24 The Design of GFRC Architectural Panels that meet Hurricane Resistance Specifications

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Introduction

After the devastation caused in Southern Florida by Hurricane Andrew in 1992 (Fig 1), Miami-Dade County, Florida building officials developed code specifications that all building materials must now conform to if they are to be used in exterior building applications in Southern Florida. Particular to the specifications are certain tests that materials and fabrications must pass if they are to be used externally on buildings in Miami-Dade County.

It was determined that the debris hurled around in a hurricane accounts for much of the damage to buildings and property, not just the force of the wind. For many years buildings in the USA have been designed according to wind velocities and loads set out in ANSI/ASCE 7 (ref.1) and generally buildings and structures will not be damaged just by wind forces if the building remains a sealed envelope. Problems occur from flying debris which impacts the envelope of the building and causes holes in the walls and roofs, breaks windows and doors. This allows the wind to enter the building which creates a huge vacuum sufficient to cause the walls and roof of the building to explode. The hurricane resistant codes are designed to ensure that materials and systems used to construct building exteriors can resist the impacts from flying debris and protect the integrity on the building envelope. The hurricane resistant building codes apply to all locations within 5 miles of the coast. (Fig 2) shows a map of Florida with wind speed contours overlaid.

The Miami-Dade County specifications are taking on increasing importance in that they have now been incorporated into the State of Florida building codes, under TAS 201-94(ref.2) and TAS 203-94 (ref. 3). All other states in the USA that border the Atlantic Ocean and the Gulf of Mexico are adopting the same standards for building materials and fabrications. Australia has similar hurricane resistance standards and there was a project in the Philippines this year that required the GFRC panels to meet the Florida standards. The Miami-Dade County specifications could well be adopted world-wide where ever hurricanes or typhoons are possible.

The Building Codes

Florida is the most advanced of the states in the USA in its requirements for hurricane resistance in that it has a formal Acceptance procedure by which a manufacturer can submit their product and test data to the Building Code Compliance Office and if deemed to meet all code requirements they receive a Notice of Acceptance (NOA). GFRC Cladding Systems, of Garland, Texas has such a number for their hurricane resistant GFRC panel design, NOA No. 05-0901.03 (Fig. 3) (Ref.4).

Other states, such as Texas (ref.5), have incorporated the testing requirements into their codes but GFRC manufacturers have to submit their test data every time they bid on projects requiring hurricane resistance.

The two tests that have to be satisfied are covered by two ASTM standards. The first standard is ASTM E1886-05, “Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials” (ref.6). The second standard is ASTM E1996-09, “Standard Specification of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes” (ref.7). E1886-05 covers details of how to perform both the impact test and the air pressure cycling test. E1996-09 provides the necessary specification criteria for determining whether the product has passed or failed the tests.

The first test performed under E1886-05 is the impact, or missile test. There are two missile tests in this standard, a small missile test and a large missile test. Only the large missile test will be discussed here because if a product passes the large missile test it is accepted that it will pass the small missile test.

In the large missile test the product is subjected to various impacts with a piece of wood (the missile) weighing approximately 9 lbs, and measuring 2in.x4in.x9 ft in size. The missile is fired from a compressed air canon at a speed of either 50 ft/sec. (15.25 m/s) or 80 ft/sec. (24.38 m/s). The former speed is for Class 2 rated materials and the latter is for a higher Class 4 rating. Class 2 applies to most types of building; class 4 is for critical buildings such as hospitals, emergency shelters, etc. The testing for both these classes assumes Zone 4 wind speeds of greater than 140 mph (63 m/s).

Impact and Pressure Testing

A complete GFRC panel is tested, with the GFRC skin attached to a metal stud frame via “L” anchors and bonding pads (Fig. 4). The panel must include face coat (if used on the production panel) and GFRC back-up. The panel is mounted in the side of a chamber with the GFRC face outward from the chamber. The chamber is used for the second, air pressure differential cycling, test but also provides a convenient way to hold the panel during the missile test.

Three panels are tested, each impacted twice. The target areas for each impact are shown in (fig 5). Impacts where bond pads occur are not allowed, for the center panel shots the thinnest section of the panel is targeted. As fig. 5 shows one panel is first hit in the center and the second impact is aimed within 6 inches (150 mm) of one corner. The second panel is first hit within 6 inches (150 mm) of the opposite corner to the first panel and the second shot targets the center of the panel. The third panel is first shot within 6 inches (150mm) of the opposite corner to the second panel and the second shot targets the center of the panel. If one panel should fail a fourth panel may tested in exactly the same way as the failed panel and if this panel passes the test the failed panel is ignored. The panel is deemed to have failed if the missile penetrates the panel. The panel can also be deemed to have failed if, although the missile does not penetrate the panel, it sufficiently damages the panel that it cannot pass the air cycling test.

After a panel has received its two impacts it is subjected to the air pressure differential cycling test (Fig. 6). The purpose of the test is to determine if the Integrity of the panel, and therefore the integrity of the building envelope, has been breached. As was stated earlier if the building envelope integrity is breached the building can explode. The panel is sealed into one of the walls of the chamber and the air pressure in the chamber is cycled 9,000 times between positive and negative pressure differentials across the panel. If the pressure differential at any time in the test cannot be achieved then the panel is deemed to have failed the test. Clearly if the missile has penetrated the panel and a hole has been created then the panel has failed but the panel could also fail even though it may have resisted the impact without penetration. If the panel cracked through its thickness it would leak air and could fail to maintain the required pressure differential.

Also a maximum allowable deflection is calculated for the panel when subjected to the maximum pressure differential. During the test the dynamic deflection of the panel is measured and any residual deflection is also measured. If either deflection exceeds the maximum value the panel may be deemed to have failed. Again a cracked panel could cause a panel to fail this criteria.

Basically the test requires for the panel to pass the tests that the missile should simply bounce off the panel without penetration or causing cracks through the panel. Unfortunately basic 5% fiber content sprayed, or cast, GFRC will not pass the hurricane resistance test but GFRC can be designed so that it will pass.

GFRC designed to pass the Hurricane resistance test

The design developed by GFRC Cladding that has passed all hurricane resistance tests is covered by Miami-Dade County Building Code Compliance Office, Notice of Acceptance (NOA) No. 05-0901.03 (Fig.3) (Ref.4). The NOA expired on 05/31/2011, after this paper was written, but the new NOA will be available at the Congress.

The NOA is not generic in that each manufacturer has to have their design and product tested to receive their own NOA.

Because 5% random chopped fiber content of sprayed, or cast GFRC will not pass the large missile impact test a way of enhancing the impact properties of random fiber 5% GFRC had to be found. Increasing the chopped fiber content to 6% did not solve the problem and increasing it beyond 6% was not practical because the properties of GFRC start to decline at this level due to poor compaction caused by the high fiber content. Also making the panel thicker was not a solution because it required such a big increase that it was uneconomic.

It was known that the addition of AR glass fiber scrims, or textile fabrics, can increase the properties of GFRC (Fig.7). Initially light weight scrims, NEG's TD10x10 and TD5x5 (Fig. 8) were tried but adding even two layers of TD5x5, the heavier weight of the two scrims, into the spray up composite did not pass the impact test. Other heavier weight fabrics were investigated and it was found that a 20 oz/sq.yd.(0.66kg/sq.mt.) leno weave AR fabric (Fig. 9) offered possibilities based on small scale impact testing.

Panels were made in which the 20 oz. fabric was laid ¼ inch off the outer face of the panel and the final minimum thickness of the GFRC was ¾ inch. This panel passed the large missile impact test and also passed the cyclic air pressure differential test. The location of the fabric is very important in that, if it is too far from the outer face of the panel the panel can resist penetration of the missile but the panel may crack and fail the cyclic air pressure differential test. The panel design accepted by Miami-Dade County is shown in (figs. 10-13). The position of the fabric in the panel is shown in the drawings. It is not sufficient that the fabric be heavy enough to allow GFRC to pass the tests but it must also be flexible enough to follow the contours of the panel as shown in the panel drawings in (figs. 10-13.

(Fig.14) shows a building that was done by GFRC Cladding Systems in Miami where the GFRC panels meet class 2 hurricane resistance.

Conclusions

One layer of 20 oz/sq.yd. AR glass fiber fabric laid ¼ inch from the outer face of a 5% spray up GFRC panel will pass the ASTM E1886-05 large missile impact and the cyclic air pressure differential tests. The panel design has received Miami-Dade County and the state of Florida approval for class 2 hurricane resistant wall panels.

The higher class 4 rating can also be achieved by the incorporation of a second layer of the 20 oz. fabric about 3/4 inch from the outer face. This does require that the overall thickness of the panel be increased to a minimum of 1 inch.

The inclusion of AR glass fiber textile fabrics in random chopped fiber sprayed or cast GFRC to improve impact properties also opens the possibility of using this same design concept to manufacture GFRC that is blast resistant. Although this is a different type of impact force than the large missile test some preliminary testing has suggested that this is certainly a possible fruitful application to research.

References

(1) ANSI/ASCE 7, American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures – available from American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, Va 20191, USA, www.asce.org

(2) TAS 201-94 – Protocol for conducting the Impact Test as required by section 1626 of the Florida Building Code. Available from Department of Community Affairs, Building Codes and Standards, 2555 Shumard Oak Blvd., Tallahasee, Fl 32399, USA, www.dca.state.fl.us/fbc

(3) TAS 201-94 – Protocol for conducting the Cyclic Wind Pressure Loading Test required by FBC and TAS 201-94. Availability as for reference (2).

(4) Notice of Acceptance (NOA) available at: www.miamidade.gov/buildingcode.

(5) 2006 Texas Revisions to the 2006 International Residential Code (effective January 1, 2008). Available from Texas Department of Insurance, 333 Guadalupe, Austin, TX 78701, USA – www.tdi.state.tx.us/wind/geninfo.html

(6) ASTM E1886 – Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials. Available from ASTM , 100 Barr Harbor Drive, PO Box C700, West Conshocken, PA 19428, USA – www.astm.org

(7) ASTM E1996 – Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes – availability as for reference (5).

Fig 1 Hurricane Andrew

Fig 8 Lightweight Scrims

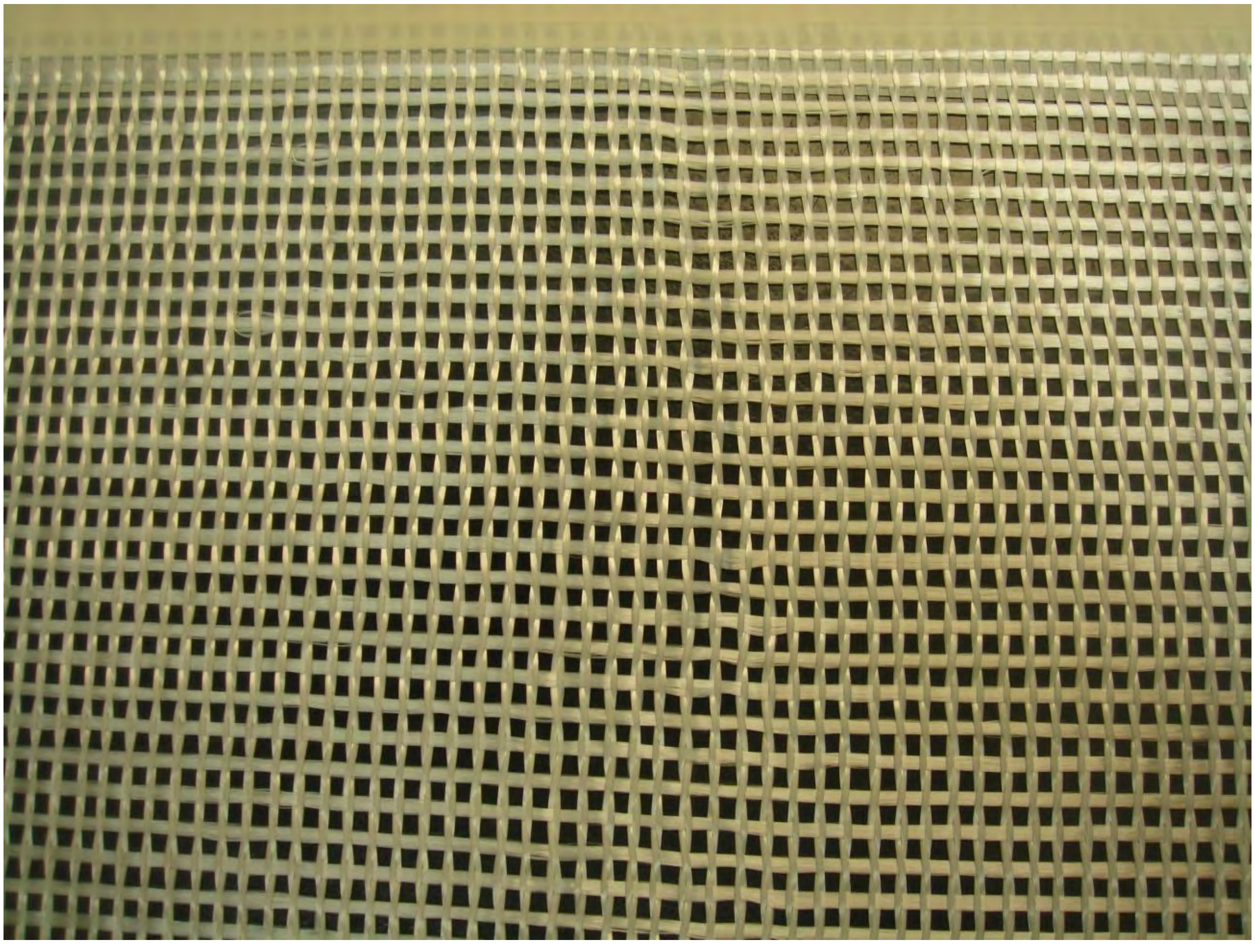


Fig 9 20 oz scrim

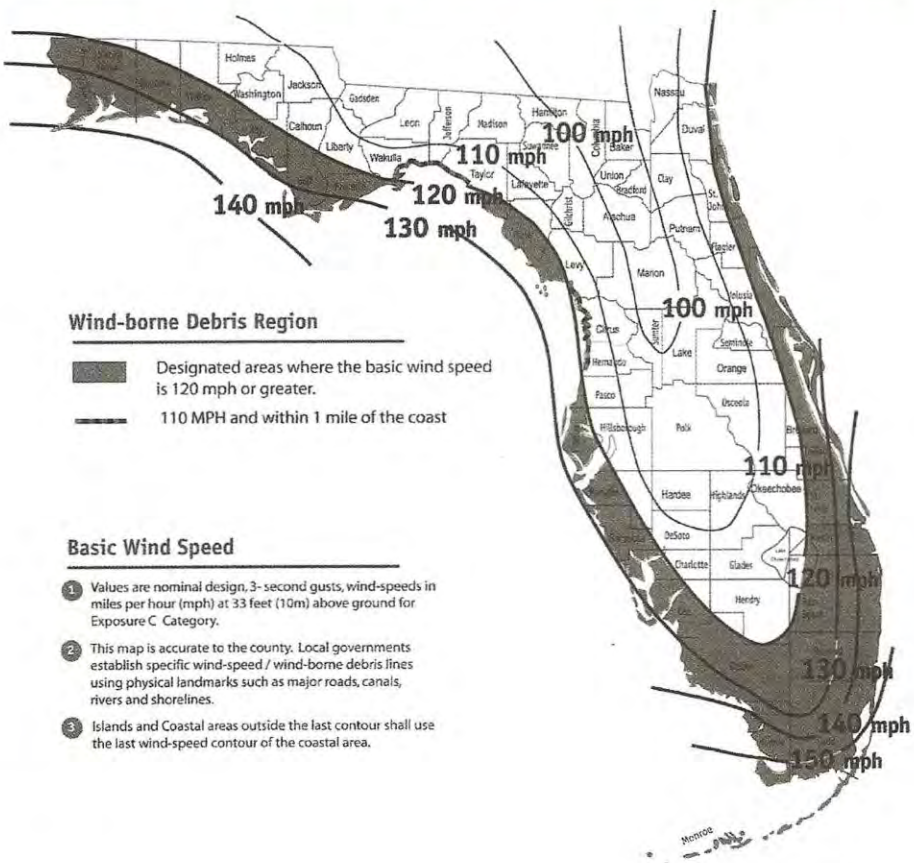
Fig. 14 Miami Hospital clad in hurricane resistant GFRC panels

Fig. 2 Wind speed contours in Florida

As Amended by Law cs /HB 1A - 2007

State of Florida

Wind-Borne Debris Region



www.florida building.org

FIGURE 1609
STATE OF FLORIDA DEBRIS REGION & BASIC WIND SPEED

FIG. 3 Notice of Acceptance (NOA) No. 05-0901.03

MIAMI-DADE COUNTY
BUILDING CODE COMPLIANCE OFFICE (BCCO)
PRODUCT CONTROL DIVISION

MIAMI-DADE COUNTY, FLORIDA
METRO-DADE FLAGLER BUILDING
140 WEST FLAGLER STREET, SUITE 1603
MIAMI, FLORIDA 33130-1563
(305) 375-2901 FAX (305) 375-2908
www.miamidade.gov

NOTICE OF ACCEPTANCE (NOA)

GFRC Cladding Systems, Inc.
118 North Shiloh Road
Garland, Texas 75042

SCOPE:
This NOA is being issued under the applicable rules and regulations governing the use of construction materials. The documentation submitted has been reviewed by Miami-Dade County Product Control Division and accepted by the Board of Rules and Appeals (BORA) to be used in Miami Dade County and other areas where allowed by the Authority Having Jurisdiction (AHJ).

This NOA shall not be valid after the expiration date stated below. The Miami-Dade County Product Control Division (In Miami Dade County) and/or the AHJ (in areas other than Miami Dade County) reserve the right to have this product or material tested for quality assurance purposes. If this product or material fails to perform in the accepted manner, the manufacturer will incur the expense of such testing and the AHJ may immediately revoke, modify, or suspend the use of such product or material within their jurisdiction. BORA reserves the right to revoke this acceptance, if it is determined by Miami-Dade County Product Control Division that this product or material fails to meet the requirements of the applicable building code.

This product is approved as described herein, and has been designed to comply with the High Velocity Hurricane Zone of the Florida Building Code.

DESCRIPTION: " Class 2 " Glass Fiber Reinforced Concrete Wall Panels

APPROVAL DOCUMENT: Drawing No. 1037, titled "Class 2 Glass Fiber Reinforced Concrete Wall Panels ", sheets 1 through 4 of 4, prepared by W. W. Schaefer Engineering & Consulting, P.A., dated 01/29/2001, signed and sealed by Warren W. Schaefer, P.E. on 08/17/2005, bearing the Miami-Dade County Product Control Revision stamp with the Notice of Acceptance number and expiration date by Miami-Dade County Product Control Division.

MISSILE IMPACT RATING: Large and Small Missile Impact

LABELING: Each panel shall bear a permanent label with the manufacturer's name or logo, city, state and the following statement: "Miami-Dade County Product Control Approved", unless otherwise noted herein.

RENEWAL of this NOA shall be considered after a renewal application has been filed and there has been no change in the applicable building code negatively affecting the performance of this product.

TERMINATION of this NOA will occur after the expiration date or if there has been a revision or change in the materials, use, and/or manufacture of the product or process. Misuse of this NOA as an endorsement of any product, for sales, advertising or any other purposes shall automatically terminate this NOA. Failure to comply with any section of this NOA shall be cause for termination and removal of NOA.

ADVERTISEMENT: The NOA number preceded by the words Miami-Dade County, Florida, and followed by the expiration date may be displayed in advertising literature. If any portion of the NOA is displayed, then it shall be done in its entirety.

INSPECTION: A copy of this entire NOA shall be provided to the user by the manufacturer or its distributors and shall be available for inspection at the job site at the request of the Building Official.
This NOA **revises & renews NOA #01-0216.05** and consists of this page 1, evidence submitted page E-1 as well as approval document mentioned above.
The submitted documentation was reviewed by **Helmy A. Makar, P.E.**

Helmy A. Makar
07/13/2006

NOA No 05-0901.03
Expiration Date: 05/31/2011
Approval Date: 07/13/2006
Page 1

GFRC Cladding Systems, Inc.

NOTICE OF ACCEPTANCE: EVIDENCE SUBMITTED

1. EVIDENCE SUBMITTED UNDER PREVIOUS APPROVAL #01-0216.05

A. DRAWINGS

1. *Drawing No. 1037, sheets 1 through 4 of 4, prepared by W. W. Schaefer Engineering & Consulting, P.A., dated January 29, 2001, signed and sealed by Warren W. Schaefer, P.E. on May 1, 2001.*

B. TESTS

1. *Test report on Large Missile Impact Test, Cyclic Wind Pressure Test and Uniform Static Air Pressure Test on GFRC Glass Fiber Reinforced Concrete Wall Panel, prepared by Hurricane Test Laboratory, Inc., Report No. 0250-1203-00, dated February 14, 2001, signed and sealed by Vinu J. Abraham, P.E.*

C. *CALCULATIONS*

1. *Calculations, dated February 2, 2001, 3 pages, prepared by W. W. Schaefer Engineering & Consulting, P.A., signed and sealed by Warren W. Schaefer, P.E. on February 5, 2001.*

D. MATERIAL CERTIFICATIONS

1. *Daracem ML 500 Superplasticizer ASTM Type A and Type F by Grace Construction Products.*
2. *Technical data and specifications.*

2. NEW EVIDENCE SUBMITTED

A. DRAWINGS

1. *Drawing No. 1037, titled "Class 2 Glass Fiber Reinforced Concrete Wall Panels", sheets 1 through 4 of 4, prepared by W. W. Schaefer Engineering & Consulting, P.A., dated 01/29/2001, signed and sealed by Warren W. Schaefer, P.E. on 08/17/2005.*

B. TESTS

1. *None.*

C. CALCULATIONS

1. *None.*

D. QUALITY ASSURANCE

1. *By Miami-Dade County Building Code Compliance Office.*

E. MATERIAL CERTIFICATIONS

1. *None.*

F. STATEMENTS

1. *Letter from W. W. Schaefer Engineering & Consulting, P.A., signed and sealed by Warren W. Schaefer, P.E., stating that he is still in the engineering business, dated January 13, 2006.*

Helmy A. Makar, P. E.
Product Control Examiner
NOA No 05-0901.03
Expiration Date: 05/31/2011
Approval Date: 07/13/2006

Fig. 4 GFRC panel

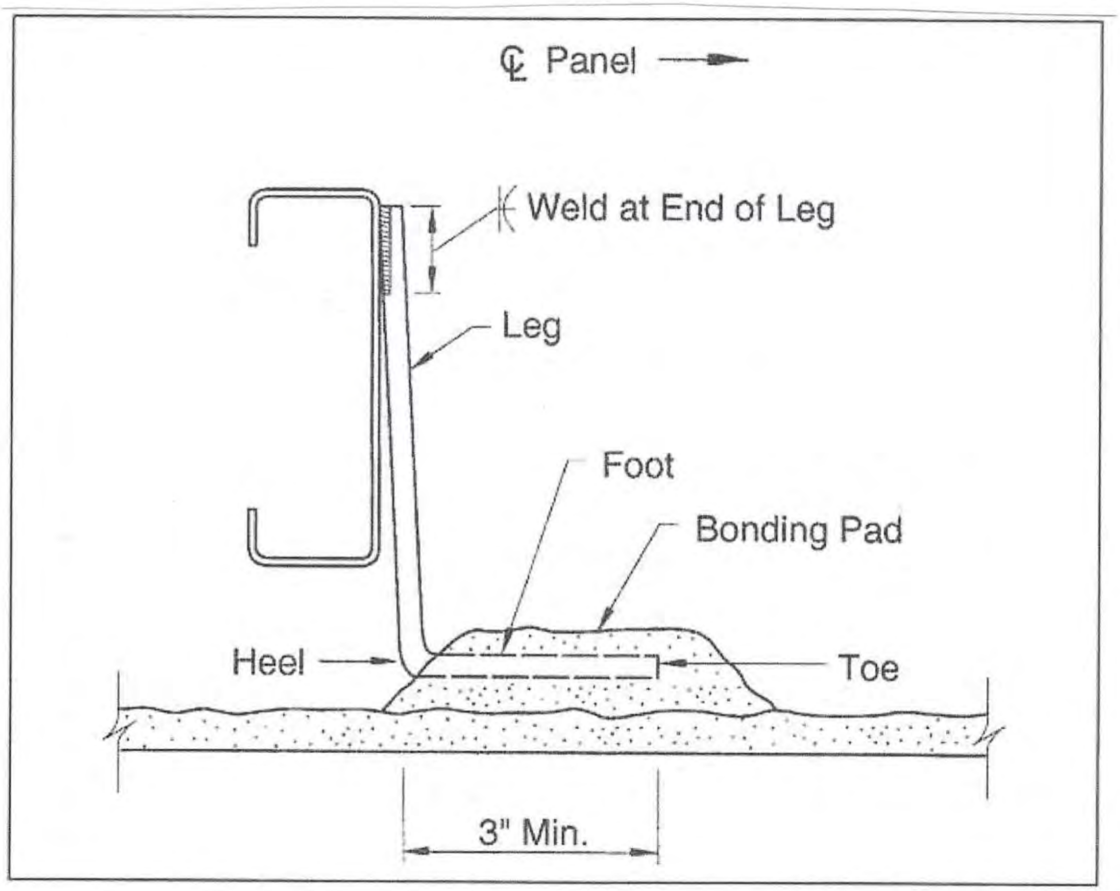
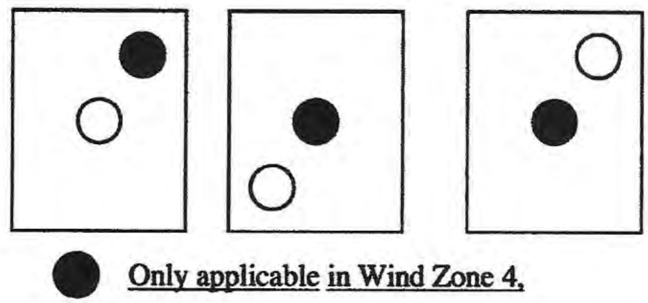


Fig. 5 Impact Test Target areas



NOTE 1—The white circles denote first impact and the black circles denote second impact.

Fig. 6 cyclic wind pressure test

TABLE 1626
CYCLIC WIND PRESSURE LOADING

INWARD ACTING PRESSURE		OUTWARD ACTING PRESSURE	
RANGE	NUMBER OF CYCLES[1]	RANGE	NUMBER OF CYCLES[1]
0.2 P_{MAX} to 0.5 P_{MAX}[2]	3,500	0.3 P_{MAX} to 1.0 P_{MAX}	50
0.0 P_{MAX} to 0.6 P_{MAX}	300	0.5 P_{MAX} to 0.8 P_{MAX}	1,050
0.5 P_{MAX} to 0.8 P_{MAX}	600	0.0 P_{MAX} to 0.6 P_{MAX}	50
0.3 P_{MAX} to 1.0 P_{MAX}	100	0.2 P_{MAX} to 0.5 P_{MAX}	3,350

NOTES:
1. Each cycle shall have minimum duration of 1 second and a maximum duration of 3 seconds and must be performed in a continuous manner 1.
2. P_{MAX} denotes maximum design load in accordance with ASCE 7. The pressure spectrum shall be applied to each test specimen beginning with inward acting pressures followed by the outward acting pressures in the order from the top of each column to the bottom of each column.

inches (127 mm) and $^1/_{16}$ inch (1.6 mm) in width through which air can pass.

1626.3.9 If only one of the three test specimens in a test fails to meet the above listed criteria, one retest of the system (another test sequence with three specimens) of construction shall be permitted.

1626.4 Construction assemblies deemed to comply with Section 1626.

1. Exterior concrete masonry walls of minimum nominal 8-inch (203 mm) thickness, constructed in accordance with Chapter 21 (High-Velocity Hurricane Zones) of this code.
2. Exterior frame walls or gable ends constructed in accordance with Chapter 22 and Chapter 23 (High-Velocity Hurricane Zones) of this code, sheathed with a minimum $^{19}/_{32}$-inch (15 mm) CD exposure 1 plywood and clad with wire lath and stucco installed in accordance with Chapter 25 of this code.
3. Exterior frame walls and roofs constructed in accordance with Chapter 22 (High-Velocity Hurricane Zones) of this code sheathed with a minimum 24-gage rib deck type material and clad with an approved wall finish.
4. Exterior reinforced concrete elements constructed of solid normal weight concrete (no voids), designed in accordance with Chapter 19 (High-Velocity Hurricane Zones) of this code and having a minimum 2-in. (51 mm) thickness.
5. Roof systems constructed in accordance with Chapter 22 or Chapter 23 (High-Velocity Hurricane Zones) of this code, sheathed with a minimum $^{19}/_{32}$-inch (15 mm) CD exposure 1 plywood or minimum nominal 1-inch (25 mm) wood decking and surfaced with an approved roof system installed in accordance with Chapter 15 of this code.

All connectors shall be specified by the building designer of record for all loads except impact.

Fig. 7 Scrim properties

Table 1 - Composite Configuration and 28 Day Test Results

PANEL	TYPE OF SCRIM	NUMBER OF LAYERS	NUMBER OF FACES	CHOPPED STRAND %	FACE MIX	MOR psi.	STRAIN TO FAILURE	FACE IN TENSION
A	TD5X5	1	1	3	NONE	2774	.175	SCRIM FACE
B	TD5X5	2	1	3	NONE	4014	.213	SCRIM FACE
C	TD5X5	1	2	3	NONE	2560	.102	EITHER FACE
D	TD5X5	2	2	3	NONE	3114	.153	EITHER FACE
E	TD5X5	1	2	0.5	NONE	1712	.165	EITHER FACE
F	TD5X5	2	2	0.5	NONE	3411	.230	EITHER FACE
G	TD10X10	1	2	3	NONE	2028	.140	EITHER FACE
H	TD10X10	2	2	3	NONE	2430	.167	EITHER FACE

Fig. 10 panel details of class 2 hurricane resistant GFRC panels

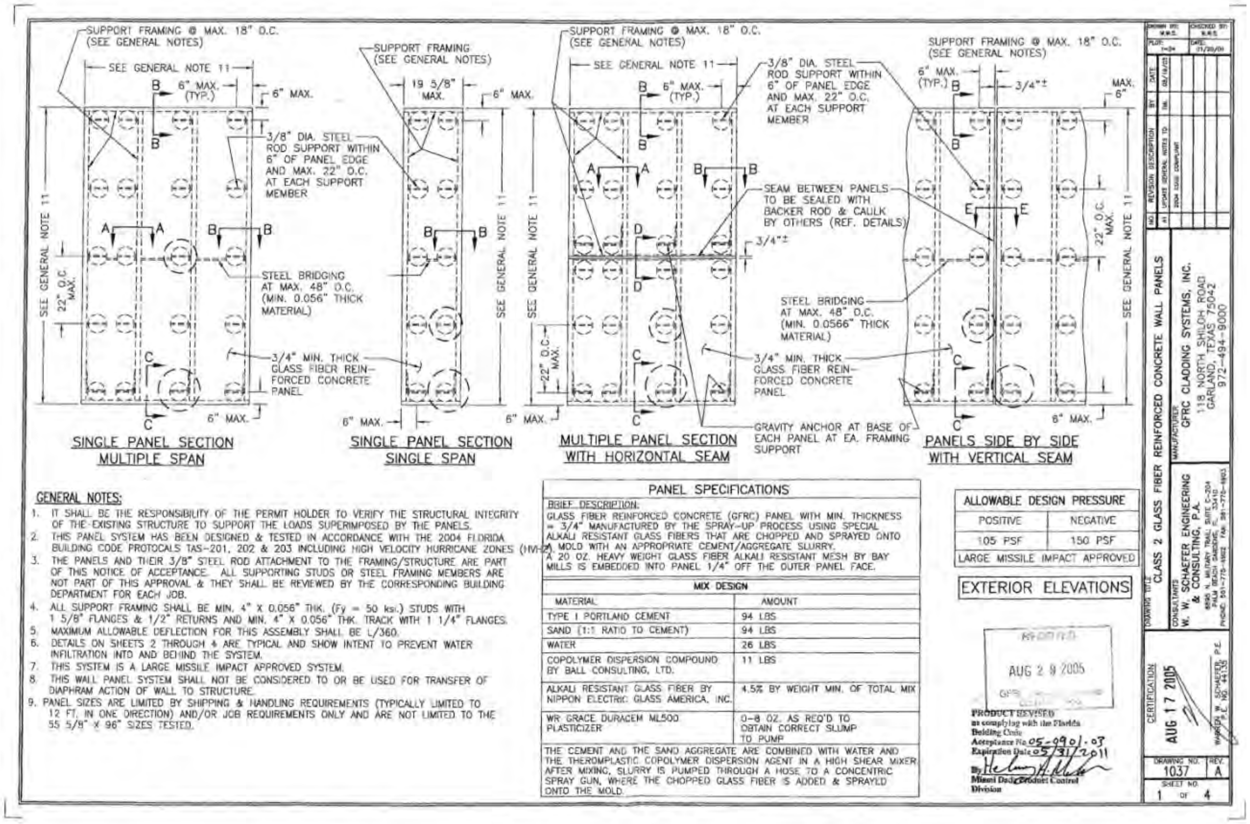


Fig. 11 details of class 2 hurricane resistant GFRC panels

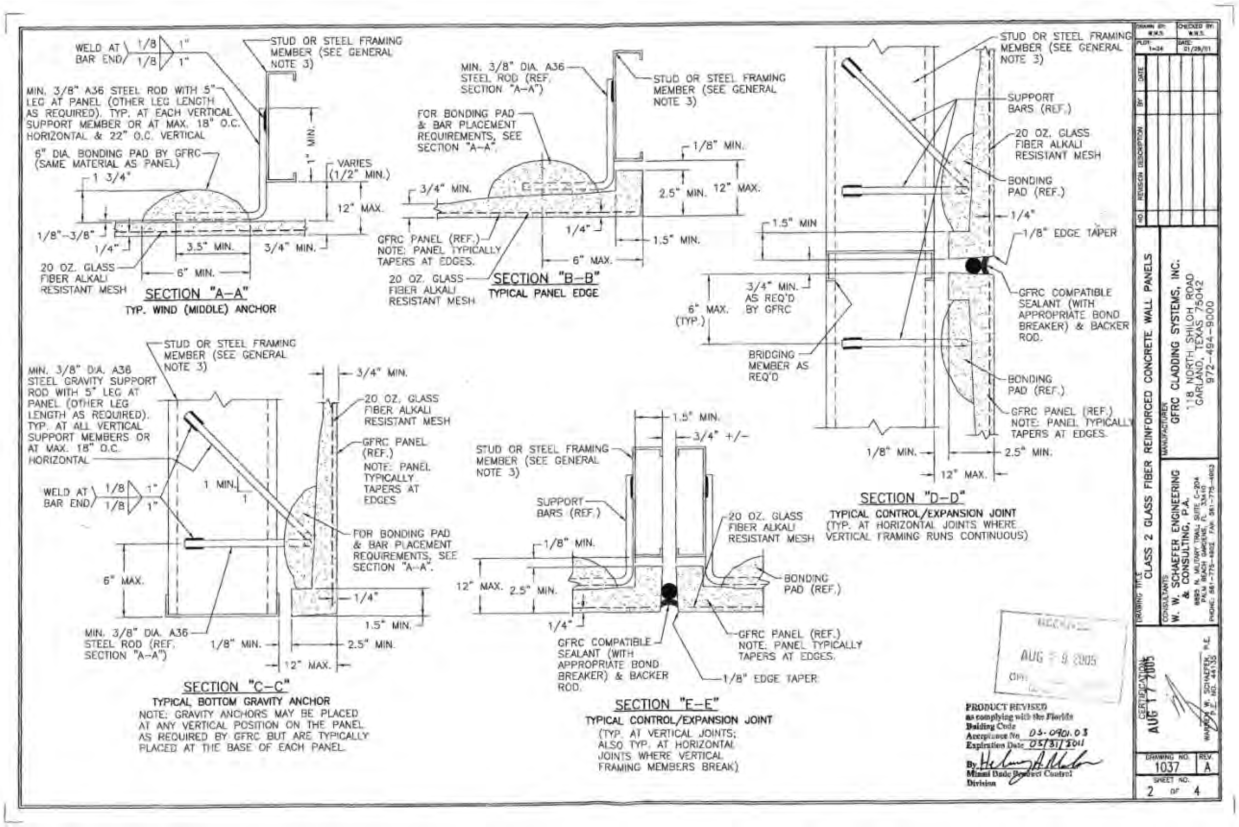


Fig. 12 Details of class 2 hurricane resistant GFRC panels

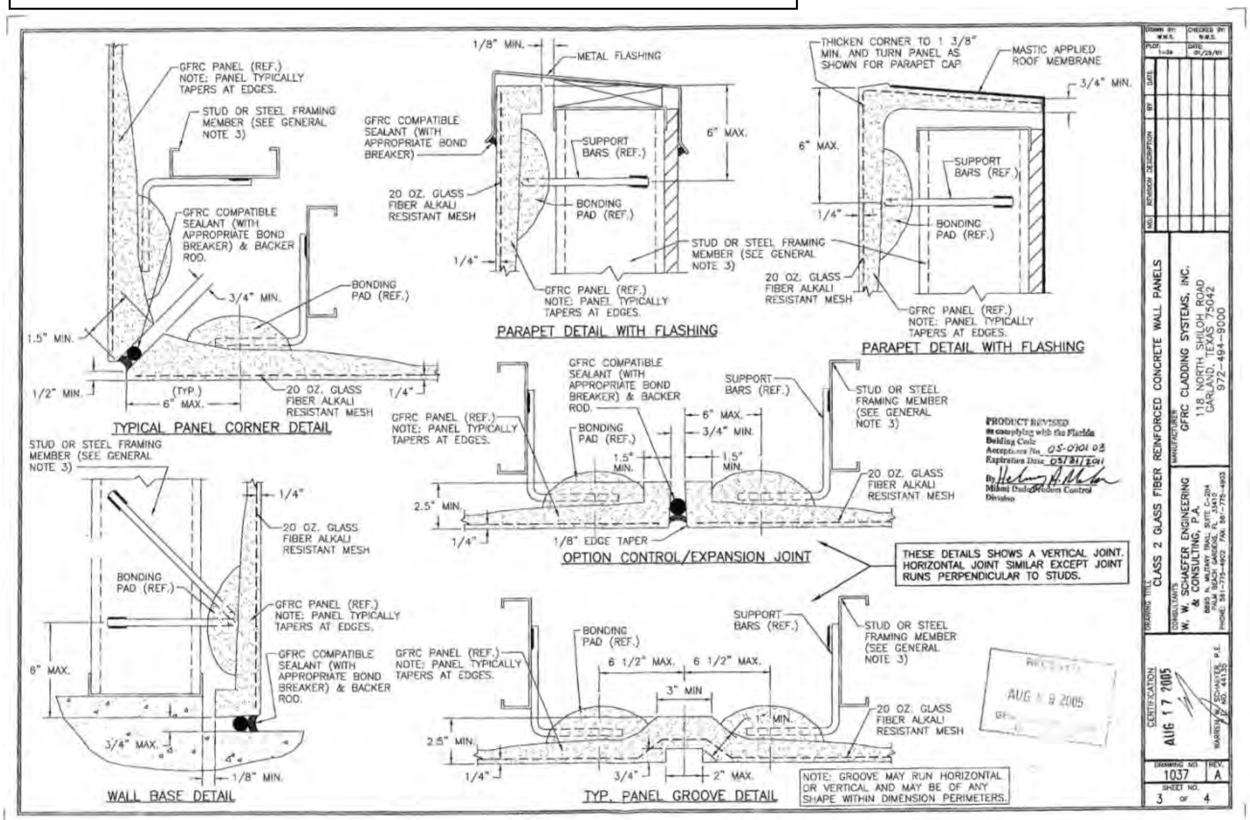


Fig. 13 Details of class 2 hurricane resistant GFRC panel