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THE STUDY ON BEHAVIOUR OF OUTRIGGERS FOR TALL BUILDINGS SUBJECTED TO LATERAL LOAD

Chethan Patel Y G[1], Kiran Kuldeep K N[2]

[1]PG Student, Department of civil engineering SJBIT, Bengaluru
[2]Assistant Professor. Department of civil engineering SJBIT, Bengaluru

Abstract - *Tall buildings, subjected to excessive drifts due to lateral loads especially in high seismic areas and wind load dominant regions. There is necessity to reduce the structural or non-structural damage due to these loads. Outriggers are one of the such effective structural systems that support building against lateral loads. This paper deals with RCC structure having different methods of outrigger and belt truss system that can be provided for tall buildings. The various parameters considered for the study are Deflection, Story Drift, Core wall bending moment and Optimum position of outriggers and belt truss. Results show that using Multi-outrigger system can reduce the effect of lateral load on building and by providing outrigger lateral load resisting system it is observed that deflection values lies within the limit.*

***Key Words*: Conventional outrigger, Virtual outriggers, Lateral displacement, Story Drift, Core moment. BT-Belt Truss.**

1. INTRODUCTION

In the recent days, major cities are experiencing the shortage of land due to growing population which leads to increase in construction of tall buildings and in the other hand in view of economic power there is competitiveness in mankind to have a tallest building which make the way for opportunities in building profession. As these tall building are critical to resist lateral loads structural engineer has been challenged to meet drift requirement and to minimize the effect.

1.1 Structural View

The concept of structural system in view of narrow tall building usually considered as beam cantilevering from earth and these are weak in resisting lateral loads i.e. wind and seismic loads. Wind loads are not uniform with respect to time and height due to these loads tall buildings are subjected to both shear and moment. Therefore to resist shear force the building should not get separated because of lateral force (fig.1.a) and should be strain within the elastic limit (fig.1.b).

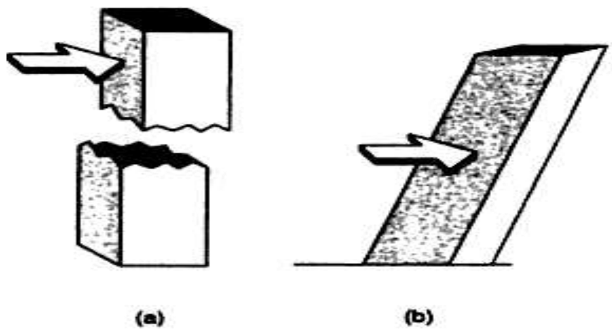

Fig.1 Building shear resistance

Similarly, to resist bending moment building must satisfy three needs (fig.2) they are, The building should not rotate due to application of lateral force, deflection should be in elastic limit and the building should not undergo compressive or tension failure at earlier stage only.

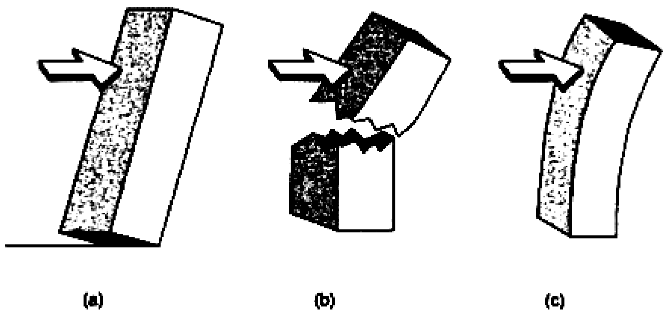

Fig.2 Bending resistance of building.

1.2 Introduction to Outriggers.

The outriggers serve to reduce the overturning moments in shear wall otherwise it will act as a pure cantilever. Outriggers were proved in history with respect to structural style and efficiency. The outriggers are integrated into high-rise buildings since last 35 years but they have much longer history. To resist the wind forces in sailing ships then and even now outriggers are being served.

These days, almost all the high-rise buildings for the elevator purpose central core wall had been included and there will be free floor space between the exterior columns and core wall. These two plays a prominent role in resisting overturning forces present in high rise buildings but they are separated, by including outriggers in high-rise buildings it is possible to connect these two structures elements and increases the resistance to lateral load and overturning forces.

For the building with height 35-40 stories core wall alone can effectively serve as resisting system but in case of seismic regions and wind dominant areas, the variation of the wind load is not linear as the height of building increases however, the resistance the core system provide to the overturning component of drift decreases approximately cube of the height.

The outriggers are connected from central core wall to exterior columns the core wall may be centrally located or at the side of the building. The direct connection between central core wall to exterior columns by connecting strong stiff outriggers is called conventional outrigger system (fig.3.a) and if floor diaphragms are used to connect exterior columns to central core wall, using outrigger around the exterior of building then it is called virtual outrigger system. (fig.3.b).

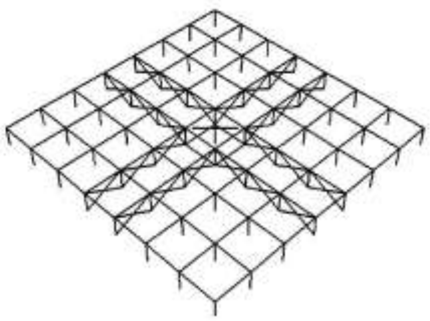

Fig.3.a Conventional outrigger system.

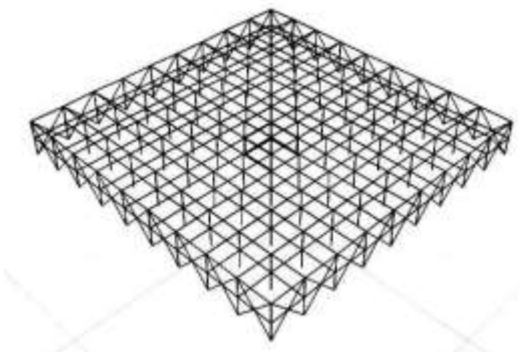

Fig.3.b Virtual outrigger system.

When the building is subjected to lateral loads outriggers resist the rotation of core wall by creating the tension in the windward columns and compression in leeward columns. As these outriggers are connected from both sides of shear wall to exterior columns it will create a restoring couple in wall which reduces the bending moment in shear wall and hence building drift.

R. Shankar Nair(1998) conducted a model on 75-storey steel-framed office tower and used to investigate the effectiveness of belt trusses as virtual outriggers. Designs with conventional outriggers and virtual outriggers will be compared. 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. The lateral displacement at the top of the building due to wind loading was found to be 25.3 in. for the design with conventional outriggers and 37.1 in. for the design with belt trusses as virtual outriggers. The structure was also analyzed with no outriggers at all(and no change in core member sizes). The displacement increased to 108.5 in. It is clear from the example that the virtual outrigger concept works as intended. However, with the same outrigger column sizes and locations, virtual outriggers will be less effective than conventional direct outriggers because of the reduced stiffness of the indirect force transfer mechanism.
Benefits of using virtual outrigger system (compared to conventional outrigger):

1. Between the core and building exterior there are no trusses.
2. All exterior columns participate in resisting overturning moment.
3. The difficult connection of outrigger truss to core is eliminated
4. Fewer constraints on location of exterior column.

P.M.B RajKiranNanduri, B.Suresh, MD.IhteshamHussain (2013)
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. The objective of this thesis is to study the behaviour of outrigger and, outrigger location optimization and the efficiency of each outrigger when three outriggers are used in the structure. 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 (90m) with constant storey height of 3 meters. The outriggers are placed at different levels and arrangements at (1/4, 1/2, 3/4th and top) of the storey height.

1. The use of this system will increase the stiffness and makes structure more efficient under lateral load.
2. The optimum location of the outrigger is between 0.5 times its height.
3. 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 is not much reductions in drift with belt truss.
4. 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.

ShruthiBadami and M.R.Suresh(2014)
This paper describes an investigation has been carried out to examine the most common structural systems that are used for reinforced concrete tall buildings under the action of gravity and wind loads. These systems include "Rigid Frame", "Shear Wall/Central Core", "Wall- Frame Interaction", and "Outrigger". The basic modeling technique and assumptions are made by "ETABS" Program, in 3-D modeling. Design considerations are made according to Indian Standards. The model consists of different stories(G+15,G+30,G+45 and G+60) with storey height 3.5m.By comparative study it is observed that, storey drift is maximum in rigid frames , and minimum in case of outriggers and drift is more in rigid frames with shear wall systems. As the building height increases time period has increased i.e., 45% to 50% increase can be observed from the graphs for every addition of 15 stories. Maximum base shear at the base of the building increase with the increase in number of stories. Hence it can be conclude that base shear depends mainly on seismic weight of the building. The reduction in the displacement of rigid frame with shear wall framed structure is 50 % with respect to R.C.C. frame Structure, 25% in case of shear walls and 60 % when outrigger is used.

2. OBJECTIVES AND DETAILS OF PRESENT STUDY

In this present study main objective is to study the use of conventional and virtual outrigger system subjected to wind and earthquake load. Wind load and earthquake load are calculated based on IS 875(Part 3) and IS 1893 (Part-1): 2002 respectively and load combinations are taken according to IS 875(Part 5). In the present study with respect to shear wall two types of modeling has been done. First one, providing shear wall at center and another one, shear wall is provided at corners of the building. In both the types outriggers and belt truss are provided at different location to obtain reducing lateral displacement. To perform the analysis ETABS software has been used. The type of building considered for analysis is RC building, all the building models analyzed are of 32 storey's having an constant storey height of 3 meters and it will not represent any real structure for study purpose symmetric tall building has been taken for which outrigger would be a accurate solution.

The main problem of providing outriggers is that it will occupy the floor free space which can be used for any other purpose, to overcome this difficulty two types of modeling has been done,

1. Conventional outrigger with belt truss provided only at top of the building and for 2nd outrigger position virtual belt truss outrigger is provided at different heights of building and models has been analyzed.

2. Instead of providing shear wall at the center, it has been provided at corners of building they are connected using belt truss at different heights of building and used for analysis.

In the present work the model considered for the study is of 96 meters high rise reinforced concrete building frame. The plan area of building is 49.5 X 49.5m, columns being placed at 5.5m center to center. All the floors are considered as typical floors. The location of the building was assumed to be at Lucknow. An elevation and plan view of building is shown in fig. 4 and 5.

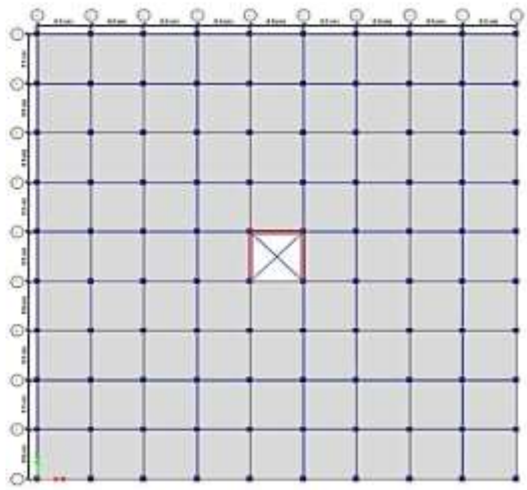

Fig.4.a Plan view of building with central core wall .

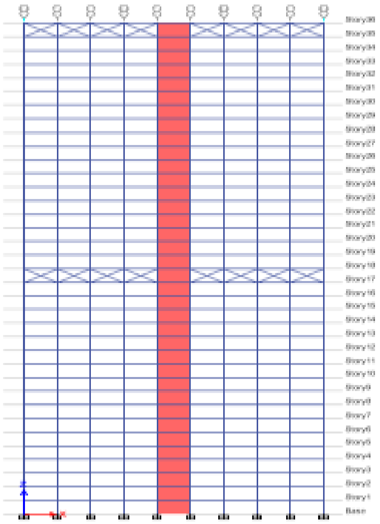

Fig.4.b Elevation view of building with central core wall .

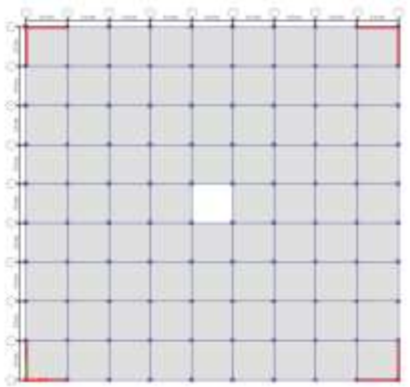

Fig.5.a Plan view of building with core wall at corner.

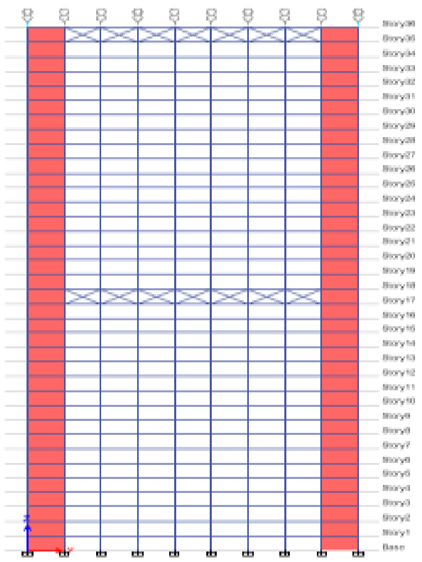

Fig.5.b Elevation view of building with core wall at corner.

The different arrangements made in the present work for outrigger location are:

- CENTRAL CORE WALL CONVENTIONAL OUTRIGGER SYSTEM.

1. Structural Model without Outrigger.
2. Structural Model with conventional Outrigger at top floor.
3. Structural Model with conventional outrigger at top floor and at mid height of building.
4. Structural Model with conventional outrigger at top floor and at 0.75 height of building.
5. Structural Model with conventional outrigger at top floor and at 0.25 height of building.

- CENTRAL CORE WALL CONVENTIONAL OUTRIGGER WITH BELT TRUSS SYSTEM.

1. Structural Model conventional outrigger with belt truss at top floor
2. Structural Model conventional outrigger with belt truss at top floor and at mid height of building.
3. Structural Model conventional outrigger with belt truss at top floor and at 0.75 height of building.
4. Structural Model conventional outrigger with belt truss at top floor and at 0.25 height of building

- CENTRAL CORE WALL CONVENTIONAL AND VIRTUAL OUTRIGGER SYSTEM.

1. Structural Model conventional outrigger with belt truss at top floor and 2nd virtual belt truss at 0.5 height of building.
2. Structural Model conventional outrigger with belt truss at top floor and 2nd virtual belt truss at 0.75 height of building.
3. Structural Model conventional outrigger with belt truss at top floor and 2nd virtual belt truss at 0.25 height of building.

- CORE WALL AT CONERS.

1. Structural Model with only core wall at corners.
2. Structural Model with 1st belt truss at top floor and 2nd belt truss at 0.5 height of the building.

The thickness of the shear wall is 300mm, provided for entire height of the building. The outrigger beams are of cross section 230mm wide and 450mm deep and other beams in the building are of cross section 300mm wide and 450mm deep. All the columns inside and outside the building are of 550X550mm size. Grade of concrete considered for entire height of building is 40N/mm^2.

It is assumed that there is a rigid connection between core and foundation. Material behaviour is in linear elastic range. The bending resistance in the core due to presence of outrigger system will provide lateral resistance to building and there will be no change in mass and stiffness with time.

As the building is assumed to be an hotel building live load is taken as 3kN/m². Floor finish is considered as 1.5kN/m², applied on all the floors and wall load of 8kN/m² is applied on all the beams as the member load and wall is considered to be made of light weight bricks .In the present work wind load is considered as per the IS 875 (part3). The location of building is assumed to be Lucknow. As per the code the basic wind speed in the city is V_b = 47m/s. The structural class considered as 'B' and terrain category as '3'. The coefficient K_1 and K_2 are considered as 1.0. Based on h/w and l/w ratio the net pressure co-efficient C_p windward and leeward side is calculated as 0.8 and 0.5 respectively.

The response spectrum analysis function is given in the ETABS model for calculating the earthquake load. Zone factor is given as 0.16, Lucknow city lie in "zone 3".

3. RESULTS AND DISCUSSIONS.

3.1 CORE WALL AT CENTER [CONVENTIONAL OUTRIGGER SYSTEM].

STORY DRIFT.

The one of the important factor that was considered in the present work is story drift. In the fallowing figure 6 it is observed that by providing outrigger at mid height of building in conventional outrigger system without BT 15% of drift is reduced and with BT outrigger system 18% of drift is reduced when compare to building with core wall only. The optimum location of second outrigger is at mid-height of the building for story drift criteria.

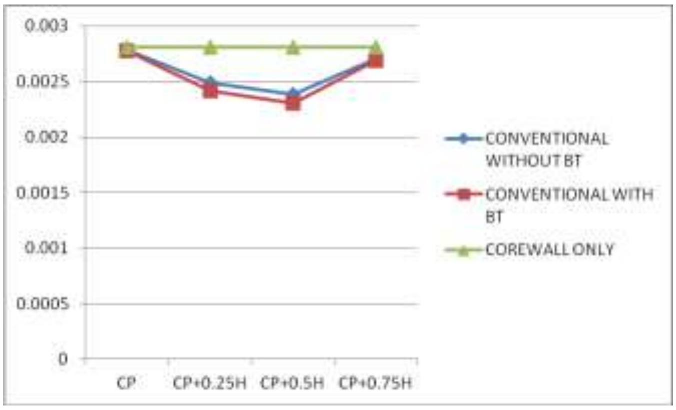

Fig.6 Story drift conventional outrigger system with and without belt truss.

LATERAL DISPLACEMENT

The analysis is done by considereing the load combination according to IS 875(PART 5) and in all the cases the lateral displacement is more for combination 1,5(DL-EQX). It is observed that 21.45% and 27.5% of lateral displacement is reduced for conventional with and without BT outrigger system respectively when compared with core wall only. Here also optimum location of second outrigger is at mid-height of the building.

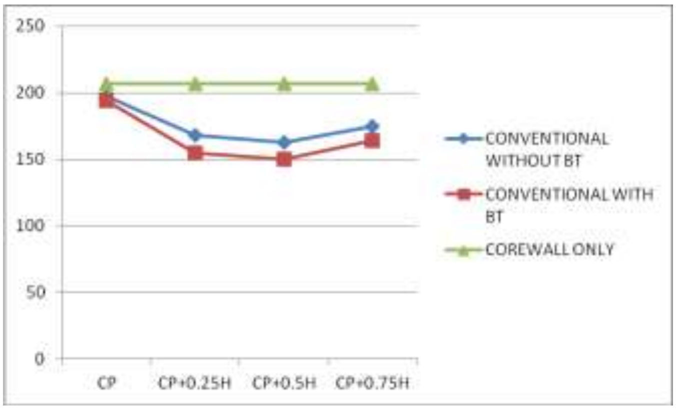

Fig.7 Lateral displacement (mm) conventional outrigger system with and without belt truss.

CORE WALL MOMENT.

The moment of the core wall is observed for earthquake load and optimum location of 2nd outrigger position was found to be at 0.25 height of the building for moment criteria.

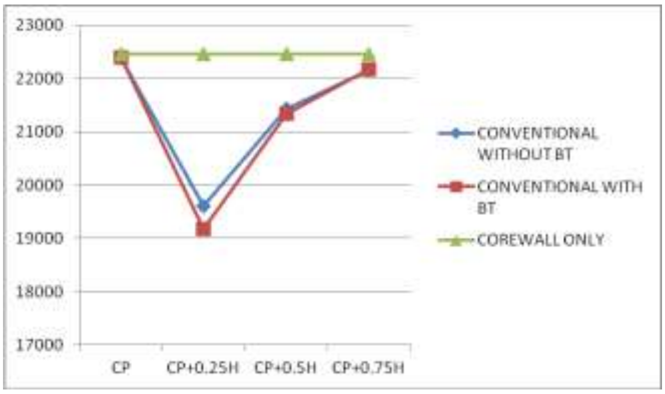

Fig.8 Core moment conventional outrigger system with and without belt truss.

3.2 CORE WALL AT CENTER [CONVENTINAL AND VIRTUAL OUTRIGGER SYSTEM].

To utilize the floor area space here for 2nd outrigger position only virtual belt truss system is provided at different locations.

STORY DRIFT.

The optimum location of second outrigger for providing virtual belt truss is found to be 0.5H for drift criteria and it can be observed in fallowing figure 9.

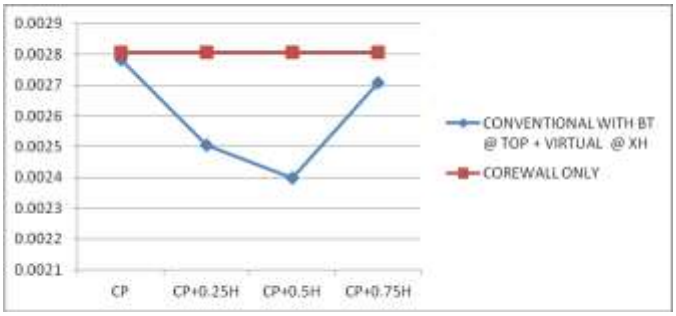

Fig.9 Story drift conventional with BT @ top and virtual at different height.

LATERAL DISPLACEMENT.

In this case also optimum location of 2nd oytrigger belt truss is found to be at 0.5 height of building and only slight increase in displacement when compsred to virtual outrigger system.

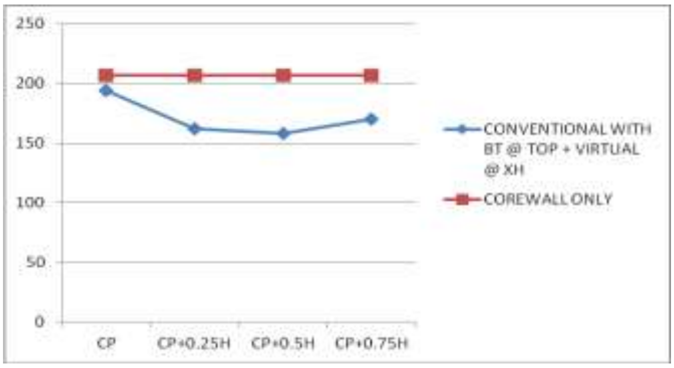

Fig.10 Lateral displacement (mm) conventional with BT @ top and virtual at different height.

CORE WALL MOMENT.

The moment of the core wall is observed for earthquake load and optimum location of 2nd outrigger position was found to be at 0.25 height of the building for moment criteria.

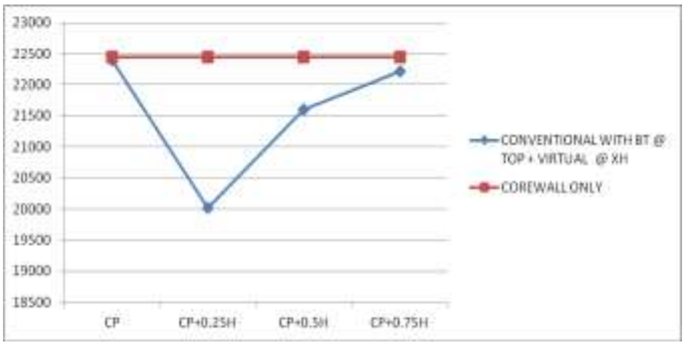

Fig.11 Core wall moment (kN-m) conventional with BT @ top and virtual at different height.

3.1 CORE WALL AT CORNER [BELT TRUSS SYSTEM].

LATERAL DISPLACEMENT.

In the present work the lateral displacement is checked for building having only shear wall and 2nd model having belt truss at top and mid height of the building and results are shown in fallowing figure.

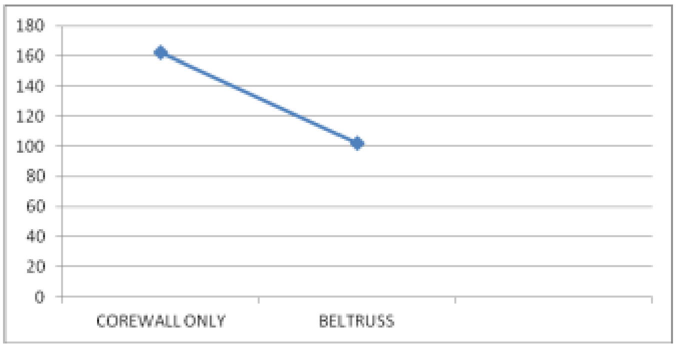

Fig.10 Lateral displacement (mm) core wall at corner belt truss system.

3. CONCLUSIONS.

1. The lateral load resisting efficiency of the building increases with increase in the stiffness on providing outrigger and belt truss system.
2. The conventional outrigger with belt truss found to be more effective compared to conventional outrigger without belt truss and virtual outrigger system.
3. In both the cases conventional outrigger system with and without belt truss the optimum location of 2nd outrigger is at mid height of building for drift and lateral displacement criteria.
4. The optimum location of 2nd outrigger for reducing moment in core wall was found to be at 0.25H of building.
5. The main disadvantage of providing outrigger system is that it will occupy floor area space to overcome this difficulty providing conventional with belt truss at top only and virtual belt truss at mid height of building can increase the stiffness and lateral load resisting efficiency of building.

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BIOGRAPHIES

CHETHAN PATEL Y G, PG Student SJBIT Bengaluru.

Mr. Kiran Kuldeep K.N, Assistant Professor, SJBIT Bengaluru.