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International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** XI **Month of publication:** November 2026

DOI: https://doi.org/10.22214/ijraset.2026.85729

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue XI Nov 2026- Available at www.ijraset.com

Comparative Analysis of G+30 Building With and Without Outrigger System by Using ETABS Software

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Abstract *A tall building has to resist wind and earthquake forces in addition to the gravity loads, and as the height increases the lateral stiffness becomes the main design requirement. An outrigger system connects the lateral load resisting frame with the outer columns and helps in reducing the sway of the building without increasing the member sizes much. The location of the outrigger along the height has a direct effect on how well it works.*
This paper presents the seismic analysis of a G+30 reinforced concrete building, about 93 m high, with a plan of 36 m x 36 m. Six models are studied: a bare frame, outrigger at storey 10, outrigger at storey 20, and outriggers at storeys 5 and 15, 10 and 20, and 15 and 25. Response spectrum analysis is carried out in ETABS for Seismic Zone V.
Storey displacement, base shear, time period, frequency, storey acceleration, storey drift, storey shear, torsion and bending moment are compared for all the models. The top displacement reduced by 8.2% to 21.6% and the top acceleration by 9.1% to 36.1% when outriggers were provided. The best performance was seen for the outriggers at storeys 15 and 25.
Keywords: Outrigger, tall building, storey displacement, storey drift, storey shear, time period, ETABS.

I. INTRODUCTION

As the number of storeys increases, the lateral loads due to wind and earthquake start governing the design of a building instead of the gravity loads. The overturning moment, storey shear, torsion and drift all increase with the height, and the structure must be stiff enough to keep the sway within the permissible limits. A moment resisting frame is enough for buildings of medium height. In a very tall building the frame alone becomes uneconomical, because the beams and columns have to be made much larger to control the deflection. Shear walls, braced frames, tube systems and outrigger systems are some of the ways used to improve the lateral stiffness of tall buildings. Among these, the outrigger system is popular for buildings where a stiff core or a stiff inner frame is available to resist the lateral load.

A. Outrigger System

An outrigger is a stiff member, either a deep beam or a braced truss, that connects the inner lateral load resisting system to the columns on the outer side of the building. When the building bends under lateral load, the outrigger pulls the outer columns into axial tension on one side and compression on the other. This produces a restoring couple which reduces the overturning moment on the inner system and also reduces the lateral deflection at the top. The same idea can be used with belt trusses, which tie all the outer columns together at that level. The improvement depends on the stiffness of the outrigger, the number of levels where it is provided and the level in the building. A single outrigger placed at the wrong level gives only a small benefit, while a well placed one can reduce the top displacement considerably. So, the location is an important design parameter and is checked by comparing different arrangements.

B. Objectives of the study

1) To model a G+30 reinforced concrete building in ETABS without outrigger and with outriggers at different storey levels.
2) To analyse all the models by response spectrum analysis as per IS 1893 (Part 1):2016.
3) To compare storey displacement, base shear, time period, storey acceleration, storey drift, storey shear, torsion and bending moment of the models.

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To find the effect of the location and the number of outriggers on the response, and to find the best arrangement among the cases studied.

II. LITERATURE REVIEW

Gore and Mhatre (2018) reviewed the outrigger structural systems and compared the main types, namely conventional, offset and virtual outriggers. They explained how the connection between the core and the outer columns increases the lateral stiffness of the building.

Smith and Willford (2007) introduced the damped outrigger concept for tall buildings. In this, dampers are placed in the load path of the outrigger, which increases the damping of the building and reduces the vibration due to wind. The work shows that an outrigger can be used for response control and not only for stiffness.

Bhuta and Pareekh (2016) studied a 40 storey reinforced concrete building with shear wall, outrigger and diagrid systems in ETABS. Static, response spectrum and time history analyses were done, and the top displacement, drift and time period were compared.

Vellaichamy and Chakkaravarthi (2022) modelled G+20, G+26 and G+30 buildings with outriggers placed at the top, middle and bottom levels and also changed the depth of the outrigger beam. They reported that both the location and the relative stiffness of the outrigger affect the displacement, storey shear and drift.

Subramani and Murali (2018) analysed tall buildings with outrigger and belt truss arrangements for seismic and wind loads using ETABS, in order to find an effective configuration.

Alhaddad (2020) and Alhaddad et al. (2020) gave a detailed review of outrigger and belt truss systems. The number of outriggers, their position and their stiffness are listed as the main factors, and the search for the optimum location is discussed.

Kavyashree et al. (2021) presented a state of the art review on the development of outrigger systems, from the conventional type to the virtual, damped and active types.

III. METHODOLOGY OF THE PROJECT

A. Response spectrum analysis

Response spectrum analysis is a linear dynamic method. The maximum response of the building in each mode of vibration is taken from the design response spectrum, which depends on the seismic zone, the type of soil and the damping. These modal values are then combined by a modal combination rule such as SRSS or CQC to get the total response. Unlike the equivalent static method, this method includes the effect of the higher modes, and therefore it is preferred for tall buildings.

In the present study the design spectrum of IS 1893 (Part 1):2016 for medium soil (Type II) and 5% damping is used in ETABS. Wind loads are defined as per IS 875 (Part 3):2015.

B. Model specifications

In the present study, a G+30 storey building in Seismic Zone V is analysed in ETABS. The basic parameters considered for the analysis are given below.

1.	Grade of concrete	M40
2.	Grade of steel	HYSD Fe550
3.	Plan size	36 m x 36 m
4.	Grid spacing	4 m in both directions
5.	Height to width ratio	about 2.6
6.	Number of storeys	G+30
7.	Storey height	3 m
8.	Total height	about 93 m
9.	Beam size	300x450 to 600x750 mm
10.	Column size	450x450 to 800x800 mm
11.	Slab thickness	125 mm to 180 mm
12.	Outrigger members	500 x 500 mm
13.	Live load	3.5 kN/m²
14.	Dead load	2.5 kN/m²
15.	Density of concrete	25 kN/m³

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16.	Seismic zone	V
17.	Site type	II (medium soil)
18.	Importance factor	1.5
19.	Response reduction factor	5
20.	Damping ratio	5%
21.	Basic wind speed	39 m/s
22.	Factors k1, k2, k3	1.08, 1.14, 1.36
23.	Wind design code	IS 875 (Part 3):2015
24.	RCC design code	IS 456:2000
25.	Steel design code	IS 800:2007
26.	Earthquake code	IS 1893 (Part 1):2016

C. Modelling procedure

The models are prepared in ETABS with the following steps. First the grid system and the storey data are defined, with 10 grid lines at 4 m spacing in both directions and a height of 3 m for every storey. The material properties of M40 concrete and Fe550 reinforcement are then entered, and the concrete frame design preferences are set to IS 456:2000. After this, the beam, column and slab sections are defined and assigned to the frame and area objects. The slabs are modelled as shell elements and a rigid diaphragm is assigned at every floor.

The load patterns for dead load, live load, earthquake and wind are then created. The floor loads are applied as uniform surface loads on the slabs, and the member loads are applied on the frames where required. The support condition at the base is taken as fixed for all the columns. The mass source is defined from the self weight and the applied loads, and the analysis is run for all the load cases. The same procedure is followed for every model, and only the bracing members are added in the outrigger models.

D. Building models in ETABS

All the columns are fixed at the base and the slabs are modelled as rigid diaphragms. The bare frame is the reference model M1. In the other five models, X bracing members are provided across all the bays at the selected storey levels, as shown in Fig. 1, and the rest of the structure is kept the same. The outrigger levels of each model are given in Table 1.

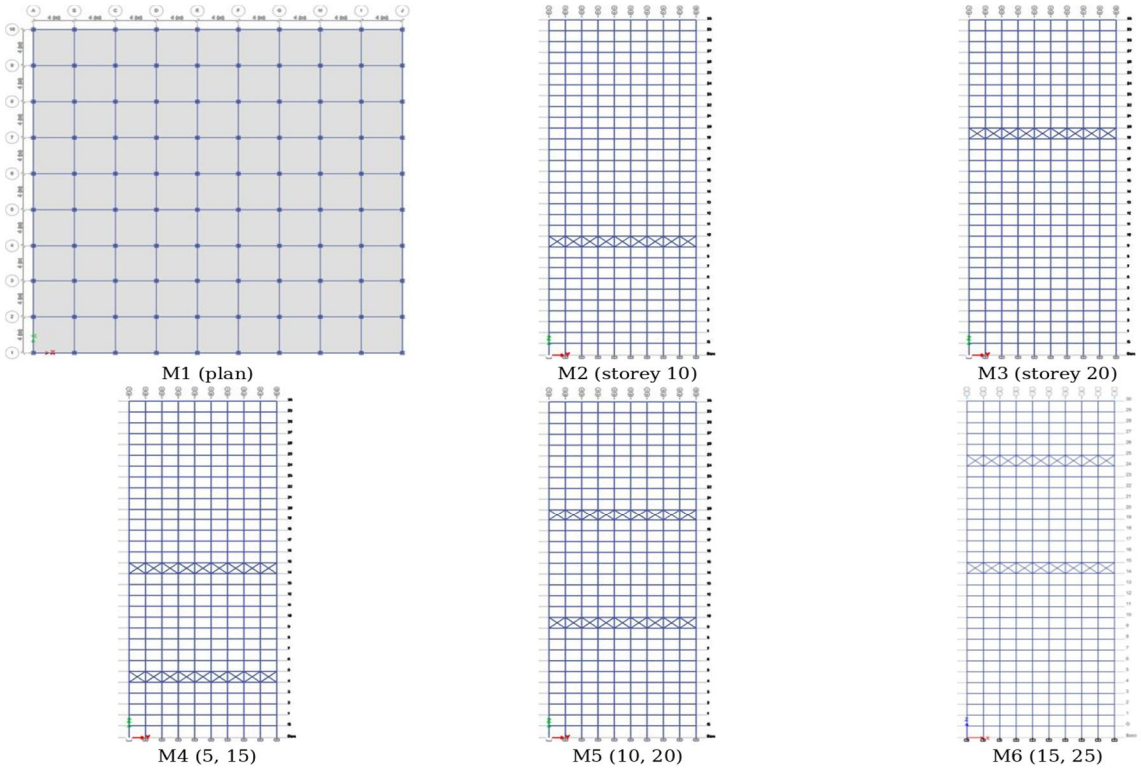


Fig. 1: ETABS models (plan of M1 and elevations of M2 to M6)

Table 1: Models considered

Model	Outrigger at storey	Number of levels
M1	None	0
M2	10	1
M3	20	1
M4	5 and 15	2
M5	10 and 20	2
M6	15 and 25	2

IV. RESULTS AND ANALYSIS

The results of M2 to M6 are compared with the bare frame M1, and the percentage change is calculated with respect to M1.

A. Comparison of storey displacement

Fig. 2 shows the displacement along the height. All the outrigger models give lower displacement than the bare frame at every storey. The top displacement of M1 is 32.68 mm, which is about H/2855 and is much less than the usual limit of H/500. With outriggers it comes down to 30.01 mm for M2 and 25.61 mm for M6, which is a reduction of 8.2% to 21.6% (Table 2). For a single outrigger, the one at storey 20 (10.9%) is better than the one at storey 10 (8.2%). Among the two level cases, M5 and M6 are better than M4, and M6 gives the maximum reduction. The top displacement of M6 corresponds to H/3643, compared with H/2855 for the bare frame.

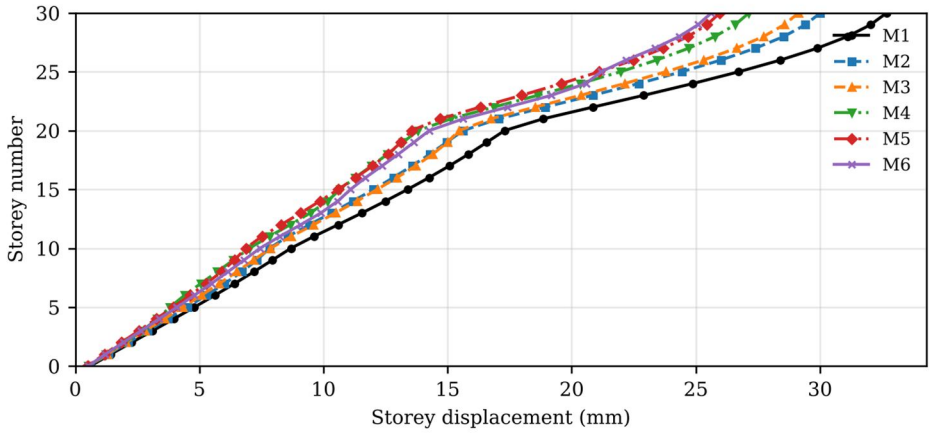


Fig. 2: Comparison of storey displacement

Table 2: Top displacement and fundamental mode

Model	Top disp. (mm)	Reduction (%)	T1 (s)	f1 (Hz)
M1	32.679	-	1.507	0.664
M2	30.011	8.16	1.489	0.672
M3	29.132	10.85	1.498	0.667
M4	27.137	16.96	1.464	0.683
M5	25.967	20.54	1.480	0.676
M6	25.614	21.62	1.473	0.679

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B. Comparison of time period and base shear

The fundamental time period of M1 is 1.507 s. It reduces to 1.464 s to 1.498 s in the outrigger models, so the change is only 0.6% to 2.9%, and the frequency increases by the same small amount. The first two modes have the same time period in all the models because the plan is symmetrical. The base shear (Table 3 and Fig. 3) increases slightly with outriggers, by 0.3% to 4.8%. This is due to the extra weight of the bracing members and the shorter time period, which gives a slightly higher spectral acceleration.

Table 3: Base shear

Model	Base shear (kN)	Change (%)
M1	10053.67	-
M2	10264.66	+2.10
M3	10081.35	+0.28
M4	10536.14	+4.80
M5	10325.14	+2.70
M6	10431.87	+3.76

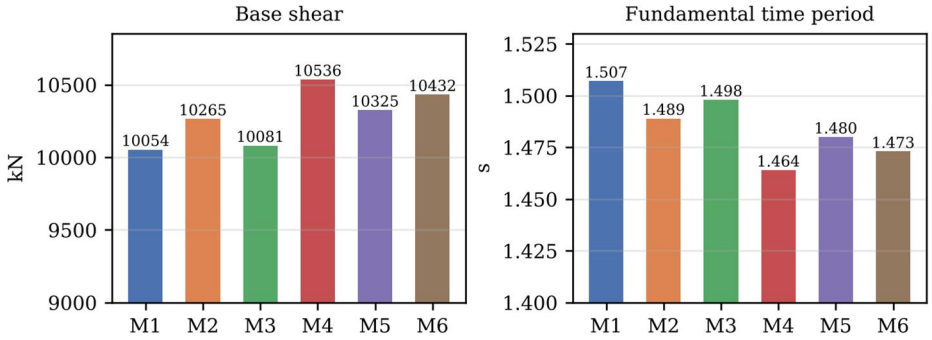


Fig. 3: Comparison of base shear and fundamental time period

C. Comparison of storey drift

The drift ratio of each storey is plotted in Fig. 4. The maximum drift of M1 is 0.000893 at storey 22. In the outrigger models it varies from 0.000887 to 0.000949, so the maximum drift is not reduced by the outriggers (Table 4). All the values are far below the limit of 0.004 given in IS 1893 (Part 1):2016. At the storeys where the bracing is provided the drift is lower by about 24% to 32% in M2 to M5, but the adjacent storeys take a little more, and so the peak value does not change.

Table 4: Maximum storey drift

Model	Max. drift ratio	Storey	Change (%)
M1	0.000893	22	-
M2	0.000907	22	+1.57
M3	0.000887	22	-0.67
M4	0.000919	22	+2.91
M5	0.000906	22	+1.46
M6	0.000949	21	+6.27

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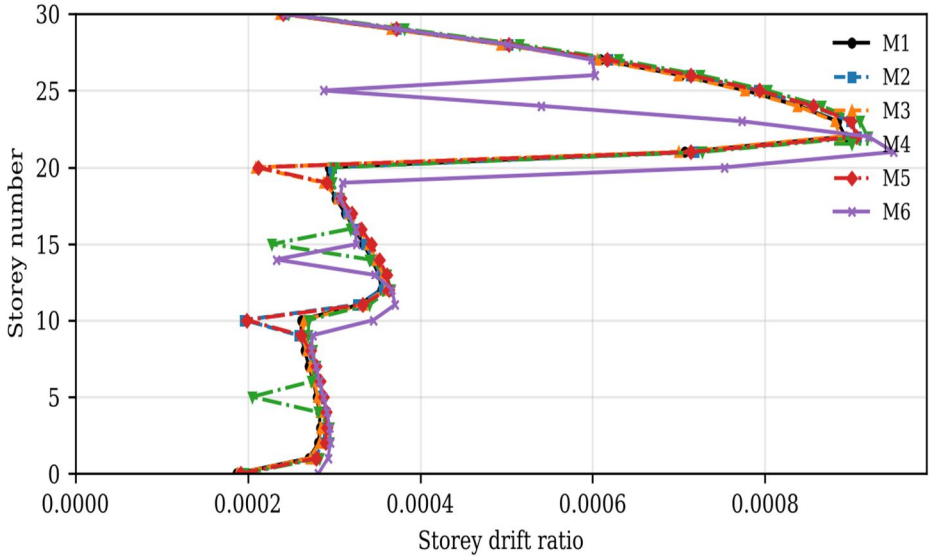


Fig. 4: Comparison of storey drift

D. Comparison of acceleration, storey shear, torsion and bending moment

These quantities show the largest improvement with outriggers (Table 5). The top storey acceleration reduced by 9.1% to 36.1%. At the base level, the storey shear and torsion reduced by 8.1% to 35.7% and the bending moment by 8.6% to 34.5%. M6 gives the largest reduction in all four quantities, followed by M5, and M2 gives the smallest. The values are plotted in Fig. 5 and the reductions with respect to M1 are shown in Fig. 6.

E. Effect of location and number of outriggers

Two points can be seen from the results. First, the location matters. For a single outrigger, storey 20 gave better results than storey 10 in displacement, acceleration, shear and bending moment. Second, two outriggers are better than one, since M5 and M6 improve on M3 in every quantity. Among the two level cases, the response improves as the outriggers are moved up (M4, M5, M6). This is the arrangement for this building only, and the best level can change if the height, plan size or member sizes are changed.

The effect of the number of outrigger levels can also be seen by dividing the reduction in top displacement by the number of levels. The reduction per level is 8.2% for M2 and 10.9% for M3, 8.5% for M4, 10.3% for M5 and 10.8% for M6. So, two outriggers do not give twice the benefit of one outrigger placed at a good level, because the second level shares a part of the load already taken by the first. The advantage of the second level is mainly in the acceleration, shear and bending moment, which are reduced much more in M5 and M6 than in M3.

Table 5: Response at top and base level

Model	Top acc.	Shear (kN)	Torsion (kN-m)	Bending (kN-m)
M1	992.47	10053.67	180966	483914
M2	902.27	9238.19	166287	442315
M3	825.56	8468.33	152430	412588
M4	832.59	8428.91	151720	399799
M5	718.90	7434.10	133814	360654
M6	634.26	6467.76	116420	317228

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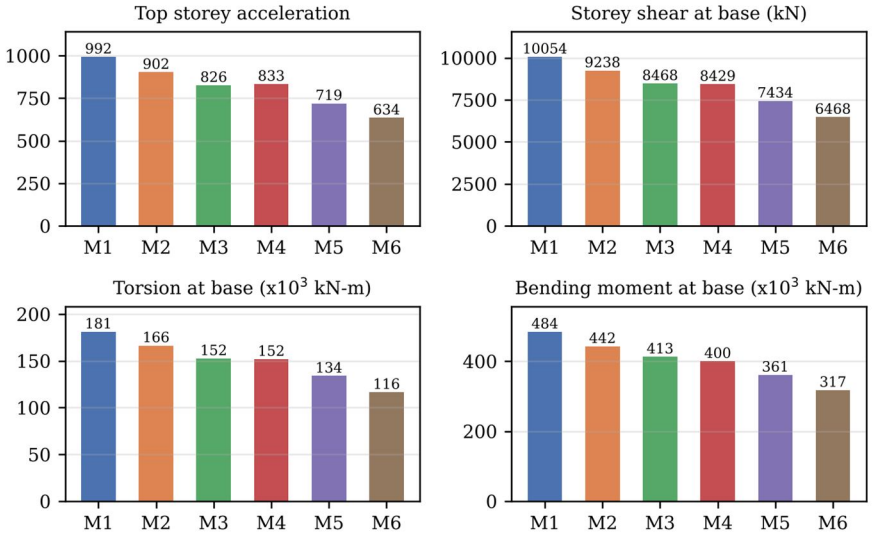


Fig. 5: Top storey acceleration and base level storey shear, torsion and bending moment

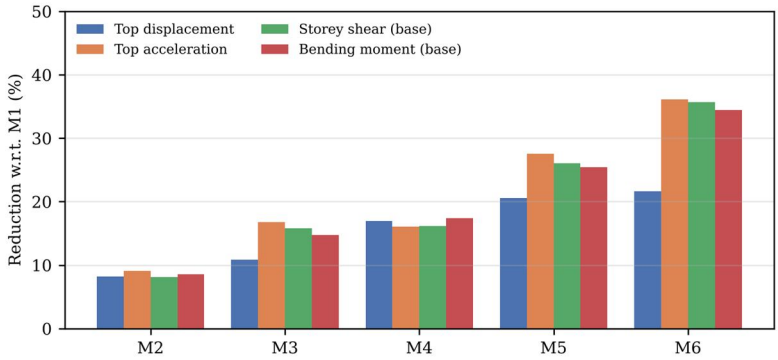


Fig. 6: Reduction of responses with respect to M1

The overall trend is in line with the findings of the earlier studies on outriggers, in which both the level and the number of outriggers were found to control the efficiency. In the present study the improvement in acceleration, shear and bending moment is much larger than the improvement in displacement, which shows that the outriggers help mostly in reducing the force demand and the vibration of the building. The small increase in base shear should be considered while designing the foundation.

V. CONCLUSIONS

From this analysis the following conclusions were made

1) A G+30 reinforced concrete building was analysed by response spectrum analysis in ETABS as a bare frame and with five outrigger arrangements.

2) The top displacement reduced by 8.2% to 21.6% with outriggers. The maximum reduction was for the outriggers at storeys 15 and 25.

3) The top storey acceleration reduced by up to 36.1%, and the storey shear, torsion and bending moment at the base reduced by up to 35.7%, 35.7% and 34.5%, again for M6.

4) The fundamental time period reduced only by 0.6% to 2.9%, while the base shear increased by 0.3% to 4.8%. This small increase should be considered in the foundation design.

5) The maximum storey drift was not reduced by the outriggers and was within the code limit in all the models. The drift reduced only at the braced storeys.

6) Two outriggers gave better results than one, and outriggers in the upper part of the building were more effective than those in the lower part.

7) The reduction in top displacement per outrigger level was between 8.2% and 10.9%, so a second level did not double the benefit of a single well placed outrigger.

8) The present work is for a frame without core or shear wall and with one size of bracing member. Further work can be done with a core, different outrigger stiffness, belt trusses, wind load and time history analysis.

VI. ACKNOWLEDGEMENT

The authors thank the Department of Civil Engineering, Sanketika Vidya Parishad Engineering College, Visakhapatnam, for the support given during this work, and the faculty members for their suggestions.

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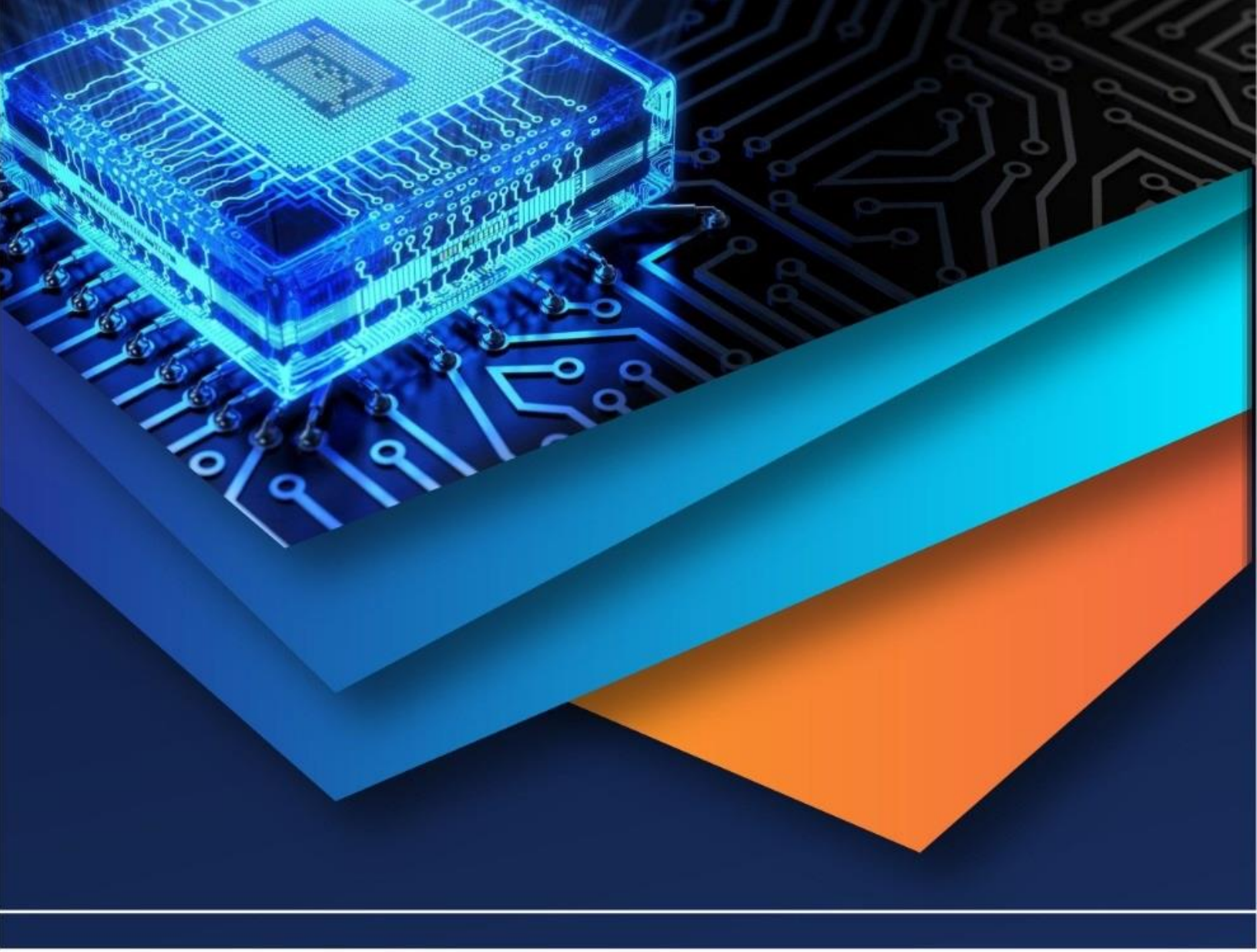
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