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A REVIEW, COMPARATIVE STUDY OF EVEN AND UNEVEN STORY HEIGHT OF HIGH-RISE STRUCTURE BY USING TIME HISTORY ANALYSIS

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Abstract*— In this comprehensive comparative study, the seismic behaviour of multi-story reinforced concrete (RC) buildings was analyzed using various analysis methods and earthquake events. The research findings emphasize the importance of time history analysis in capturing the nonlinear behaviour of irregular structures and providing more accurate predictions of structural response compared to equivalent static analysis and response spectrum methods. The study highlights key factors that influence base shear, storey displacements, and storey drifts, such as irregular mass distribution, the presence of weak floors, and the inclusion of shear walls. It underscores the significance of considering these factors to enhance the seismic performance of low-rise buildings. The results suggest that time history analysis is essential for an accurate assessment of structural safety, especially in irregular structures. By accounting for the dynamic characteristics of the earthquakes and the nonlinear behavior of the building, time history analysis offers more precise predictions of the structural response. Furthermore, the study recommends incorporating plan irregularities and properly distributing the lateral inertia force to improve the seismic performance of low-rise buildings. By addressing these aspects during the design stage, the safety and resilience of structures can be significantly enhanced. Overall, this research contributes valuable insights to the field of seismic analysis and design. It highlights the importance of considering irregularities, employing time history analysis, and optimizing structural features to develop safer and more resilient buildings. The findings can guide engineers and designers in making informed decisions to ensure the structural integrity and performance of RC buildings under seismic loads.

Keywords— G+11, Even and uneven structure, frame load combination, seismic zone, Indian standard code, Analysis of structure, time history analysis, ETABS.

I. INTRODUCTION

The construction of houses in India plays a crucial role in social progress, with engineers and architects constantly developing new techniques to ensure economical and efficient construction that meets community requirements. Multistory buildings with uneven and even heights have become popular due to their aesthetic appeal and functional advantages. However, these structures are exposed to dynamic loads such as earthquakes and wind, which can lead to significant damage and endanger lives.

To achieve robust design and structural integrity in high-rise buildings, time history analysis plays a pivotal role in accurately assessing dynamic loads and optimizing structural response. This analysis allows engineers to identify vulnerabilities and make design modifications to enhance the building's resistance to dynamic forces.

This project focuses on the comparative study of even and uneven story heights in high-rise structures using time history analysis. The aim is to analyse and design a building using ETABS software, which incorporates various analysis engines for comprehensive analysis and design. By evaluating the performance of structures with different story height configurations, this study provides valuable insights to optimise designs and enhance the safety and stability of high-rise structures under seismic loads.

Overall, this review emphasises the importance of considering story height variations in the design of high-rise structures. Time history analysis and adherence to relevant design codes ensure accurate and reliable results. The findings contribute to the body of knowledge in structural engineering and design, benefiting professionals in the field and promoting efficient and resilient building practises.

II. LITERATURE REVIEW

1. Bahadur Begheri (2012) "Comparative Study of the Static and Dynamic Analysis of Multi-Storey Irregular Buildings." Inconsistent displacement patterns are observed in

a building, where maximum displacements increase from the first to the last floor except for the 16th floor. The center of mass displacements at the 16th floor are lower than the 15th floor due to plan property variations. Response spectrum analyses capture maximum structural response during earthquakes.

2. A. S. Patil and P. D. Kumbhar (2013) "Time history analysis of multistoried RCC buildings for different seismic intensities". The study reveals consistent patterns in the seismic responses (base shear, storey displacements, and storey drifts) across different intensities (V to X), time histories, and both models considered. The values of these responses increase as the seismic intensities escalate from V to X. Specifically, the base shear, storey displacements, and storey drifts in both X and Y directions are significantly higher (1.85, 3.56, 7.86, 15.1, and 17.15 times) for intensities VI to X compared to intensity V, regardless of the presence of a soft story in the models. Importantly, the realistic time history method used for seismic analysis offers a more effective means of evaluating the safety of structures designed according to the IS code, as it captures actual dynamic behaviour and provides accurate results.

3. Mr. Gururaj B. Katti and Dr. Basavraj S. Balapgol (2014) "Seismic analysis of multistoried RCC buildings due to mass irregularity by time history analysis". The study suggests that for irregular structures, time history analysis is crucial to capture the non-linear behaviour. Equivalent static analysis tends to overestimate displacements compared to dynamic analyses like response spectrum and time history analysis. Irregular buildings require dynamic analysis due to the non-linear distribution of forces. The variations in base shear values among the different methods highlight the limitations of equivalent static analysis and the advantages of time history analysis in capturing variable mass and non-linear effects. Overall, time history analysis provides a more realistic and reliable assessment of structural safety compared to equivalent static analysis and response spectrum methods.

4. Mayuri D. Bhagwat, Dr. P.S. Patil (2014), "Comparative Study of Performance of RCC Multistory Buildings for Koyna and Bhuj Earthquakes." The analysis of the research findings reveals several important observations. Firstly, the base shear values for the Bhuj earthquake are 49.11% higher than those for the Koyna earthquake. Additionally, the response spectrum method yields results that are 50% higher than those obtained from time history analysis. Moreover, when comparing time history analysis and response spectrum analysis, it is noted that the response spectrum analysis produces higher values for base shear and top story displacement. Specifically, for the Koyna earthquake, the response spectrum analysis results are 39.70% higher for base shear and 31.18% higher for top-story displacement, while for the Bhuj earthquake, these values are 40.53% and 31.99% higher, respectively. Furthermore, the study confirms that the floor drifts for all stories remain within the permissible limits. on this conclusion, it is strictly recommended that time history analysis be employed as it provides a more accurate prediction of the structural response compared to response spectrum analysis.

5. Arvindreddy, R.J. Fernandes (2015) "Seismic analysis of RC regular and irregular frame structures". Based on the study conducted, it can be concluded that structures with stiffness irregularities exhibit non-conservative behaviour. The results obtained from static analysis show lower storey displacement values compared to response spectrum analysis, indicating a possible influence of nonlinear force distribution. In both static and response spectrum methods, diaphragm irregularity leads to reduced storey displacement and storey drift when compared to regular structures. Furthermore, the pushover curve demonstrates that stiffness irregularity displays nonlinear behaviour at an earlier stage than other structures, making it more susceptible to enhanced earthquake effects. Moreover, time-history analysis reveals that stiffness irregularities in a 15-story structure exhibit the lowest base force compared to other structures. Overall, the behaviour of stiffness irregularity and diaphragm irregularity becomes reversed as the number of stories increases.

6. Sayed Mahmoud, Magdy Genidy, and Hesham Tahoon (2016) "Time-history analysis of reinforced concrete frame buildings with soft storeys". The research study focused on reinforced concrete-framed buildings with both fully and partially infilled walls under seismic loads. The findings revealed that masonry infill walls have a significant impact on the overall performance of the building, affecting structural responses such as displacements, moments, and shear forces. The incorporation of masonry infill walls reduces storey displacements but increases storey moments and shear forces. By controlling displacements, reducing storey drifts, and increasing lateral stiffness, these walls significantly improve the seismic performance of the structure. The level of a soft storey plays a significant role in induced storey shear forces, especially at lower storeys, while its effect on storey displacements and moments is more pronounced under near-fault motion. Infill frame models with soft storeys experience sudden increases in responses at specified levels, regardless of loading direction and earthquake records. The presence of a soft storey amplifies storey drift at that level, surpassing the values of bare frame cases. The study suggests the need for magnification factors for storey response and reduction factors for displacements in building codes, considering the effects of masonry infill actions.

7. Mohaiminul Haque, Sourav Ray, and Amit Chakraborty (2016) "Seismic performance analysis of RCC multi-story

buildings with plan irregularity". The analysis of variously shaped multi-story buildings reveals that all structures meet the displacement criteria for equivalent static analysis, although Model-1 pushes the allowable limit. However, Model-1 exhibits deflection exceeding 80% compared to
The storey drift indexes in Model-4 show an initial increase with storey height, peaking at the 3rd storey, followed by a decrease. Displacements from time history analysis exceed limits, while response spectrum analysis yields lower but still excessive maximum displacements.
Displacement differences among the shapes are negligible in lower stories but increase in higher stories, with irregular structures (Models 1 and 2) exhibiting greater displacement than regular ones (Models 3 and 4). Overall, the research concludes that buildings with irregular plans are more vulnerable to earthquake loads compared to regular-shaped buildings.

8. Alhamd Farqaleet, Jamia Millia Islamia (2016) "Dynamic Analysis of a Multi-Storey RCC Building". The research findings indicate that the storey drift increase from base to top floor in analysed building. However, the maximum storey drift remains within the permissible range specified by IS 1893:2002. For a ten-story building, the maximum drift recorded was 0.106m, which is below the permissible limit of approximately 0.124m. maximum base shear in the X and Y directions is calculated to be 2528.2 kN and 184.59 kN, respectively. The study acknowledges the extensive research conducted on the dynamic effects of buildings with symmetrical configurations in the past. The analysis focused on key parameters such as lateral force, base shear, storey drift, and storey shear, and the results were carefully calculated. The study recommends the use of time history analysis as it provides a more accurate prediction of the structural response compared to response spectrum analysis. Additionally, the research involves considering 12 mode shapes with corresponding time periods, frequencies, and eigenvalues. Plots were generated to demonstrate changes of base shear and storey drift in both the X and Y directions with respect to the El Centro earthquake time history.

9. P.P. Debnath and S. Choudhury (2016) "Nonlinear analysis of shear walls in unified performance-based seismic design of buildings". This study focuses on the interpretation of RC shear walls using double-layered shell elements, offering a more realistic representation compared to column elements. However, the challenge lies in understanding hinge formation in shear walls. Stress and moment-rotation diagrams are insufficient for distinguishing elastic and plastic rotations, highlighting the need for accurate identification of rotations in performance-based design and seismic simulations. Further improvements in multi-layered shell element modelling are crucial for seismic design advancements.

10. Atul N. Kolekar and Y.P. Pawar (2017) "Comparative Study of the Performance of RCC Multi-Storey Buildings for Koyna and Bhuj Earthquakes". Comparing the Bhuj and Koyna earthquakes, seismic response analysis reveals higher base shear values in Bhuj (45.44% difference) using time history analysis, while both earthquakes show higher base shear values (Koyna: 37.01%, Bhuj: 41.30%) in the response spectrum method. Top story displacements are also higher in the response spectrum method. Despite variations, storey drifts remain within permissible limits, confirming the seismic safety of the building. Time history analysis is recommended for accurate structural response prediction.

11. Sampath Nagod, Prof. A.J. Zede (2017) "Comparative Study of the Performance of RCC Multi-Storey Buildings for Koyna and Bhuj Earthquakes". The study finds that base isolation in buildings reduces base shear by approximately 40% compared to fixed-base buildings. Mass irregular buildings experience a 30% increase in base shear compared to regular buildings. Regular buildings with base isolators exhibit the lowest base shear. Base isolation increases the building's time period by 27% and reduces base displacements. Time history analysis using seismic records and considering mass irregularities is recommended for accurate assessment and design of multi-story buildings for earthquakes.

12. Pruthviraj N. Juni, S.C. Gupta, and Dr. Vinubhai R. Patel (2017) "Nonlinear Dynamic Time History Analysis of Multistoried RCC Residential G+23 Buildings for Different Seismic Intensities". The study reveals that seismic responses, such as base shear, storey displacements, and storey drifts, follow a similar pattern of increase with intensities (V to X) for both models considered. Maximum values for intensities VI-X are significantly higher compared to intensity V (2.50-17.35 times). Time history analysis is crucial for realistic seismic analysis and safety assessment of structures designed according to the IS code.

13. A. Krishna Srinivas, B. Suresh, and A. Madhusudhan Reddy (2017) "Time History Analysis of Irregular RCC Building for Different Seismic Intensities". This research underscores the importance of addressing irregularities in the planning and design of low-rise buildings to withstand earthquakes. Irregularities in distribution of seismic mass lead to significant lateral oscillations and unsatisfactory performance. Incorporating plan irregularities proportionally across lateral load-resisting systems enhances seismic performance and structural integrity.

14. Chandana Kurma, G. Siva Vignan, and T. Sai Krishna Teja (2018) "Nonlinear Analysis of Multistoreyed Buildings with and Without Shear Wall". The research reveals that 10- and 15-story buildings with moderate resistance perform well

within acceptable limits of immediate occupancy and life safety levels, even under 1% and 2% transient drifts. Introduction of shear walls reduces displacement and base shear, maintaining structural integrity without damage. Performance-based seismic design proves effective, requiring less steel reinforcement than code-based design. Shear walls enhance seismic performance of buildings.

15. Gaurav Kapgate, Prof. D. L. Budhlani (2018) "Non-Linear Time History Analysis of Structure with and Without Shear Wall". Nonlinear time history analysis using ETAB 2016 software evaluates the seismic performance of special moment resisting (SMRF) structures. Shear walls increase base shear compared to a bare frame, while the inner shear wall effectively reduces displacements and mitigates peak spectral acceleration better than the outer shear wall. Incorporating inner shear walls enhances seismic performance of SMRF structures.

16. Abdul Ahad Faizan, Osman Kirtel (2019) "Seismic non-linear time history analysis of multi-story RCC residential buildings subjected to different earthquakes." The study conducted non-linear time history analysis on a multi-storied RC building for Landers, Kobe, and ChiChi earthquakes. Results showed floor shear decreasing with height and highest at the base. Base shear and displacements increased with higher PGA values. Time history analysis provides realistic assessment for seismic design in zones and should be considered by designers.

17. Tanveer M1, C. S. Vijaya Kumar, and Dr. M. N. Shivakumar (2019): "Time history analysis of multistory buildings with and without base isolation". The study shows that the base isolation system results in higher displacements in both the X and Y directions compared to a fixed base. Additionally, the isolated base exhibits higher drift in both directions. This is attributed to the reduced stiffness of the isolated building, which provides flexibility and helps reduce the impact of seismic loads on the structure. Furthermore, it is observed that the story acceleration is lower for the isolated base up to the 6th story, but from the 7th to the 13th story, the acceleration is higher than the fixed base. Ultimately, the study concludes that a structure with an isolated base demonstrates greater resistance to seismic loading compared to a fixed base.

18. Rohan G. Raikar, Dr. Shivakumaraswamy, Dr. S. Vijaya, and M. K. Darshan (2020): "Seismic Analysis of Framed R.C. Structure with Base Isolation Technique using E-Tabs". The study focuses on enhancing the base isolation system to reduce storey drift, base forces, and moments under extreme excitations. Semi-active control is recommended for adjusting mechanical properties. Base-isolated buildings showed reduced shear force, bending moment, acceleration, and base shear, with increased lateral displacement at the base. The model outperformed fixed-base buildings in reducing damage to structural elements and exhibited decreased storey drift with increasing height.

19. Kalpak A. Zagade, Aniket Patil, and Abhijeet Galatage (2021): "A review paper on time history analysis and nonlinear dynamic analysis of high-rise buildings using ETABS". The study focuses on enhancing the base isolation system to reduce storey drift, base forces, and moments under extreme excitations. Semi-active control is recommended for adjusting mechanical properties. Base-isolated buildings showed reduced shear force, bending moment, acceleration, and base shear, with increased lateral displacement at the base. The model outperformed fixed-base buildings in reducing damage to structural elements and exhibited decreased storey drift with increasing height.

20. Prajapati Ramdev, Prashant R. Barbude, and Dr. A.P. Patil (2021): "Dynamic Analysis of Multistory Structure Using Linear Time History Analysis". The research analyzed a G+12 RC building using seismic analysis methods: equivalent static, response spectrum, and time history. Time history analysis provided the highest deflection and shear values, indicating its accuracy compared to other methods. The study emphasized the importance of time history analysis in accurately estimating building response and recommended its use for seismic design.

21. J. Selwyn Babu, J. Rex, V. Priya Reddy, and M.S. Britto Jeyakumar (2021): "Comparative study on non-linear time history analysis of a building with and without base isolation using ETABSThe research findings show that as the number of stories increases, building displacements, drifts, overturning moments, and base shears also increase. However, incorporating LRB as a base isolation system increases displacements and drifts, improving structural flexibility during earthquakes. LRB significantly reduces overturning moments, storey shears, and base shears, leading to more stable structures and cost-effective designs.

22. Somesh Pol (2023): "A Review Paper on Linear and Nonlinear Analysis of G+15 Story Building with and without Shear Wall by Using the Time History Analysis Method". The literature review compares time history analysis and response spectrum analysis for assessing structural response. Time history analysis provides accurate predictions by considering input forces over time, while response spectrum analysis only estimates maximum response. Time history analysis is recommended, especially in seismically active regions. Shear walls effectively reduce displacement and spectral acceleration, meeting seismic design criteria for safety and occupancy.

III. IMPORTANT FINDINGS

These research studies analyse the seismic performance of multi-story RCC buildings using various methods such as static analysis, dynamic analysis, time history analysis, and response spectrum analysis. They highlight the importance of time history analysis in capturing non-linear behaviour and providing more accurate results compared to other methods. The studies also emphasise the influence of irregularities in buildings, such as mass irregularity and plan irregularity, on the structural response. Incorporating measures like base isolation and shear walls can significantly improve the seismic performance of buildings. Overall, these studies contribute to our understanding of seismic behaviour and provide recommendations for designing safer structures.

Research Gap for the Project "Comparative Study of Even and Uneven Story Height of High-Rise Structure by Using Time History Analysis":

1. Limited studies have specifically focused on the comparative analysis of even and uneven story height configurations in high-rise structures using time history analysis.
2. Existing research often overlooks the significance of story height variations and primarily focuses on other structural aspects.
3. The effect of uneven story heights on the seismic performance of high-rise structures has not been thoroughly explored and requires further investigation.
4. There is a lack of comprehensive data and analysis on the response characteristics, including structural deformations, inter-story drifts, and accelerations, for both even and uneven story height configurations.
5. The effect of uneven story heights on the distribution of lateral forces and their transfer through the structure needs to be investigated to understand the overall structural behaviour.
6. Comparative studies that directly compare the seismic performance and structural integrity of high-rise buildings with even and uneven story heights are limited.
7. The design guidelines and code provisions often do not provide clear recommendations for handling uneven story height configurations, and further research is needed to fill this gap.
8. The economic feasibility and constructability aspects of high-rise structures with uneven story heights need to be evaluated to assess their practical implementation.
9. The potential benefits and drawbacks of using even and uneven story height configurations in terms of architectural aesthetics, functional spaces, and occupant comfort require deeper analysis.
10. The incorporation of advanced analysis techniques, such as nonlinear time history analysis, can provide more accurate and realistic results for evaluating the comparative performance of even and uneven story height configurations in high-rise structures.

IV. CONCLUSION

Based on the various research studies on the seismic analysis of multi-story RCC buildings, the following conclusions can be follows:

1. Time history analysis is crucial. Many studies emphasise importance of time history analysis in capturing non-linear behaviour and providing a more accurate prediction of structural response compared to equivalent static analysis and response spectrum methods. Time-history analysis takes into account the actual dynamic behaviour of the structure during earthquake ground motion.
2. Performance of irregular buildings: Irregular buildings, especially those with plan irregularities and stiffness irregularities, exhibit non-conservative behaviour and are more vulnerable to earthquake loads compared to regular-shaped buildings. Dynamic analysis is required for irregular structures due to the non-linear distribution of forces.
3. The inclusion of masonry infill walls in buildings has a notable impact on their performance. Although they decrease storey displacements, they increase storey moments and shear forces. The presence of a soft storey further influences the induced shear forces and drifts experienced by the structure.
4. Base shear and storey drift: Base shear values generally increase with higher seismic intensities. Storey drifts tend to increase from the base to the top floor, but they remain within permissible limits specified by design codes.
5. Shear walls enhance seismic performance. The inclusion of shear walls in RCC structures reduces displacements, base shear, and spectral acceleration demands. Shear walls effectively distribute lateral inertia forces and improve the overall seismic performance of buildings.
6. When comparing analysis methods, response spectrum analysis tends to produce higher values for base shear and top story displacement compared to

time history analysis. However, time history analysis is deemed more reliable and realistic in capturing the actual dynamic behavior of structures and delivering accurate results.

7. Importance of considering seismic records: Comparisons between different earthquakes (such as Koyna and Bhuj earthquakes) reveal variations in base shear values. Therefore, it is essential to consider specific seismic records for accurate assessment and design of multi-story buildings for earthquake events.

The research studies underscore the importance of time history analysis, irregularities, shear walls, and accurate seismic assessment in designing multi-story RCC buildings. They stress the need to consider dynamic behavior, non-linear effects, and force distribution for ensuring structural safety during earthquakes.

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