Reviews: Effects of Outrigger on High-Rise Structure

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Abstract

The high-rise buildings have been viewed as the landmark of the city with the rapid development of the economy and construction technology. Thus, more high-rise buildings are being built across the world. The Designer of high-rise buildings consider strength, stiffness, stability as an important criterion that are influenced by the lateral loads induced by wind and earthquake. The Lateral stiffness of the building reduces as the height of the building increases. In modern tall buildings, lateral loads induced by wind or earthquake are often resisted by a system of coupled shear walls. To provide sufficient lateral stiffness to the high-rise structures by lateral load resisting system such as outrigger beams which connect the central core and external columns are used. The outrigger with belt truss is used as one of the structural systems to effectively control the excessive drift due to lateral loads. In this paper, an attempt has been made to collect the information from the literature review of research papers related to the analysis of high-rise RC building for outrigger structural system under the action of lateral loads. The objective of this paper is to study the behaviour of outrigger structural system and the effect of disadvantage of column shortening for dynamic analysis under seismic loading.

Keywords: Belt Truss, Central Core, Outrigger, Tall Building, Seismic Analysis

I. INTRODUCTION

The process of designing high-rise buildings have changed over the past years. In the most recent years, it is not unusual to model full three-dimensional finite element models of the buildings. In the past few decades, high-rise buildings have received a renewed interest in many city business locations, where land is scarce, as per their economics, sustainability and other benefits. Taller & taller towers are being built everywhere in the world. In the design of high-rise structures steel and concrete are to most commonly used materials. The tall buildings shall be designed to withstand the gravitational loads and lateral loads due to the actions of wind, earthquake, etc. therefore, there is a requirement of having a good lateral load resisting systems for maintaining the lateral stability of the building. Based on the height and other arrangements of the building, the most suitable structural system is selected.

II. STRUCTURAL SYSTEM

A building to be stabilised for horizontal load and to achieve this, several different structural systems can be chosen. The advances in

Structural designs and high strength materials, building weight has reduced, in turn increasing the slenderness, which necessitates taking into account majority the lateral load such as wind and earthquake. There are many types of structural systems that can be used for the lateral load resistance of tall buildings. Some of these are shown in [fig. 01]

1) Type 1. Shear frames.
2) Type 2. Interacting frames systems.
3) Type 3. Partially tubular systems.
4) Type 4. Tubular systems.

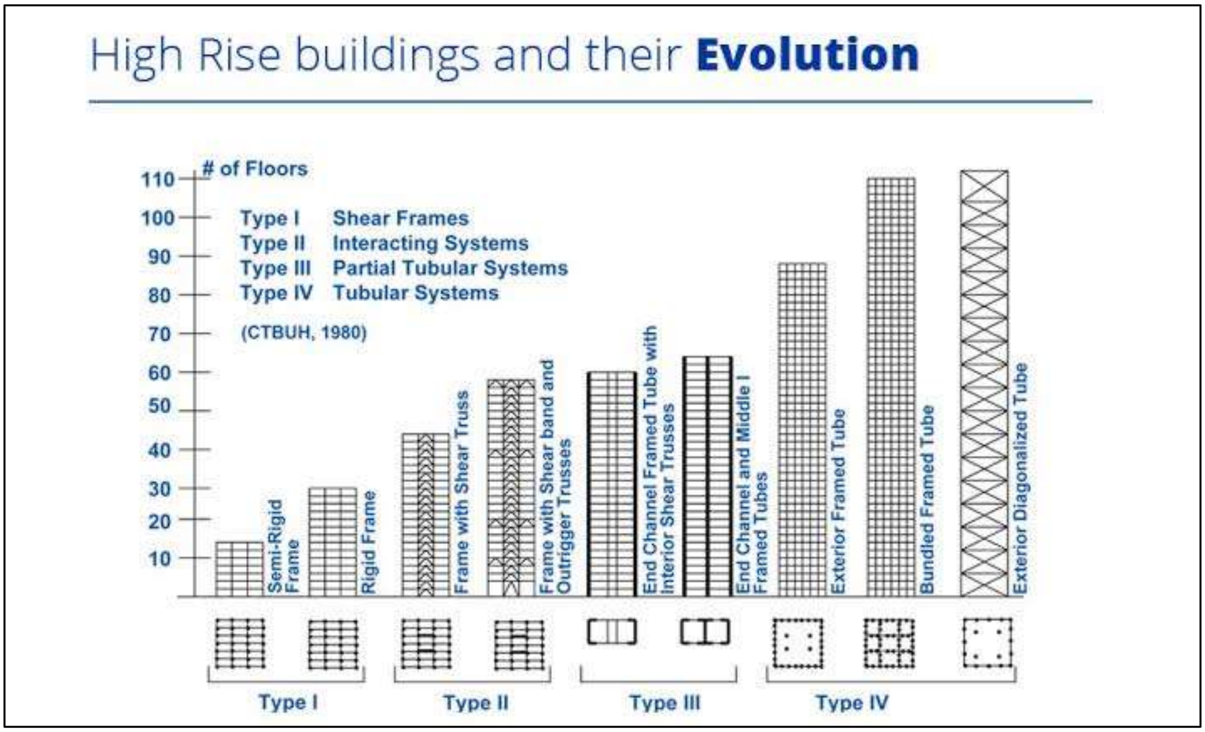

Fig. 01: Types of structural systems (from CTBUH, 1980)

III. OUTRIGGER STRUCTURAL SYSTEM

A. *Introduction*

An outrigger braced high-rise structure consists of a reinforcement concrete or braced steel frame main core connected to the exterior column by flexural stiff horizontal cantilevers. The core may be located between the column lines with outrigger extending on both sides. Or it may be located on one side of the building with cantilevers connecting to columns on the other side. When the structure is located horizontally, vertical plane rotations of the core are restrained by the outriggers through tension in the windward columns and compression the leeward columns. The effective structural depth of the building is greatly increased.

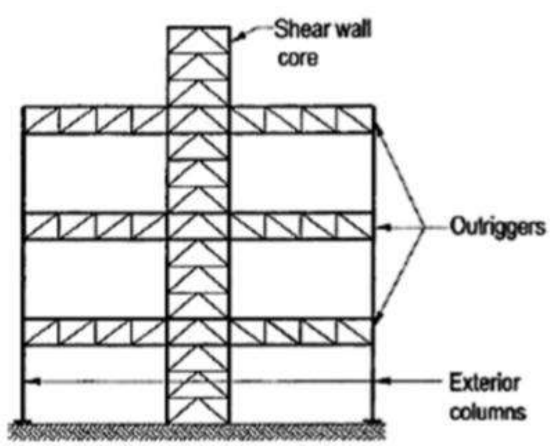

Fig. 02: Outrigger with central core.

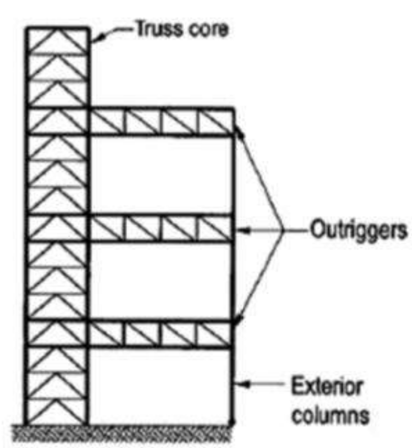

Fig. 03: Outrigger with offset core.

B. *Behaviour of outrigger*

The structural configuration of an outrigger system consist central concrete core or braced core tied to the exterior periphery columns by means of rigid horizontal braced or concrete members names as outriggers. To make outriggers sufficiently stiff in flexural and shear, the depth of outrigger and belt truss can be taken as one or two stories deep. In addition to those columns located at the ends of the outriggers. It is usual to also mobilize other peripheral columns to assist in resting the outriggers. 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.

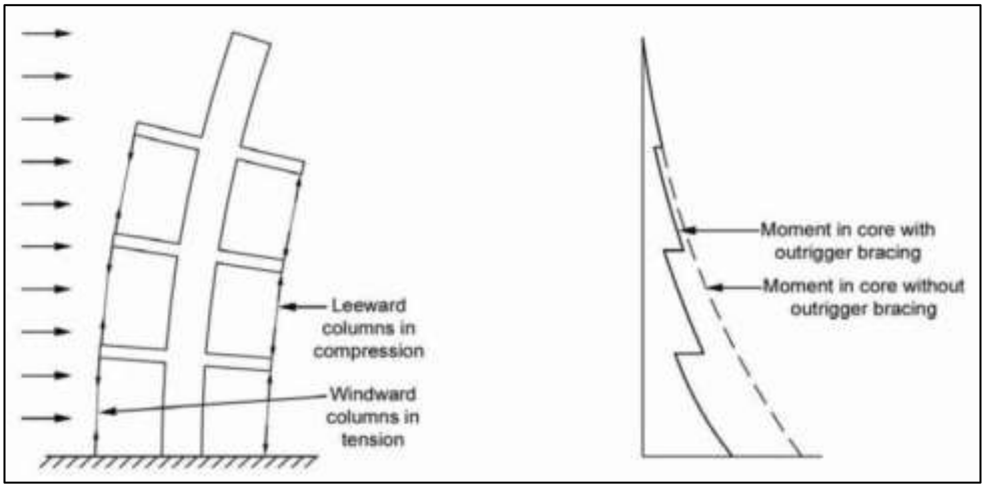

Fig. 4: Behaviour of outrigger structural system (from Dr. K. S. Sathyanarayanan, 2012)

C. *Types of outrigger structural system*

There are two types of outrigger system:
1) Conventional outrigger system
2) Virtual outrigger system

1) Conventional outrigger system:

In the conventional outrigger system, the outriggers are directly connected to the core structure, and the column located at the periphery of the structure. 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. Shortening and elongation of the columns and deformation of the trusses will allow some rotation of the core at the outrigger. (fig.5)

2) Virtual outrigger system:

In the virtual outrigger system, the overturning moment is transferred from the core structure to the columns without a direct connection between the core and peripheral columns. 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 of virtual outrigger system 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 then convert the horizontal couples into vertical couples in columns or other structural elements outboard of the core. (fig.6)

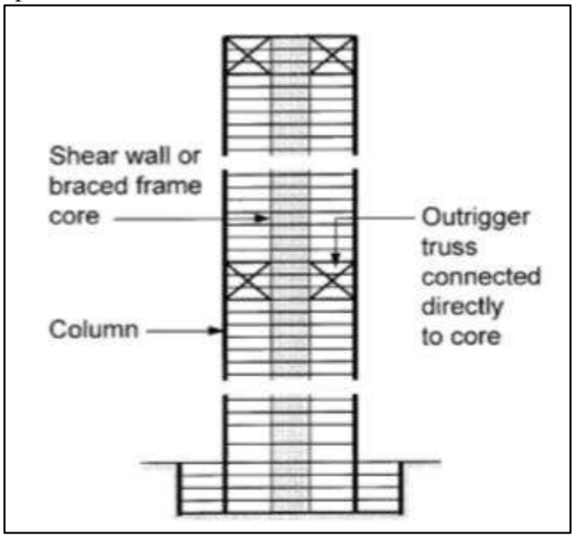

Fig. 05: Conventional Outrigger System

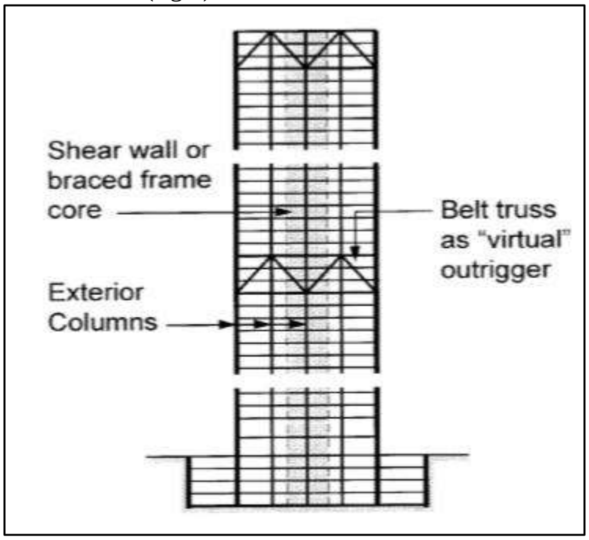

Fig. 06: Virtual Outrigger System

D. *Advantages of outrigger system:*

1) Provides room for a large proportion of open space for creating natural surroundings.
2) The economy in a profit of less land for construction.
3) Permits better day- lighting and greater flow of air.

4) Floors above the ground provides freedom from street noise.
5) Provides facilities like common recreation centres, park, car parking, swimming pool, etc.

E. Disadvantages of outrigger system:

1) More number of people residing in a small area.
2) Difficulty in preventing congestion.
3) Difficult to prevent accidents due to fire, earthquake disaster etc.
4) Due to excessive population, there is an imbalance load on municipal services like water supply, sewage, electricity etc.
5) Very tall buildings bear wind and seismic forces apart from dead and live loads.
6) Buildings above 100 story heights face the problem of oscillation sometimes resulting in crashing of windowpanes.

IV. LITERATURE REVIEW

Komal Jain. J, Mr. G. Senthil Kumar (2016) presented an analytical study on outrigger structure using non- linear dynamic time history analysis. The aim behind the study was the various factors such as drift, displacement, base shear and time history analysis that is calculated using static & dynamic analysis. In this study, with the complexity of vertical stiffness distribution with the existence of belt truss, static non- linear pushover analysis. For the analysis of this problem research have chosen different storey ht. of both symmetrical and asymmetrical RC structure with central core wall with outrigger, without outrigger and outrigger with belt truss the different position in building. The earthquake load considers according to Indian standard code. This study it is concluded that the performance of the building improves if the outrigger is placed at the mid height of the building. The outrigger with belt truss system is effective in controlling drift of the building. From time history analysis the accelerations are low for outrigger based high rise structure which makes it more stiff and rigid.

Anju Akbar, Sadic Azeez (2016) presented research involving investigation of the effect outrigger system in a multi storied irregular building. An outrigger is a stiff beam that connects the shear wall with exterior column and it reduce the lateral load and overturning moment by resisting the rotation of the core. This paper presents the result of investigation based on displacement, drift ad overturning moment reduction. The analysis was done by response spectrum analysis method as per IS Code using ETABS software. Researchers analysed several 40 storied building with core shear wall. The analysis and design of complete core and outrigger system is not that simple distribution of forces between the core and outrigger system depends on relative stiffness of each element. The result concluded that the storey drift of the irregular building gets reduced by the presence of multiple outrigger system. The presence of belt truss also influences the story drift of the building.

Abeen Mol N M, Rose Mol K George (2016) presented research involving the performance of different outrigger structural systems. The outrigger structural system is one of the horizontal load resisting systems. The objective of this thesis to study the use of outrigger at various locations in a 30-storey building. Two types of analysis are carried out time history & pushover analysis. Find the performance of outriggers at various storeys with various types of bracings and evaluate the efficiency of outrigger in different stories of the high-rise building. The main aim of study focuses on analysing the performance of the outrigger structures with conventional structures due to make it economical. Which is 90m high rise building frame. The study concluded that the outrigger structural system for tall building substantially increases stiffness and stability against lateral loads. The lateral displacement is observed to be increase as the storey height increases.

Sreelekshmi S, Shilpa Kurian (2016) the study of outrigger systems for high rise buildings. Outrigger systems are one such prominent system and are considered to be most popular because they are easier to build and provide good lateral stiffness. In tall buildings, lateral loads i8nduced by earthquake & wind were battled by an arrangement of coupled shear walls. The results of an investigation on drift, displacement and base shear reduction in steel building frame with rigid outriggers. Outrigger braced structure is an efficient structural form in which the central core is connected to the outer columns. In this study, different shear wall was considered and a best arrangement is determined by using time history analysis. The model considered is 120 m high rise steel building frame and it represents 40 storied building. The roofs & floors were modelled as rigid diaphragms. Outrigger were provided at top, one fourth, and three fourth and mid height. Cap trusses were provided in all these cases. The results were concluded when the outriggers are provided at top and ¾th ht. the Displacement value satisfies. The limiting value 0.002 times the building height. The introduction of double outrigger results in 65.49 % and 78.87% displacement and drift reduction respectively. The bare shear also reduction is 60.94%.

Daril John Prasad, Srinidhilakshmish Kumar (2016) presented a research containing Comparison of Seismic Performance of Outrigger and Belt Truss System in a RCC Building with Vertical Irregularity. The main object of this paper is to compare models with outrigger, belt truss and outrigger with belt truss in which their position remains constant in all the models. Compares the parameters such as base shear, lateral displacement and storey drift. The analysis of structure was done by equivalent static and response spectrum method as per Indian standard code practice. This paper aims in concluding the efficient lateral load resisting system. In this study, 30 storey models having vertical irregularity were taken as per IS 1893 (Part-1): 2002 using finite element software ETABS. It was observed through this research that, the base shear is increasing for building with outrigger and building with outrigger with belt truss. The displacement is increasing by for building with outrigger. Since building with outrigger and belt truss may be uneconomical and also reduces the working space, building with only belt truss can be chosen as the lateral load resisting element in buildings with vertical irregularity. The storey drift is increasing by 25.6 % to 39.4 % for building with outrigger and 45 % to 46.6 % for building with belt truss.

Roy Shyam Sundar, Gore. N. G (2017) have carried out a comparative study and analysis of tall RC structure with & without outrigger system subjected to seismic and wind loading. The behaviour of tall RC structure in terms of time period, base shear, base moment, storey displacement & storey drift. Compare the effect of outriggers by both equivalent static and dynamic analysis method (RSM) along with gust factor analysis. The deflection and displacement are within the permissible limits as specified by IS Code- 1893:2002. Due to reduction of lateral stiffness with the increases in height of structures, outrigger system has been proposed in the present study to minimize the effect due to loss of stiffness. To execute this study researches, have G+50 3D model in ETABS and to Analyse the structure using finite element analysis approach. It can be concluded from this study that the outrigger system provides reduction in displacement, drift and base moment, which will further the size and depth of foundation. The use of outrigger system in high rise structure increases the stiffness and makes the structure more efficient under seismic and wind loading.

Bishal Sapkota, Surumi R.S, Jeyashree T.M (2017) the investigation on the seismic performance of a high-rise building with outrigger belt truss system and damper as energy dissipation system. Utilization of outrigger and belt truss framework is a possible method to improve the structural behaviour of the high rise building under lateral loads. Non-linear time history analyses of three-dimensional building models were performed by using SAP2000 software program. The aim of this investigation a series of time history analysis of the building with outrigger systems and with dampers are carried out using three different seismic waves. In this study the researcher studied the 40 storey RC building with different numbers and locations of outrigger belt truss systems and dampers are compared with that of the conventional building. The result concluded that, Seismic performance of the building with dampers as energy dissipation system is superior to the building with outrigger belt truss frameworks. Both structural systems i.e., outrigger belt truss and dampers can increase the performance of the building while subjected to earthquake ground motion by reducing the lateral deflection of the building.

Kasi venktesh, B. Ajitha (2017) this study the behaviour of outrigger & outrigger location optimization and the efficiently of each outrigger when three outriggers are used in the structure. In this research paper the author’s objective to study the use of belt truss and outrigger placed at different location subjected to earthquake and wind load. The locations of outriggers and lateral displacement. The present study to RC multi storied symmetrical building. In RCC structure is taken into consideration and the analysis is done as per IS Code. The model considered is a 60m high rise RC building frame. The building represents 20 stories building. The location of the building is assumed to be Hyderabad, (zone II). The study concluded that the optimum location of the outrigger is between 0.5 times its building heights. The use of belt truss and outrigger system in high rise buildings increase the stiffness and makes the structural form efficient under lateral load.

Chetan Patel Y G, Kiran Kuldeep K N (2017) presented the study on behaviour of outriggers for tall buildings subjected to lateral load. Their study included analysis of RCC structure having different methods of outrigger and belt truss system. The emphasis was given to the story drift, deflection, core wall bending moment and optimum position of outrigger and belt truss. The main object of this paper to study the use of conventional and virtual system subjected to wind and earthquake load as per IS Code. To perform the analysis ETABS has been used. Researchers analysed several 32 storey RC building having a constant storey height. The results were concluded that the main disadvantage of providing outrigger system is that it will occupy floor area space to overcome this difficulty providing conventional with belt truss at top only and virtual belt truss at mid height of building can increase the stiffness and lateral load resisting efficiency of building. The lateral load resisting efficiency of the building increase with increase in the stiffness on providing outrigger and belt truss system.

Alok Rathore, Dr. Savita Maru (2017) presented analysis, a performance-based analysis of outrigger structural system for vertical irregular tall building. The main object of this study, comparison of models by changing the depth of outrigger and belt truss by locating at different position along the height of building. The author made model a three-dimensional 50 storey RCC vertically irregular building using ETABS software. The results included the lateral displacement and storey drift under dynamic analysis. In RCC structure is taken into consideration and the analysis is done as per IS Code. The result concluded that, the stability and stiffness is increase on using outrigger structural system against the seismic load. There is reduction in lateral displacement and storey drift on seismic load in both directions. The location of outrigger structural system has critical influence on lateral behaviour of structure under seismic load and optimum outrigger locations of building have to be carefully selected in building design.

Premalatha J, Mrinalini M (2018) investigated, its performance with different configuration of belt truss system under wind forces and seismic forces. The outrigger system is one of the most common and efficient system than can be used to improve the performance of tall building under wind & seismic forces. In this paper, the researcher studied seismic behaviour of a multi–storied RC irregular building with outrigger belt truss system. The earthquake load consider according to IS code and checked the building in max. Storey drifts, max. Storey displacements. In this study, the researcher studied the three-dimensional 30 story RC model frame with different storey. The performance of asymmetrical building with outrigger and belt truss system using Response spectrum analysis, time history analysis and static analysis due to wind forces. The study concluded that the storey drifts off this frame also is found to be reduced and indicates the increase in stiffness of the building frame. The RC frame with two belt trusses i.e., one at 0.6h and another truss at 0.4h performed better than the other models.

Iqra Bano Ayaz Ahmad Khan, Prof. N. G. Gore (2018) presented this paper, the most effective outrigger structural system i.e., Conventional outrigger belt truss is compared with virtual outrigger system. To study the effect of outrigger structural system on high rise structures subjected to lateral loads in different zones (III IV V). The structure analysed by response spectrum method & time history analysis. Concrete and steel are used to carry out the comparative performance of materials for outrigger. In this thesis, 4 no. of steel outrigger with belt truss is provided on corresponding floors. For that the author made of 80 storey structures of a commercial building. The structure has been analysed for both static and dynamic, wind and earthquake forces. Conclusion are made on the result obtained from the analyses; virtual outrigger is one of the best alternatives to deal with the problems associated with conventional outrigger system. Displacement, acceleration and velocity of the structure are reduced after applying outriggers. Outrigger structural system provides stiffness to the structure hence making it one of the most effective systems against seismic as well as wind forces.

Nehal M Ayash, Mohammed H Agamy (2019) the outriggers are the structural elements the connecting the outer columns to the central core at different levels to increase the stiffness of the structure and to control the excessive drift. Have worked on nonlinear seismic analysis of high raised RC buildings with outrigger systems. The main scope of this research is the optimum location of outrigger systems. Identified the optimum location of single and double. Outrigger system in addition to cap outrigger in structure which are undergoing inelastic behaviour. For the analysis of this problem researchers have chosen a 55 storied 3D model as multi-storey concrete frames with a 5% damping ratio. The comparative studies have been carried out based on the lateral story displacements, story drift, story & base shear, story & base moment and time period. The result was obtained by response spectrum analysis as per the IS 1893 (part 1), linear history analysis and nonlinear time history analysis. The study concluded that existing outrigger systems increased the building stiffness, increasing number of internal outrigger systems increasing building stiffness. The building is reduced and the building response also are reduced.

C Bhargav Krishna, V. Rangarao (2019) have carried out a comparative study of usage of outrigger and belt truss system for high rise concrete buildings. The basic concept of this research work was to carry out the comparative study of result of result obtained for the lateral displacement, max. Story drift, storey moment and storey shear forces by response spectrum analysis and equivalent static Analysis for optimum outrigger location. In this investigation G+85 story models have been analysed by different shapes rectangle Y, C, shaped RC buildings. The result concluded the best reasonable formation is C formed edifice for the unsymmetrical shapes as compared to other edifice Y modelled edifice both in static and response spectrum technique. The response spectrum analysis shown much higher values due to the combination of all forces including static and dynamic freight. The shear force in the static analysis is having the least values in negative as compared to the response spectrum analysis.

Mohd. Imran Mohd. Azahar, Hemant B. Dahake (2019) in this paper, a parametric study is performed, effective position of shear walls and braces as an outrigger system in tall building with and without outrigger systems located in seismic zone (IV). This study to compare in term of various parameters such as lateral displacement, time period and base shear. The comparative analysis of 3D regular shaped symmetrical plan G+24 story structure. The analysis of structure was done by response spectrum method. The aim of this study to improve the seismic performance of multi-storey buildings after incorporations of outrigger systems of various types at various locations. The result concluded that, the use outrigger system in high rise buildings increase the stiffness and makes the structural form efficient under lateral load.

N.G. Gore, S. K. Ukarande (2019) have investigated focused on performance of dual outrigger structural system in geometrically irregular shaped high-rise building. To determine the optimum location of belt truss and outrigger arrangement by static and dynamic actions. The parameters discussed include story drift, base shear, base moment, torsion, story displacement and time period. The analysis was carried out by considering the three-dimensional G+70 storied building with concrete shear core and concrete belt truss. The beams, columns and shear walls are3 modelled as RC elements and outrigger as modelled as structural steel truss. To perform static and dynamic analysis of geometrically irregular L shaped building models by response spectrum method using IS code. The study concluded that for different outrigger configurations, base shear does not affect to great extent in static and dynamic behaviour when we consider the storey displacement and storey drift 0.4H i.e., Height of the building.

Mr. Raeed Aslam Bhatkar, Prof. Narayan Gorakh Gore (2019) presented a research containing comparative study of the two most effective and popular structural system viz. outrigger and diagrid structural systems. Diagrid are made up of triangular pattern, they are effective in both lateral forces and gravity. Compared to conventional moment resisting frame structure with shear walls, outriggers and diagrid systems performs better. This study, major factors such as story drift, modes shapes and top story displacement have been compared for this structure. The concluded of this comparative analysis the resistance to diagrid structure to torsion in all the three models was more than outrigger and normal structures. Diagrid structure is greater than the outrigger structure it performs better. The performance of the diagrid structural system is evidently superior to outrigger and conventional rigid frame with shear wall structural systems.

V. D. Sawant, V.M. Bogar (2019) have worked on parameters comparison of high rise RCC structure with steel outrigger and belt truss by linear and nonlinear analysis. The basic concept of this research work was to carry out the comparative study of result obtained for the lateral deflection, base shear and story drift with steel outriggers with X- type and V- type bracing systems. The reduction I displacement with the increase in base shear for the increase in the number of outriggers. Analysed the model by response spectrum method as per the Indian Standard Codes. The results obtained by nonlinear time history analysis observed that increment in base shear is very small by using outriggers and belt trusses than the conventional building, outriggers are of the steel material the increase in base shear is very less because the dead weight of RC is more than steel. The study concluded that, the linear analysis of RCC building, with X- type bracings, the lateral displacement and top story drift get reduced by 18.47% and 22.40%. The nonlinear analysis the lateral displacement and top story drift get reduced by 14.44% and 17.46% of conventional RCC building.

Rohit B Khade, Prof. Prasad M Kulkarni (2019) presented a research containing to study the effect of outriggers in symmetrical & asymmetrical buildings under earthquake & wind load on lateral displacement. The outrigger system is very effective in increasing structures flexural stiffness. The basic concept of this research work to carry out the comparative study of result obtained for the lateral displacement and story drift of both symmetrical & asymmetrical building by using equivalent static analysis method for optimum outrigger location. Equivalent static analysis strategy is utilized for estimation of structural displacement demands. They have carried out the analysis on a 40 storied high-rise building. These are 6 no. of models are examined for both irregular and regular structure. The complete comparative analysis reveals that, from economical and displacement point of view the concrete outrigger are better than the steel outriggers. The results shows that the symmetrical building shows more resistant to lateral deflection & story drift than the asymmetrical building. Story drift of the regular building is less than the story drift of irregular building.

Varsha Virde, Dr. R. Singh, Alok Rathore (2020) presented a research containing analysis of high-rise building with outrigger using non dimensional parameter. The optimum position of the outrigger beam is necessary to increase the stiffness of the structure and to make structure more proficient under the action of lateral forces. The object of this paper, two non-dimensional parameter core-to-column rigidity having constant value and core-to-outrigger having different value are used observe the behaviour of outrigger structural building. The parameters included the story drift, lateral deflection and overturning moment due to rotation of the core. The analysis was carried out by considering the three-dimensional G+39 storied RC building with belt truss. The performance of tall building under wind load as per using IS 875 (part-3):2015. The result concluded that, the top storey lateral displacement, storey drift ratio and overturning moment was reduced when outrigger was introduced in structural system. Top storey lateral displacement having smaller value for smaller value of non-dimensional parameter.

Krutagn Patel, Prof. Kumar Patel, Dr. Snehal Mevada (2020) presented paper basically covers design of core outrigger structural system. Core and outrigger structural system provide a large column free area and better resistance to seismic forces. Outrigger system act as a heavy deep beam and provides large lateral stiffness. The research studied connection with regular moment resisting framed RCC building, cost efficiency analysis compares to framed RCC building. The result was concluded that the cost of estimation 5% more cost is needed for steel building construction compared to RCC building. The steel structure is light structure but steel with core becomes heavy to resist wind loads. 5% more cost can give better seismic response. The research was analysed the time history scale graph comparison the ultimate displacements, accelerations and velocity are more in case of core and outrigger structural system compared to RCC structure.

Kushagra Ashara, Keval Patel, Abbas Jamani (2020) studies a RC building with outrigger belt truss systems and buckling restrained braces (BRB). The outrigger with buckling restrained braces is used for resisting the lateral loads on the RC building. The aim of the study obtained the response of RC building with BRB configuration under seismic motion is compared in terms of various

Parameters like time period, storey displacement and inter storey drift ratio and comparison of BRB configuration in outrigger and belt truss is to be carried out with various parameters. Buckling restrained braces have full balanced hysteresis loops with comparison and tension yielding behaviour. Buckling restrained braces perform control over displacement. The analysis was done by equivalent static and response spectrum method. The behaviour of BRB outrigger under effects of seismic load. For that, the author made model of G+36 storeys building. Outrigger systems built which counters the effect on the core of structure and increases Stiffness. The study concluded that the maximum reduction in lateral displacement is 43.74% while inter storey drift ratio is 42.35% and their percentage reduction is better than single and dual BRB outrigger models with belt truss.

V. FUTURE SCOPE

1) The building models are compared by changing the soil interaction or types of soil to provide better information about the response of the system.
2) The behaviour of building for other types of irregular building can be studied
3) The base isolation or spring technique may be used with outrigger structural system.
4) The building models analysed basically for the connection design of outriggers.
5) The effect of column shortening can be overcome with the use of outrigger structure system.
6) The behaviour of building studied for connections with outrigger dampers.

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