

Study of Different Aspects of Outrigger Structural System: A Review

Iqra A. Khan¹, N. G. Gore²

ME Student, Dept. of Civil Engineering, MGM's College of Engg. and Tech., Navi Mumbai, Maharashtra, India¹
Assistant Professor, Dept. of Civil Engineering, MGM's College of Engg. and Tech., Navi Mumbai, Maharashtra,
India²

ABSTRACT: One of the most rapid developments in today's world is the construction of high-rise structures. Due to a continuous increase in population, the land crisis has emerged out as one of the most critical problems of our nation today. And high-rise structures are the only solution to this problem. As the height of the structure is increased, the structure becomes more prone to lateral forces. To deal with the wind and earthquake loads acting on the structure, several lateral force resisting systems have been introduced such as the braced tube, shear wall frames, diagrid, space truss and different types of outrigger structural system etc. Out of which, Virtual outrigger has proved itself to be a very efficient structural system. This paper presents a review of different aspects related to outrigger system such as optimum position and selection of outrigger system. It is concluded that the virtual outrigger can be adopted as an effective system over conventional outrigger system for some major disadvantages associated with it.

KEYWORDS: belt truss, optimum location, highrise, virtual Outrigger, ETABS, earthquake, wind

I. INTRODUCTION

The development in concrete technology over the twentieth century covering material, structural system, analysis and construction techniques, made it possible to build concrete tall buildings. As the height of a building is increased, the material starts to play more important roles for the stability of the structure. Steel is one of the most important materials used in construction and it is used in different ways to improve its performance [1].

Karan D. Sitapara et al. [2] discussed different lateral load resisting systems that have been brought in use in highrise structures to mitigate the losses occurring due to lateral loads. Out of that, outrigger structural system has proved itself to be one of the best methods usually being used in highrise structures. And it was seen that the stiffness of the structural system increases by 20 to 30% by introducing the outrigger structural system. Apart from that, some disadvantages are also associated with this system, but by using outrigger system optimally, that can be minimized too.

R. Shankar Nair [3] proposed the idea of belt truss and basement as a virtual outrigger which can serve the same purpose as that of conventional outrigger by increasing the stiffness of the belt truss. Even though it is not as stiff as conventional one, but can provide the necessary deflection control with the advantages such as availability of more space due to the absence of outrigger beam, participation of all the columns located at the periphery, elimination of the difficult connection of outrigger beam with core and exterior columns.

As stated above, to overcome the problems related to conventional outrigger system, a variation of this system i.e. offset and alternate offset outrigger (virtual outrigger) was studied by Andrew J. Horton [4]. And it was observed that some modifications in virtual outrigger system can lead to an equal performance as that of the conventional outrigger.

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II. LITERATURE REVIEW

Since outrigger system is emerging out as an effective system, researchers have been and are working on the concept, to make it more effective with minimum losses. The studies have been done for wind or earthquake or for both analyses. Here, some papers have been reviewed and summarized below, covering different aspects of outrigger system.

Review of Literature based On Optimum Position of Outrigger Structural System

Roy Shyam S. et al. [5] carried out an investigation on outrigger system on a G+50 storey RC building using ETABS software. The structure had been analyzed for earthquake loads by Equivalent Static Method and response spectrum method and for wind loads using the Static Coefficient method and Gust factor method. IS 1893:2002 and IS 875-2015 (part 3) were used for former and later analyses respectively. The outriggers were placed at 0.4H, 0.7H and H and it was concluded that the maximum deflection at top of the structure was 368.6 without outrigger which was reduced to 202.5 after application of outriggers. Also, the reduction in drift was found to be more than 50% of the structure without outrigger.

Anju Akbar et al. [6] presented the study of outrigger-belt truss system on a 40 storey building irregular in plan. For that, a multi-outrigger system was preferred in which one outrigger was employed at the top, one at the bottom and the other at the 3/4th height of the building. Wind and earthquake loads in this study were established in accordance with IS 875(part 3) and IS 1893 (part 1)-2002 respectively. It was seen that maximum displacement, overturning moment and drift at the top were 1.61m, 789.35kNm and 0.0089 without outrigger which reduced to 1.04m, 789.35kNm and 0.0077 with outriggers respectively.

Abbas Haghollahi et al. [7] analyzed a 20 and 25 storey steel frame building models by Response spectrum method and time history method against 7 ground motions to find out and compare the optimum location of outrigger in AISC-ASD and FEMA 356 softwares. The optimum positions of outrigger and belt truss obtained by Response spectrum method (Case 1) were 0.44H and 0.5H (from top of the building) for 20 and 25 storey building respectively. While optimum positions of outrigger and belt truss were 0.3H and 0.36H (from top of the building) for 20 and 25 storey building respectively in case of time history analysis (Case 2).

Chetan Patel et al. [8] carried out the investigation on models of two types of RC building of 32 storey with respect to the position of shear wall wherein shear wall in center and shear wall at corners are employed with different positions of outrigger and belt truss to reduce lateral displacement. The study was done for wind and earthquake load which were calculated on the basis of IS 875(Part 3) and IS 1893 (Part-1): 2002. It was seen that for 1st outrigger fixed at top, in both the cases conventional outrigger system with and without belt truss, the optimum location of 2nd outrigger was found to be at mid-height of building for drift and lateral displacement criteria but 0.25H for reducing moment at core.

KasiVenkatesh et al. [9] analyzed a 20 story office RC building model for different positions of outrigger and belt truss and the optimum location has been found out by using ETABS software. The analysis was done for wind or earthquake loads which were calculated based on IS 875 (Part 3) and IS 1893 (Part-1): 2002 respectively. They observed that 18.55% and 23.06% of the drift is controlled by providing the outrigger and outrigger with belt truss at mid-height of the building respectively in addition to cap truss as compared to building with no outrigger. Also, the maximum reduction in bending moment was seen to have occurred for the same arrangement.

Kiran Kamath et al. [10] studied about the optimum position of outriggers in a 40 storey multi-outrigger structure subjected to seismic loads as per IS 1893 (PART 1):2002 by using ETABS software for zone III. And they resulted that, outriggers for a relative height of 1.5 reduced the lateral displacement up to 31.74% whereas outriggers for relative height 6.67 reduced the bending moment in core up to 32.60% as compared to the building without outrigger.

*Relative height = H_2/H_1 where H_1 and H_2 are heights of the building where first and second outriggers are placed from ground respectively.

Kiran Kamath et al. [11] presented the study in which a 3D, 40 storey building with different arrangements of outriggers by varying H_s/H ratio from 0.975 to 0.4 having a relative stiffness (EI_o/EI) between 0.25 and 2 has been modeled and analyzed in ETABS software. Lateral wind load conforming to IS-875-part3 (1987) and equivalent static analysis for seismic in accordance with IS 1893-2002 had been carried out. For dynamic analysis, response spectrum analysis is carried out for historical earthquake time histories. It was observed that, the reduction in lateral displacement at top, when

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outrigger was placed at top was found to be 37% for wind analysis and 34% for seismic analysis and reduction in lateral displacement at top, when outrigger was placed at mid-height was 61% for wind analysis and 64% for seismic analysis as well as 95% reduction in bending moment was seen in core at the base in comparison with model without outrigger. N. Heranath et al. [12] selected a 50 storey high rise RC building frame to identify the behavior of structure under earthquake loads. The STRAND 7 finite element package was used to simulate the model and two-dimensional analysis was conducted. It was found that, in case of single outrigger (Case 1), the optimum location of outrigger was in between level 20 to level 30 whereas, in case of two outriggers (Case 2) with the 1st outrigger fixed at top, the optimum position of the 2nd outrigger was in between level 22 to level 24.

Gerasimidis S. et al. [13] designed a 2D 30 storey model of steel structure including only the basic structural elements (concrete core, steel columns and steel outriggers) and analyzed it using the software. Here, two outriggers were used, out of which the 1st outrigger was fixed at the top and optimum location of the 2nd outrigger is determined. In this study, only dead load and wind load had been taken into consideration. And they concluded that the optimum location of the 2nd outrigger for drift and core moment criteria was at mid-height of building whereas at 21m from bottom and 1/3rd of height from the bottom for outrigger moment and column axial forces criteria.

Minu Mathew et al. [14] modeled a G+45 storey RC framed building in ETABS software to find out the optimum position of RC outrigger and belt wall. Wind and seismic analysis had been done and loads were taken in accordance with the IS-875(Part 3) and IS 1893(2002) respectively. Without outrigger, the maximum lateral displacements for earthquake and wind loads were found to be 329mm and 339mm respectively which reduced to 195mm and 118mm respectively after applying outrigger. This reduction was achieved by putting the 1st outrigger fixed at the top and optimally locating the 2nd and 3rd outriggers at 15th and 30th storey respectively for earthquake (Case 1) as well as wind (Case 2) loadings.

Shruti B. Sukhdeve [15] modeled and analyzed a G+40 story RC building in ETABS software to find out the optimum location of outrigger wall. The model was analyzed under wind and earthquake loads as per the recommendation of IS: 875 (Part 3) 1987 and IS 1893 (Part 1) 2002 respectively. 29.45%, 43.94% and 54.98% reductions in deflection were observed by providing 1st outrigger at mid-height, 2nd outrigger at the 3/4th height of structure and 3rd outrigger at the 1/3rd height of structure from the bottom, respectively as compared to deflection without the outrigger.

Sandesh K. Shirole et al. [16] carried out the study of the behavior of outrigger structural system by different methods and for all the analyses, they selected a 30 storey building, modeled in ETABS software in zone III. They analyzed the structure using IS code 1893:2002 (case 1) to find out the optimum location of the outrigger. Also, the behavior of outrigger was observed by time history analysis (case 2) and capacity spectrum method (case 3) by putting the outrigger at 4 different positions as at 5th, 15th, 20th and 30th floor. For case-1, the maximum storey displacement at the top was found to be 40.741mm when outrigger was placed at the 20th storey and the maximum storey drift was 0.00059 when the outrigger was located at the 19th storey which were the lowest values compared to other outrigger locations. For case-2, the maximum displacement in the building was found to be minimum when outrigger was placed at the 20th storey and it was reduced to 17.31 mm. Also, the base force was decreased to 110.52kN from 1873.35kN when no outriggers were used. For case-3, Outriggers placed at 15th storey gave the base force of 128.2kN and displacement of 60.1mm which was found to be minimal when compared with the values obtained when outriggers were placed at 5th, 20th, 30th and with no outrigger.

Shivacharan K. et al. [17] modeled a 30 storey 3D structure with vertical irregularity designed for gravity loading only, in ETABS software. Then they placed outrigger and belt truss for certain height and found out the optimum position of 1st outrigger which was at 0.67H from the bottom. Then keeping 1st outrigger fixed and by varying the position of the 2nd outrigger, optimum position of 2nd outrigger and belt truss was obtained. It was observed that 45.1% and 40% of the deflection and drift was controlled by providing outrigger with belt truss at 0.5H when compared with the bare frame.

Alpana L. Gawate et al. [18] worked on a 3D model of a 30 storey building. The work was done for finding out the optimum location of outrigger for single and double outriggers, using ETABS software. The model was analyzed for wind as well as earthquake load (response spectrum analysis) in accordance with IS 875: Part III-1987 and IS 1893: 2002 respectively. For drift control, they concluded that, for single outrigger (Case 1), the optimum location of the outrigger was at 0.47H from bottom of the building and for two outriggers, out of which one was fixed at top floor (Case 2), the optimum location of the 2nd outrigger was at 0.30H from bottom of the building. Also, when two outriggers had to place at 0.333H away from each other (Case 3), the optimum locations of the outriggers were at 0.333H and 0.667H from the bottom of the building.

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Review of Literature based on Virtual Outrigger Structural System

R. Shankar Nair [3] investigated on a 75-story steel-framed office tower to study the effectiveness of belt trusses as virtual outriggers and for that conventional outriggers and virtual outriggers were compared. The maximum lateral displacement with conventional outrigger was found to be 25.3 inches and its was 26 inches with virtual outrigger with the modification of 10-fold increase in floor diaphragm stiffness and 10-fold increase in belt truss area.

Andrew J. Horton [4] applied the Nair's belt trusses and basements as virtual outrigger to continuous belt trusses and belt walls at outrigger levels for a 75-storey steel framed office tower. The deflection was seen to be 29.2% for conventional outrigger and 27.2% for modified belt walls as compared to without outrigger. He discovered that a 2-fold increase in outrigger diaphragm thicknesses with a 16% increase in belt truss area were very well sufficient to control the deflection approximately equal to that of conventional outrigger system.

Z. Bayati et al. [19] presented an investigation on drift reduction in uniform belted structures with rigid outriggers, with a sample structure of 80-story steel-framed office tower, using ETABS software. Where three sets of 4-storey deep outriggers were employed at three places. Comparative study between conventional and virtual outrigger was made in which the maximum lateral displacement was found to be 70cm with conventional outriggers and 95cm with belt trusses as virtual outriggers. After 10-fold increase in floor stiffness and belt truss area of virtual outrigger, the deflection reduced to 65cm.

Daril John Prasad et al. [20] analyzed a 30-storey structure with vertical irregularity, subjected to seismic loading using ETABS software. They employed three different types of outrigger structural system which were modeled with outrigger and belt truss, only outrigger and only belt truss and achieved maximum deflection of 60.2mm in the model with conventional outrigger and 77mm in the model with only belt truss i.e. virtual outrigger. They concluded that with respect to lateral displacement criteria, building with both outrigger and belt truss and only belt truss system performed better than the building with only outrigger system. By considering all important aspects mainly economy, it was recommended to select virtual outrigger.

Chetan Patel et al. [6] showed the conventional outrigger with belt truss to be more effective compared to conventional outrigger without belt truss and virtual outrigger system.

Indumathi H. D. et al. [21] carried out the analysis of 70 storey steel building situated in zone V using ETABS software to study the effectiveness of belt truss system in which different arrangement of belt truss were made in tube in tube and in framed tube structure. It was found that in tube in tube with belt truss at every 10 storey, the maximum lateral displacement and storey drift were found to be 55.51mm and 0.00002 respectively which were the lowest values as compared to all other structural arrangements.

Karthik A. L. et al. [22] worked on five structural frameworks which were Regular steel structure, Tube structure, Bundled tube structure, Bundled tube structure with belt-truss, Bundled tube structure with belt-truss and mega bracings on a 110 storey steel structure in ETABS. Results showed that the steel bundled tube structure with belt-truss and mega bracings framework gave out the lateral displacement and drift as 192.2024mm and 0.000273 which were least as compared to all other structures.

Eltobgy H. H. et al. [23] made an investigation over some of the common structural systems viz. Simple Connection Model (SCM), Corner Rigid Columns Model (CRCM), Partial Rigid Columns Model (PRCM), Moment Resisting Frame Model (MRFM) and Belt Truss Model (BTM) for a 10 storey steel building along with their related risk of progressive collapse resistance capacity and optimal system to be adopted. It was found that the percentage of weight increase in BTM is 14% compared with the GRM whereas the increase is 55% in the case of SCM and 67% for the MRFM.

Pamuda Pudjisuryadi et al. [24] took into consideration, a 60 story building with Shearwall-frame combined with belt truss as lateral load resisting system in seismic zone II. A three story belt truss was installed at $2/3^{\text{rd}}$ of building height and it was design according to the current Indonesian Seismic and Concrete Codes. The results of this study showed that plastic hinges mainly developed in beams above the truss, columns below the truss, and bottom levels of the wall.

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III. SUMMARY OF RESULTS

A number of researchers have worked on finding out the optimum location of outrigger and belt truss system. Some of the papers have been reviewed above and summarized below in the form of graphs to have the genuine recommendation for providing the outrigger system to the structure. The figure below, gives a comprehensive and perspicuous representation of the optimum location of outrigger-belt truss for different height of building with different plans as well as for different analyses.

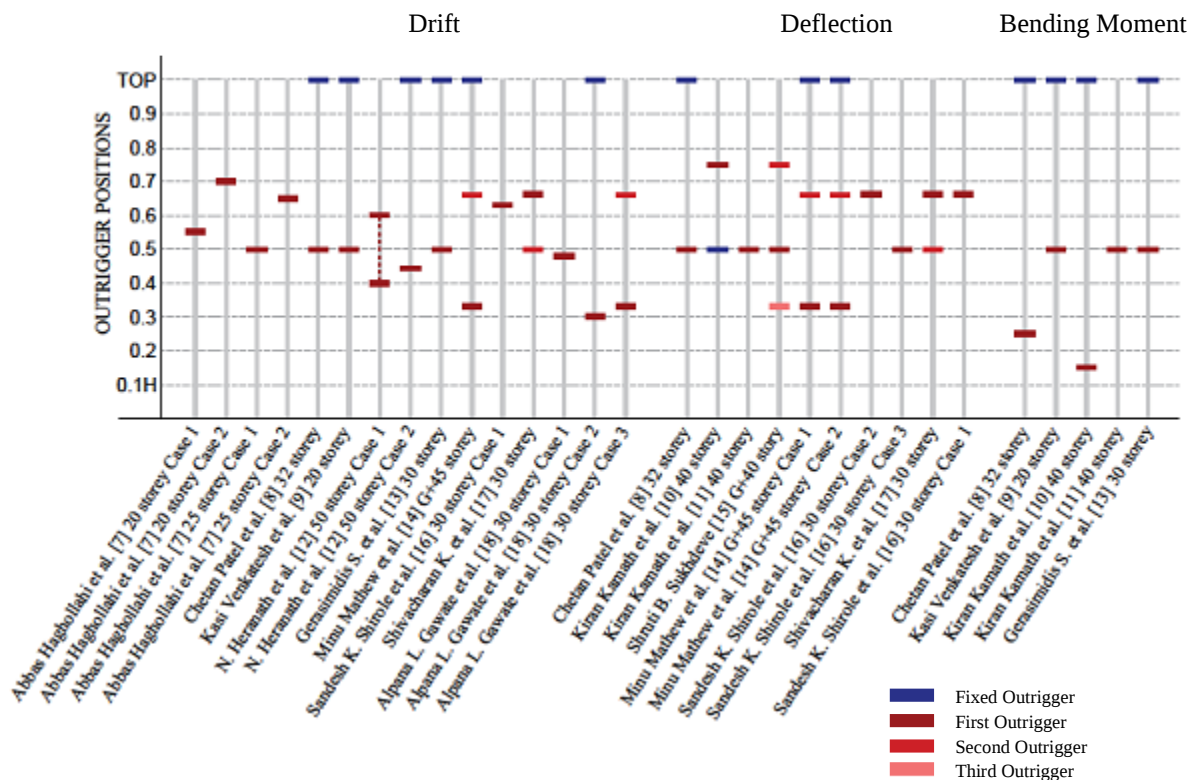


Fig. 1 Optimum Location of Outrigger and Belt Truss

Since the conventional outrigger system comprises so many drawbacks not only related to space but related to construction also. And virtual outrigger, though is capable of overcoming moderate magnitude of lateral forces only, has an ability to minimise the major losses associated with conventional one after some modification made to it. Not many researchers, till date, have worked on the comparative study of above mentioned two types of outrigger systems. Out of that, a few papers have been reviewed above and are being summarized in the form of a graph. The graph below, shows the relative effectiveness of the two outrigger system. And hence, gives the idea of preciseselection of the outriggersystem as per the requirement.

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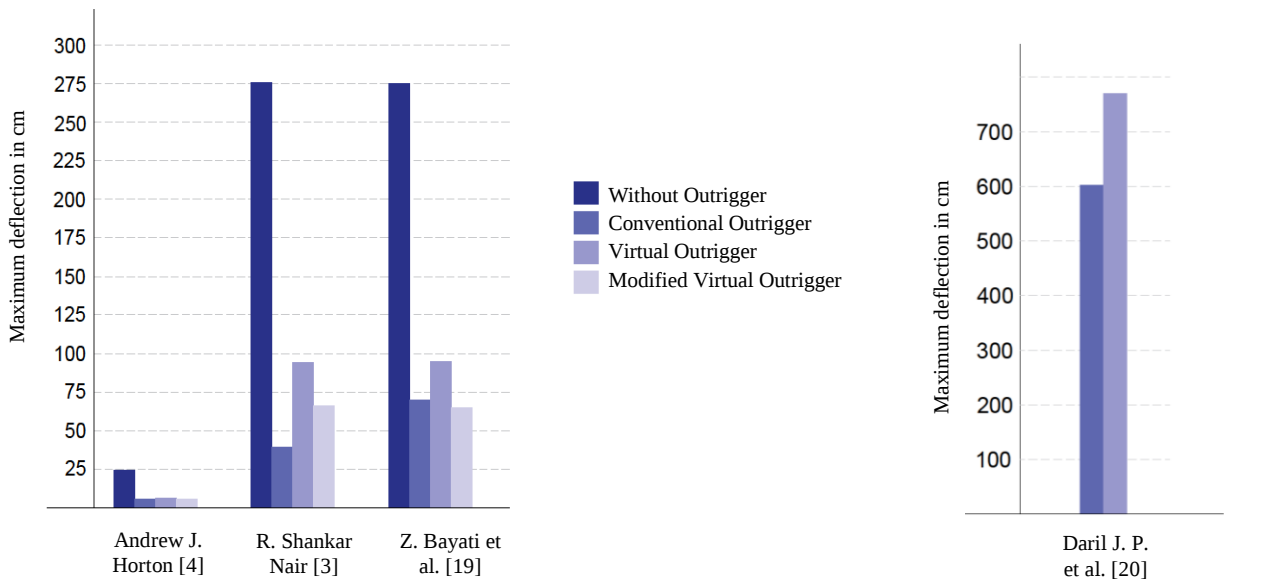


Fig. 2 Maximum Deflection in Different Outrigger System

IV. DISCUSSION

So many researchers have been working on different features of outrigger structural system since a long time and conveyed the idea of efficient use of outrigger system. They have discovered the optimum location of outrigger system for different criteria such as deflection, drift, core moment, outrigger moment and column reaction etc. [2, 5-6] have discussed about the fruitfulness of outrigger system in tall building. Finding out the optimum location of outrigger is the main purpose of papers [7-18] for different criteria. When taken in account, the lateral displacement and drift criteria, the optimum positions of outrigger and belt truss obtained by Response spectrum method are 0.44H from top and 0.5H for 20 and 25 storey building respectively. While optimum positions of outrigger and belt truss are 0.3H and 0.36H from top for 20 and 25 storey building respectively in case of time history analysis [7]. The optimum location of single outrigger is at mid-height of the building [9-12, 16, 18] and it is at 0.66H from bottom [16]. In case of double outrigger, the optimum location of 1st and 2nd outriggers are found to be at top and mid-height of the building [8, 13-14]. [14] Observed the optimum locations to be at 0.33H and 0.66H from bottom respectively for wind loading and the same positions are determined by [18]. When three outriggers are used, they are placed optimally as 1st outrigger at top, 2nd at 0.75H of structure and 3rd at 0.33H of structure from bottom respectively [15] whereas they are placed at top and at 0.33H from bottom of structure [18]. Optimum locations of 1st and 2nd outriggers were found to be at 0.67H from bottom and 0.5H respectively [17]. When the moment in core is considered, the optimum locations of two outriggers are as 1st outrigger at top and 2nd at 0.25H from the bottom [8]. Though the virtual outrigger is not as stiff as conventional one but can give the desired results by having some modifications in it along with the advantages of eliminations of the problem related to conventional outrigger system [3-4, 19-20]. Belt truss is an efficient system which reduced the drift to 18% when used with outrigger from 15% with only outrigger, also, the lateral displacement is reduced to 27.5% from 21.45% respectively [6]. Out of different lateral load resisting structural systems, belts truss (Virtual outrigger) can be said to be the most efficient system [21-23]. Plastic hinges mainly developed in beams above the truss, columns below the truss, and bottom levels of the wall [24].

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V. CONCLUSIONS

The behavior of a structure against lateral loads is highly dependent on the location of outrigger beam. From the results of above papers, it can be concluded that the optimum location of outrigger beam changes with the change in design, method of analysis and criteria to be controlled etc. and hence discovered that the location of outrigger beam for drift and deflection criteria is different from core moment criteria and even for earthquake analysis, the location found by response spectrum analysis is different from time history analysis. The optimum location of outrigger beam, in general, can be said to be at mid-height of the building for single outrigger. The optimum location of outriggers, considering drift and deflection criteria were found to be in between $0.4H$ to $0.75H$ from the bottom of the building and it is found to be at or below $0.5H$ of the building for base moment criteria along with the application of cap truss. Also, the Virtual outrigger is the most cost-effective type of outrigger and are mostly used in highrise structure due to its numerous advantages over conventional outrigger system.

VI. SCOPE OF FUTURE STUDY

- a. Since most of the works have been carried out on the geometrically regular plan, the usage of outrigger system on structures with irregular plan or buildings with vertical irregularity should be studied.
- b. There's deficiency of work on an actual architectural plan since all the analyses have been examined on grid plans.
- c. Most of the models are studied with linear analysis and only some of the researchers have analyzed the model by non-linear method such as time history method in zone V.
- d. Outrigger system has been employed in building with the height of 40 to 60 floors only. Building models with height up to 100 floors can be made to study.
- e. The modification in conventional outrigger system i.e. Virtual and Damped outrigger system are comparatively fewer analyzed in highrise structure.
- f. Steel outrigger and belt truss are most frequently used in structures. The effect of concrete outrigger and belt walls can be studied in different zones.
- g. The concept of offset and alternate outrigger can be compared with different outrigger system.
- h. Since Virtual outrigger is inadequate in bringing out the desirable results in areas which are very highly prone to lateral loading, the modifications can be tried to make it work in Zone 5 or in areas of high wind velocity.
- i. Optimum locations of outrigger beams could be found for more than 3 outriggers.
- j. Necessity and effects of double and triple storey deep outrigger can be studied.
- k. There're only a few researchers who worked on a single model with different types of outrigger system. The study can be done to have optimum usage of the outrigger.

REFERENCES

- [1] Ali SherifS. Rizk, "Structural Design Of Reinforced Concrete Tall Buildings", CTBHU Journal, Issue 1, pp. 43-4, 2010
- [2] Karan D.Sitapara and N.G. Gore, "Review On Feasibility Of High Rise Outrigger Structural System In Seismically Active Regions" International Research Journal of Engineering and Technology, Vol. 03 Issue 07, pp.197-203, 2016
- [3] Nair R. S., "Belt trusses and basements as virtual outriggers for tall buildings", Engineering Journal AISC, Fourth Quarter, 140-146, 1998
- [4] Andrew J. Horton, "Virtual Outriggers in Tall Buildings"
- [5] Roy ShyamSundar and N. G. Gore "A Study on Tall RC Structure with Outrigger System Subjected to Wind and Seismic Loading" International Journal of Engineering Research and Technology, ISSN: 2278-0181, Vol. 6, Issue 02, February-2017
- [6] Anju Akbar and SadicAzeez, "Effect of Outrigger System in a Multi-Storied Irregular Building", International Journal of Modern Trends in Engineering and Research, ISSN: 2349-9745, 2016
- [7] Abbas Haghollahi, Mohsen BesharatFerdous and Mehdi Kasiri "Optimization of Outrigger Locations in Steel Tall Buildings subjected to Earthquake Loads", The 15th World Conference on Earthquake Engineering, 2012
- [8] Chethan Patel Y. G. and Kiran Kuldeep K. N. "The Study On Behaviour Of Outriggers For Tall Buildings Subjected To Lateral Load", International Research Journal of Engineering and Technology, ISSN: 2395-0056, Vol. 04, Issue 07, July-2017
- [9] KasiVenkatesh and B. Ajitha "Behavior of a Building with Outrigger System", 6th International Conference on Recent Development in Engineering Science, Humanities and Management, ISBN: 978-93-86171-36-8, 2017
- [10] Kiran Kamath, Avinash A. R. and SandeshUpadhyaya K., "A Study on the performance of multi-outrigger structure subjected to seismic loads", IOSR Journal of Mechanical and Civil Engineering, ISSN: 2278-1684,

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

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- [11] Kiran Kamath, N. Divya and Asha U. Rao, "A study on static and dynamic behavior of outrigger structural system for tall buildings", Bonfring International Journal of Industrial Engineering and Management Science, Vol. 2, No. 4, 2012
- [12] N. Herath, N. Haritos, T. Ngo and P. Mendis, "Behavior of outrigger beams in high rise buildings under earthquake loads", Australian Earthquake Engineering Society Conference, 2009
- [13] Gerasimidis S., Efthymiou E. and Baniotopoulos C., "Optimum outrigger locations of high-rise steel buildings for wind Loading", EACWE 5 Florence, 2009
- [14] Minu Mathew and Manjusha Mathew, "Optimum Position of Outrigger with Belt Wall", International Journal of Innovative Research in Science, Engineering and Technology, ISSN: 2319-8753, Vol. 6, Issue 6, June 2017
- [15] Shruti B. Sukhdeve, "Optimum Position of Outrigger in G+40 RC Building", International Journal of Science Technology & Engineering Vol. 2, Issue 10, April 2016
- [16] Sandesh Kumar Shirole Y., Dr. B. K. Raghu Prasad and Dr. Amarnath K, "Study Of Behavior Of Outriggers In A High Rise Building Under Seismic Loading", International Research Journal of Engineering and Technology, Vol. 03, Issue: 08, August 2016
- [17] Shivacharan K., Chandrakala S., Narayana G. and Karthik N., "Analysis of outrigger system for tall vertical irregularities structures subjected to lateral loads", International Journal of Research in Engineering and Technology, Vol. 04, Issue 05 May 2015
- [18] Alpana L. Gawate and J.P. Bhusari, "Behaviour of outrigger structural system for high-rise building", International Journal of Modern Trends in Engineering & Research, ISSN: 2349-9745, July 2015
- [19] Z. Bayati, M. Mahdikhani and A. Rahaei, "Optimized use of multi-outriggers system to stiffen tall buildings", The 14th World Conference on Earthquake Engineering, 2008
- [20] Daryl John Prasad and Srinidhilakshmi Kumar, "Comparison Of Seismic Performance Of Outrigger And Belt Truss System In A RCC Building With Vertical Irregularity", International Journal of Research in Engineering and Technology, Vol. 05 Special Issue 20, 2016
- [21] Indumathi H. D. and Ganesh M. and Spandana B., "Study On High Rise Steel Tubular Structures with Belt Truss Subjected To Seismic Loading", International Journal of Research in Engineering and Technology, Vol. 06, Issue 06, June 2017
- [22] Karthik A. L., Geetha K., "Dynamic Analysis Of Bundled Tube Steel Structure With Belt-Truss And Mega Bracings", International Research Journal of Engineering and Technology, Vol. 03, Issue 07, July 2016
- [23] Eltobgy, H. H., Nabil, A. and Bakhoun, M. M., "Effect of Belt Truss Systems on the Enhancement of Progressive Collapse of Steel Buildings", 2013
- [24] Pudjisuryadi, P., Lumantarna, B., Tandya, H. and Loka, "Ductility of a 60-story shearwall frame-belt truss (virtual outrigger) building"
- [25] Akshay Khanorkar, S. V. Denge and S. P. Raut, "Belt Truss as Lateral Load Resisting Structural System for Tall Building: A Review", International Journal of Science Technology & Engineering, Vol. 2, Issue 10, April 2016