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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**

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

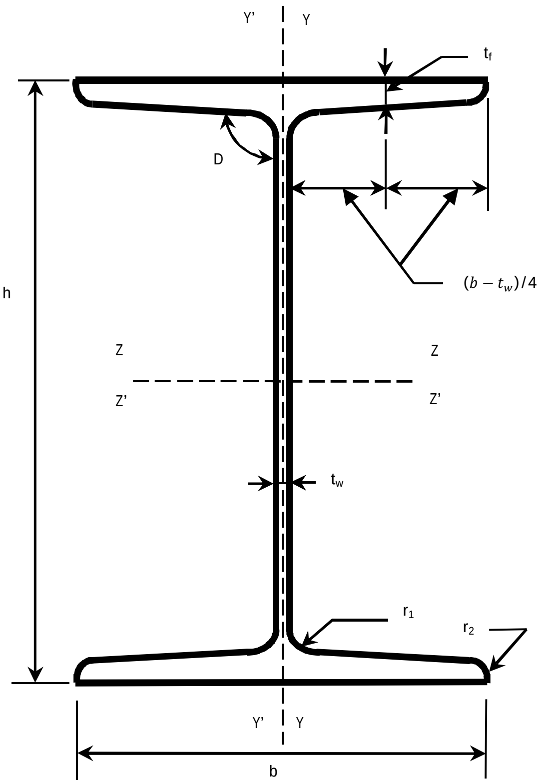

Figure 1 I- SECTION

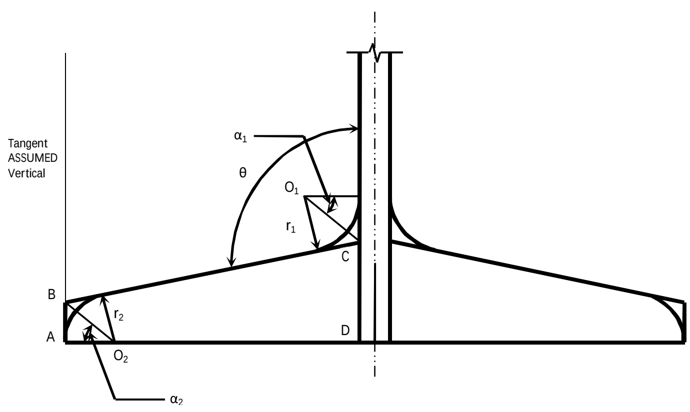

Fig. 2 Flange Geometry for I, C & T Sections

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

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

AB = t_f – { (b_1/2) X tan(θ-90) } = 12.5 – { (78.5 / 2) X tan(98-90) } = **6.9838 mm**

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

Therefore, A_t = AD × ((AB + CD) / 2) = 78.5 × { (6.9838 + 18.0162) / 2 } = **981.25 mm^2**

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

= (78.5/3) X {(6.9838+2X18.0162) / (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 mm^2**

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

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

$= \{16\ X\ (\sin0.71558\ X\ \cos0.71558 + 2\ X\ \tan0.71558 - 3\ X\ 0.71558)\} \ / \ \{ 3\ X\ (\sin0.71558 - 0.71558\ X\ \cos0.71558)\}$

$=$ **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 mm^2**

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

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

$= \{8\ X\ (\sin0.71558\ X\ \cos0.71558 + 2\ X\ \tan0.71558 - 3\ X\ 0.71558)\} \ / \ \{ 3\ X\ (\sin0.71558 - 0.71558\ X\ \cos0.71558)\}$

$=$ **1.9989 mm**

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

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

$= 6400.0000$ 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 mm^3**

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 mm^3**

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 mm^3**

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

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

$=151412.2848$ **mm^3** (without rounding off any value)

$=$ (*1,51,412.294* **mm^3** 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 mm^2**

$AD = b_1 =$ **30.0000 mm ;** $AB =$ **6.3919 mm ;** $CD =$ **10.6081 mm ;** $A_t =$ **255.0000 mm^2** ; $x_t =$ **16.2401 mm ;** $y_t =$ **4.3371 mm ;** $\alpha_1 =$ **0.7156 radians ;**

Area of Positive Spandrel at Fillet = = **9.8369 mm^2 ;** $x_1 =$ **1.9989 mm ;** $\alpha_2 =$ **0.7156 radians ;**

Area of Negative Spandrel at Flange end = **2.4592 mm^2 ;** $x_2 =$ **0.99945 mm ;**

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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 × ((AB + CD) / 2)} X (b - $2x_t$) = 255.0000 X (65 – 2 X 16.2401)

= **8,292.549 mm^3**

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

{r_1^2 [(tan α) - α]} X { t_w+2 [x_1 cos(90-θ/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 α) - α]} X {b -2 x_2 cos(90-θ/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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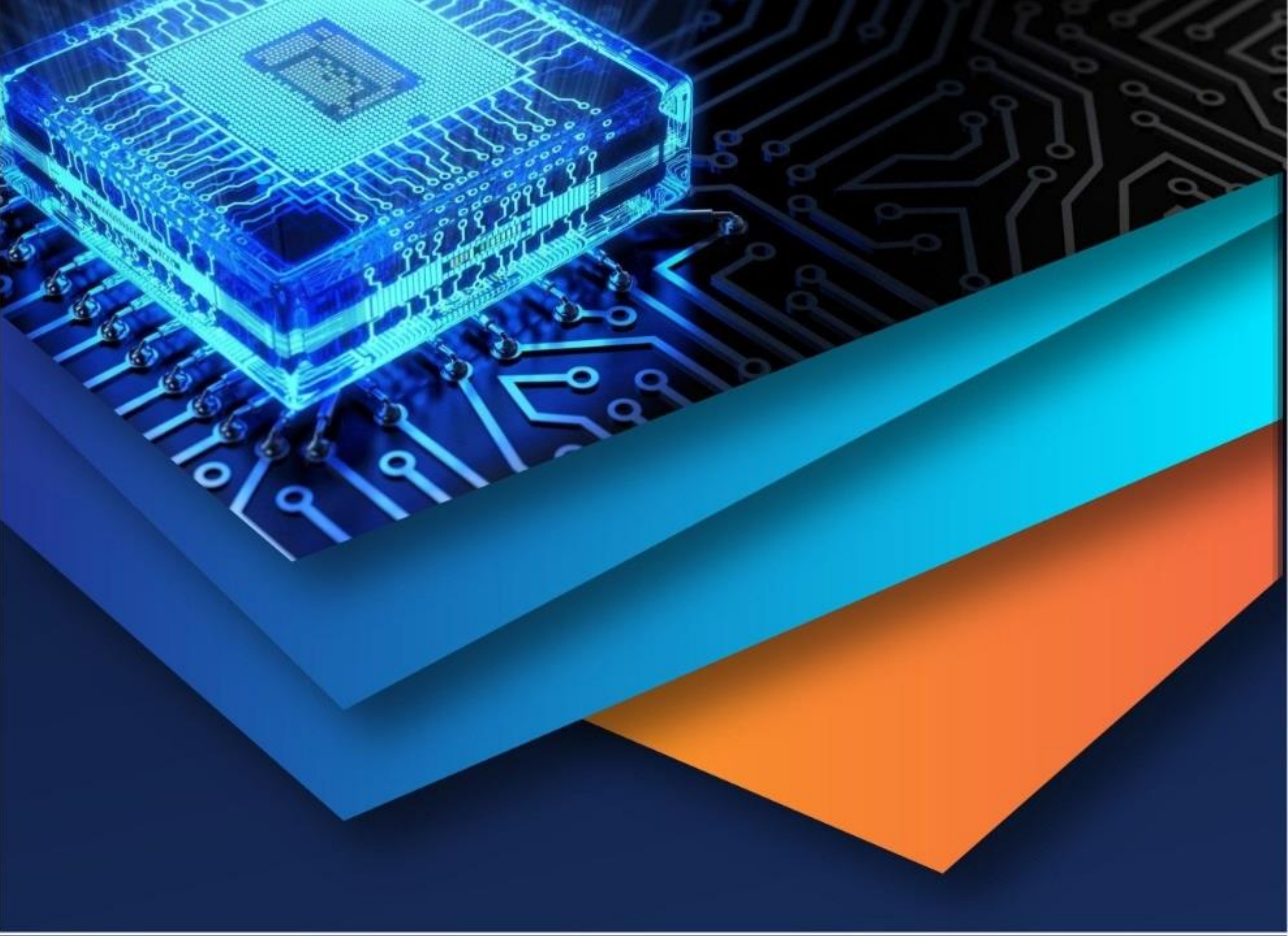

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