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Failure Modes for I-Section GFRP Beams

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Failure Modes for I-Section GFRP Beams

Mamadou Konate [α] & Zia Razzaq [σ]

Abstract- This paper presents calculations for the failure modes for I-section Glass Fiber Reinforced Polymer (GFRP) beams with single mid-span web brace. Theoretical predictions are made using ASCE-LFRD Pre-Standard for FRP structures. For the member length considered, it is found that for small and medium I-sections the failure mode is governed by lateral-torsional buckling and for bigger I-sections the failure mode is governed by material rupture. The outcome of the predicted lateral-torsional buckling mode is compared with that observed experimentally.

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I. Introduction

Razzaq, Z, Prabhakaran, R., and Sirjani, M. B [1] have conducted an experimental and theoretical study of the flexural-torsional behavior of reinforced beams using LFRD approach. The same authors have also provided a load and resistance factor design (LFRD) approach for fiber-reinforced plastic (FRP) [2]. The paper presents the outcome of a study on failure modes for I-section GFRP beams.

II. Experimental Study

A 93 inches long GFRP beam with a 8 x 4 x 0.5 in. is tested as shown in Figure 1.

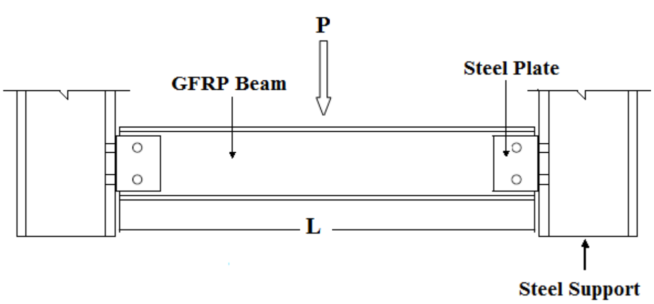

Fig. 1 : Schematic of I-Section GFRP beam

The test procedure involved applying the load, P, in small increments and recording the resulting deflections. Figure 2 shows the experimental test setup. In this figure, the ends have shear-type connections and a hydraulic jack of 50-kip capacity with load cell and a loading device are also shown.

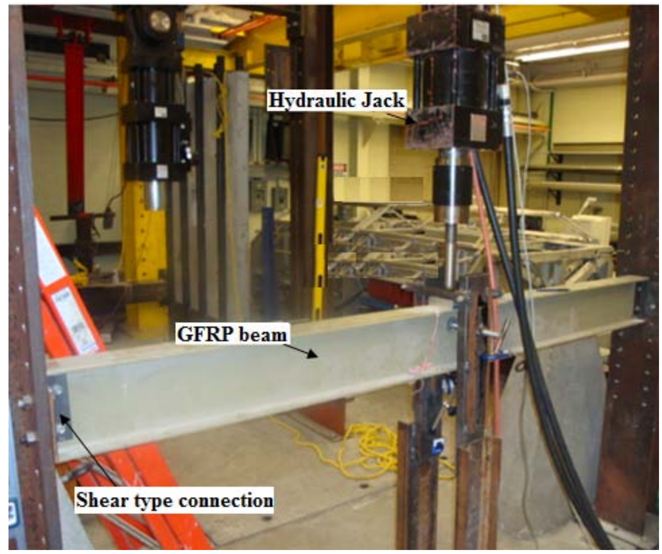

Fig. 2 : Test setup

Furthermore, bracing is provided at the mid-span on both sides of the web at 0.81 in. below the bottom surface of the top flange. It is observed that the tested GFRP beam first buckled and then cracked.

III. Basis For Predictions

The critical stresses are based on following ASCE-LRFD Pre-Standard formulae given in Reference 3:

$$f_{fcr} = \frac{4}{(\frac{b_f}{t_f})^2}\left(\frac{7}{12}\sqrt{\frac{E_{L,f}E_{T,f}}{1+4.1\xi}} + G_{LT}\right) \quad (1)$$

$$f_{wcr} = \frac{11.1\pi^2}{12(\frac{h}{t_w})^2}\left(1.25\sqrt{E_{L,w}E_{T,w}} + E_{T,w}v_{LT} + 2G_{LT}\right) \quad (2)$$

In Equations 1 and 2, f_{fcr} is the critical stress for the compression flange local buckling; f_{wcr} is the critical stress for the web local buckling; and the other terms are defined as:

G_{LT} = characteristic in-plane shear modulus, ksi
v_{LT} = characteristic longitudinal Poison's ratio
b_f = Full width of the flange, in.
h = Full height of the member, in.
t_f = Thickness of the flange, in.
t_w = Thickness of the web, in.
ξ = Coefficient of restraint
k_r = Rotational spring constant, kip/rad
$E_{L,f}$ = Characteristic longitudinal modulus of the flange, ksi

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$E_{L,w}$ = Characteristic longitudinal modulus of the web, ksi
$E_{T,f}$ = Characteristic transverse modulus of the flange, ksi
$E_{T,w}$ = Characteristic transverse modulus of the web, ksi

There are four nominal moments that are calculated next using the following formulae given in Reference 3:
Lateral-Torsional Buckling:

$$M_{LB} = C_b \sqrt{\frac{\pi^2 E_{L,f} I_y D_J}{L_b^2} + \frac{\pi^4 E_{L,f}^2 I_y C_w}{L_b^4}} \qquad (3)$$

in which M_{LB} is the nominal flexural strength due to lateral-torsional buckling and the other terms are defined as follows:
C_b = Moment modification factor for unsupported spans with both ends braced
D_J = Torsional rigidity of an open section $= G_{LT} \sum \frac{1}{3} b_i t_i^3$, $kip - in.^2$
C_ω = Warping constant $= \frac{t_f h^2 b_f^3}{24}$, $in.^6$
Herein, the resistance factor ϕ = 0.7 is used.
Local Instability:

$$M_{fLT} = f_{fcr} \frac{E_{L,f} I_f + E_{L,w} I_w}{y E_{L,f}} \qquad (4\text{ a})$$

$$M_{wLT} = f_{wcr} \frac{E_{L,f} I_f + E_{L,w} I_w}{y E_{L,w}} \qquad (4\text{-b})$$

In these equations, M_{fLT} and M_{wLT} are the nominal flexural strengths due to local instability in the flanges and webs, respectively; the other terms are defined as follows:
I_f = Moment of inertia of the flange(s) about the axis of bending, in^4.
I_w = Moment of Inertia of the web(s) about the axis of bending, in^4.
y = Distance from the neutral axis to the extreme fiber of the member, in. The resistance factor ϕ = 0.80 is used.
Material Rupture:

$$M_{cr} = \min\left(\frac{F_{L,f}\,(E_{L,f} I_f + E_{L,w} I_w)}{y_f E_{L,f}}, \frac{F_{L,w}\,(E_{L,f} I_f + E_{L,w} I_w)}{y_w E_{L,w}}\right) \qquad (5)$$

in which M_{cr} is the nominal flexural strength due to material rupture and the other terms are defined as follows:
$F_{L,f}$ = characteristic longitudinal strength of the flange (in tension or compression),ksi
$F_{L,w}$ = characteristic longitudinal strength of the web (in tension or compression),ksi
I_f = Moment of inertia of the flange(s) about the axis of bending, in^4.
I_w = Moment of inertia of the web(s) about the axis of bending, in^4.
y_f = Distance from the neutral axis to the extreme fiber of the flange, in.
y_w = Distance from the neutral axis to the extreme fiber of the web, in. The resistance factor ϕ = 0.65 is used.

Lastly, applying the formula of maximum moment for a simply supported beam with a point load as shown in Figure 1, the respective loads are obtained:

$$P_{LT} = \frac{4M_{LT}}{L} \qquad (6)$$

$$P_{fLT} = \frac{4Mf_{LT}}{L} \qquad (7)$$

$$P_{wLT} = \frac{4Mw_{LT}}{L} \qquad (8)$$

$$P_{cr} = \frac{4M_{cr}}{L} \qquad (9)$$

In Equations 6 through 9, P_{LT}, P_{fLT}, P_{wLT}, and P_{cr} are the load-carrying capacities due to lateral-torsional buckling, local instability in the flanges, local instability in the webs, and material rupture, respectively.

If $P_{LB} = P_{fLT} = P_{wLT} = P_{cr} = P_c$ is the load-carrying capacity of the member, a LFRD approach is proposed as follows:

$$P_c = \phi P_n \qquad (10)$$

where P_n is the minimum of the values obtained in Equations 6-9. The resistance factor ϕ = 0.7, 0.8, and 0.65 depending whether the failure is due to lateral torsional buckling, local instability in the flanges or webs, and rupture of the materials, respectively. The beam design load is expressed as:

$$P_u = 1.2P_D + 1.6P_L \qquad (11)$$

in which P_D and P_L are the dead and live loads for the beam. The proposed LFRD approach criterion for the member can finally be written as:

$$P_u \leq P_c \qquad (12)$$

where P_u and P_c are defined in Equations 10 and 11, respectively. Table 1 shows the maximum loads for the following I-beams: 3x1x0.25 in., 6x3x0.375 in., 8x4x0.5 in., 10x5x0.375 in., and 12x6x0.5 in.

Table 1: Maximum loads for failure modes.

I -Section in.	ϕP_{LB} lbs	ϕP_{fLB} lbs	ϕP_{wLB} lbs	ϕP_{cr} lbs
3x1.5x0.25	170	2526	35389	8867
6x3x0.375	2041	8506	162479	4980
8x4x0.50	8026	20162	385136	11804
10x5x0.375	13581	15522	279162	13890
12x6x0.5	37399	20220	592231	26635

For 8 x 4 x 0.5 in., the experimental lateral-torsional buckling load is found to be 4.70% higher than the predicted result. However, the experimental cracking load is 27.60% lower than the predicted result. As seen in Table 1, for the first three I-sections namely 3x1x0.25, 6x3x0.375, 8x4x0.50, the failure mode is governed by lateral-torsional buckling. However, for the last two I-sections namely 10x5x0.375 and 12x6x0.5, the failure mode is governed by material rupture.

IV. Conclusion

A study on failure modes for I-section GFRP beams is presented. The predicted buckling load for the GFRP beam is in agreement with the experimental value. Based on the analysis for the member length considered, the failure mode is governed by lateral-torsional buckling for smaller and medium cross sections. However, the material rupture governs the failure mode for the bigger sections.

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