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A Review on Plan Irregularity and Importance Factor Criteria

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Abstract: Due to India's high population density, a significant shortage of land for both residential and commercial purposes has been observed. In response, the construction of taller buildings with increased land coverage and enhanced aesthetic appeal has been undertaken by engineers. However, the structural stability of such architecturally unique buildings is often compromised due to their unconventional designs. In this review paper, an extensive evaluation of previous research studies related to enhancing the stability of these structures has been presented. Conclusive outcomes have been identified through a detailed examination of existing literature, forming the foundation for the stated research objectives. Technical insights and strategies have been compiled to address stability-related concerns in future designs. Emphasis has been placed on establishing practical recommendations for continued investigation in this field. With these findings, a framework for improving the structural resilience of modern architectural buildings has been proposed in upcoming research work.
Keywords: Drift Analysis, Plan irregularities, Residential Apartment, Response Spectrum Method, Actual Soil.

I. INTRODUCTION TO PLAN IRREGULARITY

In multistorey buildings, the term plan irregularity is commonly defined as the horizontal displacement of vertical structural elements like beams or columns in a direction perpendicular to their longitudinal axis, relative to neighbouring components. Due to factors such as foundation settlement, construction tolerances, or specific design intents, this offset is often introduced. The building's overall stability and structural integrity can be adversely impacted by excessive displacement. During both the planning and execution stages, careful attention must be given to monitor and limit such offsets. Considerable importance is therefore placed on controlling out of plane deviations for the safety of the structure. Throughout the design and construction process, these offsets are required to be thoroughly assessed. Ensuring the long-term performance of multistorey structures can be achieved by strictly managing these displacements.

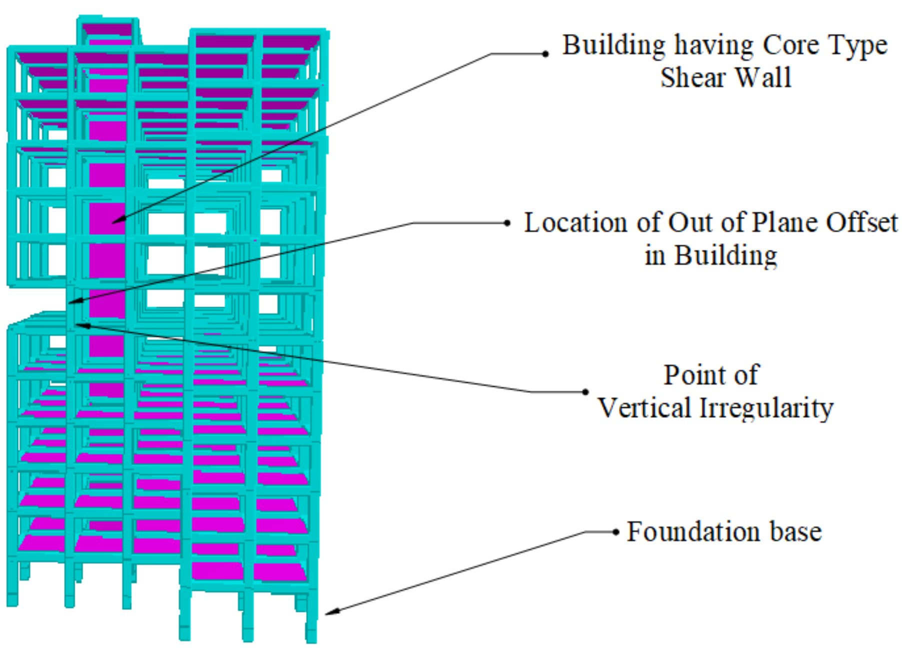

Fig. 1: Structure having plan irregularity configuration with dual structure configuration

Recommendation provided as per Indian Standards:

The load path of a building is often disrupted by the out-of-plane offset of vertical elements, which compromises its seismic safety. Such an irregularity is identified when frames or structural walls are shifted away from the primary building plane at any floor level. For buildings situated in Seismic Zone II, reference to specialized literature has been considered advisable during design. To maintain safety in higher seismic zones-III, IV, and V, two essential conditions are mandated. A lateral drift of less than 0.2 percent must be maintained in the affected story and those below it. Furthermore, the elimination of out-of-plane offset irregularity should be guided by expert literature. Guidelines for addressing such irregularities in multistorey structures have been established by Indian Standardization. Showed in Fig. 1 is a representative case of an out-of-plane offset in a building. Meanwhile, Fig. 2 illustrates a dual structural system incorporating a central shear wall, and Fig. 3 concludes the visual reference with a structural configuration showing the offset condition.

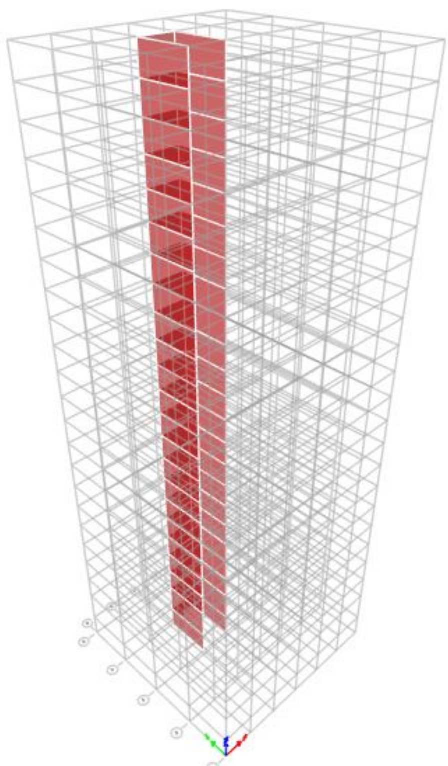

Fig. 2: Structure with shear wall at core

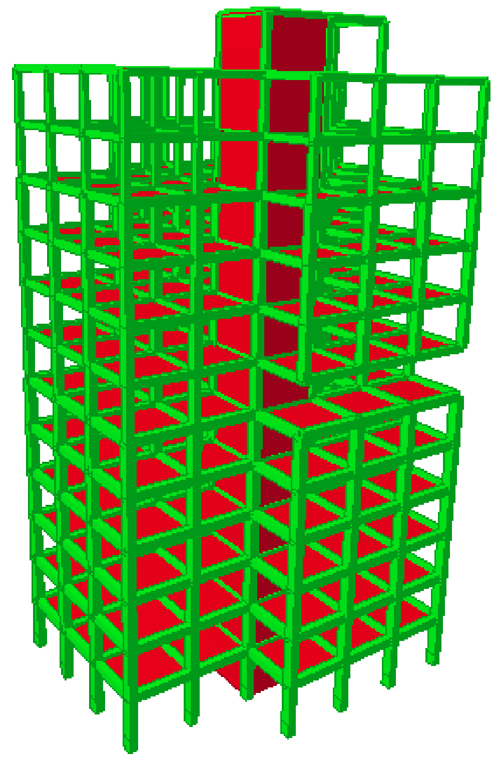

Fig. 3: Structure view with out of plane offset

II. IMPORTANCE FACTOR AND ITS IMPORTANCE

The importance factor, as defined in IS 1893:2016, is a critical multiplier applied to account for the varying importance and occupancy of structures during seismic events. This factor ensures that essential and high-risk buildings receive additional safety considerations. As per the code, ordinary buildings are assigned an importance factor of 1.0, while important structures like hospitals, schools, and emergency response buildings are given higher values, typically 1.2 or 1.5. These values reflect the potential consequences of failure and the need for continued functionality post-earthquake. The increased factor directly influences the design base shear, thereby enhancing the structural resilience. By incorporating this factor, the code promotes differential design strategies based on usage and criticality. It also aligns Indian practices with international seismic design standards. Ultimately, the importance factor plays a pivotal role in safeguarding human life and infrastructure continuity during earthquakes.

III. LITERATURE REVIEW

Shiva Kumar, et. al., (2019), In order to comprehend the complex response of vertically irregular structures, nonlinear dynamic analysis was applied using ETABS. This study compared the behavior of buildings with mass, stiffness, and setback irregularities against regular configurations.

Base shear, displacement, and storey drift served as the principal parameters for this comparative assessment. The presence of irregularities was found to significantly enhance torsional responses due to eccentricity. Such in-depth evaluations provide seismic engineers with clearer strategies for irregular structural design.

Prashanth Kumar N et. al. (2018), This investigation examined 15-storey RC buildings with vertical irregularities under seismic effects. Using IS 1893-2016, buildings were analyzed in ETABS via linear static, response spectrum, and time history methods. The Bhuj earthquake record was employed in the time history approach to assess structural responses. Irregular buildings showed greater vulnerability, especially in terms of base shear and story displacements. Hence, seismic design for such configurations must incorporate enhanced stiffness-based provisions.

T. M. Prakash, et. al., (2017), With increasing urban demands, vertically irregular high-rise buildings have become essential. This research adopted pushover analysis in ETABS 2015 to evaluate mass irregularity scenarios. It was found that buildings with greater vertical mass irregularity experienced amplified storey shear. Both static and dynamic methods were needed to capture nonlinear seismic performance accurately. Ultimately, the study proved regular mass distribution improves resilience under seismic actions.

Sudarshan Kulkarni, (2016), Space optimization in high-rise buildings has led to the rise of floating column designs. This study analyzed 3D models of G+14 buildings using SAP2000 with equivalent static analysis. Both regular and irregular layouts were evaluated to determine optimal floating column positions. Findings pointed toward significant structural differences based on column placement and plan type. Such assessments pave the way for safer, regulation-compliant multi-story designs.

Poonam, et. al., (2012), A detailed evaluation of IS 1893:2002 irregularity provisions was conducted using a 10-storey frame model. Mass and stiffness irregularities were introduced by altering floor mass ratios and storey stiffness values. Dynamic responses like storey drift, beam deflection, and storey shear were carefully assessed. The presence of tall first storeys and floating columns intensified the building’s lateral response. These findings support refinements in code-based design to enhance irregular building safety.

Isha Patel (2024), In this paper the researcher evaluated IS 1893 2016 and IS 1893 2023 Part I and Part II for their impact on seismic design and structural safety. A G plus 4 frame structure measuring twenty by twenty meters and fifteen meters in height was analyzed under Zone IV seismic conditions. Updated code provisions regarding seismic zones, load combinations, base shear, importance factors, and soil structure interaction were examined. Base shear, shear force, and bending moment were computed using revised procedures to assess structural response to earthquake loading. Comparative analysis revealed improved design precision and increased structural safety in the updated 2023 code provisions. Cost efficiency and construction optimization were noted as outcomes of the refined design methodology and code alignment. Importance of code compliance and seismic zone based detailing was highlighted for earthquake resistant design practice. Enhanced safety, refined analysis methods, and cost effective seismic solutions in Zone IV were their conclusive outcomes.

M. T. Raagavi, Dr. S. Sidhardhan (2021), In this paper the researcher reviewed multiple studies addressing structural irregularities and their influence on earthquake and seismic resistance. Irregularities were categorized into plan and vertical types, which commonly arise due to mass eccentricity, stiffness imbalance, and geometric distortions.

Specific forms such as torsional coupling, ductility constraints, and combined irregularities were critically examined. The seismic vulnerability of structures was linked to deficiencies in strength, stiffness, and the interaction between mass and stiffness centers. Response Spectrum Analysis and Time History Analysis methods were identified as effective tools to assess and improve earthquake resistance. Analytical strategies focused on identifying structural weaknesses and enhancing performance under dynamic ground motion. Technical literature emphasized that response accuracy improves when irregularities are included in computational modeling. Refined seismic analysis methods and code based planning to mitigate structural failure under irregular conditions were their conclusive outcomes.

Umamaheswara Rao Tallapalem et. al. (2019), In this paper the researcher analyzed a G plus 7 multi storey building using STAAD Pro to assess seismic performance across Zones II III IV and V in India. Load calculations including base shear, support reactions, and displacement were evaluated for a building measuring twelve by twelve meters and twenty four meters in length. Base shear and displacement were found to be highest in Zone V compared to all other zones under identical conditions. Steel quantity and support reactions increased significantly in higher seismic zones indicating a need for stronger structural response. Seismic forces acting on the structure were observed to influence stiffness, mass distribution, and lateral displacement in each zone. Zone wise variation demonstrated the direct dependency of seismic performance on regional zone factors and soil conditions. All results were compared graphically and numerically with emphasis on code based planning using IS 1893 provisions. Increased vulnerability and demand for reinforcement in Zone V buildings across all load aspects were their conclusive outcomes.

Biyyala Sai Ramesh, G. Swathi (2022), In this paper the researcher investigated the seismic response of rectangular, C, H, and L shaped multi storey buildings across Zones II, III, IV, and V as per IS 1893 2002. Structures were analyzed under different soil types including hard, medium, and soft strata using various irregular configurations. The failure of structures was attributed to irregular geometry and poor performance in resisting earthquake induced forces. Storey drift was found highest in L shaped buildings while maximum bending moment was recorded in H shaped structures. C shaped and rectangular buildings showed improved performance in terms of seismic resistance and economic feasibility. Storey drift, stiffness, and mass were calculated in relation to both load types and seismic zone classifications. Irregular structural forms demonstrated increased vulnerability in high intensity seismic regions, particularly under soft soil conditions. Improved design preference for regular configurations in severe zones for better safety and economy were their conclusive outcomes.

Nilesh Choudhary, et. al. (2022), In this paper the researcher analyzed a G plus 20 multi storey structure located in seismic Zones II III IV and V using STAAD Pro as per IS 1893 2016 Part I. Structural failure due to asymmetric mass distribution, inadequate stiffness, and geometric irregularities was assessed in zone specific conditions. The Equivalent Static Method was employed to evaluate seismic forces using the seismic coefficient approach. Base shear was computed and distributed across floors followed by floor wise calculation of resultant lateral forces. Higher shear forces and bending moments were observed in both regular and irregular structures in Zone V. Irregular structures experienced greater storey displacement when compared to regular frames under identical conditions. Soil properties, material strength, and building type were identified as critical parameters influencing seismic performance. Increased vulnerability of irregular buildings in high intensity zones requiring enhanced design consideration were their conclusive outcomes.

Sarthak Jain, Dr J N Vyas (2023), In this paper the researcher studied irregular multi storey structures with a focus on seismic response related to structural geometry and load path. Typical design practice was evaluated where wall and secondary loads were excluded, leading to reduced seismic reliability. Increased storey drift and stiffness variation were found to alter the natural frequency and contribute to structural irregularities. Plan shapes including L, U, O, and pulse forms were analyzed for mass, stiffness, and geometry irregularities as per IS 1893 2016 Part I. Plan irregularities caused by torsion, asymmetry, and discontinuities, and vertical irregularities from mass and storey weakness were examined. Soft storey behavior and large openings such as commercial or parking areas were identified as high risk under seismic loads. Top storey displacement and drift ratios were observed to increase with building height and irregularity severity. Elevated base shear, stiffness, and displacement in irregular frames compared to regular structures were their conclusive outcomes.

Purushottam Dewangan et. al. (2018), In this paper the researcher analyzed the unavoidable structural irregularities in G plus 8 multi storey buildings using SAP 2000 as per IS 1893 2022 and IS 13920 1993. Modular design analysis was carried out to assess strength, stiffness, and ductility under varying seismic and lateral load conditions. Graphical and mathematical evaluations were presented for bending moments, vibration effects, load factors, and displacement. It was observed that re entrant columns caused increased bending moments and higher base shear in irregular structures. Ductility ratio and response reduction factors were significantly elevated in irregular configurations compared to regular frames. Soil based criteria, concrete and steel design requirements were considered according to updated construction technology standards. Structural behavior under different seismic zones was simulated for both regular and irregular frames with force application studies. Improved accuracy in representing real structure responses and updated design practices through modular analysis were their conclusive outcomes.

Siva Naveen E et. (2019), In this paper the researcher examined earthquake affected structures by analyzing both regular and irregular G plus 8 multi storey buildings using ETABS 2000. The Finite Element Method was applied to study mass, stiffness, geometry, and displacement through modular seismic evaluation. A total of 20 causes in 34 regular configurations and 54 irregular configurations were modeled to observe structural performance. Vertical irregularities were found to reduce storey drift by approximately 30 percent and alter stiffness and displacement significantly. Horizontal irregularities including torsion effects and re entrant corners contributed to increased vulnerability in irregular forms. Graphical output highlighted dynamic response variations in H and L shaped buildings under seismic conditions. Material quantity, design factors, and IS code provisions were evaluated to address failure risks in irregular structures. Identified irregularity effects and improved design parameters for enhanced seismic resistance were their conclusive outcomes.

Varun Vijayvargiya et. al. (2020), In this paper the researcher investigated the seismic performance of a G plus 9 residential building using ETABS 2018 through three dimensional analysis. The structure was evaluated under gravity and lateral loads with irregularities in mass, stiffness, and geometry as per IS 1893 2016 and IS 13920 1993.

Vertical irregularities including asymmetric plans, re entrant corners, diaphragm discontinuities, and stiffness imbalance were examined. Plan irregularities caused by uneven mass and stiffness distribution were found to significantly impact seismic behavior. Mathematical and graphical analysis was carried out using Equivalent Static Method, Response Spectrum Analysis, and Time History Analysis. Base shear, storey drift, and displacement were recorded and compared across Zones II to V to assess structural vulnerability. Zone V displayed the highest values in all parameters, indicating critical seismic risk when irregularities are present. Greater structural instability in irregular configurations under severe seismic zones were their conclusive outcomes.

Rajeev Chauhan, et. al. (2021), In this paper the researcher analyzed a G plus 6 multi storey structure under various load conditions using a case based approach in three dimensional space. The seismic behavior was assessed with emphasis on horizontal forces in the X and Y directions, where earthquake motion primarily acts. Zone classifications from the 1970 five zone system were updated to Zones II through V in accordance with IS 1893 2016 guidelines. Plan and vertical irregularities caused by stiffness, mass, and geometry were examined using IS 875 Part 1 and Part 2 for load inputs. Bending moments, shear forces, storey drift, and joint displacements were calculated for both regular and irregular models. It was found that shear forces and bending moments were lower in irregular models, while storey drift and displacement increased with height. Mathematical modeling revealed higher joint displacement in both regular and irregular structures as storey level increased. Design understanding rooted in structural engineering concepts and national codes for economy and safety were their conclusive outcomes.

Md. Sabbir Hossain et. al. (2022), In this paper the researcher investigated two multi storey reinforced concrete structures of G plus 9 and G plus 25 using ETABS under seismic loading per IS 1893 2016. Static and dynamic methods including Equivalent Static, Nonlinear Static, Response Spectrum Analysis and Time History Analysis were applied. Seismic response was analyzed zone wise for Zones II to V by evaluating base shear, storey displacement and storey drift. Eight irregular structural models were developed to compare seismic performance in each zone using ground motion inputs. RSA was used to compute peak acceleration, velocity and displacement while THA assessed base reactions during ground movement. Zone V showed the highest values of displacement and drift in both G plus 9 and G plus 25 structures across all models. Graphical analysis confirmed that structure performance declined with increasing height and zone severity. Elevated deformation and shear demands in Zone V compared to other zones were their conclusive outcomes.

Ravindra N. Shelke, et. al. (2017), In this paper the researcher examined a G plus 14 reinforced concrete irregular building using ETABS and the Response Spectrum Analysis method as per IS 1893 2016. Vertical irregularities including stiffness, mass discontinuity, and geometric shifts were considered for seismic response evaluation. Stress, displacement, shear force, and bending moment were calculated at each node using graphical and numerical approaches. Irregular configurations showed higher base shear, larger storey drift, and increased bending moment at top storeys compared to regular structures. Zone based analysis indicated that structural responses in Zone V were significantly greater than in Zones II, III, and IV. Equivalent Static, Time History, and RSA methods were compared, with RSA providing precise and computationally stable results. Height and load increments were identified as key contributors to seismic vulnerability in irregular reinforced concrete frames. Elevated seismic forces and deformation patterns in irregular structures across severe seismic zones were their conclusive outcomes.

Rajgure Kalyani, et. al. (2018), In this paper the researcher performed a comparative modular analysis of G plus 5 and G plus 10 multi storey buildings using ETABS under different seismic zones based on IS 1893 2002 Part I. Response Spectrum Analysis was applied to evaluate lateral loads and seismic forces according to respective zone factors. Structural performance parameters such as storey drift, mass participation, and displacement were assessed across all four Indian seismic zones. Zone V was found to produce the highest values of storey drift and lateral displacement due to increased height and seismic demand. Seismic resistance was further analyzed using serviceability, strength, and ductility criteria as prescribed in IS 456 2000. Ductility was influenced primarily by reinforcement detailing and dynamic behavior under increasing seismic loads. Base shear and drift responses showed significant variation between zones, highlighting the role of structure configuration and load intensity. Improvements in design strategy for different heights and zones based on detailed analysis outcomes were their conclusive outcomes.

Puppala Sesha Pavani et. al. (2020), In this paper the researcher investigated a G plus 10 multi storey building with regular and irregular shapes using Equivalent Static Method and Time History Analysis as per IS 1893 2016 in Zone III. Structural weaknesses were examined through discontinuities in mass, stiffness, and geometry, causing plan and vertical irregularities. Five types of vertical irregularities were considered as primary factors contributing to seismic vulnerability. The building models were designed in STAAD Pro and analyzed to compare lateral response using both static and dynamic methods. Base shear in regular and irregular frames was found lower in static analysis but increased in dynamic analysis. Axial forces and bending moments were observed to be higher under static loads while displacements were larger in dynamic conditions.

Storey drift and mass response in irregular configurations exceeded those in regular frames across all metrics. Improved understanding of seismic performance through methodical comparison of static and dynamic results were their conclusive outcomes.

M. Rame Gowda, et. al. (2022), In this paper the researcher evaluated three vertically irregular G+15 structures using ETABS, applying Linear Static, Response Spectrum (RSA), and Time History Analysis (THA) methods per IS code. Vertical geometric irregularities defined by mass, stiffness, and plan discontinuities were studied across seismic zones II to V. Graphical outputs for storey drift, displacement, and base shear were generated to compare performance in each seismic zone. Model I showed lower response values but still posed significant risk in Zone V due to high seismic demands. Model II exhibited moderate drift and base shear, yet remained vulnerable in higher zones due to structural irregularity. Model III recorded the highest displacement, drift, and base shear, indicating poor performance in Zone V. Elastic methods such as RSA and THA confirmed critical instability in all three models under Zone V conditions. Recommendations to minimize geometric irregularities for improved seismic resilience and economic design were their conclusive outcomes.

Arun R. et. al. (2019), In this paper the researcher assessed a G+6 multi-storey building's seismic performance through base shear comparison using manual methods and STAAD Pro. Linear static analysis was conducted in both regular and irregular configurations across Zones II to V as per IS 1893-2002. Vertical irregularities, including discontinuities in stiffness, mass, and geometry, were identified as primary contributors to structural failure. Base shear, storey drift, and displacement were computed in both X and Z directions for varied soil and zone factor conditions. Manual calculations showed elevated base shear in Zone V, which was further verified by STAAD Pro for both regular and irregular frames. Zones II and III showed nominal seismic effects, while critical performance drops and instability risks were observed in Zones IV and V. Collapse potential under lateral and wind loads emphasized the need for seismic strengthening elements in vulnerable regions. Enhanced structural stability through the application of shear walls and braced column systems were their conclusive outcomes.

Maitrey Jambhulkar et. al. (2024), In this paper the researcher modeled a G+11 multi-storey building in ETABS and analyzed its seismic response using the RSA method per IS 1893-2002. Structural irregularities, including plan (torsion and re-entrant corners) and vertical (mass and stiffness), were considered in seismic zones II to V. Ground acceleration, velocity, and structural mass distribution were factored into the zone-based performance evaluation. A belt wall system was incorporated to improve lateral strength and connect the exterior columns with the core wall. Storey drift, displacement, shear force, and bending moment were extracted for all seismic zones using finite element simulation. Zone V demonstrated the highest values for joint displacement, storey drift, and internal forces among all the zones. Comparative results revealed that zone V posed the most significant structural threat, highlighting its high-risk classification. Reduction in seismic vulnerability through the application of belt walls and improved performance metrics were their conclusive outcomes.

S. Natarajan et. al. (2016), In this paper the researcher analyzed a G+15 multi-storey building using ETABS to compare structural behavior with and without shear walls. Finite Element Method and Response Spectrum Analysis were employed to evaluate seismic and wind load responses. As per IS 1893-2002 Part I Section 7, vertical and plan irregularities were defined based on mass, stiffness, and geometry discontinuities. Shear walls were applied to resist flexure, torsion, and horizontal loads, enhancing both lateral stiffness and overall ductility. Base shear and bending moments were observed to increase in equivalent static analysis for structures with added wall systems. The use of shear walls was found to control displacement and improve resistance under seismic ground motion frequencies. Inelastic and elastic strength demands were assessed based on location-specific earthquake histories and structural irregularities. Improved seismic performance through increased mass capacity, stiffness, and lateral resistance were their conclusive outcomes.

Kavita Verma, et. al. (2018), In this paper the researcher investigated a G+6 multistorey building subjected to seismic forces across all seismic zones using STAAD Pro. Static analysis was conducted following IS 1893-2002 provisions under the limit state design approach. Zone factors, base shear, and lateral loads were analyzed to determine the structural demands of each seismic region. It was observed that Zone V, having the highest zone factor, required increased volumes of concrete and steel reinforcement. Variations in elastic response led to changes in support reactions, beam deflections, and internal force distributions. Structural elements such as columns and beams experienced zero shear and bending moments at mid-spans under symmetric loading. Mass, stiffness, displacement, and ductility were identified as critical parameters influencing seismic performance. Enhanced structural safety and energy dissipation across varying zones through optimized material use were their conclusive outcomes.

Sukumar V, Dr. D. C. Haran Pragalath, (2016), In this paper the researcher evaluated the seismic response of RC structures using Importance Factors as defined in IS 1893-2002. A reinforced concrete frame with M25 concrete and Fe415 steel was modeled using STAAD Pro for analysis.

Time history analysis was implemented to observe variations in base shear, storey drift, and displacement. Importance Factor 1.0 for general buildings and 1.5 for public structures were considered in the study. No prior investigation in the Indian context has emphasized the role of Importance Factor in seismic design. Graphical representations of response curves and shear stress were utilized to assess structural behavior. Live and dead loads with floor load ratios were applied to simulate realistic conditions of built environments. Improved seismic resistance and performance level predictions with varying Importance Factors were their conclusive outcomes.

IV. CONCLUSIONS AND OUTLINE OF PROPOSED WORK

A noticeable gap in the existing literature has been identified concerning the impact of out-of-plane offsets in multistorey buildings subjected to seismic forces. The influence of this factor on a building's structural behavior and earthquake performance is considered significant for design purposes. In order to formulate effective mitigation strategies, further investigation into this parameter will be required. Development of design guidelines must be prioritized to minimize its adverse effects on structural response.

From the detailed literature review, a set of conclusions has been drawn to emphasize the core findings and outline the required steps forward:

1) A comprehensive analysis of plan irregularities in multistory buildings in both directions has to be undertaken for lateral force assessment.
2) Compliance of different importance factors as prescribed in Indian standards should be checked.
3) Use of actual geotechnical data relevant to the proposed site has been advised to enhance the reliability of structural analysis.
4) Seismic zonal conditions in dual structural systems are to be investigated thoroughly for accurate seismic response predictions.
5) Evaluation of lateral drift limits in accordance with codal provisions has deemed essential for structural integrity.

The feasibility of constructing buildings with out-of-plane configurations is intended to be assessed, with particular emphasis on identifying maximum allowable limits under site-specific soil conditions, making it a cornerstone for future research developments.

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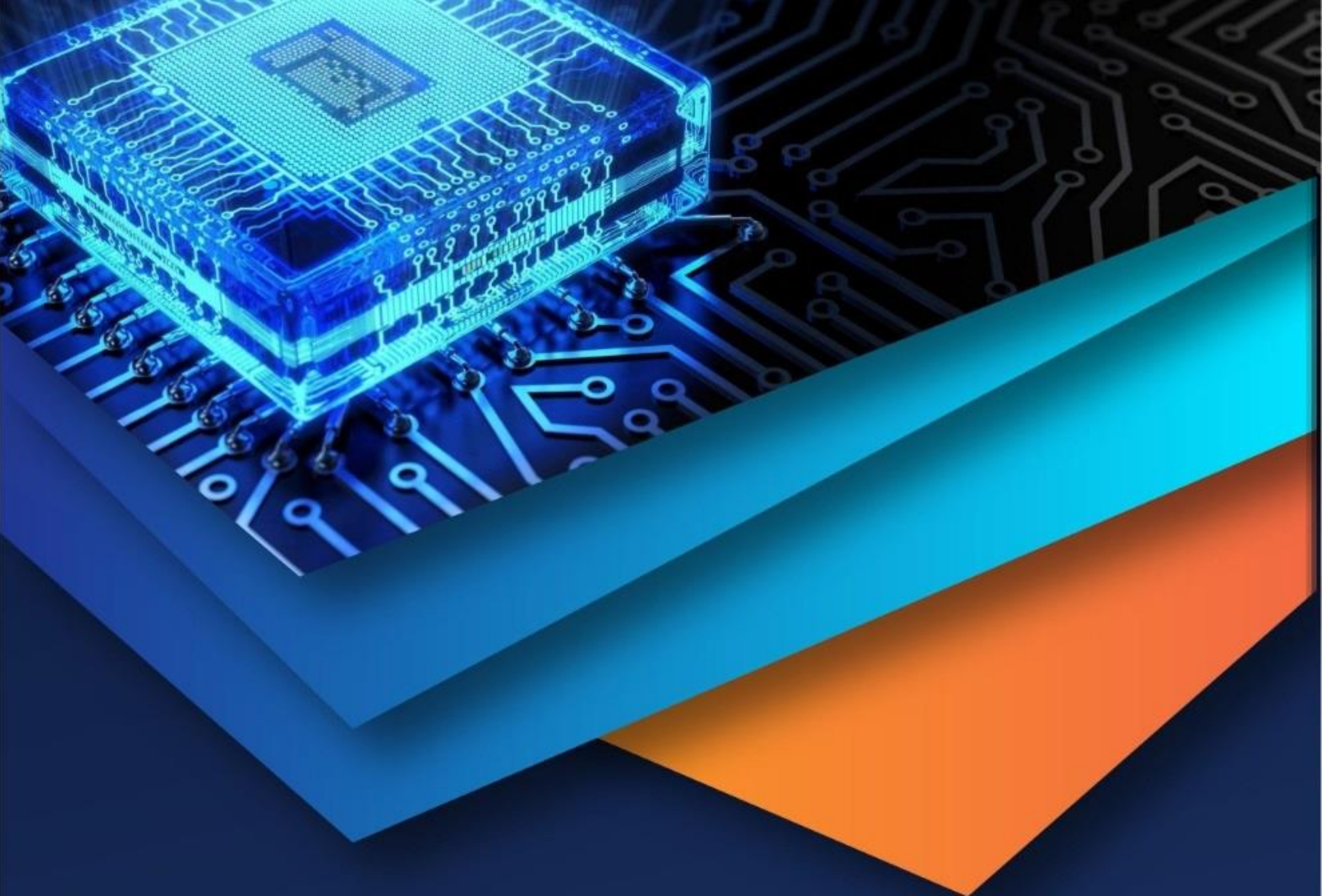

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