International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 06 | June 2021 www.irjet.net p-ISSN: 2395-0072

Review on Determining Optimum Position of Outrigger in RCC High Rise Structures for Different Earthquake Zones and Soils

Swapnil A. Bhosale[1], Popat D. Kumbhar[2]

[1]PG Student, Dept. of Civil Engineering, Rajarambapu Institute of Technology, Maharashtra, India
[2]Associate Professor, Dept. of Civil Engineering, Rajarambapu Institute of Technology, Maharashtra, India

---***---

Abstract - *The population growth, scarcity of land and fascination of mankind to reach greater heights have caused the countries to emerge as centers for high rise structures. As height of structure increases, its stiffness reduces and hence displacement increases. Outrigger system is one of the lateral load resisting systems which provides significant control on displacement and drift occurring due to wind and earthquake forces. Numerous studies have been carried out for determining optimum positions of outriggers in high rise structures; however, effect of earthquake zones and soil types on optimum position of outriggers has not been adequately studied. This paper aims in exploring scope for studying the effect of earthquake zones and soil types on optimum position of outriggers.*

Key Words: High rise structures, Displacement, Optimum position of outrigger, Earthquake zones

1.INTRODUCTION

Mankind has always been fascinated for the height; and from the ancient times, it has constantly sought to metaphorically reach for the stars. From the historical pyramids to today's modern skyscraper, a civilization's power has been repeatedly expressed through spectacular and monumental structures [1].

The Indian Territory is prone to earthquakes and has experienced a number of the world's greatest earthquakes over the last century. The Bureau of Indian Standards (BIS) has classified the Indian territory into four seismic zones on the basis of historical seismic activity [2]. Severe earthquakes with magnitudes greater than 7 Richter scale have occurred in many parts of India that resulted in killing of many people and collapse of structures. The Bhuj (Gujrat, 2001) and Killari (Maharashtra, 1993) earthquakes are the examples of deadliest earthquakes which have occurred in India in the recent past. The disasters occurred due to such earthquakes have made the structural engineers to think seriously in addressing the causes of poor performance of structures, devising of new repair schemes, determining new design procedures that would produce desired ductile behaviour and modify building codes to avoid similar failures in future earthquakes [3, 4].

In recent years, construction of high-rise structures is on rise the world over due to population density problems in the towns and cities, lack of available land and due to the competition in constructing high rise structures to show the power and progress status of the nation. The sky scrapers with heights greater than 1Km are being constructed (Jeddah Tower, Australia) [5]. Such high-rise structures usually suffer excessive lateral sways due to greater heights and cause the discomfort and mental breakdown. Hence, the structural control concepts are receiving considerable attention in the analysis and design of high-rise structures [1].

Many new techniques such as bracings, outriggers, RC shear walls, shear cores, steel plate shear walls, box systems, base isolation, dampers etc. are developed to control the excessive deflections and drifts in the tall structures [6]. However, the outrigger systems are found to be more preferred in high rise structures particularly in seismically active zone or wind dominant regions. This is due to the participation of all exterior columns for resisting overturning moments causing considerable reduction in the net tensile forces in columns and foundations. The outrigger system is a type of lateral load resisting system which consists of core and outriggers. The addition of outrigger to the structure, helps in resisting the rotation of the core, hence storey displacement and drift can be minimized when compared to the freely standing that is without outrigger structure [7].

1.1 Outrigger Structural Systems:

The outrigger structural system is broadly classified into
(a) conventional outrigger system
(b) Virtual outrigger system.

(a) Conventional outrigger system:
In this system, the outrigger trusses or girders are connected directly to shear walls or braced frames at the core and to the columns located at the periphery of the structure as shown in the Figure 1.

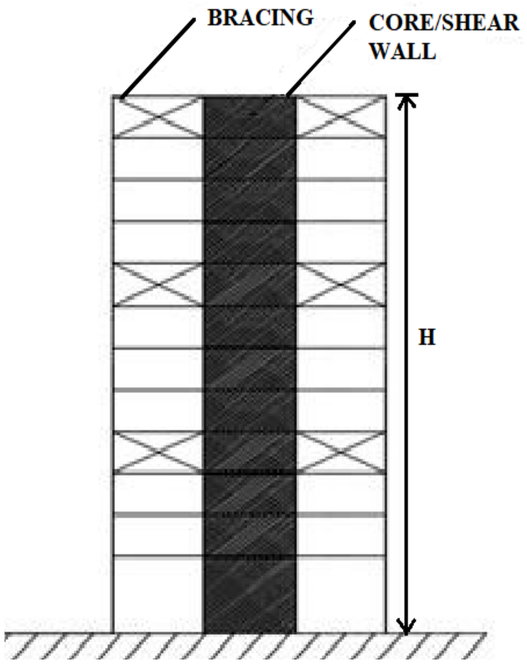

Fig -1: Conventional outrigger system [8]

(b) Virtual outrigger system:
In this system, the transfer of overturning moment from core to peripheral columns is achieved without a direct connection between the peripheral columns and the core as shown in the Figure 2. This is achieved using floor diaphragms which transfer overturning moment in the form of a horizontal couple from core to the outboard. A belt truss connecting the peripheral is also added.

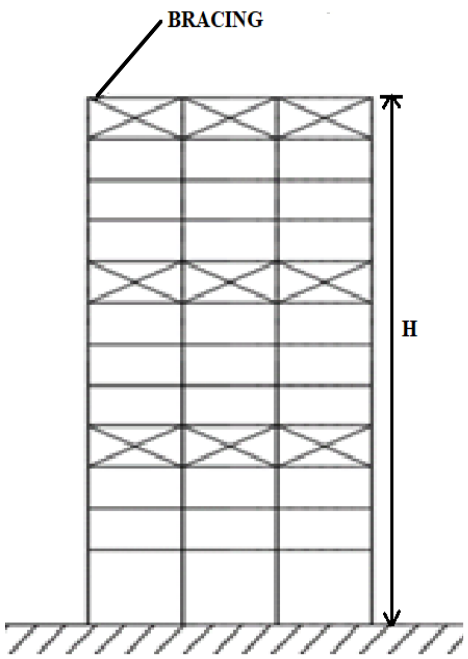

Fig -2: Virtual outrigger system [8]

The research studies indicate that the virtual outrigger system is more efficient than the conventional outrigger system in providing strength and stiffness to resist the lateral loads induced by earthquakes and wind in high rise structure [8].

1.2 Optimum position of outriggers:

The design of tall structures is mainly controlled by the factors viz. strength (material capacity), stiffness (drift) and serviceability (motion perception and accelerations), caused by lateral loads. Providing outriggers along the height of structure helps in significantly controlling these factors. As several layers of outrigger can be provided in a high-rise structure, it becomes necessary to determine the optimum location of outrigger. However, the optimum location depends on a multitude of structural factors such as location of the outriggers, the axial rigidity of the columns, the flexural rigidity of the core and the outriggers; and the efficiency of each outrigger when more number of outriggers are provided in the structure [1]. The optimum position is proven to be at 0.5 H from the base, however it gets changed based on the number of outriggers and their locations [1, 9, 10].

2. LITERATURE REVIEW

Many researchers have studied the behavior and performance of the outrigger systems in the high-rise structure, especially in the seismic active regions. The present theories published by various researchers related to the behavior of high-rise structures using outrigger system is presented in the following section.

Al-Subaihawi Safwan et al. (2020), determined floor acceleration of 40 storied tall steel framed building provided without and with different number of nonlinear viscous dampers and stiffness multipliers subjected to wind load. The analysis was done by using Hybrid FEM-MH software. Four model cases were analyzed considering different number of dampers viz. (2, 3, 4, 6) located between outrigger truss and column at 20th and 30th storey with different stiffness multipliers as (1, 3, 5, 10). A significant reduction of up to 43% in the root mean square (RMS) of the roof accelerations and 37% in the maximum roof accelerations is achieved for the case with four dampers and with three times increase in the original stiffness of outrigger truss and column. The researchers conclude that damping devices placed between outrigger trusses and columns contributed in mitigating the dynamic vibrations in the tall building structure. The number of dampers used and the stiffness of the members in the load path of the dampers (i.e., in the outrigger truss and columns) both play a major role in controlling the wind-induced vibrations [11].

Wang et al. (2020), investigated dynamic characteristics viz. damping ratio, damping coefficient, story drift and wind acceleration of a 60-storey structure (height 210m) by providing conventional outrigger (CO), conventional damped outrigger (CDO) and negative stiffness damped outrigger (NSDO). Results showed that the NSDO is found to be effective in resisting the responses of the structure against wind and earthquake forces. NSDO decreased the maximum seismic inter story drift by 18.9% and total wind excited acceleration by 34.9% as compared to a CDO. Authors concluded that it is essential to provide an extra CO at the top of building while providing an NSDO [12].

Raut and Dahake (2020), analyzed a 30 storied building to study the responses viz. lateral displacement, story drift and time period using ETABS. The analysis was carried out considering the building with and without X bracing outrigger system. The X bracing outriggers were provided at one-third and one-half of the building height (H) for determining optimum position. The results show that storey displacement, drift and time period reduces by 18.41, 12.16 and 12.47% when outrigger system is provided at mid height of building. Authors concluded that the optimum position of outrigger lies at mid height (0.5H) [13].

Osama and Omar (2018), designed a 60 storied (H) RCC building with and without outrigger system in accordance with American Concrete Institute design code (ACI) 2011 to evaluate deformation in x, y and z direction subjecting it to seismic forces. Outrigger systems was provided at 20th (H/3), 40th (2H/3) and 60th storey. The results show that presence of outrigger decreased the lateral deformation 37.8, 63.81 and 57.68% in x, y and z direction. The researchers conclude that the outrigger system helps in reducing the lateral displacements up to 37% and hence decreases opportunities of the collapse of building [14].

Samadi and Jahan (2019), conducted analytical study on the capability and effective level of outrigger in preventing the collapse of tall buildings with belt truss system by subjecting to two sets of far and near field earthquakes. Building models of 28 and 56 storeys were designed to meet the requirements of structural codes [20, 21, 22, 23, 24]. The outrigger and belt truss were added at various levels of the structures along the height of model (H) i.e., at ¼H, ½H, ¾H and H. The incremental dynamic and nonlinear time history analyses were carried out to study the performance of structures. Results of the study indicated that structure with braced core consisting of stronger braces, designed in accordance with [20], will collapse under severe near-field records as a result of failure of their columns. Similar buildings with either optimized braces, designed according to [23], or RC shear wall core could survive same earthquakes. Author concluded that in order to successfully prevent the collapse of studied structures under severe near-field records, two outriggers must be used, one at the second story and the other at about 0.14 height of structure [15].

Moon (2016), investigated the structural performance of a 60 storied building provided with outrigger systems. The three twisted, tilted and tapered buildings were designed by varying the angles of twisting, tilting and tapering of the building. The building was designed by subjecting it to wind load using SAP 2000 software. The authors concluded that for twisted tall buildings, its lateral stiffness gets reduced as the rate of twist increases. However, for tilted and tapered tall buildings the lateral stiffness gets increased as the tilting angle and rate of taper gets increased [16].

Jian-Guo (2014), performed finite element analysis (FEA) and experimental study on the seismic behavior of joints between steel K-style outrigger truss and concrete core in tall buildings. Two new joint types with outside steel plates and encased steel plates, were tested under cyclic loads. It was found from the experimental results that the seismic performance of specimen OTJ-1 with outside steel plates is better than those of specimen OTJ-2 with encased steel plates for the following reasons: the average initial stiffness and maximum load of specimen OTJ-1 are 8.1 and 6.3% higher than those of specimen OTJ-2, respectively, whereas the displacement corresponding to the maximum load of specimen OTJ-1 is obviously larger; the ductility coefficient μ and equivalent damping coefficient for OTJ-1 are 11.0 and 17.6% larger than those for OTJ-2; the cracking of the wall is more severe for specimen OTJ-2, such as the spalling of a large amount of concrete on the wall below the lower joint plate and horizontal cracks on the wall where encased steel plate exists. FEA models of the tested joints were showed, simulated average maximum load is only 2.4% higher than test results. Author concluded that the from FEA and experimental results, the joints exhibited favorable seismic performance which could transfer the loads reliably, and the joint with outside steel plates was better than that with encased steel plates, with more construction convenience, higher buckling load, and less concrete cracks and proposed simplified FEA model for a more general purpose in routine design practice [17].

Nanduri et al. (2013), analyzed a 30 storied (height (H), 90m) symmetrical RCC building provided with outriggers and belt truss system at different locations viz. at the top, 3H/4, H/2 and H/4 respectively. The building was analyzed using ETABS by subjecting it to wind and earthquake loads for determination of the optimum location based on the results of lateral displacement. The study indicated that the lateral displacement gets reduced with outriggers by 23% when the first outrigger is provided at the top and the second outrigger is in the mid height (H/2) of the building. Thus, the optimum location is found to be at 0.5H times the heights of the building [1]

Sathyanarayanan et al. (2012), determined the optimum locations of outrigger for the three multi-storied structures of 30m, 45m and 60m heights (H) using finite element based standard software. The outriggers were provided at single and two levels (one at top and other with varying heights) and also placed parallel to shorter and longer sides of the structure. The results of analysis indicated that the lateral displacements, internal forces and base shear values are found to be significantly reduced for buildings with heights of 30m, 45m and 60m respectively for single and two levels of outrigger provided parallel to shorter and longer side of the structures. From the study it is concluded that optimum positions of outriggers lie at H/2, H/2.5 and H/2.85 when the outriggers are provided in single level and also parallel to shorter as well as longer sides of the structure for 30m, 45m and 60m from top [7].

Fawzia et al. (2010), carried out a study for controlling the deflection by analyzing a 60 storied (H) composite building provided with belt truss and outrigger system. Finite element analysis was performed considering wind load and with one (0.6H), two (H and 0.5H) and three (H, 2H/3 and H/3) outrigger levels using STRAND 7 software. The results of the analysis indicated that the deflection of the building gets reduced by 34%, 41% and 51% for one, two and three outrigger levels respectively when compared with the deflection values of the building without outrigger. From the study, it is concluded that the belt truss and outrigger system is proficient in controlling the overall lateral displacement to a maximum extent when building is provided with three outrigger levels [9].

Herath et al. (2009), analyzed 50 storied (H) structure to determine the optimum position of outrigger under nine different earthquake loads by considering the response parameters viz. lateral displacement and inter storey drift using STRAND 7 software. Single level outrigger (by varying floor to floor) and two level outrigger (one fixed at top and second varying floor to floor) was provided. The result obtained from this study is that minimum displacement and drift was found out for both outrigger level is between 22-24 storey. Therefore, researcher was concluded that the optimum position of outrigger is between 0.44 - 0.48H times the height of structure [18].

Bayati et al. (2008), determined displacement reduction in without and with uniform belted structures as virtual outriggers and conventional outriggers for 80 storied high rise steel framed tower. A 3-D elastic structure analyzed in ETABS software with three sets of 4-story deep outriggers: between Levels 77 and 73 (at the top); between Levels 46 and 50; and between Levels 21 and 25. The result show that outrigger system was reduce lateral displacement from 23 to 34% compared to without outrigger system. Authors concluded that virtual outriggers will be less effective than conventional outriggers because of the reduced stiffness of the indirect force transfer mechanism [19].

3. CONCLUSIONS

From the literature review, following conclusions can be drawn:

i. The behavior of the outrigger structural system depends upon the outrigger type, location, depth and the material of outrigger.

ii. The concrete core and RCC outrigger structural systems are proved to be effective in minimizing storey displacement and drift compared to steel outrigger systems.

iii. The optimum position of outrigger for most of the high-rise structures is found to be located at 0.5 times the height (H) of the structure when provided with single outrigger. However, for double outriggers, one provided at the top, i.e., at H and the other varied between H to ¼ H, the optimum position is found to be located at 0.5 H and H respectively.

iv. Analysis of high-rise structures carried out by considering earthquake zones III and IV with medium and hard strata have indicated that the responses viz. story drift, story displacement, time period and base shear gets reduced by up to 30%.

v. There is scope to carry out research studies for determining optimum position of outriggers in the high-rise structures considering the outriggers of different materials, various seismic zones and the types of soil strata.

ACKNOWLEDGEMENT

The authors are very grateful to Dr. Mrs. Sushma S. Kulkarni, Director of RIT and Dr. Pandurang S. Patil for allowing to utilize the library facilities and for their motivation.

REFERENCES

[1] P. M. B Raj Kiran Nanduri, B. Suresh, MD. Ihtesham Hussain, "Optimum position of system for high-rise reinforced concrete buildings under wind and earthquake load," American Journal of Engineering Research, Vol. 02, Issue 08, 2013, pp. 76-89.

[2] Wikipedia,<https://en.wikipedia.org/wiki/Earthquake_zones_of_India> (accessed 25 March 2021).

[3] Wikipedia,<https://en.wikipedia.org/wiki/2001_Gujarat_earthquake> (accessed 28 March 2021).

[4] Wikipedia,<https://en.wikipedia.org/wiki/1993_Latur_earthquake> (accessed 28 May 2021).

[5] Wikipedia,<https://en.wikipedia.org/wiki/Jeddah_Tower> (accessed 1 April 2021).

[6] N. Patel and S. Jamle, "Use of Shear Wall Belt at Optimum Height to Increase Lateral Load Handling Capacity in Multistory Building: A Review," International Journal of Advanced Engineering Research and Science, Vol. 06, Issue 04, April 2019, pp. 310-314.

[7] K. S. Sathyanarayanan, A. Vijay and S. Balachandar, "Feasibility studies on the use of outrigger system for RC core frames," International Journal for Advance Innovations, vol. 01, Issue 03, June 2012, pp. 1-9.

[8] P. A. Kakde and R. Desai, "Comparative Study of Outrigger and Belt Truss Structural System for Steel and Concrete Material," International Research Journal of

Engineering and Technology, Vol. 04, Issue 05, May 2017, pp. 142-147.

[9] Fawzia, Sabrina, Fatima and Tabassum, "Deflection control in composite building by using belt truss and outriggers systems," Proceedings of the World Academy of Science, Engineering and Technology, August 2010, pp. 1-8.

[10] K. Shivacharan, S. Chandrakala, G. Narayana and N. M. Karthik, "Analysis of Outrigger System for Tall Vertical Irregularities Structure Subjected to Lateral Load," International journal of Research in Engineering and Technology, Vol. 04, Issue 05, May 2015, pp. 84-88.

[11] S. Al-Subaihawi, C. Kolay, T. Marullo, J. M. Ricles and S. E. Quiel, "Assessment of wind-induced vibration mitigation in a tall building with damped outriggers using real-time hybrid simulations," Elsevier, Vol. 205, February 2020, pp. 1-13.

[12] M. Wang, S. Nagarajaiah and F. Sun, "Dynamic Characteristics and Responses of Damped Outrigger Tall Buildings Using Negative Stiffness," American Society of Civil Engineers, Vol. 146, Issue 12, September 2020, pp. 1-18.

[13] R. Raut and H. Dahake, "Comparison of Outrigger System in Tall Building," Journal of Engineering Science, Vol. 11, Issue 07, July 2020, pp. 332-336.

[14] O. A. Mohamed and O. Najim, "Outrigger systems to mitigate disproportionate collapse in building structures," ELSEVIER, Vol. 161, 2016, pp. 839-844.

[15] M. Samadi and N. Jahan, "Determining the effective level of outrigger in preventing collapse of tall buildings by IDA with an alternative damage measure," ELSEVIER, Vol. 191, March 2019, pp. 104-116.

[16] K. S. Moon, "Outrigger system for structural design of complex shaped tall buildings," Council on Tall Buildings and Urban Habitat, Vol. 05, Issue 01, March 2016, pp. 13-20.

[17] J. Nie, R. Ding, J. Fan and M. Tao, "Seismic Performance of Joints between Steel K-Style Outrigger Trusses and Concrete Cores in Tall Buildings," American Society of Civil Engineers, Vol. 140, June 2014, pp. 1-19.

[18] N. Herath, N. Haritos, T. Ngo and P. Mendis, "Behavior of Outrigger Beams in High rise Buildings under Earthquake Loads," Australian Earthquake Engineering Society Conference, 2009, pp. 1-9.

[19] Z. Bayati, M. Mahdikhani and A. Rahaei, "Optimized Use of Multi-Outriggers System to Stiffen Tall Buildings," The 14th World Conference on Earthquake Engineering, Vol. 64, Issue 02, October 2008, pp. 183-194.

[20] UBC 97-1997 Uniform Building Code. International Conference of Building Officials; 1997.

[21] ASCE standard. ASCE/SEI 7-16, minimum design loads and associated criteria for buildings and other structures. American Society of Civil Engineers, Reston; 2017.

[22] ANSI/AISC 360-16. Specification for Structural Steel Buildings; 2016.

[23] ANSI/AISC 341-16. Seismic Provisions for Structural Steel Buildings; 2016.

[24] ASCE standard. ASCE/SEI, 41-17, seismic evaluation and retrofit of existing buildings. Reston: American Society of Civil Engineers; 2017.

BIOGRAPHIES

He is pursuing M. Tech. Structural Engineering in Rajarambapu Institute of Technology, Rajaramnagar [M.S.]. He has obtained his Bachelor degree in Civil Engineering from Nanasaheb Mahadik College of Engineering, Pethnaka. His areas of interest are analysis and design of Earthquake Resistant Structural Systems, and Industrial Structures.

He has obtained his Bachelor degree in Civil Engineering from Rajarambapu Institute of Technology, Rajaramnagar [M.S.] in 1989 and his Master's Degree in Structural Engineering from Walchand College of Engineering, Sangli in 1993. He obtained his Doctoral degree from Shivaji University, Kolhapur in 2013. He has about 64 papers to his credit including publications in International and National level journals and conferences. Presently he is working as Associate Professor and Head in the Department of Civil engineering at Rajarambapu Institute of Technology, Rajaramnagar. He has guided number of students for their Post-Graduation and currently guiding for Doctoral degree. He is also reviewer for various National and International Journals.