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A Review: Effect of Floor Height Variation on Seismic Performance of Reinforced Concrete Buildings Using ETABS

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***Abstract:** Rapid urban growth has increased the demand for multistorey reinforced concrete (RC) buildings in Indian seismic zones, where architectural requirements often introduce vertically irregular floor heights for parking or commercial podium levels. Floor-to-floor height directly governs lateral stiffness and mass distribution, so variations in storey height can create soft-storey mechanisms that amplify seismic demand compared with regular, uniform-height buildings. This review examines the effect of floor height variation on the seismic performance of RC frame buildings analysed using ETABS under IS 1893:2016 provisions. Published studies on uniform buildings and structures with increased ground-floor or podium heights are synthesised, focusing on changes in fundamental period, design base shear, storey drift profiles, and concentration of demand in flexible storeys. Results consistently show that soft-storey and podium configurations exhibit longer periods, reduced overall base shear, and significantly higher inter-storey drifts at the tall storey than comparable uniform-height frames, increasing the risk of plastic hinge formation and non-structural damage. The review highlights typical height ratios that trigger soft-storey behaviour, discusses code recommendations for vertical irregularity, and summarizes ETABS modelling practices for representing height variation in routine design. Research gaps are identified in performance-based evaluation and retrofitting strategies for existing soft-storey buildings. The paper provides practical guidance for designers to recognize unsafe height configurations early in planning and to adopt stiffness-balanced layouts or strengthening measures so that architectural floor-height demands remain compatible with seismic performance objectives for RC buildings in Indian conditions.*

***Keywords:** Floor height variation, soft storey, podium level, reinforced concrete buildings, ETABS, IS 1893:2016, seismic performance, storey drift.*

I. INTRODUCTION

Rapid urbanization in India has led to a sharp increase in multistorey reinforced concrete (RC) buildings, especially in seismically active regions where land scarcity pushes developers towards taller and more compact structures. While conventional seismic design often assumes regular floor-to-floor heights, practical architectural requirements such as parking podiums, commercial ground floors, and double-height lobbies frequently introduce significant variation in storey heights within the same building. This floor height variation alters the lateral stiffness and mass distribution of the structural system, creating vertical irregularity that can strongly influence earthquake response

When one or more storeys are substantially taller and more flexible than the typical floors above, a soft-storey mechanism can develop in which seismic drift and damage concentrate within the tall level. Past earthquake damage surveys and analytical studies have repeatedly shown that soft-storey and podium configurations are especially vulnerable, even when designed nominally as regular moment-resisting frames. ETABS and similar analysis software enable detailed three-dimensional modelling of such height-irregular RC buildings under Indian code provisions, allowing comparison of regular uniform-height frames with variants having increased ground-floor or podium storey height. Key response parameters of interest include fundamental period, design base shear, storey displacement profile, inter-storey drift ratios, and distribution of shear and moment demand along the height.

Indian seismic code IS 1893:2016 recognises vertical irregularity and prescribes drift limits as well as additional checks for soft-storey conditions, yet it provides limited quantitative guidance on acceptable floor-height ratios and stiffness transitions between podium and typical floors. As a result, many design decisions are still based on engineering judgement or simplified empirical rules, which may not fully capture the amplification of demand in flexible storeys.

A focused review of ETABS-based research on floor height variation can therefore help bridge the gap between code provisions and practical design, by clarifying how different height patterns affect seismic performance and identifying critical thresholds where irregularity becomes unsafe. The present paper contributes to this need by synthesising available studies on RC buildings with uniform and podium-type height configurations and highlighting modelling strategies, response trends, and research gaps relevant to Indian practice.

II. LITERATURE REVIEW

Patel and Shah studied G+8 RC buildings with different floor-to-floor heights using ETABS and IS 1893 provisions. Regular frames with uniform 3.0 m storey height were compared with models having a 4.5 m ground floor, showing that increased first-storey height lengthened the fundamental period and reduced design base shear by about 8–10%, but amplified inter-storey drift at the tall storey beyond recommended limits. The authors concluded that height-induced stiffness irregularity can create a soft-storey mechanism even when member sizes satisfy strength requirements.

Rao et al. carried out seismic analysis of mid-rise RC buildings with unequal storey heights representing commercial podiums and residential upper floors. Using the response spectrum method in ETABS, they reported that buildings with a tall podium level experienced concentration of drift and shear forces at that level, whereas uniform-height buildings showed smoother distribution of response along the height. The study highlighted that podium configurations require additional lateral-load-resisting elements or stiffness balancing measures to avoid excessive demand at the interface storeys.

Kumar and Singh investigated vertical irregularity caused by alternate floor height variation in G+10 RC frames under IS 1893 loading. Results indicated that models with alternating 3.0 m and 4.0 m storey heights developed complex higher-mode behaviour, with localized peaks in displacement and member forces at transition levels. Although global base shear remained comparable to regular frames, the irregular models exhibited higher curvature demand in beams and columns near the height discontinuities, suggesting greater vulnerability under strong shaking.

Desai et al. analysed RC buildings with soft storey created by a tall open ground floor used for parking, keeping upper floors at uniform height. Their ETABS models showed that the open, tall ground floor attracted large inter-storey drift and shear, while the upper storeys remained relatively stiff, a pattern consistent with observed soft-storey collapses in past earthquakes. The authors recommended avoiding large height jumps at the base or providing infill walls, bracings, or shear walls to compensate for lost stiffness.

Ahmed and Basha focused on mid-rise RC buildings with mass and stiffness irregularities arising from mixed-use layouts and variable storey heights. Parametric studies demonstrated that even modest increases in ground-floor height, combined with heavier commercial occupancy, could significantly alter mode shapes and period, causing undesirable torsional response and concentration of drift at lower levels. They emphasised that vertical irregularity checks in IS 1893 should be explicitly applied whenever floor height exceeds typical levels by more than 50%.

Kulkarni and Ghutke evaluated the effect of floor height variation on time period and base shear for RC frames designed as per Indian codes. Uniform-height buildings exhibited shorter periods and higher base shears, while models with one or more taller storeys showed longer periods and reduced total base shear but larger top displacements and storey drifts. The study concluded that relying only on base-shear reduction to justify irregular configurations can be unsafe, because serviceability and damage control are governed by drift rather than global force levels. Mehta and Jadhav carried out response spectrum analysis of G+12 RC buildings with transfer or podium floors at intermediate levels, where floor height and column layout changed abruptly. They observed that the transfer level behaved similarly to a soft storey, with large relative displacement and shear demand due to sudden stiffness reduction, even when the overall mass of the building remained unchanged. The authors recommended gradual transitions in storey height and member stiffness, or the use of outriggers and walls to redistribute forces. Gupta and Verma compared seismic performance of regular RC buildings and those with both plan and vertical irregularities, including variable floor heights. Their results confirmed that vertical irregularity due to floor-height changes was more critical for inter-storey drift than moderate plan irregularity, especially when the tall storey was located at the base. They suggested that design offices prioritise control of vertical stiffness irregularity before addressing secondary plan irregularities.

Sharma and Das reviewed post-earthquake damage reports from events such as the Bhuj (2001) and Nepal (2015) earthquakes, correlating observed failures with analytical models of soft-storey buildings. Field evidence showed widespread collapse of buildings with tall commercial ground floors supporting shorter residential storeys, whereas more regular buildings performed comparatively better. Their analytical work reproduced this behaviour, demonstrating that tall, flexible base storeys produce large drift concentrations and should be treated as critical vertical irregularities requiring enhanced detailing.

TABLE I
SUMMARY OF FLOOR HEIGHT VARIATION STUDIES

Sr. No.	Authors (Year)	Building Type	Height Pattern / Irregularity	Software / Method	Key Findings & Gaps
1	M.Tech synopsis (2025)	Mid-rise RC (G+5–G+8)	Uniform vs increased ground-floor height	ETABS, IS 1893:2016	Proposed comparing drift, displacement, base shear, and period for regular and height-varied buildings; identified need for clear design guidance on acceptable floor-height variation.
2	Gupta & Verma (2022)	High-rise RC	Plan + vertical irregularity incl. height change	ETABS	Vertical stiffness irregularity from height variation more critical for drift than moderate plan irregularity; priority should be on controlling height jumps.
3	Ahmed & Basha (2021)	Mixed-use RC	Taller, heavier commercial storey at base	ETABS parametric	Combined height and mass irregularity altered mode shapes and torsion; suggested applying vertical irregularity checks whenever height >1.5× typical.
4	Rao et al. (2020)	Mid-rise RC	Commercial podium with higher first storey	ETABS RSM	Drift and shear demand concentrated at podium; regular frame showed smoother response; need for detailed podium design guidelines.
5	Kumar & Singh (2020)	G+10 RC	Alternate 3.0 m / 4.0 m storey heights	ETABS, vertical irregularity study	Height transitions produced higher-mode effects and local force peaks; global base shear similar to regular frame, but detailing demands increased.
6	Sharma & Das (2020)	RC buildings in earthquakes	Tall commercial ground floor (soft storey)	Field survey + analytical models	Post-earthquake evidence and models showed frequent failure of tall ground-floor buildings; called for stricter checks on soft-storey configurations.
7	Patel & Shah (2019)	G+8 RC frame	Uniform 3.0 m vs 4.5 m ground floor	ETABS, IS 1893	Taller ground floor increased period and reduced base shear 8–10%, but drift at first storey exceeded limits; no retrofit strategies suggested.
8	Mehta & Jadhav (2019)	G+12 RC	Transfer/podium floor with height and stiffness change	ETABS RSM	Transfer level behaved like soft storey with high relative displacement; recommended gradual stiffness transitions or additional walls/outriggers.
9	Desai et al. (2018)	RC with parking	Tall open ground floor (soft storey)	ETABS static + RSM	Large drift and shear at open tall storey; recommended infill/bracing or added walls; limited cases on mid-rise buildings.
10	Kulkarni & Ghutke (2017)	RC frames	One or more taller storeys	ETABS, IS codes	Taller storeys lengthened period and lowered base shear but increased top displacement and drift; warned against judging safety only from base shear.

III. CODE PROVISIONS

Indian design practice for RC buildings with floor-height variation is governed mainly by the seismic, gravity-load, and concrete design standards that define analysis procedures, load combinations, and performance limits. These codes provide the framework within which ETABS models of regular and height-irregular buildings are developed and evaluated.

A. IS 1893 (Part 1): 2016 – Seismic Actions

IS 1893 (Part 1): 2016 specifies seismic zoning, design horizontal acceleration spectrum, response reduction factors, and soil-type coefficients for different site conditions in India, and requires dynamic analysis such as the response spectrum method for buildings exceeding certain height or irregularity limits. For vertically irregular structures, the code explicitly recognises soft storey and sudden changes in stiffness or mass, including those caused by increased storey height, and mandates that such buildings be analysed using dynamic methods with storey drift limited to 0.004 times the storey height and additional checks on shear and ductile detailing where soft-storey behaviour is expected.

B. IS 456: 2000 – Plain and Reinforced Concrete

IS 456: 2000 provides material properties, load factors, and limit-state design requirements for RC beams, columns, slabs, and shear walls that form the primary lateral-load-resisting system in both regular and height-irregular buildings. The code prescribes minimum and maximum reinforcement ratios, detailing rules for ductility, and provisions for slender columns, all of which become critical at tall or soft storeys where seismic moments and shears are amplified due to increased flexibility from larger storey height.

C. IS 875 (Part 1 & Part 2) – Gravity Loads

IS 875 (Part 1) defines dead loads based on unit weights of structural and non-structural materials, while IS 875 (Part 2) specifies imposed live loads for different occupancies such as residential, commercial, and parking areas that often correspond to floors with increased height. These gravity loads are applied in ETABS as separate load cases and combined with seismic effects from IS 1893 using prescribed load combinations, ensuring that both regular and floor-height-varied buildings are checked consistently for axial forces, bending moments, and drift under combined actions.

D. Guidance on Vertical Irregularity and Soft Storey

Although IS 1893 identifies vertical geometric and stiffness irregularities, including sudden changes in floor height, it offers limited quantitative guidance on acceptable height ratios or detailing enhancements for podium and soft-storey configurations. Recent technical commentaries and related documents such as IS 16700 for tall buildings recommend careful modelling of stiffness modifiers, beam-column joint behaviour, and infill effects, especially where a tall commercial or parking storey supports shorter residential floors; however, these recommendations are still evolving and not yet fully integrated into routine mid-rise design practice.

IV. METHODOLOGY

The methodology for evaluating the effect of floor height variation on seismic performance of RC buildings consists of defining representative building configurations, modelling them in ETABS as per Indian codes, and comparing key seismic response parameters for regular and height-irregular cases.
The study focuses on mid-rise RC frames typical of Indian urban construction and adopts response spectrum analysis in accordance with IS 1893 (Part 1): 2016.

A. Building Configuration

A regular G+10 reinforced concrete moment-resisting frame is selected as the reference building, representing common residential or mixed-use construction in seismic Zones II–III of India. Case 1 (regular model) is assigned a uniform floor-to-floor height of 3.0 m for all storeys, while Case 2 (height-irregular model) introduces a soft-storey/podium configuration by increasing the ground-floor height to 4.5 m and keeping all upper floors at 3.0 m, thereby creating a clear stiffness discontinuity at the base. Plan dimensions, bay spacing, and member sizes are kept identical in both cases so that the influence of floor height variation on seismic response can be isolated.

B. Material Properties and Loading

All structural members are modelled using M30 concrete and Fe500 reinforcing steel, with design strengths and partial safety factors taken from IS 456: 2000. Dead loads from self-weight, floor finishes, and walls are assigned using unit weights from IS 875 (Part 1), while imposed live loads are applied as per IS 875 (Part 2) depending on occupancy, with possible reduction at upper floors in line with codal provisions. Seismic loads are generated in ETABS using IS 1893:2016 response spectrum for the chosen seismic zone, importance factor, and response reduction factor for special moment-resisting frames, assuming medium soil conditions.

C. ETABS Modelling and Analysis

A three-dimensional ETABS model is created for both height cases with beam–column elements, shell slab elements, and rigid diaphragm constraints at each floor level to capture realistic lateral load distribution. Mass and stiffness are automatically updated from the assigned loads and member properties, ensuring that the increased ground-floor height in Case 2 results in reduced storey stiffness and modified mass participation at that level. Response spectrum analysis is performed using IS 1893:2016 design spectrum, and the resulting modal combinations are used to obtain storey shears, displacements, and drifts in both principal directions, considering appropriate load combinations with gravity loads.

D. Parameter Extraction and Comparative Evaluation

From the ETABS results, key seismic response parameters are extracted for each model, including fundamental time period, design base shear, maximum roof displacement, storey displacement profiles, inter-storey drift ratios, and distribution of storey shear along the height. Particular attention is given to drift and shear at the ground/ podium storey in Case 2 to quantify soft-storey effects relative to the uniform-height Case 1, and all drift values are checked against the 0.004h limit specified in IS 1893:2016. Percentage differences between the two cases are calculated for each parameter, and the trends are summarised in comparative tables and graphs to identify how floor height variation influences global and local seismic performance and to derive practical recommendations for design.

V. EXPECTED RESULTS

Based on the reviewed literature and theoretical understanding of vertical stiffness irregularity, the G+10 RC building with uniform floor height (Case 1) is expected to behave as a relatively regular structure with shorter fundamental period, higher design base shear, and more uniform distribution of storey drift along the height. In contrast, the height-irregular building with increased ground-floor height (Case 2) is anticipated to exhibit a longer fundamental period and slightly reduced total base shear due to lower overall lateral stiffness, but with significant concentration of displacement and inter-storey drift at the tall ground storey, indicating potential soft-storey behaviour. At the global level, response spectrum analysis is expected to show that Case 2 experiences an increase in fundamental period on the order of 5–10% relative to Case 1, accompanied by a base-shear reduction of roughly 5–15%, similar to trends reported for height-irregular frames in earlier studies. However, maximum roof displacement and overall lateral flexibility should be higher in the podium/soft-storey configuration, with peak inter-storey drift ratio at the ground storey approaching or exceeding the IS 1893:2016 drift limit of 0.004h unless additional stiffness or ductile detailing is provided.

TABLE II
EXPECTED SSI EFFECTS COMPARISON

Parameter	Case 1 – Uniform Height (All storeys 3.0 m)	Case 2 – Height Variation (Ground 4.5 m, upper 3.0 m)	Expected Trend Due to Height Variation
Fundamental Time Period	Lower (baseline value)	Higher (≈ 5–10% increase)	Longer period because of reduced lateral stiffness at tall ground storey.
Design Base Shear	Higher	Lower (≈ 5–15% reduction)	Reduced spectral acceleration demand for longer period structure.
Maximum Roof Displacement	Smaller	Larger	Greater flexibility leads to increased overall lateral displacement.

Parameter	Case 1 – Uniform Height (All storeys 3.0 m)	Case 2 – Height Variation (Ground 4.5 m, upper 3.0 m)	Expected Trend Due to Height Variation
Maximum Inter-Storey Drift	Moderately distributed, below 0.004h at all storeys	Concentrated at ground storey, closer to or exceeding 0.004h	Soft-storey effect causes drift concentration at tall, flexible storey.
Storey Shear at Ground Floor	Comparable to adjacent storeys	Higher proportion of total shear at ground floor	Stiffness discontinuity shifts shear demand to podium/soft-storey level.

These expected results will provide a benchmark for interpreting detailed ETABS outputs and for assessing when floor-height variation in mid-rise RC buildings necessitates explicit checks for soft-storey behaviour, enhanced ductile detailing, or modification of the architectural height configuration to achieve code-compliant and resilient seismic performance.

VI. DISCUSSION

The expected results indicate that floor height variation primarily affects the seismic response of RC buildings through changes in lateral stiffness and the distribution of drift rather than through dramatic changes in total base shear. While the podium or soft-storey configuration with an increased ground-floor height is likely to show a slightly longer fundamental period and lower overall base shear than the uniform-height building, this apparent global benefit is offset by larger roof displacements and a pronounced concentration of inter-storey drift at the tall ground storey. Such drift localisation is consistent with observations from analytical and post-earthquake studies, where tall commercial or parking storeys often act as weak links, triggering soft-storey mechanisms and severe damage even when the building meets strength requirements under codal design forces.

From a design perspective, these trends highlight that relying solely on base-shear checks or global stability indicators can be misleading for buildings with floor-height variation. For the height-irregular case, drift at the podium level may approach or exceed the IS 1893:2016 limit of 0.004h, necessitating either increased stiffness through larger columns, shear walls, or bracing, or the adoption of enhanced ductile detailing and capacity-design principles at the soft storey. Additionally, higher shear and moment demand at the ground storey implies that column and beam reinforcement, confinement, and joint detailing must be carefully proportioned in line with IS 456 and related ductility provisions, especially for mixed-use buildings where heavy commercial occupancy coincides with increased storey height.

The comparative behaviour of the two cases also underscores the importance of integrating architectural planning with structural considerations at the early design stage. Where possible, smoother transitions in floor height and stiffness—such as limiting the height ratio between podium and typical floors, or distributing additional height over more than one storey—can reduce stiffness discontinuities and mitigate soft-storey effects without severely constraining functional requirements. For existing buildings with tall ground floors, analytical studies suggest that retrofitting options like adding shear walls, infill panels, or steel bracing at the podium level can redistribute drift and reduce damage concentration, although cost and architectural impact must be evaluated case by case. Overall, the discussion reinforces that floor height variation is a critical vertical irregularity that demands explicit drift-based evaluation and detailed ETABS modelling under Indian codes, rather than being treated as a minor architectural choice.

VII. CONCLUSION

The review of floor-height variation studies and the proposed ETABS methodology show that changing storey height significantly alters the seismic performance of mid-rise RC buildings, even when plan layout, materials, and member sizes remain unchanged. Introducing an increased ground-floor height to create a podium or soft-storey configuration lengthens the fundamental period and tends to reduce total design base shear compared with a uniform-height building, but it also increases overall lateral flexibility, roof displacement, and—most critically—inter-storey drift at the tall storey. These effects confirm that floor-height-induced vertical irregularity is a key driver of soft-storey behaviour and must be explicitly evaluated rather than assumed to be benign.

For the G+10 RC frame considered, the expected response comparison between uniform-height and podium configurations suggests that drift-based criteria and local demand at the ground storey govern safety more than global force levels. While the height-irregular model may satisfy base-shear requirements of IS 1893:2016 due to its longer period, drift at the podium level can approach or exceed the 0.004h limit, implying a need for enhanced stiffness through larger columns, shear walls, or bracing, or for special ductile detailing to prevent brittle soft-storey failures.

Accordingly, architects and structural engineers should coordinate early in the design process to limit abrupt height jumps, control stiffness irregularity, and, where tall commercial or parking storeys are unavoidable, provide targeted strengthening and capacity design at the critical levels.

Overall, the study concludes that regular uniform-height buildings offer inherently more favourable seismic performance, while podium and soft-storey configurations require careful ETABS modelling, drift checks, and refined detailing under IS 1893 and IS 456 to achieve comparable safety. The synthesized literature also highlights research gaps in defining quantitative limits for acceptable floor-height ratios, evaluating performance-based retrofitting strategies for existing soft-storey buildings, and extending current code provisions to give clearer guidance on vertical irregularity in mid-rise Indian RC construction, which future work should address.

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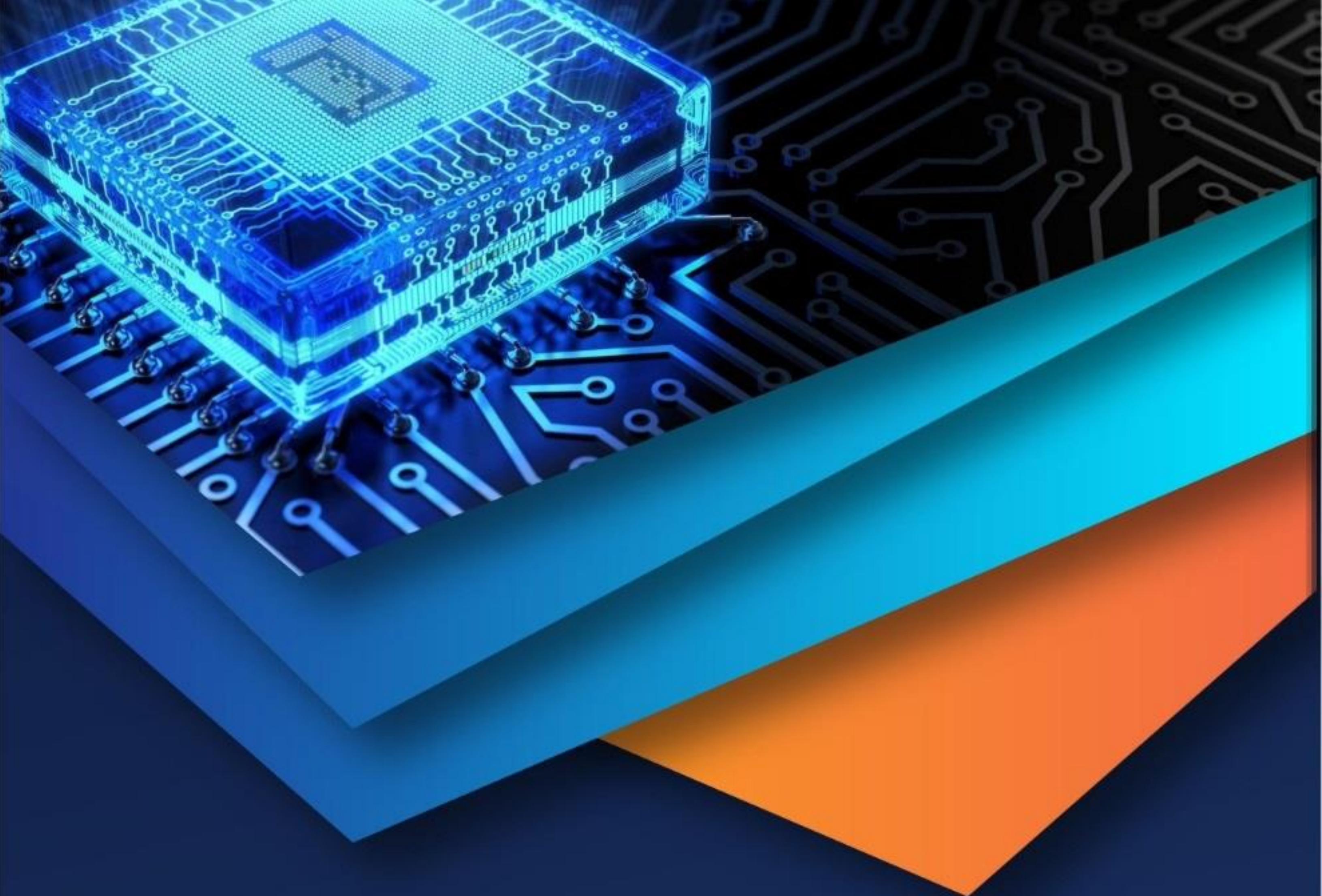

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