Comparative Study on Efficiency of Different Types and Configuration of Virtual Outrigger Systems for High Rise Buildings

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Abstract - *Nowadays in this generation, there is a huge demand of high rise buildings and skyscrapers. With continuous demand of taller buildings, we have created need for more efficient lateral force resisting structural systems. But as the height of the building increases, the stiffness of the structure becomes more important to deal with the lateral (wind and earthquake) forces acting on a structure. Several lateral force resisting systems have been introduced such as the Braced frames, braced tubes, shear wall frames, Diagrid tubes, mega tubes, outrigger system etc. In this research, the most effective outrigger structural system i.e. conventional outrigger-belt truss is compared with Virtual outrigger System. This research also deals with the study of Virtual outrigger systems for high-rise building with different types and configuration for highest efficiency against Lateral force. Various parameter like Storey Drift, Joint Displacement, and Moment have been compared in different models with different configuration of Outrigger systems.*

Key Words: Virtual Outrigger system, Conventional outrigger system, lateral response, drift

1. INTRODUCTION

Strength, Stiffness and Serviceability are the three main factors on which the design of tall and slender structures depend mainly. As the height of skyscrapers is more the wind load is the most governing load for serviceability factor and the drift and displacement limit considerations become more important. There are many lateral force resisting systems used in high-rise building design which are shear core frame, shear wall frame, shear tube, diagrid, outrigger systems etc. However, the outriggers and belt trusses system are better in providing reduction in drift and displacement against lateral loading. 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 Story Drift of any story due to lateral loading should not be more than 0.004 time the story height as per Indian Standard. There are mainly two types of outrigger structural systems. They are as follows:-

a) Conventional Outrigger System
b) Virtual Outrigger System.

1.1 Outrigger Structural System

Outrigger structural system consists of a core mainly of bracings or shear walls located centrally in the building along with horizontal trusses, girders or walls known as Outrigger trusses which connects the central core to the outer column. The structural response of an outrigger system is based on tension-compression couple induced in the outer columns. The outrigger behaves as a stiff brace connecting outer columns of the building and the central core. The lateral load when acting upon the central core is transferred to peripheral columns via outriggers and the overturning moment is reduced.

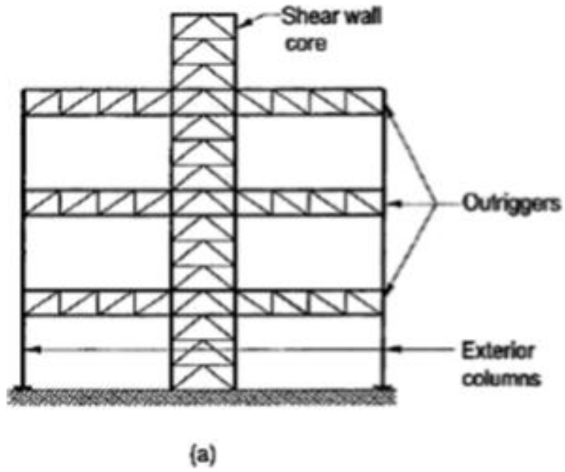

Fig-1: Outrigger structural system

1.2 Advantages of Outrigger Structural system

Following are the advantages of outrigger structural system listed below:

i. Each and every exterior columns including other than outrigger columns can participate in resisting overturning moment.
ii. The reverse moment applied to the core at each outrigger connection reduces the core overturning moments.
iii. Outrigger system can be used in various material as steel, concrete and even composite form.
iv. Outrigger provide resistance towards excessive displacement, story drift and the overturning moment of structure.

v. When the outriggers are used to 2 or 3 floors directly, were the virtual outrigger system, this increases the space in the floor.
vi. As the outrigger structure behaves like a connecting arm for free cantilever tall building, it provides reduction in core overturning moments up to 40 percent.

1.3 Disadvantages of Outrigger Structural system

i. Outriggers interfere with usable and rental space.
ii. The outrigger system increases the dead load of the structure

2. OBJECTIVE OF STUDY

2.1 Objectives

➢ To understand the working of Virtual Outrigger System and Offset Outrigger System against lateral Loading.
➢ Model different cases for Conventional, Virtual and Offset Outrigger system in a Structural analysis software like Etabs.
➢ Compare Conventional, Virtual and Offset Outrigger System in a High Rise Building.
➢ Determine the efficiency of Conventional, Virtual and Offset Outrigger system for different Configurations.

2.2 Scope of Work

➢ Modelling and Analysis of different types of outrigger and their different configurations in a Structural Analysis software like Etabs.
➢ Carry out comparison of different types of Outrigger systems and their type for following parameters i.e., Max Storey Displacement, Storey Drift and Story Stiffness
➢ Considering different cases for Building, Models have been analyzed in ETABS and results have been compared.

3. METHODOLOGY

3.1 Structural Data for Modelling

➢ Building Type = Steel Frame Building
➢ Number of stories = 50 story
➢ Height of each story = 3 m
➢ Total height of building = 150 m
➢ Length of building in X-direction = 35 m
➢ Length of building in Y-direction = 45 m
➢ Bay width in both direction = 5 m
➢ Number of bays in X-direction = 7 Nos.
➢ Number of bays in Y-direction = 9 Nos
➢ Sections to be used = Indian Standard sections
➢ Structural steel grade = Fe250
➢ Grade of concrete for deck slab = M25

3.2 Loading Data

A. Dead Load
Height of block masonry wall was considered as 3 m and of 230 mm thickness which induces a uniformly distributed load of 9.66 kN/m and Floor finishing of 1 kN/m2 is to be applied.

B. Live Load
Live Load on Slab is considered as 4 kN/m2.
Buildings for all seven cases were analyzed for Dynamic Wind Analysis. All Models were analyzed for 3 critical wind zones which are as below:
1) Wind – 1 (Vb=55m/s) Location: Leh
2) Wind – 2 (Vb=50m/s) Location: Kolkata
3) Wind – 3 (Vb=47m/s) Location: Udaipur

In this study a 50 storey steel building with various outrigger systems are analyzed by Dynamic wind analysis method. The performance of the building is noted in terms of lateral displacement, story drift and story stiffness. Gust factor for all three locations have been calculated and wind loading is applied accordingly. In this study the primary load cases are Dead Load, Live Load, Wind Load and Seismic Load. Combinations for these primary load cases have been considered.

4. ANALYTICAL MODELLING

Considering seven different cases of different lateral force resisting systems in each pf the three wind zones considered for this study, a total of 21 building models were bifurcated and analyzed in a 3D Structural analysis software named ETABS.

4.1 Assumption in Analysis

The assumptions considered for this study are stated as bellows:
1) The analysis and the behavior of the structure are linearly elastic.
2) The outriggers are rigidly attached to the core and the core is rigidly attached to the foundation.
3) The outrigger system shows best results when placed at both top of the structure and at mid-height of the structure.

4.2 Model Description

Seven different cases of model are considered for the comparative study amongst them. For better understanding of results these models have been named as following.
1) Model 1- No Shear Core and No outrigger (Bare Frame model Name: BF)
2) Model 2- Shear Core only (Name: SC)
3) Model 3- Conventional Outrigger (Name: CO)

4) Model 4- Conventional Outrigger with Belt Truss (Name: COBT)
5) Model 5- Offset Truss System (Name: OT)
6) Model 6- Offset Truss System with Belt Truss (Name: OTBT)
7) Model 7- Only Belt Truss System (Name: BT)
Theses outrigger systems are introduced at 25th and 50th story of the structure. These configurations have been shown below for 25th story.

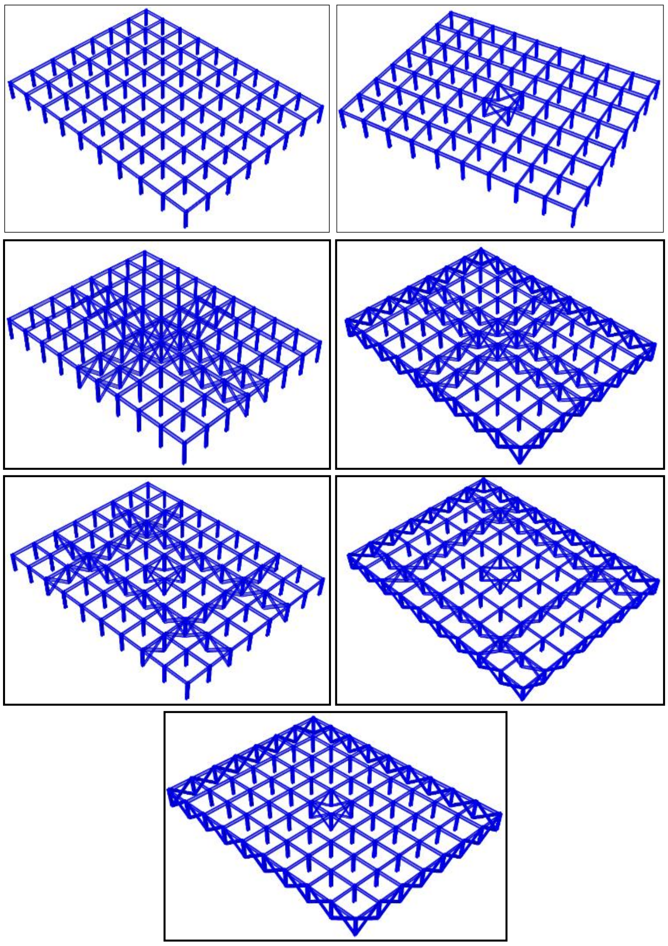

Fig-2: Different Outrigger Configurations

4.3 Structural Sections used in modelling

The member profile used in Columns, Beams and Outriggers were designed and optimized to the nearest unity ratio according to IS 800 2007. The sections used were as following:
1) M.S. Column up to 25th Story = 2-ISMB 600(clear spacing 100mm) + 4 side 20mm thick plate
2) M.S. Column from 26th story to 45th story = 2-ISMB 600 (clear spacing 100mm) + 2 side 20mm thick plate
3) M.S. Column from 46th story to 50th story = 2-ISMB 600 (clear spacing 0 mm)
4) M.S. Beam up to 30th story = ISMB 600
5) M.S. Beam from 31st story to 50th story = ISMB 500
6) Member for shear core throughout height = ISMC 300
7) Member for outrigger and belt truss (at 25th story and 50th story) = 2-ISMC 400 toe to toe (clear spacing 0 mm)

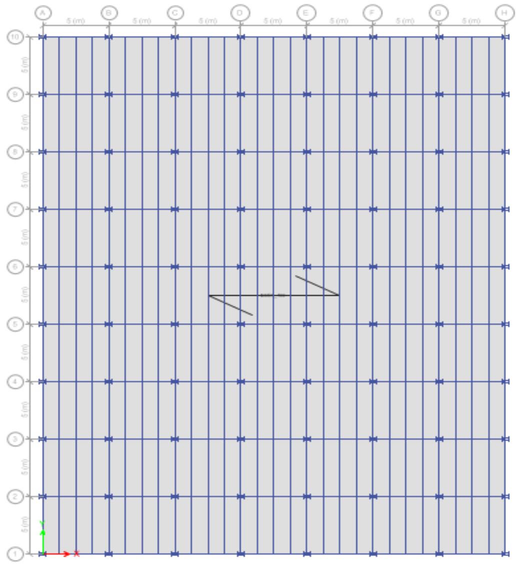

Fig-2: Plan of Model-4

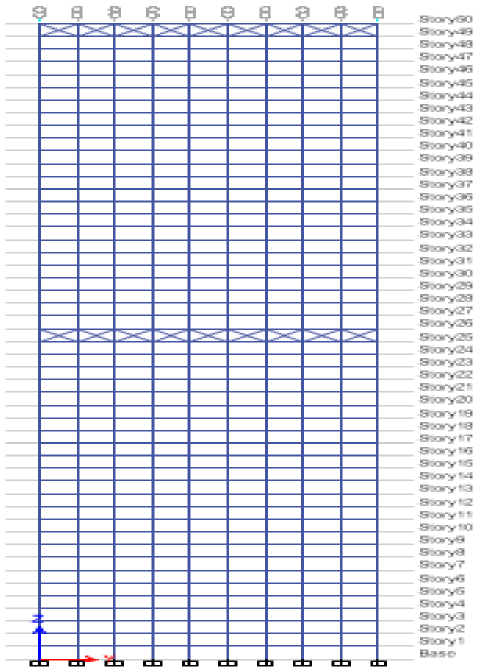

Fig-3: Elevation of Model-4

5. RESULTS

The results are obtained for all the three wind zones and compared with each other to obtain the most efficient outrigger structural system against lateral loading. These results have been obtained for different unfactored load combinations like DL+LL, DL+LL+WL, DL+LL-WL, DL+LL+EQ, DL+LL-EQ, DL+WL, DL-WL, DL+EQ, DL-EQ.
Where,
DL = Dead Load
LL = Live Load
WL = Wind Load
EQ = Earthquake Load

5.1 Maximum Displacement

A. For X Direction:

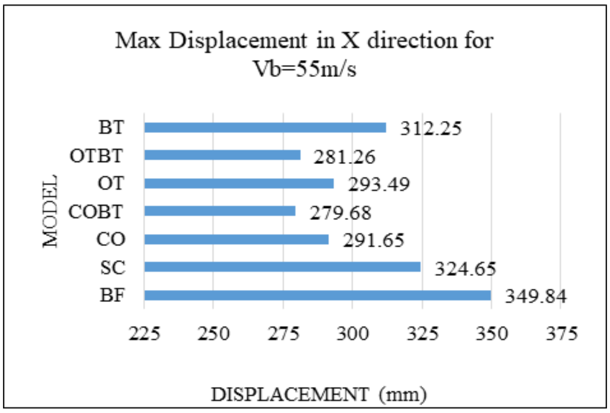

Chart - 1 Maximum Displacement in X direction

B. For Y Direction:

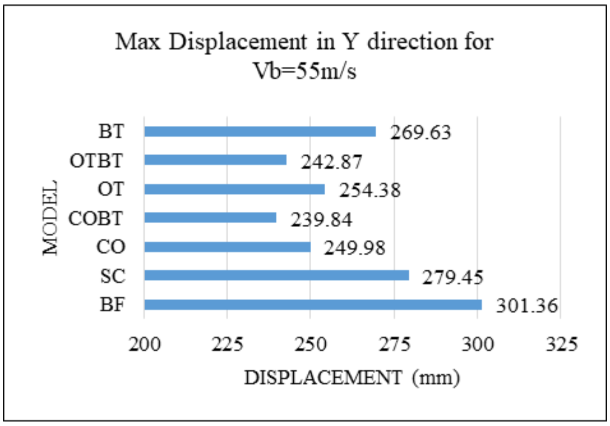

Chart - 2 Maximum Displacement in Y Direction

5.2 Story Drift

A. For X Direction:

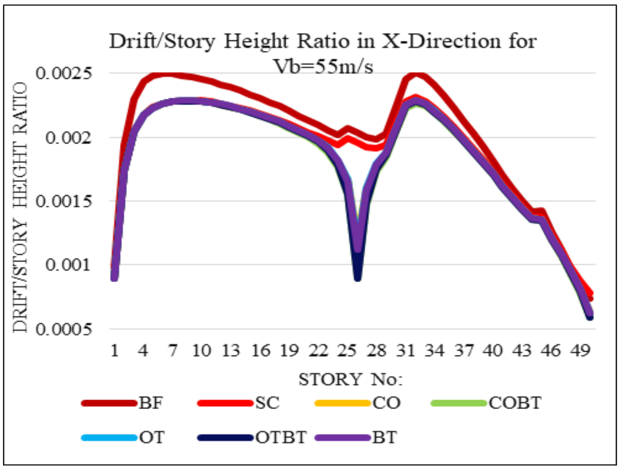

Chart - 3 Story Drift in X Direction

B. For Y Direction:

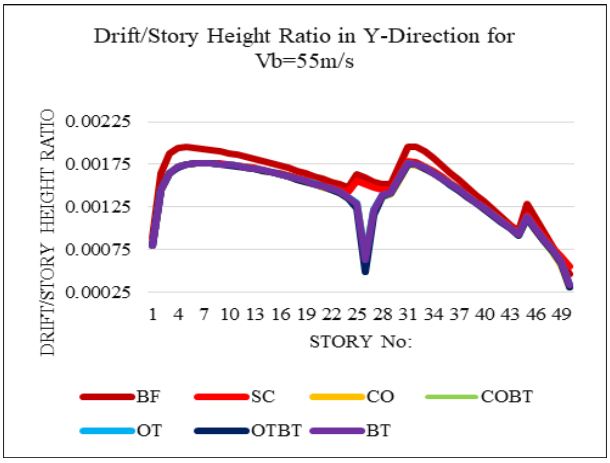

Chart - 4 Story Drift in Y Direction

5.3 Quantity of Structural Steel Used

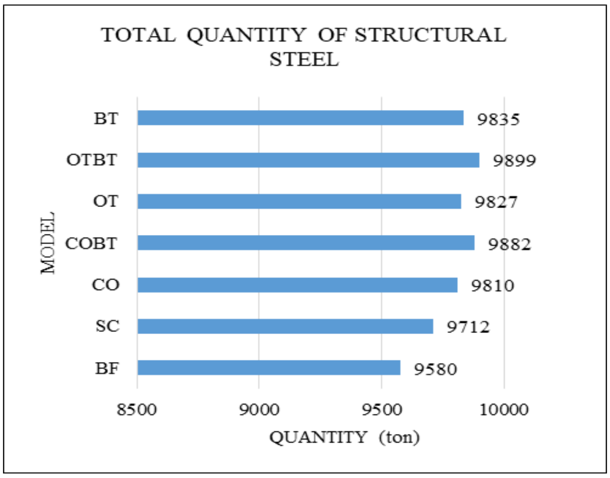

Chart - 5 Quantity of Steel used

5.4 Story Stiffness

A. For X Direction:

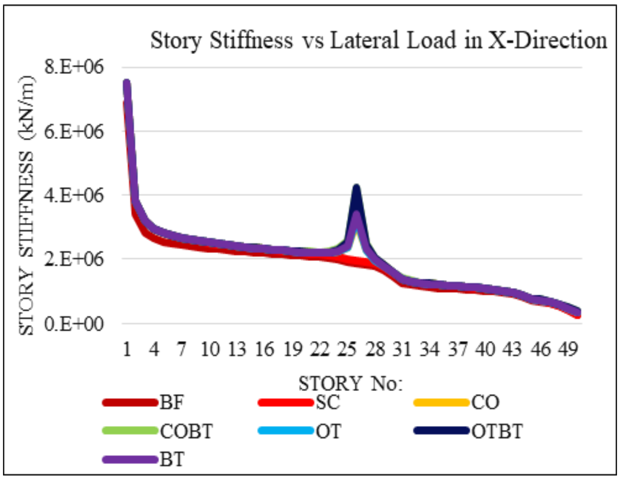

Chart - 6 Story stiffness for X Direction

B. For Y Direction:

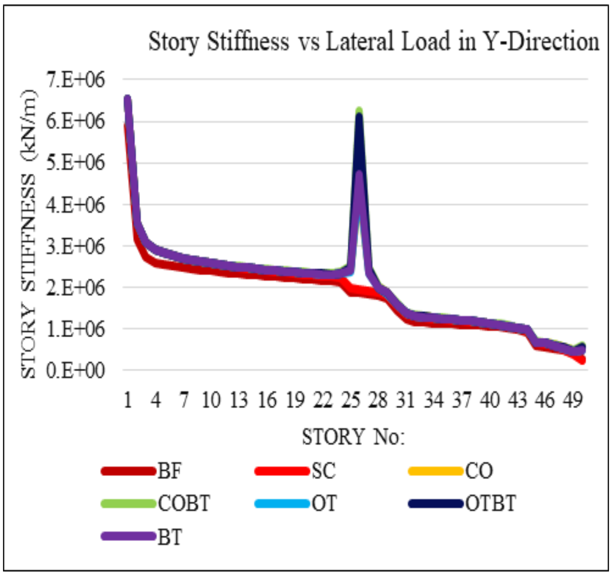

Chart - 7 Story Stiffness for Y Direction

6. OBSERVATIONS

6.1 Reduction in Maximum Displacement

There was a notable percentage reduction in maximum displacement in each model from that obtained in Model-1 Bare Frame model and are shown below:

A. For X Direction:

Table 1 Percentage reduction in maximum displacement in X direction

Percentage Reduction in Max Displacement (Vb=55m/s) X-Direction				
Sr No:	Model	Displacement	Difference	Reduction in %
1.)	Bare Frame	349.84 mm	(max)	-
2.)	Shear Core	324.65 mm	25.19 mm	7.20%
3.)	Conventional Outrigger	291.65 mm	58.19 mm	16.63%
4.)	Conventional Outrigger with Belt Truss	279.68 mm	70.16 mm	20.05%
5.)	Offset Truss	293.49 mm	56.35 mm	16.11%
6.)	Offset Truss with Belt Truss	281.26 mm	68.58 mm	19.60%
7.)	Belt Truss Only	312.25 mm	37.59 mm	10.74%

B. For Y Direction:

Table 2 Percentage reduction in maximum displacement in Y direction

Percentage Reduction in Max Displacement (Vb=55m/s) Y-Direction				
Sr No:	Model	Displacement	Difference	Reduction in %
1.)	Bare Frame	301.36 mm	(Max)	-
2.)	Shear Core	279.45 mm	21.91 mm	7.27%
3.)	Conventional Outrigger	249.98 mm	51.38 mm	17.05%
4.)	Conventional Outrigger with Belt Truss	239.84 mm	61.52 mm	20.41%
5.)	Offset Truss	254.38 mm	46.98 mm	15.59%
6.)	Offset Truss with Belt Truss	242.87 mm	58.49 mm	19.41%
7.)	Belt Truss Only	269.63 mm	31.73 mm	10.53%

6.2 Reduction in Story Drift

There was a notable percentage reduction in story drift at 25th story in each model from that obtained in Model-1 Bare Frame model and are shown below:

A. For X Direction:

Table 3 Percentage reduction in story drift at 25th story in X direction

Percentage Reduction in Drift at 25th Story (Vb=55m/s) in X-Direction				
Sr No:	Model	Story Drift (mm)	Difference (mm)	Reduction in %
1.)	Bare Frame (Max)	0.00611	-	-
2.)	Shear Core	0.00587	0.00024	3.93%
3.)	Conventional Outrigger	0.00362	0.00248	40.69%
4.)	Conventional Outrigger with Belt Truss	0.00269	0.00341	55.87%
5.)	Offset Truss	0.00347	0.00263	43.14%

6.)	Offset Truss with Belt Truss	0.00269	0.00341	55.87%
7.)	Belt Truss Only	0.00335	0.00275	45.11%

B. For Y Direction:

Table 4 Percentage reduction in Drift at 25 th story for Y direction

Percentage Reduction in Drift at 25th Story (Vb=55m/s) in Y-Direction				
Sr No:	Model	Story Drift (mm)	Difference (mm)	Reduction in %
1.)	Bare Frame (Max)	0.00477	-	-
2.)	Shear Core	0.00454	0.00023	4.84%
3.)	Conventional Outrigger	0.00204	0.00273	57.30%
4.)	Conventional Outrigger with Belt Truss	0.00143	0.00335	70.13%
5.)	Offset Truss	0.00198	0.00279	58.49%
6.)	Offset Truss with Belt Truss	0.00146	0.00332	69.50%
7.)	Belt Truss Only	0.00189	0.00288	60.38%

6.3 Increment in Story stiffness

There was a notable percentage increment in story stiffness at 25th story in each model from that obtained in Model-1 Bare Frame model and are shown below:

A. For X Direction:

Table 5 Increment in story stiffness at 25th story for X direction

Increment in Story Stiffness at 25th Story for X-Direction				
Sr No:	Model	Story Stiffness (kN/m)	Difference (kN/m)	Increment in %
1.)	Bare Frame	1870233	(Minimum)	-
2.)	Shear Core	1948114	77881	4.16 %
3.)	Conventional Outrigger	3154413	1284180	68.66 %
4.)	Conventional Outrigger with Belt Truss	4246317	2376084	127.05 %
5.)	Offset Truss	3293231	1422998	76.09 %
6.)	Offset Truss with Belt Truss	4243712	2373479	126.91 %
7.)	Belt Truss Only	3412117	1541884	82.44 %

B. For Y Direction:

Table 6 Increment in story stiffness at 25th story for Y direction

Increment in Story Stiffness at 25th Story for Y-Direction				
Sr No:	Model	Story Stiffness (kN/m)	Difference (kN/m)	Increment in %
1.)	Bare Frame	1860134	(Minimum)	-
2.)	Shear Core	1955778	95644	5.14 %
3.)	Conventional Outrigger	4364450	2504317	134.63 %
4.)	Conventional Outrigger with Belt Truss	6251979	4391845	236.10 %
5.)	Offset Truss	4491345	2631212	141.45 %
6.)	Offset Truss with Belt Truss	6112232	4252099	228.59 %
7.)	Belt Truss Only	4707667	2847534	153.08 %

7. CONCLUSIONS

From the Study we can conclude the following:

1) The outrigger structural system for tall building increases stiffness and stability against lateral loads.
2) Outrigger Structural system gives noticeable reduction in "Lateral Displacement" and "Story Drift" of the structure against Lateral Loading.
3) Outrigger Structural system also increases "Story stiffness" at the story where it is provided.

Talking About Displacement:

4) Displacement of Structure against lateral loading was Maximum in the Bare Frame model irrespective of any wind zone.
5) By using Shear core at the central bay throughout the structure, the displacement due to wind loading was reduced by 7 to 8% from the maximum that in Bare Frame.
6) By using Only Belt Truss at 25th and 50th Story of the structure, the displacement due to wind was reduced by 10 to 11%.
7) Reduction in Displacement was around 16 to 17% by using Conventional Outrigger and Offset Truss (Virtual Outrigger) in the model.
8) Reduction in Displacement was Maximum around 20 to 21% by using Conventional Outrigger + Belt Truss and

Offset Truss + Belt Truss (Virtual Outrigger) in the model.

9) Reduction in displacement in model with Conventional outrigger system and with Virtual Outrigger system had a very low difference of 1.5 to 2%.
10) Hence Virtual outrigger system is also effective as compared to Convention outrigger system in reduction of displacement.

Talking About Story Drift:

11) Maximum Story Drift in both X and Y directions were to be recorded in the Bare Frame Model irrespective of any Wind Speed Zone.
12) Reduction in story drift in Y-direction is more than X-direction because of large span of building in Y direction.
13) Story drift was seen reduced specifically on 25th story of the model as the outrigger system was used at that story.
14) By using Only Shear Core in the model the story drift was reduced by around 4 to 5% for both X and Y directions in all wind zones.
15) For X direction, the Story drift was reduced by 40 to 45% by using Conventional outrigger, Offset Truss (Virtual outrigger) and Only Belt Truss systems in the model for all wind zones.
16) For Y direction it was reduced by 57 to 61% by using above three systems in model.
17) Maximum reduction in story drift was recorded by 55 to 57% in X direction and 70 to 72% in Y direction by using Conventional outrigger + Belt truss and Offset truss + Belt truss.
18) Reduction in story drift in model with Conventional outrigger system and with Virtual Outrigger system had a difference of 4.2 to 5%
19) Hence Virtual outrigger system is also effective as compared to Convention outrigger system in reduction of story drift.

Talking About Story Stiffness:

20) Story stiffness of the 25th story was increased by the use of different outrigger systems.
21) Story stiffness was increased more in Y direction than in X direction because of the large span of structure in Y direction.
22) The lowest story stiffness of the 25th story was recorded in the Bare Frame model in both directions.
23) The story stiffness is increased by 4% in X direction and by 5% in Y direction by using only Shear Core in the model.
24) Increment of 70 to 80% in X direction and of 130 to 150% in Y direction was recorded by using Conventional outrigger, Virtual outrigger (offset truss) and only belt wall systems.
25) Maximum increment of about 120 to 125% in X direction and of 228 to 236% in Y direction was obtained by use of Conventional outrigger + Belt Truss and Offset Truss + Belt Truss systems in the model.
26) By all the conclusions it can be stated that Virtual Outrigger systems are as much as effective as Conventional Outrigger systems in tall structure against response to the lateral loading.

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