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Addition of Warping Constant and Shape Factor as a Sectional Property for Narrow Parallel Flange (NPB) Sections in IS 12778:2004

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Abstract *– Structural steel is an ideal material when it comes to the construction of bridges, buildings and other structures that are large structures. Today, most commercial and industrial buildings are constructed with the help of structural steel. This is a high quality metal which has many industrial uses too. The sectional properties of hot rolled parallel flange steel section includes 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. The additional sectional property includes the warping constant and the shape factor which is frequently required while designing by the limit state method.*

Keywords – Narrow Parallel Flange Section, Warping Constant, Shape Factor.

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. 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.

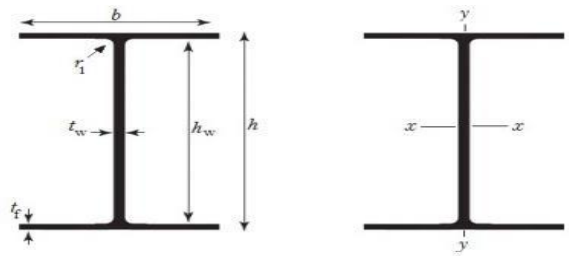

Fig.1 Parallel Flange Beams

The Narrow Parallel Flange Sections (NPB) are the type of Indian Standard Parallel Flange Sections in which the nominal flange widths are generally lower than the nominal depth. These sections are designated by nominal depth and nominal flange width and mass of the section in kg/m. For example, NPB 400 x 200 x 67.28 shows the nominal depth as 400 mm, nominal flange width as 200 mm and the mass as 67.28 kg/m.

The compression flange of an beam acts like a column and will buckle side-ways if the beam is not sufficiently stiff or the flange is not restrained laterally. The bending of a beam in the plane of its strong axis, and buckling about its weak axis and accompanied by twisting is characterized as lateral-torsion buckling and the flanges therefore wrap. The warping of beam-flanges is characterized by out-of-plane deformation due to rotation of the beam cross section about the longitudinal axis of the beam. The load at which such a beam buckles can be much less that that causing the full moment capacity to develop. From the elastic stability theory, the expression for the stability limit state, for a steel beam applied with uniform moment, the critical moment Mcr is given by:-

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

where, EIy = 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 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 is given by equation :-

$$M_{cr} = \frac{\pi^2 E I_y}{(L_{LT})^2}\left(\frac{I_w}{I_y} + \frac{G I_t (L_{LT})^2}{\pi^2 E I_y}\right)^{0.5}$$

where, I_y, I_w, It = 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

For a ductile material like structural steel, a member reaching yield at the extreme fibers retain a reserve of strength that varies with the shape factor. Higher the shape factor, more ductile will be the section and will give greater deflection at collapse. This implies that such a section gives longer warning before collapse. In other words, shape factor gives an indication of reserve capacity of a section from onset of yielding at extreme fibers to full plastification. Shape factor may be defined as the ratio of the plastic moment and the yield moment of the section. It is a function of cross section form or shape.

METHOLOGY

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 :-

$$M_{cr} = \frac{\pi^2 E I_y}{(L_{LT})^2}\left(\frac{I_w}{I_y} + \frac{G I_t (L_{LT})^2}{\pi^2 E I_y}\right)^{0.5}$$

This expression for the elastic critical moment for the basic problem clearly demonstrates the influence of moment of inertia about the minor axis (Iy), torsional and warping constants (It and Iw respectively) of the cross section; it also demonstrates the importance of unsupported length of the beam.

Warping constant is given as:-

$$I_w = \frac{1}{4} I_y h_s^2$$

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:-

$$I_W = \frac{1}{24} . t_f . b_f^3 . \left(D - t_f\right)^2$$

where, t_f = thickness of the flange.

b_f= width of the flange.
D = overall depth of the section

As the shape factor varies with the reserved strength of the structural steel giving an idea of the ductility of the section, it can be given by :-

$$\text{Shape Factor (S)} = \frac{M_p}{M_y} = \frac{f_y Z_p}{f_y Z_e} = \frac{Z_p}{Z_e}$$

The Elastic section modulus Ze is defined as the first moment of area and is expressed as I/y, where I is the moment of inertia of the section and y is the distance of the extreme fibre distance from the neutral axis whereas plastic section modulus is the combined statical moment of the cross-sectional area above and below the equal area axis of a completely yielded section.

CONCLUSION

These sections are economical and more efficient as compared to conventional tapered sections. The uses of NPB sections were not very common in India, until few years before, due to non-availability of the same in medium in large sizes. Such sections are now being produced in India and are expected that use of such sections will increase in few years ahead.

The addition of such sectional properties of the NPB sections helps to reduce the work time and its addition in the IS code will make it more easier for the practicing designers and budding engineers for designing purposes as the values will be readily available for them.

The shape factor of all the NPB sections generally lies in the range of 1.0 to 1.25. This means that even when the extreme fibers has yielded, it can take up to 25% more moment than the applied one before it gives up for good.

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Table 1: Additional Sectional Properties of Narrow Parallel Flange (NPB) 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		WARPING CONSTANT (Iw)	SHAPE FACTOR (S)
									(Ix)	(Iy)	rx	ry	Zx	Zy	Zpx	Zpy		
		kg/m	cm2	mm	mm	mm	mm	mm	cm4	cm4	cm	cm	cm3	cm3	cm3	cm3	(dm6)	
1	NPB 100X55X	8.1	10.3	100	55	4.1	5.7	7	171	15.9	4.07	1.24	34.2	5.8	39.41	9.15	0.000351378	1.152339
2	NPB 120X60X	10.37	13.2	120	64	4.4	6.3	7	318	27.7	4.9	1.45	53	8.6	60.73	13.58	0.000889591	1.145849
3	NPB 140X70X	12.89	16.4	140	73	4.7	6.9	7	541	44.9	5.74	1.65	77.3	12.3	88.35	19.25	0.001981356	1.14295
4	NPB 160X80X	15.77	20.1	160	82	5.0	7.4	9	869	68.3	6.58	1.84	108.7	16.7	123.87	26.1	0.003958869	1.139558
5	NPB 180X90X	15.37	19.6	177	91	4.3	6.5	9	1063	81.9	7.37	2.05	120.1	18	135.34	27.96	0.00593301	1.126894
6	NPB 180X90X	18.8	23.9	180	91	5.3	8	9	1317	100.9	7.42	2.05	146.3	22.2	166.42	34.6	0.007431215	1.137526
7	NPB 180X90X	21.27	27.1	182	92	6	9	9	1505	117.3	7.45	2.08	165.4	25.5	189.16	39.91	0.008739507	1.143652
8	NPB 200X100X	18.42	23.5	197	100	4.5	7	12	1591	117.2	8.23	2.23	161.6	23.4	181.67	36.54	0.010529167	1.124196
9	NPB 200X100X	22.36	28.5	200	100	5.6	8.5	12	1943	142.4	8.26	2.24	194.3	28.5	220.26	44.62	0.012988089	1.133608
10	NPB 200X100X	25.09	32	202	102	6.2	9.5	12	2211	168.9	8.32	2.3	218.9	33.1	249.44	51.9	0.015565904	1.139516
11	NPB 200X130X	27.37	34.9	207	133	5.8	8.5	12	2666	334	8.74	3.1	257.5	50.2	288.18	77.47	0.032830964	1.119146
12	NPB 200X130X	31.55	40.2	210	134	6.4	10	12	3153	401.9	8.86	3.16	300.3	60	337.19	92.46	0.040101733	1.122844
13	NPB 200X150X	30.45	38.8	194	150	6	9	12	2675	507	8.3	3.62	275.7	67.6	306.78	103.54	0.043316016	1.112731
14	NPB 200X165X	35.68	45.5	201	165	6.2	10	12	3414	749.5	8.67	4.06	339.7	90.9	376.8	138.58	0.068282172	1.109214
15	NPB 200X165X	42.47	54.1	205	166	7.2	12	12	4166	916	8.77	4.11	406.4	110.4	454.3	168.48	0.085193976	1.117864
16	NPB 200X165X	48	61.1	210	16	6.5	14.5	12	5025	1106.4	9.07	4.25	478.6	133.3	534.68	202.43	9.45824E-05	1.117175
17	NPB 220X110X	22.18	28.3	217	110	5	7.7	12	2317	171.4	9.05	2.46	213.5	31.2	240.23	48.49	0.018706649	1.125199
18	NPB 220X110X	26.2	33.4	220	110	5.9	9.2	12	2772	204.9	9.11	2.48	252	37.3	285.43	58.11	0.022672314	1.132659
19	NPB 220X110X	29.35	37.4	222	112	6.6	10.2	12	3134	239.4	9.16	2.53	282.3	42.8	321.17	66.91	0.026785201	1.13769
20	NPB 240X120X	26.15	33.3	237	120	5.2	8.3	15	3290	240.1	9.94	2.68	277.7	40	311.61	62.41	0.031256685	1.12211

Table 1 (Continued): Additional Sectional Properties of Narrow Parallel Flange (NPB) 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		WARPING CONSTANT (Iw)	SHAPE FACTOR (S)
									(Ix)	(Iy)	rx	ry	Zx	Zy	Zpx	Zpy		
		kg/m	cm2	mm	mm	mm	mm	mm	cm4	cm4	cm	cm	cm3	cm3	cm3	cm3	(dm6)	
21	NPB 240X120X	30.71	39.1	240	120	6.2	9.8	15	3892	283.6	9.97	2.69	324.3	47.3	366.68	73.93	0.037391183	1.130681
22	NPB 240X120X	34.31	43.7	242	122	7	10.8	15	4369	328.5	10	2.74	361.1	53.9	410.31	84.4	0.043678495	1.136278
23	NPB 250X125X	30.11	38.4	250	125	6	9	15	4138	294.3	10.39	2.77	331.1	47.1	373.65	73.63	0.042539795	1.128511
24	NPB 250X150X	34.08	43.4	258	146	6.1	9.2	15	5120	478.6	10.86	3.32	369.9	65.6	444.26	101.53	0.073847518	1.201027
25	NPB 250X150X	39.78	50.7	262	147	6.6	11.2	15	6200	594.5	11.06	3.43	473.3	80.9	530.17	124.91	0.093242487	1.120156
26	NPB 250X150X	46.48	59.2	266	148	7.6	13.2	15	7381	715.2	11.17	3.48	555	96.7	625.47	149.71	0.113946758	1.126973
27	NPB 250X175X	43.94	56	244	175	7	11	15	6091	984.2	10.43	4.19	499.3	112.5	555.6	172.49	0.133354425	1.112758
28	NPB 270X135X	30.73	39.1	267	135	5.5	8.7	15	4917	358	11.21	3.02	368.3	53	412.53	82.35	0.05950564	1.120092
29	NPB 270X135X	36.07	45.9	270	135	6.6	10.2	15	5790	419.9	11.23	3.02	428.9	62.2	484.04	96.96	0.070577867	1.128561
30	NPB 270X135X	42.26	53.8	274	136	7.5	12.2	15	6974	513.5	11.36	3.09	507.1	75.5	574.69	117.71	0.08764045	1.133287
31	NPB 300X150X	36.52	46.5	297	150	6.1	9.2	15	7173	519	12.42	3.34	483.1	69.2	541.83	107.33	0.107159812	1.121569
32	NPB 300X150X	42.24	53.8	300	150	7.1	10.7	15	8356	603.8	12.46	3.35	557.1	80.5	628.4	125.23	0.125934053	1.127984
33	NPB 300X150X	49.32	62.8	304	152	8	12.7	15	9994	745.7	12.61	3.45	657.5	98.1	743.86	152.59	0.157690021	1.131346
34	NPB 300X165X	39.88	50.8	310	165	5.8	9.7	15	8795	727.6	13.61	3.78	567.4	88.2	630.54	135.7	0.163728012	1.11128
35	NPB 300X165X	45.76	58.3	313	166	6.6	11.2	15	10210	855.6	13.23	3.83	652.4	103.1	727.91	158.77	0.194432794	1.115742
36	NPB 300X165X	53.46	68.1	317	167	7.6	13.2	15	12123	1026.8	13.34	3.88	764.8	123	857.61	189.65	0.236421867	1.121352
37	NPB 300X200X	59.56	75.9	303	203	7.5	13.1	15	12860	1828.6	13.02	4.91	848.9	180.2	940.72	275.19	0.383746651	1.108164
38	NPB 300X200X	66.75	85	306	204	8.5	14.6	15	14511	2068.5	13.06	4.93	948.4	202.8	1056.85	310.27	0.438542018	1.11435
39	NPB 300X200X	75.37	96	310	205	9.4	16.6	15	16676	2386.8	13.18	4.99	1075.9	232.9	1204.62	356.48	0.512954269	1.119639
40	NPB 330X160X	42.97	54.7	327	160	6.5	10	18	10231	685.2	13.67	3.54	625.7	85.6	702	133.28	0.171501227	1.121943

Table 1 (Continued) : Additional Sectional Properties of Narrow Parallel Flange (NPB) 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		WARPING CONSTANT (Iw)	SHAPE FACTOR (S)
									(Ix)	(Iy)	rx	ry	Zx	Zy	Zpx	Zpy		
		kg/m	cm2	mm	mm	mm	mm	mm	cm4	cm4	cm	cm	cm3	cm3	cm3	cm3	(dm6)	
41	NPB 330X160X	49.15	62.6	330	160	7.5	11.5	18	11767	788.1	13.71	3.55	713.1	98.5	804.4	153.69	0.199097323	1.128033
42	NPB 330X160X	57	72.6	334	162	8.5	13.5	18	13910	960.4	13.84	3.64	833	118.6	942.86	185	0.245653886	1.131885
43	NPB 350X170X	50.21	64	357.6	170	6.6	11.5	18	14515	944.3	15.06	3.84	811.8	111.1	906.84	171.87	0.281991853	1.117073
44	NPB 350X170X	57.09	72.7	360	170	8	12.7	18	16266	1043.5	14.95	3.79	903.6	122.8	1019.22	191.11	0.313580328	1.127955
45	NPB 350X170X	66.04	84.1	364	172	9.2	14.7	18	19047	1251.2	15.05	3.86	1046.6	145.5	1186.16	226.93	0.380266971	1.133346
46	NPB 350X250X	79.18	100.9	340	250	9	14	18	21530	3650.1	14.61	6.02	1266.5	292	1402.36	446.2	0.968661458	1.107272
47	NPB 400X180X	57.38	73.1	397	180	7	12	21	20293	1170.6	16.66	4	1022.3	130.1	1144.02	202.09	0.4322241	1.119065
48	NPB 400X180X	66.3	84.5	400	180	8.6	13.5	21	23128	1317.8	16.55	3.95	1156.4	146.4	1307.26	229.02	0.490048471	1.130457
49	NPB 400X180X	75.66	96.4	404	182	9.7	15.5	21	26747	1564.2	16.66	4.03	1324.1	171.9	1502.29	269.11	0.587647194	1.134574
50	NPB 400X200X	67.28	85.7	400	200	8	13	21	24224	1738.4	16.81	4.5	1211.2	173.8	1355.08	269.29	0.648999	1.118791
51	NPB 450X190X	67.15	85.5	447	190	7.6	13.1	21	29759	1502.4	18.65	4.19	1331.5	158.1	1494.42	245.76	0.704855604	1.122358
52	NPB 450X190X	77.57	98.8	450	190	9.4	14.6	21	33743	1675.9	18.48	4.12	1499.7	176.4	1701.93	276.4	0.791005069	1.134847
53	NPB 450X190X	92.36	117.7	456	192	11	17.6	21	40923	2085.4	18.65	4.21	1794.9	217.2	2046.4	341.01	0.997576485	1.140119
54	NPB 500X200X	79.36	101.1	497	200	8.4	14.5	21	42933	1939.2	20.61	4.38	1727.7	193.9	1946.16	301.64	1.125230208	1.126446
55	NPB 500X200X	90.68	115.5	500	200	10.2	16	21	48199	2141.7	20.43	4.31	1927.9	214.2	2194.27	335.9	1.249365333	1.138166
56	NPB 500X200X	107.31	136.7	506	202	12	19	21	57777	2621.7	20.56	4.38	2283.7	259.6	2613.13	408.55	1.547584567	1.144253
57	NPB 550X210X	92.07	117.3	547	210	9	15.7	24	59979	2432.2	22.61	4.55	2193	231.6	2474.87	361.53	1.710117403	1.128532
58	NPB 550X210X	105.52	134.4	550	210	11.1	17.2	24	67116	2667.6	22.35	4.45	2440.6	254.1	2787.22	400.56	1.884098144	1.142022
59	NPB 550X210X	122.52	156.1	556	212	12.7	20.2	24	79157	3224.4	22.52	4.55	2847.4	304.2	3263.59	480.54	2.302253432	1.146165
60	NPB 600X220X	107.56	137	597	220	9.8	17.5	24	82919	3116.3	24.6	4.77	2777.8	283.3	3141.42	442.09	2.607364391	1.130902

Table 1 (Continued) : Additional Sectional Properties of Narrow Parallel Flange (NPB) 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		WARPING CONSTANT (Iw)	SHAPE FACTOR (S)
									(Ix)	(Iy)	rx	ry	Zx	Zy	Zpx	Zpy		
		kg/m	cm2	mm	mm	mm	mm	mm	cm4	cm4	cm	cm	cm3	cm3	cm3	cm3	(dm6)	
61	NPB 600X220X	122.45	156	600	220	12	19	24	92083	3387.3	24.3	4.66	3069.4	307.9	3512.64	485.68	2.84552671	1.144406
62	NPB 600X220X	154.46	196.8	610	224	15	24	24	118302	4520.8	24.52	4.79	3878.8	403.6	4471.27	640.11	3.859573244	1.152746
63	NPB 700X250X	113.45	144.5	694	250	9	16	24	118957	4176.5	28.69	5.38	3428.1	334.1	3859.34	518.31	4.788375	1.125796
64	NPB 700X250X	128.41	163.6	695	250	11.5	16.5	24	128015	4312.4	27.98	5.13	3683.9	345	4220.06	543.03	4.945297607	1.145541
65	NPB 700X250X	143.42	182.7	700	250	12.5	19	24	145636	4966.4	28.23	5.21	4161	397.3	4765.55	625.38	5.736626953	1.14529
66	NPB 700X250X	153.86	196	704	250	13	21	24	159165	5488.8	28.5	5.29	4521.7	439.1	5171.33	690.11	6.377779297	1.143669
67	NPB 700X250X	171.47	218.4	709	250	14.5	23.5	24	178390	6145.5	28.58	5.3	5032.2	491.6	5777.24	775.44	7.18938208	1.148055
68	NPB 750X270X	145.29	185.1	750	265	13.2	16.6	17	161958	5165.3	29.58	5.28	4318.9	398.8	5009.9	616.68	6.923349874	1.159994
69	NPB 750X270X	174.54	222.3	760	270	14.4	21.6	17	206351	7107	30.46	5.65	5430.3	526.4	6244.16	827.22	9.65866666	1.149874
70	NPB 750X270X	202.48	257.9	770	270	15.6	26.6	17	249537	8752.4	31.1	5.83	6481.5	648.3	7431.05	1016.07	12.05609887	1.146502