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ANALYSIS OF STRUCTURE TO LOCATE THE OPTIMUM POSITION OF OUTRIGGER AND BELT TRUSS SYSTEM IN TALL BUILDINGS

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Abstract— Tall Building has always been a vision of dreams and technical advancement leading to the progress of the world. Presently, with the rapidly increasing urbanization, tall building has become a more convenient option for office and residential housing. Thus the burgeoning growth of tall buildings around the world requires novel design methodologies to resolve design challenges. The different lateral load resisting systems are used in high-rise building as there is effect of wind and earthquake forces. Structural system development has evolved continuously to overcome the problems related to lateral stability and sway. Thus to increase stiffness of building against lateral load and to minimize the risk of structural and non-structural damage structural system such as outrigger and belt truss structural system is used. In this study, the position of outriggers and belt truss varies from first storey to top storey in high rise RC buildings of particular storey height. This paper presents the various techniques and methods used to investigate the optimum location of outrigger system and belt truss in a tall building. The analysis of the structure is carried out and various parameters like storey drift, top storey displacement and natural time period are studied.

Keywords—outrigger, belt truss, shear wall, structural systems, wind, earthquake, lateral displacement, storey drift, base shear, time period, optimum position

I. INTRODUCTION

A. *General*

In today's world high rise building is a vision of dreams and technical advancement which leads to the progress of the mankind. Now a day, there is rapid growth in urbanization as people from small towns migrate towards big cities in search of work. That is the reason tall buildings have become more convenient option for office and residential housing. High rise buildings are the optimum solution for this increase in population as there are several problems like limitation of land, increase in land prices, industrialization. There are many reasons for increase in demand of high-rise buildings such as

- Due to industrialization there in increase in demand for residential buildings.
- For purpose of offices, work spaces in developing cities to increase the aesthetic view and economy of the city.

B. *Structural Systems*

As in present world there is necessity of high-rise building, there are various advancements in structural designs and structural systems so as to prevent the structural as well as non-structural damage of the building. Due to these advancements there is reduction in weight of the building which in turn increases the slenderness of the building. As the slenderness and flexibility of the building increases, the buildings are more prone to be damaged by lateral loads resulting from wind and earthquake. To make it capable of resisting the lateral loads such as earthquake and wind, it becomes more prominent to use the proper structural system depending upon the height of the building. There are many structural systems that can be used for the lateral resistance of tall buildings.

Structural systems for tall buildings

- Rigid frame systems
- Braced frame systems
- Shear-walled frame systems
- Braced frame and shear-walled frame systems
- Outrigger and belt truss system
- Framed-tube systems
- Bundled-tube systems

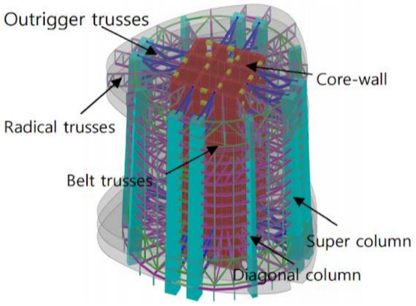


Figure 1: Outrigger, core wall and mega frame system [18]

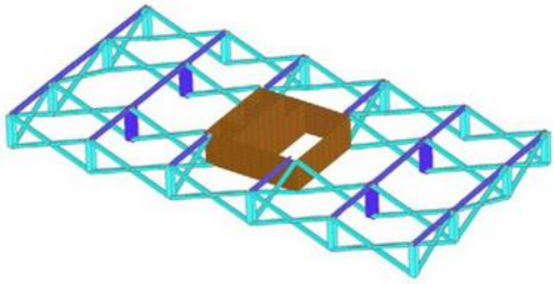


Figure 2: 3-D view of outrigger and belt truss

- **OUTRIGGER AND BELT TRUSS SYSTEM**

Outrigger and belt truss system is used in tall buildings constructed since the last 50 decades, which came into existence after the tubular frame systems which were previously preferred. The outrigger and belt truss system became more popular as they comprise the unique combination of architecture flexibility and structural efficiency as compared to old tabular frame systems in which the columns were placed close and consisted of deep spandrel girders.

Outrigger and belt truss system is a system which resists the lateral loads on building like wind and earthquake. In this system the exterior columns of the building are connected to the central core or shear wall by using very stiff outriggers. The belt truss is connected to the peripheral columns of the building and outrigger engages them to the central core of the building. By using outrigger together with belt truss system creates the unique design which solves many construction problems. Thus to increase stiffness of building against lateral load like wind and earthquake and to minimize the risk of structural and non-structural damage structural system such as outrigger and belt truss structural system is used.

C. Concept of Outrigger and Belt truss

From the past to the present the sailing ship industry has been adequately using outriggers so as to resist wind. The comparison of building and ship was made such that the core is considered as mast of the ship and the horizontal outriggers as spreaders of the ship and the stays of the ship as the exterior columns of the building. Thus from this arrangement of the ship the concept of using outriggers and belt truss in high rise building so as to resist the wind came into existence.

D. Behavior of Outrigger and Belt truss

The basic structural arrangement for this system consists of a concrete core wall which is connected to the exterior columns by means of outriggers. The core is located at the centre or at one side of the building. As the outriggers are connected to the central core and the exterior columns the outriggers induce the tension compression couple in outer columns when the core tries to tilt its rotation. Due to this the restoring moment acts on the core resisting the tilting of the structure as the core is vertical member. Thus, it is also important to mobilize the external columns so as to restrict the rotation of outriggers. This is done by providing the belt truss around the periphery connecting the exterior columns

Figure 3: Concept of Outrigger Structural system

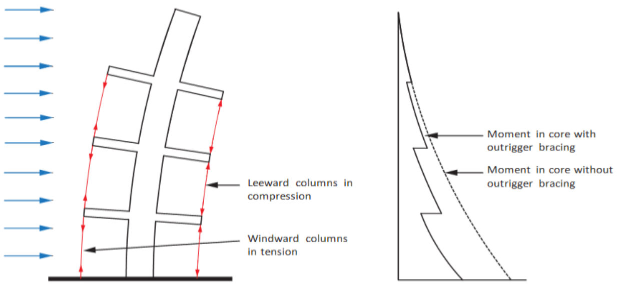


Figure 4: Behaviour of Outrigger Structural systems [2]

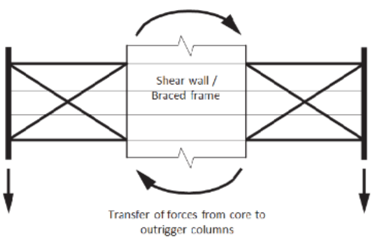


Figure 5: Behaviour of Outrigger Structural systems [2]

II. LITERATURE REVIEW

Outrigger system performance depends on outrigger locations through the height of a building, the number of levels of outriggers provided, their plan, presence of belt trusses to engage columns, outrigger truss depths, and the primary structural materials used [1]. The study of behaviour of tall building having multi-outrigger structural system was carried and structural system was analyzed under the action of dynamic loading changing the depth of outrigger beam and belt truss from one storey to two storeys and other by placing the outrigger system at different position along the height of building [2].In order to determine the optimum location of outrigger to minimize the drift due to wind load in high rise concrete building a 60 storey R.C building was developed using ETABS software. From the work the authors concluded that the results of analysis show the optimum location to construct the outrigger is one third of the height of the building [3]. When outrigger was placed by varying outrigger depth, to optimize the outrigger depth and to find the behaviour of outrigger for earthquake load and wind load model of 50 storey building was considered. The percentage reduction in lateral displacement and storey drift up-to 3% – 4% and 5% - 6% is observed in model of 50 storey building when depth of outrigger is reduced to 2/3rd, 1/3rd and 1/2 of the storey height respectively compared with outrigger of full storey height. On application of wind load the storey displacement of the building with outrigger of full storey height is reduced to 18.79% that of building without outrigger and also reduces the inter storey drifts [4]. A 60 storey RC building with three cases such as Case 1: RC bare frame having shear wall without outrigger in zone IV and V, Case 2: RC bare frame having shear wall with outrigger and belt truss at multiple stories, Case 3: RC bare frame having shear wall with only outrigger were studied and analyzed. It was found that the natural time period, storey drift and displacement of building reduces when outrigger with belt truss is placed at, 15, 15-30, 15-30-45 storey of the building [5]. The study of seismic behaviour of outrigger braced buildings was carried out to find out the optimum location of outrigger in high rise 2-D steel buildings. From the results it was concluded that after the placement of outrigger at the top storey the base shear significantly increases with decrease in roof displacement. After addition of outrigger at 0.3H to 0.6H height of building, the stiffness increases. Hence optimum location of the outrigger is 0.3H to 0.6H. Provision of multi-outrigger is very effective with one outrigger at the top and another at the suggested height of buildings [6]. The optimum location of the outrigger is 0.44-0.48 times the height of the building taken from the bottom was observed when the responses of the building for earthquake load were determined by response spectrum considering parameters such as lateral displacement and inter storey drift [7]. Several models were developed considering 40 storey and 60 storey height of building. From the analysis and results it was found that by providing first outrigger at the top and second outrigger at the middle of the structure height in the 2D 40‒storey model, 65% maximum displacement reduction can be achieved. For the 3D 60‒storey structural model subjected to the earthquake load the reduction in maximum displacement when the outrigger truss was placed at the top and the 33rd level was achieved about 18 % [8]. To examine the most common structural system that are used for RC tall buildings such as ‘Rigid Frame’, ‘Shear Wall/Central Core’, ‘Wall Frame Interaction’, and ‘Outrigger’ a study was carried out. The efficiency is measured by Time Period, Storey Displacement, Drift Lateral displacement and Base Shear. It was observed that as the height of the building increases the time period also increased by 45% to 50%. Hence ‘Outrigger structural system’ should be used above 40 storeys as compared to other structural systems [9]. Further a study was conducted in which steel and concrete outrigger systems were compared and Wind analysis was carried out. Based on this study it was observed that steel outriggers were found to be efficient in reduction of displacement as compared to concrete outriggers and also storey drift and base shear of steel outriggers were found to be less that of concrete outriggers [10]. The different types bracings like X type, V type and eccen forward type can be used as outriggers in tall building and optimum position of the outriggers can be located [11]. X type, V type and inverted V type belt truss can be used to tie the exterior columns and can effectively reduce the seismic effect. The usage of belt truss increases the structural stiffness of the building hence reduction in base shear under static and dynamic load. By providing shear core at the centre of the building the % displacement and storey drift is also reduced. Use of concrete belt truss is more effective in reducing the lateral displacement and storey drift for concrete building rather than using steel belt truss which gave negligible results [12]. Introducing outrigger structural systems in tall buildings the stiffness of structure is increased which makes the structure efficient under lateral loads. It is also observed that in building having L shape plan the lateral displacement is reduced by 19.41% in Y direction and hence L shaped structure is suitable for seismic Zone 3 [13]. When the building is in irregular configuration torsion irregularity become an important factor and when seismic analysis is considered some of the major factors like lateral displacement, storey drift, and stability of columns in particular storey due to lateral forces come into picture. When compared to other general structures the tube structure and ‘L’ shape shear wall is more stable and does not have torsion irregularity and also the displacement is less. Outrigger acts as high drift controller when it is provided at storey which has maximum drift. Drift can also be controlled by providing outrigger at optimum location of the building [14]. The seismic performance of the building with outrigger belt truss frame work is inferior to that of the building with dampers as energy dissipation system. Also, the inter-storey drift of the building with outrigger belt truss framework is less uniform than the building with dampers as energy dissipation system [15]. To minimize structural response of the buildings to wind loads, by identifying limited number of outrigger structural systems can also be done by using topology optimization. The design procedure repetitively analyzes the structural system performance and searches for the optimal outrigger location using topology optimization [16].

III. OBJECTIVE AND MODEL DESCRIPTION

A. *Objective*

1. To model the building with Outrigger and Belt Truss System at different levels in ETABS software and to perform linear dynamic analysis.
2. To find the optimum location of Outrigger and Belt Truss System in the building.
3. To examine the lateral displacement for the models considered and to compare the minimum displacement values of all the models.

4. To observe the storey drift for all the models and to observe the storey in which the minimum drift occurs.
5. To observe the Natural time period for all the models.

B. Modelling

Modelling of example concrete buildings illustrates with structural configuration of outrigger and belt truss braced buildings at different locations and the loadings considerations.

Following material are used for all structural members.

- Fe500 for all reinforcement.
- M40 for Column and M30 for Beam, Slab and Shear wall.
- Fe325 for all steel Outrigger and Belt truss members.

All properties taken as per IS456:2000 and Indian standard steel table

TABLE I: Properties of Structure

Plan Dimensions	40m X 40m	Size of long column	300mm x1500mm
Storey height	3m	Size of beam	380mm x 600mm
Number of storeys	G+60	OBT section	ISWB 450
Total height of building	183m	Shear wall thickness	400mm
Size of column	600mm x 600mm	Slab thickness	150mm

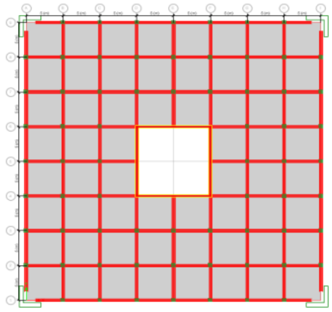
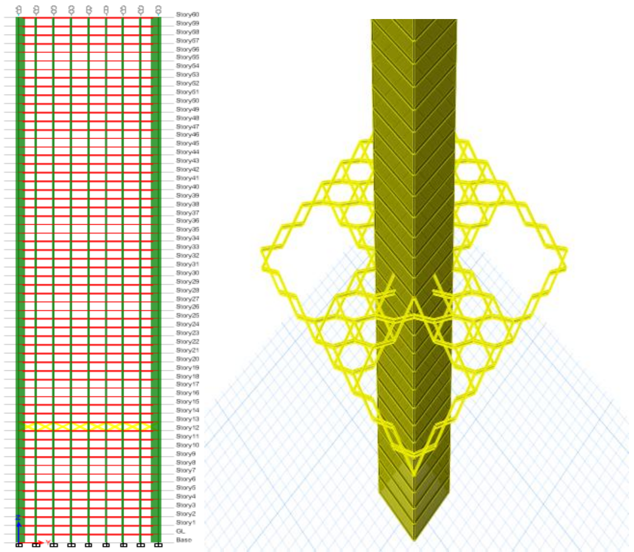


Figure 8: Floor Plan of arrangement of beam and column



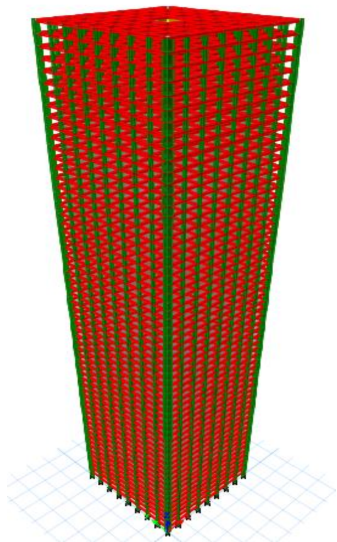


Figure 9: Model with OBT *Figure 10: Model without OBT*

TABLE II: Models considered for analysis

Models	**Structure with shear wall with Outrigger and Belt truss system**
Type I	**For Single Outrigger system**
Model 1 (OBT@0.2H)	Outrigger with Belt truss at 0.2 H position from ground level (**12^{th} storey**)
Model 2 (OBT@0.4H)	Outrigger with Belt truss at 0.4 H position from ground level (**24^{th} storey**)
Model 3 (OBT@0.5H)	Outrigger with Belt truss at 0.5 H position from ground level (**30^{th} storey**)

Model 4 (OBT@0.6H)	Outrigger with Belt truss at 0.6 H position from ground level (**36th storey**)
Model 5 (OBT@0.8H)	Outrigger with Belt truss at 0.8 H position from ground level (**48th storey**)
Model 6 (OBT@H)	Outrigger with Belt truss at H position from ground level (**60th storey**)
Type II	**For Double Outrigger system**
Model 7(OBT@0.2H-H)	1st Outrigger with Belt truss at 0.2H position from ground level (**12th storey**) and 2nd Outrigger with Belt truss at H position from ground level (**60th storey**)
Model8(OBT@0.4H-0.8H)	1st Outrigger with Belt truss at 0.4H position from ground level (**24th storey**) and 2nd Outrigger with Belt truss at 0.8 H position from ground level (**48th storey**)
Model 9 (OBT@0.5H-H)	1st Outrigger with Belt truss at 0.5 H position from ground level **(30th storey)** and 2nd Outrigger with Belt truss at H position from ground level (**60th storey**)
Model 10 (Without OBT)	Model without Outrigger and Belt truss system.

C. Loading and load combination

The Loads which are acting on the structure are as follows:
1) Dead Load: Self-weight of structural members
2) Superimposed load: - For outer beam: 7.2 KN/m2
For Floor: 1.5 KN/m2
3) Live load: - 3 KN/m sq. which is uniformly distributed on slab.
4) Seismic Load: -
i) In X-direction: - As per IS 1893:2002
ii) In Y-direction: - As per IS 1893:2002
5) Wind load: - As per IS 875 (part3)

TABLE III- Load Combinations

Sr. No.	Load Combinations	Sr. No.	Load Combinations	Sr. No.	Load Combinations
1	1.5DL +1.5LL	10	1.2DL+1.2LL+1.2WLx	19	0.9DL-1.5EQx
2	1.5DL +1.5WLx	11	1.2DL+1.2LL-1.2WLx	20	0.9DL+1.5EQy
3	1.5DL-1.5WLx	12	1.2DL+1.2LL+1.2WLy	21	0.9DL-1.5EQy
4	1.5DL+1.5WLy	13.	1.2DL+1.2LL-1.2WLy	22	1.2DL+1.2LL+1.2EQx
5	1.5DL-1.5WLy	14	1.5DL+1.5EQx	23	1.2DL+1.2LL-1.2EQx
6	0.9DL+1.5WLx	15	1.5DL-1.5EQx	24	1.2DL+1.2LL+1.2EQy
7	0.9DL-1.5WLx	16	1.5DL+1.5EQy	25	1.2DL+1.2LL-1.2EQy
8	0.9DL+1.5WLy	17	1.5DL-1.5EQy		
9	0.9DL-1.5WLy	18	0.9DL+1.5EQx		

IV. RESULT AND DISCUSSIONS

The analysis of the seismic load, linear static analysis of the wind load was carried out for all the structures with ETABS 2016 v 16.2.1. The following parameters were considered for analysis:

- Maximum Storey displacement
- Storey drift
- Time period

The results of the analysis are presented in the parameters discussed above and are based on lateral loads, since the high rise structures are critical in the lateral loading and comparison between the maximum storey displacement, time period and Storey drifts are made. The following graphs and tables show the variation of these parameters along the height of the structure.

- Storey Displacement of models for Earthquake load and Wind Load

The following table shows the results for storey displacements for both types of models

The below table shows the comparison of all models for Earthquake loading and Wind Loading in X and Y direction. From the above chart it is observed that there is minimum Storey displacement for the Type II- Model 8 (OBT@0.4H-0.8H) for both Earthquake and Wind loading as compared to other models.

Table IV.
Value of Storey displacement in Type I (for EQ loading)

Models	Displacement (mm)
Without OBT	422.687
OBT@0.2H	390.362
OBT@0.4H	385.384
OBT@0.5H	385.909
OBT@0.6H	387.804
OBT@0.8H	394.415
OBT@H	401.088

Table V.
Value of Storey displacement in Type II (for EQ loading)

Models	Displacement (mm)
Without OBT	422.687
OBT@0.2H-H	384.236
OBT@0.4H-0.8H	373.244
OBT@0.5H-H	380.228

Table VI.
Value of Storey displacement in Type I (for Wind loading)

Models	Displacement (mm)
Without OBT	246.744
OBT@0.2H	214.683
OBT@0.4H	213.318
OBT@0.5H	214.512
OBT@0.6H	216.256
OBT@0.8H	220.235
OBT@H	223.204

Table VII.
Value of Storey displacement in Type II (for Wind loading)

Models	Displacement (mm)
Without OBT	246.744
OBT@0.2H-H	211.754
OBT@0.4H-0.8H	207.77
OBT@0.5H-H	211.808

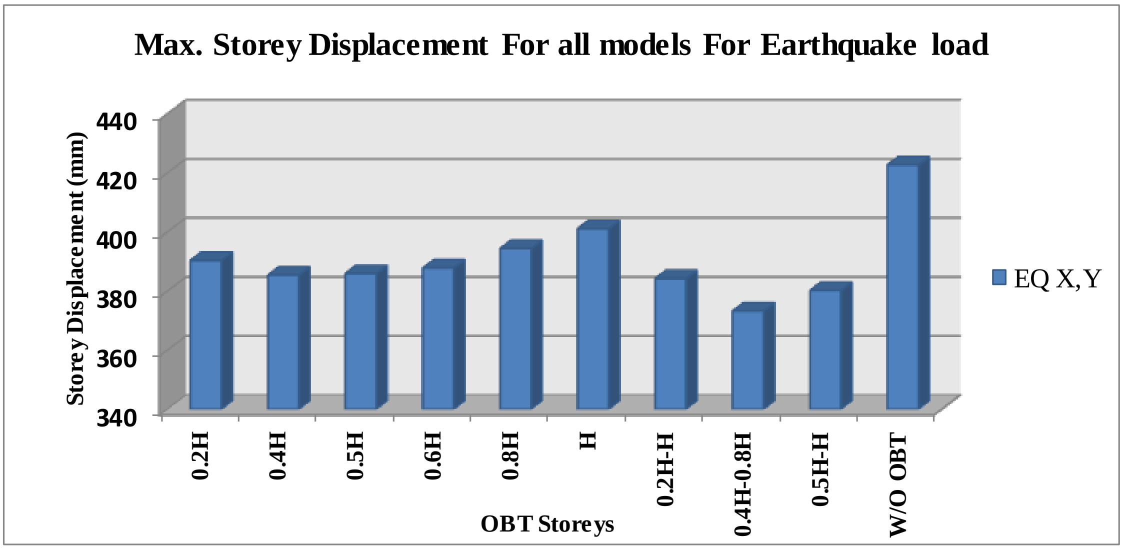


Figure 11: Max Storey Displacement for all models for Earthquake load

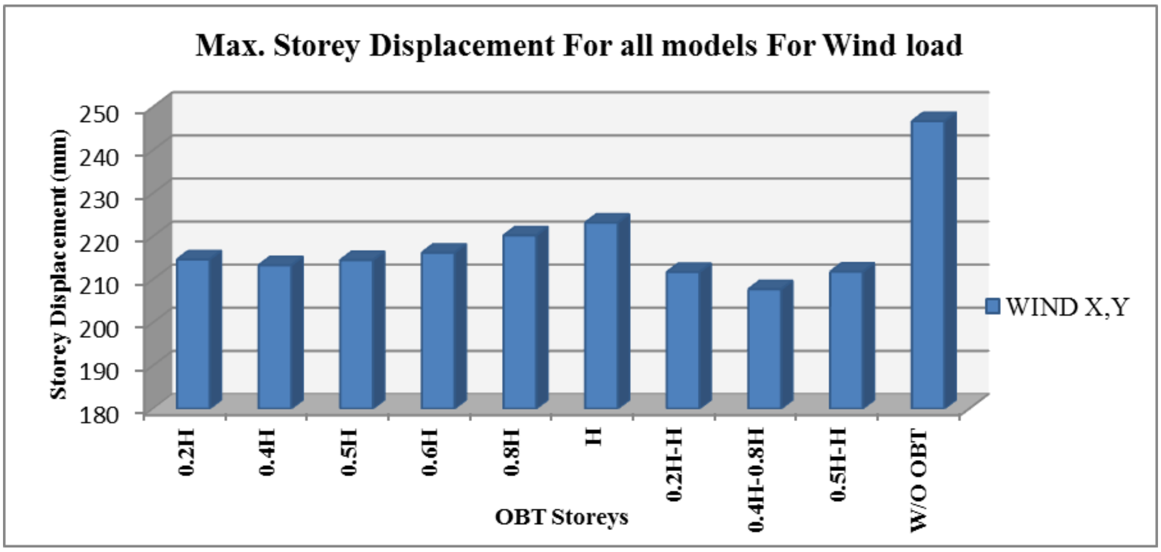


Figure 12: Max. Storey displacement for all models for Wind load

- Storey Drift of models for Earthquake load and Wind Load

The following table shows the results for storey drifts for both types of models

Table VIII.
Value of Storey drift in Type I
(for EQ loading)

Models	Displacement (mm)
Without OBT	0.002843
OBT@0.2H	0.001373
OBT@0.4H	0.001803
OBT@0.5H	0.001886
OBT@0.6H	0.001898
OBT@0.8H	0.001753
OBT@H	0.001548

Table IX.
Value of Storey drift in Type II
(for EQ loading)

Models	Drift ratios at OBT floors
Without OBT	0.002843
OBT@0.2H-H	0.001375,0.001545
OBT@0.4H-0.8H	0.001797, 0.001739,
OBT@0.5H-H	0.001011, 0.000771

Table X.
Value of Storey drift in Type II
(for Wind loading)

Models	Displacement (mm)
Without OBT	0.001714
OBT@0.2H	0.000858
OBT@0.4H	0.001013
OBT@0.5H	0.001014
OBT@0.6H	0.000984
OBT@0.8H	0.000876
OBT@H	0.000777

Table XI.
Value of Storey drift in Type II
(for Wind loading)

Models	Drift ratios at OBT floors
Without OBT	0.001714
OBT@0.2H-H	0.000858, 0.000775
OBT@0.4H-0.8H	0.001009, 0.000868
OBT@0.5H-H	0.001884, 0.001536

The below chart shows the comparison of all models for Earthquake loading and Wind Loading in X and Y direction. From the above chart it is observed that there is minimum Storey drift for the Type II- Model 8 (OBT@0.4H-0.8H) for both Earthquake and Wind loading as compared to other models.

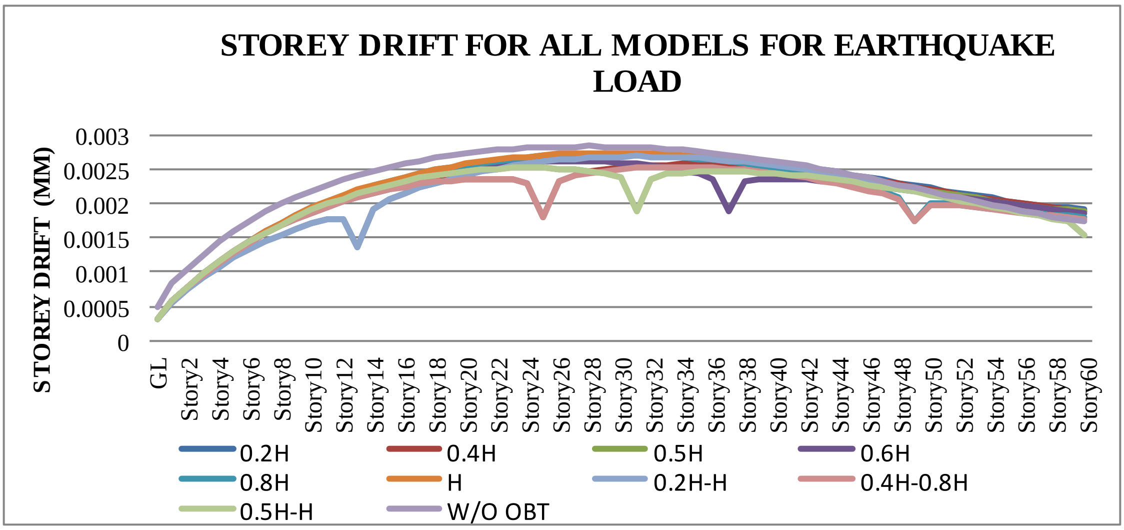


Figure 13: Storey Drift for all models for Earthquake load

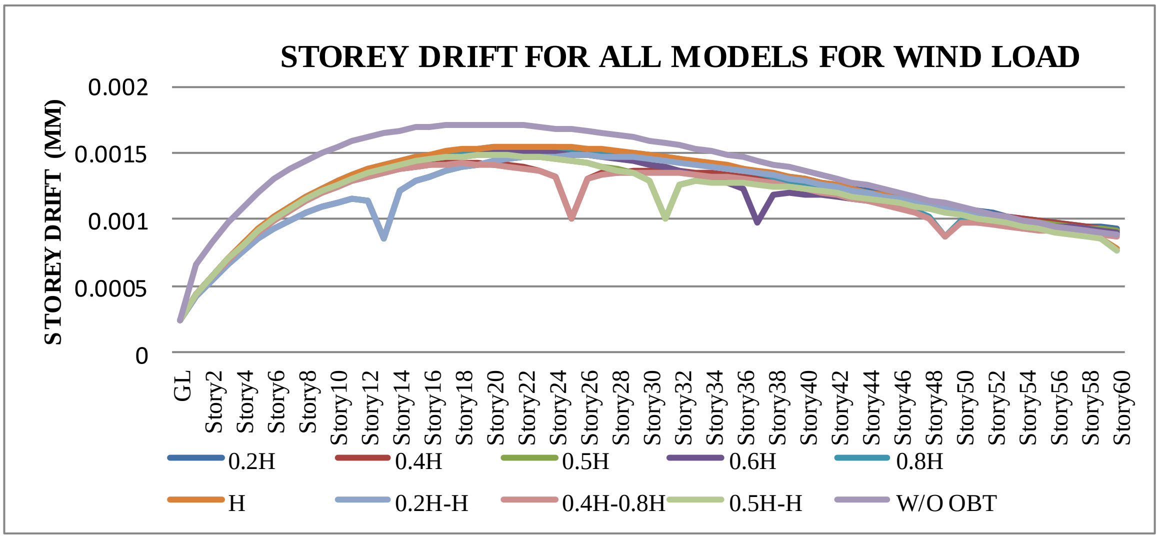


Figure 14: Storey Drift for all models for Wind load

V. CONCLUSIONS

- From the above result it can be conclude that the most effective model for Outrigger and Belt truss structural system is **Type 2- Model 8 (OBT@0.4H-0.8H)**, On the basis of their storey displacement and storey drifts i.e. least value as compared to other model.
- For the Model 8 (OBT@0.4H-0.8H) the Storey displacement is observed to be minimum in X and Y direction for Earthquake load i.e. **373.244 mm** and for Wind load **207.77 mm** at top storey.
- For the **Type 2- Model 8 (OBT@0.4H-0.8H)** it is observed that the storey drift is reduced at 24th floor and 48th floor where OBT is provided for Earthquake and Wind load in both directions and the values for Earthquake and Wind load are **0.001797 mm** and **0.001009 mm** for 12th floor and **0.001739 mm** and **0.000868** mm for 60th floor which are minimum as compared to other models.
- The optimum position of Outrigger and Belt truss system if used for single storey can be observed from **Type 1- Model 2 (OBT@0.4H)** as the storey displacement, storey drift is less as compared to other models with one storey outrigger and belt truss system.
- The optimum position of Outrigger and Belt truss system if used for two storeys can be observed from **Type 2- Model 8 (OBT@0.4H-0.8H**) as the storey displacement, storey drift is less as compared to other models with two storey outrigger and belt truss system.
- From the above analysis and results it can be concluded that the optimum position of Outrigger and Belt truss system is at **0.4H-0.8H** i.e. **24th floor and 48th floor** of the building which can be observed from all types of models compared with each other as the storey displacement, storey drift is less as compared to other models.

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