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Addition of Local Buckling Ratio and Torsional Constant as a Sectional Property for Parallel Bearing Piles (PBP) Sections in IS 12778:2004

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Abstract – *Generally all the structural steel products are essential for construction purposes, as they help in designing and building industrial and warehouse spaces. Structural steel is known for its shear strength, hardness, durability and more. In addition, this metal can easily absorb shocks, due to which most residential, industrial, and commercial buildings are constructed with structural steel. The sectional properties of hot rolled parallel flange steel sections listed in IS 12778:2004 for PBP sections include Moment of Inertia, Radius of Gyration, Elastic Section Modulus and Plastic Section Modulus; each about the major and minor axes which is generally required from design point of view. Few other properties which are frequently required while designing by limit state method and can be added in IS 12778:2004 are the local buckling ratio and the torsional constant.*

INTRODUCTION

According to the IS 12778:2004, covering the nominal dimensions, mass and sectional properties of hot rolled parallel flange beams, columns and bearing piles, the pile sections are classified as parallel flange bearing piles. These parallel flange bearing piles, generally known as PBP, is the type of IS Parallel Flange Sections, in which flanges and webs are of same 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, a section PBP 300 x 150.00 would mean that the bearing pile section having nominal depth of 300 mm, nominal flange width of 300 mm and a mass of 150.00 kg/m. They are doubly symmetric wide flange shapes and are generally used as bearing piles. The bearing piles are used for compression members. The load carrying capacities of parallel flange sections under direct compressions are much higher than that of sections available today. Also the connections to the flanges are easier and simpler since no tapered washers, etc. are required.

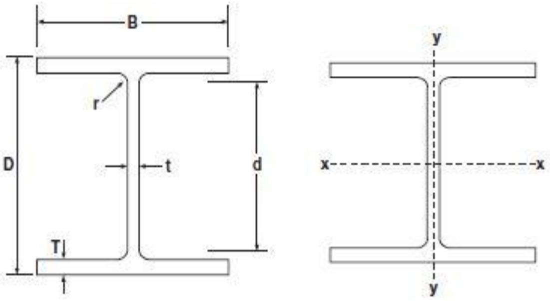

Fig.1 Parallel Bearing Piles

METHOLOGY

The shear center is the point through which the applied loads must pass to produce bending without twisting. If a shape has a line of symmetry, the shear center will always lie on that line; for cross-sections with two lines of symmetry, the shear center is at the intersection of those lines (as is the centroid). The torsional constant, also known as the St. Venants torsional constant, occurs due to the torsional restraint in which the cross-section is prevented from rotation about the shear centre.

The stability of a flexural member is very often a function of its torsional stiffness. One of the assumption made in the theory of torsion is that a plane section remain plane after twisting, which is true for round shapes only. It is because no warping exists on a circular cross-section and the entire torque is transferred entirely by the shear. However, the steel beam sections are normally open non circular thin walled sections. For such sections torsional rigidity is much less than flexural rigidity.

The nature of buckling process for an ideal beam is same as that of an ideal column. This implies that the beam is stable with no tendency of lateral-torsional buckling until the bending moments reaches a certain critical magnitude M_{cr}, whereupon the beam becomes unstable and undergoes rotations and deflections of any magnitude, leading to collapse. The torsional behavior of the structural steel shapes is different and is described by two phenomena:- St.Venant torsion and warping torsion. From the elastic stability theory, the expression for the stability limit state, for a steel beam applied with uniform moment, the critical moment M_{cr} is given by:-

$$M_{cr} = \frac{\pi}{L}\sqrt{EI_y GI_t + (\frac{\pi E}{L})^2 I_w I_y}$$

where, EI_y = flexural rigidity (minor axis)
GI_t = torsional rigidity
I_t, I_w = torsion constant and warping constant.
L = unbraced length of the beam subjected to constant moment in the plane.

The above equation for calculating the elastic critical moment corresponding to lateral torsional buckling of a doubly symmetric torsionally restrained prismatic beam subjected to uniform moment in the unsupported length can be simplified and given as :-

$$M_{cr} = \frac{\pi^2 EI_y}{(L_{LT})^2}(\frac{I_w}{I_y} + \frac{GI_t(L_{LT})^2}{\pi^2 EI_y})^{0.5}$$

where, I_y, I_w, I_t = moment of inertia about the minor axis, warping constant and torsional constant, respectively.
G = modulus of rigidity
L_{LT} = effective length against lateral-torsional buckling

The Torsional constant is given by :-

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

where,

$$\alpha = -0.042 + .220\frac{t_w}{t_f} + 0.136\frac{R}{t_f} - 0.0865\frac{t_w.\mathrm{R}}{t_f^2} - 0.0725\frac{t_w^2}{t_f^2}$$

and ,

$$\varphi = \frac{(t_f + \mathrm{R})^2 + t_w(\mathrm{R} + \frac{t_w}{4})}{2\mathrm{R} + t_f}$$

Most of the structural members are made economical by placing most of it away from the centroidal axis and by making the elements thin. But such members may buckle locally out of their original plane under compression. Local buckling adversely affects the load carrying capacity of columns and beams due to reduced stiffness and strength of the locally buckled plate elements of the section.

For an I-Section beam, the compression flange undergoes local buckling, whereas web being partially in compression and partially in tension, buckles as a plate subjected to in-plane bending. The local buckling generally may occur in the region of maximum bending moment only. The local buckling can be prevented by controlling the width-to-thickness ratio or by adopting higher thickness of the elements.

Depending on the cross section elements such as b, d, D, t_w and t_f, the local buckling can be found by using the formulas :-

For flange:-

$$Local\ buckling\ ratio(flange) = \frac{b}{t_f} = \frac{b_f/2}{t_f}$$

For web:-

$$Local\ buckling\ ratio(web) = \frac{d}{t_w}$$

where, $d = depth\ of\ web = D - 2t_f - 2r$
b_f = width of the flange.
t_f = thickness of the flange.
t_w = thickness of the web.

The Local buckling ratio is generally used to classify the section under 4 categories as:-

- Plastic (Class 1) if the section satisfies the condition $(\frac{b}{t_f} < 9.4\varepsilon\ and\ \frac{d}{t_w} < 83.9\varepsilon)$.
- Compact (Class 2) if the section satisfies the condition $(\frac{b}{t_f} < 10.5\varepsilon)$

- Semi-compact (Class 3) if the section satisfies the condition ($\frac{b}{t_f} < 15.7\varepsilon$)
- Slender (Class 4) if the section satisfies the condition ($\frac{b}{t_f} > 15.7\varepsilon$)

Depending upon the cross-section of different PBP sections falling under different classes, the section can be governed as the most critical section.

CONCLUSION

These sections are more efficient in terms of strength, workability and economy. Uses of such sections are increasing in India, nowadays, mostly because they have a greater resistance against pure bending.

Addition of properties such as warping constant and local buckling ratio for flange and web is suggested either in IS 12778:2004 or elsewhere for ready reference because these properties are frequently required while designing by limit state method and are presented here. Addition of these properties will make it easier and simpler for the practicing designers and budding engineers as these will be readily available for them for designing.

A majority of PBP sections are classified as Class 2 Compact or better when in pure bending. They can therefore attain their full plastic moment capacity. Also, a majority of sections are classified as Class 3 Semi-Compact or better when loaded upto its maximum capacity. The whole cross-section of these sections is therefore effective. The remaining sections may behave as Class 3 Semi-Compact, if subjected to relatively smaller axial loads instead of loading them to their maximum capacity. No PBP section, except PBP 360 x 83.44, is classified as Class 4 Slender under pure bending.

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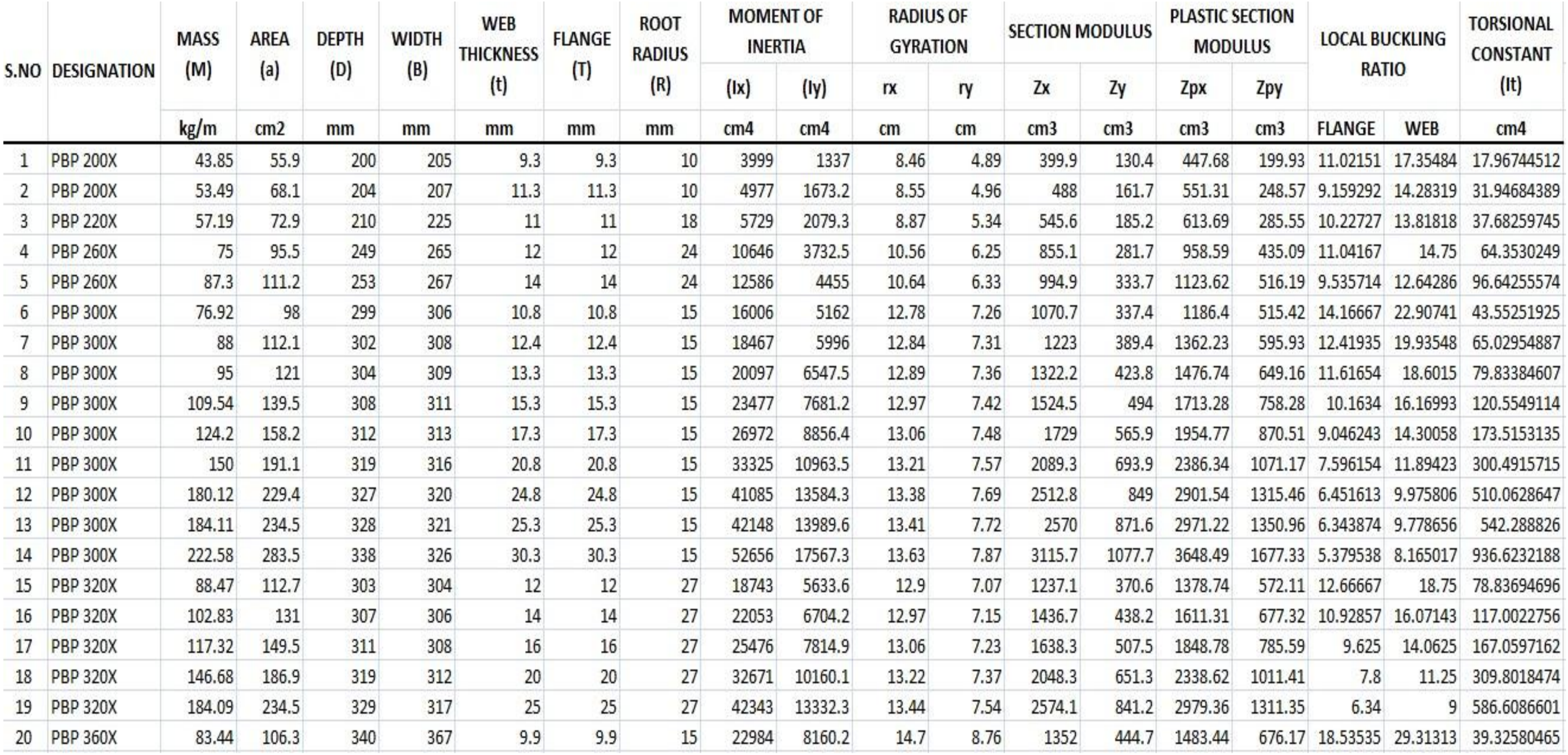
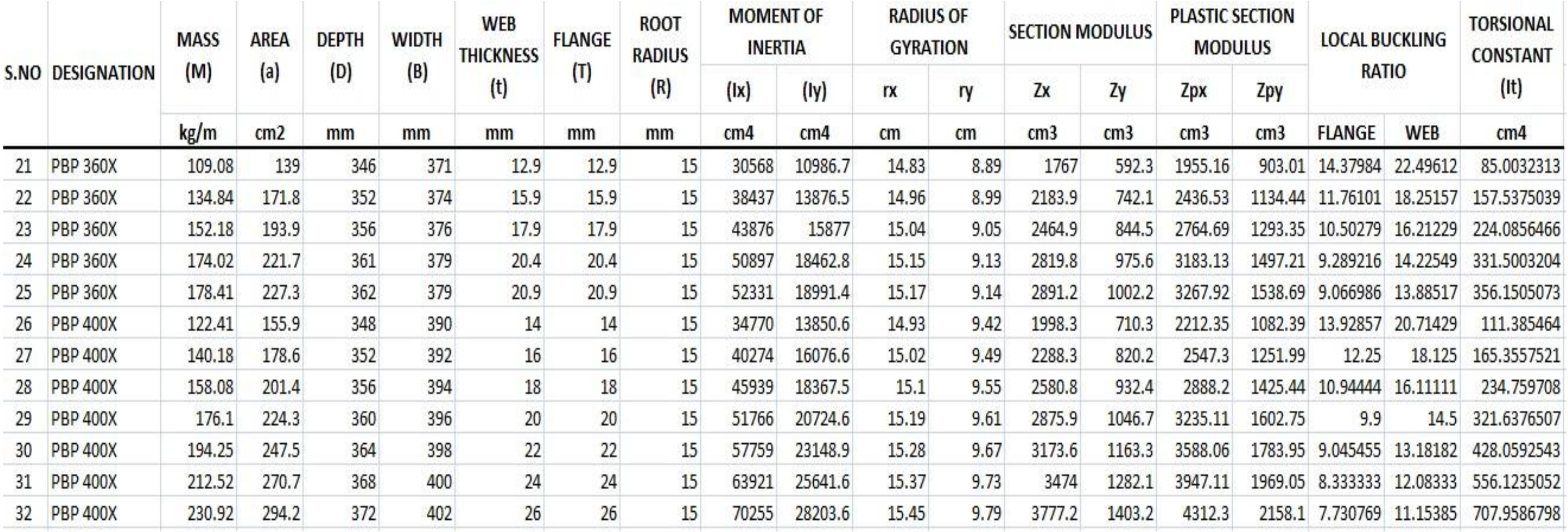
Table 1: Additional Sectional Properties of Parallel Flange Bearing Piles (PBP) Sections



S.NO	DESIGNATION	MASS (M)	AREA (a)	DEPTH (D)	WIDTH (B)	WEB THICKNESS (t)	FLANGE (T)	ROOT RADIUS (R)	MOMENT OF INERTIA		RADIUS OF GYRATION		SECTION MODULUS		PLASTIC SECTION MODULUS		LOCAL BUCKLING RATIO		TORSIONAL CONSTANT (It)
									(Ix)	(Iy)	rx	ry	Zx	Zy	Zpx	Zpy			
		kg/m	cm2	mm	mm	mm	mm	mm	cm4	cm4	cm	cm	cm3	cm3	cm3	cm3	FLANGE	WEB	cm4
1	PBP 200X	43.85	55.9	200	205	9.3	9.3	10	3999	1337	8.46	4.89	399.9	130.4	447.68	199.93	11.02151	17.35484	17.96744512
2	PBP 200X	53.49	68.1	204	207	11.3	11.3	10	4977	1673.2	8.55	4.96	488	161.7	551.31	248.57	9.159292	14.28319	31.94684389
3	PBP 220X	57.19	72.9	210	225	11	11	18	5729	2079.3	8.87	5.34	545.6	185.2	613.69	285.55	10.22727	13.81818	37.68259745
4	PBP 260X	75	95.5	249	265	12	12	24	10646	3732.5	10.56	6.25	855.1	281.7	958.59	435.09	11.04167	14.75	64.3530249
5	PBP 260X	87.3	111.2	253	267	14	14	24	12586	4455	10.64	6.33	994.9	333.7	1123.62	516.19	9.535714	12.64286	96.64255574
6	PBP 300X	76.92	98	299	306	10.8	10.8	15	16006	5162	12.78	7.26	1070.7	337.4	1186.4	515.42	14.16667	22.90741	43.55251925
7	PBP 300X	88	112.1	302	308	12.4	12.4	15	18467	5996	12.84	7.31	1223	389.4	1362.23	595.93	12.41935	19.93548	65.02954887
8	PBP 300X	95	121	304	309	13.3	13.3	15	20097	6547.5	12.89	7.36	1322.2	423.8	1476.74	649.16	11.61654	18.6015	79.83384607
9	PBP 300X	109.54	139.5	308	311	15.3	15.3	15	23477	7681.2	12.97	7.42	1524.5	494	1713.28	758.28	10.1634	16.16993	120.5549114
10	PBP 300X	124.2	158.2	312	313	17.3	17.3	15	26972	8856.4	13.06	7.48	1729	565.9	1954.77	870.51	9.046243	14.30058	173.5153135
11	PBP 300X	150	191.1	319	316	20.8	20.8	15	33325	10963.5	13.21	7.57	2089.3	693.9	2386.34	1071.17	7.596154	11.89423	300.4915715
12	PBP 300X	180.12	229.4	327	320	24.8	24.8	15	41085	13584.3	13.38	7.69	2512.8	849	2901.54	1315.46	6.451613	9.975806	510.0628647
13	PBP 300X	184.11	234.5	328	321	25.3	25.3	15	42148	13989.6	13.41	7.72	2570	871.6	2971.22	1350.96	6.343874	9.778656	542.288826
14	PBP 300X	222.58	283.5	338	326	30.3	30.3	15	52656	17567.3	13.63	7.87	3115.7	1077.7	3648.49	1677.33	5.379538	8.165017	936.6232188
15	PBP 320X	88.47	112.7	303	304	12	12	27	18743	5633.6	12.9	7.07	1237.1	370.6	1378.74	572.11	12.66667	18.75	78.83694696
16	PBP 320X	102.83	131	307	306	14	14	27	22053	6704.2	12.97	7.15	1436.7	438.2	1611.31	677.32	10.92857	16.07143	117.0022756
17	PBP 320X	117.32	149.5	311	308	16	16	27	25476	7814.9	13.06	7.23	1638.3	507.5	1848.78	785.59	9.625	14.0625	167.0597162
18	PBP 320X	146.68	186.9	319	312	20	20	27	32671	10160.1	13.22	7.37	2048.3	651.3	2338.62	1011.41	7.8	11.25	309.8018474
19	PBP 320X	184.09	234.5	329	317	25	25	27	42343	13332.3	13.44	7.54	2574.1	841.2	2979.36	1311.35	6.34	9	586.6086601
20	PBP 360X	83.44	106.3	340	367	9.9	9.9	15	22984	8160.2	14.7	8.76	1352	444.7	1483.44	676.17	18.53535	29.31313	39.32580465

Table 1 (Contd.) : Additional Sectional Properties of Parallel Flange Bearing Piles (PBP) Sections



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									(Ix)	(Iy)	rx	ry	Zx	Zy	Zpx	Zpy			
		kg/m	cm2	mm	mm	mm	mm	mm	cm4	cm4	cm	cm	cm3	cm3	cm3	cm3	FLANGE	WEB	cm4
21	PBP 360X	109.08	139	346	371	12.9	12.9	15	30568	10986.7	14.83	8.89	1767	592.3	1955.16	903.01	14.37984	22.49612	85.0032313
22	PBP 360X	134.84	171.8	352	374	15.9	15.9	15	38437	13876.5	14.96	8.99	2183.9	742.1	2436.53	1134.44	11.76101	18.25157	157.5375039
23	PBP 360X	152.18	193.9	356	376	17.9	17.9	15	43876	15877	15.04	9.05	2464.9	844.5	2764.69	1293.35	10.50279	16.21229	224.0856466
24	PBP 360X	174.02	221.7	361	379	20.4	20.4	15	50897	18462.8	15.15	9.13	2819.8	975.6	3183.13	1497.21	9.289216	14.22549	331.5003204
25	PBP 360X	178.41	227.3	362	379	20.9	20.9	15	52331	18991.4	15.17	9.14	2891.2	1002.2	3267.92	1538.69	9.066986	13.88517	356.1505073
26	PBP 400X	122.41	155.9	348	390	14	14	15	34770	13850.6	14.93	9.42	1998.3	710.3	2212.35	1082.39	13.92857	20.71429	111.385464
27	PBP 400X	140.18	178.6	352	392	16	16	15	40274	16076.6	15.02	9.49	2288.3	820.2	2547.3	1251.99	12.25	18.125	165.3557521
28	PBP 400X	158.08	201.4	356	394	18	18	15	45939	18367.5	15.1	9.55	2580.8	932.4	2888.2	1425.44	10.94444	16.11111	234.759708
29	PBP 400X	176.1	224.3	360	396	20	20	15	51766	20724.6	15.19	9.61	2875.9	1046.7	3235.11	1602.75	9.9	14.5	321.6376507
30	PBP 400X	194.25	247.5	364	398	22	22	15	57759	23148.9	15.28	9.67	3173.6	1163.3	3588.06	1783.95	9.045455	13.18182	428.0592543
31	PBP 400X	212.52	270.7	368	400	24	24	15	63921	25641.6	15.37	9.73	3474	1282.1	3947.11	1969.05	8.333333	12.08333	556.1235052
32	PBP 400X	230.92	294.2	372	402	26	26	15	70255	28203.6	15.45	9.79	3777.2	1403.2	4312.3	2158.1	7.730769	11.15385	707.9586798