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Performance of High Rise Structure with Lead Rubber Base as an Isolation System

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***Abstract:** A weak story, often referred to as a soft story, is one that has insufficient ductility to withstand the forces placed on the building by an earthquake. Buildings with soft stories typically have a story with a lot of open space. Since soft stories are traditionally associated with retail establishments and parking garages, they are frequently located on the lower stories of a building. As a result, when they collapse, they have the potential to bring the entire structure down, resulting in severe structural damage that may render the building completely unusable. However, there have only been a few studies on the impact of soft storeys at various levels in tall structures. This study will therefore investigate the impact of soft storey level variation in 45 storey building with and without LRB isolated structures.*
***Keywords:** Weak story, insufficient ductility, tall structures, soft stories, LRB isolated structures.*

I. INTRODUCTION

One of the goals of seismic isolation is to lower a structure's fundamental frequency so that it is substantially lower than both its fixed-base frequency and the frequency of earthquakes that occur most frequently. The low horizontal rigidity of the isolation systems makes this possible. Utilizing an isolation system also has the secondary goal of increasing energy dissipation, which lowers the acceleration transferred to the superstructure. By separating the structure from ground motion, the ductility requirement and inter- story drifts are reduced, and the seismic energy is prevented from entering the building. This decoupling is achieved by placing low horizontal stiffness structural elements between the foundation and the superstructure. By doing so, the fundamental frequency of structural vibration is lowered below the main energy-containing frequencies of earthquake ground motions, and a mechanism for energy dissipation is provided, lowering the transmitted acceleration to the superstructure.

A. Framed Tube System

High-rise structures can improve their structural efficiency and stability by using the framed tube system, a structural design idea. Fazlur Rahman Khan, an architect, originally popularized it in the 1960s. The technique uses a network of outside steel or concrete columns that are joined and tightly spaced to create a rigid tube that serves as the building's main load-bearing structure. The framed tube system's exterior tube withstands most lateral stresses, including wind and seismic forces, while the internal space is devoid of structural components, enabling variable floor plans. The framed tube system's benefits include its structural effectiveness, which maximizes the use of vertical space, lowers the amount of building materials needed, and improves the structure's overall strength and stability. The Willis Tower (formerly Sears Tower), the John Hancock Centre, and the Petronas Towers in Kuala Lumpur are notable examples of structures that make use of the framed tube system. Overall, the framed tube system is a ground-breaking structural design idea that transformed the creation of high-rise structures while providing both architectural and engineering benefits. It is a well-liked option for buildings all around the world due to its effective use of materials and improved structural stability.

B. Base Isolation System

Seismic isolation also known as base isolation is one of the best earthquake resistant design concept in which a building is decoupled from the earthquake ground motion or seismic waves. In base isolation the base of the structure is isolated using isolators (normally bearing isolators) which help in decoupling. When a building is decoupled from ground motion it significantly reduces response in the structure which would have affected building if it is fixed base. Base isolation decouples the building from ground motion by decreasing the fundamental frequency when compared to fix based building. Base isolation concept is also useful in other infrastructures like bridges, nuclear power plants and liquid storage tanks etc. The concepts of earthquake resistant structures are divided as rigid structures and flexible structures.

In rigid structures the inter-story displacements are reduced by providing diagonal bracings, shear walls, and using composite materials which help in making the structure inflexible but rigid structures results in large inter-storey drifts, due to which the building components and non-structural components may get damaged very badly even if the building is stiff during earthquake. In flexible structures the excitation input is reduced with the help of concepts like using dampers and Isolators. Dampers are one of the oldest methods of designing seismic resistant buildings, in which the acceleration is basically reduced.

II. LITERATURE REVIEW

Radmila B. Salic, et al., (2008) studies a GF+7 storey, orthogonally almost symmetric, shear wall residential tower building in all details in order to clarify the influence of lead-rubber bearings (LRB) seismic isolation upon its seismic performance. General conclusions resulting from analytical and experimental study of the selected structure, entirely verify positive aspects of the seismic isolation on the structural earthquake response such as Increase of natural period, Reduction of base-shear, Increase of displacements, Reduction of interstory drifts, Reduction of story accelerations.

F. Hejazil, et al., (2011) investigates the effects of soft stories on high-rise buildings' structural behavior as well as seismic retrofitting and rehabilitation of soft storey structures using bracing devices. The study examines a 12-storey reinforced concrete building with a soft storey on the ground floor that was built as a hotel. The study talks on how soft stories affect structures and how high-rise buildings affect earthquakes. The study examines the soft storey structural response of high-rise structures with various bracing configurations and, by taking the needed performance level into account, determines the best design of earthquake-resistant soft storey.

A. V. Hadian, et al., (2013) determines the best configuration of the LRB in the G+8 structure by calculating the response of the structure, roof level acceleration and inter story displacement based on the ground motion records. The comparison of the inter-story displacement, drifts frames and top level acceleration response of the LRB system with the Fixed Base System (FBS) using spectrum and time history analysis shows that the base shear reduces by 65–75% in response spectrum analysis, while in time history analysis base shear reduces by 75–85%. This system would help in reducing the cost in the long time and increase the safety of the structure.

A.B.M. Saiful Islam, et al., (2014) covers the effects of rubber-steel bearing nonlinear models on soft storey constructions in tall buildings during earthquakes in this article. The study compares the performance of linear and nonlinear rubber-steel bearing models by simulating the behavior of a 10-storey building with a soft storey using a finite element model. Based on the findings, it can be concluded that the nonlinear model is superior in terms of minimizing the displacement and acceleration of the building during an earthquake. The purpose of the RSBs is to reduce the displacement and acceleration of the building by absorbing and dissipating energy during an earthquake. As a result, adding RSBs to soft storey structures can strengthen the structural integrity of tall buildings and guard against catastrophic damage caused by earthquakes.

Anusha R Reddy, et al., (2015) considers two building’s in this study, first structure is G+13 storey building and second is G+5 storey building which is designed and analyzed in E TABS 13.2.1 software. Lead rubber isolator are provided to both the structures and then linear response spectrum and time history analysis are carried out for both fixed base and base isolated buildings under zone v and soil type II. Research findings were :For response spectrum analysis the base shear for G+ 13 storeys building in X and Y direction for fixed condition is 760.77 kN and for G+5 storey is 753.81 kN. After providing rubber isolator the base shear for G+13 storey building is 611.85 kN and for G+5 storey is 392.3 kN. For time history analysis the base shear for G+ 13 storeys building in X and Y direction for fixed condition is 1219.09 kN and for G+5 storey is 2266.32 kN. After providing rubber isolator the base shear for G+13 storey building is 1071.76 kN and for G+5 storey is 608.18 kN.

Sunita Tolani, et al., (2016) performs a parametric study of a base isolated building and compares the seismic response of a fixed base building and a base isolated building. A three-story reinforced concrete building with one lateral degree of freedom at each floor level serves as the structural system under study. In order to assess how fixed base and base isolated buildings react to three different seismic ground motions, the study used non-linear time history analysis. The performance of buildings is also examined in relation to various isolation systems, such as the Friction Pendulum System, Lead Rubber Bearing, and Laminated Rubber Bearing. According to the findings, base isolation techniques can dramatically lower a building's seismic reaction, and the selection of an isolation system and its characteristics can greatly affect how well a building performs.

B.Athamnia, et al., (2017) focuses on the soft-storey behavior of RC structures with lead core rubber bearing (LRB) isolation systems under near and far-fault motions. In this study a 12-story RC building was modeled to study the effect of a soft story on the dynamic behavior of the building under near and far-fault motion. A nonlinear time history analysis method is used to perform seismic analysis on isolated reinforced concrete buildings.

The analysis looks at inter-storey drifts, absolute acceleration, displacement, base shear forces, hysteretic loops, and the distribution of plastic hinges. These findings reveal that increasing the height of a storey has a greater impact on the performance of a base isolated RC structure under near-fault motion than on far-fault motion. Shahriar gholamin, et al., (2017) studies a 10-storey building of reinforced concrete moment frame which is designed as isolated and fixed-base, where Lead-rubber bearing (LRB) is used as an isolation system. The behaviors of designed models under dynamic loads are analyzed using SAP2000 software. In base – isolated structure large reduction is observed in acceleration value, base shear force and relative storey displacement with respect to conventional structure. The results show that using base isolator could decrease the weight of rebar and volume of concrete about 14% in a concrete moment frame. However, the costs of isolators are not considered. But in design of structures , drift and base shear force are the most important parameter, which Using seismic isolation have decreased , As a result , the damage of structure will be decreased. Rajesh Reddy, et al., (2017) investigates the effectiveness of base isolation in multistory reinforced concrete buildings in this research. The study analyses the seismic performance of fixed base and base isolated buildings employing friction pendulum and lead rubber bearing systems. Under different earthquake ground motions, the analysis is performed on two different building models, a G+5 storey building and a G+17 storey building. The results reveal that foundation isolation reduces the seismic response of buildings greatly, including the time period, base shear, and inter-story drift. The lead rubber bearing system is proven to be more successful than the friction pendulum system in decreasing seismic response. Dhiraj Narayan Sahoo, et al., (2018) compares the seismic responses of a fixed base building with a base isolated building as well as doing a parametric study of a base isolated building. The aim of present study was to analyze building at seismic zone i.e. in zone-II without and with base isolator and to assess the seismic behavior of structure. Following conclusions can be drawn after analyzing the results of 3-D analysis of G+ 10, G+ 15 storeys building in seismic zone II using ETABS software: The time period of structure increases approximately 2 times after providing the base isolator to fixed base structure. Due to this increase in time period, structure experiences less amount of seismic forces. The lateral earthquake Load, storey shear, column forces and moment are reduced to significant amount due to use of base isolator to the structure. The maximum storey stiffness of structure decreases in base isolated structure.

III.METHODOLOGY & PRELIMINARY DATA

A. Methodology

1) Structures having soft storeys in different elevation i.e., ground floor (storey 1), 22nd floor (storey 22) and 42nd floor (storey 42) will be modelled with and without LRB isolation system with the help of ETABS 18.
2) Three buildings with LRB below the soft storey, whereas the remaining three can be modelled without LRB for each model.
3) All models can be analyzed for response spectrum, results can be obtained, such as storey displacement, storey drift, storey stiffness and time period which can be analyzed and validated.
4) All models can be analyzed for wind analysis, obtained results such as storey displacement & storey drift can be analyzed and validated
5) Observation and comparison of result.
6) Conclusion

B. Preliminary Data

Table 1: Detail of building plan and properties of material

Sr. No.	Description	Value
1	No. of Storeys	45
2	Total length along X-direction	40 m
3	Total length along Y-direction	40 m
4	Slab thickness	150 mm
5	Thickness of wall at core	400 mm
6	Lift walls	240 mm
7	Columns	800mm x 800mm
8	Beams	350mm x 750mm
9	Height of the building	138 m
10	Grade of Concrete for column	M60
11	Grade of Concrete for beams & slabs	M35
12	Grade of steel	Fe500

Table 2: Response spectrum properties as per IS 1893 part 1 (2016)

Sr. No.	Description	Value
1	Zone	IV
2	Soil Condition	II
3	Seismic zone factor	0.24
4	Response reduction factor	4
5	Importance factor	1.2

Table 3: Load types and their values as per IS 875 part 1 & IS 875 part 2

Sr. No.	Type of load	Load Calculation
1	Live load on typical storey	4kN/m2
2	Floor finish on typical floor	1.5kN/m2

Table 4: Gust factor constants and parameters as per IS 875 PART 3-2015

Sr. No.	Description	Value
1	Basic wind speed (Vb) (m/sec)	50
2	Risk coefficient K1	1
3	Terrain Category K2	4
4	Topography Factor K3	1
5	Importance Factor K4	1
6	Soil Type	II (medium)

Table 5: Input values for LRB at ground floor

Sr. No.	Description	Value
1	Rotational Inertia 1	2.011 KN/m
2	For U1 Effective Stiffness	12476620 KN/m
3	For U2&U3Effective Stiffness	12476.62 KN-m
4	For U2&U3Effective Damping	5%
5	For U2&U3 distance from J	0.0032 m
6	For U2&U3 non- linear Stiffness	114967.3 KN/m
7	For U2&U3Yield Strength	365.53 KN

Table 6: Input values for LRB at 22nd floor

Sr. No.	Description	Value
1	Rotational Inertia 1	0.5268 KN/m
2	For U1 Effective Stiffness	6407330 KN/m
3	For U2&U3Effective Stiffness	6407.33 KN-m
4	For U2&U3Effective Damping	5%
5	For U2&U3 distance from J	0.0032 m
6	For U2&U3 non-linear Stiffness	59041.1 KN/m
7	For U2&U3Yield Strength	187.72 KN

Table 7: Input values for LRB at 42nd floor

Sr. No.	Description	Value
1	Rotational Inertia 1	0.0098 KN/m
2	For U1 Effective Stiffness	889850 KN/m
3	For U2&U3Effective Stiffness	889.85 KN-m
4	For U2&U3Effective Damping	5%
5	For U2&U3 distance from J	0.0032 m
6	For U2&U3 Stiffness	8199.8 KN/m
7	For U2&U3Yield Strength	26.06 KN

C. Building Structural Plan

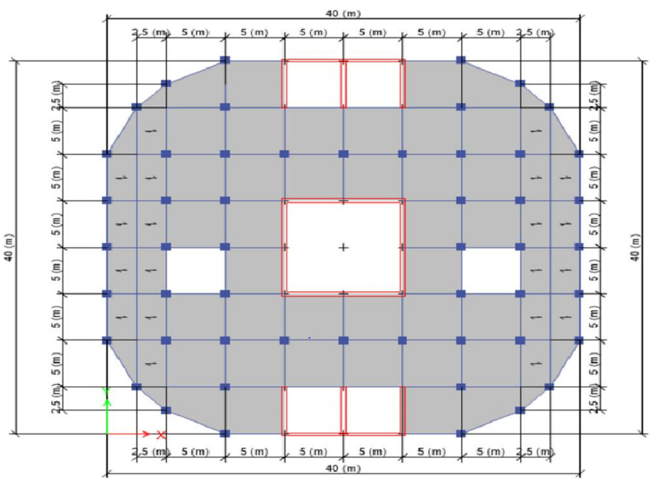

Fig 1: Typical ETABS model plan with dimensions

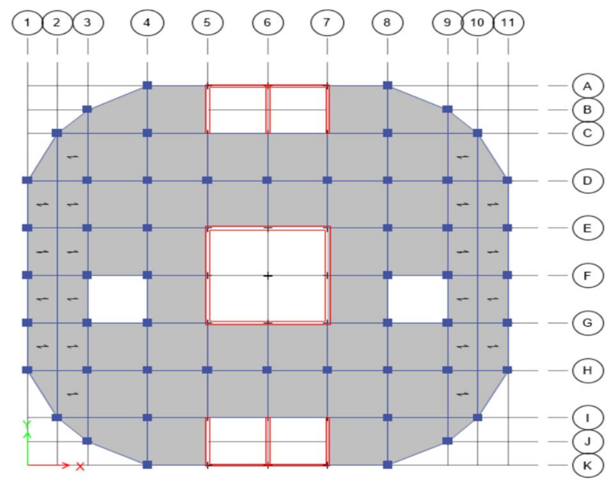

Fig 2: Typical ETABS model plan with grids

D. Building 3D View

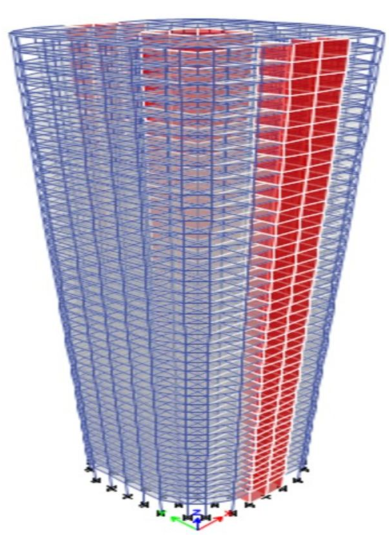

Fig. 3: Soft Storey at G floor (storey 1) without LRB

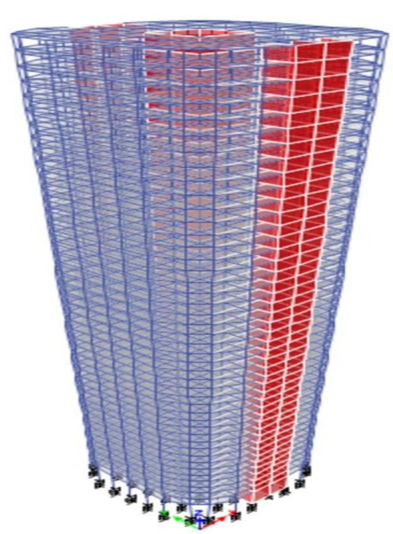

Fig. 4: Soft Storey at G floor (storey 1) with LRB

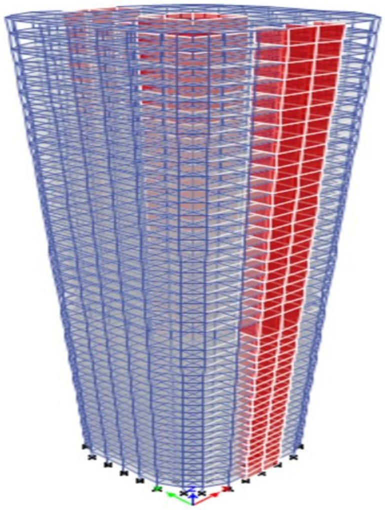

Fig. 5: Soft Storey at 22nd floor (storey 22) without LRB

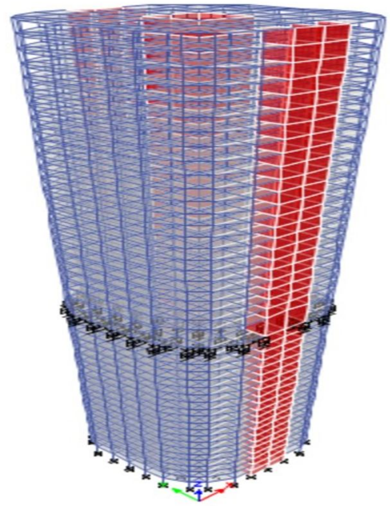

Fig. 6: Soft Storey at 22nd floor (storey 22) with LRB

Fig. 7: Soft Storey at 42nd floor (storey 42) without LRB

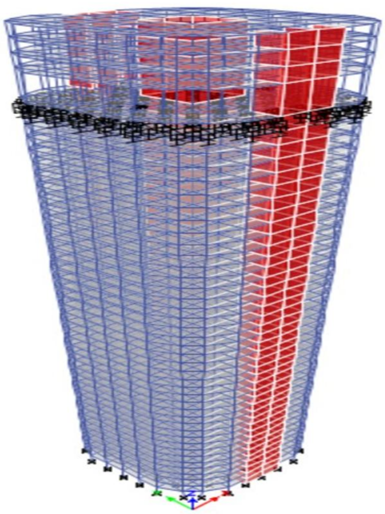

Fig. 8: Soft Storey at 42nd floor (storey 42) with LRB

IV. RESULT AND DISCUSSION

A. Response Spectrum Analysis

1) Effect of Story Displacement with and without LRB

The displacement in soft storey on ground floor increases slightly in isolated building compared to non-isolated building when LRB is on ground floor , while displacement in soft storey on 22nd floor is reduced by 73.97% in X direction and 79.85% in Y direction in isolated building compared to non-isolated building when LRB is on 22nd floor.

The displacement is decreased by 69.7% in X and 77.56% in Y direction when compared to the absence of the isolated structure when soft story is on 42nd floor. The results reveal that when the structure is isolated at ground level, the building is more flexible than when it is isolated at mid floor.

2) Effect of Story Drift on Soft Storeys with and without LRB

When compared to a non-isolated building, the drift in the soft story on the ground level of the isolated building is more while in non-isolated structure the drift is less when LRB is on ground. This is due to the isolators' flexible nature absorbing energy and allowing additional movement in the structure.

When compared to a non- isolated building, the drift in the soft story on the 22nd level of the isolated building was reduced by 66.81% in X direction and 72.05% in Y direction when LRB is on 22nd floor. This decrease implies that isolating the 22nd level makes it more resistant to lateral movement during seismic events. The isolators have restricted the transfer of lateral forces to this floor, reducing its drift.
When compared to a non-isolated building, the drift in the 42nd soft storey was reduced by 70.68% in X direction and 78.66% in Y direction in the isolated building when LRB is on 42nd floor. This outcome is comparable to the 22nd-floor situation, demonstrating that isolation helps prevent drift in soft levels in general.

3) Effect of Story Stiffness on Soft Storeys with and without LRB

The Story Stiffness decreases by 3.71% in X and 3.19% in Y direction on ground floor after providing LRB on ground floor.
In structures without isolation, the stiffness of the 22nd floor is 52% less than that of the 23rd floor. According to the data, the story stiffness of the 22nd floor with respect to 23rd floor increases by 11% in Y direction when without LRB is compared to the LRB implementation on 22nd floor.
In structures without isolation, the stiffness of the 42nd floor is 59% less than that of the 43rd floor. According to the data, the story stiffness of the 42nd floor with respect to 43rd floor increases when without LRB is compared to the LRB implementation on 42nd floor.
This indicates the isolation system's effectiveness in limiting the soft storey effect by reducing the transfer of forces to the floors above in isolating 22nd and 42nd floor.

4) Effect of Time Period of Structure with and without LRB

The time period increases by 0.1% after isolating the ground floor because the building is more flexible than a fixed base.
Whereas on the 22nd floor after isolation, time is decreased by 44.21% since the floor below moves with the isolator.
The time on the 42nd floor after isolation is decreased by 52.74% because the below floor moves with the isolator and the above floor stiffens.

B. Wind Analysis

1) Effect of Story Displacement on Soft Storeys with and without LRB

When compared to a non-isolated building, displacement in the soft storey on the ground level of the building isolated on ground floor rose. This displacement increase is due to the isolators' flexibility in absorbing wind-induced forces.
When compared to a non-isolated building, displacement in the soft storey on the 22nd level of the building isolated on 22nd floor was reduced by 75% in X direction and 80.5%in Y direction. This indicates that isolating the 22nd floor has greatly reduced its displacement during strong wind events. The wind forces were absorbed and dissipated by the isolators, limiting excessive movement.
When compared to a non-isolated building, displacement in a 42nd floor soft story was reduced by 73% in X direction and 79%in Y direction in the building isolated on 42nd floor. This result, like the 22nd-floor case, shows that isolation can be beneficial in limiting displacement during gust wind events.

2) Effect of Story Drift on Soft Storeys with and without LRB

The storey drift of isolated structure is almost similar when compared to non-isolated structures when soft storey is on ground floor.
The isolated buildings have a significant 67.17% reduction in X direction and 72.35% reduction in Y direction in soft storey drift on the 22nd level when compared to non-isolated buildings.
The isolated buildings have a significant 80% reduction in X direction and 86.61% reduction in Y direction in soft storey drift on the 42nd level when compared to non-isolated buildings.
This data imply that isolated structures perform better in terms of minimizing drift during strong winds, especially on higher floors. The somewhat larger drift observed on the ground level in the isolated building is due to the isolation system's particular features and force distribution.

V. CONCLUSION

In this study different structures were analysed by seismic and wind analysis. The study aimed to determine the effect of soft storeys within structures on variables such as storey displacement, storey drift, storey stiffness and time period. Based on the results obtained by analysis the following conclusions have been made:

1) It was observed from the result that after isolating the building at three different levels at ground, mid and top it was effective to reduce the forces transferring the above floor. The effectiveness of the isolation system in controlling the soft storey effect was found.
2) As the result from time period, it was observed that when the structure is isolated from ground it is more flexible than the building isolated on mid and top floor. This results in an increase in drift and displacement when the structure is isolated on ground as compared to mid and top floor.
3) When the building is subjected to wind there is an increase in drift and displacement when the building is isolated on ground. There is more reduction of drift and displacement when the building is isolated on mid and top level.

Ground-floor isolation efficiently reduced force transmission, whereas upper floor isolation reduced soft storey effects. The findings show the potential of storey isolation for seismic and wind resistance in structures. The results indicate that isolating the mid and top floors is more efficient than isolating the ground floor in all aspects.

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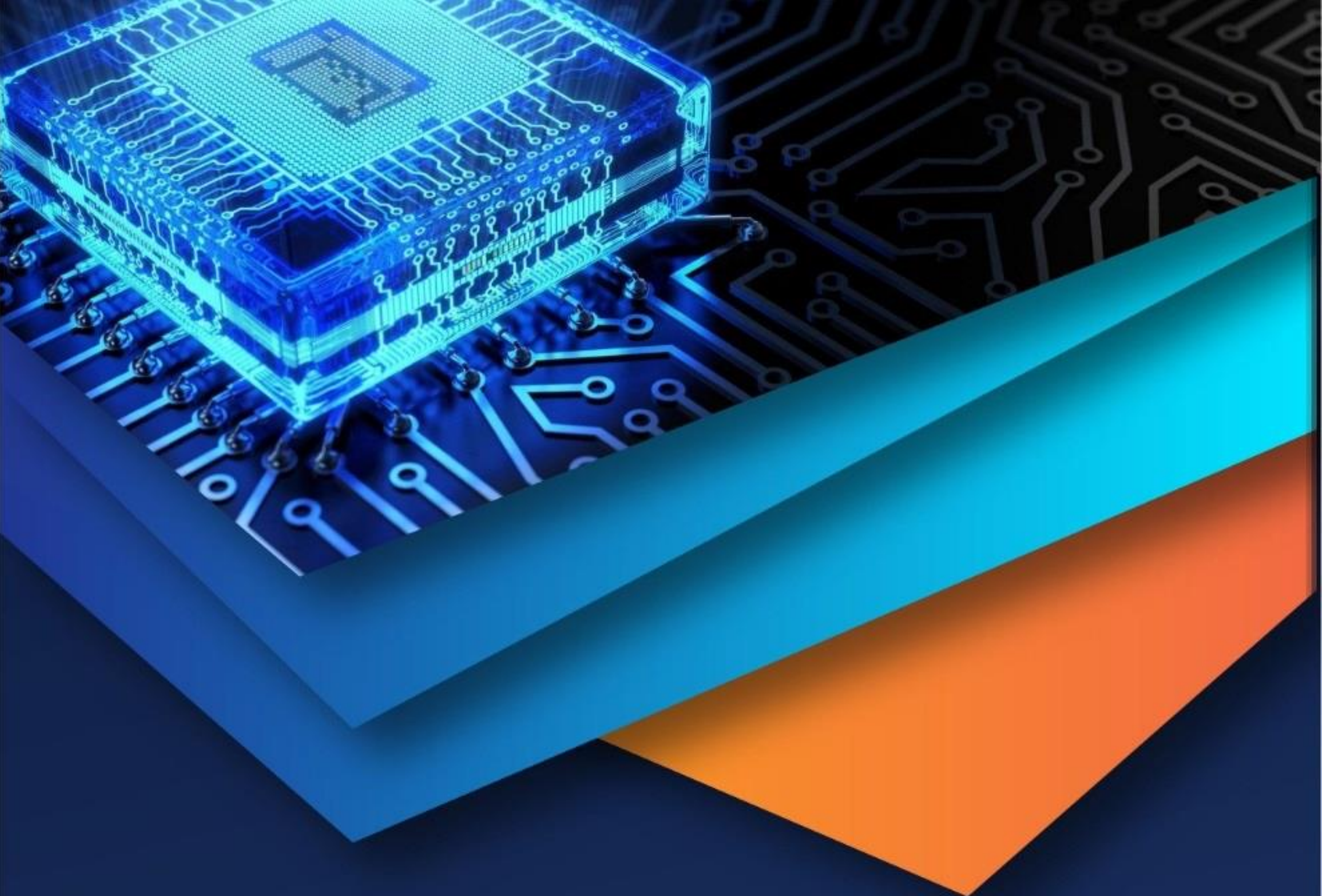

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