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Effect of Outrigger Structural System on Highrise Structures, Subjected to Lateral Loads

Iqra Bano Ayaz Ahmad Khan[1], Prof. N. G. Gore[2]
[1]*(ME Student, Dept. of Civil Engineering, MGM's College of Engg. And Tech., University of Mumbai, India)*
[2]*(Dept. of Civil Engineering, MGM's College of Engg. And Tech., University of Mumbai, India)*

Abstract: *There are several factors which have made it compulsory for our nation and the world to go for highrise structures and the skyscrapers. One of such factors is rapidly increment in population in urban areas. But it is a big challenge to build a highrise structure as number of aspects to be considered in it are more as compared to lowrise structures such as lateral stability. To deal with the lateral (wind and earthquake) froces acting on a structure, several lateral force resisting systems have been introduced such as the Braced tube, Shear wall frames, Diagrid, Space truss and Outrigger structural system etc. In this paper, the most effective outrigger structural system i.e. conventional outrigger-belt truss is compared with Virtual outrigger System. Also, Concrete and steel are used to carry out the comparative performance of materials for outrigger. Virtual Outrigger while eliminating the disadvantages occurring by Convectional outrigger, has proved itself to be the most effective among all other types of outrigger system, in all aspects.*

Keywords: *Belt truss, Convectional, Virtual, Response Spectrum, Time History, Zone*

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I. Introduction

It's a big troublesome for engineers to satisfy the structure for deflection as well as strength criteria in highrise structures. Generally, to deal with such problems, initially, a core is provided at the center of the building. Since the structure cannot be and need not be taken to null deflection, IS Code provides the lateral deflection limits for wind and earthquake loads. As per Indian standard code 875-2015 part3, "Under transient wind load, the lateral sway at the top, should not exceed H/500, where H is the total height of the building". Also, "The storey drift in any storey due to the minimum design lateral force, with partial load factor of 1.0 shall not exceed 0.004 times the storey height".

Though, Conventional Outrigger is very effective, contains many problems regarding its design such as connection and space utilization. The whole floor becomes useless for work when this outrigger is provided. To deal with these problems, a new system was proposed that is called Virtual Outrigger structural system. In this system, only belt truss is provided with some modification as stated by [1, 2].

II. Literature Review

R. Shankar Nair [1] proposed the idea of belt truss and basement as a virtual outrigger which can serve the same purpose as that of conventional outrigger by increasing the stiffness of the belt truss. Even though it is not as stiff as conventional one but can provide the necessary deflection control with the advantages such as availability of more space due to the absence of outrigger beam, participation of all the columns located at the periphery, elimination of the difficult connection of outrigger beam with core and exterior columns.

As stated above, to overcome the problems related to conventional outrigger system, again a variation of this system i.e. offset and alternate offset outrigger (virtual outrigger) was studied by Andrew J. Horton [2]. And it was observed that some modifications in virtual outrigger system can lead to an equal performance as that of the conventional outrigger.

Suresh et al. [3] worked on the analysis of a model of a 44 storey Moment resisting RC frame building using software ETABS. In this study, they modelled the outrigger with different types of bracing such as X, V and inverted V type of bracings. It was observed from the analysis that the 29.21% of top storey displacement and 26.64% of maximum story drift was controlled by providing X-braced outriggers. Also, the model with steel outrigger was found to be less effective in controlling displacement as compared with concrete outriggers.

Abdul Karim Mullah et al. [4] modelled four 20-storey RC regular and irregular (vertically) buildings each with and without outrigger with a central rigid shear wall by using the software ETABS in different zones. The concrete outrigger and steel outrigger were compared in regular and irregular building models with outrigger placed at two places, one was at the top and another one was at the middle of the building. And it was seen that for equivalent static analysis the concrete outrigger showed 18% and 16% less displacement as compared with steel outrigger at the top and 0.5H respectively for irregular building model. Likewise, 6% less displacement was seen by concrete outrigger when compared with steel one for the case of response spectrum method. The base shear was found to reach 4926.34kN and 4527.28kN in regular and irregular building respectively after the implementation of outrigger from 4087.68kN without the outrigger.

III. Outrigger Structural System

Outriggers are deep and stiff beam/truss which connect the central core to the exterior most columns in a frame. This reduces the deflection of the building by keeping all the columns in their position and making the building act as a single unit. This reduces the horizontal movement of core and makes the structure stiffer.

Types of Outrigger System:

Outriggers and belt trusses together and separately are being employed in structures in different way and hence named differently. These are chosen on the basis of requirement of the structure. These can also be used in combination for a single structure. Some of the outriggers are shown below.

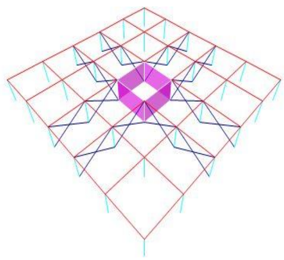

Fig. 1 Conventional Outrigger

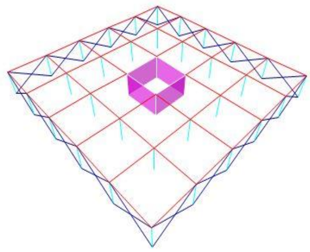

Fig. 2 Virtual Outrigger (Belt Truss)

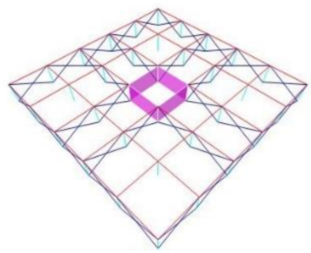

Fig. 3 Conventional Outrigger-Belt Truss

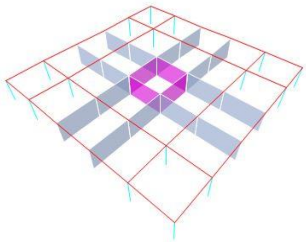

Fig. 4 Outrigger Wall

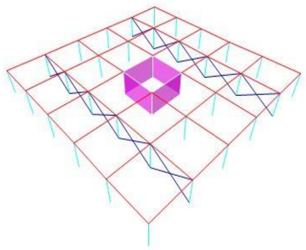

Fig. 5 Offset Outrigger

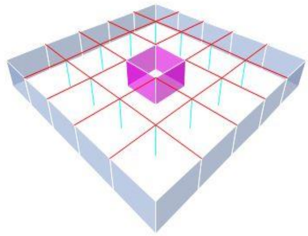

Fig. 6 Belt Wall

IV. Objectives of the Work

1. To study the behavior of tall RC structure subjected to lateral loads, in different zones (zone III, IV, V)
2. To analyze the structure with and without the lateral force resisting system
3. To compare steel and concrete outrigger system
4. To analyze the structure With Gust Factor Method
5. To analyze the structure by Response spectrum method and Time history analysis
6. To compare conventional outrigger-belt truss system to Virtual outrigger system
7. To examine the most effective yet economical system of outrigger
8. To compare the results of models in respect of;
    - Base shear
    - Base moment
    - Time Period
    - Storey displacement
    - Storey drift
9. To compare the results from time history analysis for time verses;
    - Base shear
    - Base moment
    - Displacement
    - Velocity
    - Acceleration

V. Concept of the Study

The most effective outrigger structural system is conventional outrigger with belt truss. But there exists number of problems regarding connection as well as space in conventional outrigger system. The whole floor becomes useless for work when this outrigger is provided. To deal with these problems, a modified system was proposed that is called Virtual Outrigger structural system. In this system, only belt truss is provided with some modification as stated by [1, 2]. In this thesis, 4 nos. of steel outrigger (Conventional outrigger) with belt truss is provided on corresponding floors. And in case of virtual outrigger, the modification done is increment in cross sectional area of the steel tube to two times of the member used in conventional outrigger and belt truss system. In addition to that, these outriggers are two storey deep. Because of the absence of the direct connection to core, the virtual outriggers are weaker in function. These two modifications have not proved themselves to be effective enough to compete with conventional outrigger with belt truss system in X-direction. Therefore, it is again modified with cross sectional area which is 2.5 times the conventional outrigger with belt truss' area. Now, it can give rise not only comparable but somewhere more acceptable results. The absence of trusses on the floors in this system has provided a quality space on the floor. Also, since the outriggers are two storey deep, there are not many problems regarding ventilation and hence these floors can be used exactly like other floors. No modification in floor diaphragm is required like [1, 2]. Also, one more model is prepared of steel outrigger with concrete belt truss to bring out the comparative performance of concrete and steel materials for outriggers. Since concrete required huge cross-sectional area as compared to steel to pass the strength criteria, steel is adopted for studying the virtual outrigger system. All outriggers and belt trusses are X-braced.

The performance of conventional steel outrigger with steel belt truss has been carried out for ISB 500X500X50mm (90000mm2). First modification is to double the cross-sectional area and hence provided the steel ISB 600X600X87.5mm (179375mm2). The latter modification was increasing the area to 2.5 times of the conventional outrigger system and hence provided the ISB 600X600X116mm (224576mm2). Varying cross sectional area is provided for the concrete belt truss as to pass the strength criteria from 500X500mm M60 to 800X1000mm M60. Since the area becomes so huge when it is doubled therefore concrete is avoided for the further study of virtual outrigger system. Also, it is concluded from the study that steel can give an equal performance even with the smaller section and, hence providing more space.

VI. Methodology

In this project, an 80-storey structure of a commercial building with 3.5m floor to floor height has been analysed by Finite Element Method using ETABS software in different zones (III, IV and V). The plan selected is square in shape. It is not the plan of any existing or proposed building but is an architectural plan. The structure has been analysed for both static and dynamic wind and earthquake forces. Four outriggers have been provided throughout height of the structure. Soil condition-I has been selected for the structure.
Methods of analysis of the Structure:

- Wind analysis
- IS Code method
- Wind gust method
- Seismic analysis
- Equivalent static analysis
- Response spectrum method
- Time history method

Geometrical Details:
Type of the Building / Floor dimensions: Commercial / 55mmX55mm
Height of the building / Floor to Floor height: 280m / 3.5m
No. of Storeys: 80
Depth of slab: 160mm
Size of Beam: Varying cross section from 230X600 to 900X1100mm
Size of Column: 1000X1000mm and 1100X1100mm
Size of Core wall: Varying thickness from 800mm to 1000mm for different walls (a wall of 1200mm in Zone V)
Size of Steel Outrigger and Steel Belt Truss: ISB 500X500X50mm
Size Virtual Outrigger: ISB 600X600X87.5mm/ISB 600X600X116mm
Size Concrete Outrigger: Varying cross section from 500X500mm to 850X1000mm

Grade of the Materials:
Concrete grade for Beams/Slabs: M40
Concrete grade for Columns: M40/M50/M60/M70 for Columns from storey 61-80/41-60/21-40/1-20
Grade of Rebar: 415N/mm^2 and 500N/mm^2

Grade of Structural steel: Fe 345
Density of infill walls: 22kN/m^3

Gravity loads on structure:
Live load on floor/terrace: 4kN/m^2, 1.5 kN/m^2
Floor finish/terrace: 2kN/m^2, 3kN/m^2
Wall load on external beams/parapet load on terrace: 14.16 kN/m^2, 6.072 kN/m^2
Lift Machine load: 10kN/m^2

Data for analyses:
Seismic zone/Seismic zone factor: III-0.16, IV-0.24, V-0.36
Response Reduction Factor/Importance factor: 5, 1
Soil type: I (Hard Rock)
Terrain category/ Wind speed: IV, 50m/s (for all zones)
Modal load case type: Ritz
Time history data: El-Centro (Imperial Velley-02, magnitude 6.95) for all zones
Mass source: 1DL+0.5LL (excluding terrace live load, including NRLL of Lift machine with load factor 1)
P-Delta combination: 1.2DL+0.6LL
IS Codes: 875 (part I), 875 (part II), 875 (part III)-2015, 1893 (part I)-2016

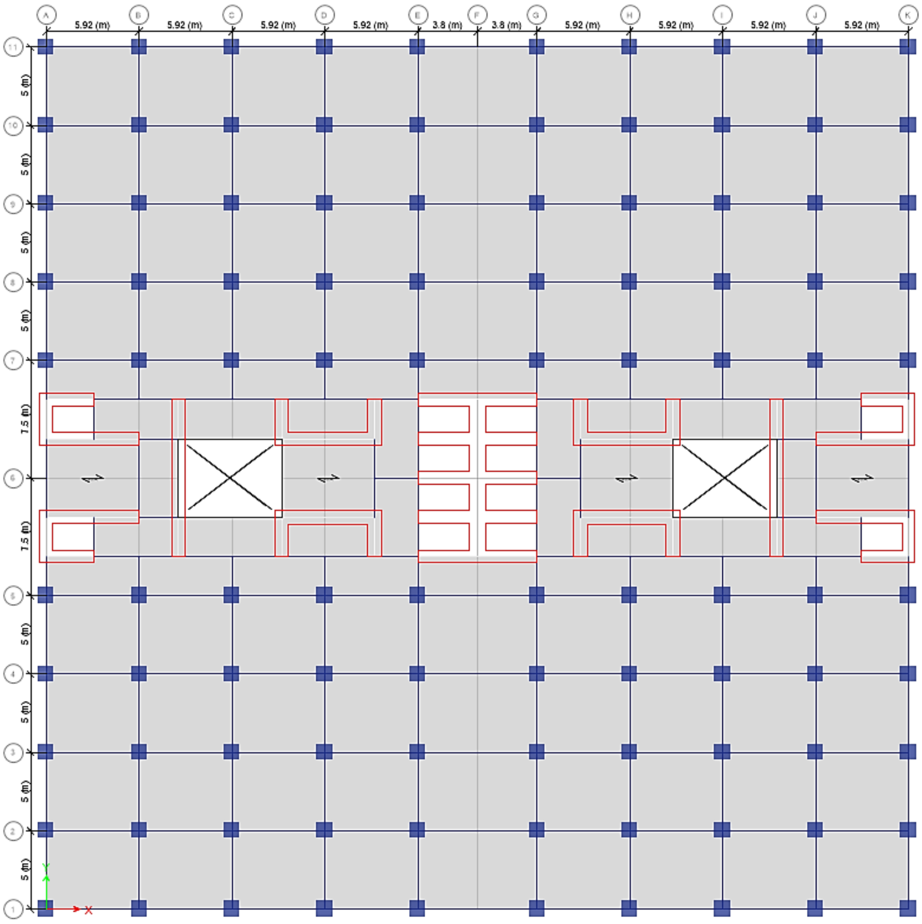

Fig. 7 Plan of the Structure

Locations of Outrigger system:
According to Bryan Stafford Smith, for Optimum performance of an n-Outrigger Structure, the Outriggers are placed at 1/ (n+1), 2/ (n+1) up to the n/ (n+1) height locations [5].
Therefore, positions of various Outriggers for all the models are as follows:

- 1st Outrigger = 1/ (4+1) = 0.2H- at 16th floor
- 2nd Outrigger = 2/ (4+1) = 0.4H- at 32nd floor
- 3rd Outrigger = 3/ (4+1) = 0.6H- at 48th floor
- 4th Outrigger = 4/ (4+1) = 0.8H- at 64th floor

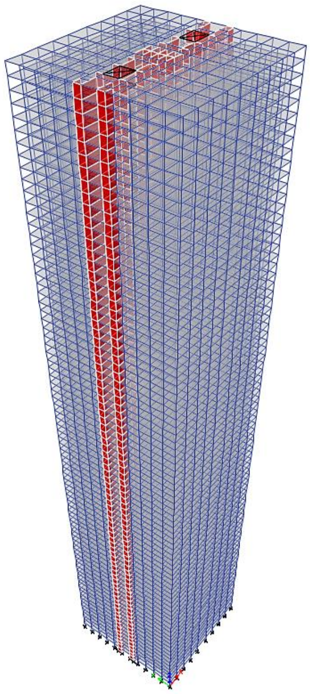
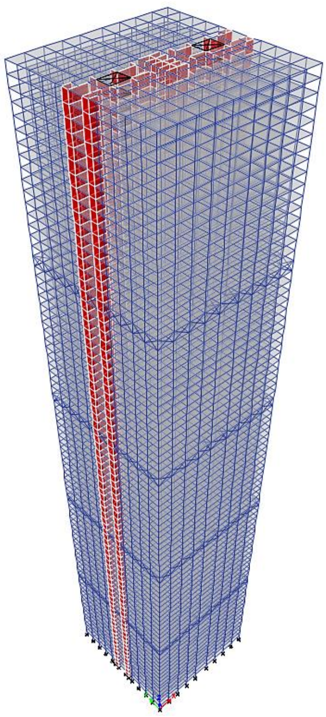
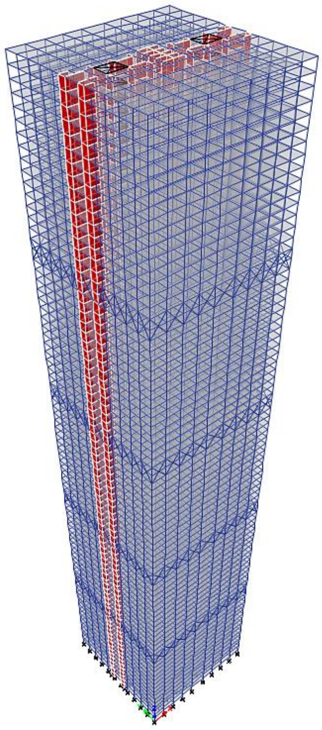

Fig. 8 Model without Outrigger   Fig. 9 Model with Conv. Out. With BT   Fig. 10 Model with Virtual Outrigger

List of models:

The numbers 3, 4 and 5 before the model names indicate the respective zone.

1. 3-Without Outrigger: Without Outrigger in Zone III
2. 3-SO+Steel BT: With Steel Outrigger - Steel Belt Truss in Zone III
3. 3-SO+Concrete BT: With Steel Outrigger - Concrete Belt Truss in Zone III
4. 3-Virtual Outrigger-t87.5: With two storey deep Virtual Outrigger of section thickness 87.5mm in Zone III
5. 3-Virtual Outrigger-t116: With two storey deep Virtual Outrigger of section thickness 116mm in Zone III
6. 4-Without Outrigger: Without Outrigger in Zone IV
7. 4-SO+Steel BT: With Steel Outrigger - Steel Belt Truss in Zone IV
8. 4-SO+Concrete BT: With Steel Outrigger - Concrete Belt Truss in Zone IV
9. 4-Virtual Outrigger-t87.5: With two storey deep Virtual Outrigger of section thickness 87.5mm in Zone IV
10. 4-Virtual Outrigger-t116: With two storey deep virtual Outrigger of section thickness 116mm in Zone IV
11. 5-Without Outrigger: Without Outrigger in Zone V
12. 5-SO+Steel BT: With Steel Outrigger - Steel Belt Truss in Zone V
13. 5-SO+Concrete BT: With Steel Outrigger - Concrete Belt Truss in Zone V
14. 5-Virtual Outrigger-t87.5-: With two storey deep Virtual Outrigger of section thickness 87.5mm in Zone V
15. 5-Virtual Outrigger-t116: With two storey deep Virtual Outrigger of section thickness 116mm in Zone V

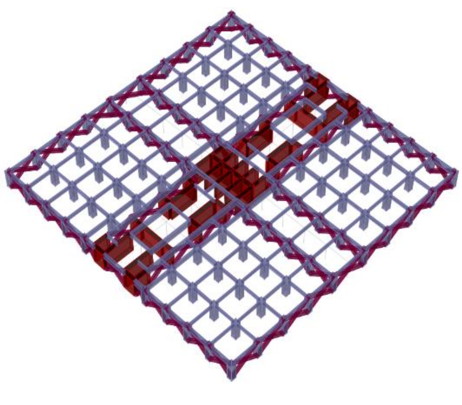

Fig. 11 Conventional Outrigger with Belt Truss

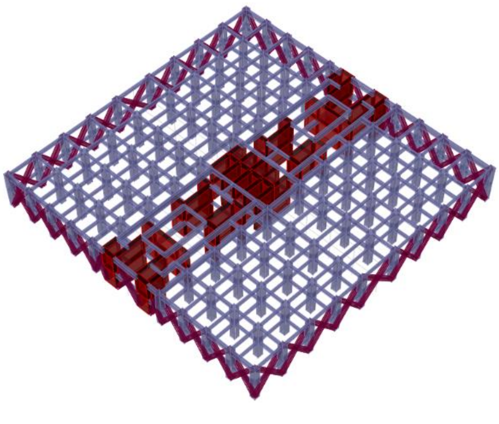

Fig. 12 Virtual Outrigger

VII. Results

The results obtained from all the analyses are displayed below. Variation in time period is shown for all zones. All other results are shown for zone V, since similar results are obtained for other zones also.

Time Period:

Table 1 % Reduction in Time Period

Models	Time Period (Sec)	% Reduction in Time Period
3-Without Outrigger	15.571	----
3-SO+Steel (Concrete) BT	9.815	37%
3-Virtual Outrigger-t87.5(t116)	8.698	44%
4-Without Outrigger	15.568	----
4-SO+Steel (Concrete) BT	9.702	38%
4-Virtual Outrigger-t87.5(t116)	8.698	44%
5-Without Outrigger	15.727	----
5-SO+Steel BT	9.53	39%
5-SO+Concrete BT	9.701	38%
5-Virtual Outrigger-t87.5(t116)	8.524	46%

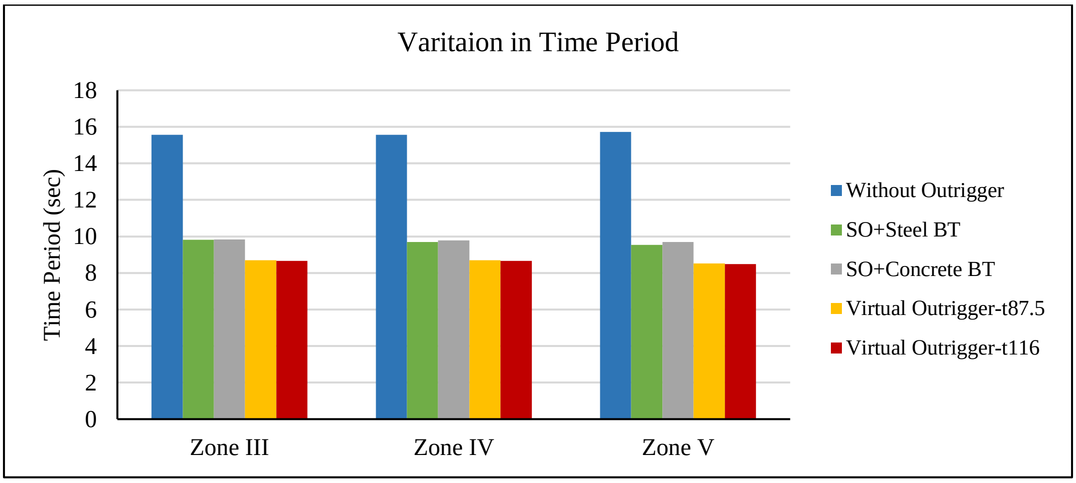

Chart 1 Time Period

Base Shear and Base Moment in X and Y-direction:

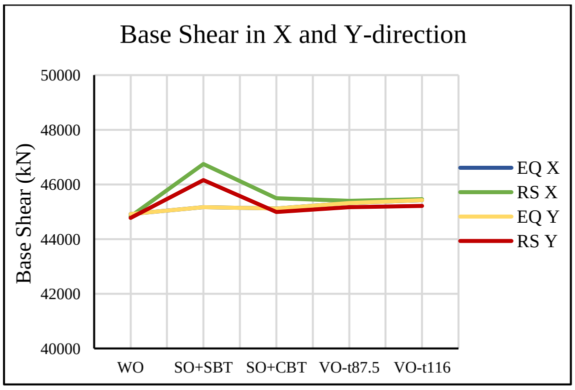

Chart 2 Base Shear

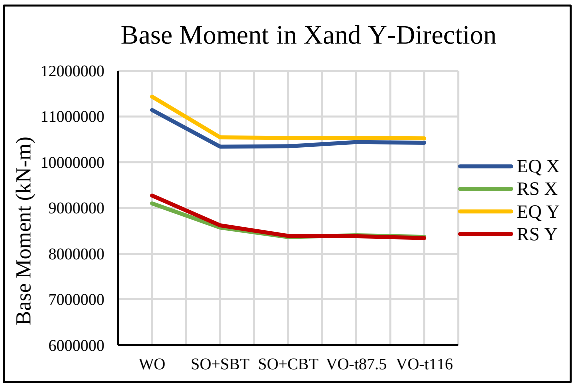

Chart 3 Base Moment

Storey Displacement:

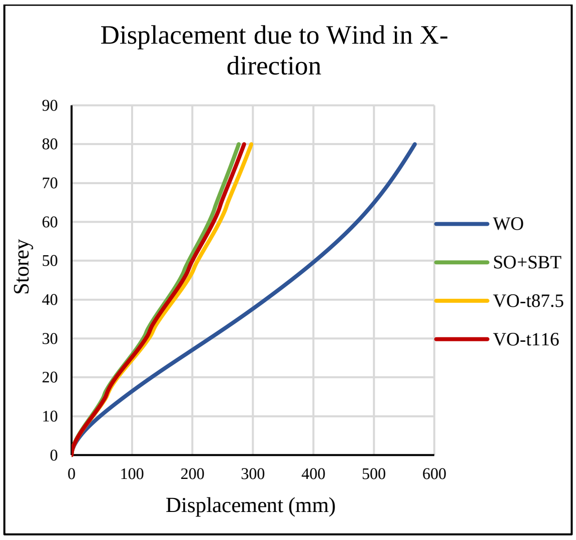

Chart 4 Displacement Due to Wind in X-direction

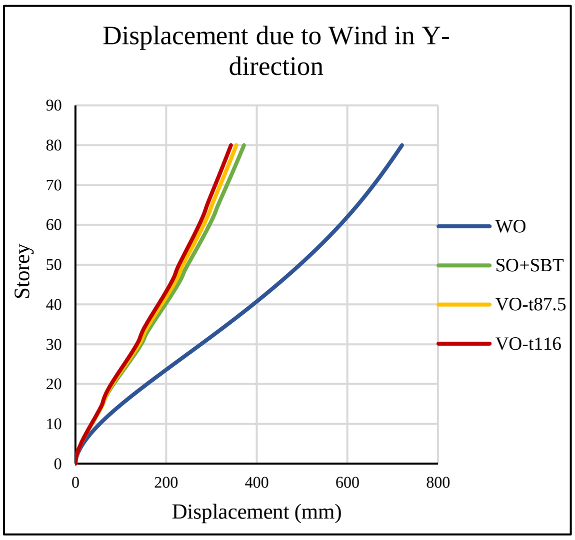

Chart 5 Displacement due to Wind in Y-direction

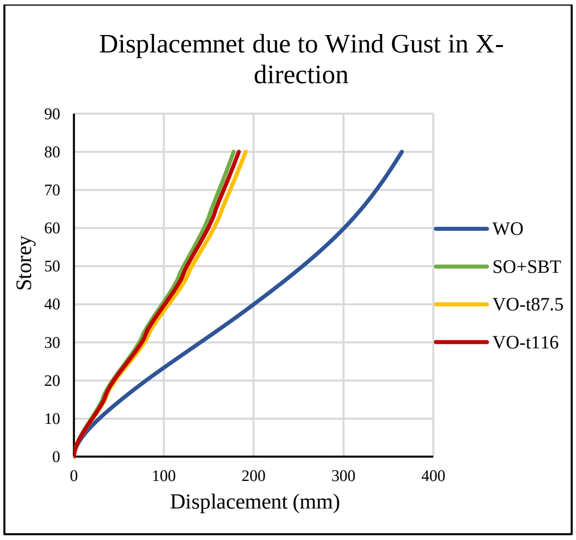

Chart 6 Displacement due to W-Gust in X-Direction

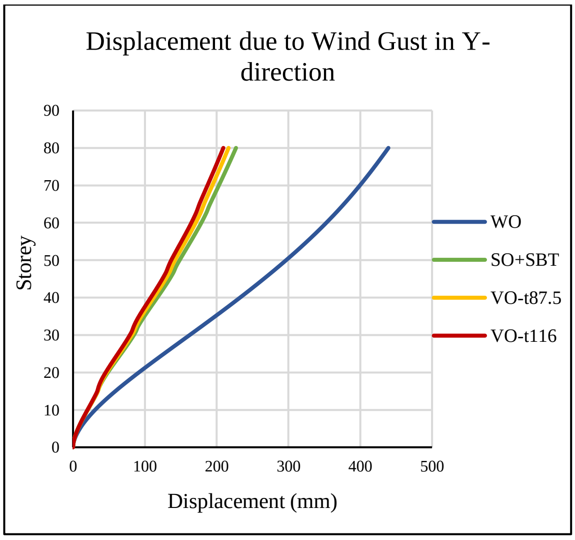

Chart 7 Displacement due to W-Gust in Y-direction

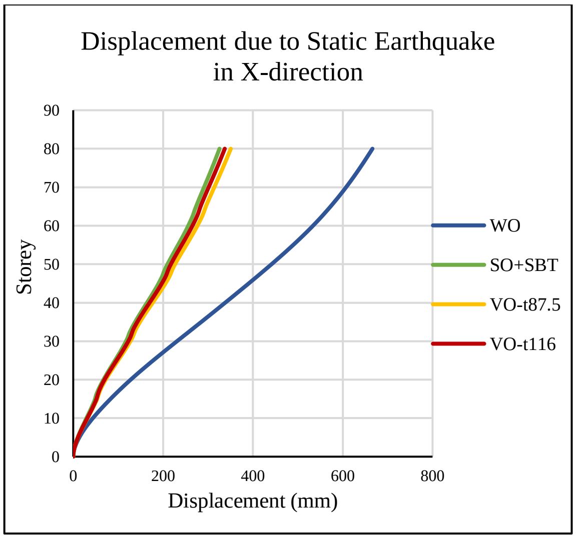

Chart 7 Displacement due to EQ in X-direction

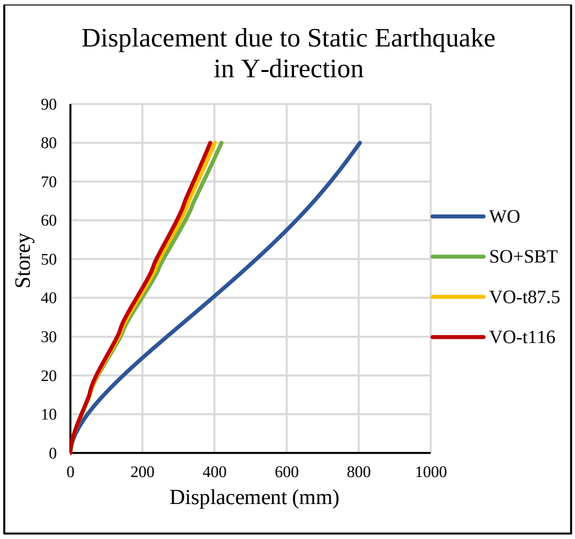

Chart 8 Displacement due to EQ in Y-direction

Storey Drift:

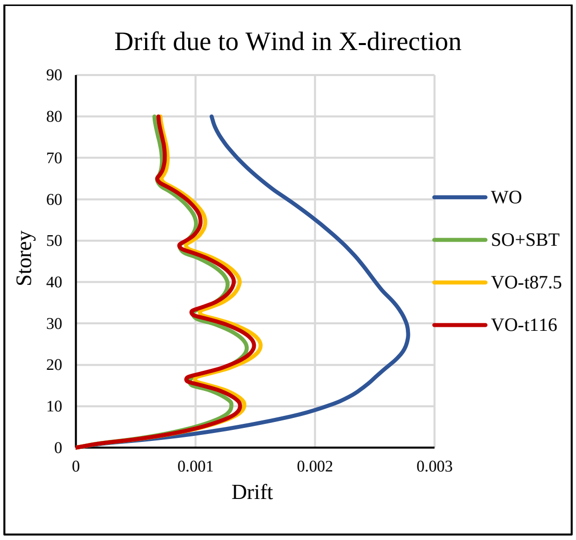

Chart 9 Drift Due to Wind in X-direction

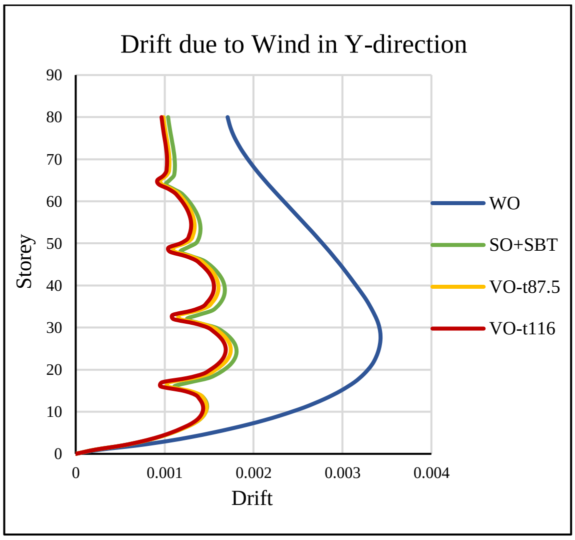

Chart 10 Drift due to Wind in Y-direction

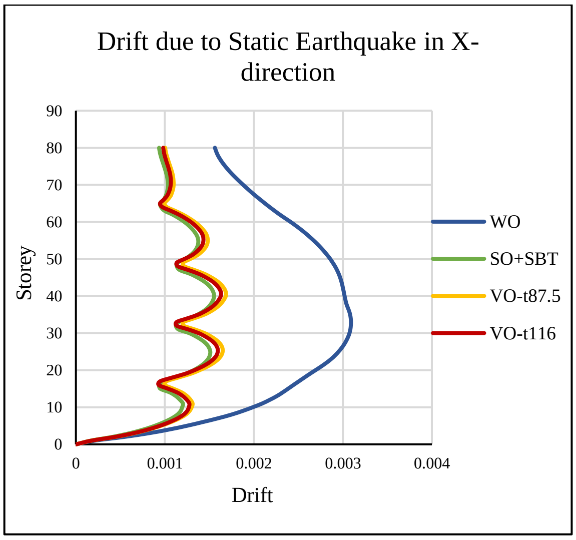

Chart 11 Drift Due to Wind Gust in X-direction

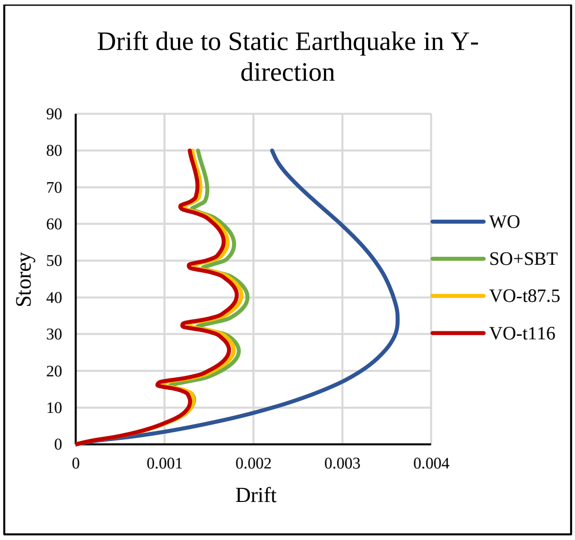

Chart 12 Drift due to Wind Gust in Y-direction

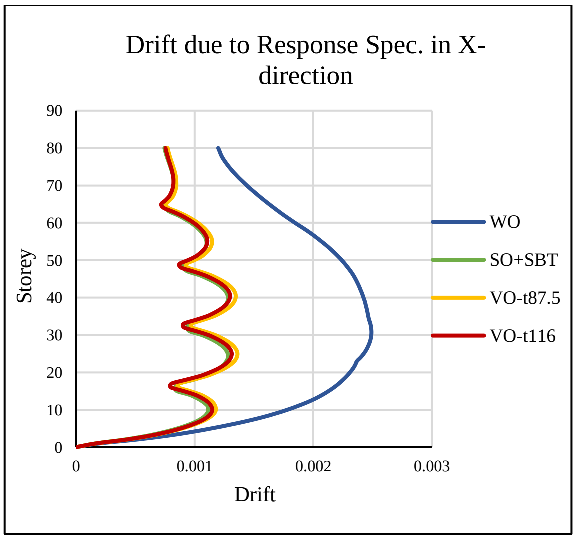

Chart 13 Drift Due to EQ in X-direction

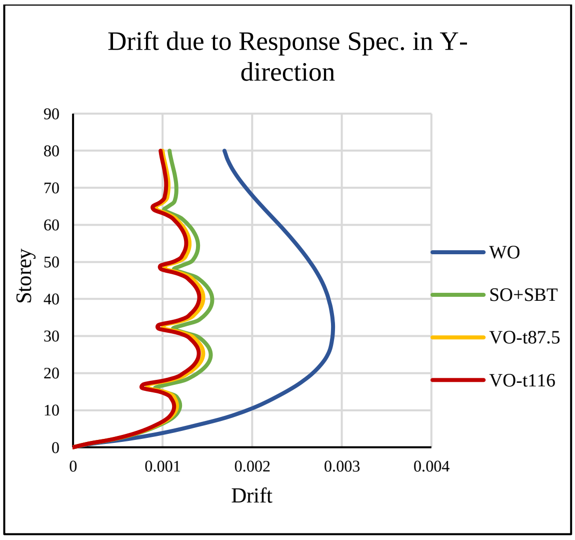

Chart 14 Drift due to EQ in Y-direction

Time History Graphs:

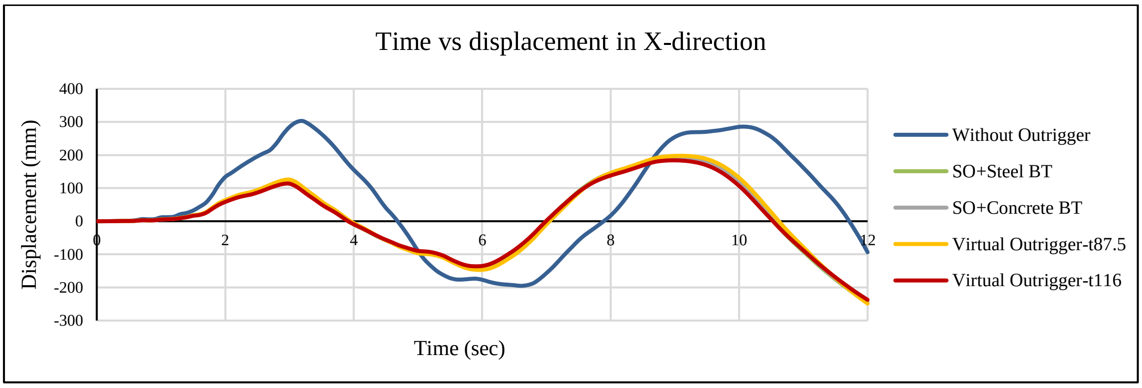

Chart 15 Time vs Displacement in X-direction in Zone V

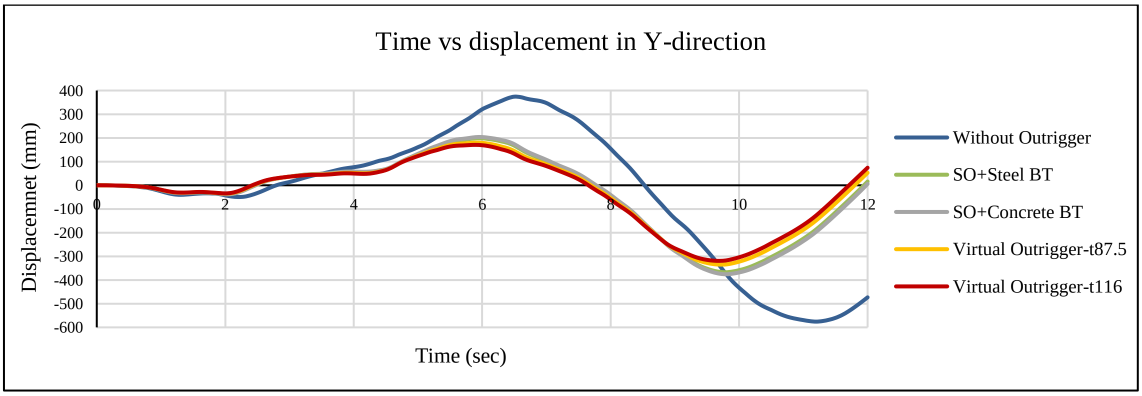

Chart 16 Time vs Displacement in Y-direction in Zone V

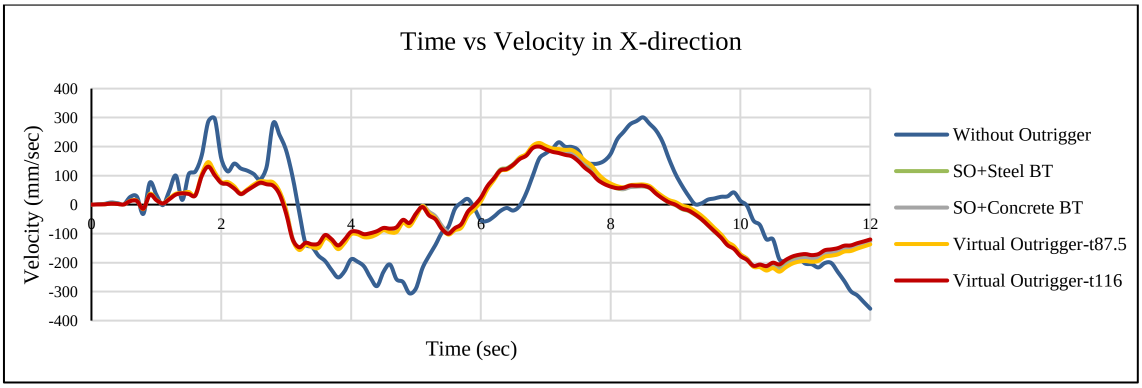

Chart 17 Time vs Velocity in X-direction in Zone V

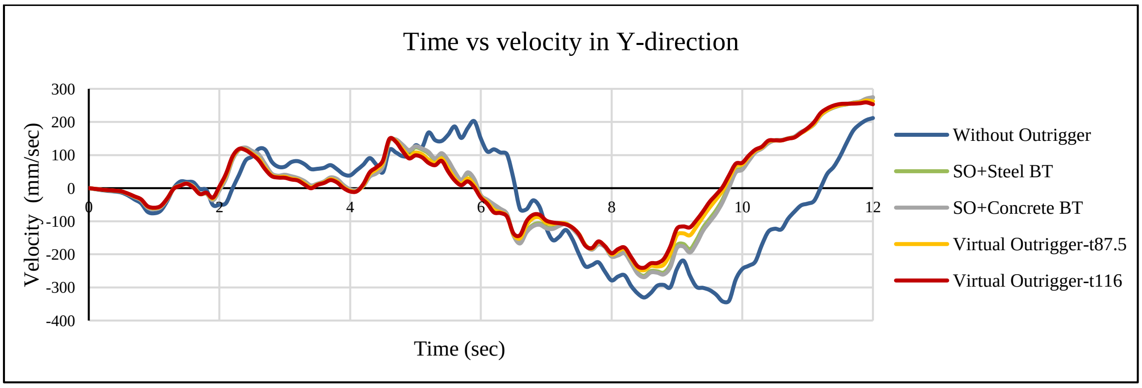

Chart 18 Time vs Velocity in Y-direction in Zone V

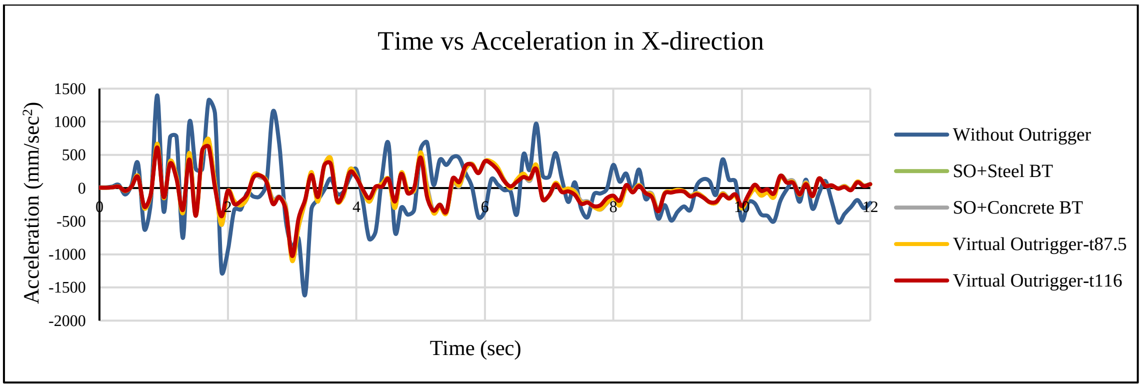

Chart 19 Time vs Acceleration in X-direction in Zone V

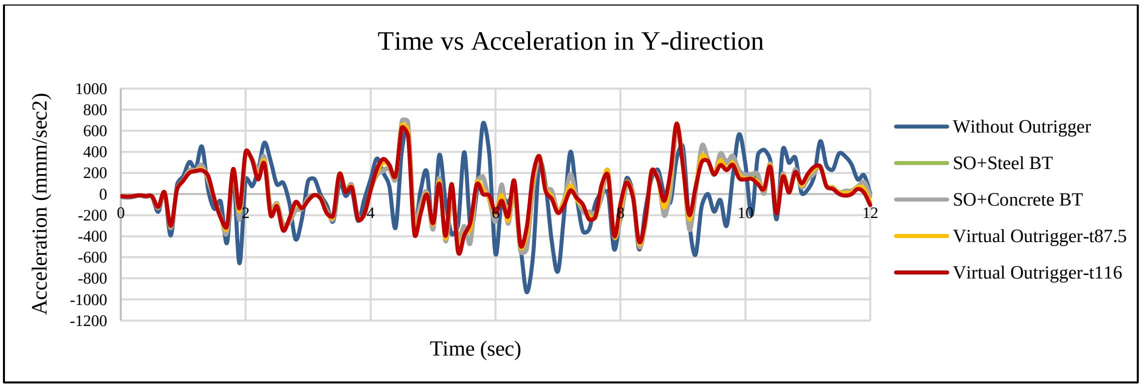

Chart 20 Time vs Displacement in Y-direction in Zone V

VIII. Discussions

In this project, different types of outrigger structural system in respect of material and design have been studied in detail. It is the secondary aim of the project to convey the fruitfulness of outrigger structural system. The foremost aims of the project are to estimate the performance of steel and concrete outrigger and to compare the performance of conventional and virtual outrigger. To get the precise idea of the work, four outriggers are introduced in the structure in the manner mentioned above. From all the literatures and results of present study, it is noticed that conventional outrigger in combination with belt truss structural system is the most effective type of outrigger system. But when it comes to consumption of floor space for the system, conventional outrigger system has an immense disadvantage. In this case, virtual outrigger system has proved itself to be one of the best alternatives.

Since the belt truss alone is not enough to provide the equal stiffness to the structure as that of conventional with belt truss. It is stated from the results that the modified Virtual outrigger-t116 can provide the desired results and somewhere even much better results. Model SO+SBT and SO+CBT show exactly the same results, but concrete members need higher cross-sectional area. Base shear is maximum in case of virtual outrigger-t116 and hence it is proved to be the best models for resisting earthquake forces. Base moment is decreasing after applying outrigger system. Maximum time period of 15.57 sec is noted in model 3-Without Outrigger which reduced to 9.8 sec for 3-SO+Steel/Concrete BT and 8.6 sec for 3-Virtual Outrigger-t116 i.e. 37% and 44% reductions in time period are observed. Since the earthquake force is the most dominating force in Zone V, deflection caused due to earthquake load is maximum in this zone. 666 mm and 803.50 mm deflection are seen in X and Y-direction respectively due to seismic loads which reduced to 377 mm and 388.19 mm respectively.

More deflection is seen in Y-direction because all the shear walls are directed along X- axis, reducing the deflection in the same direction. Maximum deflection observed in X-direction and Y-direction due to wind force are 602.37 mm and 726.99 mm without outrigger which drops down to 288.4 mm and 355.53 mm respectively after addition of virtual outrigger-t116 to the structure hence reducing the deflection to 50%. Up to 60% reduction in drift is achieved in both X and Y-direction and utmost reduction in drift is observed at outrigger levels. Maximum reduction in drift is seen when outriggers are put. Though, conventional with belt truss and virtual system provide approximately same results, the results of Time history show better performance for virtual system for all zones, the reduction in displacement, velocity and acceleration of the structure during earthquake reduced to minimum in model with Virtual Outrigger-t116 in all zones.

IX. Conclusions and Future Scopes of the Study

Other than Equivalent wind and Equivalent seismic analyses, all the models are analyzed with and without the outrigger system in their respective zones for various method such Wind Gust method, Response spectrum method and Time History method. Few conclusions are made on the basis of all the results obtained from the analyses which are listed below.

1. Outrigger structural system provides stiffness to the structure hence making it one of the most effective systems against seismic as well as wind forces.
2. Orientation of the shear wall affects the deflection and therefore deflection in Y-direction is more as compared with X-direction which is having more shear walls along it.
3. Out of all load cases, wind is the governing force in all zones being to have maximum base shear as well as creating maximum deflection.
4. Steel outrigger should be preferred over concrete outrigger since concrete outrigger required more cross section to pass the design check while providing the same deflection.
5. Virtual outrigger is one of the best alternatives to deal with the problems associated with conventional outrigger system.
6. Deflection and time period are seen to be higher in zone III. After applying outrigger system, up to 50% reduction is seen in both X and Y-direction.
7. More reduction in drift is observed on the levels of outrigger. % reduction observed in average is up to 50%.
8. Displacement, velocity and acceleration of the structure are reduced after applying outriggers. It is clear from the time history graphs that maximum reduction in all these values are occurring by the model Virtual outrigger-t116 in all zones.
9. Virtual outrigger-t116 provides best performance, better ventilation besides not disturbing the plan and floor space of the structure.

Future Scope of the Study:

1. The usage of outrigger system on structures with irregular plan or buildings with vertical irregularity should be studied.
2. There’s deficiency of work on an actual architectural plan.
3. Only some of the researchers have analyzed the model by non-linear method such as time history method in zone V.
4. Building models with height up to 100 floors can be made to study.
5. The modification in conventional outrigger system i.e. Virtual and Damped outrigger system can be implemented.
6. The effect of concrete outrigger and belt walls can be studied in different zones and on different soil.
7. Optimum locations of outrigger beams could be found for more than 3 outriggers or more than 3 belt trusses.
8. Necessity and effects of double and triple storey deep outrigger can be studied and compared with the two and three number of outriggers on a structure.
9. There’re only a few researchers who worked on a single model with different types of outrigger system. The study can be done to have optimum usage of the outrigger.

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