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Effective Utilization of Rolled Sections in Hydrocarbon Plant Structures

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***Abstract*– "Make in Steel" strategy is one of the core contributor to take India towards $5-trillion economy goal. Hydrocarbon industry is one of the major sectors, where structural steel consumption is substantial. Along with the growth of the nation, capacities of refineries and petrochemicals are also growing noticeably and thereby demanding variety of structural steel rolled sections in huge quantity. Age-old vicious cycle of demand-supply is continuing to be unbeatable for rolled sections as well. In past few years, manufacturers have geared up to produce more variety of sections. Though it is fascinating for the structural engineers to have more options, tradeoff between various sections becomes difficult; moreover ordering process and inventory management get more stringent for both of the contractors and manufacturers. Various structural components have a particular pattern of axial force and bending moment carrying mechanism; by deep understanding of the same and mapping certain types of rolled sections along with a specific types of structural components, sections can be effectively utilized and variety of sections can be reduced thereof. This paper aims at reducing variety of structural steel rolled sections, by effective utilization of axial and bending capacities of the sections, particularly for structures associated with hydrocarbon industry.**

Keywords–Structural steel, Rolled section, Axial Capacity, Bending Capacity, Hydrocarbon industry

INTRODUCTION

Steel has a crucial role in India's growth and the journey towards $5-trillion economy goal. Structural steel being a subset of total steel consumption of the nation, increase of its usage is equally important. Major component of Refinery and petrochemical plants are built in structural steel, thereby hydrocarbon industries are significant contributors towards economic growth of India.

Structural steel rolled sections are primarily used in the structures of hydrocarbon plants. Leading steel manufacturers are evolving continuously in terms of introducing variety of rolled sections and also structural steel grades to expand its base and facilitate its usage. Though enlistment of numerous sections and their huge variety in the manufacturer's catalogue fascinates structural engineers, tradeoff between various sections sizes becomes precarious decision. Moreover, too many varieties of sections cause bottlenecking of the ordering process and inventory management down the line. Certain rolled sections perform well under axial load than under bending moment; whereas the other set of sections show better performance against bending moment than axial load. Also, various components of a structure have a particular pattern in terms of their load transferring mechanism. Rolled sections can be effectively utilized when these two aspects namely section's predominant capacity and structural component's load transferring pattern are mapped properly. Thus, reducing the variety of sections for usage in structures associated with hydrocarbon industry. Though there is a paper available on selection of parameter for I-beam [1], above mentioned aspects is not covered in the study.

The aim of this paper is to reduce the variety of rolled steel sections by shortlisting them on the basis of their predominant axial and bending capacity and by effective utilization in various structural components.

STUDY DESIGN

Process units of refinery and petrochemical plants primarily have three types of major structures. Depending on the capacity of the process units,

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size of the below mentioned structures may vary; however, configuration remains the same.

Type-I: Pipe racks are the structures that carry all process and utility pipes throughout the process units. Various components (Fig.1) of a pipe rack are (a) column, (b) portal beam, (c) longitudinal beam and (d) horizontal/vertical bracing.

Portal beams and columns are connected through moment connections whereas longitudinal beams and the vertical bracings are connected to the columns through shear connections. All the pipes are supported over the portal beams.

Type-II: Technological structures are the structures that support various equipments, pipes, valves and occasionally air-fin coolers. Various components (Fig. 1) of technological structures are (a) column, (b) portal beam, (c) longitudinal beam, (d) equipment supporting beam, (e) horizontal/vertical bracing. Grating supporting beams being nominal in quantities shall not form part of this study.

Type-III: Compressor sheds, as the name

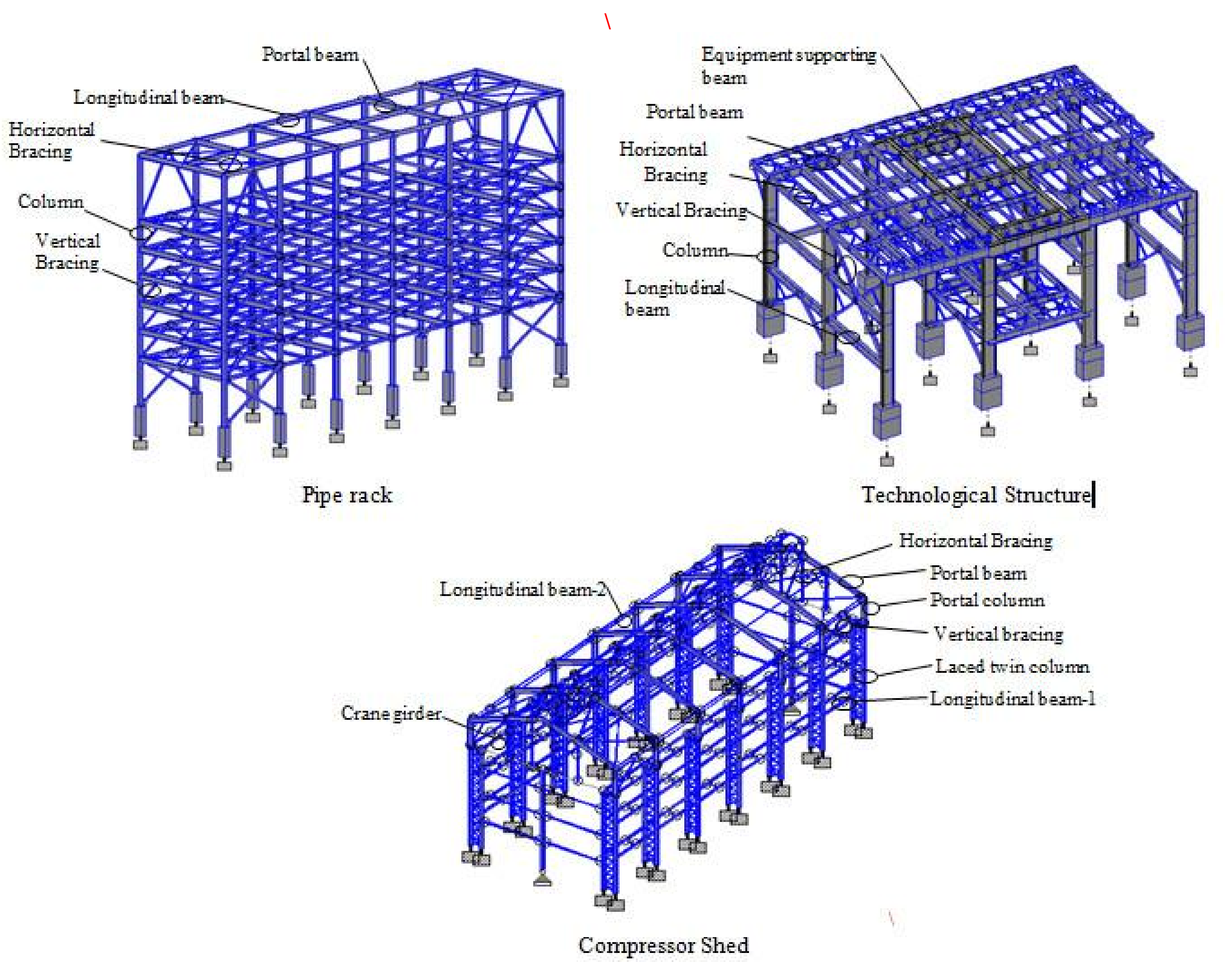

Fig. 1: 3D View

suggest are for housing compressors

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along with EOT cranes for removal of part of the motors. Various components (Fig. 1) of compressor sheds are (a) laced twin column, (b) portal column, (c) portal beam, (d) longitudinal beam-1 (with moment connection at the level of twin column) (e) longitudinal beam-2 (with shear connection at the level of portal column, (f) horizontal/vertical bracing. (g) Crane girder.

Percentage utilization in axial and bending for the above mentioned components of various structures are tabulated (Table-1) and the percentages are mentioned against utilization factor. Range of rolled structural steel sections namely NPB and WPB are selected for detailed study of their axial and bending capacities. Bending capacities, maximum and corresponding to lateral torsional buckling (LTB) length of 1.5m, 3m and 4m for the selected NPB and WPB sections are tabulated (Table-2); maximum and minimum (LTB length=4m) bending capacities are plotted for NPB400 to NPB600 and WBP200 to WPB360 against weight (Fig.-2); bending capacities for WPB600 to WPB900 are plotted (Fig.-3) separately. Similarly, axial capacities for the selected NPB and WPB sections are tabulated (Table-3) and plotted for NPB400 to NPB600 and WBP200 to WPB360 against weight (Fig. 4); axial capacities for WPB600 to WPB900 are plotted (Fig. 5) separately.

Result and Discussion

A: Structural component wise Axial & Bending capacity Utilization Factor.

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From the utilization factors mentioned in Table-1, it is evident that some of the components predominantly behave as bending members; e.g. portal beams of pipe racks; portal beams and equipment supporting beams of technological structures; portal columns, portal beams, longitudinal beams-1 of compressor sheds etc. Similarly some of the components predominantly behave as axial members; e.g. longitudinal beams, horizontal/vertical bracing of pipe racks; longitudinal beams, horizontal/vertical bracing of technological structures; individual section of laced twin columns, longitudinal beams-2, horizontal/vertical bracing of compressor sheds etc. Few of the components such as columns behave as combined bending and axial members.

TABLE 1:
(TITLE: Utilization Factor against Axial and Bending Capacities for Various Structural Components)

STRUCTURE TYPE	**MEMBER**	**UTILIZATION FACTOR**		**PREDOMINENT BEHAVIOUR**
		AXIAL	**BENDING**	
Piperack	Column	30- 60%	40-70%	Combined Axial & Bending
	Portal Beam	1-5%	95-99%	Bending
	Longitudinal Beam	90-95%	5-10%	Axial
	Horizontal/ Vertical Bracing	100%	Negligible	Axial
Technological Structure	Column	30- 60%	40-70%	Combined Axial & Bending
	Portal Beam	Negligible	100%	Bending
	Longitudinal Beam	100%	Negligible	Axial
	Equipment Supporting Beam	Negligible	100%	Bending
	Horizontal/ Vertical Bracing	100%	Negligible	Axial
Compressor Shed	Laced Twin Column (Individual Sections)	100%	Negligible	Axial
	Portal Column	15-20%	80-85%	Bending
	Portal beam	15-20%	80-85%	Bending
	Longitudinal Beam-1	1-8%	92-99%	Bending
	Longitudinal Beam-2	70-95%	5-30%	Axial
	Horizontal/ Vertical Bracing	100%	Negligible	Axial
	Crane Girder	0.4-1%	99-99.6%	Bending

B: Bending capacities of NPB & WPB Sections - Maximum and against various LTB lengths.

Refer Table-2, maximum bending capacities to weight ratio for NPB sections (67.2-154.5kg/m)

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varies from 0.5-0.7 (T-m)/(kg/m), whereas for WPB sections with similar weight (50.9-197.7kg/m) varies from 0.2-0.4. Refer Fig. 2, maximum bending capacities of NPB sections (67.2–154.5kg/m) vs. weight is represented in Curve-IA and WPB sections (50.9– 197.7kg/m) is represented in Curve-IB. Slope of the best fit line of Curve-IA is steeper than that of curve-IB. From the slope of the best fit lines of these two curves, it is evident that, for same weight, NPB sections give more bending capacities than WPB sections, or NPB sections are more effective in bending than WPB sections of the mentioned weight range. With increase of LTB length, ratio of bending capacity against weight reduces for NPB sections and remains the same for WPB sections. Bending capacities corresponding to LTB length equals to 4m vs. weight for NPB sections (67.2–154.5kg/m) is represented in Curve-IIA and WPB sections (50.9–197.7kg/m) is represented in Curve-IIB. Difference in slope of the best fit lines for Curve-IIA & Curve-IIB is less than that of Curve-IA & Curve-IB. Thus, it can be opined that with increase in LTB length, bending capacities of NPB sections reduces more as compared to WPB sections.

TABLE 2:
(TITLE: BENDING CAPACITIES VS. WEIGHT FOR NPB & WPB SECTIONS)

SECTION NAMES	**WT. kg/m**	**M_{d_max} T-m**	**M_d/ Wt.**	**$M_{d\_1.5m}$ T-m**	**$M_{d\_1.5m}$ / Wt.**	**M_{d_3m} T-m**	**M_{d_3m}/ Wt.**	**M_{d_4m} kN-m**	**M_{d_4m}/ Wt.**
NPB450X190X67.2 (a)	67.2	34.0	0.5	32.5	0.5	28.3	0.4	24.0	0.4
NPB400X180X75.7 (b)	75.7	34.1	0.5	32.6	0.4	28.5	0.4	24.6	0.3
NPB500X200X79.4 (c)	79.4	44.2	0.6	42.6	0.5	37.5	0.5	32.3	0.4
NPB500X200X90.7 (d)	90.7	49.9	0.5	47.9	0.5	42.2	0.5	36.5	0.4
NPB450X190X92.4 (e)	92.4	46.5	0.5	44.6	0.5	39.4	0.4	34.5	0.4
NPB500X200X107.3 (f)	107.3	59.4	0.6	57.2	0.5	50.9	0.5	44.9	0.4
NPB600X220X107.6 (g)	107.6	71.4	0.7	69.2	0.6	62.2	0.6	55.1	0.5
NPB600X220X122.5 (h)	122.5	79.8	0.7	77.3	0.6	69.2	0.6	61.3	0.5
NPB600X220X154.5 (i)	154.5	101.6	0.7	98.6	0.6	89.4	0.6	80.9	0.5
WPB200X200X50.9 (j)	50.9	11.9	0.2	11.6	0.2	10.8	0.2	10.1	0.2
WPB250X250X73 (k)	73.1	22.2	0.3	21.9	0.3	20.7	0.3	19.7	0.3
WPB250X250X103.9 (l)	103.9	32.6	0.3	32.3	0.3	30.7	0.3	29.7	0.3
WPB300X300X100.8 (m)	100.8	36.0	0.4	35.9	0.4	34.3	0.3	33.1	0.3
WPB300X300X117.0 (n)	117.0	42.5	0.4	42.4	0.4	40.5	0.3	39.2	0.3
WPB360X370X136.7 (o)	136.7	59.2	0.4	59.2	0.4	57.4	0.4	55.8	0.4
WPB360X370X150.9 (p)	150.9	66.0	0.4	66.0	0.4	64.0	0.4	62.4	0.4
WPB300X300X182.0 (q)	182.0	80.4	0.4	80.4	0.4	78.1	0.4	76.2	0.4
WPB360X370X197.7 (r)	197.7	87.7	0.4	87.7	0.4	85.3	0.4	83.3	0.4
WPB600X300X128.8 (a’)	128.8	82.3	0.6	81.5	0.6	76.5	0.6	72.1	0.6
WPB700X300X149.9 (b’)	149.9	110.0	0.7	108.7	0.7	101.7	0.7	95.4	0.6

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WPB600X300X177.8 (c')	177.8	121.6	0.7	120.9	0.7	114.6	0.6	109.6	0.6
WPB700X300X204.5 (d')	204.5	159.8	0.8	158.7	0.8	149.9	0.7	142.9	0.7
WPB600X300X211.9 (e')	211.9	146.0	0.7	145.3	0.7	138.0	0.7	132.4	0.6
WPB800X300X224.4 (f')	224.4	197.7	0.9	196.0	0.9	184.6	0.8	175.1	0.8
WPB700X300X240.5 (g')	240.5	189.3	0.8	188.6	0.8	178.0	0.7	170.2	0.7
SECTION NAMES	**WT. kg/m**	**M_{d_max} T-m**	**M_d/ Wt.**	**$M_{d\_1.5m}$ T-m**	**$M_{d\_1.5m}$ / Wt.**	**M_{d_3m} T-m**	**M_{d_3m}/ Wt.**	**M_{d_4m} kN-m**	**M_{d_4m}/ Wt.**
WPB900X300X251.6 (h')	251.6	245.7	1.0	243.2	1.0	228.6	0.9	216.1	0.9
WPB800X300X262.3 (i')	262.3	232.5	0.9	230.5	0.9	217.5	0.8	207.1	0.8
WPB600X300X285.5 (j')	285.5	199.4	0.7	198.6	0.7	189.5	0.7	183.1	0.6
WPB900X300X291.5 (k')	291.5	286.0	1.0	283.2	1.0	266.6	0.9	252.9	0.9
WPB700X300X300.7 (l')	300.7	239.5	0.8	238.2	0.8	226.4	0.8	217.7	0.7
WPB800X300X317.4 (m')	317.4	283.8	0.9	281.7	0.9	266.8	0.8	255.2	0.8

Refer Curve-IA of Fig. 2, sections above best fit line, as represented by point "a", "c", "g" and "h" have better bending capacity to weight ratio than rest of the sections. Sections represented by points "d" and "i" are lying over the best fit line, ratio of maximum bending capacity to weight ratio of NPB500x200x90.7, represented by point "d" is 0.5 (T-m)/(kg/m), whereas the same ratio of NPB500x200x79.4, represented by point "c" is 0.6 (T-m)/(kg/m); so for the same depth 500mm and same flange width 200mm, utilization of NPB500x200x79.4 in bending capacity is better than that of NPB500x200x90.7. However, from Curve-IB, WPB sections represented by points are near to the best fit line, so in this range most of the WPB sections are more or less similar in terms of utilization.

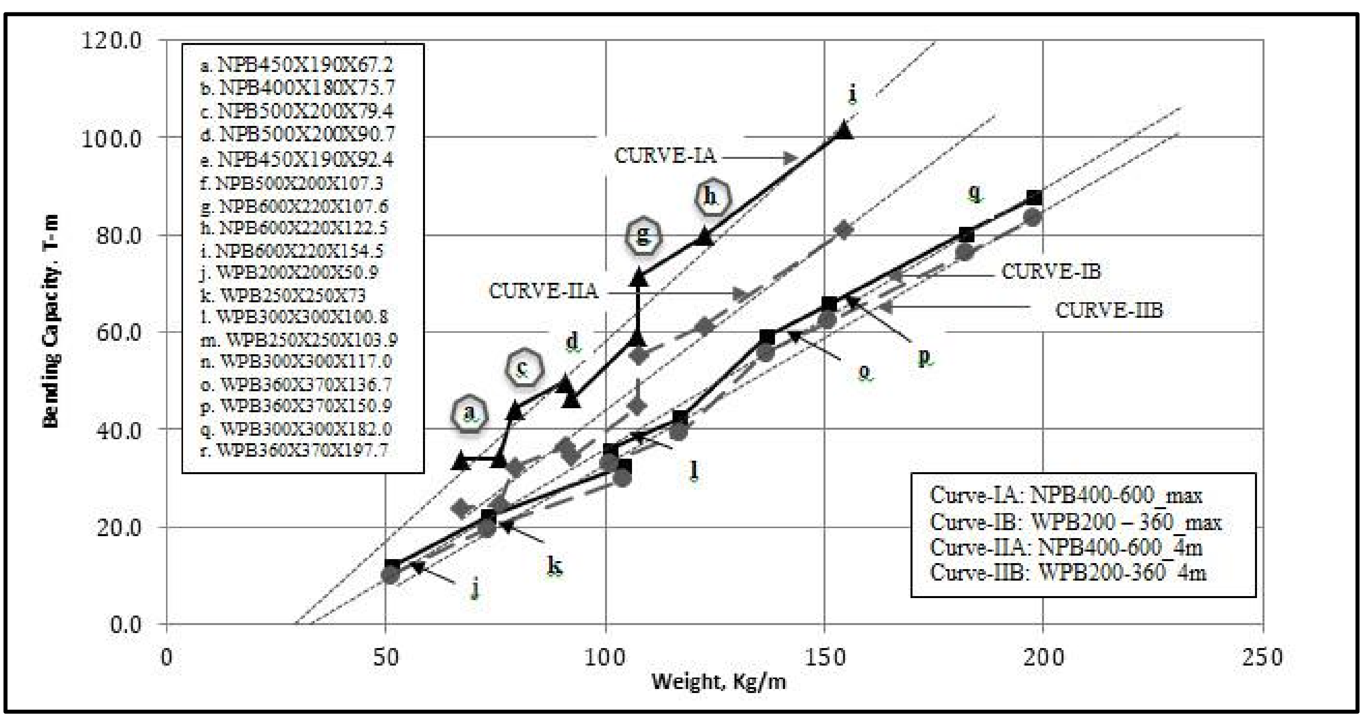

Fig. 2: Weight vs. Bending Capacity for NPB400-600 & WPB200-360

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In reference to Curve-IC of Fig. 3, WPB sections represented by points b', d', f', h', i', k' are lying above the best fit line, and therefore, they are utilized better than the rest of the sections in terms of bending capacity w.r.t. weight. WPB 900x300x291.5, represented by point k' is having more bending capacity as compared to WPB 800x300x317.4, though the weight of earlier section is less than that of the later. Thus, WPB 800x300x317.4 is not effective in terms of its utilization in bending capacity. Also, slopes of the best fit lines of the Curves-IC & IIC are almost similar; therefore, it is clear that bending capacities of this range of WPB sections do not reduce much as compared to their maximum capacities up to LTB length of 4m and thus the sections are well utilized for this length. For higher LTB lengths further study can be done to understand the utilization.

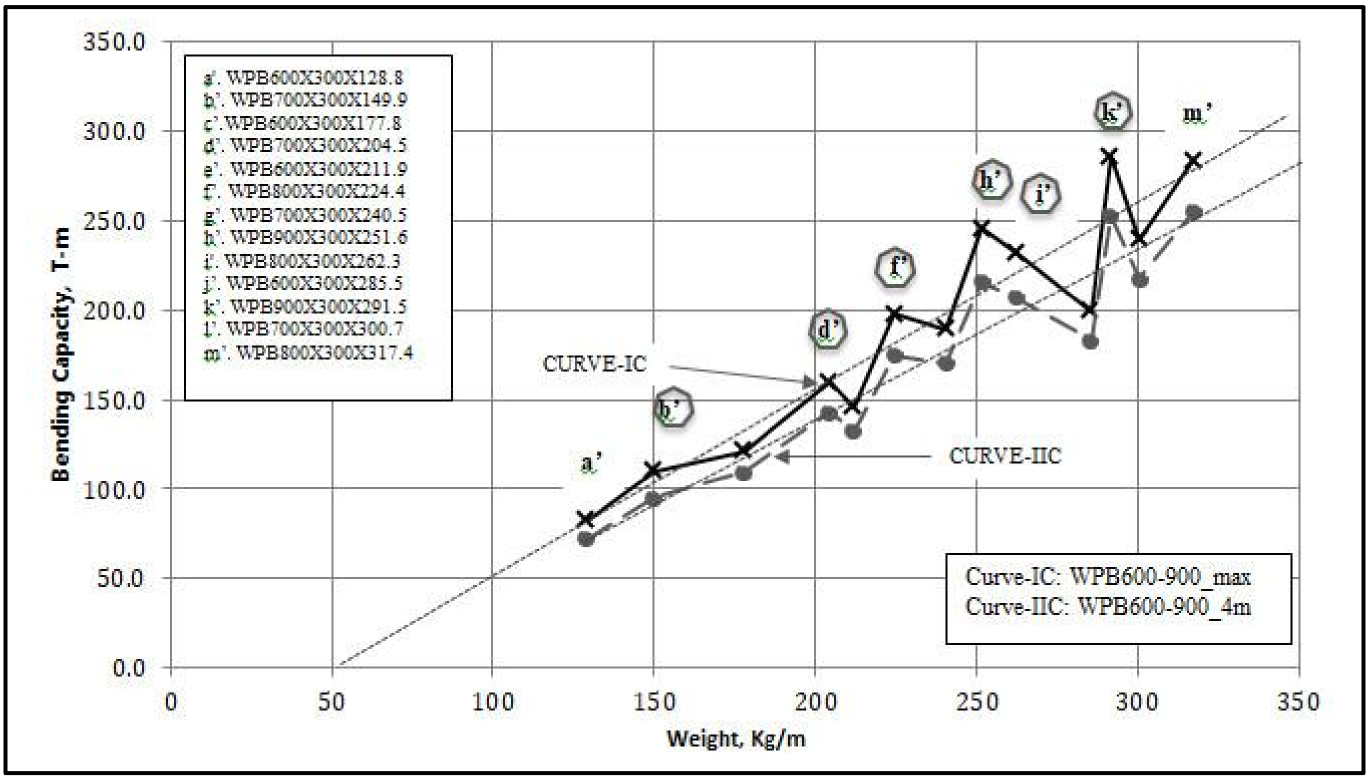

Fig. 3: Weight vs. Bending Capacity for WPB 600 900

C: Axial capacities of NPB & WPB Sections - Maximum and against various unsupported lengths.

Refer Table-3, though maximum axial capacities for NPB400 to 600 sections and WPB200 to 360 sections with similar weight range varies, axial capacities of NPB sections for higher unsupported length, say 4m are quite less than that of WPB sections. Thus, it is evident that, WPB sections are better for axial members than NPB sections. Refer Fig.4, difference in slope of Curve-IIIA and IVA is much more than that of Curve-IIIB and IVB. Therefore, it is evident that utilization of WPB sections against axial capacity is much better than NPB sections. Fig.5 also depicts similar pattern for WPB600 to 900 sections.

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However, in case of axial capacity, all the sections of NPB and WPB for the mentioned range of weights have uniform efficiency in terms of axial capacity w.r.t. weight.

TABLE 3:
(TITLE: AXIAL CAPACITIES VS. WEIGHT FOR NPB & WPB SECTIONS)

SECTION NAMES	**WT. kg/m**	**Axial_max T**	**Axial_max/ Wt.**	**Axial_1.5m T**	**Axial_1.5m / Wt.**	**Axial_3m T**	**Axial_3m /Wt.**	**Axial_4m T**	**Axial_4m /Wt.**
NPB450X190X67.2	67.2	194.3	2.9	185.0	2.8	154.0	2.3	119.2	1.8
NPB400X180X75.7	75.7	219.1	2.9	207.6	2.7	169.5	2.2	128.0	1.7
NPB500X200X79.4	79.4	229.8	2.9	219.8	2.8	186.6	2.4	148.5	1.9
NPB500X200X90.7	90.7	262.5	2.9	250.7	2.8	211.3	2.3	166.6	1.8
NPB450X190X92.4	92.4	267.5	2.9	254.8	2.8	212.6	2.3	165.1	1.8
NPB500X200X107.3	107.3	310.7	2.9	297.2	2.8	252.3	2.4	200.8	1.9
NPB600X220X107.6	107.6	311.4	2.9	300.3	2.8	262.8	2.4	219.4	2.0
NPB600X220X122.5	122.5	354.5	2.9	341.2	2.8	296.4	2.4	244.4	2.0
NPB600X220X154.5	154.5	447.3	2.9	431.6	2.8	378.1	2.4	316.3	2.0
WPB200X200X50.9	50.9	147.5	2.9	140.3	2.8	118.2	2.3	98.3	1.9
WPB250X250X73	73.1	211.8	2.9	206.3	2.8	182.7	2.5	162.4	2.2
WPB250X250X103.9	103.9	300.9	2.9	294.4	2.8	263.2	2.5	236.7	2.3
WPB300X300X100.8	100.8	292.0	2.9	289.4	2.9	264.4	2.6	244.3	2.4
WPB300X300X117.0	117.0	338.9	2.9	336.1	2.9	307.6	2.6	284.7	2.4
WPB360X370X136.7	136.7	394.3	2.9	394.3	2.9	370.7	2.7	351.2	2.6
WPB360X370X150.9	150.9	436.8	2.9	436.8	2.9	411.0	2.7	389.6	2.6
WPB300X300X182.0	182.0	527.0	2.9	527.0	2.9	496.7	2.7	471.2	2.6
WPB360X370X197.7	197.7	572.3	2.9	572.3	2.9	539.6	2.7	512.0	2.6
WPB600X300X128.8	128.8	373.0	2.9	368.1	2.9	342.7	2.7	318.0	2.5
WPB700X300X149.9	149.9	433.9	2.9	427.5	2.9	396.5	2.6	365.7	2.4
WPB600X300X177.8	177.8	514.8	2.9	510.3	2.9	479.1	2.7	450.3	2.5
WPB700X300X204.5	204.5	592.0	2.9	585.9	2.9	548.4	2.7	513.0	2.5
WPB600X300X211.9	211.9	613.6	2.9	608.4	2.9	571.5	2.7	537.5	2.5
WPB800X300X224	224.	649.5	2.9	641.8	2.9	598.8	2.7	557.5	2.5

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.4	4								
WPB700X300X240 .5	240. 5	696.4	2.9	689.3	2.9	645.5	2.7	604.3	2.5
WPB900X300X251 .6	251. 6	728.4	2.9	718.8	2.9	668.8	2.7	620.0	2.5
WPB800X300X262 .3	262. 3	759.5	2.9	750.7	2.9	700.7	2.7	653.0	2.5
WPB600X300X285 .5	285. 5	826.6	2.9	820.4	2.9	772.1	2.7	728.1	2.6
WPB900X300X291 .5	291. 5	843.9	2.9	832.9	2.9	775.4	2.7	719.5	2.5
WPB700X300X300 .7	300. 7	870.5	2.9	862.6	2.9	809.4	2.7	760.1	2.5
WPB800X300X317 .4	317. 4	918.9	2.9	909.0	2.9	850.1	2.7	794.3	2.5

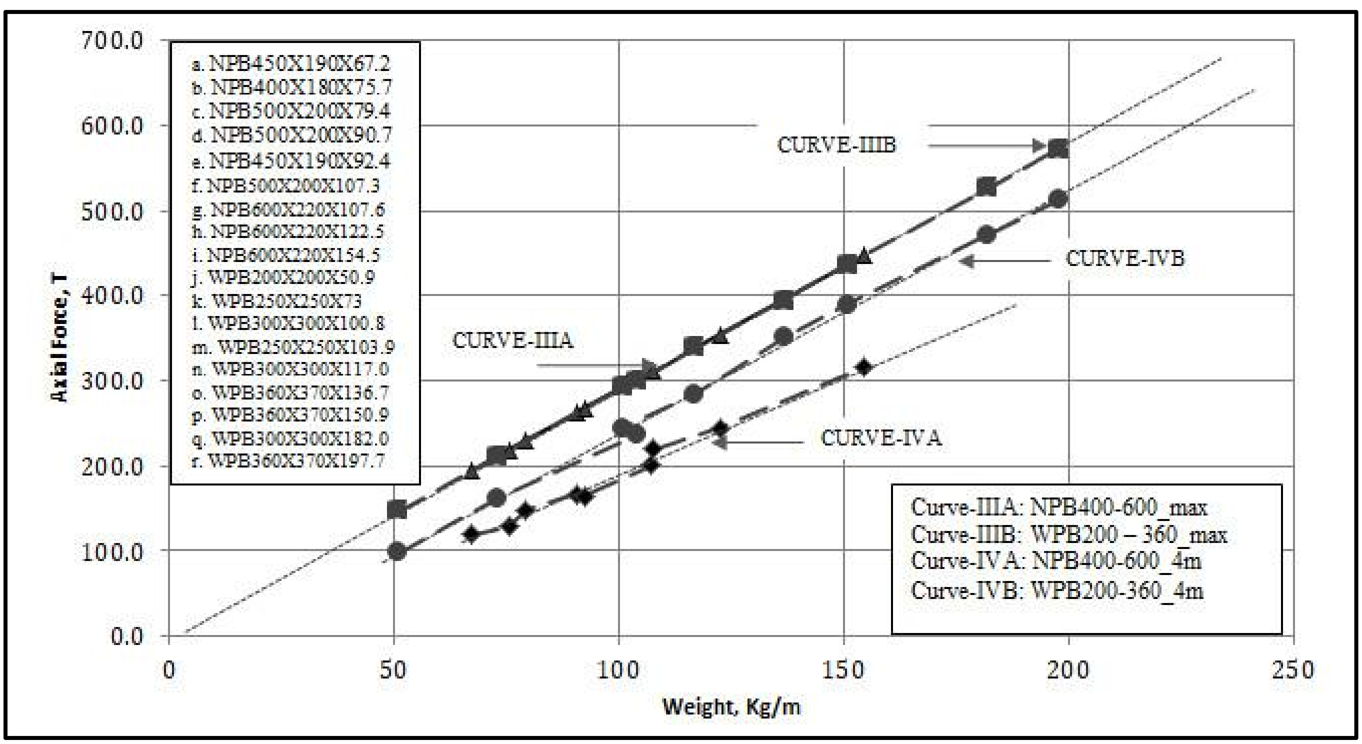

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Fig. 4: Weight vs. Axial Capacity for NPB 400 – 600 & WPB 200 – 360

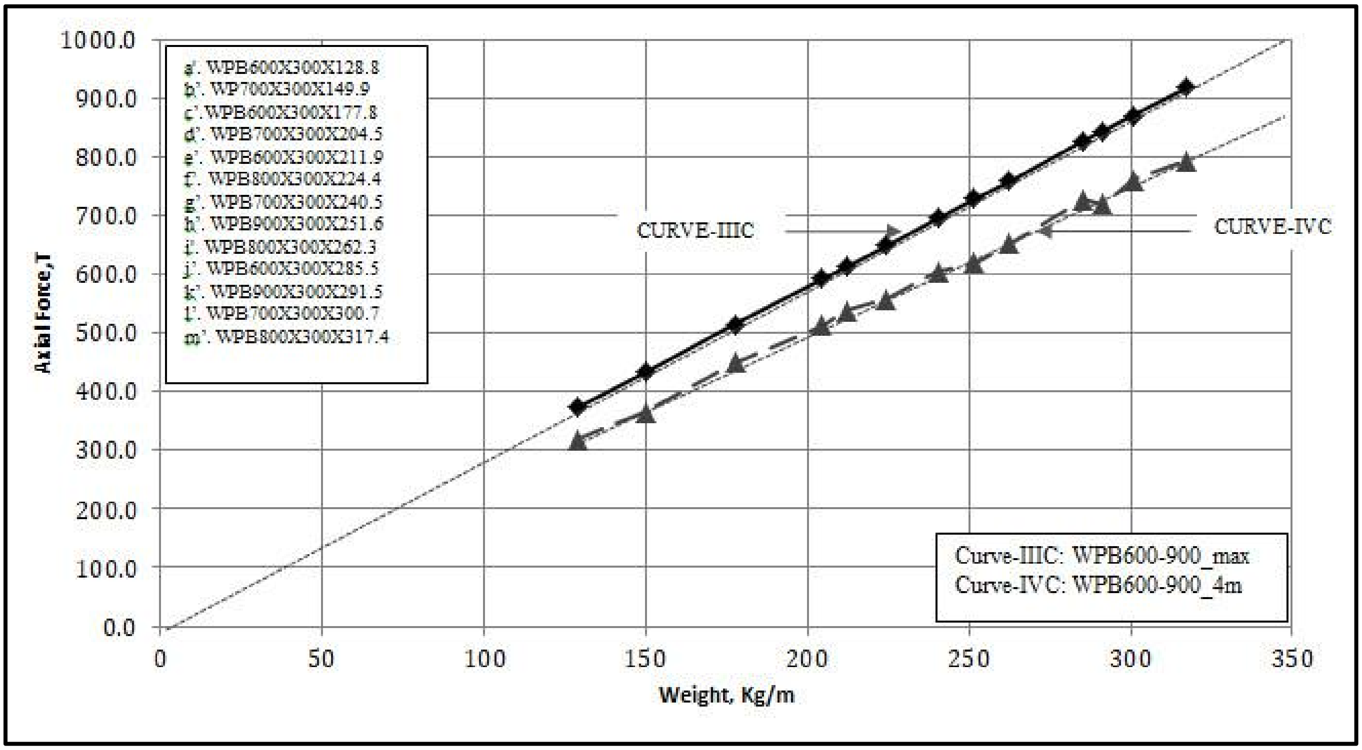

Fig. 5: Weight vs. Axial Capacity for WPB 600 - 900

CONCLUSION

On the concluding note, findings from the present study can be summarized as below –

1. NPB400 to 600 sections (67.2-154.5kg/m) are more efficient as bending member than as axial member, especially for LTB length up to 3 to 4m. Thus, they may be better utilized as portal beams of lightweight pipe racks, portal beams and equipment supporting beams of lightweight technological structures; portal beams, columns, and longitudinal beams at twin column level.

2. WPB200 to 360 sections (50.9-197.7kg/m) are more efficient as axial member than as bending member. Thus, they may be better utilized as longitudinal beams in braced frame directions for pipe racks, technological structures and compressor sheds. These sections are also effective as bending members for LTB length more than 4m; thus they may also be effectively used for beams where the same cannot be laterally restraint up to 4m.

3. For column of lightly loaded piperack or technological structures, any of the abovementioned sections may be used based on actual predominant behavior either axial or bending. Laced twin column of the compressor sheds being almost restraint against LTB, any of the NPB or WPB section based on actual requirement of axial capacity may be used.

4. WPB600 to 900sections (128.8-317.4kg/m)are efficient as bending as well as axial member; thus may be effectively used as portal beams, columns, equipment supporting beams etc.

5. For horizontal/vertical bracings, some small sizes of WPB sections may be used, though angle sections and square hollow sections (SHS) are more effective for the same. However, angle and SHS sections are not in the purview of this paper, separate study may be carried out in similar line for these sections.

6. Few sections are more efficient in terms of their utilization in bending or axial capacities w.r.t. weight than other sections, those sections may be shortlisted at the onset of any projects based on nature and size of process units, so as facilitate ordering and inventory management by means of reduction in variety.

This study, thus suggests a concept, which may be adopted for other industries as well. However, values mentioned here are relevant for this case study only and the same should not be used for other areas without analytical backup.

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