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Analysis and Design of Box Culvert for Durability against Varying Thickness of Cushion

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Abstract: This study presents the structural analysis of a reinforced concrete (RCC) box culvert with dimensions 1m x 2m x 1.5m, subjected to varying cushion loadings of 0.770m, 1.010m, and 1.200m, using STAAD.Pro software. The analysis focuses on both Ultimate Limit State (ULS) and Serviceability Limit State (SLS) criteria to ensure the structural integrity and durability of the culvert. For ULS, load combinations include dead load, live load, earth pressure, and cushion load, assessing the culvert's capacity to withstand maximum expected loads without failure. The study evaluates bending moments, shear forces, and ensures that the flexural and shear strengths of the culvert are within permissible limits. Results indicate that even under the highest cushion loading, the culvert design remains robust with appropriate reinforcement. For SLS, the analysis incorporates quasi-permanent load combinations to evaluate deflections and crack widths, ensuring the structure's functionality and aesthetic durability under normal service conditions. Deflections and crack widths for all cushion depths were found to be within acceptable limits, demonstrating the culvert's ability to maintain serviceability and resist long-term degradation. Overall, the analysis confirms that the RCC box culvert, when designed according to the principles of ULS and SLS, achieves a balance between safety, functionality, and durability, ensuring reliable performance over its service life.
Keywords: RCC Box Culvert, Cushion Loading, Serviceability, Durability, Ultimate Limit State (ULS), Serviceability Limit State (SLS), Load Combinations, Structural Integrity, Vehicular Loads.

I. INTRODUCTION

Box culverts are like the sturdy backbone of bridges, especially handy when roads or railways need to cross over high embankments or streams with a gentle flow. When the water flow in a drain or channel is minimal and the ground isn't too strong, a box culvert fits the bill perfectly for building a bridge. These culverts are essentially reinforced concrete boxes with square or rectangular openings, typically used for spans up to 4 meters, and usually not exceeding 3 meters in height. Design of box culverts so practical is their strength and the fact that they're built all in one go, without needing separate foundations. They just sit right on the soil, like a slab on the ground. For smaller water flows, a single-cell box culvert does the job, but when things get heavier, you bring in the multi-cell ones. While designing the box culvert: we assure the top slab can handle all sorts of weight, from vehicles driving over it to the pressure from the earth and water around it. The design process involves treating the structure like a rigid frame, using a method called moment distribution to figure out how the moments are distributed across the slab and walls.

Now, there are some details that designer's debate about, like how deep the cushion should be, what the earth pressure coefficient should be, or how wide the live load dispersion should be. But getting these details right is crucial for making sure the bridge is safe and sound. So, we take our time studying how things like the cushion, earth pressure, and load dispersion angle affect the design, making sure we've got all our bases covered for building a solid structure that people can rely on.

II. OBJECTIVES

1) *Evaluate Structural Integrity:* To assess the structural integrity of an RCC box culvert under varying cushion loadings, ensuring it meets safety standards.
2) *Determine Ultimate Limit State (ULS) Capacity:* To analyze the culvert's ability to withstand maximum expected loads without failure, focusing on bending moments and shear forces.
3) *Assess Serviceability Limit State (SLS) Performance:* To evaluate deflections and crack widths, ensuring the culvert's functionality and durability under normal service conditions.
4) *Validate Design Compliance:* To confirm that the culvert design adheres to relevant engineering standards and codes, ensuring a balance between safety and serviceability.
5) Provide Design Recommendations: To offer practical recommendations for the design and construction of RCC box culverts, based on the analysis of structural performance and durability.

III. METHODOLOGY

All tasks will be executed manually, with reliance on Staad pro software. Subsequently, various loading scenarios, including Class 70 (R) will be systematically addressed with and without cushion cases. The analytical process will guide the study towards the result and conclusion section.

The methodology entails the following approach:

1) *Case Selection:* Different loading types, including Class 70 (R), will be considered for analysis.
2) *Analysis:* The modeling and analysis of the bridge will be performed using manual calculations. The bridge under investigation is a box culvert bridge.
3) *Design Loads:* Design loads will adhere to the specifications outlined in IRC 6.
4) *Comparison:* Utilizing Staad-pro software, the box culvert bridge will be designed, and the results obtained will be manually compared.

Methodology involves manual execution of all tasks, including analysis and comparison, without software assistance. The process will ensure accuracy and reliability in the assessment of the box culvert bridge's performance under different loading conditions.

A. Design Steps

1) Detailed Case Selection

a) *Identify Loading Scenarios:* Select and document various loading scenarios, including Class 70 (R) with and without cushion cases.
b) *Define Parameters:* Clearly define the parameters and variables for each loading scenario to ensure consistent analysis.

2) Manual Analysis

Perform Manual Calculations: Conduct manual calculations for the box culvert bridge using the defined loading scenarios. This includes:

a) Calculating design loads as per IRC 6 specifications.
b) Determining structural responses, such as moments, shears, and deflections.

3) Software Analysis

a) *Model in STAAD Pro:* Create a detailed model of the box culvert bridge in STAAD Pro, incorporating all relevant parameters and loading scenarios.
b) *Run Simulations:* Perform simulations to analyze the structural response under various conditions.
c) *Extract Results:* Gather and organize the results from the STAAD Pro simulations for comparison.

4) Comparison of Results

a) *Cross-Verification:* Compare the manual calculation results with the STAAD Pro analysis results.
b) *Identify Discrepancies:* Document and analyze any discrepancies between the manual and software results.
c) *Validation:* Validate the accuracy of the STAAD Pro model based on the manual calculations.

5) Documentation

a) *Prepare Reports:* Compile detailed reports documenting the methodology, analysis, and findings.
b) *Include Visuals:* Use diagrams, charts, and tables to illustrate the structural responses and comparisons.
c) *Summarize Findings:* Provide a comprehensive summary of the findings, highlighting key insights and conclusions.

6) Review and Revision

a) *Peer Review:* Have the methodology, analysis, and findings reviewed by peers or experts in the field to ensure accuracy and validity.
b) *Revise as Needed:* Make any necessary revisions based on feedback received during the review process.

7) *Conclusion and Recommendations*
c) *Conclude Study:* Write a conclusion summarizing the study's findings and their implications for the design and performance of box culvert bridges.
d) *Provide Recommendations:* Offer recommendations for future studies or practical applications based on the study's results.

8) *Presentation*
a) *Prepare Presentation:* Develop a presentation summarizing the study's methodology, analysis, findings, and conclusions.
b) *Present Findings:* Present the findings to relevant stakeholders, such as engineers, project managers, or academic peers.

By following these next steps, the study will progress in a structured and organized manner, ensuring thorough analysis and accurate conclusions regarding the performance of the box culvert bridge under different loading conditions.

Table 1 Design Calculations of Box Culvert of Size 1 x 2 x 1.5

Parameter	Value
Number of Cells	1 x 1 No’s
Skew Angle	0 deg.
Effective Span C/C	2.225 m
Clear Span	
Effective Span C/C Clear Span	1 x 2.225 m
Clear Span (Skew)	1 x 2.00 m
Clear Height (Max)	1 x 1.500 m
Width of Box	
Width of Box	10.00 m
Width of Box (Skew)	10.00 m
Wearing coat thickness	0.065 m
Max Height of fill over the top slab	0.770 m
Min Height of fill over the top slab	0.065 m
Thickness of Top slab	0.200 m
Thickness of Bottom slab	0.225 m
Thickness of External Vertical Wall	0.225 m
Size of Haunch	0.150 m x 0.150 m
Width of Parapet Wall/ Crash Barrier	0.500 m
Width of Safety kerb	0.00 m
Distance of edge of parapet wall/Crash Barrier from edge of box	0.50 m
Height of surcharge	1.20 m
Safe Bearing Capacity of the soil	12.0 t/m²
Permissible Settlement	10 mm = 0.01 m

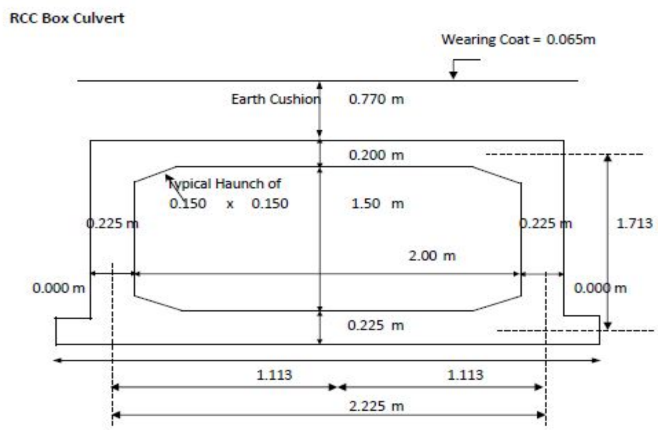

Figure No. 1 Box Culvert with Cushion thickness 0.777m

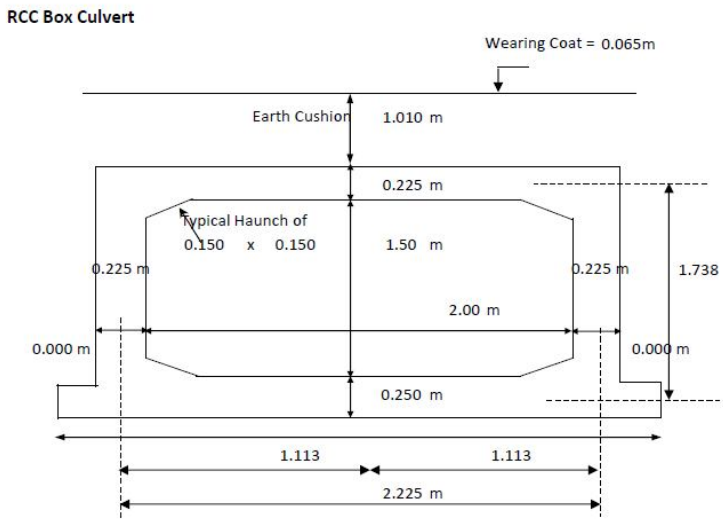

Figure No. 2 Box Culvert with Cushion thickness 1.010m

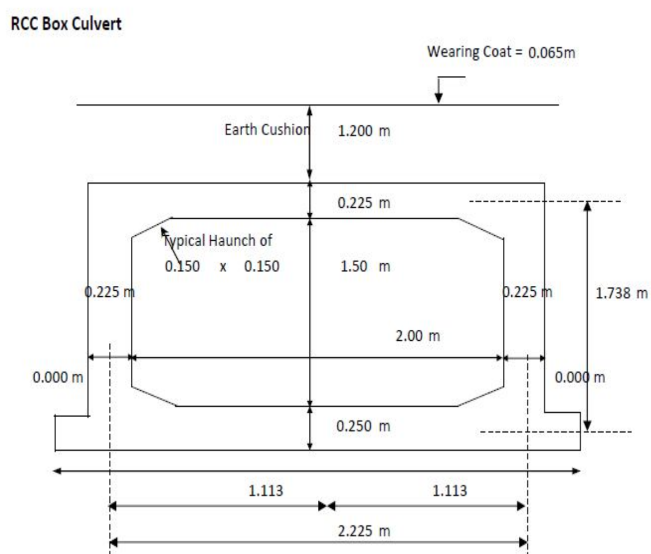

Figure No. 3 Box Culvert with Cushion thickness 1.200m

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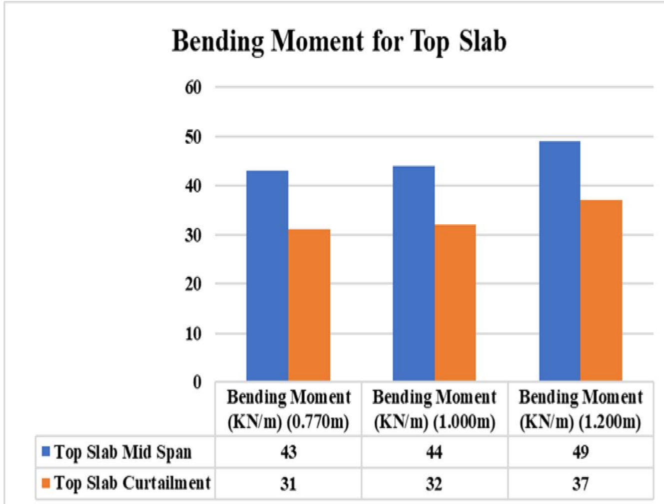
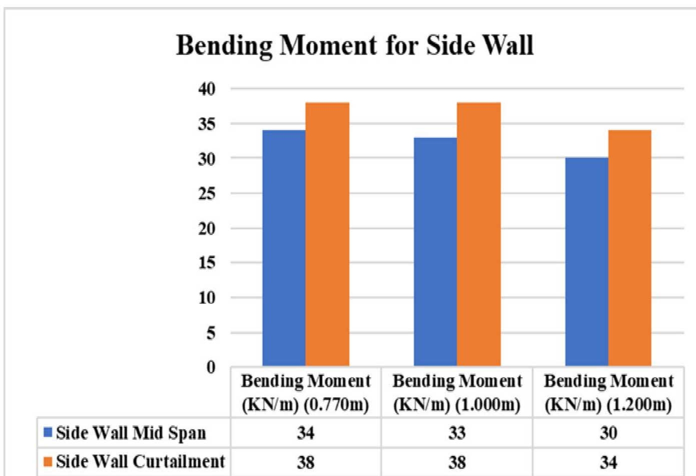
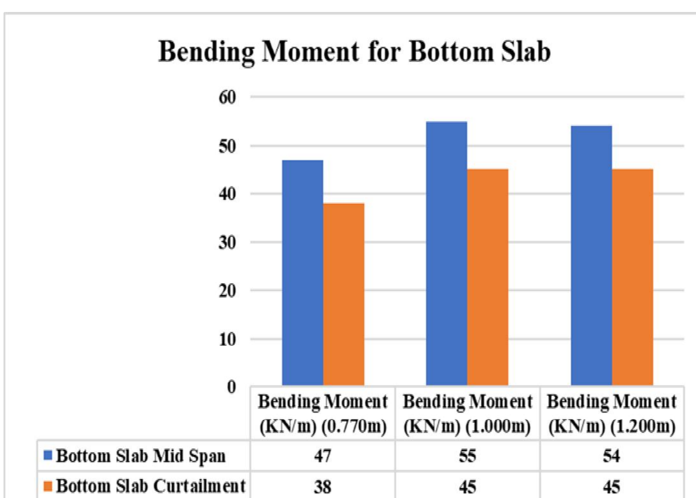
IV.RESULT & DISCUSSION



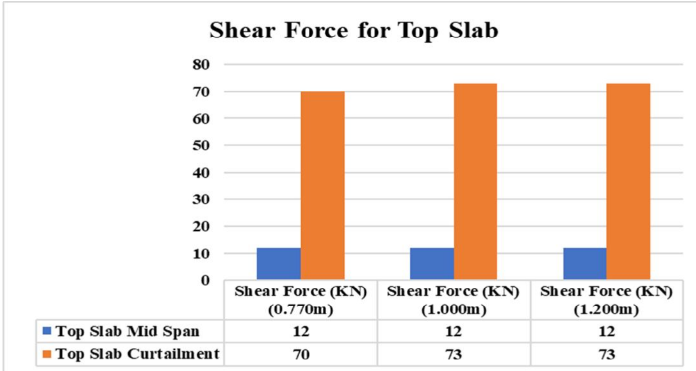
Graph No.1 Bending Moment for Top Slab



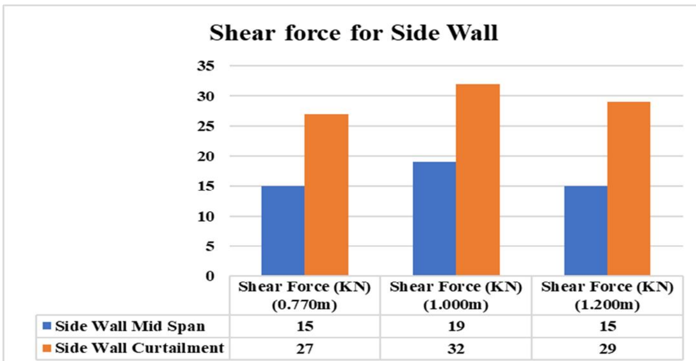
Graph No.2 Bending Moment for side wall



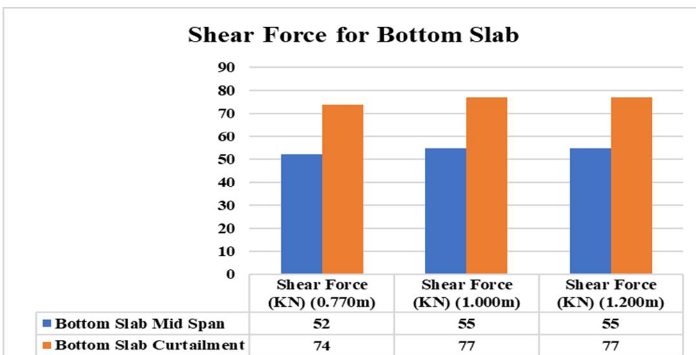
Graph No.3 Bending Moment for Bottom Slab



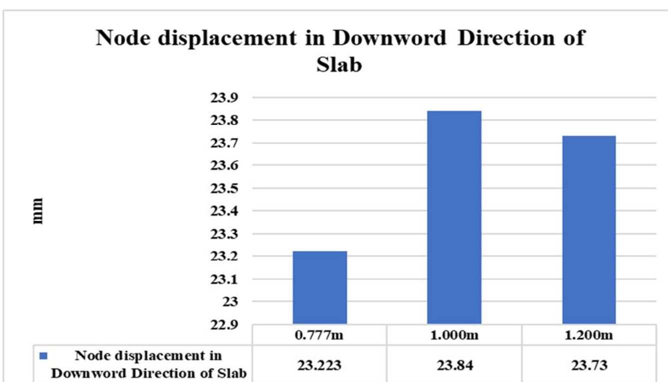
Graph No. 4 Shear force for Top Slab



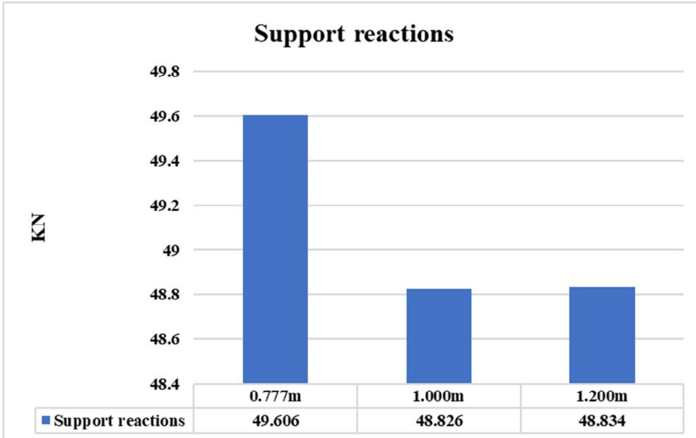
Graph No. 5 Shear force for Side Wall



Graph No. 6 Shear force for Bottom Slab



Graph 7 Node Displacement in Downwards Directions of top slab



Graph 8 Support reactions

V. CONCLUSION

The analysis of the RCC box culvert with varying cushion depths (0.770m, 1.000m, and 1.200m) using STAAD Pro has provided valuable insights into the structural behavior under different loading conditions. The comparative evaluation of bending moments and shear forces at critical sections of the top slab, side walls, and bottom slab has revealed the following key findings.

A. Top Slab

Bending Moment: The bending moment at the mid-span of the top slab increases with an increase in cushion depth, from 43 KN/m (0.770m) to 49 KN/m (1.200m). Similarly, the bending moment at the curtailment section increases from 31 KN/m (0.770m) to 37 KN/m (1.200m).

Shear Force: The shear force at the mid-span remains constant at 12 KN for all cushion depths, while at the curtailment section, it increases slightly from 70 KN (0.770m) to 73 KN (1.200m).

B. Side Wall

Bending Moment: The bending moment at the mid-span of the side wall decreases with an increase in cushion depth, from 34 KN/m (0.770m) to 30 KN/m (1.200m). At the curtailment section, the bending moment remains relatively constant, around 38 KN/m for 0.770m and 1.000m, but decreases to 34 KN/m for 1.200m.

Shear Force: The shear force at the mid-span increases from 15 KN (0.770m) to 19 KN (1.000m) but decreases back to 15 KN (1.200m). At the curtailment section, the shear force increases from 27 KN (0.770m) to 32 KN (1.000m), then slightly decreases to 29 KN (1.200m).

C. Bottom Slab

Bending Moment: The bending moment at the mid-span of the bottom slab increases significantly from 47 KN/m (0.770m) to 55 KN/m (1.000m), then slightly decreases to 54 KN/m (1.200m). At the curtailment section, it increases from 38 KN/m (0.770m) to 45 KN/m for both 1.000m and 1.200m cushion depths.

Shear Force: The shear force at the mid-span increases slightly from 52 KN (0.770m) to 55 KN for both 1.000m and 1.200m cushion depths. At the curtailment section, it increases from 74 KN (0.770m) to 77 KN for both 1.000m and 1.200m cushion depths.

D. Key Observations

The top slab experiences increased bending moments and shear forces with increased cushion depth, indicating higher stresses and potential for increased reinforcement requirements.

The side wall shows a mixed response, with bending moments generally decreasing at the mid-span but remaining stable or decreasing at the curtailment section. Shear forces show a slight increase or stability, suggesting moderate impact due to cushion depth variations.

The bottom slab shows a significant increase in bending moments at the mid-span with increased cushion depth, while shear forces show slight increases or stability.

E. Durability Implications

Increased Stresses: Higher cushion depths generally lead to increased bending moments and shear forces in the structural elements of the culvert. This results in higher internal stresses that can accelerate wear and tear, cracking, and other forms of structural degradation over time.

Reinforcement Needs: To maintain durability with increased cushion depths, the design must incorporate sufficient reinforcement to counteract the higher stresses. This includes both flexural and shear reinforcement to prevent cracking and structural failure.

Maintenance and Inspection: Structures with higher cushion depths may require more frequent maintenance and inspections to monitor for signs of stress-induced damage and to ensure that any emerging issues are addressed promptly to extend the culvert's lifespan.

while thicker cushion layers provide benefits in terms of load distribution and reduced support reactions, the associated increase in lateral forces necessitates a robust design to ensure long-term durability. Balancing these factors is key to enhancing the overall performance and lifespan of the culvert. Regular maintenance and structural monitoring will further support its durability.

The cushion depth has a direct impact on the durability of the RCC box culvert. Higher cushion depths increase the bending moments and shear forces, leading to higher stresses in the structural elements. To ensure long-term durability, it is essential to incorporate adequate reinforcement and design considerations that address the increased loads. Regular maintenance and inspections are also crucial to monitor the structural integrity and address any issues that arise due to the higher stresses associated with deeper cushion depths.

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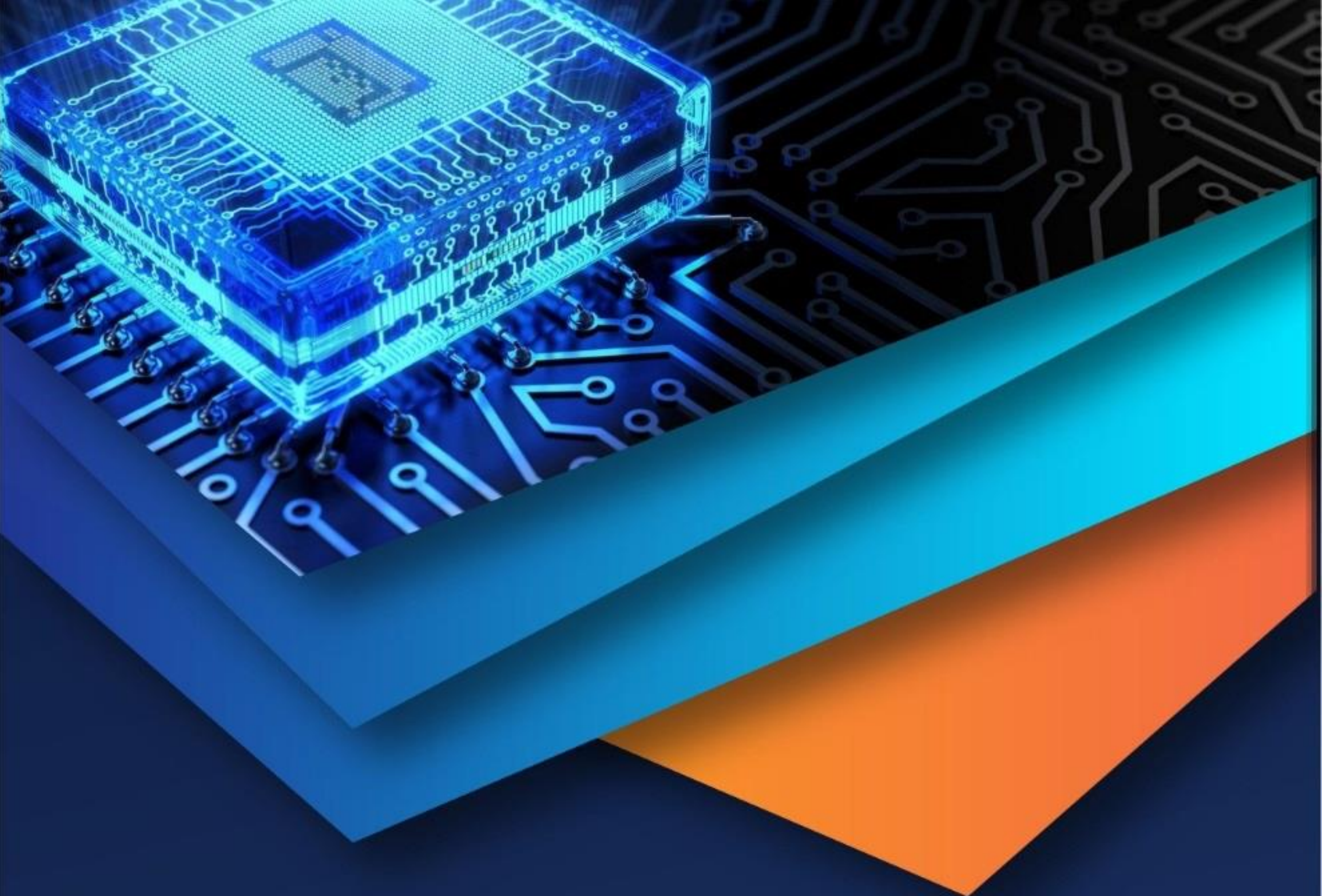

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