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Seismic Performance Evaluation of Outrigger and Belt Truss System in High-Rise Structures: A Review

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***Abstract*— There are numerous high-rise buildings being built within major cities. The larger the cities, the taller buildings become. If buildings are too high, they have to be robust enough to prevent them from shaking too much when an earthquake occurs. To cope with this problem, engineers use a unique support system referred to as an outrigger and a belt truss system. The support system can ensure the stability of buildings and prevent excessive movement as a result of an earthquake or wind forces. The paper review of past works related to the use of outrigger and belt truss systems within high-rise buildings and the results obtained are clearly described within this paper. It shows that when outriggers and belt trusses are used together, the building becomes stronger and safer than when only one of them is used.**

***Index Terms*— Outrigger, Belt Truss, Tall Building, Lateral Displacement.**

I. INTRODUCTION

Many people are now residing in big cities, so builders construct very tall buildings to accommodate everyone, and this building have become a symbol of development for the nations. However, while planning the construction of such tall buildings, proper consideration should be given to safety and the geographical conditions of the area. High-rise buildings are very costly to construct, and engineers try to choose systems that are strong as well as economical. An efficient way of achieving this is through the use of a belt truss with outriggers. These systems also work towards reducing lateral displacement [1].

Nowadays, many people want to live in big cities, so very tall buildings are built. These buildings are thin and tall and, therefore, can move or shake due to strong wind or moving ground. In a very tall building, the walls of the inside are not strong enough on their own to stop the shaking altogether. Those work only for relatively small buildings. For that reason, big supports are needed to keep a tall building safe. One such helpful support is what is called an outrigger. There is a lot of usages of an outrigger [2].

When buildings are very tall, the biggest problem is stopping them from moving too much when the wind blows. As buildings become taller and thinner, it becomes harder for engineers to keep them steady without changing how the building looks. To solve this problem, engineers have many smart ways to help tall buildings stay strong. Engineers use these different support methods in tall building to help the structure safe during strong winds or during earthquakes [3].

Outrigger are large horizontal structures beam that tie the building core to the columns. We have seen these in tall buildings for many years and recent designs have only made them better.

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At time these strong beams or trusses extend out to all sides from the middle and at other times they extend to one side to support the building better [4].
The outrigger system, A lateral load resisting mechanism, is widely used in tall structure to reduce excessive lateral overall lateral displacement and enhance overall structural stability. Outrigger are horizontal components the building and perimeter columns to the external columns [5].

A. Outrigger System

A tall building has a strong middle part, called the core, from the core, there are outrigger, that reach out to the sides of the building. These outriggers hold the building tightly. The outriggers are very strong and help the outside columns stay in place, so the building does not shake or bend too much. Because of this, the building stays more stable and safer.

B. Belt Truss System

A belt truss is like a strong belt wrapped around a tall building. It holds all the outside columns together. When the building tries to bend because of wind or shaking, this belt helps the building move less and stay straight. When belt trusses work together with outriggers, the building becomes much safer and gets less damaged. The belt takes the pushing force from the middle of the building and passes it around to the outside columns.

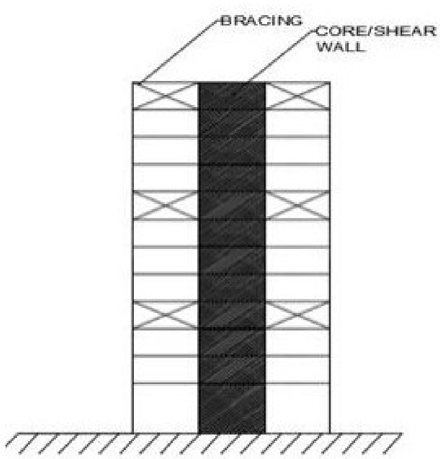

Fig.1. conventional outriggers

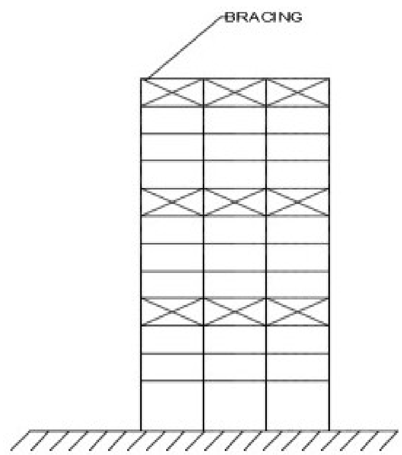

Fig. 2. Belt truss

II. Literature Review

Po Seng Kian et al. [1] investigated the 40-story two-dimensional model for wind loads and the 60-story three-dimensional model for earthquake loads. In two-dimensional analysis of the 40-story model. To further reduce the maximum displacement in the 60-floor building, the study indicated that providing the first at the roof level was most effective in controlling lateral displacement in the 60-story structure. Putting one outrigger at the very top of the building and another at the 33rd floor helps the building move less. With this setup, the building movement is reduced by about 18%.
Midhusha KM [4] This analysis considered a tall building, which was irregular. Engineer placed outriggers and belt trusses at various floors to determine how they assist the building in remaining stable. The building consisted of 30 floors with larger column spacing at the lower floors and smaller spacing at the higher floors. The study indicate that the location of outrigger and belt has a influence on the stability of the building. The most effective performance was observed when these systems were placed at two-thirds of the total building height and next most effective arrangement was when they were placed around the mid height of the structure, when compared to the supports positioned at the two-thirds height position, indicating a significant difference in structure stabilization with regards to support positions.
Hasan Raza Siddique [5] In this study, the effects of having more support structures added to the building to control the movement of the 26-floor high-rise building will be examined. In the process of carrying out the analysis, belt trusses and outriggers have been used at various floor levels to observe the effects of the structure's positions on the building response during the increase in the height of the building.

Shruti B. Sukhdeve [6]. the researchers examined a tall building to determine where outriggers should be placed for the best structural performance. The main aim was to find the most effective locations for the outrigger and to check how well each outrigger works when three of them are incorporated into the structure. After checking how the building behaves, it was seen that the outrigger work very well. The best place to put them were found at three levels. Putting outriggers at three places helps the building stay steady and not move too much.

Tae Sung Eom [7] This study has studied the behavior of the belt walls as outrigger when seismic forces act upon the building. The transfer of forces through these walls and the performance in such seismic condition of loading. Belts walls are placed under high shear forces, and therefore, the researchers suggested a strengthening method to reinforce belt walls with high strength prestressing strands. The researchers wanted to observe the strength of help of special concrete walls to a high-rise building. The research presented sound design principles to engineers interested in strengthening belt walls through the use of high-strength prestressing strands to manage shear of improving the lateral behavior of high rise without affecting the structural efficiency.

Fawzia, S [8] in this paper, the researchers focused on a very tall building and examined how to minimize its movement using special support structures referred as outriggers in varying numbers of floors. They began with just one support structure, then two supports and then with three. Each time they added more supports, the movement of the building became minimal. When three supports were used, the building remained stable compared to when no supports were added at all.

Mayur M. Solanki [9] examined the performance of outrigger systems under lateral loading conditions with the aim of identifying suitable outrigger locations along the building height. Three-dimensional models of a 30-storey structure model was analyzed in two cases: one without any additional support system and another with outrigger and belt-truss arrangements, were analyzed under wind and seismic loads. Different configurations of outrigger and belt-truss system placement were considered to assess their effectiveness. The results showed that providing a single outrigger at two-thirds of the total building height leads to a noticeable reduction in storey displacement and drift. Improved performance was achieved when outriggers were combined with belt trusses, resulting in substantially greater control of lateral displacement and storey drift compared to the without any additional support.

Akash A. Karande [10] in this study, the building was examined by putting the outrigger at different heights to see how it behaves. The building was first checked without any outrigger and the checked again after adding it at different levels. When we place one outrigger on the 20th floor, the displacement of the building becomes less, and the displacement reduces by 24.2 percent. When we place many outriggers from the 6th to the 20th floor, the lateral displacement of the building becomes less in both transverse directions, and the percentage of displacement in the both direction reduces by 33.9 percent and 39.8percent.

Perla Saicharan [11] This research examined 60-storey building models to see how outrigger and belt truss behave during wind and seismic loads. The main focus was on measuring how much the buildings sway sideways. When the outrigger system was placed at one-quarter of the building height, the building moves less and it helped to control the drift. Without a belt truss, the drift dropped by about 22.6%, and with a belt truss, the reduction was nearly 24.7%. The second outrigger worked best when it was placed about one-quarter of the building height.

Mohd Abdus Sattar et al. [12] has worked on earthquake & wind analysis of reinforced concrete buildings of height 45m, 60m, 75 m & 15, 20, 25 storey respectively for earthquake & wind loads on RCC buildings with earthquake & wind loads were considered according to the Indian standard code 875 (part-3) & earthquake load were calculated following the Indian standard code 1893(part-1). The study shows that the floors are already strong enough to carry the weight of the building, so don’t need to make them stronger. The bending forces in corner columns are less than those in the middle columns. Similarly, the outer columns are less bending compared to the interior columns.

Swati Nigdikar[13] studied how tall buildings move during earthquakes. The 40-storey buildings were analyzed with and without outriggers and belt trusses using a computer program called ETABS. The study showed that if the building has both outriggers and belt trusses together, it moves less during an earthquake, up to 21%. Using only outriggers makes it move 16.5%, and using only belt trusses makes it move 18%. So, combining both systems works best to make the building stronger and safer.

Srinivas Kogilgeri [14] Researchers studied very tall steel building to see how outrigger help it from over displacement. They used a computer software to see what happens to the building when there is an earthquake. The building moves around during an earthquake. The results show that using belt truss and outrigger together is the way to keep the steel building steady and make it stronger during earthquake. The steel building will not move much when it has outrigger and belt truss. This helps the building stay safe during winds and earthquakes.

Sudarshan Pradhan [15] In this paper talks about the parts and setups od outrigger and belt truss system that other people have studied before. It looks at the things that affect how well these systems work. The paper also describes how these systems behave when they are subjected to seismic loads. The paper present information, on outrigger and belt truss systems. This paper studied outrigger and belt truss system and explains why they sometimes work really well and sometimes don't. The paper highlights important design consideration to provide a basic understanding for future analytical and experimental studies.

Pudjisuryadi et al. [16] researchers studied a tall 60-storey building that had strong wall, a bare frames and belt truss at bottom. Researchers wanted to see how the building would bend and shake during a strong push. They noticed that some parts of the building move more than others. The most critical spots were the walls above the first floor, the columns near the bottoms and the base of the walls. These are the places that are likely to get damaged first when the building sways a lot.

Eltobgy et al. [17] carried out a numerical evaluated to identify economical and efficient structural systems that can improve progressive collapse. The researchers studied a ten-storey steel office building to see how to make it safer if building start to collapse. They used belt truss ate the top of the building and found that these supports make the building much safer. The belt trusses help to spread the weight when something breaks, so building does not collapse easily.

M. Mahdikhani [18] An analytical study was conducted on an 80-storey steel building, to examine the belt truss. The structural performance of conventional outrigger systems was compared with virtual outrigger arrangements. The building was modeled with a constant floor-to-floor height of four meters and included three sets of four-storey outrigger levels placed near the top, around the mid-height, and in the lower-middle portion of the structure. The building was analyzed using software. The analysis showed that the structure with outriggers, at top storey displacement of 70cm, while the model with belt trusses showed a 95cm. In comparison, the structure without any outrigger system exhibited a much larger displacement, reaching nearly 275cm.

Nehal M [19] ETABS software was used to analyze a 55-story reinforced concrete structure with an outrigger system. Finding the best height positions for single and double internal outriggers used in conjunction with a cap outrigger was the main goal of the study. The findings showed that, when compared to non-linear time-history analysis, linear time-history analysis yields higher estimates, while response spectrum analysis typically yields lower response values. The evaluation revealed that the best places for a single internal outrigger with a cap outrigger were between 0.67 and 1.0 times the overall building height. It was found that the effective positions of the double internal outrigger were about .67, .75 and 1 times the overall building height.

TABLE I: SUMMARY OF KEY RESULTS

Ref. No.	Building Details	Structural System	Types of Load	Key Findings
[1]	40-Storey & 60-storey	Outrigger and Belt truss	For 40 storey Wind, For 60 storey Earthquake	For 40-storey, 65% displacement reduction and for 60-Storey, 18% displacement reduction
[4]	30-Storey vertically irregular	Belt truss and outrigger	Earthquake	Best position at 0.67 times height & 0.5 times height of building
[5]	26-Storey	Belt truss and outrigger	Earthquake and wind	Outriggers with shear walls and reduced base shear
[8]	60-Storey	Outrigger & Belt truss	Earthquake	Lateral Deflection reduced at 1st level – 34 % at 2nd level – 42 % at 3rd level– 51%
[6]	40-Storey	Multiple outrigger	Earthquake and wind	Outriggers locations at mid-height, 3/4 height & 1/4 height of building
[9]	30-Storey	Outrigger & Belt Truss	Earthquake and wind	At 1/3 & 2/3 height of building
[13]	40-Storey	Combined Outrigger & Belt truss	Earthquake	Reduced displacement up to 21 %
[19]	80-Storey	Conventional & Virtual outrigger	Earthquake	Top displacement: Conventional outrigger – 41% Virtual outrigger - 36% Without any outrigger - 57%

III. DISCUSSION

From these studies, we can see that many researchers have tried different ways to understand how belt trusses and outriggers behave during seismic loads and wind forces.

Many researchers have studied different ways to see where to place outriggers and belt truss in tall buildings [20] [21] [22] [23]. Focused on controlling the deflection of a sixty-storey structure using belt and outrigger system [8] [22] [24]. They found that putting these outrigger and belt truss system in the right places helps the building move less and become stronger during earthquake or winds loading [3] [25] [26] [27] [28].
The investigation was carried out to determine the optimum placement of the outrigger and belt truss system, which was observed at one-fourth, mid-height, and three-fourths of the overall building height [6] [11] [29]. It was observed that providing a single outrigger at two-third of the building height resulted in a reduction in displacement and storey drift [9].
Different types of building model analysis were done following the design rules [30] [31] [32] [33] [34]. The effect of changing positions of outrigger system in building heights has been investigated [10] [23] [27].
Studies indicate that placing a second outrigger at approximately one-fourth of the total building height significantly lowers storey drift and overall displacement. [6] [11] [26]. The results showed that using belt truss and outrigger provides better control of displacement [13] [14]. The performance of the building improves as the number of outriggers and belt truss increased. [10] [19] [25].

IV. Conclusion

From the studies, we can see that outriggers and belt truss really help tall buildings shake less. Many researchers have tried to find the best places to put them. According to previous research, optimal results are achieved when outrigger are near the center of the building height or roughly at one-third of the structure height. According to the height of the structure and design criteria, the position may vary of belt and outrigger system.

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