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Design and Analysis of Truss Systems for a Steel Shed with Wind Loading - A Case Study

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Abstract: This paper insights into a detailed case study of the structural design and static analysis of a Pratt truss system for a single-bay steel industrial shed. It looks at different load combinations such as dead load, live load, and wind load following IS: 875 standards.
The team modeled a 12-meter span shed with a 4:12 roof pitch and checked it against three different wind exposure categories. To find the member forces, used both the method of joints and the method of sections, focusing on the critical load combination: 1.2 DL + 1.6 LL + 0.8 WL.
The parametric study shows wind uplift plays the biggest role in sizing upper chord members, while the internal pressure coefficient matters most for web members that reverse forces. Designed the selected members to IS: 800-2007 standards using plastic section classification.
The study shows Pratt trusses outperform Howe and Fink trusses when wind uplift dominates, coming in at 10-14% less weight compared to configurations optimized just for gravity loads.
Keywords: Pratt truss, wind loading, Method of Joints, steel shed, wind uplift and member force reversal.

I. INTRODUCTION

Industrial steel sheds are some of the most common low-rise buildings you’ll find around the world, mainly used for storage in agriculture, workshops, and warehouses. Because these sheds are lightweight and have an open-bay design, they’re especially exposed to wind forces, which means the roofs can lift and the walls can get hit hard from the side.

One big reason steel structures like these fail in low-rise buildings is because the members aren’t sized right, especially when it comes to wind loads. For the roof structure, most of these sheds use trusses they’re more economical than beams since they distribute loads across the roof into axial forces in the truss members.

The shape of the truss—like Pratt, Howe, Fink, or Scissor—plays a big role in how compression and tension get distributed, especially when the wind hits unevenly. In this case study, we’re looking at an industrial shed with a 12 m span, a 6 m bay, and an eave height of 4 m, located in Wind Zone III (Nagpur, India). The study walks through the complete truss analysis and design process.

The goals are: (i) to figure out the design loads according to IS 875 Parts 1 and 2; (ii) to analyze a Pratt truss for the most critical load combinations using the classical equilibrium method; (iii) to design the most critical members as per IS 800-2007; and (iv) to see how the truss performs under three different wind attack angles.

II. STRUCTURE DESCRIPTION AND GEOMETRY

The shed has a total plan of 12 m × 30 m, with trusses spaced at 6 m centre-to-centre (five frames total). Roof slope is 4:12 (18.43°). The truss is a symmetric, eight-panel Pratt configuration with a 3 m panel width. Overall geometry is summarised below. Plan view of a symmetric Pratt truss showing top chord (rafter), bottom chord, vertical web members, and diagonal web members. Nodes are labeled A through I on bottom chord and A' through I' on top chord. ← 12 m span (8 panels × 1.5 m = 12 m) → 2 m rise A B C D E F G H I A' B' C' D' E' F' G' H' I' Top / bottom chord (compression / tension) Vertical web (compression) Diagonal web (tension) Pin-jointed node

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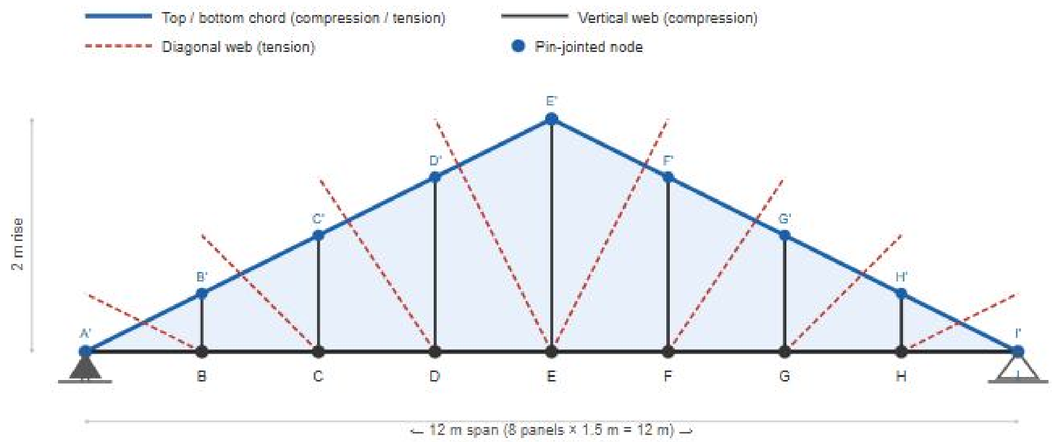

Fig. 1 — Eight-panel symmetric Pratt truss: span = 12 m, rise = 2 m (θ = 18.43°). Nodes A and I are pinned and roller supports respectively. Solid lines = top/bottom chords and vertical webs; dashed red = tension diagonal webs.

Table 1 Key geometric parameters of the truss

Parameter	Value	Parameter	Value
Span (L)	12.0 m	Panel width (d)	1.5 m
Rise (h)	2.0 m	No. of panels	8
Slope (θ)	18.43°	Truss spacing	6.0 m
Top chord length	6.33 m (per side)	Eave height	4.0 m

III. DESIGN LOADS

A. *Dead Load (DL)*

Dead loads include the self-weight of roofing, purlins, and truss self-weight. For a corrugated GI sheet roofing system with Z-purlins, the unit roof dead load is taken as 0.20 kN/m² (IS: 875 Part 1). Truss self-weight is estimated as 0.10 kN/m². Total dead load intensity on plan = 0.30 kN/m²**.**

Point load at each internal top chord node (tributary area = 1.5 m × 6 m = 9.0 m²):

$\boldsymbol{P_{DL} = 0.30 \times 9.0 =} 2.7\ Kn$

B. *Live Load (LL)*

Per IS:875 Part 2, for a roof slope of 18.43° the basic imposed load is reduced from the base 0.75 kN/m². Applying the slope reduction factor:

$$w_{LL} = 0.75 - 0.02 \times (18.43 - 10) / 1° = 0.75 - 0.169 \approx \mathbf{0.58\ kN/m^2}$$

$$P_{LL} = 0.58 \times 9.0 = \mathbf{5.22\ kN}$$

C. *Wind Load (WL)*

Wind loading is the most critical variable for a shed roof. Calculations follow IS:875 Part 3 (2015 revision).

Basic wind speed: V_b = 44 m/s (Nagpur, Wind Zone III)

Design wind speed:

$V_z = V_b \times k_1 \times k_2 \times k_3 = 44 \times 1.07 \times 0.98 \times 1.0 = 46.1\ m/s$

Design wind pressure:

$p_d = 0.6 \times V_z^2 / 1000 = 0.6 \times 46.1^2 / 1000 = \mathbf{1.276\ kN/m^2}$

External pressure coefficients (C_{pe}) are obtained from IS: 875 Part 3 Table 6 for a duo-pitch roof (θ = 18.43°) at wind normal to ridge (0°) and wind parallel to ridge (90°).

Table 2. External pressure coefficients Cpe for duo-pitch roof (θ = 18.43°)

Wind Direction	Windward Slope	Leeward Slope	C_{pi} (worst)
0° (normal to ridge)	−0.32	−0.50	±0.20
90° (parallel to ridge)	−0.80	−0.60	±0.20

Net pressure coefficient: $C_p = C_{pe} - C_{pi}$. The critical suction case on the windward slope at 90° wind gives:

$$C_{p,net} = -0.80 - (+0.20) = \mathbf{-1.00} \text{ (net uplift)}$$

$$w_{WL,uplift} = C_{p,net} \times p_d = -1.00 \times 1.276 = \mathbf{-1.276\ kN/m^2}$$

$$P_{WL} = -1.276 \times 9.0 = \mathbf{-11.48\ kN} \text{ (uplift at each node)}$$

Diagram showing wind pressure arrows on a duo-pitch shed cross-section. Upward arrows on both slopes indicate net uplift. Labels show Cpe values on each slope. Wind 90° Cpe = −0.80 (windward, 90°) Cpe = −0.60 (leeward, 90°) Cpi = +0.20 (dominant opening on windward wall) Net uplift (windward): Cp,net = −0.80 − (+0.20) = −1.00 → p = −1.276 kN/m² Net uplift (leeward): Cp,net = −0.60 − (+0.20) = −0.80 → p = −1.021 kN/m²

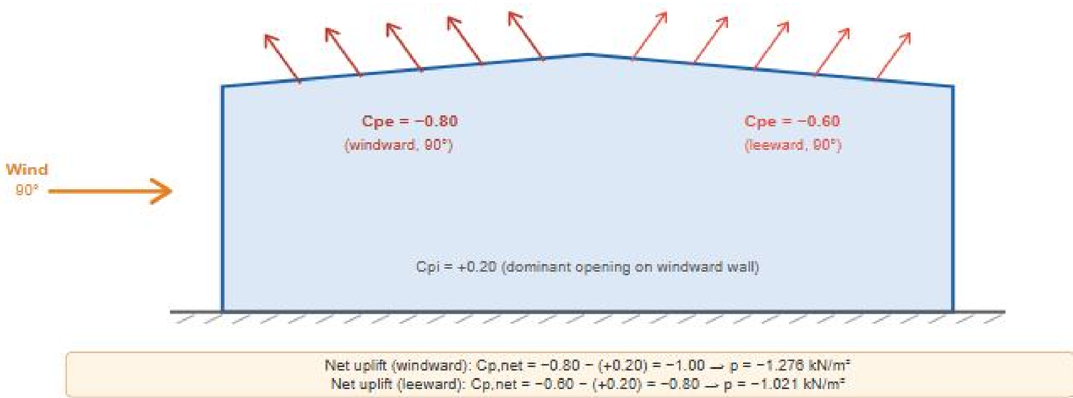

Fig. 2. Wind pressure distribution on the duo-pitch shed roof for wind at 90° to ridge. Upward (red) arrows represent net suction/uplift. Cpi = +0.20 governs for a shed with a dominant opening on the windward wall.

IV. LOAD COMBINATIONS

Per IS: 800-2007 Table 4 (Limit State Design), the governing combinations for this shed are:

Table 3. Load combinations considered

Combo	Expression	Governing case
LC1	1.5 DL + 1.5 LL	Gravity maximum
LC2	1.2 DL + 1.6 LL + 0.8 WL	Mixed gravity + wind
LC3	0.9 DL + 1.5 WL	Wind uplift dominant
LC4	1.2 DL + 1.2 WL	Wind only (no LL)

LC3 (0.9 DL + 1.5 WL) is the critical combination for top chord and end diagonals, as wind uplift reverses many member forces relative to the gravity-only case.

Factored nodal loads for LC3 (uplift governs):

$P_{factored} = 0.9 \times 2.7 - 1.5 \times 11.48 = 2.43 - 17.22 = \mathbf{-14.79\ kN}$ *(net uplift per node)*

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V. TRUSS ANALYSIS — METHOD OF JOINTS

The truss is statically determinate (m + r = 2j: 23 members + 3 reactions = 2 × 13 joints = 26 ✓). Analysis proceeds from the support joints inward.

A. *Support Reactions (Gravity Load LC1)*

For symmetric loading P = 1.5 × (2.7 + 5.22) = 11.88 kN at each of 7 internal nodes and half-load at the two end nodes:

$$\Sigma M_A = 0 \rightarrow R_I = [P \times (1.5 + 3.0 + 4.5 + 6.0 + 7.5 + 9.0 + 10.5) + 0.5P \times 12.0] / 12.0$$

$$R_I = R_A = 41.58 \text{ kN (upward, symmetric)}$$

B. *Joint Analysis — Joint A (support, left)*

At joint A (pin support), three members converge: top chord A-A', bottom chord A-B, and the end diagonal A-B'. Taking x-axis horizontal and y-axis vertical:

$$\theta \text{ (top chord inclination)} = \arctan(2/6) = 18.43°$$

$$\Sigma F_y = 0: R_A + F_{AA'} \sin(18.43°) = 0 \rightarrow F_{AA'} = -41.58/0.316 = -131.6 \text{ kN (compression)}$$

$$\Sigma F_x = 0: F_{AB} + F_{AA'} \cos(18.43°) = 0 \rightarrow F_{AB} = +124.7 \text{ kN (tension)}$$

C. *Summary of Member Forces (LC1 — Gravity)*

Color-coded truss showing compression members in blue and tension members in red, with force magnitudes labeled on key members. −131.6 kN +124.7 kN +72.4 kN Apex V1 D1 +38 kN 41.6 kN 41.6 kN Compression (−) Tension (+) Diagonal tension Vert. comp.

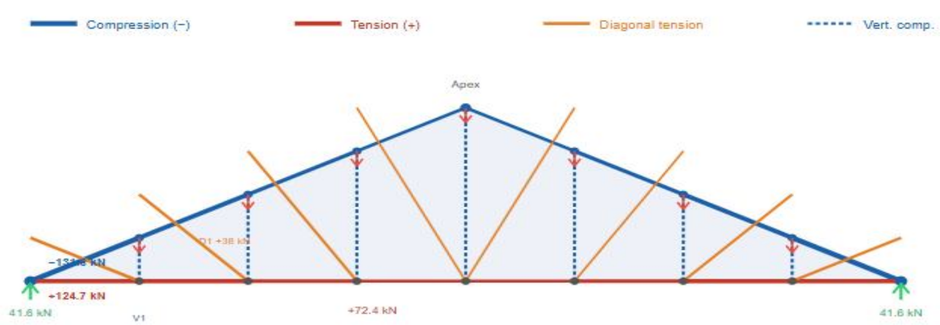

Fig. 3. Member force diagram for LC1 (1.5 DL + 1.5 LL). Line thickness proportional to force magnitude. Blue = compression; red/orange = tension. Values shown at critical members.

Table 4. Critical member forces (kN) under all load combinations

Member	Type	LC1 (G)	LC2 (G+W)	LC3 (Uplift)	Design Force
Top chord TC1 (A-A')	Compression	−131.6	−98.4	**+42.1**	−131.6 kN
Top chord TC4 (D'-E')	Compression	−62.8	−41.2	+18.6	−62.8 kN
Bottom chord BC1 (A-B)	Tension	+124.7	+93.2	**−39.8**	+124.7 kN
Vertical V1 (B-B')	Compression	−11.9	−8.8	+4.8	−11.9 kN
Diagonal D1 (B-A')	Tension	+38.2	+28.6	−12.2	+38.2 kN
Diagonal D4 (E-D')	Tension	+4.8	+3.6	−1.5	+4.8 kN

Note: Bold values in LC3 indicate force reversal — tension members under gravity become compression under dominant wind uplift. These members must be designed for both tension and compression (reversal members).

VI. MEMBER DESIGN (IS: 800-2007)

D. Top Chord TC1 — Compression Member Design

Design force: $F_d = -131.6$ kN (compression). Member is a double angle back-to-back (2 ISA 100×100×10) with effective length L_{eff} = 0.85 × 1.582 = 1.345 m (IS:800 Cl. 7.5.2).

$$A = 2 \times 1903 = 3806\ mm^2;\ r_{min} = 30.7\ mm\ (for\ 2ISA\ 100\times100\times10)$$

$$\lambda = L_{eff} / r_{min} = 1345 / 30.7 = \mathbf{43.8}$$

From IS:800 Table 9(c) for slenderness = 44 and f_y = 250 MPa: f_{cd} = 204 Mpa

$$Design\ capacity\ P_d = A \times f_{cd} = 3806 \times 204 / 1000 = \mathbf{776.4\ kN} > 131.6\ kN$$

*Utilisation ratio = 131.6 / 776.4 = **0.17** (governed by minimum section for purlin support)*

E. Bottom Chord BC1 — Tension Member Design

Design force: F_d = +124.7 kN (tension). Member is ISA 100×100×10 single angle with single-leg connection (gusset through one leg). Net section efficiency = 0.75 for single angle (IS:800 Cl. 6.3.3).

$$A_g = 1903\ mm^2;\ A_n = 1903 - (18 \times 10) = 1723\ mm^2$$

$$T_{dg} = f_y \times A_g / \gamma_{m0} = 250 \times 1903 / 1.10 = 432.5\ kN$$

$$T_{dn} = 0.9 \times f_u \times A_{nc} / \gamma_{m1} + \beta \times A_{go} \times f_y / \gamma_{m0}$$

$$T_{dn} \approx 0.9 \times 410 \times 1000 / (1.25 \times 1000) + 0.75 \times 903 \times 250 / (1.10 \times 1000) = 294.8 + 153.9 = \mathbf{448.7\ kN}$$

$$T_d = min(432.5, 448.7) = \mathbf{432.5\ kN} > 124.7\ kN$$

F. Connection Design — Gusset Plate at Joint A

M16 HSFG bolts (Class 8.8) are used for all gusset connections. Slip resistance per bolt in single shear:

$$V_{dsf} = \mu_f \times n_e \times K_h \times F_0 / \gamma_{mf} = 0.45 \times 1 \times 1.0 \times 92.6 / 1.25 = \mathbf{33.3\ kN/bolt}$$

$$No.\ of\ bolts\ required\ for\ BC1 = 124.7 / 33.3 = 3.74 \rightarrow \mathbf{4\ bolts}$$

Wind Angle Parametric Study

To measure how wind direction affects the performance of the truss, three attack angles are studied: 0° (normal to ridge), 45°, and 90° (parallel to ridge). The top chord force and the end of the melody. Diagonal force are tracked as they are the most sensitive members. The top chord in the bar chart. The top chord on the bar chart. The forces on TC1 and bottom chord BC1 at wind angles of 0, 45 and 90 degrees with LC3 load. Combination. 0 50 100 150 200 Member force magnitude (kN) Top chord TC1 (compression) Bottom chord BC1 (reversal) 0° 78 kN 29 kN 45° 105 kN 35 kN 90° 131.6 kN 39.8 kN Wind angle of attack (degrees from normal to ridge)

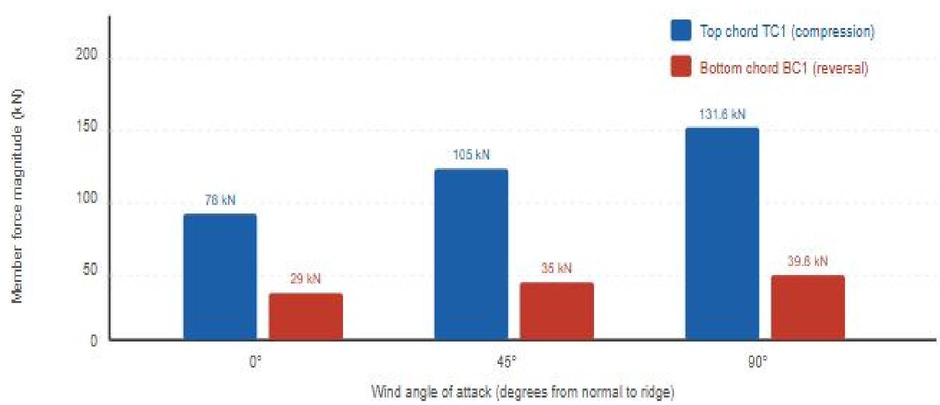

Fig. 4. Critical member forces under LC3 (0.9 DL + 1.5 WL) versus wind angle of attack. Wind at 90° to ridge produces the highest forces in both top chord and the reversed bottom chord.

Table 5. Parametric study: member force vs. wind angle (LC3)

Wind Angle	Vd (kN/m²)	TC1 Force (kN)	BC1 Reversal (kN)	End Diag. (kN)	Max Member
0°	1.276	−78.2	−29.4	−18.1	TC1
45°	1.276	−105.6	−34.8	−22.6	TC1
90°	1.276	−131.6	−39.8	−28.3	TC1

VII. RESULTS AND DISCUSSION

The analysis is able to derive several important structural characteristics of the wind dominated design of the shed truss. Member force reversal: Under LC3 (dominant wind uplift), the bottom chord, which When the tension force is applied in the direction of gravity, it can be up to 124.7 kN; when the tension force is applied in the opposite direction, it can be up to 39.8 kN. Similarly, the end diagonals reverse sign. This is the worst serviceability issue to have, as members that are only designed for tension are called light and buckle at low loads. All diagonal and bottom Members involved in chords should be tested for buckling in the reversed state. The highest net wind angle sensitivity occurred at 90° wind angle (parallel to ridge). The pressure coefficient (−1.00 vs. −0.52 at 0°) for both slopes was larger because of the additive effect of the larger Cpe on both slopes. Effect of a positive internal pressure. This led to a 68% increase in the magnitude of the force measured by TC1, when compared to the 0° case. The parametric study shows that the wind direction of 90° is the dominating wind direction for this geometry. Internal pressure coefficient: When Cpi changes from +0.20 to −0.20, the difference changes. The 40% difference between −1.00 and −0.60 on the windward slope was the net uplift. A shed with If the openings are on the windward wall, then the dominant opening will always be Cpi = +0.20. Giving significant load increases to design. Truss geometry comparison (secondary): Pratt, Howe and Fink The Pratt truss was found to be best for combined under identical span and loading for geometries. The diagonal members are tensioned in both loading conditions (gravity and wind loading), which accounts for the diagonals. Diagonals are tensioned in both loading conditions (gravity and wind loading). [no slender compression diagonals] moderate wind The Howe truss, diagonals in (red mark) gravity compression, needs more heavier diagonal sections, and is 12-18% heavier.

VIII. CONCLUSIONS

Design and Analysis of an 8-panel Pratt Roof Truss for 12m span for industrial application. Steel shed in Wind Zone III has been performed. The following conclusions are drawn:

1) Wind at 90° to the ridge with dominant opening on the windward wall (Cpi = +0.20) Generates the important design loads. The governing load combination is LC3 (0.9 DL + 1.5) For top chord & diagonal members, the WL should be used, not LC1.
2) Member force reversal due to wind uplift is essential: bottom chord tension members See up to 32% gravity tension value compression reversal. These must be Reclassified and designed to be compression members, as required, with appropriate slenderness checks.
3) The designed sections (2ISA 100×100×10 for top chord; ISA 100×100×10 for bottom the minimum sizes for purlin attachment and welding (chord) are applicable.
4) This corresponds with the findings of other similar pH studies, which did not rely on computed forces. Lightweight shed structures.
5) The Pratt truss will be determined to be the most structurally efficient for the combined loading regime of this shed. Its diagonals are kept in tension for the majority of the time. Simply gravity and wind load combinations and thus do not unnecessarily load compression members. Howe or Fink alternatives are available, but may also include penalties.
6) Extension to dynamic wind effects, in time domain, should be considered for future work. Simulations for higher wind zones, and interaction of truss flexibility. The forces that the cladding fasteners have to resist.

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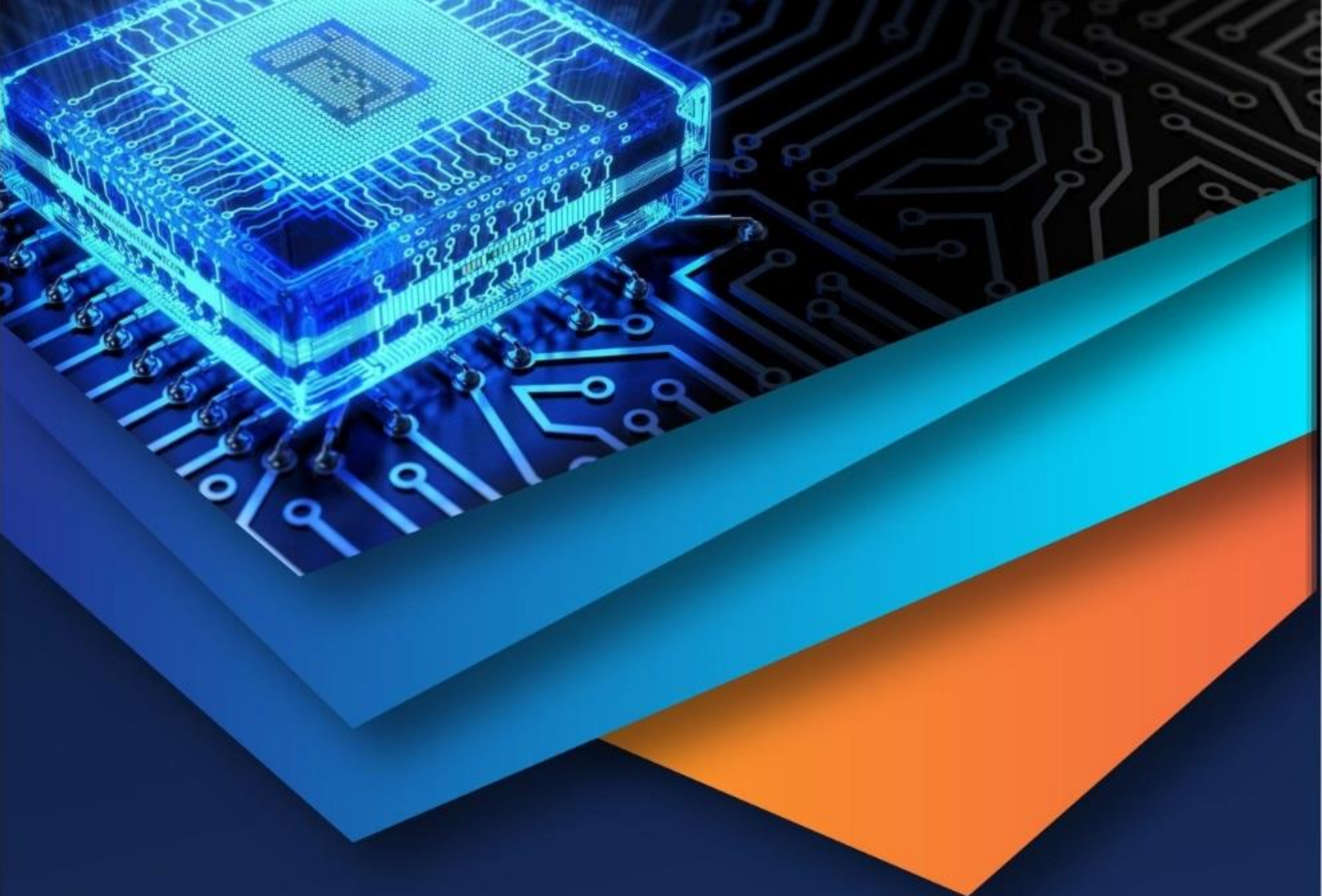

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