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Review on Behavior of Outrigger System in High Rise Building

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Abstract - *In recent years, high rise structures are considered as symbols of economic power and leadership. Developing countries like India are also emerging as centers for new high-rise buildings. As land is becoming scarce and expensive, especially in urban areas, tall buildings represent the best solution to the problem. Also, rapid developments of materials, construction technologies, and new structural systems are contributing for increased constructions of high-rise buildings. But, as building's height increases, its stiffness reduces or flexibility increases which make the structure more susceptible to vibrations due to wind and earthquake forces. Several systems are available to control vibrations or deflections, however, outrigger system is considered to be the most effective systems to improve lateral stiffness and overall stability of high-rise buildings. Use of structural steel and reinforced concrete is more common for construction of elements of outrigger system.*

The objective of this paper is to discuss basic concepts of various outrigger systems and study their effects on the behavior of high rise building through literature review. The paper provides the future scope for carrying out studies for analyzing the multi-storied buildings using different materials for elements of outrigger system, incorporating dampers and base isolation technique and also the blast loading for seismic analysis.

Key Words*: *Lateral Load Resisting System, Conventional and Virtual Outriggers, Optimum Location of Outrigger, Earthquake Responses.

1. INTRODUCTION

The development of high-rise buildings has progressed rapidly in recent years, especially in metropolitan cities, mainly to tackle the problem of acute housing shortage caused due to the enormous growth of population. Also, the rapid developments in the modern construction materials, technological innovations in the construction sector and structural systems have given rise to increased use of skyscrapers. A high-rise building is considered as a multi-story structure in which most occupants have to depend on the elevators or lifts to reach their destinations. In majority of the countries, the most important tall buildings are called 'high-rise buildings' and 'tower blocks' in Britain and some European countries. In India, like any other developed country, high rise buildings are emerging due to increase in population density. As most of the part of India is susceptible to damaging levels of seismic hazards, high rise structures need to be designed earthquake resistant to minimize the lateral displacement.

There are various lateral load resisting systems employed in high-rise buildings as earthquake or wind forces create complexities. These lateral forces can produce critical stresses and undesirable vibrations and may cause excessive lateral sway of the structure. To address these problems or challenges, the existing techniques such as bracing, isolation, dampers and outriggers etc. perform well to safeguard the structures against wind and seismic forces [1]. However, the outriggers system has proved to be a dominant lateral load resisting system in high-rise buildings for minimizing the vibrations and lateral displacement; and improves the stiffness. The outriggers are deep and rigid horizontal beam/truss elements designed to enhance building's overturning stiffness and strength by connecting the core shear wall.

The present paper focuses on the concept and working principle of various configurations of outriggers; and also on the studies carried out by several researchers for understanding the behaviour of high rise building due to the effect of outrigger system.

2. COMPONENTS OF OUTRIGGER SYSTEM

The outrigger system consists of various following components namely core wall, outrigger and belt truss or panel. The details of these components are briefly described in the following section

A. Core Wall

The central of arterial or main part of a multistory building which integrates functions and service needs for established occupants. It is one of the main lateral load bearing components of the structure, mainly designed to resist earthquake and wind forces. The core wall is generally located at the geometric center of the building and is also core is used to install lifts and to accommodate services. It is basically a big shear wall cage.

B. Outrigger

Outrigger is a deep and rigid beam designed to enhance building strength by connecting to the core shear walls from external column. It is used in both types of building namely RCC or Steel and is generally made up of steel, concrete or composites. The outrigger is used in the form of a truss (X or V shaped bracings) or a deep beam.

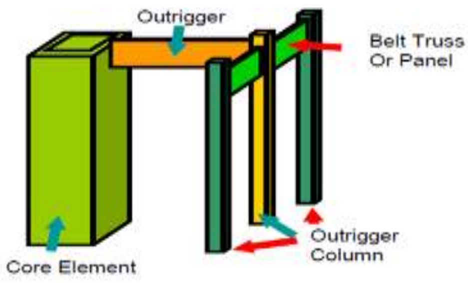

Fig. 1. Component of Outrigger System

C. Belt Truss or Panel

Belt truss, generally known as virtual outrigger, is used to engage the peripheral columns of the building. It is made up from steel or concrete beam and used to reduce overturning moment.

III. CONCEPT OF OUTRIGGER SYSTEM

The concept of outrigger system can be easily understood by assuming the ship as a structure in the sea (Fig. 2). Usually, the ships employed with wooden outriggers to resist the wind forces in their sails. The central core of any high-rise building can be taken as the mast of the ship, while outriggers behave like the spreaders; and peripheral columns of the structure work like the shroud of the ship. The function of outrigger system is to resist the lateral forces produced by earthquake ground motions and transfer the load to the foundation through exterior columns.

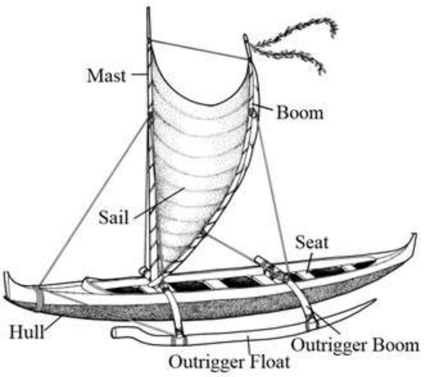

Fig. 2. Outrigger Ship

The outrigger system is generally classified as conventional outrigger system and virtual outrigger system. In the conventional system, external columns are linked to the core wall of building with very stiff outriggers (Fig. 3).

But in the virtual system, the outriggers are used to engage the peripheral columns of the building with each other. The both these systems can be used as structural systems to reduce the displacements produced by lateral loads. Hence, during wind or earthquake load, the use of outrigger or belt truss system reduces the possibility of structural and non-structural damages.

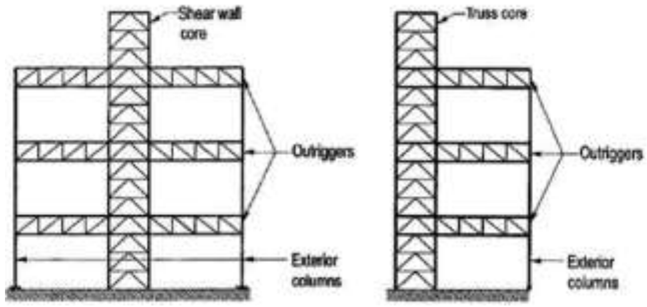

Fig. 3 (a) Outrigger with Fig. 3(b) Outrigger system with a central core offset core

In seismic active zone or the area where the wind load is dominant, this system can play an important role for high-rise structure [3].

IV. Force transfer mechanism in Outrigger Systems

On the basis of connectivity to the core, the force transfer mechanisms in conventional and virtual type of outriggers are different and are discussed in the following sections.

1. Force Transfer Mechanism in Conventional Outrigger System

In the conventional outrigger system, core wall and peripheral column of building is connected using outrigger truss (Fig. 4a). The number of outriggers can be varied according to the height of the high-rise building. The overturning moments generated due to lateral forces are reduced by the use of outrigger trusses by preventing rotation of the central core (Fig. 4b). The exterior columns can withstand the overturning moments produced by earthquake or wind loads [4].

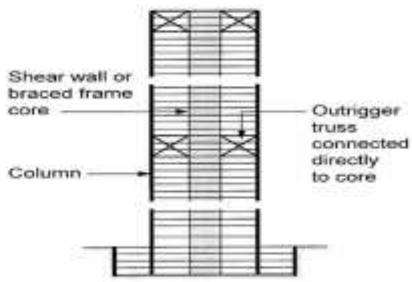

Fig. 4 (a) Tall Building with Conventional Outrigger

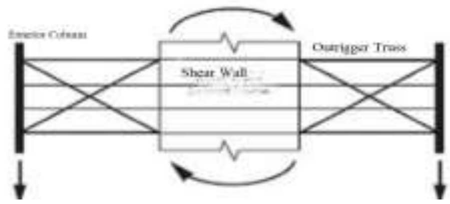

Fig. 4 (b) Force Transfer in Conventional Outrigger

2. Force Transfer Mechanism in Virtual outrigger System

In the virtual outrigger system, the overturning moment is transferred from the core to the exterior columns without a direct connection between the outrigger trusses and the core. The basic idea behind the virtual outrigger is to make use of floor diaphragm. The floor diaphragm is typically very stiff and strength is more in its own plane. Hence, floor diaphragm is used to transfer moment in the form of a horizontal couple from the core to outrigger trusses and trusses to exterior column. Belt trusses are well suited to use as virtual outriggers (Fig. 5a). The overturning moment in the core is transformed into a vertical couple at the location of exterior columns in case of conventional outrigger but for virtual outrigger system floor diaphragm converts some part of overturning moment into horizontal couple (Fig. 5b).

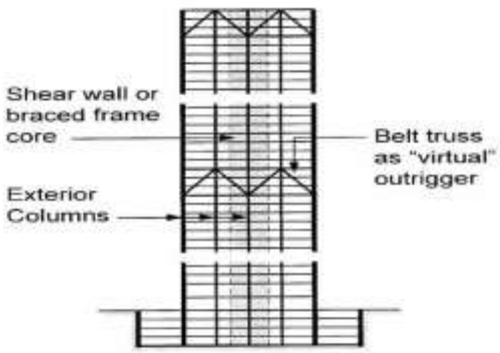

Fig. 5 (a) Tall Building with Virtual Outrigger

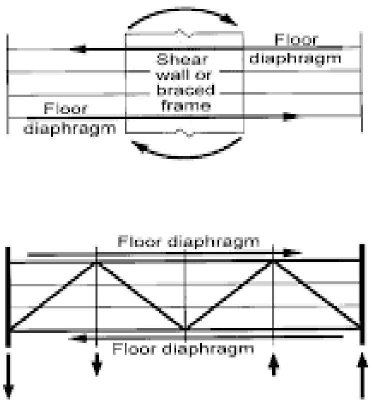

Fig. 5 (b) Force Transfer Using Belt Truss as Virtual Outrigger

This horizontal couple is completed through the truss chords between two floors and forces are transferred to the vertical exterior column [5].

IV. LITERATURE REVIEW

Several researchers have studied the behavior and performance of the outrigger systems in the high rise building, especially in the seismic active regions. The present theories and practices published by various researchers elated to the behavior of high rise building using outrigger structural system is presented in the following section.

Al-Subaihawi Safwan et al. (2020) have investigated the performance of damping devices incorporated between outrigger trusses and perimeter of the column to reduce dynamic vibrations in 40-storey high-rise structures by using real-time hybrid simulation (RTHS) approach. The physical substructure which used for experimental modeling in RTHS contains two full-scale nonlinear viscous dampers, and remaining part of the building is modeled numerically as the analytical substructures. The results of the study show that a reduction in the maximum wind-induced roof acceleration is possible up to 37% when building gets subjected to 177km/hr basic wind speed. The investigators conclude that the stiffness of the component which is collinear with damping force path and number of dampers used play a vital role in controlling the wind-induced vibrations [6].

Khade R. B. and Kulkarni P. M. (2019) have examined the detailed analysis on how various earthquake responses (i.e. lateral displacement, storey drift etc.) are affected by the outrigger stiffness, outrigger optimum locations. The study is carried out considering outriggers of concrete and steel for a 40-storeyed Rectangular and L-shaped buildings using ETABS. The results show that the rectangular building offer more resistance to lateral deflection and story drift than the L-shaped building. Researchers conclude that the concrete outriggers perform better than the steel outriggers from view point of economy and displacement of the buildings [7].

Kumar A. S. and Varkey M. V. (2019) have carried out non-linear static seismic analysis of a 30-storey vertical regular and irregular building frames, provided with and without outrigger-braced systems, for determining the optimum locations of outriggers. The analysis of the building frames has been carried out for determination of reduction in the storey displacement and base shear values using ETABS software by time history method. The results show that the conventional outrigger with X-bracing gives maximum reduction (up to 10%) in lateral displacement than the virtual outrigger system with V-bracing. The researchers conclude that location of outrigger (top, 3/4th height, middle and at 1/4th height) plays an important role in high-rise structure to increase the strength and stiffness against the lateral load induced by earthquake [8].

Tavakoli Reihaneh et al. (2019) have studied the seismic behavior of outrigger-braced building. The investigators determined the optimum locations of outrigger and belt truss systems by considering soil-structure interaction (SSI) and fixed base in a 30-storeyed steel high-rise building using OpenSees software. The results show that, the incorporation of outrigger-belt truss at 0.4H-0.5H (where, H is the height of building) reduces the 16% roof displacement for buildings with SSI and fixed base. The responses (i.e. lateral displacement, base shear etc.) obtained from elastic and inelastic analyses are related with the fixed base. The study concludes that the roof displacement increases by 3-4% with SSI than the fixed base [9].

Zhou Kang et al. (2018) proposed a decision framework for developing optimal installation plan for the outrigger system by integrating construction simulation and safety analysis of the overall structural system. The decision framework was applied on a 600m high-rise structure by developing its Finite Element Model (FEM), to be used for construction simulation, got validated by field measurements during typhoon 'Nida'. Using the validated FEM model, lower and upper limits for installing outrigger system were determined. A rational plan was then developed for installation of the outrigger system into the high rise structure. Authors conclude that, this proposed decision framework would be very useful to structural engineers and researchers engaged in construction management of installing the outriggers into tall buildings [10].

Tavakoli Reihaneh et al. (2018) determined optimum location of belt truss system in a 30 storey high-rise steel building subjected to blast loading (5m and 10m away from the building) considering nonlinear dynamic method using OpenSees software. Also, the study was conducted for various types of loading with and without post-buckling effect for all members of the belt truss system. It is observed that the installation of belt truss system at first or second floor minimizes the roof displacement and this becomes the idle condition for a belt truss system. The investigators conclude that the post-buckling effect increases 10% base moment when the blast occurs near to the building framework [11].

Mohammad O. A. and Najm O. (2018) have presented a case study of a 60 storey RCC building to evaluate the effect of outrigger system on the resistance to the disproportionate collapse associated with the loss of a primary load member. Effectively employed outrigger systems (at 20th, 40th and 60th storey) are capable of transferring loads associated with the collapse of the perimeter column to other parts of the structural system, even when loss is due to lateral loads of wind and earthquake. If the failure of vertical member occurs in high-rise building then the reversal internal axial force changes compression to tension in stories above which column is failed. The researchers conclude that the well-designed outrigger system resist the tension as well as compression induced by lateral forces and decreases opportunities for further collapses which are consecutive to initial collapse [12].

Gadkari A. P. and Gore N. G. (2016) have carried out research work on the efficiency of outrigger system in high-rise structure under the lateral load induced by wind or earthquake. The study of literature is investigated by the researchers according to various aspects of outrigger structural system like outrigger system in RCC, Steel or Composite building considering vertically regular and irregular building shapes with seismic effect. The researchers concludes that the outrigger between 0.44-0.48 times its height of the building plays an important role in reducing storey displacement and base shear but also increases the structural flexural stiffness when the structure is subjected to earthquake static and dynamic loads [4].

Sarfaraz et al. (2016) have worked on a 42-storey high rise building with and without outrigger system which was modeled and analyzed by response spectrum method using software ETABS considering earthquake zone 3. The various responses (storey displacement, base shear etc.) are obtained and result shows that construction of high-rise building provided with outriggers reduces 38% both i.e. lateral displacement and storey drift than the high-rise building without outriggers. In addition, the result shows that the introduction of outrigger causes only 3-4% increment in base shear because the increase in seismic weight due to addition of outrigger self-weight. It can be concluded that outriggers are efficient in controlling the displacements [1].

Moon K. S. (2016) has carried out the research work on complex shaped high rise buildings like twisted, tilted and tapered provided with outrigger system. To examine this approach the first building was twisted up to 3 degrees per floor, second building was tilted by varying angle from 0 to 13 degrees and third building was tapered within range of angle between 0 to 3 degrees. The results showed that the rate of stiffness reduces as the twist of building increases (0º, 1.5º, 3º) hence displacement increases (42mm, 50mm, 60mm). But incorporation of outrigger reduces displacement up to 10-15mm. The investigators conclude that the unique compositional characteristics of outrigger system increases the strength, efficiency with its aesthetic appearance in high-rise complex-shaped buildings [13].

Kamgar R. and Rahgozar R. (2015) have developed a simplified procedure for determining optimum location of outrigger system in non-uniform high-rise building by strain energy method. The building was modeled with a combination of various structural system like framed tube, shear core, belt truss and outrigger by considering continuum approach. In this approach, the framed tube system was modeled as a cantilevered beam with box cross-section. Then the rotational spring is placed for belt truss and outrigger under lateral loading in framed tube model. The maximum energy absorption was the deciding criteria for determining optimum location of outrigger system. Researchers provide the graphs which would be helpful for finding optimum location of belt truss and outrigger system [14].

Sathyanarayanan et al. (2012) have studied the effect of provision of outriggers for single bay frame with heights (H) of 30m, 45m, and 60m using finite element software. The frame and outriggers are modeled by three degrees of freedom per node of beam element. Both symmetrical and unsymmetrical provisions of outriggers are provided by considering static loads. The reduced lateral displacements of core frame are considered as the index of efficiency of outrigger system at a particular level. Optimum position of single-level symmetrical and unsymmetrical outriggers for 30m, 45m and 60m are found to be at H/2, H/2.5 and H/2.85 from top [15].

3. SUMMARY

The use of outrigger system reduces the lateral displacements and storey drift. For optimum location of outrigger system in a building, the corresponding maximum reduction in lateral displacement can be considered as criteria. The optimum location of outrigger is observed to in the range of 0.45-0.5 times the height of building, which varies according to the number of outriggers placed at different storey and the height of building.

The concrete outrigger is found to be more efficient in reducing the lateral storey displacement than the steel outrigger in tall RCC buildings. Virtual outrigger system is observed to be the more efficient than the conventional outrigger in providing more strength and stiffness to resist the lateral loads induced by earthquakes in high rise buildings. The use of dampers in the outrigger system also improves the efficiency of the structure to resist lateral loads. For high rise buildings subjected to blast loadings, the installation of belt truss system at first or second floor minimizes the roof displacement.

Scope for further study

From the literature study, it is observed that no research has been yet carried out for analysis of high rise buildings with the use of pre-stressed concrete as a material for outriggers. Further, study of outriggers systems in combination of dampers and base isolation for carrying out seismic analysis of high rise buildings could be a future research area. Also, more scope is seen for the investigation of multi-outrigger system in vertically symmetrical and unsymmetrical high-rise buildings.

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BIOGRAPHIES

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