

Study on Strength characteristics of FRP pultruded I-section using ANSYS®

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Abstract— For steel beam buckling analysis is a critical area of study to determine overall section capacity subjected to bending. Pultruded I-beams are manufactured using fiber and matrix composite lamina hence is usually orthotropic compared to conventional steel I-beams. Many researchers have studied the buckling characteristics of simply supported pultruded FRP beams for various types of loadings. In this paper an attempt has been made to study the buckling characteristics of cantilever beam subjected to point load at free end for WF (wide flange) & NF(narrow flange) section. The validation has been made with experimental data. The effect of ratio like bf/bw is also studied. The buckling behavior of Pultruded I-beam under uniform axial loads is also studied. Various buckling modes of FRP Pultruded I-beam is studied. The effect of slenderness on global lateral torsional buckling (PO) and local flange buckling (PL) under uniform axial loading and bending is also studied.

Keywords — Pultruded I-beams, buckling characteristics, buckling modes, lateral torsional buckling, local flange buckling.

I. INTRODUCTION

By decades the use of composite material is increased. By good knowledge of the fundamental properties of composites the rise of composites can be explained. FRP profiles have been used over more over past few years, due to high ratio of strength to weight. In the construction industry, recent applications have shown the structural and cost efficiency of FRP structural shapes, such as thin-walled open sections made through so-called pultrusion process. FRP beam and column offers great benefits in placement of composites with the help of lighter machine and initial haulage. It also offers the less schedule of maintenance and offer easy attachment of fittings, with FRP structures being engineered for a long service life. The physical and chemical properties of the composites make them a very attractive material option for selection particularly in more corrosive environments where traditional materials are known to deteriorate. To realize these benefits, the world of FRP requires demystifying, and the selection of these products made more easily understood. Pultruded profiles for commercial and structural applications which are produced by many manufacture the world. Most manufacturers produce custom profiles for commercial applications. A number of industry groups represent and loosely coordinate the activities of pultrusion manufacturers. Leading groups are the Pultrusion Industry Council of the European Pultrusion Technology Association (EPTA) and the American Composites Manufacturers Association (ACMA). Commonly produced pultruded profiles are usually available as wide-flange, I, rectangular tube, channel, square tube, plate materials and angle profiles. Standard profiles range from width to approximately 12 in. (300 mm) and 2 in. (50 mm) in height and have material thicknesses of two in. (6 to 13 mm). At this time there is no proper guidelines for the design of framed structures using either pultruded structural profiles as there are for concrete structures strengthened with FRP strengthening systems or reinforced with FRP rebar. However, two design manuals are developed: The Euro comp Design Code and Handbook (Euro comp, 1996) and The Structural Plastics Design Manual (ASCE, 1984).

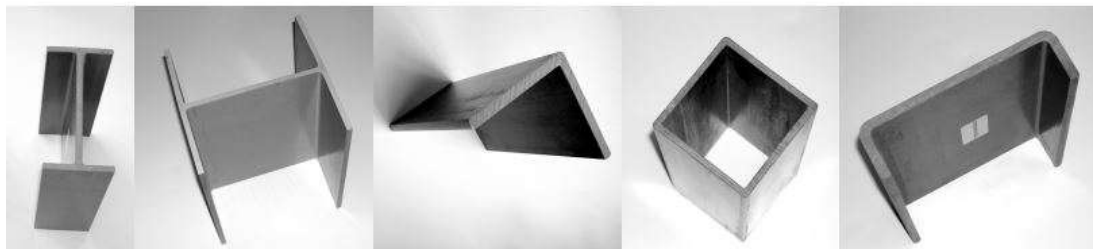


Figure 1 Pultruded profiles: I, wide flange, angle, tube, and channel

II. LITERATURE REVIEW

M.M. Alinia, A. Dibaie, et al [1] studied buckling behavior of I-beams. The typical plated columns, one is 1m height and second is 4m height having similar section properties are considered. The web and flange width are assumed to be 1000mm and 300mm. The web and flange thickness is carried out 5mm and 30mm. During parametric studies for web and flange slenderness ratio, thickness is varied. Selections of flange and web thickness are as per limits defined in AISC360. The ABAQUS software is used in incremental nonlinear large displacement push over analysis. The nonlinear push over analysis is carried out by utilizing the modified Risk method, allowing for both softening and stiffness hardening of plated structures. The structural elements are taken

as four nodes doubly curved shell element S4R in ABAQUS. This element accounts for large rotation and finite membrane strains. The S4R element has three rotational and three translation of freedom at each node. It is based on isoperimetric formulation and uses one integration point on its mid-surface to form the element internal force vector. The reduced integrated formulation is used to reduce time and provide accurate results.

Ever J. Barbero & Ioannis G. Raftoyiannis et al [2] has studied pultruded I-beams subjected to various loading conditions and their elastic buckling modes. The lateral and distortional buckling coupling to appear in thin-walled cross verify to their predict bending-twisting coupling and shear effects are accounted. The effect of volume fraction and fiber orientation in the matrix is taken into account for parametric study. The buckling strength determine as overall strength of the member. The energy criterion for equilibrium of structure is used for theory approach. The solution of the problem is attempted by Rayleigh-Ritz method. The pre buckling solution is derived using laminated beam theory. Coupling of local and lateral buckling modes always occurs due to the low stiffness of the material in the perpendicular direction to the beam axis. For high depth-width ratio, lateral buckling is the governing mode of failure. For low height-depth ratio coupled local and distortional buckling results in a reduced section. The simply supported beams with free warping in both the ends and having concentrated load at the centroid is considered in the specific cases, the theoretical formulation and the solution methodology can be easily applied for any boundary conditions.

Rami Haj-Ali, Hakan Kilic et al [3] has invested Coupon tests and they are used to calibrate 3D micromechanical models and to verify their prediction for the non-linear elastic behaviour of pultruded FRP composites. The material system is made from E-glass/vinyl ester composite plate with both continuous filament mat (CFM) layers and glass roving layers. Tension, shear and compression tests were performed, using off-axis coupons cut with different roving reinforcement orientation. The overall linear elastic properties are identified along with the nonlinear stress-strain behaviour under in-plane multi-axial tension and compression loading. The tests were carried out of coupons with off-axis angles: 0°, 15°, 30°, 45°, 60° and 90°, where each test was carried out three to five times. Finite element analysis is used to examine geometry condition end-clamping condition and axis orientation. Lower initial elastic modulus and softer nonlinear stress-strain responses observed in the tension compared to those in compression for all axis orientation. The nonlinear behaviour can be attributed to the relatively low overall fiber volume fraction in pultruded composites and manufacturing defects such as micro cracks and voids. End coupling effect for the tested geometry is small at the centre and allows extracting the non-linear stress-strain response of anisotropic material. Shear tests are used to calibrate the in situ nonlinear elastic properties of the matrix. The material has a lower initial stiffness and lower ultimate tensile stress in tension compared to the corresponding values of compression tests, regardless of thickness and angles approaching angle of 90°. Good scalability of material and geometry appear to exist between the ¼ and ½ in. thickness coupons tension and compression of axis (45°) tests can be used to determine the initial shear modulus of FRP pultruded material.

Lawrence C. Bank, et al [4] has considered the shear stiffness of pultruded FRP beam. A new material stiffness property called shear modulus is taken into account for the shear deformation effects. Results of an experimental program conducted to obtain the section shear modulus for variety of FRP beams. The analysis of a rigid portal frame structure is presented to demonstrate the influence of the beam section stiffness properties on frame deflection and forces. The stiffness property can be obtained for standard pultruded beams using test methodology that gives beam flexure modulus. Using the stiffness properties designers can take account for the effect of shear deformation.

J. Lee, S.-E. Kim, K. Hong et al [5] has studied lateral buckling of a laminated composite I-section beam. General analytical model applicable to the lateral buckling of section subjected to various loading types is developed. The model is based on classical lamination theory. It accounts for the material coupling for arbitrary laminate stacking sequence and various boundary conditions. The effect of the location of applied load on buckling capacity is also included. A finite element model and a displacement model is developed to predict buckling modes and critical loads of a thin walled composite beam with boundary conditions. Numerical results are obtained under, uniformly distributed load; pure bending and central point load with angle-ply laminates. The effects of location of applied load, types of loads and orientation of fiber are studied. Lateral buckling capacity of beams with transverse loads is affected by the fiber orientation as well as location of loads. The maximum buckling loads occurs near 45° fiber angle for all cases of span to height ratio. For beam under pure bending with off-axis fiber orientation, orthotropic closed-form solution is not appropriate for lateral buckling loads due to existence of coupling stiffness.

Pizhong Qiao, Julio F. Davalos, Jialai Wang et al [6] has carried out an analytical study of local buckling of discrete laminated panels or plates FRP structural shapes. Flanges of FRP shapes are modelled as discrete panels subjected to uniform axial loads. Two cases with different boundary conditions and elastic restraints of composite plates are studied. Using the regression analysis simplified expressions for predictions of plate buckling stress resultants are formulated in terms of coefficients of boundary elastic restraints. The effects of restraint at the flange web connection are considered. The theoretical predictions show good agreement with experimental data and FEM eigen value analysis for local buckling of FRP columns. The present formulation can be applied to several cases to determine buckling capacities.

III. PARAMETRIC STUDY FOR BF/BW VARIATION:-

Two different profiles I 0.2 x 0.2 x 0.095 m & I 0.4 x 0.4 x 0.095m having 3m span are taken for this study. Each profile is modelled as cantilever beam with end condition ($U_x=U_y=U_z=0$) at all nodes of the flange and web at one end. The material properties are as is shown in Table 6.1. Vertical node at mid height of web is applied and eigen buckling analysis is carried out.

Fy=1N is applied as an initialization load for eigen buckling. Modelling is done using SHELL 181, special element which facilitates the laminate analysis with orthotropic and anisotropic lamina stacking arrangement material.

TABLE 1 bf/bw variation study

	Profile	bf/bw	P0/PL
A	I 0.134X0.2X0.01m	0.67	0.231786
	I 0.080X0.2X0.01m	0.4	0.051005
	I 0.060X0.2X0.01m	0.34	0.031494
	I 0.057X0.2X0.01m	0.285	0.021647
B	I 0.268X0.4X0.01m	0.67	0.755901
	I 0.16X0.4X0.01m	0.4	0.225151
	I 0.136X0.4X0.01m	0.34	0.13693
	I 0.114X0.4X0.01m	0.285	0.09454

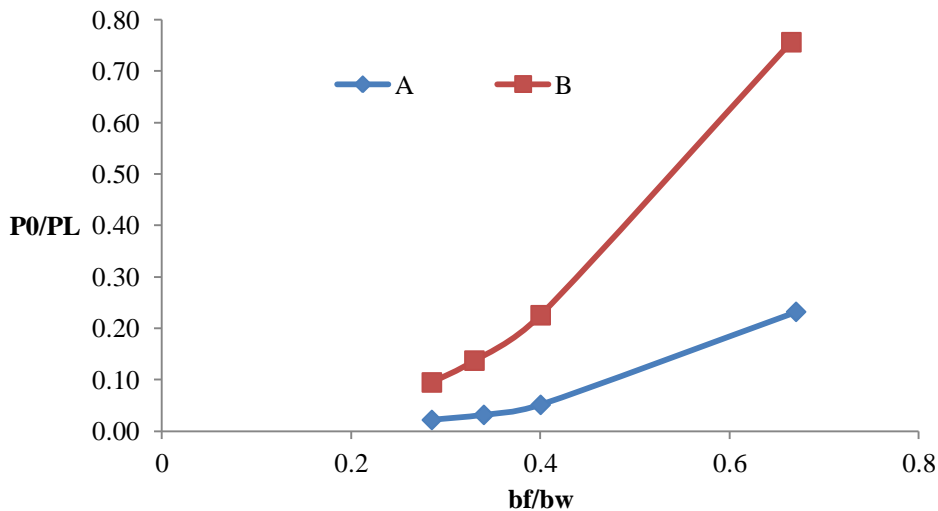


FIGURE 2 bf/bw vs. P0/PL

Where, P0 = Critical buckling load for 1st mode of global lateral torsional buckling.
 PL = Critical buckling load for 1st mode of Local flange buckling.

IV. EFFECT OF L/r SLENDERNESS UNDER BENDING:-

Two wide flange profiles WF 0.1 x 0.1 x 0.006m (4x4x1/4”), WF 0.15 x 0.15 x 0.0095m (6 x6 x3/8”), and two narrow flange profiles NF 0.1 X 0.2 X 0.0095m (4x8x3/8”), NF 0.07 X0.15 X 0.0095m (3x6x3/8”) of FRP I-beams Profiles are taken for study. Each profile is modelled as cantilever beam with end condition (Ux=Uy=Uz=0) at all nodes of the flange and web at one end .The material properties are as is shown in Table 6.1.SHELL 181 element is used for eign buckling analysis. Vertical node at mid height of web is applied and eigen buckling analysis is carried out. Fy=1N is applied as an initialization load for eigen buckling.

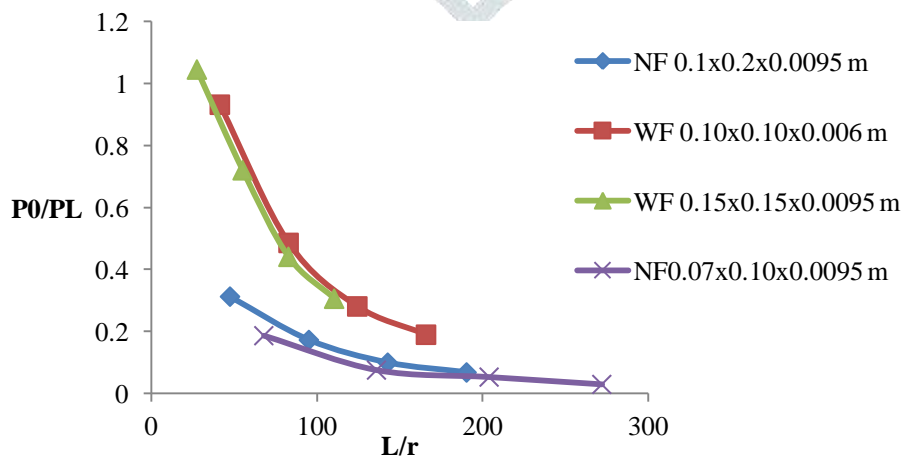


FIGURE 3 L/r Vs. P0/PL (under bending)

TABLE 2 Effect of L/r ratio under bending

Profile	Length (m)	L/r	P0/PL
<i>NF 0.1mX0.2mX0.0095m</i>	1	47.62	0.31
	2	95.24	0.17
	3	142.86	0.10
	4	190.47	0.07
<i>WF 0.10mX0.10mX0.006m</i>	1	41.49	0.93
	2	82.99	0.49
	3	142.48	0.28
	4	165.98	0.19
<i>WF 0.15X0.15X0.0095m</i>	1	27.62	1.05
	2	55.25	0.72
	3	82.87	0.44
	4	110.50	0.31
<i>NF 0.07X0.10X0.0095m</i>	1	68.30	0.19
	2	136.05	0.08
	3	204.08	0.05
	4	272.11	0.03

Where, P0 = Critical buckling load for 1st mode of global lateral torsional buckling.
 PL = Critical buckling load for 1st mode of Local flange buckling.

V. EFFECT OF L/r SLENDERNESS UNDER AXIAL LOADS

In this study one narrow flange NF 0.1x0.2x0.0095 m (4x8x3/8”) and one wide flange WF 0.15x0.15x0.0095 m (6x6x3/8”) profiles having 3m span are taken for study. Each profile is modelled as cantilever beam with end condition $U_x=U_y=U_z=0$ at all nodes of the flange and web at one end .The material properties are as is shown in Table 6.1.SHELL 181 element is used for eigen buckling analysis. Uniform axial load at free end of section is applied and eigen buckling analysis is carried out. $F_y=1N$ is applied as an initialization load for eigen buckling.

TABLE 3 Effect of L/r ratio under axial loads

Profile	Length (m)	L/r	P0/PL
<i>NF 0.1mX0.2mX0.0095m</i>	1	47.62	0.11
	2	95.24	0.03
	3	142.86	0.01
	4	190.47	0.01
<i>WF 0.15mX0.15mX0.0095m</i>	1	27.62	0.48
	2	55.25	0.10
	3	82.87	0.04
	4	110.50	0.03

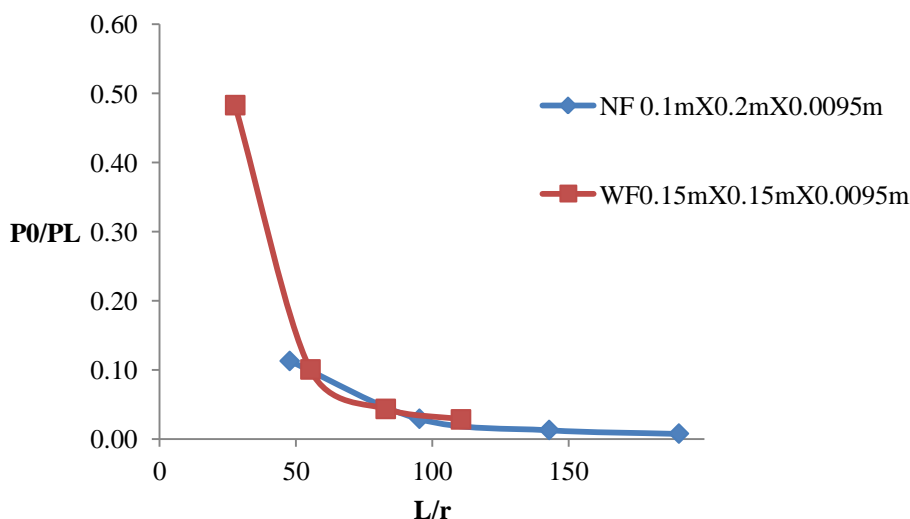


FIGURE 4 L/r Vs. P0/PL (under axial loads)

Where, P0 = Critical buckling load for 1st mode of global lateral torsional buckling.
 PL = Critical buckling load for 1st mode of Local flange buckling.

VI. BUCKLING MODE STUDY FOR CANTILEVER PULTRUDED I-BEAM

One narrow flange section NF 0.1 x0.2x0.0095 m (4x8x3/8”) and one wide flange section WF 0.15 x 0.15 x 0.0095 m (6x6x3/8”) having different spans are taken for study. Material properties are taken as described in Table-6.1. Uniform axial load at free end of section is applied and eigen buckling analysis is carried out. Fy=1N is applied as an initialization load for eigen buckling.

TABLE 4 Critical Buckling loads for cantilever beam (NF-profile)

<i>NF 0.1m x 0.2m x 0.0095 m</i>		
L(m)	PL(kN)	P0(kN)
0.15	938.28	-
0.35	948.02	-
0.50	923.63	-
1	686.22	87.10
2	721.62	22.04
3	738.66	9.78
4	728.95	5.52

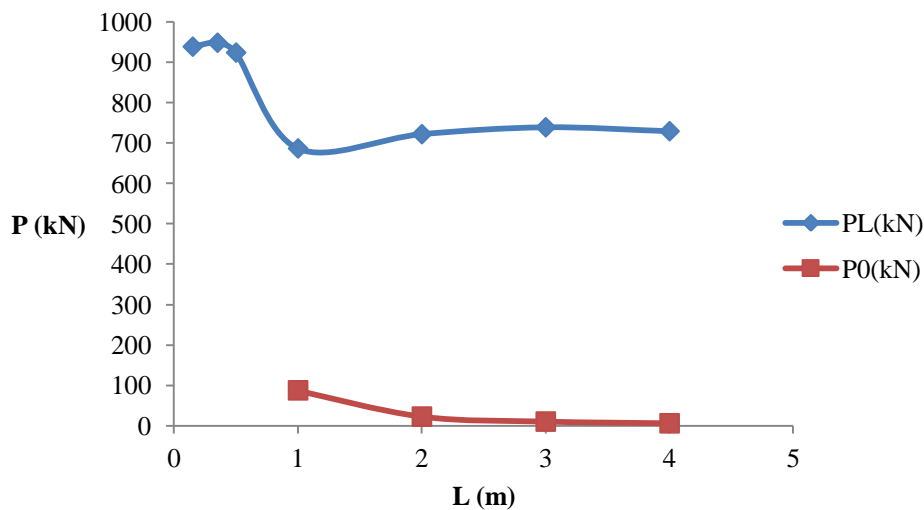


FIGURE 5 Critical Buckling load curves for cantilever beam (NF profile)

TABLE 5 Critical Buckling loads for cantilever beam (WF-profile)

<i>WF 0.15m x 0.15m x 0.0095 m</i>		
L(m)	PL(kN)	P0(kN)
0.15	682.91	-
0.35	677.69	-
0.50	691.59	-
1	631.90	303.381
2	589.33	79.1453
3	606.63	34.1757
4	564.01	19.851

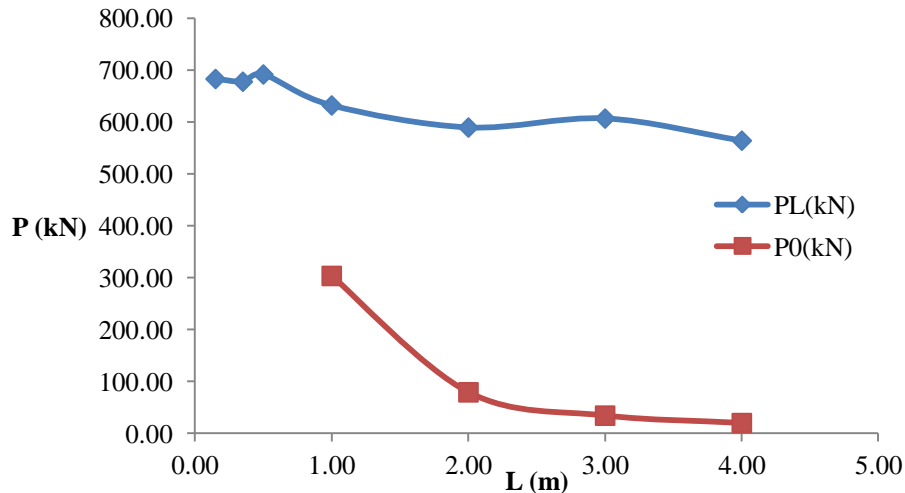


FIGURE 6 Critical Buckling load curves for cantilever beam (WF profile)

Where, P0 = Critical buckling load for 1st mode of global lateral torsional buckling.
 PL = Critical buckling load for 1st mode of Local flange buckling.

VII. CONCLUSION

With the increase in ratio like bf/bw (with bw as constant) the ratio $P0/PL$ also increases. Hence for the profile being other section dimension constant, the increase in bf/bw ratio helps a lot to increase sections' buckling resistance by improved warping capacity. The reported increment in $P0/PL$ ratio actually due to increase in Global lateral torsional capacity (P0) and simultaneous decrease in local flange buckling capacity (PL). The decrement in PL for constant bw is due to increase in unsupported flange dimension due to increase in bf , which on the other side results in increase of global lateral torsional capacity (P0). From the study presented, it is cleared that slenderness of the beam directly affects both the P0 and PL value. For a wide flange section $P0/PL$ values are more close to unity compare to narrow flange section which suggests that the local buckling and global buckling modes are in a close vicinity. In case of uniform axial loading the ratio $P0/PL$ decreases with the increase in length. From the comparison of variation of $P0/PL$ ratio with the increase of slenderness for same profile under uniform axial load (Table-3) and bending under point load (Table-2), it is concluded that the global lateral torsional buckling will be a critical mode in case of a cantilever beam subjected to axial load compared to under the action of bending due to point load at its free end. there is no distinct point of bifurcation between local flange buckling (PL) and global lateral torsional buckling (P0) in case of cantilever beam subjected to point load at free end. In major cases, for both WF section and NF section, P0 is the governing buckling mode for length above 1m.

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