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Finite Element Analysis on Lateral Torsional Buckling Behaviour of I Beam with Web Opening Using Etabs Software

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Abstract: The lateral-torsional buckling behavior of I-beams with web openings has been a subject of great interest and significance for structural engineers due to the potential impact on their strength and stiffness. A thorough understanding of this behavior is essential for the design of steel structures. Finite Element Analysis (FEA) has emerged as a widely accepted tool for investigating structural responses under various loading conditions. In this study, FEA using the ETABS software, a commonly employed tool for structural analysis and design, was utilized to analyze the lateral-torsional buckling behavior of I-beams with web openings.The objective of the study was to examine the influence of different web opening characteristics, including shapes, sizes, and locations, on the buckling strength of the beams. To validate the FEA simulations, experimental data available in the literature were utilized. The analysis considered various types of web openings, such as circular, rectangular, and elliptical shapes, with different sizes and positions along the beam span.The findings revealed that the presence of a web opening significantly reduced the strength and stiffness of the I-beam, thereby rendering it more susceptible to buckling failure. Among the studied parameters, the location of the web opening exerted a more pronounced effect on the buckling behavior compared to its size and shape. The FEA simulations demonstrated good agreement with the experimental data available in the literature, which confirmed the accuracy of the ETABS software in predicting the buckling behavior of I-beams with web openings.These results emphasize the importance of carefully considering the presence of web openings when designing I-beams, as they can significantly affect their structural performance. Engineers should pay close attention to the location and size of web openings, implementing appropriate strengthening techniques when necessary to mitigate the adverse effects on buckling behavior. The findings of this study provide valuable insights that can aid in the design and analysis of steel structures incorporating I-beams with web openings, ensuring their overall stability and reliability.
Keywords: Finite element analysis, Lateral-torsional buckling, I-beams, Web openings, ETABS software, Structural analysis, Steel structures, Load-bearing capacity, Stiffness, Strength.

I. INTRODUCTION

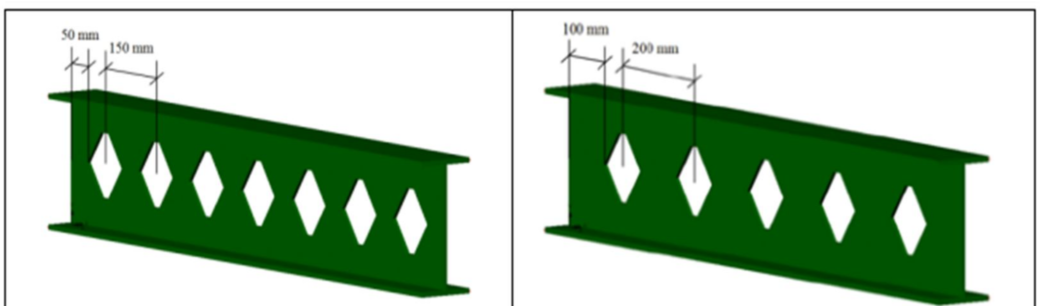
In recent years, a great deal of design for both steel and composite beams with web openings. Among the benefits is the behavior of steel and composite beams is quite similar at web openings. It was clearly found that the stress and the deflection values are higher when the web opening is provided near to the support. Therefore, it is preferable to provide web openings in the predominant bending region. Besides that, by strengthening the plate with 70mm offset and thickness of the strengthening plate equal to the thickness of the flange, there is a reduction in stress ratio and deflection for the I section. However, the behavior of statically indeterminate castellated composite beams is more complex than that of simply supported beams. This is because instability effects of the castellated composite beam are subjected to the negative moment regions where the bottom compression flange is unrestrained. The restrained distortional buckling mode is a torsional distortional for shorter beam spans while for longer spans the buckling mode changes towards the lateral- distortional Recently, there are two known types of open web beams: castellated beams with hexagonal openings, and cellular beams with circular web openings. The recent increase in usage of castellated and cellular beams highlights the need for additional research. Castellated steel beam which is fabricated from standard hot-rolled I-section has a lot of advantages such as aesthetic architectural appearance, ease of services through the web openings, optimum self-weight-depth ratio, economic construction, larger section modulus, and greater bending rigidity. However, the castellation of the beam results in distinctive failure modes depending on geometry of the beams, size of web openings, web slenderness, type of loading, quality of welding and lateral restraint condition [1]

Lateral Torsional Buckling (LTB) is a failure criterion for beams in flexure. The AISC defines Lateral Torsional Buckling as: the buckling mode of a flexural member involving deflection normal to the plane of bending occurring simultaneously with twist about the shear center of the cross-section. They are discussed here briefly: The distance between lateral braces has considerable influence on the lateral torsional buckling of the beams. The restraints such as warping restraint, twisting restraint, and lateral deflection restraint tend to increase the load carrying capacity. If concentrated loads are present in between lateral restraints, they affect the load carrying capacity. If this concentrated load applications point is above shear centre of the cross-section, then it has a destabilizing effect. On the other hand, if it is below shear centre, then it has stabilizing effect. For a beam with a particular maximum moment-if the variation of this moment is non-uniform along the length the load carrying capacity is more than the beam with same maximum moment uniform along its length. If the section is symmetric only about the weak axis (bending plane), its load carrying capacity is less than doubly symmetric sections. For doubly symmetric sections, the torque-component due to compressive stresses exactly balances that due to the tensile stresses. However, in a mono-symmetric beam there is an imbalance and the resistant torque causes a change in the effective torsional stiffeners, because the shear centre and centroid are not in one horizontal plane.[2]

Lateral torsional buckling is one of the main failure modes controlling the strength of the slender thin-walled members. A transversely or transversely and axially combined loaded member that is bent with respect to its axis of greatest flexural rigidity may buckle laterally and twist as applied load reaches its critical value unless the beam is provided with a sufficient lateral support. This study intends to present a unique convenient equation that it can be used for calculating critical lateral-torsional buckling load of simply supported European IPE and IPN beams. First, an analytical model is introduced to describe lateral torsional buckling behavior of beams with monosymmetric cross-section. The analytical model includes first order bending distribution, load height level and monosymmetric property of the section. Then, parametric study is carried out using the analytical solutions in order to establish a simplified equation with dimensionless coefficients. The effect of slenderness and loading positions on lateral-torsional buckling behavior of IPE and IPN beams are studied. The proposed solutions are compared to finite element simulations where thin-walled shell elements and beam elements including warping are used. Good agreement between the analytical, parametric and numerical solutions is demonstrated. It is found out that the lateral-torsional buckling load of European IPE and IPE beams can be determined by presented equation and can be safely used in design procedures.[4]

II. PROBLEM STATEMENT

Two types of 200×100×8×6mm model, five shapes and three sizes of web opening was used. There are two types of models namely model 1 and model 2. For the model 1, the distance between two openings is equal to 150 mm centre to centre and 200 mm centre to centre for model 2. Meanwhile, the edge length is 50 mm for model 1 and 100 mm for Model 2. Figure 1 shows the details summarize of the model.



(a) Model 1	(b) Model 2

The study is carried out to achieve following objectives:

1) To investigate the behavior of flexure and lateral torsional buckling of steel I-beam with web opening and its ultimate load carrying capacity.
2) To investigate the effect of shape of opening, total depth to opening depth (D/Do) ratio and spacing to opening depth (S/Do) ratio on the lateral torsional behavior of steel beam.
3) To investigate the buckling moment resistance using finite element analysis.
4) To check the effect of various depths on lateral torsional buckling.

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III. SCOPE OF THE PROJECT

Based on objectives, this research focused on

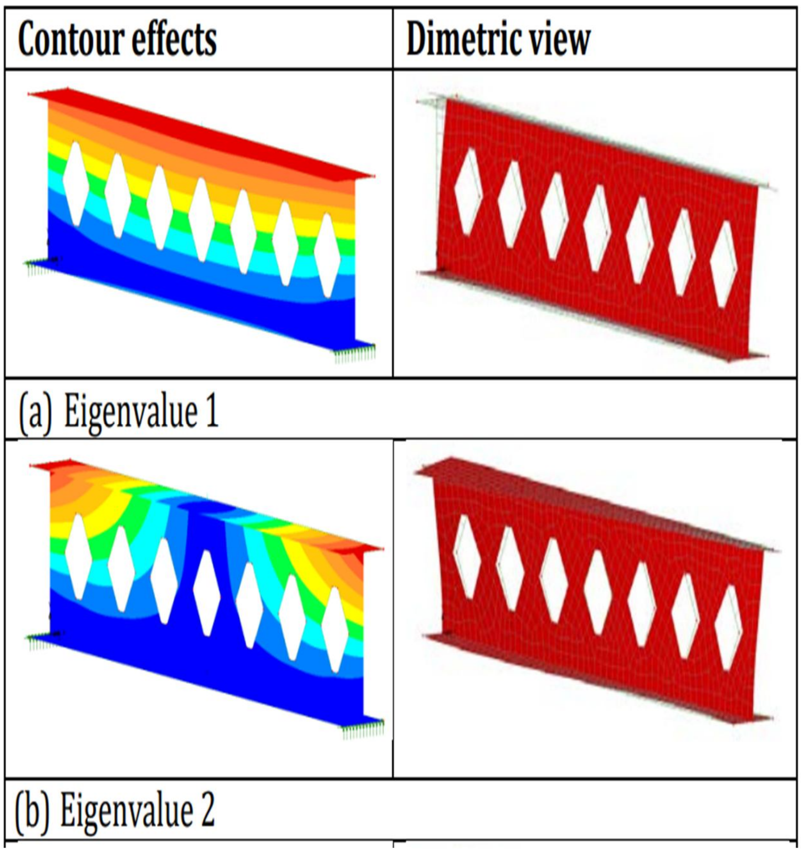
1) To investigate the buckling moment resistance using finite element analysis of given I beam with web opening.
2) To investigate the strength of given I beam with various shapes of web opening.

IV. RESULT

The numerical analysis consists of two main models of I-beam with different type of web opening and without web opening. In order to study the buckling behaviour, five types of web opening models were derived by varying the shape of the web opening.

A. Deformation of I-Beam With C-Hexagonal Web Opening

Figure 5.1 show the deformation and contours results of I-beam with c-hexagonal opening based on eigenvalue number.



B. Bukling Factor Of I-Beam With Various Shapes Of Web Opening

Table 5.1: Shows the Buckling Factor of I-Beam with various web opening

Table 5.1: Buckling factor results

SCALE FACTOR					
MODE	MODEL-1	MODEL-2	MODEL-3	MODEL-4	MODEL-5
1	2.024	3.198	5.228	10.262	2.228
2	10.512	10.67	10.696	10.725	10.696
3	15.803	13.811	13.813	13.814	13.813
4	35.264	37.52	37.91	38.347	37.91
5	38.313	37.572	32.962	40.4	37.962
6	45.314	34.573	37.963	49.4	43.963

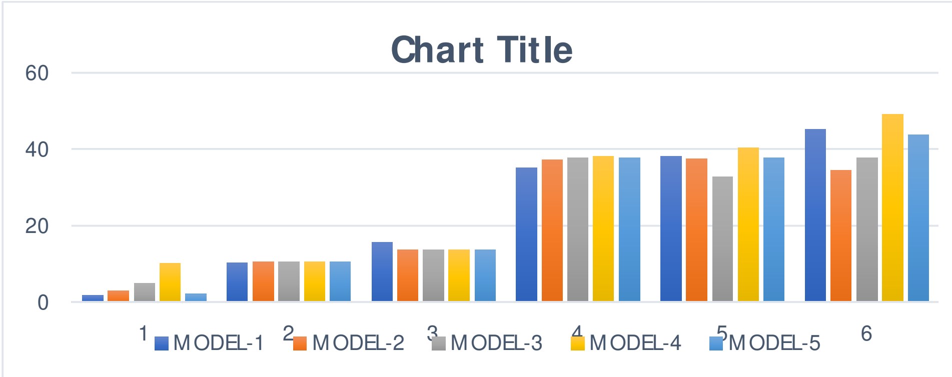


Fig. 5.2: Buckling factor

C. Modal Participation Factor Of I-Beam

Table 5.2: Shows the Modal Participation Factor of Model's

Table 5.2: Modal participation factor

Model	Model-1	Model-2	Model-3	Model-4	Model-5
Mode	Modal Stiff. Kn-m	Modal Stiff. Kn-m	Modal Stiff. Kn-m	Modal Stiff. Kn-m	Modal Stiff. Kn-m
1	3.00E-05	3.00E-05	3.00E-05	3.00E-05	0.00003
2	0.00045	0.00045	0.00045	0.00045	0.00045
3	0.0005	0.0005	0.0005	0.0005	0.0005
4	0.0088	0.00951	0.00961	0.00973	0.00961
5	0.00883	0.00953	0.00964	0.00975	0.00964
6	0.00887	0.00956	0.00966	0.00977	0.00966
7	0.0103	0.01113	0.01125	0.01139	0.01125
8	0.0103	0.01113	0.01125	0.01139	0.01125
9	0.10825	0.10825	0.10825	0.10825	0.10825
10	0.14247	0.14247	0.14247	0.14247	0.14247
11	0.14251	0.14251	0.14251	0.14251	0.14251
12	0.20312	0.2337	0.23852	0.24378	0.23852

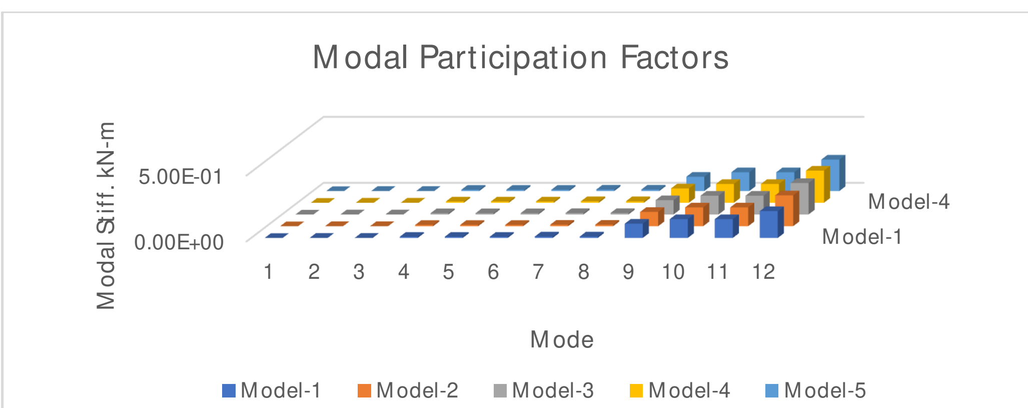


Fig 5.3: Modal participation factor

D. Modal Period And Frequency Of I-Beam With Various Shapes Of Web Openings

Table 5.3: Shows the Modal Period and Frequency

Table 5.3: Modal period & frequency

Model	Period	Frequency
	sec	cyc/sec
Model-1	0.014	71.729
Model-2	0.013	76.939
Model-3	0.013	73.729
Model-4	0.013	78.582
Model-5	0.013	75.729

Figure 5.4: Shows the Frequencies of models

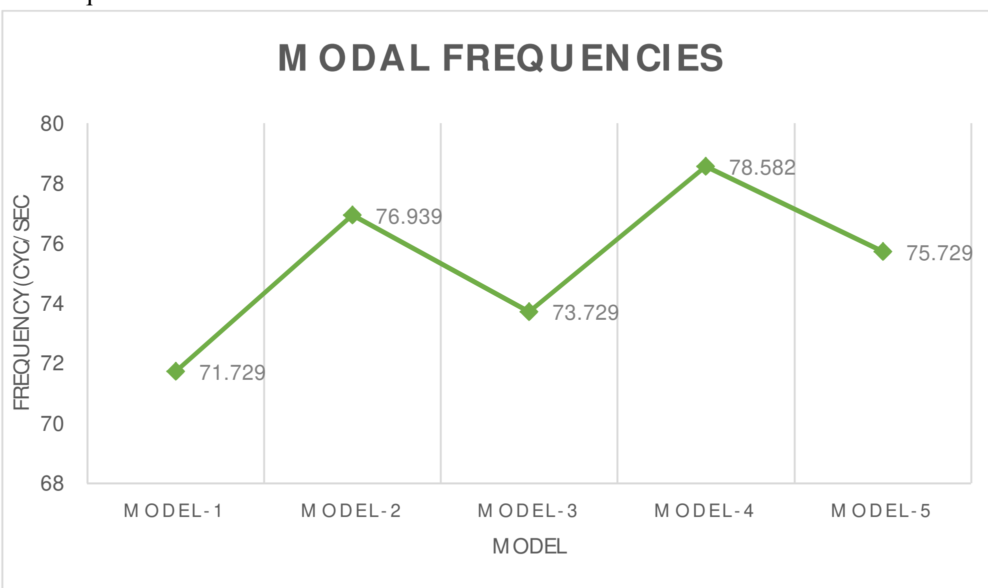


Fig. 5.4: Frequencies of models

E. Story Drift Values Of I-Beam With Various Shapes Of Web Opening

Table 5.4: Shows the Story Drift Results

Table 5.4: Story drift

Model	Drift (M)
Model-1	0.000501
Model-2	0.000428
Model-3	0.000419
Model-4	0.000408
Model-5	0.000419

Figure 5.5: Shows the Story Drift

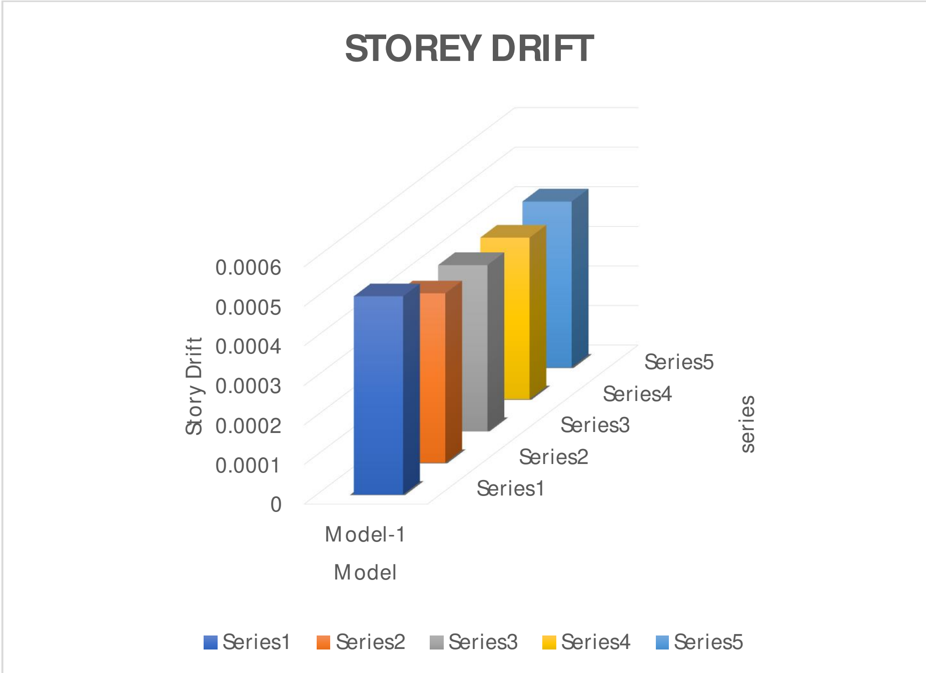


Table 5.5: Story Drift

F. Maximum Srory Drift Over Average Drift Of I-Beam With Various Types Of Web Opening

Table 5.5: Shows the Maximum Story Drift over Average Drift

Table 5.5: Max. story drift over avg. drift

Model	Ratio
Model-1	1.54E+15
Model-2	5.27E+15
Model-3	1.29E+15
Model-4	7.53E+15
Model-5	1.29E+15

Figure 5.6: Shows the Maximum Story Drift Over Average Drift

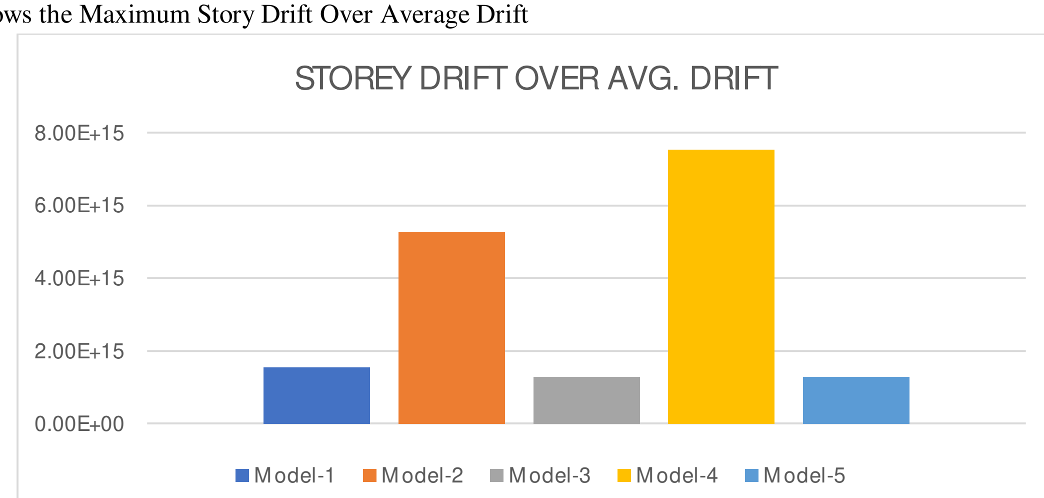


Fig 5.6: Max. story drift over avg. drift

V. CONCLUSION

A. Buckling Factor

The presence of a web opening in an I-beam reduces its overall stiffness and can significantly decrease its buckling load capacity. The web opening acts as a stress concentration point, leading to localized deformation and reduced resistance to buckling. Consequently, an I-beam with a web opening is more prone to lateral torsional buckling compared to a solid-web I-beam. The buckling factor of model 4 is comparatively higher than other models.

B. Bukling Modes

Lateral torsional buckling in I-beams can occur in different modes depending on the boundary conditions and loading conditions. With a solid-web I-beam, the buckling modes are typically dominated by lateral bending and torsion. However, when a web opening is present, additional modes such as local plate buckling around the opening may become significant.

C. Modal Participation Factor

The modal participation factor is a measure of how strongly a given mode contributes to the response of the structure when subjected to force/displacement excitation in a specific direction. The modal participation factor of model 4 is comparatively higher than the other models and the model 1 has lower modal participation factor.

D. Opening Size And Location

The size and location of the web opening play a crucial role in determining the buckling behavior. Larger openings or openings closer to the beam's supports tend to have a more pronounced effect on reducing the buckling load capacity. Additionally, openings near regions of high bending or torsional stresses are more critical in terms of buckling.

E. Modal Period & Frequency

The modal frequency of models is calculated for knowing the strength of that section. The modal frequency of model 4 has higher frequency than other models. And model 1 has comparatively lesser than other models.

F. Story Drift

Storey drift is the lateral displacement of a floor relative to the floor below, and the storey drift ratio is the storey drift divided by the storey height. The story drift shows the displacement of floor/story. The model 1 has higher story drift than others.

G. Maximum Srory Drift Over Average Drift

The maximum story drift over average drift is the ratio of maximum story/floor displacement to the average story displacement. The model 4 is comparatively very high ratio than other models.

In the current analysis, the finite element analysis is used to investigate the lateral torsional buckling behavior of I-beam with and without web opening. Analysis results show that the size of web opening has slightly effect on the buckling moment values. The four shapes of opening with 1.0m section length. It is important to note that the specific conclusions may vary depending on the details of the analysis, including the material properties, loading conditions, and geometric parameters of the I-beam. Therefore, conducting a comprehensive finite element analysis with appropriate considerations is necessary to obtain accurate and reliable conclusions for a specific I-beam design.

VI. ACKNOWLEDGMENT

We have great pleasure in delivering the project on the topic “Finite Element Analysis on Lateral Torsional Buckling Behavior of I-Beam with web opening using E-Tab Software". This project has helped to express extracurricular knowledge with incredible help from the guide of our project Prof. P.R. Admile We would like to thank especially the HOD civil department Prof. R.B. Ghogare As well as staff members of the civil department, all of them very compassionate and went off their way to help. We would like to thank especially Prof. S.M. Kale, Project coordinator, for his timely help and guidance toward the successful completion of our project.

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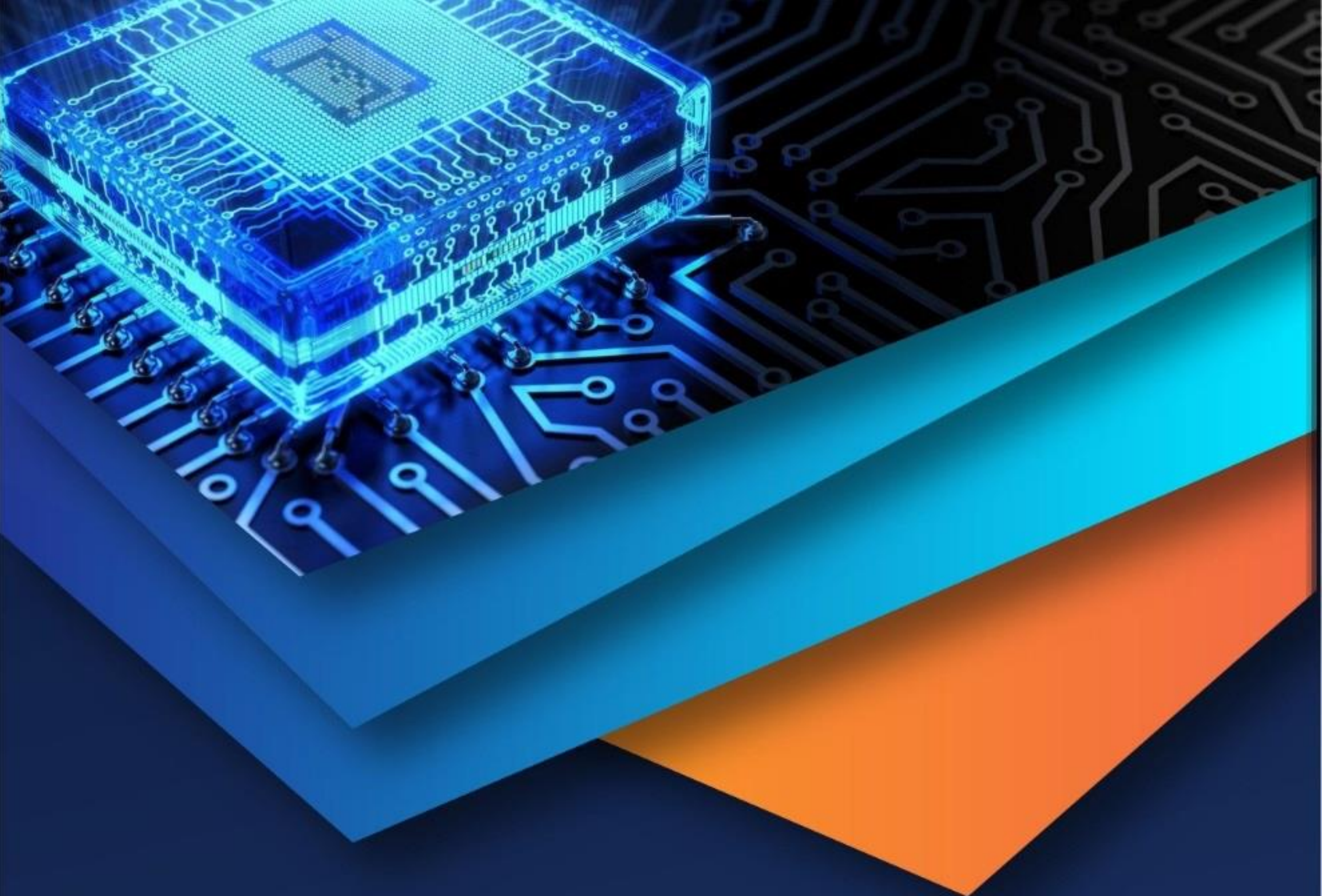

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