IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified ⁙ Impact Factor 8.066 ⁙ Peer-reviewed / Refereed journal ⁙ Vol. 10, Issue 4, April 2023

DOI: 10.17148/IARJSET.2023.10465

A Review of Diagrid and Belt Truss Designs Structural Systems for High-Rise Buildings

D. N. RAJDEV[1], V. B. Patel[2], P. M. BHATT[3]

Structural Engineering Department, Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar 388120,Gujarat, India[1-3]

Abstract: Exoskeleton structures have gained popularity in recent years due to their aesthetic appeal and structural efficiency. They offer excellent seismic performance, particularly in reducing inter-story drift and providing greater lateral stiffness. This study uses ETABS-2020 to analyze the structures under various loading conditions, including static earthquake forces, dynamic earthquake forces (per IS: 1893 – (part-1) 2016 guidelines), and wind dynamic forces (per IS-875 (part-3)-2015). The structures are designed based on IS: 800-2007, and parameters such as story displacement and story drift are observed. The study compares different types of lateral load resisting systems to determine the most effective and economical system for resisting lateral loads such as wind and seismic loads. The lateral load resisting systems under investigation include diagrid, belt truss systems for 20, 30, 40, and 50 story structures with plan dimensions of 50m X 50m. Additionally, the study analyzes various percentages of plan dimension in the diagrid structure.

Keywords: Diagrid Structural System, High rise buildings, Structural design.

1 INTRODUCTION

1.1 GENERAL

In the modern world, high-rise buildings play a crucial role in the development of any country. India has experienced numerous natural disasters in the past, such as earthquakes and tsunamis, and some regions in the country are witnessing a rise in the frequency of earthquakes. While earthquakes cannot be predicted, their damages can be mitigated by incorporating various lateral load resisting systems in building designs.

Buildings are subjected to two types of loads - vertical loads due to gravity and lateral loads due to earthquakes and wind. Lateral load resisting systems are incorporated to resist these forces. In multi-storey buildings, lateral loads are the governing factor in design. There are various lateral load resisting systems that can be used, such as shear walls, belt trusses, outriggers, belt truss + outrigger systems, diagrids, staggered trusses, tube-in-tube systems, and more.

These systems are designed to increase the stiffness of the structure and absorb lateral forces generated during earthquakes and wind events. They provide additional strength and stability to the building, reducing the risk of structural damage and collapse. By incorporating these lateral load resisting systems, high-rise buildings in India and other earthquake-prone regions can enhance their seismic resilience and safeguard against potential disasters.

With the increasing vertical development of buildings due to limited availability of land in recent years, high-rise structures are becoming slenderer. As the height of a building increases, lateral loads, including wind and seismic loads, become more dominant than gravity loads in governing the design. Therefore, it is crucial to incorporate effective and economical lateral load resisting systems in high-rise building designs to ensure their structural stability and resilience against lateral loads.

This research work focuses on comparing different types of lateral load resisting systems to determine the most efficient and cost-effective system for resisting lateral loads, such as wind and seismic loads. The study involves a comprehensive review of literature and a comparative analysis of various lateral load resisting systems, including shear walls, belt trusses, outriggers, belt truss + outrigger systems, diagrids, staggered trusses, and tube-in-tube systems.

Analysis has been conducted using ETABS-2020 software, considering different methods of analysis for static earthquake forces, dynamic earthquake forces (Response Spectrum analysis as per guidelines of IS: 1893-(Part 1) 2016), and static wind forces as per IS 875 (Part-3)-2015. The design is based on IS: 800-2007 code provisions. The aim of the research is

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified ⋇ Impact Factor 8.066 ⋇ Peer-reviewed / Refereed journal ⋇ Vol. 10, Issue 4, April 2023

DOI: 10.17148/IARJSET.2023.10465

to identify the most effective and economical lateral load resisting system for high-rise buildings in the given context, taking into account the requirements of seismic and wind load resistance.

1.2 Structural Systems for Tall Building

1.2.1 Belt Truss System

The belt truss system is a widely adopted structural system that effectively mitigates excessive drift caused by lateral loads. It helps minimize the risk of structural and non-structural damage during lateral load events such as wind or earthquakes. The belt truss system consists of horizontal members that are strategically placed along the perimeter to connect the exterior columns. This system plays a crucial role in controlling lateral displacements, ensuring structural stability, and reducing the potential for damage caused by lateral loads.

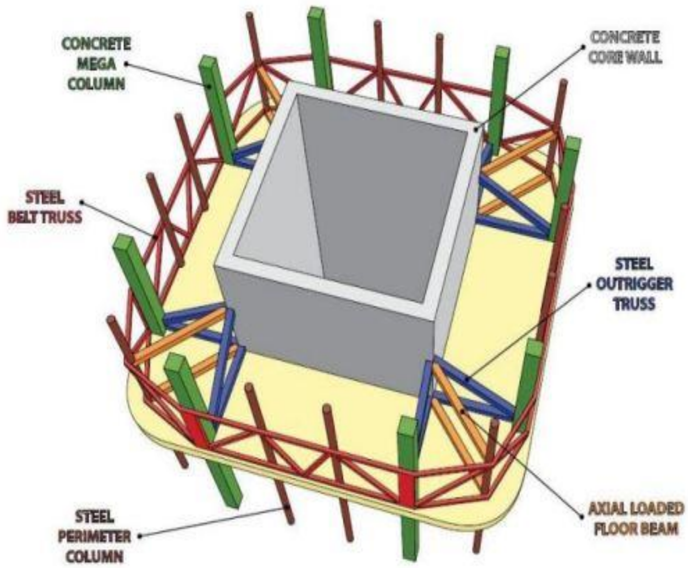

Figure 1.1Belt Truss

(https://theconstructor.org/exclusive/outriggers-high-rise-building/247964/)

1.2.2 Diagrid System

This system consists of grids of RCC or steel placed in a structure diagonally with certain specific geometry. In Diagrid system, all vertical columns at the periphery is removed and replaced by inclined columns. The conguration of diagrid structure reduces perimeter element and allow more passage for air and light from outside and also less obstruct outside view.

The major difference between a braced tube building and a diagrid building is that, there are no vertical columns in the perimeter of diagrid buildings shown in the Figure 1.8. Diagrid is particular type of truss which made up of a series of triangulated truss system. Diagrid structures are more effective in minimizing shear deformation because they carry lateral shear by axial action of Diagrid member.

In diagrid, the diagrids are considered as pin jointed truss elements. Which means thatthey carry shear as well as bending by axial actions only. Due to the triangular configuration of diagonals, diagrid can carry gravity loads as well as the lateral loads efficiently

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified ⁜ Impact Factor 8.066 ⁜ Peer-reviewed / Refereed journal ⁜ Vol. 10, Issue 4, April 2023

DOI: 10.17148/IARJSET.2023.10465

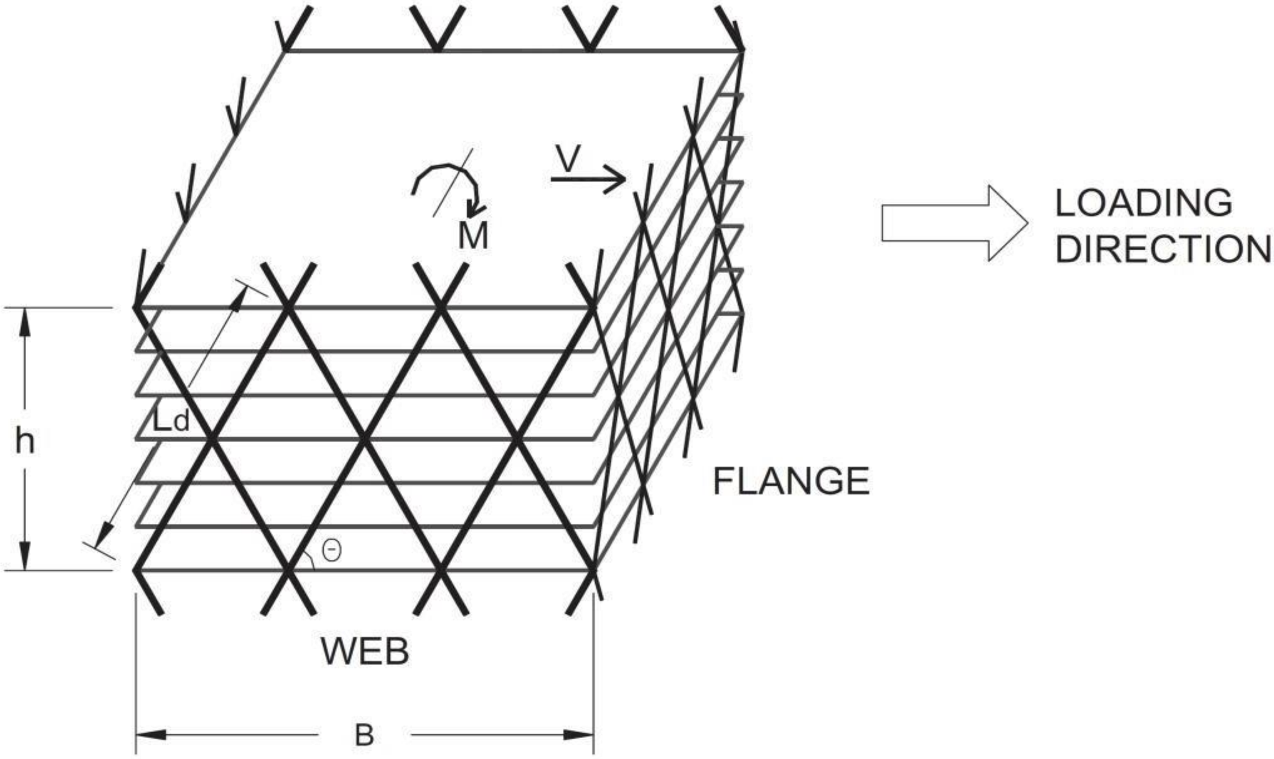

Figure 1.2Storey Diagrid Module (Moon, Connor and Fernandez 2007)

Additionally, in super-tall buildings that utilize diagrid as a structural system, the overall structure can be further strengthened and stiffened by incorporating a core of vertical gravity columns. The diagrid system is known for its high efficiency, as it forms an exterior tube that maximizes the moment arm and provides superior torsional rigidity compared to other systems, such as the outrigger system. Moreover, when considering the cost of steel, the diagrid system is found to be more cost-effective than expected (K. S. Moon 2008). In fact, diagrid structures can save up to 20% to 30% of structural steel compared to other structural systems, making them a financially viable option for high-rise buildings.

LITERATURE REVIEW

Moon (2008), conducted a study that proposed a stiffness-based design methodology for determining the initial sizes of diagonal members in diagrid structures. The results of the study were presented for uniform angle diagrid structures with aspect ratios ranging from about 4 to 9. The optimal angle of inclination for the diagonals was found to be between 60 to 70 degrees, based on stiffness considerations. The study found that for diagrid structures with an aspect ratio smaller than 7, the use of uniform angle diagonals resulted in more efficient designs. This indicates that the stiffness-based design methodology can be used to optimize the design of diagrid structures by selecting the appropriate angle of inclination for the diagonal members. Overall, this study provides valuable insight into the design of diagrid structures and highlights the importance of considering stiffness in determining the sizes and angles of diagonal members. It also highlights the potential for optimization of diagrid structures through the use of the proposed design methodology.

Kim and Lee [9] (2012), conducted a study that investigated the seismic performance of diagrid structures using nonlinear static and dynamic analyses. The study aimed to identify the most efficient diagonal angle for diagrid structures and to examine the effect of diagonal slope on the structural performance.The results of the study showed that the diagonal angle between 60° and 70° was the most efficient for the diagrid structures. However, as the slope of diagonals increased, several performance parameters were adversely affected. These included the natural period, the mass participation factor, the mean value of the maximum drift, and the shear lag effect, which all increased. Conversely, the lateral strength decreased as the slope of diagonals increased.It should be noted that this study was limited to 36-story diagrid structures with an aspect ratio of 3.6. Nonetheless, the findings provide valuable insights into the seismic performance of diagrid structures and emphasize the importance of considering the slope of diagonals in design optimization.Overall, the study conducted by Kim and Lee offers important contributions to the literature on diagrid structures, highlighting the need for

ISO 3297:2007 Certified ⁜ Impact Factor 8.066 ⁜ Peer-reviewed / Refereed journal ⁜ Vol. 10, Issue 4, April 2023

DOI: 10.17148/IARJSET.2023.10465

comprehensive seismic analysis and the importance of selecting appropriate diagonal angles for optimal structural performance.

Manthan at al. [10] (2016) conducted a parametric study and detailed comparison of diagrid structural systems with conventional frames for symmetrical buildings. The study aimed to identify the most efficient structural system and to develop formulas to determine the required cross-sectional area of diagrid members.Seven steel buildings with identical base area and loadings but different heights were designed in ETABS to compare the optimum sections for both structural systems. The results of the study showed that diagrid structures were more efficient than conventional frames in terms of lateral displacement and base shear, especially for taller buildings with a height greater than 30 storiesTo determine the required cross-sectional area of diagrid members, several formulas were developed using regression analysis. The formulas were based on various parameters, including building height, aspect ratio, and the number of diagonals per floor. These formulas were found to provide accurate results for determining the required cross-sectional area of diagrid members, and can be used in the design of diagrid structuresOverall, the study provides valuable insights into the efficiency of diagrid structural systems compared to conventional frames for symmetrical buildings. The study also offers practical formulas that can be used to determine the required cross-sectional area of diagrid members for optimal structural design.

Anna Reggio and Luciana Restuccia (2020) In this paper focused on the seismic performance of exoskeleton structures. These structures are self-supporting external systems that are connected to the primary inner structures in order to enhance or protect them. The authors conducted a study to investigate how exoskeleton structures behave under seismic loadingThe paper begins with an introduction to the concept of exoskeleton structures and their advantages over traditional structural systems. The authors highlight the ability of exoskeleton structures to provide additional stiffness and strength to buildings, as well as their potential for improving structural performance during earthquakes.The literature review section of the paper provides a comprehensive overview of previous research in the field of exoskeleton structures. The authors discuss various types of exoskeleton systems, including those made from concrete, steel, and timber, and examine their seismic performance in previous studies.The review also considers the role of exoskeleton structures in the design of tall buildings. The authors discuss how exoskeletons can be used to improve the lateral stability of tall structures and prevent excessive deformations during earthquakes. They also highlight the importance of considering the interaction between exoskeletons and primary structures in the design process.The paper then goes on to describe the experimental program carried out by the authors to investigate the seismic performance of exoskeleton structures. The experiments involved testing a 1:6 scale model of an exoskeleton structure under simulated seismic loading.In conclusion, the authors found that exoskeleton structures can provide significant benefits in terms of seismic performance. They suggest that further research is needed to optimize the design of exoskeleton systems and to develop guidelines for their use in practical applications. Overall, this paper provides a valuable contribution to the growing body of literature on exoskeleton structures and their potential for improving the seismic performance of buildings.

Anna Reggio and Luciana Restuccia(2009) In this paper, Anna Reggio and Luciana Restuccia investigated the feasibility and effectiveness of exoskeleton structures for seismic protection. The authors examined the ability of exoskeletons to absorb seismic loads and enhance the performance of the main structure.The paper begins with an introduction to the concept of exoskeleton structures and their potential benefits for seismic protection. The authors highlight the importance of improving the seismic performance of buildings, particularly in earthquake-prone regions, and suggest that exoskeletons could be an effective solution.The literature review section of the paper provides an overview of previous research on the use of exoskeleton structures for seismic protection. The authors discuss various types of exoskeleton systems and their potential benefits, including increased stiffness, strength, and energy dissipation.The authors then describe a parametric study carried out in the frequency domain to investigate the feasibility and effectiveness of exoskeleton structures. The study involved simulating the seismic response of a range of different exoskeleton systems, varying the properties of the exoskeleton and the main structure.The results of the study showed that exoskeleton structures can be effective in reducing earthquake-induced dynamic response. The authors suggest that the effectiveness of exoskeletons depends on a range of factors, including the properties of the exoskeleton and the main structure, as well as the characteristics of the seismic excitation.In conclusion, the authors suggest that exoskeleton structures have the potential to be a feasible and effective solution for seismic protection. They recommend further research to optimize the design of exoskeleton systems and to develop guidelines for their use in practical applications. Overall, this paper provides valuable insights into the potential benefits of exoskeleton structures for improving the seismic performance of buildings.

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified ⁙ Impact Factor 8.066 ⁙ Peer-reviewed / Refereed journal ⁙ Vol. 10, Issue 4, April 2023

DOI: 10.17148/IARJSET.2023.10465

Toreno et al.(2011) In this paper, investigated the structural performance of diagrid structures in tall buildings. The authors provided an overview of the characteristics of diagrid systems, with a focus on their behavior under both gravity and lateral loads. They also reviewed the strength-based and stiffness-based design criteria for diagrid structures.The paper then presented a comparative analysis of the structural performance of some recent tall buildings that utilized diagrid systems. The buildings discussed in the analysis included the Swiss Re building in London, the Hearst Headquarters in New York, and the West Tower in Guangzhou.The authors analyzed the design and construction of each building, including the materials used and the geometry of the diagrid systems. They also evaluated the structural performance of each building, considering factors such as lateral stiffness, strength, and energy dissipation.The comparative analysis revealed that diagrid structures can provide significant benefits in terms of both structural performance and architectural expression. The authors noted that the use of diagrid systems can result in reduced material consumption, increased stiffness and strength, and improved seismic performance.Overall, the paper provides valuable insights into the structural performance of diagrid structures in tall buildings. The comparative analysis of recent diagrid buildings demonstrates the potential benefits of this structural system and highlights the importance of considering the behavior of these systems under both gravity and lateral loads.

2 CONCLUSION

Diagrid and Belt Truss structural systems have emerged as innovative and effective solutions for the design of high-rise buildings. The review likely provides a comprehensive review and analysis of the design principles, structural behavior, and performance characteristics of these two systems.The review may highlight the advantages and limitations of each system, including their ability to withstand dynamic loads such as wind and seismic forces, as well as their aesthetic and architectural properties. The review may also evaluate the sustainability and cost-effectiveness of each system, and provide recommendations for optimizing their design and construction.

Overall, the review is likely to contribute to the growing body of research on innovative structural systems for high-rise buildings, and may have important implications for the future design and construction of tall buildings

REFERENCES

1. Ali, M.M. & Moon, K. S. (2007). Structural developments in Tall building: Current Trends and Future Prospects. Architectural Science Review, 50(3), 205-223.
2. Anna Reggio, Luciana Restuccia (2019). Feasibility and effectiveness of exoskeleton structures for seismic protection. The Structural Design of Tall and Special Buildings, 24(15), 912-940.
3. Anna Reggio, Luciana Restuccia (2020). Seismic performance of exoskeleton structures. The Structural Design of Tall and Special Buildings, 24(15), 912-940.
4. Chengqing Liu, Qinfeng Li, Zheng Lu, Handan W. (2017). A review of the diagrid structural system for tall buildings. The Structural Design of Tall and Special Buildings, 27(5), 180-202.
5. Feng Zhao and Chonghou Zhang (2015). Diagonal Arrangements of Diagrid Tube Structures for Preliminary Design. Struct. Design Tall Spec. Build., 24(3), 159-175.
6. Gaur. H. & Goliya, R. K. (2015). Mitigating shear lag in tall buildings. International Journal of Advanced Structural Engineering, 7(3), 269-279
7. Giovanni Maria Montuori, Monica Fadda, Gianpaolo Perrella and Elena Mele (2015). Hexagrid – hexagonal tube structures for tall buildings: patterns, modeling, and design. The Structural Design of Tall and Special Buildings, 24(15), 912-940.
8. Jinkoo Kim, Junhee Park, Sung-woo Shin and Kyung-won Min (2009). Seismic Performance Of Tubular Structures With Buckling Restrained Braces. The Structural Design Of Tall And Special Buildings, 18(4), 351-370.
9. Kim and Young Ho Lee (2012). Seismic Performance Evaluation Of Diagrid. Struct. Design Tall Spec. Build, 21(10), 736-749.
10. Manthan I. Shah, Snehal V. Mevada, Vishal B. Patel (2016). Comparative Study of Diagrid Structures with Conventional Frame Structures. Int. Journal of Engineering Research and Applications, 6(5), 22-29.
11. Moon, K. S. (2007). Structural developments in Tall building: Current Trends and Future Prospects. Architectural Science Review, 50(3), 205-223.
12. Toreno M., Arpino R., Mele E., Brandonisio G. and Luca A. (2013). An Overview on Diagrid Structures for Tall Buildings. The Structural Design of Tall and Special Buildings, 22(17), 1310-1329.
13. Sree Harsha and K Raghu. "Analysis Of Tall Building For Desired Angel Of Diagrids". International Journal of Research in Engineering and Technology, Volume:04 Issue: 04, Apr-2015.

DOI: 10.17148/IARJSET.2023.10465

14. Khushbu Jani and Paresh V. Patel. "Analysis And Design Of Diagrid Structural System For High Rise Steel Building". Procedia Engineering, Vol. 51, 2013, pp. 92-100.

15. Naga Subramanian and Augustine Maniraj Pandian. "Evaluation of structural efficiency of steel diagrid system for multi-story buildings". International Conference on Emerging Trends in Engineering, Science and Management, ICEIS-2016.

16. Raghunath Deshpandey and Sadanand Patil. "Analysis and Comparison Of Diagrid And Conventional Structural System". International Journal of Engineering Research and Technology, Volume:02, Issue:03, June-2015.

17. Sahana and Aswathy S. Kumar. "Comparative Study Of Diagrid Structures With And Without Corner Columns". International Journal of Scientific Research, Volume 5, Issue 7, July-2016.

18. Harshita Tripathi and Dr. Sarita Singla. "Diagrid Structural System For R.C. Framed Multistoried Building". International Journal of Scientific & Engineering Research, Volume 7, Issue 6, June-2016.

19. Kiran Kamath and Sachin Hirannaiah. "An Analytical Study On Performance Of A Diagrid Structure Using Nonlinear Static Pushover Analysis". Procedia Engineering, Vol. 142, 2016, pp. 48-55.

20. Ravish Khan and Sangeeta Shinde. "Analysis Of Diagrids Using Symmetric And Asymmetric Plan Geometry". International Journal of Innovative Research in Science, Engineering and Technology, ISSN:2347-2812, Volume-4, Issue-3, 2016.

21. Nikesh Ganesh Rathod and P. Saha. "Diagrid: An Innovative Technique For High Rise Structure". International Journal of Emerging Research in Management &Technology, ISSN:2349-8404, Volume 2, Issue 5, June-2015.

22. Amol Gorle and S.D. Gowardhan. "Optimum Performance Of Diagrid Structure". International Journal of Engineering Research, Volume 05, Issue 03, Feb-2016.

23. K Moon. "Design And Construction Of Steel Diagrid Structures". National Steel Construction Conference 2009.

24. Pallavi Bhale and P.J. Salunke. "Analytical Study And Design Of Diagrid Building And Comparison With Conventional Frame Building". International Journal of Advanced Technology in Engineering and Science, Volume 04, Issue 01, January 2016.

25. Saket Yadav and Vivek Garg. "Advantage Of Steel Diagrid Building Over Conventional Building". International Journal of Computer Science and Engineering Research, Volume 03, Issue 01, Sep-2015.

26. Ravi Revankar and R.G. Talasadar. "Pushover Analysis Of Diagrid Structure". International Journal of Engineering and Innovative Technology, Volume 4 Issue 3, Sep-2014.

27. Raghunath Deshpande and Sadanand Patil. "Analysis And Comparison Of Diagrid And Conventional Structural System". International Research Journal of Engineering and Technology, Volume 02, Issue 03, June-2015.

28. Deshpande, R., & Patil, S. (2015). Analysis and comparison of diagrid and conventional structural system. International Journal of Engineering Research and Technology, 02(03), June.

29. Ganesh Rathod, N., & Saha, P. (2015). Diagrid: An innovative technique for high rise structure. International Journal of Emerging Research in Management & Technology, 02(05), June.

30. Gorle, A., & Gowardhan, S. D. (2016). Optimum performance of diagrid structure. International Journal of Engineering Research, 05(03), Feb.

31. Harsha, S., & Raghu, K. (2015). Analysis of tall building for desired angel of diagrids. International Journal of Research in Engineering and Technology, 04(04), Apr.

32. Jani, K., & Patel, P. V. (2013). Analysis and design of diagrid structural system for high rise steel building. Procedia Engineering, 51, 92-100.

33. Kamath, K., & Hirannaiah, S. (2016). An analytical study on performance of a diagrid structure using nonlinear static pushover analysis. Procedia Engineering, 142, 48-55.

34. Khan, R., & Shinde, S. (2016). Analysis of diagrids using symmetric and asymmetric plan geometry. International Journal of Innovative Research in Science, Engineering and Technology, 04(03).

35. Moon, K. (2009). Design and construction of steel diagrid structures. National Steel Construction Conference.

36. Revankar, R., & Talasadar, R. G. (2014). Pushover analysis of diagrid structure. International Journal of Engineering and Innovative Technology, 04(03), Sep.

37. Sahana, & Kumar, A. S. (2016). Comparative study of diagrid structures with and without corner columns. International Journal of Scientific Research, 05(07), July.

38. Tripathi, H., & Singla, S. (2016). Diagrid structural system for R.C. framed multistoried building. International Journal of Scientific & Engineering Research, 07(06), June.

39. Yadav, S., & Garg, V. (2015). Advantage of steel diagrid building over conventional building. International Journal of Computer Science and Engineering Research, 03(01), Sep.

DOI: 10.17148/IARJSET.2023.10465

40. Bhale, P., & Salunke, P. J. (2016). Analytical study and design of diagrid building and comparison with conventional frame building. International Journal of Advanced Technology in Engineering and Science, 04(01), January.
41. Subramanian, N., & Pandian, A. M. (2016). Evaluation of structural efficiency of steel diagrid system for multi-story buildings. International Conference on Emerging Trends in Engineering, Science and Management, ICEIS-2016.