Evaluation of Frame in Tube Structureswith a Combination of Vertical Irregularites for Various Shaped Plan Configuartions

Mohd Nouman Sahariar[1], Syed Khaleelullah Shah Quadri[2],
[1]M.E Student, [2]Assistant Professor, [1]Department of Civil Engineering,
[1]Nawab Shah Alam Khan College of Engineering and Technology, Hyderabad, India.

Abstract: **The rapid increase in population and urbanization has intensified the demand for land, making tall structures a critical solution to address space constraints. Historically, structural design primarily focused on resisting gravity loads; however, the rise in building heights and the understanding of seismic zones necessitate the consideration of lateral loads such as wind and earthquake forces. Advances in three-dimensional structural analysis and computational power have enabled the efficient and secure construction of taller buildings. Modern design approaches prioritize minimizing structural motion over traditional strength-based methods to ensure stability and performance.**

This study investigates the seismic behavior of irregular building frames employing tube systems, which are increasingly favored for their excellent resistance to lateral forces and suitability for tall structures. A time history analysis was performed on six G+40-storey reinforced concrete buildings located in Zone-V, as defined by IS 1893.Among these, four buildings feature irregular plans, while two have regular plans, with all models designed without shear walls. The study examines the seismic performance of these buildings under the influence of mass-stiffness irregularity and setback-stiffness irregularity. Key parameters analyzed include overall building drift, storey drift, storey shear, storey acceleration, and storey torsion.

The findings of this research aim to provide insights into optimizing the seismic design of tall buildings, especially those with irregular configurations, contributing to the advancement of safe and resilient high-rise constructionpractices.

Keywords: Seismic behavior, Frame in tube system, Linear Time history analysis, Mass – Stiffness irregularity and Setback Stiffness irregularity

I.INTRODUCTION

Earthquakes are dynamic and unpredictable phenomena that impose significant demands on structural engineering, particularly in high-rise construction. Modern design philosophies emphasize not only ensuring the safety of human life but also enhancing the performance of structures during seismic events. High-rise buildings, due to their height and slenderness, are inherently vulnerable to lateral forces induced by wind and seismic activity. These lateral forces often lead to excessive storey displacements, structural instability, and potential collapse if not adequately addressed.

The growing demand for tall structures, driven by urbanization and limited land availability, has necessitated the adoption of advanced lateral load-resisting systems. Among these, tubular structural systems—such as framed tubes, trussed tubes, tube-in- tube, bundled tubes, and hybrid systems—have gained prominence. These systems leverage the concept of a hollow cantilevered tube, offering enhanced stiffness, reduced material consumption, and efficient resistance to lateral forces. The configuration of these systems, which integrates tightly spaced perimeter columns anddeep spandrel beams, ensures that both gravity and lateral loads are effectively distributed and resisted.

Dynamic analysis is critical for evaluating the seismic performance of tall buildings. Unlike static analysis, which assumes constant loading, dynamic analysis considers the time-dependent nature of seismic forces, capturing the complex interplay of inertia, damping, and stiffness. This approach enables the accurate prediction of structural responses, including storeydrift, torsion, and shear distribution.

This study investigates the seismic behavior of irregular high-rise reinforced concrete frames designed with tubular systems. The focus is on understanding the influence of plan irregularities (suchas re-entrant corners and torsional effects) and verticalirregularities (such as stiffness and setback irregularities) on seismic performance. The research employs time history analysis in Zone-V seismic conditions, as per IS 1893 guidelines, to evaluate parameters including overall building drift, storey drift, storey shear, storey acceleration, and torsional behavior. The findings aim to contribute to the optimization of high-rise designs for enhanced seismicresilience and structural efficiency.

II.OBJECTIVE OF THE STUDY

To analyze the performance of high-rise structures under lateral loads using linear time history analysis.

To Study the behavior of Frame in tube structures with different plan configurations with vertical irregularities

To study the forced vibration behavior (Base shear, strorey drift, storey shear, Torsion displacement). By performing linear dynamic analysis to all models with the combination of Mass - stiffness irregularity and Setback – Stiffness irregularity

III.NEED OF STUDY

Modern architectural designs frequently incorporate irregular structures characterized by discontinuities in geometry, mass, or load-bearing components, as opposed to regular structures with symmetrical configurations. Plan irregularities, often unavoidable due to asymmetrical land availability, generate significant torsional forces, necessitating an assessment of high-rise framed tube buildings with such configurations.

The growing demand for tall buildings, driven by population growth and advancements in structural analysis and construction technology, has heightened their vulnerability to lateral forces such as earthquakes and wind. Ensuring safety, serviceability, and economy in structural design is paramount, particularly in seismic regions. Past earthquakes have demonstrated the catastrophic failure of traditional designs, with excessive storey displacement being a critical factor in structural collapse.

This study addresses the challenges posed by irregular layouts, focusing on the performance of high-rise framed tube systems under seismic conditions to enhance resilience and ensure structural safety.

IV.SCOPE OF THE STUDY

This study focuses on the seismic performance of seven G+40 reinforced concrete (RCC) structures with different plan dimensions and column arrangements. The models were designed to replicate tubular structural behavior, with columns placed at close intervals along the periphery of the plan to form a framed tube system. Specifically, the peripheral columns were spaced at 2-meter intervals, while the inner columns were spaced at 4-meter intervals. This configuration ensures the structure behaves like a tubular system, enhancing its lateral load resistance. All models were designed without shear walls, with auniform floor-to-floor height of 3 meters.

The study incorporates two types of irregularity conditions: mass-stiffness irregularity and setback-stiffness irregularity. These irregularities are critical to understanding the behavior of tall buildings with non-uniform geometries and mass distributions under seismic loads. The buildings were analyzed under Zone-V seismic conditions, adhering to the guidelines of IS 1893-2016, which represents the highest seismic hazard level in India.

Linear Time History Analysis was employed as the primary method to evaluate the dynamic response of these structures. This analysis was conducted using ETABS 2019 software, which provides robust tools for modeling, analysis, and design of high-rise buildings. The results of this study offer valuable insights into the performance of framed tube systems in seismic regions, aiding in the development of safer and more resilient designs for tall buildings.

V.METHODOLOGY

The methodology focuses on evaluating the seismic performance of structures through Linear Time History Analysis, a dynamic approach that determines structural responses like displacements and forces under time-dependent earthquake loads. The dynamic equilibrium equation Ku(t)+Cdtdu(t)+Mdt2d2 u(t)=r(t) was solved using Modal Superposition and Direct Integration Methods, with nonlinear material properties approximated as linear elastic for simplicity. ETABS 2019 software was employed for three-dimensional modeling, analysis, and design. In the models, walls and slabs were represented as shell elements to provide in-plane stiffness, while slabswere treated as rigid diaphragms. The out-of-plane bending stiffness of slabs was neglected to account for potential cracking caused by creep and shrinkage. This comprehensive approach facilitated an accurate assessment of the dynamic behavior and seismic resilience of the structures.

VI.MODEL INFORMATION

In this study, 7 RCC structures of G+40 storeys having various plan dimensions (as described below) and column arrangement is selected. The models are made in such a way that they behave like a tubular structure. All the models are made without shear wall. The columns in the periphery of the plan are placed very close at a distance of 2 meters to each other so that it behaves like tube. The columns in the inner area of the plan are placed at a distance of 4 meters. In this way the structure is made like Framed Tube Structure. A floor-to-floor height of 3m is assumed with Mass - Stiffness Irregularity combination and Setback - Stiffness Irregularity combinations. The location of the buildings is assumed to be in Zone-V according to IS 1893. By using ETABS 2019 software, which helps to analyse and design the models, the analysis method used for this study is the Linear Time History Analysis for dynamic analysis for providing force vs. displacements curves.

Shapes:

- Square Shape
- Rectangle Shape
- Plus – Shape
- L – Shape
- C – Shape
- T – Shape
- Model Details
  - Building Height: 123m (G+40)
  - Storey Height: 3m
  - Plan Area:
- Square Shape: 2304 m2
- Rectangle Shape: 2304 m2
- Plus – Shape: 2304 m2o
- RCC Frame: SMRF
  - Live Load: 3 kN/ m2
  - Floor Load: 1.5 kN/ m2
  - Wall Load: 7kN/m
  - Seismic Load: Zone V
- L – Shape: 2304 m2
- C – Shape: 2304 m2
- T – Shape: 2304 m2
- Mass - Stiffness Irregularity combination and Setback - Stiffness Irregularity combination
- Importance Factor – 1.5
- Response Reduction Factor – 5
- Soil Type – 1 (Hard Soil)
  - Calculated using Excel Sheet and Imported in ETABS.

Models:

Mass - Stiffness Irregularity:

M1. Square Shape

M2. Rectangle Shape

M3. L – Shape

M4. C – Shape

M5. T – Shape

M6. Plus – Shape

Setback - Stiffness Irregularity:

M7 Square Shape

M8. Rectangle Shape

M9. L – Shape

M10. C – Shape

M11. T – Shape

M12. Plus – Shape

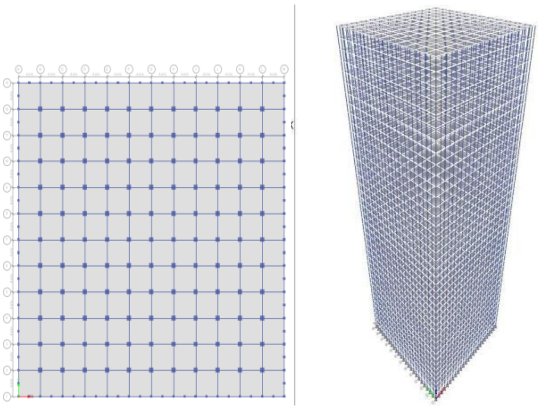

Fig.1 Plan view and 3-Dimensional view of Square - Shape model

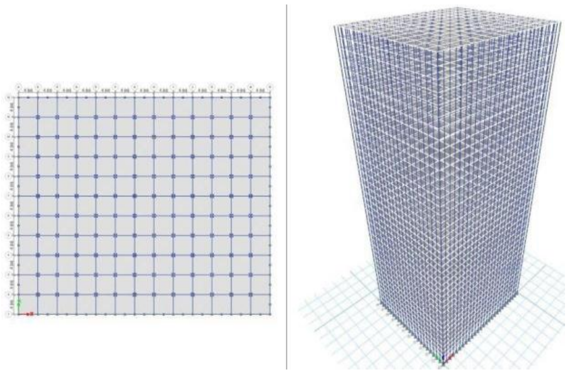

Fig.2 Plan view and 3-Dimensional view of rectangle - Shape model

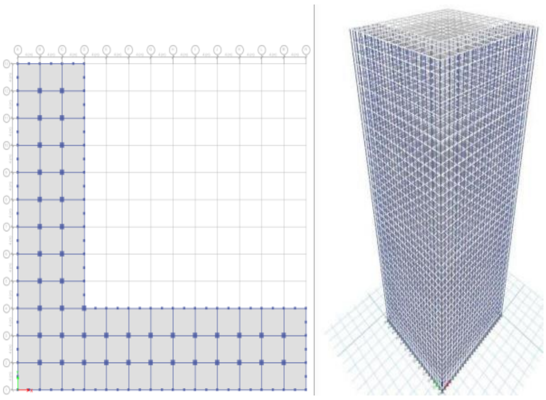

Fig.3 Plan view and 3-Dimensional view of L -Shape model

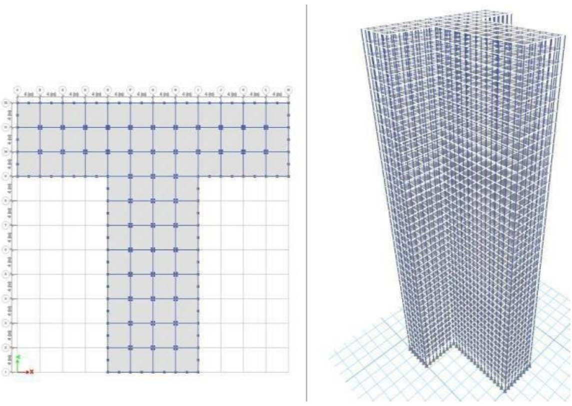

Fig.4 Plan view and 3-Dimensional view of T -Shape model

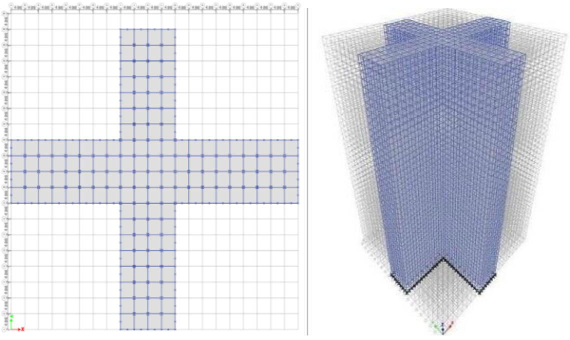

Fig.5 Plan view and 3-Dimensional view of Plus -Shape model

VII.RESULTS AND DISCUSSION

Mass - Stiffness Irregularity

Base shear

- In L- shaped model the Base Shear is 13.11% lessthan T- shaped model and 16.82% less than C- shaped model.
- In T- shaped model the Base Shear is 3.28 % less than C- shaped model.
- In Square shaped model the Base Shear is 0.51% less than Plus shaped model and 0.88% less than Rectangle shaped model.
- In Plus shaped model the Base Shear is 0.37% lessthan Rectangle shaped model

Storey Drift

- In T- shaped model the Storey Drift is 11.25% lessthan C- shaped model and 18.27% less than L- shaped model.
- In C- shaped model the Storey Drift is 6.31 % lessthan L- shaped model
- In Plus shaped model the Storey Drift is 1.63% lessthan Rectangle shaped model and 2.77% less than Square shaped model.
- In Rectangle shaped model the Storey Drift is 1.12%less than Square shaped model

Storey Shear

- In L- shaped model the Storey Shear is 22.3% less than T- shaped model and 26.3% less than C- shapedmodel.
- In T- shaped model the Storey Shear is 3.27 % lessthan C- shaped model.
- In Plus shaped model the Storey Shear is 0.52% lessthan Rectangle shaped model and 3.26% less than Square shaped model.
- In Rectangle shaped model the Storey Shear is 2.72% less than Square shaped model.

Storey Torsion

- In L- shaped model the Storey Torsion is 11.92% less than C- shaped model and 58.16% less than T-shaped model.
- In C- shaped model the Storey Torsion is 41.32 %less than T- shaped model.
- In Square shaped model the Storey Torsion is 7.6% less than Rectangle shaped model and 75.66% less than Plus shaped model.
- In Rectangle shaped model the Storey Torsion is 63.25% less than Plus shaped model.

Storey Displacement

- In L- shaped model the Storey Stiffness is 0.16% less than T- shaped model and 1.12% less than C-shaped model.
- In T- shaped model the Storey Stiffness is 0.95 %less than C- shaped model

- In Square shaped model the Storey Stiffness is 0.47% less than Rectangle shaped model and 1.77%less than Plus shaped model.
- In Rectangle shaped model the Storey Stiffness is1.29% less than Plus shaped model

Setback - Stiffness IrregularityBase shear

- In L- shaped model the Base Shear is 0.9% less thanC- shaped model and 3% less than T- shaped model.
- In C- shaped model the Base Shear is 2.1 % less than T- shaped model
- In Square shaped model the Base Shear is 2.21% less than Plus shaped model and 2.75% less than Rectangle shaped model.
- In Plus shaped model the Base Shear is 0.53% lessthan Rectangle shaped model

Storey Drift

- In T- shaped model the Storey Drift is 29.51% lessthan L- shaped model and 37.69% less than C- shaped model.
- In L- shaped model the Storey Drift is 6.31 % lessthan C- shaped model.
- In Square shaped model the Storey Drift is 2.72%less than Plus shaped model and 4.41% less than Rectangle shaped model.
- In Plus shaped model the Storey Drift is 1.64% lessthan Rectangle shaped model.

Storey Shear

- In L- shaped model the Storey Shear is 4.34% less than C- shaped model and 6.53% less than T- shapedmodel.
- In C- shaped model the Storey Shear is 2.1 % less than T- shaped model.
- In Square shaped model the Storey Shear is 2.22%less than Plus shaped model and 2.75% less than Rectangle shaped model.
- In Plus shaped model the Storey Shear is 0.52% lessthan Rectangle shaped model.

Storey Torsion

- In L- shaped model the Storey Shear is 11.92% lessthan C- shaped model and 58.16% less than T- shaped model.
- In C- shaped model the Storey Shear is 41.31 % lessthan T- shaped model.
- In Square shaped model the Storey Shear is 7.6% less than Rectangle shaped model and 75.66% lessthan Plus shaped model.
- In Rectangle shaped model the Storey Shear is 63.25% less than Plus shaped model.

Storey Displacement

- In T- shaped model the Storey Shear is 9.34% lessthan L- shaped model and 24.98% less than C- shaped model.
- In L- shaped model the Storey Shear is 14.31 % lessthan C- shaped model
- In Square shaped model the Storey Shear is 6.05% less than Rectangle shaped model and 7.42% less than Plus shaped model.
- In Rectangle shaped model the Storey Shear is 1.29% less than Plus shaped model.

VIII.CONCLUSION

This study assessed the seismic performance of structural configurations with a focus on Mass-Stiffness Irregularity and Setback-Stiffness Irregularity. The analysis considered key parameters such as base shear, storey drift, storey shear, storey torsion, and storey displacement. The findings reveal:

Mass-Stiffness Irregularity:

Base Shear:

L-shaped models exhibited 13.11% less base shear than T-shaped models and 16.82% less than C-shaped models. Among symmetrical shapes, the Square configuration showed 0.51% less base shear than Plus-shaped and 0.88% less than Rectangle-shaped models.

Storey Drift:

T-shaped models demonstrated superior performance with storey drift 11.25% less than C-shaped models and 18.27% less than L-shaped models. Symmetrical configurations showed small variations, with Plus-shaped models having 1.63% less drift than Rectangle-shaped models.

Storey Shear:

L-shaped models had 22.3% less storey shear than T-shaped models and 26.3% less than C- shaped models. Square models performed better among symmetrical configurations, with 2.72% less storey shear than

Rectangle-shaped models.

Storey Torsion:

Torsion was lowest in L-shaped models, which showed 58.16% less torsion than T-shaped and 11.92% less than C-shaped models. Among symmetrical shapes, Square configurations exhibited 7.6% less torsion than Rectangle-shaped and 75.66% less than Plus-shaped models.

Storey Displacement:

T-shaped models had the least displacement, 0.95% less than C-shaped models and 0.16% less than L-shaped models. Among symmetrical configurations, the Rectangle model displaced 1.29% less than Plus-shaped models.

Setback-Stiffness Irregularity:

Base Shear:

L-shaped models showed 0.9% less base shear than C-shaped models and 3% less than T-shaped models. Square-shaped models performed marginally better among symmetrical shapes.

Storey Drift:

T-shaped models excelled, with storey drift 29.51% less than L-shaped models and 37.69% less than C-shaped models. In symmetrical shapes, Square configurations exhibited 4.41% less drift than Rectangle-shaped models.

Storey Shear:

L-shaped models performed well, showing 4.34% lessstorey shear than C-shaped models and 6.53% less than T-shaped models. Among symmetrical shapes, Square models outperformed by 2.75% compared to Rectangle-shaped models.

Storey Torsion:

L-shaped models reduced torsion by 58.16% compared to T-shaped and 11.92% compared to C-shaped models. Symmetrical Square-shaped configurations demonstrated a significant 75.66% reduction compared to Plus-shaped models.

Storey Displacement:

T-shaped models displaced 9.34% less than L-shaped models and 24.98% less than C-shaped models, indicating their superior stiffness. Among symmetricalshapes, Square-shaped models displaced 7.42% less than Plus-shaped models.

This comprehensive comparison highlights the influence of irregularities on seismic performance. Mass-Stiffness Irregularity was more pronounced in irregular configurations, with T-shaped and L-shaped models offering specific advantages like reduced driftand torsion.

Setback-Stiffness Irregularity showed similar trends, with symmetrical shapes, especially Square and Rectangle configurations, achieving balanced performance across parameters. These insights provide valuable guidance for designing earthquake-resilient structures, optimizing both irregular and symmetrical designs based on site-specific requirements.

IX.FUTURE SCOPE

1) The current study focused on linear time- history analysis. Further studies can be conducted using nonlinear analysis methods to investigate the behavior of structures withsignificant inelastic deformations.
2) For future study, the focus can be on using energy dissipation devices, such as dampers,to minimize the effects of vertical irregularities on the stability and performanceof buildings during seismic events.
3) Further research can be carried by using different types of bracings.

REFERENCES

[1] A S Patil and P D Kumbhar worked on “Time History Analysis of Multistoried RCC Buildings for Different Seismic Intensities”, published in International journal of Structural. & Civil Engineering Research, Volume 02, August 2013.

[2] Diwakar Chaudhary and Gurpreet Singh worked on “Performance Of TubularStructure Under Seismic Force” published in International Journal of Mechanical and Production Engineering Research and Development (IJMPERD). Volume 10, June 2020.

[3] M.Z. Habib, M.A. Alam, S. Barua, M.M.Islam worked on “Effect of Plan Irregularityon RC Buildings due to BNBC-2006 Earthquake Load” published in International Journal of Scientific & Engineering Research, Volume 7, January 2016.

[4] S. A. Powale, N. J. Pathak worked on “A Comparative Study of Torsional Effect of

Earthquake On ‘L’ And ‘S’ Shaped HighRise Buildings”, published in International Journal Of Scientific & Technology Research, Volume 8, AUGUST 2019.

[5] Hojat Allah Ghasemi worked on “Evaluation of Seismic Behaviour Of Irregular Tube Buildings In Tube Systems” published in Advances in Science and Technology Research Journal, Volume 10, March 2016.

[6] Mohd. Zameeruddin and Keshav K. Sangle reviewed “Review On Recent Developmentsin The Performance-Based Seismic Design of Reinforced Concrete Structures” published in Elsevier, March 2016.

[7] Hasan Hastemoglu worked on “Seismic Performance Evaluation Of Reinforced Concrete Frames” published in IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 12, Sept-Oct 2015.

[8] Paul Joseph and Reni Kuruvilla worked on “Effects of Irregularities on the Seismic Response of a High-Rise Structure in ETABS” published in International Journal of Engineering Research & Technology(IJERT) in 2021.

[9] E.H.Ghoniem, Nihal M.Ayyash and Ahmed Essam worked on “Seismic Response of High-rise Buildings with Different Structural Systems” published in International Journal of Engineering and Innovative Technology (IJEIT). Volume 08, November 2018

[10] Ms. Komal A. Kedge and Prof. M.S Kakmare worked on “To study the Torsional Effect on MultiStorey Building with Plan and Vertical Irregularity”, published in International Research Journal of Engineering and Technology (IRJET), Volume 08, February 2020.

[11] Jignesha Patel, Roshni J John worked on “Seismic Analysis of Frame Tube Structure” published in International Journal of Scientific & Engineering Research. Volume 06, December 2015.

[12] Syed Musthafa Khadri And B.K.Kolhapure worked on “A Comparative Study Of Frame Tube, Tube In Tube And Bundled Tube Structures Subjected To Lateral Load Under Different Zones” published in International Research Journal of Engineering and Technology (IRJET). Volume 08, October 2021.

[13] Suraj R Wadagule and Vishwanath R Charantimath worked on “Comparative Study of Tube in Tube Structure and Frame Tube Structure” published in InternationalResearch Journal of Engineering and Technology (IRJET), Volume 06, July2019.

[14] IS 1893 (part I): 2016 - Criteria for Earthquake Resistant Design of Structures.

[15] IS 456:2000 - Indian Standard code of practice for plain and reinforced concrete.

[16] IS 875:1987-PART I Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures, Dead loads – unit weights of building materials and stored materials.

[17] IS 875:1987- PART II Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures, Imposed Loads.

[18] IS 875:1987- PART III Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures, Part3-Wind Loads.

[19] IS 16700:2017 Criteria for structural safety of tall buildings.