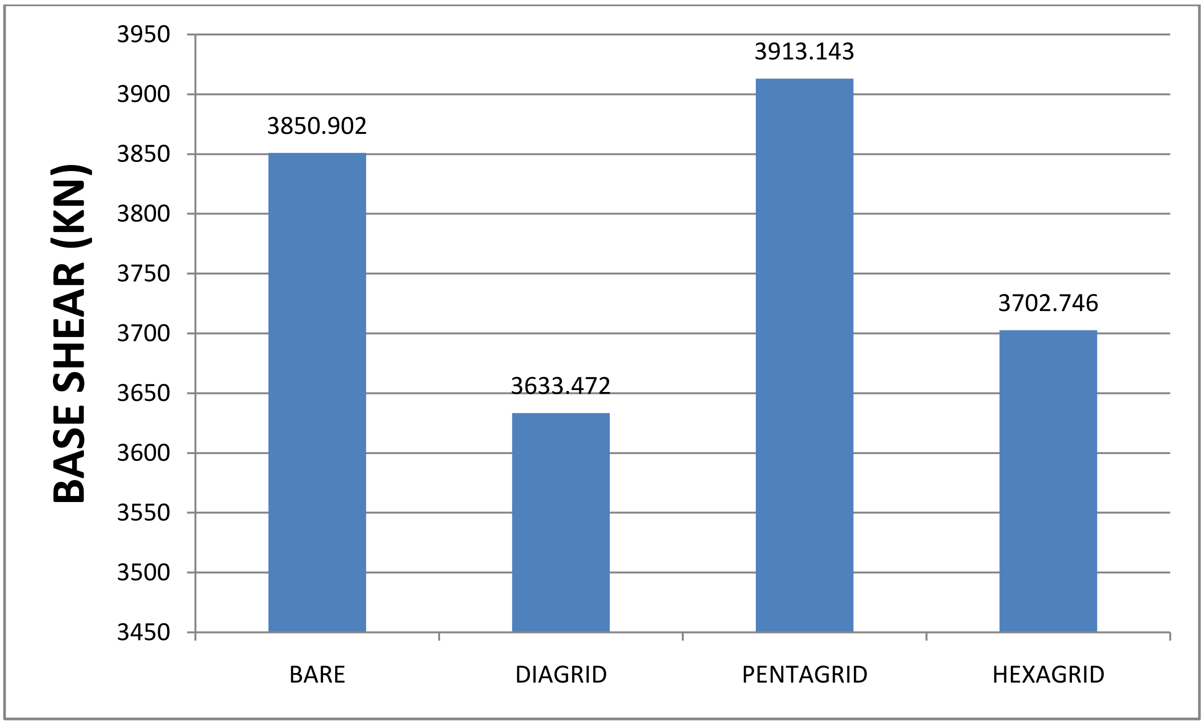


Figure 32: Base shear for 13 STOREY structure with 3 Grid with no shear

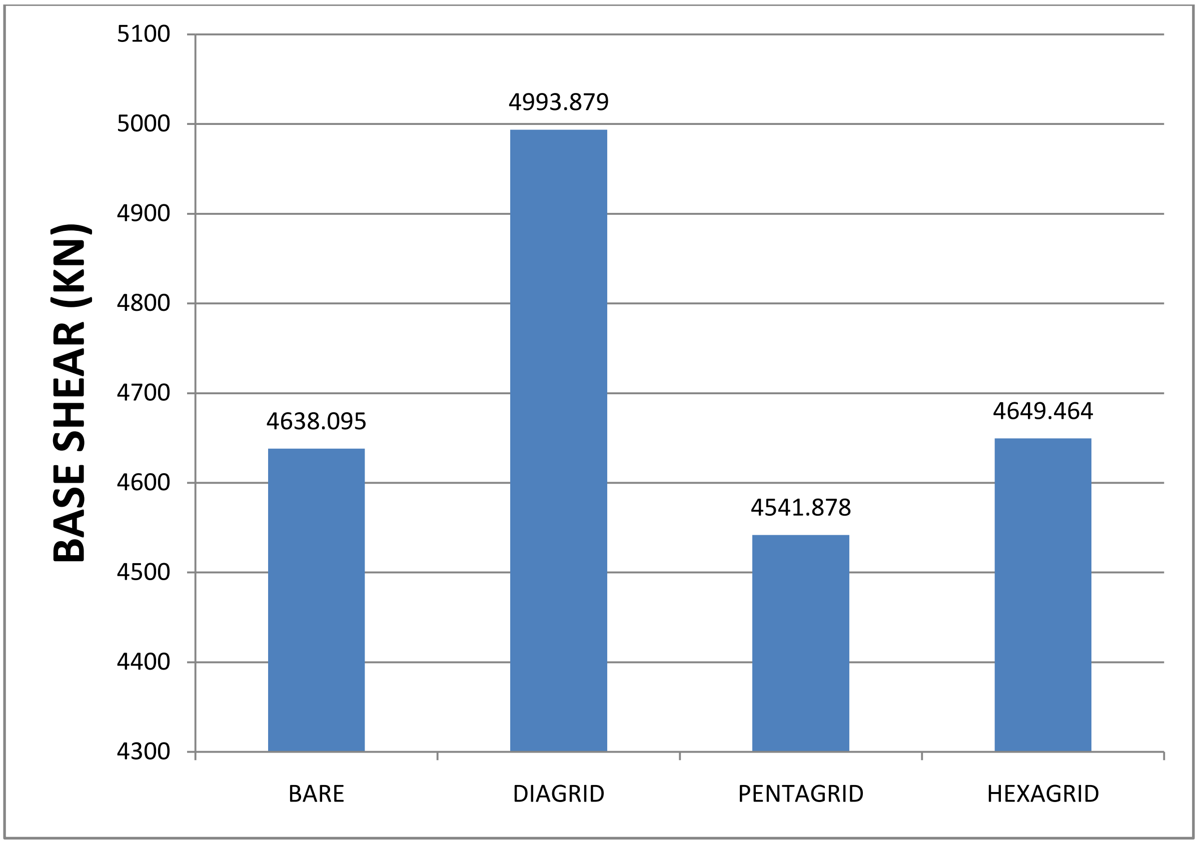


Figure 33: Base shear for 37 STOREY structure with 3 Grid with shear

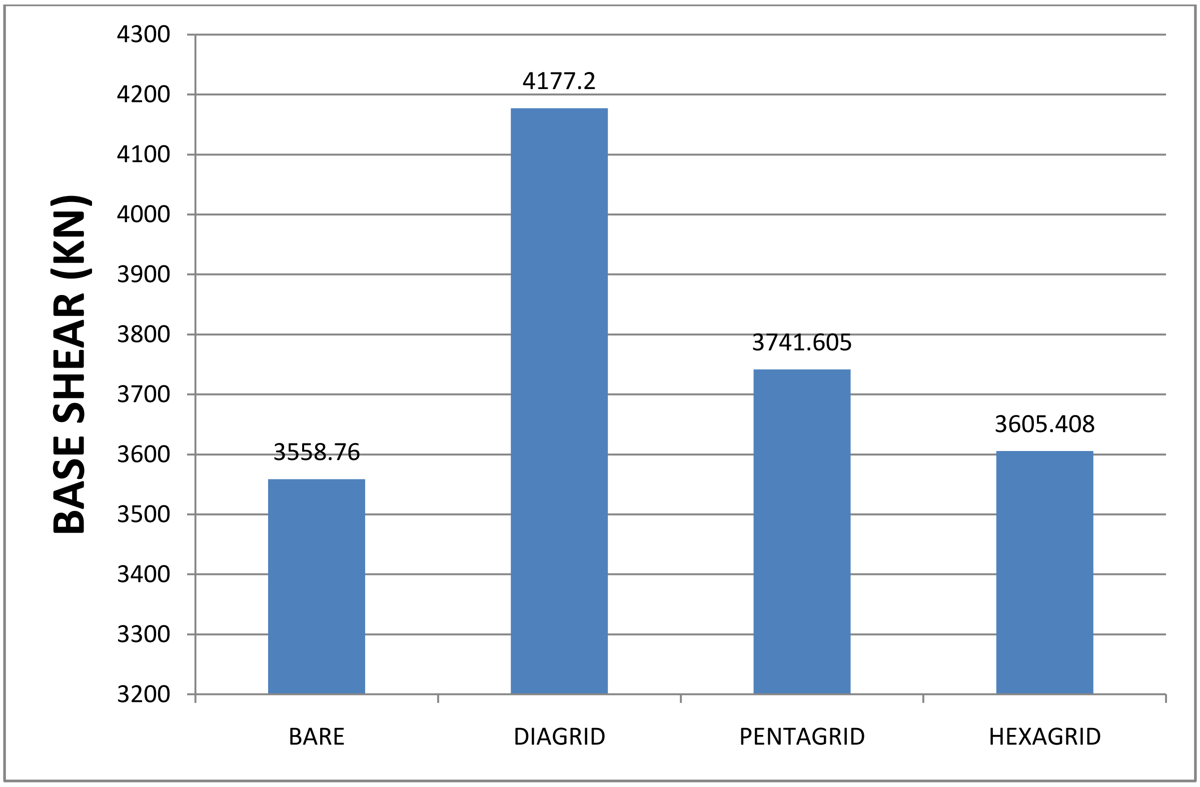


Figure 34: Base shear for 37 STOREY structure with 3 Grid with no shear

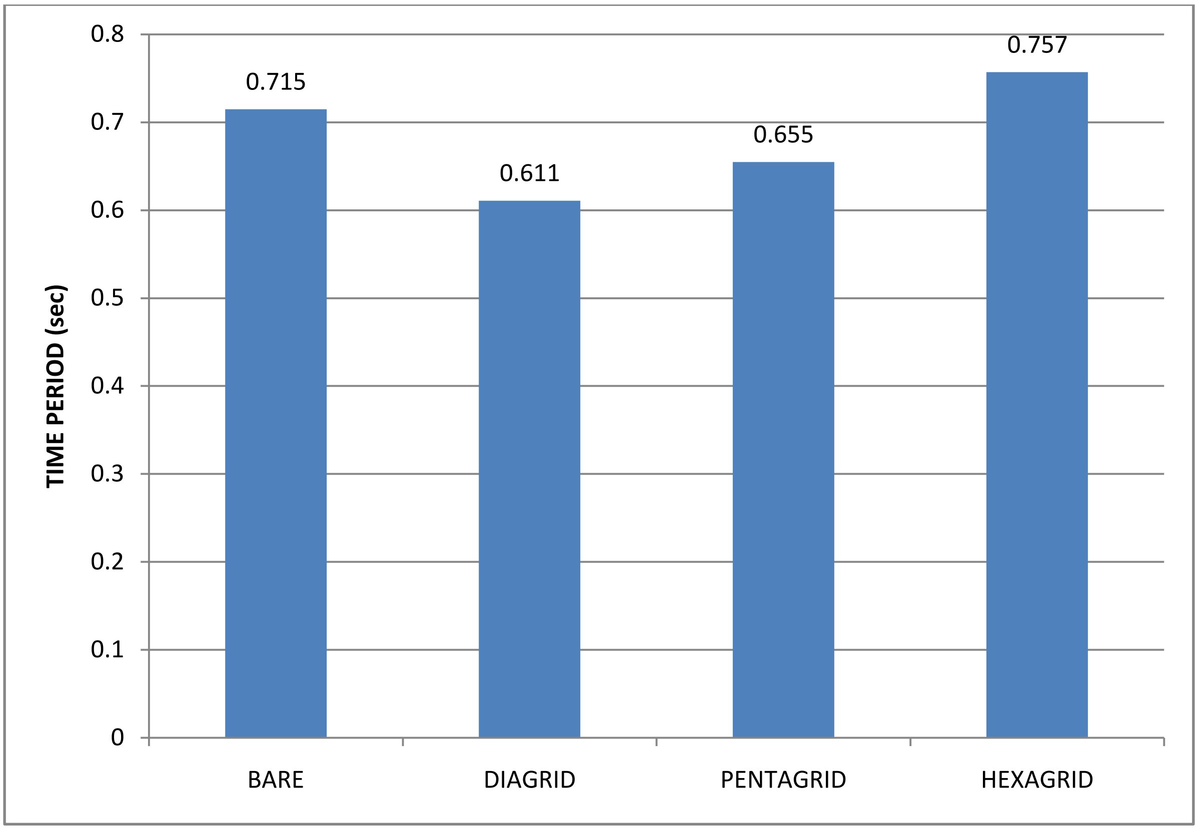


Figure 35: Time Period for 13 STOREY structure with 2 Grid with Shear

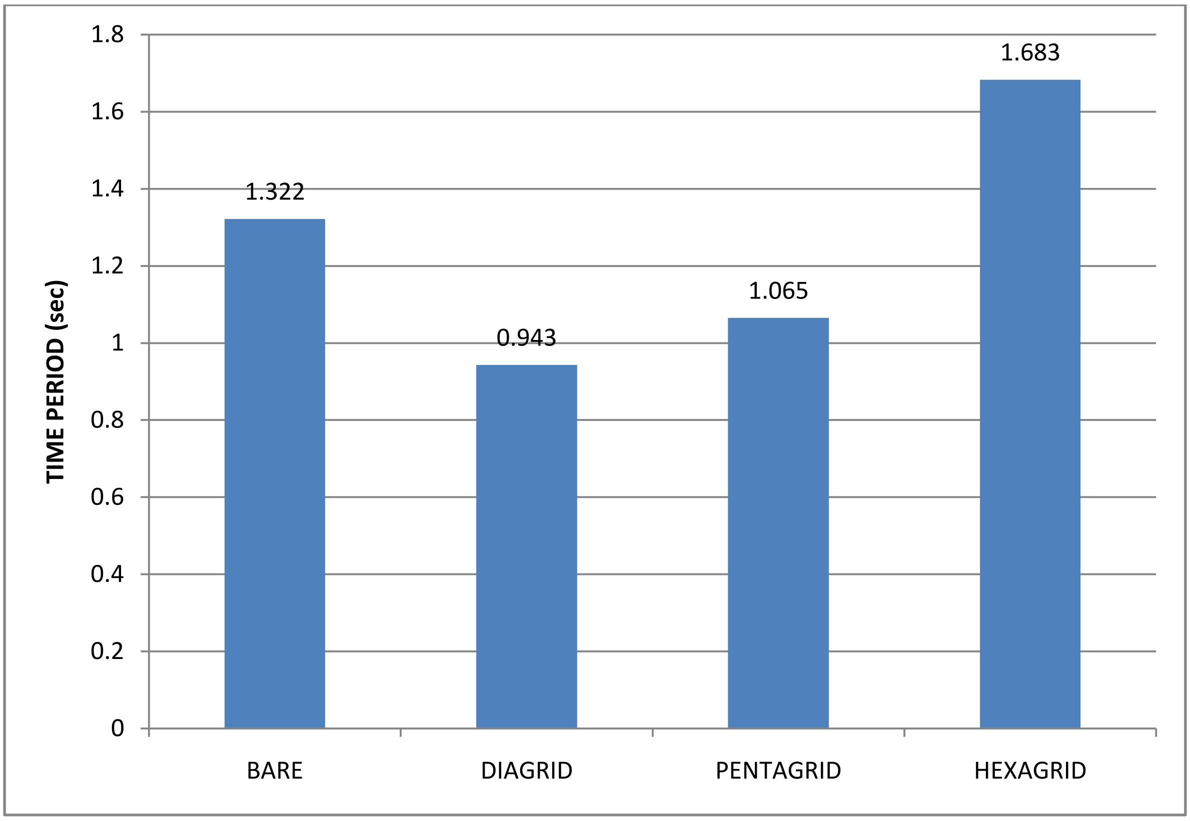


Figure 36: Time Period for 13 STOREY structure with 2 Grid with no Shear

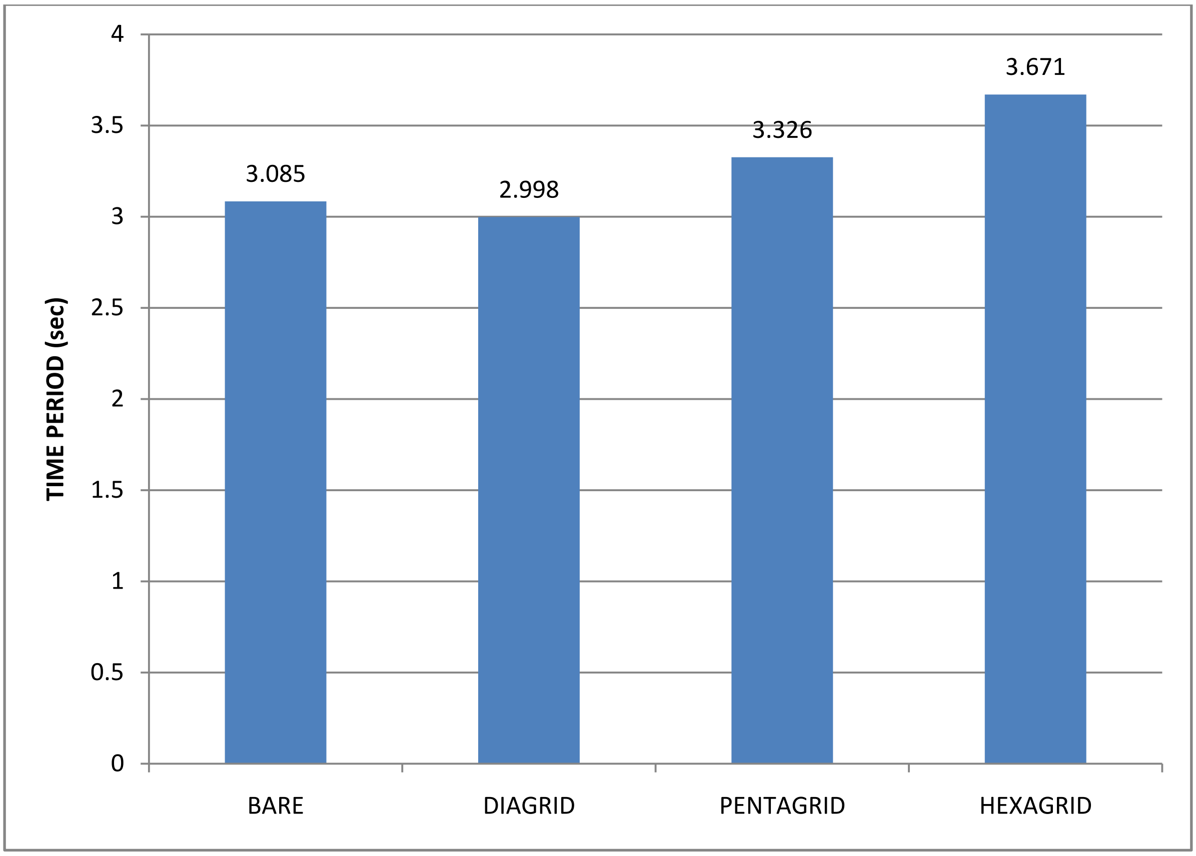


Figure 37: Time Period for 37 STOREY structure with 2 Grid with Shear

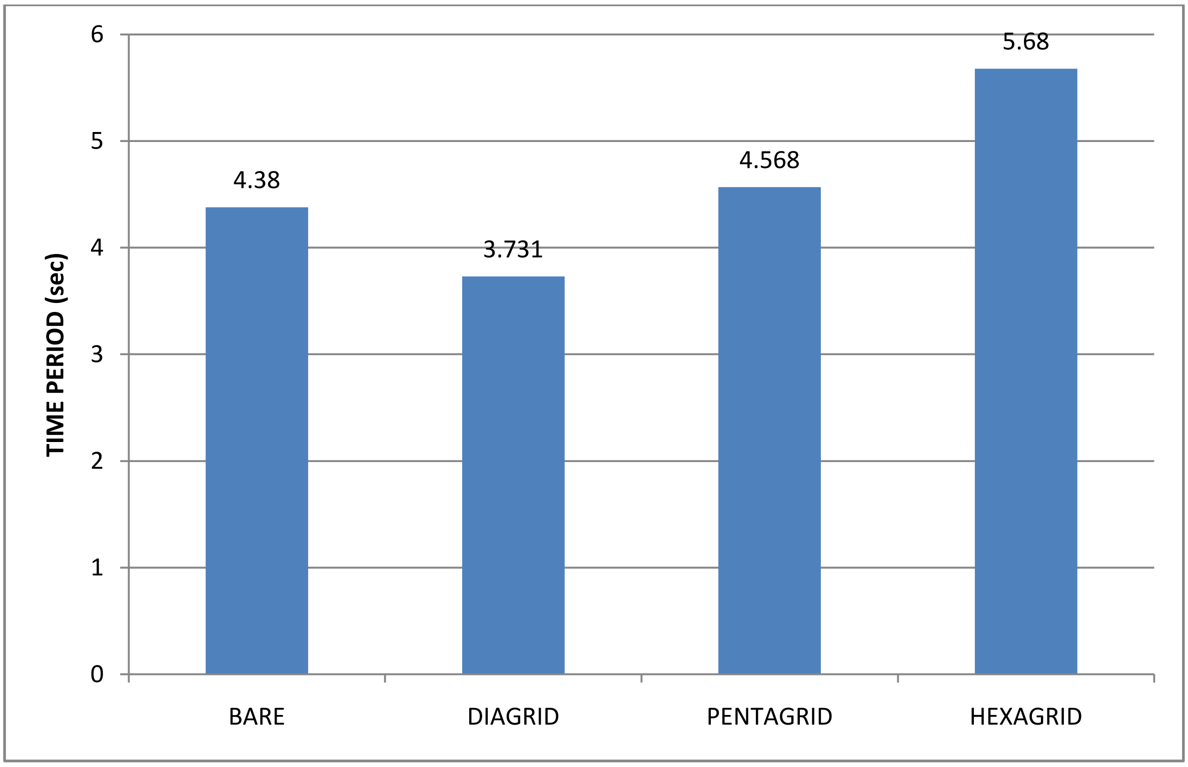


Figure 38: Time Period for 37 STOREY structure with 2 Grid with no Shear

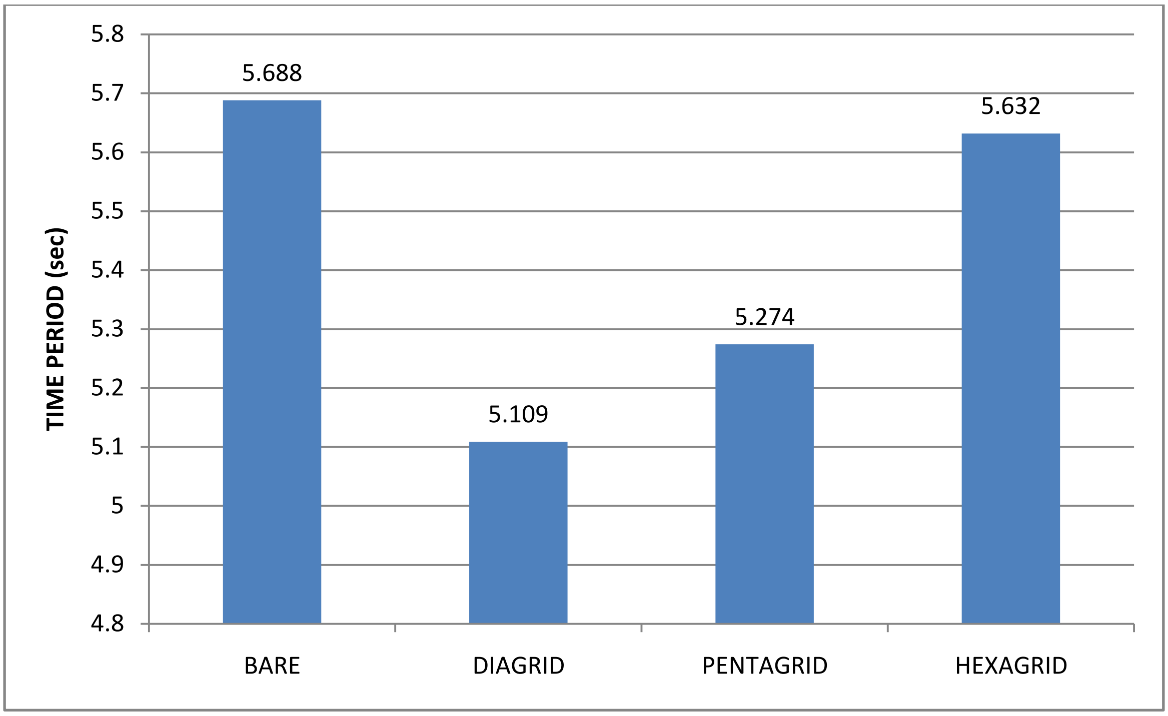


Figure 39: Time Period for 13 STOREY structure with 3 Grid with Shear

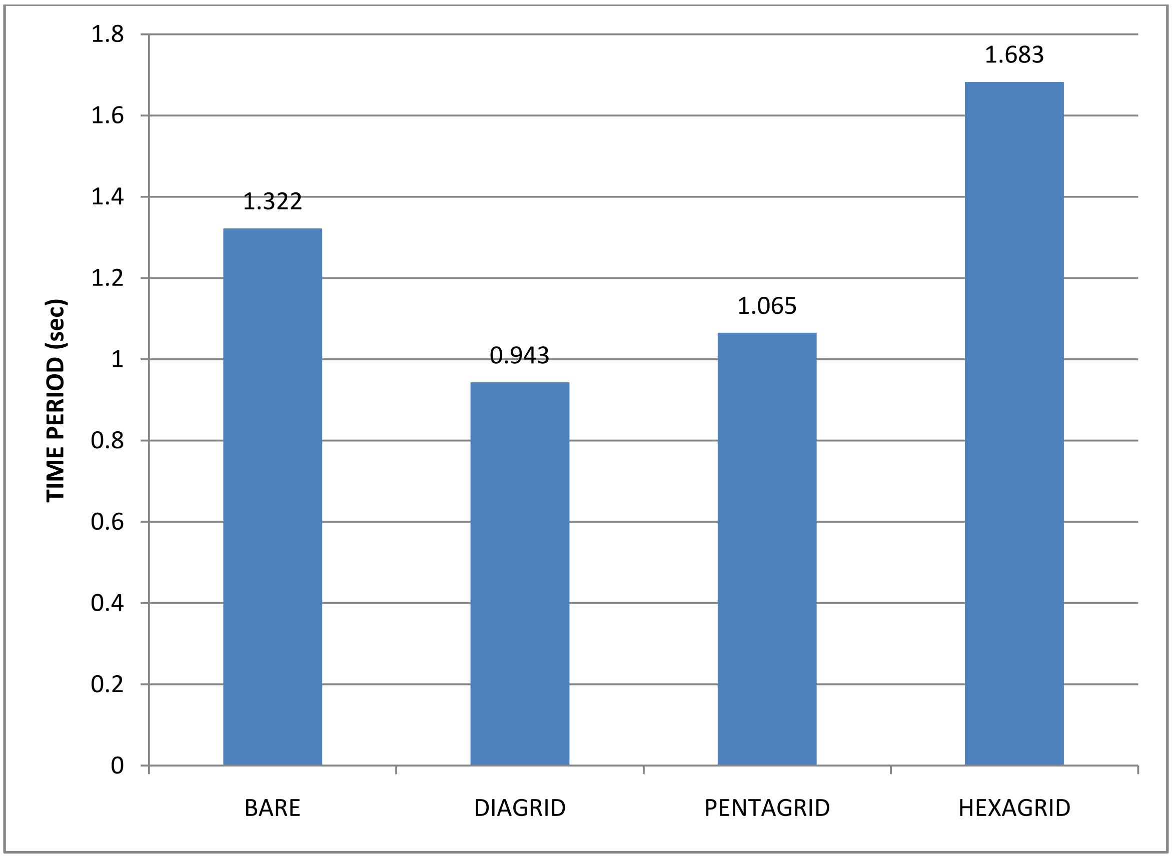


Figure 40: Time Period for 13 STOREY structure with 3 Grid with no Shear

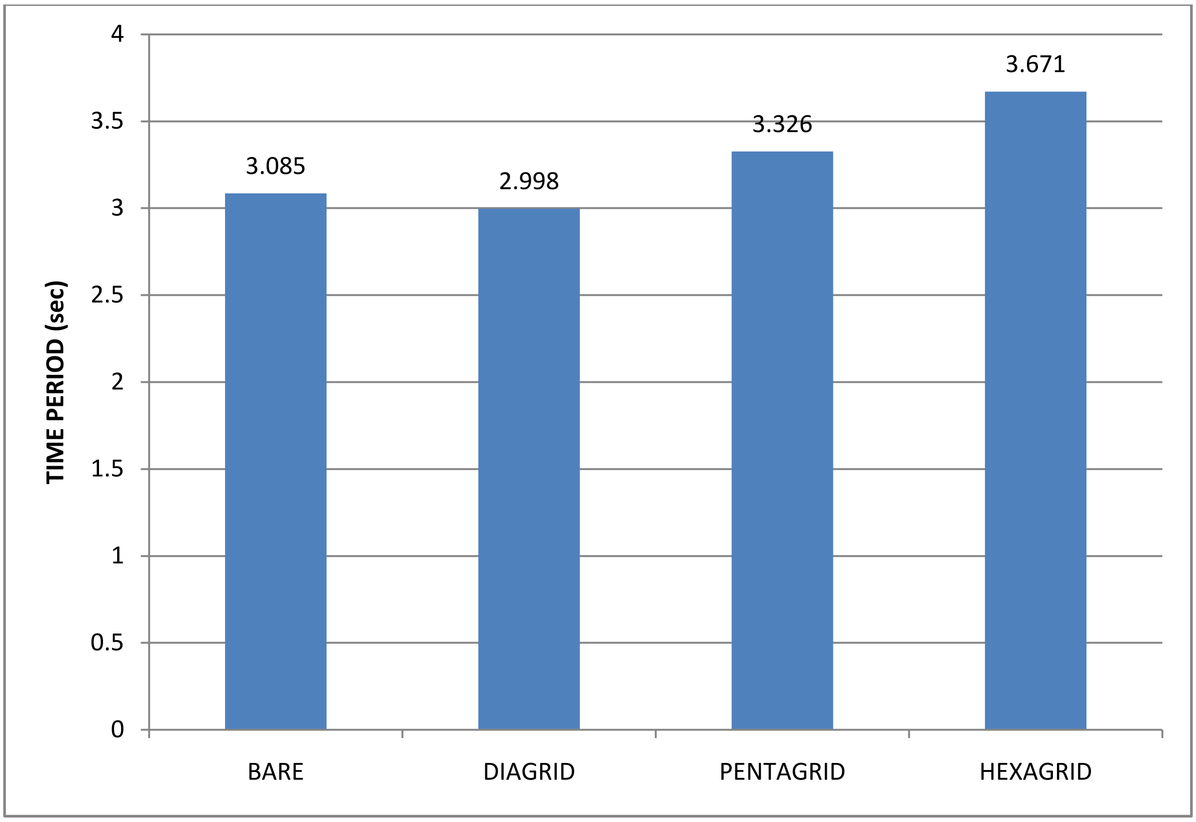


Figure 41: Time Period for 37 STOREY structure with 3 Grid with Shear

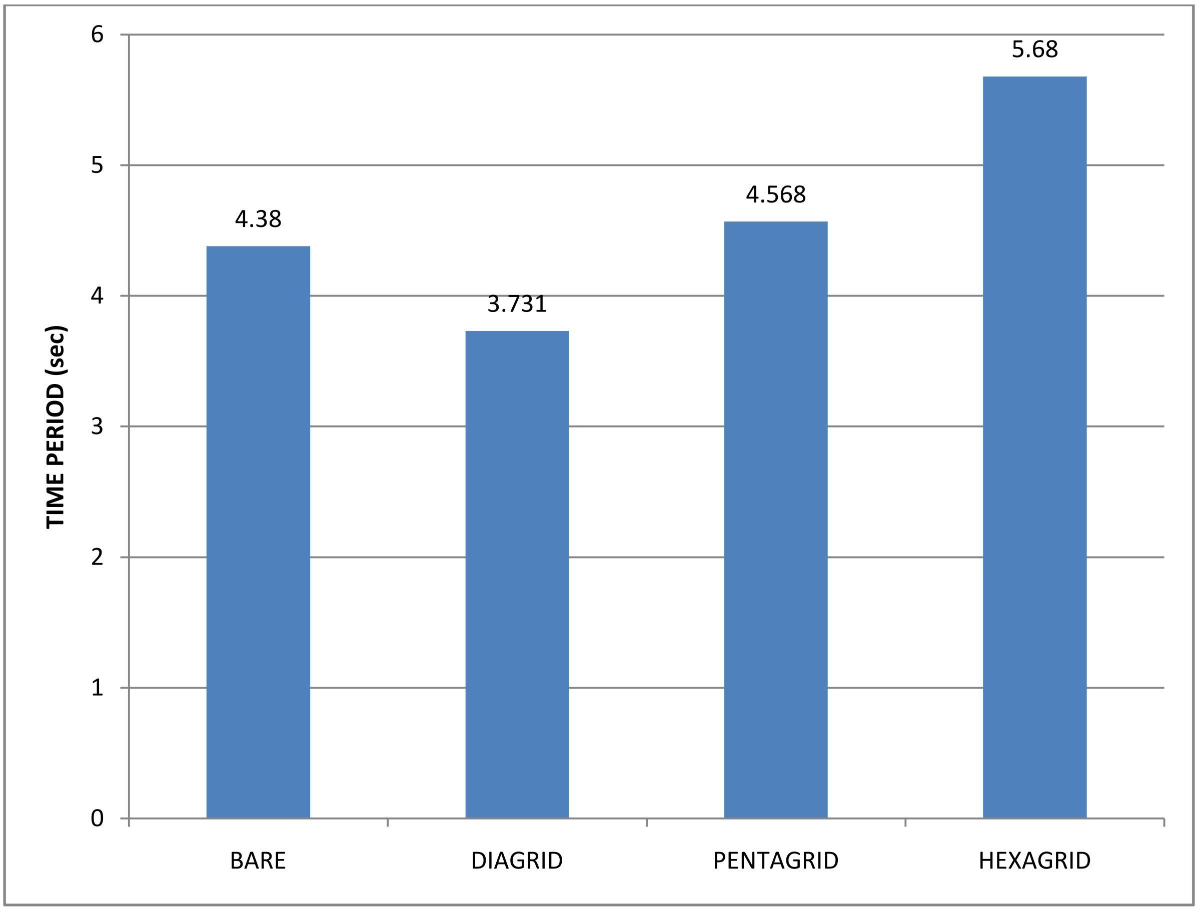


Figure 42: Time Period for 37 STOREY structure with 3 Grid with no Shear Wall

RESULTS AND CONCLUSION

		Max. Storey Displacement (mm)	Max. storey Drift (mm)	Base Shear (KN)	Time period (sec)
REGULAR	RSM	35.808	.000381	3850.9	Max 5.688
	Wind Dynamic	67.23			Min 0.715
DIAGRID	RSM	30.44	.000289	3633.47	Max 5.109
	Wind Dynamic	56.53			Min 0.611
PENTAGRID	RSM	39	.000592	3651.73	Max 5.274
	Wind Dynamic	72.11			Min 0.655
HEXAGRID	RSM	59.37	.000606	3641.26	Max 5.688
	Wind Dynamic	117.97			Min 1.683

From the above results we can say that,

- Maximum storey displacement in Diagrid structure is less as compare to other structural systems like pentagrid and hexagrid structural system.
- Maximum storey drift in Diagrid structure is less as compare to other structural systems like pentagrid and hexagrid structural system.
- Base shear in Diagrid structure is less as compare to other structural systems like pentagrid and hexagrid structural system.
- Time period in Diagrid structure is less as compare to other structural systems like pentagrid and hexagrid structural system.

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