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Seismic Analysis of Conventional, Braced, and Shell, Elevated Water Tanks for Different Seismic Zones

Chukesh Singh[1], Dr. A. K. Dwivedi[2]
[1]M. Tech Scholar, University Department, Rajasthan Technical University, Kota, Rajasthan, India
[2] Professor, University Department, Rajasthan Technical University, Kota, Rajasthan, India

Abstract: Water is stored in the tanks and then distributed through the public water supply systems. The term "overhead water tanks" (OWT) or "elevated water tanks" (EWT) refers to water tanks that are constructed at a specific height. A large mass that is concentrated at the top of the EWT is supported by thin supports. The horizontal stresses brought on by earthquakes affect it severely. The elevated water tanks all around the world either collapsed or experienced major damage as a result of the earthquake since the supporting mechanisms were either poorly constructed or selected. Different structural methods and materials have been employed by a number of researchers and designers to create safe designs that keep the EWT stable during earthquakes. The current study's objective is to analyze the conventional, braced (diagonal and cross), and shell-stagging EWT for seismic zones III and IV. For that purpose, the lateral displacement and base shear of conventional, braced (diagonal and cross), and shell-stagging elevated Intze tanks have been investigated and compared. The current study also illustrates how zones III and IV are affected by full and empty EWT situations. The shell EWT has performed better than conventional EWT when lateral displacement and base shear are compared.
Keywords: Intze Tank, Conventional Bracing, Shell Stagging, Base Shear, Lateral Displacement

I. INTRODUCTION

Water's essential to humans and all forms of life. An elevated tank is a large storage vessel intended to store different types of liquid at specific heights for the sake of proper pressure. In industries, tank storage is used to store chemicals, petroleum products, and water under the Public Water Supply System. There may be very dangerous and combustible substances in industrial liquid storage tanks, so their contents must not have been lost during an earthquake. Appropriate water distribution will be determined by the design of a water tank in an appropriate location. Various methods are used for liquid storage, such as undergrounding, ground supported, raised, and so on. Since the pressure is maintained by gravity, which does not affect the distribution system, elevated storage tanks do not require constant pump operation. For water storage, elevated storage tanks are commonly used. Water pressures may be equalized in the distribution system by the strategic location of the tank. The volume of the water pouring from an upper tank determines its pressure. Where ground storage tanks are not created due to a lack of sufficient natural height and where standpipe service is performed from wells by wind turbines or other powered pumps, elevated storage tanks shall be used. A large population or a limited group of dwellings may be served by elevated tanks. Elevated water tanks are a major and important construction; damage to these structures during earthquakes may jeopardize the drinking water supply, lead to delays in preventing massive fires, or result in significant economic losses. As a result, water tanks are essential for public utilities. The capacity of liquid storage tanks is limited compared to typical buildings in terms of ductility and energy absorption capacity. Due to this, liquid storage tanks need to have the highest level of Seismic Safety.

II. LITERATURE REVIEW

Jayadeep K. S. et al. (2022) studied the seismic response on an elevated water tank [1]. This research sought to analyze the seismic response of an elevated water tank, taking into account sloshing effects and behavior analysis. The influence of soil structure interaction in seismic zones II and III was considered by the authors for this study. According to the results, the time period (0.262 sec.), displacement (2.9mm), total Base Shear (28.91kn.), and Base moment (185. 77kn.m) was found higher in the case of the tank being full than empty.

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Diwakar Yadav and Vinayak Mishra (2021) carried out a study on elevated water tank (EWT) design and seismic study in various earthquake profiles [2]. The goal of this study turned into the overall performance of an elevated-water tank below exceptional loading instances at some stage in earthquakes. Seismic layout elements along with shear strength, base moment, and tank displacement had been analyzed in seismic zones II, III, IV, and V below empty and complete situations. The researchers observed that the Intze tank having a conical backside and some other round backside, reduces stresses along the ring beams. In a full tank condition, the lateral pressure is greater than in an empty tank, and the bottom shear is proportional to the area factor.

Sheetal Mohan Tarwatkar and Niraj Bias (2021) analyzed the seismic behavior of elevated RCC water tanks having different h/d ratios and shapes [3]. The reason for this work became required to assemble an earthquake-resistant creation for multiplied water tanks, in addition to analyzing the h/d ratio and numerous tank shapes. According to the consequences of the research, the nodal displacement will increase as such quarter factor, h/d ratio, and base shear growth from quarter II to quarter V. The round form of the multiplied water tank is extra resistant than the square design (toward seismic waves).

Tejaswini R and Mamatha A (2020) analyzed the EWT [4]. The target of the reported studies was to build an economical structure using a limit state approach instead of working stress and linear dynamic analyses with ETABS were performed on empty tanks and full tank conditions. The researchers found that, under the same conditions as described above, the area of steel used in the Limit State method was higher than in the working stress method, and the critical reaction of the raised water tanks may not always be the same, depending on the earthquake characteristics. Vangaveti Sai Santhosh et al (2020) This study examined the seismic behavior of overhead water tanks using Indian, American, and British codal provisions [5]. In this study, dynamic reaction spectrum analysis has been used to analyze the behavior of RCC overhead tanks in IS 1893:2002 seismic zone i.e. The study concludes that ACI is more affordable compared to the other two standards, and codal clauses are rated according to economic value in terms of ACI, IS or BS.

III. EWT DESIGN PARAMETERS AND METHODOLOGY

The details of conventional, braced (diagonal braced, X-Bracing,), and shell elevated intze tanks (180mm,200mm) have been analyzed and discussed.

Table 1: Design Parameter for Tank Design

Tank Details	
Tank Volume	900 m^3
Staging Height	16 m
No. of Column	8 No.
Internal Diameter of Cylindrical Portion (D)	15 m
Height of Cylindrical Portion (H)	3.7 m
Size of Top Beam	0.2 x 0.3 m
Width Of Balcony Beam	1.3m
Depth of Balcony Beam	0.15 m
Size of Main Ring Beam	0.25 x 0.6m
Diameter of Column	0.5 m
Size of Periphery Bracing	0.25 x 0.40 m
Size of Diagonal And X- Bracing	0.23 x 0.3 m
The thickness of the Top Dome	0.15 m
The thickness of the Cylindrical Wall	0.20 m
The thickness of the Conical and Bottom Dome	0.25 m

Staging an essential component of the overhead tank structure, is responsible for ensuring a safe working environment for the water tank. To shorten the column's actual length, a series of horizontal or inclined braces are placed at intermediate levels between vertical columns, forming staging. It could also act as a circular hollow shaft supporting a shear wall rather than a column and bracing. Based on the type of structure, staging is broken into two groups: shell staging and column-brace staging. Column-brace staging is further divided into three groups: 1) conventional staging, 2) diagonal staging, and 3) cross staging, 4) shell staging. all of which are used for the present study.

According to the literature review, several researchers have used different geometrical principles for constructing the EWT. The authors performed an analysis for zones III and III. In addition, a few researchers have used different forms of bracing for zone II and III. However, the effect of the different forms of bracing has not been assessed for Zone IV and Zone III. According to a literature review, the most important structural characteristics of any elevated water tank are lateral displacement and base shear. For elevated water tanks with diagonal, cross staging, and shell staging, which are designed for zones III and IV, these structural characteristics have not been compared and analyzed.

We are trying to figure out the best way to build a big water tank. We are using a real model to compare different ways of supporting the tank. We looked at three different ways of building it and tested them when the tank was empty and full of water. We used a computer program to test 18 different designs.

IV.ANALYSIS AND RESULTS

The results obtained for conventional, diagonal, cross-braced, and shell staging, EWT has been analyzed and discussed below.

A. Comparison of Base Share for Zone III

Table 2: Base shear for Zone III

Types of Bracing	Base Shear (KN.)	
	Empty Tank	Full Tank
Conventional bracing	366.06	598.84
Diagonal Bracing	723.6	1623.82
X-Bracing	772.38	2028.19
Shell staging Tank (180mm)	756.1	2013.04
Shell staging Tank (200mm)	786.73	2043.99

The base shear of Intze tanks with cross bracing is higher (772.38kN.) and (2028.19kN.) than that of those with diagonal bracing, and conventional bracing, corresponding to a larger base shear. It can be seen that the 200mm shell staging intze tank has a higher base share (786.73kN.) and (2013.04kN.) than the other types of bracing using this paper.

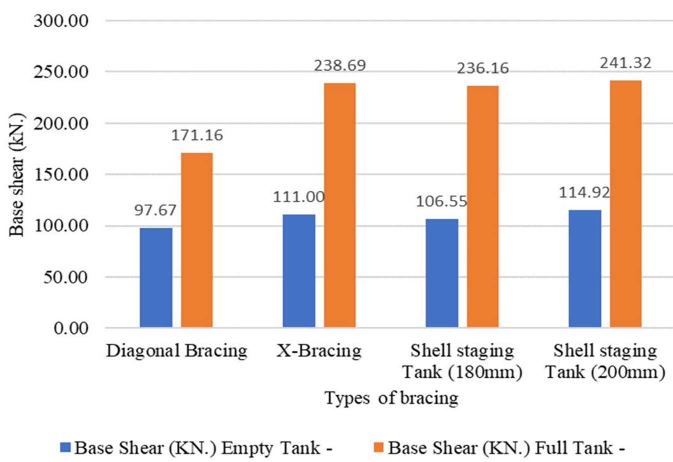

Fig. 1. Illustration Of Percentage Comparison of Base Share for Zone III.

Fig.1 shows that intze tanks with diagonal bracing have achieved 97.67% and 171.16% more base shear than conventional intze tanks. Intze tanks with X-bracing have achieved 111.00% and 238.69% more base shear than conventional intze tanks. Intze tanks with shell staging 180mm have gained 106.55% and 236.16% more base shear than conventional intze tanks. Intze tanks with shell staging 200mm have obtained 106.55% and 236.16% more base shear than conventional intze tanks.

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B. Comparison of Base Share for Zone IV

Table 3: Base shear for zone IV

Types of Bracing	Base Shear (KN.)	
	Empty Tank	Full Tank
Conventional bracing	548.79	896.9
Diagonal Bracing	1085.66	2435.03
X-Bracing	1158.84	3042.8
Shell staging Tank (180mm)	1134.42	3020.91
Shell staging Tank (200mm)	1180.36	3066.99

The base shear of Intze tanks with cross bracing is higher (1158.84kN.) and (3042.8kN.) than that of those with diagonal bracing, and conventional bracing, corresponding to a larger base shear. It can be seen that the 200mm shell staging intze tank has a higher base share (11180.36kN.) and (3066.99kN.) than the other types of bracing using this paper.

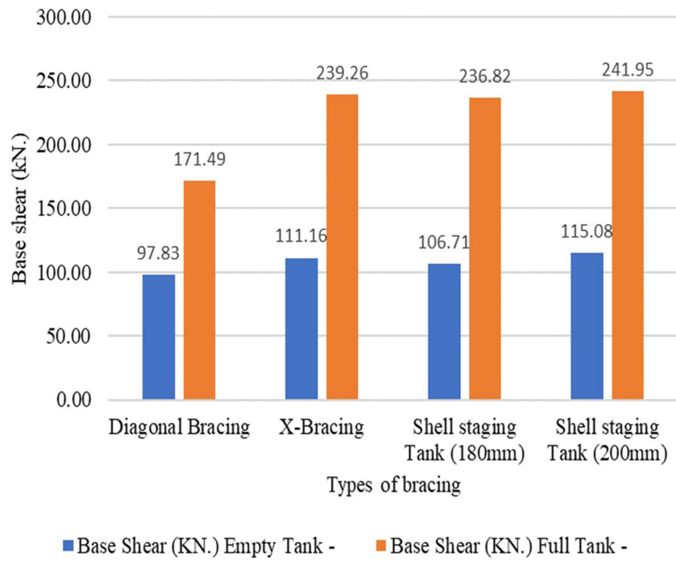

Fig. 2. Illustration Of Percentage Comparison of Base Share for Zone III.

Fig. 2 illustrates that (i) the intze tank with diagonal bracing has attained 97.83% (in empty tank condition) and 171.49% (in full tank condition) more base shear than the conventional intze tank; (ii) the intze tank with X-bracing has achieved 111.16% in empty tank conditions and 239.26% in full tank condition more base shear than conventional intze tank; (iii) intze tank with shell staging 180mm has gained 106.71% in empty tank conditions and 236.82% in full tank condition more base shear than conventional intze tank; (iv) intze tank with shell staging 200mm has obtained 115.08% in empty tank conditions and 241.32% in full tank condition more base shear than conventional intze tank.

C. Comparison of Lateral Displacement for Zone III

Table 4 shows that the lateral displacement of the intze tank (full condition) increases with the height of the tank. Table 4 results that (i) the conventional intze tank has a maximum lateral displacement of 55.819mm; (ii) the Diagonal bracing intze tank has a maximum lateral displacement of 26.517mm; (iii) X- the bracing intze tank has a maximum lateral displacement 22.923mm; (iv) shell staging tank (180mm) has maximum lateral displacement 7.156mm; (v) shell staging tank (200mm) has maximum lateral displacement 6.566mm at the top. Fig 3 illustrates the comparison of lateral displacements for different types of intze tanks designed and analyzed in this research.

Table 4: Lateral Displacement Results for Different Intze Tanks for Zone III

Height	Conventional bracing	Diagonal Bracing	X-Bracing	Shell staging Tank (180mm)	Shell staging Tank (200mm)
0	0	0	0	0	0
2.67	5.31	1.862	1.67	0.452	0.41
5.33	14.962	4.726	3.652	0.927	0.846
8	25.633	8.148	6.052	1.599	1.459
10.67	36.424	12.004	8.839	2.394	2.183
13.33	46.465	16.131	11.904	3.285	2.995
16	52.889	19.709	14.965	4.183	3.814
18.7	53.927	21.923	17.554	5.187	4.748
22.7	55.194	24.994	21.139	6.503	5.963
24.7	55.819	26.517	22.923	7.156	6.566

Fig.3 illustrates that the conventional intze tank has attained 55.819mm lateral displacement at the top of the tank. furthermore, it can be seen that the shell staging intze tank having (a 200mm thick wall) has achieved lateral displacement 88.24% less than to conventional intze tank, followed by 87.18% for the shell staging tank (180mm), 58.93% for X- bracing and 52.49% for diagonal bracing, present in fig.3.

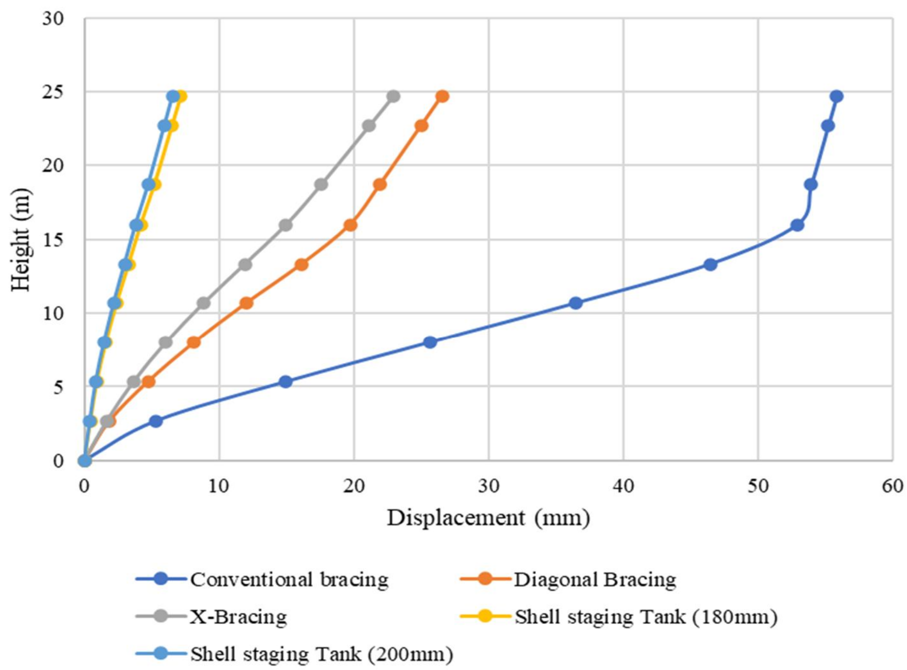

Fig.3: illustrate lateral displacement for soft soil in full condition, zone III

D. Comparison of Lateral Displacement for Zone IV

Table 5 shows that the lateral displacement of the intze tank (empty condition) increases with the height of the tank. Table 5 results that (i) the conventional intze tank has a maximum lateral displacement of 83.728mm; (ii) the Diagonal bracing intze tank has a maximum lateral displacement of 39.775mm; (iii) X- the bracing intze tank has a maximum lateral displacement 34.356mm; (iv) shell staging tank (180mm) has maximum lateral displacement 10.735mm; (v) shell staging tank (200mm) has maximum lateral displacement 9.849mm at the top. Fig 4 illustrates the comparison of lateral displacements for different types of intze tanks designed and analyzed in this research.

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Table 5: Lateral Displacement Results for Different Intze Tanks for Zone IV

Height	Conventional bracing	Diagonal Bracing	X-Bracing	Shell staging Tank (180mm)	Shell staging Tank (200mm)
0	0	0	0	0	0
2.67	7.965	2.793	2.506	0.679	0.615
5.33	22.443	7.088	5.478	1.391	1.268
8	38.45	12.222	9.078	2.398	2.188
10.67	54.636	18.006	13.259	3.591	3.275
13.33	69.697	24.196	17.856	4.927	4.493
16	79.333	29.564	22.448	6.274	5.721
18.7	80.891	32.884	26.331	7.78	7.122
22.7	82.791	37.492	31.709	9.755	8.945
24.7	83.728	39.775	34.356	10.735	9.849

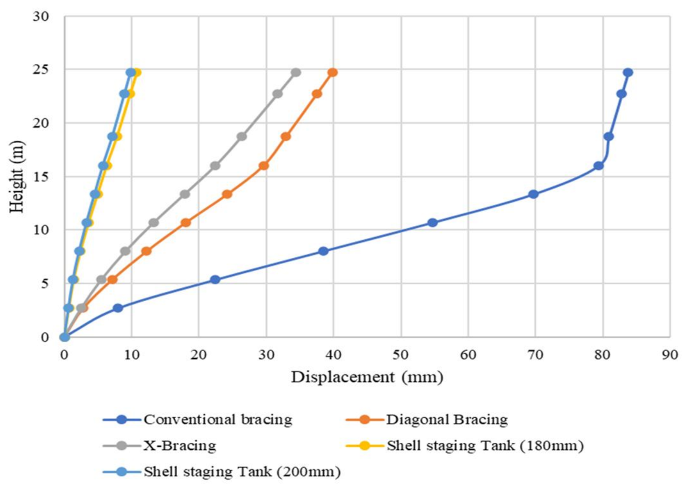

Fig.4: illustrate lateral displacement for soft soil in full condition, zone IV

Fig.4 illustrates that the conventional intze tank has attained 83.728mm lateral displacement at the top of the tank. furthermore, it can be seen that the shell staging intze tank having (200mm thick wall) has achieved lateral displacement 88.24% less than to conventional intze tank, followed by 87.19% for the shell staging tank (180mm), 58.97% for X- bracing and 52.49% for diagonal bracing, present in fig.4.

V. CONCLUSIONS

In the present research, conventional, diagonally braced, and cross-braced elevated intze tanks have been designed, analyzed, and compared. In addition, the shell staging elevated intze tank has been designed and analyzed. The complete research has been carried out for zone III and IV. The structural properties, such as lateral displacement and base shear have been compared with each other.

From the analysis and comparison of different elevated intze tanks, the following conclusions are drawn: -

1) The conventional elevated intze tank has attained maximum lateral displacement in Zone IV than Zone III. It has also been observed that cross-braced elevated intze tank has achieved less lateral displacement than diagonal-braced and conventional elevated intze tank.
2) The comparison of shell staging elevated intze tank with other intze tank demonstrates that shell staging elevated intze tank has minimum lateral displacement than conventional, diagonally braced, and cross-braced elevated intze tank in both zones, i.e., Zone III and IV.
3) The elevated intze tanks always have higher lateral displacement, when it is filled with water than empty elevated intze tanks in both earthquake zones.

4) It has also been observed that a conventional elevated intze tank has less base shear than diagonal-braced and cross-braced elevated intze tanks in each earthquake zone.
5) The comparison of the base shear of the shell staging intze tank with the conventional and braced elevated intze tank reveals that the shell staging intze tank has higher base shear in filled and empty conditions for both zones.
6) The effect of wall thickness in shell staging elevated intze tank shows that the 200mm shell staging elevated intze tank has less lateral displacement and high base shear than 180mm shall elevated intze tank.
7) The results obtained in the full tank condition demonstrate that water increases the base shear of the elevated intze tank (for all cases) and has less lateral displacement.

VI. FUTURE SCOPES

Based on the outcomes of the present research the following future scopes have been drawn: -
1) The present study may be extended for Zone V and compared with the present study.
2) The impact of the size and shape of the columns may be carried out for Zone III, IV, and V.
3) The combined effect of steel bracing (at the outer side) and inner cross/ diagonal/ square/ rectangular bracing may be studied.
4) The present research may be extended by providing chevron, global, K, and V-type of bracings in elevated intze tanks for zone III, IV, and V using STAAD Pro.
5) The present study may be carried out using SAP 2000 and ETABS software and comparison may be mapped.

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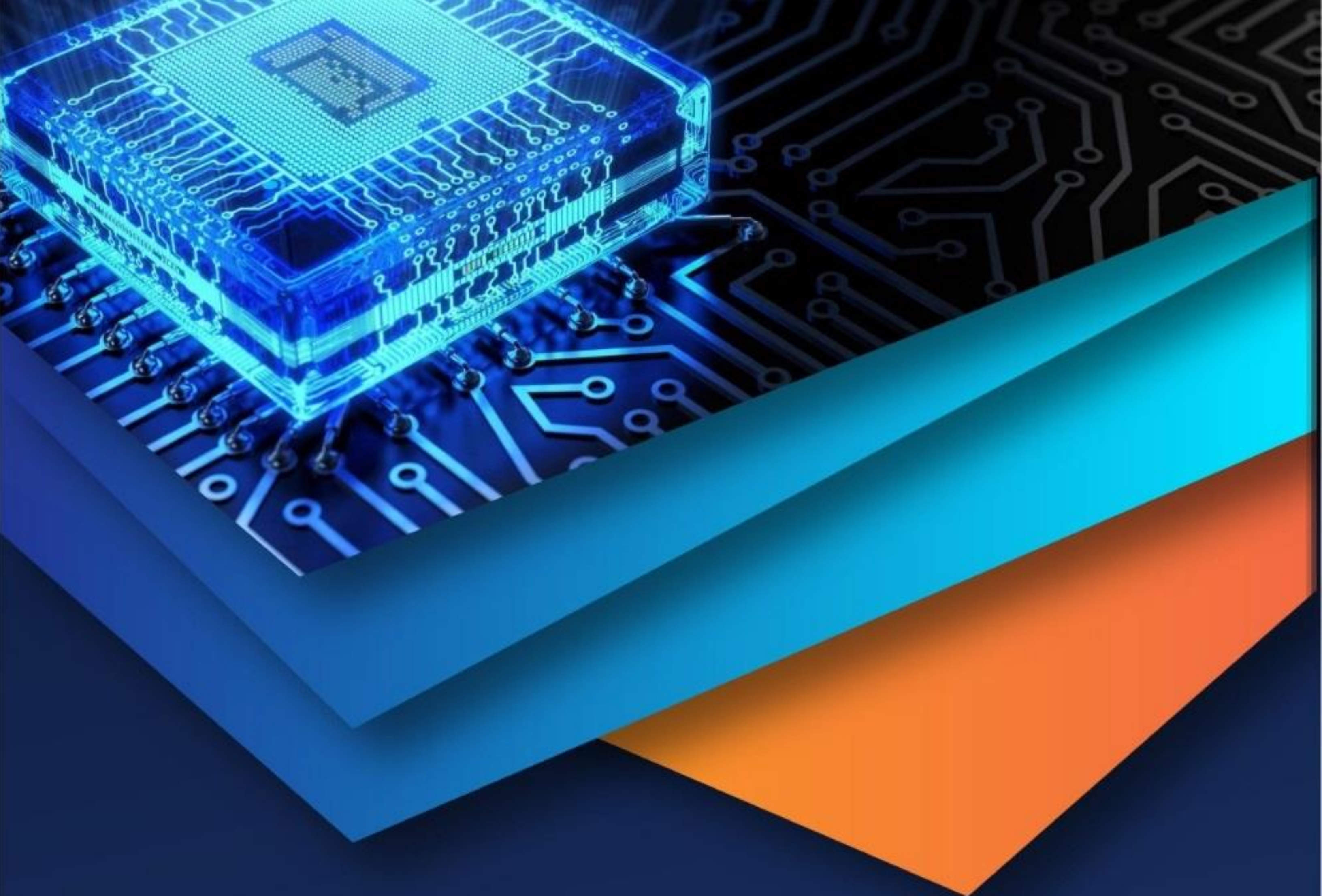

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