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Behaviour of Mid-Rise Rc Structures under Blast Loading Using Fem Software

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Abstract: This study investigates the dynamic response of mid-rise reinforced concrete (RC) buildings under blast loading, driven by the increasing threat of terrorist attacks that cause severe structural damage. The objective is to evaluate the behavior of bare moment-resisting frames (comprising columns and beams), focusing on displacement, load-carrying capacity, and damage patterns. Using SAP2000, a parametric study was conducted on buildings of varying heights (G+6, G+9, and G+12), including a G+6 irregular building. Time history analyses were performed for explosive charge weights of 10 kg, 20 kg, and 30 kg at standoff distances of 15 m, 30 m, and 45 m. The results revealed peak displacements of approximately 1100 mm in the bare frame structures. The frame, acting like a mesh structure, experiences reduced abrupt loading due to blast wave diffraction. However, these deformations still indicate potential vulnerabilities in conventional frame systems under high-intensity blast loads. To enhance blast resistance, various retrofitting techniques were investigated, including single diagonal bracing, double diagonal bracing, and steel jacketing. These methods significantly improved energy dissipation and overall structural stiffness. The study provides valuable insights into strengthening strategies for improving the resilience of urban infrastructure against explosive threats.
Index Terms: Dynamic Response, Blast loading, Displacement, Charge Weight Standoff Distance.

I. INTRODUCTION

In the contemporary world, the safety of civil infrastructure has become a critical concern in the face of increasing threats from accidental and intentional explosions. With growing urbanization and the concentration of population and resources in mid-rise and high-rise buildings, ensuring the blast resistance of such structures has emerged as an essential aspect of structural engineering. Reinforced concrete (RC) structures, being the most widely used form of construction due to their strength, durability, and economic viability, are frequently exposed to potential risks in both civilian and military settings. Mid-rise RC buildings—generally defined as those ranging from 15m to 45m storeys are especially vulnerable to blast effects due to their vertical continuity and the concentration of loads. The failure of critical components in these structures under blast loading may lead to progressive collapse, posing a serious threat to life and property. Consequently, understanding and accurately predicting the behaviour of mid-rise RC structures subjected to blast loads is vital for structural safety and resilience. While the behaviour of structural elements under conventional loading is well understood, the response under blast loading is complex due to the highly dynamic, nonlinear nature of the event. Parameters such as peak overpressure, impulse duration, and stand-off distance significantly influence the structural response. The effect is further complicated by factors like geometry, material nonlinearity, strain-rate effects, and dynamic boundary conditions. These complexities necessitate the use of advanced numerical methods and software to simulate and analyse blast scenarios with acceptable accuracy.

A. Significance of Study

In recent years, the rise in accidental and intentional explosions—from industrial incidents to terrorist attacks—has highlighted the vulnerability of civil infrastructure to blast loads. Unlike conventional forces, blast loads are dynamic, high-intensity, and act over very short durations, posing unique design challenges.

Understanding blast effects is crucial for enhancing the safety of critical facilities such as government buildings, airports, and industrial plants. These structures must resist or mitigate blast impacts to prevent collapse and protect lives. In industrial settings, where explosions may occur due to chemical reactions or equipment failures, blast-resistant design can reduce catastrophic losses.

Research in this field also informs the development of building codes and design standards, promoting consistent protective measures in vulnerable regions. With advancements in finite element software like SAP2000 and LS-DYNA, engineers can simulate complex blast-structure interactions and optimize structural performance without physical testing.

Beyond technical aspects, blast-resistant design holds ethical importance, especially in rebuilding efforts in conflict zones. Safer designs can save lives and strengthen community resilience. As security threats evolve, blast loading analysis remains essential in modern structural engineering.

B. *Blast Phenomenon and Structural Impact*

An explosion is a rapid and violent release of energy, typically resulting from chemical reactions, gas expansion, or detonation of high explosives. This sudden energy release produces a blast wave of a high-pressure shock front that travels outward from the explosion source at supersonic speed, causing severe damage to nearby structures. The blast wave is characterized by a sharp rise in pressure above atmospheric levels, known as peak overpressure, followed by a rapid exponential decay and a negative phase, where the pressure falls below ambient. This pressure-time behaviour is typically represented by the Friedlander waveform, which is widely used in blast analysis. Key parameters that define a blast load include peak overpressure, positive phase duration, impulse, and standoff distance. These parameters depend on factors such as the type and quantity of explosive, distance from the detonation point, and surrounding environment. The structural response to a blast wave is highly dynamic, involving rapid stress reversals and large strain rates, which may lead to local failures like spalling and cracking, or global effects such as collapse or instability.
Understanding the explosion and blast phenomenon is essential for engineers to predict structural behaviour under extreme conditions and to develop mitigation strategies through improved design, detailing, and retrofitting of vulnerable buildings.

II. METHODOLOGY

This research evaluates the dynamic displacement response of mid-rise reinforced concrete (RC) buildings subjected to surface blast loading, with a focus on the effectiveness of diagonal bracing and steel jacketing as retrofitting techniques. Models are developed and analyzed using SAP2000, incorporating three different building heights (G+6, G+9, and G+12), including a G+6 irregular configuration.
Four structural configurations are assessed:

1) NB (Non-Braced): Control model without any retrofitting.
2) Single Diagonal Bracing: One steel brace per bay to improve lateral stiffness.
3) Double Diagonal Bracing: Two braces forming an “X” shape for better force distribution.
4) Steel Plate Jacketing: Steel plates welded around columns to enhance confinement and strength.

Blast loads are applied as hemispherical surface explosions with charge weights of 10 kg, 20 kg, and 30 kg at standoff distances of 15 m, 30 m, and 45 m. Each model includes slabs, beams (0.25 m × 0.35 m), and columns (0.35 m × 0.4 m), with a 3.0 m floor height and 20 m × 20 m plan area (5×5 bays of 4 m × 4 m). Materials used include M30 concrete and Fe500 steel.
Blast load calculations follow standard procedures:

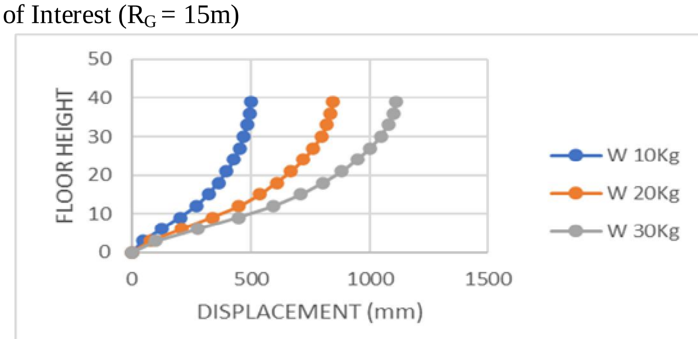
a) Scaled distance (Z) and peak overpressure (Ps) based on empirical formulas.
b) Reflected overpressure (Pr) computed using pressure coefficients.
c) Arrival time (ta) and positive phase duration (td) determined for each blast case.
d) Blast load (kN) applied to walls calculated as Pr × Area.

Each model undergoes three simulation runs for consistency. The primary output, maximum displacement, is compared across different retrofitting strategies to evaluate structural performance.

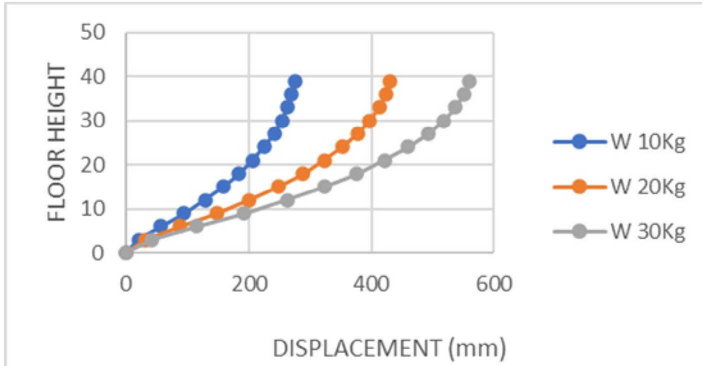
III. ANALYTICAL STUDY AND SIMULATION RESULTS

1) *Model G+12*

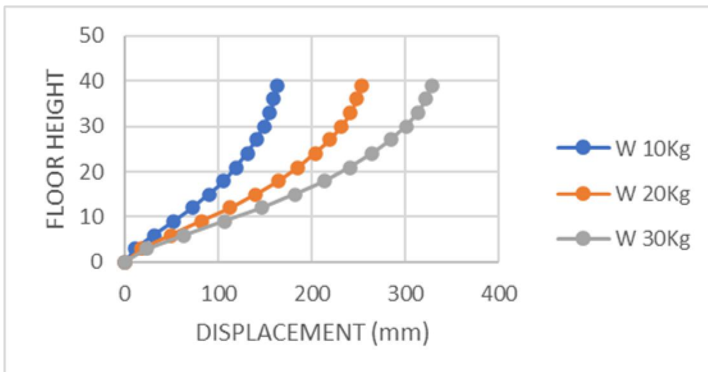
Distance from Blast to the Point of Interest (R_G = 15m)



Distance from Blast to the Point of Interest (R_G = 30m)

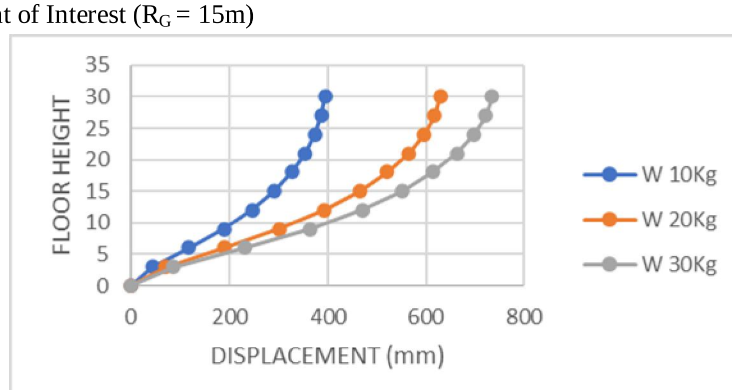


Distance from Blast to the Point of Interest (R_G = 45m)

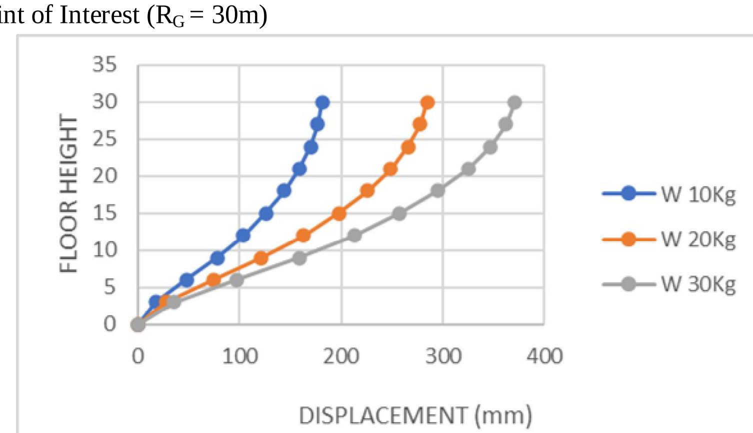


2) *Model G+9*

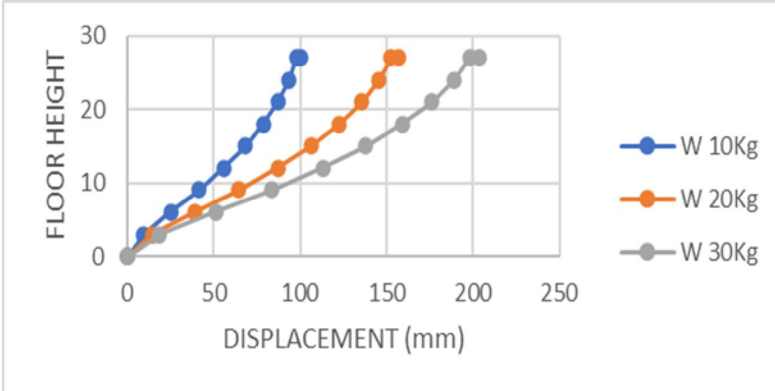
Distance from Blast to the Point of Interest (R_G = 15m)



Distance from Blast to the Point of Interest (R_G = 30m)

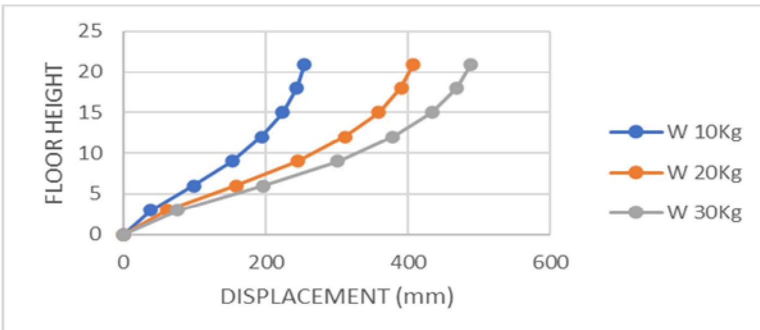


Distance from Blast to the Point of Interest (R_G = 45m)

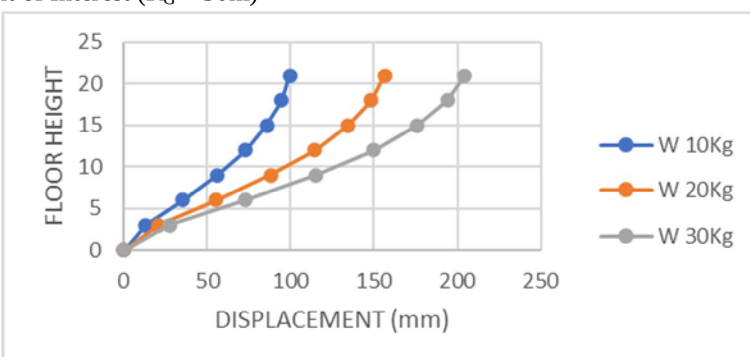


3) Model G+6

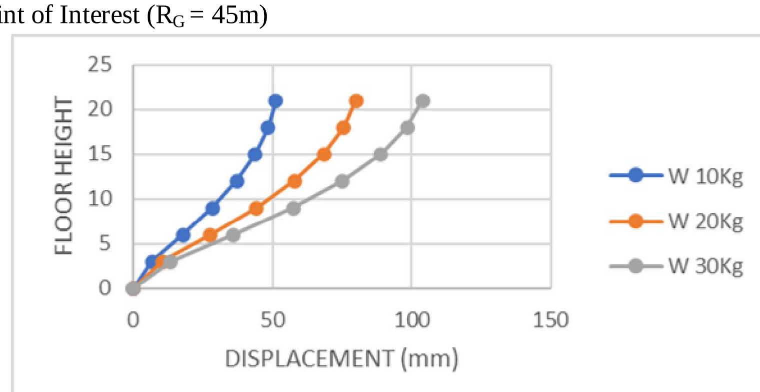
Distance from Blast to the Point of Interest (R_G = 15m)



Distance from Blast to the Point of Interest (R_G = 30m)



Distance from Blast to the Point of Interest (R_G = 45m)



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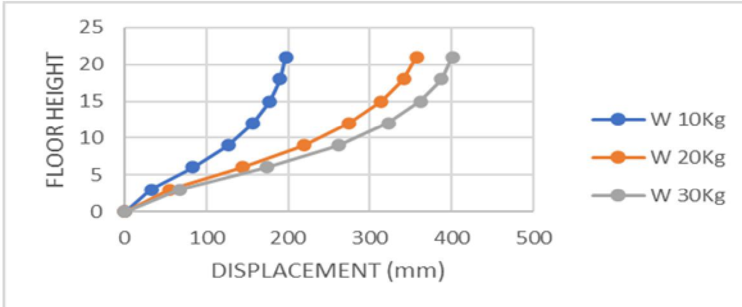
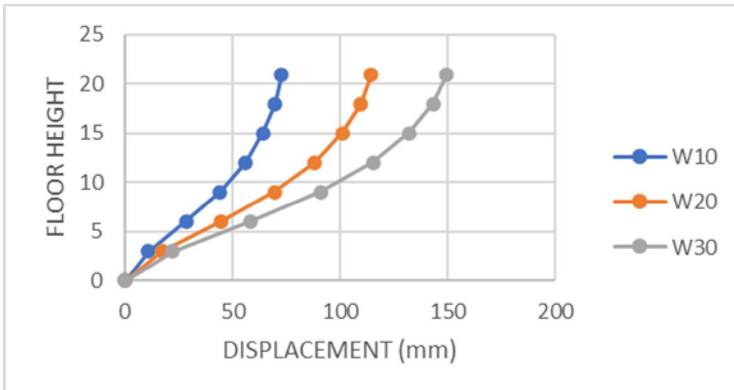
4) Model G+6 Irregular building

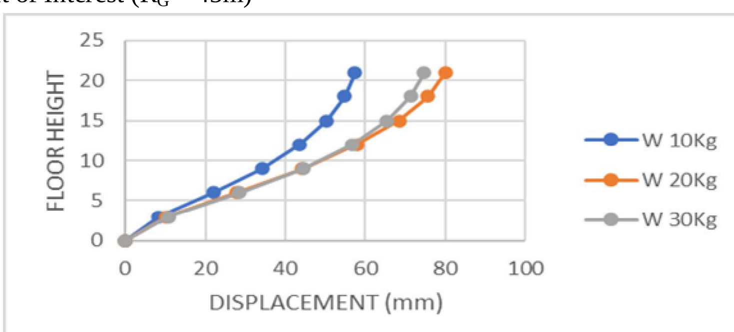
Distance from Blast to the Point of Interest (R_G = 15m)



Distance from Blast to the Point of Interest (R_G = 30m)

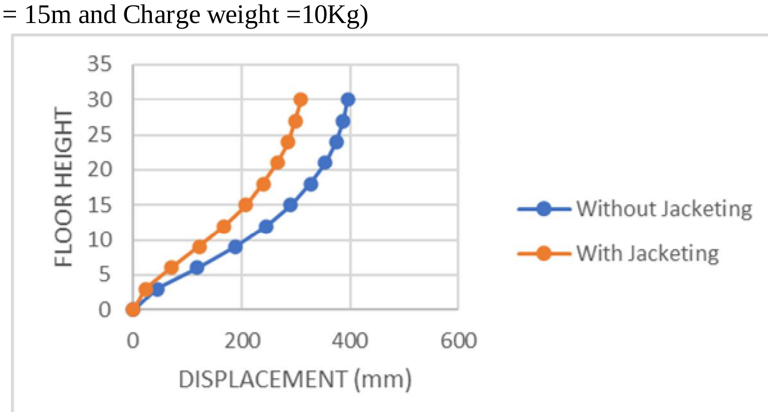


Distance from Blast to the Point of Interest (R_G = 45m)

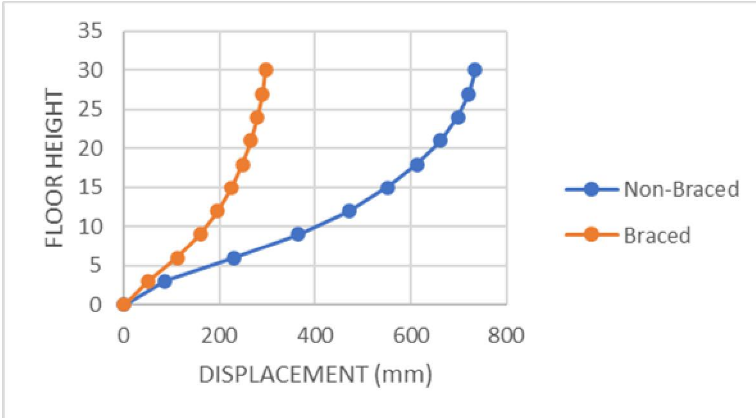


5) G+9 Retrofitting

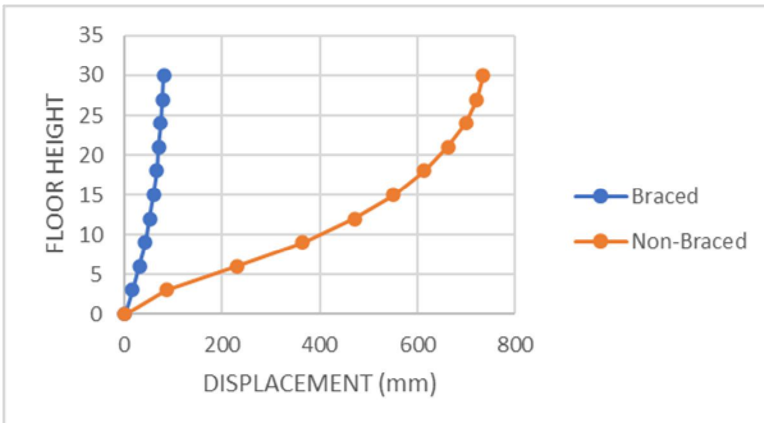
Steel Tube Jacketing (For R_G = 15m and Charge weight =10Kg)



Single Diagonal Bracing (For R_G = 15m and Charge weight =30Kg)



Double Diagonal Bracing "X" (For R_G = 15m and Charge weight =30Kg)



IV. RESULTS AND DISCUSSION

The present study evaluates the dynamic response of mid-rise reinforced concrete (RC) buildings subjected to blast loads using SAP2000. Displacement results were recorded for various structural configurations and building heights under different charge weights and standoff distances (RG = 15 m).

For the G+12 RC frame, the maximum displacement observed was 1114.17 mm under a 30 kg TNT charge, while the minimum displacement was 45.36 mm under a 10 kg charge. This indicates a considerable vulnerability to blast loads in taller unretrofitted frames.

The G+9 model, selected for retrofitting evaluation, showed a maximum displacement of 734.51 mm and a minimum displacement of 43.77 mm, corresponding to 30 kg and 10 kg charges respectively.

In the case of the G+6 model, the maximum displacement reached 487.77 mm, and the minimum was 37.62 mm. For the G+6 irregular building, the values slightly reduced, with a maximum of 400.5 mm and a minimum of 32.38 mm. These results highlight the influence of building height and regularity on blast response.

To assess the effectiveness of retrofitting techniques, the G+9 model was modified using different strengthening methods:

1) Steel Tube Jacketing, applied under a 10 kg explosive load, achieved a 21.80% reduction in displacement. This method enhances column confinement and lateral stiffness, improving blast resistance as supported by Ghobarah (2004) and Cheng & Xu (2007).
2) Single Diagonal Bracing, evaluated under a 30 kg load, led to a significant 59.53% reduction in displacement. The addition of bracing improves energy dissipation and structural ductility, effectively mitigating blast-induced deformation.
3) The highest performance was recorded for Double Diagonal "X" Bracing, which reduced the displacement by 89.12% under a 30 kg charge. This retrofitting configuration distributes the blast forces more efficiently across the structural system and demonstrates superior lateral load resistance, corroborated by findings from Bao & Li (2010) and Tagel-Din et al. (2009).

Overall, the results clearly demonstrate that retrofitting plays a crucial role in enhancing the blast resilience of RC frames. Among the methods studied, cross ("X") bracing proved most effective, indicating its suitability for structures exposed to potential explosive threats.

V. CONCLUSION

Explosions occurring in proximity to buildings can inflict significant structural damage. The destructive impact may stem not only from the direct blast wave but also from the resulting collapse of structural components, flying debris, fire, and smoke. In this study, surface blast loads were calculated and applied to a series of structural models using SAP2000, a widely adopted software for dynamic analysis.

Blast loads were modelled as time-history functions derived from established empirical equations available in the literature. A parametric analysis was conducted for building models of varying heights G+6, G+7, and G+12 under different explosive charge weights (10 kg, 20 kg, and 30 kg) and standoff distances (15 m, 30 m, and 50 m). The nonlinear dynamic analysis in SAP2000 allowed for the evaluation of maximum joint displacements under each scenario.

Results demonstrated a clear trend: as the standoff distance increased, the resulting structural displacements consistently decreased, indicating a reduction in blast impact with distance.

To enhance the structural performance under blast loads, retrofitting techniques were applied to the G+9 model at a charge weight and standoff distance. The techniques included:

1) Local Steel Jacketing of columns
2) Single Diagonal Bracing
3) Double Diagonal ("X") Bracing

Among these, bracing systems significantly reduced displacement due to their ability to absorb and redirect dynamic forces. However, it was observed that local jacketing, although less effective in reducing displacement compared to bracing, offers localized reinforcement and enhanced ductility, thereby improving structural integrity during a blast event.

In conclusion, while bracings provide superior displacement control, local jacketing remains a viable and practical solution for protecting mid-rise buildings against surface explosion threats, especially in retrofitting existing structures.

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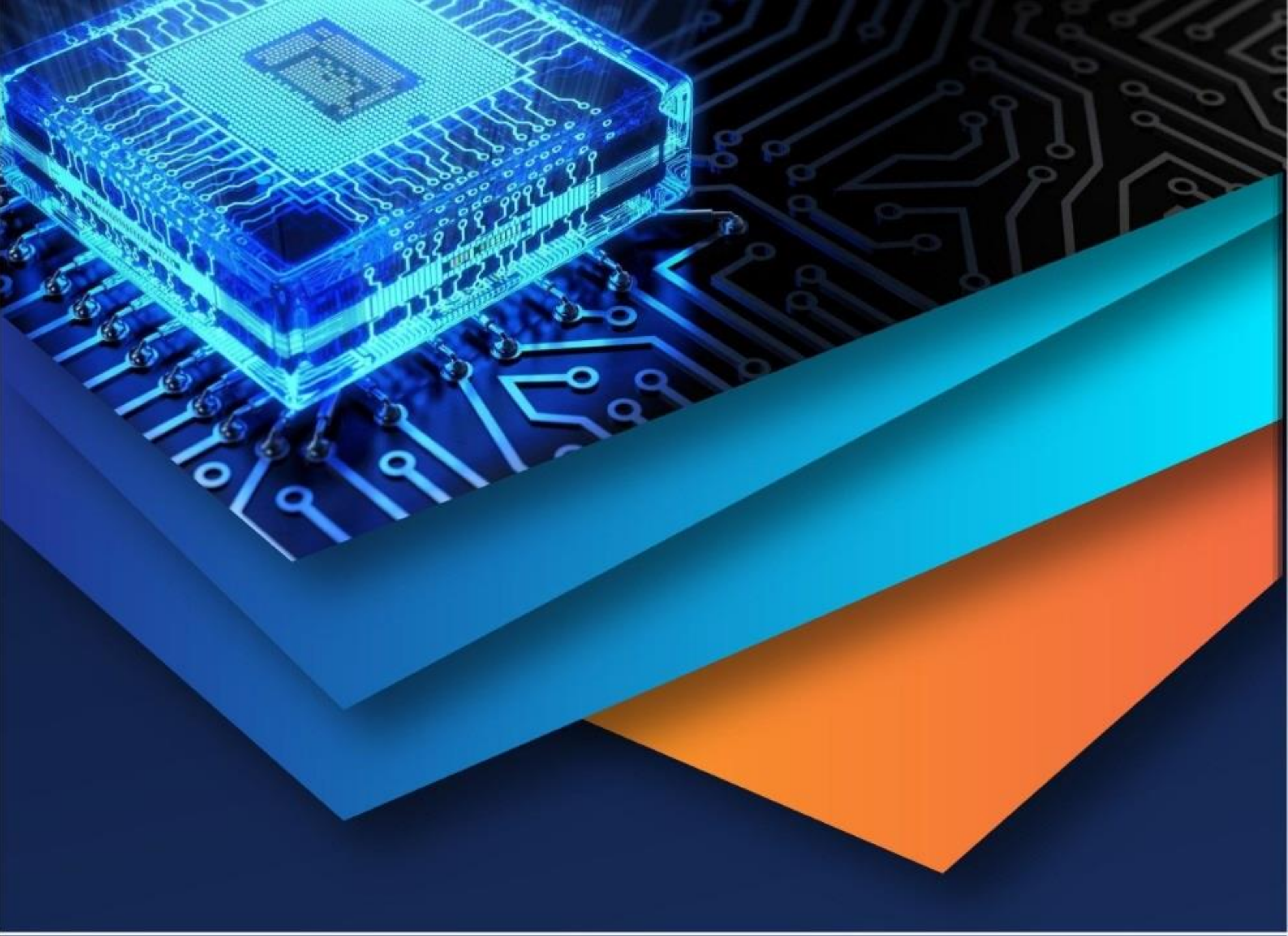

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