ADDITIONAL SECTIONAL PROPERTIES OF INDIAN STANDARD PARALLEL FLANGE SECTIONS

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INTRODUCTION

Parallel flange sections (Figure 1) are hot rolled steel sections, with parallel flanges having square toes and curves at the root of flange and web. This flange design allows efficient distribution of material in the cross-section, which results in higher section modulus. Parallel flange sections are more efficient than the conventional tapered flange sections in terms of strength, workability and economy. Connections are far simpler in parallel flange sections. In developed countries, parallel flange sections are invariably used in a variety of applications such as industrial buildings, commercial complexes, multi-level car-parks, stadiums, bridges etc.

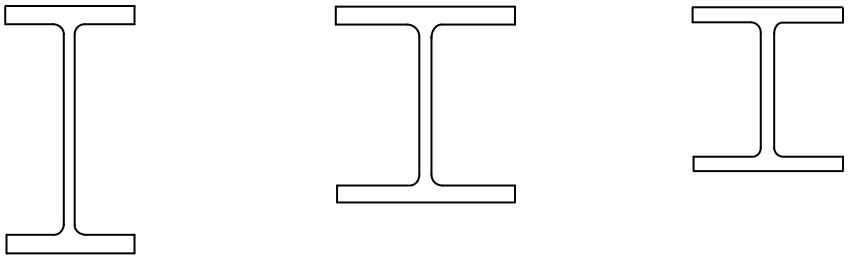

Figure 1: Parallel Flange Beams, Columns and Bearing Piles

The use of these sections was not very common in India until recently, because of non-availability of the same in medium and large sizes. Such sections are now being produced in India and it is expected that the use of these efficient sections will increase. **IS 12778 : 2004** covers the nominal dimensions; mass and sectional properties of hot rolled parallel flange beams, columns and bearing piles.

As per this standard, beams, columns and pile sections are classified as narrow parallel flange beams (NPB), wide parallel flange beams (WPB) and parallel flange bearing piles (PBP). Wide parallel flange beam sections may be used as beams or columns based on application. NPB and WPB sections are designated by nominal depth and nominal flange width and mass of the section in kg/m. For example, NPB 300 x 200 x 75.37 would mean narrow parallel flange section having nominal depth of 300 mm, nominal flange width of 200 mm and a mass of 75.37 kg/m. Likewise, WPB 300 x 300 x 237.92 would mean wide parallel flange section having nominal depth of 300 mm, nominal flange width of 300 mm and a mass of 237.92 kg/m.

Nominal flange width, in addition to nominal depth is also required in the designation because a number of parallel flange sections having the same nominal depth but with varying flange widths, flange and web thickness are available. The availability of large number of sections with different geometrical properties having the same nominal depth gives the flexibility to the structural designer to choose the most appropriate section. NPB sections have nominal flange widths generally lower than the nominal depth. The nominal flange width of WPB sections is more than that of NPB sections of same nominal depth; it is same as the nominal depth for nominal depths up to 300mm.

In Table 1, some of the sectional properties of tapered and parallel flange sections of same nominal depth are compared. It is observed that:

- NPB section is more efficient than corresponding MB section in bending, as it has a lower mass for the same section modulus about major axis; and

- NPB section is more efficient than corresponding MB section in compression, as it has a higher radius of gyration about minor axis.

Section	**Mass (kg / m)**	**Section Modulus** about major axis (cm^3)	**Radius of Gyration** about minor axis (cm)
MB 400 (Tapered Flange Section)	61.60	1022.9	2.82
NPB 400 x 180 x 57.38 (Parallel Flange Section)	57.38	1022.3	4.00

Table 1: Comparison of Sectional Properties of Tapered and Parallel Flange Sections

In parallel flange bearing piles (PBP), flanges and webs are of same nominal thickness and nominal depth and nominal flange width are also same. Accordingly, PBP sections are designated by nominal depth and mass of the section in kg/m. For example, PBP 360 x 174.02 would mean bearing pile section having nominal depth of 360 mm, nominal flange width of 360 mm and a mass of 174.02 kg/m.

Material strength of parallel flange steel sections shall be confirming to IS 2062 : 1999 for mild steel and IS 8500 : 1991 for medium and high strength steels. All of the sections listed in **IS 12778 : 2004** in the desired steel grade may not be readily available at a given point of time, due to a variety of reasons. While designing, it is a good practice to ensure that the specified sections are the ones that are actually available.

IS 800 is the Indian Standard Code of Practice for General Construction in Steel. This is a basic standard widely used and accepted by engineers, technical institutions, professional bodies and the industries across the country. Second revision of this code, IS 800 : 1984, was based on working stress method of design. This code is being revised (third revision); the draft code adopts the limit state method of design in tune with other developed countries such as America, Australia, Britain, Canada and Europe. It is likely that limit state method for structural steel design will be used and accepted well by all concerned across the country and will become, in due course, the standard method for structural steel design in India.

ADDITIONAL SECTIONAL PROPERTIES

The sectional properties of hot rolled parallel flange steel sections listed in **IS 12778 : 2004** include Moment of Inertia, Radius of Gyration, Elastic Section Modulus and Plastic Section Modulus; each about the major and minor axes. These section properties are commonly required from design point of view.

However, there are few other section properties that are frequently required **while designing by limit state method**. It would be worthwhile if these additional properties are also presented in a tabular form in **IS 12778 : 2004** or elsewhere**.** These additional properties are the depth between root fillets, local buckling ratio for flange, local buckling ratio for web, warping constant and torsional constant. It would be of great ease for the practicing designers and budding engineers if these additional properties are also readily available to them while designing. Few other properties such as section classification (under axial load, under pure bending and under combined axial load and bending) and torsional index etc. are not presented here for brevity.

In IS 12778 : 2004, the major and minor axes are represented by x – x and y – y respectively, whereas in draft IS 800, these axes are represented as z – z and y – y respectively. In this paper, the notation adopted in IS 12778 : 2004 is followed.

Local Buckling Ratio for the Flange: This ratio is computed as $\frac{b}{t_f}$ and is very frequently required for checking the section classification. Here, 'b' is the half flange width and is equal to $\frac{B}{2}$ and t_f is the thickness of the flange.

Local Buckling Ratio for the web: This ratio is computed as $\frac{d}{t_w}$ and is very frequently required for checking the section classification. Here, 'd' is the depth between root fillets is equal to D – 2T – 2R and t_w is the thickness of the web.

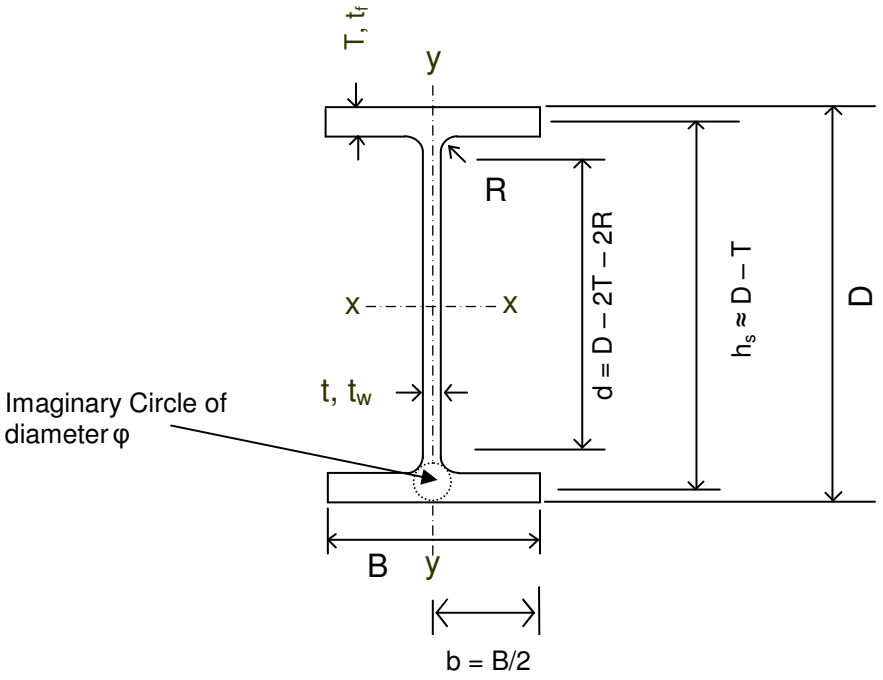

Figure 1: Notations for I Shaped Member With Parallel Flanges

Warping and Torsional Constant: Lateral torsional buckling is a potentially more significant design consideration for the beam section which is much less stiff laterally. The computation of these constants is often necessary for computing the elastic critical moment corresponding to lateral torsional buckling of a doubly symmetric prismatic beam subjected to uniform moment in the unsupported length and torsionally restraining lateral supports. This is given by the following expression in Draft IS 800:

$$M_{cr} = \frac{\pi^2 E I_y}{(KL)^2}\left[\frac{I_w}{I_y} + \frac{G\, I_t\, (KL)^2}{\pi^2 E\, I_y}\right]^{0.5}$$

This expression for the elastic critical moment for the basic problem clearly demonstrates the influence of moment of inertia about minor axis (I_y), torsional and warping constants (I_t and I_w

respectively) of the cross-section; it also demonstrates the importance of unsupported length of the beam.

Warping constant is given as:

$$I_w = \frac{1}{4} I_y . h_s^2 \qquad \textbf{(1)}$$

Fillets are generally neglected while computing the warping constant. This has a very little effect upon the values of warping constant. The above expression can be written as:

$$I_w = \frac{1}{24} t_f . b_f^3 . (D - t_f)^2 \qquad \textbf{(2)}$$

Torsional constant is given as:

$$I_t = 2.\frac{1}{3} b_f . t_f^3 + \frac{1}{3} . (D - 2t_f) . t_w^3 + 2\alpha\varphi^4 - 0.42 t_f^4 \qquad \textbf{(3)}$$

where,

$$\alpha = -0.042 + 0.220 \frac{t_w}{t_f} + 0.136 . \frac{R}{t_f} - 0.0865 . \frac{t_w . R}{t_f^2} - 0.0725 . \frac{t_w^2}{t_f^2} \qquad \textbf{(4)}$$

$$\varphi = \frac{(t_f + R)^2 + t_w \left(R + \frac{t_w}{4} \right)}{2R + t_f} \qquad \textbf{(5)}$$

An approximate expression for torsional constant is obtained by considering only the first two terms of the expression for I_t. Thus,

$$I_t = 2.\frac{1}{3} b_f . t_f^3 + \frac{1}{3} . (D - 2t_f) . t_w^3 \qquad \textbf{(6)}$$

This approximate expression is often written as:

$$I_t = \sum \frac{b_e t_e^3}{3} \qquad \textbf{(7)}$$

However, there is some difference in the values of torsional constant obtained from equations **(3)** and **(6)**. International practice is to use the value as given by equation **(3)**. This is a complex equation and it is not practicable for practicing designers and budding engineers to compute it routinely. Other properties, mentioned above, are not very time consuming to compute, but are very frequently required. Accordingly, the torsional constant and other properties such as warping constant, local buckling ratio for flange and local buckling ratio for web must be provided either in **IS 12778 : 2004,** the relevant code or elsewhere for ready reference.

Excel spreadsheets were prepared to compute these additional sectional properties. **Tables 2 to 4** provide these additional sectional properties. In these tables, only those dimensions and sectional properties of parallel flange sections are reproduced, which are necessary for computation of these additional sectional properties. In **Table 3**, dimensions of section at S. No. 56, WPB 280 x 280 x 284.13, seem to be erroneous as the thickness of web is mentioned as

105.0 mm. Another typing mistake in IS 12778 : 2004 is that the unit of moment of inertia is incorrectly mentioned as kg.mm^2 in clause 4.1.2 and as cm^2 in Tables 1, 2 and 3 of the standard.

SECTION CLASSIFICATION AS PER DRAFT IS 800

All NPB sections confirming to IS 2062 : 1999 (Yield Stress 250 N / mm^2, $\varepsilon = 1$) are classified as Class 1 Plastic ($\frac{b}{t_f} \prec 9.4\varepsilon$ and $\frac{d}{t_w} \prec 83.9\varepsilon$) in pure bending, and are therefore suitable for plastic design. A majority of WPB and PBP sections are classified as Class 2 Compact or better ($\frac{b}{t_f} \prec 10.5\varepsilon$) when in pure bending. They can therefore attain their full plastic moment capacity. No parallel flange section (NPB, WPB and PBP sections), except PBP 360 x 83.44, is classified as Class 4 Slender ($\frac{b}{t_f} \succ 15.7\varepsilon$) under pure bending.

A majority of NPB, WPB and PBP sections are classified as Class 3 Semi-Compact or better ($\frac{b}{t_f} \prec 15.7\varepsilon$ and $\frac{d}{t_w} \prec 42\varepsilon$) under full axial load (when complete cross section is at yield in compression, stress ratio is 1). The whole cross-section of these sections is therefore effective. The remaining sections having $\frac{d}{t_w} \succ 42\varepsilon$ may behave as Class 3 Semi-Compact, if subjected to relatively smaller axial loads rather than up to its maximum capacity assumed above.

CONCLUSION

Parallel flange sections are more efficient than the conventional tapered flange sections in terms of strength, workability and economy. The use of these sections was not very common in India until recently, because of non-availability of the same in medium and large sizes. Such sections are now being produced in India and it is expected that the use of these efficient sections will increase.

Comparison of the sectional properties of tapered and parallel flange sections of same nominal depth reveals that:

- NPB section is more efficient than corresponding MB section in bending, as it has a lower mass for the same section modulus about major axis; and

- NPB section is more efficient than corresponding MB section in compression, as it has a higher radius of gyration about minor axis.

Further, it is suggested that the additional properties such as the depth between root fillets, local buckling ratio for flange, local buckling ratio for web, warping constant and torsional constant be provided either in **IS 12778 : 2004** or elsewhere for ready reference. These properties are frequently required while designing by limit state method and are presented here.

All NPB sections are classified as Class 1 Plastic, while a majority of WPB and PBP sections are classified as Class 2 Compact or better in pure bending. No parallel flange section, except one, is classified as Class 4 Slender under pure bending.

A majority of NPB, WPB and PBP sections are classified as Class 3 Semi-Compact or better when loaded up to its maximum capacity. The remaining sections may behave as Class 3 Semi-Compact, if subjected to relatively smaller axial loads rather than up to its maximum capacity as in above.

NOTATIONS

Symbol	Description	Units
b	Half Flange Width	mm
b_e	Width of each Cross-sectional Element	mm
B	Flange Width	mm
d	Depth between root fillets	mm
D	Overall depth of section	mm
h_s	Distance between Shear Centre of the two Flanges of the Cross-section	mm
R	Root Radius	mm
T, t_f	Thickness of Flange	mm
t, t_w	Thickness of Web	mm
t_e	Thickness of each Cross-sectional Element	mm
E	Modulus of Elasticity	N/mm^2
G	Modulus of Rigidity	N/mm^2
I_y	Moment of Inertia about the Minor Axis	mm^4
I_w	Warping Constant of the Cross-section	dm^6
I_t	Torsional Constant of the Cross-section	cm^4
KL	Effective Length between Points of Restraint against Lateral Torsional Buckling	m
M_{cr}	Elastic Critical Moment	kN-m

REFERENCES

Draft IS 800, "Code of Practice for General Construction in Steel (Third Revision)*", Bureau of Indian Standards*, New Delhi, India, October 2004.

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IS 2062 : 1999, "Steel for General Structural Purposes", *Bureau of Indian Standards*, New Delhi, India.

IS 800 : 1984, "Code of Practice for General Construction in Steel (Second Revision)*", Bureau of Indian Standards*, New Delhi, India.

IS 8500 : 1991, "Structural Steel – Microalloyed (Medium and High Strength Qualities)", *Bureau of Indian Standards*, New Delhi, India.

Seaburg, P.A., and Carter, C. J., "Torsional Analysis of Structural Steel Members", Steel Design Guide Series No. 9, Second Printing, American Institute of Steel Construction, Chicago, Illinois, October 2003.

SteelUK - Dimensions and Properties of UK structural Steel shapes, Techno Consultants Ltd., Manchester, England, November 2000.

Table 2: Additional Sectional Properties of Narrow Parallel Flange (NPB) Sections

S. No.	Designation		Mass	Depth	Width	Web Thk.	Flange Thk.	Root Radius	Depth between root fillets	Moment of Inertia	Local Buckling Ratios		Warping Constant	Torsional Constant
			M (kg/m)	D (mm)	B (mm)	t (mm)	T (mm)	R (mm)	d (mm)	I_y (cm^4)	Flange	Web	I_w (dm^6)	I_t (cm^4)
1	NPB	100x55x	8.10	100	55	4.1	5.7	7	74.6	15.9	4.8	18.2	0.000353	1.16
2	NPB	120x60x	10.37	120	64	4.4	6.3	7	93.4	27.7	5.1	21.2	0.000895	1.69
3	NPB	140x70x	12.89	140	73	4.7	6.9	7	112.2	44.9	5.3	23.9	0.001989	2.40
4	NPB	160x80x	15.77	160	82	5.0	7.4	9	127.2	68.3	5.5	25.4	0.003976	3.54
5	NPB	180x90x	15.37	177	91	4.3	6.5	9	146.0	81.9	7.0	34.0	0.005952	2.67
6	NPB	180x90x	18.80	180	91	5.3	8.0	9	146.0	100.9	5.7	27.5	0.007463	4.73
7	NPB	180x90x	21.27	182	92	6.0	9.0	9	146.0	117.3	5.1	24.3	0.008777	6.65
8	NPB	200x100x	18.42	197	100	4.5	7.0	12	159.0	117.2	7.1	35.3	0.010577	4.14
9	NPB	200x100x	22.36	200	100	5.6	8.5	12	159.0	142.4	5.9	28.4	0.013055	6.92
10	NPB	200x100x	25.09	202	102	6.2	9.5	12	159.0	168.9	5.4	25.6	0.015647	9.36
11	NPB	200x130x	27.37	207	133	5.8	8.5	12	166.0	334.0	7.8	28.6	0.032901	8.48
12	NPB	200x130x	31.55	210	134	6.4	10.0	12	166.0	401.9	6.7	25.9	0.040190	12.81
13	NPB	200x150x	30.45	194	150	6.0	9.0	12	152.0	507.0	8.3	25.3	0.043380	10.50
14	NPB	200x165x	35.68	201	165	6.2	10.0	12	157.0	749.5	8.3	25.3	0.068356	14.59
15	NPB	200x165x	42.47	205	166	7.2	12.0	12	157.0	916.0	6.9	21.8	0.085300	24.17
16	NPB	200x165x	48.00	210	166	6.5	14.5	12	157.0	1106.4	5.7	24.2	0.105717	37.90
17	NPB	220x110x	22.18	217	110	5.0	7.7	12	177.6	171.4	7.1	35.5	0.018771	5.68
18	NPB	220x110x	26.20	220	110	5.9	9.2	12	177.6	204.9	6.0	30.1	0.022763	9.04
19	NPB	220x110x	29.35	222	112	6.6	10.2	12	177.6	239.8	5.5	26.9	0.026893	12.17
20	NPB	240x120x	26.15	237	120	5.2	8.3	15	190.4	240.1	7.2	36.6	0.031395	8.51
21	NPB	240x120x	30.71	240	120	6.2	9.8	15	190.4	283.6	6.1	30.7	0.037571	12.96
22	NPB	240x120x	34.31	242	122	7.0	10.8	15	190.4	328.5	5.6	27.2	0.043899	17.11
23	NPB	250x125x	30.11	250	125	6.0	9.0	15	202.0	294.3	6.9	33.7	0.042733	11.11

Table 2 (Continued): Additional Sectional Properties of Narrow Parallel Flange (NPB) Sections

S. No.	Designation		Mass	Depth	Width	Web Thk.	Flange Thk.	Root Radius	Depth between root fillets	Moment of Inertia	Local Buckling Ratios		Warping Constant	Torsional Constant
			M (kg/m)	D (mm)	B (mm)	t (mm)	T (mm)	R (mm)	d (mm)	I_y (cm^4)	Flange	Web	I_w (dm^6)	I_t (cm^4)
24	NPB	250x150x	34.08	258	146	6.1	9.2	15	209.6	478.6	7.9	34.4	0.074065	12.86
25	NPB	250x150x	39.78	262	147	6.6	11.2	15	209.6	594.5	6.6	31.8	0.093486	20.33
26	NPB	250x150x	46.48	266	148	7.6	13.2	15	209.6	715.2	5.6	27.6	0.114267	31.55
27	NPB	250x175x	43.94	244	175	7.0	11.0	15	192.0	984.2	8.0	27.4	0.133578	22.47
28	NPB	270x135x	30.73	267	135	5.5	8.7	15	219.6	358.0	7.8	39.9	0.059713	10.42
29	NPB	270x135x	36.07	270	135	6.6	10.2	15	219.6	419.9	6.6	33.3	0.070854	15.91
30	NPB	270x135x	42.26	274	136	7.5	12.2	15	219.6	513.5	5.6	29.3	0.087987	25.00
31	NPB	300x150x	36.52	297	150	6.1	9.2	15	248.6	519.0	8.2	40.8	0.107470	13.36
32	NPB	300x150x	42.24	300	150	7.1	10.7	15	248.6	603.8	7.0	35.0	0.126337	19.93
33	NPB	300x150x	49.32	304	152	8.0	12.7	15	248.6	745.7	6.0	31.1	0.158192	30.99
34	NPB	300x165x	39.88	310	165	5.8	9.7	15	260.6	727.6	8.5	44.9	0.164038	15.43
35	NPB	300x165x	45.76	313	166	6.6	11.2	15	260.6	855.6	7.4	39.5	0.194827	22.59
36	NPB	300x165x	53.46	317	167	7.6	13.2	15	260.6	1026.8	6.3	34.3	0.236920	35.21
37	NPB	300x200x	59.56	303	203	7.5	13.1	15	246.8	1828.6	7.7	32.9	0.384198	39.58
38	NPB	300x200x	66.75	306	204	8.5	14.6	15	246.8	2068.5	7.0	29.0	0.439111	54.32
39	NPB	300x200x	75.37	310	205	9.4	16.6	15	246.8	2386.8	6.2	26.3	0.513661	77.64
40	NPB	330x160x	42.97	327	160	6.5	10.0	18	271.0	685.2	8.0	41.7	0.172138	19.66
41	NPB	330x160x	49.15	330	160	7.5	11.5	18	271.0	788.1	7.0	36.1	0.199867	28.08
42	NPB	330x160x	57.00	334	162	8.5	13.5	18	271.0	960.4	6.0	31.9	0.246631	42.23
43	NPB	350x170x	50.21	357.6	170	6.6	11.5	18	298.6	944.3	7.4	45.2	0.282783	27.39
44	NPB	350x170x	57.09	360	170	8.0	12.7	18	298.6	1043.5	6.7	37.3	0.314660	37.46
45	NPB	350x170x	66.04	364	172	9.2	14.7	18	298.6	1251.2	5.9	32.5	0.381649	55.77
46	NPB	350x250x	79.18	340	250	9.0	14.0	18	276.0	3650.1	8.9	30.7	0.969795	63.41
47	NPB	400x180x	57.38	397	180	7.0	12.0	21	331.0	1170.6	7.5	47.3	0.433780	36.20
48	NPB	400x180x	66.30	400	180	8.6	13.5	21	331.0	1317.8	6.7	38.5	0.492140	51.32
49	NPB	400x180x	75.66	404	182	9.7	15.5	21	331.0	1564.2	5.9	34.1	0.590221	73.39
50	NPB	400x200x	67.28	400	200	8.0	13.0	21	332.0	1738.4	7.7	41.5	0.650896	48.54

Table 2 (Concluded): Additional Sectional Properties of Narrow Parallel Flange (NPB) Sections

S. No.	Designation		Mass	Depth	Width	Web Thk.	Flange Thk.	Root Radius	Depth between root fillets	Moment of Inertia	Local Buckling Ratios		Warping Constant	Torsional Constant
			M (kg/m)	D (mm)	B (mm)	t (mm)	T (mm)	R (mm)	d (mm)	I_y (cm^4)	Flange	Web	I_w (dm^6)	I_t (cm^4)
51	NPB	450x190x	67.15	447	190	7.6	13.1	21	378.8	1502.4	7.3	49.8	0.707139	47.17
52	NPB	450x190x	77.57	450	190	9.4	14.6	21	378.8	1675.9	6.5	40.3	0.794264	66.79
53	NPB	450x190x	92.36	456	192	11.0	17.6	21	378.8	2085.4	5.5	34.4	1.002006	109.01
54	NPB	500x200x	79.36	497	200	8.4	14.5	21	426.0	1939.2	6.9	50.7	1.128645	64.32
55	NPB	500x200x	90.68	500	200	10.2	16.0	21	426.0	2141.7	6.3	41.8	1.254265	89.14
56	NPB	500x200x	107.31	506	202	12.0	19.0	21	426.0	2621.7	5.3	35.5	1.554465	142.84
57	NPB	550x210x	92.07	547	210	9.0	15.7	24	467.6	2432.2	6.7	52.0	1.716402	89.37
58	NPB	550x210x	105.52	550	210	11.1	17.2	24	467.6	2667.6	6.1	42.1	1.893168	122.89
59	NPB	550x210x	122.52	556	212	12.7	20.2	24	467.6	3224.4	5.2	36.8	2.314165	187.20
60	NPB	600x220x	107.56	597	220	9.8	17.5	24	514.0	3116.3	6.3	52.4	2.616292	122.20
61	NPB	600x220x	122.45	600	220	12.0	19.0	24	514.0	3387.3	5.8	42.8	2.858551	165.30
62	NPB	600x220x	154.46	610	224	15.0	24.0	24	514.0	4520.8	4.7	34.3	3.881062	316.50
63	NPB	700x250x	113.45	694	250	9.0	16.0	24	614.0	4176.5	7.8	68.2	4.799676	107.33
64	NPB	700x250x	128.41	695	250	11.5	16.5	24	614.0	4312.4	7.6	53.4	4.963165	136.39
65	NPB	700x250x	143.42	700	250	12.5	19.0	24	614.0	4966.4	6.6	49.1	5.758057	190.90
66	NPB	700x250x	153.86	704	250	13.0	21.0	24	614.0	5488.8	6.0	47.2	6.401162	240.08
67	NPB	700x250x	171.47	709	250	14.5	23.5	24	614.0	6145.5	5.3	42.3	7.219584	328.16
68	NPB	750x270x	145.29	750	265	13.2	16.6	17	682.8	5165.3	8.0	51.7	6.945722	150.69
69	NPB	750x270x	174.54	760	270	14.4	21.6	17	682.8	7107.0	6.3	47.4	9.687455	272.19
70	NPB	750x270x	202.48	770	270	15.6	26.6	17	682.8	8752.4	5.1	43.8	12.092394	450.99

Table 3: Additional Sectional Properties of Wide Parallel Flange (WPB) Sections

S. No.	Designation		Mass	Depth	Width	Web Thk.	Flange Thk.	Root Radius	Depth between root fillets	Moment of Inertia	Local Buckling Ratios		Warping Constant	Torsional Constant
			M (kg/m)	D (mm)	B (mm)	t (mm)	T (mm)	R (mm)	d (mm)	I_y (cm^4)	Flange	Web	I_w (dm^6)	I_t (cm^4)
1	WPB	100x100x	12.24	91	100	4.2	5.5	12	56.0	92.1	9.1	13.3	0.001683	2.33
2	WPB	100x100x	16.67	96	100	5.0	8.0	12	56.0	133.8	6.3	11.2	0.002590	5.29
3	WPB	100x100x	20.44	100	100	6.0	10.0	12	56.0	167.3	5.0	9.3	0.003388	9.34
4	WPB	100x100x	41.79	120	106	12.0	20.0	12	56.0	399.2	2.7	4.7	0.009980	67.24
5	WPB	120x120x	14.56	109	120	4.2	5.5	12	74.0	158.8	10.9	17.6	0.004253	2.60
6	WPB	120x120x	19.89	114	120	5.0	8.0	12	74.0	230.9	7.5	14.8	0.006486	6.05
7	WPB	120x120x	26.69	120	120	6.5	11.0	12	74.0	317.5	5.5	11.4	0.009431	13.94
8	WPB	120x120x	52.13	140	126	12.5	21.0	12	74.0	702.8	3.0	5.9	0.024881	90.52
9	WPB	140x140x	18.07	128	140	4.3	6.0	12	92.0	274.8	11.7	21.4	0.010225	3.44
10	WPB	140x140x	24.66	133	140	5.5	8.5	12	92.0	389.3	8.2	16.7	0.015086	8.11
11	WPB	140x140x	33.72	140	140	7.0	12.0	12	92.0	549.7	5.8	13.1	0.022516	20.16
12	WPB	140x140x	63.24	160	146	13.0	22.0	12	92.0	1144.3	3.3	7.1	0.054480	118.67
13	WPB	150x150x	22.96	152	152	5.8	6.8	8	122.4	399.9	11.2	21.1	0.021078	4.69
14	WPB	150x150x	30.04	158	153	6.5	9.4	8	123.2	560.5	8.1	19.0	0.030942	10.62
15	WPB	150x150x	36.98	162	154	8.0	11.5	8	123.0	706.2	6.7	15.4	0.039989	19.27
16	WPB	160x160x	23.83	148	160	4.5	7.0	15	104.0	478.7	11.4	23.1	0.023793	6.44
17	WPB	160x160x	30.44	152	160	6.0	9.0	15	104.0	615.6	8.9	17.3	0.031471	12.11
18	WPB	160x160x	42.59	160	160	8.0	13.0	15	104.0	889.2	6.2	13.0	0.048037	31.29
19	WPB	160x160x	76.19	180	166	14.0	23.0	15	104.0	1758.8	3.6	7.4	0.108382	160.61
20	WPB	180x180x	28.68	167	180	5.0	7.5	15	122.0	730.0	12.0	24.4	0.046428	8.32
21	WPB	180x180x	35.52	171	180	6.0	9.5	15	122.0	924.6	9.5	20.3	0.060289	14.90
22	WPB	180x180x	51.22	180	180	8.5	14.0	15	122.0	1362.8	6.4	14.4	0.093883	42.23
23	WPB	180x180x	88.90	200	186	14.5	24.0	15	122.0	2580.1	3.9	8.4	0.199803	201.20

Table 3 (Continued): Additional Sectional Properties of Wide Parallel Flange (WPB) Sections

S. No.	Designation		Mass	Depth	Width	Web Thk.	Flange Thk.	Root Radius	Depth between root fillets	Moment of Inertia	Local Buckling Ratios		Warping Constant	Torsional Constant
			M (kg/m)	D (mm)	B (mm)	t (mm)	T (mm)	R (mm)	d (mm)	I_y (cm^4)	Flange	Web	I_w (dm^6)	I_t (cm^4)
24	WPB	200x200x	34.64	186	200	5.5	8.0	18	134.0	1068.5	12.5	24.4	0.084636	12.54
25	WPB	200x200x	42.26	190	200	6.5	10.0	18	134.0	1335.5	10.0	20.6	0.108176	21.07
26	WPB	200x200x	50.92	194	202	8.0	12.0	18	134.0	1651.3	8.4	16.8	0.136744	34.34
27	WPB	200x200x	61.29	200	200	9.0	15.0	18	134.0	2003.4	6.7	14.9	0.171416	59.73
28	WPB	200x200x	74.01	206	206	10.2	18.0	18	134.0	2626.7	5.7	13.1	0.232095	99.39
29	WPB	200x200x	83.52	209	209	13.0	19.5	18	134.0	2973.5	5.4	10.3	0.266948	134.14
30	WPB	200x200x	103.06	220	206	15.0	25.0	18	134.0	3651.2	4.1	8.9	0.347092	257.55
31	WPB	220x220x	40.40	205	220	6.0	8.5	18	152.0	1510.5	12.9	25.3	0.145810	15.56
32	WPB	220x220x	50.51	210	220	7.0	11.0	18	152.0	1954.6	10.0	21.7	0.193510	28.64
33	WPB	220x220x	71.47	220	220	9.5	16.0	18	152.0	2843.3	6.9	16.0	0.295817	77.06
34	WPB	220x220x	117.31	240	226	15.5	26.0	18	152.0	5012.0	4.3	9.8	0.573824	313.14
35	WPB	240x240x	47.39	224	240	6.5	9.0	21	164.0	2077.0	13.3	25.2	0.240023	22.18
36	WPB	240x240x	60.32	230	240	7.5	12.0	21	164.0	2768.8	10.0	21.9	0.328961	42.18
37	WPB	240x240x	83.20	240	240	10.0	17.0	21	164.0	3922.7	7.1	16.4	0.487680	103.93
38	WPB	240x240x	156.67	270	248	18.0	32.0	21	164.0	8152.6	3.9	9.1	1.154490	626.11
39	WPB	250x250x	67.21	247	252	11.0	11.1	24	176.8	2969.9	11.4	16.1	0.413179	51.31
40	WPB	250x250x	73.14	252	250	9.0	13.6	24	176.8	3548.8	9.2	19.6	0.504236	67.66
41	WPB	250x250x	85.04	253	255	14.0	14.1	24	176.8	3910.3	9.0	12.6	0.557933	95.67
42	WPB	250x250x	97.03	260	256	12.7	17.6	24	176.8	4932.9	7.3	13.9	0.724615	140.32
43	WPB	250x250x	103.97	264	257	11.9	19.6	24	176.8	5555.5	6.6	14.9	0.829594	174.44
44	WPB	250x250x	117.57	269	259	13.5	22.1	24	176.8	6412.3	5.9	13.1	0.977228	244.73
45	WPB	250x250x	133.91	275	261	15.4	25.1	24	176.8	7454.1	5.2	11.5	1.163772	351.88
46	WPB	250x250x	148.37	280	263	17.3	27.6	24	176.8	8388.5	4.8	10.2	1.335989	466.84

Table 3 (Continued): Additional Sectional Properties of Wide Parallel Flange (WPB) Sections

S. No.	Designation		Mass	Depth	Width	Web Thk.	Flange Thk.	Root Radius	Depth between root fillets	Moment of Inertia	Local Buckling Ratios		Warping Constant	Torsional Constant
			M (kg/m)	D (mm)	B (mm)	t (mm)	T (mm)	R (mm)	d (mm)	I_y (cm^4)	Flange	Web	I_w (dm^6)	I_t (cm^4)
47	WPB	260x260x	54.14	244	260	6.5	9.5	24	177.0	2788.0	13.7	27.2	0.383282	30.14
48	WPB	260x260x	68.15	250	260	7.5	12.5	24	177.0	3667.6	10.4	23.6	0.517189	54.25
49	WPB	260x260x	92.98	260	260	10.0	17.5	24	177.0	5134.5	7.4	17.7	0.754852	126.75
50	WPB	260x260x	114.40	268	262	12.5	21.5	24	177.0	6455.9	6.1	14.2	0.980688	224.63
51	WPB	260x260x	141.51	278	265	15.5	26.5	24	177.0	8235.7	5.0	11.4	1.302316	407.49
52	WPB	260x260x	172.42	290	268	18.0	32.5	24	177.0	10448.6	4.1	9.8	1.732019	720.32
53	WPB	280x280x	61.25	264	280	7.0	10.0	24	196.0	3664.2	14.0	28.0	0.590999	35.55
54	WPB	280x280x	76.35	270	280	8.0	13.0	24	196.0	4762.6	10.8	24.5	0.786412	63.52
55	WPB	280x280x	188.53	310	288	18.5	33.0	24	196.0	13162.8	4.4	10.6	2.524921	807.41
56	**WPB**	**280x280x**	**284.13**	**280**	**280**	**105.0**	**18.0**	**24**	⇐ These dimensions from IS 12778 : 2004 seem to be erroneous.					
57	WPB	300x300x	69.79	283	300	7.5	10.5	27	208.0	4733.5	14.3	27.7	0.878730	47.88
58	WPB	300x300x	88.33	290	300	8.5	14.0	27	208.0	6309.6	10.7	24.5	1.201600	87.85
59	WPB	300x300x	100.84	294	300	10.0	16.0	27	208.0	7211.4	9.4	20.8	1.393315	124.06
60	WPB	300x300x	117.03	300	300	11.0	19.0	27	208.0	8562.8	7.9	18.9	1.690318	189.30
61	WPB	300x300x	237.92	340	310	21.0	39.0	27	208.0	19403.1	4.0	9.9	4.394851	1411.00
62	WPB	320x300x	74.24	301	300	8.0	11.0	27	225.0	4959.1	13.6	28.1	1.042651	53.67
63	WPB	320x300x	97.63	310	300	9.0	15.5	27	225.0	6985.2	9.7	25.0	1.514570	111.96
64	WPB	320x300x	126.65	320	300	11.5	20.5	27	225.0	9238.8	7.3	19.6	2.071807	230.58
65	WPB	320x300x	244.96	359	309	21.0	40.0	27	225.0	19709.3	3.9	10.7	5.014095	1506.25
66	WPB	340x300x	78.89	320	300	8.5	11.5	27	243.0	5184.7	13.0	28.6	1.233599	60.10
67	WPB	340x300x	104.78	330	300	9.5	16.5	27	243.0	7436.0	9.1	25.6	1.827067	131.51
68	WPB	340x300x	134.15	340	300	12.0	21.5	27	243.0	9689.9	7.0	20.3	2.457413	262.98
69	WPB	340x300x	247.92	377	309	21.0	40.0	27	243.0	19710.7	3.9	11.6	5.596311	1511.80
70	WPB	360x300x	83.69	339	300	9.0	12.0	27	261.0	5410.4	12.5	29.0	1.446322	67.22
71	WPB	360x300x	122.06	350	300	10.0	17.5	27	261.0	7886.8	8.6	26.1	2.179838	153.45
72	WPB	360x300x	141.80	360	300	12.5	22.5	27	261.0	10141.2	6.7	20.9	2.887865	298.48
73	WPB	360x300x	250.26	395	308	21.0	40.0	27	261.0	19521.7	3.9	12.4	6.150556	1513.09

Table 3 (Continued): Additional Sectional Properties of Wide Parallel Flange (WPB) Sections

S. No.	Designation		Mass	Depth	Width	Web Thk.	Flange Thk.	Root Radius	Depth between root fillets	Moment of Inertia	Local Buckling Ratios		Warping Constant	Torsional Constant
			M (kg/m)	D (mm)	B (mm)	t (mm)	T (mm)	R (mm)	d (mm)	I_y (cm^4)	Flange	Web	I_w (dm^6)	I_t (cm^4)
74	WPB	360x370x	136.20	356	369	11.2	17.8	27	266.4	14919.4	10.4	23.8	4.266174	192.78
75	WPB	360x370x	150.87	360	370	12.3	19.8	27	266.4	16731.3	9.3	21.7	4.841036	256.70
76	WPB	360x370x	165.34	364	371	13.3	21.8	27	266.4	18571.5	8.5	20.0	5.436846	333.21
77	WPB	360x370x	182.01	368	373	15.0	23.8	27	266.4	20607.1	7.8	17.8	6.103495	432.73
78	WPB	360x370x	197.65	372	374	16.4	25.8	27	266.4	22520.9	7.2	16.2	6.748075	546.15
79	WPB	400x300x	92.39	378	300	9.5	13.0	27	298.0	5861.4	11.5	31.4	1.952213	81.41
80	WPB	400x300x	124.80	390	300	11.0	19.0	27	298.0	8563.8	7.9	27.1	2.946825	193.29
81	WPB	400x300x	155.26	400	300	13.5	24.0	27	298.0	10819.0	6.3	22.1	3.823867	361.18
82	WPB	400x300x	255.74	432	307	21.0	40.0	27	298.0	19335.5	3.8	14.2	7.427926	1520.25
83	WPB	400x400x	191.10	368	391	15.0	24.2	27	265.6	24131.9	8.1	17.7	7.130882	467.49
84	WPB	400x400x	219.66	375	394	17.3	27.7	27	265.6	28265.8	7.1	15.4	8.523360	691.65
85	WPB	400x400x	239.62	380	395	18.9	30.2	27	265.6	31054.9	6.5	14.1	9.499697	887.87
86	WPB	450x300x	99.74	425	300	10.0	13.5	27	344.0	6087.5	11.1	34.4	2.577025	91.49
87	WPB	450x300x	139.75	440	300	11.5	21.0	27	344.0	9465.3	7.1	29.9	4.154344	250.24
88	WPB	450x300x	171.11	450	300	14.0	26.0	27	344.0	11721.3	5.8	24.6	5.268021	448.14
89	WPB	450x300x	263.32	478	307	21.0	40.0	27	344.0	19339.0	3.8	16.4	9.275178	1534.45
90	WPB	500x300x	107.45	472	300	10.5	14.0	27	390.0	6313.8	10.7	37.1	3.311020	102.72
91	WPB	500x300x	129.77	480	300	11.5	18.0	27	390.0	8115.9	8.3	33.9	4.330725	179.26
92	WPB	500x300x	155.07	490	300	12.0	23.0	27	390.0	10367.0	6.5	32.5	5.652322	317.96
93	WPB	500x300x	187.33	500	300	14.5	28.0	27	390.0	12623.9	5.4	26.9	7.031007	548.31
94	WPB	500x300x	270.27	524	306	21.0	40.0	27	390.0	19154.7	3.8	18.6	11.217759	1544.38
95	WPB	550x300x	119.98	522	300	11.5	15.0	27	438.0	6766.5	10.0	38.1	4.348305	126.78
96	WPB	550x300x	166.23	540	300	12.5	24.0	27	438.0	10819.0	6.3	35.0	7.201559	360.51
97	WPB	550x300x	199.44	550	300	15.0	29.0	27	438.0	13076.9	5.2	29.2	8.874017	610.36
98	WPB	550x300x	278.19	572	306	21.0	40.0	27	438.0	19158.4	3.8	20.9	13.555718	1559.20

Table 3 (Concluded): Additional Sectional Properties of Wide Parallel Flange (WPB) Sections

S. No.	Designation		Mass	Depth	Width	Web Thk.	Flange Thk.	Root Radius	Depth between root fillets	Moment of Inertia	Local Buckling Ratios		Warping Constant	Torsional Constant
			M (kg/m)	D (mm)	B (mm)	t (mm)	T (mm)	R (mm)	d (mm)	I_y (cm^4)	Flange	Web	I_w (dm^6)	I_t (cm^4)
99	WPB	600x300x	128.79	571	300	12.0	15.5	27	486.0	6993.4	9.7	40.5	5.395063	141.88
100	WPB	600x300x	177.77	590	300	13.0	25.0	27	486.0	11271.3	6.0	37.4	8.995202	407.04
101	WPB	600x300x	211.92	600	300	15.5	30.0	27	486.0	13530.2	5.0	31.4	10.989905	677.31
102	WPB	600x300x	285.47	620	305	21.0	40.0	27	486.0	18975.5	3.8	23.1	15.958396	1569.75
103	WPB	650x300x	137.97	620	300	12.5	16.0	27	534.0	7220.6	9.4	42.7	6.585476	158.54
104	WPB	650x300x	189.69	640	300	13.5	26.0	27	534.0	11723.9	5.8	39.6	11.049659	457.77
105	WPB	650x300x	224.78	650	300	16.0	31.0	27	534.0	13984.0	4.8	33.4	13.395309	749.42
106	WPB	650x300x	293.38	668	305	21.0	40.0	27	534.0	18979.2	3.8	25.4	18.712732	1584.57
107	WPB	700x300x	149.89	670	300	13.0	17.0	27	582.0	7673.1	8.8	44.8	8.179697	186.45
108	WPB	700x300x	204.48	690	300	14.5	27.0	27	582.0	12178.8	5.6	40.1	13.383557	521.71
109	WPB	700x300x	240.51	700	300	17.0	32.0	27	582.0	14440.8	4.7	34.2	16.109579	839.02
110	WPB	700x300x	300.67	716	304	21.0	40.0	27	582.0	18797.4	3.8	27.7	21.474902	1595.12
111	WPB	800x300x	171.51	770	300	14.0	18.0	30	674.0	8133.7	8.3	48.1	11.499100	243.20
112	WPB	800x300x	224.37	790	300	15.0	28.0	30	674.0	12638.7	5.4	44.9	18.346463	608.87
113	WPB	800x300x	262.33	800	300	17.5	33.0	30	674.0	14903.7	4.5	38.5	21.919207	958.98
114	WPB	800x300x	317.35	814	303	21.0	40.0	30	674.0	18627.4	3.8	32.1	27.898071	1657.70
115	WPB	850x300x	179.89	835	292	14.0	18.8	30	737.4	7836.3	7.8	52.7	13.051014	264.11
116	WPB	850x300x	195.73	840	292	14.7	21.3	30	737.4	8877.3	6.9	50.2	14.875463	343.87
117	WPB	850x300x	214.24	846	293	15.4	24.3	30	737.4	10230.0	6.0	47.9	17.268007	459.45
118	WPB	850x300x	230.55	851	294	16.1	26.8	30	737.4	11397.7	5.5	45.8	19.356305	579.52
119	WPB	850x300x	253.68	859	292	17.0	30.8	30	737.4	12833.4	4.7	43.4	22.006562	802.91
120	WPB	900x300x	198.00	870	300	15.0	20.0	30	770.0	9041.4	7.5	51.3	16.331029	321.99
121	WPB	900x300x	251.61	890	300	16.0	30.0	30	770.0	13547.5	5.0	48.1	25.049328	749.27
122	WPB	900x300x	291.45	900	300	18.5	35.0	30	770.0	15815.9	4.3	41.6	29.584629	1150.49

Table 4: Additional Sectional Properties of Parallel Flange Bearing Piles (PBP) Sections

S. No.	Designation		Mass	Depth	Width	Web Thk.	Flange Thk.	Root Radius	Depth between root fillets	Moment of Inertia	Local Buckling Ratios		Warping Constant	Torsional Constant
			M (kg/m)	D (mm)	B (mm)	t (mm)	T (mm)	R (mm)	d (mm)	I_y (cm^4)	Flange	Web	I_w (dm^6)	I_t (cm^4)
1	PBP	200x	43.85	200	205	9.3	9.3	10	161.4	1337.0	11.0	17.4	0.121555	17.97
2	PBP	200x	53.49	204	207	11.3	11.3	10	161.4	1673.2	9.2	14.3	0.155329	31.95
3	PBP	220x	57.19	210	225	11.0	11.0	18	152.0	2079.3	10.2	13.8	0.205856	37.68
4	PBP	260x	75.00	249	265	12.0	12.0	24	177.0	3732.5	11.0	14.8	0.524127	64.35
5	PBP	260x	87.30	253	267	14.0	14.0	24	177.0	4455.0	9.5	12.6	0.636185	96.64
6	PBP	300x	76.92	299	306	10.8	10.8	15	247.4	5162.0	14.2	22.9	1.071879	43.55
7	PBP	300x	88.00	302	308	12.4	12.4	15	247.2	5996.0	12.4	19.9	1.257184	65.03
8	PBP	300x	95.00	304	309	13.3	13.3	15	247.4	6547.5	11.6	18.6	1.383266	79.83
9	PBP	300x	109.54	308	311	15.3	15.3	15	247.4	7681.2	10.2	16.2	1.645184	120.55
10	PBP	300x	124.20	312	313	17.3	17.3	15	247.4	8856.4	9.0	14.3	1.922904	173.52
11	PBP	300x	150.00	319	316	20.8	20.8	15	247.4	10963.5	7.6	11.9	2.437275	300.49
12	PBP	300x	180.12	327	320	24.8	24.8	15	247.4	13584.3	6.5	10.0	3.101460	510.06
13	PBP	300x	184.11	328	321	25.3	25.3	15	247.4	13989.6	6.3	9.8	3.204573	542.29
14	PBP	300x	222.58	338	326	30.3	30.3	15	247.4	17567.3	5.4	8.2	4.158149	936.62
15	PBP	320x	88.47	303	304	12.0	12.0	27	225.0	5633.6	12.7	18.8	1.192647	78.84
16	PBP	320x	102.83	307	306	14.0	14.0	27	225.0	6704.2	10.9	16.1	1.438872	117.00
17	PBP	320x	117.32	311	308	16.0	16.0	27	225.0	7814.9	9.6	14.1	1.700229	167.06
18	PBP	320x	146.68	319	312	20.0	20.0	27	225.0	10160.1	7.8	11.3	2.270808	309.80
19	PBP	320x	184.09	329	317	25.0	25.0	27	225.0	13332.3	6.3	9.0	3.080295	586.61

Table 4 (Concluded): Additional Sectional Properties of Parallel Flange Bearing Piles (PBP) Sections

S. No.	Designation		Mass	Depth	Width	Web Thk.	Flange Thk.	Root Radius	Depth between root fillets	Moment of Inertia	Local Buckling Ratios		Warping Constant	Torsional Constant
			M (kg/m)	D (mm)	B (mm)	t (mm)	T (mm)	R (mm)	d (mm)	I_y (cm^4)	Flange	Web	I_w (dm^6)	I_t (cm^4)
20	PBP	360x	83.44	340	367	9.9	9.9	15	290.2	8160.2	18.5	29.3	2.222961	39.33
21	PBP	360x	109.08	346	371	12.9	12.9	15	290.2	10986.7	14.4	22.5	3.047590	85.00
22	PBP	360x	134.84	352	374	15.9	15.9	15	290.2	13876.5	11.8	18.3	3.918835	157.54
23	PBP	360x	152.18	356	376	17.9	17.9	15	290.2	15877.0	10.5	16.2	4.537314	224.09
24	PBP	360x	174.02	361	379	20.4	20.4	15	290.2	18462.8	9.3	14.2	5.354598	331.50
25	PBP	360x	178.41	362	379	20.9	20.9	15	290.2	18991.4	9.1	13.9	5.524086	356.15
26	PBP	400x	122.41	348	390	14.0	14.0	15	290.0	13850.6	13.9	20.7	3.862794	111.39
27	PBP	400x	140.18	352	392	16.0	16.0	15	290.0	16076.6	12.3	18.1	4.537460	165.36
28	PBP	400x	158.08	356	394	18.0	18.0	15	290.0	18367.5	10.9	16.1	5.245942	234.76
29	PBP	400x	176.10	360	396	20.0	20.0	15	290.0	20724.6	9.9	14.5	5.989409	321.64
30	PBP	400x	194.25	364	398	22.0	22.0	15	290.0	23148.9	9.0	13.2	6.768970	428.06
31	PBP	400x	212.52	368	400	24.0	24.0	15	290.0	25641.6	8.3	12.1	7.585811	556.12
32	PBP	400x	230.92	372	402	26.0	26.0	15	290.0	28203.6	7.7	11.2	8.441055	707.96