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# Performance of Different Shapes of Building with Different Positions, Shapes of Outrigger System

**Ms. S. S. Salkade, Mrs. P. A. Padalkadr**
Assistant Professor, Department of Civil Engineering
Guru Gobind Singh College of Engineering and Research Centre, Nashik, Maharashtra, India

**Abstract:** *In rapidly growing construction industry, to meet all structural safety demands, in tall buildings, some efficient systems like outriggers are proposed. Outrigger is the key structure component which reduces rotation in the building. It is an efficient system which depends on very simple principle but at the same time, its analysis and design, is very complicated in the practice. When the outrigger is incorporated in the building, it enhances as well as threatens the performance of structure in different ways. The main aim of this project is to understand the exact impact of the provision of the outrigger system in the tall building. For this purpose, 8 buildings with different specifications and different outrigger systems are modelled by using ETABS software and are analysed by using Response Spectrum Method. The overturning moments, maximum average displacements in building, drifts and bending moments in columns, axial force in columns are critically analysed to study the influence of outrigger system.*

**Keywords:** Outrigger System, ETABS, Response Spectrum Analysis

## I. INTRODUCTION

With rapid urbanization and economic growth, tall building has become a symbol of wealth. Also, with the enormous availability of developed construction technologies and materials, tall building construction has been increased especially in urban region all over the world.

In the tall buildings, as the height increases, stability and stiffness of the building become major issues. Generally, these buildings are subjected to the lateral loads due to earthquake and wind. These forces can generate undesirable stresses in the building. To enhance its performance against the lateral loadings, it is utmost important that the structures - with the help of some lateral force resisting system - should be safeguarded against the undesirable lateral forces. To effectively control the deformities in the building and to enhance its performance, provision of outrigger system between the stiff interior shear core and the exterior columns is the best solution.

Outriggers are the stiff horizontal members in the tall structure, precisely designed to withstand lateral loading. Generally, the structural arrangement of this system consists of centrally placed stiff concrete core and outriggers extending outside, towards the peripheral columns. This column restrained outrigger system resists the undesirable rotation in the structure due to lateral loads.

Jianguo Nie et al (1) in 2013 did the experimental study on the seismic behaviour of K-style steel outrigger truss to concrete core tube wall joints. They concluded that the composite joints could transfer the load reliably and exhibit favourable seismic performance. Andres Tovar et al (2) in 2014, studied the placement of the outrigger system, by using the topology optimization. They concluded that, the complications due to the wind load reduces to a large extent by using outrigger systems. Osama Ahmed et al (3) in 2016 studied the mitigation of the collapse in the building structure by using outrigger system. They concluded that, the provision of outrigger system, effectively mitigates the disproportionate collapse of the building due to primary load carrying members. David P. Dilrukshie et al (4) in 2017 studied the interaction between outrigger-belt system and structural frames in high-rise buildings having composite columns. They concluded that, the connections between of outrigger walls and peripheral columns can minimize the adverse effects of differential axial shortening. Huanjun Jiang et al (5) in 2017 introduced energy dissipating outrigger system. In this they used outriggers with buckling restraining braces. They concluded that, this energy dissipating outrigger system, provides more seismic resistance.

Outrigger is an efficient system which depends on very simple principle but at the same time, its analysis and design is very complicated in the practice. When the outrigger is incorporated in the building, it enhances as well as threatens the performance of structure in different ways.

## II. MODELLING

To understand the exact impact of the provision of the outrigger system in building and to study the uneven and irrational behaviour of the structure, 8 RC buildings with different specifications and 3 different outrigger systems are modelled by using ETABS software and analysed by using Response Spectrum method. All these 8 buildings are grouped in to 2 cases with buildings differing in heights and plan dimensions. The detailed specifications of buildings, positions of outriggers and lateral loadings are as shown in tables below

| No | Content | Case A | Case B |
|---|---|---|---|
| 1 | Length (m) | 35 | 35 |
| 2 | Width (m) | 35 | 35 |
| 3 | Height (m) | 90 | 180 |
| 4 | Concrete | M45 | M45 |
| 5 | Steel | Fe 500 | Fe 500 |
| 6 | Column Sizes(mm) | 650X650, 550X550, 450X450 | 1550X1550, 1450X1450, 1350X1350, 1250X1250, 1150X1150, 1050X1050 |
| 8 | Outrigger | 300x300x50 | 300x300x50 |
| 9 | Shear Wall Thickness (mm) | 200 | 200 |
| 10 | Shear Wall material | M60 | M60 |

Table 1 General specifications of the buildings

| **Outrigger Levels** | | |
|---|---|---|
| 1. | Single outrigger system | (H/2) (from top) |
| 2. | Double outrigger system | H/3, 2H/3 (from top) |
| 3. | three outrigger system | H/4, H/2, 3H/4 (from top) |

Table 2 Position of outriggers

| **Earthquake Load (Is 1893: 2016)** | | |
|---|---|---|
| 1. | Earthquake Zone | 3 |
| 2. | Z | 0.16 |
| 3. | Response Reduction Factor(R) | 5 (SMRF BUILDING) |
| 4. | Importance Factor | 1.2 |
| 5. | Time Period | 1.36sec |
| 6. | Soil Type | 2 (Medium or Stiff Soil) |
| **Wind Load (Is 875: 2015)** | | |
| 1. | Basic Wind Speed | 50m/Sec |
| 2. | Terrain Category | 4 |

Table 3 Details of Lateral loading Fig 1 and Fig2 are the schematic diagrams of the models.

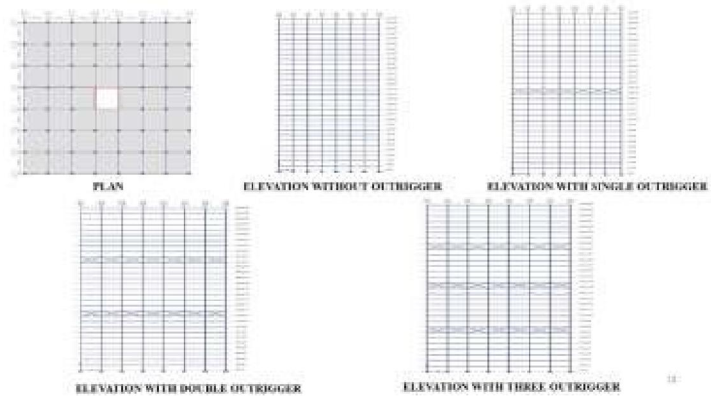


Fig 1 Plan and elevations for case A type building

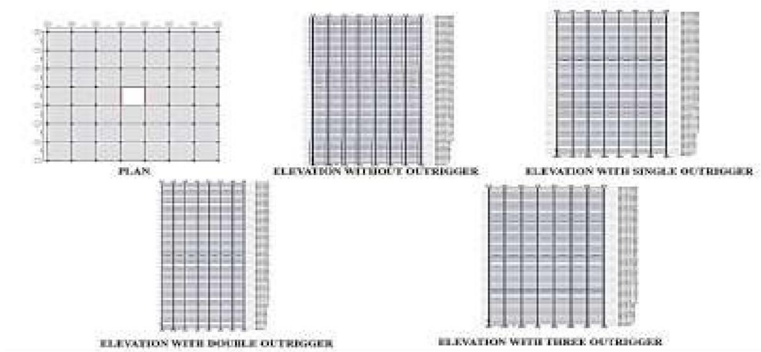


Fig 2 Plan and elevations for case B type building

## II. Results And Observations

### 2.1 Storey Displacement

The maximum storey displacements in all buildings are as shown in Fig-3 , Fig-4Table 4 and table 5 give the reduction in the maximum storey displacement for all different cases.

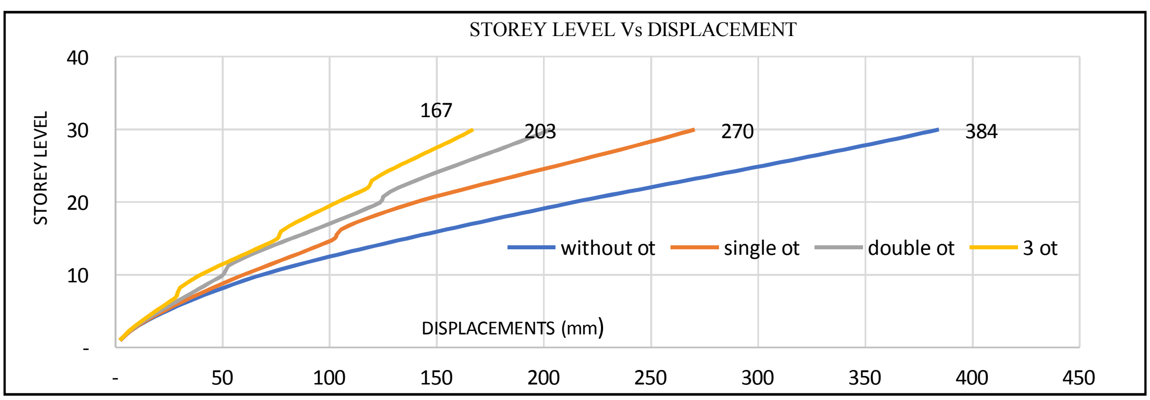


Fig. 3 Displacement reduction for case A

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| No | Condition | Displacements | Reduction |
|---|---|---|---|
| | | mm | % |
| 1 | Without Outrigger | 384 | |
| 2 | With Single Outrigger | 270 | 30 |
| 3 | With Double Outrigger | 203 | 47 |
| 4 | With Three Outrigger | 167 | 57 |

Table 4 Storey displacement reduction (case A)

CASE A: As per IS 1893, maximum allowable displacement is 360mm. So, from figures we can say that the safety conditions can be achieved after provision of single outrigger system.

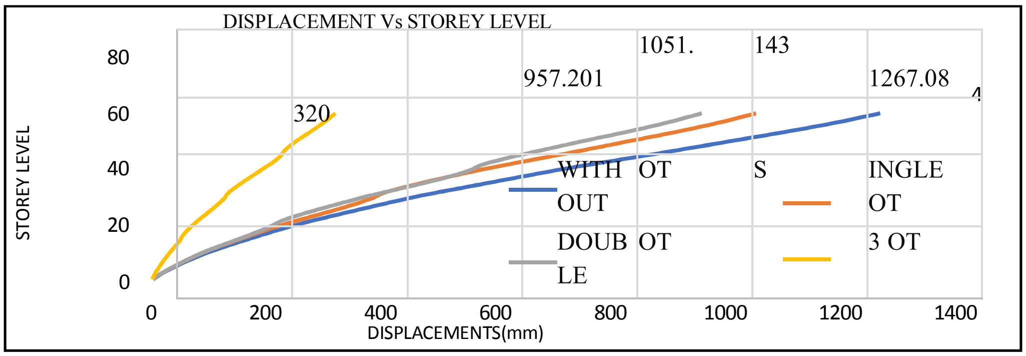


Fig. 4 Displacement reduction for case B

| No | Condition | Displacements | Reduction |
|---|---|---|---|
| | | mm | % |
| 1 | Without Outrigger | 1,267 | |
| 2 | With Single Outrigger | 1,051 | 17 |
| 3 | With Double Outrigger | 957 | 24 |
| 4 | With Three Outrigger | 320 | 75 |

Table 5 Storey displacement reduction (case B)

CASE B: Similarly, as per IS 1893, maximum allowable displacement is 720 mm. So, the safety conditions can be achieved after provision of three outrigger system

Now, let us see the impact of outrigger on the overturning moment in the building.

### 2.2 Overturning Moments

When the outrigger system is introduced in the building, it tends to form a reversible moment restraining couple. Due to this, the overturning moment in the building reduces to some extent. Table-6, Table -7give the comparison of the overturning moment for all different cases.

| No | Condition | Overturning | Reduction |
|---|---|---|---|
| | | kN-m | % |
| 1 | Without Outrigger | 13414984 | |
| 2 | With Single Outrigger | 13114984 | 4 |
| 3 | With Double Outrigger | 8583264 | 36 |
| 4 | With Three Outrigger | 7672060 | 42 |

Table 6 overturning moments reduction (case A)

| No | Condition | Overturning | Reduction |
|---|---|---|---|
| | | kN-m | % |
| 1 | Without Outrigger | 5,72,66,830 | |
| 2 | With Single Outrigger | 4,00,20,774 | 30 |
| 3 | With Double Outrigger | 3,33,21,683 | 42 |
| 4 | With 3 Outrigger | 2,64,09,452 | 54 |

Table 7 overturning moments reduction (case B)

In all the 2 cases, after provision of three outrigger system, 40% to 50% overturning moment gets reduced.

**2.3 Drifts**

The drifts in buildings for all three cases, are as shown in figures 5, & 6.

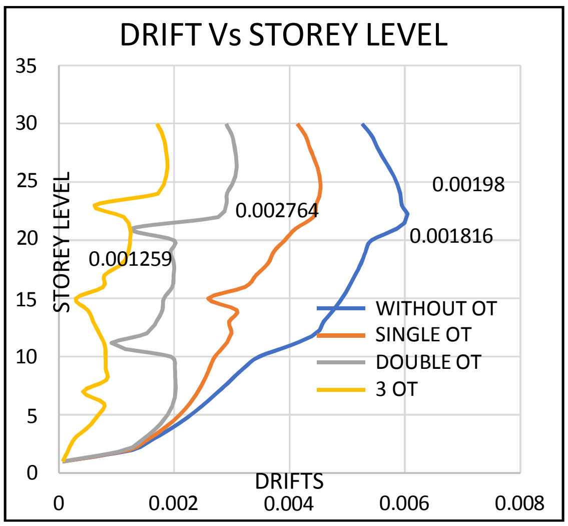


Fig. 5 Storey drifts for case A

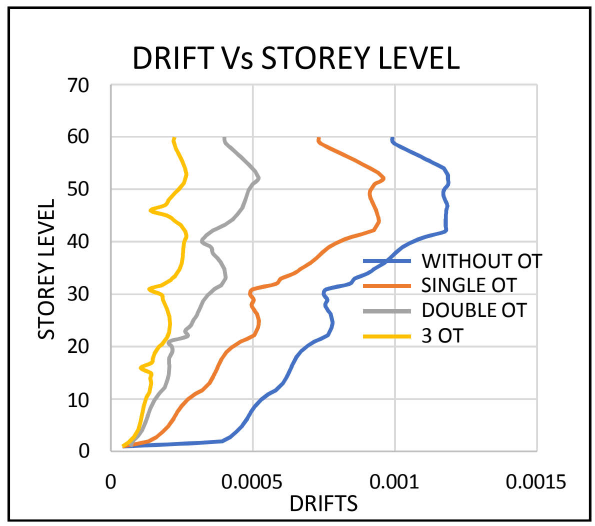


Fig. 6 Storey drifts for case B

In all the 2 cases after provision of outrigger systems, there is reduction in drift and maximum reduction occurs when three outrigger system is provided. The maximum drifts in all buildings are well within limits i. e. (0.004xh) stated by IS 1893

**2.4 Moments In Column**

Due to the provision of outrigger, moment in the column reduces. Table 8, gives the comparison of the moments for one exterior and one interior column for all different cases at the **base** level.

| Building Type | Particulars | without outrigger | | Single outrigger | | Double outrigger | | Three outriggers | |
|---|---|---|---|---|---|---|---|---|---|
| | | Interior | exterior | Interior | exterior | Interior | exterior | Interior | exterior |
| | | (kN-m) | (kN-m) | (kN-m) | (kN-m) | (kN-m) | (kN-m) | (kN-m) | (kN-m) |
| CASE A | Capacity | 185 | 185 | 185 | 185 | 185 | 185 | 185 | 185 |
| | Demand | 362 | 456 | 289 | 358 | 216 | 251 | 143 | 165 |
| | D/C Ratio | 1.96 | 2.46 | 1.56 | 1.94 | 1.17 | 1.36 | 0.77 | 0.89 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | % Reduction in demand | | | 20 | 21 | 40 | 45 | 60 | 64 |
| **CASE B** | Capacity | 3351 | 3351 | 3351 | 3351 | 3351 | 3351 | 3351 | 3351 |
| | Demand | 12732 | 12745 | 12686 | 12691 | 5740 | 5823 | 2234 | 2188 |
| | D/C Ratio | 3.80 | 3.80 | 3.79 | 3.79 | 1.71 | 3.79 | 0.67 | 0.65 |
| | % Reduction in demand | | | 0.36 | 0.42 | 54.92 | 54.31 | 82.45 | 82.83 |

Table 8 comparison of moments in columns

From the above table we can observe that, after provision of three outrigger system, maximum safety conditions can be achieved. Till now, we have observed that, the excellent performance of the building can be achieved after provision of three outrigger systems or double outrigger systems. So now, with same outrigger systems (i.e. three outrigger system and double outrigger system) let us check the performance of all buildings for the following factors.

### 2.5 Axial Forces in Columns

Outrigger system helps to restrain the rotation of the core by converting the part of the moment in the core into a vertical couple and the part of external moment is resisted by axial compression and tension in the exterior columns. Thus, there is increase in the axial forces in the column. Table 9, gives the axial forces for exterior and interior columns for all 3 cases at the **base level**. The (demand/capacity) ratios of these columns are compared when building is without outrigger and when the three-outrigger system is incorporated in the building.

| Building Type | Condition | Position | Demand` (kN) | Capacity (kN) | D/C | Comment |
|---|---|---|---|---|---|---|
| **CASE A** | Without Outrigger | Exterior | 6475 | 13974 | 0.46 | Increase In D/C Ratio |
| | | Interior | 7694 | 13974 | 0.55 | |
| | Three Outrigger System | Exterior | 13060 | 13974 | **0.93** | |
| | | Interior | 15631 | 13974 | **1.11** | |
| **CASE B** | Without Outrigger | Exterior | 10689 | 79463 | 0.13 | Increase In D/C Ratio |
| | | Interior | 12072 | 79463 | 0.15 | |
| | Three Outrigger System | Exterior | 56888 | 79463 | **0.71** | |
| | | Interior | 72630 | 79463 | **0.91** | |
| | | Interior | 4479 | 18604 | 0.24 | |
| | Three Outrigger System | Exterior | 13279 | 18604 | **0.71** | |
| | | Interior | 11486 | 18604 | **0.61** | |

Table 9 comparison of axial forces in columns

From the table we can observe that, previously, with the three-outrigger system, building has achieved maximum safety conditions and now with the same outrigger system, the performance of the building has dropped down to large extent.

### 2.6 Moments In Column

As we have seen above in table outrigger system helps to restrain the moments in the columns by formation of moment restraining couple. The moments in columns with three outrigger system are very less as compared to the building without outrigger system and well within safety limits at all levels. But at the same time, there is sudden change in the moments in the column which are at the level of outrigger and moments in the columns which are above and below the outrigger level. The moments in the columns at the level of outrigger system suddenly increase and are much more as compare to the moments in the columns which are above and below the outrigger level. Sometimes, these suddenly increased moments might exceed the moment carrying capacity of the column at that level. Table 10 gives the column moments for exterior and interior columns for case B above, below and at the level of outrigger at (H/2 = at 30th floor). The (demand/capacity) ratios of these columns are compared when building is without outrigger and when the Three-outrigger system is incorporated in the building.

| Building | | Location | Demand | Capacity | D/C |
|---|---|---|---|---|---|
| CASE B | Without Outrigger System | Above Outrigger (at 31st floor) | 3,997 | 2,737 | 1.46 |
| | | At the Outrigger (H/2= at 30th floor) | 4,034 | 2,737 | 1.47 |
| | | Below Outrigger (at 29th floor) | 4,234 | 3515 | 1.20 |
| | Three Outrigger System | Above Outrigger (at 31st floor) | 1,039 | 2,737 | 0.37 |
| | | At the Outrigger (H/2= at 30th floor) | 2,942 | 2,737 | 1.07 |
| | | Below Outrigger (at 29th floor) | 1,124 | 3515 | 0.32 |

Table 10 comparison of moments in columns at the level of outrigger

From the table we can observe that, due to the provision of 'three-outrigger system', there is good amount of reduction in the column moments just above, below and at the level of outrigger at (H/2), as compare to building 'without outrigger system', But at the same time there is sudden change in moment in columns at (H/2) so that, it exceeds the moment carrying capacity of the column at that level.

### 2.7 Interstorey Drift

As we have seen before, after provision of 'double outrigger system', the maximum drifts in the building are well within the permitted limits for both case A and case B. Now, let us focus on the storey drifts in case A and case B buildings with 'double outrigger system' at the level of topmost outrigger at (H/3) from top and the storey just below that. Similarly consider the same storeys in building 'without outrigger' (As shown in fig.5 & Fig6). The respective drifts in these four storeys and difference between their drifts is shown in the table 11 below, for all the two cases.

| Building Type | Condition | Location | Drift | %Change |
|---|---|---|---|---|
| CASE A | Without outrigger system | at outrigger | 0.00198 | 8.28 |
| | | below outrigger | 0.001816 | |
| | Double outrigger system at (H/3) | at outrigger | **0.002764** | 54.45 |
| | | below outrigger | **0.001259** | |
| CASE B | Without outrigger system | at outrigger | 0.0087885 | 7.54 |
| | | below outrigger | 0.0081255 | |
| | Double outrigger system at (H/3) | at outrigger | **0.004746** | 60.20 |
| | | below outrigger | **0.0018885** | |

Table 11 comparison of storey drifts

From the table, we can observe that, the difference between the drifts in the storey at the level of topmost outrigger at (H/3) from top and the storey just below that suddenly increases as compare to the same storeys in building 'without outrigger'. This sudden change if exceeds 60%, may results in the formation of soft storey.

So, from all the above observations we can say that

## III. Conclusion

1. In all cases i.e. Case A, Case B, as we increase the number of outrigger systems, there is a decrease in the maximum storey displacements, overturning moments, and moments in the column., Along with that, there is an increase in the axial forces in the column as compared to the building in which outrigger system is not provided.
2. In a building having greater height, (Case B) provided with single outrigger system, initially, the reduction in the displacements and moments in columns is negligible. But with increase in the number of outriggers, we can achieve maximum reduction as compare to other two buildings.

3. Outrigger can enhance the performance of the structure by bringing out reduction in overall maximum displacements, overturning moments and drifts.
4. But at the same time, the safety of the structure is threatened due to increase in axial forces, sudden increase in column moments, and possibility of formation of soft storey.

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