Review on Behavior of Outrigger System in High Rise Building

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Abstract *– In the modern society there is a huge demand of high rise buildings and with the evolution and continuous demand of taller buildings have created need for more and more unconventional and efficient structural systems. One such system is Outrigger System. The paper aims at summarizing in detail the concept and working principle of various configurations of Outriggers and the current trends in integration of Outriggers in tall structures. In addition to this various problems associated with the Outriggers are also discussed. A detailed scrutiny of literature available in the field of Outrigger system is carried out and the summary and gaps encountered in the study are listed in this paper.*

A relatively new concept of Virtual Outrigger is introduced in this paper. In which, using only the belt truss in the building in order to increase the performance of the building under the dynamic loads is studied. Emphasis is given to the various benefits of employing Virtual Outriggers instead of Conventional ones. Concept of Basements as Virtual outrigger is also reviewed in the paper.

Key Words**: Outrigger, High Rise Building, Lateral Load Resisting System, Lateral Deflection, Inner Storey Drift**

1. INTRODUCTION

The development in tall buildings has evolved rapidly in recent years. Population from rural areas is migrating in large numbers to metro cities. Due to this, metro cities are getting densely populated day by day. As population is getting denser the availability of land is diminishing and cost is also increasing. Hence to overcome these problems multi-storey buildings is most prominent and efficient solution. There is no formal definition for Tall Buildings, building having height more than 35 meters is considered as tall building. It doesn't necessarily depend upon height but also the locality in which the building is to be constructed, for example - A 12 storied building may not be considered a tall building in a High-rise city such as Hong Kong or Singapore but could be considered a tall building in less developed cities.

Development in tall buildings involves various compound aspects for example,

- Shortage of land in urban areas
- Increasing demand for business and residential space
- Technological Advancements
- Innovations in structural systems
- Economic growth
- Concept of city skyline
- Cultural signification and prestige
- Human aspiration to build higher

In developing country like India and increased number of population, tall buildings could be effectively used to meet the demands of the technologically advancing society of our generation and solve the problem of limited availability of land for construction and is most suitable option.

1.1 Evolution of Structural system

Adequate and economical tall buildings cannot be designed without taking into account the factors that affect for the selection of structural system for tall buildings. In modern tall buildings, lateral loads induced by wind or earthquake are often resisted by a system of coupled shear walls. But when the building increases in height say 90m, the stiffness of the structure becomes more important and introduction of lateral load resisting system is used to provide sufficient lateral stiffness to the structure. The lateral load resisting system effectively control the excessive drift due to lateral load, so that, during small or medium lateral load due to either wind or earthquake load, the risk of structural and non-structural damage can be minimized. For high-rise buildings, particularly in seismic active zone like north-east states of India and west India particularly north part of Gujarat, the system that can be used to developed the tall building.

Lateral Load Resisting System:

Following are the lateral load resisting system which can be used in tall building,

- Rigid frame system
- Braced frame system
- Shear wall frame system
- **Outrigger system**
- Tube system

a. Frame tube system
b. Braced tube system
c. Bundled tube system
d. Trussed tube

- Dia-grid Frame

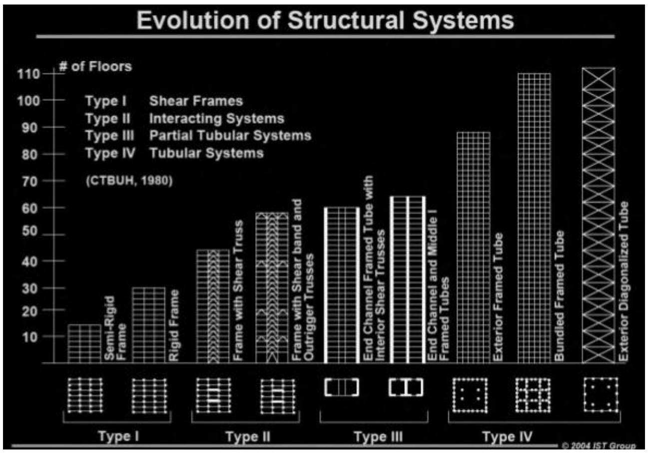
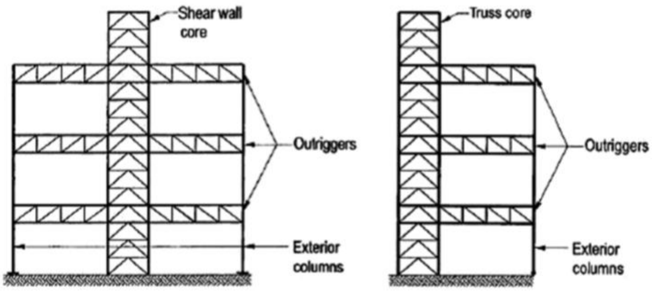


Fig -1: Evolution of Structural Systems

2. OUTRIGGER STRUCTURAL SYSTEM

Outriggers are rigid horizontal structures designed to recover the building overturning stiffness and strength by connecting the building core wall to the External column. Outrigger system for tall buildings has been used for narrow and tall buildings to provide resistance to lateral loads. As the outrigger is connected between core and the exterior column, this reduces the over turning moment and efficiently reduces resulting lateral displacement at top floors.



(a) (b)

Fig -2: (a) Outrigger System with Central Core (b) Outrigger System with Offset Core

When Horizontal loading acts on the building, the column restrained outriggers resist the rotation of the core, causing the lateral deflections and moments in the core to be smaller than if the free standing core alone resisted the loading. The result is to increase the effective depth of the structure when it bends as a vertical cantilever, by inducing tension in the windward columns and Compression in the leeward columns. It should be noted that while the outrigger system is very effective in increasing the structure's flexural stiffness, it doesn't increase its resistance to shear, which has to be carried mainly by the core.

2.1 Concept of Outrigger System

The concept of the outrigger system is a very old concept which is used in sailing ships to help resist the wind forces in their sails. Like the ship, the core in the tall building can be related to the mast of the ship, the outrigger acting like the spreaders and the exterior columns like the stays or shroud of the ship.

2.2 Advantages of Outrigger System

1. All exterior columns (not just certain designated outrigger columns) participate in resisting overturning moment.
2. Core overturning moments can be reduced through the reverse moment applied to the core at each outrigger connection.
3. Exterior framing can consist of simple beam and column framing without the need for rigid-frame-type connection, thus reducing the overall cost.
4. Reduction or elimination of uplift and net tension forces without the column and foundation system.
5. There are no trusses in the space between the core and the building exterior.

2.3 Problems with Outrigger System

There are several problems associated with the use of outriggers, problems that limit the applicability of the concept in the real world:

1. At the floor where the outrigger is located that place cannot be used especially the outrigger in diagonal in shape.
2. Architectural and functional limitation may prevent placement of large outrigger columns where they could most conveniently be engaged by outrigger beam extending out from the core.
3. The connections of the outrigger trusses to the core can be very complicated, especially when a concrete shear-wall core is used.
4. The core and the outrigger columns will not shorten equally under gravity load. The outrigger trusses, which need to be very stiff to be effective as outriggers, can be severely stressed as they try to restrain the differential shortening between the core and the outrigger columns.

2.4 Types of Outrigger System

There are two types of outrigger system,

1. Conventional outrigger concept
2. Virtual outrigger Concept

1**. Conventional Outrigger Concept:**

In the conventional outrigger concept, the outrigger trusses or beams are connected directly to shear walls or braced frames at the core and to columns located outboard of the core. Typically (but not necessarily), the columns are at the outer edges of the building. Figure 3 is an idealized section through a tall building with two sets of outrigger trusses, including one at the top. The outrigger trusses in Figure 3 are shown three stories tall, with double diagonals in an "X" configuration. The number of outriggers over the height of the building can vary from one to three or more.

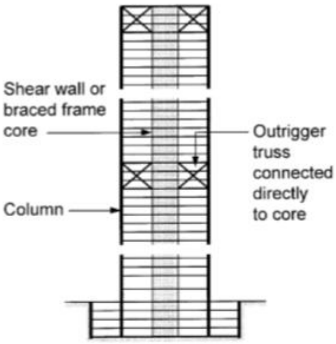


Fig -3: Tall Building with Conventional Outrigger

The way in which the outboard columns resist part of the overturning moment produced by lateral loads such as earthquake load or wind load on the building, the outrigger trusses which are connected to the core and to columns outboard of the core, restrain rotation of the core and convert part of the moment in the core into a vertical couple at the columns. Shortening and elongation of the columns and deformation of the trusses will permit some rotation of the core at the outrigger. In most designs, the rotation is small enough that the core undergoes reverse curvature below the outrigger.

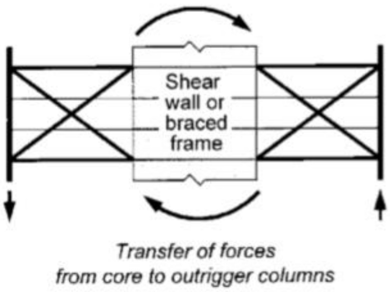


Fig -4: Force Transfer in Conventional Outrigger

2. Virtual outrigger Concept:

In the conventional outrigger concept, outrigger trusses connected directly to the core and to outboard columns convert moment in the core into a vertical couple in the columns. In the "virtual" outrigger concept, the same transfer of overturning moment from the core to elements outboard of the core is achieved, but without a direct connection between the outrigger trusses and the core.

The basic idea behind the virtual outrigger concept is to use floor diaphragms, which are typically very stiff and strong in their own plane, to transfer moment in the form of a horizontal couple from the core to trusses and trusses to exterior column. Belt trusses and basement walls are well suited to use as virtual outriggers.

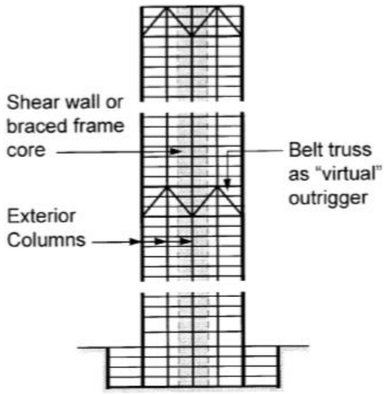


Fig -5: Tall Building with Virtual Outrigger

The way in which overturning moment in the core is converted into a vertical couple at the exterior columns in case of conventional outrigger, rotation of the core is resisted by the floor diaphragms at the top and bottom of the belt trusses; thus, part of the moment in the core is converted into a horizontal couple in the floors (Figure 6a). The horizontal couple, transferred through the two floors to the truss chords, is converted by the truss into vertical forces at the exterior columns (Figure 6b).

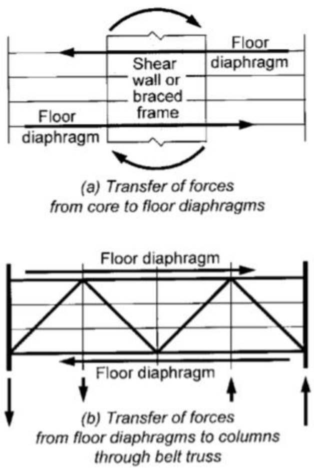


Fig -6: Force Transfer Using Belt Truss as Virtual Outrigger

2.4.1 Benefits offered by Virtual Outrigger

1. There are no trusses in the space between the core and the building exterior.

2. The need to locate large exterior columns where they can be directly engaged by outrigger trusses extending from the core is eliminated.
3. All exterior columns (not just certain designated outrigger columns) participate in resisting overturning moment.
4. The difficult connection of the outrigger trusses to the core is eliminated.
5. Complications caused by differential shortening of the core and the outrigger columns are avoided.

2.4.2 Basement as Virtual Outrigger

The basement of a tall building can serve as a virtual outrigger, to create a base with a greater effective width for resisting overturning. This can reduce lateral load-induced forces in foundation elements and eliminate uplift. The principle is similar to belt trusses when used as virtual outriggers. Some fraction of the moment in the core is converted into a horizontal couple in the floors at the top and the bottom of the basement. This horizontal couple is transmitted through the floor diaphragms to the side walls of the basement, which convert the horizontal couple into a vertical couple at the ends.

3. LITERATURE REVIEW

The outrigger system is one of the lateral load resistance system used in high rise building to control the deflection of building causing due to earthquake loads and wind loads. Researchers have been studding the behavior and the performance of outrigger system in high rise building in specially a seismic active region. Several research papers have also been published internationally and nationally by incorporating the outrigger system in tall building to see the behavior of the building in different loads conditions. In this review paper few papers have studied to get the knowledge of particular field of outrigger system. And to known the how to control the lateral load under various conditions.

P.M.B. Raj kiran Nanduri et. al., investigated, as the height of the building increases the stiffness of the building decreases. To increase the stiffness of the building some lateral system should incorporate in the building which can resist the lateral load such wind load and earthquake load acting on building. In this paper, the researcher studied the behavior of the outrigger system in 30 storey reinforced concrete building, in which the outrigger placed in between central core and exterior column of the building. They also investigated the optimization of the outrigger location and the efficiency of the each outrigger under the wind load and earthquake load.

The analyzed the building by installing the multi outrigger system with several combinations such as without outrigger, with outrigger and outrigger with belt truss at the different position in building. Belt truss was placed along the periphery of the building. The earthquake load and wind load consider according to Indian standard code and checked the building in lateral displacement, drift, bending moment and column axial force. The study concluded that the maximum reduction in lateral displacement occurred when the outrigger and belt truss placed at top and mid height of the building. Using the concrete section instead of steel section in outrigger it shows that outrigger performs better because of the rigid connection with core of a building.

In July 2015, Abdul karimmulla and Srinivas B.N.presented a research containing comparative study on behavior of the outrigger in regular and irregular structure. In this paper the researcher gave a brief introduction of the conventional and virtual concept of outrigger system. The conventional outrigger is connected to braced frame or shear wall directly at the core but not necessary to column to locate at outer edges of the building. Virtual outrigger is connecting core and perimeter system is eliminated directly and belt truss is used with strong diaphragm. Virtual outrigger couldn't compete the conventional outriggers under acute conditions of lateral loading. That's why the scope for the virtual outrigger is limited to regions of less severe winds and earthquakes.

The researcher studied the two models of 20 storey in which one was regular building with and without outrigger and another irregular building with and without outrigger which changes the shape along the height. The models were analyzed under equivalent static method and response spectrum method and checked in storey drift, natural time period and lateral displacement. Models were also analyzed varying the seismic zones as per the Indian standards. Steels bracing were used for belt truss with the RC frame. After the analyzed the mode, it conclude that concrete outrigger are more efficient than the steel outrigger when it compare with lateral story displacement. Irregular building with vertical floor irregularity due to the reduced self weight is more effective than regular building but at the same time it reduces the stiffness of the building. To increase the stiffness of the building particularly in irregular building, location of the outrigger is the most important factor is to be considered.

In July 2015, Srinivas Suresh Kogikgeri and Beryl Shanthapriya studied on behavior of outrigger system on high rise steel structure. The focus of the study was to study the static and dynamic behavior of the outrigger structural system and steel structure by reducing the depth of the outrigger. In this study the researchers studied the 40 storey steel building with braced core. Chevron bracing was used for both core and outrigger system. The structure was initially compared with braced core with the structure with cap truss only and then additionally outrigger and belt truss was added in the structure at mid height of the building. The depth of the outrigger was reduced by 2/3rd and 1/3rd of the storey height along with the full depth. The depth of the belt truss was same to the height of the floor. The structure was analyzed under the equivalent static method and response spectrum method as per the IS 1893 (part 1) and the structure subjected to wind load as per IS 875 (part 3).

The results were analyzed by considering the parameter, lateral deflection and storey drift. It was found out that installing the additional outrigger at mil height of the structure decrease the lateral deflection and storey drift as compare with structure with only cap truss. It was also found that by reducing the depth of the outrigger in structure it shows around the same result by comparing the full depth of the outrigger and decrease the depth of the outrigger.

In 2015, M. R. Suresh and Pradeep K.M. studied the high rise structure by incorporating outrigger system under the different seismic zones. In this research paper the author's objective was to increase the stiffness of the building by using the outrigger system in building with different height and check the performance of the building in different seismic zones in India. For that, the author made model of 30 storeys building and providing the outrigger at different levels along the height of the building by varying relative stiffness of the outrigger. The relative stiffness of the outrigger was considered by taking the ratio of depth of outrigger beam to depth of conventional beam.

The results were obtained by considering the parameters such as lateral displacement, inner storey drift and base shear. It was found that model with high relative stiffness shows better result in all seismic zones as compare to others. Reduction in lateral displacement and inner storey drift with respect to bare frame varies for different model configuration. Overall, by increasing the stiffness of the building or stiffness the outrigger, building will perform better against the lateral load acting on building.

In December 2012, KiranKamathet. al. presented a study on behavior of outrigger system in tall building under the static and dynamic condition. The aim behind the study was to give the structure to a lateral stability against the lateral load acting by wind load and earthquake load. For that the author examined the three dimensional 40 storey of reinforced concrete structure with central core wall with outrigger and without outrigger by varying the relative flexural rigidity of the structure and placing the outrigger at different location by taking the relative height ratio. Relative height ration equals to height where the outrigger placed by total height of the building.

The analysis was done by equivalent static method and response spectrum method considering the historical earthquakes occurred in California region. And it was found that placing the outrigger at mid height is more effective than placing at top height of the building. The author also suggested that though the outrigger at top is less efficient but it has observed that by pacing the outrigger at top it reduces the top storey drift and peak acceleration considerably. Overall, by increasing the flexural rigidity of the outrigger and placing outrigger at mild height of the building gave the better result in lateral displacement, shear force, bending moment and storey drift of the building.

In 2009, N Herath et al. studied the high rise building under the earthquake load by adopting the outrigger beam system. The idea behind this study was to increase the stiffness and strength of the building by using the outrigger beam connecting the core and exterior column of the building to resist the lateral load acting on structure. The study also aimed to optimizing the location of the outrigger beams in structure in order to achieve maximum stiffness and economy in building. In this study a concrete outrigger beams were used instead of steel truss beams which were proved to be very effective as the connections of the RC outrigger beam to exterior columns worked better than its connections with steel truss.

Researchers analyzed several 50 storied RC frames with different location of outrigger beams by response spectrum method and it was found that the optimum location of the 2nd outrigger beam was near the mid height of the building. The researchers were analyzed the models by considering the 9 ground acceleration of actual earthquakes in past to study the displacement and the drift of building.

In 2012,Abbashaghollahi presented a study on outrigger locations in steel tall buildings subjected to earthquake load. The main aim of the study was to obtain the optimum locations of the outrigger structure in the building and compares the behavior of the outrigger system by response spectrum method and nonlinear time history method. According to author to determine the outrigger optimum location, drift was used as measurable parameter. He also observed that optimum location of outrigger is where the drift ratio of stories are minimum, for this reason location of the outrigger should be changed along the height of structure and several analyses are needed. Location of the outrigger was taken by taranath's method i.e. 0.445 of the structure's height from the top of it. Several combinations of the outrigger location were used for both response spectrum and time history method. In this study the models studied under the seven history of earthquakes which was occurred in past.

The results were concluded that optimum location of outrigger and belt truss from response spectrum analysis for 20 and 25 storey models was 0.44 and 0.5 of the structure's height from top of it respectively and from time history analysis the optimum location of the outrigger and belt truss was 0.3 and 0.36 of the structure's height from top of it for 20 and 25 storey respectively. Overall the location of the outrigger beam has a critical influence on the lateral behavior of the structure under the earthquake load and the optimum outrigger location of the building have to be carefully selected in building design.

Shivacaran K. et.al., May-2015, investigated the behavior of the outrigger system when the building was vertically irregular. According to researcher when structure changes the shape along with height it loses its strength and stiffness and it is difficult to withstand under the lateral load. In this study researcher analyzed the tall vertical irregular structure by finding the optimum position of the outrigger system and belt truss under the lateral load condition.

Three dimensional 30 storeys building in which building changes the shape at 10th and 20thstorey. The researcher fixed the 1st outrigger at optimum position and varies the second outrigger position and checked for storey drift, deflection and shear force under the 6 combinations of DL, LL, WL and EQL according to Indian standard codes. The result of the research revealed that max. Deflection and drift were controlled by providing outrigger with belt truss at 0.67h and 0.5h where h is the total height of the building. This research need further research by analyzing structure in response spectrum method and time history method.

In August 2015, Vijaya kumara gowda M R and Manohar B C carried out a study on dynamic analysis of tall structure under the different seismic zones. In this study the researchers studied the concept of the virtual outrigger system which is the one of outrigger system to control the defection of the tall structure due to the lateral load. In this concept, the outriggers connecting core and perimeter system is eliminated and instead a belt truss is used with a combination of stiff and strong diaphragms. In this study the researchers used the different type of belt truss such as 'X' shape and inverted 'V' shape truss with shear core and without shear core and analysis the structure under equivalent static and response spectrum methods.

The analysis was carried out by considering the 30 storey RC building with concrete shear core and concrete belt truss. Total five models were analysis with the different combination of belt truss and shear wall under the different seismic zones. The location of the belt truss was fixed at the top of the building and the mid height of the building.. The result was concluded that the usage of the belt truss system in the building increases the building stiffness by reducing the base shear under action of the seismic load. Belt truss with shear core increases the percentage of the storey drift in the building in all seismic zones. It was also concluded that inverted 'v' shape of the belt truss show the good performance in all the seismic zones.

3.1 Summary of Literature

1. Using the outrigger system in building it increases the stiffness and the strength of the building and also resists the lateral load causes due to the earthquake load and wind load.
2. Outrigger improved the performance of the building by reducing the base shear, lateral displacement and inner storey drift,
3. The multi outrigger system used in building its increase the performance of the building as compared to single outrigger system
4. Using the outrigger with belt truss gives the more stability and stiffness to the building and reduces the max. Defection of the building.
5. Concrete outrigger is more efficient than the steel outrigger as the connection of the outrigger to core is simple.
6. Decreasing the depth of the outrigger shows no significant reduction in the lateral deflection and storey drift as compare to full floor depth of the outrigger
7. Irregular building with vertical floor irregularity due to the reduced self weight is more effective than regular building but at the same time it reduces the stiffness of the building. To increase the stiffness of the building particularly in irregular building, location of the outrigger is the most important factor is to be considered.
8. Using only belt truss in the building its increases the performances under the dynamic load conditions.
9. Using the virtual outrigger, dead load of structure reduces and structure becomes economical.
10. Comparing the virtual outrigger with the conventional outrigger, conventional outrigger with belt truss gives good results.
11. The behavior of a structure under the earthquake load is different from earthquake to earthquake. The location of the outrigger beam has a critical influence on the lateral behavior of the structure under the earthquake load and the optimum outrigger locations of the building have to be carefully selected in the building design.
12. Optimum position of the outrigger at mild height shows the max. Reduction in lateral deflection in the building.
13. The usage of the belt truss system or virtual outrigger system in building plays the important role in increasing the structural stiffness and reducing the base shear under the earthquake and wind load.

4. GAPS IN LITERATURES

After study of various national and international researches papers on the behavior and performance of the outrigger system, the gaps and problems which are still not studied, are mentioned below.

1. The analysis of the models has done in grid models only. No researchers have done by taking actual plan of the building.
2. Most of the researches are done by conventional outrigger system and outrigger with belt truss, but very few researches are done with taking only "Virtual Outrigger".
3. The study of outrigger system mostly performed by considering 40 storey building, but it can be used in 70-80 storey building by using the multiple outrigger system.
4. Mostly the analysis of the high rise building has done under the seismic zone 3. There is few researches been done in zone IV and zone V.
5. The outrigger system has analyzed under the wind load but has not analyzed under the earthquake loads as height of the building increases above the 40 storey.

6. Non linear time history analysis for high rise structure has not yet studied.
7. New concept of basement virtual outrigger system is not yet used in high rise structure.

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