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Optimum Position of Outrigger System for High-Rise Reinforced Concrete Buildings Under Wind And Earthquake Loadings

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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 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).

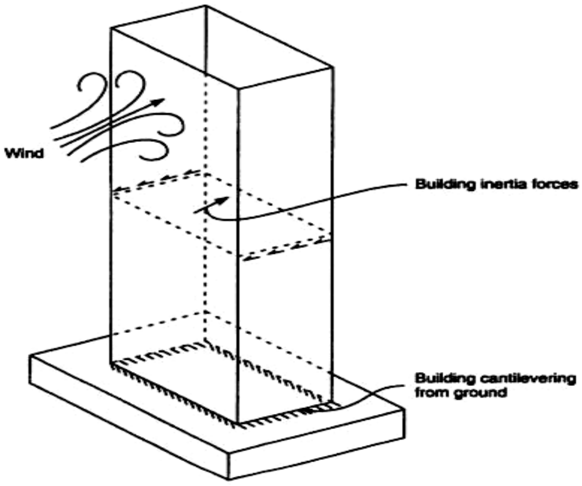


Fig. 2 Structural concept of tall building

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.3.a), and must not strain beyond the limit of elastic recovery (fig.3.b).

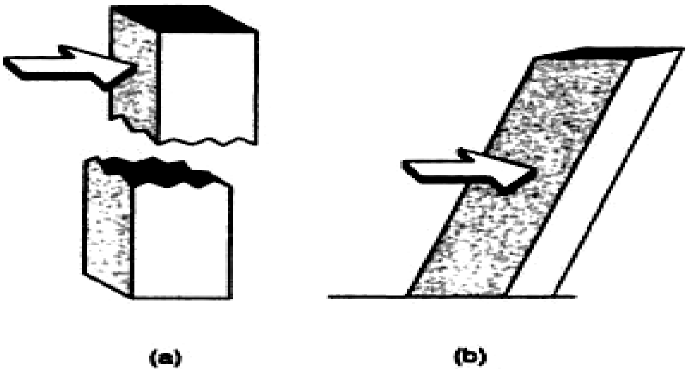


Fig.3 Building shear resistance; (a) building must not break (b) building must not deflect excessively in shear

Similarly, the system resisting the bending must satisfy three needs (fig.4). 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.

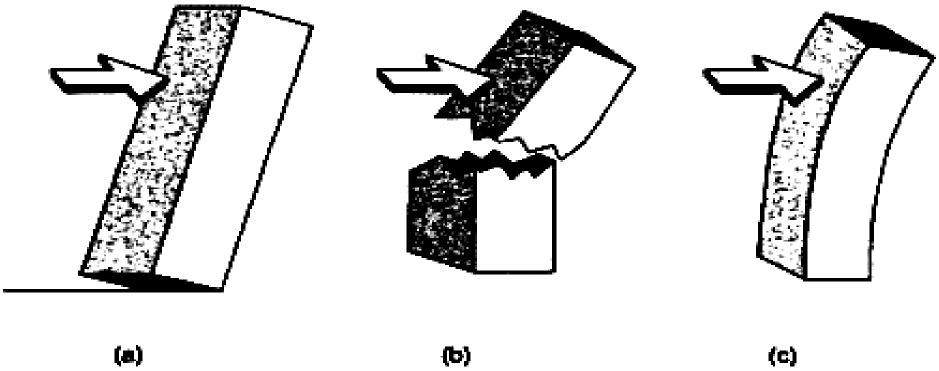


Fig. 4 Bending resistance of building (a) Building must not overturn (b) Columns must not fail in tension or compression
(c) Bending deflection must not be excessive

In the structure's resistance to bending and shear, a tug-of-war ensues that sets the building in motion, thus creating a third engineering problem; motion perception or vibration. If the building sways too much, human comfort is sacrificed, or more importantly, non-structural elements (glass fascia) may break resulting in expensive damage to the building contents and causing danger to the pedestrians.

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).

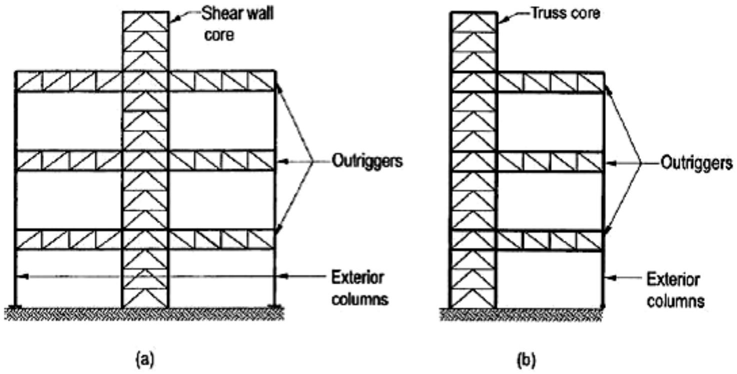


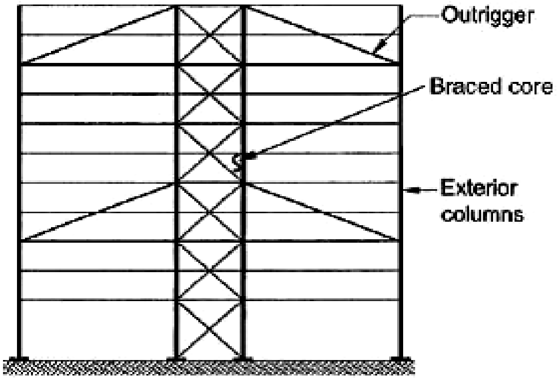
Fig.5 (a) Outrigger system with a central core (b) Outrigger system with offset core

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 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.



(c)

Fig.6 Diagonals acting as outriggers

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.

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 application and effectiveness of belt trusses as virtual outriggers is demonstrated through an example:

Table 1 Results of analysis of 75 – Storied Building

Type of outrigger	Lateral displacement at top due to wind (inches)
No outrigger	108.5
Convention outrigger	25.3
Belt truss as virtual outrigger	37.1
Belt truss as virtual outrigger : 10-fold increase in floor diaphragm stiffness	31.0
Belt truss as virtual outrigger : 10-fold increase in floor diaphragm stiffness, 10-fold increase in belt truss and stiffness	26

The conclusions of his study can be summarized as follows:

Techniques for using belt trusses and basements as "virtual" outriggers in tall buildings have been proposed. Belt trusses used as virtual outriggers offer many of the benefits of the outrigger concept, while avoiding most of the problems associated with conventional outriggers.

In many applications, the reduced effectiveness or efficiency of the virtual outrigger system (compared to conventional direct outriggers) will be more than compensated for by the following benefits offered by the proposed concept:

- There are no trusses in the space between the core and the building exterior.
- There are fewer constraints on the location of exterior columns. The need to locate large exterior columns where they can be directly engaged by outrigger trusses extending from the core is eliminated.
- All exterior columns (not just certain designated outrigger columns) participate in resisting overturning moment.
- The difficult connection of the outrigger trusses to the core is eliminated.
- Complications caused by differential shortening of the core and the outrigger columns are avoided.

In the lateral load analysis of a building with the proposed virtual outrigger system (or any other type of indirect or offset outrigger system), the in-plane stiffness of the floors that transfer horizontal forces from the core to the outriggers should be modeled accurately. These floors cannot reasonably be idealized as rigid diaphragms. **Su** et al (2005) investigated the complete load transfer mechanism between the outrigger brace and the core wall using strut-and-tie method.

Hoenderkamp et al (2008) presented a simple method of analysis for preliminary design of outrigger braced high-rise shear walls subjected to horizontal loading. Further, these studies showed that the position of the outrigger can substantially affect the behavior and lateral deflection of the structure.

Gerasimidis S, Efthymiou E & Baniotopoulos C. C. [10] conducted a basic design optimization technique of tall steel structures for lateral loads, mainly wind, into trying to find the optimum number of outriggers for a specific high-rise building. The structure is analyzed for an indicative wind loading. The geometry produced by stress based design, although below the stress limit, is very flexible and exhibits horizontal displacements and inter-story drifts much above the acceptable limits, due to the wind loading. Then the structure is analyzed with all the possible outrigger locations monitoring important factors, such as the drift of the building or the moments on the core. In the analysis, he included all the possible different analyses simulating the second outrigger in each one of the floors of the building.

N. Herath, N. Haritos, T. Ngo & P. Mendis [11] investigated the optimum number of the Outrigger Beams or Trusses subjected to Earth Quake forces, for an economical design on a 50 storied building. His study assessed the global behaviour of outrigger braced building under earthquake loads from which the following conclusions can be drawn based on the above results:

- The behaviour of a structure under earthquake load is different from earthquake to earthquake. This well known phenomenon is well presented in the lateral displacement results obtained for both of the options.
- The location of the outrigger beam has a critical influence on the lateral behaviour of the structure under earthquake load and the optimum outrigger locations of the building have to be carefully selected in the building design.

To control the time period and the fundamental frequencies and the vibrations induced due to lateral loads, the concept of Dampers was introduced. To gain insight into the conceptual design of such damped outrigger system in a tall structure, a simple beam-damper system model for a building with such dampers installed was developed and studied by **Y. Chen, D. M. McFarland, Z. Wang, B. F. Spencer. Jr. L. A.**

Bergman [12].

A closed-form analytical solution is developed for vibration of the beam by analyzing the regions above and below the damper separately using separation of variables. This solution was used to determine design curves for optimal damper position and size.

Research has pointed out that the damping ratio for a tall building will become smaller with an increase in its height; as a result, the system damping assumed in the design of buildings over 200 m may be overestimated in comparison with the damping found in as-built.

It was found that there exists an optimal damper size, which results in system modal damping approaching its maximum value, for an assigned damper location. Obviously, this maximum system modal damping varies with damper location and modal order.

There can be several layers of outriggers in a structure. There optimum placement depends on a multitude of structural factors such as location of the outriggers, the axial rigidity of the columns, the flexural rigidity of the core and the outriggers and the efficiency of each outrigger when several outriggers are used in the structure. These issues were discussed in depth by **Ali Lame [13]** and developed a program (using visual basic) to calculate the top deflection of the outrigger structure and the moment at the base. The algorithm used in the program can be used for infinite no. of outriggers.

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. BEHAVIOR OF OUTRIGGERS

To understand the behaviour of an outrigger system, consider a building stiffened by a story high outrigger at top, as shown in Fig.7.c. Because the outrigger is at the top, the system is often referred to as a cap or hat truss system. The tie-down action of the cap truss generates a restoring couple at the building top, resulting in a point of contra-flexure in its deflection curve. This reversal in curvature reduces the bending moment in the core and hence, the building drifts.

The core may be considered as a single-redundant cantilever with the rotation restrained at the top by the stretching and shortening of windward and leeward columns. The result of the tensile and compressive forces is equivalent to a restoring couple opposing the rotation of the core. Therefore, the cap truss may be conceptualized as a restraining spring located at the top of the cantilever. Its rotational stiffness may be defined as the restoring couple due to a unit rotation of the core at the top.

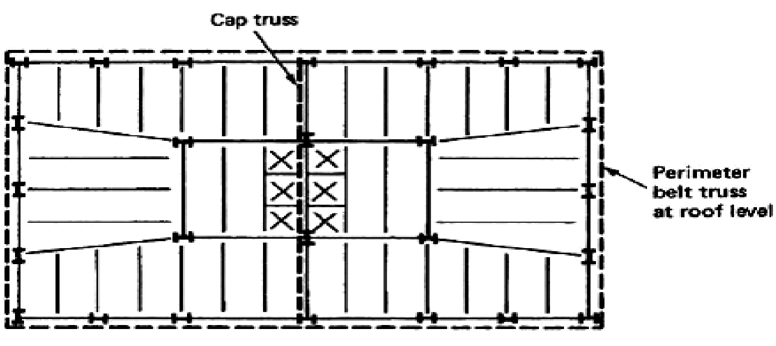


Fig. 7 (a) Building plan with cap truss

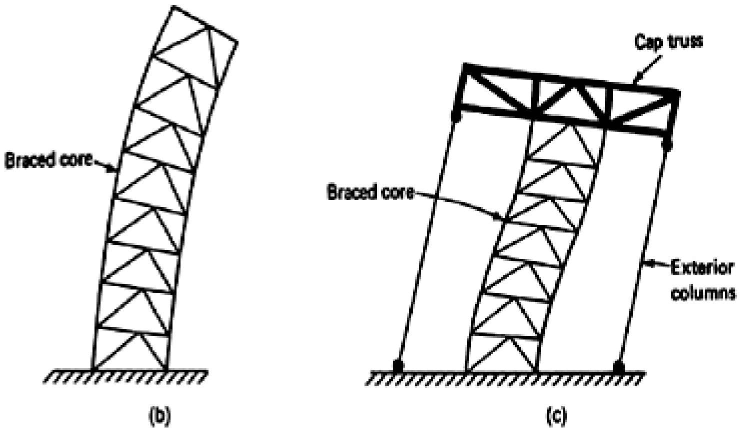


Fig. 7 (b) Cantilever bending of core; (c) tie-down action of cap truss.

Assuming the cap truss is infinitely rigid, the axial elongation and shortening of columns is equal to the rotation of the core multiplied by their respective distances from the center of the core. If the distance of the equivalent column is $d/2$ from the center of the core, the axial deformation of the columns is then equal to $\theta d/2$, where θ is the rotation of the core. Since the equivalent spring stiffness is calculated for unit rotation of the core (that is, $\theta = 1$), the axial deformation of the equivalent columns is equal to $1 \times d/2 = d/2$ units.

The corresponding axial load is given by ,

$$P = \frac{AEd}{2L}$$

Where,
P = axial load in the columns
A = area of columns
E = modulus of elasticity
d = distance between the exterior columns
L = height of the building.

The restoring couple, that is, the rotational stiffness of the cap truss, is given by the axial load in the equivalent columns multiplied by their distance from the center of the core. Using the notation K for the rotational stiffness, and noting that there are two equivalent columns, each located at a distance $d/2$ from the core, we get

$$K = P.\frac{d}{2}.2$$
$$=Pd$$

The reduction in drift depends on the stiffness K and the magnitude of rotation θ at the top.

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 storeys 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 90m high rise reinforced concrete building frame. The building represents a 30 storied 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 Floors. The location of the building is assumed to be at Hyderabad. An elevation and plan view of a typical structure is shown in fig. 8 and 9.

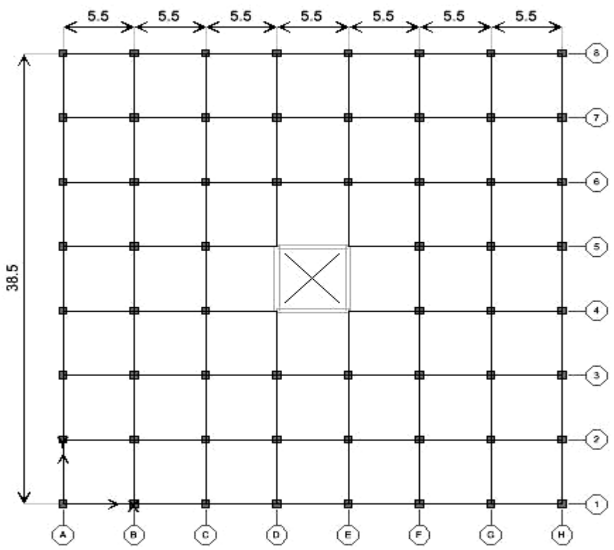


Fig.8 Building Plan dimensions and column centre spacing

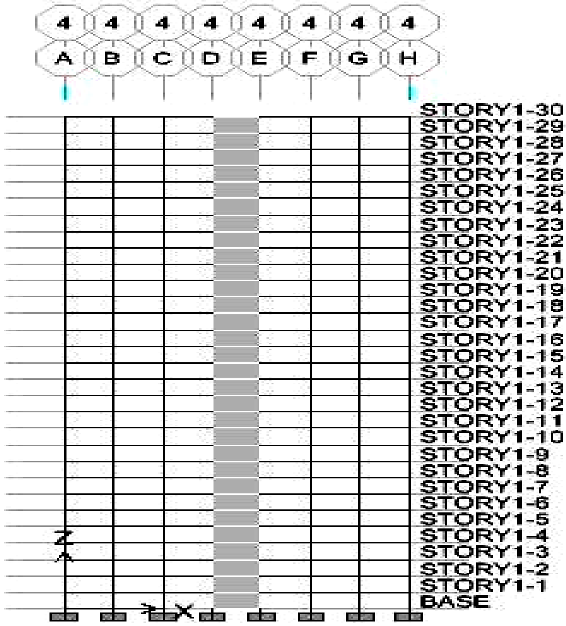


Fig.9 Building Elevation with central core portion.

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).
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 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,

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

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±$WL_{(x \text{ or } y)}$

iii) DL+LL±$EL_{(x \text{ or } y)}$

iv) DL±$WL_{(x \text{ or } y)}$

v) DL±$EL_{(x \text{ or } y)}$

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.

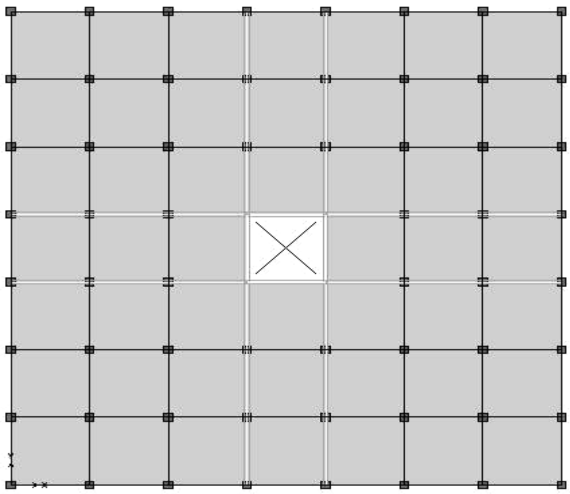


Fig.10 Plan view of the model with central core and extended outrigger on all the four sides.

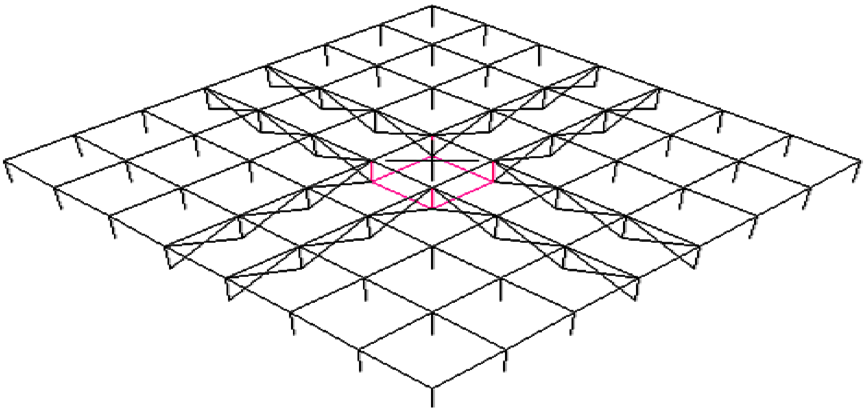


Fig.11 Perspective view of the model with central core and extended outrigger on all the four sides without belt truss.

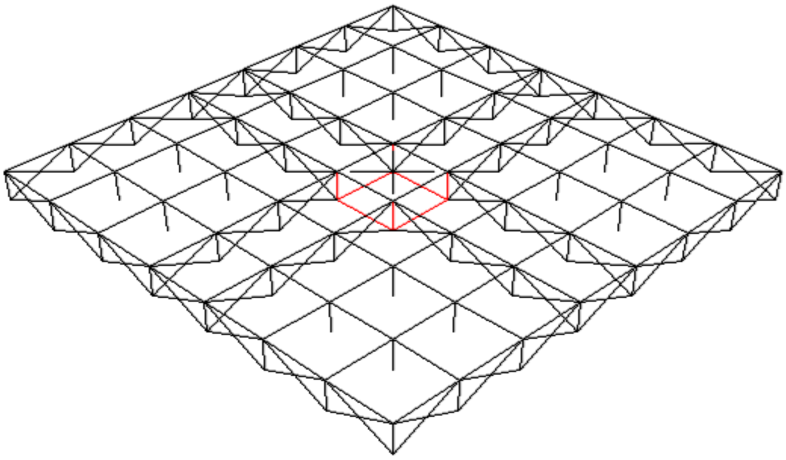


Fig.12 Perspective view of the model with central core and extended outrigger on all the four sides with belt truss.

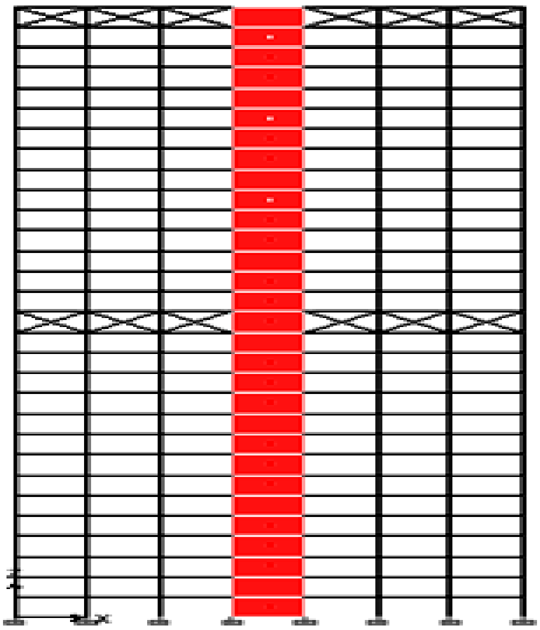


Fig.13 Elevation view of the model with central core and outrigger at 15th and 30th floor.

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 14 shows the variation of drift and from the figure 14 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.

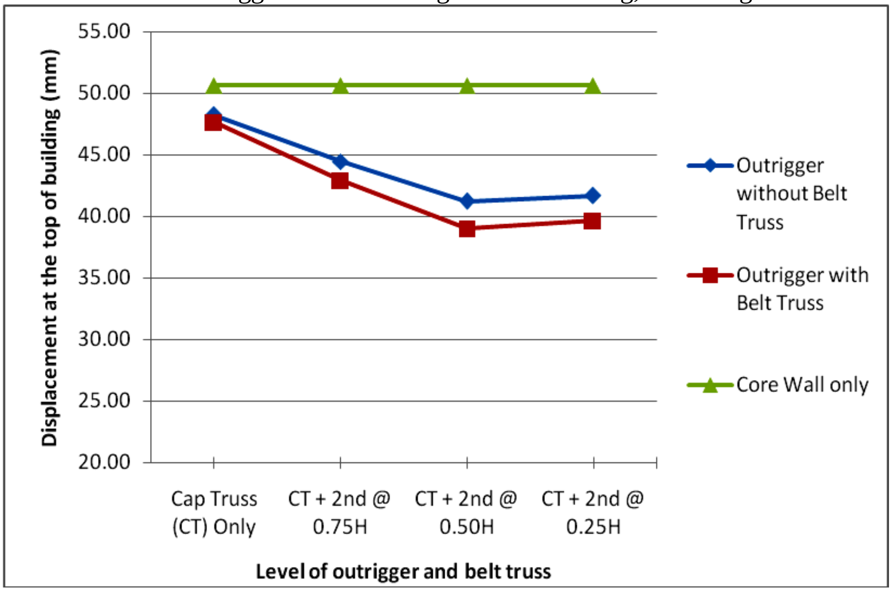


Fig.14 Lateral Displacement of the top storey as a function of level of outrigger and belt truss

5.2 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 (C39)
(b) Interior Column – away from the core (C46)
(c) Exterior Column – periphery of the building (C53)

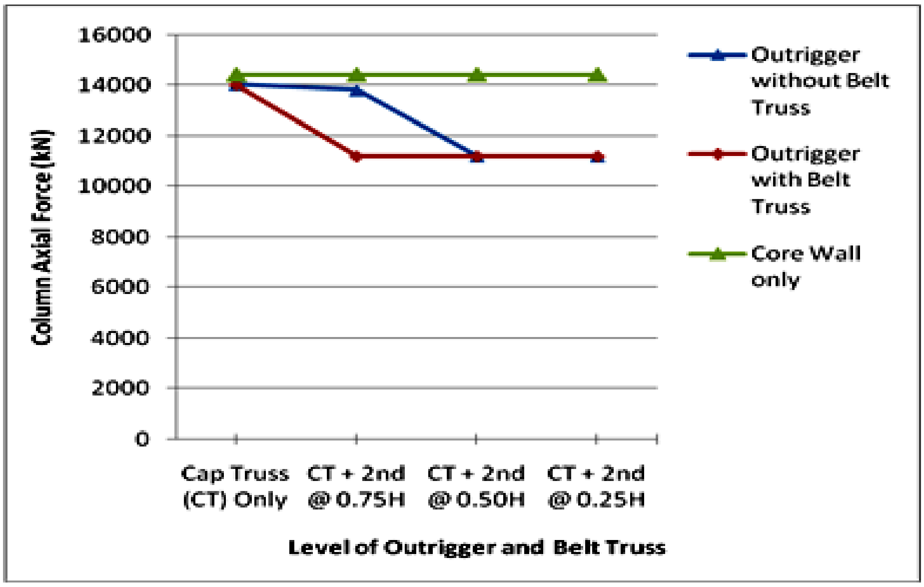


Fig. 15.a Compression forces in column(C39) for different levels of outrigger and belt truss.

From the above figure fig.15.a it is observed that the Inner columns are 2.76% and 2.85% less stressed than the building with core when compared to the cap truss with and without belt respectively.There is not much variation in the columns with respect to the position of second outrigger.

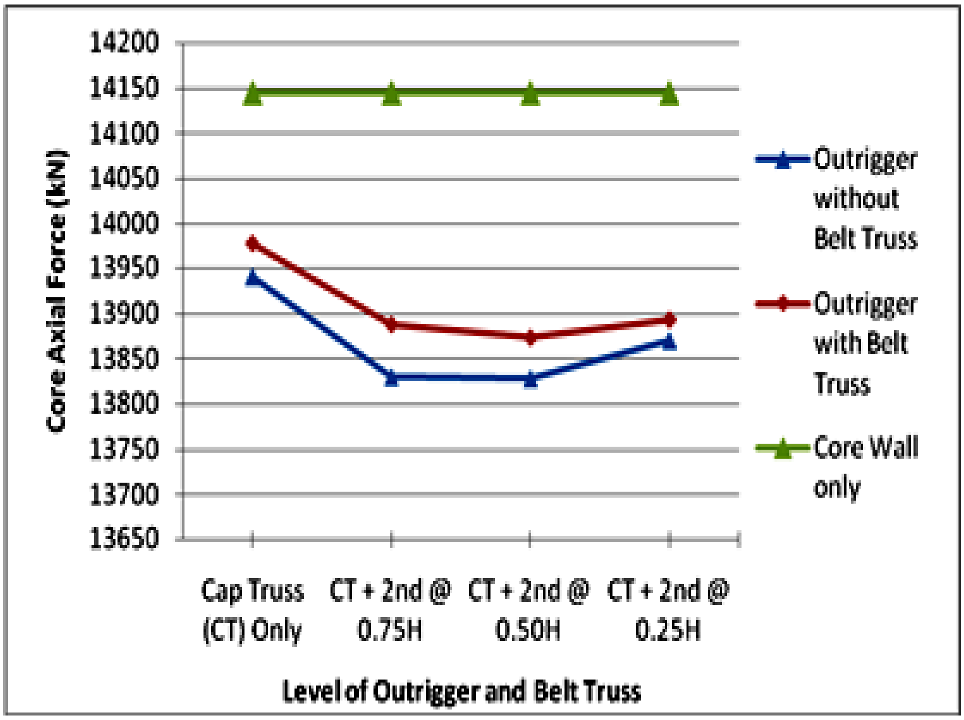


Fig. 15.b Compression forces in column(C46) for different levels of outrigger and belt truss.

From the above figure fig.15.b it is observed that the Inner columns are 1.44% and 2.24% less stressed than the building with core when compared to the cap truss with and without belt respectively. The optimum location of the outrigger system is proven to be at 0.5H, from the base.

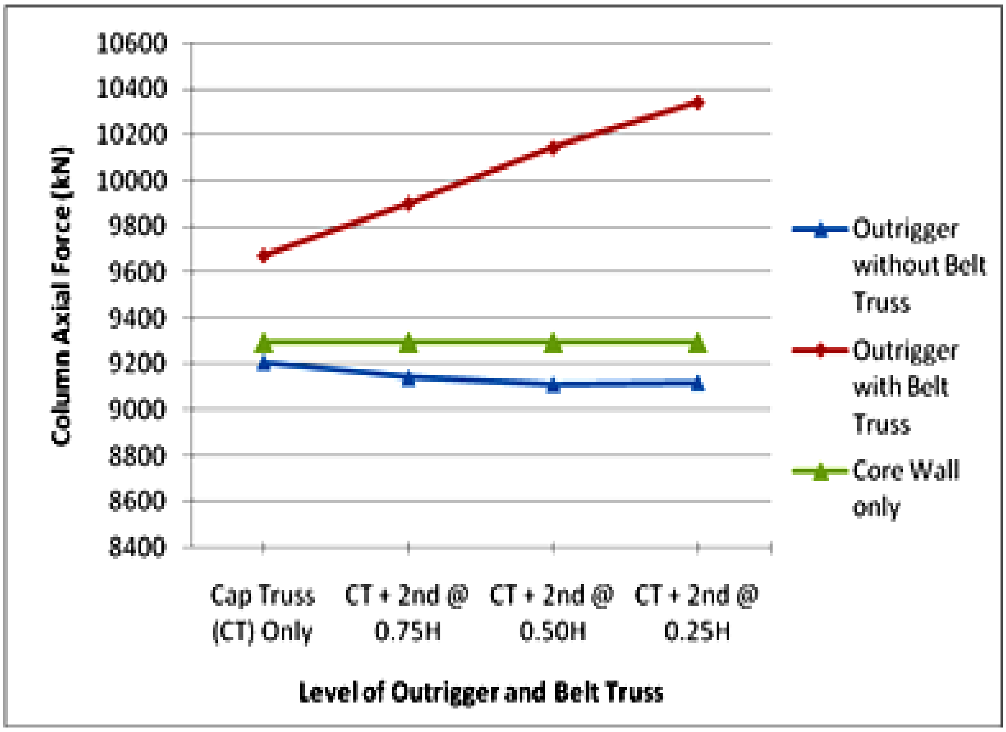


Fig.15.c Compression forces in column(C53) for different levels of outrigger and belt truss.

From the above figure fig.15.c it is observed that the columns are proven to be more stress in case of (cap truss) outrigger or belt truss system at bottom floor only.The columns seems to be lightly stress in case of second outrigger provided with the cap truss.

5.3 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.

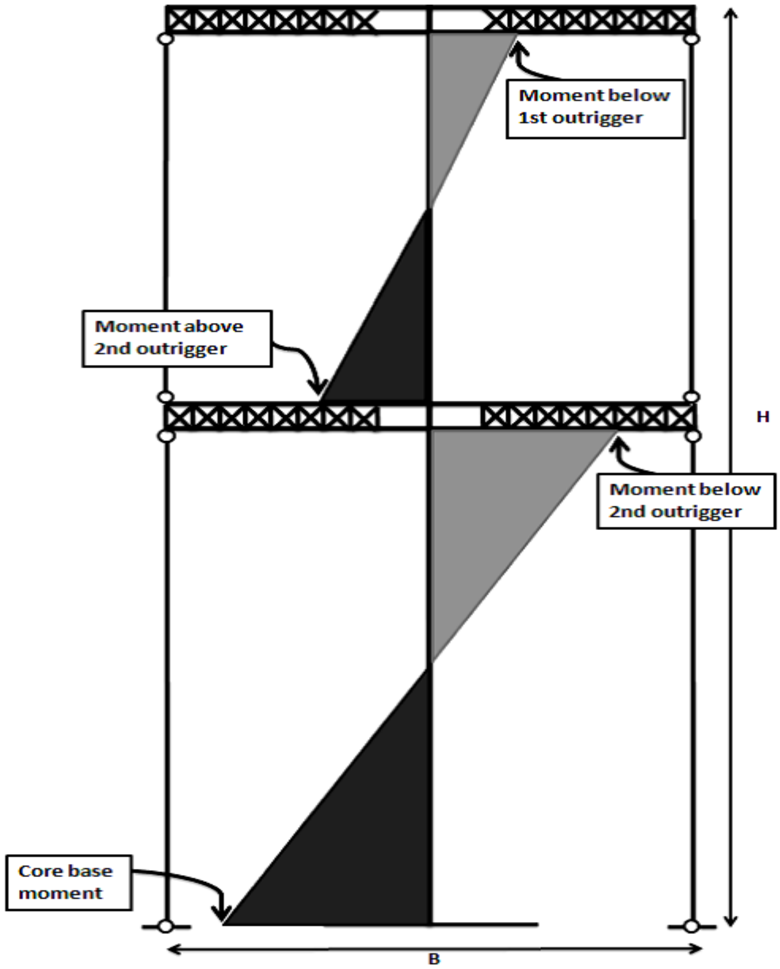


Fig. 16 The typical behaviour of a system with very stiff concrete core along with outrigger and belt truss.

V. CONCLUSIONS

The following conclusions are made from the present study

1. The use of outrigger and belt truss system in high-rise buildings increase the stiffness and makes the structural form efficient under lateral load.
2. The maximum drift at the top of structure when only core is employed is around 50.63 mm and this is reduced by suitably selecting the lateral system. The placing of outrigger at top storey as a cap truss is 48.20 mm and 47.63 mm with and without belt truss respectively. Hence there are not much reductions in drift with belt truss.
3. Using second outrigger with cap truss gives the reduction of 18.55% and 23.01% with and without belt truss. The optimum location of second outrigger is middle height of the building.
4. It can be conclude that the optimum location of the outrigger is between 0.5 times its height.

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