# Review on Behaviour of Outrigger Structural System in High-Rise Building

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***Abstract* - Tall building development has been rapidly increasing worldwide introducing new challenges. As the height of the building increases, the stiffness of the building reduces. The Outrigger and Belt trussed system is the one of the lateral load resisting systems that can provide significant drift control for tall buildings. Thus, to improve the performance of the building under seismic loading, this system can prove to be very effective. The outrigger and belt truss system is commonly used as one of the structural system to 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 or wind load dominant, this system can be chosen as an appropriate structure. The objective of this paper is to study, the performance of outrigger structural system in high-rise RC Building subjected to seismic load and Wind Load. Study of the literature is reviewed in this paper on various aspects of outrigger structural system as; Behaviour of outrigger structural system in High-Rise RC building, Behaviour of Outrigger structural system in High-Rise Steel and composite Building, Behaviour of outrigger structural system in vertically irregular structures and Effect of seismicity on irregular shaped structure.**

*IndexTerms* - **Outrigger, Belt Truss, Lateral load resisting structural system, Irregularity, Non Linear Dynamic Analysis.**

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## I. INTRODUCTION

### *A.* General

Tall Building has always been a vision of dreams and technical advancement leading to the progress of the world. Presently, with the rapidly increasing urbanization, tall building has become a more convenient option for office and residential housing. Tall buildings are usually designed for Residential, office or commercial use. They are primarily a reaction to the rapid growth of the urban population and the demand by business activities to be as close to each other as possible.

A large portion of India is susceptible to damaging levels of seismic hazards. Hence, it is necessary to consider the seismic load for the design of high-rise structure. The different lateral load resisting systems are used in high-rise building as the lateral loads due to earthquake are a matter of concern. These lateral forces can produce critical stresses in the structure, inducing undesirable stresses in the structure, and undesirable vibrations or cause excessive lateral sway of the structure.

### *B. Structural System*

In the past years, structural members were assumed to carry primarily the gravity loads. Today, however, by the advances in structural design/systems and high strength materials, building weight has reduced, in turn increasing the slenderness, which necessitates taking into account majorly the lateral loads such as wind and earthquake. Specifically for the tall buildings, as the slenderness, and flexibility increases, buildings are severely affected from the lateral loads resulting from wind and earthquake. Hence, it becomes more necessary to identify the proper structural system for resisting the lateral loads depending upon the height of the building. There are many structural systems that can be used for the lateral resistance of tall buildings.

**Structural systems for tall buildings**

a. Rigid frame systems
b. Braced frame and shear-walled frame systems
c. Braced frame systems
d. Shear-walled frame systems
e. Outrigger systems
f. Framed-tube systems
g. Braced-tube systems
h. Bundled-tube systems

## II. OUTRIGGER STRUCTURAL SYSTEM

### *A.* Introduction

The outrigger and belt truss system is one of the lateral loads resisting system in which the external columns are tied to the central core wall with very stiff outriggers and belt truss at one or more levels. The belt truss tied the peripheral column of building while the outriggers engage them with main or central shear wall. The outrigger and belt truss system is commonly used as one of the structural system to 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 or wind load dominant, this system can be chosen as an appropriate structure.

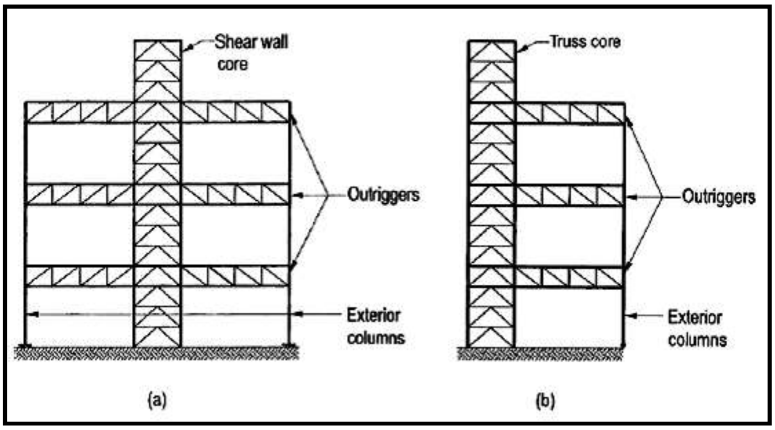


**Fig. 1** (a) Outrigger with a central core (b) Outrigger system with offset core

### *B.* Concept of Outrigger

The great sailing ships of the past and present use outriggers 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.

The narrow boat will overturn when toss by unexpected wave but the small amount of flotation (i.e. upward resistance) or weight (i.e. downward resistance) acting through outrigger is sufficient to avoid overturning. In the same manner building outrigger are connected to perimeter columns capable of resisting upward and downward forces can greatly improve the building resistance.

**Fig. 2** Concept of Outrigger Structural system

### *C.* Behaviour of Outrigger

The structural arrangement for this system consists of a main concrete core connected to exterior columns by relatively stiff horizontal members such as a one or two-story deep walls commonly referred to as outriggers. The core may be centrally located with outriggers extending on both, or it may be located on one side of the building with outriggers extending to the building columns on one side.

The basic structural response of the system is quite simple. Because outrigger act as a stiff arm engaging outer columns, when central core tries to tilt its rotation at outrigger level induced a tension compression couple in outer columns and acting in opposite to that moment. The result is the Type of restoring moment acting on the core at that level. As a result, the effective depth of the structure for resisting bending is increased when the core bend as a vertical cantilever, by the development of tension in the windward columns, and by compression in the leeward columns.

In addition to those columns located at the ends of the outriggers, it is usual to also mobilize other peripheral columns to assist in restraining the rotation of outriggers. This is achieved by tying the exterior columns with a one- or two-story deep wall commonly referred to as a "belt wall," around the building

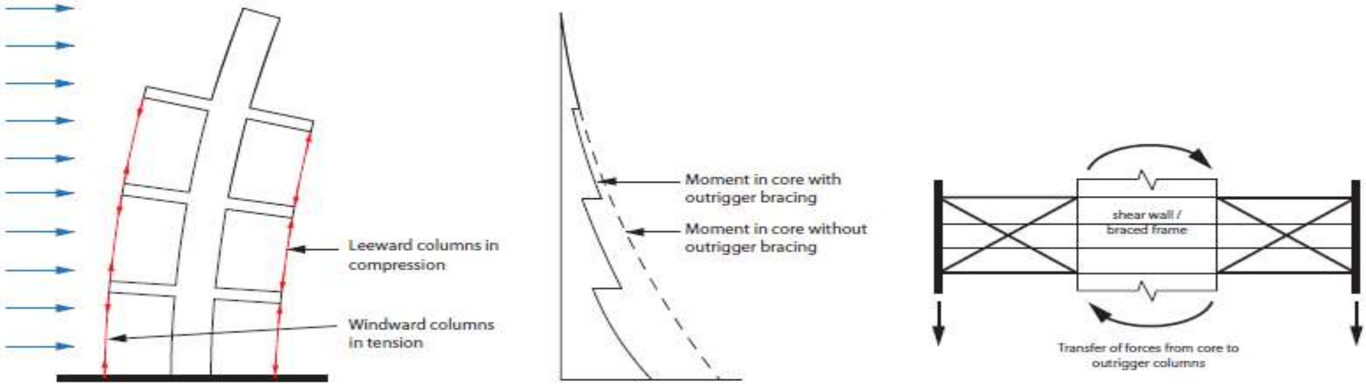


**Fig. 3** Behaviour of Outrigger Structural system (Retrieved from - CTBUH Technical Guide)

### *D.* Types of Outrigger structural system

On the basis of connectivity to the core there are two types of outrigger truss;
Conventional Outrigger system
Virtual Outrigger system

**Conventional Outrigger System**

In the conventional outrigger system, the outrigger trusses or girders are connected directly to shear walls or braced frames at the core and to columns located outboard of the core. Generally but not necessarily, the columns are at the outer edges of the building. The number of outriggers over the height of the building can vary from one to three or more. 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 allow 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.

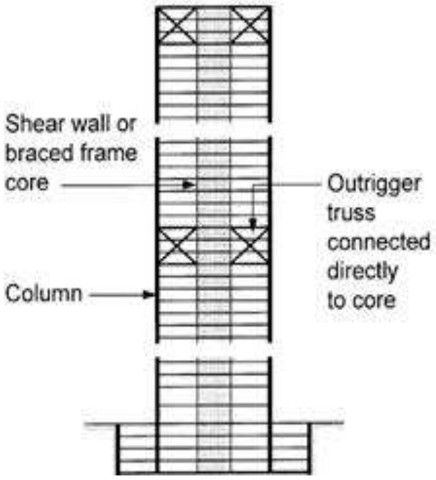


**Fig. 4** Conventional Outrigger Structural System

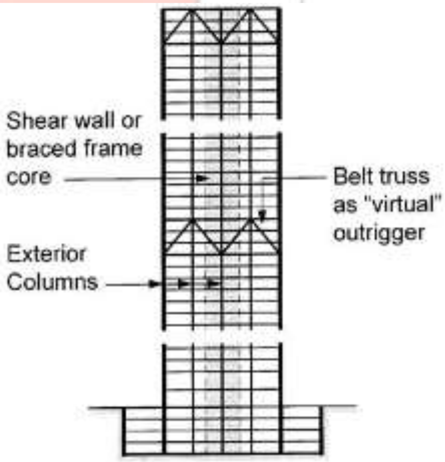


**Fig. 5** Virtual Outrigger Structural System

**Virtual Outrigger System**

In the conventional outrigger system, outrigger trusses connected directly to the core and to outboard columns convert 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 elimination of a direct connection between the trusses and the core avoids many of the problems associated with the use of outriggers.

The basic concept behind the virtual outrigger 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 or walls that are not connected directly to the core. The trusses or walls then convert the horizontal couples into vertical couples in columns or other structural elements outboard of the core. Belt trusses and basement walls are well suited to use as virtual outriggers.

**Belt Trusses as Virtual Outriggers**

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 floor. The horizontal couple, transferred through the two floors to the truss chords, is converted by the truss into vertical forces at the exterior columns.

The forces and moments in all components can be determined by three-dimensional elastic analysis of the lateral load-resisting system, which includes the core, the trusses, the exterior columns, and the floors that connect the core to the trusses. When the core is a steel braced frame, the transfer of horizontal forces between the core and the floors can be achieved through shear studs on the horizontal frame members. When the core is a concrete shear wall, forces may be transferred through the concrete-to-concrete connection, with reinforcing steel extending through the connection. The transfer of horizontal forces between the floor diaphragms and the chords of the belt trusses can be achieved through shear studs on the chords.

**Basements as Virtual Outriggers**

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. Basement walls are of adequate strength and stiffness to be effective as outriggers.

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.

The effectiveness of the basement as an outrigger may be greatest when the core has a “soft” support, such as footings on soil or long caissons subject to elastic length changes. A “hard” support, such as footings directly on rock, may result in most of the moment in the core going down directly into the core foundation, not into the outrigger system.

### *E.* Advantages of Outrigger systems:

1. The outrigger systems may be formed in any combination of steel, concrete, or composite construction.
2. Core overturning moments and their associated induced deformation can be reduced through the “reverse” moment applied to the core at each outrigger intersection. This moment is created by the force couple at the exterior columns to which the outrigger connect. It can potentially increase the effective depth of the structural system from the core only to almost the complete building.
3. Significant reduction and possibly the complete elimination of uplift and net tension forces throughout the column and the foundation systems.
4. The exterior column spacing is not driven by structural considerations and can easily mesh with aesthetic and functional considerations.
5. Exterior framing can consist of “simple” beam and column framing without the need for rigid-frame-type connections, resulting in economies.
6. For rectangular buildings, outriggers can engage the middle columns on the long faces of the building under the application of wind loads in the more critical direction. In core-alone and tubular systems, these columns which carry significant gravity load are either not incorporated or underutilized. In some cases, outrigger systems can efficiently incorporate almost every gravity column into lateral load resisting system, leading to significant economies.

### *F.* Disadvantages of outrigger systems.

The most significant drawback with use of outrigger systems is their potential interference with occupancy and rentable space. This obstacle can be minimized or in some cases eliminate by incorporation of any of the following approaches:

1. Locating outrigger in mechanical and interstitial levels
2. Locating outriggers in the natural sloping lines of the building profile
3. Incorporating multilevel single diagonal outriggers to minimize the member’s interference on any single level.
4. Skewing and offsetting outriggers in order to mesh with the functional layout of the floor space.
5. Another potential drawback is the impact the outrigger installation can have on the erection process. As a typical building erection proceeds, the repetitive nature of the structural framing and the reduction in member sizes generally result in a learning curve which can speed the process along.

## III. Literature Review

### *A.* Introduction

Technical papers of various journals from India and abroad are studied to understand the importance and necessity of this research in consideration of wind and seismic resistant Design. It presents a brief summary of the literature review. Following review of Literature gives an outlook on the behaviour of outrigger structural system in high rise building.

### *B.* Review of Literature

**Review of Literature on Study of Different Lateral Load resisting Structural System**

**Thejaswini R. M. and Rashmi A. R. (2015)** have carried out a comparative study and analysis of different lateral load resisting structural systems to understand the realistic performance of the building during earthquake and under the excessive wind pressure as well as to select structural system of tall building to stay in good condition with effect of gravity, live load and external lateral load, moment, shear force and torque with acceptable strength and stiffness.

For this research work they have modelled a geometrically irregular 14 storey RCC high rise building with different forms of structural system, such as Rigid frame structure, Core wall structure, and Shear wall structure with different configurations of shear wall location, Tube structure and outrigger structure. Results of the analysis reveal that the values of displacement were less in tube structure and outrigger structural system. The authors have also stated that in geometrically irregular structure; stability of structure will boost and the columns sway can be reduced by implementing L-shaped shear wall along the corners of the structure. One important conclusion that the researchers have drawn from this study is that when outrigger structural system is provided at a story which has maximum drift, it can perform as a maximum drift controller.

**Review of Literature on Behaviour of Outrigger Structural System in High rise RC Building**

**Po Seng Kiran and Frits Torang Siahaan (2001)** have worked on the idea to increase the stiffness and make the structure proficient under wind as well as seismic load by introducing outrigger and belt truss system connecting core to exterior column. In this research work authors have studied the application of diagonal outrigger and belt truss with different configurations. They have carried out the analysis on a 40 storied 2-dimensional models subjected to wind load by introducing outrigger and belt truss systems with eight different configurations by varying the locations of outrigger as per the British standard. Similarly 60 storied 3-dimensional models subjected to earthquake load by incorporating outrigger and belt truss system with 5 different configurations by varying Locations, numbers and height of diagonal outrigger beam and belt truss. A comparative study has been carried out to examine the reduction in lateral displacement. Researchers have also focused on to determine the optimum location of outrigger. Investigation of this research paper have found that 65% maximum reduction in displacement is attained in the 40 storied 2-dimensional models subjected to wind load by providing two outriggers. The first outrigger is assigned at the top and second at the mid height of the structure. Further, about 18% maximum reduction in displacement is attained in 60 storied 3-dimensional model subjected to earthquake load by providing optimum location of outrigger truss at the top and 33rd level.

**N. Herath et al. (2009)** carried out the research based on the understanding that earthquake ground motion can occur anywhere in the world and the risk associated with tall buildings, especially under severe earthquakes, should be given special attention, since tall buildings often accommodate thousands of occupants. When the height of building increases, the consideration of stiffness is very important in tall building. In such case outrigger beam is proposed to be provided in between the shear wall and external columns to improve satisfactory lateral stiffness to the structure. The main intention of this research was to optimize the location of Outrigger for safety against Earthquakes and Economy in design. For this purpose, researchers have consider 9 previous earthquake records and based on acceleration to velocity ratios (A/V Ratio) namely, Park field (28 June 1966), Friuli (6 may 1976), Patras (29 Jan 1974), Gazli (17 may 1976), El Centro (18 May 1940), Spitak (7 Dec 1988), Mexico City (19 Sep 1985), Tabas (13 Sep 1978), San Fernando (9 Feb 1971). The performance of high rise building has been examined by studying different configurations of outrigger structural system.

A model of 50 stories was analyzed for three different ratios of peak ground acceleration to peak ground velocity. In each category of earthquake records were incorporated in this research study to provide a consistent level of approach. Response spectrum analysis was conducted to determine behaviour of the building considering parameters such as lateral displacement and inter storey drift. It was proved from this study that the structure is optimized when the outrigger is placed between 22-24 levels. Therefore it can be concluded that the optimum location of the structure is between 0.44-0.48 times its height (taken from the bottom of the building).

**Kiran Kamath et al. (2012)** fulfilled the study of efficient Outrigger Structural System in high rise reinforced concrete building. The basic thought behind this research study was to increase the stiffness and make the structural form efficient under the lateral load acting on the structure due to wind load as well as earthquake loads. Their research examined the behaviour of reinforced concrete structure with central core wall with various configurations of outrigger system by varying relative flexural rigidity. In this paper authors had also focused on optimum location of outrigger system in tall buildings by considering the relative height of outrigger beam i.e. (ratio of height of outrigger to total height of building).

In this research article researchers have considered 40 storey three dimensional models of 6 different configurations of outrigger of varying Hs/H ratio and varying relative flexural rigidity between 0.25 to 2 for modelling of structure. For static behaviour purpose equivalent static analysis was performed as well as for dynamic behaviour purpose Time history analysis by considering the previous earthquake data of peak ground acceleration of California region as per Indian standard codes was carried out. A comparative study for the investigation of various parameters, such as lateral deflection, peak acceleration and inter story drift has been performed. From the whole investigation it is observed that by considering the criteria for reduction in top displacement, optimum position of outrigger is at mid height of the building with relative flexural rigidity of 0.25 by static and dynamic analysis. Further, according to the authors, in time history analysis the response of structure does not show any particular trend with peak acceleration, though for all earthquake histories of California region the top lateral displacement was least for outrigger structure with relative height of 0.5.

**Alpana L. Gawate and J. P. Bhusari (2015)** have published their paper which focused on enhancement the lateral stiffness of tall buildings, because as the height of the building increases the core alone is not adequate to keep the drift within permissible limit. Therefore some other structural element is to be added in that building to take care of drift. Outriggers are the structural system, which help in reducing the lateral drift increasing the stiffness of the structure by huge amount.

In this paper, the optimum location of the outrigger is found by considering few constraint conditions. The parameters on which the conclusions made are the lateral drift and formation of soft storey. A soft storey is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storeys above. It also takes into account the change in results due to changes in sizes of cross sections of columns and shear walls.

For the analysis of this problem researchers have chosen a 30 storied three dimensional model with various configurations of outrigger such as system with single and double outrigger by changing cross sectional dimensions of columns and thickness of shear wall. The said model was analyzed by response spectrum analysis as per Indian standard codes and following conclusion has been drawn. When there was provision of only one outrigger, the system was not effective as concerning of drift. There was a remarkable change observed in the drift profile when two outriggers were provided. One important conclusion figured out from this research is no story was found as soft story for all 9 trials made in model with two outriggers with changes in cross sectional dimensions of columns and thickness of shear wall.

**Vijaya Kumari Gowda M R and Manohar B C (2015)** have worked on lateral load resisting structural system by introducing belt truss at top and mid height of building. This proved to be cost effective to improve the performance of building subjected to earthquake load. Basically belt truss is the truss which is provided along the peripheral columns of structure at certain height of building to improve the stiffness and firmness against lateral loads. In this research work researchers have carried out a comparative study by using different types of belt truss which includes X, V, inverted V diagonal etc. for different seismic zone criteria to understand the importance of belt truss.

To execute this study researchers have modelled 30 storied 3-dimensional models by implementing different types of belt truss and analyzed the model by equivalent static analysis and response spectrum method as per the Indian Standard codes. A comparative study has been performed based on percentage reduction of displacement and story drift at the different seismic zones. It is found from the study that for reducing lateral displacement and story drift, Concrete belt truss is more efficient compared to structural steel belt truss as it gives negligible results. Each type of trusses gives different results for different seismic zones, therefore based on economical conditions researchers have concluded that inverted V-type of belt truss is one of the best type of belt truss in all seismic zones to increase the efficiency of the building.

**Kiran Kamath et al. (2012)** have worked on the differential column shortening due to long term effect in tall building by using outrigger structural system. The basic idea for this research is that the cumulative differential shortening of columns causes the slabs to tilt with resulting rotation of partitions. Improper functioning of elevators, deformation, or damage to pipelines, cracking of partitions and finishes, and many other service problems can appear in the building due to differential shortening of columns. Therefore it is very important to study the effect of column shortening and need special consideration in design. The primary objective of this research was to find out the optimum location of outrigger in high-rise RC building to reduce differential column shortening.

In this research work researchers have analysed a 60 storied 3-dimensional model with various configurations of outriggers with different H/h1 ratios. From the analytical investigation it is observed that the differential shortening was decreased by 34% when one outrigger system was introduced at H/h1 = 1.715 as well as the same model was analysed by keeping one outrigger fixed at its optimum position with H/h1=1.715 and second outrigger optimum position is found to be at H/h2=1.33 which will further reduce the differential shortening by a total of 58% so this study conclude that differential shortening of columns was reduced to a great extent by introduction of outriggers.

**Review of Literature on Behaviour of Outrigger Structural System in High rise Steel Building**

**Abbas Hangollahi et al. (2012)** have worked on high rise steel framed building subjected to earthquake load to optimize the location of outrigger. The basic concept of this research work was to carry out the comparative study of results obtained for the lateral displacement and story drift by response spectrum and non-linear time history methods for optimum outrigger location. In this investigation, 20 and 25 story models had been analysed by considering ground accelerations of several actual earthquakes in the past to study displacement and drift. Total 7 earthquakes were selected namely, Northridge 17/1/1994, Loma Perieta 18/10/1990, Tabas 16/09/1978, Cape Mendocino 25/04/1992, Victoria Mexico 9/6/1980, San Fernando 9/02/1971, Chi Chi 20/09/1999. Researchers have concluded that by employing response spectrum analysis method, optimum location of outrigger and belt truss in 20 and 25 story model was at story 10 and story 14 (i.e. 0.44 and 0.5 times the height of structure from top). Similarly by employing Non linear Dynamic Time History analysis optimum location of outrigger and belt truss was at story 14 and story 16 (i.e. 0.3 and 0.36 times the height of structure from top). So according to author it may be safe to claim that outrigger optimum location at real status should be located in upper level.

**Review of Literature on Behaviour of Outrigger Structural System in Vertically Irregular high- rise RC Building.**

**Shivshankar K et al. (2015)** presented research involving investigation of the action of outrigger structural system in Tall vertical irregularity structure. Vertical geometric irregularity shall be considered to exist where the horizontal dimension of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent storey.

In this study, 30 storey models having vertical irregularity were taken. The building plan changes at 11th and 21st story. These models were analysed with only bare frame and bare frame with one outrigger and belt truss for 6 configuration of outrigger beam by changing their position. Similarly bare frame with two outrigger and belt truss for 5 different configurations and the response of the structure was evaluated under the different parameters i.e. Lateral displacement, building drift, maximum story shear and axial load of different columns. To examine the behaviour of vertical irregularity of outrigger structural system, linear static analysis has been carried out as per the Indian standard.

It was recognized through this research that around 28.58% and 27% lateral deflection and building drift was restrain by providing outrigger structural system in high rise vertical irregularity structure when it is provided at 0.67 times its height compare to bare frame as well as 37.7% and 36.11% of the Deflection and drift is controlled by providing outrigger with belt truss at 0.67 times its height and 0.5 times it's when compared with bare frame. This study concluded that the optimum location of outrigger was between 0.5 times its height in tall vertical irregularity structure.

**Abdul Karim Mulla and Shrinivas B.N (2015)** had carried out research in regular as well as vertically irregular structure to increase axial stiffness with exterior columns to resist the overturning moment by introducing Outrigger structural system with steel bracing. Irregular structure has discontinuity in mass, stiffness and geometry of the structure. According to author the major reason of earthquake was vertical irregularities though it can be avoided by providing outrigger to increase lateral stiffness.

In this article researchers have performed the comparative analysis of 3 dimensional regular and vertically irregular shaped symmetrical plan 20 storey structures with and without providing outrigger beam subjected to earthquake load. The analysis of structure was done by equivalent static method and response spectrum method as per the Indian standard code practice. To measure the efficiency of the structure authors have considered parameters such as lateral displacement, story drift, base shear and fundamental natural period. On the same line authors have also examined the response of the structure with varying seismic zones as well as the behaviour of outrigger by equivalent static and response spectrum method by incorporating concrete and steel outrigger. Further they have also focused on the determination of optimum location of outrigger beam to lower the lateral displacement.

It was observed through this research that there is considerable reduction in Time period when outrigger was introduced in regular and irregular building structure which will improve the overall stiffness of the structure. Base shear will reduce and minimize the inter story drift by incorporating outrigger. Geometric vertical irregularity was more effective due to reduction of self weight compared to regular building and Concrete outrigger are more effective than steel outrigger with X bracing type in reducing lateral story displacement.

**Review of Literature on Effect of Seismicity on Irregular shape structures.**

**Dr. S.A. Halkure et al. (2014)** have investigated the effect of seismicity on irregular shape structure in high rise reinforced concrete building. They have carried out this research to study the seismic response of irregular shaped structure which will reduce displacement by incorporating shear walls to increase stiffness of structure. In tall building it is very important to identify the effective, efficient and ideal location as well as orientation of shear wall.

In the said investigation 11 story irregular and unsymmetrical building (having C- shape in plan) is comparatively analysed by performing Equivalent lateral force method as per Indian Standard Code practice, by introducing shear wall with 14 different configurations by varying percentage length of shear wall with possible combination of location of shear wall. Accordingly, the model which gives good seismic response when subjected to earthquake load by considering parameters, such as top displacement, base shear, beam moment and column moment, story drift and torsion is figured out.

From the whole investigation study, researchers have found that application of shear wall about 23-31% of perimeter structure was found very much effective in controlling displacement.

**Mr. Gururaj B. Katti and Dr. Basavraj Baapgol (2014)** have focused on the effect of floor which has different loads i.e. mass irregularity in multi-storeyed reinforced concrete building. The main objective of this research work was to examine the seismic response of high-rise building by performing various seismic analysis methods, such as Equivalent static analysis, Response Spectrum analysis and Time History Analysis by considering Earthquake data of BHUJ Earthquake (Jan 26, 2001) and KOYNA Earthquake (Dec 11, 1964) to know the realistic behaviour during earthquake So in this research work researchers have modelled 10 storied RCC Building and performed seismic analysis as per Indian Standard Code by different methods as mentioned above to examine the performance of multi-story building by considering parameters of base shear and story displacement.

The complete comparative analysis reveals that, to know the non linear behaviour of irregular structure time history analysis must be performed.

### *C.* Summary of Literature

1. By studying various lateral load resisting structural system such as Rigid Frame System, Rigid Frame with Shear Wall System, Shear wall system with opening and outrigger system, it was found that outrigger structural system is not only

proficient in controlling top displacement but also plays an important role in reducing inter story drift. It is suggested that outrigger system is efficient up to 60 storey High-rise building.

2. In geometrically irregular structure symmetric along the y-axis, stability of structure will boost and the columns sway can be reduced by implementing L-shaped shear wall along the corners of the structure. By providing proper symmetry in the structure tensional irregularity can be avoided and by providing outrigger structural system having maximum drift at a story, it performs as the maximum drift controller.
3. In geometrically regular and symmetrical structure with simple grid plan, about 65% maximum reduction in displacement is attained in 40 story two dimensional models subjected to wind load by providing 2 outriggers. Here, first outrigger is provided at the top and second at the mid height of the structure. Further, about 18% maximum reduction in displacement is attained in 60 story three dimensional model subjected to earthquake load by providing optimum location of outrigger truss at the top and 0.55 times its height.
4. In geometrically regular and symmetrical structure with simple grid plan it is proved that by considering the previous earthquake records of acceleration velocity ratio, the structure was optimized when outriggers were placed at 22-24 level in 50 storey high-rise building therefore optimum location of outrigger is between 0.44-0.48 times its height.
5. In geometrically regular and symmetrical structure with simple grid plan it is found that by considering the criteria for reduction in top displacement, optimum position of outrigger is at mid height of the building with relative flexural rigidity of 0.25. In time history analysis in all earthquake histories of California region the top lateral displacement was least for outrigger structure with relative height of 0.5.
6. When there is consideration of soft story in outrigger structural system, no story was found as a soft story with various configurations of cross sectional dimensions of column and thickness of shear wall. When there is provision of only one outrigger, the system is not effective for maximum drift controller. There is a remarkable change in drift profile when two outriggers are provided.
7. Application of belt truss in High-rise building increase the structural stiffness by reducing base shear under the action of Static and Dynamic loads. For reducing lateral displacement and story drift, Concrete belt truss is more efficient compared to structural steel belt truss as it gives negligible results. In zone II due to less intensity of seismic force we can build a building without shear wall. Based on economical condition inverted V type of belt truss is one of the best types of belt truss in all seismic zones to increase the efficiency of the building.
8. By incorporating outrigger beam, differential shortening of column is decreased to a great extent. When only one outrigger was incorporated, the differential shortening of column was shortened by 34% at 1.715 relative height ratio of outrigger. When two outriggers were incorporated, the differential shortening of column was shortened by total 58% at 1.715 relative height ratio of first outrigger and at 1.33 relative height ratio of second outrigger.
9. Optimum location of outrigger and belt truss in 20 and 25 story model was at story 10 and story 14 (i.e. 0.44 and 0.5 times the height of structure from top) by employing response spectrum analysis method. Similarly optimum location of outrigger and belt truss was at story 14 and story 16 (i.e. 0.3 and 0.36 times the height of structure from top) by employing Non linear Dynamic Time History analysis. So it may be safe to claim that outrigger optimum location at real status should be located in upper level.
10. Stiffness and stability against lateral loads caused by wind and earthquake will boost by implementing outrigger beam in High-rise building. In geometrically regular and symmetrical structure with simple grid plan it was found that, the building having outrigger location at 0.5 times its height and 0.67 times its height will have good resistance to the lateral displacement as by performing Non Linear Dynamic Time History analysis. When concrete outrigger and braced outrigger with belt truss are compared then there was 35% reduction in maximum story drift and braced outrigger with belt truss (X shaped) is convenient as weight of building get reduced.
11. In high rise building having geometric vertical irregularity with simple grid plan, around 28.58% and 27% lateral deflection and building drift is restrain by providing outrigger structural system at 0.67 height from the bottom when compared to bare frame. Similarly 37.7% and 36.11% of the Deflection and drift is controlled by providing outrigger with belt truss at 0.67 and 0.5 when compared with bare frame.
12. Outrigger performs an essential role in improving the structural flexural stiffness by reducing base shear when the structure is subjected to earthquake static and dynamic loads. There is a considerable reduction in Time period when outrigger was introduced in regular and irregular building structure which will improve the overall stiffness of the structure by reducing lateral displacement and inter story drift. Geometric vertical irregularity is more effective due to reduction of self weight compared to regular building. Concrete outrigger is more effectual than steel outrigger with X bracing type in reducing lateral story displacement.
13. In high rise building having geometric irregularity in plan, to resist seismic effects provision of shear wall as closed box type is extremely effective as compare to provision of shear wall in interior bays. Application of shear wall about 23-31% of perimeter structure is found very much effective in controlling displacement as well as minimizing bending moments and increasing percentage of shear wall beyond 31% in structural framing does not improve the seismic performance of structure to great extent. Base shear increases with increase in percentage of shear wall. Building with shear wall on exterior perimeter is more resistance to twisting effects. Provision of L shaped shear wall near corner and at the end of projections which are parallel to direction of lateral load is very effective in resisting seismic effects.
14. To know the non linear behaviour of irregular structure time history analysis must be performed. It was found that from the results of story displacement, the values of displacement obtained by equivalent static analysis are higher than results of dynamic analysis by Response spectrum method and Time History method.

15. The value of base shear is almost same in Equivalent static analysis and Response Spectrum analysis, but if we considered the non linear dynamic analysis by Time History Method particularly for BHUJ Earthquake then said value decreases about 33% in X direction and 65% in Y direction. The important reason for this sudden change in values was variable mass at different floors which were not considered in Equivalent Static Analysis and Response Spectrum Analysis. Therefore the Time History Analysis contributes the realistic response for seismic analysis which contributes better check for the safety of structure.

## IV. Gaps In Literature

Based on the literature review studied with reference to the outrigger structural system, there is certain absence of research work which is not studied earlier, as mentioned below:

1. From the earlier research work till now, various researchers have carried out study for geometrically regular shaped building by incorporating outrigger structural system. However, there is an absence of scientific research dealing with performance of outrigger structural system in High rise Building especially with geometrically irregular and unsymmetrical shape in plan.
2. Various researchers have carried out the investigation considering static and dynamic behaviour under elastic limits. Nowadays using modern softwares we can also analyse the buildings by non linear methods, such as Time History analysis.
3. Researchers have also performed studies on the behaviour of outrigger structural system by considering simple grids in place of real building plan.
4. In the earlier research work, most of the study based on the assessment of Outrigger structural system is done up to 40 storey building model. However, it can be extended to super high rise building having height up to 300 to 350 m (80-90 Stories).
5. From the previous study it was also found that there is absence of research work considering Multi-outrigger approach. By adopting three different outrigger levels or outrigger with double storied depth, we can study the performance of tall building.

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