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SUITABILITY OF INDIAN HOT- ROLLED PARALLEL FLANGE SECTIONS FOR USE IN SEISMIC STEEL MOMENT RESISTING FRAMES

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ABSTRACT

Use of parallel flange I beam sections is advantageous than tapered flange I beam sections due to, increased lateral stiffness, sections do not have sloping flanges and excessive material in web and easy to weld and bolt. Nowadays the hot rolled parallel flange, narrow parallel flange beams (NPB) and wide parallel flange beams (WPB) sections as per Indian standards, having yield stress, 300 MPa, 350 MPa and 410 MPa are being manufactured. Available range of these sections can be used for steel moment resisting frames (SMRF's) and prequalified connections as per AISC codes. When the cross section of a steel shape is subjected to large compressive stresses, the thin plates that make up the cross section may buckle before the full strength of the member is attained if the thin plates are too slender. This failure mode may be prevented by selecting suitable width-to-thickness ratios of component plates. In the present exercise, a suitability of NPB and WPB section for use in SMRF's as per width-to-thickness limitations of AISC 341-2010 and AISC 341-2005 codal provisions is studied.

Keywords: *steel moment resisting frames, local buckling, slenderness limits, parallel flange, I beam*

1.0 INTRODUCTION

Steel moment resisting frame structures are frequently used as seismic load resisting systems for building in seismic regions. SMRF's are rectilinear assemblies of columns and beams that are typically joined by welding or high-strength bolting or both. Resistance to lateral load is provided by flexural and shearing actions in the beams and columns. Lateral stiffness is provided by flexural stiffness of the beams and columns [1]. AISC- Seismic provisions for structural steel buildings [2-4], defines three types of seismic steel moment resisting frames: special moment frames (SMF), intermediate moment frames (IMF) and ordinary moment frames (OMF). When subjected to the forces resulting from the motions of the design earthquake: SMF are expected to withstand significant inelastic deformations; IMF are expected to withstand limited inelastic deformations; OMF are expected to withstand minimal inelastic deformations, in their members and connections. Reliable inelastic deformation requires that width-to-thickness ratios of compression elements be limited to a range that provides a cross section resistant to local buckling into the inelastic range [5]. Seismic provisions, require member flanges to be continuously connected to the web(s) and width-thickness ratios of the compression elements must be less than or equal to those that are resistant to local buckling when stressed into the inelastic range.

Based on the width-to-thickness ratios ($\frac{b_f}{t_f}$, $\frac{h}{t_w}$) of the plate elements that make up member's cross sections, AISC 341-2005 [3] & 360-2005[6] uses a term 'seismically compact',

'compact' and 'noncompact' to categorize the members. However, as per AISC 341-2010 [2], members are classified into 'highly ductile' and 'moderately ductile'.

Compact section is a section capable of developing a fully plastic stress distribution and possessing a rotation capacity of approximately three before the onset of local buckling Noncompact section is a section that can develop the yield stress in its compression elements before local buckling occurs, but cannot develop a rotation capacity of three. A higher level of compactness termed as 'seismically compact' is a section, expected to be able to achieve a level of deformation ductility of at least 4. Beam and column members should satisfy the requirements of width-to-thickness ratios as specified by AISC codes for above members, unless otherwise qualified by tests.

Highly ductile member is a member expected to undergo significant plastic rotation (more than 0.02 rad) from either flexure or flexural buckling under the design earthquake. Moderately ductile member is a member expected to undergo moderate plastic rotation (0.02rad or less) from either flexure or flexural buckling under the design earthquake. Beam and column members used for SMF are highly ductile members, for IMF moderately ductile members and for OMF there are no limitations on width-to-thickness ratios of members.

Usually, as per Indian standard (IS), IS 800-2007, IS 808 -1989 and IS 1852 -1985 [7-9] hot rolled tapered flange (Fig. 1A), I- sections are classified into four types namely, light (ISLB), medium (ISMB), wide flange (ISWB) and heavy (ISHB) beams. Further, as per IS 12778 -2004, IS12779-1989 [10, 11] hot rolled parallel flange sections are classified as (Fig. 1B) as narrow parallel flange beams (NPB), wide parallel flange beams (WPB) and parallel flange bearing pile sections (PBP). All above sections having yield stress 250MPa [12] are most commonly produced and used for steel structures in India. Parametric analysis [13] has shown that Indian hot- rolled I sections (parallel as well as tapered) having yield stress 250 do not meet compactness requirements specified in Indian standards as well as those of countries with advanced seismic provision for SMF. Even those that satisfy the stability requirements, their sizes are so small that they are insufficient from strength and stiffness points of view to be able to construct large span and high rise earthquake resistant constructions in strong seismic regions.

Figure 1: A) Hot rolled tapered flange I section, B) Hot rolled parallel flange I section

After the 1994 Northridge and 1995 Kobe earthquake, a significant amount of research activity was initiated on the behavior of fully restrained steel connections. Various types of beam-to-column connections have been proposed and investigated. So far, three general approaches were followed in improving connection details: 1) improving unreinforced connections / toughening schemes, 2) strengthening approach: strengthening connection by addition of cover plates, ribs or haunches, and 3) weakening approach: locally weakening the beam away from the column face by reduced beam section (RBS) or slotted web [14, 15, 16]. All these schemes are often used in combination. The AISC codes [2-4, 6, 15-17] specifies the guidelines about design of seismic steel moment resisting frames, beam-to-column connection details, width-to-thickness limitation for members and other details . Although these connections/schemes are widely investigated and used in US, Japan and Europe, however design of such type of connections are not presented and used in India.

Nowadays the hot rolled parallel flange NPB and WPB sections as per IS 8500 -1991[18], having yield stress, 300 MPa, 350 MPa and 410 MPa are being manufactured in India. Available range of these sections can be used for steel moment resisting frames (SMRF's) as well as prequalified connections as per AISC 358-2005, 2010 [15, 16]. As per IS code 12778 -2004 [10] NPB sections are mostly used as beams and WPB sections are generally used as beams or columns. In the present exercise, these parallel flange members are classified as per width-to-thickness limitation of AISC 341-2005 and AISC 341-2010 provisions and their suitability for use in seismic steel moment resisting frames is studied.

2.0 CLASSIFICATION OF SECTIONS FOR LOCAL BUCKLING

The cross sections of steel shapes tend to consist of an assembly of thin plates. When the cross section of a steel shape is subjected to large compressive stresses, the thin plates that make up the cross section, may buckle before the full strength of the member is attained, if the thin plates are too slender. When a cross sectional element fails in buckling, then the member capacity is reached. Consequently, local buckling becomes a limit state for the strength of steel shapes subjected to compressive stress. This failure mode may be prevented by selecting suitable width-to-thickness ratios (Fig. 2) of component plates [19].

In the following sections, classification of NPB (beam) and WPB (column) sections is considered as per width-to-thickness limitation of AISC 341-2005 and AISC 341-2010 provisions. Usually NPB sections are used for beams, slenderness check is also considered to verify their suitability as a column member.

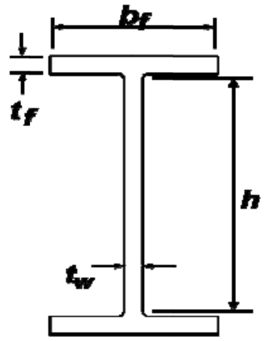

Figure 2: Typical parallel flange section

2.1 CLASSIFICATION ACCORDING TO AISC 341-2005

With respect to the following formulae, classification of NPB and WPB sections as per AISC 341-2005 & 360-2005 is as shown in Equations 1 to 7.

Limiting width-to-thickness ratios for compression elements for seismically compact members:

$$\frac{b_f}{2t_f} \leq 0.30\sqrt{\frac{E}{F_y}} \tag{1}$$

$$C_a \leq 0.125, \frac{h}{t_w} \leq 3.14\sqrt{\frac{E}{F_y}}\left[1 - 1.54C_a\right] \tag{2}$$

$$C_a > 0.125, \frac{h}{t_w} \leq 1.12\sqrt{\frac{E}{F_y}}\left[2.33 - C_a\right] \geq 1.49\sqrt{\frac{E}{F_y}} \tag{3}$$

Where

$$C_a = \frac{P_u}{\Phi_b P_y}$$ ..... for Load and Resistance Factor Design (LRFD)

$$C_a = \frac{\Omega_b P_a}{P_y}$$ ...... for Allowable Strength Design (ASD)

Limiting width-to-thickness ratios for compression elements for compact members:

$$\frac{b_f}{2t_f} \leq 0.38\sqrt{\frac{E}{F_y}} \quad (4)$$

$$\frac{h}{t_w} \leq 3.76\sqrt{\frac{E}{F_y}} \quad (5)$$

Limiting width-to-thickness ratios for compression elements for noncompact members:

$$\frac{b_f}{2t_f} \leq 1\sqrt{\frac{E}{F_y}} \quad (6)$$

$$\frac{h}{t_w} \leq 5.70\sqrt{\frac{E}{F_y}} \quad (7)$$

As per IS code [10], 70 numbers of NPB and 122 numbers of WPB sections are available. Therefore, 192 numbers of member can be used as beam and 122 as column. Beam members (total number of sections) [20], satisfying $\frac{b_f}{2t_f}$ and $\frac{h}{t_w}$ ratio are as shown in Table 1.

Table 1: NPB and WPB sections satisfying width-to-thickness ratio as beam

Slenderness Limit		Steel with F_y MPa					
		300		350		410	
		NPB	WPB	NPB	WPB	NPB	WPB
SMF	$\frac{b_f}{2t_f} \leq 0.30\sqrt{\frac{E}{F_y}}$	≤7.74		≤7.17		≤6.63	
		56	73	51	64	38	56
	$\frac{h}{t_w} \leq 3.14\sqrt{\frac{E}{F_y}}$	≤81.07		≤75.06		≤69.35	
		ALL	ALL	ALL	ALL	ALL	ALL
IMF	$\frac{b_f}{2t_f} \leq 0.38\sqrt{\frac{E}{F_y}}$	≤9.80		≤9.08		≤8.93	
		69	96	68	87	67	81
	$\frac{h}{t_w} \leq 3.76\sqrt{\frac{E}{F_y}}$	≤97.08		≤89.88		≤83.04	
		ALL	ALL	ALL	ALL	ALL	ALL

WPB members are considered as column members. Table 2 Shows: a) Column sections satisfying $\frac{b_f}{2t_f}$ limit as recommended by Equations 1, b) Maximum web depth-to-thickness ratio is given by Equation 2 and 3, giving a range of 38.47, 35.59 and 32.91 for $\frac{P_u}{\phi P_y} = 1$ and increasing it to 81.07, 75.06 and 69.35 for $P_u = 0$, for steel having yield stress 300, 350 and 410MPa respectively. Column sections (total number of sections) used for IMF satisfying limits as per Equations 4 & 5 are shown in Table 3.

Table 2: WPB sections satisfying width-to-thickness as column

Sl. No.	Section number as per IS code [10]	Section WPB	SMF					
			Yield Stress (MPa)					
			300		350		410	
			$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$
			≤ 7.74	Range, 38.47 for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 81.07 for $P_u = 0$	≤ 7.17	Range, 35.59 for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to75.06 for $P_u = 0$	≤ 6.63	Range, 32.91 for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 69.35 for $P_u = 0$
1	96	540×300×12.5×24					√	
2	100	590×300×13×25			√		√	
3	104	640×300×13.5×26	√		√		√	
4	105	650×300×16×31					√	
5	108	690×300×14.5×27	√		√		√	
6	109	700×300×17×32					√	
7	112	790×300×15×28	√		√		√	
8	113	800×300×17.5×33	√		√		√	
9	116	840×292×14.7×21.3	√		√			
10	117	846×293×15.4×24.3	√		√		√	
11	118	851×294×16.1×26.8	√		√		√	
12	119	859×292×17×30.8	√		√		√	
13	120	870×300×15×20	√					
14	121	890×300×16×30	√		√		√	
15	122	900×292×18.5×35	√		√		√	
Total			11		11		13	

Table 3: WPB sections satisfying width-to-thickness as column

Slenderness Limit		Steel with F_y MPa					
		300		350		410	
		WPB		WPB		WPB	
IMF	$\frac{b_f}{2t_f} \leq 0.38\sqrt{\frac{E}{F_y}}$	≤9.80		≤9.08		≤8.93	
		96		87		81	
	$\frac{h}{t_w} \leq 3.76\sqrt{\frac{E}{F_y}}$	≤97.08		≤89.88		≤83.04	
		ALL	ALL	ALL	ALL	ALL	ALL

Mostly all WPB and NPB sections satisfy limit for OMF.

2.2 CLASSIFICATION ACCORDING TO AISC 341-2010

Classification of NPB and WPB sections as highly ductile and moderately ductile according to following formulae as per AISC341-2010 is shown in Equations 8 to 13.

Limiting width-to-thickness ratios for compression elements for highly ductile members:

$$\frac{b_f}{2t_f} \le 0.30\sqrt{\frac{E}{F_y}} \tag{8}$$

$$C_a \le 0.125, \frac{h}{t_w} \le 2.45\sqrt{\frac{E}{F_y}}\left[1-0.93C_a\right] \tag{9}$$

$$C_a > 0.125, \frac{h}{t_w} \le 0.77\sqrt{\frac{E}{F_y}}\left[2.93-C_a\right] \ge 1.49\sqrt{\frac{E}{F_y}} \tag{10}$$

Limiting width-to-thickness ratios for compression elements for moderately ductile members:

$$\frac{b_f}{2t_f} \le 0.38\sqrt{\frac{E}{F_y}} \tag{11}$$

$$C_a \le 0.125, \frac{h}{t_w} \le 3.76\sqrt{\frac{E}{F_y}}\left[1-2.75C_a\right] \tag{12}$$

$$C_a > 0.125, \frac{h}{t_w} \le 1.12\sqrt{\frac{E}{F_y}}\left[2.33-C_a\right] \ge 1.49\sqrt{\frac{E}{F_y}} \tag{13}$$

Where

$C_a = \frac{P_u}{\Phi_c P_y}$ ..... for Load and Resistance Factor Design (LRFD)

$C_a = \frac{\Omega_c P_a}{P_y}$ ...... for Allowable Strength Design (ASD)

For I-shaped beams in SMF systems, where C_a is less than or equal to 0.125, the limiting ratio $\frac{h}{t_w}$ shall not exceed $2.45\sqrt{\frac{E}{F_y}}$. For I-shaped beams in IMF systems, where C_a is less than or equal to 0.125, the limiting width-to-thickness ratio shall not exceed $3.76\sqrt{\frac{E}{F_y}}$. Beam members (total number of sections), satisfying $\frac{b_f}{2t_f}$ and $\frac{h}{t_w}$ ratio are as shown in Table 4.

Table 4: NPB and WPB sections satisfying width-to-thickness ratio as beam

Slenderness Limit		Steel with F_y MPa					
		300		350		410	
		NPB	WPB	NPB	WPB	NPB	WPB
SMF	$\frac{b_f}{2t_f} \le 0.30\sqrt{\frac{E}{F_y}}$	$\le$7.74		$\le$7.17		$\le$6.63	
		56	73	51	64	38	56
	$\frac{h}{t_w} \le 2.45\sqrt{\frac{E}{F_y}}$	$\le$63.25		$\le$58.56		$\le$54.11	
		ALL	ALL	ALL	ALL	ALL	ALL
IMF	$\frac{b_f}{2t_f} \le 0.38\sqrt{\frac{E}{F_y}}$	$\le$9.80		$\le$9.08		$\le$8.93	
		69	96	68	87	67	81
	$\frac{h}{t_w} \le 3.76\sqrt{\frac{E}{F_y}}$	$\le$97.08		$\le$89.88		$\le$83.04	
		ALL	ALL	ALL	ALL	ALL	ALL

WPB sections satisfying $\frac{b_f}{2t_f}$, $\frac{h}{t_w}$ limt for SMF and IMF as recommended by equations 8, 9, 10, 11, 12 and 13 are shown in Table 5 & 6.

Table 5: WPB sections satisfying width-to-thickness ratio as column

Sl. No.	Section number as per IS code [10]	Section WPB	SMF					
			Yield Stress (MPa)					
			300		350		410	
			$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$
			≤ 7.74	Range, 38.47 for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 63.25 for $P_u=0$	≤ 7.17	Range, 35.61 for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 58.56 for $P_u=0$	≤ 6.63	Range,32.91for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 54.11 for $P_u=0$
1	96	540×300×12.5×24					√	
2	100	590×300×13×25			√		√	
3	104	640×300×13.5×26	√		√		√	
4	105	650×300×16×31					√	
5	108	690×300×14.5×27	√		√		√	
6	109	700×300×17×32					√	
7	112	790×300×15×28	√		√		√	
8	113	800×300×17.5×33	√		√		√	
9	116	840×292×14.7×21.3	√		√			
10	117	846×293×15.4×24.3	√		√		√	
11	118	851×294×16.1×26.8	√		√		√	
12	119	859×292×17×30.8	√		√		√	
13	120	870×300×15×20	√					
14	121	890×300×16×30	√		√		√	
15	122	900×292×18.5×35	√		√		√	
Total			11		11		13	

Table 6: WPB sections satisfying width-to-thickness ratio as column

Sl. No.	Section number as per IS code [10]	Section WPB	IMF		
			Yield Stress (MPa)		
			300	350	410
			$\frac{b_f}{2t_f} \le 9.80$; $\frac{h}{t_w}$: Range, 38.47 for $\frac{P_u}{\Phi_c P_y} = 1$ and increasing to 97.08 for $P_u = 0$	$\frac{b_f}{2t_f} \le 9.08$; $\frac{h}{t_w}$: Range, 35.61 for $\frac{P_u}{\Phi_c P_y} = 1$ and increasing to 89.88 for $P_u = 0$	$\frac{b_f}{2t_f} \le 8.93$; $\frac{h}{t_w}$: Range,32.91 for $\frac{P_u}{\Phi_c P_y} = 1$ and increasing to 83.04 for $P_u = 0$
1	91	480×300×11.5×18			√
2	96	540×300×12.5×24			√
3	99	571×300×12×15.5	√		
4	100	590×300×13×25		√	√
5	103	620×300×12.5×16	√		
6	104	640×300×13.5×26	√	√	√
7	105	650×300×16×31			√
8	107	670×300×13×17	√	√	
9	108	690×300×14.5×27	√	√	√
10	109	700×300×17×32			√
11	111	770×300×14×18	√	√	√
12	112	790×300×15×28	√	√	√
13	113	800×300×17.5×33	√	√	√
14	115	835×292×14×18.8	√	√	√
15	116	840×292×14.7×21.3	√	√	√
16	117	846×293×15.4×24.3	√	√	√
17	118	851×294×16.1×26.8	√	√	√
18	119	859×292×17×30.8	√	√	√
19	120	870×300×15×20	√	√	√
20	121	890×300×16×30	√	√	√
21	122	900×292×18.5×35	√	√	√
Total			16	15	18

Mostly all WPB and NPB sections can be used for OMF

2.3 CLASSIFICATION OF NPB SECTIONS CONSIDERING AS A COLUMN MEMBER

Though, WPB sections are considered as column member, it can be observed from above Tables 2, 3, 5 & 6: a) for SMF as per both codes, sections which qualify the limit are same and very few in number; b) for IMF according to AISC 341-2005 more WPB sections satisfy slenderness ratio than AISC 341-2010; c) mostly all WPB sections satisfy limit for OMF.

Therefore, width-to-thickness check is applied to NPB sections considering them as a column section as per both codes.

NPB sections satisfying $\frac{b_f}{2t_f}$, $\frac{h}{t_w}$ limit for SMF as recommended by AISC 341-2005, as per Equations 1, 2, 3 are shown in Table 7. For IMF, NPB sections satisfying the limits are as per Table 1.

Table 7: NPB sections satisfying width-to-thickness ratio as column

Sl. No.	Section number as per IS code [10]	Section NPB	SMF					
			Yield stress (MPa)					
			300		350		410	
			$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$
			≤ 7.74	Range ,38.47 for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 81.07 for $P_u = 0$	≤ 7.17	Range, 35.59 for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 75 for $P_u = 0$	≤ 6.63	Range, 32.91for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 69.35 for $P_u = 0$
1	29	270×135×6.6×10.2					√	
2	35	313×166×6.6×11.2	√					
3	36	317×167×7.6×13.2					√	
4	41	330×160×7.5×11.5			√			
5	43	357.6×170×6.6×11.5	√					
6	44	360×170×8×12.7			√			
7	47	397×180×7×12	√					
8	48	400×180×8.6×13.5	√		√			
9	49	404×182×9.7×15.5					√	
10	50	400×200×8×13	√					
11	51	447×190×7.6×13.1	√					
12	52	450×190×9.4×14.6	√		√		√	
13	53	456×192×11×17.6					√	
14	54	497×200×8.4×14.5	√		√			
15	55	500×200×10.2×16	√		√		√	
16	56	506×202×12×19					√	
17	57	547×210×9×15.7	√		√			
18	58	550×210×11.1×17.2	√		√		√	
19	59	556×212×12.7×20.2			√		√	
20	60	597×220×9.8×17.5	√		√		√	

21	61	600×220×12×19	√	√	√
22	62	610×224×15×24			√
23	64	695×250×11.5×16.5	√		
24	65	700×250×12.5×19	√	√	√
25	66	704×250×13×21	√	√	√
26	67	709×250×14.5×23.5	√	√	√
27	69	760×270×14.4×21.6	√	√	√
28	70	770×270×15.6×26.6	√	√	√
Total			19	16	17

NPB sections satisfying $\frac{b_f}{2t_f}$, $\frac{h}{t_w}$ limt for SMF and IMF as recommended by AISC 341-2010, as per Equations 8,9,10,11,12 and 13, are shown in Table 8 and 9 respectively.

Table 8: NPB sections satisfying width-to-thickness ratio as column

<table>
<tr><td rowspan="5">Sl. No.</td><td rowspan="5">Section number as per IS code [10]</td><td rowspan="5">Section NPB</td><td colspan="6">SMF</td></tr>
<tr><td colspan="6">Yield stress (MPa)</td></tr>
<tr><td colspan="2">300</td><td colspan="2">350</td><td colspan="2">410</td></tr>
<tr><td>$\frac{b_f}{2t_f}$</td><td>$\frac{h}{t_w}$</td><td>$\frac{b_f}{2t_f}$</td><td>$\frac{h}{t_w}$</td><td>$\frac{b_f}{2t_f}$</td><td>$\frac{h}{t_w}$</td></tr>
<tr><td>≤ 7.74</td><td>Range ,38.47 for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 63.25 for $P_u=0$</td><td>≤ 7.17</td><td>Range, 35.61 for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 58.56 for $P_u=0$</td><td>≤ 6.63</td><td>Range,32.91for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 54.11 for $P_u=0$</td></tr>
<tr><td>1</td><td>29</td><td>270×135×6.6×10.2</td><td colspan="2"></td><td colspan="2"></td><td colspan="2">√</td></tr>
<tr><td>2</td><td>35</td><td>313×166×6.6×11.2</td><td colspan="2">√</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>3</td><td>36</td><td>317×167×7.6×13.2</td><td colspan="2"></td><td colspan="2"></td><td colspan="2">√</td></tr>
<tr><td>4</td><td>41</td><td>330×160×7.5×11.5</td><td colspan="2"></td><td colspan="2">√</td><td colspan="2"></td></tr>
<tr><td>5</td><td>43</td><td>357.6×170×6.6×11.5</td><td colspan="2">√</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>6</td><td>44</td><td>360×170×8×12.7</td><td colspan="2"></td><td colspan="2">√</td><td colspan="2"></td></tr>
<tr><td>7</td><td>47</td><td>397×180×7×12</td><td colspan="2">√</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>8</td><td>48</td><td>400×180×8.6×13.5</td><td colspan="2">√</td><td colspan="2">√</td><td colspan="2"></td></tr>
<tr><td>9</td><td>49</td><td>404×182×9.7×15.5</td><td colspan="2"></td><td colspan="2"></td><td colspan="2">√</td></tr>
<tr><td>10</td><td>50</td><td>400×200×8×13</td><td colspan="2">√</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>11</td><td>51</td><td>447×190×7.6×13.1</td><td colspan="2">√</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>12</td><td>52</td><td>450×190×9.4×14.6</td><td colspan="2">√</td><td colspan="2">√</td><td colspan="2">√</td></tr>
<tr><td>13</td><td>53</td><td>456×192×11×17.6</td><td colspan="2"></td><td colspan="2"></td><td colspan="2">√</td></tr>
<tr><td>14</td><td>54</td><td>497×200×8.4×14.5</td><td colspan="2">√</td><td colspan="2">√</td><td colspan="2"></td></tr>
<tr><td>15</td><td>55</td><td>500×200×10.2×16</td><td colspan="2">√</td><td colspan="2">√</td><td colspan="2">√</td></tr>
<tr><td>16</td><td>56</td><td>506×202×12×19</td><td colspan="2"></td><td colspan="2"></td><td colspan="2">√</td></tr>
<tr><td>17</td><td>57</td><td>547×210×9×15.7</td><td colspan="2">√</td><td colspan="2">√</td><td colspan="2"></td></tr>
<tr><td>18</td><td>58</td><td>550×210×11.1×17.2</td><td colspan="2">√</td><td colspan="2">√</td><td colspan="2">√</td></tr>
</table>

19	59	556×212×12.7×20.2		√	√
20	60	597×220×9.8×17.5	√	√	√
21	61	600×220×12×19	√	√	√
22	62	610×224×15×24			√
23	64	695×250×11.5×16.5	√		
24	65	700×250×12.5×19	√	√	√
25	66	704×250×13×21	√	√	√
26	67	709×250×14.5×23.5	√	√	√
27	69	760×270×14.4×21.6	√	√	√
28	70	770×270×15.6×26.6	√	√	√
Total			19	16	17

Table 9: NPB sections satisfying width-to-thickness ratio as column

Sl. No.	Section number as per IS code [10]	Section NPB	IMF					
			Yield stress (MPa)					
			300		350		410	
			$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$
			≤ 9.80	Range,38.47 for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 97.08 for $P_u=0$	≤ 9.08	Range,35.61 for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 89.36 for $P_u=0$	≤ 8.93	Range,32.91 for $\frac{P_u}{\Phi_c P_y}=1$ and increasing to 83.04 for $P_u=0$
1	5	177×91×4.3×6.5						√
2	8	197×100×4.5×7						√
3	17	217×110×5×7.7						√
4	20	237×120×5.2×8.3				√		√
5	23	250×125×6×9						√
6	24	258×146×6.1×9.2						√
7	28	267×135×5.5×8.7		√		√		√
8	29	270×135×6.6×10.2						√
9	31	297×150×6.1×9.2		√		√		√
10	32	300×150×7.1×10.7						√
11	34	310×165×5.8×9.7		√		√		
12	35	313×166×6.6×11.2		√		√		√
13	36	317×167×7.6×13.2						√
14	40	327×160×6.5×10		√		√		√
15	41	330×160×7.5×11.5				√		√
16	43	357.6×170×6.6×11.5		√		√		√
17	44	360×170×8×12.7				√		√
18	45	364×172×9.2×14.7						√
19	47	397×180×7×12		√		√		√
20	48	400×180×8.6×13.5		√		√		√
22	49	404×182×9.7×15.5						√
23	50	400×200×8×13		√		√		√
24	51	447×190×7.6×13.1		√		√		√
25	52	450×190×9.4×14.6		√		√		√
26	53	456×192×11×17.6						√

27	54	497×200×8.4×14.5	√	√	√
28	55	500×200×10.2×16	√	√	√
29	56	506×202×12×19			√
30	57	547×210×9×15.7	√	√	√
31	58	550×210×11.1×17.2	√	√	√
32	59	556×212×12.7×20.2		√	√
33	60	597×220×9.8×17.5	√	√	√
34	61	600×220×12×19	√	√	√
35	62	610×224×15×24			√
36	63	694×250×9×16	√	√	√
37	64	695×250×11.5×16.5	√	√	√
38	65	700×250×12.5×19	√	√	√
39	66	704×250×13×21	√	√	√
40	67	709×250×14.5×23.5	√	√	√
41	68	750×265×13.2×16.6	√	√	√
42	69	760×270×15.6×26.6	√	√	√
Total			24	28	40

If NPB sections are considered as column member it can be observed from above Tables 1, 7, 8 and 9: a) for SMF as per both codes, sections which qualify the limit are same and reasonable in number; b) for IMF according to AISC 341-2005 more NPB sections satisfy slenderness ratio than AISC 341-2010; c) mostly all NPB sections satisfy limit for OMF.

In the above paper, adequacy of Indian hot rolled parallel flange sections having yield stress 300MPa, 350 MPa and 410 MPa, as per slenderness limits of AISC 341-2005 & AISC 341-2010 code is discussed. Thus, suitable parallel flange section of Indian profile, satisfying width-to-thickness limit can be selected from the above Tables to build planned SMRF i.e. SMF, IMF, OMF and prequalified connection.

3.0 CONCLUSIONS

An exercise was carried out to understand suitability of parallel flange sections (Indian profile) for use in seismic steel moment resisting frames, reflects following:

- Guidelines provided in tabular form to choose sections for proposed moment frame.
- Sufficient numbers of beam sections are available for SMF, IMF and OMF. Column sections (WPB) suitable for SMF are available in limited number.
- Slenderness check applied to NPB members shows that, these sections, which satisfy the slenderness limit can be used as column members, however, when both (NPB and WPB) sections are considered, more choice is available for use as column members for SMF and IMF.
- When used as a column member for IMF, according to AISC 341-2005 more NPB & WPB sections satisfy slenderness ratio than AISC 341-2010.
- With the available members, suitability of these sections for connections with cover plates, ribs, haunches, reduced beam sections, slotted web etc. can be studied for Indian parallel flange profile sections.

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NOTATION

F_y	=	The specified minimum yield stress of the material of the yielding element (beam/column).
E	=	Modulus of elasticity
P_a	=	Required axial strength of a column using ASD load combinations
P_u	=	Required axial strength using LRFD load combinations
P_y	=	Nominal axial yield strength of a member
C_a	=	Ratio of required strength to available strength
b_f	=	Width of flange
h	=	Clear distance between flanges less the fillet or corner radius for rolled shapes
t_w	=	Thickness of web
t_f	=	Thickness of flange
ϕ_c	=	Resistance factor for compression (0.9)
Ω_c	=	Safety factor for compression(1.67)
ϕ_b	=	Resistance factors for axial compression (0.9)
Ω_b	=	Factors of safety for axial compression (1.67)