

# Review of Damped Outrigger Structural System on Tall Building Subjected to Lateral Loads

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**ABSTRACT:** Having a history of 150 years, the modern tall structures originated from the western countries. High rise structure are not only representing economic prosperity and social development but also the combination of traditional engineering and inventive technology. As height of structure increases chances of destruction also increases, to control such kind of destruction a different type of lateral load system is stabilised that is outrigger. Which provides strength to high rise structure to tolerate seismic effect as well as wind load effect. In the field of Structural Engineering, it is widely known that outriggers are generally appropriate for resistance against eminent wind load and earthquake. To keep these things in mind, a new type of outrigger is introduced, i.e. Damped Outrigger. This is the most efficient type of outrigger. In this system, a damper is inserted between outrigger and external column. When this is done, there is smaller increase in stiffness of building but a significant increase in damping. For a tall building, where resonant wind loading is significant compare to static, this is huge benefit. As compared to other outrigger, it provides more strength to the structure. This paper gives review of damped outrigger in high rise structures.

**KEYWORDS:** High rise building, Outrigger, Viscous damper, Lateral Forces, ETABS software.

## I. INTRODUCTION

In the early structures at the beginning of the 20th century, structural members were assumed to carry primarily the gravity loads. Today, however, by the advances in structural systems and high-strength materials, building weight is reduced, and slenderness is increased, which necessitates taking into consideration mainly the lateral loads such as wind and earthquake. Development in structural system is shown in fig (i). Understandably, especially for the high-rise buildings, currently there are many structural systems that can be used for the lateral load resistance. In this context, these systems can be classified based on the basic reaction mechanism/structural behaviour for resisting the lateral load.

- i. Rigid frame systems
- ii. Braced frame and shear-walled frame systems
- iii. Braced frame systems
- iv. Shear-walled frame systems
- v. Outrigger systems
- vi. Framed-tube systems
- vii. Braced-tube systems
- viii. 8. Bundled-tube system

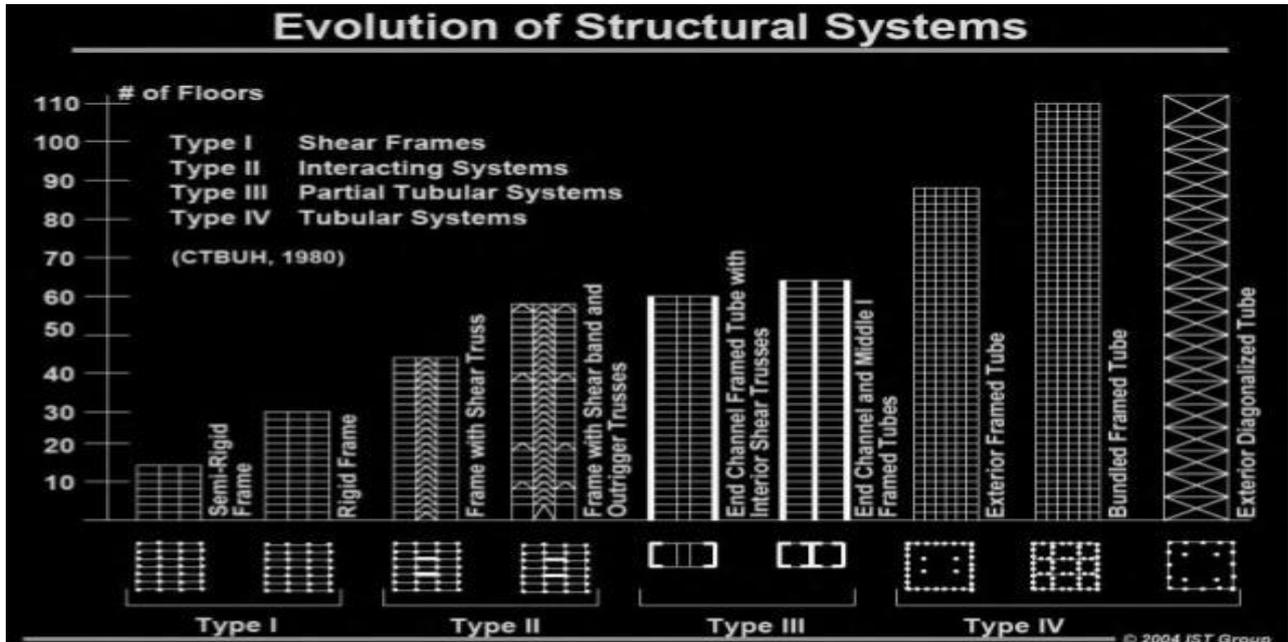


Fig .1 Evolution of structural system

There are given different three types of outrigger with schematic diagram. Due to revolution in world for living a well-managed life first thing required is a well-designed and well planned city. As a result of this Structural engineers discovered different types of structural system. Among them Outrigger is one of the advance system. There are three types of outrigger.

- i. Conventional Outrigger
- ii. Virtual Outrigger
- iii. Damped Outrigger

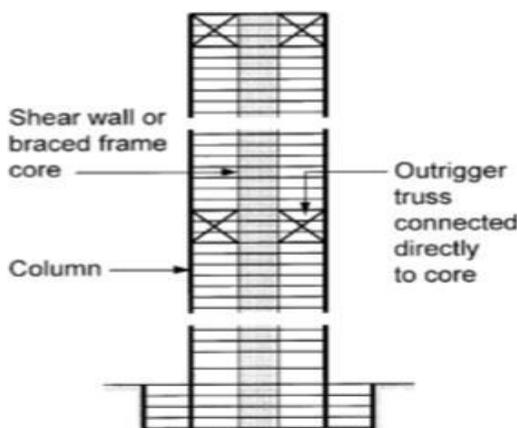


Fig. 2 Conventional Outrigger

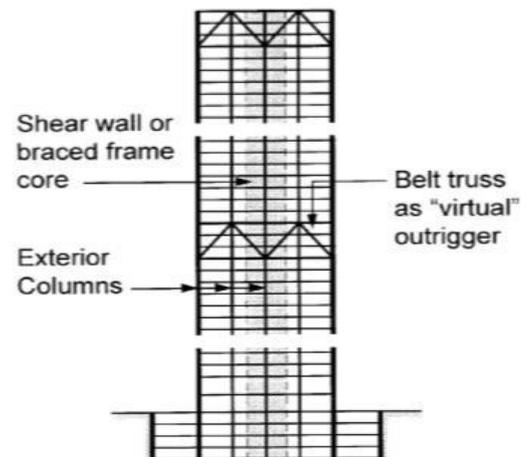


Fig. 3 Virtual Outrigger

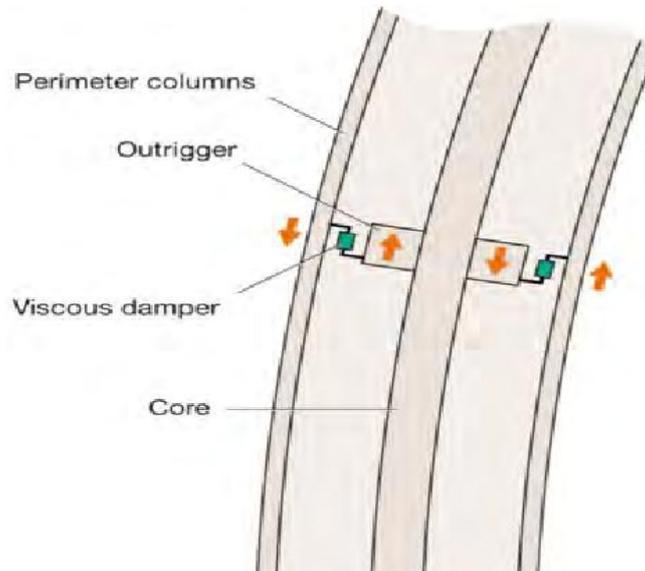


Fig.4 Damped Outrigger (source ARUP)

## II. LITERATURE REVIEW

The objective of literature review is to be accustomed with the current trends in High-rise Earthquake resistant building design. There are several papers which deals with outrigger and its different types. After studying in the field of Structural Engineering, it has been widely known that outrigger beams/truss are generally appropriate for resistance against eminent wind loads, but incorporating outriggers for earthquake resistance has been intriguing area for research. Many researchers have analysed the effects of featuring outriggers with various configurations in the high-rise building frames in order to reduce and control the deflections and stresses.

In 2007, **Rob Smith et al.** described a new concept known as damped outrigger by this paper. The paper explained a new philosophy in design for tall structures exposed to extreme wind loads, such as cyclone and typhoons. In such extreme condition tall structure with conventional outrigger were not proficient enough in controlling the deflection and moments. To solve such kind of problem a new concept developed i.e. damped outrigger. The author has designed a building in Philippine with 8 dampers which were incorporated in combination with the outriggers. Two different types of dampers were studied for comparison namely tuned Mass Dampers and viscoelastic dampers. Out of these two, viscoelastic Dampers were found to be more efficient under typhoon winds resulting in lesser peak acceleration moment as compared to Tuned Mass Dampers. The research also proved to be very cost effective since, it reduced the requirement of high Strength and stiffness resulting in lighter frame apart from this investigation on typhoon winds, authors also brought to attention the significance of reliability, maintenance and replacement of dampers from time to time for safe functioning of the building. The author also indicated that, Damped Outrigger concept could also be incorporated for Earthquake Resistant Design where Performance based approach is preferred. At the end, it was concluded that for eminent winds the concept of Damped outrigger was very effective dependable structural damping was enhanced by a factor of 5 by incorporation of Damped Outrigger.

In 2009, **N. Herath et al.** worked on idea of increasing safety and stiffness of tall buildings by incorporating outrigger beams connecting core to exterior columns for regions of high seismicity. The idea was inspired by the vulnerability of tall structures under seismic loads and the possible disasters by collapse of such buildings. According to the author most realistic way of assessing strunnder same ground accelerations which were recorded in the past. The study also aimed at optimizing the location of the outrigger beams in structure in order to achieve maximum stability of design and economy in construction. The idea of using deep RC beams (about 3.7m deep) instead of Steel truss was very innovative at the time. It proved to be very effective as well because connections of RC Outrigger beams to exterior columns worked better than its connections with Steel trussctural damage due to

earthquake was to analyze the model. Researchers analyzed several 50 storied RC frames with different locations of Outrigger beams by Response Spectrum method and found out that optimum location of 2nd outrigger was near the centre height of the building. In addition to this models were also analyzed for ground accelerations of several actual earthquakes in the past to study displacement and drift. 9 ratios namely, Park field (28 June 1966), Friuli (6 May 1976), Patras (29 Jan 1974), Gazli (17 May 1976), El Centro (18 May 1940), Spitak (7 Dec 1988), Mexico City (19 Sep 1985), Tabas (13 Sep 1978), San Fernando (9 Feb 1971). Behavior of the structures under these earthquakes and subsequent reduction in response due to outriggers were studied in this research earthquakes were chosen based on acceleration to velocity.

In 2010 **Y. Chen et al.** proposed a novel damped outrigger system for tall buildings, and is quite promising. To gain insight into the conceptual design of such systems, a simple beam-damper system model for a building with such dampers installed is developed and studied. A partial differential equation governing the motion is derived assuming a Bernoulli-Euler beam. A closed-form analytical solution is developed for vibration of the beam by analyzing the regions above and below the damper separately using separation of variables. By applying appropriate boundary conditions at the ends, a transcendental characteristic equation is obtained that governs the system's complex natural frequencies. An explicit form for the complex mode shape is determined for dynamic analysis. A numerical iteration scheme is adopted to solve the characteristic equation for the complex eigen values i.e., the system modal frequencies and damping ratios. This solution was used to determine design curves for optimal damper position and size. For engineering convenience, empirical equations were provided by fitting numerical results. These equations include one for determining the optimal location of the damper for each mode, and two for determining the optimal damping coefficient and for calculating the maximum modal damping ratio of the system while the beam vibrates in its first mode. Furthermore, relatively accurate approximations of the pseudo undamped natural frequency and damping ratio of the first mode were obtained using a Taylor expansion of the characteristic equation. All of the results obtained are non dimensionalized for convenience of analysis and application.

In 2013 **Ying Zhou et al.** explained damped outriggers for tall buildings draw increasingly attentions to engineers. With a shaking table test, two models of a high-rise steel column-tube structure are established, one with outriggers fixed to the core and hinged at the columns, whereas the other's cantilevering outriggers are connected to columns by viscous dampers. According to their dynamic properties, five earthquake waves are selected from the Ground Motion Database of Pacific Earthquake Engineering Research Center (PEER), and two artificial waves are generated by software SIMQKE\_GR. Under various peak ground accelerations (PGAs), nonlinear time-history analysis is applied to compare structural elastic seismic responses, including accelerations, inter-story drifts, base shear force, damper's response and additional damping ratios. It is concluded that under minor earthquakes, accelerations, inter-story drifts and base shear force of structure with damped outriggers are larger than or nearly equal to those of the one with fixed outriggers, and the viscous dampers hardly work. But as PGA increases, the contrary situation happens, and the effect of viscous dampers is enhanced as well. The additional damping ratio reaches around 4% under mega earthquakes.

In 2013 **Kailai Deng et al.** explained simplified model is developed to estimate the seismic response of high-rise buildings equipped with hysteresis damped outriggers. In the simplified model, the core tube is considered as a cantilever beam and the effects of outriggers on the core tube are considered as concentrated moments. Modal decomposition method is adopted to obtain the seismic response of the simplified model. To investigate the accuracy and effectiveness of the simplified model, a high-rise building with a height of 160 m was adopted as the example structure, and its response subjected to a ground motion was analyzed using the simplified model. A corresponding finite element model was built and analyzed by a finite element program called SAP2000 (Computers and Structures, Inc. Berkeley, California, United States). The analysis results obtained from the two models were compared. To consider the randomness of the ground motion, comparisons between the two models were further conducted using another 22 ground motions. It is found that the analysis results obtained from the simplified model agree well with those obtained from the finite element model, and the computation time used for the simplified model is almost negligible compared to that used for the finite element model. Such observations demonstrate that the simplified model is accurate and effective.

In 2013 **Takehiko Asai et al.** The focus of this study is to experimentally investigate and verify smart outrigger damping systems for high-rise buildings subjected to scaled El Centro and Kobe earthquake records using RTHS. Through RTHS, the efficacy of the smart outrigger damping system is demonstrated for two historical

earthquakes. The building used in this study is the St. Francis Shangri-La Place in Philippines [32,15,4]. This 60-story building has a height of 210 m and has 12 perimeter columns which are 20 m from the building centerline. The concrete core is assumed to be 12 m \* 12 m with 0.5 m thickness. The total mass of the building is 30,000 tons and the outrigger system installed consists of 16 viscous dampers, 8 of which control the response in each of the two orthogonal directions. This study shows that MR dampers can be employed effectively in outrigger damping systems using passive and semi-active controllers. The MR damper's restoring force can be simulated quite well by the proposed MR damper model for the two earthquake records; however, differences are still present. In particular, discrepancies between simulations and RTHS were found in the base shear. Moreover; the physical specimen contains no modeling errors, while it is subject to experimental error such as magnitude and time delay. The numerical model provides a good verification tool for RTHS, however is subject to numerical errors, is only valid within the range of behavior for which the model is calibrated, and cannot fully represent the complex specimen behavior. Thus, the importance of combining RTHS with numerical simulation to ensure accurate results is demonstrated. The following general conclusions can be drawn with regard to the RTHS framework employed in this research: (a) RTHS work when all modes of the structure were lightly damped, demonstrating the robustness of the actuator controller without the need for adding numerical damping; (b) the actuator control strategy used in this study demonstrated stable and accurate results in MDOF structural systems; (c) RTHS can be employed for validation of structural control algorithms; (d) RTHS provides an effective means for assessing the system performance of rate-dependent components in complex structures. However, due to the feedback loops in RTHS, high-frequency noise can manifest as high-frequency actuator command. Improvements to filtering, or actuator control will be sought in future work to allow for stronger semi active controllers to be implemented in RTHS.

In 2015 C. J. Fang et al. this paper presents a general solution for performance evaluation of a tall building with multiple damped and undamped outriggers. First, general rotational stiffness (GRS) is proposed to model an outrigger that consists of the stiffness of perimeter columns and an outrigger connection and the damping of dampers in an outrigger. By utilizing the dynamic stiffness method, the GRS can be represented by complex stiffness in an outrigger element. To analyze the dynamic characteristics of a tall building with multiple outriggers. A dynamic transcendental equation is obtained from the combination of the GRS and dynamic stiffness method. The structural responses can be calculated through the Fourier transform based on this equation. Moreover, the GRS can also be blended into a finite element (FE) model to generate an augmented statespace equation for the Applications to various outriggers are illustrated. In the numerical analysis, good agreements are found between the GRS and the FE that validates the proposed method, and the performances of various outrigger systems are evaluated parametrically. As the results of a tall building with multiple damped or undamped outriggers, the proposed method is capable of providing an optimally parametric design with respect to the position of outriggers, damping, and core-to-column and core-to-outrigger stiffness ratio.

In 2015 Takehiko Asai et al. The number of high-rise buildings in urban areas around the world has been increased rapidly. To protect such high-rise buildings from external disturbances, tuned mass dampers (TMDs) have been proposed as an energy dissipation system. The effectiveness of this strategy to wind loadings has been shown, while it is limited against earthquakes due to the limitation of the supplemental mass. Tuned viscous mass dampers (TVMDs) have been developed as an alternative method where an amplified apparent mass is realized by an inertial mass through a ball screw mechanism. However, since they are installed inter-story, they become less effective in high-rise buildings due to insufficient inter-story drifts. To increase the effectiveness of the TVMDs in high-rise buildings, this paper proposes outrigger tuned viscous mass damping systems, in which the TVMDs are installed vertically between the outrigger and perimeter columns of high-rise buildings to achieve large energy dissipation. And the design method for the TVMDs to be tuned to the bending of the building is introduced. Then the validity of the proposed damping system subject to earthquake records are verified through numerical simulation.

In 2016 Rob Smith et. al (8) in this paper author explained use of outriggers with dampers is cost effective method of adding structural damping to a high rising building. In this paper methods used to design such system is highlighted. All high rise buildings require additional lateral stiffening to prevent excessive displacement during both wind and seismic events. There are many structural typologies that can provide sufficient strength and stiffness, including single core tube structures bundled tubes, etc. Each has a different optimum height range and suitability, based upon the usage and location of the building. Buildings with traditional outriggers are typically best suited for heights of between 150 and 400 m. Author explored three developments of the concepts.

In 2016 Neville John Mathias et. al (9) in this paper author explained concept of using relatively rigid outriggers in tall buildings in conjunction with viscous damping devices to supplement damping has been excellently developed. The concept of introducing viscous damping devices between outrigger and perimeter column in tall building to provide supplementary damping and improve performance, reduce structural costs and increase available usable area was developed and implemented. It was recognized that the relative vertical movement that would occur between the ends of outriggers and columns, if they were not connected, could be used to generate damping. The movements, and correspondingly damping, can potentially be increased by amplifying then using simple “mechanism”. The mechanism also make it possible to increase the number of available dampers and thus further increase supplementary damping. The feasibility of mechanism to amplify supplementary damping and enhance structural performance of tall, slender buildings is studied with particular focus on its efficiency in improving structural performance in wind loads.

In 2016 Zheng Lu et. al (10) In this paper author targeted on a super high-rise building with multi-outrigger, viscous dampers are installed between an outrigger at some height and the mega column, namely to adopt energy dissipation outrigger with viscous dampers, thus the overlarge wind vibration control by viscous dampers installed in an outrigger at different levels. With the increasing height of building, the frame-central core tube-outrigger structure system is widely used in super tall building. It becomes more and more popular to employ multioutrigger in taller and super high rise buildings. However because of the fact that the vibration period of these skyscrapers is close to that of the fluctuating wind, the acceleration of structure caused by wind generally exceeds the level of comfort regulated by the corresponding codes.

### III. CONCLUSION

1. Damped Outriggers is the new philosophy for the design of highrise buildings to introduce a new level of dependable supplemental damping for the primary purpose of reducing dynamic wind effects.
2. The application can be used to control response from both wind and seismic loading, but in both cases nonstandard analytical techniques are required in design process.
3. A uniform straight cantilever beam with two intermediate cantilever-attached viscous dampers was employed to characterize a novel damping system for tall buildings with damped outrigger.
4. It is found that there exists an optimal damper size, which results in system modal damping approaching its maximum value for an assigned damper location.
5. For the structure without dampers, because of the abrupt change of stiffness at outrigger stories, inter storey drifts are obviously smaller than their adjacent stories.
6. In contrast, the stiffness change of the structure with dampers is not that sudden and this phenomenon cannot be seen on inter story drift.
7. The study shows that mr dampers can be employed effectively in outrigger damping systems using passive and semi-active controllers.
8. In particular discrepancies between simulations and rths were found in the base shear. moreover, the physical specimen contains no modeling errors, while it is subject to experimental error such as magnitude and time delay.
9. In outrigger tuned mass viscous damper (tvmd) system, rotational viscous mass dampers are installed on an outrigger highrise building, through supporting springs.
10. The core of the building to the outside columns. since the columns connected to the outriggers attract more load, these are often slightly larger than typical columns, or in the case of mega columns are deliberately made to be larger.
11. The idea of using mechanism to amplify relative movements in damped outrigger systems in tall buildings to increase additional damping and mitigate the effects of wind and seismic loads was studied.
12. Viscous dampers are velocity-dependent and will not largely affect the stiffness of the overall structure. in fact vertically installing viscous dampers outriggers and mega columns do enlarge the structure period, but this influence is rather small.
13. Placing viscous dampers at the middle high outrigger (0.66 times of structure height) is the best choice for controlling the inter-story drifts and floor displacements. meanwhile, all damping schemes have obvious smaller response than the convent

### REFERENCES

- [1] N. Herath, N. Haritos, T. Ngo & P. Mendis, “Behavior of Outrigger Beams in High rise Buildings under Earthquake Loads”, Australian Earthquake Engineering Society Conference, 2009

- [2] Kiran Kamath, N. Divya, Asha U Rao, "Study on Static and Dynamic Behavior of Outrigger Structural System for Tall Buildings". Bonfring International Journal of Industrial Engineering and Management Science, December 2012
- [3] P. M.B. Raj Kiran Nanduri, B.Suresh, MD. Ihtesham Hussain, "Optimum Position of Outrigger System for High-Rise Reinforced Concrete Buildings under Wind and Earthquake Loadings", American Journal of Engineering Reserch, 2013
- [4] Kiran Kamath, Avinash A. R., Sandesh Upadhyaya K., "A Study on the performance of multi-outrigger structure subjected to Seismic loads", IOSR Journal of Mechanical and Civil Engineering, 2014
- [5] Srinivas Suresh Kogilgeri, Beryl Shanthapriya, "A study on Behavior of Outrigger System on High Rise Steel Structure by Varying Outrigger Depth", IJRET: International Journal of Research in Engineering and Technology, 2015
- [6] Thejaswini R M, Rashmi A R, "Analysis and Comparison of Different Lateral Load Resisting Structural Forms", International Journal of Engineering Research & Technology (IJERT), 2015
- [7] Abdul Karim Mulla, Srinivas B. N, "A Study on Outrigger System in a Tall R.C Structure with Steel Bracing", International Journal of Engineering Research & Technology (IJERT), 2015
- [8] Vijaya Kumari Gowda M R, Manohar B C, "A Study on Dynamic Analysis of Tall Structure with Belt Truss Systems for Different Seismic Zones", International Journal of Engineering Research & Technology (IJERT), 2015
- [9] Boggs, P.C., Casparini, D.A. (1983). Lateral stiffness of core outrigger systems. Engineering Journal, AISC 20: 172-180.
- [10] Hoenerkamp, J C D, Bakker, M C M. (2003). Analysis of high-rise building braced frames with outrigger belts. Structural Design of Tall and Special Buildings. 12:335-350.
- [11] Hoenerkamp, J C D. (2004). Shear wall with outrigger trusses on wall and column foundations. Structural Design of Tall and Special Buildings. 13: 73-87.
- [12] Herath, N., Haritos, N., Ngo, T., and Mendis, P. (2009). Behaviour of outrigger beams in high rise buildings under earthquake loads. Australian Earthquake Engineering Society Conference.
- [13] McNabb, J.W. (1975). Drift reduction factors for belted high rise structures. Engineering Journal, AISC 14:44-47.
- [14] Moudarres, F.R. (1985). Free vibration of outrigger braced structures. Proceeding of Institute of Civil Engineering. 16: 105-117.
- [15] Prestandard and Commentary for the Seismic Rehabilitation of Buildings, FEMA 356 (2000). Federal Emergency Management Agency. Washington, DC.
- [16] Rutenburg, A., T.D. (1987). Lateral load response of belted tall building structures. Engineering Structure. 9: 53-67.
- [17] Smith, B., and Coull, A. (1991). Tall Building Structures: Analysis and Design. John Wiley & Sons.
- [18] Taranath, B. S. (1975). Optimum belt truss locations for high rise structures. The Structural Engineering. 53: 345-348.
- [19] Taranath, B.S. (1988). Structural analysis and design tall building. New York: McGraw-Hill.
- [20] Wu, J.R., LI, Q.S. (2003). Structural performance of multi outriggered brace tall buildings. Structural Design of Tall Buildings. 12: 155-176.
- [21] Tall Building Initiative. Guidelines for Performance-Based Seismic Design of Tall Buildings. (2010), Pacific Earthquake Engineering Research Center (PEER).
- [22] Zeidabadi, N., Mirtalae, K. (2004). Optimized use of the outrigger system to stiffenthe coupled shear walls in tall buildings. Structural Design of Tall Buildings. 13: 9-27.