Analytical Study on Outrigger and Hexagrid System in High-Rise Buildings

Zahid Manzoor, Gurpreet Singh

***Abstract:** The innovation of high strength structural materials as well as the introduction of predominant development methods gave a lift in the development of tall structures. As the height of the structure increases, they become progressively vulnerable to wind load and seismic load. The opposition of tall structures to lateral loads is the fundamental determinant in the formulation of new basic structural frameworks that develop by the constant endeavors of structural engineers to go on increasing the building height while keeping the deflection inside worthy points of confinement and limiting the measure of materials. In this paper, an analytical study was made on such systems like outrigger system with core shear wall and hexagrid systems, so as to determine their structural efficiency in transferring the lateral loads safely to the ground. A comparison of outrigger system with core shear wall and a hexagrid system was made on a 38-story building reinforced concrete building by using standard package ETABS 2016 by comparing different parameters such as Maximum Story Displacement, Maximum Story Drift and Story Shears.*

***Keywords:** Outrigger system, Hexagrid System, Lateral Drift, Time Period, Response Spectrum Method*

I. INTRODUCTION

In the history of structures, maybe nothing is more dazzling than the human goal to make progressively tall structures. Different social and financial factors, for example, migration of people from to urban areas looking for better way of life and openings for work, the increment in land values in urban regions and higher population density, have prompted an incredible increase in the number of tall structures all over the world. As the tall structure is best to land use strategy in present time it can spare a ton of land, hence the horizons of the world's urban areas are ceaselessly being punctured by particular and recognizable tall structures as great as mountain ranges, and achieving more height keeps on being the challenge and goal. However, there are some incredible challenges which are to be looked by the designer every day to make these structures a reality. Out of many challenges, one is that of lateral loads i.e. seismic load and wind load. So there is a need to stabilize the tall buildings against these lateral loads and to provide comfort to the occupants.

This is done by providing lateral load resisting systems which include shear wall-frame, closed spaced perimeter tube, exterior diagonal tube, outrigger structural system, diagrid system, hexagrid system and many more.

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A. Outrigger Structural System

Outrigger systems are modified type of braced frame and shear-walled outline frameworks and are used in steel and composite constructions. As an imaginative and effective basic framework, the outrigger framework involves a central core, including either braced frame or shear walls, with horizontal "outrigger" brackets or supports connecting the center to the outside sections or columns. Besides, by and large, the outer columns are interconnected by exterior belt girder. In the event that the structure is exposed to the horizontal loading, the rotation of the core is anticipated by the column-restrained outriggers. The outriggers and belt girder ought to be at least one and often two stories profound to acknowledge sufficient stiffness. Consequently, they are for the most part situated at plant levels to lessen the obstruction they make. Contingent on the number of levels of outriggers and their solidness, the outer columns of an outrigger structure play out a composite conduct with the core.

B. Hexagrid Structural System

All the more as of late, the diagrid structural framework with tubular conduct is being utilized as basically productive as well as architecturally fulfilling basic framework for tall structures. Outer diagonals act as a veneer, which oversees the outer style of the structure to an extraordinary degree. So as to improve the efficiency of the tube type system in tall structures, another auxiliary framework called Hexagrid (Beehive) is presented. In the hexagrid structure framework, practically all the outer customary vertical sections are dispensed with. Hexagrid structural framework comprises of a hexagrid border which is comprised of a system of multi-story tall hex-angulated truss framework. Hexagrid is framed by joining the inclining and horizontal segments. This impact can be better valued by visualizing the outcomes in terms of story drift, time period and lateral displacement.

II. RESEARCH METHODOLOGY

In this study, a 38 story building was considered having a typical story height of 3.5 m. The plan dimension of the building was 36 x 24 m with six bays of 6 m in X direction and five bays of 6 m in Y direction. The total height of the building was 133 m. M45 grade of concrete was used for columns, shear wall, and coupling beam, while as M35 grade of concrete was used for beams and slab and Fe500 grade of steel was used in different members of structures. The size of the column was taken as 0.9 x 0.6 m for outrigger system and 1.0 x 0.75 m for a hexagrid system. Similarly, the size of the beam was taken as 0.75 x 0.5 m for both the systems

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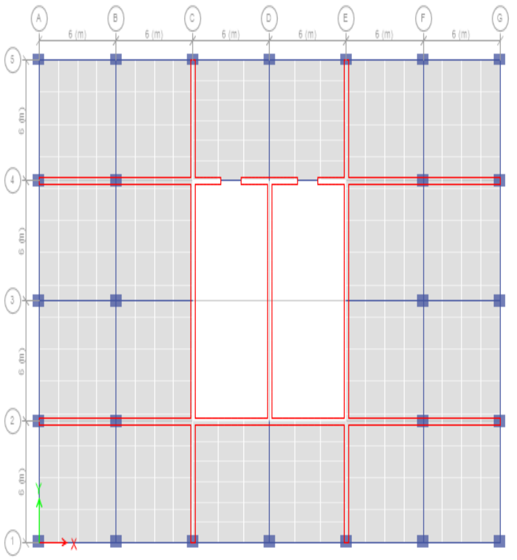
and ISHB450-2 was used for outrigger beams. The thickness of the slab was kept as 0.15 m and that of the shear wall was 0.35 m. The dimensions of the coupling beam were taken as 1.2 x 0.35 m. Vertical and horizontal loads were applied as per recommendations of IS 456, IS-1893 (Part1) and IS-875 (Part 3). The design dead load on the floor slab was taken as 2.5kN/m^2 and the wall load was also considered. The live load acting on the floor slab was taken as 3kN/m^2. The design lateral load because of wind for investigation of the structure was determined for basic wind speed equivalents to 47 m/sec according to IS: 875 (Part 3)- 2015. The design seismic load was determined for seismic zone IV according to IS: 1893 (Part 1)- 2002. ETABS programming was utilized for modeling and investigation purposes, two types of analysis were done i.e. Response Spectrum and Static Wind Analysis.



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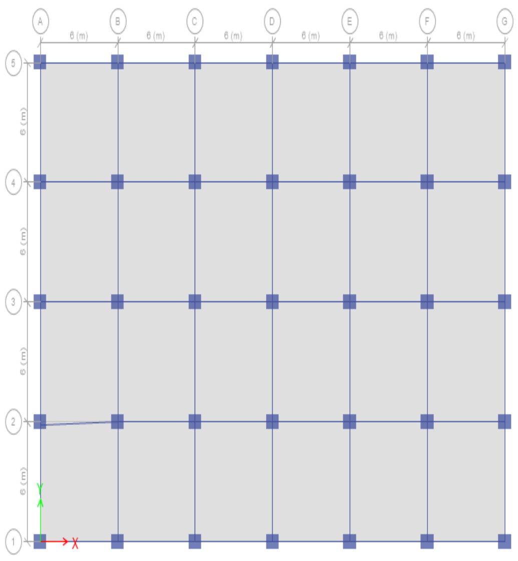


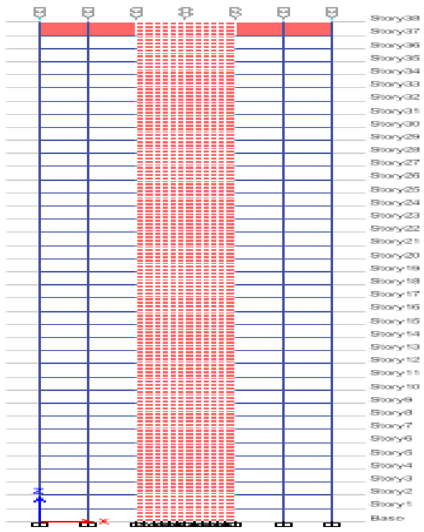
(b)

Figure 1 Plan of the Model with **(a)** outrigger system, **(b)** Hexagrid System

A. Test Models and Analysis

For the analysis of work, the models of high rise reinforced concrete frame building (38) floors were made to know the realistic behavior of building during earthquake and wind loads. Different models of this 38 storey high building were analyzed for both wind load and seismic load by using ETABS software. The test models include (a) Bare frame (b) Frame with core shear wall, (c) Frame with core shear wall and outrigger at various depths and (d) Frame with an outer hexagrid system. The designation of the test models are:

1. MB1 – Model without core shear wall and outrigger.
2. MB2 – Model with core shear wall only.
3. MB3 – Model with core shear wall and outrigger at the top only.
4. MB4 – Model with core shear wall and outrigger at a mid-height only.
5. MB5 - Model with core shear wall and outrigger at H/4 height from the top only.
6. MB6 – Model with core shear wall and outrigger at mid-height and top.
7. MB7 – Model with core shear wall and outrigger at H/3 and 2H/3 heights from the top.
8. MB8 – Model with an outer hexagrid system with 3 storey in a module (one hexagrid formed around 3 storey heights)
9. MB9 – Model with an outer hexagrid system with 4 storey in a module



(a)

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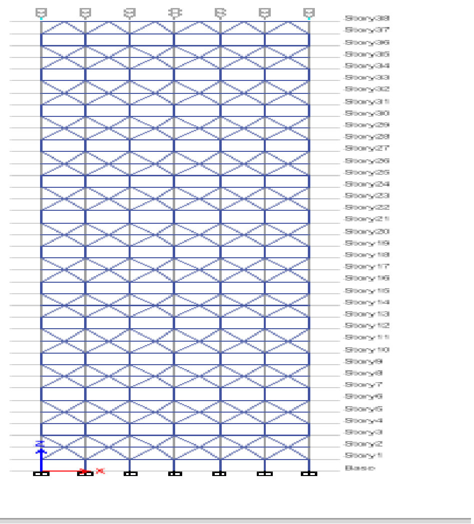

(b)

Figure 2 Elevation of the Model with **(a)** outrigger system and **(b)** hexagrid system

III. RESULTS AND DISCUSSION

After analyzing the various models in ETABS software by applying Response Spectrum Analysis and Static Wind Analysis following results were obtained:

A. Results for Seismic load

It can be seen that for a hexagrid system with 3 storeys in 1 module is the most effective with minimum lateral displacement for a seismic load. In the X direction the reduction was 306.45mm (75%) as compared to hexagrid system with 4 storeys in 1 module and 257.46mm (71.6%) as compared to bare frame, while as in Y direction the decrease was seen to be 340.81 mm (70.51 %) as compared to bare frame and 209.19 mm (59.48%) as compared to frame with core shear wall.

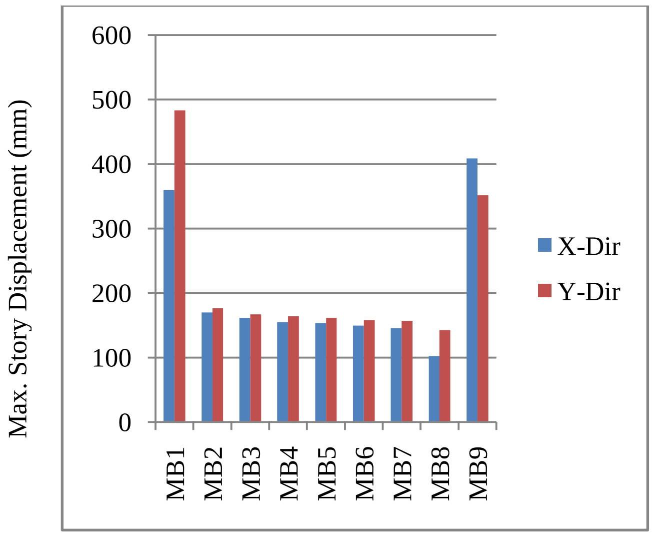

Figure 3 Variation of Maximum Story Displacement

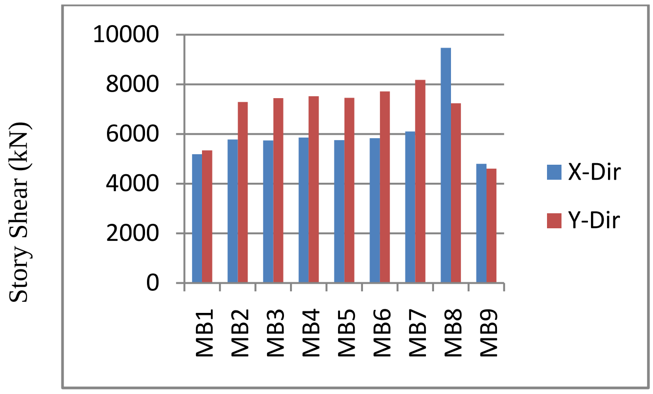

Figure 4 Comparison of Story Shear

The results showed that the hexagrid system with 3 storeys in 1 module has maximum base shear of 9472.34 kN followed 6097.83 kN for model with 2 outriggers one at H/3 and other at 2H/3, while as hexagrid system with 4 storeys in 1 module has minimum base shear of 4800.82 kN, a reduction of 4671.52 kN (49.32%) and 1426.31 (23.4%) respectively from above two models.

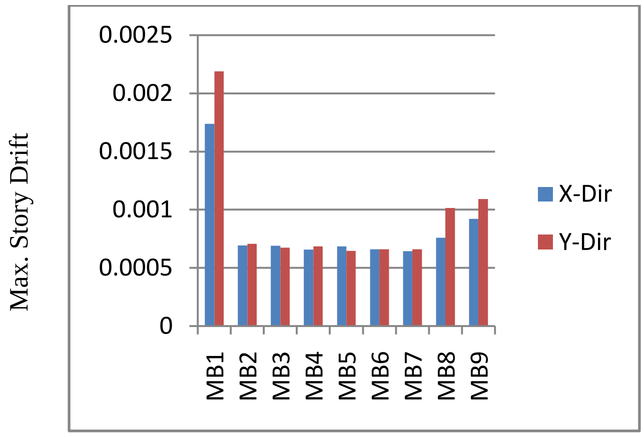

Figure 5 Comparison of Story Drift

In X- direction the story drift is maximum 0.001737 for bare frame model followed by 0.000921 for a model with a hexagrid system having 4 storeys in a module. The model with 2 outriggers one at H/3 and other at 2H/3 shows minimum story drift of 0.000643 which shows a reduction of 62.98% from a bare frame and 30.18% from a model with a hexagrid system. For Y- direction bare frame has maximum story drift of 0.002189 while as the model with outrigger at H/4 from the top has a minimum of 0.000647, a reduction of 70.44% was seen.

Figure 6 Comparison of Time Period

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It can be seen that the model with 2 outriggers one at H/3 and other at 2H/3 has a minimum time period of 3.255 seconds and the bare frame has a maximum time period of 7.272 seconds.

B. Results for Wind Load

For wind load it can be seen that for hexagrid system with 3 storeys in 1 module has minimum displacement in the X direction The reduction was 541.40 mm (83.66%) as compared to bare frame and 157.50 mm (59.84%) as compared to frame with core shear wall, while as in Y direction the model with 2 outriggers one at H/3 and other at 2H/3 has minimum displacement. The decrease was seen to be 1028.57 mm (78.92%) as compared to the bare frame and 88.08 mm (24.27%) as compared to a frame with core shear wall.

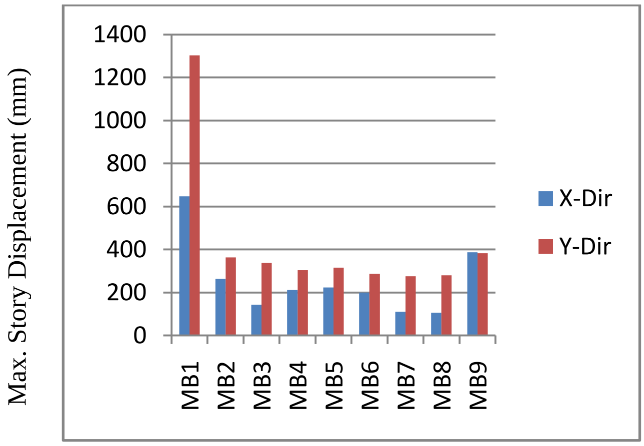

Figure 7 Comparison of Maximum Story Displacement

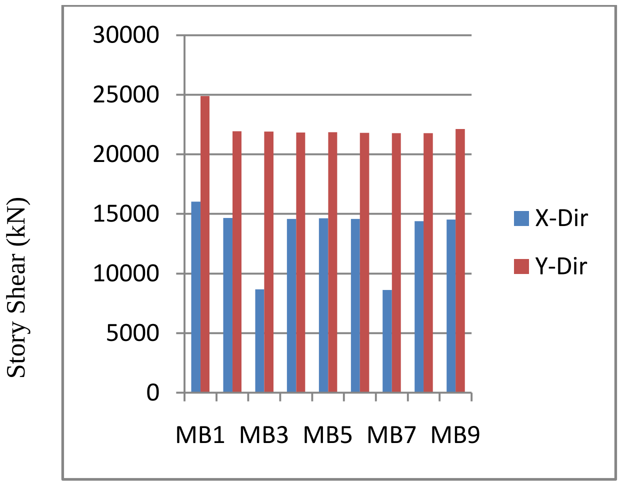

Figure 8 Comparison of Story Shear

For X- direction it can be seen that the bare frame has maximum base shear of 16022.45 kN, while a model with 2 outriggers one at H/3 and other at 2H/3 has a minimum base shear of 8609.88 kN, a reduction of 46.26%. In Y- direction bare frame has maximum base shear of 24905.57 kN followed by a hexagrid system with 4 storeys in 1 module 22136.41 kN, while as the hexagrid system with 3 storeys in 1 module has a minimum base shear of 21788.16 kN.

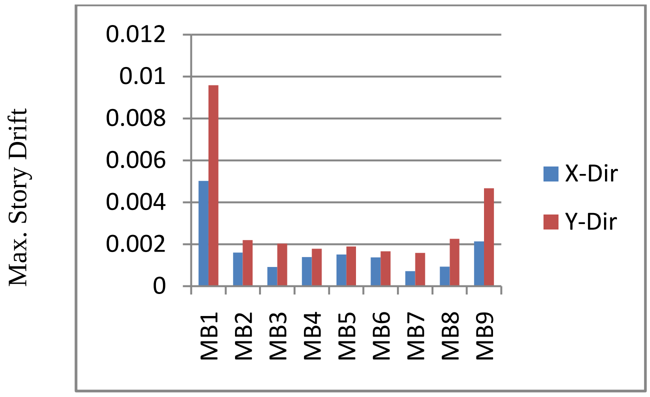

Figure 9 Comparison of Story Drift

From the figure it can be seen that In X- direction the story drift is maximum 0.00503 for bare frame model followed by 0.002142 for hexagrid system with 4 storeys in 1 module, while as the model with 2 outriggers one at H/3 and other at 2H/3 has minimum story drift of 0.000713 which shows a reduction of 85.822 % from bare frame and 66.71% from hexagrid system. Similar is the case for Y direction, with a bare frame having maximum and model with 2 outriggers one at H/3 and other at 2H/3 having minimum story drift.

From figure 10 it can be seen that the bare frame has a maximum time period of 7.27 seconds and the hexagrid system has a minimum time period of 2.905 seconds.

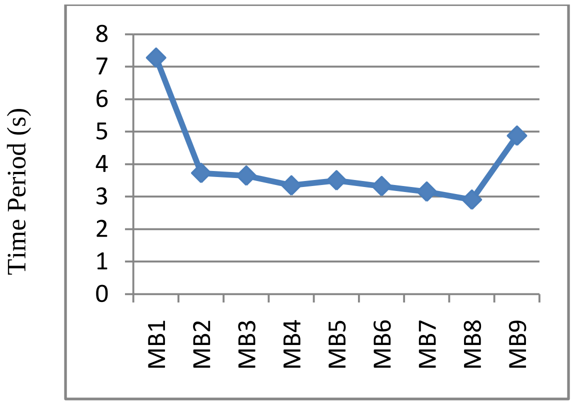

Figure 10 Comparison of Time Period

IV. CONCLUSIONS

In this paper, a comparison was made between the outrigger structural system and hexagrid structural system so as to determine their proficiency in terms of their performance. The conclusions are made as follows

1. The lateral displacement is minimum for the hexagrid system with 3 storeys in 1 module for both lateral loads with a maximum reduction of 75% for seismic load and 83.66% for wind load.
2. The story shear is minimum for the hexagrid system with 4 storeys in 1 module with a reduction of 49.32% under seismic load, while as it is minimum for a model with 2 outriggers one at H/3 and other at 2H/3 in 1 module with a maximum reduction of 46.26% under wind load.
3. The model with outrigger at H/4 from top shows minimum story drift

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under seismic load with a maximum reduction of 70.44% under seismic load, while as the model with 2 outriggers one at H/3 and other at 2H/3 shows minimum drift under wind load,

4. For seismic load, the model with 2 outriggers one at H/3 and other at 2H/3 has a minimum time period of 3.255 seconds and the bare frame has a maximum time period of 7.272 seconds while as for wind load hexagrid system with 3 storeys in 1 module has a minimum time period of 2.905 seconds.

5. The hexagrid system is most effective as it has minimum lateral displacement and it gives a better architectural appearance to the building. Though the outrigger system also performs well but it causes architectural disturbance and utmost down free space for the inhabitance.

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