International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 05 | May 2020 www.irjet.net p-ISSN: 2395-0072

The Behavior and Different Aspects of Outrigger Structural System: A Review

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Abstract - *The tall buildings have enchanted humankind from the beginning of civilization and initially, it was constructing for defense and ecclesiastical purposes. The considerable growth of the world population and migration of people to the cities for facilities and job opportunities, the land crisis has arisen as critical problems for humankind. For solution structural engineer start constructing tall buildings to lodge the present population. Increment of building height directly effect on augmentation of lateral forces on tall buildings. Lateral loads tend to rotate the building that causes lateral displacement; this causes discomfort of the occupants. To handle seismic and wind loads acting on the structure, engineers introduce several lateral force resisting structural systems such as rigid frame, shear wall structure, braced structure, core wall structure, outrigger structure, and tube structure. . Outrigger structure system is one of an effective system among them. This study presents a review on the behavior of outrigger structural system in high-rise buildings under lateral loads as well as different features related to the outrigger system such as effectiveness and selection of material, optimum position, and depth of outrigger. From the review, it has concluded that outrigger provide more stiffness in face of story drift, deflection at top of building when compare to other structural systems. Optimum configuration of outrigger related to vertical and horizontal regularity, depth of belt, outrigger, material and height of building.*

***Key Words*: Lateral Force Resisting Systems, Outrigger Structural System, Belt-truss, Dynamic Analysis**

1. INTRODUCTION

The tall buildings have enchanted humankind from the beginning of civilization and initially, it was constructing for defense and ecclesiastical purposes. The considerable growth of the world population and migration of people to the cities for facilities, modern life, and job opportunities, it decreases the land and increases the cost of land so it coercion the structural engineer to construct tall buildings to lodge the present population. In the previous two decades, there are impressive progress in science of material, construction equipment and computer aid design, which paves the way for more sophisticated and delicate structural systems for tall buildings, which depends on the architectural requirements of space plan and aesthetics.

1.1 Structural systems

As we know the increment of height effect on augmentation of lateral load on tall buildings increases. Lateral loads tend to rotate the building that causes lateral displacement; this causes discomfort of the occupants. The big concern of a building is stiffness of the building when its height increases so it is important to select enough stiff structure to resist lateral load properly which are introduce by structural engineers as below.

- Rigid frames
- Braced frames
- Shear wall system
- Outrigger with belt system
- Frame tube
- Truss tube
- Bundled tube

2. OUTRIGGER

Outrigger efficiency and structural dignity have deep roots in history and become main structural elements in effective and cost-effective design of high-rise buildings. Although in the last 35 years, outrigger has only been built into tall buildings. The outrigger idea dates back to 50 years, it originates from deep beams. Firstly, it has started from deep beam for concrete walls but nowadays become full story deep even apart full story outrigger.

The outrigger system is the almost broadly used structural systems. It constructed from steel or concrete brace and shear wall connected with core and periphery columns or outriggers are rigid deep beam or brace that attaches the periphery column of the frame to the central core. The outrigger structural system contains core that is connected to the periphery column by fairly rigid horizontal bracing or beams called outrigger. The outrigger beam could be construct from deep wall concrete and truss concrete or steel. The central core also could be make from steel brace or concrete wall. The core could be located centrally with outriggers spreading on either edges of periphery columns or it could be placed on one side of the core with outriggers spreading to the periphery columns on one side (fig.1). Once lateral loads are expose to the outrigger structure, outrigger-restrained column resists the core rotation and decrease the displacement. Making the building's lateral deflection smaller than when the freestanding core withstand the loading alone. The intention is to increase the structure's effective depth by causing stress in the windward column and contraction in the leeside columns when it flexes as a vertical cantilever.

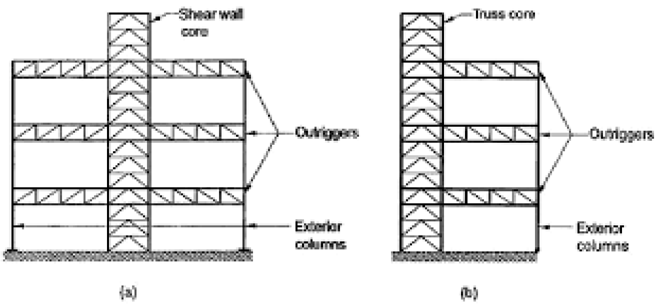

Fig-1: Core possible position

The lateral load is resist now by bending of core and axial (compression and tension) of perimeter columns so using outrigger system has the advantage of avoiding core rotation and significantly reducing the lateral deflection a reversal moment. Besides the column at the ends of the outriggers, other peripheral columns are normally mobilize to help to restrain the outriggers. This is accomplish through the addition of a deep beam, girder or belt around the frame at the outrigger levels. The outrigger and belt truss is typically at least one story, and often three to four stories deep. It should be remember that outrigger system effectively upsurge the flexural rigidity of the structure but it does not upsurge the shear resistance which will be carryout by the core.

2.1 Concept of Outrigger

For a long time, outriggers have used extensively for wind-resistant sailing ship manufacturing. The slender mast was attach to the horizontal outrigger, and this mast acts as the core, the outriggers work as spreaders while the periphery columns work as shrouds (fig.2).

Fig-2: Concept of outrigger

2.2 Types of Outrigger

There are two types of outrigger systems based on core connectivity.

1. Conventional outrigger system
2. Virtual outrigger system

In conventional system, the braced frame or shear wall's core and periphery outrigger columns are directly attached by outrigger beam or outrigger braces. The columns are mostly, but not required at the outside boundaries of the frame. The outrigger beam or truss linking the outer columns with the core avoids the rotational aspect of the overturning moment in the core and convert it to couple force in column (fig. 3-5). In virtual system, the braced frame or shear wall's core and periphery outrigger columns are not directly connected by outrigger beam or trusses but the overturning moment is still obtain from the core element to periphery columns. The virtual outrigger system uses floor diagrams that are very rigid and strong. It transfer moment from the core to the trusses or beams and trusses or beams to exterior columns in the form of couple-moments. It is appropriate to use basement walls and belt trusses as virtual outriggers (fig.6-8).

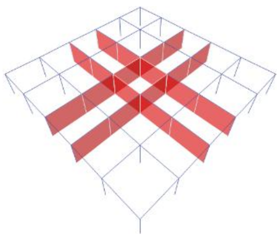

Fig-3: Conventional wall outrigger

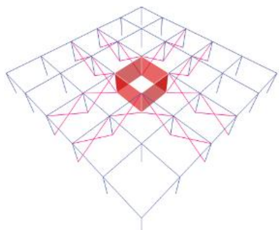

Fig-4: Conventional truss outrigger

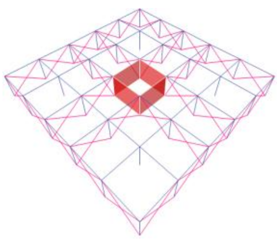

Fig-5: Conventional truss outrigger with belt

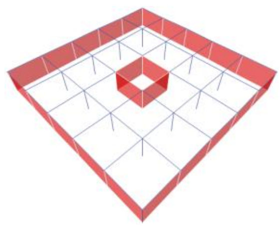

Fig-6: Virtual wall outrigger

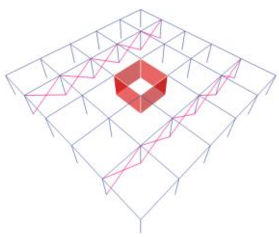

Fig-7: Virtual offset outrigger

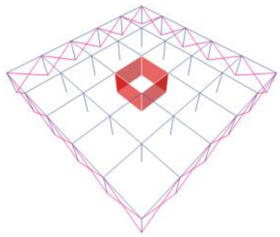

Fig-8: Virtual belt truss outrigger

3. LITERATURE REVIEW

Comparison study has been investigated for lateral load resisting structural systems (rigid frame structure, Core wall structure, and tube structure, shear wall with diverse conformation and outrigger structure). The models had been analyze for lateral load to perceive the performance of the models during lateral load also to choice a safe structural system. Tube structure and outrigger structural system provide less displacement. In addition, researcher has stated that columns sway in geometrically irregular structures can be reduce by providing shear wall of L-type in the corners of the structure. Outrigger performs as a maximum drift controller when it is furnished at a level that has the max drift [1]. Study has carried out on analysis of different structural system and conclude that, Shear wall/central core system is economical and upsurges the flexural rigidity as compared to the RCC frame and outrigger structure. Outrigger system reduces inter-story drifts and controls the top displacement as well as increases the flexural rigidity but do not upsurge system recital to shear which has supported ty core. [2].

Study has carried out on performance and behavior of the outrigger structure system under seismic load, worked on analysis of 40 stories RC building for seismic load by static method using ETABS. In this study, they use two outriggers with one story depth at different level based on relative axial rigidity results shows that, reduction of lateral displacement due to the performance of the outrigger structure with the core wall structure for H2/H1=1.5 and a=0.75 is 31.74% But with multi outrigger for H2/H1=6.67 and a=0.5 is 32.6%[3]. Study was conducted to evaluate the efficiency of steel and concrete content for outrigger and worked on analysis of a model of 20-storey RC vertical regular and irregular building for lateral load by equivalent static and the response spectrum methods in different zone using structure analysis software ETABS according to IS code and results shows that in static method, concrete outrigger provides 18% and 16% of less displacement from steel outrigger respectively for regular and irregular buildings likewise, in dynamic method concrete outrigger provides 6% of less displacement as compared to steel outrigger. The base shear was increased from 4087.68KN to 4926.34KN and 4526.28KN for regular and irregular respectively [4].

Study was performed to evaluate the efficiency of steel and concrete outrigger and worked on the analysis of a model of 80 stories commercial building use single depth outrigger and analysis shows that, Steel outrigger is preferable over the concrete outrigger due to concrete outrigger required more cross-section while providing the same deflection. By providing outrigger, up to 50% reduction of drift is seen in both X and Y-direction [5].

In as study three story belts with x-shape has been proven efficient as compare to N-shaped and warren belt system for the double outrigger belt system. There is 39.38% of story drift reduction by using the RC shear wall compared to the core of braced frame with an outrigger at 0.75H of height plus topmost [6].

Study was conduct to evaluate the efficiency of steel and concrete content for outrigger and belt truss, worked on 36 stories RC building for lateral load by static and dynamic analysis accordance to IS codes using simulation software of ETABS. In this study, they have provided seven modelled with shear wall core, steel wall core, steel belt truss, concrete belt truss, steel outrigger and concrete outrigger with four single story outrigger with different combinations. In result, they have found that, bare frame model is very flexible among other models so to resist lateral forces such as seismic waves and wind force we provide a conventional outrigger with a core. By providing outriggers and belt trusses in tall buildings increases the stability and stiffness of buildings. Concrete outriggers with belt truss are effective as compared to steel and provide minimum lateral displacement [7].

A study has performed on performance of outrigger for tall structures with seismic loads, worked on the analysis of models 0f 50 stories RC building for lateral loads by dynamic analysis (Response Spectrum) method. In this study, they provide single and double outrigger of concrete with single story height. Analytical results show that, under earthquake load, one of critical influence on behavior of structure under lateral is the position of the outrigger and should be carefully selected in the design. And under earthquake, the behavior of the structure is various from the seismic to the seismic and 0.44-0.48 of height is the best position of the outrigger from below [8].

Study has carried out on the performance and efficiency of the outrigger and the belt brace structure system, Worked on analysis of 44 stories two dimensional RC models for wind and earthquake load by static and dynamic method using structural analysis software ETABS. In this study, they use four outriggers at (0.2, 0.4, 0.6, and 0.8) of height with single story height. Core is provided from core wall and steel bracing and outrigger bracing is provided as X and V shapes. In Analytical results, X-braced outrigger provides better efficiency compared to V-Braced and the Core wall is better in lateral displacement against the braced core. It is better to provide outrigger in the inner frames of a structure compared to provide it in the outer part [9].

In this study work has performed on analysis of a 45 stories frame building models for El-Centro earthquake load by linear time history method using structural analysis software ETABS accordance to IS:875, IS:800 and IS:456. The models are provide with 7 different combinations of outrigger material both steel and concrete. They installed four outriggers at 0.2, 0.4, 0.6 and 0.8 of height positions with and without belt truss and used both steel and concrete core. Analytical results show that, concrete core and concrete outrigger X braced shaped give 80.3mm and

0.000703 displacements and drift respectively which were found to be minimum as compared to all other combinations and provide minimum base shear 4419 KN for the same combination and for time history analysis it gives less variation compared to steel core and outrigger [10]. Studied on analysis of a 14-storey RC building for the seismic load using structural analysis software ETABS. The modeled are provided with various kinds of bracing as inverted V, combine V, V, Diagonal, K and X type. Bracing afforded for periphery columns on four sides and as well as on any two parallel sides of the models to find out the effect on displacement and base shear. Analytical results show that, the X type of combine V type of steel and concrete bracing showed minimum displacement of 0.11mm and 0.1mm respectively for bracing on four sides and two parallel sides respectively from 0.25mm for without bracing system [11]. Have investigated to optimize the position of the outrigger and belt truss on tall buildings, analyzed a 40 story steel building frame by a time history method for wind load and seismic analysis using ETABS. In this study, they modelled the frame using two outriggers first as cap truss on top and second vary (1/4th H, 1/2th H, 3/4th H) throughout the height with X bracing and they use steel belt truss with three story depth. It was observed from the analysis that, one of serious effect on performance of building in lateral load is best position of the outrigger and the best outrigger position is found to be 0.75H of height with cap truss when afforded with three stories depth and it provides more stiffness as compared to other models [12].

The best position for outriggers is 0.5, 0.25, and 0.75 time of height for displacement and shear force reduction [13]. have investigated to optimize the position of the outrigger and belt truss on tall building, Worked on the analysis of a model of two dimensional 40 stories and three dimensional 60 stories RC frame building for wind and seismic load by static and dynamic method using structural analysis software ETABS. In this study, they provide eight models of 2D and five models of 3D with one and two outrigger and belt at various position with constant depth. Analytical results show that, outrigger and belt usage provides stiffness and better performance under lateral load. Two-dimensional models with a one outrigger at middle provide a 56 % reduction of displacement, but with two outriggers, one at top and second at middle provide a 65 % reduction of displacement. Three-dimensional models with outriggers at 33rd story and at top provide an 18% reduction of lateral deflection [14].

It has investigated to optimize the position of the outrigger and belt truss on tall buildings, worked on the analysis of a model of 60 stories RC frame building for wind load using structural analysis software ETABS. In this study, they modelled the single outrigger concrete beam at different position of height for optimum location. Analytical results show that, Between 0.25-0.33H is ideal location of outrigger in tall building under lateral load from below [15].

Using belt truss is effective in reducing drift with single outrigger and it is more effective in reducing drift with a double outrigger (18.55% and 23.01% with and without belt truss) one at top and second at middle and it can be inferred that the second outrigger's optimum position is about 0.5 times its height [16]. 29.8% and 36.9% of the lateral displacement and drift are reduce by affording outrigger at 0.67H as match to the simple frame. 45.1% and 40% of lateral displacement and drift are reduce by affording outrigger with belt at 0.67H and 0.5H as match with a simple frame. 13% and 14.64% of the lateral displacement and drift is reduced by matching the first and second location of the outriggers [17].

Study has carried out on performance and behavior of the outrigger structure system under seismic load, worked on analysis of 40 stories RC building for seismic load by static method using ETABS. In this study, they use two outriggers with one story depth at different level based on relative axial rigidity. Analytical study shows that, the best position of outrigger at both static and dynamic analysis was mid-span and there is less efficiency to place the outrigger at the top. Outriggers decrease the force in core and control top displacement [18]. Studied have carried out to find out useful depth for outrigger beam and belt truss, Worked on the analysis of a model of 50 stories irregular RC building for seismic by dynamic, Response Spectrum Analysis using ETABSv16 in accordance to IS 1893 (part I) 2002. In this study, they modelled the frame with concrete and steel outrigger with different (single and double) story depth and placing it in different position along the height of the building. In result shows that, stiffness and stability is increased by using a double outrigger structural system at (10th and 30th) stories with two-story depth against the seismic load. The best position of outrigger at both static and dynamic analysis was mid-span and there is less efficiency to place the outrigger at the top. Outriggers decrease the force in core and control top displacement [19].

Studied have carried out to find out useful depth for outrigger beam and belt truss, worked on the analysis of a model of a 40 story steel frame by Equivalent static and Response spectrum methods accordance with IS codes using structural analysis software ETABSv13. In this study, they modelled the Steel building with a core at center and compare the vary depth steel outrigger. The outrigger depth is decrease to 2/3rd then 1/3rd of the story height, another with the full story height with similar belt depth. Analytical results shows that, diminution in depth shows slight difference in stiffness against lateral load when compare it full story depth [20]. Worked on analysis of a 50 stories RC building models for lateral load. Analytical results show that, the maximum story displacement reduced up to 82mm by providing full story deep outrigger compared to bare frame system and by depth diminution of outrigger to 2/3, 1/3 and 1/2 of story height have a diminution in deflection and story drift up-to (3–4%) and (5-6%) respectively when compare it full story height. [21].

Depth diminution of outrigger to 2/3, 1/3 and 1/2 of story height have a diminution in deflection and story drift up-to (3–4%) and (5-6%) respectively when compare it full story height. Hence, there is augmentation with outrigger depth diminution and the outrigger structural systems have efficient roll in controlling top displacement and reducing inter-story drift [22]. Conventional outrigger provide 70 cm deflection at the top of structure due to wind load and virtual outrigger of belt brace provide 95 cm of deflection and outer columns participate in undertaking overturning moment [23].

4. SUMMARY OF LITERATURE

- After studying different lateral load resisting structural systems like RCC frame, shear wall structure with different configuration and location, core wall structure, wall-frame interaction, tube structure, outrigger structure, it was found that rigid frame is flexible among other models and shear wall/central core system is economical and upsurges the flexural stiffness as compare to the RCC frame but tube structure and outrigger structural system are stiffer and provide less displacement.
- Outrigger structural system resists the lateral load due to seismic and wind, increases the flexural stiffness, reduces forces on the core, reduces inter-story drifts and controls the top displacement but outrigger inversely reduce resistance against shear, which has to be supported by the core.
- By providing the outrigger at level with max drift, it will control and performs as drift controller.
- By adding the belt truss in tall building reduce the base shear and increase structural stiffness under action of static and dynamic loads.
- Concrete outrigger and belt has proven effective in diminution of deflection and drift as compared to steel.
- In both static and dynamic methods, concrete outrigger provides less displacement as compared with steel outrigger for regular and irregular buildings but the base shear was increased and its connection to the core is easy.
- Steel outrigger is preferable over the concrete outrigger due to concrete outrigger required more cross-section while providing less difference in deflection.
- Reinforced concrete core walls provide sufficient result of story drift and lateral displacement as compared to the braced frame core.
- X-shape brae of outrigger belt is extra effective as compare to warren and N-type outrigger belt system.
- The best location for single outrigger is mid-height of building with single story depth and for double outrigger, one at topmost and second at meddle of building height with single story depth.
- Increasing the number of outrigger and belt brace is efficient in reducing drift and stiffness of the structure.
- Increasing depth of belt truss to double story height and triple story height increase the performance of structure towards lateral load and decrease drift.
- Diminution in depth of outrigger as compare to full depth shows slight difference in resisting of lateral load.

5. CONCLUSION

The behavior of the outrigger structural system depends upon the type of outrigger, location of the outrigger, depth of outrigger, the material of outrigger, type of bracing of outrigger and belt truss. From the results of the above papers, it can be concluded that concrete core, outrigger, and concrete belt is effective in diminution deflection and drift compare to steel. X-type bracing has seen to be more effective among all other types of bracing and which are followed by inverted V and combine V-type bracing. The best position of outrigger for single is 0.5H and for double outrigger 0.5H & H of the height. Increasing the depth of the belt truss up to double and triple story height increase the efficiency of the structure and reducing depth from one story reduces the efficiency of the structure.

6. FUTURE SCOPES OF THE STUDY

- There is a deficiency of work in a different type of virtual outrigger, which should be studied.
- Optimum depth of floor diaphragms should be studied.
- The concept of basement outrigger should be studied with different materials.
- The usage of the outrigger system in a complex plan or irregular plan, actual plan and circular plan should be studied.
- Building a model up to 100 or above floors should be made and study.
- Optimum location of outriggers beams and belt truss more than 4 should be studied.

ACKNOWLEDGEMENT

The authors would like to thank Chandigarh University for providing facilities and special thanks to faculty for guidance.

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