CHAPTER 3

TEST PROGRAM

3.1. Introduction

The large missile impact test method used in the research is presented in this chapter. This includes details of the test method and assumptions, performance classifications and expectations, and acceptable performance criteria for the testing. Based on the previous research conducted on wall and roof assemblies mentioned in Chapter 2, wall/roof assemblies were selected for the current research.

3.2. Performance Classifications and Expectations

Failure of a test assembly is defined in this section based on previous research and test standards, as described in Section 2.8 of Chapter 2. Failure of a barrier or target may be defined in various ways, depending upon the intended application or use of the target. According to FBC (2001), penetration of the missile is the failure criteria. A wall or roof assembly passes the test, if it rejects the missile without penetration. Anderson (1995) performed large missile impact tests on metal-clad structures. It was observed that even if the missile did not penetrate or perforate the test panels, large openings in the seam between panels were developed in a few tests. These openings were of sufficient size to allow the wind to pass through. According to the FBC (2001), these test assemblies passed the large missile impact test although there was a possibility of wind passing through the assemblies. This does not meet the intent of the code, which is to prevent damaging wind from entering the building during a hurricane. FBC (2001) further states that any specimen that passes the large missile impact test needs to be tested for small missile impact test if the specimen has an opening that a 3/16 in. sphere can pass through. SSTD 12 (1999) and ASTM C-1996 (2004) provide an acceptance criterion, which may be used to overcome this deficiency in FBC (2001) standard. SSTD 12 (1999) and ASTM C-1996 (2004) state that porous test specimens must resist the large missile impact without penetration to pass the test. For non-porous specimens, these standards allow an opening with diameter less than 3 in.

FEMA-361 (2002) developed a large missile impact test standard for tornado shelters or components based on the research performed at TTU (2002). In this standard, failure is defined as the behavior that might cause injury to occupants of a building. Perforation by the missile, scabbing of target material that would create debris, or large deformations of the target would constitute failure. But the definition of failure of a test assembly is not clear in the above statement. It does not mention the amount of scabbing material or deformation that may be considered as failure of the specimen. According to FEMA-361 (2002), permanent deformation of 3 in. or more after impact is deemed unacceptable.

Research related to the design of nuclear power facilities produced relatively large body of information and design guides for predicting the response of reinforced concrete walls and roofs to the impact of windborne debris. The failure modes were identified as penetration, threshold spalling, spalling, barrier perforation, and complete missile perforation (Twisdale and Dunn 1981). From a sheltering standpoint, penetration of the missile into, but not through, the wall surface is of no consequence unless it creates spalling, where concrete is ejected from the inside surface of the wall or roof. As the size of the spalling increases, so does the velocity with which it is ejected from the wall or roof surface. When spalling occurs, physical injury and death to people directly behind the impact point are possible. In barrier perforation, a hole occurs in the wall, but the missile still bounces off the wall or becomes stuck in the hole. A plug of concrete about the size of the missile is knocked into the room and may injure or kill occupants. Complete missile perforation may cause injury or death to people hit by the primary missile or wall fragments. So, failure criteria for reinforced concrete barriers should be the spalling of concrete.

3.3. Testing Method

3.3.1. Significance of the Test: It was previously mentioned that the basic large missile impact test may not be sufficient for EOCs, schools and light commercial buildings. To provide "Hurricane Enhanced Protection" to the EOCs or according to DCA, schools and other commercial buildings, enhanced large missile impact test needs to be performed. The enhanced impact is termed as enhanced-A in this study. In the present study, both the basic and enhanced-A tests were performed. The basic test was performed according to the TAS 201-94, Impact Test Procedures, described in FBC (2001). The missile test criteria for the basic and enhanced-A tests were FBC specified 2x4 in. 9 lb missile at 34 mph and DOE specified 2x4 in. 15 lb missile at 50 mph, respectively. For the enhanced-B test, a 2x4 in. 15 lb missile was impacted at a speed of 60 mph. The missile test criteria for basic, enhanced-A and enhanced-B tests are given in Table 3.1. The missile impact test procedure provides a means of determining whether a particular wall, roof, exterior window, exterior door and any other similar device used as external protection to maintain the envelope of the building, provides sufficient resistance to windborne debris.

Table 3.1: Large Missile Impact Test Criteria

Tests	Missile	Missile Size (lb)	Missile Speed (mph)
Basic	2x4 in. stud	9	34
Enhanced-A	2x4 in. stud	15	50
Enhanced-B	2x4 in. stud	15	60

3.3.2. Test Assembly: There were three major components to the assembly, as shown in Figs. 3.1-3.3: a simulated concrete foundation, top steel cross-beam support, and the wall or roof test specimen. Two concrete foundation blocks were bolted to the strong floor at the UF structures laboratory. Each foundation block had a dimension of 1 ft x 1 1/2 ft x 9 1/2 ft. Prior to casting, the concrete forms were fitted with PVC pipe passing completely through the formwork, reinforcing bars, and J-bolts. The foundation blocks were secured to the floor using threaded rod once they were sufficiently cured. Each foundation block was placed with the rod passing through the PVC pipe in the concrete. A nut was placed on each rod and tightened sufficiently to secure the block to the laboratory floor. Each foundation block had six J-bolts extending 6 in. out of the top of the concrete to secure the base of each test specimen. The exposed ends of these bolts were used to secure the bottom of each specimen in place, simulating the method used to secure a stud wall to its foundation. Each steel beam consisted of a 3/4 in. plate on each end of an MC 10x8.4 channel. The larger plate was bolted to each side of the strong wall using 5/8 in. A325 structural bolts, while the smaller plate was used to connect the two beams at midspan. This provided lateral stability for the header of each specimen. The specimens were attached using 1/2 in. bolts through the channel and specimen header.

Erection of the specimen was accomplished by first placing the specimen over the embedded J-bolts and attaching with a washer and nut. A steel bracket was used to temporarily support the specimen prior to the cross-beam placement. The bracket was attached and removed from the strong wall to allow finishing of the “interior” portion of the specimen after erection was complete. A clamp was used to secure the specimen to the bracket. Finally, the channels were lifted into place and secured at all appropriate locations.

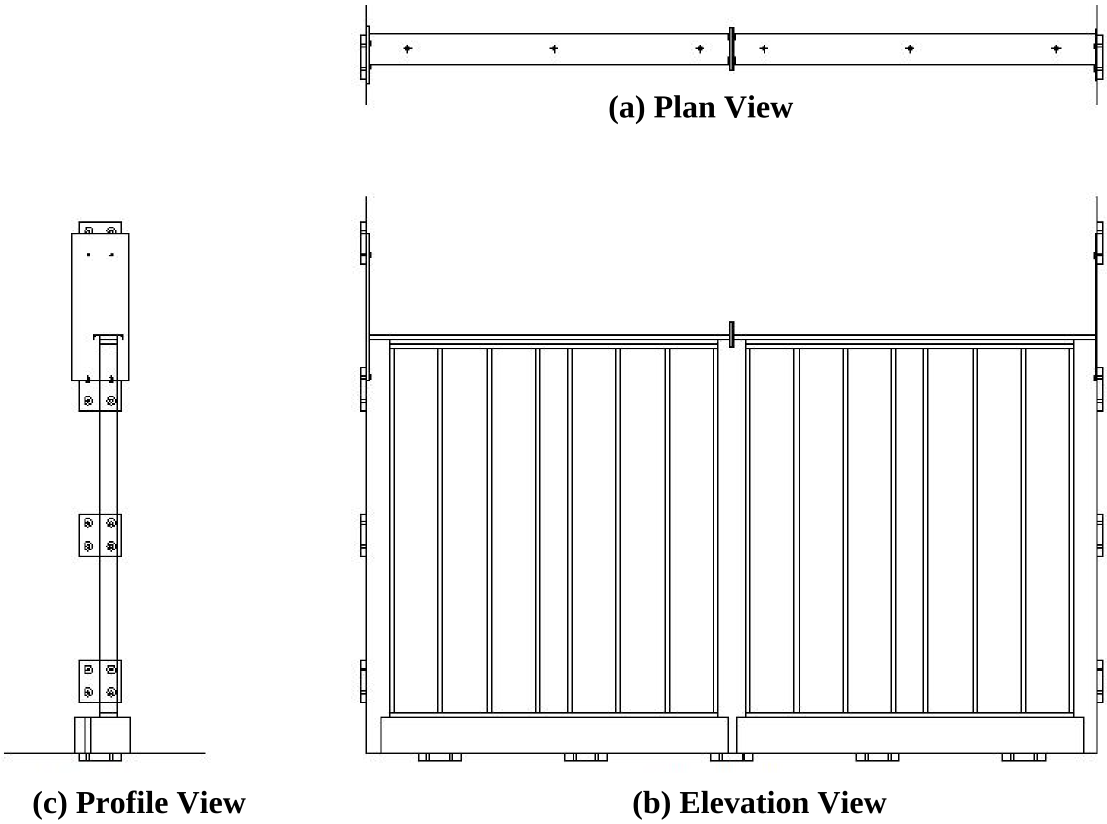

Figure 3.1: Test Assembly Schematic

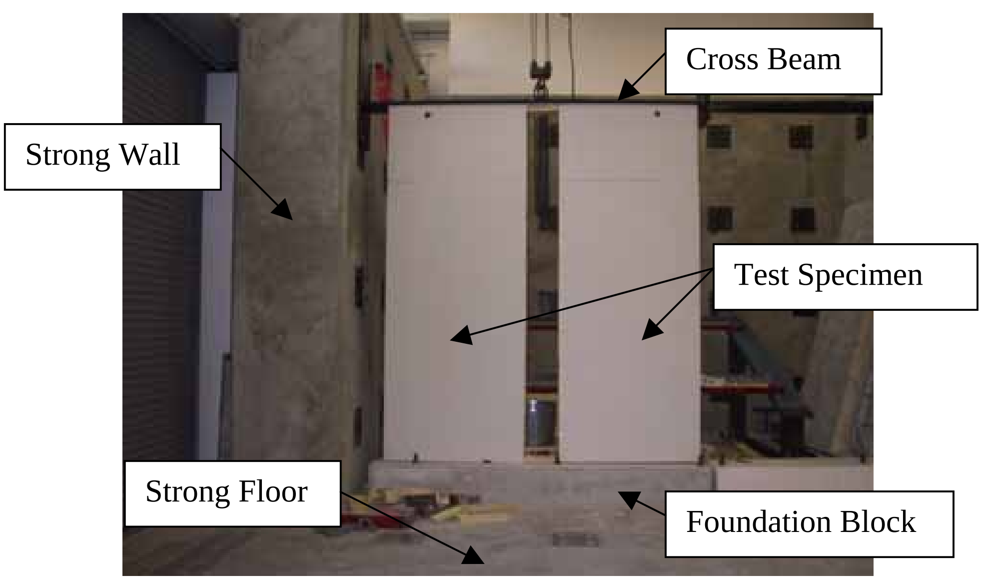

Figure 3.2: Overall Testing Assembly

Figure 3.3: Close-up of Concrete Foundation Block with J-Bolts and Threaded Rod

Figure 3.4: A 9 lb and a 15 lb Missile

3.3.3. Missile: Each missile was constructed using surface dry Southern Pine 2x4 in. boards. Figure 3.4 shows a typical basic 9 lb and an enhanced-A5 lb missile. The missiles were sized such that the weight was between 9 and 9 1/2 lb with a length between 7 and 9 ft. or with a weight between 15 and 15 1/2 lb. and a length between 11 and 13 ft. in accordance with FEMA-361 (2002). Missiles were chosen such that no knots appeared within 12 in. of the leading edge. The trailing edge of each missile was affixed with a plastic sabot to facilitate launching. This connection was accomplished by using a 3 in. long, 5/8 in. diameter screw. The sabot's weight did not exceed 1/2 lb.

3.3.4. Large Missile Cannon: The large missile cannon at UF used compressed air to propel a large missile at the test specimen at standard testing speeds in accordance with FBC (2001) TAS 201-94 Impact Test Procedures and DOE Standard 1020 (1994). The basic and enhanced-A large missile impact tests required a 9 lb. and a 15 lb. missile to be fired at 50 ft/sec. (34 mph) and 73 ft/sec (50 mph), respectively. Several major components comprised the missile cannon including the following:

1. Compressed air supply
2. Pressure release mechanism
3. Pressure gage
4. Barrel and frame
5. Timing system
6. Data Acquisition System

Figures 3.5 through 3.7 display the large missile cannon at UF. A steel tube frame mounted on casters supported the entire mechanism, allowing mobility of the apparatus. The cannon barrel rested on an aluminum beam, which was hung from steel

Figure 3.5: Large Missile Cannon at UF

Figure 3.6: Large Missile Cannon Firing Mechanism

Figure 3.7: Penetration of Plywood by 15 lb Missile During Calibration

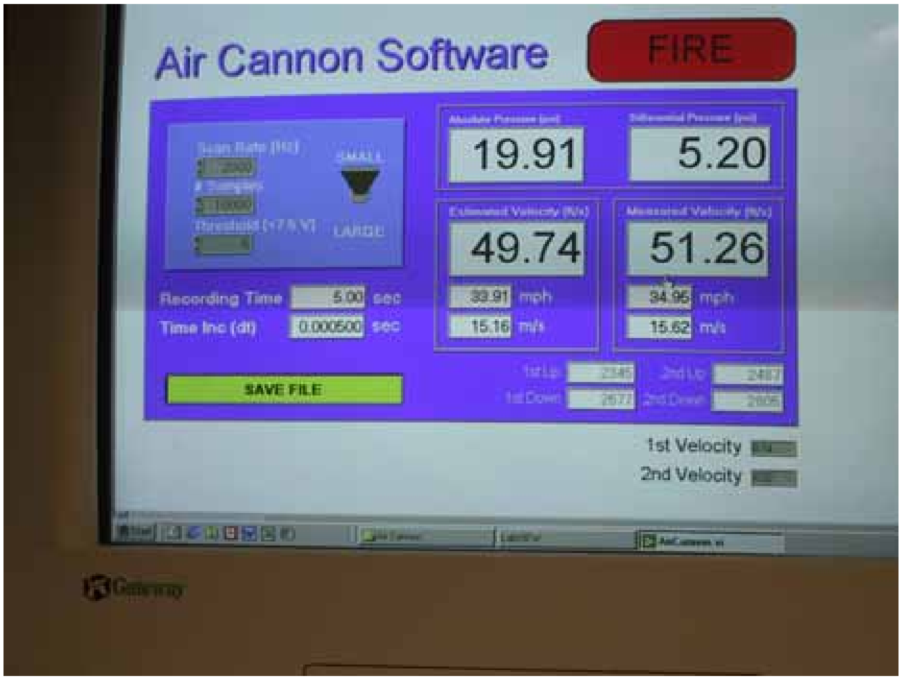

Figure 3.8: Labview Data Acquisition System

cables supported by the frame. These cables could be adjusted using a pair of winches, thereby adjusting the height of the cannon barrel. Two air compressors were mounted onto the frame. The larger of the two compressors provided the air pressure required to facilitate launching, while the smaller one powered the trigger release mechanism. The firing mechanism is shown in Figure 3.8. Once the desired launching pressure was attained, pushing the trigger activated a piston, powered by the small air compressor, which opened the release valve. With this setup, it was assured that the release valve was opened rapidly and with consistency. The cannon barrel was approximately 20 ft. long with a stopping bolt located near the firing controls. The stop assured that each missile was fired from a consistent location in the barrel.

3.3.5. Measurement and Data Acquisition System: The large missile cannon timing system comprised of two photoelectric sensors, a data collection computer running Labview, shown in Figure 3.8, handwritten data collection sheets, shown in Figure 3.9, and an optional oscilloscope. This timing system was capable of measuring speeds accurate to ±2 %. The speed of the missile was measured anywhere between the points where 90% of the missile was outside of the cannon and where the missile was 1 ft. away from the test specimen. The speed was not measured while the missile was accelerating.

The timing system on the cannon at UF had the photoelectric sensors attached near the end of the cannon. The sensors, located 3.28 ft apart, were triggered as the missile passed. Using the photoelectric sensors, in addition to a pressure transducer, the computer recorded the gage and absolute pressure in the cannon, and trigger times for both photoelectric sensors, which was then used to calculate the exit velocity of the missile. As the firing pressure in the cannon was

Large Missile Impact Data Collection Sheet

Test Date ____________

Test Name	Projectile			Cannon to Specimen Distance		Oscilloscope	
	Length						Calculated
	Feet	Inches	Weight (lb)	Feet	Inches	Time Reading (ms)	Speed (mph) **

Lab View Data		
Differential Pressure (psi.)	Estimated Velocity (ft/s)	Measured Velocity (ft/s)

Impact Result	Notes

**Speed (ft/s) = $\frac{3281}{\text{Time (ms)}}$

Figure 3.9: Handwritten Data Collection Sheet

charged, Labview calculated the estimated missile velocity. This calculation was made using equations developed during the calibration process. During calibration, each size missile was fired using a range of pressures. The measured velocity and pressure were recorded for each firing and entered into an Excel spreadsheet. These values were plotted for each missile and a logarithmic curve was fitted to each plot, as shown in Fig. 3.10. The generated equations for both missiles are as follows:

9 lb. Missile $$V = 58.51 \ln(p) - 46.724 \tag{3.1}$$

15lb. Missile $$V = 49.846 \ln(p) - 46.113 \tag{3.2}$$

where p is the gage pressure in psi and V is in ft/sec.

It was found that the pressure-velocity relationship was nearly independent of the missile's weight. Figure 3.11 shows the large missile calibration data plot. If the oscilloscope was in use, the time difference between the trailing edges of the two channel's signal plots was measured on the device, which produced a travel time over the 3.28 ft distance. The missile's speed was then calculated from this time by dividing the distance between the sensors by the travel time.

3.3.6. Large Missile Impact: Each of the test specimens received a maximum of two impacts, as shown in Fig. 2.10, for each of the basic, enhanced-A and enhanced-B tests. The missile impacted normal to the surface of the specimen at the required velocity for the given test. One of the impacts was within a 10 in. circle with its center point at the midspan between studs. The second impact occurred within a 10 in. circle having its center 6 in. away from any supporting members. The initial two impacts were made using the basic test protocols. The enhanced-A test was only run if the specimen passed the basic test. Should the specimen fail the basic test, it

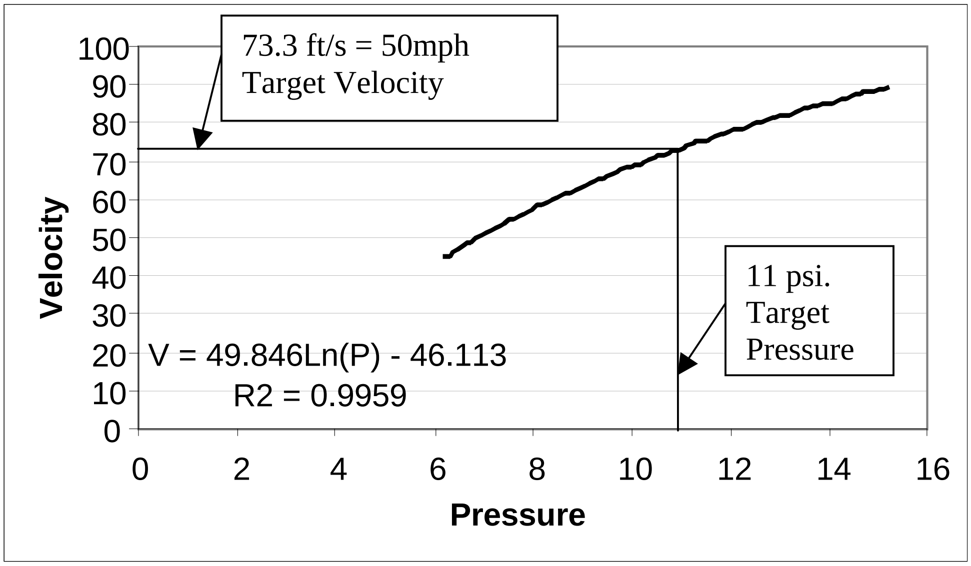

Figure 3.10: Large Missile Calibration Curve

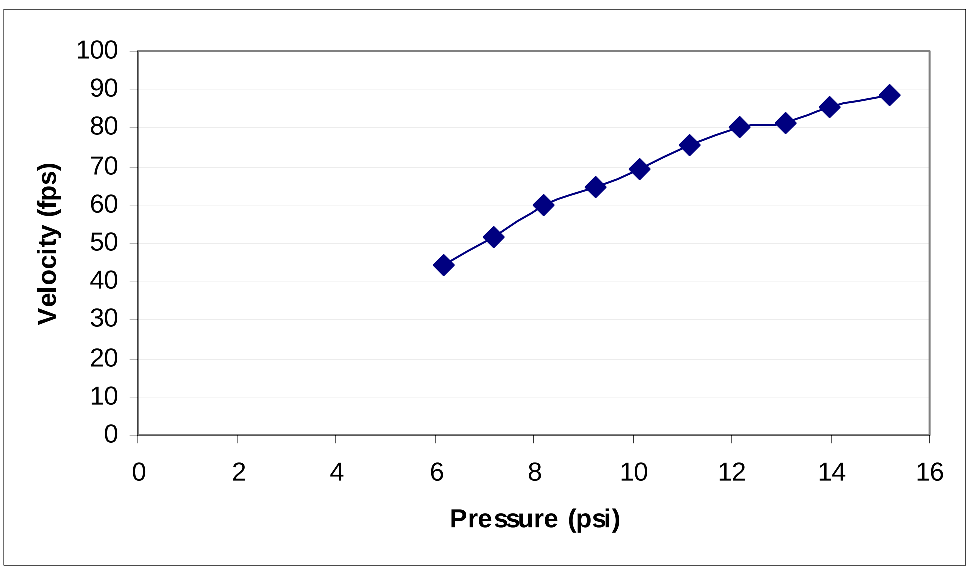

Figure 3.11: Large Missile Calibration Data Plot

would also fail the more rigorous enhanced-A test. Similarly the enhanced-B test was run only if the specimen passed the basic and enhanced-A tests.

3.3.7. Acceptance Criteria: The study herein primarily followed the FBC (2001) large missile impact test acceptance criteria, which states that a specimen passes the test if it rejects the missile without any penetration. As this criterion is not clear, a few more conditions were added based on the discussion in Section 3.2. The objective of this project was to provide a safe place for the occupants during a hurricane. Based on this objective, test acceptance criteria for the basic, enhanced-A and enhanced-B large missile impact tests should be the same. The test criteria are provided in Table 3.2. The FEMA recommended 3 in. or more permanent deformation of the metal assembly was not utilized in this research, mainly due to two reasons. Firstly, FEMA recommendations were applicable to areas, which are susceptible to tornado, whereas, this research was applicable to hurricane-prone regions in Florida. Secondly, any deformation in the wall or roof assembly does not lead to the total failure of the structure, as it may happen in case of an opening in the assembly.

3.4. Commonly Used Florida Wall and Roof Assemblies

A number of engineering design companies were contacted to gather information on commonly used wall and roof assemblies for Florida public and commercial building facilities. A comprehensive list of such wall and roof assemblies was prepared through compilation of information from each company. Tables B.1 and B.2 in Appendix B present the wall and roof assemblies commonly used in Florida, respectively.

Table 3.2: Acceptance Criteria for Basic, Enhanced-A and Enhanced-B Large Missile Impact Test

<table>
<tr><th rowspan="2">Item No.</th><th rowspan="2">Wall/Roof Assembly Type</th><th colspan="2">Acceptance Criteria</th></tr>
<tr><th>FBC</th><th>Additional Criteria</th></tr>
<tr><td>1</td><td>Wood</td><td rowspan="3">Rejection of the missile without any penetration.</td><td>• No separation of the test assembly, which may cause injury or death of the occupants.</td></tr>
<tr><td>2</td><td>Metal</td><td>• No opening through which a 3 in. diameter sphere can pass.
• No separation of the test assembly, which may cause injury or death to the occupants.</td></tr>
<tr><td>3</td><td>Reinforced Concrete or CMU</td><td>• No opening through which a 3 in. diameter sphere can pass.
• No spalling of concrete, which may cause injury or death to the occupants.</td></tr>
</table>

Table 3.3: Validity of Specified Deemed to Comply List

<table>
<tr><th rowspan="2">Description of the Assembly</th><th>Validity of the Test</th><th colspan="2">Description of the Test</th></tr>
<tr><th>From Tables A.1 – A.6</th><th>Source</th><th>Test Type and Result</th></tr>
<tr><td colspan="4">FBC</td></tr>
<tr><td>8 in. CMU wall</td><td>Item no. 2 of Table A.3</td><td>UF</td><td>Passed the basic test criteria</td></tr>
<tr><td>Exterior frame walls or gable ends, sheathed with a minimum 19/32 in. CD exposure 1 plywood</td><td>Item no. 44 of Table A.3</td><td>Miami Dade Building Code Compliance Office</td><td>Passed the basic test criteria</td></tr>
<tr><td>Exterior frame walls and roofs sheathed with a minimum 24 ga. rib deck type material</td><td>Several items in Table A.3</td><td>UF, Miami Dade Building Code Compliance Office, Florida Dept. of Education</td><td>Passed the basic and enhanced-A test criteria</td></tr>
<tr><td>Exterior reinforced concrete elements having a minimum 2 in. thickness.</td><td>Not found</td><td>---</td><td>---</td></tr>
<tr><td>Roof systems sheathed with a minimum 19/32 in. CD exposure 1 plywood or minimum nominal 1 in. wood decking</td><td>Item no. 44 of Table A.3</td><td>Miami Dade Building Code Compliance Office</td><td>Passed the basic test criteria</td></tr>
<tr><td colspan="4">Department of Energy</td></tr>
<tr><td>8 in. CMU wall with trussed horizontal joint reinforced at 16 in. o.c.</td><td>Item no. 34 of Table A.6</td><td>TTU</td><td>Failed the test criteria (2x4 in. 12.5 lb missile at 89 and 104 mph).</td></tr>
<tr><td>Single width brick veneer with stud wall</td><td>Item no. 9 of Table A.2</td><td>TTU</td><td>Failed the enhanced-A test criteria.</td></tr>
<tr><td>4 in. concrete slab with #3 rebar at 6 in. o.c. each way in middle of slab</td><td>Not found</td><td>---</td><td>---</td></tr>
</table>

3.5. Validity of FBC Deemed to Comply List

FBC (2001) contains a "deemed to comply" list for missile impact resistance of building exterior systems, which covers some basic assemblies used mostly in residential construction. These assemblies are:

- Exterior concrete masonry wall (CMU) of minimal 8 in. thickness.
- Exterior frame walls or gable ends, sheathed with a minimum 19/32 in. CD exposure 1 plywood and clad with wire lath and stucco.
- Exterior frame walls and roofs sheathed with a minimum 24 ga. rib deck type material and clad with an approved wall finish.
- Exterior reinforced concrete elements having a minimum 2 in. thickness.
- Roof systems sheathed with a minimum 19/32 in. CD exposure 1 plywood or minimum nominal 1 in. wood decking and surfaced with an approved roof system.

It is observed from Tables A.1 – A.6 that most of the FBC specified deemed to comply assemblies were previously tested and passed the basic large missile impact test. Table 3.3 lists the sources of these tests.

The Department of Energy (1994) recommends wind missile barriers for Performance Categories 3 and 4. The enhanced-A test with 2x4 in. 15 lb timber planks are used as the missile for these categories. Missiles are impacted on the target at a speed of 50 mph. Recommended barriers are:

- 8 in. CMU wall with trussed horizontal joint reinforcement at 16 in. o.c.
- Single width brick veneer with stud wall
- 4 in. concrete slab with #3 rebar at 6 in. o.c. each way in middle of slab.

A sample 8 in. CMU wall with trussed horizontal joint reinforcement at 16 in. o.c. was tested with a 2x4 in. 12.5 lb at a speed of 89 and 104 mph at TTU and it failed the test. A single width brick veneer with stud wall was also tested at TTU. The 2x4 in. 15 lb missile impacted the target at 69.4 mph and the assembly failed. The only assembly not located in the background review conducted herein was the reinforced concrete element. Table 3.3 lists the sources of these tests.

3.6. Selected Wall and Roof Assemblies for the Test

Figure 3.12 presents the flowchart that was followed to obtain the wall and roof assemblies that were required to be tested. Previous research on large missile impact tests were summarized in Tables A.1-A.6, which list the basic, enhanced-A and non-standard large missile impact tests previously performed on wall and roof assemblies. Tables B.1 and B.2 were compared with Tables A.1-A.6 to obtain Tables B.3 and B.4, which list the commonly used Florida wall and roof assemblies that were previously tested according to the basic and the enhanced-A large missile impact tests, respectively.

Tables B.3 and B.4 were compared with Tables B.1 and B.2 to identify target assemblies for the basic, enhanced-A and enhanced-B tests. Wall and roof assemblies requiring the basic, enhanced-A and enhanced-B tests are listed in Tables 3.4 and 3.5, respectively. If any wall or roof assembly from Tables B.1 or B.2 was not found in Tables B.3 and B.4, the assembly was chosen for the basic, enhanced-A and enhanced-B tests. An assembly was selected for the basic test only, if it was not found in Table B.3, but found in Table B.4. No such wall or roof

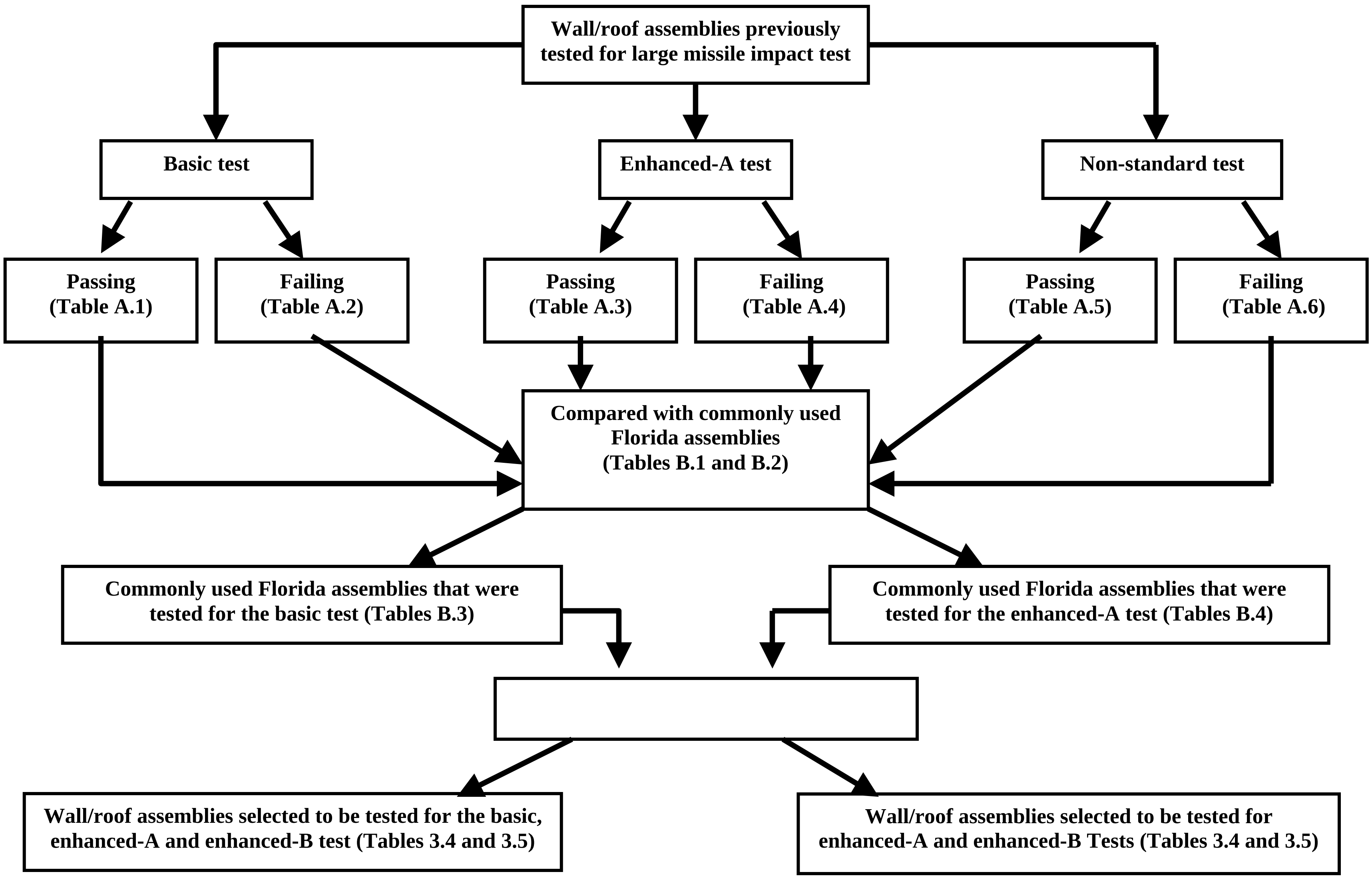

Figure 3.12: Approach Followed to Obtain the Wall/Roof Assemblies to be Tested

Table 3.4: Identified Wall Assemblies for Basic, Enhanced-A and Enhanced-B Testing

<table>
<tr><th rowspan="2">Item No</th><th rowspan="2">Name of the Assembly</th><th colspan="2">Description of the Assembly</th></tr>
<tr><th>Exterior Siding</th><th>Framing</th></tr>
<tr><td colspan="4">Wood stud framing system</td></tr>
<tr><td>1*</td><td>Stud wall with plywood</td><td>Stucco on 1/2 in. CD grade plywood</td><td rowspan="9">2x6 in. surface dry Southern Pine studs spaced @ 16 in. o.c.</td></tr>
<tr><td>2*</td><td>Stud wall with OSB</td><td>Stucco on 7/16 in. OSB</td></tr>
<tr><td>3*</td><td>Stud wall with gypsum board</td><td>Stucco on 5/8 in.gypsum board</td></tr>
<tr><td>4*</td><td>Stud wall with dinsglass</td><td>Stucco on 1/2 in. dinsglass</td></tr>
<tr><td>5*</td><td rowspan="2">Stud wall with Hardiboard</td><td>5/16 in. Hardiboard with horizontal siding on 1/2 in. plywood</td></tr>
<tr><td>6*</td><td>5/16 in. Hardiboard with horizontal siding on 7/16 in. OSB</td></tr>
<tr><td>7*</td><td>Stud wall with Advantech</td><td>3/4 in. Advantech</td></tr>
<tr><td>8*</td><td rowspan="2">Stud wall with brick veneer</td><td>Brick veneer on 7/16 in. OSB</td></tr>
<tr><td>9*</td><td>Brick veneer on 1/2 in. plywood</td></tr>
<tr><td colspan="4">Metal stud framing system</td></tr>
<tr><td>10*</td><td rowspan="2">Stud wall with Hardiboard</td><td>5/16 in. Hardiboard on 1/2 in. plywood</td><td rowspan="3">8 in. C studs spaced @ 16 in. o.c.</td></tr>
<tr><td>11*</td><td>5/16 in. Hardiboard on 7/16 in. OSB</td></tr>
<tr><td>12*</td><td>Stud wall with metal siding</td><td>5V Galvalume: 26 ga. on 1/2 in. plywood</td></tr>
<tr><td colspan="4">Concrete Panels</td></tr>
<tr><td>13**</td><td>Concrete Masonry Unit (CMU)</td><td colspan="2">6 in. CMU with hollow cells</td></tr>
<tr><td>14**</td><td>Concrete Masonry Unit (CMU) with horizontal reinforcement</td><td colspan="2">6 in. CMU with hollow cells and horizontal reinforcement</td></tr>
<tr><td>15*</td><td>Autoclaved Aerated Concrete (AAC) block</td><td colspan="2">Wall with 8x8x24 in. AAC blocks</td></tr>
<tr><td>16*</td><td>Insulated Concrete Forms (ICF)</td><td colspan="2">6 in. Concrete walls using ICF</td></tr>
<tr><td>17*</td><td>Tilt up</td><td colspan="2">5 in. wall with #5 bar @ 12 in. o.c. vertical reinforcement and #3 bar @ 12 in. o.c. temperature and shrinkage reinforcement</td></tr>
</table>

Note: *1/2 in. gypsum board was used as interior finish in all wood and metal stud framing systems assemblies*
** Basic, enhanced-A and enhanced-B tests were performed on these test assemblies*
*** Enhanced-A and enhanced-B tests were performed on these test assemblies*

Table 3.5: Identified Roof Assemblies for Basic, Enhanced-A and Enhanced-B Testing

<table>
<tr><th rowspan="2">Item No</th><th rowspan="2">Name of the Assembly</th><th colspan="2">Description of the Assembly</th></tr>
<tr><th>Deck/Roof</th><th>Support</th></tr>
<tr><td colspan="4">Metal Framing System</td></tr>
<tr><td>1*</td><td>Metal deck with 5V Galvalume</td><td>26 ga. 5V Galvalume on 1/2 in. plywood</td><td rowspan="4">Top chords were placed @ 48 in. o.c. and purlins were placed @ 24 in. o.c.</td></tr>
<tr><td>2*</td><td>Metal deck with standing seam</td><td>26 ga. Standing seam on 1/2 in. plywood</td></tr>
<tr><td>3*</td><td>Metal deck with 1-1/2 in. structural deck</td><td>1-1/2 in. structural deck (22 ga.) with 26 ga. 5V Galvalume roofing</td></tr>
<tr><td>4*</td><td>Metal deck with OSB roofing</td><td>Wood, clay or asphalt tiles on 7/16 in. OSB</td></tr>
<tr><td>5*</td><td>Metal deck with 3 in. metal deck</td><td>3 in. metal deck (22 ga)</td><td>Steel beams @ 12 ft. o.c.</td></tr>
<tr><td colspan="4">Concrete Panel</td></tr>
<tr><td>6**</td><td>Hollow core slab</td><td colspan="2">6 in. hollow core slab</td></tr>
<tr><td>7**</td><td>Hollow core slab</td><td colspan="2">8 in. hollow core slab</td></tr>
</table>

Note: ** Basic, enhanced-A and enhanced-B tests were performed on these test assemblies*
*** Enhanced-A and enhanced-B tests were performed on these test assemblies*

assemblies were found in this study. Enhanced-A and enhanced-B tests were required for assemblies, which were not found in Table B.4, but found in Table B.3. If a wall or roof assembly was found in both Table B.3 and B.4, the assembly was not selected for any tests. Selected wall and roof assemblies presented in Tables 3.4 and 3.5 are simplified by the following assumptions:

- No insulation was provided in test assemblies to make the test result conservative.
- Thickness of a particular exterior siding may vary. Test assemblies in this research were made utilizing the minimum thickness of the siding materials.
- As the test procedure clearly mentions that wall and roof assemblies should be impacted at their thinnest sections or sections, which are not reinforced, it was expected that the exterior siding materials and their thickness controls the test results rather than the support materials and their sizes.
- The largest support or stud sizes were used from the commonly used Florida supports, as these would reduce the energy absorbing capability of the test panel.

For each assembly in Tables 3.4 and 3.5, the basic large missile impact tests were performed first. The test assembly was not accepted for any of the basic, the enhanced-A or the enhanced-B test protection if it fails the basic test. If the assembly passed the basic test, the same test specimen was tested in accordance with the enhanced-A test. If a specimen passed the enhanced-A test, it was tested for the enhanced-B test. The assembly was accepted for both the basic and the enhanced-A test protections if it passed the enhanced-A test, but failed the enhanced-B test. If a specimen passed the enhanced-B test, it was accepted for the basic, the enhanced-A and the enhanced-B missile test protection. Figure 3.13 shows the flow chart of the approach followed for the acceptance of a test assembly from Tables 3.4 and 3.5.

3.7. Construction of Test Specimens

The large missile impact test was performed on full size specimens. The nomenclature used to describe each test specimen is described in Table 3.6. Each test specimen was described using an alphanumeric string. The name describes the type of test (basic, enhanced-A or enhanced-B), target location (corner or midspan), and attempt number. Following the test description, the components of the specimen are described, in order from interior facing to exterior facing, using a number to describe the size and a two-letter abbreviation for each type of material. For example, test EC1 - 1/2GY 6SD 1/2PL ST describes a specimen tested with the enhanced-A test, corner impact, 1st attempt composed of 1/2 in. gypsum board on the interior, 2x6 timber studs, 1/2 in. plywood cladding, and finished with stucco.

3.7.1. Wood Stud Framing System for Walls: The wood frame systems were constructed with 2x6 in. surface dry Southern Pine studs spaced 16 in. o.c. Each frame stood 10'-4 1/2 in. high and 9 ft. wide. To add strength, 2x6 in. cross braces were added between the studs. Two test specimens were included on each of the frames. The specimens were the full height of the frame and 4 ft. wide. For example, Figs. 3.14 and 3.15 show part of the overall construction for the test specimen having stucco over Dinsglass and gypsum. Cladding for these specimens was attached using 6d nails spaced at 6 in. o.c. for the panel edges and 12 in. o.c. on intermediate studs as per FBC (2001) 2308.2.2.1. Two holes were drilled through the specimens on each frame and

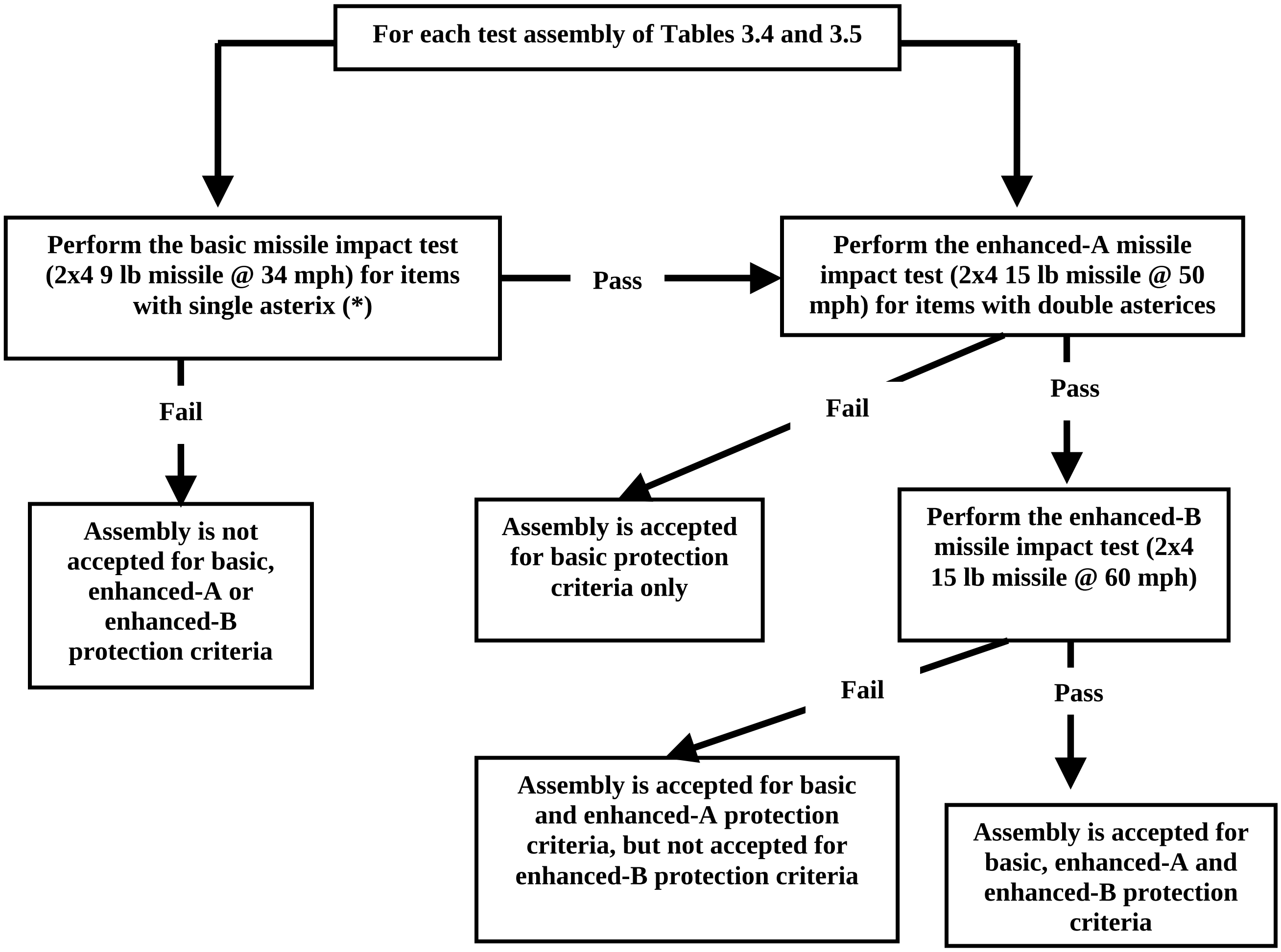

Figure 3.13: Approach Followed for the Testing of Wall/Roof Assemblies

Table 3.6: Large Missile Impact Test Nomenclature for Wall/Roof Assemblies

Test Type	Abbreviation	Impact Location	Abbreviation	Size	Abbreviation	Material	Abbreviation
Basic	B	Midpoint	M	7/16 in.	7/16	Gypsum	GY
Enhanced-A	E	Corner	C	1/2 in.	1/2	Wood Stud	SD
Enhanced-B	E (60)			5/8 in.	5/8	Channel	CH
				3 in.	3	Plywood	PL
				6 in.	6	OSB	OS
				8 in.	8	Dinsgold	DG
				2x4	4	Advantech	AD
				2x6	6	Galvalume	GA
						Stucco	ST
						Hardiboard	HB
						Brick Veneer	BV
						Hollow Core	HC
						Tilt Up	TU
						ICF	ICF
						Autoclaved Concrete	AAC
						Steel Deck	DK
						Pre-Engineered Trusses	PT
						Hat Channel	HC
						Standing Seam	SL
						Horizontally Reinforced	HR
						Asphalt Shingles	AS

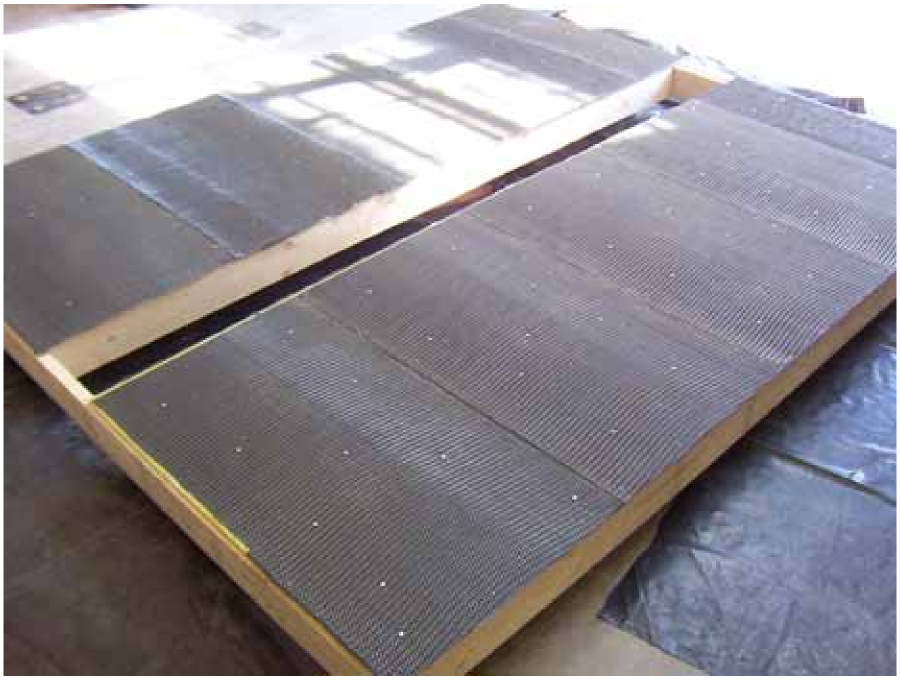

Figure 3.14: Stucco Lath Applied to Test Frame with Gypsum Specimen (Upper Left) and Dinsglass Specimen (Lower Right)

Figure 3.15: Finished Stucco over Gypsum Specimen (Upper Left) and Dinsglass Specimen (Lower Right)

steel plates added to the header joints to facilitate lifting them onto the foundation block with the overhead crane.

3.7.2. Metal Stud Framing System: For the steel framed specimens, 8 in. 16 ga. C-shaped channels were used as studs, as shown in Fig. 3.16. The studs were attached and bridging was added between the studs using self-tapping screws. The plywood and OSB coverings were attached using self-tapping drywall screws. The 5V Galvalume panel alignment and fastener pattern was determined using the manufacturer's installation manual. The panels were fastened using #14 x 7/8 in. screws, 24 in. o.c. to 1/2 in. plywood covered with 30 lb. felt.

3.7.3. Concrete Panels: The concrete and masonry specimens were constructed in place, with the exception of the tilt-up and hollow core specimens. The tilt-up panel, as shown in Fig. 3.17, was constructed in a precast yard and transported to the laboratory. PVC pipes were embedded in the panel to allow it to rest on the foundation block over the top of the j-bolts. Lifting devices were embedded into the top of the tilt-up walls to allow lifting and placement with the laboratory crane. The tilt-up specimen was supported using the shoring system described earlier in this chapter. At the time of construction, two 4x8 in. cylinders were cast. These cylinders were tested to determine the concrete's 28-day compressive strength, which was found to be 4150 psi. The hollow core slabs were placed on the foundation block with the j-bolts falling in the cells. Two holes were drilled in each of the slabs through which threaded rod was placed to secure lifting hooks. Again, the slabs were lifted and placed using the laboratory crane.

The CMU specimens were constructed in place. No. 6 reinforcing bars were epoxied into the foundation block and allowed to extend out approximately 36 in. These bars were

Figure 3.16: Steel Stud Wall Specimen

Figure 3.17: Construction of the Tilt-up Panel

located such that they would fall in the end cells of each CMU specimen as seen in Fig. 3.18. These end cells were grouted as a safety precaution. One of the two CMU specimens had horizontal truss type reinforcement in it.

The ICF wall specimen, shown in Fig. 3.19, was constructed in-house. Four #6 reinforcing bars were epoxied into the foundation blocks. The forms were placed over these bars with #3 bars as horizontal reinforcing. The bars and forms were secured together using wire ties to protect against separation during the concrete pour. The open ends of the forms were closed off by attaching 2x10 in. timber studs initially using nylon reinforced tape. Once the first lift of concrete had been poured, ratcheting straps were added to the forms to prevent the concrete from dislodging the studs. The concrete for the specimen was mixed in the laboratory mixer. Each batch provided a 1 ft. lift. Lifts were placed in pairs, and then allowed to cure for 1 hour before the next set of lifts were placed. This procedure was followed in order to prevent failure of the forms due to the hydrostatic pressure exerted by the concrete. Eight cylinders were cast at the same time and allowed to cure for 28 days at which time they were tested. They were allowed to cure in the same conditions as the test specimen. Three of the cylinders were tested and the 28-day compressive strength was found to be 7250 psi.

The 6 in. and 8 in. hollow core slabs were constructed at Gate Concrete Products in Jacksonville, Florida and shipped to the University of Florida for testing.

The AAC specimen was constructed by Painter Masonry on the concrete foundation block, as shown in Fig. 3.20. The AAC blocks measured 8x8x24 in. and were secured using thin-set mortar. No reinforcement was included in the specimen based on common building practices. The blocks were cored to fit over the J-bolts in the foundation block. The

Figure 3.18: Construction of CMU Specimen

Figure 3.19: Completed ICF Specimen

constructed specimen was supported using the same shoring system as the other concrete specimens.

3.7.4. Roof Truss Systems: The roof truss systems were constructed using a frame consisting of 3-5/8 in. cold-formed steel studs at 48 in. o.c., simulating the top truss chord, and 16 ga. 1-1/2 in. hat channel purlins at 24 in. o.c. The exterior cladding was secured to the purlin system, as seen in Fig. 3.21. Fifteen pound felt was used over the top of the plywood and OSB cladding. The 5V Galvalume panels were fastened in the same way as in the steel wall frame specimen.

The standing seam specimens were secured as per the manufacturer's instructions. The panels were secured on one side using #10-12 x 1 in. pancake head screws at 7 in. o.c. The other edge was secured to the previous panel by snapping them together.

The 1-1/2 in. deck was secured to the roof trusses using the same self-tapping screws that were used to construct the metal frames. These screws were placed at 12 in. o.c. along the length of the specimen.

The OSB and roofing material specimen was constructed using 3 tab asphalt shingles. The shingles were applied over the top of 15 lb tar paper. One inch galvanized roofing nails were used to secure the shingles.

Initially, the 3 in. steel deck specimen was welded in the vertical position using 3/4 in. puddle welds. The deck was secured to 2 steel channels, spaced 12 ft. o.c. Two W12x40 columns with base plates were bolted to the strong floor to which the channels were clamped using wrench clamps.

Figure 3.20: Completed AAC Specimen

Figure 3.21: Plywood Attached to Purlins