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# Plastic Section Moduli for I.S. Rolled Steel Beam Sections $Z_{py}$ about Y-Y Axis

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***Abstract:** There are many situations in which the I-Sections used in construction are subjected to moments about their weaker axis, i.e. the y-y axis. For such purposes the Plastic Section Modulus about y-y axis becomes necessary. In the present paper an attempt has been made to calculate and present the values of $Z_{py}$, for I.S. Rolled Steel Beam Sections (with tapered flanges). Since IS 800 : 2007[2] has not given the values of $Z_{py}$, of any section, one tapered flange I-Section, viz., 125 TFB @ 13.1 kg/m, from "Onesteel" (Australia),[4] has been used to ascertain the correctness of calculations. The results are presented in table form in descending order.*
***keywords:** I-Sections, $Z_{py}$, IS 800: 2007[2], y-y axis.*

## I. INTRODUCTION

I.S. Rolled Steel Beam and Channel Sections are used as Beams, Columns, components of Built-up Beams/Columns, Members of Lattice Girder Bridges, Gantry Girders, Crane Girders, etc. There are many situations in which the I-Sections used in construction are subjected to moments about their weaker axis, i.e. the y-y axis, like eccentric loads on columns, members acting as beam-columns, etc. Hence, the knowledge of Plastic Moment of Resistance becomes necessary – especially when site conditions demand the use of smaller sections. Also, the strength of any section about the main axes, both z-z and y-y axes, is of academic interest. For such purposes the Plastic Section Modulus about y-y axis becomes necessary. Leading steel manufacturers and distributors in the world e.g. British Steel, Fletcher Easy Steel (New Zealand), Onesteel (Australia)[4], Nippon steel (Japan) etc., publish the values of $Z_{py}$, Plastic Section Modulii about y-y axis, in their brochures alongside the values of $Z_{pz}$, i.e., Plastic Section Modulii about z-z axis. In the present paper an attempt has been made to calculate and present the values of $Z_{py}$, for I.S. Rolled Steel Beam Sections (with tapered flanges).

## II. METHOD OF CALCULATION

Typical calculations of $Z_{py}$ for the I-Section – ISLB 400 @ 558.2 N/m have been given hereunder. The I-Section has been divided into 13 component areas. The area of each component is calculated and the position of centroid of each component is identified and used in the calculation of the Plastic Section Modulus of the cross section about Y-Y axis. Further, the same procedure is applied for calculation of $Z_{py}$ of one tapered flange I-Section, viz., 125 TFB @ 13.1 kg/m, from Onesteel (Australia),[4] to ascertain the correctness of calculations.

### A. *Plastic Section Modulus, $Z_{py}$, of ISLB 400 @ 558.2 N/m:*

For ISLB 400@ 558.2 N/m the various geometrical parameters, as per SP: 6(1)-1964,[1] are as follows:
$h = 400$ mm ; $b = 165$ mm ; $t_f = 12.5$ mm ; $t_w = 8$ mm ; (D)$\theta = 98^o$ ; $r_1 = 16$ mm ; $r_2 = 8$ mm ;
In the Figure 1 :
Z-Z represents the horizontal neutral axis
Z'-Z' represents the horizontal Equal Area Axis – Z-Z and Z'-Z' axes coincide.
Y-Y represents the vertical neutral axis
Y'-Y' represents the vertical Equal Area Axis – Y-Y and Y'-Y' axes coincide.

#### 1) *Calculations Of Areas, Centroids And Plastic Section Modulus*

Refering to Figure 2 –
Entire Web is taken as a Rectangle of -- ($h$ X $t_w$) = 400 X 8.0 = **3200.0000 mm²**

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Each Tapered Flange Outstand is taken as --

i) Trapezium, ABCD

ii) Positive Spandrel area with radius $r_1$, i.e. the fillet between flange and web

iii) Negative Spandrel area at the toe of flange of radius $r_2$

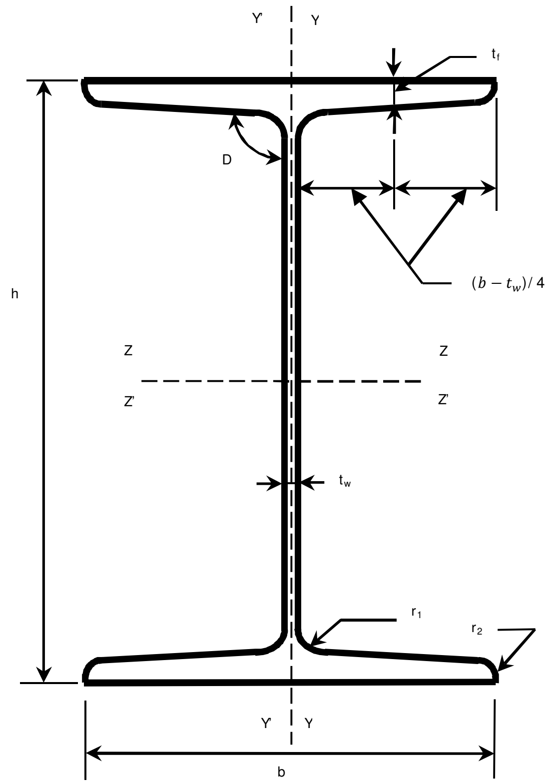


**Figure 1 I- SECTION**

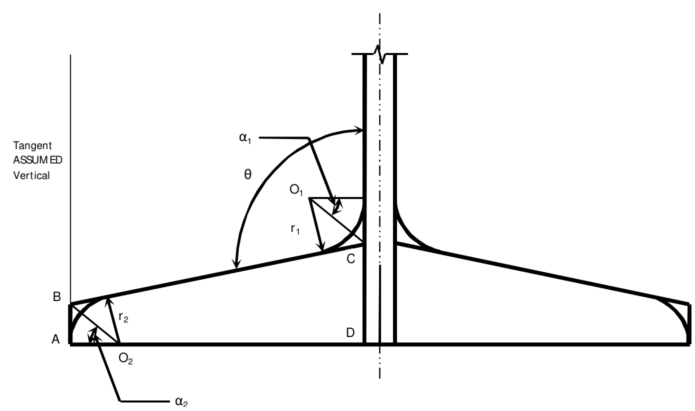


**Fig. 2 Flange Geometry for I, C & T Sections**

Area of Trapezium: $A_t = AD \times ((AB + CD) / 2)$ , where,

$AD = b_1 = \{ (b - t_w) / 2 \} = (165 - 8) / 2 =$ **78.5000 mm**

$AB = t_f - \{ (b_1/2) \text{ X } \tan(\theta\text{-}90) \} = 12.5 - \{ (78.5 / 2) \text{ X } \tan(98\text{-}90) \} =$ **6.9838 mm**

$CD = t_f + \{ (b_1/2) \text{ X } \tan(\theta\text{-}90) \} = 12.5 + \{ (78.5 / 2) \text{ X } \tan(98\text{-}90) \} =$ **18.0162 mm**

Therefore, $A_t = AD \times ((AB + CD) / 2) = 78.5 \times \{ (6.9838 + 18.0162) / 2 \} =$ **981.25 mm²**

Centroid of Trapezium from AB: $x_t = (b1/3) \text{ X } \{ (AB + 2CD) / (AB + CD) \}$

$= (78.5/3) \text{ X } \{(6.9838+2\text{X}18.0162) / (6.9838+18.0162)\}$

**= 45.02365 mm**

Centroid of Trapezium from AD: $y_t = \{AB^2+(ABXCD)+CD^2\} \ / \ \{3X(AB+CD)\}$

$= \{6.9838^2+(6.9838 \ X18.0162)+18.0162^2\}/\{3X(6.9838 +18.0162)\}$

**= 6.6557 mm**

Area of Positive Spandrel at Fillet: $= r_1^2 \{ ( \tan \alpha ) - \alpha \}$, where,

$\alpha_1 = \{(180-\theta)/2\} \ X \ (\pi/180)$ radians

$= \{(180-98)/2\} \ X \ (\pi/180) =$ **0.71558 radians**

Therefore, required area $= 16^2 \ X \ \{(\tan 0.71558) - 0.71558\}$

**= 39.34765 mm²**

Centroid of Spandrel from apex C in figure above, along bisector:

$x_1 = \{ r_1 (\sin\alpha \cos\alpha + 2\tan\alpha - 3 \alpha )\} \ / \ \{ 3(\sin\alpha - \alpha \cos\alpha) \}$

$= \{16 \ X \ (\sin 0.71558 \ X \cos 0.71558 + 2 \ X \tan 0.71558 - 3 \ X \ 0.71558)\} \ / \ \{ 3 \ X \ (\sin 0.71558 - 0.71558 \ X \cos 0.71558)\}$

**= 3.9978 mm**

Area of Negative Spandrel at Flange end: $= r_2^2 \{ ( \tan \alpha ) - \alpha \}$, where,

$\alpha_2 = \{(180-\theta)/2\} \ X \ (\pi/180)$ radians

$= \{(180-98)/2\} \ X \ (\pi/180) =$ **0.71558 radians**

Therefore, required area $= 8^2 \ X \ \{(\tan 0.71558) - 0.71558\}$

**= 9.8369 mm²**

Centroid of Spandrel from apex B in figure above, along bisector:

$x_2 = \{ r_2 (\sin\alpha \cos\alpha + 2\tan\alpha - 3 \alpha )\} \ / \ \{ 3(\sin\alpha - \alpha \cos\alpha) \}$

$= \{8 \ X \ (\sin 0.71558 \ X \cos 0.71558 + 2 \ X \tan 0.71558 - 3 \ X \ 0.71558)\} \ / \ \{ 3 \ X \ (\sin 0.71558 - 0.71558 \ X \cos 0.71558)\}$

**= 1.9989 mm**

### *B. Plastic Section Modulus OF ISLB 400@558.2 N/m ABOUT Y-Y AXIS (VERTICAL)*

Web : $(h \ X \ t_w^{\ 2}) / 4 = (400 \ X \ 8^2) / 4$

$= 6400.0000 \text{ mm}^3$

Left and Right Trapeziums at bottom (or top) of web :

$\{AD \times ((AB + CD) / 2)\} \ X \ ( b - 2x_t ) = 981.25 \ X \ ( 165 - 2X \ 45.02365)$

**= 73,547.3369 mm³**

Left and Right Positive Spandrels at bottom (or top) of web:

$\{r_1^2 \ [( \tan \alpha ) - \alpha ]\} \ X \ \{ t_w+2 \ [x_1 \cos(90-\theta/2)]\} = 39.34765X\{8+2X[3.9978 \ X \cos(90-98/2)]\}$

**= 552.2189 mm³**

Left and Right Negative Spandrels at bottom (or top) of web:

$\{r_2^2 \ [( \tan \alpha ) - \alpha ]\} \ X \ \{b -2 \ x_2 \cos(90-\theta/2) \ ]\} = 9.8369X\{165-2X[1.9989X\cos(90-98/2)]\}$

**= 1,593.4088 mm³**

Therefore, Plastic Section Modulus of ISLB 400@ 558.2 N/m about y-y axis is:

= 6400.0000 + 2 X(73,547.3369 +552.2189 - 1,593.4088)

=151412.2848 **mm³** (without rounding off any value)

= (*1,51,412.294* **mm³** small error due to rounding off)

### *C. Plastic Section Modulus of 125 TFB @13.1 kg/m (ONESTEEL, Australia)[4] ABOUT Y-Y AXIS (Vertical)*

For 125 TFB @13.1 kg/m, the various geometrical parameters are as follows:

$h = 125$ mm ; $b = 65$ mm ; $t_f = 8.5$ mm ; $t_w = 5$ mm ; (D)$\theta = 98^o$ ; $r_1 = 8$ mm ; $r_2 = 4$ mm ;

Area of web -- $(h \ X \ t_w) = 300 \ X \ 7.6 =$ **625.0000 mm²**

AD = $b_1$ = **30.0000 mm ;** AB = **6.3919 mm ;** CD = **10.6081 mm ;** $A_t$ = **255.0000 mm²** ; $x_t$ = **16.2401 mm ;** $y_t$ = **4.3371 mm ;** $\alpha_1$ = **0.7156 radians ;**

Area of Positive Spandrel at Fillet = = **9.8369 mm² ;** $x_1$ = **1.9989 mm ;** $\alpha_2$ = **0.7156 radians ;**

Area of Negative Spandrel at Flange end = **2.4592 mm² ;** $x_2$ = **0.99945 mm ;**

Plastic Section Modulus

(i) Web : $(h \times t_w^{\,2}) / 4 = (125 \times 5^2) / 4$ **= 781.2500 mm$^3$**

(ii)Left and Right Trapeziums at bottom (or top) of web :

$\{AD \times ((AB + CD) / 2)\} \times (b - 2x_t) = 255.0000 \times (65 - 2 \times 16.2401)$

**= 8,292.549 mm$^3$**

(iii)Left and Right Positive Spandrels at bottom (or top) of web:

$\{r_1^2 [(\tan\alpha) - \alpha]\} \times \{t_w + 2[x_1 \cos(90-\theta/2)]\}$= **9.8369** X{5+2X[**1.9989** X cos(90-98/2)]}

**= 78.8642 mm$^3$**

(iv)Left and Right Negative Spandrels at bottom (or top) of web:

$\{r_2^2 [(\tan\alpha) - \alpha]\} \times \{b - 2x_2 \cos(90-\theta/2)\}$ = **2.4592** X{65-2X[**0.99945**Xcos(90-98/2)]}

**= 156.1381 mm$^3$**

Therefore, Plastic Section Modulus of 125 TFB @13.1 kg/m about y-y axis is:

= 781.2500 + 2 X(8,292.549 +78.8642 - 156.1381)

=17,211.8315 **mm$^3$** (without rounding off any value)

= (*17,211.8002* **mm$^3$** small error due to rounding off)

The corresponding value given in the Onesteel (Australia)[4] Brochure is 17.2 X $10^3$ mm$^3$, which exactly matches with the value calculated above, considering the accuracy adopted in the brochure.

## III. RESULTS AND DISCUSSIONS

The above calculations are done for all I.S. Rolled Steel I-Sections and and presented in descending order, in tabular form below. As the value of $Z_{py}$ calculated by the above method for a typical I-Section, i.e., 125 TFB @13.1 kg/m, from the Onesteel (Australia)[4] brochure has exactly matched with the value given in the brochure, it may be said that the method of calculation is satisfactory.

| TABLE 1 DECENDING ORDER OF $Z_{py}$ VALUES OF I.S. ROLLED STEEL I - | | |
|---|---|---|
| Section | Area(mm$^2$) | $Z_{Py}$ |
| ISWB600 @145.1kg/m | 18514.0395 | 696001.5597 |
| ISWB600 @133.7kg/m | 17037.9861 | 619235.2059 |
| ISWB550 @112.5kg/m | 14333.9369 | 500178.7515 |
| ISMB600 @122.6kg/m | 15621.2421 | 429350.3500 |
| ISWB500 @95.2kg/m | 12121.9119 | 406829.5384 |
| ISHB450 @92.5kg/m | 11789.3459 | 402733.9091 |
| ISHB450 @87.2kg/m | 11114.3459 | 394145.0247 |
| ISHB400 @82.2kg/m | 10465.8898 | 368174.0224 |
| ISHB400 @77.4kg/m | 9865.8898 | 360549.6050 |
| ISHB350 @72.4kg/m | 9221.0742 | 332453.8195 |
| ISMB550 @103.7kg/m | 13211.0781 | 328074.7930 |
| ISHB350 @67.4kg/m | 8591.0742 | 324438.3527 |
| ISLB600 @99.5kg/m | 12668.9421 | 306840.6438 |
| ISHB300 @63.0kg/m | 8024.9545 | 298562.9823 |
| ISHB300 @58.8kg/m | 7484.9545 | 291583.5232 |
| ISWB450 @79.4kg/m | 10115.0511 | 284181.8457 |
| ISHB250 @54.7kg/m | 6970.7471 | 268551.8492 |
| ISHB250 @51.0kg/m | 6495.7471 | 262155.2645 |
| ISMB500 @86.9kg/m | 11074.3794 | 259630.9756 |
| ISLB550 @86.3kg/m | 10997.3981 | 246298.6750 |
| ISWB400 @66.7kg/m | 8501.2544 | 234192.5658 |
| ISLB500 @75.0kg/m | 9549.8194 | 206685.6693 |
| ISHB225 @46.8kg/m | 5966.3071 | 206508.0806 |
| ISHB225 @43.1kg/m | 5493.8071 | 200491.5207 |
| ISWB350 @56.9kg/m | 7249.9020 | 200470.7328 |

| | | |
|---|---|---|
| ISMB450 @72.4kg/m | 9226.6287 | 187142.4228 |
| ISLB450 @65.3kg/m | 8313.5629 | 174700.6499 |
| ISWB300 @48.1kg/m | 6132.7538 | 171017.3535 |
| ISHB200 @40.0kg/m | 5094.4317 | 163466.5906 |
| ISHB200 @ 37.3kg/m | 4754.4317 | 159280.8236 |
| ISLB400 @56.9kg/m | 7243.0429 | 151412.2848 |
| ISMB400 @61.6kg/m | 7845.5766 | 149677.9681 |
| ISWB250 @40.9kg/m | 5204.6097 | 149672.2745 |
| ISLB350 @49.5kg/m | 6301.3229 | 134609.8771 |
| ISMB350 @52.4kg/m | 6671.3366 | 129734.4638 |
| ISLB325 @43.1kg/m | 5489.8429 | 111885.2017 |
| ISMB300 @44.2kg/m | 5626.3766 | 110469.0531 |
| ISHB150 @34.6kg/m | 4407.7485 | 105310.2341 |
| ISWB225 @33.9kg/m | 4323.9499 | 99773.2533 |
| ISHB150 @30.7kg/m | 3897.7485 | 98250.5616 |
| ISHB150 @27.1kg/m | 3447.7485 | 92741.4388 |
| ISLB300 @37.7kg/m | 4807.7887 | 89983.8892 |
| ISMB250 @37.3kg/m | 4755.4268 | 89709.9925 |
| ISWB200 @28.8kg/m | 3670.8699 | 78704.1064 |
| ISLB275 @33.0kg/m | 4201.7366 | 73546.4652 |
| ISMB225 @31.2kg/m | 3971.4992 | 66320.5747 |
| ISLB250 @27.9kg/m | 3552.8868 | 55372.3314 |
| ISWB175 @22.1kg/m | 2811.2942 | 51273.4065 |
| ISMB200 @25.4kg/m | 3232.6737 | 49994.2680 |
| ISLB225 @23.5kg/m | 2991.6392 | 39228.1679 |
| ISLB200 @19.8kg/m | 2526.7608 | 36916.0099 |
| ISMB175 @19.3kg/m | 2462.0105 | 32098.0608 |
| ISWB150 @17.0kg/m | 2166.5342 | 31940.0391 |
| ISLB175 @16.7kg/m | 2129.7208 | 28339.0502 |
| ISMB150 @14.9kg/m | 1900.3895 | 22322.7948 |
| ISLB150 @ 14.2kg/m | 1808.3208 | 22120.6197 |
| ISMB125 @13.0kg/m | 1660.4695 | 19583.5487 |
| ISLB125 @11.9kg/m | 1512.2067 | 18374.8708 |
| ISMB100 @11.5kg/m | 1459.7495 | 18224.3327 |
| ISJB225 @12.8kg/m | 1627.7958 | 16290.2658 |
| ISJB200 @9.9kg/m | 1264.3682 | 9353.5390 |
| ISLB100 @8.0kg/m | 1021.0958 | 8204.7936 |
| ISLB75 @6.1kg/m | 771.3828 | 6395.9855 |
| ISJB175 @ 8.1kg/m | 1027.6482 | 6320.9247 |
| ISJB 150 @7.1 kg/m | 900.7682 | 5960.8423 |

## IV. CONCLUSIONS

All leading Steel manufacturers and distributors in the world provide the values of Plastic Section Modulii for z-z and y-y axes of all sections manufactured/distributed by them. IS 800:2007[2] gives Plastic Section Modulii about z-z axis only, and further, only for two types of sections, viz. I and C sections.

The importance of $Z_{py}$ values has already been mentioned in the introductory part. Hence, the values presented here for $Z_{py}$, verified for a typical section of Onesteel (Australia)[4] may be considered to be correct and useful. However, a further scrutiny of the methodology and calculations, presented here, is always helpful.

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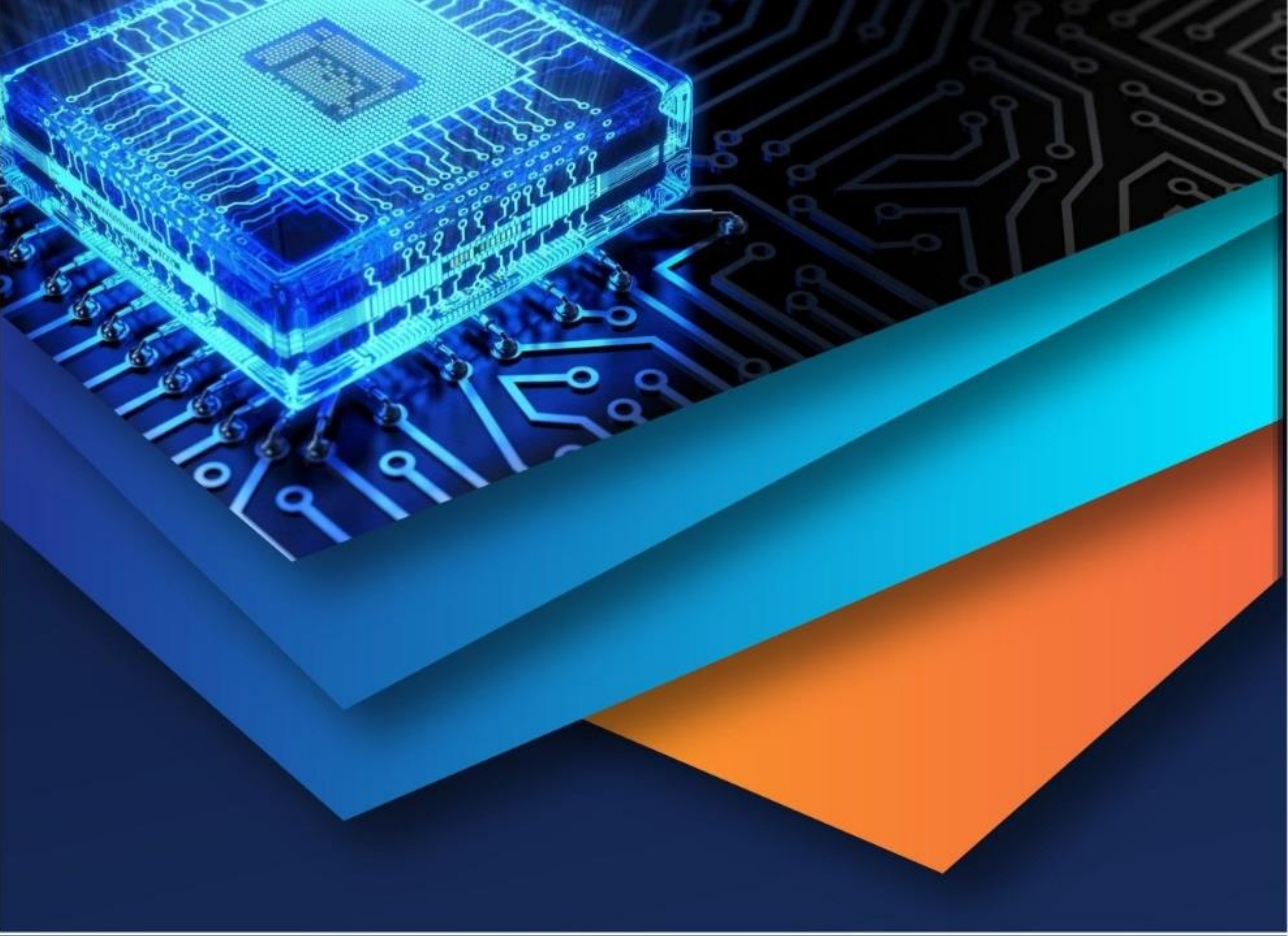

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