Design, Detailing, and Testing of Cladding Panels Using GFRP Ties

Kromel Hanna, Eliya Henin, Nathan Toneies, George Morcous, and Maher K. Tadros
Kromel Hanna, Ph.D, University of Nebraska—Lincoln
Eliya Henin, Ph.D Candidate, University of Nebraska—Lincoln
Nathan Toneies, M.S, University of Nebraska—Lincoln
George Morcous, Ph.D, PE, University of Nebraska-Lincoln
Maher K. Tadros, Ph.D, PE, University of Nebraska—Lincoln

ABSTRACT

Glass fiber-reinforced polymer (GFRP) ties are used as structurally and thermally efficient shear connectors for precast concrete sandwich panels (PCSPs) to link two concrete wythes through a layer of insulation. The excellent mechanical properties and high thermal resistance of these ties have resulted in the growing use of PCSPs in building construction. This paper presents the use of PCSPs with GFRP ties in cladding panels. The lightweight, structural efficiency, thermal insulation, and speed of construction are the main advantages of these panels. This paper presents experimental investigation conducted on three cladding PCSPs to optimize the design of 16 ft wide and 8 ft high panels subjected to a wind load of 30 psf. Wythe thickness in all panels was 1 ¾ in., while the insulation thickness varied from 2½ in. to 3 in. Flexural capacity was determined by loading two simply supported panels at mid-span and one cantilevered panel at the free. Test results and failure modes indicate that the flexural capacity of all panels is adequate. Panels failed in horizontal shear as the GFRP ties were pulled out of the thin concrete wythes at ultimate loads. Minimum embedment depth of GFRP ties was also experimentally investigated. The minimum embedment of GFRP ties was determined based on the pull out force of 1/4, 3/8, and ½ in. diameter GFRP ties with embedment depths ranging from 0.5 in. to 2.5 in.

Keywords: Sandwich Panel, Shear Connector, Composite Action, Embedment Depth, Flexural Capacity.

INTRODUCTION

Precast concrete sandwich panels (PCSP) are a structurally and thermally efficient system that is used for exterior walls in multi-story residential and commercial buildings. A typical PCSP consists of two precast/prestressed concrete wythes separated by a layer of insulation (i.e. Extruded Polystyrene [XPS]) and connected across the insulation by shear connectors to achieve the composite action required for flexural resistance and stiffness. These connectors can be concrete webs or blocks, steel elements, plastic ties, or any combination of these components (Al-Einea, et al. 1991). The low thermal resistance of steel and concrete connectors makes these products unattractive as it significantly reduces the thermal efficiency of the PCSP through thermal bridging. A new system was developed and patented by researchers at the University of Nebraska-Lincoln (UNL) on August 15, 1995 (Tadros et al., 1995). In this system, connectors are made of glass fiber-reinforced polymer (GFRP) because of its excellent thermal and mechanical properties (Al-Einea, et al. 1994). Fig. 1 shows the different generations of GFRP ties. The investigation presented in this paper uses the fifth generation of GFRP ties.

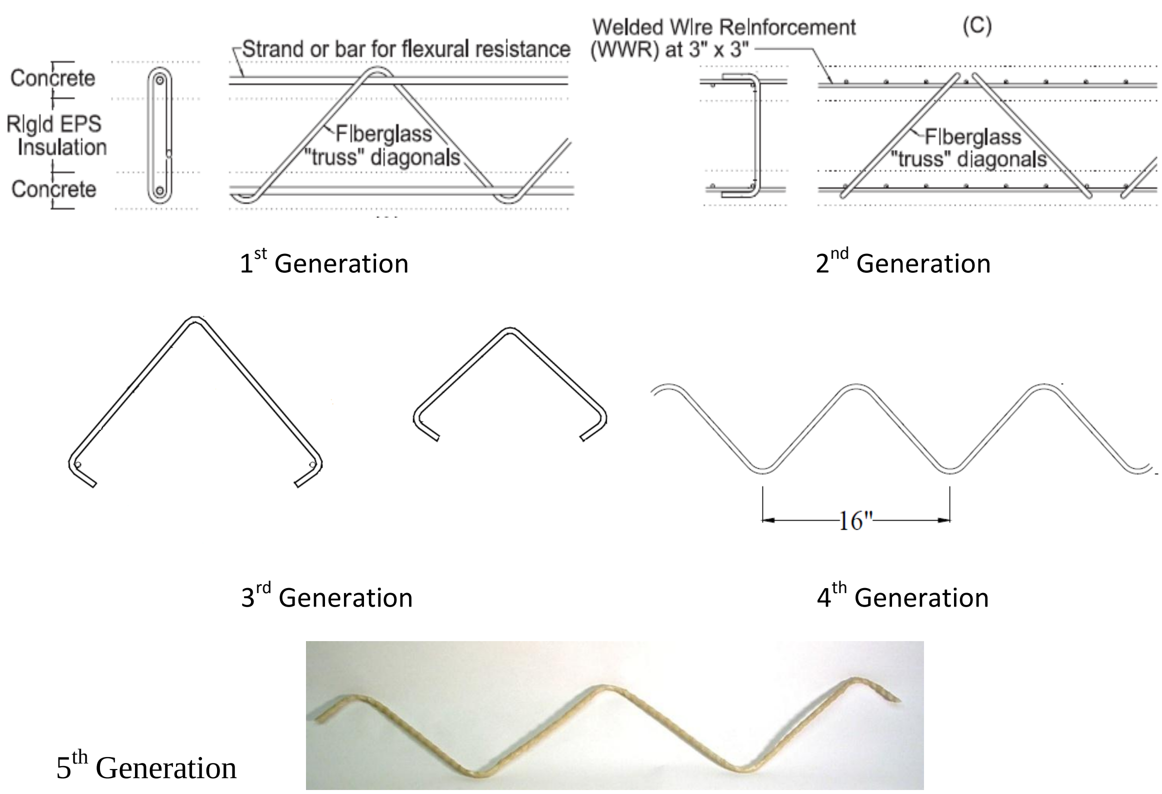


Figure 1: Generations of GFRP connectors

Several experiments were conducted to investigate the optimal distribution of ties, level of composite action achieved, and thermal conductivity of the panels (Song et al. 2009). This paper presents the research conducted to optimize the design of cladding PCSPs that are 16 ft wide, 8 ft high, and subjected to a wind load of 30 psf. Concrete wythe thickness of 1.75 in. and insulation thickness from 2.5 in. to 3 in. were used in all panels. Also, the minimum embedment depth of the GFRP ties was determined based on an experimental investigation of ¼, 3/8, and 0.5 in. diameter GFRP ties with embedment depths ranging from 0.5 in. to 2.5 in.

This paper consists of three parts. The first part presents cladding PCSPs design, analysis, fabrication and testing, while the second part presents the embedment depth investigation of GFRP bars. The last part summarizes test results and presents research conclusions and recommendations.

ANALYSIS AND DESIGN OF CLADDING PANELS

A 32 ft wide by 8 ft high area is covered by two cladding PCSPs with dimensions 16 ft by 8 ft each. The two panels were supported at six lateral supports and spliced at the middle two supports as shown in Fig. 2. Both panels were subjected to a wind load of 30 psf. Each panel acts as a simply supported beam in the longitudinal direction and a cantilever in the transverse direction. The panel was designed as a test specimen for evaluating flexural and horizontal shear capacities. Panels were required to resist the wind load combination (1.2D+1.6W) calculated according to ACI 318-08. This load combination results in an ultimate moment (M_u) of 12.28 kip.ft.

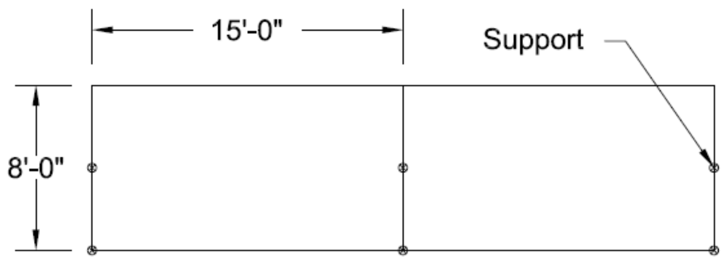


Figure 2: The area covered using two cladding PCSPs

Three 16 ft by 8 ft panel specimens were designed to resist the given load effect using 8 ksi concrete. The first two panels (A and B) were fabricated at Concrete Industries, Inc. – Lincoln, NE and tested at the structural laboratory of UNL in Omaha Campus. The two wythes were reinforced using W2.9xW2.9 @ 4x4 in. and connected using 3/8 in. diameter GFRP ties distributed as shown in Fig. 3. A 3.5 in. thick concrete wythes with 2.5 in. thick insulation were used to create a total panel thickness of 6 in. (1.75-2.5-1.75). The nominal flexural capacity of this panel (M_n) based on strain compatibility and assuming full-composite action was estimated at 21.4 kip.ft.

The last panel (C) was fabricated and tested at the structural laboratory of UNL in Omaha Campus. The two wythes were reinforced using 1/4 in. diameter GFRP bars spaced at 12 in. both directions and connected using ten 3/8 in. diameter GFRP ties distributed as shown in Fig. 4. The panel was 6.5 in. thick with 3 in. thick insulation, and 1.75 in. thick concrete wythe at the top and the bottom (1.75-3-1.75). The nominal flexural capacity of this panel (M_n) based on strain compatibility and assuming full-composite action was estimated at 25 kip.ft.

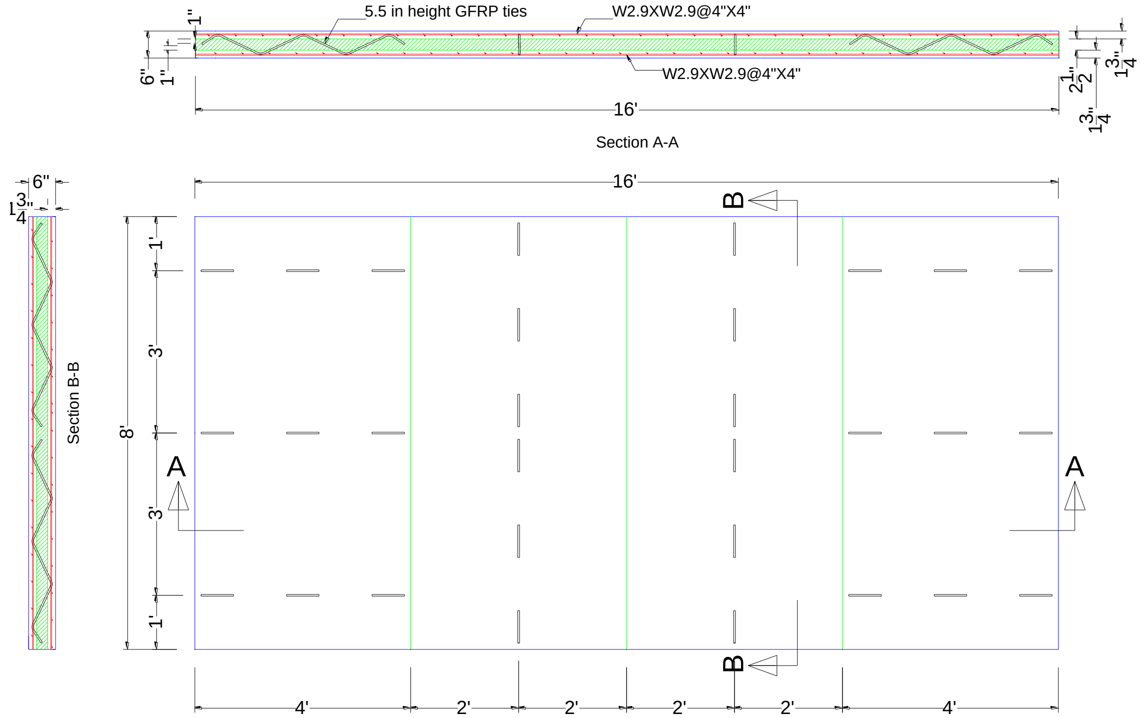


Figure 3: Dimension and Reinforcement details of PCSPs A and B

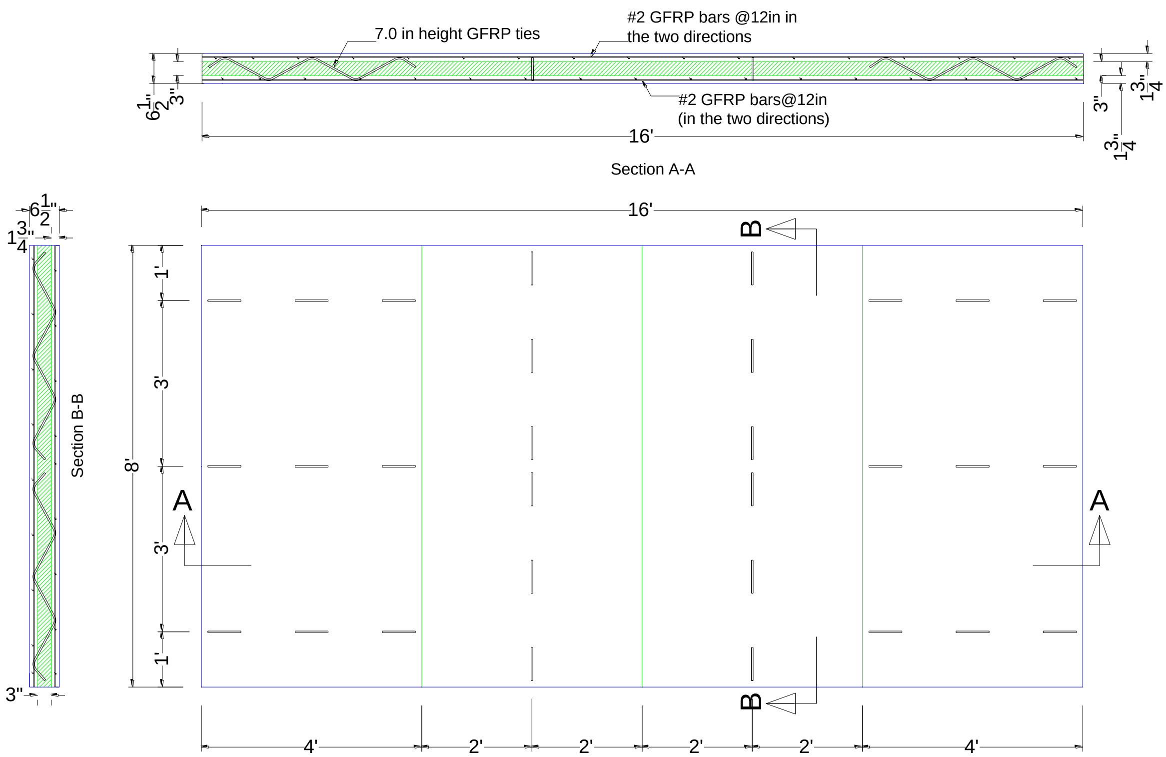


Figure 4: Dimension and Reinforcement details of PCSP C

FABRICATION AND TESTING OF CLADDING PANELS

Fabrication of PCSP using GFRP ties is conducted in a very efficient and unique process: 1) place the bottom wythe reinforcement, 2) place and level the bottom wythe concrete, 3) place the insulation panels with the GFRP ties, 4) place the top wythe reinforcement, and 5) place and level the top wythe concrete. For more details on this process, refer to Morcous, et al., 2010. Fig. 5 shows the fabrication steps of panels A and B while Fig. 6 shows the fabrication of Panel C.

Figure 5: Fabrication sequence of PCSPS A and B

Figure 6: Fabrication sequence of PCSP C

Panels A and C were tested as simply supported members in the longitudinal direction. Fig. 7 shows the test setup of panels A and C, which is a one point loading at the center of a 15 ft span. The test results of panel A indicate that the panel failed at a total equivalent wind load of 59 psf, which is almost twice the demand. The measured flexural capacity was found to be 3.4 % less than the nominal panel capacity. The panel experienced a horizontal shear failure due to the pull out of ties as shown in Fig. 8. Panel C behaved the same as panel A. From the test results, panel C failed at a total equivalent wind load equal to 50 psf, which is 1.65 times the demand load. The measured flexural capacity was found to be 10 % less than the nominal panel capacity. Panel C experienced a horizontal shear failure due to the pull out of ties as shown in Fig. 9

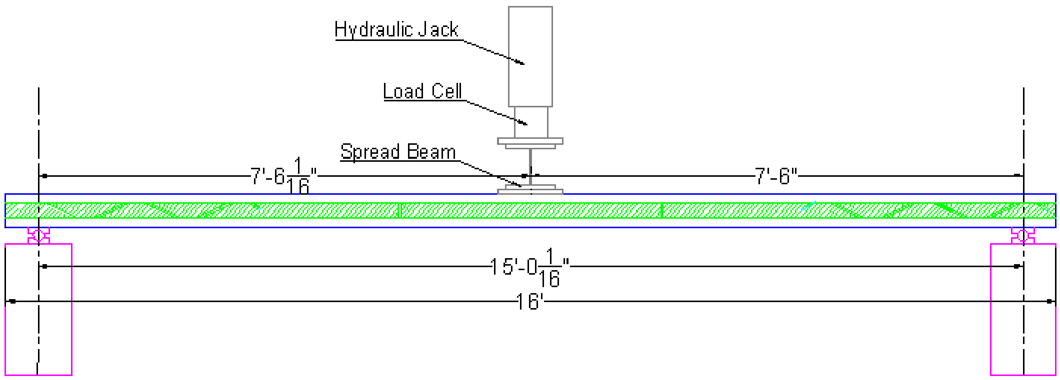


Figure 7: Test setup for panel A and C

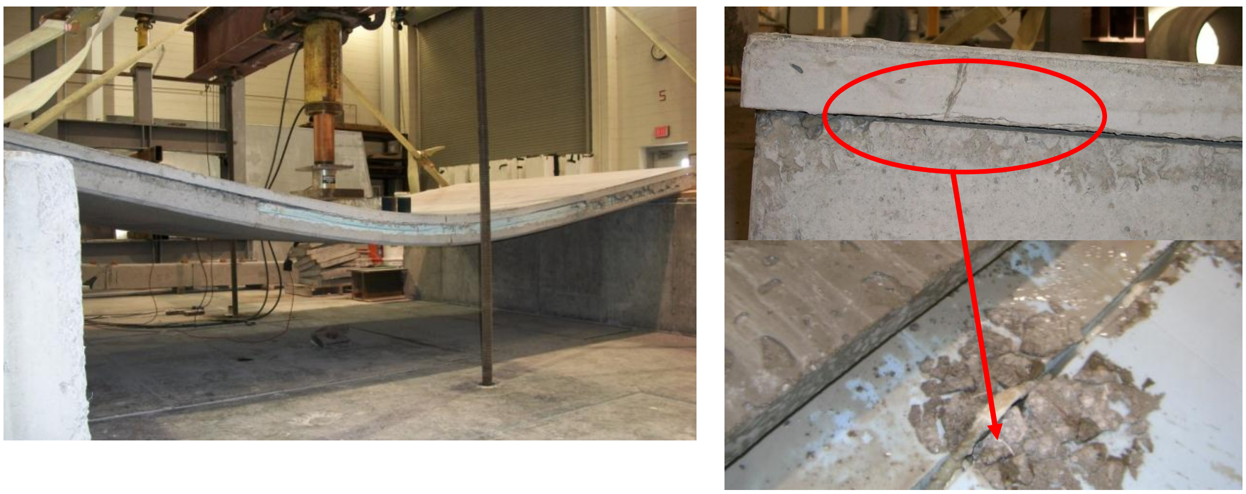


Figure 8: Testing and failure mode of panel A

Figure 9: Test setup and failure mode of panel C

Panel B was tested as a cantilever beam with a span equals to 4.0 ft in the transverse direction. Fig. 10 shows the test setup. Test results indicate that the panel failed at a total equivalent wind load of 180 psf, which is 6 times the demand wind load. The measured flexural capacity was found to be 10 % less than the nominal panel capacity. The panel experienced a horizontal shear failure due to the pull out of the ties as shown in Fig. 11.

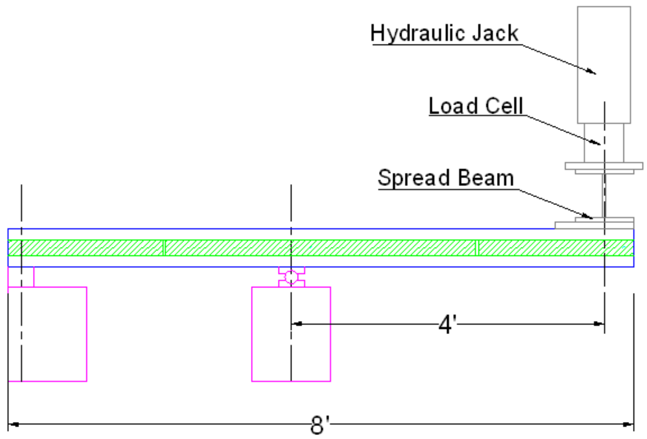


Figure 10: Test setup for panel B

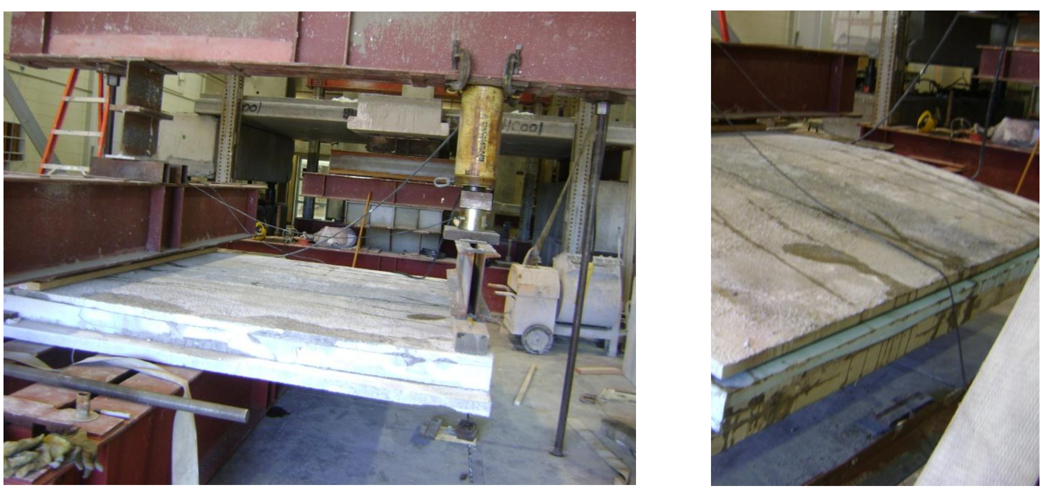
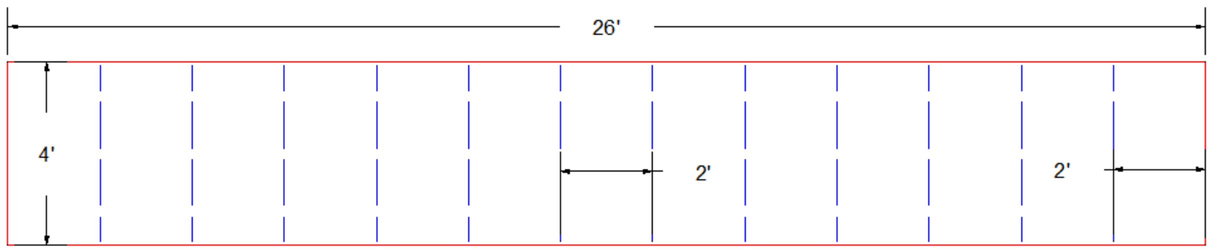


Figure 11: Setup and failure mode of panel C

EMBEDMENT DEPTH OF GFRP TIES

It is clear from the previous section of this paper that cladding panels are highly susceptible to horizontal shear failures due to the pull out of the GFRP ties from the concrete wythes. In this section, experimental work performed to investigate the capacity of three specimens made of 1/4, 3/8, and 1/2 in. diameter GFRP ties with embedment depths ranging from 0.5 in. to 2.5 in. Each specimen was a 26 ft long, 4 ft wide and 4 in. thick slab with 12

GFRP-ties embedded at 2 ft spacing as shown in Fig. 12. The slabs were reinforced with 3#3 bars in the longitudinal direction and made of 8 ksi self-consolidating concrete. Three ties were embedded at each of the four embedment depths shown in Table 1 (total of 12 ties per size).



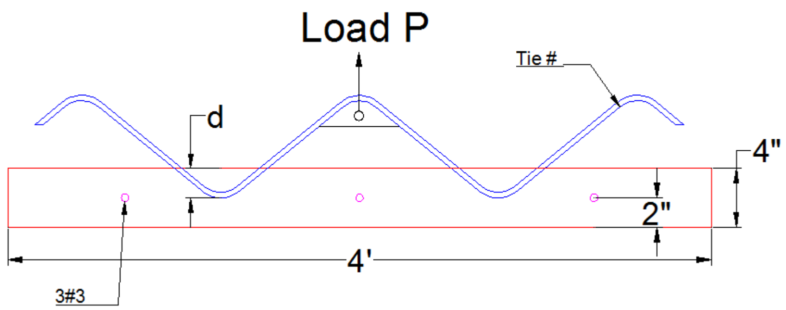


Figure 12: Plan and Section view of the test specimen

Specimens were tested by pulling out each tie from its mid-point using a specially manufactured handle, a 1/8 in. thick rubber pad, and a hydraulic jack as shown in Fig. 13. This handle was specifically made to distribute the tensile forces on the tie legs with minimal bending effects. Table 1 lists the ultimate pull out force in pounds for the three tests performed on each tie-embedment combination (36 tests). The table also indicates whether the failure occurred by the pull out of the tie from the concrete, as shown in Fig. 14, or the rupture of the tie, as shown in Fig. 15. Testing results presented in Table 1 indicate that there is a significant variation in the pull out capacity of the three tests performed on each case (coefficient of variation greater than 40% in some cases). These high values for the coefficient of variation are due to the small number of tests conducted on each case (i.e. three tests), and can be reduced if more tests are conducted. Also, the use of a steel handle with rubber pad to grip the tie for pull out testing does not perfectly simulate the embedment of the tie in concrete, and in some cases results in higher stress concentrations and rupture of ties.

Table 1: GFRP-tie size-embedment combinations and test results

NU-Tie Diameter (in.)	Embedment Depth (in.)	Ultimate Load (lb)					
		Test #1	Test #2	Test #3	Failure Mode	Average	Coefficient of Variation
1/4	0.5	251	496	319	Pull-out	355	0.36
	1	1,196	2,012	2,807	Tie rupture	2,005	0.40
	1.5	3,391	2,406	1,363	Tie rupture	2,387	0.42
	2	3,244	3,136	2,289	Tie rupture	2,890	0.18
3/8	0.75	525	623	479	Pull-out	542	0.14
	1	1,594	906	1,431	Pull-out	1,310	0.27
	1.5	3,091	3,534	1,686	Pull-out	2,770	0.35
	2	6,145	6,387	5,565	Tie rupture	6,032	0.07
1/2	1	1,396	2,445	2,093	Pull-out	1,978	0.27
	1.5	3,556	5,539	5,565	Pull-out	4,887	0.24
	2	7,453	4,199	7,606	Pull-out	6,419	0.30
	2.5	10,237	6,804	8,005	Tie rupture	8,349	0.21

Figure 13: Test specimen and setup

Figure 16 plots the average of three tests for each tie-embedment combination. This histogram clearly indicates that the deeper the GFRP-tie embedment, the higher the pull out force. It also shows that the smaller the bar size, the higher the probability of the bar rupture before pulling out from the concrete. The use of large bar sizes with small embedment depths does not improve the tie capacity, as it reduces the amount of concrete around the bar and increases the probability of the tie to pull out from concrete.

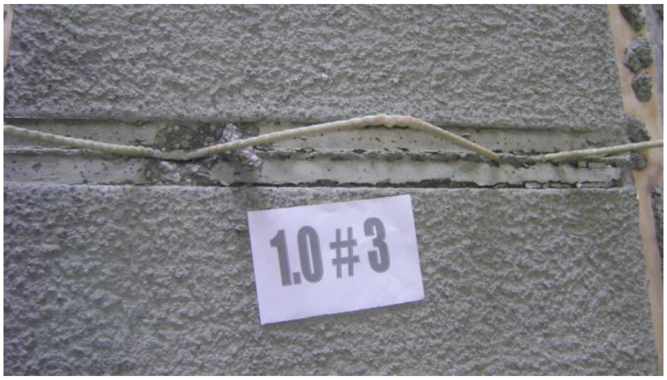


Figure 14: Pull-out of the tie from the concrete

Figure 15: Rupture of the tie

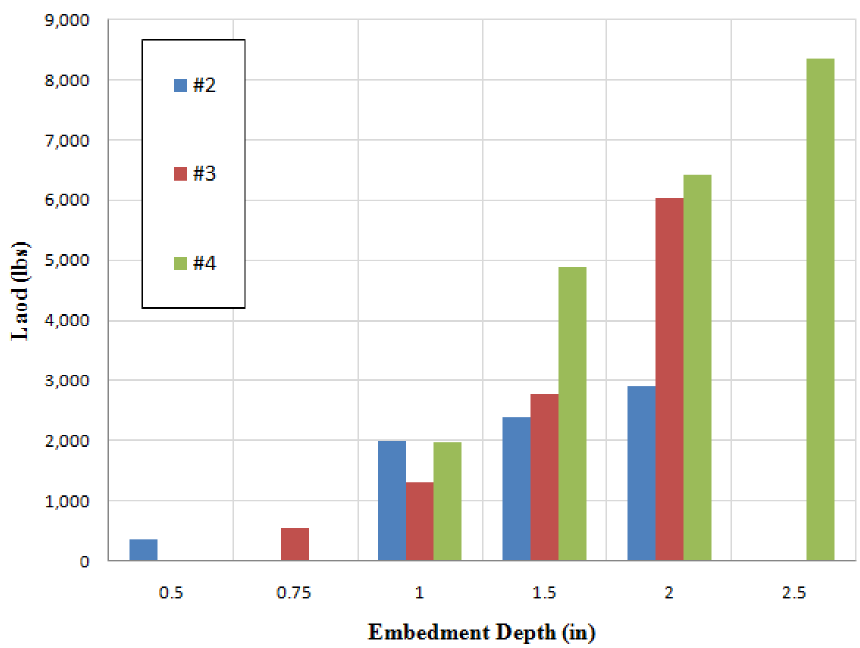


Figure 16: Average ultimate load for different tie size and embedment combination

Conclusions and Recommendations

Based on the testing results presented earlier, the following conclusions are made:

- The flexural design of the tested cladding sandwich panels (including different insulation thicknesses, panel thicknesses, welded wire reinforcement, GFRP bars reinforcement, and concrete strengths) is adequate for resisting the wind load of 30 psf.
- The number, size, and distribution of GFRP ties used in the tested panels are adequate for resisting horizontal shear required to achieve 90% of the capacity of a fully composite section.

- The horizontal shear failure occurred due to the pull out of the ties from concrete, and not due to overstressed ties. This is in agreement with study on the minimum embedment depth of GFRP ties.
- The deeper the GFRP-tie embedment, the higher the pull-out force. Also the smaller the bar size, the higher the probability that the bar will rupture before pulling out from the concrete.
- Using large bar sizes with small embedment depths does not improve the tie capacity, as it reduces the amount of concrete around the bar and increases the probability of the tie to pull out from concrete.
- The minimum embedment depth recommended for GFRP ties is as follows:
    - 1.5 in. for 1/4 in. diameter ties
    - 2.0 in. for 3/8 in. diameter ties
    - 2.5 in. for 1/2 in. diameter ties

References

Al-Einea, A., Salmon, D. C., Tadros, M. K., and Culp, T., (1994) "A New Structurally and Thermally Efficient Precast Sandwich Panel System", PCI Journal, V. 39, No. 4, pp. 90-101.

Al-Einea, A., Salmon, D.C., Tadros, M.K., Culp, T., and Fogarasi, G. J., (1991) "State-of-the-Art of Precast Concrete Sandwich Panels", PCI Journal, V. 36, No. 6, pp. 78-98.

American Concrete Institute (ACI), (2008) "Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary"

Morcous, G., Tadros, M. K., Lafferty, M., and Doug, G. (2010) "Optimized Sandwich Panel System for Energy, Composite Action and Production Efficiency", 3rd fib International Congress, Washington, DC.

Song, X., Morcous, G., Lafferty, M., Doug, G and Tadros, M. K. (2009) "Effect of Nu-Tie Distribution on The Composite Action of Precast/Prestressed Concrete Sandwich Panels" Proceeding of PCI Convention, San Antonio, TX.

Tadros, M. K., Salmon, D. C., Einea, A., and Culp, T. D. (1995), "Precast concrete sandwich panels" US Patent# 5440845.