Mathematical Statistician and Engineering Applications
ISSN: 2094-0343
2326-9865

Comparative Study of the Seismic Performance of Tubular Frame, Diagrid, Pentagrid, and Hexagrid Structural Systems using ETABS

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Article Info
Page Number: 9588 – 9599
Publication Issue:
Vol 71 No. 4 (2022)

Article History
Article Received: *15 September 2022*
Revised: *25 October 2022*
Accepted: *14 November 2022*
Publication: *21 December 2022*

Abstract: The construction of multi-story buildings is rising quickly over the world. Taller buildings utilise the land more effectively than low-rise buildings, however as a building's height increases, lateral load-resisting systems become more necessary than gravity loads. To enhance the structural performance of tall structures in both lateral and gravity loads, various structural systems have recently been introduced. The current study aims to perform a seismic analysis using the response spectrum method on a multistory steel tube building with various structural systems, which include tubular frame, diagrid, pentagrid, and hexagrid. To achieve this, ETABS V.19 is used to design and analyse steel tube buildings. Models for seismic zone-V are compared for result parameters which include storey displacement, storey drift, and storey shear.

Keywords— Tubular Frame, Diagrid, Pentagrid, Hexagrid

1. Introduction

Due to their efficiency and sustainability, high-rise structures are more in demand nowadays, but the problem is to prevent collapse and earthquake strain. Numerous engineers are focusing on analysing these issues via the configuration of various structural systems. The ability to withstand lateral loads and distribute loads equally is one of the main goals of structural system configuration. The tubular frame, Diagrid, Pentagrid, and Hexagrid structural systems offer improved structural efficiency, stability, and strength.

1.1. Tubular Frame Structure

For tall buildings, tubular constructions have been frequently used as an effective structural system. Typical tube systems consist of perimeter moment-resisting frames that withstand all lateral stresses and inside frames that only support gravity loads. The tubular behaviour gives architects a great deal of flexibility when designing the interior space. Tubular systems were used in the construction of many extremely tall structures, such as the 110-story Willis Tower (Fig. 1(a)).

1.2. Diagrid Structure

Diagrid structures are a specific type of structural system that is made up of diagonal grids connected by horizontal rings and create a beautiful and redundant structure that is especially suitable for tall buildings. The 40-story Swiss Re Tower in London (Fig. 1(b)) and the 46-story Hearst Tower in New York (Fig. 1(c)) are two recent examples of buildings utilising diagrid structural systems that have become famous icons for their masterful architecture.

1.3. Pentagrid Structure

By cleverly arranging multiple technically advanced irregular pentagons that are alternately reversed in both horizontal and vertical orientations, the pentagrid structural system is created. This structural system was created using the multi-angle idea, in which all of the elements partially share both lateral and gravitational loads. The pentagrid structure artwork known as "Structure 6 C 2" was made by Gerard Caris in 1975 (Cornelie Leopold) (Fig. 1(c)).

1.4. Hexagrid Structure

The hexagonal (beehive) structural system is created when the horizontal and diagonal members intersect. By rerouting the member forces, hexagrid transmits both lateral and gravitational stresses. High-rise buildings don't need exterior vertical columns thanks to this cutting-edge structural design, which also offers fantastic interior panoramic vistas. The Sinosteel International Plaza in China (Fig. 1(e)) and Al Bahar in Abu Dhabi (Fig. 1(f)) are two examples of hexagrid structural systems.

Numerous researchers have studied the structural behaviour and seismic performance of structural systems namely the tubular frame, diagrid, pentagrid, and hexagrid. Shearwall structures outperform mesh structures in terms of structural efficiency (Hyun-Su Kim, 2005). The framed tube structures showed decreased stiffness and strength when compared to tube structures with diagonal braces. The braced tube structures showed greater strength than framed tube structures, but less overall ductility (JINKOO KIM, 2009). In comparison to non-uniform diagrid, uniform angle diagrid exhibits greater axial actions that more effectively withstand bending moments (Kyoung Sun Moon, 2008). In a diagrid structure connection, the rigid box component of the node's core, which also included the plastic hinge mechanism, was created near the end of the side stiffener (Young-Ju Kim, 2010). It improves the performance of the diagrid structure by adding more shear links (Nasim S. Moghaddasi B, 2013). For diagrid structures, tubular configurations are recommended because they are feasible, effective, and need less material (Giovanni Maria Montuori E. M., Secondary bracing systems for diagrid structures in tall buildings, 2014). Three models based on regular diagrid, varying angle diagrid, and varying density diagrid were compared, and it was found that model 1 of the varying angle diagrid was the most efficient (Giovanni Maria Montuori E. M., Geometrical patterns for diagrid buildings: Exploring alternative design strategies from the structural point of view, 2014). When compared to bundled-tube, braced-tube, and diagrid structures, the vertical double-layer space structure performs better under gravity and lateral stresses given to members in tension and compression rather than bending and shear (Hendry Yahya Sutjiadi, 2014). In facade structures, the bracing system is stiffer than the diagrid system, whereas in floor plans, compared to a square plan, a hexagonal plan is more-stiff (Arpitha L M, 2016). In the comparison of diagrid and iso truss grid (ITG) systems, the iso truss grid system showed slightly better structural efficiency in terms of the steel tonnage of the exterior columns and lateral displacement at the top (Tae-Heon Kim, 2017). By using the diagrid system, Compared to the traditional shear wall approach, the structural system's weight contribution is drastically reduced—by about 80% (H.M.A.D. Jayasundara, 2017). Diagrid structural system provides better planning flexibility for the building's interior and exterior spaces (Pooja Liz Isaac, 2017). In comparison to conventional braced structures, the diagrids provide more member stiffness (Mohammed Abdul Rafey, 2018). Compared to simple models, diagrid models have higher lateral stiffness (Swaral R. Naik, 2018). The efficiency and design of the diagrid system led to a reduction in the number of structural elements when compared to a conventional building frame (Neha Tirkey, 2019). In terms of all seismic zones, diagrids are stiffer than structures with shear walls (Thota Sai Charan, 2019). Shear walls perform better than diagrids when it comes to seismic vibrations in terms of slowing down the acceleration of buildings, although diagrids perform well in terms of lateral load resistance (Ravikiran G, 2019). The diagrid structural system is more economical in terms of the consumption of steel and concrete than a simple frame structure (Sawan Rathore, 2019). After using the response spectrum and time history methods, it was proved that the diagrid structure is stiffer and heavier than the shear wall structure (Mohammad Rafi

Uzzama, 2020). Diagrid has a higher resistance to lateral loads because of the diagonal columns on its periphery. As a result, inner columns relax, supporting only gravity loads (Rahul Birla, 2020). In comparison, the inner and outer columns of a conventional building are both designed for lateral and gravity loads.In comparison to pentagrid and hexagrid structural systems, diagrid with shear walls produces better performance (Naveen Rewapati, 2020). Pentagrid structure is more efficient than Hexagrid structure for lateral load resistance of tall building elements (Taranath S. D., 2014). Seismic performance tests reveal that diagrid structures are less ductile than hexagrid structures because they use a lot of belt trusses (Niloufar Mashhadiali, Proposing the hexagrid system as a new structural system for tall buildings, 2012). Under aberrant gravity loads, hexagrid systems outperformed diagrid systems in terms of ductility and capacity (Niloufar Mashhadiali, Progressive collapse assessment of new hexagrid structural system for tall buildings, 2013). Hexagrids, which are stretch-dominated structures, are intrinsically more rigid than diagrids, which are bending-dominated structures. As a result, they are more weight-efficient (Giovanni Maria Montuori M. F., 2015). The hexagrid structure, whose diagonal angle is 130°, increases the structural system's stiffness by reducing top storey displacement, time period, and structure mass (DIYA SUSAN EBIN, 2016). The diagrid system has better stiffness between the region of 63 to 75 degrees (diagonal angle) (Dr.Gopisiddappa, 2017). Compared to the tube and diagrid structural systems, the hexagrid system results in less lateral displacement (Saeed Kia Darbandsari, 2017). Hexagrid and diagrid systems both provide a more efficient shear distribution than conventional systems (Divya M. S., 2017). A honeycomb structure is shown to have a dead load that is 16% lower than a conventional structure, and after optimization, it is shown to be 38% lower (Zeba J. Sayyed, 2017). The hexagrid system is the most efficient since it has the least amount of lateral displacement and improves the building's architectural beauty. The outrigger system works effectively, but it also disturbs the architecture and leaves very little space for habitation (Zahid Manzoor, 2019). Minimum displacement occurs in G+30, G+40, and G+50 in the sequence C<L<Symmetric<T based on plan irregularity (X-direction) (Safiya Daliya Ahammed, 2019). In hexagrid structural systems, Models with variable density 1 performed better (P A Krishnan, 2019). The tall structure with a hexagrid structural system performs better against earthquakes than the diagrid system, allowing for greater fortification (Armin Mosavat, 2020). For tall tube-type RC buildings, diagrid and hexagrid systems are recommended (Meman Suraiyabanu, 2020). When compared to diagrid and shear wall structures, the displacement value for the hexagrid structure is higher (SAYED AADIL SAYED MISBAHUL ABEDIN, 2021). Hexagrid is more effective than diagrid because of its low weight, low base shear, and low storey displacement (Nimisha K J, 2021).

(a) (b)

(c) (d)

(e) (f)

Figure 1: Examples of Structural System: (a) Willis Tower, Chicago (britannica.com) (b) Swiss Re Tower, London (pinterest.jp) (c) Hearst Tower, New York (pinterest.com) (d), Structure 6 C 2, Gerard Caris (Cornelie Leopold) (e) Sinosteel Tower, China (2.bp.blogspot.com) and (f) Al Bahar, Abu Dhabi (assets.newatlas.com)

2. Objective

i. Design and analysis of facade shapes of the tubular frame, diagrid, pentagrid, and hexagrid structure by response spectrum method using ETABS software.
ii. To compare the performance of the tubular frame, diagrid, pentagrid, and hexagrid tall building based on storey shear, deflection and storey drift under earthquake action.
iii. To check the performance of pentagrid structure by changing the orientation.
iv. To check the performance of hexagrid structure by changing the orientation.

3. Methodology And Analysis

In this section, the methodology is explained through a flowchart (Fig. 2).

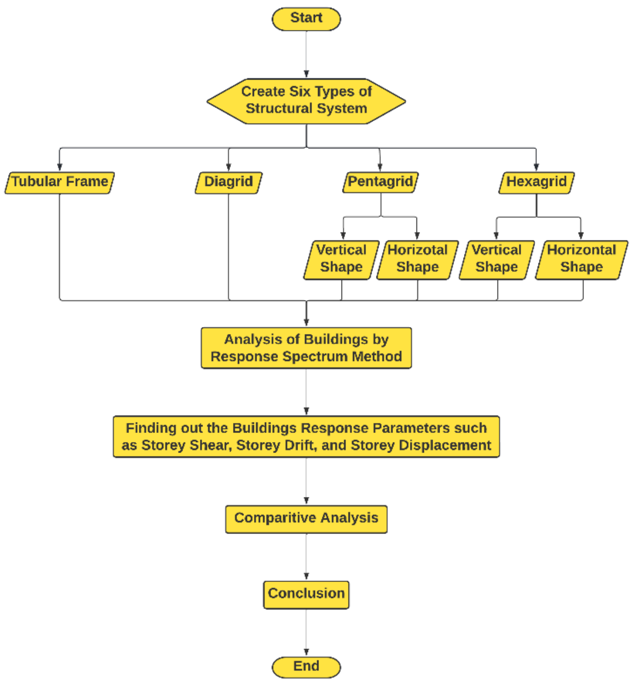


Figure 2: Flowchart of Methodology

3.1. Response Spectrum Method

To record the structural behaviour under a linear dynamic load, the response spectrum approach is applied. This approach is used to calculate a building's seismic load.

3.2. Building Configuration

Because of the structural system's effectiveness and distinctive design, high-rise structures are using it more frequently. Six different facade patterns have been generated using the tall building model, and their geometrical characteristics, weight, and structural performance have been evaluated. The reference building is 30 stories tall, with a square plan measuring 24 m x 24 m and a central core measuring 12 m x 12 m. Its total height is 90 m, including each storey's 3 m height (Kutbuddin A Ranpurwala, 2021). Every joint, including the supports and framework, is fixed. In Fig. 3, the floor framing plan is shown.

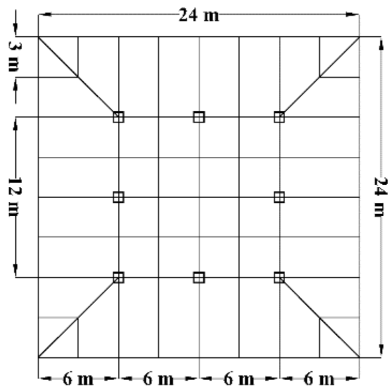


Figure 3: Floor Plan of Building

The dimension of the tubular section used in the internal column, beam, and outermost framework that resists lateral and gravitational loads are shown in Fig. 4.

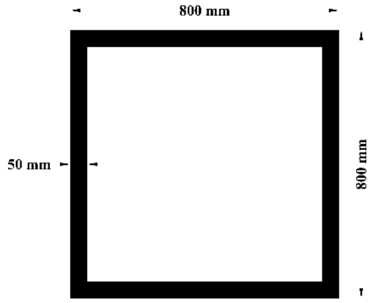


Figure 4: Tubular Section

3.3. Building Elevation

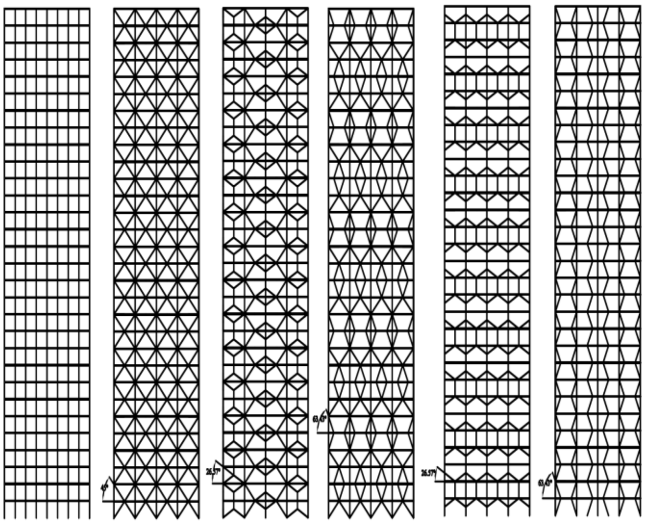
According to various façade patterns, the elevations are taken into consideration for the study as shown below (Fig. 5).

Tubular Frame Structure: In this section, with a single-storey module height and four pieces (Fig. 6a), each level produces a consistent pattern (JINKOO KIM, 2009) (Fig. 5a).

Diagrid Structure: In this section, the final design contains four parts in each diagrid shape of a tubular element (Fig. 5b), with constant module size and consistent diagonal density, and two-storey module height and constant angle (Jinkoo Kim, 2010) (Fig. 6b).

Pentagrid Structure: In this section, (Fig. 5c-d) by switching the module's orientation from horizontal to vertical and producing two models with constant forms and two-storey module height, a pattern with constant module size and five elements in each pentagrid shape of a tubular structure was produced (Cornelie Leopold) (Fig. 6c).

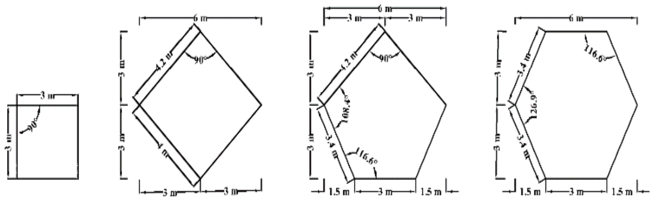
Hexagrid Structure: In this section, (Fig. 5e-f) By switching the module's orientation from horizontal to vertical and making two models with fixed shapes and two-storey module height, a pattern with fixed module size and six elements in each hexagrid shape of a tubular structure was produced (Mobi Ria Mathews, 2016) (Fig. 6d).



(a) (b) (c) (d) (e) (f)

Figure 5: Elevation of Buildings: (a) Tubular Frame; (b) Diagrid; (c) Vertical Pentagrid; (d) Horizontal Pentagrid; (e) Vertical Hexagrid; (f) Horizontal Hexagrid

Figure 6 illustrates the module dimensions with angles based on shape configuration.



(a) (b) (c) (d)

Figure 6: Based on shape configuration: (a) Tubular Frame Structure; (b) Diagrid Structure; (c) Pentagrid Structure; (d) Hexagrid Structure

3.4. Analysis Data

ETABS software is used to do the analysis. The IS 1893 (Part-1):2016 (Navanit Patel) seismic parameters are cited. The response spectrum method has been chosen to assess seismic parameters. Self-weight and live load were considered to be 1 and 2 kN/m^2, respectively. For the examination of the structure, the following materials with different grades were considered: Fe345 grade steel for the inner column, beam, and outermost framework, and M30 grade concrete for the 150 mm thick slab. Table 1 mentions the seismic factor for the lateral load analysis.

Table 1: Seismic Consideration

Particulars	**Values**
Seismic Zone	V
Seismic Zone Factor	0.36
Important Factor	1
Soil Type	Medium
Response Reduction Factor	5
Function Damping Ratio	5%
Modal Combination Method	CQC
Directional Combination Type	SRSS
Diaphragm Eccentricity	5%

4. Results and Discussion

Three parameters are used to compare and show the outcome of six different types of structures.

4.1. Storey shear

In this section, The graph shows that the storey shear started at 30 storey and increased gradually until it reached 1 storey (Fig. 7).

4.2. Storey Displacement

In this section, the storey displacement started at 1 storey and increased gradually until it reached 30 storey, as shown in the graph. (Fig. 8).

4.3. Storey Drift

In this section, according to the graph, the storey drift started at 1 storey and increased irregularly or regularly until it reached 30 storey (Fig. 9).

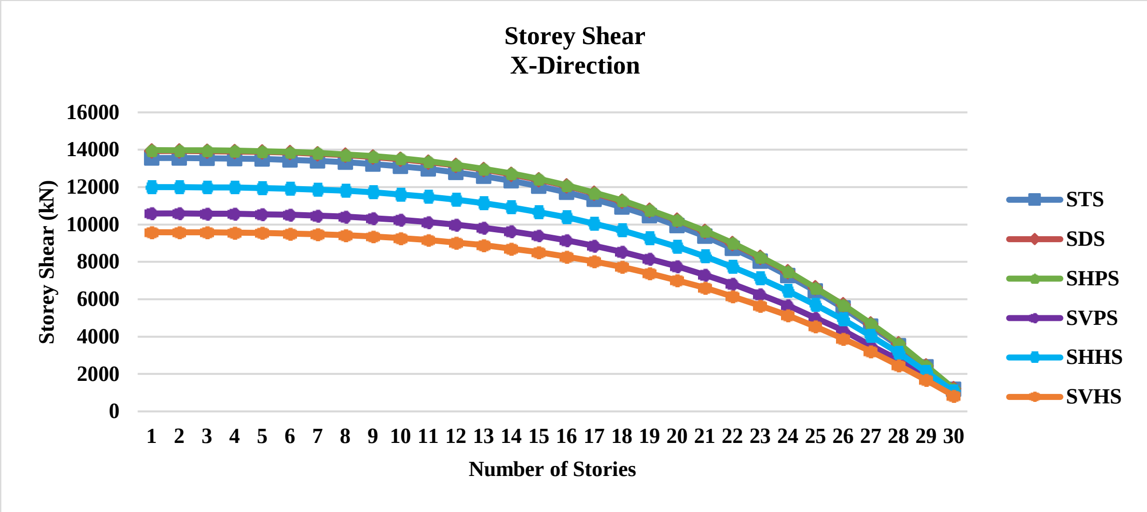


Figure 7: Storey Shear at Bottom

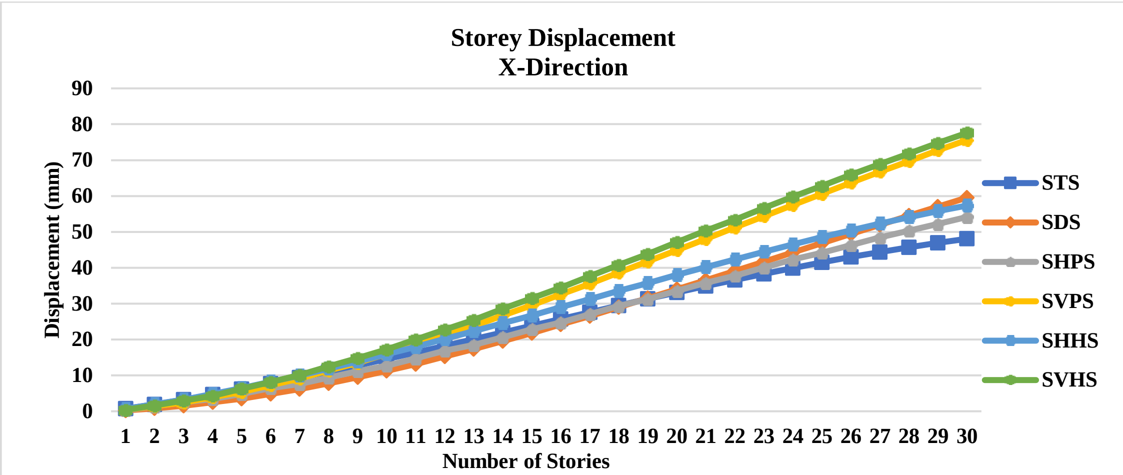


Figure 8: Storey Displacement at X-Direction

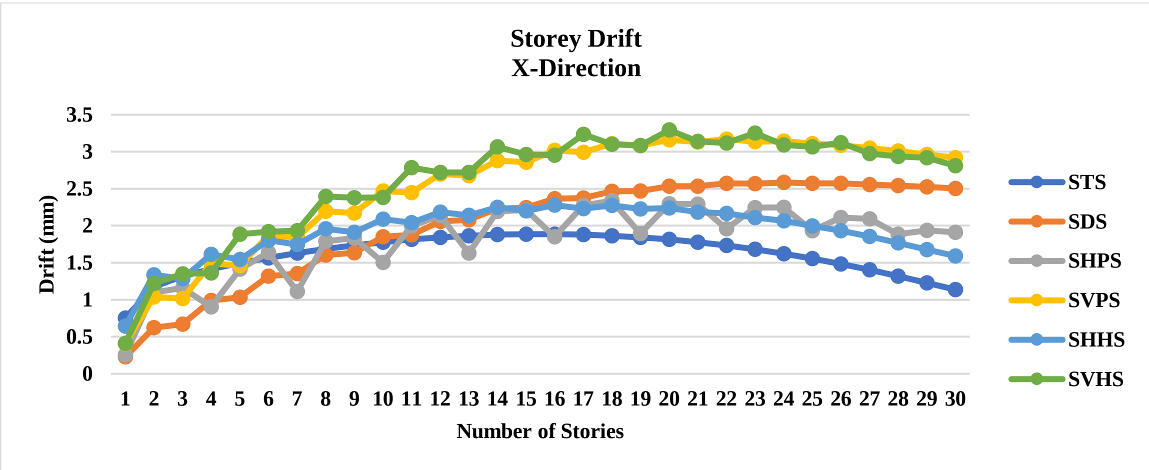


Figure 9: Storey Drift at X-Direction

5. Conclusion

This study presents a comparison of the diagrid, pentagrid, hexagrid, and tubular frame structures. Here are some of the analysis's findings, including storey shear, storey displacement, and storey drift. The study's conclusions are listed below:

i. In storey shear, the horizontal pentagrid structure had the maximum weight, whereas the vertical hexagrid structure had the minimum weight. The six buildings are arranged in ascending order according to the graph, SVHS<SVPS<SHHS<STS<SDS<SHPS. The number of elements at each floor's outermost structure affects the weight of the building.
ii. Similar weight was shown in storey shear for the horizontal pentagrid structure and the diagrid structure.
iii. A vertical hexagrid structure weight was 9.48% less than a vertical pentagrid structure, and a tubular frame structure weight of 2.68% less than a diagrid structure.
iv. In storey displacement, the vertical hexgrid structure has maximum structural behaviour, while the tubular frame structure showed minimum structural behaviour. The six buildings are arranged in ascending order according to the graph, STS<SHPS<SHHS<SDS <SVPS<SVHS. The stiffness of the elements determines whether the structural behaviour increases or decreases.
v. Vertical pentagrid and vertical hexagrid structures showed similar structural behaviour in storey displacement.
vi. The tubular frame structure showed 11.22% stiffer than the horizontal pentagrid structure.
vii. In storey drift, vertical hexgrid structure showed irregular and maximum structural behaviour, whereas tubular frame structure showed regular and minimum structural behaviour. The six buildings are arranged in ascending order according to the graph, STS<SHHS <SHPS<SDS<SVHS<SVPS. The irregular structural behaviour is due to stiffness irregularity (Navanit Patel).
viii. The horizontal pentagrid structure was more irregular than the diagrid structure.
ix. The structural behaviour increases in storey displacement and storey drift after switching from a horizontal to a vertical orientation, while it reduces in storey shear.

Acknowledgement

I'm thankful to God for giving me the strength and knowledge that need to complete this work and also thankful to Barkha Verma (Assistant Professor), who suggested the idea, edited this paper, and significantly improved the manuscript.

References

[1] Armin Mosavat. (2020). A Comparative Study on Seismic behavior of Tall Structures with Hexagrid and Diagrid Systems by using Non-linear Dynamic Analysis. *Advance Researches in Civil Engineering, 2*, 15-23.

[2] Arpitha L M, S. T. (2016). Comparative Study of Diagrid Structures over Braced tube Structures. *International Journal of Innovative Research in Science, Engineering and Technology, 5*(7), 13652-13660. doi:10.15680/IJIRSET.2016.0507209

[3] Cornelie Leopold. (n.d.). Geometry and Aesthetics of Pentagonal Structures in the Art of Gerard Caris. *Bridges Finland Conference Proceedings.* Descriptive Geometry Technical University of Kaiserslautern Pfaffenbergstrasse 95 D-67663 Kaiserslautern, Germany.

[4] Divya M. S., B. S. (2017). COMPARATIVE ANALYSIS OF HIGH RISE STEEL BUILDING WITH HEXAGRID, DIAGRID AND CONVENTIONAL STRUCTURAL SYSTEM. *International Research Journal of Engineering and Technology (IRJET), 04*(04), 1902-1905. Retrieved from www.irjet.net

[5] DIYA SUSAN EBIN, a. D. (2016). STUDY ON STRUCTURAL BEHAVIOUR OF HEXAGRID STRUCTURAL SYSTEMS IN MULTI STOREY BUILDINGS. *Int. J. Chem. Sci., 14*, 330-340. Retrieved from http://www.sadgurupublications.com/

[6] Dr.Gopisiddappa, M. S. (2017). PERFORMANCE STUDY OF HIGH RISE BUILDING WITH DIAGRID SYSTEM UNDER DYNAMIC LOADING. *International Research Journal of Engineering and Technology (IRJET), 04*(06), 2690-2695. Retrieved from www.irjet.net

[7] Giovanni Maria Montuori, E. M. (2014). Geometrical patterns for diagrid buildings: Exploring alternative design strategies from the structural point of view. *Engineering Structures, 71*, 112-127. Retrieved from http://www.elsevier.com/locate/engstruct

[8] Giovanni Maria Montuori, E. M. (2014, June). Secondary bracing systems for diagrid structures in tall buildings. *Engineering Structures, 75*, 477-488. Retrieved from http://www.elsevier.com/locate/engstruct

[9] Giovanni Maria Montuori, M. F. (2015, April 19). Hexagrid – hexagonal tube structures for tall buildings: patterns, modeling, and design. *THE STRUCTURAL DESIGN OF TALL AND SPECIAL BUILDINGS, 24*, 912–940. doi: 10.1002/tal.1218

[10] H.M.A.D. Jayasundara, S. K. (2017, November). Comparative Study of Diagrid System and Shear Wall System for Resisting Wind Loads Using Different Design Approaches. *SOCIETY OF STRUCTURAL ENGINEERS, SRI LANKA*. Retrieved from https://www.researchgate.net/publication/321309498

[11] Hendry Yahya Sutjiadi, a. A. (2014, November 7). Structural design and analysis of vertical double-layer space structures in super-tall buildings. *THE STRUCTURAL DESIGN OF TALL AND SPECIAL BUILDINGS, 23*, 512–525. doi:10.1002/tal.1057

[12] Hyun-Su Kim, D.-G. L. (2005, February 17). Efficient three-dimensional seismic analysis of a high-rise building structure with shear walls. *Engineering Structures, 27*, 963–976. doi:10.1016/j.engstruct.2005.02.006

[13] Jinkoo Kim, a. Y.-H. (2010). Seismic performance evaluation of diagrid system buildings. *THE STRUCTURAL DESIGN OF TALL AND SPECIAL BUILDINGS*. doi:10.1002/tal.643

[14] JINKOO KIM, J. P.-W.-W. (2009). SEISMIC PERFORMANCE OF TUBULAR STRUCTURES WITH BUCKLING RESTRAINED BRACES. *THE STRUCTURAL DESIGN OF TALL AND SPECIAL BUILDINGS, 18*, 351–370. doi:10.1002/tal.420

[15] Kutbuddin A Ranpurwala, V. V. (2021, April). A Comparative Study on Different Exterior Vertical Grid System in Tall Building. *International Journal of Advanced Research in Science, Communication and Technology (IJARSCT), 4*(2), 392-402. doi:10.48175/IJARSCT-1041

[16] Kyoung Sun Moon. (2008, May 27). Optimal Grid Geometry of Diagrid Structures for Tall Buildings. *Architectural Science Review, 51:3*, 239-251. doi:10.3763/asre.2008.5129

[17] Meman Suraiyabanu, M. S. (2020, July). COPARATIVE STUDY OF DIAGRID SYSTEM, HEXAGRID SYSTEM AND SHEAR WALL SYSTEM IN TALL TUBE-TYPE BUILDING. *Multidisciplinary International Research Journal of Gujarat Technological University, 2*(2), 118-131.

[18] Mobi Ria Mathews, J. M. (2016). A Study on the Seismic Performance of Hexagrid System with Different Patterns. *Applied Mechanics and Materials, 857*, 30-35. doi:10.4028/www.scientific.net/AMM.857.30

[19] Mohammad Rafi Uzzama, a. S. (2020). ANALYSIS OF HIGH RAISED STRUCTURES IN DIFFERENT SEISMIC ZONES WITH DIAGRID AND SHEAR WALLS USING E-TABS. *6*(1), 309-318. Retrieved from http://www.ijariie.com/

[20] Mohammed Abdul Rafey, a. M. (2018, January). Comparative Analysis of a Diagrid Structure and a Conventional Structure with Chevron Bracing. *International Journal of Applied Engineering Research, 13*, 12311-12317. Retrieved from http://www.ripublication.com

[21] Nasim S. Moghaddasi B, a. Y. (2013, September). Seismic analysis of diagrid structural frames with shear-link fuse devices. *EARTHQUAKE ENGINEERING AND ENGINEERING VIBRATION, 12*, 463-472. doi:10.1007/s11803-013-0186-9

[22] Navanit Patel. (n.d.). Criteria For Earthquake Resistant Design of Structures. In *IS 1893 (Part1):2016.* IDOC.

[23] Naveen Rewapati, a. P. (2020). An Assessment Of Diagrid, Pentagrid And Hexagrid. *International Journal of Science, Engineering and Technology*.

[24] Neha Tirkey, a. G. (2019). Analysis on the diagrid structure with the conventional building frame using ETABS. *Materials Today: Proceedings*. Retrieved from http://www.elsevier.com/locate/matpr
[25] Niloufar Mashhadiali, a. A. (2012). Proposing the hexagrid system as a new structural system for tall buildings. *THE STRUCTURAL DESIGN OF TALL AND SPECIAL BUILDINGS*. doi:10.1002/tal.1009
[26] Niloufar Mashhadiali, a. A. (2013, May 12). Progressive collapse assessment of new hexagrid structural system for tall buildings. *THE STRUCTURAL DESIGN OF TALL AND SPECIAL BUILDINGS*. doi:10.1002/tal.1097
[27] Nimisha K J, B. V. (2021). Seismic Performance of Combined Grid System on Tall Structures with Irregularity Condition. *International Journal of Research in Engineering and Science (IJRES), 9*(7), 14-28. Retrieved from http://www.ijres.org/
[28] P A Krishnan, R. K. (2019, July). A Study on Seismic Performance of Hexagrid Structures. *International Journal of Engineering Research And Management (IJERM), 06*(07), 38-45. Retrieved from www.ijerm.com
[29] Pooja Liz Isaac, B. A. (2017, May). Comparative Study of Performance of High Rise Buildings with Diagrid, Hexagrid and Octagrid Systems under Dynamic Loading. *International Research Journal of Engineering and Technology (IRJET), 04*(05), 2840-2846. Retrieved from www.irjet.net
[30] Rahul Birla, H. S. (2020, Sept-Oct). Structural Behaviour of Hexagrid and Diagrid Comparison System in Staadpro. *International Journal of Scientific Research & Engineering Trends, 6*(5), 3206-3211.
[31] Ravikiran G, H. R. (2019, Jun). Comparative Study on the Seismic Behaviour of Diagrid Structure and Shear Wall Structure. *International Journal for Research in Applied Science & Engineering Technology (IJRASET), 7*(VI), 2720-2725. Retrieved from http://www.ijraset.com/
[32] Saeed Kia Darbandsari, a. M. (2017). A Comparative Study on Seismic Performance of Hexagrid, Diagrid, and Tubular Structural Systems. *Journal of Structural Engineering an d Geotechnics, 7*(1), 55 -65.
[33] Safiya Daliya Ahammed, s. S. (2019, February 2). Seismic Behaviour of Hexagrid Type Structural System. *International Journal of Engineering Research & Technology (IJERT), 8*(2), 169-173. Retrieved from http://www.ijert.org/
[34] Sawan Rathore, P. S. (2019, December). Dynamic Analysis of Diagrid Structural System for R.C. Building Structure. *International Journal for Research in Applied Science & Engineering Technology (IJRASET), 7*(XII), 48-56. Retrieved from www.ijraset.com
[35] SAYED AADIL SAYED MISBAHUL ABEDIN, P. P. (2021, June). Study On High Rise (G+40) Story Building With Diagrid, Hexagrid And Shear Wall Against Earthquake. *International Research Journal of Engineering and Technology (IRJET), 08*(06), 3309-3312. Retrieved from http://www.irjet.net/
[36] Swaral R. Naik, a. D. (2018, December). Earthquake responses of diagrid buildings and conventional moment frame buildings having different H/B ratio considering seismic non-linear time history analysis. *International Journal of Civil Engineering and Technology (IJCIET), 9*(13), 1532-1539. Retrieved from http://www.iaeme.com/IJCIET/index.asp
[37] Tae-Heon Kim, H.-U. L.-C. (2017). Development of a building structural system using an IsoTruss grid. *Procedia Engineering, 171*, 1077-1084. Retrieved from www.elsevier.com/local/procedia
[38] Taranath S. D., M. N. (2014, August). Comparative Study of Pentagrid and Hexagrid Structural System for Tall Building. *Journal of Civil Engineering and Environmental Technology, Volume 1*, 10-15.
[39] Thota Sai Charan, D. V. (2019, September). Design and Analysis of Diagrid and Shear Wall Structures Subjected to Seismic Loads. *International Journal of Innovative Technology and Exploring Engineering (IJITEE), 8*(11), 3725-3733. doi:10.35940/ijitee.K2567.0981119
[40] Young-Ju Kim, I.-Y. J.-K.-J.-D. (2010, September). Cyclic Behavior of Diagrid Nodes with H-Section Braces. *JOURNAL OF STRUCTURAL ENGINEERING © ASCE*, 1111-1122. doi:10.1061/(ASCE)ST.1943-541X.0000203

[41] Zahid Manzoor, G. S. (2019, May). Analytical Study on Outrigger and Hexagrid System in High-Rise Buildings. *International Journal of Innovative Technology and Exploring Engineering (IJITEE), 8*(7), 367-371.
[42] Zeba J. Sayyed, P. A. (2017, July). Seismic Analysis of Honeycomb Structure over Conventional Structure with the Comparative Study by Using STAAD PRO. *International Journal of Innovative Science and Research Technology, 2*(7), 260-264. Retrieved from www.ijisrt.com
[43] Vadivu, N. S., Gupta, G., Naveed, Q. N., Rasheed, T., Singh, S. K., & Dhabliya, D. (2022). Correlation-based mutual information model for analysis of lung cancer CT image. BioMed Research International, 2022, 6451770. doi:10.1155/2022/6451770
[44] Veeraiah, D., Mohanty, R., Kundu, S., Dhabliya, D., Tiwari, M., Jamal, S. S., & Halifa, A. (2022). Detection of malicious cloud bandwidth consumption in cloud computing using machine learning techniques. Computational Intelligence and Neuroscience, 2022 doi:10.1155/2022/4003403