# STUDY ON BEHAVIOR OF TUBULAR DIAGRID STRUCTURES DURING SEISMIC EXCITATION

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**Abstract -** *Diagrids structures have evolved as an effective and innovative form used in the present decades. Diagrid buildings have grids employed in a diagonal manner and have gained popularity in tall structures as they have higher structural efficiency & decorative attributes. Very few research works have been performed examining on the behavior of structures and its performance under dynamic loads.*
*In this study, a G+50 storey structure with tubular diagrid configuration is used with modelling done in ETABS and a non-linear type of investigation is performed on the different models having varied angles along the height of the structure. Also the building is situated in zone III and medium soil is used. From the analysis, various diagrid angles used in the structure are assessed for different parameters of earthquake and results are studied.*

***Key Words***: Varied angles of Diagrids, Tall structures, Displacements etc.

## 1. INTRODUCTION

It is very much important to make the developing design strategies in the present days for the tall buildings systems to make sure it uses a minimum amount of the structural material. By this reduction in the material consumption, we can contribute for constructing the sustainable built environments, and also to save the limited resources which are significant. The amount of material required i.e. the structural material, which resist the lateral loads will increase considerably as height of the building increases due to the premium for height. Nowadays, because of the high cost of the land and also because of faster growth of urban population, there is very much pressure on the limited space which have influenced the domestic development of the city. Due to all these reasons, the tall structures are emerging rapidly. As we know, these tall structures are constructed comparatively to resist the lateral loads. We know that there are many moment resisting systems, out of which diagrid structures have been chosen for the present study.

The emergence of tall structures with diagrids came into existence in the late 1960's, but it is developed and widely used more recently. In the tall buildings, the diagrids, i.e. the diagonal members are positioned in the exterior of the building, which reduces the lateral forces and also it decreases the shear force and moment in the interior beams. The major difference that is observed when compared to conventional building is that, in conventional building there will be number of vertical columns, but in case of diagrids, vertical columns are replaced by the inclined columns i.e. the diagonals. There are many diagrids structures around the world.

## 2. LITERATURE REVIEW

**Kyoung Sun Moon (2008)** studies the stiffness based design and the characteristics of the diagrid buildings. He considered the diagrid structures which are 40 stories, 50 stories, 60 stories, 70 stories and 80 stories. The diagonals were placed at various angles with gradually change in the angles along the height of building. This is done to determine the optimum angle for individual structure with difference in height and also to observe the potential of the structure of diagrids with change in angles. In the result part, it is seen that, in the region 60º to 70º, the optimum angle was determined, and the aspect ratio is seen to be within the range of 4 to 9.

**Kiran Kamath, et.al (2016)** one of the seismic analysis is nonlinear pushover analysis. To know the performance of diagrids, this study has been made. Circular shape models are considered in this paper which has the aspect ratio H/B that is, height /base, ranging from 2.67 to 4.26. The angles used are $54^{O}$, $78^{O}$ and $71^{O}$ for external bracings in this condition. At 12m height, the base width is constant and the structure height is altered accordingly. For modeling the nonlinear response of components, FEMA 356 procedures are used in which moment curvature relationship is explained, and plastic hinge which is used for modeling is based on this relation. There is increase in the aspect ratio for $71^{O}$ angled model base shear as taken in this study.

### 2.1 Objectives

1. To know the behaviour of tubular steel structures with variable angled "diagrid" in comparison with the tubular steel structure.
2. Study is done for Steel tubular structure provided with diagrids of different angles i.e., 45º, 60º, 70º.

3. The Analysis is done using equivalent static method using IS 1893-2002 and dynamic time history analysis using ETABS for high seismic zone.
4. Efficiency of tubular steel structures with respect the base shear, displacement, drift are found out for all geometric configurations.
5. The influence of applying the diagrids on behavior of tall tubular steel structures is briefed using the obtained results, by concluding the optimum angle of diagrid used for tall tubular steel structures.

## 3. Modelling

The modeling and analysis is done for all four models using ETABS software, the analysis is done by considering seismic zone III. Tubular steel model is being compared with tubular diagrid structures. And also comparison is done among the tubular diagrid models to know the optimum angle.

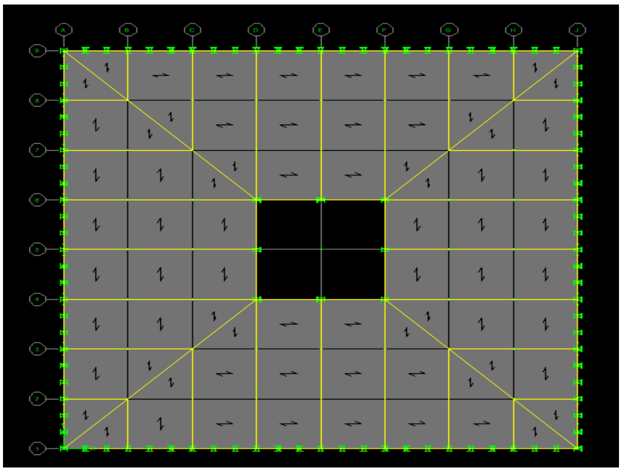

**Fig -1**: Plan of Tubular Steel building

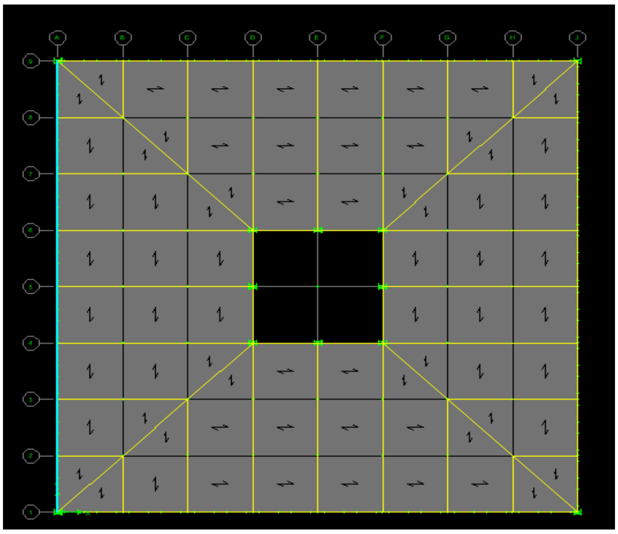

**Fig -2**: Plan of Tubular Diagrid building with 45º Angle

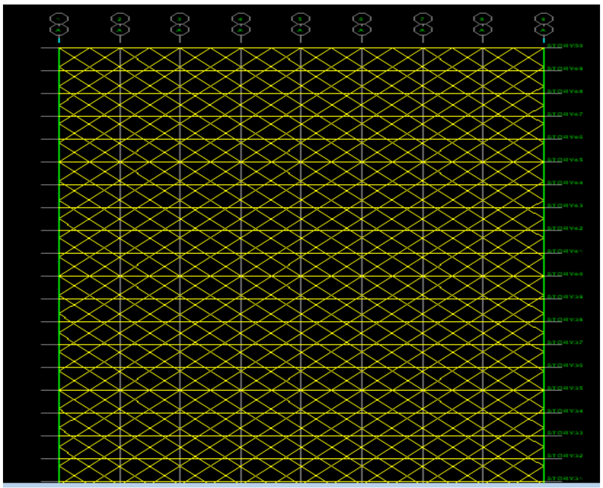

**Fig -3**: Elevation of Tubular Diagrid Structure with 45º Angle

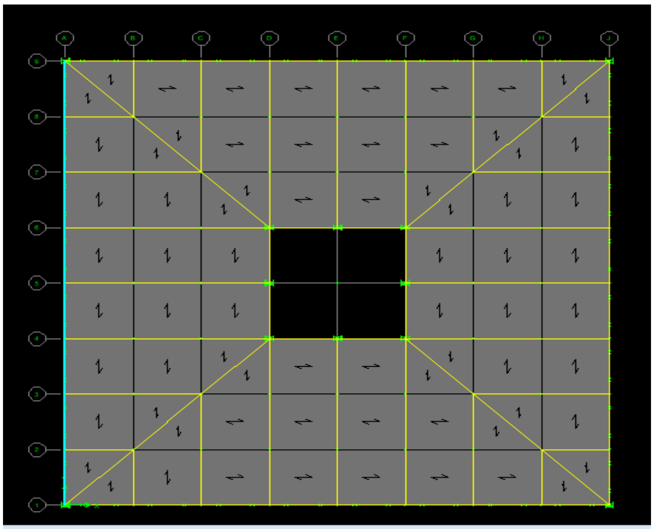

**Fig -4**: Plan of Tubular Diagrid Structure with 60º Angle

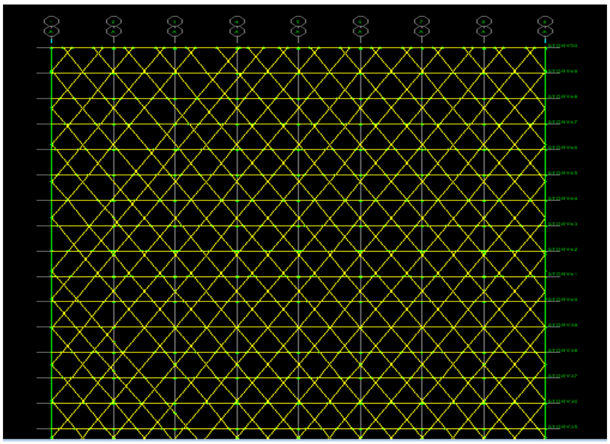

**Fig -5**: Elevation of Tubular Diagrid Structure with 60º Angle

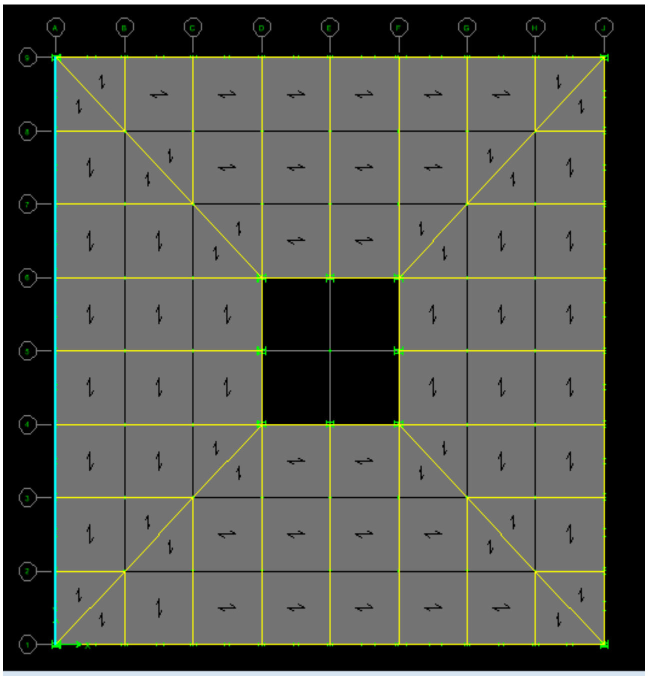

**Fig -6**: Plan of Tubular Diagrid Structure with 75º Angle

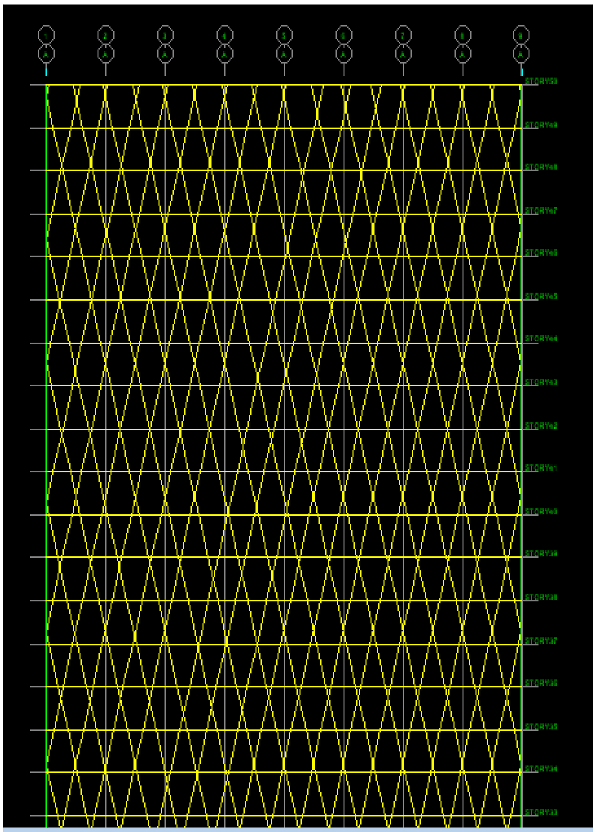

**Fig -7**: Elevation of Tubular Diagrid Structure with 75º Angle

### 3.1 Modelling Of Building Frames

Four different building models are taken and analyzed under the seismic zone III. The four models are as follows

1. Model 1- tubular steel structure
2. Model 2- diagrid structure with 45º
3. Model 3- diagrid structure with 60º
4. Model 4- diagrid structure with 75º

### 3.2 Description of Analytical Model

The general geometric details and structural details such as dimensions of the structural members, material properties, load intensities and seismic data considered in the modelling are as follows

**Table -3.1:** Details of the Building

| | |
|---|---|
| No. of storey's | G+50 |
| Building type | Tubular steel structure |
| Building dimension | 40mx40m |
| Typical storey Height | 3m |
| Seismic zone | III |
| Reduction factor | 5 |
| Importance factor | 1 |
| Soil type | Medium soil |

**Table 3.2:** structural members of the building

| | |
|---|---|
| Thickness of deck | 0.2m |
| beam | ISMB600 |
| column | ISWB600-2 |
| Wall thickness | Glazing load is considered |

**Table -3.3:** Material Properties of the Building

| | |
|---|---|
| Grade of concrete | M30 |
| Grade of steel | Fe350 |
| Density of concrete | 25 KN/m³ |
| Young's modulus of concrete | 27386x10³kN/m² |
| Poisson's ratio | 0.2 |

**Table -3.4:** Assumed Load Intensities

| | |
|---|---|
| slab live load | 4kN/m² |
| Floor finish | 1.5kN/m² |
| Glazing load | 1kN/m² |

## 4. Results and Discussion

Find the results for lateral displacements, storey drift, shear force, bending moment axial force. Then compare the result to recognize the effective system between provided different bracings systems under zone IV. Resulting tables and graphs are obtainable to find efficient bracings system under following as.

### 4.1 Lateral Displacement

It is seen that for all the models the maximum value of displacement is found to be in the top storey. Compared to rest of the models, the model which has angle of diagrid 60$^{\circ}$ has lesser displacement values.

**Table 4.1:** Displacement Values

| DISPLACEMENT | | | | |
|---|---|---|---|---|
| Storey | Model1x | Model2x | Model3x | Model4x |
| 50 | 170.8981 | 88.0866 | 65.4585 | 85.2238 |
| 49 | 169.7657 | 85.8852 | 64.0314 | 84.0924 |
| 48 | 168.4763 | 83.6671 | 62.59 | 82.8576 |
| 47 | 167.0028 | 81.4379 | 61.1354 | 81.6016 |
| 46 | 165.3431 | 79.1982 | 59.6536 | 80.2963 |
| 45 | 163.5012 | 76.945 | 58.1525 | 78.9014 |
| 44 | 161.4835 | 74.6866 | 56.6333 | 77.4563 |
| 43 | 159.2971 | 72.4172 | 55.1038 | 75.9631 |
| 42 | 156.949 | 70.1425 | 53.556 | 74.3972 |
| 41 | 154.4466 | 67.8641 | 51.9462 | 72.8202 |
| 40 | 151.7972 | 65.5797 | 50.3494 | 71.1503 |
| 39 | 149.008 | 63.2972 | 48.7754 | 69.4768 |
| 38 | 146.0862 | 61.0124 | 47.1832 | 67.7604 |
| 37 | 143.0389 | 58.7319 | 45.5883 | 65.9802 |
| 36 | 139.8732 | 56.4577 | 43.9889 | 64.1805 |
| 35 | 136.596 | 54.1876 | 42.3817 | 62.3552 |
| 34 | 133.2141 | 51.9293 | 40.7747 | 60.4914 |
| 33 | 129.7344 | 49.6792 | 39.1705 | 58.6238 |
| 32 | 126.1635 | 47.4456 | 37.5691 | 56.7231 |
| 31 | 122.5078 | 45.2306 | 35.9666 | 54.7846 |
| 30 | 118.7738 | 43.0316 | 34.3733 | 52.8351 |
| 29 | 114.9679 | 40.8562 | 32.7962 | 50.8779 |
| 28 | 111.096 | 38.7009 | 31.2216 | 48.903 |
| 27 | 107.1644 | 36.5759 | 29.6586 | 46.909 |
| 26 | 103.1789 | 34.4836 | 28.1178 | 44.9277 |
| 25 | 99.1452 | 32.4203 | 26.5897 | 42.9424 |
| 24 | 95.069 | 30.3937 | 25.0757 | 40.938 |
| 23 | 90.9558 | 28.4 | 23.5914 | 38.9505 |
| 22 | 86.811 | 26.4518 | 22.1271 | 37.0226 |
| 21 | 82.6399 | 24.5514 | 20.6807 | 34.6817 |
| 20 | 78.4475 | 22.6936 | 19.2749 | 32.7706 |
| 19 | 74.2389 | 20.8865 | 17.8909 | 30.8959 |
| 18 | 70.0189 | 19.1258 | 16.5311 | 28.693 |
| 17 | 65.7923 | 17.4262 | 15.217 | 26.833 |
| 16 | 61.5637 | 15.7903 | 13.9333 | 25.0438 |
| 15 | 57.3376 | 14.2111 | 12.6803 | 22.8762 |
| 14 | 53.1186 | 12.6974 | 11.474 | 21.0324 |
| 13 | 48.9109 | 11.2432 | 10.3107 | 19.2804 |
| 12 | 44.7189 | 9.867 | 9.1848 | 17.508 |
| 11 | 40.5468 | 8.5689 | 8.105 | 15.7473 |
| 10 | 36.3989 | 7.3426 | 7.0842 | 14.094 |
| 9 | 32.2794 | 6.1952 | 6.1031 | 12.4355 |
| 8 | 28.1927 | 5.1237 | 5.1684 | 10.7822 |
| 7 | 24.1434 | 4.1452 | 4.3093 | 9.2584 |
| 6 | 20.137 | 3.263 | 3.4953 | 7.7642 |
| 5 | 16.1804 | 2.4693 | 2.7309 | 6.2464 |
| 4 | 12.2863 | 1.7662 | 2.0509 | 4.8667 |
| 3 | 8.4848 | 1.1565 | 1.429 | 3.5518 |
| 2 | 4.8645 | 0.6582 | 0.8649 | 2.2002 |
| 1 | 1.7122 | 0.2814 | 0.3786 | 0.9465 |

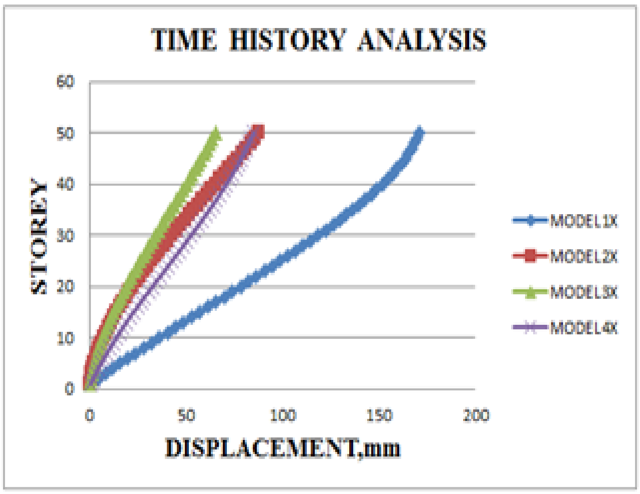


**Fig -4.1**: Displacement for Different Models

## 4.2 Storey Drift

The results of drifts are extracted for all the models and graph has been plotted below. It is found that, for model 4 the drift value is lesser. As per IS 1893-2002 the criteria for story drift that is .004 times the height of the story is satisfied.

**Table 4.2:** Drift Values

| DRIFT | | | | |
|---|---|---|---|---|
| STOREY | MODEL1X | MODEL2X | MODEL3X | MODEL4X |
| 50 | 0.000379 | 0.000735 | 0.000476 | 0.000377 |
| 49 | 0.000431 | 0.00074 | 0.000481 | 0.000412 |
| 48 | 0.000493 | 0.000744 | 0.000485 | 0.000419 |
| 47 | 0.000555 | 0.000748 | 0.000494 | 0.000435 |
| 46 | 0.000616 | 0.000752 | 0.000501 | 0.000465 |
| 45 | 0.000674 | 0.000754 | 0.000507 | 0.000482 |
| 44 | 0.00073 | 0.000758 | 0.00051 | 0.000498 |
| 43 | 0.000784 | 0.000759 | 0.000516 | 0.000522 |
| 42 | 0.000836 | 0.000761 | 0.000537 | 0.000526 |
| 41 | 0.000885 | 0.000763 | 0.000532 | 0.000557 |
| 40 | 0.000931 | 0.000762 | 0.000525 | 0.000558 |
| 39 | 0.000975 | 0.000763 | 0.000531 | 0.000572 |
| 38 | 0.001017 | 0.000761 | 0.000532 | 0.000594 |
| 37 | 0.001057 | 0.000759 | 0.000533 | 0.0006 |
| 36 | 0.001094 | 0.000758 | 0.000536 | 0.000609 |
| 35 | 0.001129 | 0.000754 | 0.000536 | 0.000622 |
| 34 | 0.001161 | 0.000751 | 0.000535 | 0.000623 |
| 33 | 0.001192 | 0.000746 | 0.000534 | 0.000634 |
| 32 | 0.00122 | 0.000739 | 0.000534 | 0.000646 |
| 31 | 0.001246 | 0.000734 | 0.000531 | 0.00065 |
| 30 | 0.00127 | 0.000726 | 0.000526 | 0.000652 |
| 29 | 0.001292 | 0.00072 | 0.000525 | 0.000658 |
| 28 | 0.001312 | 0.000709 | 0.000521 | 0.000666 |
| 27 | 0.00133 | 0.000698 | 0.000514 | 0.00066 |
| 26 | 0.001346 | 0.000689 | 0.000509 | 0.000662 |
| 25 | 0.00136 | 0.000677 | 0.000505 | 0.000668 |
| 24 | 0.001373 | 0.000666 | 0.000495 | 0.000663 |
| 23 | 0.001383 | 0.00065 | 0.000488 | 0.000644 |
| 22 | 0.001392 | 0.000635 | 0.000482 | 0.000788 |
| 21 | 0.001399 | 0.00062 | 0.000469 | 0.000639 |
| 20 | 0.001404 | 0.000603 | 0.000461 | 0.000627 |
| 19 | 0.001408 | 0.000588 | 0.000453 | 0.000741 |
| 18 | 0.00141 | 0.000568 | 0.000438 | 0.000623 |
| 17 | 0.001411 | 0.000546 | 0.000428 | 0.000599 |
| 16 | 0.00141 | 0.000527 | 0.000418 | 0.00073 |
| 15 | 0.001408 | 0.000506 | 0.000402 | 0.000617 |
| 14 | 0.001404 | 0.000486 | 0.000388 | 0.000585 |
| 13 | 0.001399 | 0.000461 | 0.000375 | 0.000592 |
| 12 | 0.001392 | 0.000433 | 0.00036 | 0.000587 |
| 11 | 0.001384 | 0.000409 | 0.00034 | 0.000552 |
| 10 | 0.001375 | 0.000384 | 0.000327 | 0.000554 |
| 9 | 0.001364 | 0.000357 | 0.000312 | 0.000552 |
| 8 | 0.001351 | 0.000328 | 0.000286 | 0.000509 |
| 7 | 0.001337 | 0.000294 | 0.000271 | 0.000499 |
| 6 | 0.00132 | 0.000264 | 0.000255 | 0.000506 |
| 5 | 0.0013 | 0.000236 | 0.000227 | 0.000461 |
| 4 | 0.001269 | 0.000203 | 0.000207 | 0.000439 |
| 3 | 0.001208 | 0.000168 | 0.000188 | 0.000451 |
| 2 | 0.001052 | 0.000131 | 0.000162 | 0.000418 |
| 1 | 0.000571 | 0.000087 | 0.000126 | 0.000316 |

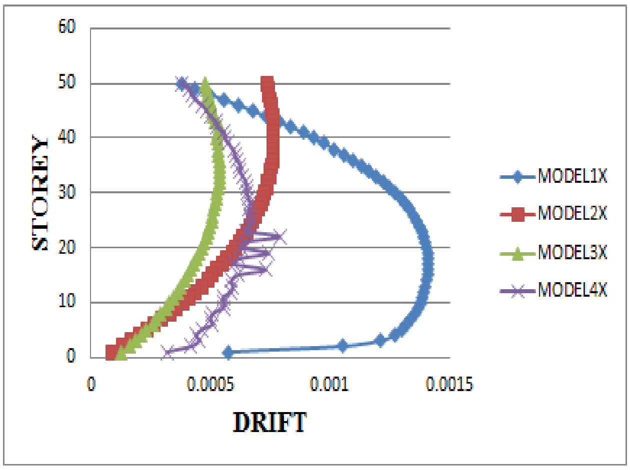


**Fig -4.2**: storey drift for Different Models

## 4.3 Time Period

As smaller the time period, the higher is the frequencies in the structure. Thus, the model 1 has higher time period which reflects on the stiffness of the components. Model 3 has lesser time period and it is subjected to reduced vibration.

**Table 4.3:** Time Period

| TIME PERIOD | | | | |
|---|---|---|---|---|
| Mode | Model 1 | Model 2 | Model 3 | Model4 |
| 1 | 5.943416 | 3.719709 | 3.275062 | 3.952147 |
| 2 | 5.861811 | 3.717983 | 3.272548 | 3.940478 |
| 3 | 3.673473 | 0.843878 | 1.080902 | 1.931211 |
| 4 | 1.947602 | 0.796284 | 0.842964 | 1.233793 |
| 5 | 1.918011 | 0.795415 | 0.841571 | 1.22813 |
| 6 | 1.222897 | 0.364268 | 0.412638 | 0.664014 |
| 7 | 1.117002 | 0.363784 | 0.411816 | 0.66032 |
| 8 | 1.097695 | 0.281572 | 0.3607 | 0.6451 |
| 9 | 0.786024 | 0.234122 | 0.278028 | 0.465082 |
| 10 | 0.771293 | 0.233774 | 0.277399 | 0.462128 |
| 11 | 0.731744 | 0.172266 | 0.216976 | 0.388256 |
| 12 | 0.602318 | 0.171985 | 0.209701 | 0.357368 |

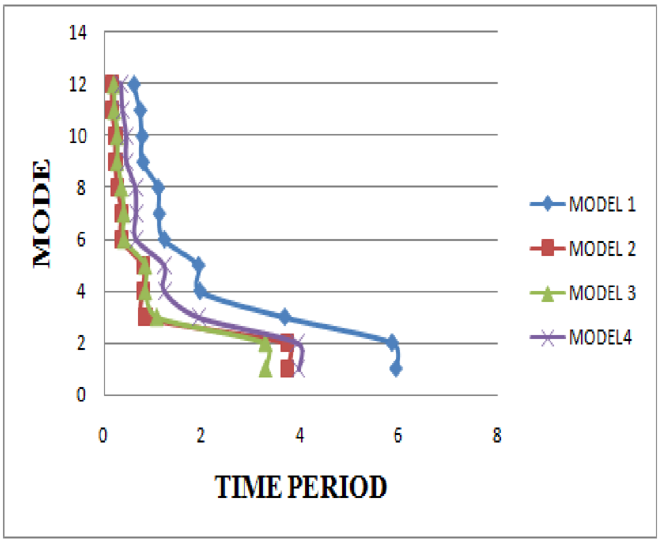


**Fig -4.3**: Time Period for Different Models

## 4.4 Base Shear

From the below table of base shear we can observe that different values are obtained for each models and model 4 gives the lesser base shear value.

**Table 4.4:** Base Shear

| BASE SHEAR | | | |
|---|---|---|---|
| MODEL 1 | MODEL 2 | MODEL 3 | MODEL 4 |
| 6196.41 | 6224.31 | 6172.33 | 6120.35 |

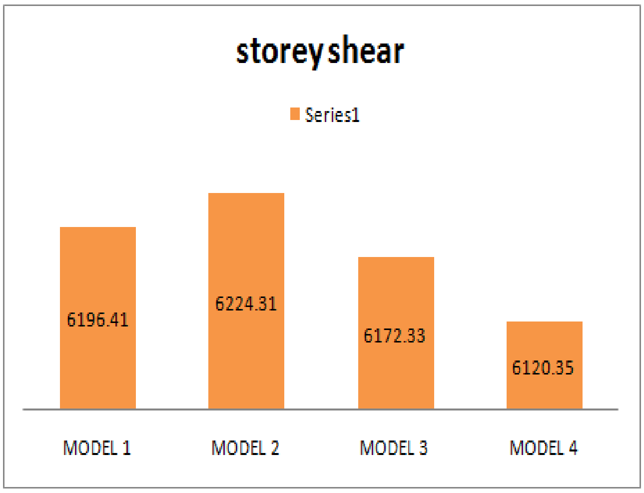


**Fig -4.4**: Base Shear for Different Models

## 5. CONCLUSIONS

1. The concept of using steel bracings is one of the useful concepts to increase the strength of the structure.
2. After the application of bracings to the building frame, lateral displacement and storey drift is decreases.
3. The maximum lateral displacement found within the permissible limit as specified by code (IS: 1893-2002(Part-1)) in both static and dynamic analysis, after the application of X bracing and the shear wall.
4. The maximum lateral displacement found within the permissible limit as specified by code (IS: 1893-2002(Part-1)) in both static and dynamic analysis, after the application of X bracing and the shear wall.
5. Storey drift will maximum at the soft storey level.
6. Use of X bracing is efficient in resisting lateral displacement and storey drift compared to other specified bracings.
7. When two soft storeys are present in a building at different levels than the displacement and storey drift will be higher in this case compared to building with one soft storey.
8. Steel bracings reduce flexure and shear demands in beams and flexure demands in columns when compared to unbraced frame.
9. Base shear for all the models are fairly same except model.
10. The soft storey in RCC framed structure is avoided but if that is necessary then it should be provided on ground storey of the structure and not at top of the structure.

## REFERENCES

1) Kiran Kamath, Sachin Hirannaiah, Jose Camilo Karl Barbosa Noronha, "An analytical study on performance of a diagrid structure using nonlinear static pushover analysis"- published by Elsevier limited.
2) Kyoung sun moon, "optimal grid geometry of diagrid structures for tall buildings", architectural science review volume 51.3, pp 239-251.
3) Giovanni Maria Montuori , Elena Mele, Giuseppe Brandonisio, Antonello De Luca, "Secondary bracing systems for diagrid structures in tall buildings"- published by Elsevier limited.
4) Kyoung sun moon, "Diagrid Structures for Complex-Shaped Tall Buildings"- published by Elsevier limited.
5) Nishith B. Panchal, Dr. V. R. Patel, Dr. I. I. Pandya, "Optimum Angle of Diagrid Structural System" International Journal of Engineering and Technical Research (IJETR) ISSN: 2321-0869, Volume-2, Issue-6, June 2014.
6) Deepa Varkey and Manju George, "Dynamic Analysis Of Diagrid System With Complex Shape" IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 3 Issue 8, August 2016.