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Comparative Analysis of Diagrid and Chevron Braced Frame Structure under Dynamic Loading

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Abstract: The diagrid structures have proven to be highly adaptable in structuring a wide range of building types, spans and forms. In most of the applications, diagrid provides structural support to the buildings that are non rectilinear, adapting well to highly angular buildings and curved forms. The origin of the diagrid structural technology lies at the crossroads of engineering and architecture. The term "diagrid" have come from perimeter diagonals which have good structural efficiency and is gaining new interests in designing of tall structures because of its lattice like look. The term "diagrid" is a blending of the words "diagonal" and "grid" and refers to a structural system that gains its structural integrity through use of triangulation. In the diagrid structures, the vertical columns from the periphery are eliminated and this constructs the main difference between diagrids and chevron braced frame structures. Having triangulated configuration, the diagrids are able to carry the gravity and lateral loads. They also effectively reduce shear deformation as the diagonals carry the loads axially. The diagrid structural system is adopted these days for tall buildings because of its stiffness and flexibility in the architectural planning. This Dissertation paper represents the study of G+ 29 storeys in which "Diagrid structure is compared with chevron braced frame structure under dynamic loading." Analysis results of both the models are presented in terms of Lateral displacement, top storey displacement, storey drift, material consumptions.

Keywords -Diagrid structures, Chevron braced frame structure, Dynamic analysis, STAAD pro, Storey displacement, Storey drift.

I. INTRODUCTION

The developments of structural system concepts for tall buildings have been driven by the increasing need to achieve greater heights. For more than 100 years, structural engineers have been able to design and construct buildings which have risen higher and higher. This continuous process involved many outstanding advances and numerous new and innovative structural systems. In the modern world, diagrids are gaining more popularity because of its structural flexibility and elegance in appearance. Structural engineers and architects have now made considerable progress in the trends following diagrid structures. The vertical columns in the periphery of a structure is eliminated in diagrid structures. This is the main extinguishing difference between diagrids and other braced forms of buildings. A triangulated arrangement is framed in the diagrid basic frameworks due to the modules and these modules viably convey every one of the heaps i.e. lateral and gravity load and disseminate them in an exceptionally uniform and consistent design. Structural performance of braced tubesand diagrid structures are very familiar in a manner that both systems are able to carry lateral loads very efficiently with their structural member's axial actions. While bending rigidity in braced tubes is provided primarily by vertical perimeter columns, bending rigidity in diagrids is provided by diagonals which also give shear rigidity because the system is typically composed of only diagonals. In real, the diagrid systems is called as the evolution of braced tube structures with large-diagonal members that spread over the diagrids provide increased stability due to triangulation. The combination of gravity and lateral load bearing systems potentially provides more efficiency. Also, the reduced weight of the superstructure can translate into a reduced load on the foundations. A diagrid's module has a diamond shape which has a number of stories. Modules are describe into four different groups including small modules for (2-4 stories), mid-size modules for (6-8 stories), large modules for (more than 10 stories) and irregular modules. Diagrid's angle is the angle of diagonal members. Modules and angles both play a key role in structural, architectural and aesthetic concepts of these structures. The primary idea behind the development the diagrid system was recognition of the savings possible in the removal most of the vertical columns. The vertical columns were only engineered to carry gravity loads and were incapable of providing lateral stability.The diagonal grid, if properly spaced, was capable of assuming all the gravity loads as well as providing lateral stability due to its triangular configuration. As the exterior diagrid tube is include the diamond shape, triangulation meets where the floor edge beams tie into the grid. "Carry shear by axial action of the diagonal members, while conventional framed tubular structures carry shear by the bending of the vertical columns."Where the original diagonal bracing members were laid over a regularly framed exterior support system as a supplementary method of support, the current (standard high-rise) diagrid system uses an exterior frame comprised exclusively of diagonal members as the primary means of support. If properly engineered, such systems can use less steel than conventionally framed tall buildings. Where early conventionally framed office towers did not necessarily strive for a column free interior, most diagrid towers work towards elimination of columns between the exterior structure and the core.A diagrid tower is models as a vertical cantilever. The size of the diagonal grid is analyzed by dividing the height of the tower into a series of modules. Numerous studies have been conduct towards the optimization of the module size as function of the building height and angles of the inclined members. Normally the height of the base module of the diamond grid will extend over several stories. In this way the beams that define the edge of the floors can frame into the diagonal members providing both connection to the core, support for the floor edge beams, and stiffness to the unsupported length of the diagonal member as a significant part of the cost simplifying the connection between the node and the diagonal to speed up erection. Usually shear wall core, braced frame and their combination with rakes are interior system, where lateral load is resist by centrally located elements. While framed tube, braced tube structural system resist lateral loads by elements provided on periphery of structure. It is very important that the selected structural system is such that the structural elements are utilized effectively, while satisfying design requirements. Recently diagrid structural system is adopted in tall buildings due to its structural efficiency and flexibility in architectural planning. Compared to closely space vertical columns in framed tube, diagrid structure consists of inclined columns on the exterior surface of building. Due to inclined columns lateral loads is resisted by axial action of the diagonal compared to bending of vertical columns in framed tube structure. Diagrid structures generally do not require core because lateral shear can be carried by the diagonals on the periphery of building [1].

Diagrid is a specific type of space truss; it is the texture of perimeter grid made up of a series of triangulated truss systems. The some examples of world-famous diagrid and braced frame structuresare shown in figure 1 to figure 5, i.e. fig. 1 Hearst Tower in New York. Fig. 2 Cybertecture Egg(under construction) in Mumbai, India, fig. 3 CCTV Beijing, China, fig. 4 Swiss re in London, fig. 5 Poly international plaza(under construction), Beijing, China, fig 6 Alcoa building, California USA.


Fig. 1


Fig. 2


Fig. 3


Fig. 4


Fig. 5


Fig. 6

III. MODELLING & MATERIAL SPECIFICATIONS

The modelling and analysis of a G+29 storey diagrid and chevron braced frame model is analysed by using STAAD.pro V8i software. The modelling data is listed below. The sizes of members are obtains from the analysis for both the model are given in the table-1

A. Both models with 24X24m plan dimension, and 3m height of each storey is taken.

B. The dead load is taken 4kN/m^2 on floor level.wall load at floor level beams is 5KN/m and terrace level beams is 2KN/m. The live load is taken 2KN/m^2 on terrace level and 4kN/m^2 on floor level of both the models, as per IS 875-1987, part-I and part-II.

C. The seismic effects on the buildings are taken as zone

factor 0.1, soil type II, Importance factor 1.5,Response Reduction 5 and Damping ratio 5% as per IS-1893-2002. For Bhopal location.

The wind loads coefficients are taken for Bhopal location, The basic wind speed 39 m/s, Terrain category 3, Structure class C, Risk Coefficient K_1 1.06, Topography Factor K_3 1.

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The Supports are taken fixed. Hinged condition is applied to diagrids only.

The characteristics compressive strength of concrete is 40 N/mm^2 for columns and 30 N/mm^2 for slab. The yield strength of main reinforcement 415 N/mm^2 in columns and slabs. The yield strength of steel is 250 N/mm^2 and the ultimate tensile strength is 420 N/mm^2.

Table-1 Structural members specifications and design data.

Members	Members no	Diagrid Structure	Chevron Braced frame Structure	Properties
Beams	B	ISMB550	ISMB550	Steel
Interior columns	C_1	1X1 M.	1X1 M.	Concrete
	C_2	1.2X1.2 M.	1.2X1.2 M.	
	C_3	1.4X1.4 M.	1.4X1.4 M.	
Exterior columns			ISMB600	Steel
Slabs	S_1	0.12 M., thickness with 20mm cover	0.12 M., thickness with 20mm cover	Concrete
Bracings	b_1		ISA 200X200X25 ST	Steel
Diagrids	D_1	450mm pipe25mm thick., $\theta=56^0 18^{'}$		Steel

The interior column C_3 is only in ground floor in both structures.

The diagrid and chevron braced frame structure are analyzed here by STAAD.PRO. The final process of the structural analysis is the post processing of the diagrid and chevron braced frame structure for seismic and wind load analysis. As per the solution, we can check the comparative analysis results of both structures in different aspects of suitable design lateral load, wind load and earthquake load whichever will be greater than it is further analyzed for lateral displacement, top storey displacement, storey drift and material consumption.

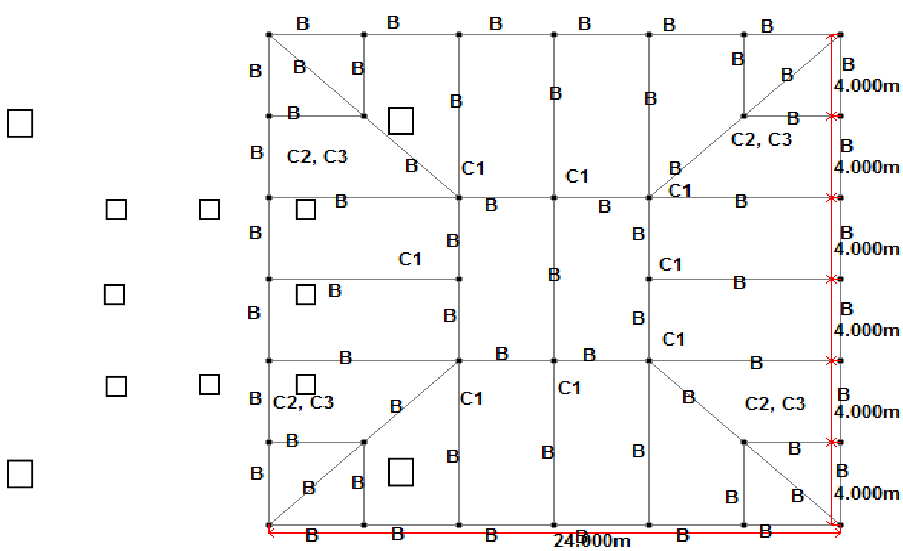

Figure 7:Plan views of both structures.

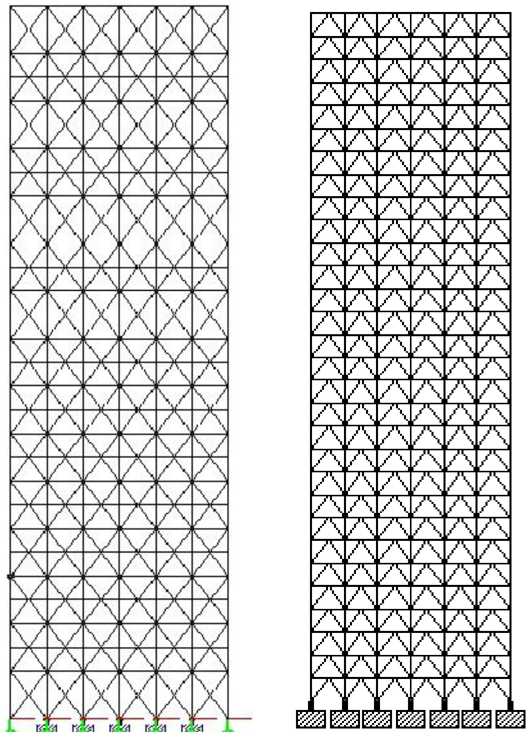

Figure 8:Elevation of diagrid and chevron braced frame model.

IV. RESULTS & DISCUSSION

The obtained comparative analysis results of both structureshas been tabulated andplotted as followings, in all line diagrams below, the total lateral force due to earthquake and wind in x and z direction of both structures are plotted.

From the analysis, it is found that amount of wind load is Greater than earthquake load and hence, wind load dominates in the design of both the structural models.

Table 2 Total lateral forceson both structures after analysis.

Type of load	Diagrid structure	Chevron braced frame structure
Earthquake in X-direction	2257.139KN	2201.630KN
Earthquake in Z-direction	2257.139KN	2201.630KN
Wind in X-direction	47029.88KN	23739.61KN
Wind in Z-direction	47029.88KN	23739.61KN
Gravity loading	283025.97	276725.16

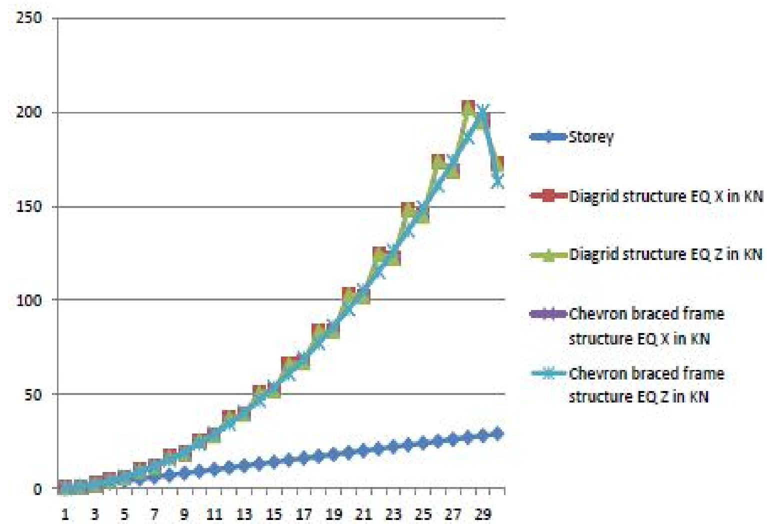

Figure 9: Seismic analysis results.

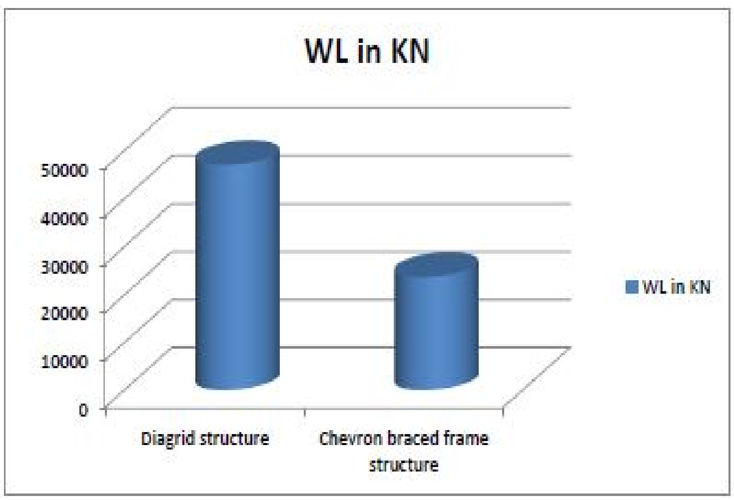

Figure 10: Wind load analysis result.

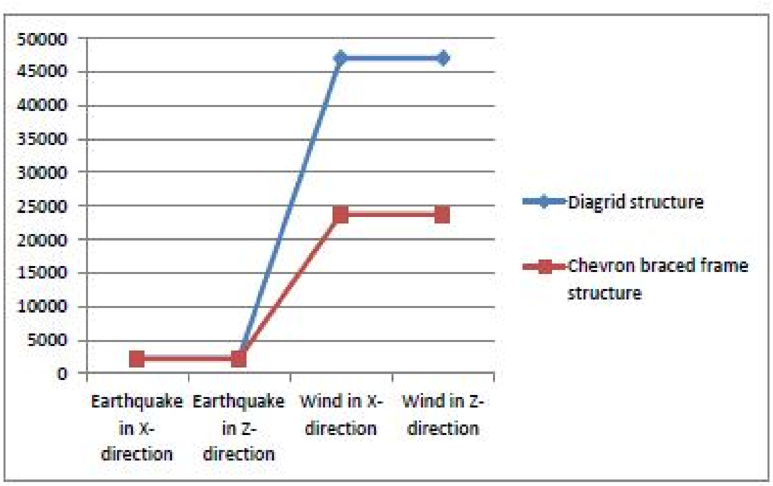

Figure11: Comparative analysis lateral load result.

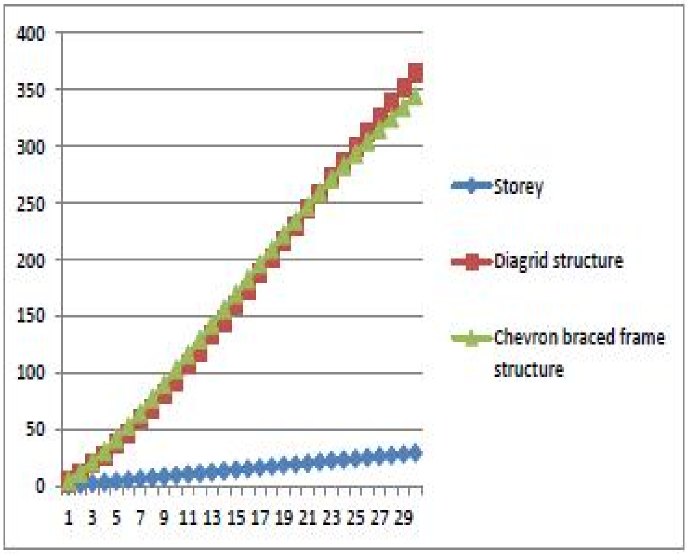

Figure 12: Comparative lateral displacement results.

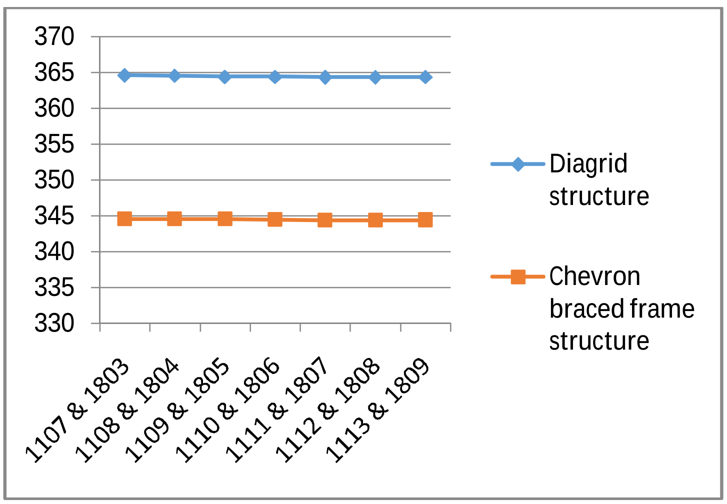

Figure 13: Top storey displacement results of both models.

The storey drift shall not be exceed 0.004 times the storey height. So, maximum limit of storey drift is 12cm.

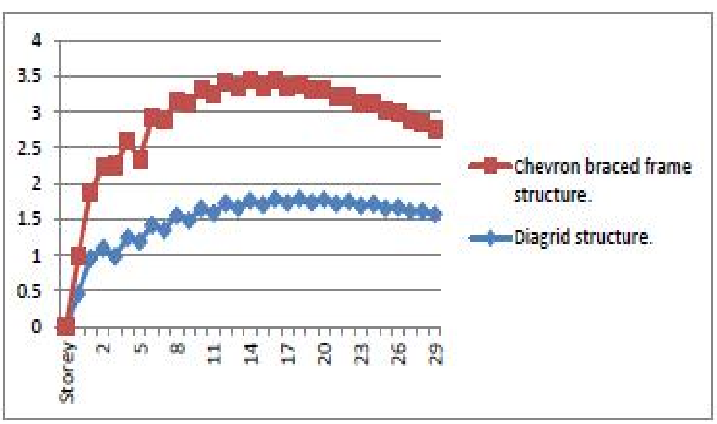

Figure 13: Storey drift of both structures.

V. METERIAL CONSUMPTION

The quantities of concrete and steel required have calculated in both the buildings. It has noted that the consumption of concrete and steel for chevron braced frame model is more than the diagrid model by 9.946% and 14.946% respectively.

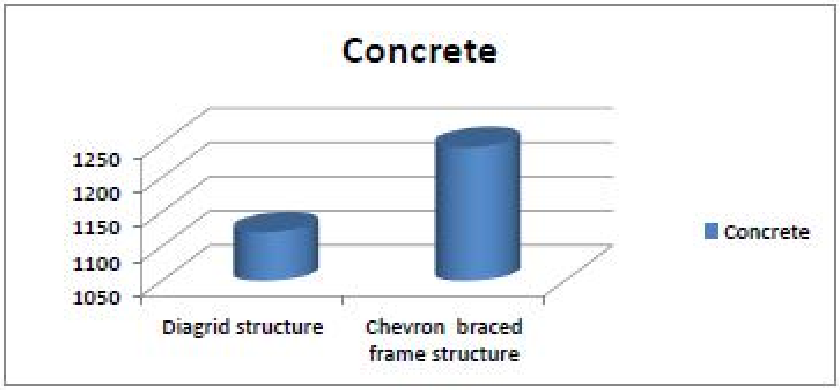

Figure 14: Concrete consumption.

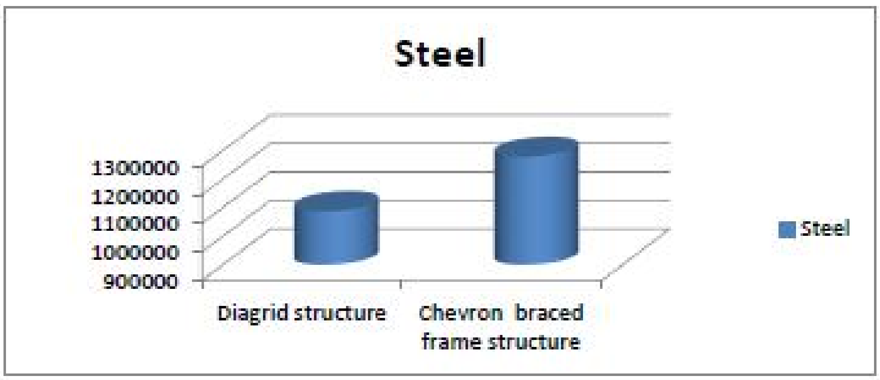

Figure 15: Steel consumption.

VI. CONCLUSIONS AND FUTURE SCOPE

The diagrid structure resists approximately the dual amount of lateral loads as compared to the chevron braced frame structure, despite all the vertical columns being eliminated in the periphery of the diagrid structure.

A. Diagrid structure provides more efficiency than chevron braced frame structure.
B. Also, same amount of lateral displacement seen in diagrid structure and thechevron braced frame structure.
C. The top storey drift of diagrid structure is more by 36.7% than in the chevron braced frame structure; and both structures has passed in storey drift acceptable limit.
D. The top storey displacement of diagrid structure is more by 5.50% than in the chevron braced frame structure.
E. All these factors make the diagrid structure more resistant than the chevron braced Frame structure.
F. Diagrid structure gives more aesthetic look and gives more of interior space due to less columns and façade of the building can also be planned more efficiently.
G. The material consumption value is approx same for we use ISMB 600 as exterior column in chevron braced frame structure. If we used all exterior concrete column in chevron braced frame structure then material consumption varies more.
H. Diagrid structure system provides more economy in terms of consumption of steel and concrete as compared to chevron braced frame structure.

The diagrids is being used for tall and complex building construction. The unique characteristic ofdiagrid structure is to gives greater structural efficiency for tall buildings. Due to increase in population, the multi-storey building construction will continue on a larger scale. This work can be advanced and improved with consideration of following parameters:

I. Performance of diagrid building for different height/base ratio can be studied.
J. Different building shapes like spherical, hexagonal, etc. can also be considered.

K. A comparison on the basis of different size of diagrid module can also be done.
L. Analysis can be performed for different seismic/ wind zones.
M. The design of diagrid node connections and its effect on overall economy of building can be studied.
N. Comparing the diagrid system with other lateral load resisting system such as differet-different bracing, shear wall etc. can also be studied.
O. A study considering the stiffness of floor system in the analysis can included in the design.

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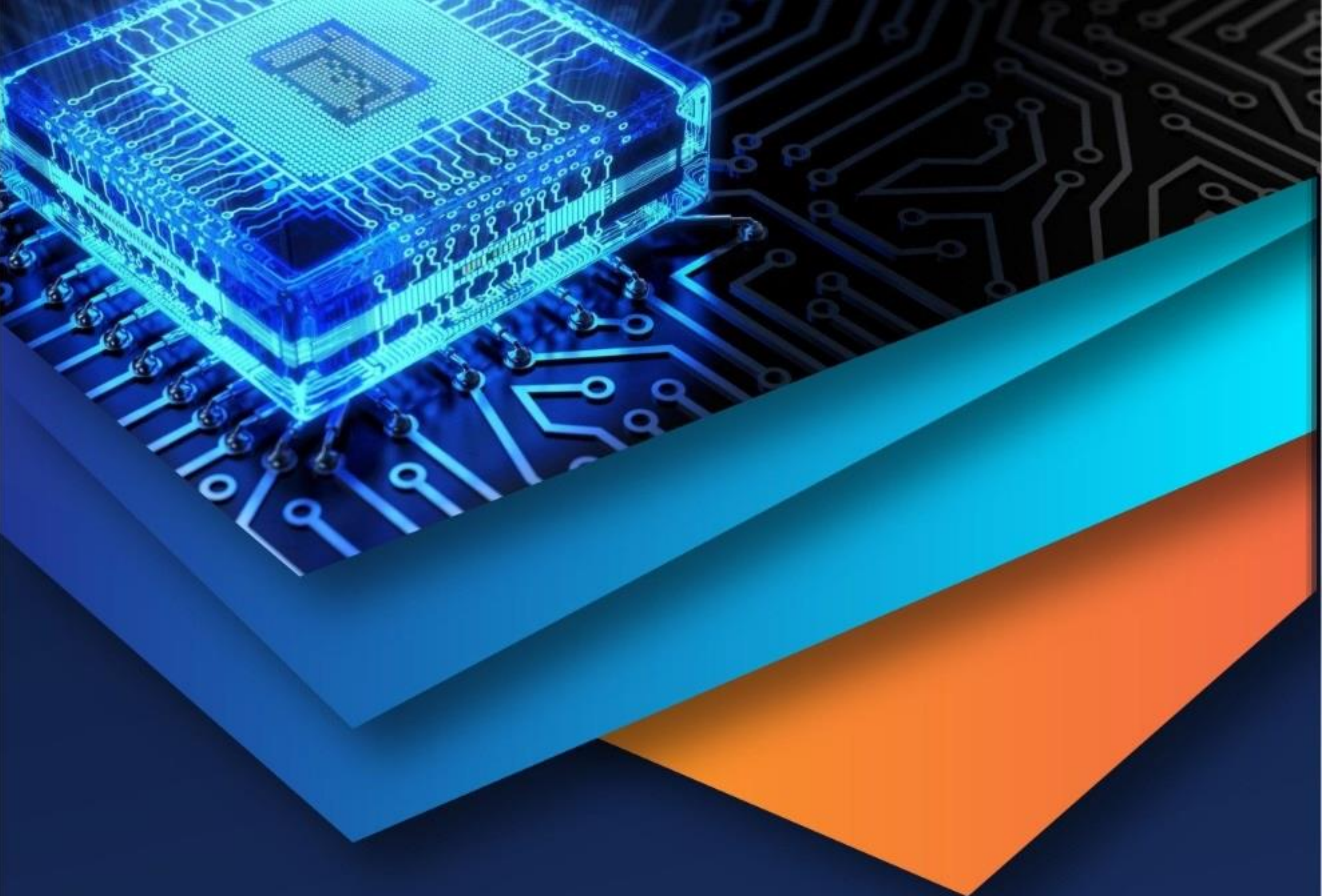

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