Final Report

Testing of Solid and ICF Concrete Wall Panels Reinforced with GFRP Bars

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Contents

1 Introduction

Testing was performed to evaluate the structural performance of solid and insulated concrete form (ICF) wall panels reinforced with glass fiber reinforced polymers (GFRP) bars compared to that of panels reinforced with conventional steel reinforcement. Three 9 ft long, 4 ft wide and 7.5 in. thick solid wall panels and three 9 ft long, 4 ft wide, and 8 in. thick ICF wall panels were tested in flexure up to failure. In each set, two panels were reinforced using 11 mm (7/16 in.) diameter plain GFRP bars and one identical panel was reinforced using 13 mm (1/2 in.) diameter (#4) Grade 60 steel bars (reference panel). Results were compared to determine the flexural capacity, deflection, and failure mode of solid and ICF wall panels when reinforced with GFRP bars instead of conventional steel reinforcement.

2 Test Setup

Each panel was simply supported using two steel roller supports that are 8 ft 4 in. apart and resting on concrete blocks as shown in **Figure 1**. A 400 kip hydraulic jack was used to apply a concentrated load at the mid-span using spreader beams as shown in **Figure 2**. A 20 kip load cell was placed under the jack to measure the applied load. Two linear variable differential transformers (LVDTs) were used to measure mid-span deflection at each side in addition to one LVDT installed on the extended bars to measure slippage. Two strain gauges were installed on the side of the panel at the mid-span section: one close to the top surface and the other close to the bottom surface of the panel as shown in **Figure 3** to measure compressive and tensile strains.

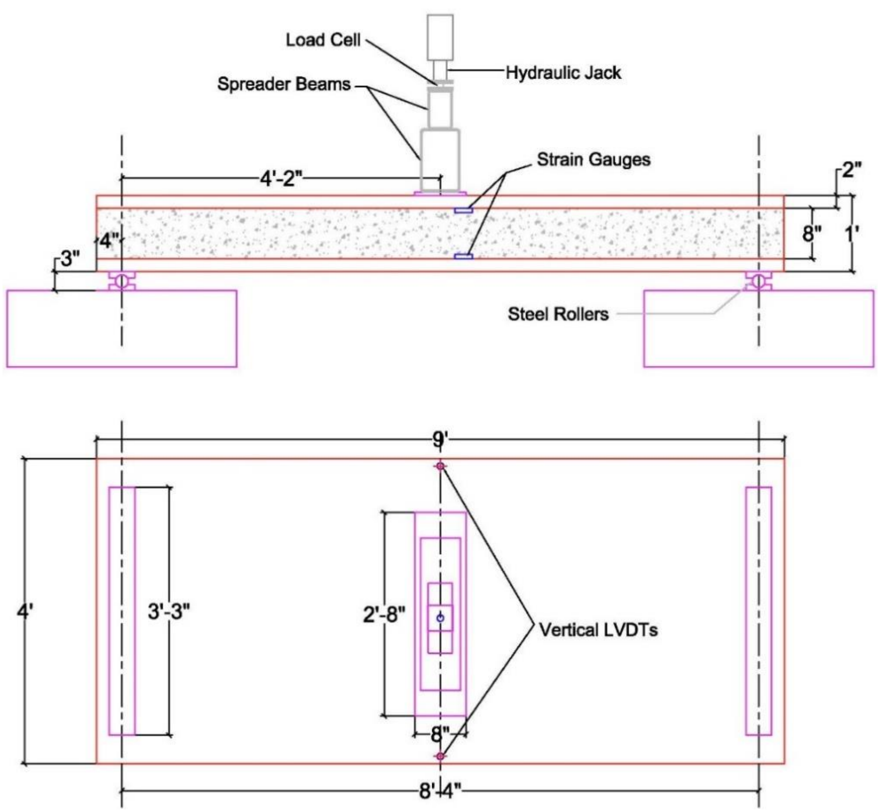

Figure 1: Test setup

Figure 2: Spreader beams and load cell

Figure 3: LVDT and strain gauges at mid-span section of the panel

3 Panel Configuration

For all tested wall panels, concrete had a 28-day compressive strength of 4,500 psi. The GFRP bars used in reinforcing the panels had an ultimate tensile strength of 134 ksi and modulus of elasticity of 6,000 ksi. Steel bars used in reinforcing the panels was grade 60 A615 steel with modulus of elasticity of 29,000 ksi. **Figure 4** shows panel configurations of steel and GFRP reinforced solid wall panels, while **Figure 5** shows panel configurations of steel and GFRP reinforced ICF wall panels. It should be noted that the ICF wall panels are 0.5 in. thicker than the solid wall panels, which results in slightly higher flexure capacity. Also, the area of the used steel reinforcement is approximately 36% higher than area of the GFRP reinforcement used, which significantly affect the flexure capacity of the panels.

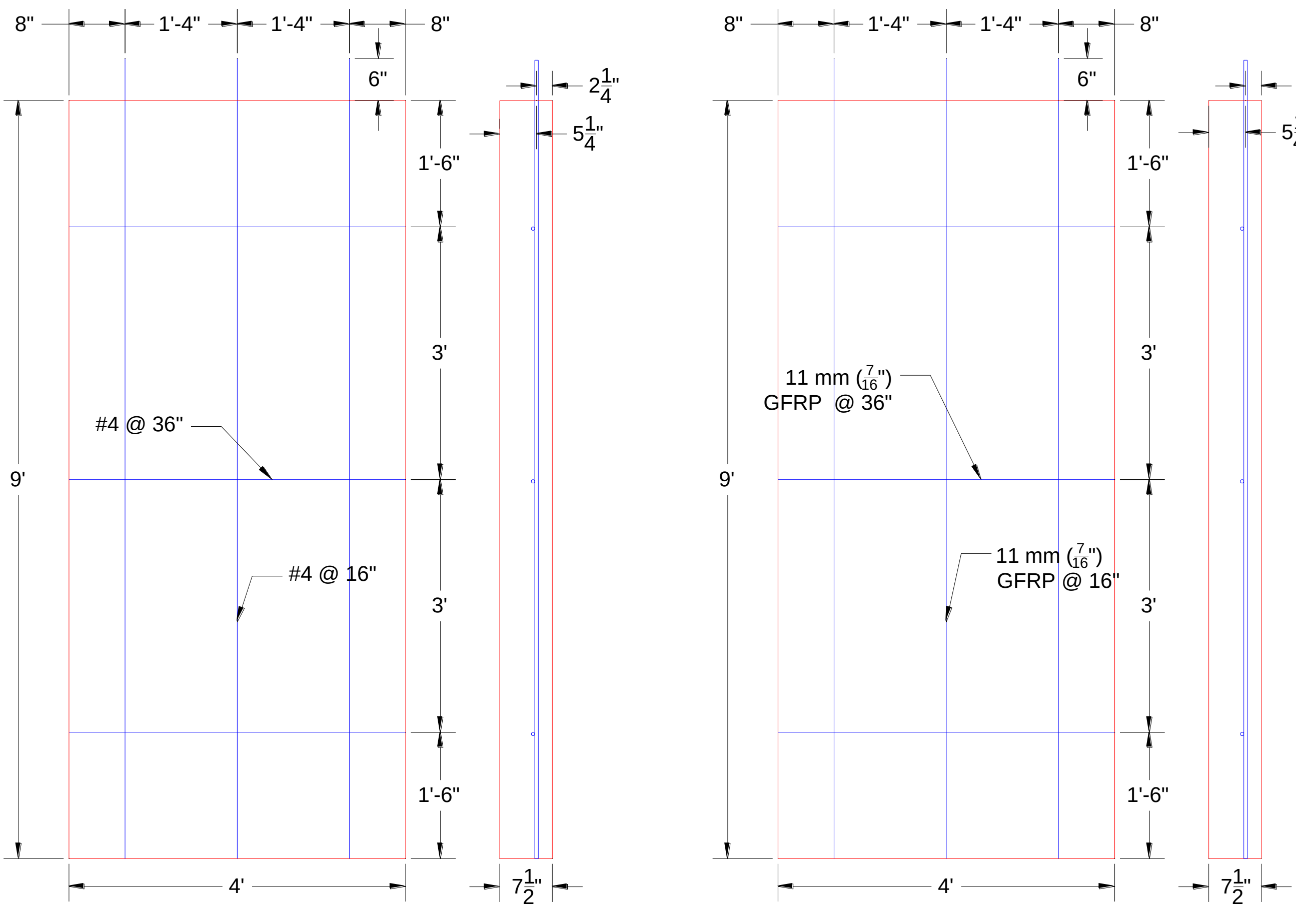

Figure 4: Configuration of the tested solid concrete wall panels with steel reinforcement (left) and GFRP reinforcement (right)

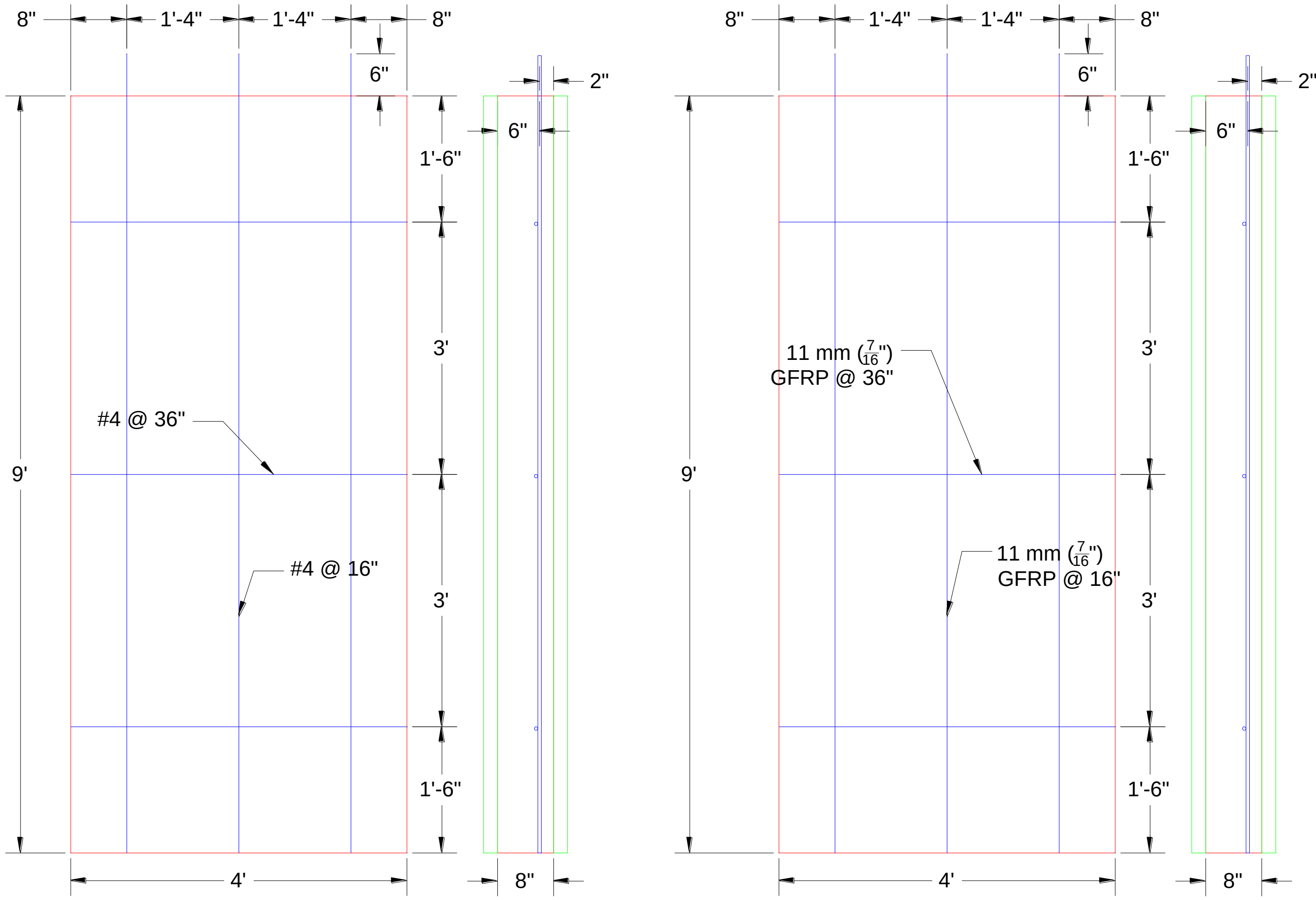

Figure 5: Configuration of the tested ICF wall panels with steel reinforcement (left) and GFRP reinforcement (right)

4 Test Results and Predicted Capacity

4.1 Solid Wall Panels

Figure 6 shows load-deflection plot for the three tested solid concrete wall panels. **Table 1** shows test results and predicted flexure capacity of the tested panels using ACI 318-14 and ACI 440.1R-15. These results indicate that steel reinforced concrete panel outperformed GFRP reinforced concrete panels in both ultimate flexure capacity and post-cracking flexure capacity. However, both GFRP and steel reinforced concrete panels exceeded their predicted nominal flexure capacity. No slippage of steel or GFRP bars was observed in the tested panels. Based on test results, the design flexure capacity of GFRP panels is slightly lower than the demand estimated from the basement wall design example shown in the Appendix.

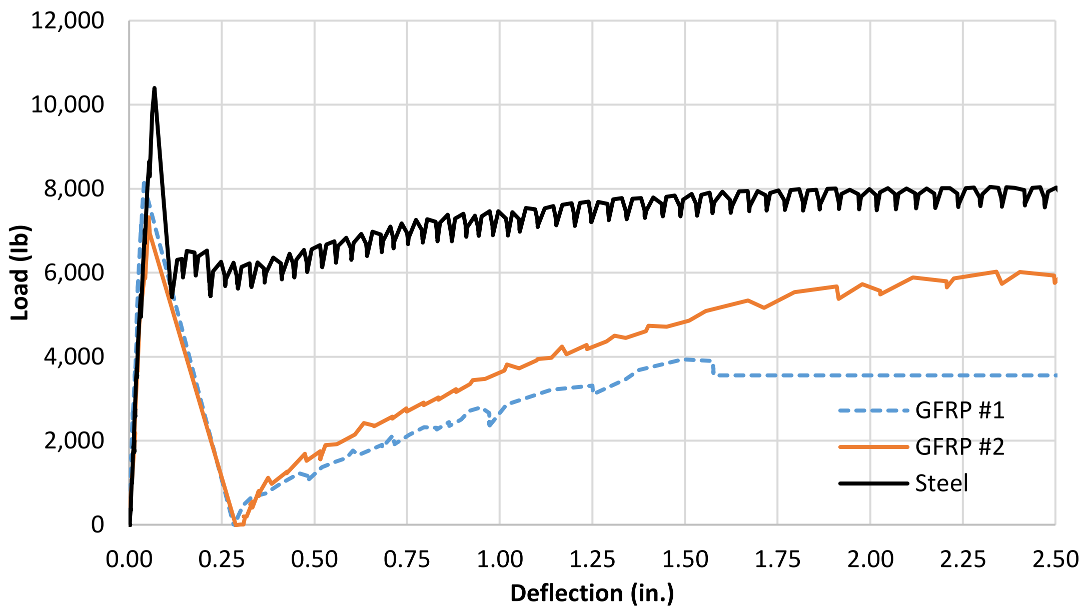

Figure 6: Load-deflection plot for solid wall panels

Table 1: Test results and predicted panel capacity for solid wall panels

	Cracking Load (lb)	Cracking Deflection (in.)	Post-Cracking Load (lb)	Corresponding Deflection (in.)	Failure Mode	Ultimate Flexure Capacity (k.ft)	Predicted Nominal Capacity (k.ft)	Design* Flexure Capacity (k.ft)
GFRP #1	8,227	0.04	3,936	1.49	GFRP Rupture	20.4	16.5	11.2
GFRP #2	7,321	0.05	6,025	2.34	GFRP Rupture	18.5	16.5	10.2
GFRP Average	**7,774**	**0.045**	**4,981**	**1.92**	**--**	**19.4**	**16.5**	**10.7**
Steel	**10,397**	**0.07**	**8,002**	**1.91**	**Steel Rupture**	**24.9**	**20.5**	**22.4**

*Design capacity is calculated using strength reduction factor of 0.55 for GFRP and 0.9 for steel

4.2 ICF Wall Panels

Figure 7 shows load-deflection plot for the three tested ICF wall panels. **Table 2** shows test results and predicted flexure capacity for the tested panels using ACI 318-14 and ACI 440.1R-15. These results indicate that ICF panels reinforced with GFRP bars had almost the same ultimate flexure capacity of the ICF panel reinforced with steel bars. However, steel reinforced ICF panel outperformed GFRP reinforced panels in post-cracking capacity. The measured capacity of all ICF panels exceeded the predicted capacity significantly due to the unrecognized contribution of the foam and its internal reinforcement. No slippage of steel or GFRP bars was observed in the tested panels. Based on test results, the design flexure capacity of all the panels exceeded the demand estimated from the basement wall design example shown in the Appendix.

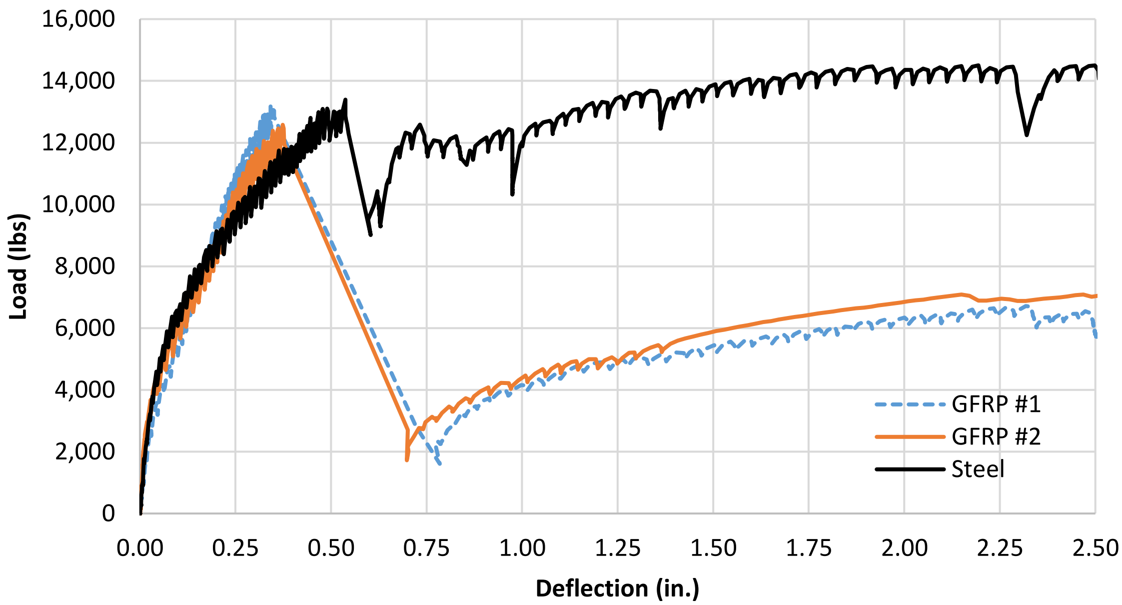

Figure 7: Load-deflection plot for ICF wall panels

Table 2: Test results and predicted panel capacity for ICF wall panels

	Cracking Load (lb)	Cracking Deflection (in.)	Post-Cracking Load (lb)	Corresponding Deflection (in.)	Failure Mode	Ultimate Flexure Capacity (k.ft)	Predicted Nominal Capacity (k.ft)	Design* Flexure Capacity (k.ft)
GFRP #1	13,176	0.34	6,544	2.47	GFRP Rupture	30.9	18.8	17
GFRP #2	12,580	0.37	7,244	2.89	GFRP Rupture	29.7	18.8	16.3
GFRP Average	**12,878**	**0.36**	**6,894**	**2.68**	**--**	**30.3**	**18.8**	**16.7**
Steel	**13,389**	**0.54**	**14,498**	**2.50**	**Steel Rupture**	**31.4**	**23.5**	**28.3**

*Design capacity is calculated using strength reduction factor of 0.55 for GFRP and 0.9 for steel

5 Failure Modes

Both steel reinforced and GFRP reinforced solid and ICF concrete panels failed by rupturing the steel and GFRP bars due to the low reinforcement ratio used in these panels (i.e. Tension Controlled). **Figure 8** shows an example of steel bar rupture, while **Figure 9** shows an example of GFRP bar rupture.

Figure 8: Rupture of Steel bars

Figure 9: Rupture of GFRP bars

6 Conclusions

1. GFRP reinforced concrete panels, whether in solid or ICF walls, have flexure capacity that exceed the predicted capacity according to ACI440.1R-15.
2. In general, ICF concrete wall panels performed better that the corresponding solid concrete wall panels due to the contribution of the bonded foam and its internal reinforcing plastic strips in flexure. This observation applies to both steel and GFRP reinforced panels.
3. For ICF walls, GFRP reinforced panels had comparable capacity to that of steel reinforced panel even when smaller area of reinforcement is used. However, for solid walls, GFRP reinforced panels had lower capacity than that of steel reinforced panel and a higher reinforcement ratio is required to achieve similar capacity.
4. Post-cracking capacity of steel reinforced panels was higher than that of GFRP reinforced panels for both solid and ICF concrete walls.

7 References

- American Concrete Institute (ACI) Committee 440 (2015) “Guide for the Design and Construction of Structural Concrete Reinforced with Fiber-Reinforced Polymer (FRP) Bars”, ACI 440.1R-15, Farmington Hills, MI.
- American Concrete Institute (ACI) Committee 318 (2014) “Building Code Requirements for Structural Concrete”, ACI 318-14, Farmington Hills, MI.

8 Appendix: Load Calculations

Parameter	Value	Unit
Wall Height	9	ft
Wall Width	4	ft
Soil Unit Weight	120	pcf
Angle of Internal Friction	30	deg.
Coefficient of Earth Pressure	0.50	N/A
Maximum Earth Pressure	540	psf
Total Force on the Wall	**9.72**	**kip**
Force Location from Bottom	3.00	ft
Maximum Moment on the Wall	**11.22**	**kip.ft**
Moment Location from the Bottom	3.81	ft