EJERS, European Journal of Engineering Research and Science
Vol. 5, No. 10, October 2020

Influence of Bracing on Buckling Strength of Pultruded Glass Fiber Reinforced Polymer Frames

Mojtaba B. Sirjani and Zia Razzaq

***Abstract* — A numerical study of the influence of structural bracing on the buckling strength of pultruded Glass Fiber Reinforced Polymer (GFRP) frames is presented. Although the influence of bracing on frames made from other materials such as steel have been studied in the past, this paper investigates the performance of pultruded GFRP portal frames with pinned or fixed column bases. Each frame is constructed with pultruded GFRP I-section members. The influence of I-section column major and minor axis orientation is also investigated. The results demonstrate the practical significance of bracing pultruded GFRP frames. The results show that the buckling loads for braced frames are seven to nine times greater than those for unbraced frames when the column bases are pinned. The corresponding gain in the buckling load capacity due to the addition of bracing is more than three times if the column bases are fixed.**

***Index Terms* — Bracing, Buckling, Fiber Reinforced, Frams.**

I. Introduction

Pultruded glass fiber reinforced polymer (GFRP) rectangular frames are susceptible to nonsway and sway buckling when subjected to gradually increasing vertical joint loads. Minghini et al [1] conducted buckling analysis of FRP pultruded frames using locking free finite elements approach. In another study [2], they studied buckling of frames with semi-rigid connections. The classical theory of frame buckling can be found in References 3 and 4. Furthermore, Reference 5 provides guidelines for buckling analysis of pultruded FRP structural members. Reference 6 uses a pair of nomograms for frame buckling analysis for columns which is based on end restraint factors known as G_A and G_B factors. The underlying theory and derivation for these factors can be found in Reference 4. Yu et al [7] presented a review of the influence of various types of structural bracing on the structural performance of steel frames. Mottram [8] presented the stability analysis of plane frames of fiber reinforced polymer with semi-rigid joints and shear-flexible members. Mottram [9] also presented an analysis for pitched portal frames of fiber reinforced polymer. The authors have previously published stability and buckling studies of GFRP beams and columns [10], [11]. Although the influence of bracing on frames made from other materials such as steel have been studied in the past [4], the focus of the present paper is on studying the influence of bracing as well as column bottom-end boundary conditions on pultruded GFRP portal frame buckling load capacity. In addition, the effect of column cross-sectional major and minor axis orientation on frame buckling load is identified.

II. Unbraced and Braced Portal Frames

Figure 1 shows four different cases of both unbraced and braced portal frame problems investigated in this paper with either pinned or fixed boundary conditions at the base. Each frame is subjected to a pair of gradually increasing vertical loads (P, P) applied at the column top ends until buckling occurs at $P = P_{cr}$. In this figure, Case 1 represents an unbraced frame ABCD with pinned boundaries at A and D. Case 2 is identical to Case 1, however, it has an X-brace. Cases 3 and 4 are similar to Cases 1 and 2 except that their bottom ends are fixed.

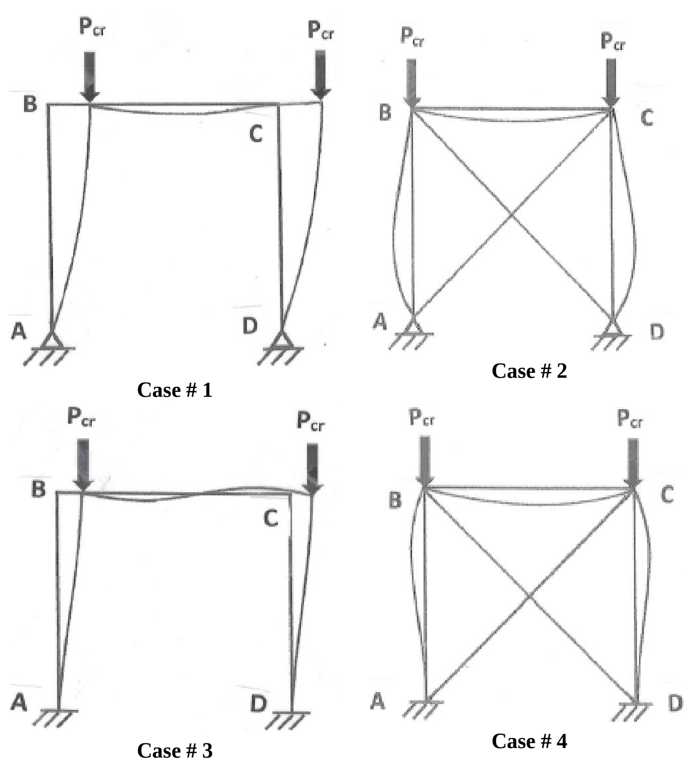

Fig. 1. Unbraced and braced frames with columns either pinned or fixed at the base.

Published on October 13, 2020.
Mojtaba B. Sirjani, Norfolk State University, USA.
(e-mail: sirjani@nsu.edu)
Zia Razzaq, Old Dominion University, USA.

III. BASIS OF GFRP FRAME BUCKLING ANALYSIS

In this paper, the classic Euler theory [3], [4] combined with end restraint factors is used, that is, based on the following expressions:

$$P_{cr} = \frac{\pi^2 EI_c}{(KL_c)^2} \quad (1)$$

$$G_A = \frac{I_C/L_C}{I_b/L_b} \quad (2)$$

$$G_B = \frac{I_c/L_c}{I_b/L_b} \quad (3)$$

In Equations 2 and 3, G_A and G_B are the respective restraint factors at ends A and B for the column AB in each of the frames shown in Figure 1. The end restraint factors can readily be computed by substituting the lengths and moment of inertias of the columns and the connecting beam into Equations 2 and 3. The other terms in the above equations are defined as follows:

P_{cr} = Frame buckling load, kips,
E = Young's modulus of elasticity, ksi,
I_c = Moment of inertia of each column, in^4,
L_c = Colum length, ft,
I_b = Beam moment of inertia, in^4,
L_b = Beam Length, ft, and
K = Effective length factor.

The effective length factor, K, can be found iteratively using Equations 4 and 5, respectively, for braced and unbraced frames [4]:

$$\frac{\pi^2 G_A G_B}{4K^2} + \left(\frac{G_A+G_B}{2}\right)\left[1 - \frac{\pi}{Ktan(^{\pi}/_K)}\right] + \frac{2Ktan(^{\pi}/_{2K})}{\pi} = 1.0 \quad (4)$$

$$\frac{\pi^2 G_A G_B/_{K^2-36}}{6(G_A-G_B)} = \frac{\pi}{Ktan(^{\pi}/_K)} \quad (5)$$

Alternatively, using G_A and G_B factors, the K factor for a given column such as column AB can be found using the alignment charts given in Reference 6. Lastly, the frame buckling load P_{cr} can be found using Equation 1.

Table 1 presents the summary of the results for elastic buckling for Frames numbered 1a through 4a when both the beam and column lengths are equal. Also, results are presented in this table for Frames numbered 1b through 4b when the beam length is twice the column length. Specifically, Frames 1a through 4a have the following input properties: $L_b = L_C = 12$ ft.; $I_c = I_y$ = 42.74 in^4; I_b = 143.48 in^4; and $E = 3000$ ksi. For Frames 1b through 4b, $L_b = 2L_C = 24$ ft., and the other properties remain unchanged. Based on the results in this table, the following observations are made:

1. When the columns and beams are of the same length, the presence of bracing (Frame Case 2a) results in more than seven times the buckling load compared with that for the frame without bracing (Frame Case 1a) if the column bases are pinned. The corresponding increase in the buckling load is about 3.5 times when the column bases are fixed (Frame Case 4a versus Frame Case 3a).

2. When the beam is twice the length of each column, the presence of bracing (Frame Case 2b) results in about 6.8 times the buckling load compared with that for the frame without bracing (Frame Case 1b) if the column bases are pinned. The corresponding increase in the buckling load is about 3.2 times when the column bases are fixed (Frame Case 4b versus Case 3b).

TABLE 1: SUMMARY OF RESULTS WHEN $I_c = I_y$

Frame	L_b ($ft.$)	L_c ($ft.$)	G_A	G_B	K	P_{cr} (kips.)
Case 1a	12	12	∞	0.30	2.1	13.84
Case 2b	12	12	∞	0.30	0.78	100.30
Case 3a	12	12	0	0.30	1.05	55.35
Case 4a	12	12	0	0.30	0.57	191.17
Case 1b	24	12	∞	0.60	2.19	12.73
Case 2b	24	12	∞	0.60	0.84	86.53
Case 3b	24	12	0	0.60	1.08	52.35
Case 4b	24	12	0	0.60	0.60	169.60

Table 2 presents the summary of the results for elastic buckling for Frames numbered 1c through 4c, and Frames 1d through 4d in a manner similar to those summarized in Table 1 except that in Table 2, I_c is taken as I_x = 127.06 in^4. Based on the results in Table 2, the following observations are made:

3. When the columns and beams are of the same length, the presence of bracing (Frame Case 2c) results in more than nine times the buckling load compared with that for the frame without bracing (Frame Case 1c) if the column bases are pinned. The corresponding increase in the buckling load is about five times when the column bases are fixed (Frame Case 4c versus Frame Case 3c).

4. When the beam is twice the length of each column, the presence of bracing (Frame Case 2d) results in about eight times the buckling load compared with that for the frame without bracing (Frame Case 1d) if the column bases are pinned. The corresponding increase in the buckling load is about 3.6 times when the column bases are fixed (Frame Case 4d versus Case 3d).

TABLE 2: SUMMARY OF RESULTS WHEN $I_c = I_x$

Frame	L_b ($ft.$)	L_c ($ft.$)	G_A	G_B	K	P_{cr} (kips.)
Case 1c	12	12	∞	0.89	2.30	34.30
Case 2c	12	12	∞	0.89	0.75	322.54
Case 3c	12	12	0	0.89	1.15	137.19
Case 4c	12	12	0	0.89	0.51	697.53
Case 1d	24	12	∞	1.78	2.60	26.84
Case 2d	24	12	∞	1.78	0.92	214.84
Case 3d	24	12	0	1.78	1.25	116.11
Case 4d	24	12	0	1.78	0.66	146.50

IV. CONCLUSIONS

The study presented in this paper shows that the presence of bracing can have a major influence on increasing the buckling strength of a GFRP frame. The buckling loads for braced portal frames are found to be seven to nine times greater than those for unbraced portal frames when the column bases are pinned. The corresponding gain in the buckling load capacity due to the addition of bracing is more than three-folds if the column bases are fixed.

REFERENCES

[1] F. Minghini, N. Tullini, F. Laudiero "Buckling anaylsis of FRP Pultruded Frames using Locking free Finite Elements Approach," Elsevier, *Engineering Structures,* Vol. 46, Issue 3. March 2008, pp. 223-241.
[2] F. Minghini, N. Tullini, F. Laudiero, "Elastic Buckling Analysis of Pultruded FRP Portal Frames having semi-rigid connections," *Elsevier, Engineering Structures,* Vol. 31, Issue 2. February 2009, pp. 292-299.
[3] S. P. Timoshenko, J. Gere, *Theory of Elastic Stability*, *McGraw-Hill Publishing Company,* Second Edition, 1988.
[4] T. V. Galambos, *Structural Members and Frames,* Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1968.
[5] American Society of Civil Engineers. *Pre-Standard for Load and Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures,* November 2010.
[6] Steel Construction (AISC) Manual, American Institute of Steel Construction
[7] X. Yu, T. Ji and T. Zheng, "A Review of Influence of Various Types of Structural Bracing to the Structural Performance of Buildings," *Engineering*
[8] J. T. Mottram, "Stability Analysis of Plane Frames of Fibre Reinforced Polymer having Semi-rigid Joints and Shear-flexible Members, *Proceedings of the 3rd International Conference on Advanced Composites in Construction*, York Publishing Services Ltd., York, 2007, pp. 61-68.
[9] J. T. Mottram, "Stability Analysis for Pitched Portal Frames of Fibre Reinforced Polymer," Fourth International Conference on FRP Composites in Civil Engineering, Zurich, Switzerland, 22-24 July,
[10] Sirjani, M. B., and Razzaq, Z., "Stability of FRP Beams under Three-point Loading and LRFD Approach," *Journal of Reinforced Plastics and Composites,* Vol. 24, No. 18, 2005.
[11] Razzaq, Z., Sirjani, M.B., and Prabhakaran, R., "LRFD Approach for FRP Channel Section Columns," *Journal of Reinforced Plastics and Composites,* Vol. 28, No. 12, 2009, pp. 1409-1415.

Mojtaba B. Sirjani was born in Mashhad Iran in 1959. He received a

Bachelor's and a Master's degree in Mechanical Engineering from Old Dominion University, North Carolina State University in Mechanical Engineering, in 1984, 1989, respectively. Also, He received a Ph.D. in Civil Engineering from Old Dominion University in 1998. He is currently a Professor in School of Science and Technology, Norfolk State University, and adjunct professor in the Department of Civil and Environmental Engineering, Old Dominion University, Virginia, USA. Before he selected academia as his career path, Dr. Sirjani has worked for two years in a consulting company as design structural engineer.

Zia Razzaq was born in Pakistan in 1945. He received a Bachelor's, Master's, and a Doctoral degree in civil engineering from the University of Peshawar, Pakistan; University of Windsor, Canada; and Washington University, St. Louis, USA, in 1966, 1968, and 1974, respectively. He is currently a University Professor in the Department of Civil and Environmental Engineering, Old Dominion University, Virginia, USA.