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OPTIMUM OUTRIGGER LOCATION IN OUTRIGGER STRUCTURAL SYSTEM FOR HIGH RISE BUILDING

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***Abstract** - In modern tall buildings, lateral loads induced by wind or earthquake are often resisted by a system of coupled shear walls. But when the building increases in height, the stiffness of the structure becomes more important and introduction of outrigger beams between the shear walls and external columns is often used to provide sufficient lateral stiffness to the structure. The outrigger and is commonly used as one of the structural system to effectively control the excessive drift due to lateral load, so that, during small or medium lateral load due to either wind or earthquake load, the risk of structural and non-structural damage can be minimized. For high-rise buildings, particularly in seismic active zone or wind load dominant, this system can be chosen as an appropriate structure. The objective of this thesis is to study the outrigger location optimization and the efficiency of each outrigger when three outriggers are used in the structure. In 40−storey three dimensional models of outrigger and belt truss system are subjected to wind and earthquake load, analyzed and compared to find the lateral displacement reduction related to the outrigger and belt truss system location.*

***Keywords –** Highrise Structure; Outrigger; Belt Truss; Multiple Outgigger; Optimum Location; Static Analysis.*

I. INTRODUCTION

Tall building development has been rapidly increasing worldwide introducing new challenges that need to be met through engineering judgment. In modern tall buildings, lateral loads induced by wind or earthquake are often resisted by a system of coupled shear walls. But when the building increases in height, the stiffness of the structure becomes more important and introduction of lateral load resisting system is used to provide sufficient lateral stiffness to the structure. The lateral load resisting system effectively control the excessive drift due to lateral load, so that, during small or medium lateral load due to either wind or earthquake load, the risk of structural and non-structural damage can be minimized. For high-rise buildings, particularly in seismic active zone or wind load dominant, this system are chosen as an appropriate structure.

1.1. Structural Concept.

The key idea in conceptualizing the structural system for a narrow tall building is to think of it as a beam cantilevering from the earth (fig. 1.1.). The laterally directed force generated, either due to wind blowing against the building or due to the inertia forces induced by ground shaking, tends both to shear, and bending.

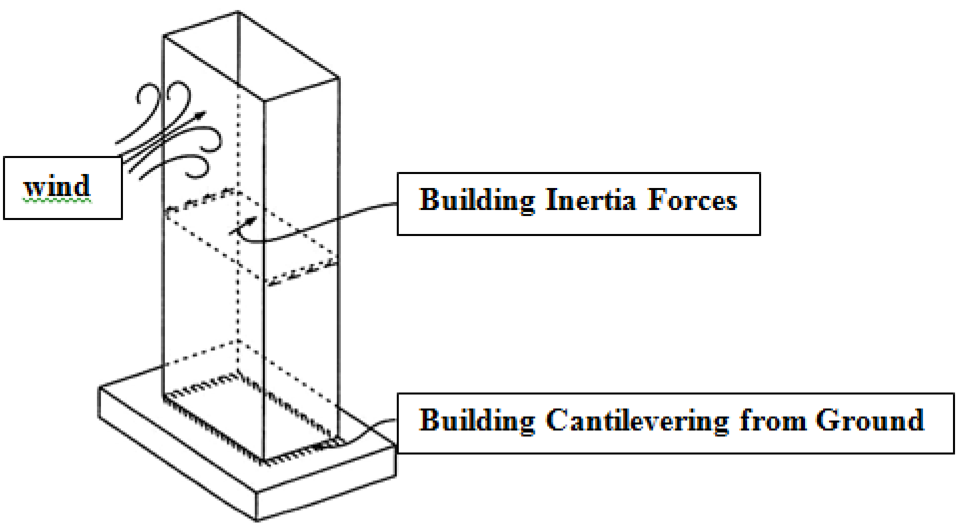
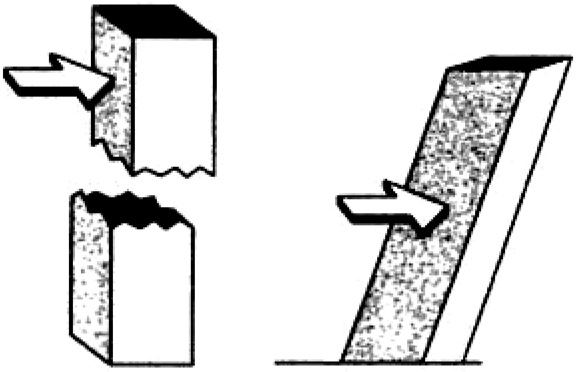


Figure 1.Structural Concept of Building.

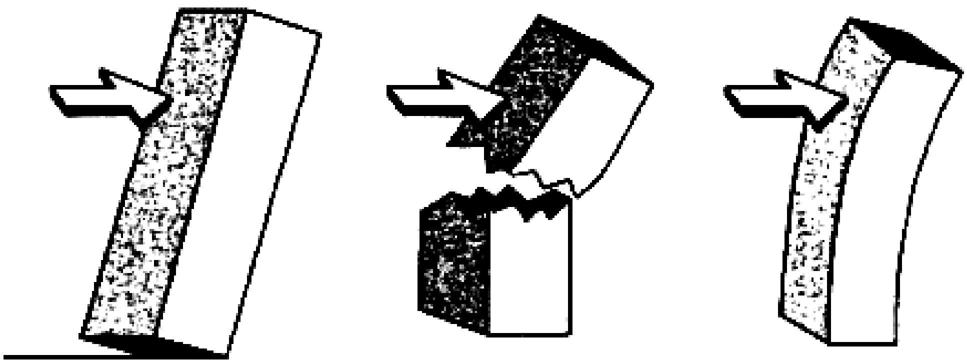
Therefore, the building must have a system to resist shear as well as bending. In resisting shear forces, the building must not break by shearing off (Fig.1.2.a), and must not strain beyond the limit of elastic recovery (Fig.1.2.b).



a) *Building should not break.*
b) *Building should not deflect.*

Figure 2.Building Shear Resistance.

Similarly, the system resisting the bending must satisfy three needs (Fig.1.3). The building must not overturn from the combined forces of gravity and lateral loads due to wind or seismic effects; it must not break by premature failure of columns either by crushing or by excessive tensile forces: its bending deflection should not exceed the limit of elastic recovery. In addition, a building in seismically active regions must be able to resist realistic earthquake forces without losing its vertical load carrying capacity.



a) Building must not overturn
b) Column should not fail in tension or compression
c) Building should not be exceed

Figure 3.Bending Resistance of Building.

1.2. Introduction to Outriggers.

Although outriggers have been used for approximately four decades, their existence as a structural member has a much longer history. Outriggers have been used in the sailing ship industry for many years. They are used to resist wind. The slender mast provides the use of outriggers. As a comparison the core can be related to the mast, the outriggers are like the spreaders and the exterior columns are like the shrouds or stays. Innovative structural schemes are continuously being sought in the field. Structural Design of High Rise Structures with the intention of limiting the Drift due to Lateral Loads to acceptable limits without paying a high premium in steel tonnage. The savings in steel tonnage and cost can be dramatic if certain techniques are employed to utilize the full capacities of the structural elements. Various wind bracing techniques have been developed in this regard; one such is an Outrigger System, in which the axial stiffness of the peripheral columns is invoked for increasing the resistance to overturning moments. This efficient structural form consists of a central core, comprising either Braced Frames or Shear Walls, with horizontal cantilever trusses or girders known as outrigger Trusses, connecting the core to the outer columns. The core may be centrally located with outriggers extending on both sides (Fig1.5) or it may be located on one side of the building with outriggers extending to the building columns on one side (Fig1.5).

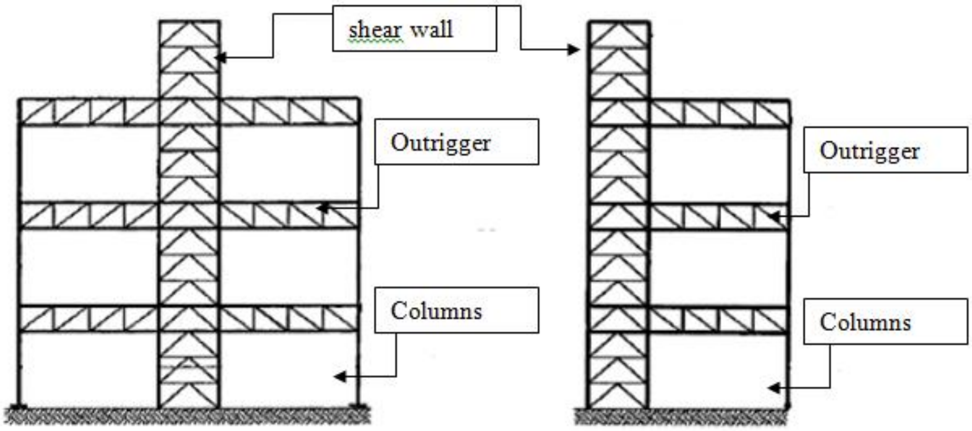


Figure 4. Outrigger System With Central Core & Offset Core.

1.4. Problems with Outriggers.

There are several problems associated with the use of outriggers, problems that limit the applicability of the concept in the real world:
1. The space occupied by the outrigger trusses (especially the diagonals) places constraints on the use of the floors at which the outriggers are located. Even in mechanical equipment floors, the presence of outrigger truss members can be a major problem.
2. Architectural and functional constraints may prevent placement of large outrigger columns where they could most conveniently be engaged by outrigger trusses extending out from the core.
3. The connections of the outrigger trusses to the core can be very complicated, especially when a concrete shear wall core is used.
4. In most instances, the core and the outrigger columns will not shorten equally under gravity load. The outrigger trusses, which need to be very stiff to be effective as outriggers, can be severely stressed as they try to restrain the differential shortening between the core and the outrigger columns. Elaborate and expensive means, such as delaying the completion of certain truss connections until after the building has been topped out, have been employed to alleviate the problems caused by differential shortening.

II. Objectives And Details Of The Present Study.

In the present context of study an R.C.C. structure is taken into consideration and the analysis is done as per the Indian standards. This building does not represent a particular real structure that has been built or proposed.
In this present study a total of ten different arrangements of outriggers analyzed using ETABS software are:

1. Structural Model without Outrigger.
2. Structural Model with One Outrigger at 40th storey.
3. Structural Model with One Outrigger at 30th storey.
4. Structural Model with One Outrigger at 20th storey.
5. Structural Model with One Outrigger at 10th storey.
6. Structural Model with 1stOutrigger at 20th storey and 2ndoutrigger at 40th storey.
7. Structural Model with 1stOutrigger at 20th storey and 2ndoutrigger at 30th storey.
8. Structural Model with 1stOutrigger at 20th storey and 2ndoutrigger at 10th storey.
9. Structural Model with 1stOutrigger at 20th storey, 2nd outrigger at 10th storey and 3rd at 40th storey.
10. Structural Model with 1stOutrigger at 20th storey, 2nd outrigger at 10th storey and 3rd at 30th storey.

The objective is to find the optimum outrigger location and the efficiency of each outrigger when two outriggers are used in the structure.

III. ANALYSIS OF A 40 STOREY BUILDING

The model considered for this study is 150m high rise reinforced concrete building frame. The building represents a 40 storied office building. The Plan area of the Structure is 42m x 42m with columns spaced at 6m from center to center. The height of each storey is 3m and all the floors are considered as Typical Floors. The location of the building is assumed to be at Vadodara. An elevation and plan view of a typical structure is shown in fig.

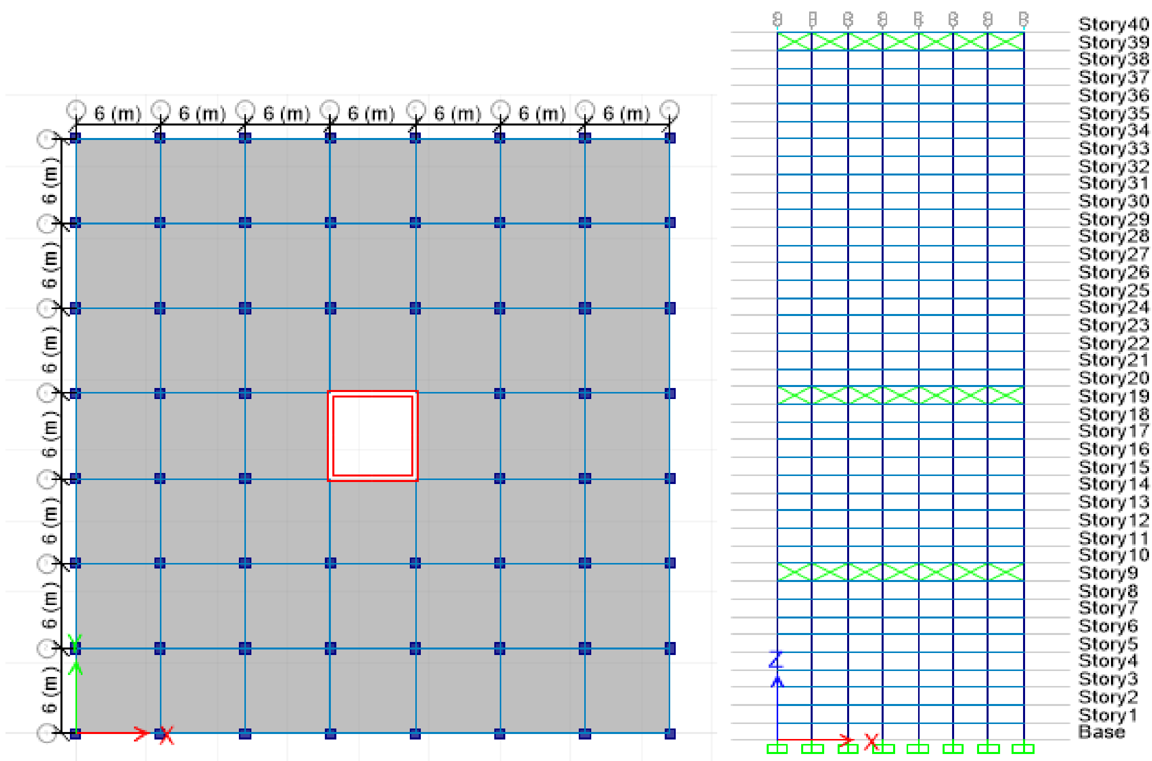


Figure 5. Plan Of Typical Storey.

All wall piers are identical with a uniform wall thickness of 350mm over the entire height. The Bracing beams (outriggers) and all other beams are 300mm wide and 600mm deep, Grade 50 concrete is considered (Compressive strength 50 N/mm²) throughout the height of the building. And number of stories considered for all the cases are 40 stories, and roof height is considered as 150m. And storey to storey height is 3.0 m. And the outer and inner columns sizes are considered as 750 x 750 mm and shear wall thickness is considered as 350 mm.

The method of analysis of the above mentioned system is based up on the assumptions that the outriggers are rigidly attached to the core; The core is rigidly attached to the foundation; The sectional properties of the core, beams and columns are uniform throughout the height; Tensional effects are not considered; Material behavior is in linear elastic range; The Outrigger Beams are flexurally rigid and induce only axial forces in the columns; The lateral resistance is provided only by the bending resistance of the core and the tie down action of the exterior columns connected to the outrigger; The rotation of the core due to the shear deformation is negligible.

Since the building is assumed to be a office building live load is considered as 3 kN/m². A floor load of 1kN/m² is applied on all the slab panels on all the floors for the floor finishes and the other things. A member load as u.d.l. of 6 kN/m is considered on all beams for the wall load considering the wall to be made of Light Weight Bricks. Wind load in this study is established in accordance with IS 875(part 3-Wind loads).

Earthquake load in this study is established in accordance with IS 1893(part 1)-2002.The city of Hyderabad falls in "zone 3" (Z=0.16). The importance factor (I) of the building is taken as 1.0. The site is assumed to be medium site (Type II). The response reduction factor R is taken as 5.0 for all frames. The fundamental time period (T_a) of all frames was calculated as per clause 7.6.1 of the aforementioned code.

$$\mathbf{Ta = 0.075*h^{0.75}}$$

Based on the above data the **ETABS** calculates the design horizontal seismic coefficient (A_h) using the Sa/g value from the appropriate response spectrum. The A_h value calculated is utilized in calculating the design seismic base shear (V_B) as,

$$V_B = A_h * W.$$

Where, W = seismic weight of the building.

The design seismic base shear so calculated is distributed along the height of the building as per the expression,

$$Qi = VB * (Wi*hi2)*(\Sigma Wj*hj2)^{-1}$$

Where, Q_i = Design lateral force at floor i.
W_i= seismic weight of the floor i
h_i= height of the floor I measured from base j = 1 to n,
n being no. of floors in the building at which masses are located.

The structure is analyzed as per the loading combinations provided in IS: 456-2000. The following load combinations are used to determine the maximum lateral deflection in the structure.

i) DL+LL
ii) DL+LL±WL$_{(x\ or\ y)}$
iii) DL+LL±EL$_{(x\ or\ y)}$
iv) DL±WL$_{(x\ or\ y)}$
v) DL±EL$_{(x\ or\ y)}$

The structure with above mentioned specifications and assumptions is analyzed using the program ETABS and bending moments, shear forces, lateral deflections are calculated for both Wind & Earthquake loading. Since the wind load cases are governing, the graph and tables are represents the same. The structure with above mentioned specifications and assumptions is analyzed using the program ETABS and bending moments, shear forces, lateral deflections are calculated for both Wind & Earthquake loading. Since the wind load cases are governing, the graph and tables are represents the same.

IV. RESULTS & DISCUSSION

4.1. Displacement

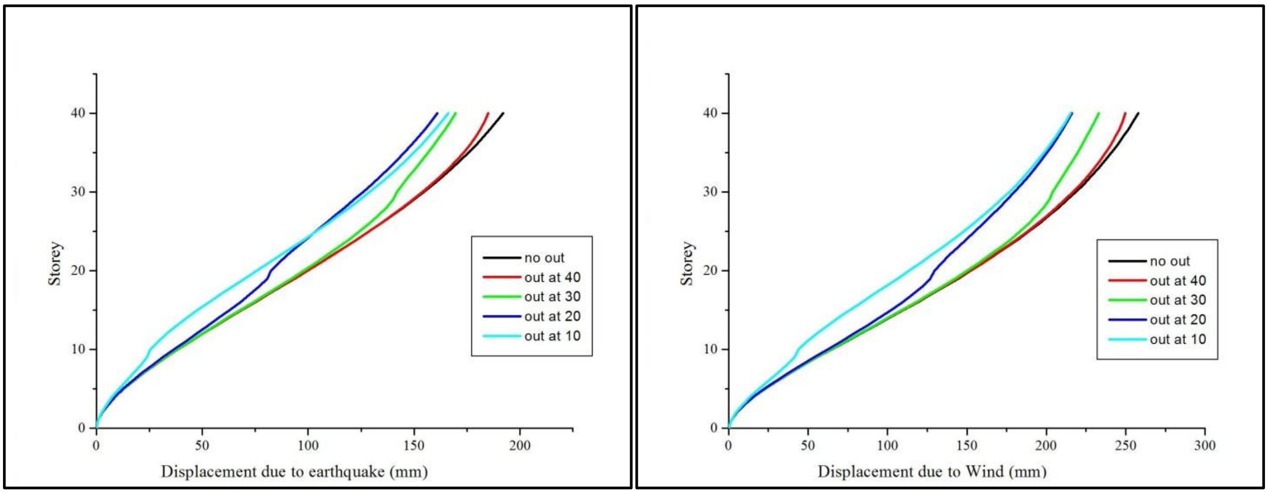


Figure 5. Displacement Due to Earthquake &Wind(mm) (single outrigger).

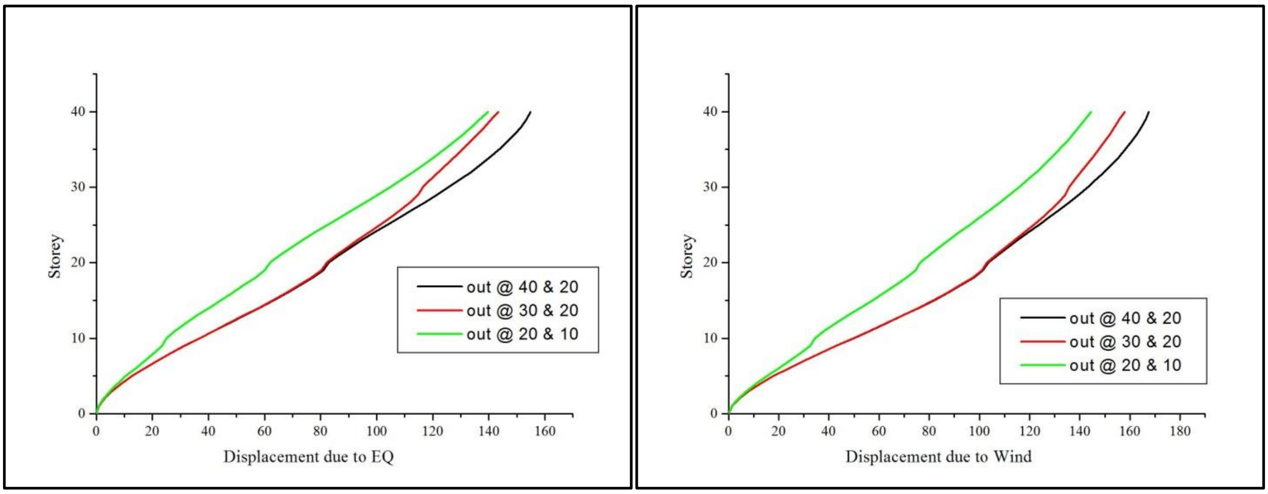


Figure 6. Displacement Due to Earthquake &Wind(mm) (double outrigger).

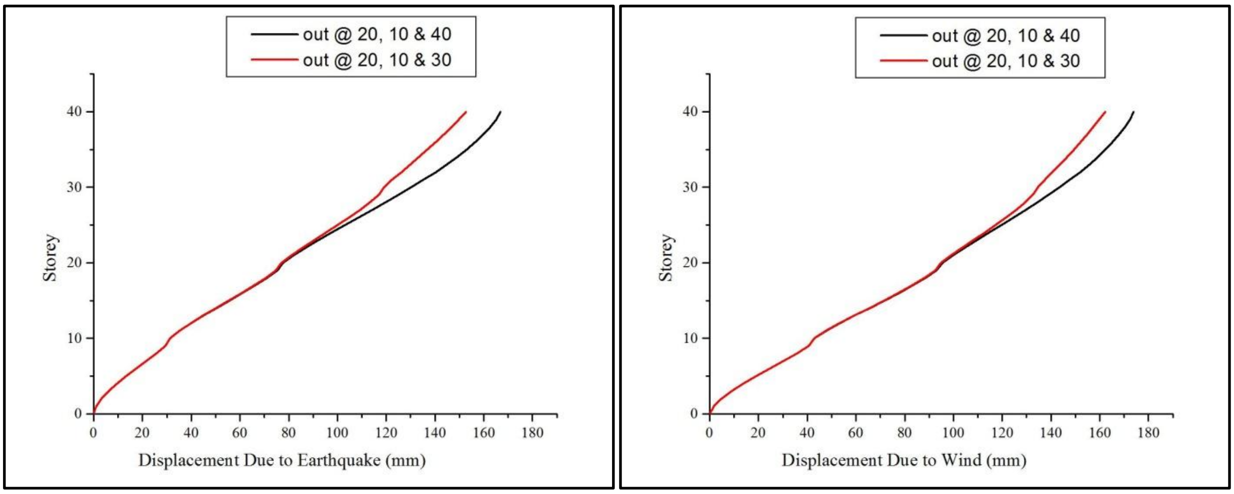


Figure 7. Displacement Due to Earthquake &Wind(mm) (triple outrigger).

4.2. Shear force

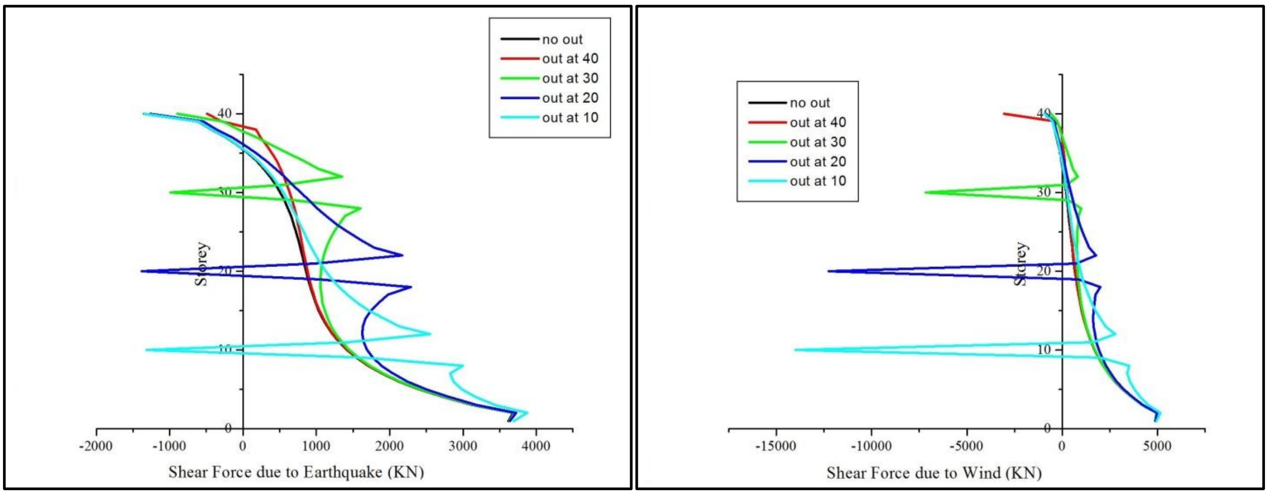


Figure 8. Shear Force due to Earthquake &Wind(KN) (single outrigger).

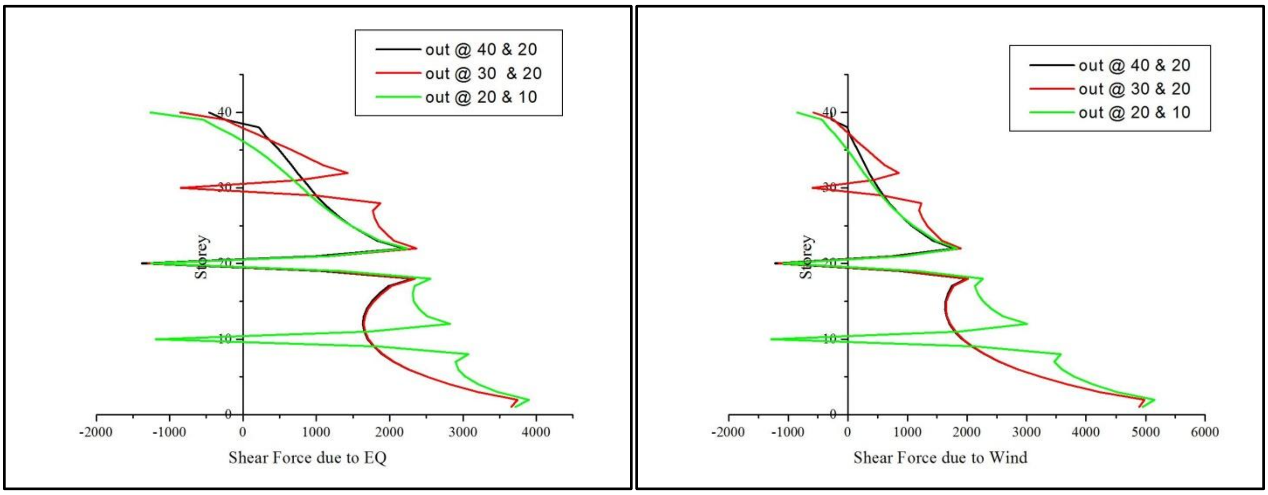


Figure 9. Shear Force Due to Earthquake &Wind(KN) (double outrigger).

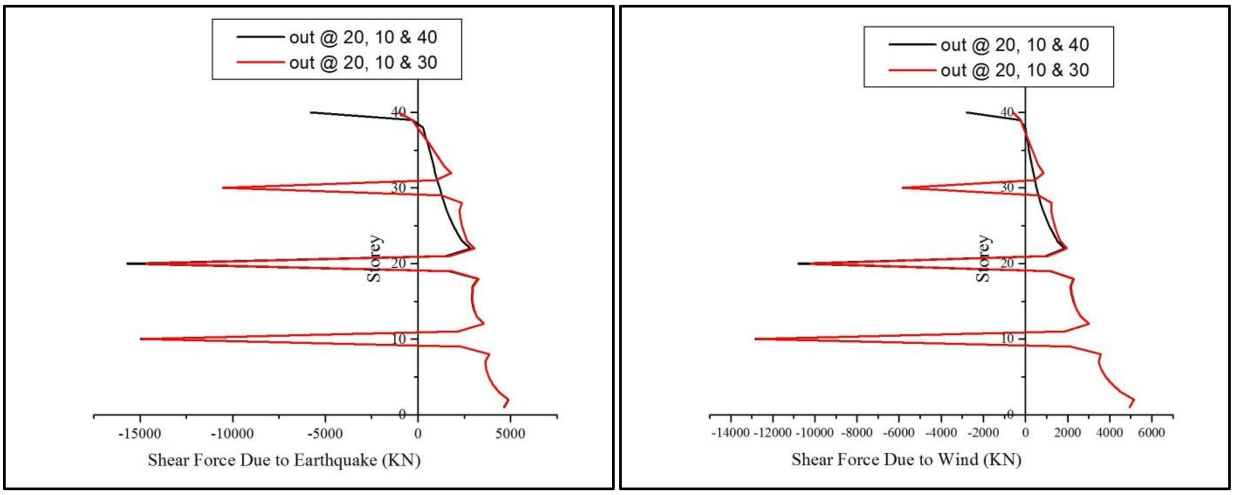


Figure 10.Shear Force Due to Earthquake & Wind(KN) (triple outrigger).

4.3. Bending Moment

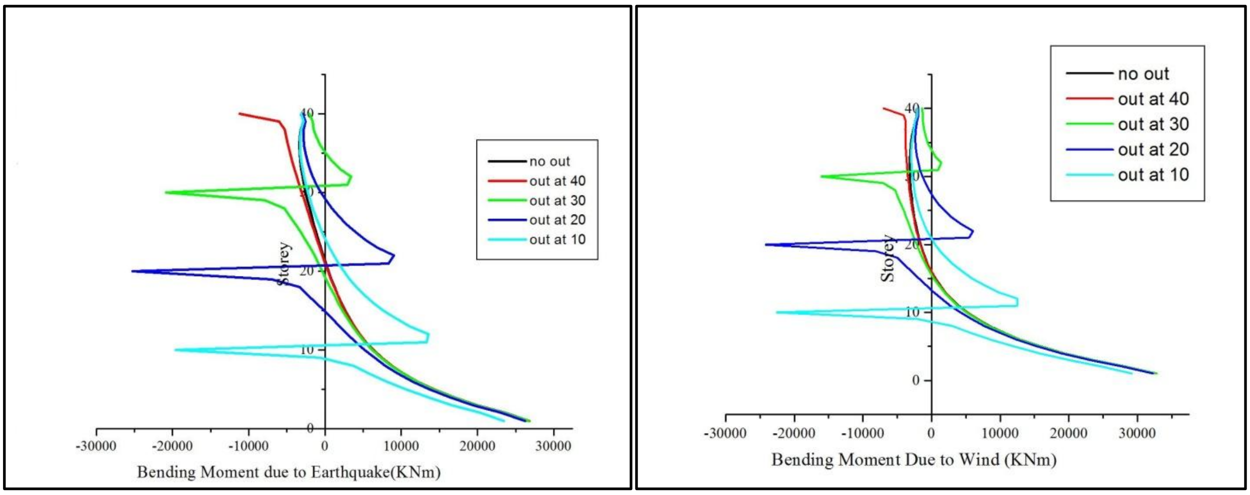


Figure 11. Bending Moment Due to Earthquake &Wind(KNm) (single outrigger).

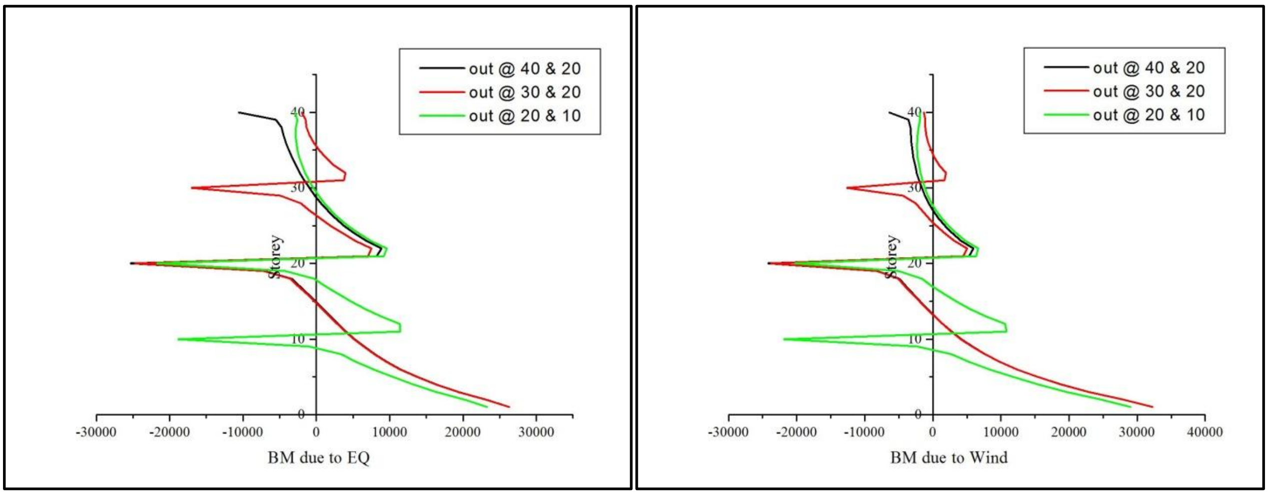


Figure 12.Bending Moment Due to Earthquake & Wind (KNm) (double outrigger).

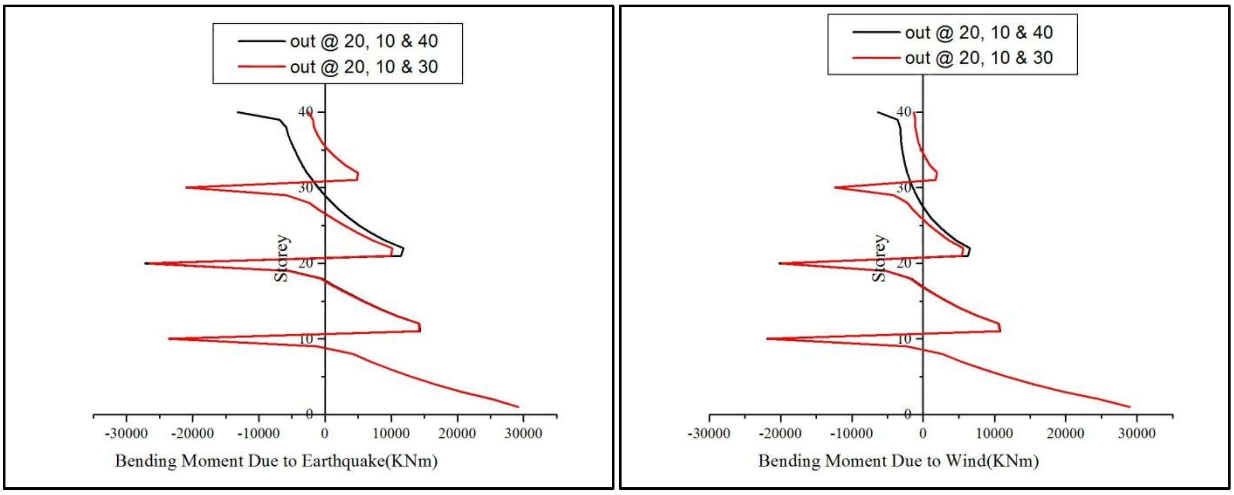


Figure 13.Bending Moment Due to Earthquake & Wind (KNm) (triple outrigger).

4.4. Drift Index

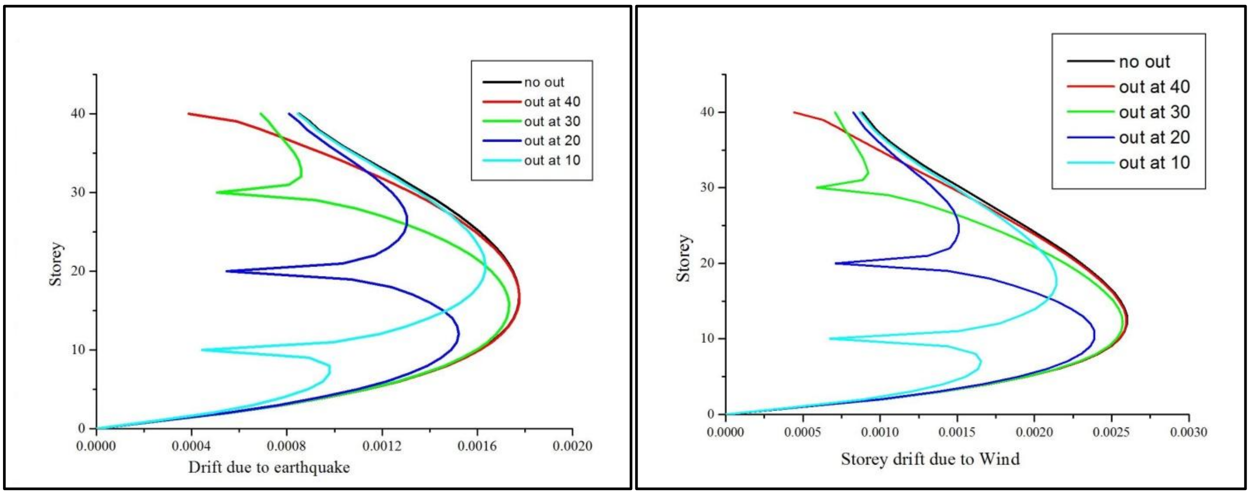


Figure 14.Drift Index Due to Earthquake & Wind (single outrigger).

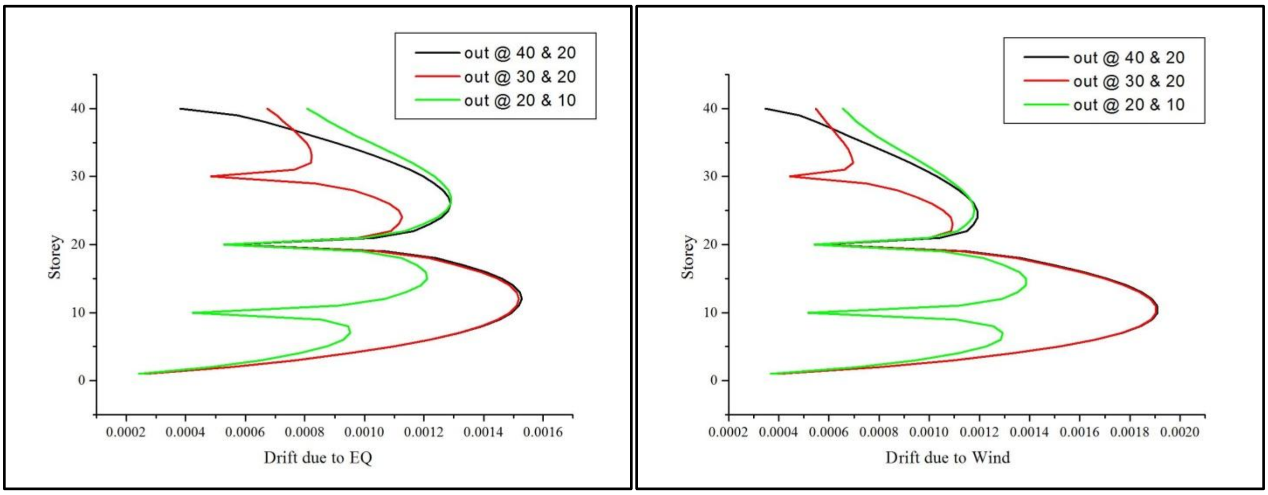


Figure 15.Drift Index Due to Earthquake & Wind (double outrigger).

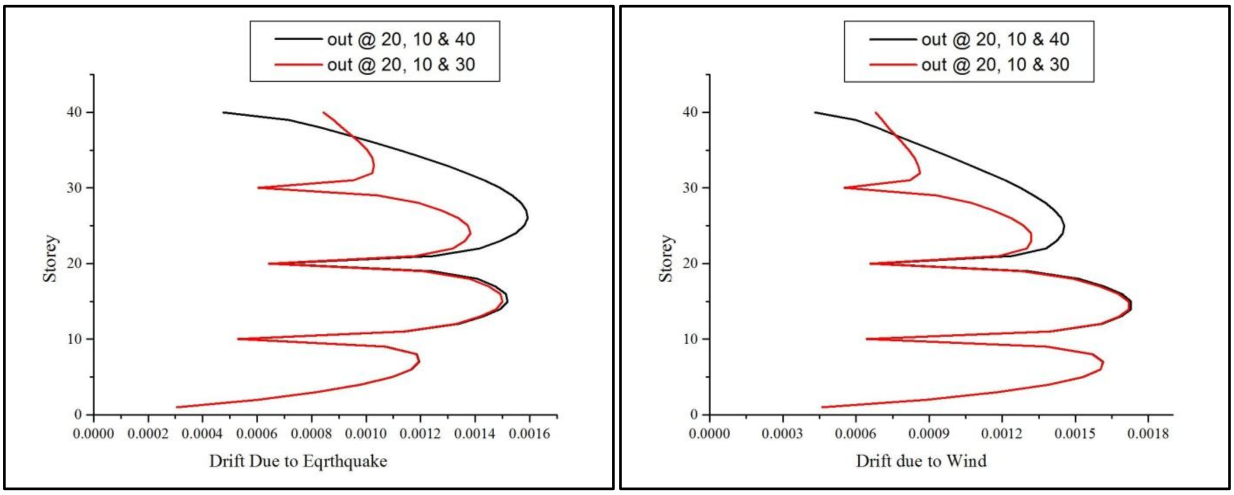


Figure 16. Drift Index Due to Earthquake & Wind (triple outrigger).

V. CONCLUSION

1. There is maximum displacement reduction when 1st outrigger is placed at 20th floor i.e. at mid height(***Figure 5***).
2. There is maximum shear fore reduction in core when 1st outrigger is placed at 20th floor i.e. at mid height (***Figure 8***).
3. If we consider overall height of building, there is maximum reduction in drift index when 1st outrigger is placed at 20th storey i.e. at mid height (***Figure 14).***
4. From above conclusion we consider 1st outrigger location is at 20th storey mid height.
5. There is maximum displacement reduction when 2nd outrigger is placed at 10th floor i.e. at 1/4th height (***Figure 6)***.
6. There is maximum shear fore reduction in core when 2nd outrigger is placed at 20th floor i.e. at m1/4th height (***Figure 9)***.
7. If we consider overall height of building, there is maximum reduction in drift index when 2nd outrigger is placed at 10th storey i.e. at 1/4th height (***Figure 15)***.
8. From above 5, 6, 7 conclusion 2nd outrigger is placed at 10th floor i.e. at 1/4th height.
9. There is maximum displacement reduction when 3rd outrigger is placed at 30th floor i.e. at 3/4th height (***Figure 7***).
10. There is maximum shear fore reduction in core when 3rd outrigger is placed at 30th floor i.e. at 3/4th height (***Figure 10***).
11. If we consider overall height of building, there is maximum reduction in drift index when 3rd outrigger is placed at 30th storey i.e. at 3/4th height (***Figure 16***).
12. From above9, 10, 11 conclusion we say 3rd outrigger location is at 30th storey 3/4th height.

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