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Belt Truss as Lateral Load Resisting Structural System for Tall Building: A Review

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Abstract

Tall building construction has been rapidly increasing worldwide. It is creating impact on innovative development of structural system for tall building. Recently, structural systems like braced tube, dia-grid, outrigger and belt truss providing great approach for development of tall building. This paper presents a review on uses of belt truss as lateral force resisting system for tall building. Belt truss is emerging as efficient structural system for tall building. It is concluded that belt truss can be used as lateral force resisting system in tall building rather than using it with outrigger due to some problem related with outrigger. Belt truss can control nearly same amount of deflection with increased in stiffness as that of outrigger.

Keywords: Tall Building, Belt Truss, Building Deflection and Optimum Position

I. Introduction

Advancement in structural system and high strength material creating impact on rapid development of tall buildings, it is also need of growing population and infrastructures in large cities. The development in concrete technology over the twentieth century covering materials, structural systems, analysis and construction techniques, made it possible to build concrete tall buildings [1].

Primarily moment resisting frame and shear wall are efficient and economical structural systems. But when building increases in height, there is effect of wind and earthquake forces therefore stiffness of the structure becomes more important aspect. Lateral load due to wind and earthquake is the major factor that affects design of tall structures. Lateral drift at top of structure is one of the most important criteria for design of tall buildings. Currently, there are many structural systems such as rigid frame, braced frame and shear-walled frame, frame-tube, braced-tube, bundled-tube, outrigger and belt truss systems that can be used to enhance the lateral resistance in tall buildings [2].

From above mentioned structural system belt truss system is effectively used as one of the structural system to control the excessive drift due to lateral load, so that, during small or medium lateral load due to either wind or earthquake, the risk of structural and non-structural damage can be minimized.

In tall building belt truss can be use to control deflection due to lateral load and to enhance stiffness of structure. R. Shankar Nair [3] proposed use of belt truss instead of outrigger and named the system virtual outrigger. R. Shankar Nair [3] showed that shear wall belt truss structure, although not as good as outrigger, could effectively reduce the lateral displacement in the elastic region. Z. Bayati et al. [4] considered a 80-story steel-framed office tower to investigate the effectiveness of belt trusses as virtual outriggers and showed the same behavior.

Belt truss connect all perimeter column of building in the form of truss in steel building and in the form of rigid concrete wall in RC building. Belt truss is not connected directly to shear core i.e. inner lift core but it transfer forces and moment through the floor diaphragm from outer column to shear core therefore floor diaphragm need to be stiff enough to transfer forces.

The floor slabs that transfer horizontal forces from the core to the belt trusses will be subjected to in-plane shear (in addition to the usual vertical dead and live load effects) and should be proportioned and reinforced appropriately. In many applications, it will be necessary to use thicker-than-normal slabs.

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.

- Connection difficulty between outrigger and core is eliminated.
- There are no diagonal trusses extending from the core to the exterior of the building.
- There would not be the effect of differential shortening of core and outer column on floor diaphragm since they are stiff in their own plane and flexible in vertical plane.
- The need to locate outrigger columns where they can be conveniently engaged by trusses extending from the core is eliminated.

Use of belt truss as virtual outrigger eliminate some problem related to conventional outrigger and because of the many functional benefits of belt truss system and the advantages outlined above, this system has lately been very popular for super tall buildings all over the world.

II. LITERATURE REVIEW

R. Shankar Nair [3] investigate the effectiveness of belt trusses as virtual outriggers using a 75-story steel-framed office tower. Result obtain for wind analysis is as follows.

Type of outrigger	*Lateral displacement*
No outrigger	*108.5inch*
Convention outrigger	*25.3 inch*
Belt truss as virtual outrigger	*37.1 inch*
Belt truss as virtual outrigger: 10-fold increase in floor diaphragm stiffness.	*31.0 inch*
Belt truss as virtual outrigger: 10-fold increase in floor diaphragm stiffness, 10-fold increase in belt truss and stiffness.	*26 inch*

Z. Bayati et al. [4] studied an 80-story steel-framed office tower to investigate the effectiveness of belt trusses as virtual outriggers. The building has three sets of 4-story deep outriggers: between Levels 77 and 73 (at the top); between Levels 46 and 50; and between Levels 21 and 25.

Type of outrigger	*Lateral displacement*
No outrigger	*275cm*
Convention outrigger	*70 inch*
Belt truss as virtual outrigger	*95 inch*
Belt truss as virtual outrigger: 10-fold increase in floor diaphragm stiffness	*80 inch*
Belt truss as virtual outrigger: 10-fold increase in floor diaphragm stiffness, 10-fold increase in belt truss and stiffness	*65 inch*

Po Seng Kian et al. [5] studied analysis of 40−storey two dimensional model for wind load and 60−storey three dimensional model for earthquake load to find the lateral displacement reduction related to the outrigger and belt system location. For Two dimensional 40−storey model First outrigger at the top and second outrigger at the 0.5 h reduces 65% maximum displacement and for the three dimensional 60−storey model Optimum location of the outrigger truss placed at the top and the 33rd level reduces 18 % maximum displacement.

P.M.B. Raj Kiran Nanduri et al. [6] studied earthquake and wind analysis on 30−storey three dimensional models of RC building with outrigger and belt truss to find the lateral displacement reduction. The design of wind load was calculated based on IS 875 (Part 3) and the earthquake load obtained using IS 1893 (Part-1): 2002.

- Max. Drift at top – only core is employed 50.63mm. Placing outrigger at top storey 48.20mm and 47.63mm with and without belt truss respectively
- 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

Mohd Irfan Moinuddin et al. [7] Analyzed and compare nine 30−storey three dimensional models of outrigger and belt truss system subjected to wind and earthquake load to find the lateral displacement reduction related to the outrigger and belt system location. 23% maximum displacement reduction was achieved by providing first outrigger at the top and second outrigger at the middle of the structure height.

S. Fawzia et al. [8] investigates deflection control by effective utilization of belt truss and outrigger system on a 60-storey composite building subjected to wind loads. The reductions in lateral deflection are 34%, 42% and 51% respectively as compared to a model without any outrigger system. Author showed that the best location for one outrigger option is at level 36, i.e. 0.6 times the height of the structure. The best location for second outrigger of two outrigger system is 0.5 times the structure height while one is fixed at the top level.

Shivacharan k et al. [9] carried out earthquake and wind analysis of building by considering tall vertical irregularity of 30th storey of 7 X 7 bays for 1 to 10th storey and 7X6 bay 11th to 20th storey and 7X5 Bay 21st to 30th storey to find the optimum position of outrigger system and belt truss. Wind load is calculated by using IS 875 (Part 3) and Earthquake load is calculated by using code IS 1893(part-1): 2000. Optimum location of the outrigger is between 0.5 times its heights.

Krunal Z. Mistry et al. [10] analyzed 40−storey three dimensional models of outrigger and belt truss system subjected to wind and earthquake load to find the lateral displacement reduction related to the outrigger and belt truss system location Wind load in this study is established in accordance with IS 875(part 3) and Earthquake load is accordance with IS 1893(part 1)-2002. There is maximum reduction in displacement and shear force when 1st outrigger is placed at 20th floor, 2nd outrigger is placed at 10th floor and 3rd outrigger is placed at 30th floor i.e. location of three outrigger are at mid height, 1/4th height, and 3/4th height.

Abbas Haghollahi et al. [11] investigated two models of 20 and 25 storey high rise steel frame building to compare optimum outrigger locations. Response spectrum and time-history analyses have been carried out against seven ground motions.

Optimum location of outrigger and belt truss resulted from response spectrum analysis

20 storeys - 0.44 of the H from the top and for 25 storey - 0.50 of the H from the top

Optimum location of outrigger and belt truss resulted from time-history analysis

20 storeys - 0.3 of the H from the top and for 25 storey - 0.36 of the Ht from the top.

Radu Hulea et al. [12] analyzed the optimum position for two to seven outriggers and belt trusses, aiming to achieve minimum bending moment and minimum drift. Results of analysis showed that if outriggers are made more rigid there is no significant reduction of core base moment for more than four outriggers, but the top drift is reduced by almost 20%.

Mohd Abdus Sattar et al. [13] studied earthquake and wind analysis of RCC building model with 45, 60, 75 m height and 15, 20, 25 storey resp. The design of wind load was calculated based on IS 875 (Part 3) and the earthquake load obtained using IS 1893 (Part-1): 2002. Results of analysis shows that floor rigidity is not required to be increased beyond that required for the load carrying of dead load and live load on floors. Moments in Corner column are less compared to the middle column. Moments in outer periphery columns are less compared to the moments in interior columns.

M. R. Jahanshahi et al. [14] presented parametric functions for static analysis of tall buildings with combined system of tube in- tube and outrigger-belt truss system subjected to three separate load cases of concentrated load at top of the structure, uniformly and triangularly distributed loads along the height of the structure. It has been shown that results computed by the energy method correlate well with those obtained by means of SAP2000 analysis.

Reza Rahgozar et al. [15] presented a new and simple mathematical model that may be used to determine the optimum location of a belt truss reinforcing system on tall buildings such that the displacements due to lateral loadings would generate the least amounts of stress and strain in building's structural members.

M. R. Jahanshahi et al. [16] presented a methodology for determining the optimum location of an outrigger-belt truss system, based on maximizing the outrigger-belt truss system's strain energy. Optimum location for outrigger-belt truss system for three types of lateral loadings, i.e. uniformly and triangularly distributed loads along structure's height, and concentrated load at top of the structure.

Optimum location of outrigger-belt truss system for concentrated load at top of the structure, uniformly and triangularly distributed loadings along height of the structure were calculated respectively as 0.667, 0.441 and 0.490 of structure's height as measured from the base.

Pudjisuryadi et al. [17] Considered a 60-story building with Shear wall-frame combined with belt truss as structural system, with a ductility set equal to 3.75, in which the post-elastic behavior and ductility of this structural system are explored. The post elastic behavior of this building is evaluated using static non-linear push-over analysis (PO) and Dynamic non-linear Time History analysis Results of this study show that plastic hinges mainly developed in beams above the truss, columns below the truss, and bottom levels of the wall.

Eltobgy, H. H. et al. [18] Investigate different structural systems to detect more practical and cost effective systems to enhance the progressive collapse resisting capacity. The study were extended to numerically investigate the effectiveness of these systems by analyzing a ten storey steel office building using alternative pass method discussed by UFC09 code. The study shows that one of the preferred practices to reduce the potentiality for progressive collapse is the use of belt trusses at the top of the building. The use of belt truss system holds the initial failure of the damaged elements and redistributes the loads supported by the failed elements with the least increase in the structure's weigh.

Table -1
Optimum Position

Ref. No.	*Lateral Load Resisting System*	*Building Specification*	*Type of Analysis*	*Optimum Position*
[5]	*Outrigger and belt system*	*40−storey 60−storey RC building*	*Wind analysis for 40 storey Earthquake analysis for 60 storey*	*For 40 storey 1st at the top and 2nd at the middle For 60 storey 1st top and 2nd at 33rd level*
[6]	*Outrigger and belt system*	*30−storey RC building*	*Earthquake and wind analysis*	*Middle height of the building*
[7]	*Outrigger and belt truss*	*30 storey RC building*	*Earthquake and wind analysis*	*0.46 times height of building from bottom height*
[8]	*Outrigger and belt truss*	*60 storey composite building*	*Dynamic along wind response analysis*	*1st is at 0.6 times the height and 2nd at top*
[9]	*Outrigger and belt truss*	*30 storey RC irregular building*	*Earthquake and wind analysis*	*0.5 times height*
[10]	*Outrigger and belt truss*	*40−storey concrete*	*Earthquake and wind analysis*	*Mid height, 1/4th height, and 3/4th height of building*
[11]	*Outrigger and belt truss*	*20 and 25 storey steel frame building*	*Nonlinear time history and response spectrum analysis*	*Response spectrum analysis 20 storey - 0.44 of the H 25 storey - 0.50 of the H Time-history analysis 20 storey - 0.3 of the H 25 storey - 0.36 of the H*
[16]	*outrigger-belt truss system*	*Cantilever beam model with box cross section*	*strain energy method*	*Uniformly distributed lateral loading-0.441 Triangularly distributed loading-0.49*

				Concentrated load applied at top-0.667

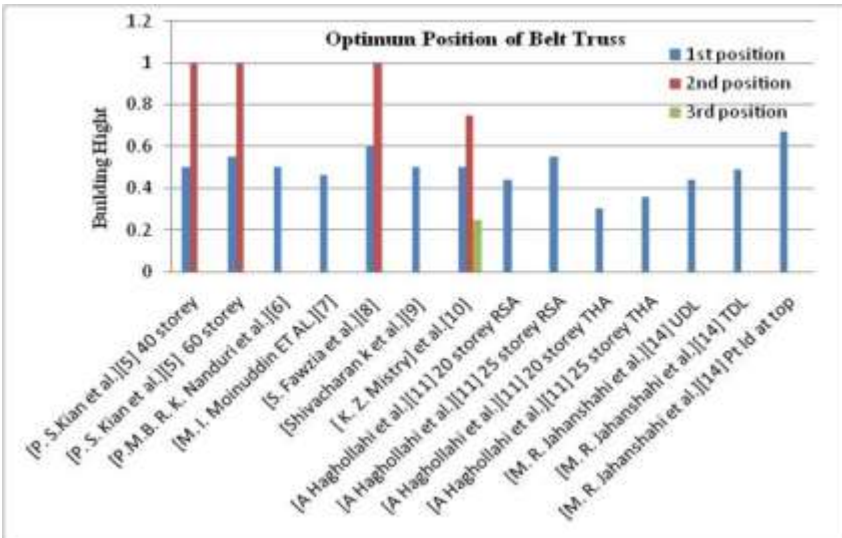

Fig. 1: Optimum Position of Belt Truss

III. Discussion

Researchers have used various techniques and methods for finding uses of belt truss in tall structure. Belt truss with stiffer floor diaphragm individually can minimize deflection as that of conventional outrigger but outrigger with belt truss can resists maximum deflection than individual belt truss or outrigger [1, 2]. Different types of analysis were conducted as per the various available standards. The common parameters studied by various researchers were position of belt truss, lateral drift, core moment, and column reaction. [3-9] focused on obtaining the optimum position of belt truss for satisfying deflection criteria. [10] focused on obtaining the optimum position of belt truss for satisfying deflection as well as moment criteria. First optimum position for belt truss is at 0.5 of structures height i.e. mid height [3-10]. Optimum position of second belt truss is at top of structures height [3, 4, 5]. Second optimum position of belt truss is significantly high compared to first optimum position [7]. The location of three outrigger and belt truss are at mid height, 1/4th height, and 3/4th height [8].

There is also effect of method of analysis on position of outrigger and belt truss. Optimum position resulted from response spectrum analysis is at 0.44 of structures height from top for 20 stored building and 0.5 for 25 stored building, from time history analysis it is at 0.3 of structures height from top for 20 stored building and 0.36 for 25 stored building [9]. If outrigger and belt truss made more rigid there is no significant reduction in core base moment for more than four outrigger but top drift reduce by almost 20% [10]. Optimum location of outrigger-belt truss system calculated by strain energy method for uniformly and triangularly distributed loads along structure's height is at 0.441 and 0.490 respectively, and for concentrated load at top of the structure it is at 0.667 of structures height [14].

Plastic hinges mainly developed in beams above the truss, columns below the truss, and bottom levels of the wall [15]. Progressive collapse resisting capacity of structure could be enhanced by providing belt truss with concrete core. Structures with belt truss remain stable after perimeter column was removed [16].

IV. Conclusion

The various methods and techniques used to investigate uses of belt truss in tall building are discussed in this paper. It is found that many researchers focused on to obtain position of belt truss to control deflection of building, controlling core moment and column reactions are the secondary need of research. Optimum position of structural system for deflection criteria is different than bending moment criteria. Although the optimum location suggest by researchers in the mid height of building, location of the system differs significantly as per design criteria. Belt truss is active and cost effective structural system which is one of the most developing structural systems. Further innovation and emerging trends could be used to increase its efficiency. As belt truss is efficient structural system to resist lateral load, There is need to carry out further research based on its stiffness irregularity along structural height.

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