Outrigger and Belt Truss System for Tall Building to Control Deflection: A Review

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Abstract

Accumulation of growing population especially in developing countries has resulted in an increased height of buildings, this need creating impact on structural development of tall building. As building increases in height there is effect of wind and earthquake forces, to increase stiffness of building against lateral load additional structural system such as belt truss and outriggers is required. This paper presents the review of various techniques and methods used to investigate uses of belt truss and outrigger system in a tall building. The various parameters like lateral displacement, storey drift, core moment and optimum position related to outrigger and belt truss are reviewed. The reviewed approach for the design and development of tall building using outrigger and belt truss is useful to provide a potential solution. The study in turn is useful for various research persons involved in design the tall buildings by using outrigger and belt truss system.

Keywords- Tall Building, Outrigger, Belt Truss, Optimum Position, Lateral Displacement, Storey Drift

I. INTRODUCTION

Tall building is need of developing scenario. Rapid development of tall building in the world has been creating impact on innovative development of structural system for tall building, result of which buildings are growing taller. There is no specific definition of tall building however Council on Tall Building and Urban Habitat (CTBUH) gives some measures to define tall building [1]. Tall building phenomenon will continue in a greater scale to meet the needs of the growing population in future large cities [2].

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 [3]. Structural system like moment resisting frame and shear wall and bracing system satisfy primary need of building [4]. As building increases in height there is effect of lateral load i.e. wind and earthquake on building structure. The impact of wind and seismic forces acting on tall building becomes an important aspect of the design. Improving the structural systems of tall buildings can control their dynamic response [5].

Wind and earthquake load plays major impact on building deflection. To overcome lateral load due to earthquake and wind, concrete core has been provided at center of building. Concrete core is a very effective and practical structural system which helpful in reducing the deflection due to seismic and wind forces. During recent years, the frame-concrete core wall hybrid structure has been rapidly developed and highly concerned by owners with its performance and economic advantages [6].

According to the bureau of Indian standard -875-part3 (1987) acceptable limit for top deflection in tall building for wind analysis is 1/500 of building height. Lateral drift at the top of building is one of the most important criteria for selection of structural system for tall building. However, as building increases in height, stiffness of core wall only is not sufficient to resist wind load and seismic force. This difficulty creates need of innovation of various modern structural systems. For each complex form category, tall buildings are designed with various structural systems, such as braced tube, dia-grid and outrigger systems [6].

Recently, belt truss and outrigger system is widely used to reduce lateral drift. To achieve required stiffness of tall building increase of bracings sizes as well as introduction of additional lateral load resisting system such as belt truss and outriggers is required [8]. The placement of outrigger trusses increases the effective depth of the structure and significantly improves the lateral stiffness under lateral load [9].

II. OUTRIGGER AND BELT TRUSS STRUCTURAL SYSTEM

Outriggers are rigid horizontal structure i.e. truss or beam which connect core wall and outer column of building to improve building strength and overturning stiffness. Outriggers have been used in tall building for nearly half century, but innovative design principle has been improving its efficiency. Outrigger system is one type of structural system which is formed from a cantilever-shaped horizontal member connected to structures inner core and outer columns. Through the connection, the moment arm of the core will be increased which lead to higher lateral stiffness of the system [10]. Central core in a building act as cantilever, outriggers are provided to reduce overturning moment in core and to transfer moment from core to outer column by connecting the core and column. Wall frame outrigger trusses is one of the most efficient and economical structures in tall building, at outer end they connected to the foundation through exterior columns. When the structure is subjected to horizontal loading, the wall and outrigger trusses will rotate, causing compression in the downwind column and tension in column on the upwind side, these axial forces will resist the rotation in the wall [11].

When the structure is subjected to lateral forces, outrigger and columns resist the rotation of the core and thus significantly reduce the lateral deflection and base moment, which would have arisen in a free core [12]. Outrigger structural systems not only proficient in controlling the top displacements but also play substantial role in reducing the inter storey drifts [13].

The outrigger systems can be produced in any combination of steel, concrete and composite construction. Normally in steel structure outrigger are in the form of trusses and in the form of wall or deep beam in concrete structure. Outrigger may be extended to both side of central core or core may be located at one side of building with outrigger extending to other side column. Outrigger connected to core and outer column act as stiff beam under action of lateral load inducing a tension-compression couple in the outer columns, to distribute these tensile and compressive forces to a large number of exterior frame columns belt trusses are often provided. Belt truss connects outer perimeter column of a building and offer a wider perimeter to resist lateral deflection of building.

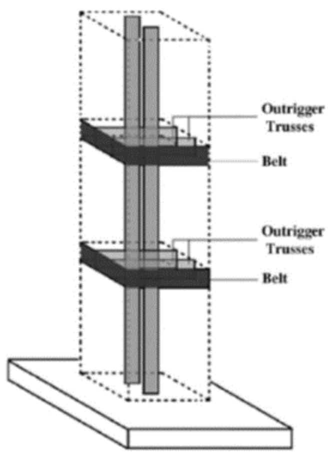

Fig. 1: Multi-Level Belt Truss and Outrigger [7]

In order to mobilize the additional axial stiffness of several columns and provide for torsional stiffness, a belt truss can be used at the outrigger levels. As building increases in height shortening of column is the main problem in construction practices, belt truss is very much effective in the control of settlement of columns. The belt trusses also help in minimizing differential elongation and shortening of columns. Behavior of outrigger with belt truss proven to be more effective when compare to the outrigger without belt truss. The exterior columns and belt truss system resist the rotation of central shear core and decrease the lateral deformation as well as bending moment at base of the structure.

The belt truss tied the peripheral column of building while the outriggers engage them with main or central shear wall. Therefore; exterior columns restrained the core wall from free rotation through outrigger arms [14]. Effectiveness of outrigger and belt truss can be affected by the various factors like position of outrigger and belt truss, number of outrigger, geometry of building, types of core i.e. concrete or steel and floor to floor height [15]. The use of outrigger and belt truss system in high-rise buildings increase the stiffness and makes the structural form efficient under lateral load [16].

There are many advantages and benefits of outrigger and belt truss system as mention above, but outrigger also creates some problem. [17, 31] The main disadvantage of outrigger is that it reduces usable space at working floor. The core and the outrigger columns will not shorten equally under gravity load, outrigger need to be very stiff as it restrains differential shortening between the core and outrigger column. When concrete shear wall core is used the connection between outrigger trusses and core can be difficult. 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.

To overcome above problem outriggers connecting core and perimeter systems is eliminated directly and instead a belt truss is used with a combination of stiff and strong diaphragms called as virtual outrigger. R. Shankar Nair [17] introduce belt truss as virtual outrigger concept, to use stiff and strong floor diaphragms in their own plain to transfer moment in the form of a horizontal couple from core to belt trusses or wall that are not directly connected to the core.

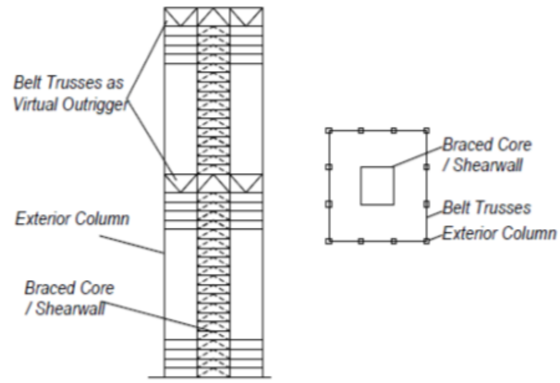

Fig. 2: Typical Belt Truss Locations in a High-rise Building [36]

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.

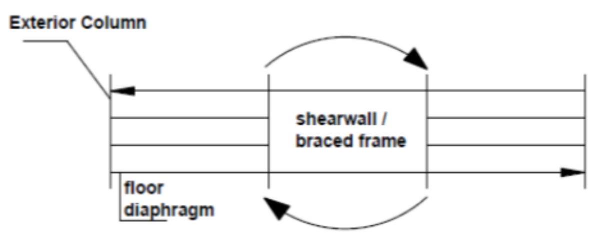

Fig. 3.1: Conversion of Core Overturning Moment into Coupled Horizontal Forces [16]

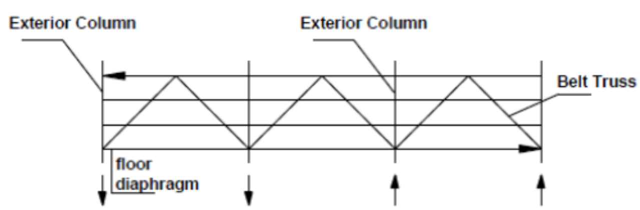

Fig. 3.2: Conversions of Coupled Horizontal Forces into Axial Forces in Exterior Columns [16]

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.

As use of belt truss as virtual outrigger eliminate some problem related to conventional outrigger so on it is also very much beneficial to use belt truss with outrigger. Because of the many functional benefits of belt truss system, outrigger systems and the advantages outlined above, this system has been lately very popular for super tall buildings all over the world.

III. LITERATURE REVIEW

S. Fawzia et al. [8] examined the effects of cyclonic wind and provision of outriggers on 28- storey, 42-storey and 57-storey composite building. The results showed that plan dimensions had vital impacts on structural heights. Increase of height while keeping the plan dimensions same, leads to the reduction in the lateral rigidity. To achieve required stiffness increase of bracings sizes as well as introduction of additional lateral resisting system such as belt truss and outriggers is required.

J. Kim et al. [9] evaluated progressive collapse potential of 36-story building structures composed of RC core walls and perimeter frames connected by outrigger trusses at the top using nonlinear static and dynamic analyses. The static pushdown analysis of the structure with mega-columns and outrigger trusses showed that the maximum strength reached only about 20% of the load specified in the GSA guideline when a mega-column in the first story was removed. According to dynamic analysis results, the vertical displacement monotonically increased until collapse as a result of buckling of some of outrigger truss members. However, the structure with outrigger and belt trusses remained stable after a perimeter column was removed.

Jaehong Lee et al. [11] formulated equations of wall-frame structures with outriggers through the continuum approach and the whole structure is idealized as a shear–flexural cantilever with rotational springs. A displacement-based one-dimensional finite element model is developed to predict lateral drift of a wall-frame with outriggers under horizontal loads. The optimum outrigger location is investigated to minimize the top drift. Optimum outrigger location for the lateral drift and moment are near h/H = 0·4 and h/H = 0·3, respectively.

Kiran Kamath et al. [12] studied three-dimensional structure having 40 stories, each storey height is of 3.5 m and the total height of the building is 140 m. The relative height of the outrigger is varied and the performance of outrigger is then studied. A static analysis on the multi-outrigger structure has been carried out by applying seismic load as per IS 1893 (PART 1): 2002. When the displacement criteria are considered, 31.74% reduction in lateral displacement at top has been observed for the multi-outrigger structure for a relative height of 1.5 when compared with a structure without outrigger. When bending moment criteria is taken into account, there has been a 32.60% reduction in bending moment when the multi-outrigger structure with a relative height of 6.67 is compared with a model without outrigger.

Kiran Kamath et al. [13] studied three-dimensional 40 storey RCC building with total height of 140m. A total of 6 different arrangements of outriggers by varying Hs/H ratio from 0.975 to 0.4 having relative stiffness (EI_O/EI) between 0.25 and 2 has been modeled and analyzed for static and dynamic condition. The static analysis is carried out for lateral wind load conforming to IS-875-part3 (1987) and equivalent static analysis for seismic in accordance with IS 1893-2002. Lateral displacement is reduced by 37% by providing the outriggers at the top and it is reduced up to 61% by providing the outriggers at mid height. there is 34% in reduction displacement at the top due to earthquake loads when the outrigger is placed at the top and it is reduced by 64% when outriggers are placed at the mid height (Hs/H=0.5). Shear force variation is negligible due the introduction of outrigger at any level. Peak acceleration is reduced up to 30% by providing the outrigger at top level.

S. Fawziaet al. [14] investigates deflection control by effective utilization of belt truss and outrigger system on a 60-storey composite building subjected to wind loads. A three dimensional Finite Element Analysis is performed with one, two and three outrigger levels. 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.

Po Seng Kian et al. [15] 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 middle of the structure height 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. [16] 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.

- Maximum drift at top is 50.6mm, 48.20mm and 47.6mm for core without any outrigger, outrigger with belt truss and outrigger without belt truss.
- Using second outrigger with cap truss gives the deduction reduction of 18.55% and 23.01% with and without belt truss.
- The optimum location of second outrigger is at middle height of the building

R. Shankar Nair [17] investigated the effectiveness of belt trusses as virtual outriggers using a 75-story steel-framed office tower. Design loads are in accordance with the City of Chicago Building Code. Result obtain for wind analysis is as follows.

Type of outrigger	*Lateral displacement (inches)*
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*

N. Herath et al. [18] investigated the optimum outrigger location in a 50 storey reinforced concrete building under earthquake loads for Response spectrum analysis, three different peak ground acceleration to peak ground velocity ratios in each category of earthquake records were incorporated. It has been observed from this study that the optimum outrigger location of a high rise building under the action of earthquake load is between 0.44-0.48 times the height of the building (from the bottom of the building)

Abdul Karim Mulla et al. [19] studied regular and irregular building with and without outrigger with centrally rigid shear wall and steel bracings as outrigger. The analysis of the model was carried out by equivalent static method and response spectrum method according to IS 1893 (part 1):2002. Displacement of the irregular building using concrete outriggers is resisted up to 18% when compared with steel at the top floors by equivalent static method of analysis. The concrete outriggers is 16% less displaced the storey at the centre of the buildings. By response spectrum analysis the concrete outriggers are 6% less displaced compared to steel outriggers.

Mohd Irfan Moinuddin et al. [20] 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.

Shivacharan k et al.[21] 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) 1987 and Earthquake load is calculated by using code IS 1893(part-1): 2000

- 29.8% and 36.9% of the deflection and drift is controlled by providing one position outrigger at 0.67 height compared to bare frame
- 45.1% and 40% of the Deflection and drift is controlled by providing outrigger with belt truss at 0.67 and 0.5 when compared with bare frame.
- 13% and 14.64% of the deflection and drift is controlled by comparing first position outrigger system and second position of outrigger system.
- Optimum location of the outrigger is between 0.5 times its heights.

Krunal Z. Mistry et al. [22] 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 outriggers are at mid height, 1/4th height, and 3/4th height.

Roslida Abd. Samat et al. [23] studied 64-story reinforced concrete Buildings in order to determine the optimum location to construct the outriggers to minimize the along-wind and across-wind responses. The along-wind responses are determined by employing the procedures from the ASCE 7-02 while the across-wind responses of the buildings are calculated based on the procedures and wind tunnel data available in a data base of aerodynamic load. Analysis result showed that the best location to construct the outrigger is between one-quarter to two-third of the height of the building in order to minimize both the along wind and the across wind responses.

Abbas Haghollahi et al. [24] 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
  1) 20 storey - 0.44 of the structure's height from the top
  2) 25 storey - 0.50 of the structure's height from the top
- Optimum location of outrigger and belt truss resulted from time-history analysis
  1) 20 storey - 0.3 of the structure's height from the top
  2) 25 storey - 0.36 of the structure's height from the top

Gerasimidis S. et al.[25] Analyzed 30 storey two dimensional models including only the basic structural elements (concrete core, steel columns and steel outriggers) for wind loading. The optimum location of the outrigger, taking account only the drift control criteria, appears to be in the exact middle of the height of the building i.e. on the 15th floor (out of 30 floors in total). The column is proven to be mostly stressed when the second outrigger is placed at the level of 27m i.e. the 9th floor. This is much lower than the 15th floor (45m) that the minimum drift is observed. Therefore, the optimum location of the second outrigger, taking into account only the activation of the couple of forces at the columns is approximately at the 1/3 of the building height.

RaduHulea et al.[26] analyzed the optimum position for two to seven outriggers and belt trusses, aiming to achieve minimum bending moment and minimum drift. A hypothetical outrigger braced structure was considered with central core and outrigger that connect the core with the exterior columns. 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%.

Z. Bayati et al. [27] studied A 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. Design loads are in accordance with Iranian Building Code.

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

T. A. Sakr et al. [28] investigated effect of the outrigger stiffness, effect of concrete strength, and effect of reinforcement arrangement by analyzing 40 storied models for coupled wall- Column system with different outrigger thicknesses of 250, 400, 550 and 700 mm.

Table 1: Effect of outrigger stiffness

Outrigger	*No outrigger*	*250 mm*	*400mm*	*550 mm*	*700mm*
Natural Period (sec)	*9.84*	*5.28*	*5.74*	*5.71*	*5.69*
Max. Drift (mm)	*1340*	*471*	*460*	*454*	*450*

A. Effect of Concrete Strength

By investigating the values of maximum lateral drift, increasing the concrete strength to 50, 60, 70 MPa reduced the lateral top drift by 8.7%, 30.1%, and 37.4%, respectively, less than that of the case of 40 MPa concrete.

B. Effect of Reinforcement Arrangement

Two models ware considered. One with uniform reinforcement through wall and column and the other has extra bars on the wall and column edge represents 0.15 percent of the concrete section as recommended by most codes. The value of maximum lateral top displacement increased about 21.7% in case of uniform reinforcement over that having extra concentrated reinforcement that indicates that cracks are more for uniform reinforcement case.It is concluded that the existence of outrigger enhances significantly the drift behavior and improve its overall behavior

Rafael Shehu et al. [29] studied ductile characteristic of the structures and investigated three reinforced concrete buildings with different heights and four types of structural models through nonlinear analysis using finite elements method. From study it is concluded that Performance of Outrigger structure is higher than without Outrigger structures, but their ductility is reduced.

J. C. D. Hoenderkamp et al. [30] presented a graphical method of analysis for preliminary design of outrigger truss braced high-rise shear wall structures with non-fixed foundation conditions subject to horizontal loading.The results show that increasing the stiffness of the exterior column foundations and the racking shear of the outrigger yields larger reductions for the horizontal deflection and bending moments in the shear wall. Increasing the stiffness of the shear wall foundation, however, will cause the outrigger to be less effective.

Mohd Abdus Sattar et al. [31] 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. Column forces and moments are minimum in case of “Building frame with Double Core arrangement of shear wall and Stringer beams” for which drift and displacement are also comparatively less. 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. [32] 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. The structure is modeled as two parallel cantilevered flexural-shear beams that are constrained at the outrigger-belt truss location by a rotational spring. The formulas proposed here have been validated by comparing them to the computer static analysis results obtained from three-dimensional studies using the finite element method. 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. [33] 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. The effect of belt truss and shear core on framed tube is modeled as a concentrated moment applied at belt truss location, this moment acts in a direction opposite to rotation created by lateral loads. The axial deformation functions for flange and web of the frames are considered to be cubic and quadratic functions respectively; developing their stress relations and minimizing the total potential energy of the structure with respect to the lateral deflection, rotation of the plane section, and unknown coefficients of shear lag, the mathematical model is developed.

M. Nicoreac et al. [34] presented simple equations for the natural lateral and rotational periods of vibration for high-rise steel structures comprising braced frames with outrigger trusses. The proposals for the natural periods of vibration given by study give results that are within 4% of those obtained from finite element analyses.

Ahsan Mohammed Khan et al. [35] carried out analysis for study of rigid core and floor rigidity of 15, 20 & 25 storey L-shape Building with different location of outrigger and belt truss. 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 Maximum Storey drift for building with outrigger and belt truss is 2.37 mm which is appreciably less by 2.90% and 97.35% for building with outrigger and building without outrigger and belt truss respectively.

M. R. Jahanshahi et al. [36] 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 is calculated 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. [37] 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.

Y. Zhou et al. [38] proposed A new concept for the structural design of super high-rise buildings, energy-dissipation story system. Nonlinear time history analyses were performed on a 252m high-rise building model, displacement, inter-story drift, additional damping ratio and base shears of the building were analyzed in detail. The results show that: (1) Seismic performance of the building with energy-dissipation stories is better than the building with outriggers. (2) The inter-storey drifts of the building with energy-dissipation stories are more uniform than the building with outriggers. (3) Energy-dissipation story system can effectively increase the model additional damping ratios of building, and its effective position is at the middle of the building.

Eltobgy, H. H. et al. [39] Investigate different structural systems to detect more practical and cost effective systems to enhance the progressive collapse resisting capacity. The study was extended to numerically investigate the effectiveness of the 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 weight.

Table 2: Optimum position of outrigger and belt truss

Ref. No.	Lateral Load Resisting System	Building Specification	Type of Analysis	Optimum Position
[11]	Outriggers	Wall-frame structures	Strain energy method	For lateral drift and moment are near h/H = 0·4 and h/H = 0·3, respectively
[12]	Concrete outrigger	40 storey RC building	Static analysis for seismic load	1.5 of relative height for displacement criteria 6.64 of relative height for bending moment criteria
[13]	Concrete outrigger	40 storey RC building	Equivalent static analysis for wind and earthquake and response spectrum analysis	1st is at mid height an d 2nd is at top for both static and dynamic behavior
[14]	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
[15]	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
[16]	Outrigger and belt system	30−storey RC building	Earthquake and wind analysis	Middle height of the building
[18]	Concrete outrigger	50 storey RC building	Response spectrum analysis	0.44-0.48 times the height of the building (from the bottom of the building)
[19]	Concrete outrigger and Steel bracing	G+20 storey RC building	Equivalent static and response spectrum method	Mid height of building
[20]	Outrigger and belt truss	30 storey RC building	Earthquake and wind analysis	0.46 times height of building from bottom height
[21]	Outrigger and belt truss	30 storey RC irregular building	Earthquake and wind analysis	0.5 times height
[22]	Outrigger and belt truss	40−storey concrete	Earthquake and wind analysis	Mid height, 1/4th height, and 3/4th height of building
[23]	Outrigger	64-story RC building	Wind load analysis	1/4th to 1/3rd of building height
[24]	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
[25]	Steel outrigger	30 storey two dimensional Model composite structure	Wind load analysis	1st is at Middle of the height and 2nd at 1/3rd of the height
[36]	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

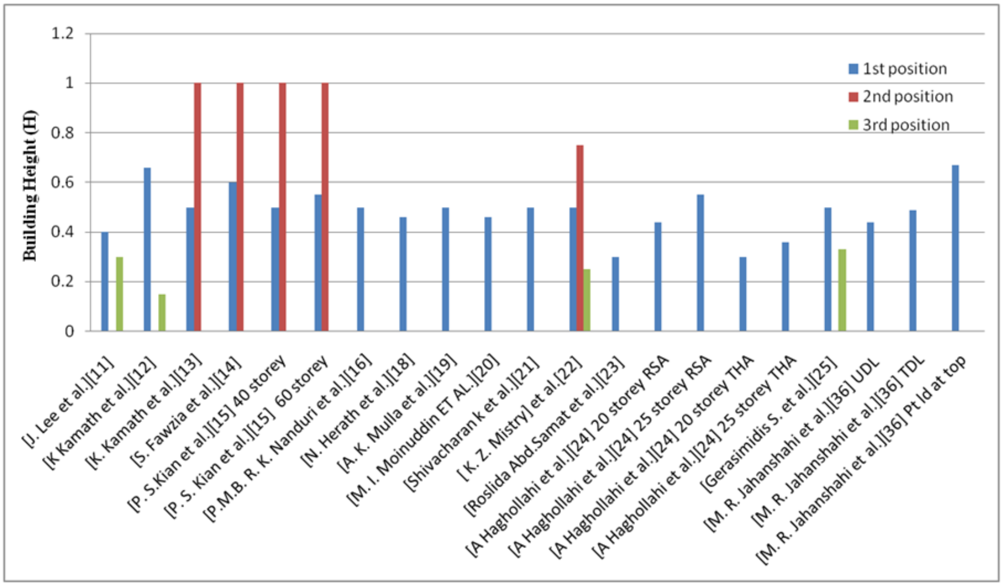

Fig. 4: Optimum Position of Outrigger and Belt Truss

Figure 4 is graph plotted for optimum position of outrigger and belt truss found by various researchers. In the graph 1st and 2nd positions define are for deflection criteria and 3rd position is for moment criteria.

IV. DISCUSSION

Researchers have used various techniques and methods for finding uses of outrigger and belt truss in tall structure. Different types of analysis were conducted as per the various available standards. From Table 2 it is observed that the common parameters studied by various researchers were position of outrigger, lateral drift, core moment, and column reaction. [13-24] focused on obtaining the optimum position of outrigger and belt truss for satisfying deflection criteria. [11, 12, 25, 26] focused on obtaining the optimum position of outrigger and belt truss for satisfying deflection as well as moment criteria. First optimum position for outrigger and belt truss is at 0.5 of structures height i.e. mid height [12-25]. [12] Observed significant reduction in lateral displacement at top of structure for relative height of 1.5 and considerable amount of reduction in bending moment observed when outrigger placed at relative height of 6.67. [23] Showed that the best location to construct the outrigger is between one-quarter to two-thirds of structures height. [11] Investigated optimum outrigger location for lateral drift is near 0.4 and for moment it is near 0.3 of structures height. Optimum position of second outrigger and belt truss is at top of structures height [11, 16, 20]. Second optimum position of outrigger is significantly high compared to first optimum position [21]. Third position of outrigger and belt truss is at one third to one fourth of structures height [11, 12, 25]. The location of three outriggers are at mid height, 1/4th height, and 3/4th height [22]. There is also effect of method of analysis on position of outrigger. 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 [24]. The more rigid the outrigger higher the optimum position of it. If outrigger made more rigid there is no significant reduction in core base moment for more than four outriggers but top drift reduces by almost 20% [26]. 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 [36].

Belt truss with stiffer floor diaphragm individually can minimize deflection as that of outrigger but outrigger with belt truss can resists maximum deflection than individual belt truss or outrigger. The Maximum Story drift for building with outrigger and belt truss is appreciably less by 2.90% and 97.35% for building with outrigger and building without outrigger and belt truss respectively [35].

Plastic hinges mainly developed in beams above the truss, columns below the truss, and bottom levels of the wall [37]. Seismic performance of the building with energy-dissipation stories is better than the building with outriggers [38]. Stiffness of belt truss and outrigger can also affect performance of system in lateral load, as stiffness of outrigger and belt truss increases its ability to resist deflection also increases. The concrete outrigger is more efficient in reducing the lateral storey displacement than the steel outrigger in the tall RC building. Increase in concrete strength of outrigger and belt truss also reduces top storey drift of structure; there is also effect of reinforcement arrangement of an outrigger on building deflection. Building deflects more in case of uniform reinforcement arrangement in wall and column than extra reinforcement provided at wall and column edge [28].

Progressive collapse resisting capacity of structure could be enhanced by providing outrigger and belt truss with concrete core. Structure with belt truss and outrigger remain stable after perimeter column was removed [9].

V. CONCLUSION

The various methods and techniques used to investigate uses of belt truss and outrigger in tall buildings structural system were discussed in this paper. It is found that many researchers focused on to obtain position of belt truss and outrigger to control deflection of building, controlling core moment and column reaction are the secondary need of research. Optimum position of structural system for deflection criteria is different than bending moment criteria. Although the optimum location suggests by researchers in the mid height of building, location of the system differs significantly as per design criteria. Manual methods studied to obtain location of structural system gives nearly accurate result as that of by software.

Outrigger and belt truss is active and cost effective structural system which is one of the most developing structural systems. The present study in turn is useful for various research persons involved in design the tall buildings by using outrigger and belt truss system.

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