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Comparative Analysis between Reinforced Concrete Structures and Metal Structures in Small-Scale Buildings

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Abstract: This article presents a comparative analysis between two small-scale structures, one in reinforced concrete and the other in metal, in a garage with 5-meter beams and 2.5-meter columns. The goal was to evaluate the structural behavior of both under the effects of self-weight and lateral wind load. Structures with fixed and simple supports were modeled, and diagrams of normal, shear, and bending moments, as well as horizontal and vertical deformations, were calculated. The structural analysis software Ftool was used to ensure accuracy and precision. The reinforced concrete beam exhibited significantly higher internal forces and deformations due to its greater self-weight and lower stiffness, despite a higher moment of inertia. In contrast, the IPE 240 metal beam, with lower weight and an elasticity modulus eight times higher than that of concrete, showed greater stiffness and lower deformations, standing out for its structural efficiency. Thus, it is concluded that, for the same span and support conditions, metal beams are structurally more advantageous in terms of performance and load response, while concrete beams require more robust design to ensure safety and functionality.
Keywords: Small-scale structures, Reinforced concrete, IPE240 metal beam

I. INTRODUCTION

Reinforced concrete and steel structures are widely used in civil construction, especially in small-scale buildings such as single-family homes, small commercial buildings, warehouses, or garages. Reinforced concrete is a combination of concrete and steel, where concrete is strong in compression and steel in tension, forming a robust and durable structural material. Steel structures, generally made from steel profiles, are known for their lightness, speed of assembly, and flexibility in architectural design. Each system has its own advantages and disadvantages. Reinforced concrete, although more economical and resistant to corrosion and fire, has a higher self-weight, requires more execution time, and is less flexible for future modifications. On the other hand, steel structures are lighter, allow for fast and clean construction, and facilitate modifications, but they can be more expensive and require specific care regarding corrosion and thermal and acoustic insulation.

In this context, we decided to make a comparative analysis between two identical small-scale structures, one made of reinforced concrete and the other of steel. We chose to analyze them with the same dimensions, selecting a garage as it is a simple and small building with 5-meter beams and 2.5-meter-high columns.

These structures will be supported on four supports: two fixed, which completely prevent movements and rotations, and two simple, which allow rotation but prevent vertical movement. Given that the garage structure has the same dimensions on all sides, we can analyze it as four identical frames with the same structural elements. We will analyze one of these frames for each structure, considering the beam's self-weight and the lateral wind action. This results in a frame with two 2.5-meter-high columns and a 5-meter beam. One column is fixed, and the other is on a roller support. Considering the beam's self-weight as a distributed load and the lateral wind as a point load applied to one of the columns, the structure becomes statically determinate, allowing easier calculation.

We will calculate the reactions at the two supports, the shear force diagrams (forces acting perpendicular to the beam axis), the normal force diagrams (tension or compression along the axis), and the bending moment diagrams (causing beam flexion). We will also assess deformations due to the distributed load (beam’s self-weight) and the point load (wind action), obtaining vertical and horizontal displacements. From this, we will thoroughly analyze both structures.

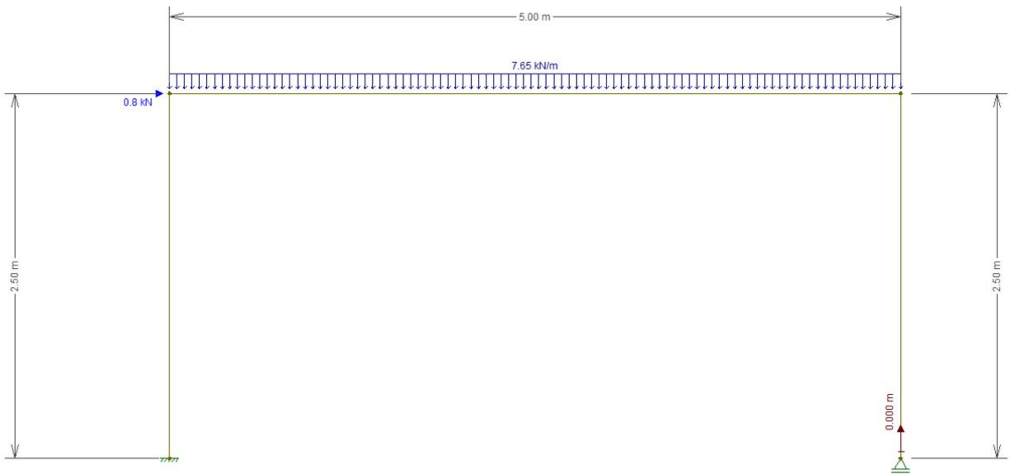

Fig.1: Reinforced concrete structure

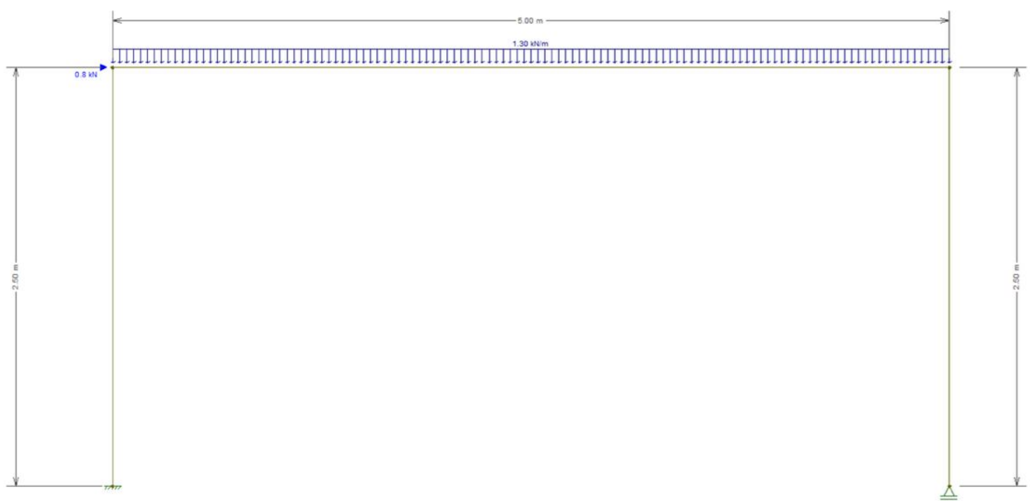

Fig.2: Metal structure

II. MATERIALS AND METHODS

A. Materials

In the reinforced concrete structure, we considered our beam to have a width of 25 centimeters, a height of 25 centimeters, and a length of 5 meters. The cross-sectional area is therefore 0.0625 square meters. Regarding the properties of this material, we worked with a Young's modulus (or modulus of elasticity) of 25,000 megapascals, which indicates the material's stiffness, a Poisson's ratio of 0.20, and a thermal expansion coefficient of 0.000010 per degree Celsius. Speaking of the moment of inertia of this beam, which is very important for understanding the structural behavior, it has a value of 0.000326 square meters. The density of our reinforced concrete beam is 2500 kilograms per cubic meter. After detailed calculations, the total weight is approximately 781.25 kilograms, which corresponds to a self-weight of 7.66 kilonewtons.

In this structure, we also considered wind action. We assumed an air density of 1.25 kilograms per cubic meter, since it is a very exposed area with extreme conditions. A drag coefficient of 1.6 and an average wind speed of 36 meters per second were adopted, acting on our column. The resulting horizontal force on the column is 0.81 kilonewtons.

Now speaking about our steel structure, to match as closely as possible the dimensions of the reinforced concrete beam, we chose an IPE 240 steel beam, also known as a standard "I" profile.

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This beam has a web width of 0.12 meters, a web and flange thickness of 0.01 meters, and a total length of 5 meters. The cross-sectional area is 0.0037 square meters. Regarding its Young's modulus, it is 205,000 megapascals, significantly higher than that of reinforced concrete. This beam has a Poisson's ratio of 0.30 and a thermal expansion coefficient of 0.000012 per degree Celsius. The moment of inertia of this beam is considerably lower than that of the reinforced concrete beam, with a value of 0.000037 square meters. For this beam, we considered a linear mass of 26.2 kilograms per meter, which gives a total mass of 131 kilograms. Thus, the self-weight of this beam is 1.30 kilonewtons.

In this structure, we also considered wind action using the same parameters as for the reinforced concrete structure. Therefore, considering lateral wind as a horizontal force acting on our column, the resulting force is again 0.81 kilonewtons.

B. Methodology

To analyze the structures mentioned above with greater detail, technical rigor, and efficiency, we used shear force diagrams, axial force diagrams, and bending moment diagrams. We also analyzed the deformed shapes — both horizontal and vertical displacements. All this was confirmed using a structural analysis software — **Ftool**.

III. RESULTS

A. Normal Stress Diagrams

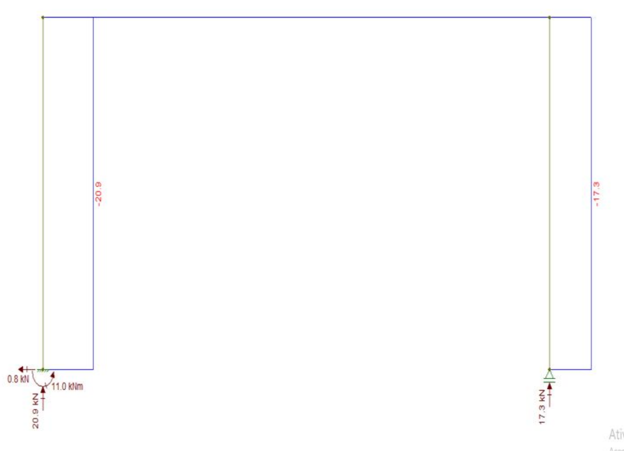

Fig.3: Reinforced concrete structure

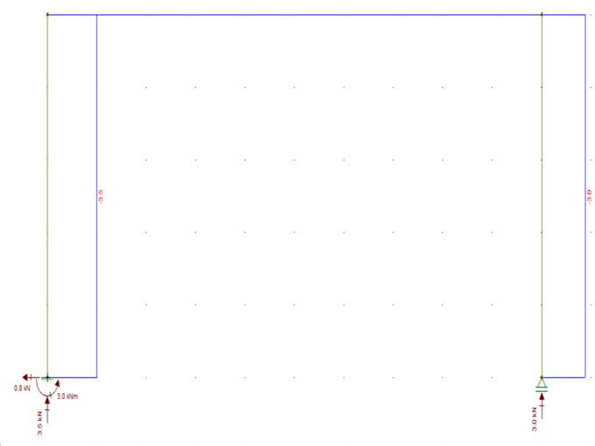

Fig.4: Metal structure

B. Transverse force diagrams

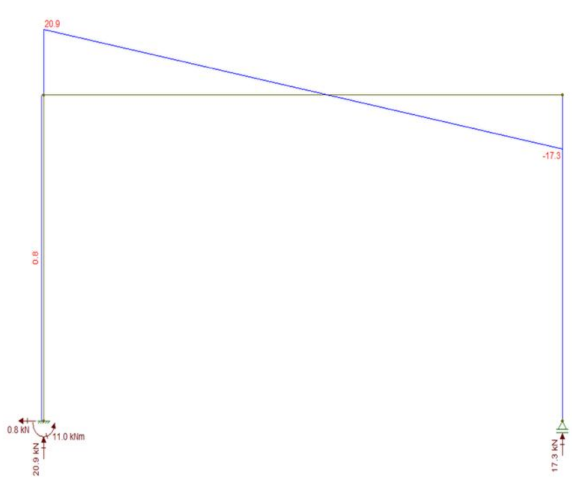

Fig.5: Reinforced concrete structure

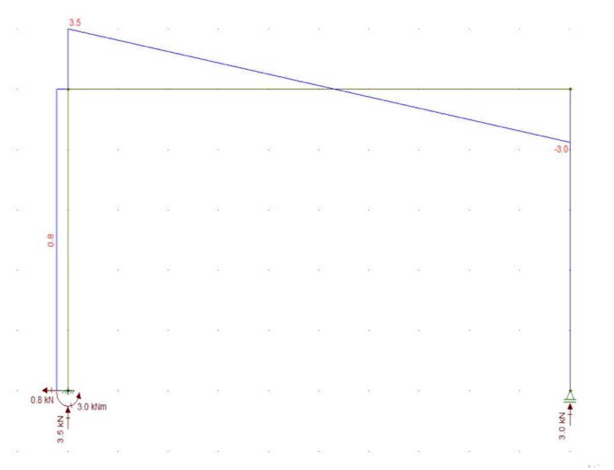

Fig.6: Metal structure

C. Bending Moment Diagram

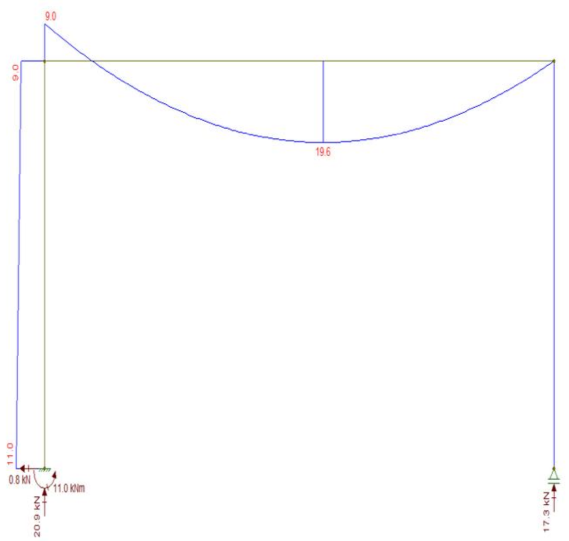

Fig.7: Reinforced concrete structure

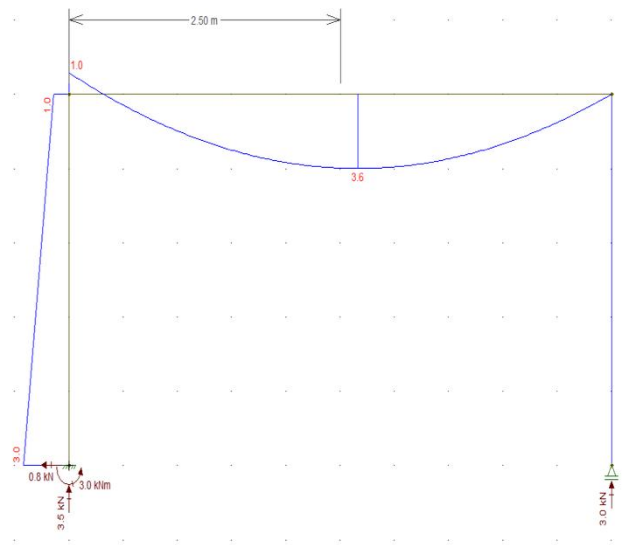

Fig.8: Metal structure

D. Horizontal Deformed Structure

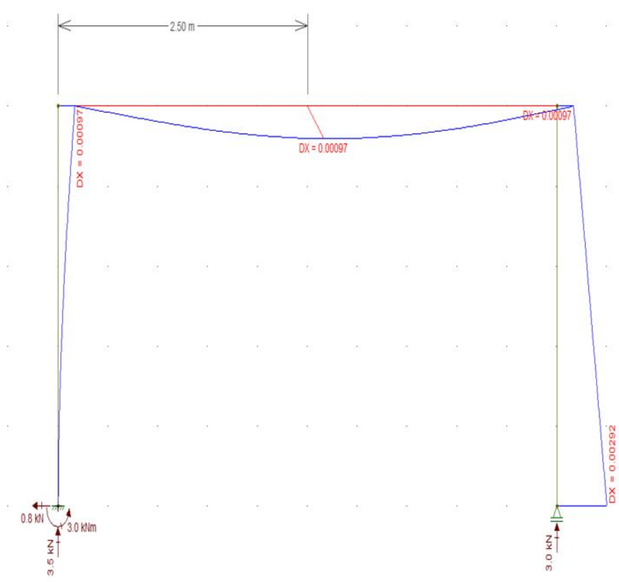

Fig.9: Reinforced concrete structure

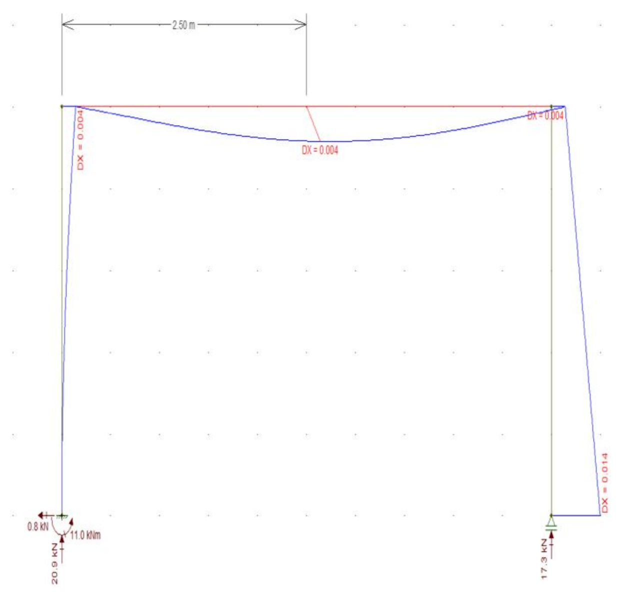

Fig.10: Metal structure

E. Vertical Deformed Structure

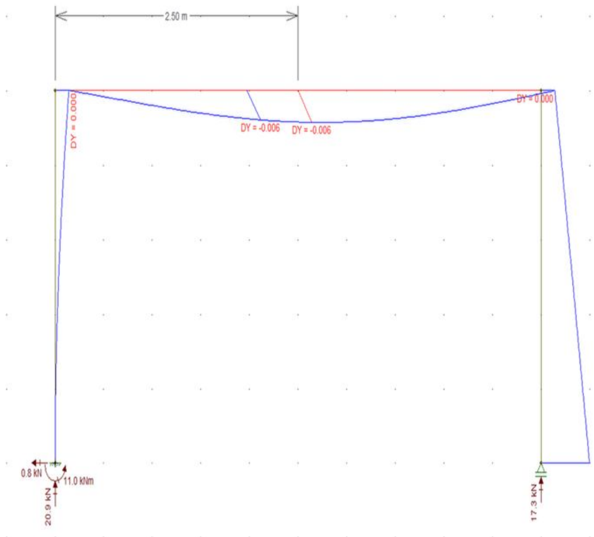

Fig.11: Reinforced concrete structure

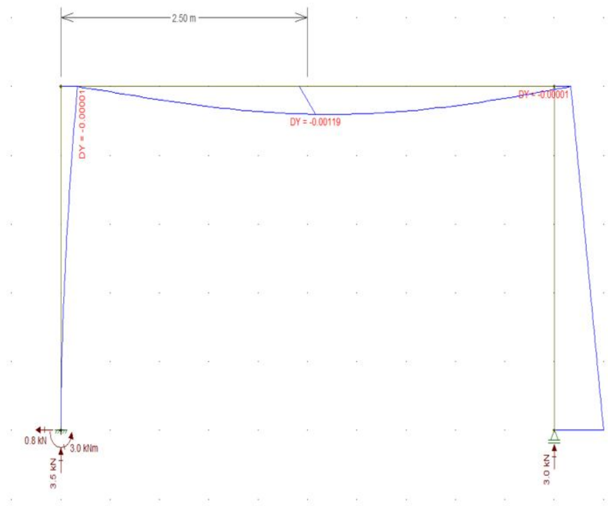

Fig.12: Metal structure

IV. DISCUSSION

With the results shown above, we are able to compare one structure to the other.

Starting with the analysis of the diagrams, we observed that in the axial force diagram, the reinforced concrete structure presents higher modulus values — that is, higher axial forces — than the steel structure. This can be explained by the structural behavior as a frame system, where part of the vertical load (self-weight) is redistributed through the vertical members (columns). Reinforced concrete, having lower axial stiffness compared to steel, tends to absorb more axial load in the columns due to its higher mass (greater self-weight), which contributes to higher axial forces. In contrast, the IPE profile, being lighter, generates less axial load in the members, resulting in lower axial force values.

Regarding the shear force diagram, the reinforced concrete beam shows significantly higher values than the steel beam, due to its higher self-weight (7.65 kN/m versus 1.30 kN/m for the IPE 240). Since shear force is directly proportional to the applied load, the concrete beam experiences greater shear, especially near the supports, demanding higher shear resistance and adequate transverse reinforcement.

The bending moment is also greater in the reinforced concrete beam, mainly due to its higher self-weight (7.65 kN/m) compared to the IPE 240 steel beam (1.30 kN/m). This weight acts as a distributed load along the beam, directly contributing to increased internal forces. As bending moment depends on the intensity and distribution of loads, a heavier structure generates higher moments. Thus, even without additional external loads, the weight of the material itself significantly influences the structural behavior and required design.

Finally, regarding deflections, the horizontal deflection values for the reinforced concrete structure at mid-span and at the end of the beam are 0.004 meters, while in the steel structure they are 0.00097 meters. As for vertical deflections, the concrete beam shows 0.006 meters at mid-span and no deflection at the support. The steel structure showed 0.00119 meters at mid-span and 0.00001 meters at the support. These higher values in the concrete structure are mainly due to the greater self-weight of the beam, which directly impacts the previously mentioned diagrams.

Additionally, the rigidity of the structures, expressed by the product EI (Young's modulus × moment of inertia), plays a crucial role. The Young's modulus for steel was considered to be 205,000 megapascals — about eight times greater than the 25,000 megapascals assumed for concrete. This factor, when combined with the moment of inertia, results in a significantly higher E × I product for the steel beam.

This E × I product is essential because it determines the flexural stiffness of the beam. Greater stiffness implies smaller deflections under the same loading. Therefore, despite the steel beam being subjected to a much lower load, its high stiffness explains the significantly reduced deflections, such as the horizontal deflection of 0.00097 m compared to 0.004 m in the concrete beam.

As a result, both horizontal and vertical displacements confirm that, for the same span and support conditions, the concrete structure shows much greater deformations due to its higher self-weight and lower stiffness.

Thus, we can conclude that, when subjected only to self-weight, steel beams are structurally more efficient in terms of deformation and internal force response, whereas reinforced concrete beams require greater sizing and reinforcement to ensure similar structural performance.

V. CONCLUSIONS

The comparative analysis between reinforced concrete beams and IPE 240 steel beams, subjected only to self-weight and lateral wind load, revealed significant differences in the structural behavior of these two widely used systems in civil engineering.

It was shown that the higher self-weight of reinforced concrete leads to substantially greater axial forces, shear forces, and bending moments compared to the steel beam, directly affecting the design requirements and the need for reinforcement. Meanwhile, the beam's rigidity — determined by the product of Young's modulus (E) and moment of inertia (I) — proves to be a decisive factor in bending response and deformation. Even though the moment of inertia of the steel beam is lower than that of the concrete beam, the high Young's modulus of steel results in a much greater $E \times I$, offering higher resistance to deformation, as confirmed by the lower horizontal and vertical displacements observed.

This study reinforces the technical-scientific understanding of the structural efficiency of steel beams in self-load scenarios, showing that they provide lighter solutions, with lower deformations and better structural performance for the same geometry — potentially contributing to more optimized and cost-effective designs.

From a technological standpoint, the use of computational tools like Ftool allowed for a rigorous and detailed analysis, facilitating the comparison and validation of theoretical concepts. This work contributes to a better practical and theoretical understanding of materials and structures.

In summary, steel beams stand out as an efficient structural solution in terms of stiffness and deformation, while reinforced concrete beams, due to their greater weight and lower stiffness, require additional attention in design to ensure safety and adequate performance.

VI. ACKNOWLEDGEMENTS

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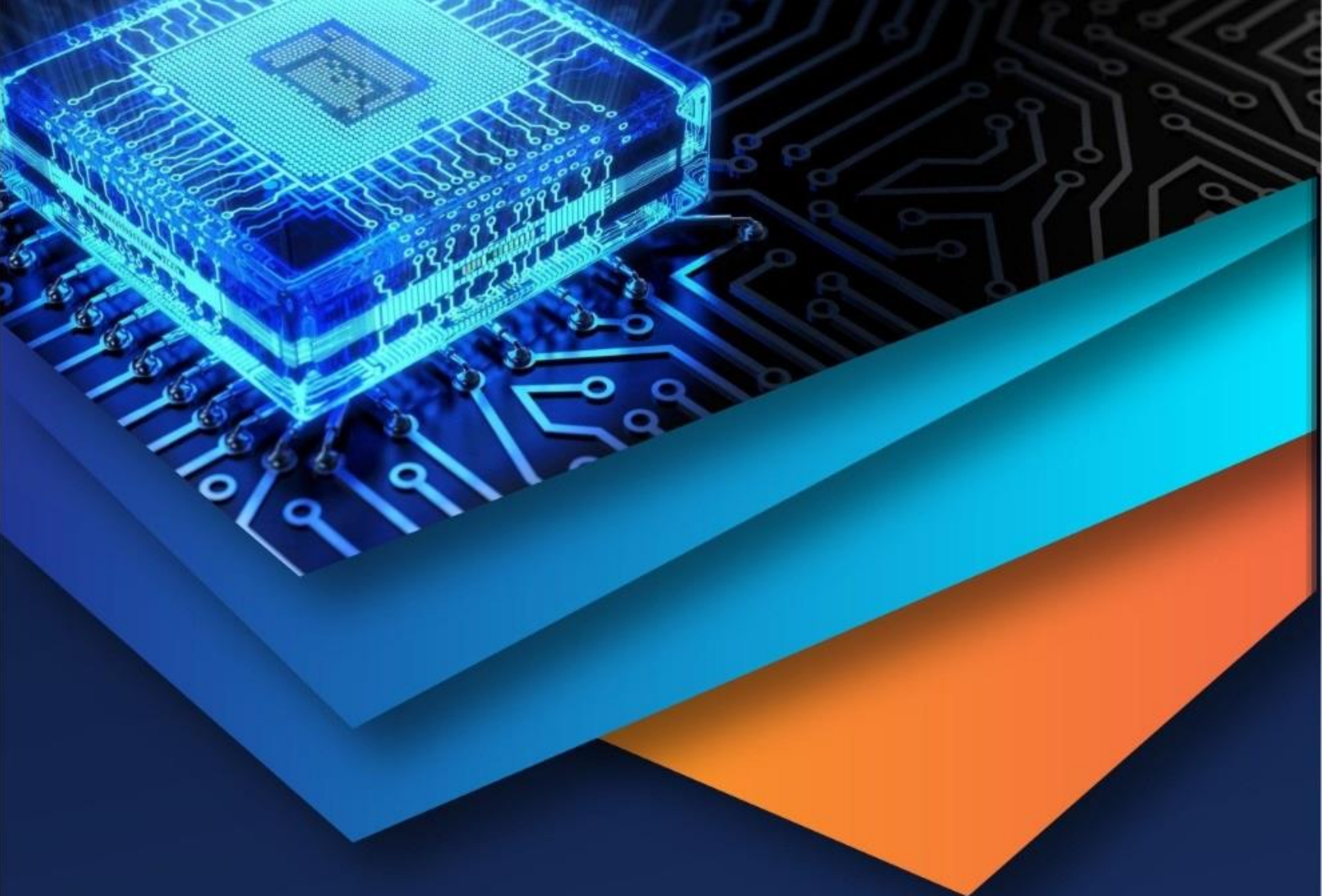

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