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Response of Exterior Beam-Column Joint with Rectangular Spiral Reinforcement under Cyclic Loading

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Abstract: This study presents an experimental evaluation of the performance of exterior beam-column joints reinforced with rectangular spiral reinforcement. Beam-column joints are critical regions in reinforced concrete structures, and their behavior significantly influences the overall seismic performance of buildings. Traditional reinforcement techniques for these joints often struggle with issues such as inadequate confinement and potential failure under cyclic loading. In an effort to improve the structural integrity and enhance the seismic resistance of these joints, the use of rectangular spiral reinforcement was explored as an alternative. The experimental program involved testing of beam-column joint specimens under cyclic loading conditions to assess their strength, crack patterns hysteresis behaviour. The specimen was designed with varying configurations of rectangular spiral reinforcement in the joint region, and their performance was compared to traditional reinforcement methods. Key parameters, including crack patterns, load-deflection behavior, and ultimate failure modes, were analysed. The results indicated that rectangular spiral reinforcement provided better confinement, resulting in improved strength and enhanced seismic performance under cyclic loading. The study concludes that rectangular spiral reinforcement can be an effective solution for improving the resilience of exterior beam-column joints in earthquake-prone regions. This research contributes to the development of more reliable reinforcement strategies for structural joints, promoting safer and more durable building designs.
Keywords: Exterior Beam-Column Joint, Rectangular Spiral reinforcement, Cyclic loading, Crack Patterns, Hysteresis Behaviour.

I. INTRODUCTION

A beam-column joint is a crucial component in reinforced concrete (RC) and steel-reinforced concrete structures. It refers to the intersection or connection between a beam and a column, which are the primary structural elements responsible for carrying loads in a building or other structure. The design and performance of the beam-column joint are critical for the overall stability and safety of the structure, especially in terms of load transfer, moment distribution, and resistance to forces like shear, bending, and torsion. Function of such beam column joint depends on proper load transfer, moment transfer, shear transfer mechanism and seismic performance under various loading conditions as explained below. Load Transfer: The primary function of a beam-column joint is to efficiently transfer loads from the beam to the column (and vice versa) while maintaining the structural integrity of the connection. These loads can include dead loads, live loads, seismic forces, and wind loads. [1] Moment Transfer: A beam-column joint must transfer bending moments between the beam and column. This is especially important in moment-resisting frames, where the joint must accommodate significant moment transfer without failure.[2] Shear Transfer: The joint must also resist shear forces that arise due to the loads applied to the beam and column. Proper detailing of the reinforcement within the joint is essential for ensuring adequate shear strength.[3] Seismic Performance: In seismic zones, the beam-column joint plays a vital role in ensuring the building's ductility and resilience under cyclic loading caused by earthquakes. It must be designed to absorb and dissipate energy, preventing brittle failure and ensuring the overall stability of the structure during an earthquake.[4].

A. *Structural Considerations for Beam-Column Joints*

The behavior of a beam-column joint is influenced by various factors:

1) *Joint Geometry*: The geometry of the joint, including the size of the beam, column, and the dimensions of the joint itself, affects how forces are transferred. A large, well-detailed joint will typically perform better under load.[5]
2) *Reinforcement Detailing:* The correct detailing of both longitudinal and transverse reinforcement within the joint is crucial. Transverse reinforcement (such as stirrups or ties) is particularly important for resisting shear and ensuring the joint's ductility under load, particularly in seismic conditions.

3) *Concrete Strength:* The strength of the concrete in the joint, particularly the compressive strength, impacts the joint's ability to resist shear and moment forces. Higher concrete strength typically enhances the performance of the joint.
4) *Type of Connection*: Beam-column joints can be classified as either rigid or pinned connections, depending on the type of moment transfer between the beam and column. A rigid joint is designed to transfer both shear and bending moments, while a pinned joint typically only resists shear forces and allows rotation between the beam and column.
5) *Seismic Detailing:* In regions with high seismic activity, beam-column joints must be designed to accommodate the demands of cyclic loads during an earthquake. This requires specific ductility and confinement measures, including increased transverse reinforcement and appropriate stirrup spacing.[6]

B. Beam-Column Joints in Seismic Design

Beam-column joints are particularly critical in seismic design because they play a central role in the overall structural behavior of the building during an earthquake. In seismic zones, these joints are subjected to dynamic forces that can cause substantial damage if not properly designed. Some specific seismic concerns include such as – Shear failure: Inadequate shear strength in the joint can lead to failure, especially in seismic conditions where the joint experiences high cyclic shear forces. [7]

Brittle failure: Poor detailing can lead to brittle failure, where the joint fails suddenly without warning, potentially leading to collapse. Ductility: A well-designed beam-column joint must exhibit sufficient ductility to withstand large deformations without loss of strength during an earthquake.

II. TYPES OF BEAM-COLUMN JOINTS AS PER DESIGN CODES

Beam-column joints can be classified based on several factors such as the type of connection (rigid or flexible), the type of reinforcement, the geometry of the joint, and the seismic requirements. The classification of beam-column joints as per various codes (like ACI 318, Eurocode 2, IS 456, NZS 3101, etc.) is typically based on their performance under different loading conditions, especially in terms of shear strength, moment transfer, and ductility.

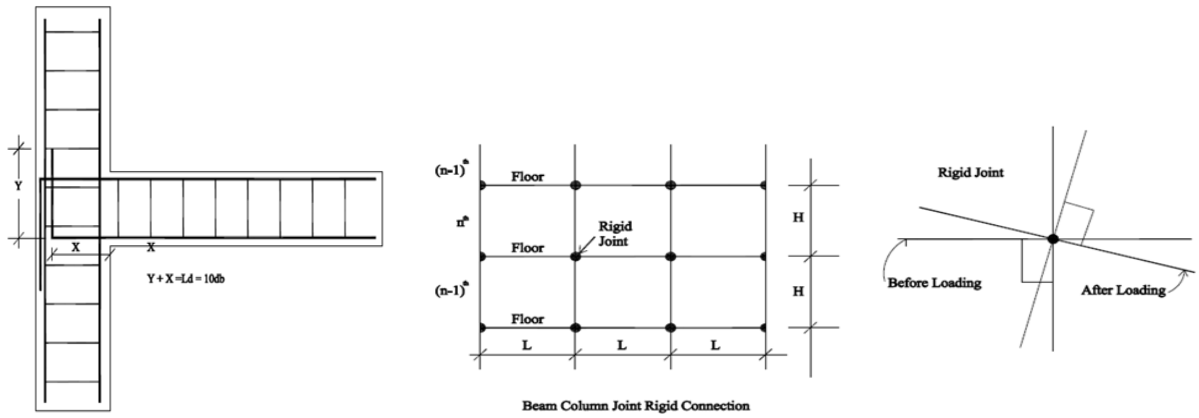
Below is an overview of the common types of beam-column joints according to design codes, followed by simplified figures:

TABLE I

COMPARISONS OF JOINTS WITH MOMENT, SHEAR TRANSFER AND SEISMIC CONDITIONS

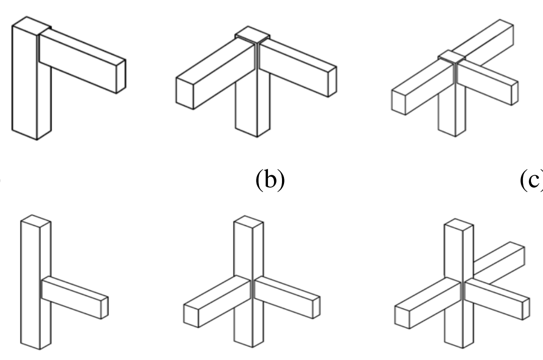
	Types of Joint	Moment Transfer	Shear Transfer	Seismic Considerations
1	Rigid Beam Column Joint	The joint is designed to transfer significant moments from the beam to the column and vice versa.	Shear forces are transferred across the joint, which requires adequate transverse reinforcement.	Rigid joints must be designed with ductility in seismic regions, ensuring the joint can withstand cyclic loading without failure.
2	Exterior Beam-Column Joint	The exterior joint often transfers moments and shear forces, but may also be subjected to torsion, especially when the beam is subjected to lateral loads.	Due to the complex loading, additional reinforcement is often required to ensure stability.	In seismic zones, torsional effects must be accounted for, and adequate confinement is required.
3	Interior Beam-Column Joint	These joints are designed to resist both shear and moment forces from beams and columns.	Adequate transverse reinforcement is essential for handling shear forces at the joint.	High ductility is required in seismic zones to ensure the joint can withstand cyclic loading.
4	Slab-Column Joint	Slab-column joints may transfer moments between the slab and the column, depending on the structural system.	The joint must be designed to handle the shear forces from the slab.	In seismic regions, adequate reinforcement is required to handle seismic loading and ensure ductility.
5	Beam-Column Joint in Seismic Design	The joint must resist high shear and bending forces during seismic events.	Closely spaced stirrups or ties are required to ensure shear strength and ductility.	High confinement reinforcement is required to improve ductility and prevent brittle failure.

1) *Rigid Beam-Column Joint*: A rigid beam-column joint is designed to transfer both shear and moment between the beam and the column. The beams and columns are typically cast monolithically, making it a moment-resisting connection. This type of joint is used in moment-resisting frames.
2) *Exterior Beam-Column Joint:* An exterior beam-column joint is located at the edge of a building or structure, where the beam is connected to the column at the exterior. This type of joint typically experiences more complex loading conditions compared to interior joints.[8]
3) *Interior Beam-Column Joint:* An interior beam-column joint is located inside the structure, where beams are connected to columns in a corner-to-corner fashion. These joints typically transfer both shear and moment and are critical for maintaining overall stability.
4) *Slab-Column Joint*: A slab-column joint is found in structures with floor slabs supported by columns. It connects the slab to the column, typically in flat-slab systems or slab-and-beam systems. This joint is primarily responsible for transferring vertical loads from the slab to the column.
5) *Beam-Column Joint in Seismic Design:* In seismic design, beam-column joints must be designed with special considerations for ductility and energy dissipation under cyclic loading. These joints are typically subjected to both shear and bending moments under earthquake conditions, so transverse reinforcement and confinement are key.



(a) (b) (C)

Fig. 1 Beam Column Joint Connection (a). (b) & (c)



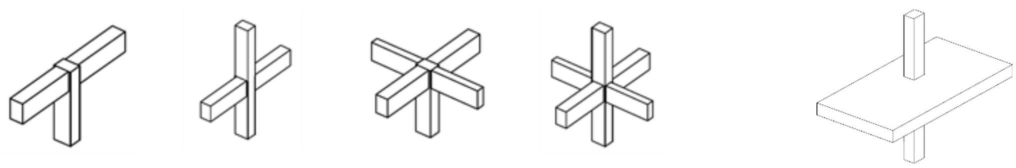
(a) (b) (c)

(d) (e) (f)

Fig. 2 Exterior beam-column joint in plane and space frame - (a) Plane frame roof corner joint (b) Space frame roof corner joint (c) Space frame roof edge joint (d) Plane frame floor corner joint (e) Space frame floor corner joint (f) Space frame floor edge joint [9]

Interior Beam Column joint

Plane Frame Space Frame



(a) (b) (c) (d) (e)

Fig. 3 Interior beam-column joint in plane and space frame - (a) Plane frame middle roof joint (b) Plane frame middle floor joint (c) Space frame middle roof joint (d) Space frame middle floor joint. (e) Slab -Beam Joint [9]

III.LITERATURE REVIEW

Beam-column joints are a critical part of reinforced concrete (RC) and steel-reinforced concrete structures, playing a key role in the transfer of loads and maintaining the structural integrity of the system. A beam-column joint under static or monotonic loading is designed to transfer shear and moment from the beam to the column, ensuring stability and strength in the structure. This literature review explores key studies, methodologies, and advancements in the design and behavior of beam-column joints under static or monotonic loading conditions.

A. Importance of Beam-Column Joints in Structural Design

A beam-column joint serves as a connection point between the horizontal beams and vertical columns. Under static loading, the joint must be able to resist shear, bending moments, and axial forces. A joint's behavior is crucial for the overall performance of reinforced concrete frames and high-rise buildings, where it plays a significant role in ensuring the load distribution and stability of the structure. The primary failure mechanisms of a beam-column joint under static or monotonic loading are: Shear failure due to insufficient shear strength at the joint. Bond failure between reinforcement bars and concrete. Failure due to inadequate confinement (especially under seismic loading). Inelastic deformation due to high bending moments.

B. Shear Strength of Beam-Column Joints

The shear strength of a beam-column joint is an important factor in its design. Several studies have focused on understanding the shear transfer mechanism at the joint interface and the role of transverse reinforcement (such as stirrups or ties) in enhancing shear capacity. Paulay and Priestley (1992), in their work on seismic design of reinforced concrete structures, emphasized the role of transverse reinforcement in increasing shear strength and preventing diagonal cracking within the joint region. They proposed a formula for shear strength based on the concrete’s compressive strength and the amount of transverse reinforcement.[10]

Moehle (1992) proposed a shear transfer model that considers the distribution of shear forces across the joint and highlighted the impact of joint geometry on shear strength. In particular, he showed that the shear strength depends significantly on the beam-column stiffness ratio and the reinforcement detailing.[11]

Priestley et al. (1996) extended the work on shear strength by studying high-strength concrete beams and columns. They concluded that high-strength concrete in the joint region does not necessarily improve the shear strength unless proper confinement reinforcement is provided. They proposed confined concrete models for more accurate predictions.[12]

C. Moment Transfer and Flexural Behavior

The transfer of bending moments between the beam and the column is another critical aspect of beam-column joint design. Under static or monotonic loading, the joint must resist flexural stress induced by the moment applied to the beam.

Dhake and Patil (2015) proposed a study on the flexural performance of beam-column joints, where they analyzed the moment-curvature behavior of beam-column connections. Their study found that flexural behavior is influenced by the amount of transverse reinforcement and the joint dimensions. The joint stiffness and strength are enhanced when appropriate reinforcement detailing is provided, especially when the column’s strength is greater than the beam.[13]

Gerson Moacyr (2013) focused on the moment transfer characteristics in monotonic loading conditions for different types of beam-column connections. They found that the quality of connection (i.e., the reinforcement detail) plays a significant role in moment distribution and the overall behavior of the structure.[14]

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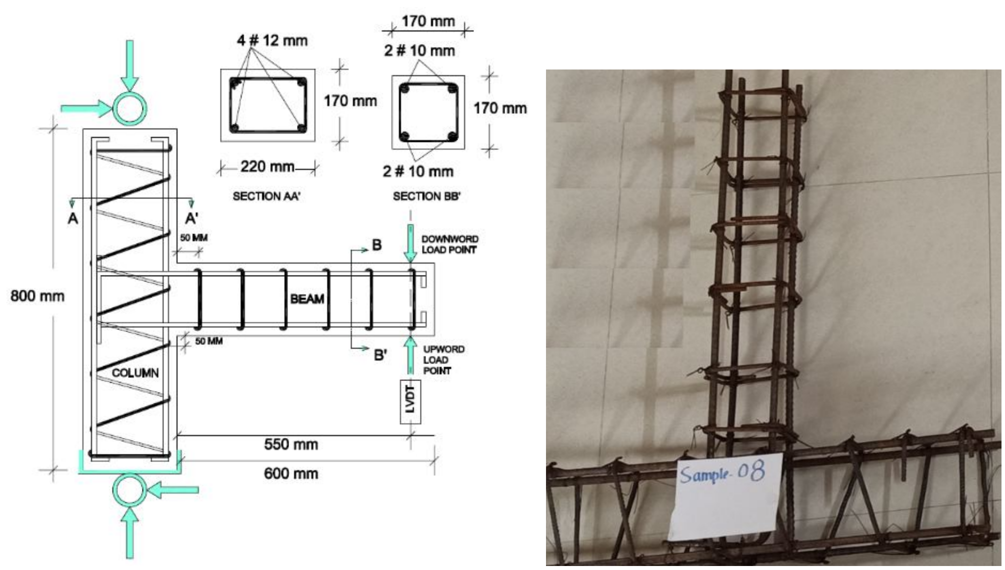
IV. MATERIALS AND METHODS

The materials used in this study were selected to meet the relevant Indian standards, ensuring the quality and consistency of the experimental outcomes. Table 2. Reinforcement details in Beam-Column Joint specimens[16]

TABLE III
MATERIALS

Reinforcement	Bars	Area (A_{st})	(IS 456:2000)
Tension Reinforcement	2 # 10 mm	A_{st}= 157 mm^2 > A_{stmin}. = 0.85 (bd/f_y) = 69 mm^2	Cl. 26.5.1.1 (a)
Beam - Shear reinforcement	2 legged vertical stirrups	A_s = 56.52 mm^2	Cl. 26.5.1.6
Spacing	6 mm ϕ	100 mm c/c	Cl. 26.5.1.5
Ld	For tension rod 10 mm	470 mm	Cl. 26.2.1
Lateral ties	Rectangular spiral reinforcement instead of regular ties.		

Experimental set up -The setup comprises the components like loading frame of 100-ton capacity, single acting jack to fix the upper portion of column. For application of reversal load, double acting hydraulic jack was used of capacity 40 ton.[15] For measurement of proper deflection LVDT is used.



(a) (b)

Fig. 4 (a) Sectional View of Specimen, (b) Skeleton View

V. RESULTS AND DISCUSSION

A. Crack Pattern

During testing of all the specimen's deflection measurement at the free end of the beam with attached LVDT and cracks formation in each cycle was carefully noted. For second specimen J2-S8, the first crack was observed in 12 mm cycle with displacement of 11.36 mm and the first crack load 5.35 KN. This specimen was tested up to 36 mm cycle with an ultimate load of 20.60 KN.

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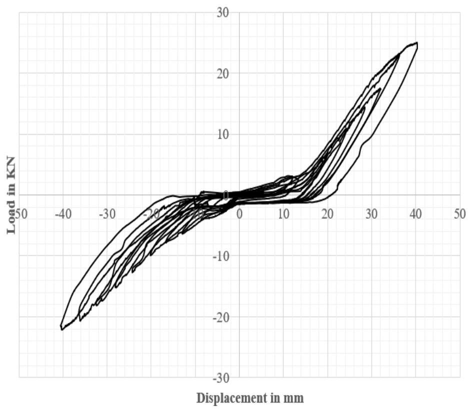
TABLE IIIII
FIRST CRACK (DISPLACEMENT AND CRACK LOAD)

Cycle	Downward Cycle (+)		Upward Cycle (-)		First crack Disp.	First crack Load
	Disp. mm	Load KN	Disp. mm	Load KN	mm	KN
1 mm	1.02	0.06	-1.10	-0.79		
2 mm	2.37	0.30	-2.02	-1.88		
3 mm	3.04	0.40	-3.01	-2.59		
4 mm	4.00	0.45	-4.00	-2.95		
8 mm	7.77	1.67	-8.07	-3.97		
12 mm	11.24	3.10	-12.18	-6.06	11.36	5.45
16 mm	16.47	4.02	-16.04	-7.54		
20 mm	20.00	6.82	-20.14	-9.88		
24 mm	24.43	10.90	-24.07	-11.92		
28 mm	28.09	14.06	-28.01	-15.14		
32 mm	32.04	17.33	-32.04	-18.00		
36 mm	36.06	22.94	-36.08	-20.60		

B. Hysteresis Behaviour

In the beam column joint the hysteresis behavior is an essential component of reinforced concrete frame structure particularly in earthquake prone region.

Specimens	Cycle	Displacement (mm)	Maximum Load (KN)
(J2-S8)	36 mm (-)	-36.08	-20.60
	36 mm (+)	36.06	22.94



(a)

(b)

Fig. 5 (a) Hysteresis Behaviour (b) Crack Patterns

VI. CONCLUSIONS

In this paper experimental investigation was carried out to evaluate the strength of beam-column joint employing rectangular spiral reinforcement in column with considered cross bar anchorage mechanism in joint core. Reverse cyclic loading was applied to the test all specimens. Rectangular spiral reinforcement provides better confinement of the concrete core compared to conventional stirrups. Experimental studies have found that this enhanced confinement often leads to increased ductility and improved performance under cyclic loading. Hence improved shear resistance in joints with rectangular spiral reinforcement. This can be particularly beneficial in seismic regions where joint shear failure is a serious concern. After testing specimen, it is observed that, continuous rectangular spiral reinforcement used specimen with smaller and more distributed cracks compared to conventional reinforcement leads to better crack control.

VII. ACKNOWLEDGMENT

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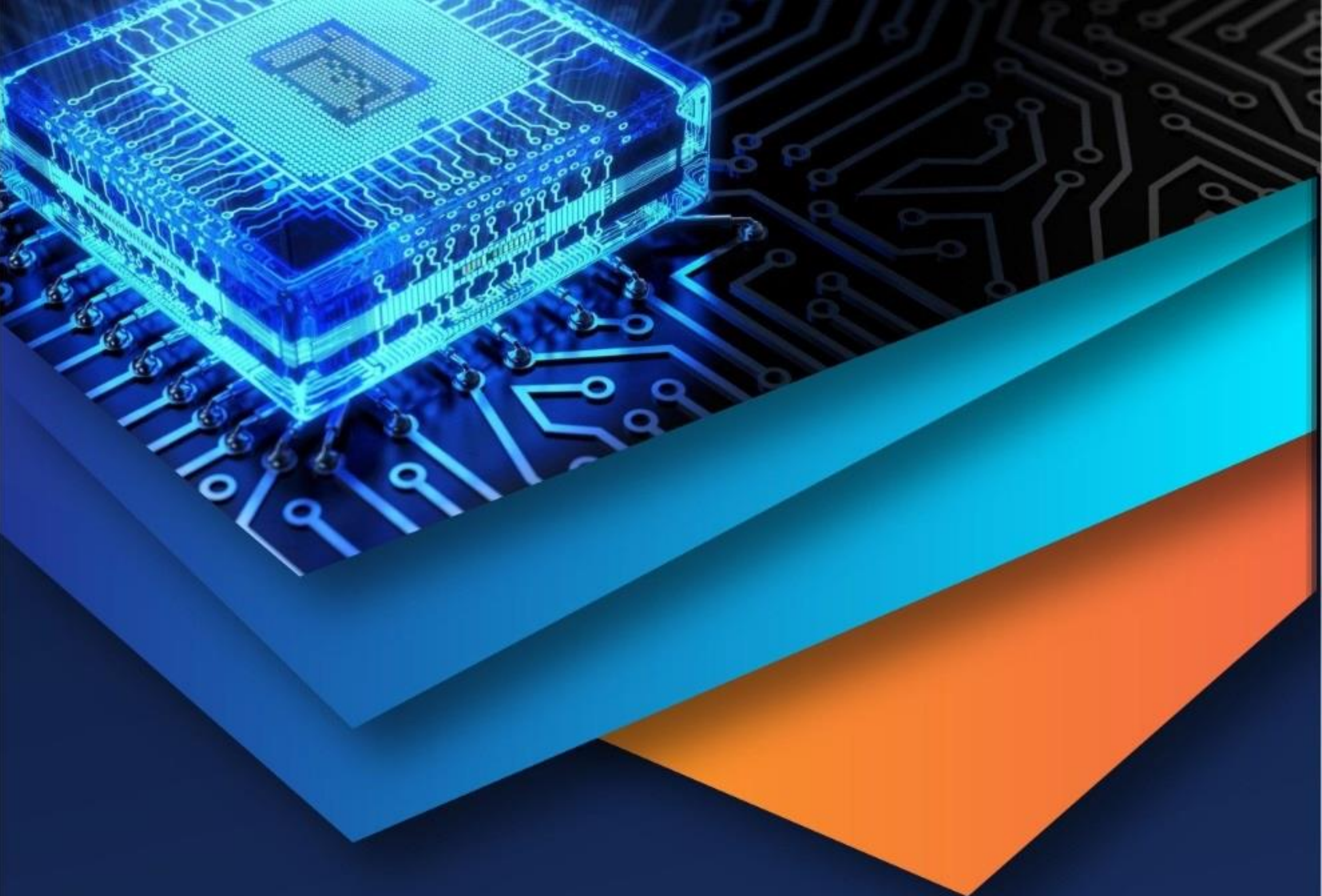

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