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Beam-Column Connections in Cold-Formed Light Gauge Steel Structures

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Abstract: The study of connection is crucial in any type of structure because it is always desirable that the structural member should fail first instead of the connection. If the structural connection fails before the failure of the member then there will be always a brittle failure and catastrophic. The main aim for our present study is to increase the use of cold form steel in steel structures by studying cold form steel connections. Usually cold form steel is used only in purlins of truss, non-load bearing wall, partition walls, floor deck system etc. In this project we tried to study the application of cold form steel in partially restrained beam-column screwed connection by determining load carrying capacity of various connection configurations. The connection are designed based on BS-5950-5 1998. Present study is focused on four types of connection namely connection with 1.5 mm thick beam-column connector using double rows of screws (Model 1), connection with 3 mm thick beam-column connector using double rows of screws (Model 2), connection with 1.5 mm thick beam-column connector and angle section using double rows of screws (Model 3) and connection with 3 mm thick beam-column connector and angle section using double rows of screws (Model 4). First connections are analysed experimentally by fabricating the structure and those similar models were analysed by FEM analysis using CATIA, HYPERMESH and ANSYS software's.
***Keywords**: Cold-Formed, Beam-column Connector, Self-tapping screws, Moment-Rotation, Model Factor, Hypermesh, ANSYS.*

I. INTRODUCTION

Steel Framing has befall to be a widely practiced construction choice in residential house and medium to low rise building construction, as it is on higher side when compared to conventional construction methods because of its advantages like dry and rapid construction, high quality controlled, cost and time saving, minimizing construction wastes and increasing sustainable development by reducing the use of timber materials.

Structural steel system is generally classified into hot rolled sections and cold formed sections. Hot rolled steel sections are fashioned under high temperature up to 1400ºC in electric arc furnace or blast furnace, while the Cold-formed steel sections are manufactured in near to room temperature from steel sheets of uniform thickness. These are specifically titled Cold Formed Steel Sections. Sometimes they are also known as Light Gauge Steel Sections or Cold Rolled Steel Sections.

The thickness of steel sheet used in cold formed construction is usually 0.8 to 4 mm. Much thicker material up to 8 mm can be formed if pre-galvanised material is not necessary for the particular application. Normally, the yield strength of steel sheets used in cold-formed sections is a minimum of 280 N/mm^2. However there is a trend to use steels of higher strengths of 450 and 550 N/mm^2.

Cold formed steel can be manufactured in two processes, such as brake pressing and rolled formed. Since Cold Formed steel is produced at room temperature and accompanied by automatic welding, it is possible to produce numerous and infinite variety of shapes based on the requirement. Some of the commonly used shapes are - Channel(C) sections , I sections formed by connecting double C sections back-to-back, Hat sections, sigma sections, T sections, rectangular hollow sections, circular hollow sections etc. All these sections may be either with or without lips.

There are diminutive guidelines for the study of cold form steel connections in terms of practical usage when compared to hot rolled steel. Hence, it is essential to widen study of cold form steel structural connections. Most of the codal design rules are only helpful in assessing the load carrying capacities of individual fasteners such as bolts and screws rather than the structural performance of connections between cold formed steel sections.

In general, there is miniature information on simple and moment connection of cold formed steel sections. Furthermore, most of the codes do not look upon cold formed steel connection to be moment resisting consequently many new cold formed steel goods are developed from experimental testing rather than design methods due to deficient design recommendations. Less information on the structural performance of moment connections using self-tapping screws among cold-formed steel sections may be found.

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II. OBJECTIVES OF THE STUDY & PROPOSED CONNECTIONS

A. Objectives of the Study

The fine purpose to study the cold form steel connection is to boost the application of cold form steel in structures. Connection consumes most of the fabrication cost in steelwork construction, reduction in cost can be done by adopting semi-rigid connection. Diminutive information on the structural performance of moment connections using self-tapping screws among cold-formed steel sections may be established from literature. An attempt has been made to study the behaviour of beam-column connection with different configuration using self-tapping screws. The connection design lies on the pedestal of semi-rigid criteria carried out using BS:5950-5-1998(Part 5 Code of practice for design of cold formed thin gauge sections). The different configuration models are fabricated and physical tests are carried out to obtain experimental results. Further FEM analysis is carried out and results are compared.

B. Proposed Connections

The four connection configurations adopted in the study are as follows:

1) *Connection with 1.5 mm thick beam-column connector using double row of screws (Model 1)*: In this type of connection, beam and column are connected using 1.5 mm thick hot rolled beam-column connector with 4 number of screws.
2) *Connection with 3 mm thick beam-column connector using double row of screws (Model 2):* In this type of connection, beam and column are connected using 1.5 mm thick hot rolled beam-column connector with 4 number of screws.
3) *Connection with 1.5 mm thick beam-column connector and angle section using double row of screws (Model 3):* In this type of connection, beam and column are connected using 1.5 mm thick hot rolled beam-column connector and angle plates with 4 number of screws.
4) *Connection with 3 mm thick beam-column connector and angle section using double row of screws (Model 4):* In this type of connection, beam and column are connected using 3 mm thick hot rolled beam-column connector and angle plates with 4 number of screws.

III.EXPERIMENTAL ANALYSIS DETAILS

The hollow box or tube section required for the beam and column is obtained by connecting two cold formed C sections with the help of self-tapping screws of span 500 mm. The C section has a web depth of 100 mm, flange width of 50 mm, lip depth of 12.5 mm and uniform thickness of 1.05 mm. A special type of connector is adopted welded toe-to-toe using hot rolled plates to form beam-column connector. Hot rolled angle plates are also used to connect beam and column flanges at top and bottom. Self-tapping screws of 5 mm are also adopted for connection of beam-column connector with beam and column sections and for angle plate connection with flanges of section. The above sections are used and connection configuration are formed with varying thickness(1.5 mm and 3 mm) of hot rolled beam-column connector and angle sections, whereas the cold formed beam and column sections are the same. The yield strength of Cold-formed section is 550 N/mm^2 and that of hot rolled section is 250 N/mm^2.

The connection setup is fixed onto the loading frame which is fixed in all six degrees at top and bottom. The vertical point load was applied to the beam at the tip of free end by the arrangement as shown in the figure below. The load is applied in incremental uniform pattern and the corresponding deflections are noted down by using dial gauge which is placed below the line of application of load. The load is applied till the failure of the connection i.e, constant load is achieved with increasing displacement.

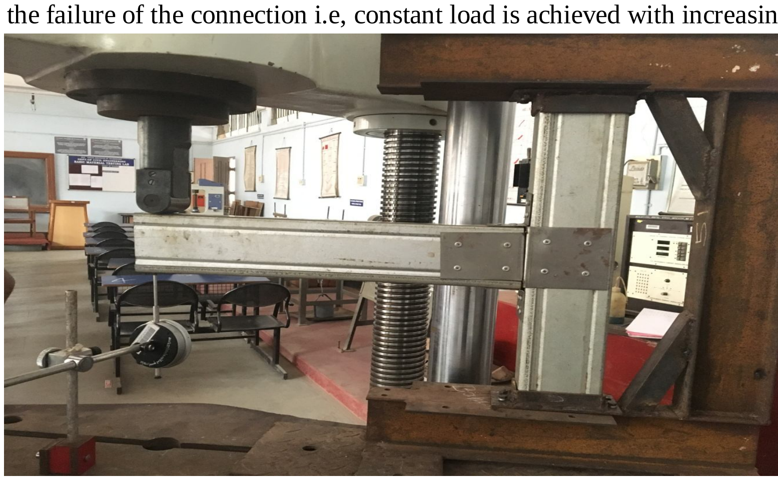

Fig. 1 Experimental Setup of Model with Loading frame

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IV. FINITE ELEMENT ANALYSIS DETAILS

The different types of connection are firstly modelled using CATIA software. These models with their geometry intact secondly are imported to Hypermesh as it is a high performance meshing software where fine meshing of the models at the mid-surface of sections using 2D quadrilateral element having Global size 5 mm, Minimum length 2 mm, Jacobian 0.7, Warpage 0.5 and Aspect ratio is 5:1 is carried out and later material properties and boundary conditions are imposed and the load is applied at free end. Lastly, these models are exported in '.cdb' format so that it can be imported to ANSYS for analysis purpose.

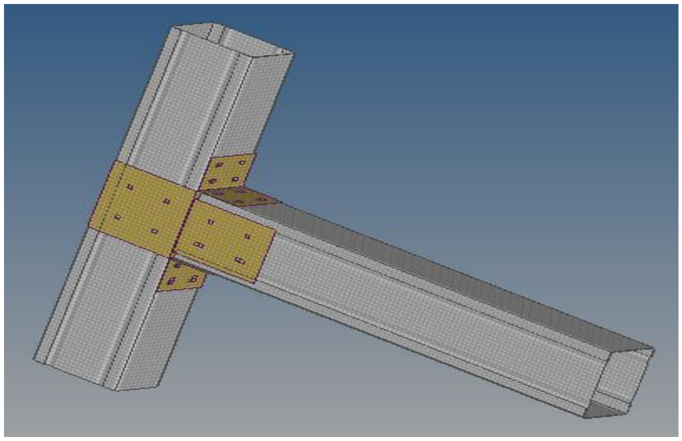

Fig. 2 FEM Model

V. RESULTS AND DISCUSSIONS

The results include the Experimental and FEM analysis output for all the four Model with their respective tabulations and graphs. The tabulation consists of Load, Deflection, Moment and Rotation at the connection as shown in Table 1 and Table 2. The initial stiffness is obtained by taking the slope of the plot of Moment v/s Rotation as shown in Fig. 3.

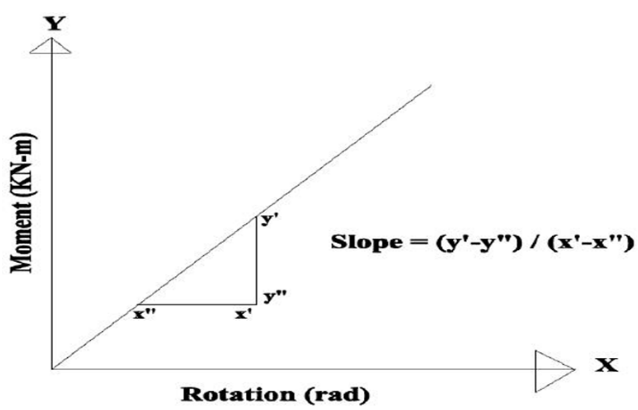

Fig. 3 General Plot of Moment v/s Rotation

TABLE I
SUMMARY OF EXPERIMENTAL RESULTS

Type of Connection	Load (kN)	Displacement (mm)	Ultimate Moment (kN)	Rotation (radians)	Initial Stiffness (kN-m/radian)
Model 1	0.8	85.2	0.352	0.1936363	1.655
Model 2	1.6	44	0.728	0.0967032	7.519
Model 3	2.4	110.6	1.152	0.2304166	4.732
Model 4	2.6	33	1.209	0.0709677	14.137

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TABLE II
SUMMARY OF ANALYTICAL(FEM) RESULTS

Type of Connection	Load (kN)	Displacement (mm)	Ultimate Moment (kN-m)	Rotation (radians)	Initial Stiffness (kN-m/radian)
Model 1	0.8	77.92	0.14291	0.020862852	6.85
Model 2	1.6	148.662	0.29015	0.04017761	18.01
Model 3	2.3	22.56	0.04834	0.312231341	0.1544
Model 4	2.4	22.32	0.04957	0.33420722	0.1478

TABLE III
SUMMARY OF MOMENT RATIO

Type of Connection	M_{rEXP} (kN-m)	M_{rFEM} (kN-m)	M_d (kN-m)	Moment Ratio
Model 1	0.352	0.14291	8.364	0.042
Model 2	0.728	0.29015	8.364	0.087
Model 3	1.152	0.04834	8.364	0.138
Model 4	1.209	0.04957	8.364	0.145

TABLE IV
SUMMARY OF MODEL FACTOR

Type of Connection	$M_{r(EXP)}$ (kN-m)	$M_{r(FEM)}$ (kN-m)	Model Factor
Model 1	0.352	0.14291	0.4059
Model 2	0.728	0.29015	0.39856
Model 3	1.152	0.04834	0.041962
Model 4	1.209	0.04957	0.04100

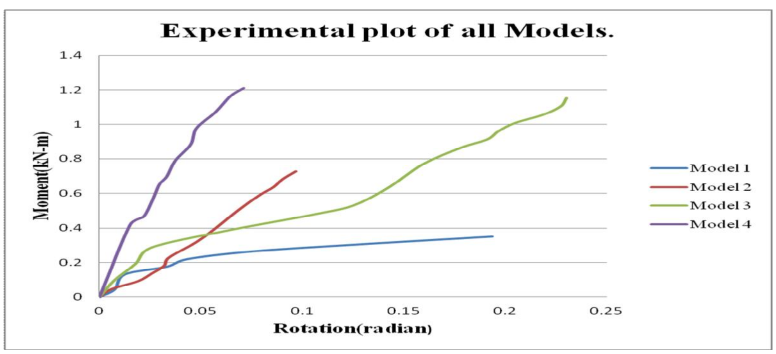

Fig. 4 Experimental plot of Moment v/s Rotation of all Models

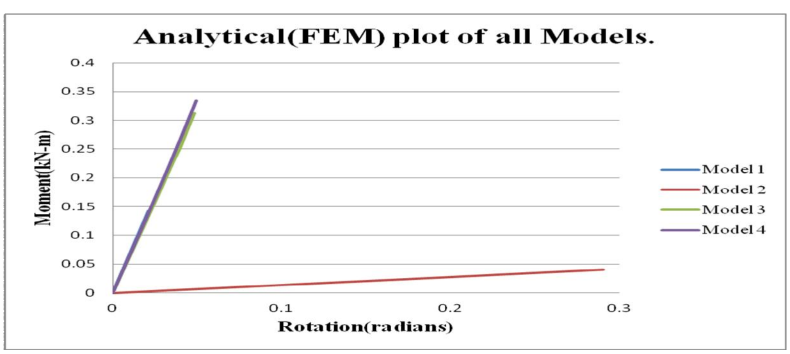

Fig. 5 Analytical(FEM) plot of Moment v/s Rotation of all Models

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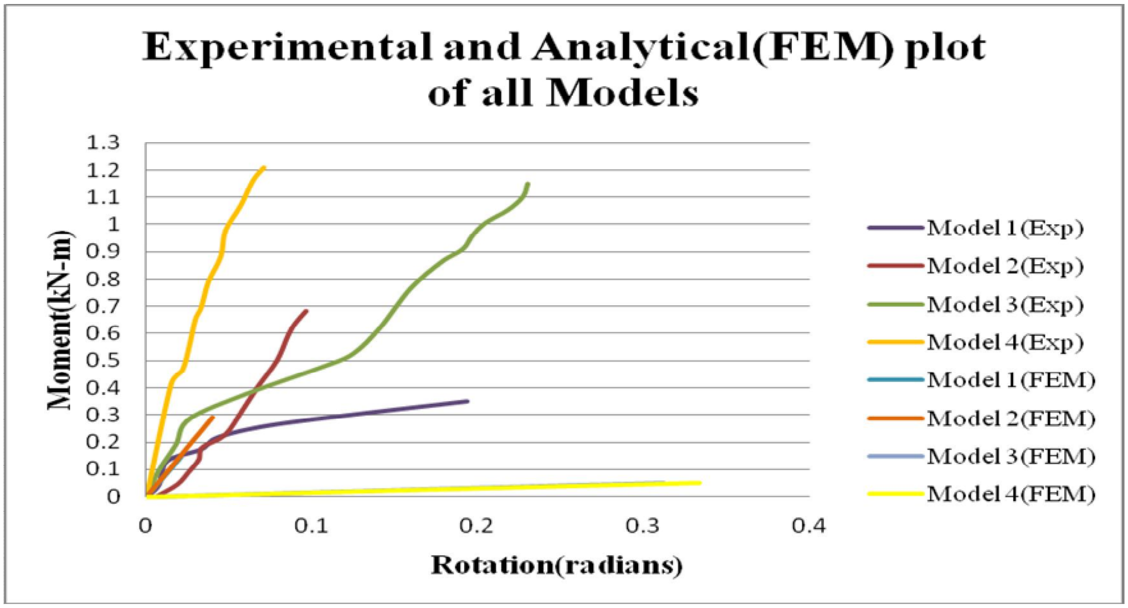

Fig. 6 Experimental and Analytical(FEM) plot of Moment v/s Rotation of all Models

Moment v/s Rotation curves are plotted for each connection Model based on the results obtained from Experimental and Analytical(FEM) analysis. This curves unveil the true behaviour of connection. The FEM analysis considers failure of the section when the stress touches its yield value or grade of steel. The yield strength of cold formed section adopted is 550 N/mm^2 . The failure in Experimental analysis is considered when there is rising displacement with a constant or stable load.

All the connection Model in Analytical(FEM) analysis have undergone failure due to torsional buckling of the beam at a point where vertical load was applied. However the failure in Experimental analysis is due to tension weld failure of beam-column connector and distortion of angle plate and screws. The load carrying capacity of Model 1, Model 2, Model 3 and Model 4 is in increasing order both in experimental and analytical(FEM) analysis because of the configuration provided i.e, increase in thickness and provision of angle sections.

From Experimental analysis, the ultimate moment capacity of Model 4 is higher when compared to other Models. However Analytical(FEM) analysis shows that Model 1 and Model 2 have higher ultimate moment capacity in comparison with Model 3 and Model 4. This is because of provision of rigid connection for weld in beam-column connector in FEM analysis. The moment-rotation curve overlaps for Model 1 and Model 2 and also for Model 3 and Model 4 in case of Analytical(FEM) analysis.

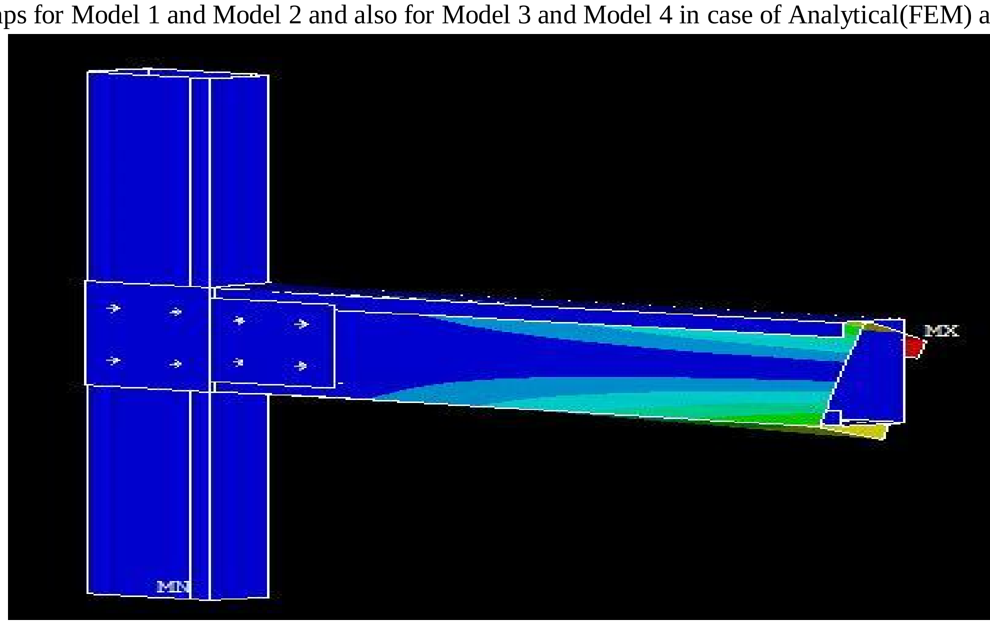

Fig. 7 Torsional Buckling Failure of FEM Model

Fig. 8 Tension weld failure of beam-column connector and distortion of angle plate in Experimental Model.

VI. CONCLUSIONS

A. Model 1 and Model 2 have larger rotation at smaller loads when compared to Model 3 and Model 4.
B. Due to the presence of angle plate and increase in thickness of connector, the load carrying capacity of Model 3 and Model 4 is higher compared to Model 1 and Model 2.
C. From test results, Model 3 and Model 4 have high moment capacity of about 13-15 % of moment capacity of beam section.
D. There is multilinear variation of Moment-Rotation curves of Experimental results with increasing initial stiffness from Model 1 to Model 4.
E. The adequacy obtained from Analytical(FEM) Model factor is 0.40.
F. There are variations in FEM analysis when compared to the experimental analysis due to rigid condition and failure modes.
G. The FEM analysis can be used to forecast the behaviour of the connections with reduction in expenditure and time.
H. In case of FEM analysis, connections failed by torsional buckling of beam where the load was applied and in case of experimental analysis, connection failed by tension weld failure of beam-column connector and distortion of angle plate.

VII. SCOPE FOR FUTURE WORK

A. Innovative connections can be designed by studying different connection configurations.
B. The same connections as studied in this project can be analysed again by using different fasteners.
C. More studies on Model factor can be carried out in order to increase the adequacy.

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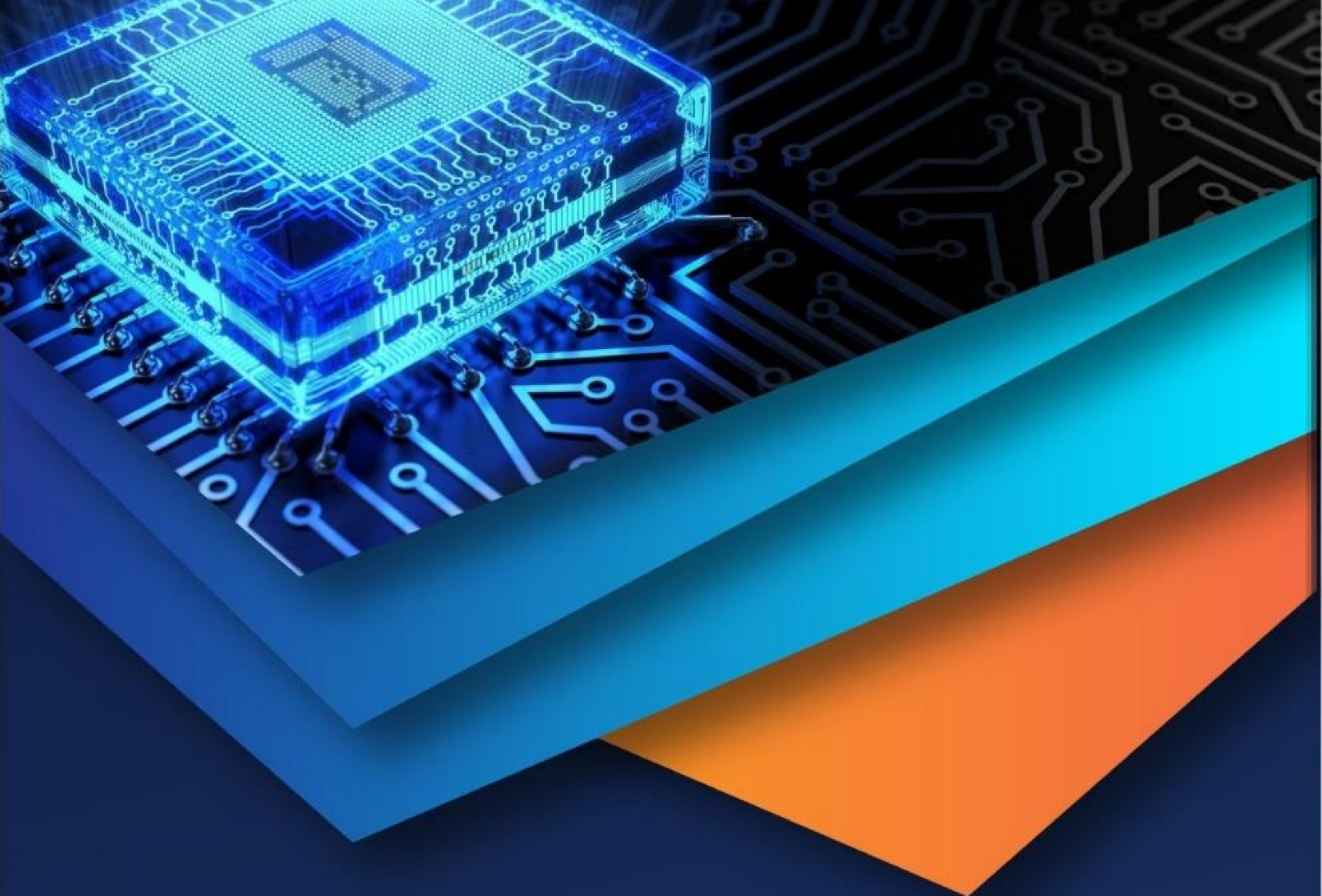

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