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Structural Behaviour of Cable- Stayed Bridge with Different Pylons using STAAD Pro

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Abstract: Cable-stayed bridges were originally developed in the late 16th century but became less popular towards the end of the 20th century when suspension and reinforced concrete designs became more commonly used. However, advancements in material and methods have made them popular again in 21st century, particularly for longer -span crossings. They are suitable for spans longer than cantilever bridges but shorter than suspension bridges, and their main feature is the direct connection of cable from the tower to the deck. Cable-stayed bridges have undergone significant technical advancements and now have impressive aesthetic appearances, thanks to improvements in material, engineering analysis and design, and construction methodology. This thesis focuses on the design and analysis of four different pylon -shaped cable- stayed bridges with semi-fan cable arrangements using STAAD.Pro V8i software for designing and MS excel for comparative analysis. The primary aim of the thesis is to provide a detailed description of the structural behaviour of these bridges and present a comparative analysis.
Keywords: Cable-stayed Bridge, Pylon, Structure, Cables, Span, Loads, Shear force, Deflection, Bending moment.

I. INTRODUCTION

Cable-stayed bridges are a type of bridge that use one or more towers to support cables that run directly to the bridge deck, arranged either in a fan pattern or parallel lines. This is different from suspension bridges, which suspend the deck vertically from the main cable anchored at the both ends of the bridge a running between the towers. Cable-stayed bridges are most suitable for spans that are longer than cantilever bridges but shorter than suspension bridges.

Cable-stayed bridges were first used in the early16th century ad widely used in the 19th century. They consist of three primary subsystems: The stiffening girder, Tower or Pylons & inclined cables. Th tower are placed in the centre of the bridge, and the girder segments are connected to the pylons using connected to one or two towers. The weight of the girder is supported by a series of cables that run directly to one or more towers. Advancements in the construction industry have made cable-stayed bridges more popular again in recent times. These advancements include improvements in materials, with improved internal structures and the use of post-tensioning technology on the bridge cables. There have also been updates in engineering analysis, design and construction methodology.

Cable- stayed bridges provide design flexibility in terms of the shape of pylons, girder shape and cable arrangements. This allows for the application of various structural systems to create cable-stayed bridges that are suitable for different geographic environments. They are highly cost-effective structures, particularly for long span bridges and also offer aesthetically pleasing design solutions.

Cable-stayed bridges are also known for their durability, with many structures lasting for decades without requiring major maintenance or repairs.

They are also more resistant to strong winds and earthquakes compared to other bridge types. Additionally, Cable-stayed bridges are often used as iconic landmarks in cities, providing a distinctive appearance and attracting tourists. One of the most notable cable-stayed bridges in the world is the Russky Bridge in Russia, which has the longest cable-stayed span in the world at 1,104 meters. Another famous cable -stayed bridge in the Millau Viaduct in France, which has the highest road bridge tower in the world at 343 meters. Cable-stayed bridges are also popular in Asia, with many notable structures such as the Sutong Tangtze River Bridge in China, the Penang Bridge in Malaysia, and the Bosphorus Bridge in Turkey.

While cable- stayed bridges offer many advantages, they also have some limitations. for instances, heir construction can be challenging due to the complex geometry of the cables and towers. Additionally, the cables require inspections and maintenance to ensure their structural integrity, which can be costly and time- consuming. Despite these challenges, cable-stayed bridges remain a popular choice for many bridge projects due to their numerous benefits.

II. CABLE STAYED BRIDGE DESCRIPTION

Cable- stayed bridges are modern engineering marvels that rely on tensioned cables to support the weight of the bridge deck. These types of Bridges consist of several crucial parts that work together to create a stable and durable structures. The main components of a Cable-stayed bridge include the Pylon, the Deck, the Cable and the Anchorage systems. Each of these components plays a critical role in the overall stability and longevity of the bridge.

1) *The Pylon* **-** It's a tall tower like structure that supports the weight of the cables and the bridge deck. They are typically made of steel, concrete or a combination of both. The choice of material depends on various factors like, height of the pylon, the location of the bridge and the environmental conditions.
2) *The Deck* – It's the horizontal roadway surface that connects the two ends of the bridge. The deck is supported by the cables, which are anchored to the pylon and the deck. The deck can be made of many materials such as concrete, steel or composite materials. The choice of material depends on various factors such as the weight of the traffic, the expected lifespan of the bridge and the aesthetic design of the bridge.
3) *The Cables* – They are responsible for supporting the weight of the deck and transmitting the load to the pylon and the anchorage systems. The cables are made of high strength steel wires that are bundled together to form a cable. The no. of wires and the diameter of the cable depends on various factors, such as the length of the span, the weight of the traffic and the environmental conditions.
4) *The Anchorage Systems* – It's a component that connects the pylon to the deck. These are designed to transmit the load from the cables to the pylon and the deck without causing and damage to the structure. The anchorage systems are typically made of steel, or concrete and are designed to with stand the tensile forces generated by the cables.

Above are the critical components of a cable-stayed bridge, and each of these parts must be carefully selected and designed to ensure the bridge's durability and safety.

III. GEOMETRIC DESCRIPTION OF THE BRIDGE

This study examines four different types of pylons – Double, Box, H and Box A for the Cable-stayed Bridge. The analysis compared three types of forces – shear, bending and displacement – to determine the most suitable pylon type of the bridge. The construction process is divided into three phrases: deck design, pylon design and cable arrangements. The STAAD Pro software is used for the analysis.

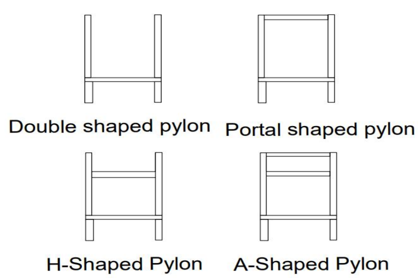
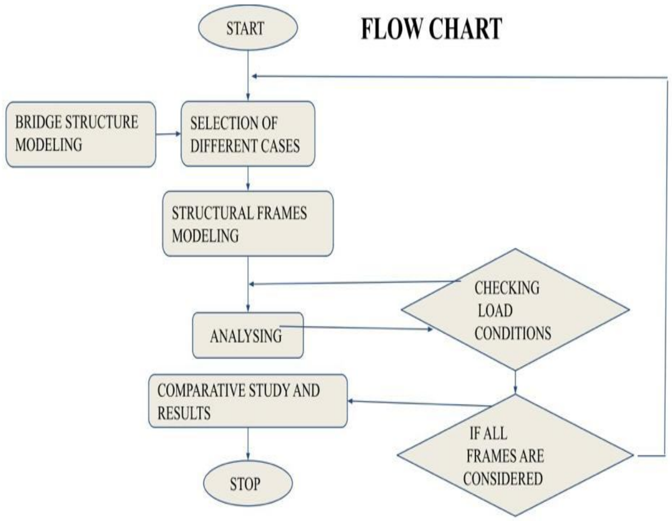


Fig. 1 Types of Pylons of Cable stayed Bridge used for comparative analysis.

S.no.	Specific Parameters	
1	Type of Cable arrangement	Harp Type
2	Type of Stay cables	Parallel wires
3	Total Span	400 meters
4	Total No. of Pylons	2 Nos
5	Height of pylon	65 meters
6	Total no. of Cables per Pylon	40
7	Deck width	10 meters
8	Thickness of the width	0.3 meters
9	No. of Lanes	3 Nos
10	Type of concrete	M60
11	Type of steel	FE500

Table 1. Cable stayed Bridge dimensional specifications.

IV. METHODOLOGY



The methodology used is conducting a comparative analysis of the cable-stayed Bridge with different cases of Pylons. To accomplish this, the analysis utilized STAAD Pro software, a powerful tool for designing and analysing structural systems. The analysis proceeded through three phases, beginning with the design of the deck, followed by the Pylon and concluding with the cable arrangements. This ensured that the design of the cable-stayed bridge was optimized for structural integrity and safety.

After the design phase, the analysis assigned various load cases to the bridge, including dead load, Live load & wind load (determined for Vizag Urban area: $q = 1.5KN/m^2$, $A = 26 \times 10^3 m^2$, $P = 5.1 \times 10^4$ KN, $F = 1.3 \times 10^6$ KN) from IS875 (Part 3), to simulate its performance under different conditions. This allowed for a through assessment of the bridge's structural integrity and capacity to withstand different loads.

Finally, the results of the load cases were analysed using a line graph to compare the shear, displacement and deflection of four different pylon types. This comparative analysis provides valuable information for optimizing the design of cable-stayed bridges, improving their performance, and ensuring their long-term safety and reliability. Based on this methodology, a rigorous approach to the analysis of cable-stayed bridges. The use of STAAD Pro software ensures that the design is safe and structurally sound, while the three-phase modelling approach and through analysis of different load cases provide valuable insights into the performance of different bridge designs.

V. DESIGN OUTPUT AND ANALYSIS

A. Design Output

We utilized the prescribed geometric specification and methodology to create design for cable-stayed bridges, each featuring four unique pylon shapes. Our design process involved using STAAD Pro tot perform geometric design, load assignments, support assignment, material property assignment and analysis. We were able to successfully execute this process without encountering any errors. As a result, we generated rendered images of the four cable-stayed bridges, each showcasing its respective pylon design.

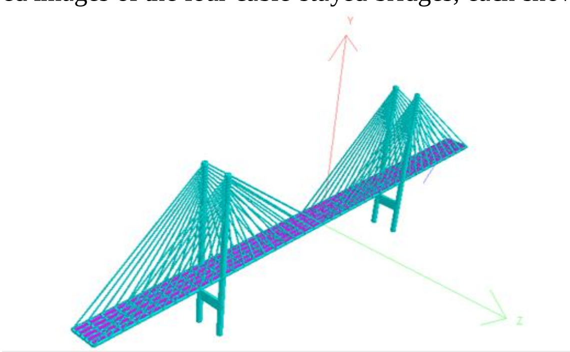


Fig. 2 Double-Shaped Pylon Cable-Stayed Bridge

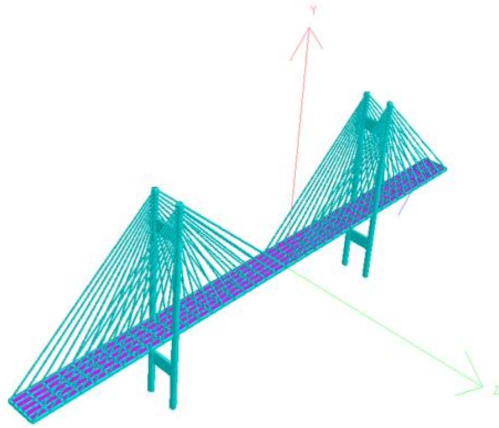


Fig. 3 -H- Shaped Pylon Cable-Stayed Bridge

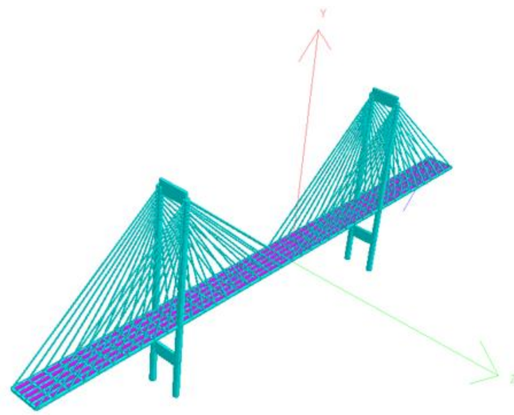


Fig. 4 Portal-Shaped Pylon Cable-Stayed Bridge

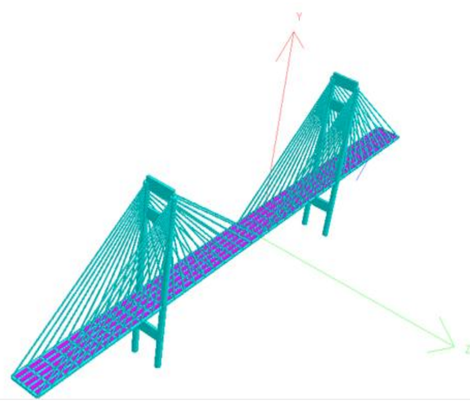


Fig. 5 Box A-Shaped Pylon Cable-Stayed Bridge

B. Comparative Analysis

Upon completion of the analysis, we obtained the values for

- *Shear Force:* Force acting perpendicular to the longitudinal axis of the bridge.
- *Bending Moment:* The moment that causes the bridge to bend.
- *Deflection:* The displacement of the bridge under loading.

Finding maximum shear force, bending moment and deflection under dead and live loads and identify which pylon is affected the highest. By comparing these parameters for each pylon, you can identify which pylon experiences the highest loads under dead and live loads. This could provide insights into the performance efficiency of each pylon design. The Obtained values are as follows:

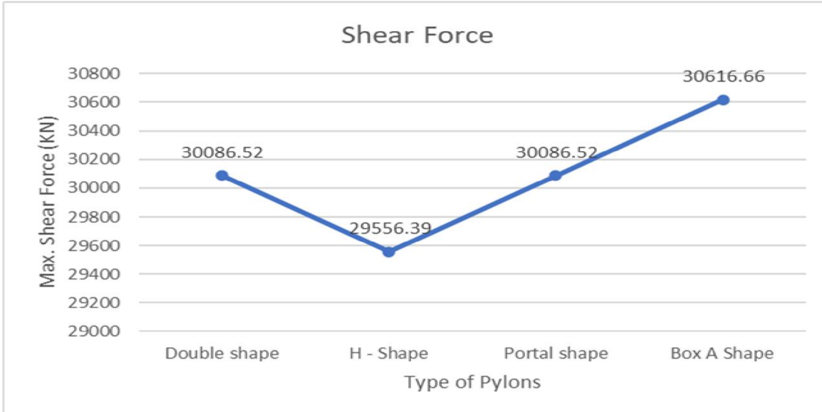


Fig. 6 Maximum Shear force of all the type of Pylons.

1) Based on Shear force values, the Box A shape bridge is the strongest, while the H shape bridge is the weakest. The Double shape and Portal shape bridges have similar shear force values which are lower than Box A shape bridge.

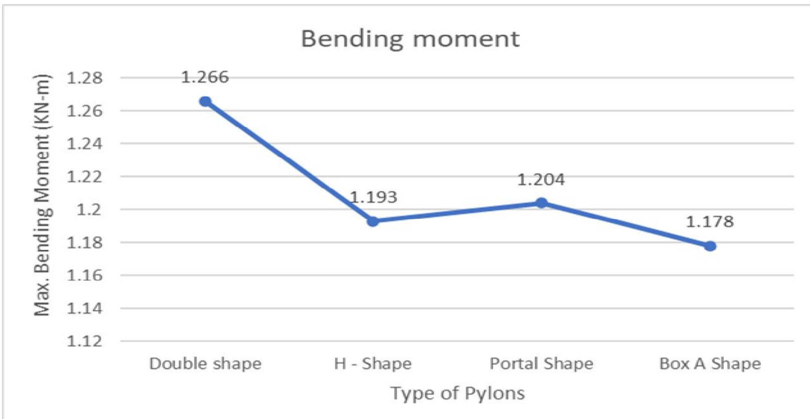


Fig. 7 Maximum Bending Moment for all type of Pylons

2) In terms of Bending moment, the Box A shape and H shape bridges have lowest values, while the Double shape has the highest value. The Box A shape bridge has a moderate bending moment value.

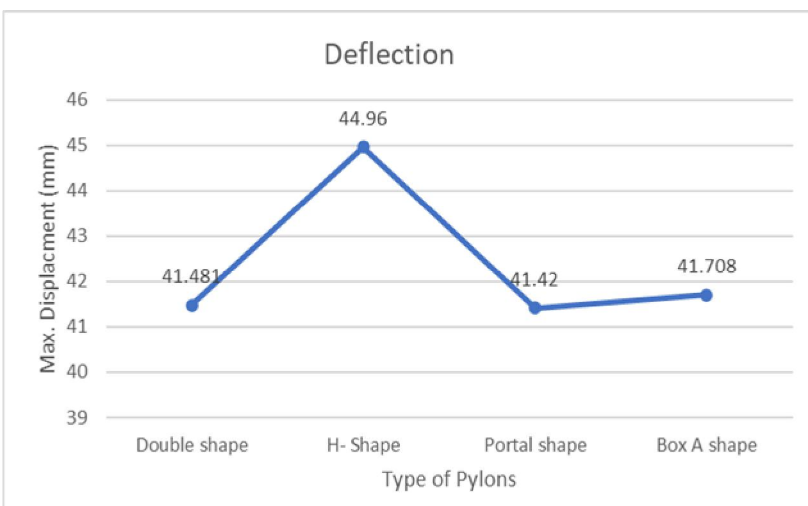


Fig. 8 Maximum Deflection for all type of Pylons

3) In terms of displacement, the Box A shape and Double shape bridges have the lowest values, while the H shape bridge has the highest value. However, the difference in displacements values is relatively small, so displacement alone may not be the most important factor in choosing the best bridge design.

C. *Vertical Load Distribution Analysis*

1) To perform a vertical analysis, you would need to divide the bridge into several segments along its length, where we take L/2 & L/4 and then calculate the load distribution and resulting displacements and shear for each segment. This would involve considering the effect of the dead load, live load, wind load and any other applicable loads on each segment.
2) Displacement along the span segments i.e., L/2 & L/4 of the Bridge.

NODE NUMBER	DISPLACEMENT IN Y DIRECTION (mm)			
	Double Shape	H - Shape	Portal Shape	Box A-shape
138	15.279	14.862	14.814	14.396
139	2.606	2.189	2.141	1.723
140	-4.954	-5.371	-5.418	-5.836
141	-4.954	-5.371	-5.418	-5.836
142	2.606	2.189	2.141	1.723
143	15.279	14.862	14.814	14.396

Table 2. Displacement at L/2

NODE NUMBER	DISPLACEMENT IN Y DIRECTION (mm)			
	Double Shape	H - Shape	Portal Shape	Box A-Shape
5	-10.224	-10.418	-10.418	-10.612
13	-15.493	-15.53	-15.563	-15.751
17	-20.603	-20.592	-20.637	-20.829
21	-20.603	-20.592	-20.637	-20.829
25	-15.493	-15.53	-15.563	-15.751
29	-10.224	-10.418	-10.418	-10.612

Table 3. Displacement at L/4

3) Shear Force along the span segments i.e., L/2 & L/4 of the Bridge.

NODE NUMBER	SHEAR IN Y DIRECTION (KN)			
	Double Shape	H - Shape	Portal Shape	Box A - Shape
247	-283.43	-283.44	-283.39	-283.3
246	-106.6	-106.6	-106.6	-106.6
245	15.904	15.904	15.908	15.904
244	138.41	138.41	138.41	138.41
243	315.245	315.244	315.202	315.202

Table 4. Shear force at L/2

NODE NUMBER	SHEAR IN Y DIRECTION (KN)			
	Double Shape	H - Shape	Portal Shape	Box A - Shape
351	-807.55	-820.27	-818.96	-826.02
350	-257.77	-261.27	-260.73	-261.82
349	15.904	15.904	15.904	15.904
348	289.576	293.074	292.539	293.63
347	839.357	852.081	850.763	857.832

Table 5. Shear force at L/4

4) Bending Moment along the span segments i.e., L/2 & L/4 of the Bridge. Where at L/2 there are 0 Bending Moments.

NODE NUMBER	BENDING MOMENT IN Y DIRECTION (KNm)			
	Double Shape	H - Shape	Portal Shape	Box A Shape
351	-2.123	-2.163	-2.158	-2.172
350	-0.421	0.252	-0.428	-0.431
349	-0.152	-0.151	-0.151	-0.15
348	0.061	0.076	0.073	0.079
347	1.832	1.91	1.899	1.927

Table 6. Bending moment at L/4.

5) We also consider the height of each pylon and the distribution of cables and stays on each pylon. As the height and distribution of the cables and stays will affect the load distribution and resulting displacements and shear at different points along the bridge span.

6) Axial Load in Pylon along the points where the cables intersect

DOUBLE SHAPE					
Left Beam Number	FX(KN)	FY (KN)	Right Beam number	FX(KN)	FY(KN)
495	-898.174	277.159	514	-1456.772	277.159
496	-1564.628	249.443	513	-993.570	249.443
497	-1099.519	221.727	512	-1488.444	221.727
498	-1404.960	194.011	511	-998.918	194.011
499	-905.201	166.295	510	-1300.030	166.295
500	-1205.634	138.579	509	-823.699	138.579
501	-751.465	110.864	508	-1121.052	110.864
502	-1054.254	83.148	507	-695.596	83.148
503	-772.344	55.432	506	-1105.430	55.432
504	-42.040	27.716	505	164.620	27.716

Table 7. Axial Load in Box Double shape Bridge Pylon

H SHAPE					
Left Beam Number	FX(KN)	FY (KN)	Right Beam number	FX(KN)	FY(KN)
499	-898.174	277.159	527	-1456.768	277.159
500	-1564.983	249.443	528	-1424.710	249.443
501	-1099.520	221.727	526	-1488.445	194.011
502	-1404.963	194.011	525	-1405.420	194.011
503	-905.215	166.296	524	-1300.044	166.295
504	-1205.689	138.579	523	-1205.617	138.579
505	-751.578	110.864	522	-1121.166	110.864
506	-1054.571	83.148	521	-1053.139	83.148
507	-775.202	55.432	520	-1108.196	55.432
508	-24.856	27.716	519	-150.788	27.716

Table 8. Axial Load in H shape Bridge Pylon

PORTAL SHAPE					
L Beam Number	FX(KN)	FY (KN)	R Beam number	FX(KN)	FY(KN)
499	-898.173	277.159	518	-1013.157	277.159
500	-1564.627	249.443	517	-1424.826	249.443
501	-1099.520	221.727	516	-1069660	221.727
502	-1404.963	194.011	515	-1405.420	194.011
503	-905.213	166.295	514	-905.858	166.295
504	-1205.681	138.579	513	-1205.609	138.579
505	-1121.105	110.864	512	-751.603	110.864
506	-697.312	83.148	511	-1053.106	83.148
507	-1120.056	55.432	510	-763.227	55.432
508	306.923	27.716	509	-151.661	27.716

Table 9. Axial Load in Portal shape Bridge Pylon

BOX A SHAPE					
L Beam Number	FX(KN)	FY (KN)	R Beam number	FX(KN)	FY(KN)
501	-1341.627	277.159	520	-1456.611	277.159
502	-1564.984	249.443	519	-1424.827	249.443
503	-1518.338	221.727	518	-1488.478	221.727
504	-1404.963	194.011	517	-1405.420	194.011
505	-1299.399	166.295	516	-1300.044	166.295
506	-1205.703	138.579	515	-1205.631	138.579
507	-1121.138	110.86	514	-1121.181	110.864
508	-1054.729	83.148	513	-1053.296	83.148
509	-1123.082	55.432	512	-1111.162	55.432
510	-11.201	27.716	511	-137.194	27.716

Table 7. Axial Load in Box A shape Bridge Pylon

From the above obtained results along the length of the bridge and the height of the pylon, we can get an overall analysis as:

1) The maximum displacement in the Y-direction at L/2 is experienced by the Double shape Girder, followed by the Portal shape Girder, the H-shape Girder, and the Box A shape Girder. At L/4, all four girders experience similar negative displacements in the Y-direction.
2) The shear forces at L/2 and L/4 are similar for all four girders, with the highest values at L/2 and lowest values at L/4.
3) The bending moment at L/4 are also similar for all four Girders, with negative values indicating that the girder is experiencing hogging or upward bending.
4) The maximum axial loads are experienced by the H-shape Bridge Pylon followed by the Portal shape Bridge Pylon, the Double-shape and the Box A Shape Bridge Pylon.

VI. CONCLUSIONS

The comparative analysis of the different bridge designs reveals that the Portal shape bridge has the highest shear force resistance and the lowest bending moment value, indicating that it is the strongest design.

However, the Portal shape bridge also has a slightly higher displacement value than the Box A bridge. Taking these factors into consideration, the Box A bridge appears to be the most suitable design option as it has a good balance of strength and displacement.

From the Vertical Load Distribution Analysis observation, we can conclude that the Double Shaped Girder is most flexible and experiences the highest displacement in the Y direction at L/2, while the H-shaped Girder is the stiffest and experiences the highest axial loads. However, all four girders experience similar shear forces and Displacement at L/2 and L/4, indicating that their overall structural performance is relatively similar.

Hence, The Box A bridge design may be the most suitable option based on the results of the comparative analysis. However, other factors must be considered before making a final decision on the design, as the selection of the most suitable bridge design is a complex process that involves considering several factors beyond strength and displacement. Factors such as cost, material and other design requirements must also be taken into before making the final decision.

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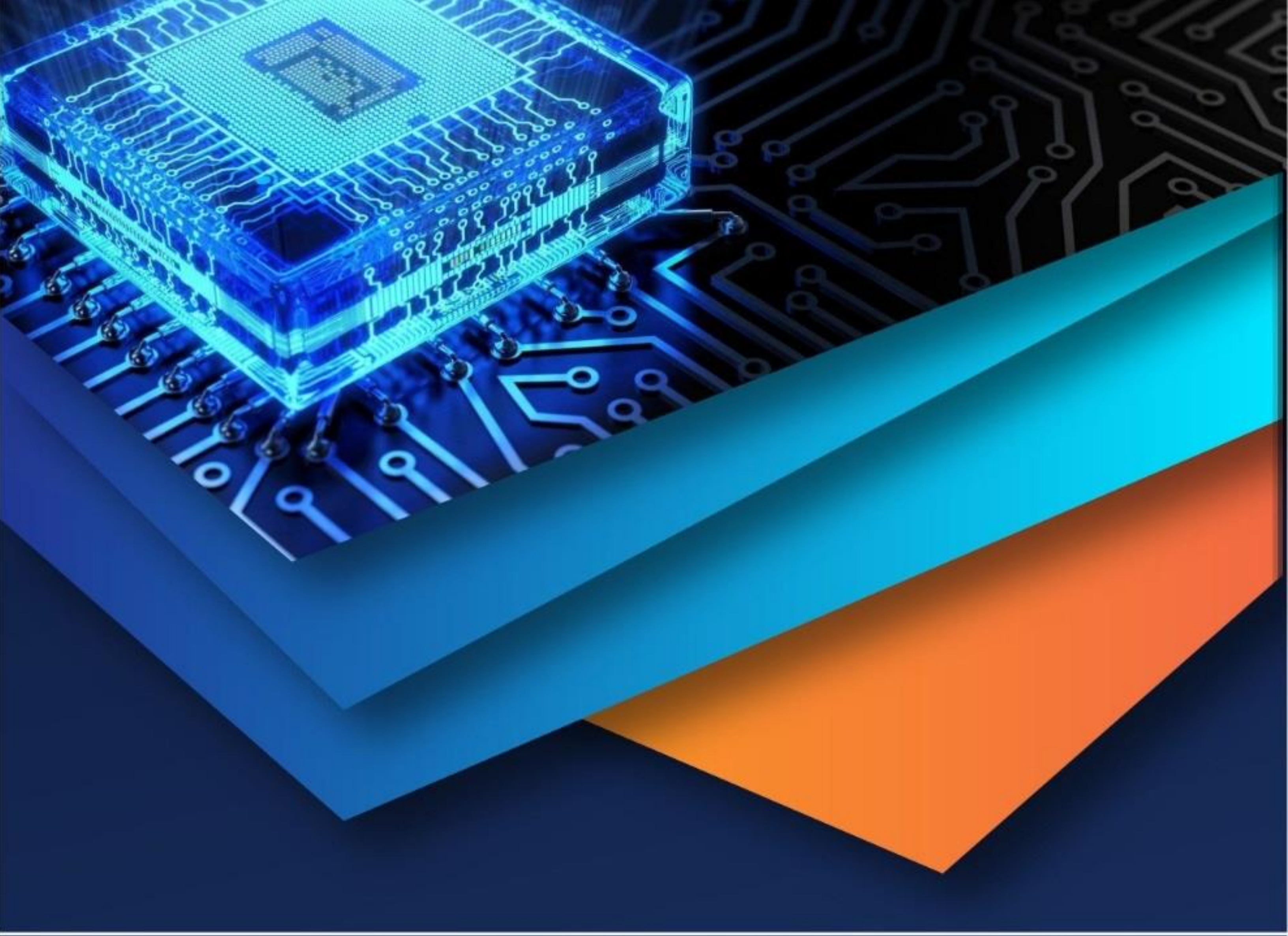

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