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BEHAVIOR OF A BUILDING WITH OUTRIGGER SYSTEM

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ABSTRACT

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 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 behavior of outrigger and, outrigger location optimization and the efficiency of each outrigger when three outriggers are used in the structure. In Nine 30−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. For 30−storey model, 23% maximum displacement reduction can be achieved by providing first outrigger at the top and second outrigger in the structure height. The influence of second outrigger system is studied and important results are tabulated and drawn.

Keywords: - Outrigger, Belt truss system, Wind, Earthquake, Lateral displacement.

I. INTRODUCTION

1.1 Introduction To Outriggers

Mankind had always fascinated for height and throughout our history, we have constantly sought to metaphorically reach for the stars. From the ancient pyramids to today's modern skyscraper, a civilization's power and wealth has been repeatedly expressed through spectacular and monumental structures. Today, the symbol of economic power and leadership is the skyscraper. There has been a demonstrated competitiveness that exists in mankind to proclaim to have the tallest building in the world.

This undying quest for height has laid out incredible opportunities for the building profession. From the early moment frames to today's ultra-efficient mega-braced structures, the structural engineering profession has come a long way. The recent development of structural analysis and design software coupled with advances in the

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finite element method has allowed the creation of many structural and architecturally innovative forms. However, increased reliance on computer analysis is not the solution to the challenges that lie ahead in the profession. The basic understanding of structural behavior while leveraging on computing tools are the elements that will change the way structures are designed and built.

The design of skyscrapers is usually governed by the lateral loads imposed on the structure. As buildings have gotten taller and narrower, the structural engineer has been increasingly challenged to meet the imposed drift requirements while minimizing the architectural impact of the structure. In response to this challenge, the profession has proposed a multitude of lateral schemes that are now expressed in tall buildings across the globe.

The design of tall and slender structures is controlled by three governing factors, strength (material capacity), stiffness (drift) and serviceability (motion perception and accelerations), produced by the action of lateral loading, such as wind. The overall geometry of a building often dictates which factor governs the overall design. As a building becomes taller and more slender, drift considerations become more significant. Proportioning member efficiency based on maximum lateral displacement supersedes design based on allowable stress criteria.

Through the design of a high-rise structure, numerous problems appear such as the number of columns or size and shape of concrete core or even basic dimensions of the structure itself. Having constraints for the building immediately defines and solves part of the unknown variables but it is the geometry of the structural system inside these basic parameters that identifies an efficient design.

Undoubtedly, the factor that governs the design for a tall and slender structure most of the times is not the fully stressed state but the drift of the building. There are numerous structural lateral systems used in high-rise building design such as: shear frames, shear trusses, frames with shear core, framed tubes, trussed tubes, super frames etc. However, the outriggers and belt trusses system is the one providing significant drift control for the building.

1.2 Structural concepts

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.). 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 snap it (shear), and push it over (bending).

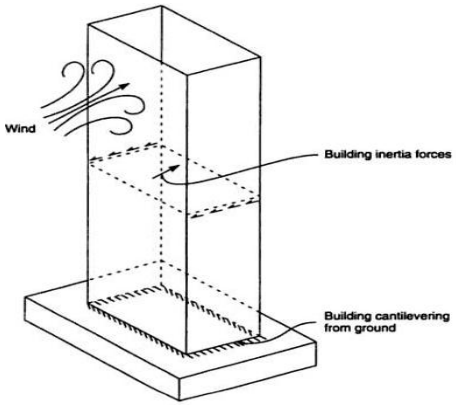

Fig. 2 Structural concept of tall building

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1.3 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 (Fig.5.a) or it may be located on one side of the building with outriggers extending to the building columns on one side (Fig.5.b).

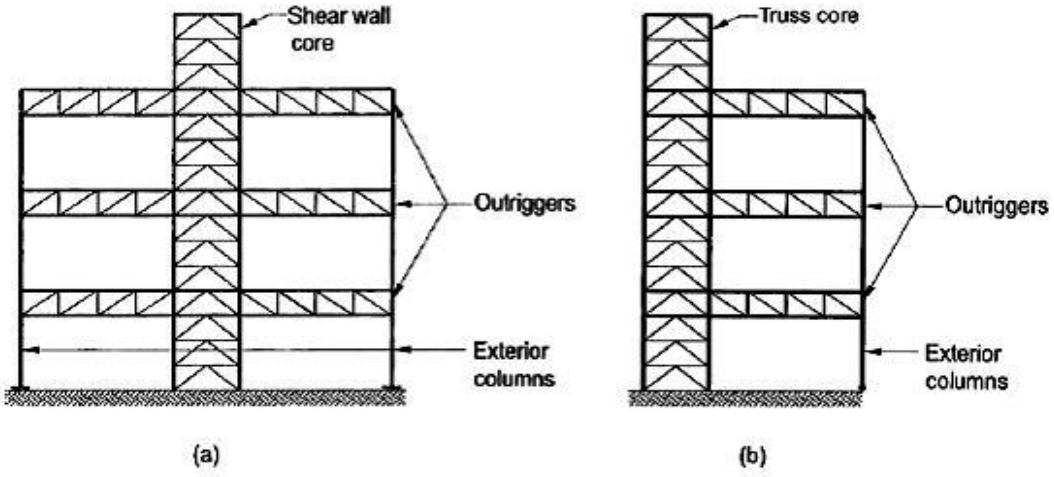

Fig.5 (a) Outrigger system with a central core (b) Outrigger system with offset core

When Horizontal loading acts on the building, the column restrained outriggers resist the rotation of the core, causing the lateral deflections and moments in the core to be smaller than if the free standing core alone resisted the loading. The result is to increase the effective depth of the structure when it flexes as a vertical cantilever, by inducing tension in the windward columns and Compression in the leeward columns.

In addition to those columns located at the ends of the outriggers, it is usual to also mobilize other peripheral columns to assist in restraining the outriggers. This is achieved by including a deep Spandrel Girder, or a Belt Truss, around the structure at the levels of the outriggers.

To make the Outriggers and Belt Truss adequately stiff in flexure and shear, they are made at least one, and often 2 – stories deep. It is also possible to use diagonals extending through several floors to act as outriggers. And finally, girders at each floor may be transformed into outriggers by moment connections to the core and, if

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desired, to the exterior columns as well.

Here, it should be noted that while the outrigger system is very effective in increasing the structure's flexural stiffness, it doesn't increase its resistance to shear, which has to be carried mainly by the core.

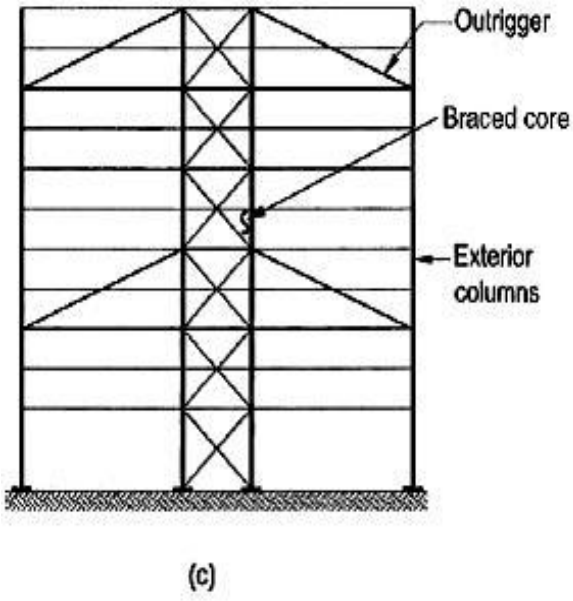

Fig.6 Diagonals acting as outriggers

II. LITERATURE REVIEW

In 1974, **Taranath** examined the optimum location of a belt truss which minimized the wind sway and discussed a simple method of analysis. **McNabb** et al (1975) extended their analysis to two outriggers and investigated governing factors in drift reduction. **McNabb** et al (1975) verified the **Taranath**'s optimum outrigger location result and showed that the optimum locations for two outriggers to be 0.312 and 0.685 of the total height from the top of the building. In 1985, **Moudarres** et al (1985) investigated the free vibration of high rise structures using dynamic analysis and this treatment took into account the effects of shear deformation and rotatory inertia of the core and included the inertia of the outrigger.

Chan and **Kuang** (1989a, 1989b) conducted studies on the effect of an intermediate stiffening beam at an arbitrary level along the height of the walls and indicated that the structural behavior of the structure could be significantly affected by the particular positioning of this stiffening beam.

For preliminary analysis of outrigger braced structures, simple approximate guidelines for the location of the outriggers were given in **Smith** et al (1991).

Moudarres [7] conducted the study of a pair of coupled shear walls stiffened at the top by a flexible outrigger, and investigated the outrigger's influence on the behavior of the walls. The treatment of coupled shear walls stiffened at the top by an outrigger is approached by considering the un-stiffened walls under the influences of external loads and internal forces, respectively. The vertical axial forces and the concentrated moments imposed at the top of the walls are internal forces due to the influence of the stiffening outrigger.

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Alex Coull and W. H. Otto Lau [8] conducted a study of a multi outrigger-braced structure based on the continuum approach in which the set of outriggers is smeared over the height to give an equivalent uniform bracing system. After their detail analysis they concluded that, Continuum analysis can give reasonably accurate results for even a very small number of Outriggers. They also presented Design Curves for assessing the lateral drift and the core base moments for any structural configuration defined in terms of two controlling structural parameters. The curves allow a direct assessment of the effectiveness of any number of outriggers.

R. Shankar Nair [9] presented a paper on the detail study of various types of outriggers and their relative behavior and performance subjected to lateral loading along with their advantages and disadvantages. He also conducted an analysis for a typical steel structure employing various types of OUTRIGGERS.

The conclusions of his study can be summarized as follows:

2.1 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.

III. OBJECTIVES AND DETAILS OF THE PRESENT STUDY

The objective of the present work is to study the use of outrigger and belt truss placed at different location subjected to wind or earthquake load. The design of wind load was calculated based on IS 875 (Part 3) and the earthquake load obtained using IS 1893 (Part-1): 2002. The location of outrigger and belt truss for reducing lateral displacement, building drift and core moments can be obtained. The ETABS software program is selected to perform analysis. The present study is limited to reinforced concrete (RC) multi-storied symmetrical building. All the building models analyzed in the study have 30 storey's with constant storey height of 3 meters. Number of base and the bay-width along two horizontal directions are kept constant for all the models for convince.

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. However, the dimensions, general layout and other characteristics have been selected to be representative of a building for which the use of outriggers would be a plausible solution. Till now all the studies have been performed on the steel structures and there was an absence of a research on slender concrete structure.

The model considered for this study is a 60m high rise reinforced concrete building frame. The building represents a 20storied office building. The Plan area of the Structure is 38.50 x 38.50m with columns spaced at 5.5m from center to center. The height of each storey is 3.00m and all the floors are considered as Typical

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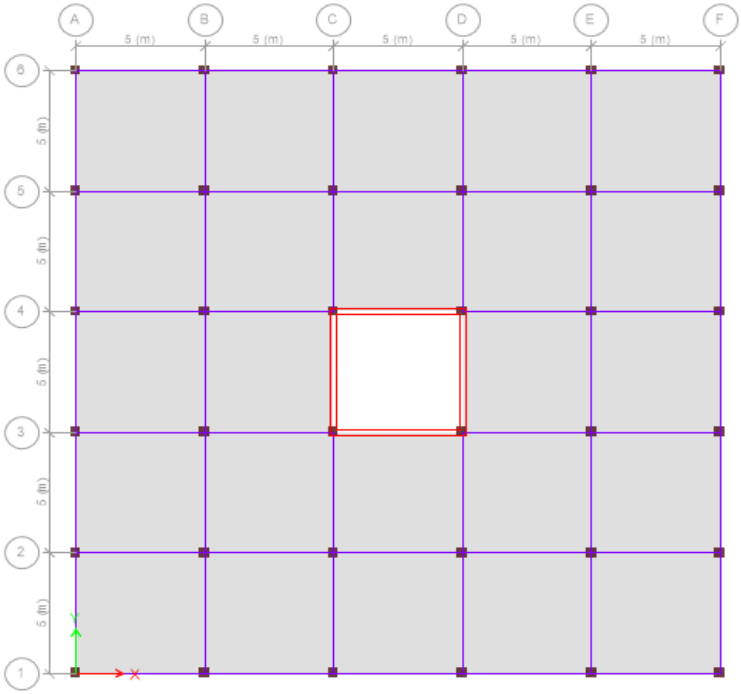
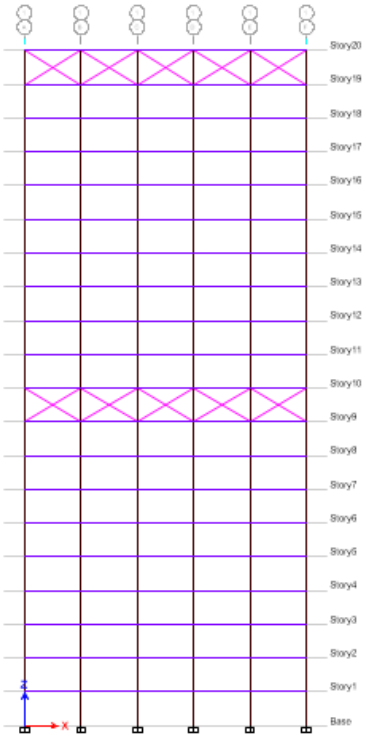
Floors. The location of the building is assumed to be at Hyderabad. An plan and elevation view of a typical structure is shown in fig. 8 and 9.





In this present study a total of seven different arrangements of outriggers analyzed using ETABS software are:

1. Structural Model without Outrigger (SOM).
2. Structural Model with One Outrigger at the top floor (SOD – TOP).

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3. Structural Model with One Outrigger at the top floor and another at 3/4th height of the building i.e. on 23rd storey (SOD – ¾).
4. Structural Model with One Outrigger at the top floor and another at mid height of the building i.e. on 15th storey. (SOD – ½)
5. Structural Model with One Outrigger at the top floor and another at 1/4th height of the building i.e. on 8th storey (SOD – ¼).
6. Structural Model with One Outrigger at the top floor with Belt Truss (SOD – BT – TOP).
7. Structural Model with One Outrigger at the top floor and another at 3/4th height of the building i.e. on 23rd storey with Belt Truss (SOD – BT – ¾).
8. Structural Model with One Outrigger at the top floor and another at mid height of the building i.e. on 15th storey with Belt Truss. (SOD – BT – ½).
9. Structural Model with One Outrigger at the top floor and another at 1/4th height of the building i.e. on 8th storey with Belt Truss (SOD – BT – 1/4).

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 230mm wide and 600mm deep, Grade 40 (Mix – M40) concrete is considered (Compressive strength 40 N/mm²) throughout the height of the building. And number of stories considered for all the cases are 30 stories, and roof height is considered as 90 M. And storey to storey height is 3.0 M. And the outer and inner columns sizes are considered as 600 x 600 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 1.5 kN/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). The location selected is Hyderabad. The Basic wind speed as per the code is V_b=44m/s. The coefficients K_1 and K_2 are taken as 1.0. The terrain category is taken as „Category 4" with structure class C. Taking internal pressure coefficient as ±0.2 the net pressure coefficient Cp (windward) works out as +0.8 and Cp (leeward) as -0.5 based on h/w and l/w ratio of table 4 of IS 875 (part3). Using the above data the **ETABS** automatically interpolates the coefficient K_3 and eventually calculates lateral wind load at each storey. Same load is applied along positive and negative X & Y axis one direction at a time to determine the worst loading condition.

Earthquake load in this study is established in accordance with IS 1893(part 1)-2002.The city of

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Hyderabad falls in "zone 2" (Z=0.10). The importance factor (I) of the building is taken as 1.0. The site is assumed to be hard/rocky site (Type I). The response reduction factor R is taken as 3.0 for all frames.

The fundamental time period ($T_{a)}$ of all frames was calculated as per clause 7.6.1 of the aforementioned code.

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

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,

$$\mathbf{V_B = A_h * W.}$$

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,

$$Q_i = V_B * (W_i*h_i^2)*(\sum W_j*h_j^2)^{-1}$$

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) $DL+LL\pm WL_{(x \text{ or } y)}$

iii) $DL+LL\pm EL_{(x \text{ or } y)}$

iv) $DL\pm WL_{(x \text{ or } y)}$

v) $DL\pm EL_{(x \text{ or } y)}$

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.

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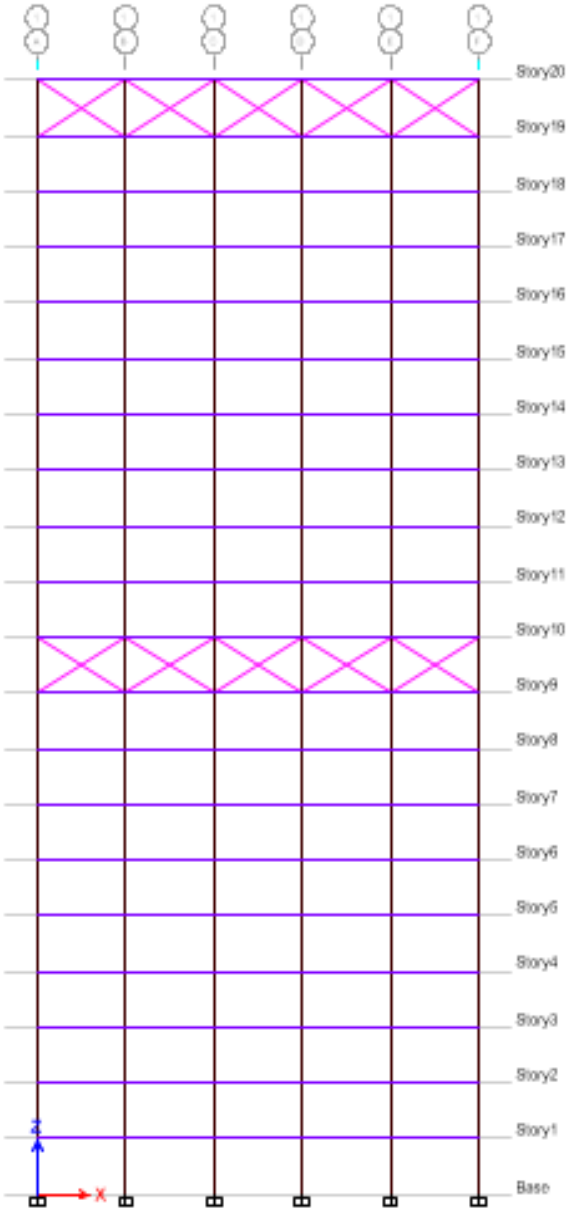

Fig.8.3 Elevation view of the model with central core and outrigger at 9th and 19th floor.

IV. RESULTS AND DISCUSSIONS

4.1 Drift

The most significant basic parameter monitored throughout the whole analysis process was drift at the top of the building. The following figure 12 shows the variation of drift and from the figure 12 it is observed as follows: It is observed that 4.8% of the drift is controlled by providing outrigger at top floor and 5.3% of the drift is controlled by providing outrigger with belt truss at top floor when compare to the building with core wall only. 18.55% and 23.06% of the drift is controlled by providing the system at middle height of the building. The optimum location of the second outrigger is the mid height of the building, according to drift control criteria.

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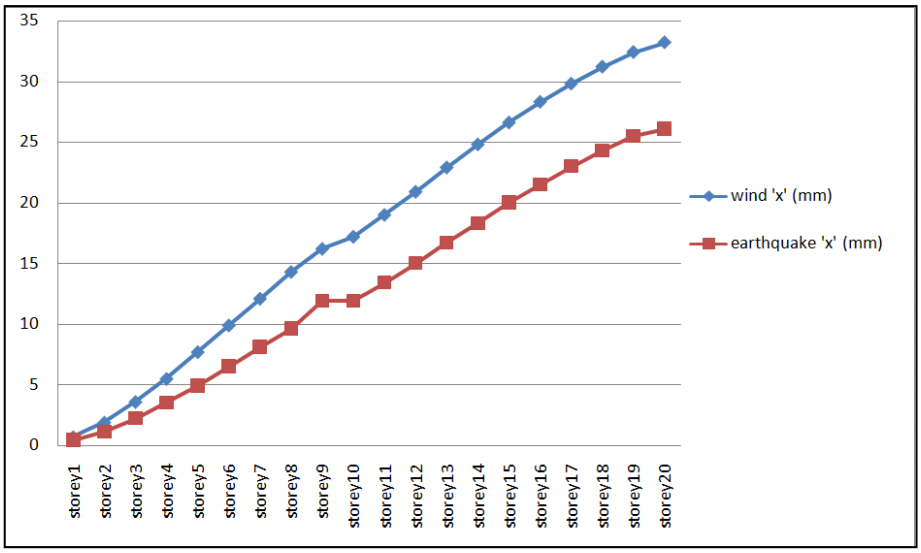


Fig. 4(a) Lateral Displacement of the top storey as a function of level 9th and 19th of outrigger and belt truss

4.2 Column axial forces

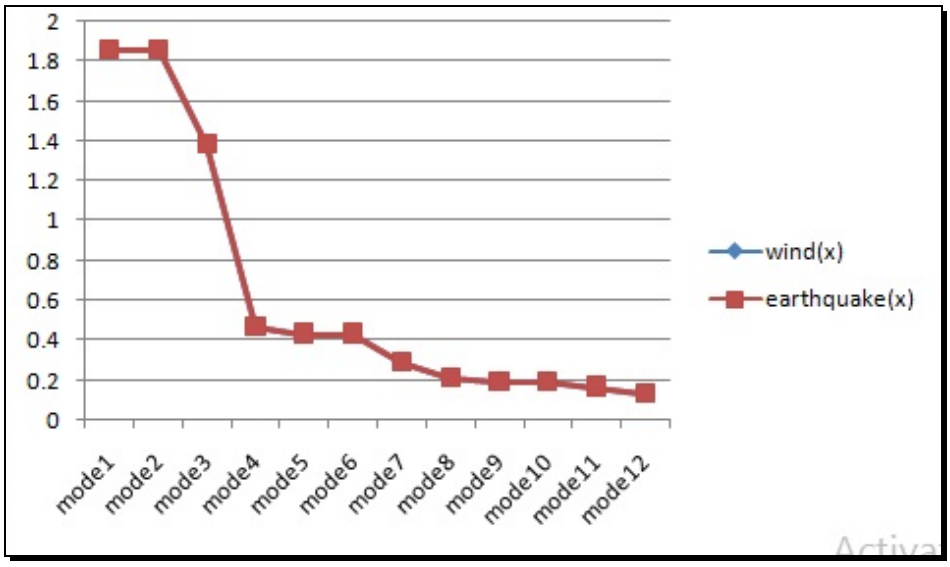
The structural scheme analyzed in the present study is activated once the outriggers are engaged and transfer the core bending moment to the outboard column as a couple of axial forces.

The behaviors of 3 columns are studied as given below:

(a) Interior Column – nearer to the core (C19)

(b) Interior Column – away from the core (C16)

(c) Exterior Column – periphery of the building (C13)



Time Period of Rigger at 20th Storey Compared to Normal Building

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The above graph shows the variation of time period for building with outrigger at 20th storey compared to normal building without rigger. The time period for normal building was 3.356 sec whereas the time period with rigger is 2.76sec.The time period with outrigger is reduced by 17.7% compared to normal building

4.3 moments

Another very important factor that is monitored is the moments along the height of the concrete core.

The moments that were monitored as shown in figure 5.3 and are

1. The moments below the first outrigger (cap truss).
2. The moments above the second outrigger.
3. The moment below the second outrigger.

4 . The core base moments.

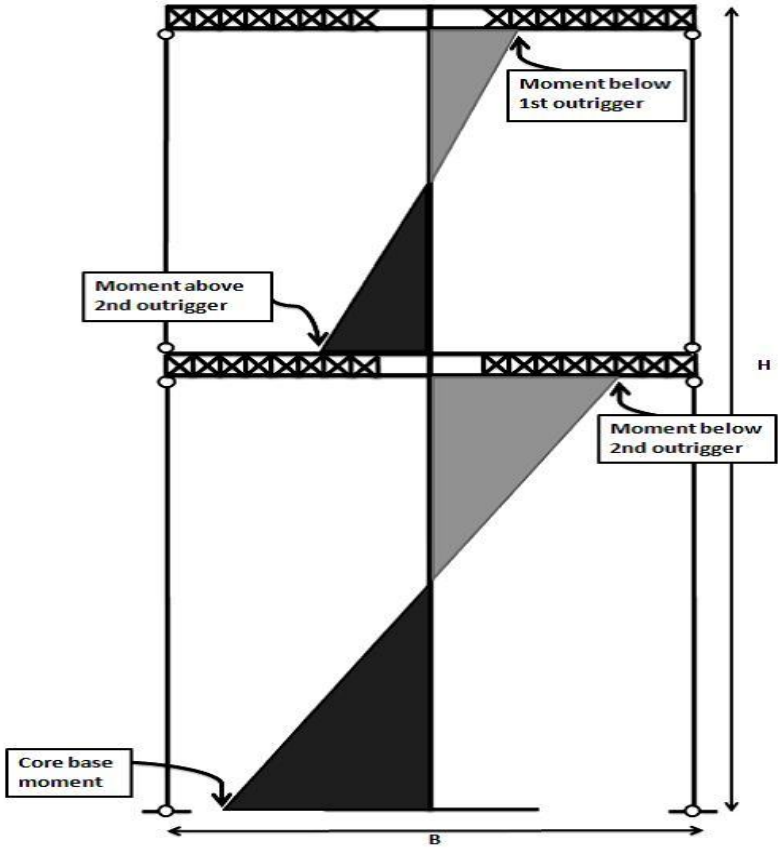

Fig.4(c) The typical behavior of a system with very stiff concrete core along with outrigger and belt truss

V. CONCLUSIONS

The following conclusions are made from the present study

- The use of outrigger and belt truss system in high-rise buildings increase the stiffness and makes the structural form efficient under lateral load.
- The maximum displacement is for structure when only core is employed without any outriggers.
- The minimum displacement at the top structure is for structure with outriggers at half of its height.

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- These are considerable effect of outriggers on the structure compare to the normal structure. More ever the lowest of outriggers also place the significant role to make a structure efficient under lateral.
- It can be conclude that the optimum location of the outrigger is between 0.5 times its building height

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