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LATERAL DESIGN OF MODERN HIGH RISE STRUCTURE USING OUTRIGGERS WITH BELT TRUSS SYSTEM: AN OVERVIEW

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Abstract: Lateral stability of high rise building is a vital parameter which is to be considered while designing the structure. One of the techniques used to improve lateral stability is outriggers with belt truss system. It improves the cantilever bending action of the structure by forming a couple. The effective depth of structure while bending is increased. It is an advantageous method since structures become more economical when the outriggers are positioned properly. Also there is no material restraint for constructing them. Considerable research have been done on this method with an aim of finding the optimum location for positioning the outriggers along the length of structure along with comparing this system with other conventional methods. However the practical feasibility of this system is not considered while modelling and designing the buildings with it. Hence research considering practical approach is needed where the utility is not disrupted and maximum benefit in terms of lateral stability along with strength and economy is achieved.

***Index Terms*: Outrigger, Belt Truss, Uplift, Core, Diaphragm, Flagged Walls**

I. INTRODUCTION

In this modern era, were development is at its peak, the construction and infrastructure industry has considerable role in it. This rapid development has led to building high rise structures especially in metropolitan regions. Modern high rise structures have to be designed considering many extra factors apart from that required in low rise buildings. One of the important factors which is to be considered is the lateral stability of the structure due to lateral loads such as wind and earthquake forces. There are many different techniques which have been adopted to optimize the lateral stability and cater to lateral loads over the years in many different remarkable high rise structures across the world. The typical ones are –

1. Structural wall system
2. Moment frame system
3. Moment frame – structural wall system
4. Structural wall – flat slab system
5. Structural wall – framed tube system
6. Framed – tube system
7. Tube – in – tube system
8. Multiple tube system
9. Hybrid system

Along with the above mentioned systems, one of the techniques used is outriggers with belt truss system which came into effect in 1980s to 1990s. This is an additional framing system on any typical system. This system supersedes the conventional tubular system which consists of closely spaced columns with deep spandrel girders thus resulting in lower sized members and more economical structures.

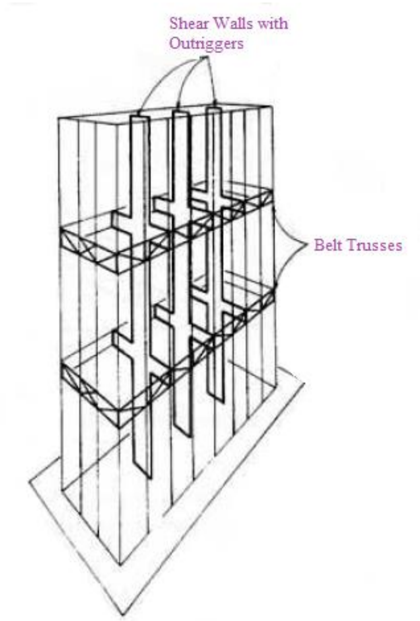

Fig. 1. Outrigger with belt truss system

II. CONCEPT OF OUTRIGGERS WITH BELT TRUSS SYSTEM

The basic concept this system is to connect the central core taking lateral forces to the peripheral columns that are pinned to take static load only. This connection reduces the lateral deflection by forming a system that couples the internal core with perimeter as a whole to resist lateral load. The connection of central core to the periphery columns is done by flexurally stiff horizontal beams. The cantilever action of a conventional system is replaced by a couple system as shown in figure below.

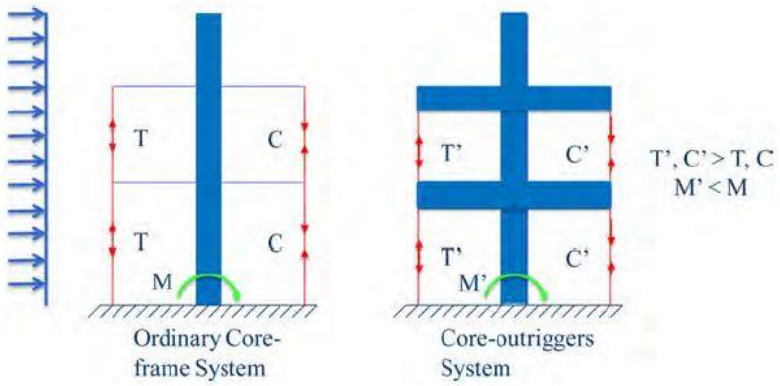

Fig. 2. Comparison of ordinary core frame system with core outriggers system

When lateral loads are applied on the building, the core tries to rotate inducing forces to the outrigger trusses or beams, which create tension in windward columns and compression in the leeward columns. This response creates a kind of restoring moment that acts on the core at the outriggers level due to which the effective depth of the structure to resist the bending moment is increased. To further improve rotation restraint of the outrigger trusses, a belt truss is provided running in the periphery which connects all of the outriggers and making the whole system stiff.

Outrigger with belt truss system tends to optimise the cantilever type of deformation of central core and portal type of deformation in frames when positioned at proper locations in the structure. The performance of this system is affected by the size, positioning and number of outriggers used throughout the building and also the size of belt truss used in periphery apart from the material used to build this system.

III. ADVANTAGES

The main structural advantage of this system is the lateral deflections and bending moments are reduced considerably in the central core as compared to the free standing core taking the loads alone. It increases the effective depth of the structure when it bends as a vertical cantilever. Other than this, the key advantages of outrigger system in high rises are as follows-

1. Outrigger systems are proven to be economic when compared to conventional systems.
2. Overall uplift of structure is reduced considerably.
3. This system can be built using any structural construction material such as concrete, steel, composite or a combination of any of these.
4. The outside peripheral columns can be adjusted in spacing as per requirement.

5. Periphery columns are utilized in lateral stability which otherwise would have only catered gravity loads.

IV. PRACTICAL APPLICATIONS

1. U.S Bank Centre, Milwaukee, USA.

This structure completed in 1973 is a steel structure first of its kind. Since this system was not widely adopted at that time, it was considered to be useful only in mid-rise buildings. Here, the engineers wanted to create a light open frame type of structure on the exterior facade where the perimeter columns are 6m apart. An overall stiffness reduction of 30% was achieved.

Fig. 3. U.S Bank Centre, Milwaukee, USA.

2. New York times tower, New York, USA.

This structure is a 52 storey high rise completed in 2007. It has a 20x27 meters braces steel core with outriggers at 28^{th} and 51^{st} floors. The perimeter columns are around 9m apart. Thermal outriggers were used to redistribute the thermal strains.

Fig. 4. New York times tower, New York, USA.

3. Waterfront place, Brisbane, Australia.

This project completed in 1990 is a RCC 40 storey structure having a massive two storey depth outriggers placed between 26^{th} and 28^{th} storey. The outriggers are connected with a belt truss since the perimeter columns are not aligned with them.

Fig. 4. Waterfront place, Brisbane, Australia.

V. LITERATURE REVIEW

Bryann Stafford Smith and Alex Coull [1] in year 1991 have published a book on Tall Building Structures and Design where the optimum location of outriggers is given such that for an n-outrigger structure, the outriggers should be placed at the 1/(n+1), 2/(n+1), up to the n/(n+1) height locations. The book also includes the method of analysis, generalized solution of forces and deflections and performance of outriggers with respect to its location, flexibility, efficiency and loading conditions.

Then, Alpa Sheth [2] in year 2008 in her work titled 'Effect Of Perimeter Frames In Seismic Performance of Tall Concrete Buildings with Shear Wall Core and Flat Slab System' studied the effect of perimeter frames for structural systems with flat slab structure and shear wall core for different locations of the shear wall core and for different heights and spans of three concrete towers. The effect of perimeter frame with outrigger system was also studied. It was concluded that the effect of outriggers is more prominent in irregular shaped building of less stories rather than rectangular buildings of more stories.

The effects of cyclonic wind with provision of outriggers on 28- storey, 42-storey and 57-storey were examined with consideration to deflection control and frequency optimization by S. Fawzia, A. Nasir and T. Fatima [3] in 2011 where it was concluded that 28 storey model had frequency and deflection within permissible limits. In the 42 storey model, the frequency limits were attainable but deflection limits required a belt truss. The 57 storey model required a truss system and extra stiffness in shear walls to attain frequency and deflection limits. The results showed that the total height of structure is governed by plan dimensions. The lateral integrity of structure is reduced by keeping the plan dimensions same. This stiffness can be improved by increasing the bracing sizes and provision of outriggers.

Srinivas Suresh Kogilgeri and Beryl Shanthapriya [4] in 2015 in their study 'A Study on Behaviour of Outrigger System on High Rise Steel Structure by Varying Outrigger Depth' studied the static and dynamic behaviour of the outrigger structural system on steel structure by reducing the depth of outriggers. 5x5 bay 40 storied steel structure was modelled in Etabs software. It was found that the decrease in the depth of the outrigger to 2/3rd of the story height reduces the percentage reduction of lateral displacement and story drift up-to 4% – 5% in comparison with outrigger depth of full story height while decrease in the depth of the outrigger to 1/3rd of the story height reduces the percentage reduction of lateral displacement and story drift up-to 6% – 7%.

The theory, concept and optimum topology of outriggers was briefly described by Goman W. M. Ho [5] in 2016. Besides that, methods on adjustable outriggers details were explained which included cross jack system and shim-plate method. Retro-casting method was explained which allows the core wall to be constructed in it originally cycle without any delay due to outrigger installation.

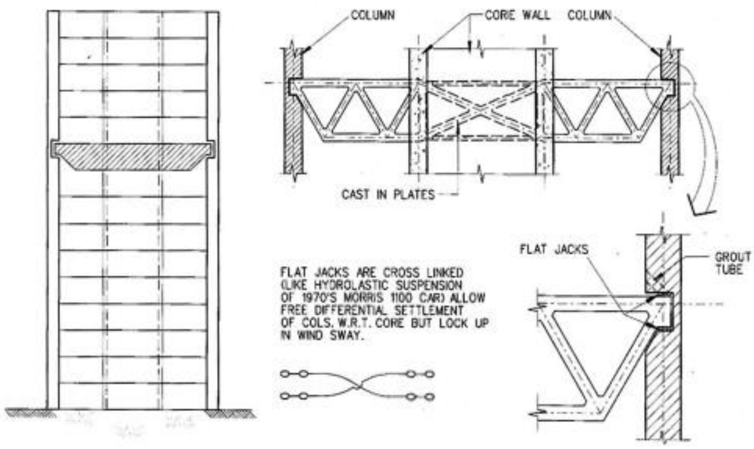

Fig. 5. Cross Jack System

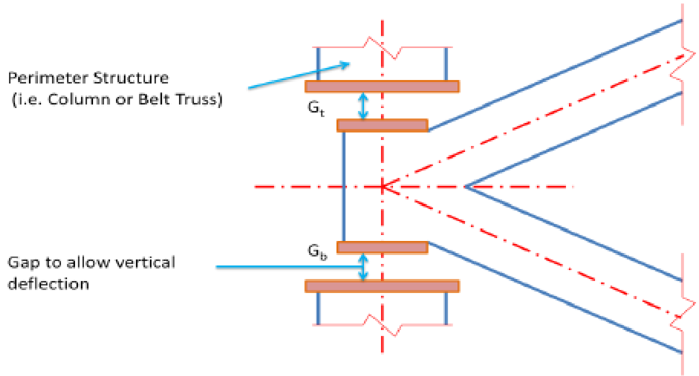

Fig. 6. Shim Plate System

Sreelekshmi. S and Shilpa Sara Kurian [6] in 2016 analyzed a 40 storied steel building in their paper ‘Study Of Outrigger Systems For High Rise Buildings’. Time history analysis was done in which outriggers were were provided in the structure a) at top, b) at top & one fourth height, c) at top & mid height d) at top & three fourth height. It was found that base shear, displacement and story drift of the structure during an earthquake are lowered and the optimum outrigger locations was found to be 0.75 times the building height along with cap truss when provided at three stories depth.

‘Effects of Perimeter to Core Connectivity on Tall Building Behaviour’ was studied by Charles Besjak, Preetam Biswas, Georgi I. Petrov, Matthew Streeter, and Austin Devin [7] where the effects of creep and shrinkage on two different structural systems with differing heights were investigated. First structure being Pertamina Energy Tower and second Manhattan West North Tower. The first structure had a rigid connection between perimeter and core with three sets of outriggers while the second system had perimeter columns floating above ground but transferring load ultimately to core. The paper presented a comparison between the systems to understand the difference in structural behavior with respect to long term effects of creep and shrinkage. The paper showed how the effects of creep and shrinkage can differ significantly depending on the structural system and material utilized, as well as the height of the tower.

Kyoung Sun Moon [8] in the year 2017 did a comparative study on ‘Comparative Evaluation of Structural Systems for Tall Buildings: Diagrids vs. Outrigger Structures’ to find out structural efficiency of the two systems i.e. rectangular structure followed by twisted and tilted buildings. It was found that for rectangular and twisted buildings, diagrid performance was better than outriggers system for lateral stiffness. However in case of tilted buildings, outriggers stiffness was found to be more than that of diagrid stiffness.

An ‘L’ shaped 60 story slender building with storey height of 3.5m was analyzed in Etabs for wind load by Akash Kala, Madhuri Mangulkar and Indrajeet Jain [9] in 2017. According to the author all previous studies were majorly done for steel structures and there was very much research done on slender concrete structures. It was found that the optimum outrigger location of a high rise building under the action of wind load is between 0.25-0.33 times the height of the building (from the bottom of the building) and by introducing outrigger at 20th story, the displacement reduced from 493mm to 385mm.

C. Bhargav Krishna, V. Rangarao [10] in 2019 in their work titled ‘Comparative Study Of Usage Of Outrigger And Belt Truss System For High-rise Concrete Buildings’ analyzed 3 slim solid RCC buildings having rectangular, C shape and Y shape and compared using outrigger and belt truss system. The various parameters like (1) Lateral displacement, (2) Maximum storey drift, (3) Storey shear forces, (4) Storey moments and (5) Storey overturning moments were considered for better comprehension of Tall building, when it was exposed to substantial seismic and wind powers. The Seismic analysis was carried out according to the Indian measures. It was found that the most advantageous building when compared to the other building's types are Y shaped building which shows the least displacements and least bending moments.

Then, the conventional outrigger system was compared to virtual outrigger system and benefits were explained by Prof. N. G. Gore and Miss Purva Mhatre [11] in 2018. Virtual outriggers are different from conventional ones as they do not involve deep beams connecting the core to periphery columns. Instead, the connectivity is given by floor diaphragms. Floor diaphragms are stiff floors used at stories which has belt trusses in the periphery. It was concluded that when designed properly, the virtual outrigger system can also be used in skyscrapers as they provide more utility and economy to the structure.

Kurdi Mohammed Suhaib, Sanjay Raj A and Dr. Sunil Kumar Tengli [12] in 2018 studied Flat Slab Structures with Outriggers. In that, high rise flat slab buildings were modeled in Etabs and conventional and virtual outriggers were compared. It was observed that maximum reduction amongst all models was 20%. Also, conventional outriggers were found to be better than virtual ones and direct connection with the core wall and the perimeter columns gives better results.

Reinforced concrete outrigger wall with multiple openings was used to replace the conventional steel outrigger trusses in tall building structures by Han-Soo Kim, Yi-Tao Huang and Hui-Jing Jin [13] in 2019 in their work titled 'Influence of Multiple Openings on Reinforced Concrete Outrigger Walls in a Tall Building'. The stiffness and strength of outrigger wall with multiple openings was designed using finite element analysis on a strut and tie model. It was found that outriggers with opening ratio below 20% doesn't affect the overall stability of structure.

Manoj Pillai, Roshni John [14] in 2019 studied the performance of RCC high rise building of G+65 with and without flag walls in their paper 'Performance Evaluation of High-rise Building with Reinforced Concrete Flag Walls Under Seismic Load'. It was observed that the flag wall system perform better than the conventional RCC structural system and can be used as an alternative to conventional outrigger system as it saves space.

Then, the optimum position of outrigger system for tall buildings was studied by F. AFSARI [15] in 2019 by using a building model of 30 stories using ETABS and BNBC code. After comparing various locations it was found that introduction of outrigger at 2/5th position of any tall buildings is effective.

'The Use of Core and Outrigger Systems for High-rise Steel Structures' was studied by Abdulaziz Alanazi [16] in 2019 where the author researched on the economic advantages of this systems. In his research analysis and comparative study - moment frames, braced core and the outrigger systems were investigated using STAAD Pro software to analyze and design a 3-dimensional, 40-story, steel structure. The effectiveness of each structural system on the building's overall stiffness against the lateral loads was found out. Subsequently, the economic advantages were found out by measuring the amount of steel in each structural model. It was found that outrigger system at outriggers located at $1/3^{rd}$ spans was more stiff with steel requirement reducing considerably by around 1500 MT.

Donny Morris [17] in the year 2020 studied the 'Effects Of Outrigger & Belt Truss System On High-rise Building Structure Performance' where four models of G+62 were used for analysis in e-tabs where Building A was without outrigger & belt truss, building B with it. The material of A and B were R.C.C. Building C was without outrigger & belt truss and building D with it. The material of C and D were steel structure. It was found that building A and B were less rigid and building A and B (concrete material) portals absorb greater story shear forces than building C and D (steel material). Building B and D displacement were found to be smaller than building A and C respectively.

Then, the 'Optimum Shape And Position Of Outrigger System For High Rise Building Under Earthquake Loading' was studied in 2020 by Ritu Khandelwal, Raghvendra Singh [18] where 30, 45 & 60-story RCC vertically regular building having symmetry along X and Y direction and square in shape were analyzed with three different types of truss used wiz. X, V and N type. It was found that X-Shape outrigger belt truss system is more efficient than V-Shaped outrigger belt truss system and N-Shape outrigger belt system.

Lastly, V. Swamy Nadh, B. Hema Sumanth, K. Vasugi, and Manish.R. Shirwadkar [19] studied the 'Ideal Location Of Outrigger System And Its Efficiency For Unsymmetrical Tall Buildings Under Lateral Loadings' in 2020 where a 30 story unsymmetrical tall building was compared in Etabs such that outriggers were located at different height apart from one fixed at top. It was found that the best position of outrigger systems is one at the top and another at 0.50 times the height of the building and Lateral displacement was reduced by about 26.69%.

VI. CONCLUSION

By studying different literatures on outrigger walls with belt trusses and their applications in designing of structures, it is concluded that-

1. Major research is done on finding the optimum location of outriggers at varying levels in the structure. These structures are then compared using various geometry of plans and its effects are studied.

2. It is observed that the optimum location of outriggers majorly depends on the type of geometry of structure in which it is used, apart from its size, material and positioning in plan.

3. Research is done using various software's in which lateral loads of wind, cyclone and earthquake is implemented on structure apart from static loads.

4. Also, the shape of various belt truss is studied so as to find out its effect on resisting lateral loads.

5. The outriggers are modified in some researches such that openings are introduced in them to find out its effects in overall stability to lateral loads. Also flagged wall system is compared to outrigger system.

6. Apart from conventional outriggers virtual outriggers are also a feasible solution to structures where deep outriggers may not be possible.

7. Diagrid system can be compared with outrigger system in twisted and tilted buildings since both the system have different impact on different type of geometry.

However, majority the building structures that are analyzed are of typical system consisting of single lift core(s) located at central location and columns placed at uniform spacing usually in a grid system. This may not be the case in practical designing of building where columns have to be adjusted as per utility of the structure and various other requirements. Also, the sizing and positioning of outriggers depends on the utility of building. The models made in previous researches have large sized outriggers and belt trusses and their positioning is based as per different trials and not as per practical requirements. Since outriggers are useful for high rise buildings, multiple disconnected lift cores are present in them, which are not incorporated in previous research done.

Since outriggers with belt truss system is not very common in India, mainly due to general philosophy in structural engineers mind such type of system is effective only in special type of important structures where lateral deflection has to be controlled to greater extents. Hence this study aims at clarifying this concept that outriggers with belt truss system can be effectively used in modern high rises without compromising in clients and end user's needs.

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