A Study on Performance of Outrigger Structural Systems during Lateral Loads on High Rise Structures

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Abstract--- *The study focused on performance of outrigger structural systems during lateral loads on high rise structures. Linear static analysis of two buildings of 30 storey and 50 storey buildings for various models were examined using ETABS software, for Building without outrigger, building with core and outrigger system by bracings, building with core by shear wall and outrigger system by bracing, building with core and outrigger system by shear wall, building exterior panel and outrigger by shear wall. The analysis includes Lateral displacement, inter-storey drift and storey stiffness for Lateral loadings. From the results it is concluded that the effective performance of the structure will be obtained by building exterior panel and outrigger by shear wall at 15th storey and top storey for 30 storey building and at 28th storey and top storey for 50 storey building is found to be more effective.*

Keywords--- *Lateral Loads, Outriggers System, Tall Buildings, Linear-Static Analysis.*

I. INTRODUCTION

THE development of high rise structures and buildings are vigorously increased these years. People started to migrate from there natives or from villages to a metro-politian cities in search of jobs. Because of this metro-politian cities are becoming denser, i,e,. densely populated. As it is getting denser the availability of land becoming less and cost is also highly increasing. Hence to overcome these problems, high rise structures, multi-storey buildings are most prominent and effective solutions. For developing country like India and other countries, the high rise structures, multi-storey buildings are best option.

The structural system for high rise structures, buildings has undergone through dramatic changes and is been continuously emerging since decades. Structural system for high rise structures, buildings can be classified as two types.

a. Interior structures
b. Exterior structures

These are classified on the basis of lateral load resisting system. If the major load resisting system is in interior of the building then it is called interior system. Similarly, if outer perimeter of the building is load resisting, it is an exterior structural system. Outrigger Structural System Outriggers are firm horizontal structures or structural elements that are designed to improve structure, from overturning stiffness and strength by connecting the structure core or spine to the distant columns. Outrigger system has been used for narrow and tall buildings to provide better resistance against lateral loads. Behavior of outriggers for structures are simple, as the core of the structure is connected simply by a stiff arm to nearby columns or external columns. Analysis and design of outrigger structural system is not simple because relative stiffness depends on each structural element.

As the outrigger is connected between core and the exterior column, this will reduces over turning moment and efficiently reduces the lateral displacement of structure or building at the top. When the multi-storeyed buildings or skyscrapers are subjected to lateral loads, the exterior columns and the outrigger handle the rotation of the central core. Thus there is considerably reduce of lateral deflection and base moments, which would have arisen in free core building. Outrigger with core wall is as shown in Fig.1. Wind forces acting on core and core with outrigger structural system are as shown in Fig.2.

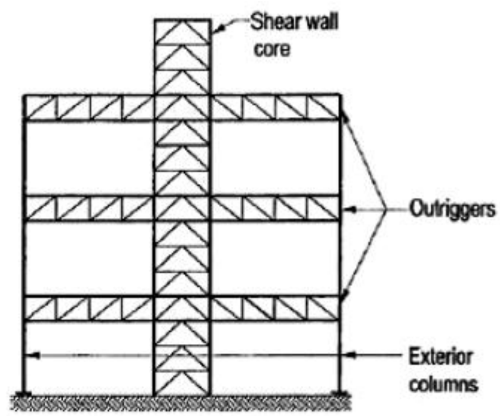

Figure 1: Outrigger with Core Wall

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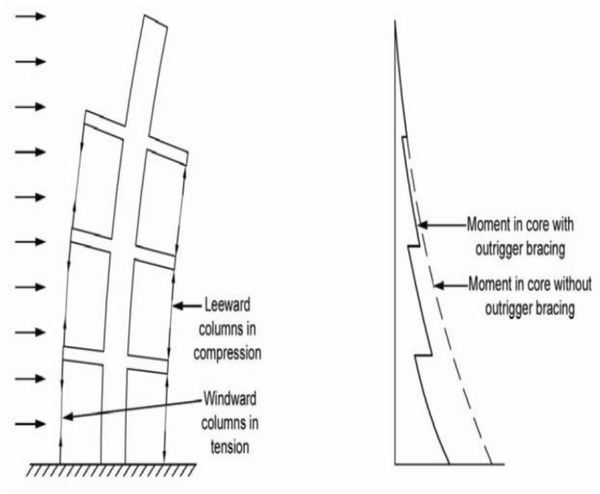

Figure 2: Core Supported Outrigger Structural System

The locations of outriggers have influence on the efficiency of the inter storey drift, storey stiffness and horizontal deflection in high rise multi-storey structures. An optimum outrigger location will be more effective in minimizing the lateral displacement and reducing storey drift, increasing storey stiffness, thus ensuring safety of structure subjected to horizontal loads.

II. Modelling of Structural Buildings

For the present study is taken with two buildings 3D models of 30 storey and 50 storey buildings.

The building further modeled for different types of structural elements combinations.

1. Building without outrigger.
2. Building with core and outrigger system by bracings (as shown in Fig.3.)
3. Building with core by shear wall and outrigger system by bracing (as shown in Fig.4)
4. Building with core and outrigger system by shear wall (as shown in Fig.5)
5. Building exterior panel and outrigger by shear wall (as shown in Fig.6)

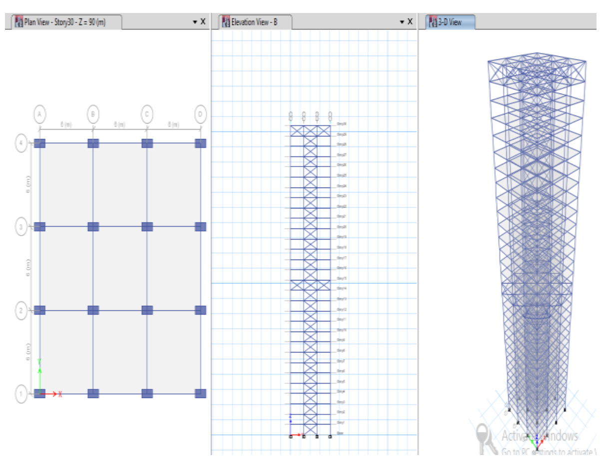

Figure 3: Building with Core and Outrigger System by Bracings

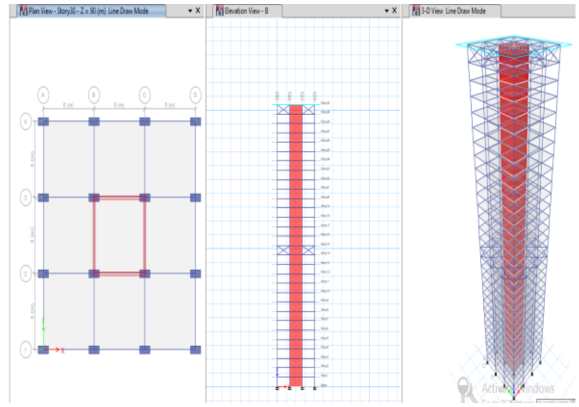

Figure 4: Building with Core by Shear Wall and Outrigger System by Bracing

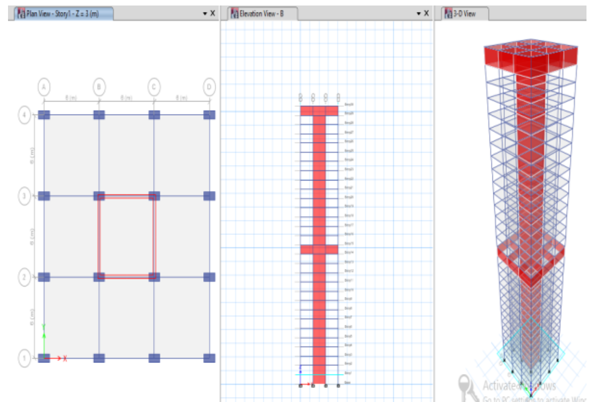

Figure 5: Building with Core and Outrigger System by Shear Wall

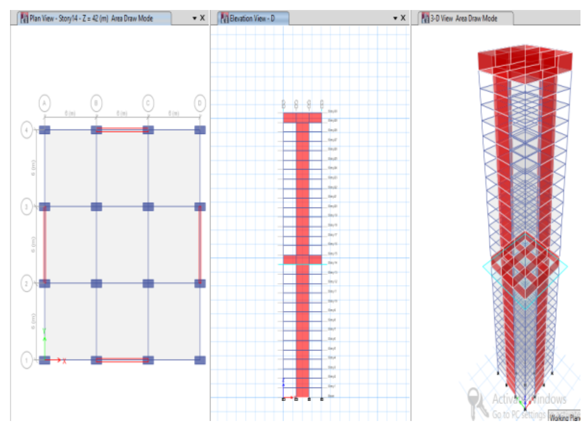

Figure 6: Building with Exterior Panel and Outrigger System by Shear Wall

The building has square plan dimensions of 18m x 18m, with 3 bays in X-direction and 3 bays along Y-direction; each bay is 6m along both directions. The shear wall of 6m x 6m is considered, the plan, elevation and 3D model view of the buildings are shown below. Typical storey height is 3m

Two outriggers are located with varying the position of outriggers. Firstly one outrigger is fixed at top storey, and by varying the position of second outrigger with the ratio of H/H1 as shown in Fig.7

Where

H - Total height of the building

H1- Height of the second outrigger from the base of the building

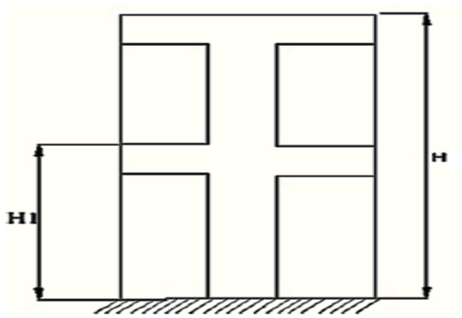

Figure 7: Relative Height of Outrigger

Following relative height of outrigger models are modeled and studied.

In 30 storeys building H/H1 ratios;

a. Location of outrigger at storey 7 and H/H_1=4.28
b. Location of outrigger at storey 15 and H/H_1=2
c. Location of outrigger at storey 21 and H/H_1=1.42

In 50 storeys building H/H1 ratios;

a. Location of outrigger at storey 7 and H/H_1=7.14
b. Location of outrigger at storey 14 and H/H_1=3.57
c. Location of outrigger at storey 21 and H/H_1=2.38
d. Location of outrigger at storey 25 and H/H_1=2
e. Location of outrigger at storey 28 and H/H_1=1.78
f. Location of outrigger at storey 35 and H/H_1=1.43
g. Location of outrigger at storey 42 and H/H_1=1.19

Consideration of Loads and Analysis

For static behavior purpose, the self-weight of the building i.e., dead load of building is considered and live load considered as 3 kN/m^2, earthquake load is considered by confirming IS 1893(Part 1)-2002. The following parameters has been taken Zone V (Z=0.36)

Soil type as medium (Type II)

Importance factor as (I=1.5)

Response reduction factor is (R=5)

Time period (T) is taken by software only as program calculated.

Analysis is done for different arrangement of outrigger braced and outrigger shear wall. Equivalent horizontal wind load confirming to IS 875(Part 3)-1987 the location selected as Bhuj, the following parameters are obtained.

The Terrain category = 2

Structure class = B

Basic wind speed V_b= 50 m/s

Risk coefficient (k1 factor) = 1.08

Topography (k3 factor) = 1.28

III. Results And Discussion

A. Building with 30 Storey

Table 1: Comparison of Displacement of Building Due to eqx, from Without Outrigger System to with Outrigger System by Bracings at Different h/h1 Ratios

S.No.	*Outrigger Location (H/H_1)*	*Maximum Displacement (mm)*
1	without outrigger	137.6
2	4.28	126.6
3	2	125.2
4	1.42	125.6

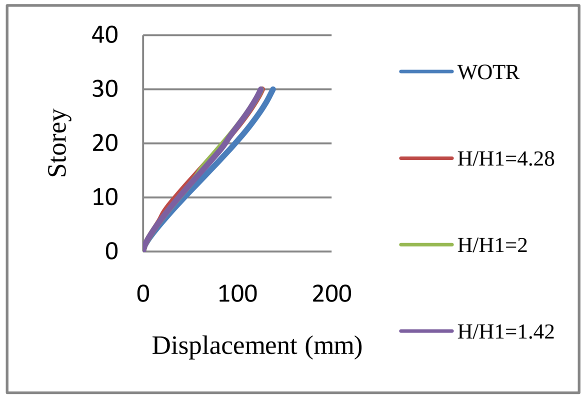

Figure 8: Variation of Displacement for Outrigger by Bracings at Different H/H1 Ratios and without Outrigger Due to EQ

Table 2: Comparison of Displacement of Building due to wind, from without Outrigger System to with Outrigger System by Bracings at Different H/H1 Ratios

S.No	*Outrigger Location (H/H_1)*	*Maximum displacement (mm)*
1	without outrigger	162.2
2	4.28	127.8
3	2	126.7
4	1.42	129.5

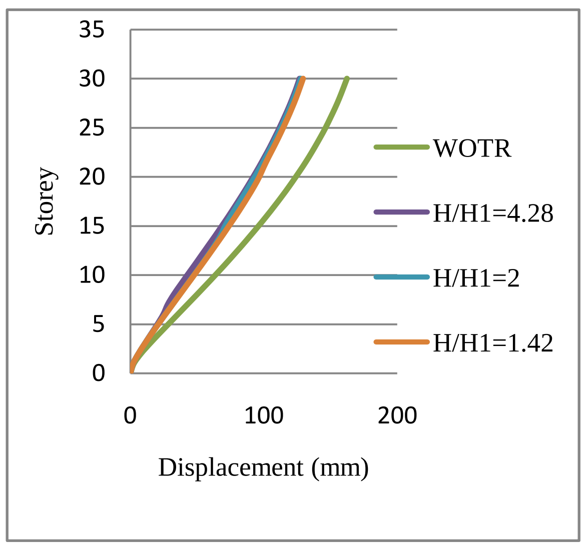

Figure 9: Variation of Displacement for Outrigger by Bracings at Different H/H1 Ratios and Without Outrigger Due to Wind

B. Building with 50 Storey

Table 3: Comparison of Displacement of Building due to EQ, from without Outrigger System to with Outrigger System by Bracings at Different H/H1 Ratios

S.No.	*Outrigger location (H/H$_1$)*	*Maximum displacement (mm)*
1	Without outrigger	183.7
2	7.14	170.4
3	3.57	170.2
4	2.38	170.1
5	1.78	169.6
6	1.43	169.9
7	1.93	170

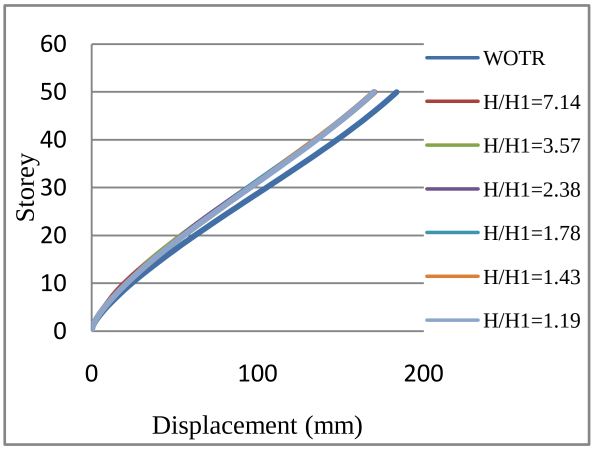

Figure 10: Variation of Displacement for Outrigger by Bracings at Different H/H1 Ratios and Without Outrigger Due to EQ

Table 4: Comparison of Displacement of Building Due to Wind, from without Outrigger System to with Outrigger System by Bracings at Different H/H1 Ratios

S.No.	*Outrigger location (H/H$_1$)*	*Maximum displacement (mm)*
1	Without outrigger	363.1
2	7.14	330.7
3	3.57	329.9
4	2.38	329.9
5	1.78	329.3
6	1.43	331.4
7	1.93	332.2

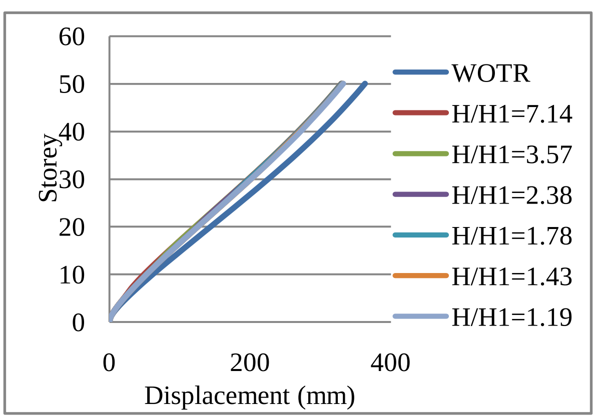

Figure 11: Variation of Displacement for Outrigger by Bracings at Different H/H1 Ratios and Without Outrigger Due to Wind

It is clearly observed that displacement in both 30storey and 50storey buildings due to earthquake load, values from Table:1& Table:3, graph from Fig.4.1 &Fig.4.3 respectively, reduction in maximum lateral displacement for building with core & outrigger system with bracings to without outrigger, and is effectively reduced at the location H/H$_1$=2, i.e., outriggers at 15th storey.

Also it is observed that the lateral displacement in both 30storey and 50storey buildings due to horizontal load i.e., by wind load, values from Table 4.2, Table 4.4 and graphs from Fig.4.2, Fig.4.4 respectively, there is reduction in maximum horizontal displacement for building with core & outrigger system with bracings to without outrigger, and is efficiently reduced at the location H/H$_1$=2, i.e. outriggers at 15th storey.

The results of both earthquake loads and wind loads are proved, that the outrigger system for the building is considerably reduces the lateral movement i.e., lateral displacement of the building. The optimum location of the outrigger system to building is at 15th storey that is H/H1=2.

C. Use of Different Structural Properties to Building Core and Outrigger System

As already the optimum location of outrigger system to the building with 30 storey and 50 storey has been found. For the further study, models of building with different structural elemental properties in the core of building and outrigger system are been modeled.

Already we know the optimum location of outrigger system to the building, so now the modeling of different models are been done only for the optimum outrigger locations. The following models are modeled for the analysis. Then the results will be tabulated and compared with the graphs.

Following are the modeled with different types of structural elements combinations for outrigger system at location for the 30 storey and 50 storey buildings at 15th floor (H/H1=2) and 28th floor (H/H1=1.78) respectively.

1. Building without outrigger
2. Building with core and outrigger system by bracings
3. Building with core by shear wall and outrigger system by bracing
4. Building with core and outrigger system by shear wall
5. Building exterior panel and outrigger by shear wall

30 Storey Building

Table 5: Comparison of Displacement due to EQ, for Different Combinations of Structural Elemental Properties to the Building and Outrigger System at H/H1=2

S.No	*Type*	*Maximum displacement (mm)*	*Reduction (%)*
1	Building without outrigger	137.6	-
2	Building with core and outrigger system by bracings	125.2	9.01
3	Building with core by shear wall and outrigger system by bracing	118.8	13.66
4	Building with core and outrigger system by shear wall	111.8	18.75
5	Building exterior panel and outrigger by shear wall	105	23.69

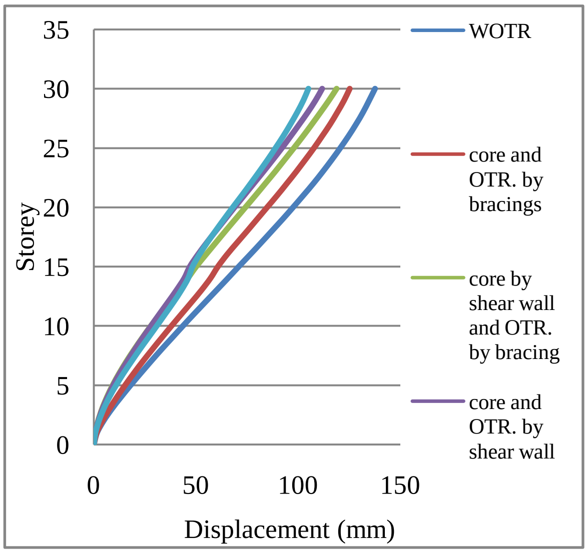

Figure 12: Comparison of Displacement from Different Structural Property Combinations of Outrigger System Due to EQ

Table 6: Comparison of Displacement Due to Wind in, for Different Combinations of Structural Elemental Properties to the Building and Outrigger System at H/H1=2

S.No	*Type*	*Maximum displacement (mm)*	*Reduction (%)*
1	Building without outrigger	162.2	-
2	Building with core and outrigger system by bracings	127.8	21.21
3	Building with core by shear wall and outrigger system by bracing	92.7	42.85
4	Building with core and outrigger system by shear wall	80.3	50.49
5	Building exterior panel and outrigger by shear wall	75.4	53.51

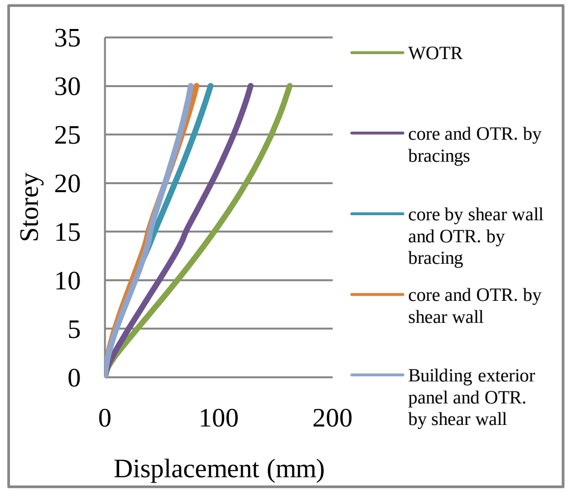

Figure 13: Comparison of Displacement from Different Structural Property Combinations of Outrigger System Due to Wind

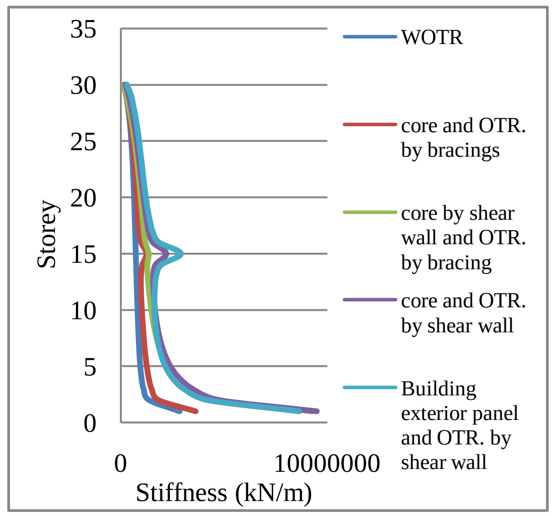

Figure 14: Comparison of Storey Stiffness from Different Structural Property Combinations of Outrigger System Due to EQ

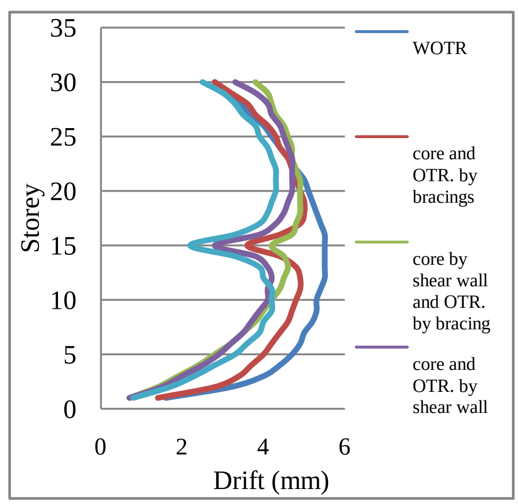

Figure 15: Comparison of Storey Drifts from Different Structural Property Combinations of Outrigger System Due to EQ

Table 7: Comparison of Displacement Due to EQX, for Different Combinations of Structural Elemental Properties to the Building and Outrigger System at H/H1=1.78

S.No	*Type*	*Maximum displacement (mm)*	*Reduction (%)*
1	Building without outrigger	183.7	-
2	Building with core and outrigger system by bracings	169.9	7.51
3	Building with core by shear wall and outrigger system by bracing	169.6	7.68
4	Building with core and outrigger system by shear wall	166.5	9.36
5	Building exterior panel and outrigger by shear wall	154.5	15.90

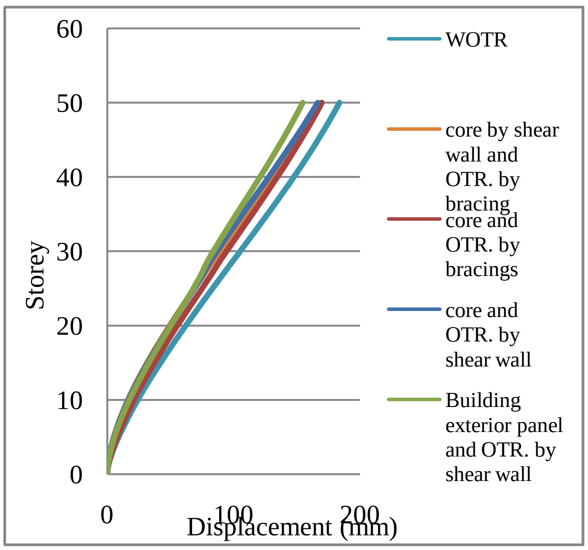

Figure 16: Comparison of Displacement from Different Structural Property Combinations of Outrigger System Due to EQ

Table 8: Comparison of Displacement due to wind, for Different Combinations of Structural Elemental Properties to the Building and Outrigger System at H/H1=1.78

S.No	*Type*	*Maximum displacement (mm)*	*Reduction (%)*
1	Building without outrigger	363.1	-
2	Building with core and outrigger system by bracings	330.9	8.87
3	Building with core by shear wall and outrigger system by bracing	279.1	23.13
4	Building with core and outrigger system by shear wall	265.9	26.77
5	Building exterior panel and outrigger by shear wall	237.5	34.59

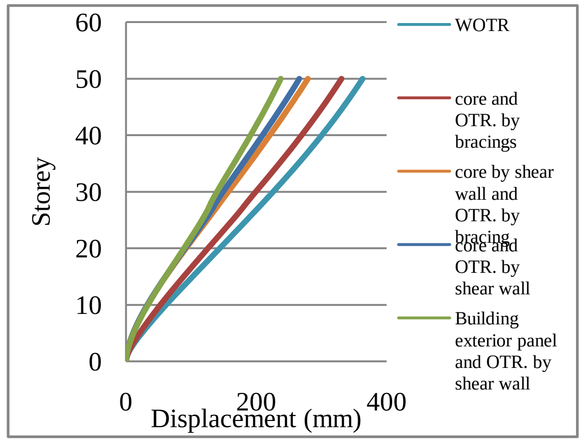

Figure 17: Comparison of Displacement from Different Structural Property Combinations of Outrigger System Due to Wind

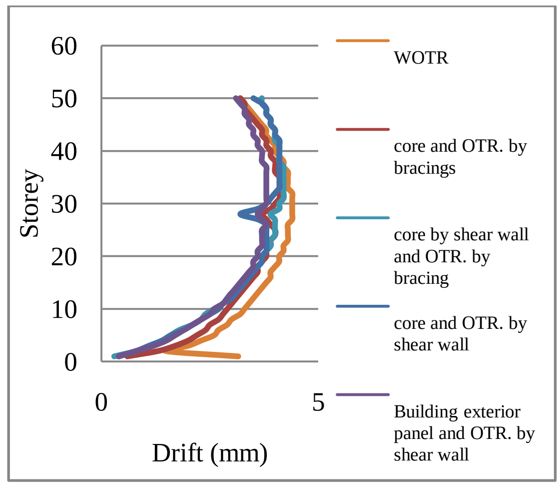

Figure 18: Comparison of Storey Drifts from Different Structural Property Combinations of Outrigger System Due to EQ

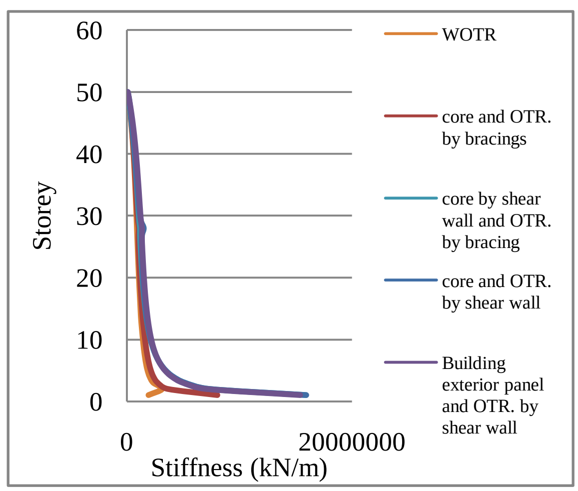

Figure 19: Comparison of Storey Stiffness from Different Structural Property Combinations of Outrigger System Due to Eq

IV. Summary and Conclusion

From the detailed study on performance of outrigger structural systems during lateral loads on high rise structures, of both 30 storey and 50 storey models following conclusions are arrived.

- Provision of outrigger structural system for high rise structures substantially increases structure stiffness and reduces lateral displacement, inter-storey drift against lateral loads, such as seismic i.e., earthquake and wind loads. The optimum location of outrigger structural system found to be for the buildings with
  - 30 storeys is at H/H1 = 2 (outrigger by bracing at top and 15th floor)
  - 50 storeys is at H/H1 = 1.78 (outrigger by bracing at top and 28th floor)
- As per IS 1893(part 1)2002 for earthquake loads lateral displacement should be less than H/250 which is 360mm and 600mm for 30 storey and 50 storey buildings respectively. Using outrigger structural system there is considerable reduction in lateral displacement.

For 30 Storeys Building

- Maximum displacement without outrigger = 146.5mm
- Maximum displacement using building core and outrigger by bracing = 130.3mm
- Maximum displacement using building exterior panel and outrigger by shear wall = 107.3mm
- There will be reduction of 11% in lateral displacement using outriggers by bracings, where as in building exterior panel and outrigger by shear wall reduction is about 27%

For 50 Storeys Building

- Maximum displacement without outrigger = 189.9mm
- Maximum displacement using building core and outrigger by bracing = 173.2mm
- Maximum displacement using building exterior panel and outrigger by shear wall = 155.7mm
- There will be reduction of 9% in lateral displacement using outriggers by bracings, where as in building exterior panel and outrigger by shear wall reduction is about 18%
  - As per IS 875(part 3)1987 for wind load maximum allowable lateral displacement is 1/500 x H, that is 180mm and 300 mm for 30 storey and 50 storey buildings respectively. Using outrigger structural system there is considerable reduction in lateral displacement.

For 30 Storeys Building

- Maximum displacement without outrigger = 190.4m
- Maximum displacement using building core and outrigger by bracing = 140.9mm
- Maximum displacement using building exterior panel and outrigger by shear wall = 79.5mm
- There will be reduction of 22% in lateral displacement using outriggers by bracings, where as in building exterior panel and outrigger by shear wall reduction is about 53%

For 50 Storeys Building

- Maximum displacement without outrigger = 376.9mm
- Maximum displacement using building core and outrigger by bracing = 340.6mm
- Maximum displacement using building exterior panel and outrigger by shear wall = 242.2mm
- There will be reduction of 10% in lateral displacement using outriggers by bracings, where as in building exterior panel and outrigger by shear wall reduction is about 35%
  - As per IS 1893 (part-1): 2002 the inter-storey drift should not exceed 0.004 times the storey height, due to minimum specified design lateral load with partial load factor of 1. That is 12mm for both 30 and 50 storeys building. The maximum inter-storey drift out of two buildings found as 5.8 mm.
  - The increase in storey stiffness found out to be more for building exterior panel and outrigger by shear wall to without outrigger buildings. It is around 4.7 times and 2.6 times increase of storey stiffness for 30 storey and 50 storey buildings respectively. When compared with building exterior panel and outrigger by shear wall to without outrigger buildings.

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