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Final Report

Department of Community Affairs

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Loss Relativities for FBC Wood Panel Shutters




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PREFACE

The Florida Department of Community Affairs (DCA) contracted with Applied Research Associates, Inc. to evaluate the effectiveness of wood panels when used as opening protection, as allowed by the Florida Building Code (FBC).

A previous Department of Community Affairs report, "Development of Loss Relativities for Wind Resistive Features for Residential Structures," includes loss relativities for opening protection, but specifically did not address the use of wood structural panels. Wood panels with a minimum thickness of 7/16 inch and a maximum span of 8 feet are permitted by FBC for opening protection in one-and two story buildings.

The purpose of this project is to develop loss relativities for 1 and 2 family residential structures that have openings protected by wood structural panels, as allowed by the Florida Building Code (FBC).

The format of the results follow that of the previous DCA loss relativity report.

The DCA, DFS-OIR, and ARA make no representations on the possible interpretations in the use of this document by any insurance company. The use of information in this document is left solely to the discretion of each insurance company.

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1.0 INTRODUCTION

1.1 Objective

Florida Statute 627.0629 reads, in part, as follows:

> *A rate filing for residential property insurance must include actuarially reasonable discounts, credits, or other rate differentials, or appropriate reductions in deductibles, for properties on which fixtures or construction techniques demonstrated to reduce the amount of loss in a windstorm have been installed or implemented. The fixtures or construction techniques shall include, but not be limited to, fixtures or construction techniques which enhance roof strength, roof covering performance, roof-to-wall strength, wall-to-floor-to-foundation strength, opening protection and window, door, and skylight strength. Credits, discounts, or other rate differentials for fixtures and construction techniques which meet the minimum requirements of the Florida Building Code must be included in the rate filing. …*

This report can be viewed as an addendum to the previous study [1], "Development of Loss Relativities for Wind Resistive Features of Residential Structures." This report included loss relativities for opening protection, but specifically did not address the use of wood structural panels.

The purpose of this study is to provide data and information on the estimated reduction in loss for wood structural panel, when installed as opening protection per the requirements of the Florida Building Code.

1.2 Scope

The scope of this study is limited solely to experimental and analytical research to estimate the adequacy of wood panels when used as "shutters" over openings (windows and doors). The modeled buildings are single-family residences

This project uses hurricanes as the windstorm to produce the loss relativities. Hurricanes dominate the severe wind climate in Florida and, hence, are the primary contributors to windstorm loss costs.

The scope of this project does not deal with adequacy of the Florida Building Code in terms of allowing wood structural panels for opening protection. The purpose is to develop defendable and reasonable loss relativities for insurance purposes for buildings that use wood structural panels that meet the specifications and/or performance requirements in the Florida Building Code.

The focus of this comparison will be for design windspeeds of 130 mph and less. In higher wind speed locations, the fastening schedule and pressure loads must be determined by a design professional. In general, we do not expect wood panels to be used in Florida in 130 mph wind regions.

1.3 Background

Wood panels with a minimum thickness of 7/16 inch and a maximum span of 8 feet are permitted for opening protection in one-and two story buildings. Table 1 presents Table 1606.1.4 from the FBC. The FBC allows the attachments in Table 1 for windspeeds ≤ 130 mph. For higher windspeeds, attachments shall be designed to resist component and cladding loads.

Table 1. Table 1606.1.4 from the Florida Building Code

TABLE 1606.1.4
WIND-BORNE DEBRIS PROTECTION FASTENING SCHEDULE
FOR WOOD STRUCTURAL PANELS

Fastener Type	Fastener Spacing (in.)[1,2]			
	Panel Span ≤2 ft	2 ft < Panel Span < 4 ft	4 ft < Panel Span < 6 ft	6 ft < Panel Span < 8 ft
2½ #6 Wood Screws[3]	16	16	12	9
2½ #8 Wood Screws[3]	16	16	16	12
Double-Headed Nails[4]	12	6	4	3

SI: 1 inch = 25.4 mm 1 ft = 305 mm

Notes:

1 This table is based on a maximum wind speed of 130 mph (58 m/s) and mean roof height of 33 feet (10 m) or less.

2 Fasteners shall be installed at opposing ends of the wood structural panel.

3 Where screws are attached to masonry or masonry/stucco, they shall be attached using vibration-resistant anchors having a minimum withdrawal capacity of 490 lb (2180kN).

4 Nails shall be 10d common or 12d box double-headed nails.

Wood panels have been tested in numerous configurations for various purposes. The most commonly used large missile is a 2x4 lumber weighing 9 pounds impacting at 50 feet per second. The specimen is then subjected to pressure cycle loads that simulate the pressure variations in hurricanes. The pressure cycle loadings test the ability of the specimen to maintain its structural integrity and the strength of the fasteners under repeated loads and load reversals. When tested against the 9 lb large missile, wood structural panels are generally perforated by the missile and hence do not pass Miami-Dade PA 201, 202, and 203. Some configurations of wood structural panels pass the SSTD 12 and ASTM E 1886 and ASTM E 1996 standards.

The Institute of Business and Home Safety funded several test series in 1998 on wood structural panels as shutters for residential buildings [2,3]. These tests were performed at the Hurricane Test Laboratory in Riviera Beach, Florida. The wood panels were tested to see if they would pass SSTD 12-97. The testing demonstrated that the wood panels system was effective overall but they did not consistently pass SSTD 12. The SSTD standard does not comply with the Miami-Dade requirements since a hole is permitted in the panel provided the hole does not allow as 3 inch sphere to pass through. The Miami-Dade protocols do not allow the protection system to be perforated.

Texas Tech University has done a number of impact tests for 2x4 lumber, 2x6 lumber, bricks, and steel conduit missiles [4]. Many of the early Texas Tech tests employed a pass/fail approach in terms of perforation of the barrier. In general these tests used a 15 pound 2x4 lumber, a much heavier missile than used in the Florida Building Code requirements. ARA has received a summary report on these test and is attempting to get more details. However, the tests done at Texas Tech are not applicable to this research because of the focus on heavier missiles, higher speeds, and lack of pressure cycle testing.

The American Plywood Associates, Inc. conducted a number of shutter impact tests, including some single panel tests. However, these data generally cover different materials and test configurations than the FBC minimum allowable.

ARA conducted a series of tests for the Hawaiian Hurricane Relief Fund to evaluate the effectiveness of the HHRF specifications [5]. Clemson University was a subcontractor to ARA for these tests. These tests were limited to impact testing only, no cyclic testing was performed. These tests included both normal and oblique impacts. These tests provide data on plywood perforation of the HHRF wood shutters. These data cannot be used for FBC wood panels because of differences in material thicknesses, bracing requirements, and attachments.

Clemson University performed missile impact tests as part of a study for FEMA on "Enhanced Protection from Severe Wind Storms" in 2000 [6]. The purpose of these tests were to determine wall configurations that would resist high velocity wind borne debris impacts for in-home shelters. The momentum required to cause penetration for a 2x4 lumber varies approximately linearly with the thickness of the sheathing material. Clemson also concluded that it takes approximately a 40% thicker sheet of OSB than plywood to achieve the same impact resistance. These tests provide a basis for designing the tests for the FBC wood panel study.

1.4 Technical Approach

The technical approach for this project involves two tasks:

1. Perform Impact and Pressure Cycling Experiments.
2. Develop Loss Relativities for Wood Panel Shutters.

The experimental portion of this work has been performed under the direction of Dr. Tim Reinhold at Clemson University. Section 2.0 summarizes the experimental tests and conclusions.

The loss relativities for wood structural panels as opening protection are developed in the same fashion as that documented in the DCA study [1]. That is, buildings are modeled with wood structural panels covering the openings with the resistances of the panels modeled from the data developed under the first task. To the extent that the panels are perforated, the perforation is treated in the analysis, allowing for pressure leakage in the building. In addition, the hole will also allow wind-driven rain to enter the building and this is also be evaluated in the computation of losses.

These effects are modeled using ARA's HURLOSS model. The modeling approach is consistent with that used in Reference 1. The development of the loss relativities for wood panels is given in Section 3.0.

2.0 IMPACT AND PRESSURE CYCLING TESTS

2.1 Objectives

The objectives of the wood panel tests included the following goals:

1. Test opening sizes ranging from small to large.
2. Test plywood and OSB panels.
3. Use several candidate missiles.
4. Perform sufficient tests to allow development of simple statistical models for perforation threshold of wood panels.
5. Evaluate wet vs dry panels by testing wood panels in a dry condition as well as a soaked condition, representative of outdoor exposure to rain.
6. Determine if pressure cycling failures occur for the fastener requirements in the FBC.
7. Perform some initial tests on cycling capacity for panels installed at the same location on a wood frame to determine if there is a reduction in capacity.

A sequence of test were designed to obtain the data as efficiency as possible given the limited budget. Wood framed wall construction was used throughout these test. No testing on masonry walls was attempted.

2.2 General

Windborne missile impact tests and cyclic pressure tests were performed on various sizes of wood panel shutters fabricated to meet the minimum requirements of the Florida Building Code. The tests were performed between April 22nd and May 26th, 2003 at the Wind Load Test Facility located at Clemson University, Clemson, South Carolina.

The windborne missile impact tests were performed with the use of the Wind Load Test Facility's air cannon and a Decatur Electronics, Inc. Genesis-I radar gun. The purpose of the impact testing was to determine the performance of the window protection designs for windborne debris. Cyclic pressure testing was conducted using the Building Research Establishment Real-time Wind Uniform Load Follower (BRERWULF). BRERWULF uses a high velocity fan ducting the air through a venturi where a valve either directs a positive or negative pressure into a test chamber. A feedback loop allows a computer to control the movement of the valve such that various time histories of positive or negative pressure fluctuations can be applied to the test chamber.

2.3 Approach

The largest missile specified in the South Florida Building Code, ASTM E 1996, and the SBCCI SS TD 12 standards is a 9-pound 2x4 piece of lumber. The missile is projected at the test object using an air canon and strikes the test object end on, perpendicular to the surface. For all buildings, other than essential facilities (hospitals and hurricane shelters), the missile impact speed specified for regions with the highest design wind speeds in the US is 50 feet per second (34 mph) in all three standards. ASTM E 1996 specifies a missile impact speed of 80 feet per second (55 mph) for essential facilities located in regions with the highest design wind speeds in the US. The test protocol requires that specimen resist impacts in the middle of the panel and in a corner of the panel.

In order for a product to pass the test, the South Florida Building Code's impact standard allows no penetration of the protective system while the SBCCI and ASTM standards allow penetration provided the hole is small enough to prevent a 3 inch sphere from passing through the hole. The SBCCI and ASTM standards include smaller (lighter) missiles in regions with lower design wind speeds. For gust speeds between 110 and 130 mph, the ASTM standard requires that shutters resist a 4.5-pound 2x4 at 40 feet per second (27 mph).

The test standards also include testing of the panel system for 9000 cycles of pressure fluctuations, of various magnitudes up to the design pressure, after the panel has been subjected to the missile impacts.

These experiments cover both impact test results aimed at determining the threshold for penetration by 2x4 missiles and S shaped clay tiles and the performance of the wood shutter and attachment system to subsequent cyclic pressure loading.

Shutters were constructed using nominal ½-inch (actual 15/32-inch) CDX plywood or 7/16-inch Oriented Strand Board (OSB) panels as allowed as an exception to the Florida Building Code for window protection in homes. The panels were installed following the guidelines specified in the Florida Building Code. Those guidelines specify a minimum nail size and spacing that depends on the span of the panel. The panels covering 2-ft by 4-ft openings were attached at the top and bottom of the opening (4-ft span) and were attached using 12d common nails installed at 4-inches on center. Panels covering a 5-ft by 7-ft opening were installed spanning either the 5-ft span (two panels spanning vertically) or the 7-ft span (two panels spanning horizontally). All panels were installed with 12d nails at 4-inch spacing for the 5-ft span and at 3-inch spacing for the 7-ft span. Code minimum fasteners were either 10d common nails (0.148-inch diameter by 3-inch length) or 12d box double-headed nails (0.128-inch diameter by 3.25-inch length).[1]

A number of Southern Yellow Pine (SYP) 2x4 boards were weighed and cut to produce missiles with weights of 9 lbs. (+/- 0.1 lbs.) and 4.5 lbs (+/- 0.1 lbs). Roofing tiles were individually weighed but the average weight was 6.6 lbs (+/- 0.1 lbs). The Genesis-I radar gun was calibrated with two tuning forks provided by Decatur Electronics, Inc. The panel or panels were mounted over a fabricated wood frame wall system, which included the desired window opening. Two sizes of openings were considered for this series of tests. One was a 2-foot by 4-foot opening which represented a typical small window. The second was a 5-foot by 7-foot opening that represented a typical large window. Two panels were required to cover the 5-foot by 7-foot opening.

The code does not require any bracing of the panels or any strengthening of the joint between the panels. Consequently, the edges of the panels were just butted up against each other. The panels were cut so that they extended 3-inches beyond the edges of the opening in all directions. Since siding and other finishes may place the panels about 1-inch away from the structural framing around the windows, spacers were used to hold the panels about 1-inch away from the framing members. These spacers were continuous around the perimeter of the windows and did not add to the anchorage of the shutter to the framing.

[1] Even with a special order, it was not possible to obtain 12d double-headed nails. Commonly available double-headed nails are either 16d or 8d. In addition, most 10d nails available in stores are either 10d box or 10 sinkers both of which have smaller shank diameters than the 10d common nails. However, 12d common nails have the same diameter as 10d common nails and the only difference is that 12d common nails are 3.25-inches long versus the 3-inch length of the 10d nails. For impact tests, the use of 12d common nails is an acceptable substitute for the code minimum 10d common nails.

2.4 Debris Impact Testing of Panels

Results of the tests and observations about localized damage or penetration of the missiles are summarized below. A detailed listing of missile characteristics, missile impact speeds and the observations for each impact on each specimen are given in Appendix A.

In general, the missile impacts caused localized punching shear failures and it was possible to impact a single panel with multiple missiles. In a few cases, particularly with the tile missile, the impact caused major cracking of the panel, which limited the panel's usefulness for further testing. With only a couple of exceptions, all 2x4 missile perforations on the OSB and plywood panels produced holes that would not allow passage of a 3-inch sphere. The same was true for tile impacts on the plywood panels. However, tile impacts on the OSB panels frequently created holes in excess of 3-inches in diameter.

Tables 2-1 and 2-2 provide a summary of the impact test results. The overall observations of the impact testing are:

1. Code minimum shutters built with nominal ½-inch plywood panels are adequate to provide protection from a 4.5-pound 2x4 missile traveling at less than 27 to 33 mph. The lower limits were typical of impacts on smaller stiffer panels or near the edges of the larger panels. The higher penetration thresholds typically occurred for impacts near the middle of the larger panels or for impacts on panels that generally seemed to have fewer flaws.
2. Code minimum shutters built with 7/16-inch OSB panels are adequate to provide protection from a 4.5-pound 2x4 missile traveling at 20 to 25 mph. The lower speeds typically occurred on the smaller stiffer panels or near the edges of the larger panels. The higher penetration thresholds typically occurred for impacts near the middle of the larger panels.
3. Impact thresholds for missile penetration through the middle area of plywood panels that had been soaked in water for 24 hours were typically 100 percent higher than for the dry plywood. Impact thresholds for missile penetration associated with edge shots were also about double those for the dry plywood specimen. With repeated wetting and drying, the panels seemed to loose the extra resiliency seen in the initial wet tests. Impact tests on two plywood panels that had been subjected to repeated wetting and drying cycles over a two week period exhibited a smaller (about 10% to 20%) increase in the threshold for missile penetration. These panels were removed from the water bath about three hours before testing so that their surfaces were dry but the cores of the panels were still wet.
4. Impact thresholds for missile penetration through the middle area of the OSB panels that had been soaked in water for 24 hours were typically 20 percent higher than for the dry specimen. There was a similar increase in penetration threshold for impacts near the panel edges for wet versus dry specimen. As with the plywood panels, repeated wetting and drying cycles tended to reduce this extra resiliency. Impact tests on two OSB panels that had been subjected to repeated wetting and drying cycles over a two week period exhibited a small (about 10%) increase in the threshold for missile penetration. These panels were removed from the water bath about three hours before testing so that their surfaces were dry but the cores of the panels were still wet.

Table 2-1. Threshold Velocities for 4.5-pound 2x4 Missile Penetration and Observations of Damage Characteristics

Panel Size (Condition)	Impacts in Middle of Panel		Impacts Near Edge of Panel	
	Penetration Speed - mph	Pass / Fail 3" diam. Sphere	Penetration Speed - mph	Pass / Fail 3" diam. Sphere
2′x4′ OSB (Dry)	25 mph	Pass	20 mph	Pass
2′x4′ Plywood (Dry)	33 mph	Pass	27 mph	Pass
2′x 4′ OSB (Wet) Repeated wet/dry	29 mph 28 mph	Pass Pass	26 mph 25 mph	Pass Pass
2′x4′ Plywood (Wet) Repeated wet/dry	60+ mph* 35 mph	Pass Pass	50 mph* 35 mph	Pass Pass
5′x7′ OSB (Dry)	26 mph	Pass	21 mph	Pass
5′x7′ Plywood (Dry)	36 mph	Pass	32 mph	Pass

* Based on doubling the 9-pound missile speed required to penetrate panel.

Table 2-2. Threshold Velocities for 6.6-pound Tile Missile Penetration and Observations of Damage Characteristics

Panel Size (Condition)	Impacts in Middle of Panel		Impacts Near Edge of Panel	
	Penetration Speed - mph	Pass / Fail 3" diam. Sphere	Penetration Speed - mph	Pass / Fail 3" diam. Sphere
2′x4′ OSB (Dry)	28 mph	Fail	27 mph	Fail
2′x4′ Plywood (Dry)	33 mph	Pass	33 mph	Pass
5′x7′ OSB (Dry)	33 mph	Fail	30 mph	Fail
5′x7′ Plywood (Dry)	41 mph	Pass	37 mph	Pass

5. The threshold for 6.6-pound clay tile missile penetration when it hit edge on was about 33 to 41 mph for the small and large plywood panels, respectively.
6. The threshold for 6.6-pound clay tile missile penetration when it hit edge on was about 27 to 33 mph for the small and large OSB panels, respectively.
7. When small sections of tile impacted at the same speed, the damage was generally considerably less. If the clay tile began to tumble and hit at an angle, very little damage was observed.

Figures 2-1 through 2-4 illustrate typical 2x4 and clay tile missile impacts on the plywood and OSB specimen.

In general, plywood failed in a less catastrophic manner than the OSB panels and it required a higher momentum for penetration of the plywood than the OSB. This is consistent with observations of 9-pound 2x4 missile impacts on multiple layers of plywood and OSB where it was observed that OSB needed to be 40 percent thicker to withstand the same impact momentum as the plywood panels.

2.5 Cyclic Pressure Testing of Panels

A series of panels were subjected to cyclic pressure testing using the 9,000 pressure cycle format specified in ASTM E1996, SBCCI SSTD 12, and the Florida Building Code. The magnitudes and number of pressure cycles involved in these tests are listed in Table 2-3. Typical wall design pressures as a function of design wind speed and exposure as prescribed

Figure 2-1. Typical 4.5 lb. 2x4 Missile Impact on Plywood Panel

Figure 2-2. Typical 4.5 lb. 2x4 Missile Impact on OSB Panel.

Figure 2-3. Typical 6.6 lb. Clay Tile Impact on Plywood Panel

Figure 2-4. Typical 6.6 lb. Clay Tile Impact on OSB Panel

in the Florida Building Code are listed in Table 2-4.

For these tests, the shutter panels were installed on spruce-pine-fir (SPF) wood frames that were sheathed with nominal ½-inch 3-ply plywood. The shutter panels were installed using 12d common nails (0.148-inch shank diameter by 3.25 inch long). The nominal ½-inch sheathing was attached with 1-inch spacers between the sheathing and wood structural members to simulate the effect of wall finishes. Thus, the nails had an embedment length of 1.75-inches (1/2-inch through the sheathing and 1.25-inches into the SPF wood structural members.

Initial tests were conducted using panels spanning 3-ft. by 5-ft. openings with the nails attached along the long sides of the panels (3'-3" span between rows of nails). This simulates a typical mid-sized window opening. In order to establish preliminary targets for the design pressures to be used in the test cycles, three panels were subjected to monotonically increasing pressures until the panel separated from the framing. The average failure pressure from three panels with nails installed 6-inches on center along the 5-foot edges of the panels was 128 psf. (minimum value of 98 psf and maximum value of 171 psf). Based on this relatively high static failure pressure (about 1.7

Table 2-3. Cyclic Wind Pressure Loading Sequence from Florida Building Code Table 1626

Inward Acting Pressure		Outward Acting Pressure	
Range	Number of cycles	Range	Number of Cycles
0.2 P_{MAX} to 0.5 P_{MAX}	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

Table 2-4. Wall Design Pressures, P_{MAX} for Mean Roof Height of 30-feet and Enclosed Building

Wall Zone	Effective Wind Area (ft^2)	Exposure B						Exposure C					
		Basic Wind Speed (3-sec gust)						Basic Wind Speed (3-sec gust)					
		110		130		150		110		130		150	
4	10	22	-24	30	-33	41	-44	31	-33	43	-46	57	-61
4	20	21	-23	29	-32	39	-42	29	-32	41	-44	54	-59
4	50	20	-21	27	-30	36	-40	27	-30	38	-42	51	-56
4	100	19	-20	26	-28	34	-38	26	-29	36	-40	48	-53
5	10	22	-29	30	-41	41	-54	31	-41	43	-57	57	-76
5	20	21	-27	29	-38	39	-51	29	-38	41	-53	54	-71
5	50	20	-25	27	-34	36	-46	27	-34	38	-48	51	-64
5	100	19	-23	26	-32	34	-42	26	-32	36	-44	48	-59

times the zone 5 negative pressure for the 150 mph basic wind speed), it was decided that the initial cyclic testing of the first panel would be based on ASCE 7 wall design pressures for a partially-enclosed building with a 30-foot mean roof height located in Exposure C (+75 psf and –94 psf).

Four un-impacted panels were subjected to the full 9,000-cycle test using a positive maximum pressure of 75 psf and a maximum negative pressure of -94 psf. Three panels (two plywood and one OSB) passed the cyclic pressure tests and subsequently were taken to failure under static loadings of 145, 150 and 154 psf, respectively. The fourth panel (the second one tested) failed during the second set of negative pressure cycles after being subjected to 50 cycles of pressures ranging from 0.3 P_{MAX} to 1.0 P_{MAX}. It was also determined that two of the nails had been driven into essentially the same holes used for attaching the first specimen. Data sheets for these specimens are included in Appendix B.

These test results show that undamaged plywood or OSB panels attached using the nailing schedule given in the Florida Building Code are capable of withstanding cyclic pressure loading that exceeds the typical pressures specified for enclosed houses located in exposure C terrain. The test results also indicate that the nailing of plywood or OSB panels is subject to some moderate level of degradation due to cyclic loading. In most cases, the nails began to back out as the panel was subjected to the negative pressure cycles. It is also apparent that re-nailing the panels in the same nail holes reduces the capacity of the connection. These last two issues are addressed in Section 2.6.

Additional tests were conducted in order to investigate the potential for damage propagation or connection degradation for panels that have been penetrated by a missile. A total of four panels covering 3-ft. by 5-ft. openings were subjected to anywhere from one to four missile shots where the missiles penetrated through the panels. Two of the panels were OSB and two were plywood. These panels were subjected to the maximum pressures for wall zone 5 on an enclosed building in exposure C for the 150 mph design pressures specified in the Florida Building Code for tributary areas of 10 square feet or less (+57 and –76 psf, see highlighted numbers in Table 4). In each of the four cases, the holes created by the missile impacts did not propagate or enlarge during application the cyclic pressure loading cycles. All four panels passed the cyclic pressure component of the testing. Data sheets for these panel tests are also included in Appendix B.

Shutter panels covering 5-ft. by 7-ft. and 6-ft.-8-inch by 7-ft openings were also subjected to cyclic pressure testing. Initially each panel was subjected to loads corresponding to wall pressures on an enclosed building located in the 130 mph wind zone. If the panels passed the 130 mph design pressures, the design pressure was increased to that of the 150 mph zone and the tests were repeated. All of the panels passed the cyclic pressure tests with pressures based on both the 130 and 150 mph design wind speeds. Data sheets for these panels are included in Appendix B.

2.6 Reduction in Fastener Capacities due to Cyclic Loading and Repeated Nailing

Due to the relatively large variability in any measurements conducted on natural wood products, it is difficult to clearly identify and extract precise information on effects such as reduced capacity due to cyclic loading and repeated nailing. The best approach is to conduct a fairly large number of tests and then try and extract overall trends from the data. This approach has been taken in the effort to extract information on reductions in capacities that are associated with these two factors.

In order to assess the potential reductions in capacity that might be associated with cyclic loading, four different frames with 3-ft. by 5-ft. openings were constructed using SPF lumber as the wall studs and sheathed with ½-inch nominal 3-ply plywood. Multiple plywood and OSB shutter panels were prepared for each of the frames and installed using 12d common nails (0.148-inch diameter by 3.25-inch length). As in the panels subjected to the battery of pressure cycles described in the previous section, the shutters were installed with the same 1-inch spacers between the surface of the wall sheathing and the shutter panel. Consequently, of the nominal 1.75-inch embedment length of the nails, ½-inch was through the plywood sheathing and 1.25-inches was in the SPF framing lumber.

An initial test was conducted by subjecting a shutter panel to a monotonically increasing quasi-static pressure until failure occurred. The 1st panel was removed and a second panel was installed using the same nailing schedule but with the nails carefully shifted so that each new nail hit a different location on the frame than the original nails. Constant amplitude cyclic pressures ranging from 0.3P to P were applied where P was a pressure lower than the original single cycle failure pressure. This process was repeated for each frame by constantly shifting the nailing locations and reducing the pressure P until it was possible to apply several thousand cycles of the chosen pressure without failing the attachment of the panel. Information obtained from these tests is included in Appendix C. The results have been normalized by the initial single cycle static failure pressure and plotted against the number of cycles to failure in Figure 2-5.

Note that there is considerable scatter in the results and, in one case; a panel was actually successfully tested to 4 cycles at a higher pressure than the original static failure pressure. Nevertheless, the trend is certainly

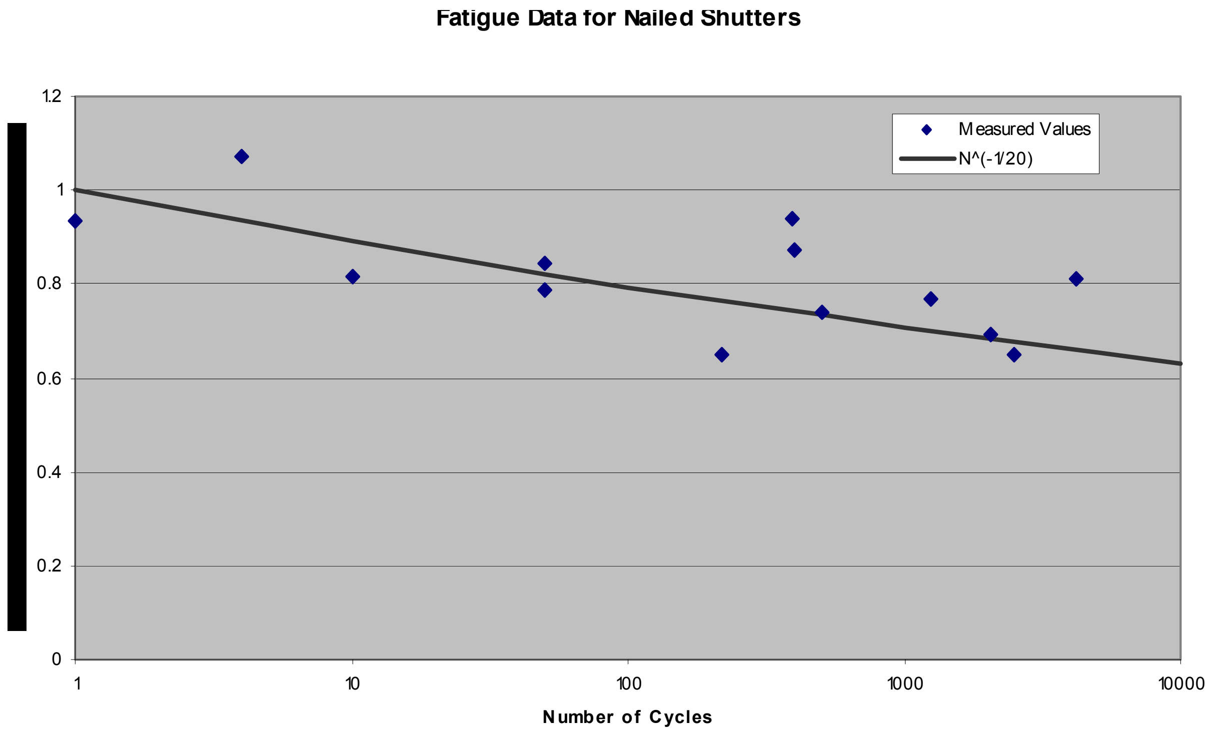


Figure 2-5. Reduction in Capacity as a Function of the Number of Loading Cycles and Load Level

towards a reduction in capacity as the number of cycles increases. An equation has been superimposed on the graph using the type of formula employed to describe the reduction in allowable stress as a function of the number of cycles for metals. It appears that as long as the load level is maintained at a level below about 60 percent of the expected ultimate capacity, that the panel attachment can sustain a large number of constant amplitude cycles. More work needs to be done to refine the curve and to determine whether a procedure such as Minor's rule for accumulation of damage can be used to combine effects from varying amplitudes of loading.

The potential for degradation of the attachment of the shutter panels from repeated attachment of the panels during multiple hurricane seasons was investigated through repeatedly installing nails in the same holes and measuring the withdrawal capacities following each installation. The procedure followed was to drive a nail into a piece of SPF framing lumber and using a portable nail extractor to measure the force required to remove the nail. A new nail was then re-installed in the same hole with the nail driven to the same depth and the force required to withdraw the new nail was measured. This was repeated ten times in the same hole before the process was started again. Results of these tests are reported in Appendix C and plotted in Figure 2-6.

Again, there is considerable scatter in the results from the repeated tests with some subsequent applications yielding higher withdrawal capacities than the initial installation. This may be due to slight differences in the nail diameters of an additional reflection of the large variability in measurements involving natural wood products. A trend line based on the average capacities obtained from the six sets of tests suggests that there is a general reduction in withdrawal capacity with repeated installation in the same hole and that the reduction may reach 50 percent after 10 repeated installations in the same hole.

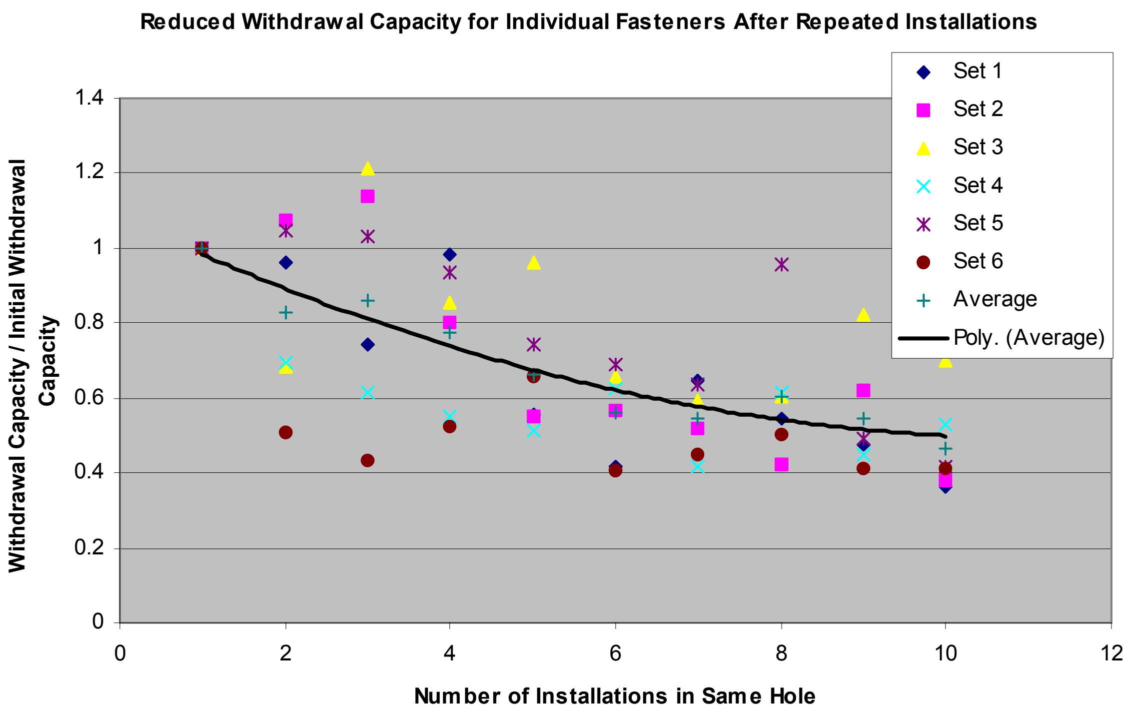


Figure 2-6. Variation in Wood Frame Withdrawal Capacity for Repeated Installation of Fasteners

3.0 WOOD PANEL LOSS RELATIVITIES

3.1 General

The approach used to model wood panel shutter loss relativities follows directly from the previous study [1]. This section summarizes the approach and results of the work to add wood panel loss relativities to the previously development format.

3.2 HURLOSS Modeling Approach

ARA's HURLOSS model is summarized in the public domain submittal to the Florida Commission on Hurricane Loss Projection Methodology (FCHLPM). The model has been approved by the Commission for the 1999, 2000, 2001, and 2002 standards. The model is used in this study to produce loss costs relativities.

The following paragraphs discuss some of the HURLOSS model features relevant to this study. The approach follows directly from Reference 1.

We simulated 300,000 years of hurricanes in the Atlantic Basin and retain all storms that strike Florida.

We used the six single-family residential buildings used in previous studies. Table 3-1 summarizes some of the pertinent information on these houses. The six houses include small, medium, and large floor plans and a range of building values

The HURLOSS model is used to compute ground-up losses and insured losses in this study. The HURLOSS modeling approach is illustrated in Figure 3-1, which is taken from ARA's submittal to the FCHLPM. The individual building model approach shown in Figure 3-1a has been used in this study.

The HURLOSS modeling approach is based on a load and resistance approach which has been validated and verified using both experimental and field data. The model includes the effects of both wind-induced pressures and wind-borne debris on the performance of a structure in a hurricane. The wind loading models replicate the variation of wind loads as a function of direction, and when coupled with a simulated hurricane wind speed trace, a time history of wind loads acting on the building is produced. The wind loading model has been validated through comparisons with wind tunnel data. The time history of wind loads is used in the damage model to account for the progressive damage that often takes place during a hurricane event. The model also allows the effects of nearby buildings and their impact on the loads acting on the exterior of the structure.

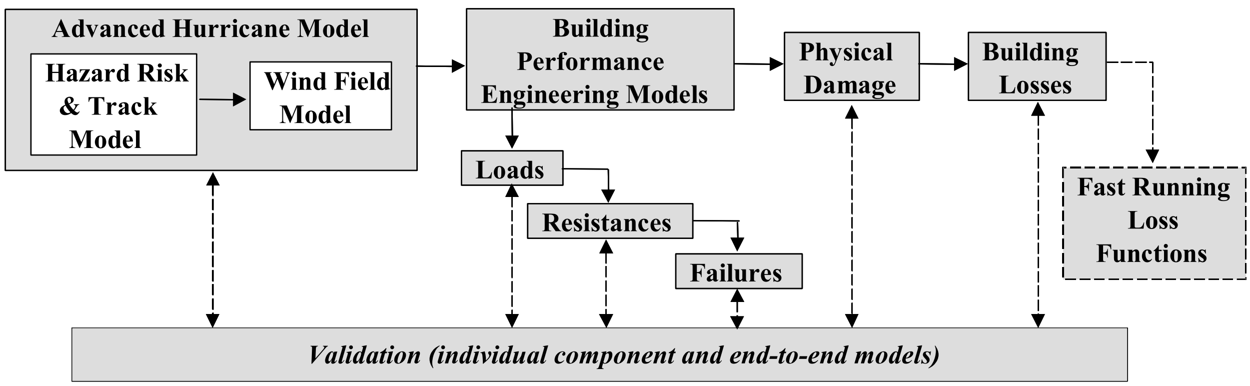
The houses are modeled with the geometrical layouts as given in Figures 3-2, 3-3, and 3-4. Hence, the specific window, door, etc. locations shown in these figures are used in the computation of loads and failures for each individual component.

Each of the 6 buildings are located at multiple points in Florida. In the HURLOSS analysis, the building orientation (with respect to compass direction, N, NE, …) is modeled as uniformly random. That is, for each simulated storm, an orientation is sampled from 0 to 360 degrees and the house is fixed in that orientation for that simulated storm.

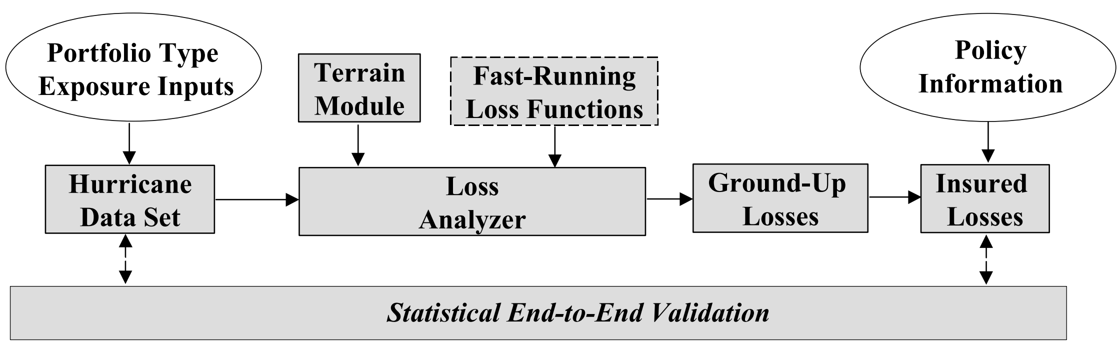
At each time step during a simulated storm, the computed wind loads acting on the building and its components are compared to the modeled resistances of the various components. If the computed wind load exceeds the resistance of the component, the

Table 3-1. Summary Data for Modeled Buildings

Reference	ARA Model Number	Roof Shape	Garage	% Fenestrations	% Glazing	Plan Sq Ft	Livable Sq Ft	Bldg Value ($)	Value/ Livable Sq Ft ($)
A	0011G	Gable	No	18	15	1200	1200	61,000	50.83
B	0011H	Hip	No	18	15	1200	1200	63,000	52.50
C	0013G	Gable	Yes	26	15	1800	1400	100,000	71.42
D	0013H	Hip	Yes	26	15	1800	1400	105,000	75.00
E	0002G	Gable	Yes	23	17	2534	2050	249,000	121.46
F	0002H	Hip	Yes	23	17	2534	2050	254,000	123.90



(a) Individual Buildings and Building Class Performance Model

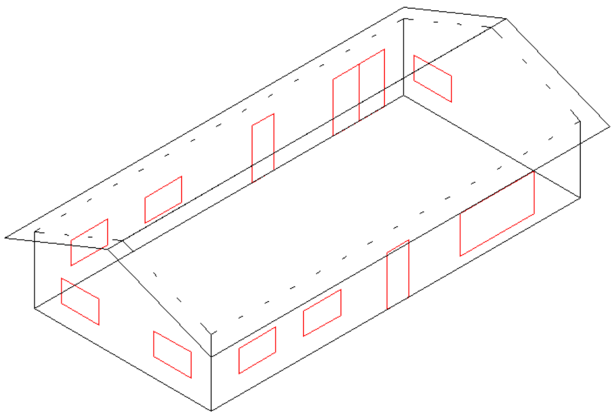


(b) Multiple Site – Multiple Building Loss Projections

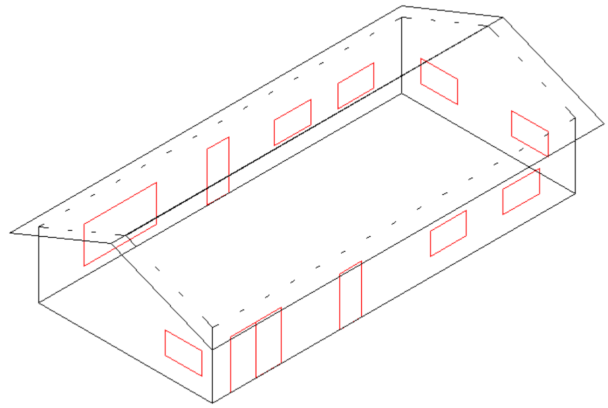
Figure 3-1. HURLOSS Modeling Approach for Hurricane Loss Projections

component fails. When a component such as a window or a door fails, the wind-induced pressure acting on the exterior of the component is transmitted to the interior of the building. This internal pressure is then added (or subtracted) from the wind loads acting on the exterior of the building to determine if any additional components have been overloaded because of the additional loads produced by the internal pressurization of the building.

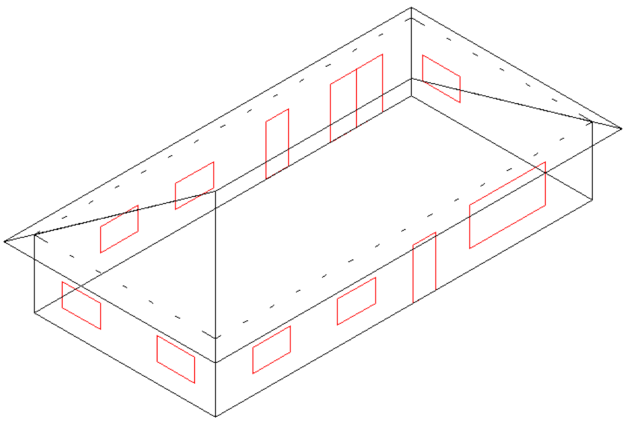
The progressive failure damage modeling approach is summarized in Figure 3-4. Estimates of wind loads as a function of wind direction are produced for building components, including roof cover, roof



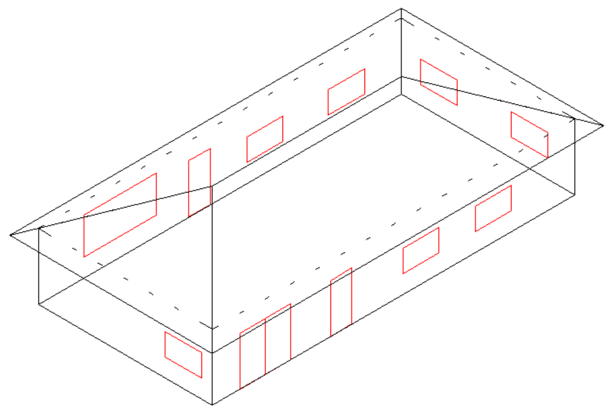
a. Front Isometric View – 0011G



b. Back Isometric View – 0011G



c. Front Isometric View – 0011H



d. Back Isometric View – 0011H

Figure 3-2. Model House 0011 – Gable and Hip

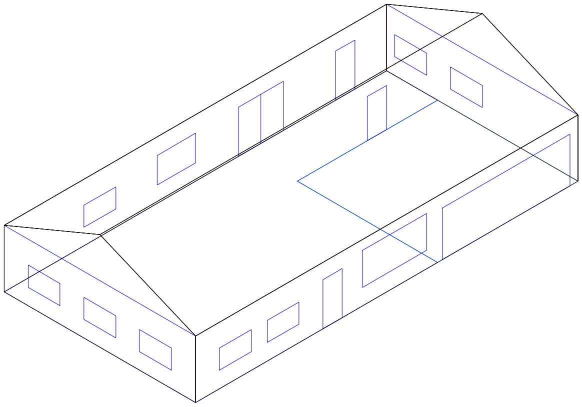
sheathing, windows and doors, as well as for larger components including the entire roof, walls and overturning or sliding of the entire building in cases where a positive attachment to the ground does not exist.

The statistical properties of the resistances of the building components are obtained from laboratory tests and/or engineering calculations. In the simulation process, the resistances of the individual building components that will be loaded are sampled prior to the simulation of a hurricane, and are held constant throughout the simulation. The model computes a complete history of the failure of the building, which can be used to make a "movie" of the building performance.

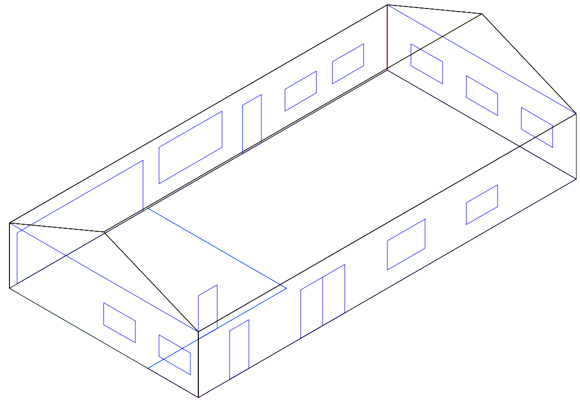
Once the building damage has been computed for a given storm and the losses for all coverages computed, the process is repeated for a new set of sampled building component resistances. Once a large number of simulations have been performed, we have derived the data necessary to develop a statistical model for the expected performance of the building given the occurrence of a storm.

3.3 Discussion of Modeled Failure Modes

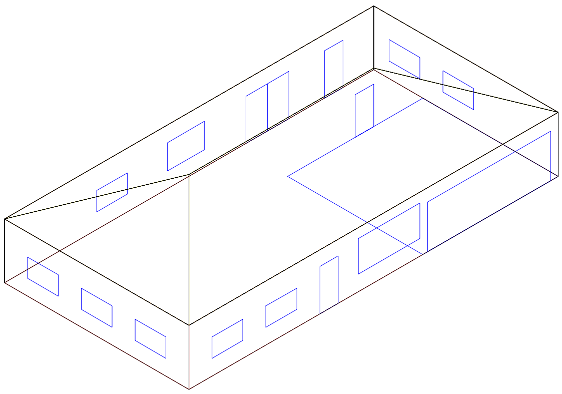
Evaluation of the impact and pressure cycling tests lead us to the following conclusions regarding implementation of a FBC code-minimum wood panel shutter model in HURLOSS:



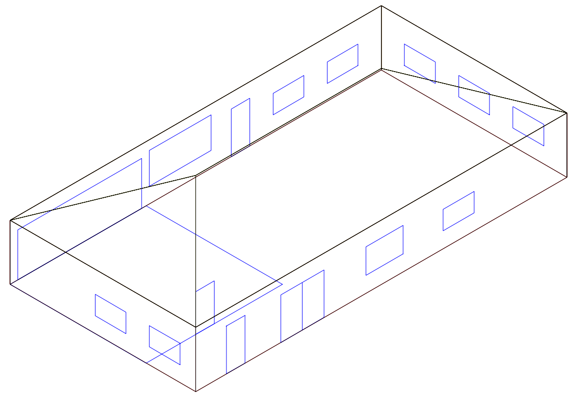
a. Front Isometric View – 0013G



b. Back Isometric View – 0013G



c. Front Isometric View – 0013H



d Back Isometric View – 0013H

Figure 3-3. Model House 0013 – Gable and Hip

1. Separate and distinct failure models are needed for plywood and OSB.
2. When attached to a wood frame building with the FBC attachment schedule, the panels pass the pressure cycling test requirements. Based on previous research performed by ARA [7], the use of a more realistic (less conservative) current pressure cycling test standing is very conservative. Hence, we do not include pressure cycling failure for wood panels as a separate failure mode in the model.
3. We will ignore the strength increase associated with wet, soaked panels. While this strength increase can be substantial, we trade off this increase with the potential for fastener pullout strength reductions associated with repeated applications of the nails into the same area of wood (see Section 2.6).

Basically the test confirmed that the code-minimum panels provide notable impact protection and that catastrophic failure is unlikely for the standard missile..

Based on these conclusions, we develop perforation models for plywood and OSB for incorporation into HURLOSS. With wood panel perforation models, the buildings in Reference 1 can be reanalyzed for loss costs

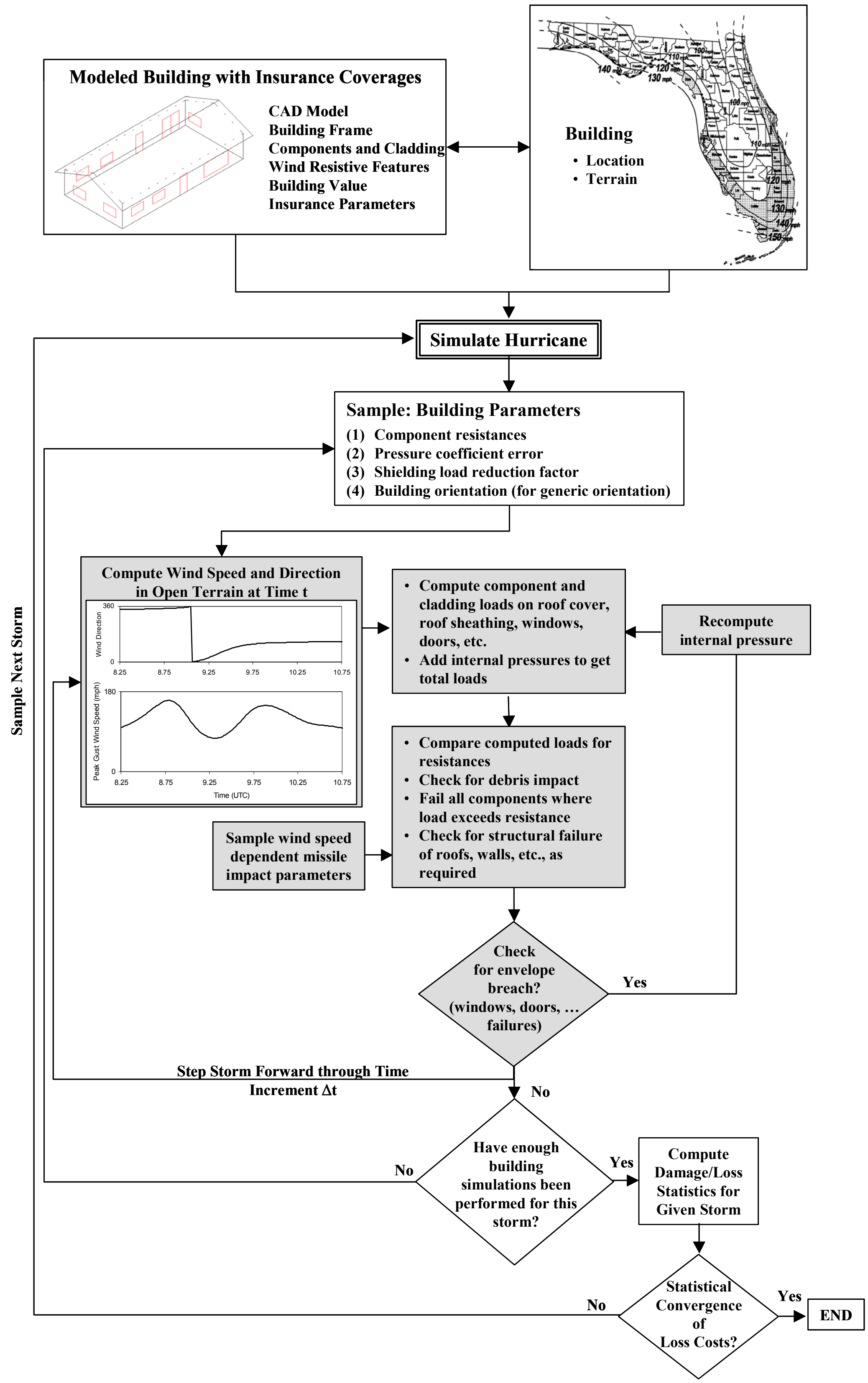


Figure 3-4. HURLOSS Building Damage Simulation Methodology

and loss relativities. Breach of the wood panel is assumed to occur if any hole is produced in the panel. Breach of the panel is assumed to break the glass behind the panel. The model calculates the internal pressure resulting from breached panels. The amount of water that enters the breach at opening is computed for the duration of the storm, considering wind direction, airflow into the building, and the HURLOSS rain model.

3.4 Implementation of Wood Panel Breach Models

The results of the Clemson University tests have been analyzed to develop perforation (breach) models for implementation into HURLOSS. Separate models for OBS and plywood have been developed because OSB is noticeably weaker than plywood panels in terms of impact resistance.

A method that is commonly used to analyze binary data such as impact perforation/no perperation data is logistic regression [8,9,10,11]. Twisdale et al. used these methods to develop reliability based design methods for hardened structures [12].

The method fits a probability distribution to the data set using the method of maximum likelihood. Often the logistic form is used as the probability distribution

$$P_b(\underline{x}) = \frac{exp[G(\underline{x})]}{1+exp[G(\underline{x})]} = \frac{1}{1+exp[-G(\underline{x})]}$$

where P_b is the probability of breach of the wood panel; x is the set of input parameters; and the function $G(\underline{x})$ is a linear combination of function of the parameters. For purposes of this study, we used the impacting momentum and impacting energy as the candidate $G(\underline{x})$) function. HURLOSS uses these parameters in the wind borne debris modeling for building damage.

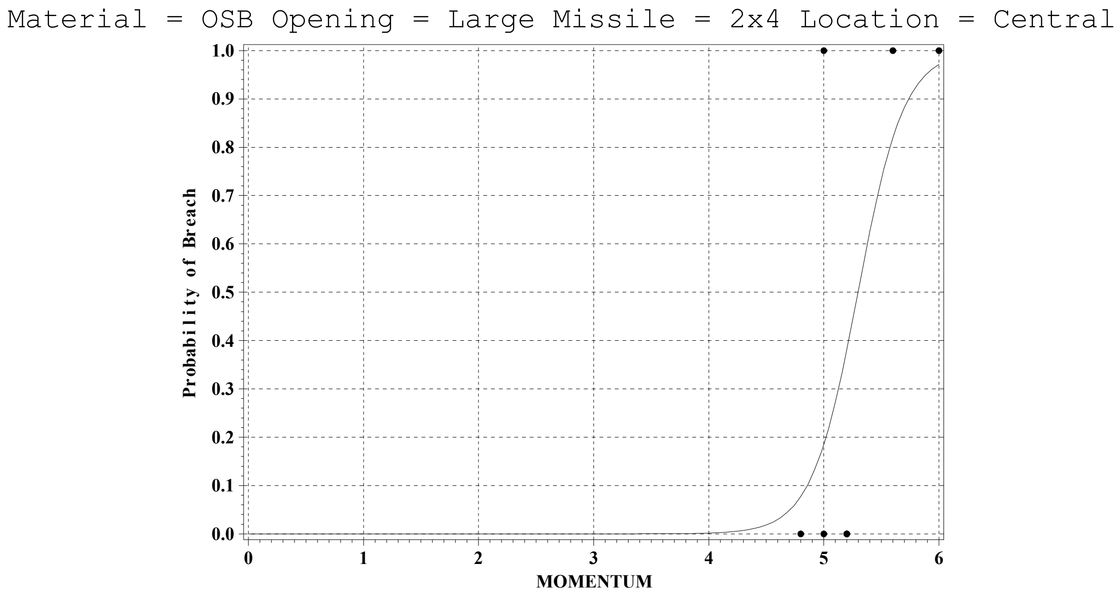
We extracted the data from Appendix A and analyzed it in various ways to develop wood panel perforation models. Some examples of the resulting logistic fits of the data for the 2x4 wood plank missile on large openings are given in Figure 3-5 through 3-8 The dots on the figures are the individual test results. Those tests with no breach of the panel (i.e., the missile bounced off the panel and did not stick in the panel or punch all the way through the panel) are plotted at the 0 probability position. Those tests that perforated the panel are plotted at the 1 probability position.

As noted in Section 2, the breach threshold for edge impacts occurs at lower velocities than the breach threshold for central impacts. Central impacts cause the panel to flex in bending, whereas edge impacts are a simple punch through shear failure. The differences in plywood and OSB can be seen in these figures, as larger momenta (impact speeds) are required for plywood failures.

3.5 Loss Relativity Tables with FBC Wood Panel Shutters

Following the analysis procedure in Ref. 1, we computed the loss relativities for the FBC wood panel shutters. The analyses covered Terrain B and Terrain C for both new and existing construction.

One of the simplifications we examined was to see if additional levels of shutters could be implemented as a separate constant factor adjustment to the Basic or Hurricane level that is already built into the tables. To determine if this simplification is possible, we produced the plots in Figures 3-9 and 3-10. These plots show normalized-within-cell-group relativities of the effect of opening protection, ranging from Hurricane (plotted at 0) and None (plotted at 1). We see that Basic Protection (175 ft-lb of energy impact resistance), Plywood, and OSB

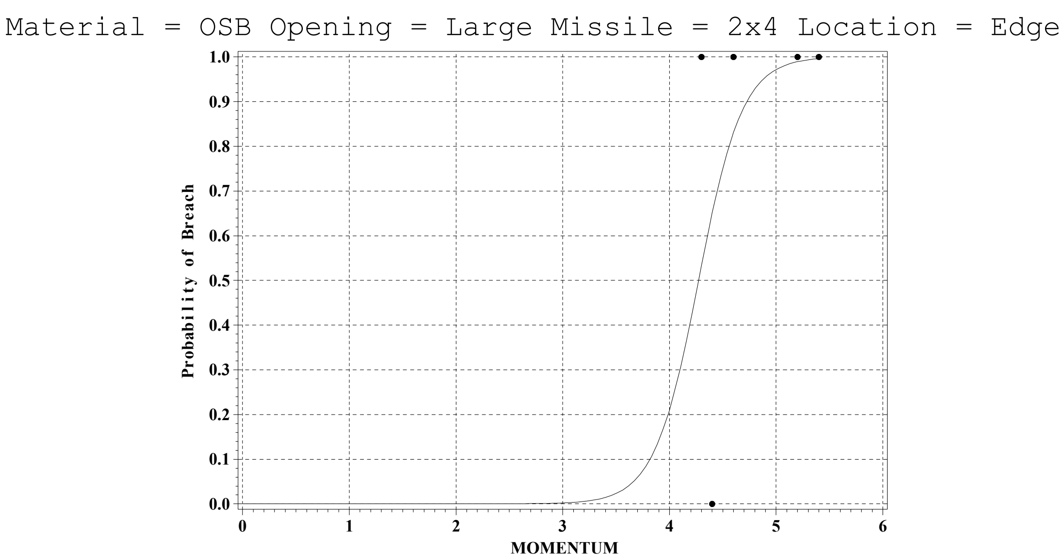


----------- MATERIAL=OSB OPENING=Large MISSILE=2x4 LOCATION=Central

Analysis of Maximum Likelihood Estimates

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate
INTERCPT	1	-26.4708	20.3911	1.6852	0.1942	.
MOMENTUM	1	4.9974	3.9220	1.6236	0.2026	1.134410

Figure 3-5. Momentum Logistic Model for OSB, 2x4 Missile, Central Impacts



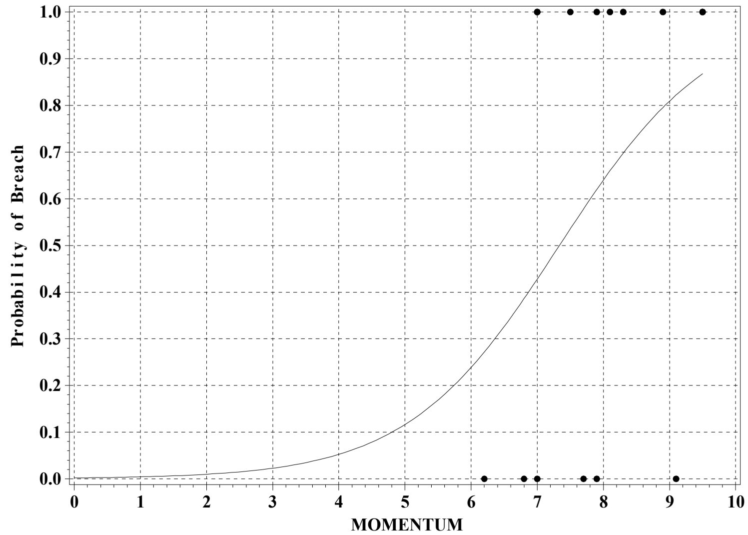
------------- MATERIAL=OSB OPENING=Large MISSILE=2x4 LOCATION=Edge

Analysis of Maximum Likelihood Estimates

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate
INTERCPT	1	-20.7693	32.3699	0.4117	0.5211	.
MOMENTUM	1	4.8614	7.3093	0.4423	0.5060	1.318489

Figure 3-6. Momentum Logistic Model for OSB, 2x4 Missile, Edge Impacts

Material = Plywood Opening = Small Missile = 2x4 Location = Central



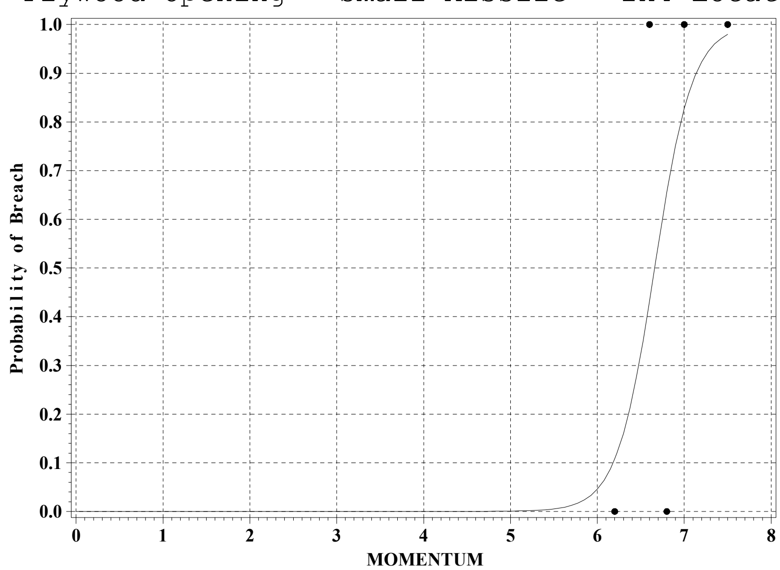
--------- MATERIAL=Plywood OPENING=Large MISSILE=2x4 LOCATION=Central

Analysis of Maximum Likelihood Estimates

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate
INTERCPT	1	-6.3722	5.0102	1.6176	0.2034	.
MOMENTUM	1	0.8684	0.6451	1.8122	0.1782	0.487076

Figure 3-7. Momentum Logistic Model for Plywood, 2x4 Missile, Central Impacts

Material = Plywood Opening = Small Missile = 2x4 Location = Edge



----------- MATERIAL=Plywood OPENING=Large MISSILE=2x4 LOCATION=Edge

Analysis of Maximum Likelihood Estimates

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate
INTERCPT	1	-30.6041	28.7864	1.1303	0.2877	.
MOMENTUM	1	4.5950	4.2849	1.1500	0.2835	1.220238

Figure 3-8. Momentum Logistic Model for Plywood, 2x4 Missile, Edge Impacts

show significant scatter in terms of renormalized relativity. These plots indicate that it is not possible to simplify the relativity tables if one desires to capture the effect of opening protection correctly. If OSB, Plywood, and Basic plotted as nearly straight lines across all house variable combinations, then these levels of protection could be treated with simple multipliers and achieve accurate loss relativity representation.

3.5.1 Existing Construction

The resulting loss relativity tables for existing construction are given in Tables 3-2 and 3-3 for Terrains B and C Existing Construction in the format in Ref. 1.

Table 3-3 gives the relativities in the DFS-OIR format (normalized to weakest house, converted to additive effects, and then tempered; see Ref. 13).

Both of these sets of tables show that the wood panels provide a level of protection that is less than Basic. The reduced impact resistance of OSB is clearly evident when compared to the loss relativity of Plywood panels. These results are for code-minimum wood panel thicknesses. The use of thicker plywood could result in a level of protection that matched Basic or even Hurricane.

Similar to the plots of component damage in Reference 1, we have produced plots of openings failures for the five levels of protection (None, OSB, plywood, Basic, and Hurricane) shown in the previous tables. Figure 3-11 shows the percentage of storms that produce failures for two houses. The "weak" house is the upper-left most entry in the tables and the "strong" house is the lower-right most entry in the tables. The effect of different levels of protection can be easily seen as you look down the page. For example, for 150 mph peak gust winds, the percent of storms that produce at least one failed fenestration is 65%,58%, 44%, 23%, and 9%, for None, OSB, Plywood, Basic, and Hurricane, respectively.

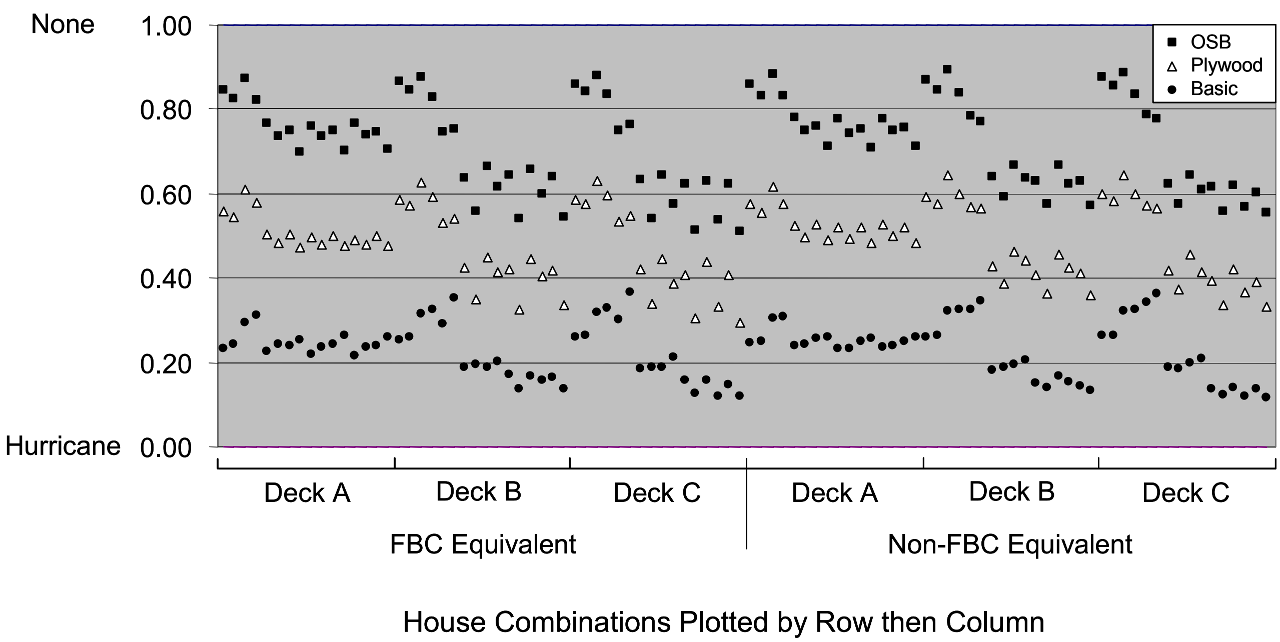


Figure 3-9. Terrain B Loss Relativities (Normalized Within Cell Group) Ranging from None (1.0) to Hurricane (0.0)

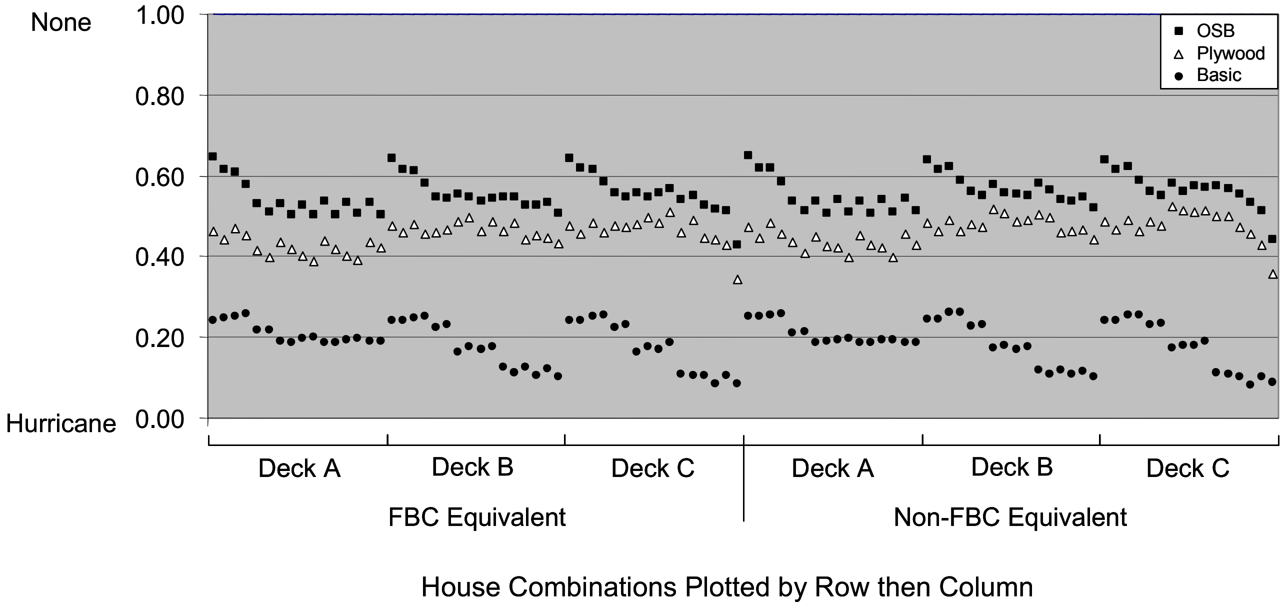


Figure 3-10. Terrain C Loss Relativities (Normalized Within Cell Group) Ranging from None (1.0) to Hurricane (0.0)

At lower windspeeds, the effect of some opening protection is more pronounced, particularly for plywood, which reduces the failure rate over no protection by about 50%.

These results assume that opening protection is in place at the time of the storm.

3.5.2 New Construction to the FBC

We updated the tables in Ref. 1 for new construction using simple interpolation with the results from the previous loss relativity tables. Table 3-6 provides the loss relativities in the same format as Ref 1. The relativity values for OSB, Plywood, and Basic are shown in parentheses above the Hurricane Protection Level. For example, for Other Roof Deck, Terrain B, > 120mph, the loss relativities are 0.58, 0.56, and 0.52 for OSB, Plywood, and Basic. The relativity of 0.48 remains for Hurricane Level as in the original Table 4-1 in Ref. 1.

Table 3-7 provides the relativities in the Reference 13 format (renormalized to the weakest house, converted to additive factors, and compressed). Because this table has highly compressed loss relativities, this table was also developed simply by interpolation.

Table 3-7 now has four entries for all locations for Opening Protection, corresponding to OSB, Plywood, Basic, and Hurricane. For the HVHZ, only the Hurricane Level is shown, consistent with Refs. 1 and 13.

At this point, we do not know how many builders will choose to implement wood panel shutters for new construction. The uncompressed version (Table 3-6) shows there is a large relative difference between the loss relativities for wood panels and Hurricane level of protection. For the compressed version, the difference between OSB and Plywood is much less.

Again, the results in the new construction tables are for FBC minimum-code level wood panel shutters. The use of thicker panels can easily increase the protection level.

Table 3-2. Terrain B Wood Panel Loss Relativities in Ref. 1 Format

Roof Cover	Roof Deck Attachment	Roof-Wall Connection	Opening Protection[1]	Other: No Secondary Water Resistance	Other: Secondary Water Resistance	Hip: No Secondary Water Resistance	Hip: Secondary Water Resistance
Non-FBC Equivalent	A	Toe Nail	None	2.37	2.22	1.26	1.18
			OSB	2.20	2.02	1.20	1.09
			Plywood	1.89	1.71	1.07	0.97
			Basic	1.53	1.37	0.91	0.83
			Hurricane	1.33	1.15	0.80	0.71
		Clips	None	1.55	1.37	0.91	0.80
			OSB	1.46	1.27	0.86	0.74
			Plywood	1.36	1.17	0.81	0.69
			Basic	1.26	1.08	0.75	0.65
			Hurricane	1.19	1.01	0.72	0.61
		Single Wraps	None	1.53	1.35	0.91	0.79
			OSB	1.44	1.25	0.86	0.73
			Plywood	1.35	1.16	0.80	0.69
			Basic	1.25	1.07	0.75	0.65
			Hurricane	1.19	1.00	0.72	0.61
		Double Wraps	None	1.53	1.35	0.91	0.80
			OSB	1.45	1.25	0.86	0.74
			Plywood	1.35	1.16	0.80	0.69
			Basic	1.25	1.07	0.75	0.65
			Hurricane	1.19	1.00	0.72	0.61
	B	Toe Nails	None	2.16	2.05	1.22	1.14
			OSB	2.00	1.87	1.16	1.06
			Plywood	1.66	1.54	1.04	0.94
			Basic	1.27	1.17	0.88	0.81
			Hurricane	1.04	0.92	0.76	0.68
		Clips	None	1.00	0.84	0.76	0.64
			OSB	0.94	0.79	0.71	0.60
			Plywood	0.89	0.75	0.68	0.58
			Basic	0.84	0.71	0.65	0.56
			Hurricane	0.80	0.66	0.63	0.55
		Single Wraps	None	0.95	0.76	0.75	0.64
			OSB	0.88	0.70	0.70	0.59
			Plywood	0.84	0.67	0.67	0.57
			Basic	0.79	0.64	0.64	0.55
			Hurricane	0.77	0.63	0.63	0.55
		Double Wraps	None	0.94	0.76	0.75	0.64
			OSB	0.88	0.70	0.70	0.59
			Plywood	0.84	0.67	0.67	0.57
			Basic	0.79	0.63	0.64	0.55
			Hurricane	0.77	0.62	0.63	0.55
	C	Toe Nails	None	2.15	2.04	1.22	1.15
			OSB	1.98	1.85	1.16	1.07
			Plywood	1.66	1.53	1.04	0.94
			Basic	1.27	1.16	0.88	0.81
			Hurricane	1.03	0.92	0.75	0.68
		Clips	None	0.98	0.82	0.75	0.64
			OSB	0.92	0.77	0.70	0.59
			Plywood	0.87	0.73	0.67	0.57
			Basic	0.82	0.70	0.64	0.56
			Hurricane	0.78	0.66	0.63	0.55
		Single Wraps	None	0.91	0.73	0.75	0.63
			OSB	0.85	0.68	0.70	0.59
			Plywood	0.81	0.65	0.67	0.57
			Basic	0.77	0.63	0.64	0.55
			Hurricane	0.75	0.62	0.63	0.55
		Double Wraps	None	0.90	0.72	0.75	0.63
			OSB	0.83	0.66	0.70	0.59
			Plywood	0.80	0.64	0.67	0.57
			Basic	0.75	0.61	0.64	0.55
			Hurricane	0.74	0.61	0.63	0.54

[1] OSB and plywood panels installed per FBC Section 1606.1.4 (7/16″ min thickness; maximum span of 8 ft; windspeeds ≤130 mph; roof height ≤33 ft with fasteners per Table 1606.1.4).

Table 3-2. Terrain B Wood Panel Loss Relativities in Ref. 1 Format (continued)

Roof Cover	Roof Deck Attachment	Roof-Wall Connection	Opening Protection[1]	Roof Shape: Other – No Secondary Water Resistance	Roof Shape: Other – Secondary Water Resistance	Roof Shape: Hip – No Secondary Water Resistance	Roof Shape: Hip – Secondary Water Resistance
FBC Equivalent	A	Toe Nails	None	2.11	2.05	1.07	1.04
			OSB	1.95	1.86	1.01	0.95
			Plywood	1.63	1.56	0.87	0.83
			Basic	1.26	1.22	0.71	0.69
			Hurricane	1.03	0.99	0.59	0.57
		Clips	None	1.22	1.19	0.67	0.65
			OSB	1.14	1.10	0.63	0.60
			Plywood	1.05	1.00	0.58	0.55
			Basic	0.94	0.91	0.53	0.51
			Hurricane	0.88	0.84	0.49	0.47
		Single Wraps	None	1.21	1.18	0.67	0.65
			OSB	1.13	1.09	0.62	0.60
			Plywood	1.04	1.00	0.58	0.55
			Basic	0.94	0.9	0.53	0.51
			Hurricane	0.87	0.84	0.49	0.47
		Double Wraps	None	1.21	1.17	0.67	0.65
			OSB	1.13	1.08	0.62	0.60
			Plywood	1.04	0.99	0.58	0.55
			Basic	0.93	0.90	0.53	0.51
			Hurricane	0.87	0.83	0.49	0.47
	B	Toe Nails	None	1.95	1.90	1.03	1.01
			OSB	1.79	1.72	0.98	0.93
			Plywood	1.46	1.39	0.85	0.81
			Basic	1.06	1.02	0.69	0.67
			Hurricane	0.80	0.78	0.56	0.55
		Clips	None	0.72	0.69	0.53	0.50
			OSB	0.68	0.64	0.49	0.46
			Plywood	0.64	0.60	0.47	0.44
			Basic	0.59	0.56	0.44	0.42
			Hurricane	0.54	0.51	0.43	0.41
		Single Wraps	None	0.65	0.61	0.52	0.50
			OSB	0.60	0.56	0.48	0.46
			Plywood	0.57	0.53	0.46	0.43
			Basic	0.53	0.49	0.43	0.41
			Hurricane	0.51	0.48	0.43	0.41
		Double Wraps	None	0.65	0.60	0.52	0.50
			OSB	0.60	0.55	0.48	0.46
			Plywood	0.57	0.52	0.46	0.43
			Basic	0.52	0.48	0.43	0.41
			Hurricane	0.51	0.47	0.43	0.41
	C	Toe Nails	None	1.94	1.89	1.03	1.01
			OSB	1.79	1.72	0.97	0.93
			Plywood	1.46	1.39	0.85	0.81
			Basic	1.05	1.02	0.69	0.67
			Hurricane	0.80	0.77	0.56	0.55
		Clips	None	0.70	0.67	0.52	0.50
			OSB	0.66	0.63	0.48	0.46
			Plywood	0.62	0.59	0.46	0.44
			Basic	0.58	0.55	0.44	0.42
			Hurricane	0.53	0.51	0.43	0.41
		Single Wraps	None	0.62	0.58	0.52	0.49
			OSB	0.57	0.53	0.48	0.45
			Plywood	0.55	0.51	0.46	0.43
			Basic	0.51	0.48	0.43	0.41
			Hurricane	0.49	0.47	0.42	0.41
		Double Wraps	None	0.61	0.57	0.52	0.49
			OSB	0.56	0.52	0.48	0.45
			Plywood	0.54	0.49	0.46	0.43
			Basic	0.50	0.46	0.43	0.41
			Hurricane	0.49	0.46	0.42	0.41

[1] OSB and plywood panels installed per FBC Section 1606.1.4 (7/16″ min thickness; maximum span of 8 ft; windspeeds ≤130 mph; roof height ≤33 ft with fasteners per Table 1606.1.4).

Table 3-3. Terrain C Wood Panel Loss Relativities in Ref. 1 Format

Roof Cover	Roof Deck Attachment	Roof-Wall Connection	Opening Protection[1]	Roof Shape: Other – No Secondary Water Resistance	Roof Shape: Other – Secondary Water Resistance	Roof Shape: Hip – No Secondary Water Resistance	Roof Shape: Hip – Secondary Water Resistance
Non-FBC Equivalent	A	Toe Nail	None	1.60	1.49	1.16	1.09
			OSB	1.38	1.24	0.93	0.82
			Plywood	1.27	1.12	0.84	0.74
			Basic	1.13	0.99	0.71	0.61
			Hurricane	0.98	0.83	0.57	0.45
		Clips	None	1.31	1.19	0.89	0.79
			OSB	1.12	0.96	0.71	0.58
			Plywood	1.07	0.91	0.67	0.55
			Basic	0.99	0.83	0.58	0.45
			Hurricane	0.90	0.73	0.51	0.38
		Single Wraps	None	1.28	1.15	0.88	0.78
			OSB	1.10	0.94	0.71	0.58
			Plywood	1.05	0.89	0.67	0.54
			Basic	0.97	0.81	0.58	0.45
			Hurricane	0.90	0.73	0.51	0.38
		Double Wraps	None	1.27	1.15	0.88	0.78
			OSB	1.10	0.94	0.71	0.58
			Plywood	1.05	0.89	0.67	0.54
			Basic	0.97	0.81	0.58	0.45
			Hurricane	0.90	0.73	0.51	0.38
	B	Toe Nails	None	1.46	1.37	1.13	1.07
			OSB	1.19	1.08	0.88	0.79
			Plywood	1.07	0.96	0.80	0.71
			Basic	0.89	0.80	0.65	0.58
			Hurricane	0.72	0.62	0.50	0.42
		Clips	None	1.00	0.89	0.69	0.56
			OSB	0.77	0.64	0.55	0.43
			Plywood	0.72	0.60	0.53	0.42
			Basic	0.60	0.47	0.43	0.33
			Hurricane	0.49	0.35	0.39	0.28
		Single Wraps	None	0.84	0.68	0.64	0.47
			OSB	0.67	0.51	0.52	0.38
			Plywood	0.64	0.49	0.50	0.37
			Basic	0.53	0.38	0.41	0.30
			Hurricane	0.48	0.32	0.38	0.28
		Double Wraps	None	0.79	0.59	0.63	0.45
			OSB	0.64	0.46	0.51	0.36
			Plywood	0.61	0.44	0.49	0.35
			Basic	0.51	0.34	0.41	0.29
			Hurricane	0.47	0.31	0.38	0.27
	C	Toe Nails	None	1.45	1.37	1.13	1.07
			OSB	1.18	1.08	0.88	0.80
			Plywood	1.06	0.96	0.80	0.71
			Basic	0.88	0.79	0.65	0.58
			Hurricane	0.71	0.62	0.50	0.42
		Clips	None	0.98	0.88	0.69	0.56
			OSB	0.75	0.63	0.55	0.43
			Plywood	0.70	0.59	0.53	0.42
			Basic	0.57	0.46	0.43	0.33
			Hurricane	0.46	0.34	0.38	0.28
		Single Wraps	None	0.81	0.64	0.63	0.44
			OSB	0.64	0.49	0.51	0.36
			Plywood	0.61	0.47	0.49	0.35
			Basic	0.49	0.36	0.40	0.29
			Hurricane	0.43	0.30	0.38	0.27
		Double Wraps	None	0.72	0.47	0.62	0.41
			OSB	0.58	0.38	0.50	0.32
			Plywood	0.55	0.37	0.47	0.31
			Basic	0.45	0.30	0.39	0.27
			Hurricane	0.42	0.28	0.37	0.26

[1] OSB and plywood panels installed per FBC Section 1606.1.4 (7/16″ min thickness; maximum span of 8 ft; windspeeds ≤130 mph; roof height ≤33 ft with fasteners per Table 1606.1.4).

Table 3-3. Terrain C Wood Panel Loss Relativities in Ref. 1 Format (continued)

Roof Cover	Roof Deck Attachment	Roof-Wall Connection	Opening Protection[1]	Other: No Secondary Water Resistance	Other: Secondary Water Resistance	Hip: No Secondary Water Resistance	Hip: Secondary Water Resistance
FBC Equivalent	A	Toe Nails	None	1.49	1.44	1.07	1.03
			OSB	1.25	1.18	0.82	0.77
			Plywood	1.12	1.06	0.74	0.69
			Basic	0.97	0.93	0.59	0.56
			Hurricane	0.81	0.77	0.43	0.40
		Clips	None	1.16	1.12	0.75	0.73
			OSB	0.95	0.90	0.57	0.52
			Plywood	0.90	0.85	0.53	0.49
			Basic	0.80	0.76	0.43	0.39
			Hurricane	0.71	0.67	0.36	0.32
		Single Wraps	None	1.12	1.09	0.75	0.72
			OSB	0.93	0.88	0.57	0.52
			Plywood	0.88	0.83	0.53	0.49
			Basic	0.79	0.74	0.43	0.39
			Hurricane	0.71	0.66	0.36	0.32
		Double Wraps	None	1.12	1.08	0.75	0.72
			OSB	0.93	0.87	0.57	0.52
			Plywood	0.88	0.83	0.54	0.49
			Basic	0.78	0.74	0.43	0.39
			Hurricane	0.71	0.66	0.36	0.32
	B	Toe Nails	None	1.36	1.32	1.04	1.01
			OSB	1.08	1.03	0.79	0.74
			Plywood	0.96	0.91	0.70	0.66
			Basic	0.78	0.75	0.55	0.53
			Hurricane	0.60	0.57	0.38	0.36
		Clips	None	0.87	0.84	0.54	0.51
			OSB	0.64	0.59	0.42	0.39
			Plywood	0.59	0.55	0.41	0.37
			Basic	0.46	0.42	0.31	0.28
			Hurricane	0.35	0.30	0.26	0.23
		Single Wraps	None	0.68	0.63	0.46	0.41
			OSB	0.52	0.47	0.37	0.33
			Plywood	0.49	0.44	0.36	0.31
			Basic	0.38	0.33	0.28	0.24
			Hurricane	0.32	0.27	0.26	0.22
		Double Wraps	None	0.60	0.53	0.45	0.39
			OSB	0.47	0.40	0.36	0.30
			Plywood	0.45	0.38	0.34	0.29
			Basic	0.35	0.29	0.27	0.23
			Hurricane	0.32	0.26	0.25	0.22
	C	Toe Nails	None	1.36	1.32	1.04	1.01
			OSB	1.08	1.03	0.79	0.75
			Plywood	0.97	0.91	0.70	0.66
			Basic	0.78	0.74	0.55	0.53
			Hurricane	0.59	0.56	0.39	0.36
		Clips	None	0.86	0.83	0.54	0.50
			OSB	0.62	0.58	0.42	0.38
			Plywood	0.58	0.54	0.40	0.36
			Basic	0.44	0.41	0.30	0.27
			Hurricane	0.32	0.29	0.26	0.23
		Single Wraps	None	0.64	0.59	0.45	0.39
			OSB	0.49	0.44	0.36	0.31
			Plywood	0.47	0.42	0.35	0.30
			Basic	0.35	0.31	0.27	0.23
			Hurricane	0.29	0.25	0.25	0.22
		Double Wraps	None	0.51	0.41	0.43	0.36
			OSB	0.41	0.33	0.34	0.27
			Plywood	0.39	0.31	0.32	0.26
			Basic	0.30	0.25	0.26	0.22
			Hurricane	0.28	0.23	0.25	0.21

[1] OSB and plywood panels installed per FBC Section 1606.1.4 (7/16″ min thickness; maximum span of 8 ft; windspeeds ≤130 mph; roof height ≤33 ft with fasteners per Table 1606.1.4).

Table 3-4. Terrain B Wood Panel Loss Relativities in Ref. 13 Format

Roof Cover	Roof Deck Attachment	Roof-Wall Connection	Opening Protection[1]	Roof Shape: Other – No Secondary Water Resistance	Roof Shape: Other – Secondary Water Resistance	Roof Shape: Hip – No Secondary Water Resistance	Roof Shape: Hip – Secondary Water Resistance
Non-FBC Equivalent	A (6d @ 6″/12″)	Toe Nail	None	0.00	0.03	0.23	0.25
			OSB	0.04	0.07	0.25	0.27
			Plywood	0.10	0.14	0.28	0.30
			Basic	0.18	0.21	0.31	0.32
			Hurricane	0.22	0.26	0.33	0.35
		Clips	None	0.17	0.21	0.31	0.33
			OSB	0.19	0.23	0.32	0.34
			Plywood	0.21	0.25	0.33	0.35
			Basic	0.23	0.27	0.34	0.36
			Hurricane	0.25	0.29	0.35	0.37
		Single Wraps	None	0.18	0.22	0.31	0.33
			OSB	0.20	0.24	0.32	0.35
			Plywood	0.22	0.26	0.33	0.35
			Basic	0.24	0.27	0.34	0.36
			Hurricane	0.25	0.29	0.35	0.37
		Double Wraps	None	0.18	0.22	0.31	0.33
			OSB	0.19	0.24	0.32	0.34
			Plywood	0.22	0.26	0.33	0.35
			Basic	0.24	0.27	0.34	0.36
			Hurricane	0.25	0.29	0.35	0.37
	B (8d @ 6″/12″)	Toe Nails	None	0.04	0.07	0.24	0.26
			OSB	0.08	0.11	0.26	0.28
			Plywood	0.15	0.18	0.28	0.30
			Basic	0.23	0.25	0.31	0.33
			Hurricane	0.28	0.31	0.34	0.36
		Clips	None	0.29	0.32	0.34	0.36
			OSB	0.30	0.33	0.35	0.37
			Plywood	0.31	0.34	0.36	0.38
			Basic	0.32	0.35	0.36	0.38
			Hurricane	0.33	0.36	0.37	0.38
		Single Wraps	None	0.30	0.34	0.34	0.36
			OSB	0.31	0.35	0.35	0.38
			Plywood	0.32	0.36	0.36	0.38
			Basic	0.33	0.36	0.36	0.38
			Hurricane	0.34	0.37	0.37	0.38
		Double Wraps	None	0.30	0.34	0.34	0.36
			OSB	0.31	0.35	0.35	0.38
			Plywood	0.32	0.36	0.36	0.38
			Basic	0.33	0.37	0.36	0.38
			Hurricane	0.34	0.37	0.37	0.38
	C (8d @ 6″/6″)	Toe Nails	None	0.05	0.07	0.24	0.26
			OSB	0.08	0.11	0.26	0.27
			Plywood	0.15	0.18	0.28	0.30
			Basic	0.23	0.26	0.31	0.33
			Hurricane	0.28	0.31	0.34	0.36
		Clips	None	0.29	0.33	0.34	0.36
			OSB	0.31	0.34	0.35	0.37
			Plywood	0.32	0.35	0.36	0.38
			Basic	0.33	0.35	0.36	0.38
			Hurricane	0.34	0.36	0.37	0.38
		Single Wraps	None	0.31	0.35	0.34	0.37
			OSB	0.32	0.36	0.35	0.38
			Plywood	0.33	0.36	0.36	0.38
			Basic	0.34	0.37	0.36	0.38
			Hurricane	0.34	0.37	0.37	0.38
		Double Wraps	None	0.31	0.35	0.34	0.37
			OSB	0.32	0.36	0.35	0.38
			Plywood	0.33	0.37	0.36	0.38
			Basic	0.34	0.37	0.36	0.38
			Hurricane	0.34	0.37	0.37	0.39

[1] OSB and plywood panels installed per FBC Section 1606.1.4 (7/16″ min thickness; maximum span of 8 ft; windspeeds ≤130 mph; roof height ≤33 ft with fasteners per Table 1606.1.4).

Table 3-4. Terrain B Wood Panel Loss Relativities in Ref. 13 Format (continued)

Roof Cover	Roof Deck Attachment	Roof-Wall Connection	Opening Protection[1]	Roof Shape: Other – No Secondary Water Resistance	Roof Shape: Other – Secondary Water Resistance	Roof Shape: Hip – No Secondary Water Resistance	Roof Shape: Hip – Secondary Water Resistance
FBC Equivalent	A (6d @ 6″/12″)	Toe Nails	None	0.05	0.07	0.27	0.28
			OSB	0.09	0.11	0.29	0.30
			Plywood	0.16	0.17	0.32	0.33
			Basic	0.23	0.24	0.35	0.35
			Hurricane	0.28	0.29	0.38	0.38
		Clips	None	0.24	0.25	0.36	0.36
			OSB	0.26	0.27	0.37	0.37
			Plywood	0.28	0.29	0.38	0.38
			Basic	0.30	0.31	0.39	0.39
			Hurricane	0.31	0.32	0.40	0.40
		Single Wraps	None	0.24	0.25	0.36	0.36
			OSB	0.26	0.27	0.37	0.37
			Plywood	0.28	0.29	0.38	0.38
			Basic	0.30	0.31	0.39	0.39
			Hurricane	0.32	0.32	0.40	0.40
		Double Wraps	None	0.24	0.25	0.36	0.36
			OSB	0.26	0.27	0.37	0.37
			Plywood	0.28	0.29	0.38	0.38
			Basic	0.30	0.31	0.39	0.39
			Hurricane	0.32	0.32	0.40	0.40
	B (8d @ 6″/12″)	Toe Nails	None	0.09	0.10	0.28	0.29
			OSB	0.12	0.14	0.29	0.30
			Plywood	0.19	0.21	0.32	0.33
			Basic	0.28	0.28	0.35	0.36
			Hurricane	0.33	0.34	0.38	0.38
		Clips	None	0.35	0.35	0.39	0.39
			OSB	0.36	0.36	0.40	0.40
			Plywood	0.37	0.37	0.40	0.41
			Basic	0.38	0.38	0.41	0.41
			Hurricane	0.39	0.39	0.41	0.41
		Single Wraps	None	0.36	0.37	0.39	0.39
			OSB	0.37	0.38	0.40	0.40
			Plywood	0.38	0.39	0.40	0.41
			Basic	0.39	0.40	0.41	0.41
			Hurricane	0.39	0.40	0.41	0.41
		Double Wraps	None	0.36	0.37	0.39	0.39
			OSB	0.37	0.38	0.40	0.40
			Plywood	0.38	0.39	0.40	0.41
			Basic	0.39	0.40	0.41	0.41
			Hurricane	0.39	0.40	0.41	0.41
	C (8d @ 6″/6″)	Toe Nails	None	0.09	0.10	0.28	0.29
			OSB	0.12	0.14	0.29	0.30
			Plywood	0.19	0.21	0.32	0.33
			Basic	0.28	0.28	0.35	0.36
			Hurricane	0.33	0.34	0.38	0.38
		Clips	None	0.35	0.36	0.39	0.39
			OSB	0.36	0.37	0.40	0.40
			Plywood	0.37	0.38	0.40	0.41
			Basic	0.38	0.38	0.41	0.41
			Hurricane	0.39	0.39	0.41	0.41
		Single Wraps	None	0.37	0.38	0.39	0.40
			OSB	0.38	0.39	0.40	0.41
			Plywood	0.38	0.39	0.40	0.41
			Basic	0.39	0.40	0.41	0.41
			Hurricane	0.40	0.40	0.41	0.41
		Double Wraps	None	0.37	0.38	0.39	0.40
			OSB	0.38	0.39	0.40	0.41
			Plywood	0.39	0.40	0.40	0.41
			Basic	0.39	0.40	0.41	0.41
			Hurricane	0.40	0.40	0.41	0.41
Reinforced Concrete Roof Deck			None				0.41
			OSB				0.41
			Plywood				0.42
			Basic				0.42
			Hurricane				0.42

[1] OSB and plywood panels installed per FBC Section 1606.1.4 (7/16″ min thickness; maximum span of 8 ft; windspeeds ≤130 mph; roof height ≤33 ft with fasteners per Table 1606.1.4).

Table 3-5. Terrain C Wood Panel Loss Relativities in Ref. 13 Format

Roof Cover	Roof Deck Attachment	Roof-Wall Connection	Opening Protection[1]	Roof Shape: Other – No Secondary Water Resistance	Roof Shape: Other – Secondary Water Resistance	Roof Shape: Hip – No Secondary Water Resistance	Roof Shape: Hip – Secondary Water Resistance
Non-FBC Equivalent	A (6d @ 6″/12″)	Toe Nail	None	0.00	0.03	0.14	0.16
			OSB	0.07	0.11	0.21	0.24
			Plywood	0.10	0.15	0.24	0.27
			Basic	0.15	0.19	0.28	0.31
			Hurricane	0.19	0.24	0.32	0.36
		Clips	None	0.09	0.13	0.22	0.25
			OSB	0.15	0.20	0.28	0.32
			Plywood	0.17	0.21	0.29	0.33
			Basic	0.19	0.24	0.32	0.36
			Hurricane	0.22	0.27	0.34	0.38
		Single Wraps	None	0.10	0.14	0.23	0.26
			OSB	0.16	0.21	0.28	0.32
			Plywood	0.17	0.22	0.29	0.33
			Basic	0.20	0.25	0.32	0.36
			Hurricane	0.22	0.27	0.34	0.38
		Double Wraps	None	0.10	0.14	0.23	0.26
			OSB	0.16	0.21	0.28	0.32
			Plywood	0.17	0.22	0.29	0.33
			Basic	0.20	0.25	0.32	0.36
			Hurricane	0.22	0.27	0.34	0.38
	B (8d @ 6″/12″)	Toe Nails	None	0.04	0.07	0.15	0.17
			OSB	0.13	0.16	0.22	0.25
			Plywood	0.17	0.20	0.25	0.28
			Basic	0.22	0.25	0.30	0.32
			Hurricane	0.28	0.31	0.34	0.37
		Clips	None	0.19	0.22	0.28	0.33
			OSB	0.26	0.30	0.33	0.36
			Plywood	0.27	0.31	0.33	0.37
			Basic	0.31	0.35	0.37	0.40
			Hurricane	0.35	0.39	0.38	0.41
		Single Wraps	None	0.24	0.29	0.30	0.35
			OSB	0.29	0.34	0.34	0.38
			Plywood	0.30	0.35	0.34	0.38
			Basic	0.33	0.38	0.37	0.41
			Hurricane	0.35	0.40	0.38	0.41
		Double Wraps	None	0.25	0.32	0.30	0.36
			OSB	0.30	0.36	0.34	0.39
			Plywood	0.31	0.36	0.35	0.39
			Basic	0.34	0.39	0.37	0.41
			Hurricane	0.35	0.40	0.38	0.42
	C (8d @ 6″/6″)	Toe Nails	None	0.05	0.07	0.15	0.17
			OSB	0.13	0.16	0.22	0.25
			Plywood	0.17	0.20	0.25	0.28
			Basic	0.23	0.25	0.30	0.32
			Hurricane	0.28	0.31	0.34	0.37
		Clips	None	0.19	0.23	0.28	0.33
			OSB	0.27	0.30	0.33	0.36
			Plywood	0.28	0.32	0.33	0.37
			Basic	0.32	0.36	0.37	0.40
			Hurricane	0.36	0.39	0.38	0.41
		Single Wraps	None	0.25	0.30	0.30	0.36
			OSB	0.30	0.35	0.34	0.39
			Plywood	0.31	0.35	0.35	0.39
			Basic	0.35	0.39	0.38	0.41
			Hurricane	0.37	0.41	0.38	0.42
		Double Wraps	None	0.28	0.35	0.31	0.37
			OSB	0.32	0.38	0.35	0.40
			Plywood	0.33	0.39	0.35	0.40
			Basic	0.36	0.41	0.38	0.42
			Hurricane	0.37	0.41	0.38	0.42

[1] OSB and plywood panels installed per FBC Section 1606.1.4 (7/16″ min thickness; maximum span of 8 ft; windspeeds ≤130 mph; roof height ≤33 ft with fasteners per Table 1606.1.4).

Table 3-5. Terrain C Wood Panel Loss Relativities in Ref. 13 Format (continued)

Roof Cover	Roof Deck Attachment	Roof-Wall Connection	Opening Protection[1]	Roof Shape			
				Other		Hip	
				No Secondary Water Resistance	Secondary Water Resistance	No Secondary Water Resistance	Secondary Water Resistance
FBC Equivalent	A (6d @ 6″/12″)	Toe Nails	None	0.03	0.05	0.17	0.18
			OSB	0.11	0.13	0.24	0.26
			Plywood	0.15	0.17	0.27	0.29
			Basic	0.20	0.21	0.32	0.33
			Hurricane	0.25	0.26	0.37	0.38
		Clips	None	0.14	0.15	0.27	0.27
			OSB	0.20	0.22	0.32	0.34
			Plywood	0.22	0.23	0.33	0.35
			Basic	0.25	0.26	0.37	0.38
			Hurricane	0.28	0.29	0.39	0.40
		Single Wraps	None	0.15	0.16	0.27	0.28
			OSB	0.21	0.23	0.32	0.34
			Plywood	0.22	0.24	0.33	0.35
			Basic	0.25	0.27	0.37	0.38
			Hurricane	0.28	0.29	0.39	0.40
		Double Wraps	None	0.15	0.16	0.27	0.28
			OSB	0.21	0.23	0.32	0.34
			Plywood	0.23	0.24	0.33	0.35
			Basic	0.26	0.27	0.37	0.38
			Hurricane	0.28	0.29	0.39	0.40
	B (8d @ 6″/12″)	Toe Nails	None	0.08	0.09	0.18	0.18
			OSB	0.16	0.18	0.25	0.27
			Plywood	0.20	0.21	0.28	0.29
			Basic	0.26	0.27	0.33	0.33
			Hurricane	0.31	0.32	0.38	0.39
		Clips	None	0.23	0.24	0.33	0.34
			OSB	0.30	0.31	0.37	0.38
			Plywood	0.31	0.33	0.37	0.38
			Basic	0.36	0.37	0.40	0.41
			Hurricane	0.39	0.41	0.42	0.43
		Single Wraps	None	0.29	0.30	0.36	0.37
			OSB	0.34	0.35	0.38	0.40
			Plywood	0.35	0.36	0.39	0.40
			Basic	0.38	0.40	0.41	0.43
			Hurricane	0.40	0.42	0.42	0.43
		Double Wraps	None	0.31	0.33	0.36	0.38
			OSB	0.35	0.37	0.39	0.40
			Plywood	0.36	0.38	0.39	0.41
			Basic	0.39	0.41	0.42	0.43
			Hurricane	0.40	0.42	0.42	0.43
	C (8d @ 6″/6″)	Toe Nails	None	0.08	0.09	0.18	0.18
			OSB	0.16	0.18	0.25	0.27
			Plywood	0.20	0.22	0.28	0.29
			Basic	0.26	0.27	0.33	0.33
			Hurricane	0.32	0.33	0.38	0.39
		Clips	None	0.23	0.24	0.33	0.34
			OSB	0.31	0.32	0.37	0.38
			Plywood	0.32	0.33	0.37	0.39
			Basic	0.36	0.37	0.41	0.42
			Hurricane	0.40	0.41	0.42	0.43
		Single Wraps	None	0.30	0.32	0.36	0.38
			OSB	0.35	0.36	0.39	0.40
			Plywood	0.35	0.37	0.39	0.41
			Basic	0.39	0.40	0.42	0.43
			Hurricane	0.41	0.42	0.42	0.43
		Double Wraps	None	0.34	0.37	0.37	0.39
			OSB	0.37	0.40	0.39	0.41
			Plywood	0.38	0.40	0.40	0.42
			Basic	0.41	0.42	0.42	0.43
			Hurricane	0.41	0.43	0.42	0.43
Reinforced Concrete Roof Deck			None				0.40
			OSB				0.42
			Plywood				0.43
			Basic				0.44
			Hurricane				0.44

[1] OSB and plywood panels installed per FBC Section 1606.1.4 (7/16″ min thickness; maximum span of 8 ft; windspeeds ≤130 mph; roof height ≤33 ft with fasteners per Table 1606.1.4).

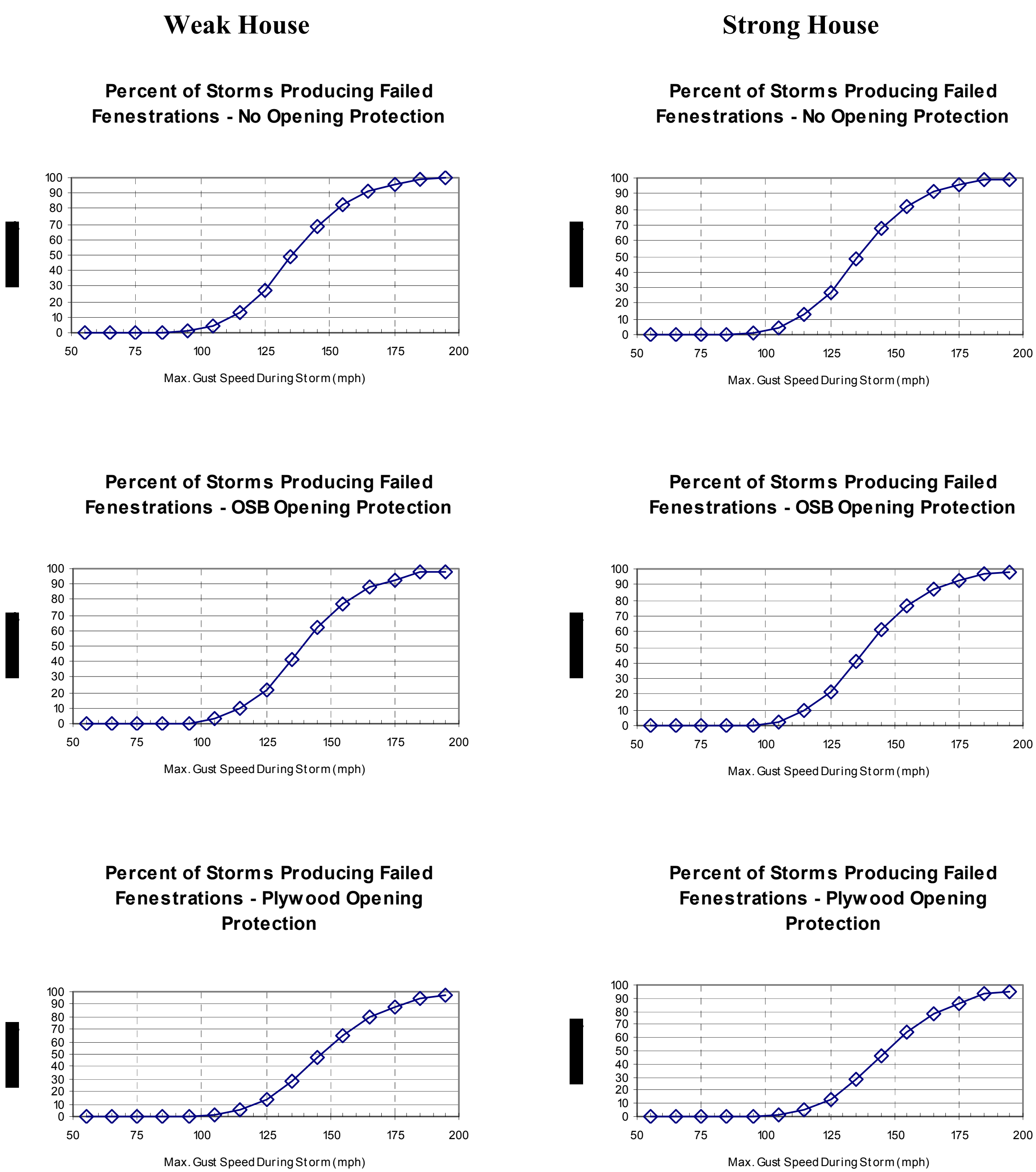
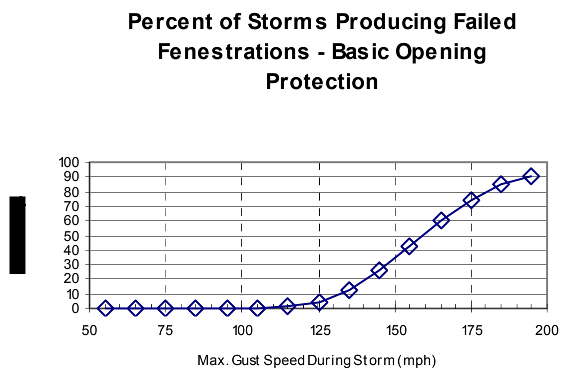
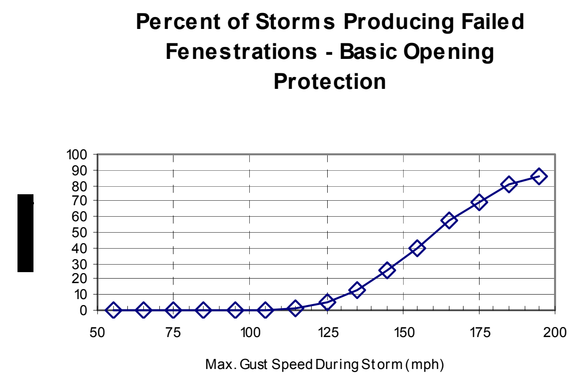
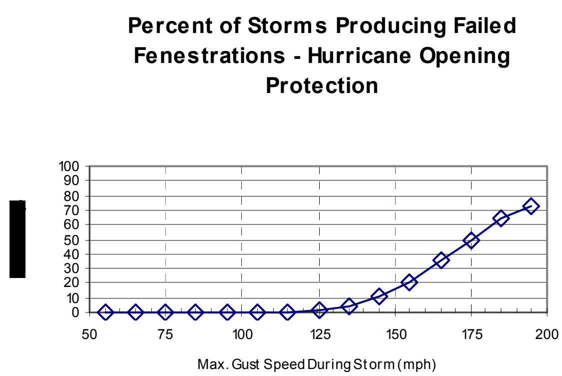


Figure 3-11. Comparison of HURLOSS Estimated Failure Rates for Various Levels of Opening Protection for Miami Location

Weak House / **Strong House**







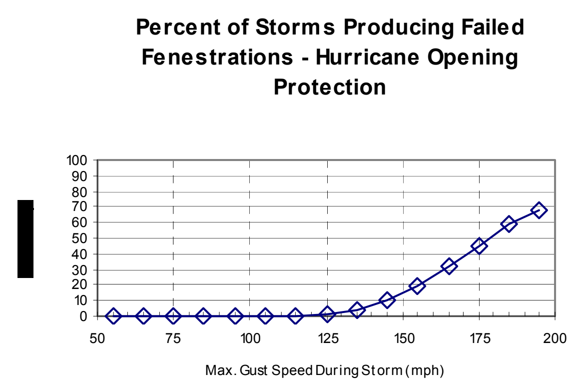


Figure 3-11. Comparison of HURLOSS Estimated Failure Rates for Various Levels of Opening Protection for Miami Location (concluded)

Table 3-6. Wood Panel Loss Relativities for Minimum Design Construction to FBC in Ref. 1 Format

FBC 2001 Construction					Other Roof Shape		Hip Roof Shape	
Roof Deck	Terrain Exposure[2]	FBC Wind Speed[11] (mph)	Internal Pressure Design[3]	WBDR[4]	No Opening Protection	Opening Protection (OSB, Plywood, Basic) Hurricane[12]	No Opening Protection	Opening Protection (OSB, Plywood, Basic) Hurricane[12]
Other Roof Deck[9]	B	100	Enclosed	No	0.76	-[5]	0.51	-[5]
		110	Enclosed	No	0.66	-[5]	0.51	-[5]
		≥ 120	Enclosed	No	0.61[6]	-	0.52[6]	-
				Yes	-	(0.58, 0.56, 0.52) 0.48	-	(0.48, 0.46, 0.43) 0.41
			Part. Enclosed	Yes	0.60	-[7]	0.51	-[7]
	C	≥ 120	Enclosed	Yes	-	(0.34, 0.32, 0.29) 0.27	-	(0.28, 0.26, 0.25) 0.23
			Part. Enclosed	Yes	0.37	-[7]	0.30	-[7]
	HVHZ		Enclosed	Yes	-[8]	0.26	-[8]	0.23
Reinforced Concrete Roof Deck[10]	B	Any	Enclosed	No	0.44	-[5]	0.44	-[5]
				Yes	-	(0.41, 0.43, 0.37) 0.36	-	(0.41, 0.43, 0.37) 0.36
			Part. Enclosed	Yes	0.43	-[7]	0.43	-[7]
	C	Any	Enclosed	Yes	-	(0.28, 0.26, 0.24) 0.18	-	(0.28, 0.26, 0.24) 0.18
			Part. Enclosed	Yes	0.31	-[7]	0.31	-[7]
	HVHZ		Enclosed	Yes	-[8]	0.17	-[8]	0.17

[1] Table is for houses built to Minimum Wind Loads of FBC 2001. Houses built to higher loads should use this table and the adjustments in Table 4-2.
[2] See Figure 6.1 and FBC 1606.1.8.
[3] FBC 1606.1.4.
[4] WBDR = Wind-Borne Debris Region (FBC 1606.1.5 and Section 2.2.1 of this report).
[5] Not applicable to Minimum Load Design in non-WBDR.
[6] This relativity applies to non-WBDR locations.
[7] Not applicable to Minimum Load Design for Partially Enclosed Buildings in WBDR.
[8] HVHZ requires WBD Opening Protection.
[9] Secondary Rating Factors: applicable to "Other Roof Decks"
i. Dimensional lumber roof deck: K = 0.96
ii. Reinforced masonry walls: K = 0.95
iii. All openings protected in non-HVHZ: K = 0.98
iv. These factors are applied per Eqn. 3-7.
[10] No secondary rating factor adjustments to these relativities.
[11] FBC wind speed corresponding to house location.
[12] Values in parentheses are for OSB, Plywood, and Basic protection. The Hurricane level is on the following row.

Table 3-7. Wood Panel Loss Relativities for Minimum Design Construction to FBC in Ref. 13 Format

						Frame, Masonry, or Reinforced Masonry							
						Other Roof Shape				Hip Roof Shape			
						No Opening Protection		Opening Protection[1]		No Opening Protection		Opening Protection[1]	
FBC 2001 Construction								Windows or All				Windows or All	
Roof Deck	Terrain Exposure	FBC Wind Speed (mph)	Wind Speed of Design (mph)	Internal Pressure Design	WBDR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
Other Roof Deck or Dimensional Lumber Deck	B	100	≥100	Enclosed	No	0.34	0.34	0.35	0.35	0.39	0.39	0.40	0.40
								0.36	0.36			0.40	0.40
								0.37	0.37			0.41	0.41
								0.37	0.37			0.41	0.41
	B	110	≥110	Enclosed	No	0.36	0.36	0.37	0.37	0.39	0.39	0.40	0.40
								0.37	0.37			0.40	0.40
								0.38	0.38			0.41	0.41
								0.39	0.39			0.41	0.41
	B	≥120	≥120	Enclosed	No	0.37	0.38	0.38	0.38	0.39	0.39	0.40	0.40
								0.38	0.38			0.40	0.40
								0.39	0.39			0.41	0.41
								0.39	0.40			0.41	0.41
	B or C	≥120	≥120	Enclosed/ Part. Encl	Yes	0.38	0.40	0.39	0.41	0.41	0.41	0.42	0.42
								0.40	0.41			0.42	0.42
								0.41	0.42			0.43	0.43
								0.41	0.42			0.43	0.43
	HVHZ			Enclosed	Yes			0.41	0.42			0.43	0.43
Reinforced Concrete Roof Deck	B	Any		Enclosed	No						0.41		0.41
													0.41
													0.42
													0.42
	B	Any		Enclosed/ Part. Encl	Yes						0.41		0.41
													0.41
													0.42
													0.42
	C	Any		Enclosed/ Part. Encl	Yes						0.40		0.41
													0.42
													0.43
													0.44
	HVHZ			Enclosed	Yes								0.45

[1] Row values correspond to OSB Plywood, Basic, and Hurricane.

4.0 SUMMARY AND RECOMMENDATIONS

A project has been undertaken to estimate the loss relativities for wood panel shutters installed per the minimum requirements of the Florida Building Code. A number of experiments were conducted at Clemson University, followed by modeling and loss analysis. This report documents the data and results of the analysis.

Overall conclusions from the testing include the following:

1. The wood structural panels accepted for opening protection as an exception to the Florida Building Code (FBC) do not pass the Miami-Dade product approval standards for large missiles because they allow a 9-pound missile to penetrate at speeds below 34 mph. However, they do generally meet the requirements of ASTM E 1996 and SBCCI's SSTD 12 because typically the hole in the panel will not allow a 3-inch sphere to pass.
2. Provided the nails are driven into virgin locations on the structural framing, the typical nailing schedule for the panels as listed in the FBC is adequate to keep the structural panel in place under the cyclic loading specified in FBC Table 1626 for enclosed homes with mean roof heights below 30 feet located in exposure C in a region with a design wind speed of 150 mph.
3. Holes in the panels created by 2x4 lumber missiles did not open up or propagate under the application of the specified cyclic pressure tests.
4. Negative cyclic loading of the panels that exceeds 60 percent of the single cycle ultimate static load capacity of the panel anchorage is expected to produce some level of degradation of the attachment capacity. Clearly, the degradation is greater as the load level approaches the single cycle ultimate capacity.
5. The repeated nailing of panels with fasteners driven in the same holes is expected to lead to significant reductions in the capacity of the connections to resist outward acting pressures on the panels.

Using the experimental results, we developed separate plywood and OSB breach models for implementation into the HURLOSS code. These models capture the mean and variance of impact resistance as observed in the Clemson tests. The HURLOSS model was then run in the same fashion as documented in Reference 1. The loss relativity tables with two new levels of opening protection were created. These tables were developed to follow the original format in Reference 1 and also the format in Reference 13.

While the results show a good level of protection for code-minimum wood panels, they also show that the panels perform well below the Hurricane protection level, which must resist the 9 lb 2x4 lumber at 50 fps. Plywood clearly outperforms OSB and that is the reason the results were not combined into a single wood panel category. Users can easily simply these results into a single level of opening protection, if needed.

A note on the Basic level of protection in Ref 1 and 13 is in order. The modeled Basic level of protection in Ref. 1 is for ½ of the impact resistance (½ of 350 ft-lb) for the Hurricane Protection Level. We note that the 4.5 lb lumber (Missile Level B) allowed in the ASTM E 1996 for less than 130 mph windspeeds corresponds to an impact energy level of 111 ft-lbs. Hence this resistance level is close to that exhibited by the plywood panels in this test program. It seems reasonable that opening protection to the ASTM E 1996 Missile B, which is allowable in the FBC, would be best treated as plywood protection in terms of loss relativity.

We do not know if shutter products will be available for the ASTM Missile Level B. Most manufacturers have focused on the 9 lb missile (Level C), which would qualify for the full Hurricane Credit. Assuming the shutters are appropriately marked, then field determination should be relatively straightforward.

This work did not address masonry wall installations. We have recently (within the past several months) heard concerns by building code officials regarding pullout of the fasteners on masonry walls under cyclic loadings. A small supplemental study is recommended to address that issue. Clearly the impact test portion of this program would not have to be repeated, but pressure cycling tests would need to be done for masonry wall fasteners.

Another recommendation is to add a requirement to the FBC regarding repeated nailing of fasteners for wood panel shutters. This requirement is needed to prevent significant capacity reductions when fasteners are driven into the same holes.

5.0 REFERENCES

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APPENDIX A
Detailed Observations from Panel Impact Tests

ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 1

Panel Type: 15/32 Plywood 3-ply

Panel Layout:
2’ x 4’ Opening Strong Axis in 4’ direction

Nailing Schedule and Location:
12d common 6” along sides of the panel

Missile Impact:
___ None
_X_ 2x4
___ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

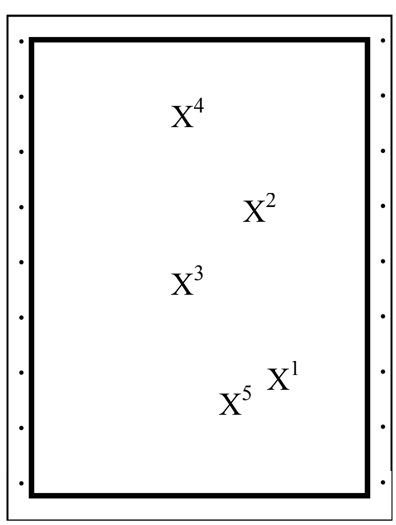
Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	9.0 lb	20 mph	Lower middle of panel – punctured panel
2	9.0 lb	22 mph	Upper middle of panel – punctured panel
3	4.54 lb	35 mph	Center of panel – punctured panel
4	4.54 lb	33 mph	Near top of panel – punctured panel
5	4.54 lb	28 mph	Hit close to impact location 1 – cracked panel, missile bounced back
6			
7			
8			
9			

2 ft.

X# - Missile strike location

4 ft.



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 2

Panel Type: 15/32 Plywood 3-ply

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

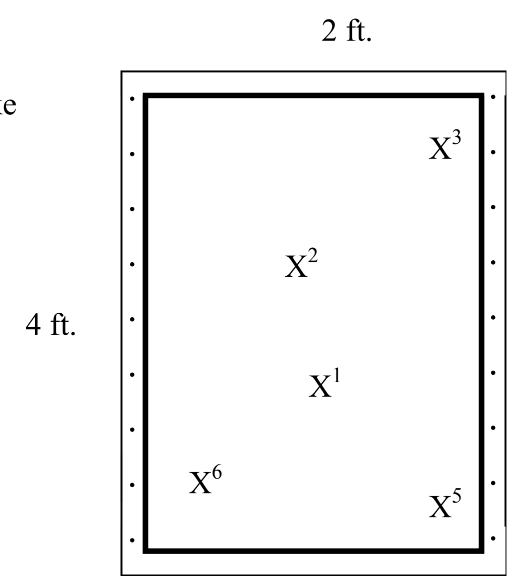
Missile Impact:
___ None
_X_ 2x4
___ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.54 lb	30 mph	2/3 from top – Indentation – no puncture
2	4.54 lb	35 mph	Center – Punctured shutter
3	4.54 lb	32 mph	Upper RHS Corner – Punctured Shutter
4	4.54 lb	29 mph	Missed shutter – hit below shutter
5	4.54 lb	NS	Punched through plywood
6	4.54 lb	30 mph	Hit close to 1st shot
7			
8			
9			
10			

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 3

Panel Type: 15/32 Plywood 4-ply

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

Missile Impact:
___ None
_X_ 2x4
___ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

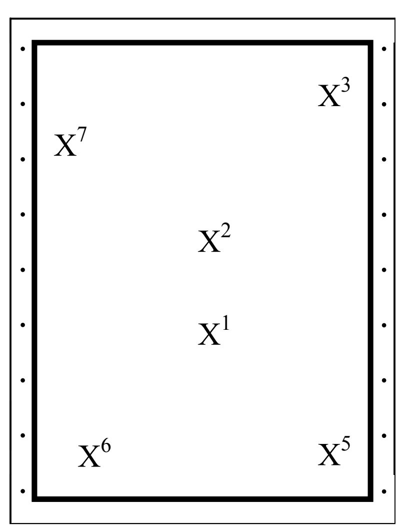
Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.54 lb	32 mph	Partial shear of panel along one edge of impact – cracking and splitting of back
2	4.54 lb	34 mph	Center of panel - no penetration but more damage to panel
3	4.54 lb	35 mph	Upper RH Corner - Punctured Shutter
4	4.54 lb	30 mph	Missed shutter - hit below shutter
5	4.54 lb	33 mph	Lower RH Corner - no penetration
6	4.54 lb	34 mph	Lower LH Corner - penetration
7	4.54 lb	33 mph	Upper LH Corner - no penetration

2 ft.

X# - Missile strike location

4 ft.



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 4

Panel Type: 15/32 Plywood 4-ply

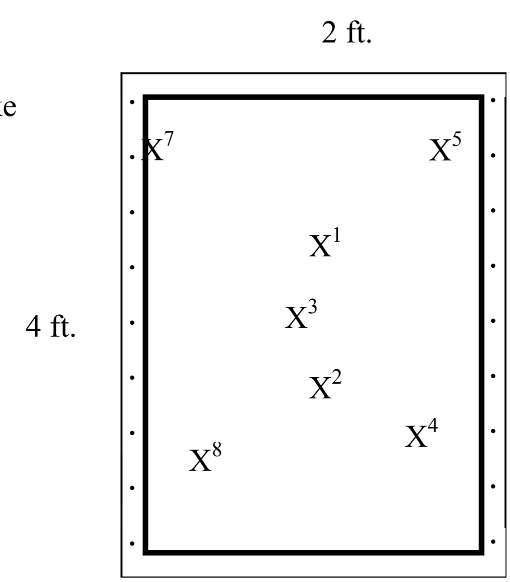
Panel Layout:	**Nailing Schedule and Location:**
2' x 4' Opening Strong Axis in 4' direction	12d common 6" along sides of the panel

Missile Impact:	**Pressure Test:**
___ None	___ None
_X_ 2x4	___ Monontoic to Failure ___ psf failure
___ Clay Tile	___ Cyclic ______ Design Wind Speed
	____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.54 lb	34 mph	Center - no penetration – slight indentation
2	4.54 lb	35 mph	Center (low) – indented panel - no penetration
3	4.54 lb	38 mph	Center - penetration
4	4.54 lb	37 mph	Middle Right – indented panel - no penetration
5	4.54 lb	38 mph	Upper Right - penetration
6	4.54 lb	38 mph	Missed High
7	4.54 lb	38 mph	Missed Left
8	4.54 lb	37 mph	Bottom Left - Penetration
9			
10			

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 5

Panel Type: 7/16 Oriented Strand Board

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

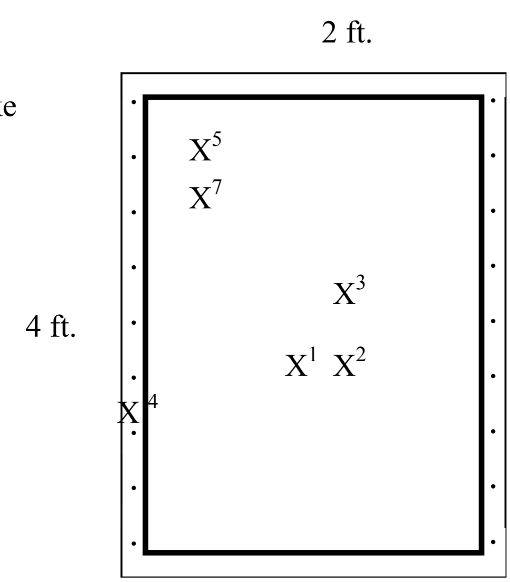
Missile Impact:
___ None
_X_ 2x4
___ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.54 lb	29 mph	Center - penetration
2	4.54 lb	26 mph	Center - penetration
3	4.54 lb	24 mph	Center Right - penetration
4	4.54 lb	NS	Missed Left
5	4.54 lb	24 mph	Upper Left - penetration
6	4.54 lb	23 mph	Upper Left - no penetration
7			
8			
9			
10			

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 6

Panel Type: 7/16 Oriented Strand Board

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

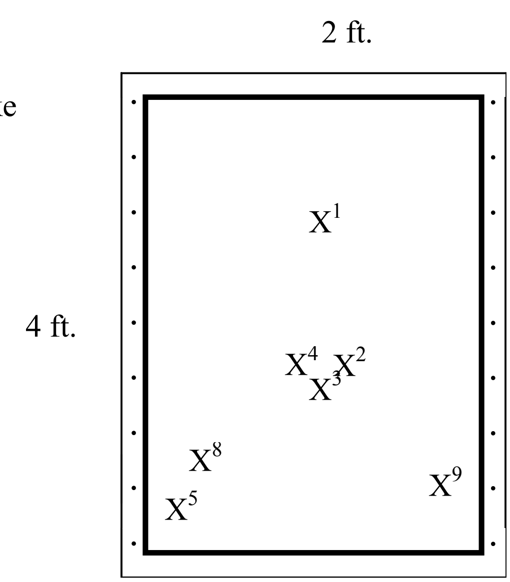
Missile Impact:
___ None
_X_ 2x4
___ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.54 lb	25 mph	Upper Middle - penetration
2	4.54 lb	21 mph	Center - penetration
3	4.54 lb	21 mph	Center - penetration
4	4.54 lb	21 mph	Middle Left - penetration
5	4.54 lb	NS	Lower Left - penetration
6	4.54 lb	19 mph	Missed Low
7	4.54 lb	19 mph	Missed Right
8	4.54 lb	18 mph	Missed Low
9	4.54 lb	19 mph	Lower Right - penetration
10			

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 7

Panel Type: 15/32 Plywood – 3 ply soaked for 24 hrs in water bath

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

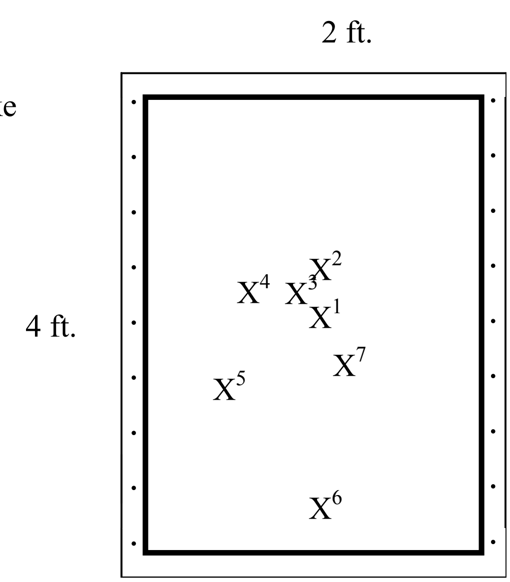
Missile Impact:
___ None
_X_ 2x4
___ Clay Tile

Pressure Test:
___ None
_X_ Monontoic to Failure 205 psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.54 lb	34 mph	Center - no penetration and no cracking – Nails across from impact starting to back out
2	4.54 lb	37 mph	No penetration
3	4.54 lb	40 mph	No penetration
4	4.54 lb	NS	Nails backing out
5	4.54 lb	44 mph	No penetration
6	9.0 lb	24 mph	Penetration
7	9.0 lb	22 mph	No Penetration
8			
9			

$X^{\#}$ - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 8

Panel Type: 15/32 Plywood – 4 ply soaked for 24 hrs in water bath

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

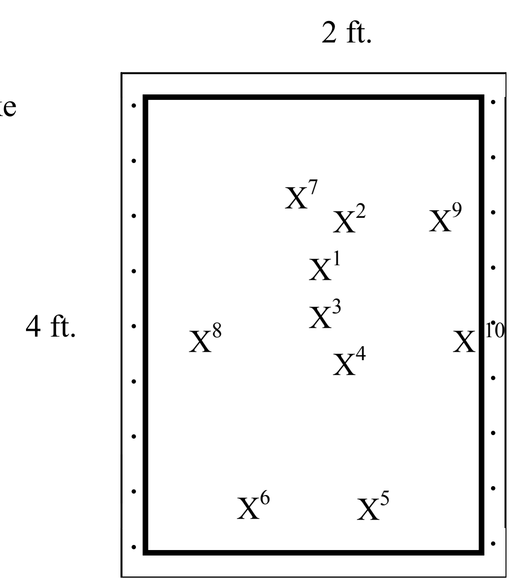
Missile Impact:
___ None
_X_ 2x4
___ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	9.0 lb	28 mph	No penetration, some nails backing out, no cracking
2	9.0 lb	32 mph	No penetration, some nails backing out, no cracking
3	9.0 lb	34 mph	No penetration, some nails backing out, no cracking
4	9.0 lb	36 mph	Cracking of plywood
5	9.0 lb	35 mph	Close to edge - penetration
6	9.0 lb	26 mph	Penetration in Lower LH Corner
7	9.0 lb	24 mph	Hit in middle of panel - No Penetration
8	9.0 lb	22 mph	No Penetration
9	9.0 lb	NS	No Penetration
10	9.0 lb	25 mph	Penetration

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 9

Panel Type: 7/16 Oriented Strand Board - soaked for 24 hrs in water bath

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

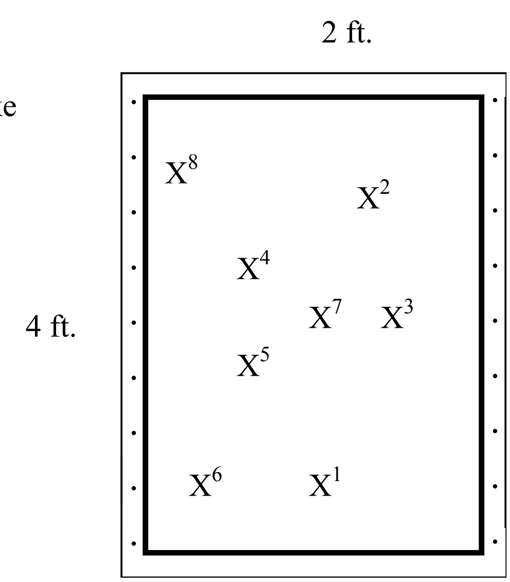
Missile Impact:
___ None
_X_ 2x4
___ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.54 lb	27 mph	Perforated panel but missile rebounded
2	4.54 lb	41 mph	Blew right through panel
3	4.54 lb	27 mph	
4	4.54 lb	26 mph	No Penetration or Perforation but dented panel
5	4.54 lb	29 mph	Punctured Panel but missile rejected
6	4.54 lb	30 mph	Perforation
7	4.54 lb	25 mph	No damage – hit middle of panel
8	4.54 lb	26 mph	Perforation along edge of panel but missile did not penetrate
9			
10			

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 10

Panel Type: 15/32 Plywood – 4 Ply

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

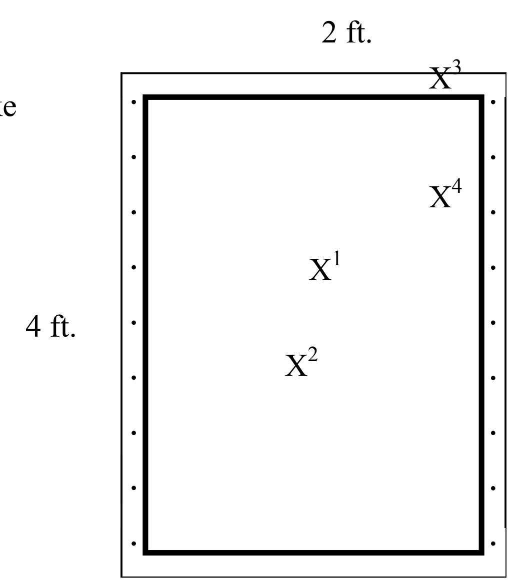
Missile Impact:
___ None
__ 2x4
_X_ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	6.68 lb	30 mph	Part of tile broke off in shutter – did not fully penetrate
2	6.67 lb	33 mph	Partial penetration
3	6.62 lb	27 mph	Hit too high
4	6.70 lb	34 mph	Tile punctured shutter and stuck in plywood (hit near edge)
5			
6			
7			
8			
9			
10			

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 11

Panel Type: 15/32 Plywood – 3 Ply

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

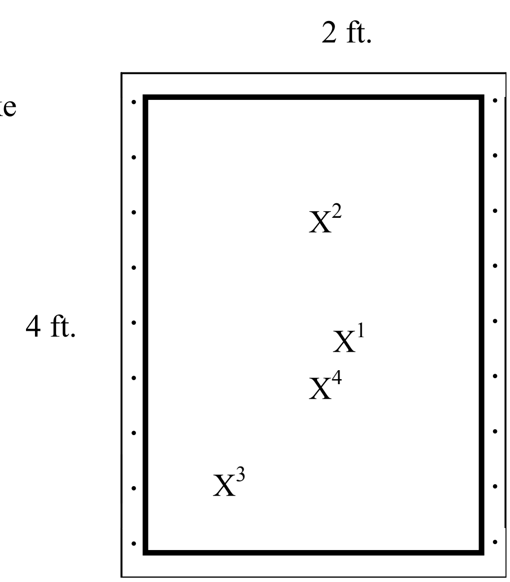
Missile Impact:
___ None
__ 2x4
_X_ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	6.74 lb	30 mph	Indented front and cracked back of shutter
2	6.67 lb	33 mph	Partial penetration, cracked large section of panel
3	6.67 lb	34 mph	Cut panel and cracked plywood
4	1.92 lb	34 mph	Partial tile, hit flat – little or no damage
5			
6			
7			
8			
9			
10			

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 12

Panel Type: 15/32 Plywood – 4 Ply

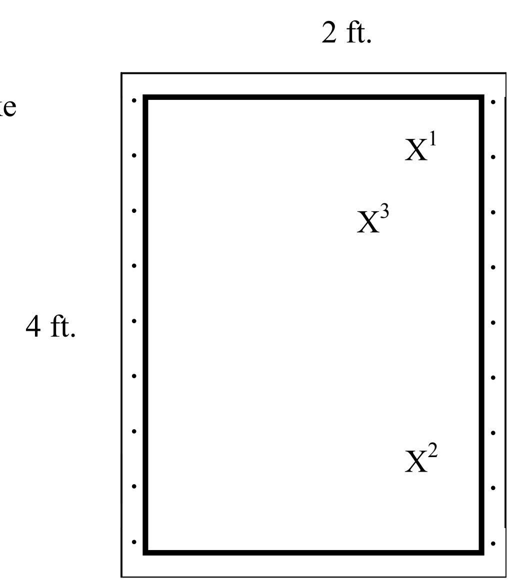
Panel Layout:	**Nailing Schedule and Location:**
2' x 4' Opening Strong Axis in 4' direction	12d common 6" along sides of the panel

Missile Impact:	**Pressure Test:**
___ None	**___ None**
__ 2x4	**___ Monontoic to Failure ___ psf failure**
_X_ Clay Tile	**___ Cyclic ______ Design Wind Speed**
	____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	**Missile Weight**	**Missile Speed**	**Damage Observation**
1	6.76 lb	37 mph	Perforation of shutter, tile bounced back, wood split
2	6.64 lb	34 mph	Punctured shutter some tile stuck in shutter
3	4.3 lb	34 mph	Indented panel surface but no perforation
4			
5			
6			
7			
8			
9			
10			

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 13

Panel Type: 7/16 Oriented Strand Board

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

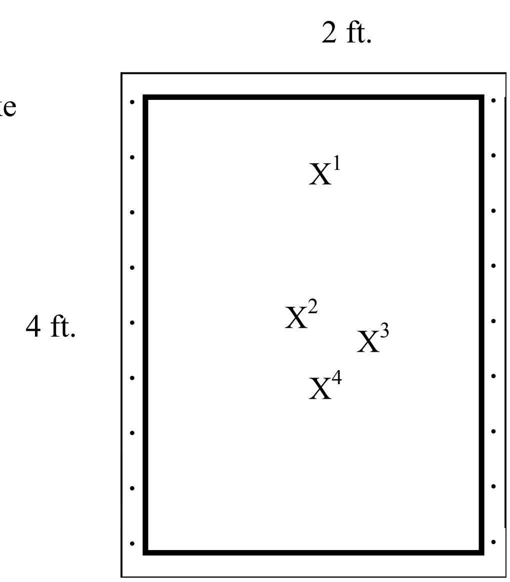
Missile Impact:
___ None
__ 2x4
_X_ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	6.64 lb	30 mph	Shutter penetrated by missile – left a large hole in shutter
2	6.70 lb	~25mph	Rotated as it hit, no visible damage
3	6.74 lb	~25mph	Rotated as it hit, no visible damage
4	6.72 lb	28 mph	Penetration of OSB – Tile stuck in OSB
5			
6			
7			
8			
9			
10			

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 14

Panel Type: 7/16 Oriented Strand Board

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

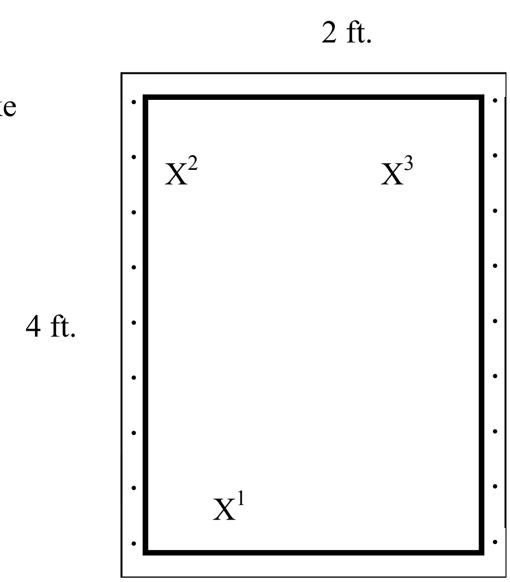
Missile Impact:
___ None
__ 2x4
_X_ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	6.72 lb	27 mph	Penetrated panel knocked big hole in panel
2	6.76 lb	NS	Slight cut in panel
3	6.74 lb	26 mph	Broke panel but tile fell to outside of panel
4			
5			
6			
7			
8			
9			
10			

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 15

Panel Type: 7/16 Oriented Strand Board

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

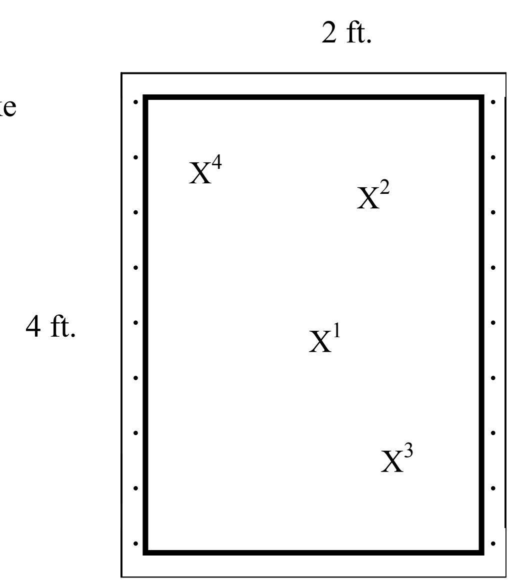
Missile Impact:
___ None
__ 2x4
_X_ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	6.64 lb	25 mph	Penetrated panel
2	6.62 lb	27 mph	Heavy damage – dented panel
3	6.62 lb	28 mph	Threshold penetration
4	6.62 lb	28 mph	Penetration
5			
6			
7			
8			
9			
10			

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panels 16 and 17

Panel Type: 15/32 Plywood – 4 Ply; Two 3'-9" by 5'-6" panels

Panel Layout:
5' x 7' Opening; Two panels with strong axis oriented in 5' direction (2 vertical panels)

Nailing Schedule and Location:
12d common 4" along top and bottom of the panel

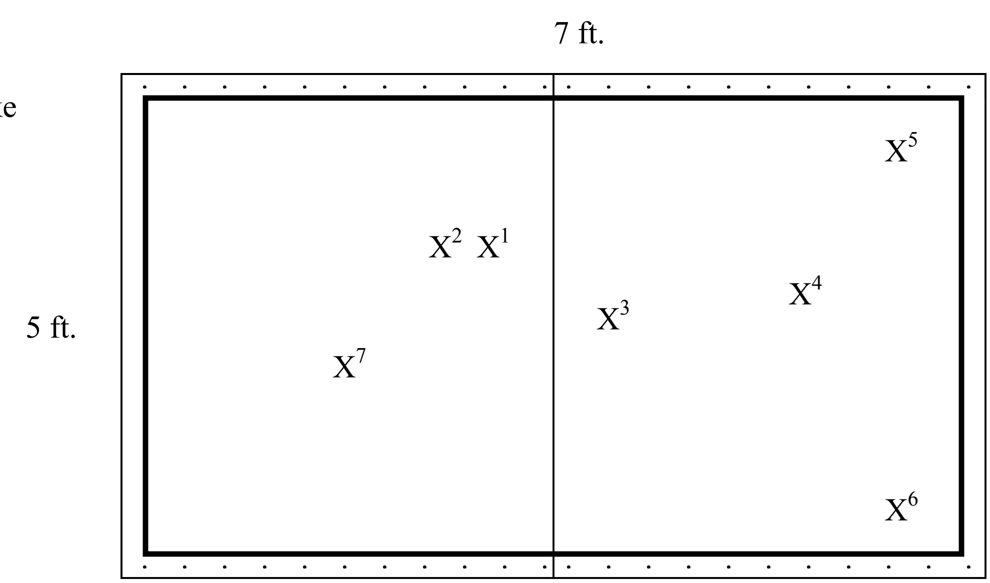
Missile Impact:
___ None
__ 2x4
_X_ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	6.64 lb	29 mph	Scuff marks on surface of panel
2	6.62 lb	33 mph	Hit on top of first hit, broke plywood but bounced off
3	6.62 lb	35 mph	Cracked plywood but bounced off
4	6.64 lb	NS	Rotating as it hit, no damage
5	6.62 lb	37 mph	Slight rotation as tile hit shutter – indented surface of shutter
6	6.64 lb	41 mph	Cut through surface of shutter, some tile stuck in the shutter
7	6.62 lb	41 mph	Cracking of already damaged plywood
8			
9			
10			

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panels 18 and 19

Panel Type: 7/16 Oriented Strand Board; Two 3'-9" by 5'-6" panels

Panel Layout:
5' x 7' Opening; Two panels with strong axis oriented in 5' direction (2 vertical panels)

Nailing Schedule and Location:
12d common 4" along top and bottom of the panel

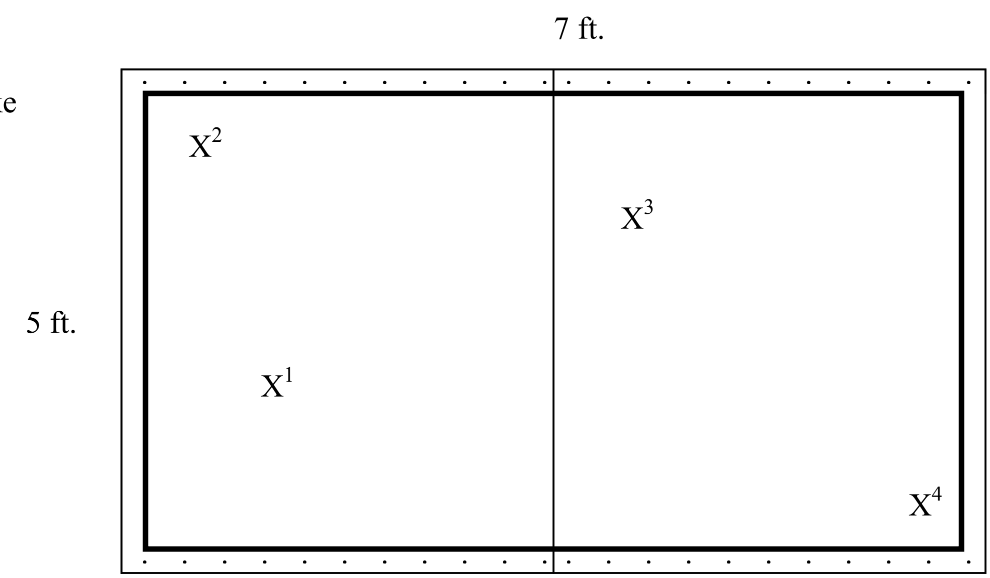
Missile Impact:
___ None
__ 2x4
_X_ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	6.62 lb	35 mph	Punched through shutter, some broken tile got past shutter
2	6.58 lb	33 mph	Surface crack, local shearing of OSB
3	6.60 lb	34 mph	Broke hole in OSB panel and split panel to middle edge
4	6.60 lb	32 mph	Indented surface at edge of panel (partial perforation)
5			
6			
7			
8			
9			
10			

$X^{\#}$ - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panels 20 and 21

Panel Type: 15/32 Plywood – 3 Ply; Two 3'-9" by 5'-6" panels

Panel Layout:
5' x 7' Opening; Two panels with strong axis oriented in 5' direction (2 vertical panels)

Nailing Schedule and Location:
12d common 4" along top and bottom of the panel

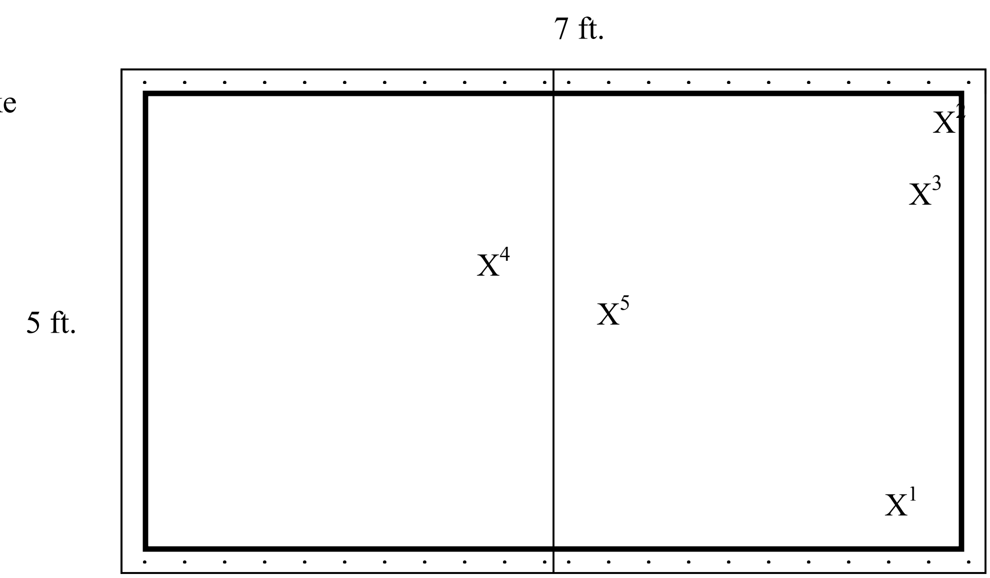
Missile Impact:
___ None
__ 2x4
_X_ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	6.58 lb	37 mph	Broke through panel – some tile inside window
2	6.62 lb	37 mph	Hit partially on support at edge of window – partially cut through shutter
3	6.70 lb	35 mph	Cracked panel, split plywood, some debris inside window
4	6.70 lb	40 mph	Cracked interior ply of plywood, panel more flexible
5	6.64 lb	41 mph	Cracked interior and exterior plys
6			
7			
8			
9			

X[#] - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panels 22 and 23

Panel Type: 7/16 Oriented Strand Board; Two 7'-6" by 2'-9" panels

Panel Layout:
5' x 7' Opening; Two panels with strong axis oriented in 7' direction (2 horizontal panels)

Nailing Schedule and Location:
12d common 3" along each side of the panel

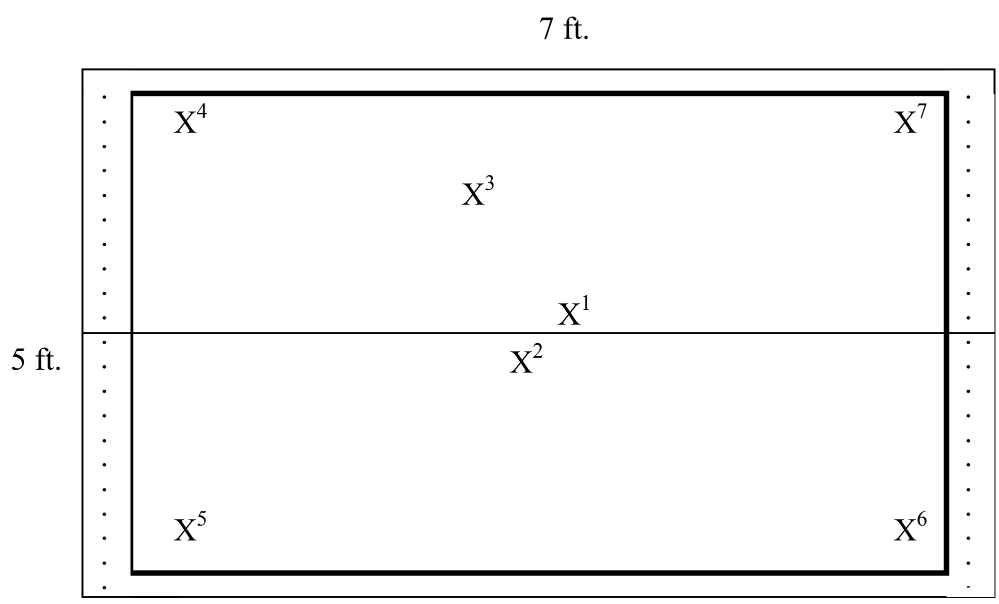
Missile Impact:
___ None
__ 2x4
_X_ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	6.62 lb	38 mph	Punched hole in shutter
2	6.62 lb	36 mph	Punched right through shutter, partially hit first hole
3	6.60 lb	35 mph	Punched right through shutter
4	6.62 lb	34 mph	Punched hole in shutter but missile bounced off
5	6.60 lb	33 mph	Sliced panel but missile bounced off
6	6.66 lb	32 mph	Sliced through panel, part of missile penetrated
7	6.66 lb	30 mph	Punched hole but missile bounced off
8			
9			
10			

X# Missile Strike Location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panels 24 and 25

Panel Type: 15/32 Plywood; Two 7'-6" by 2'-9" panels; Top panel is 3-ply and Bottom panel is 4-ply

Panel Layout:
5' x 7' Opening; Two panels with strong axis oriented in 7' direction (2 horizontal panels)

Nailing Schedule and Location:
12d common 3" along each side of the panel

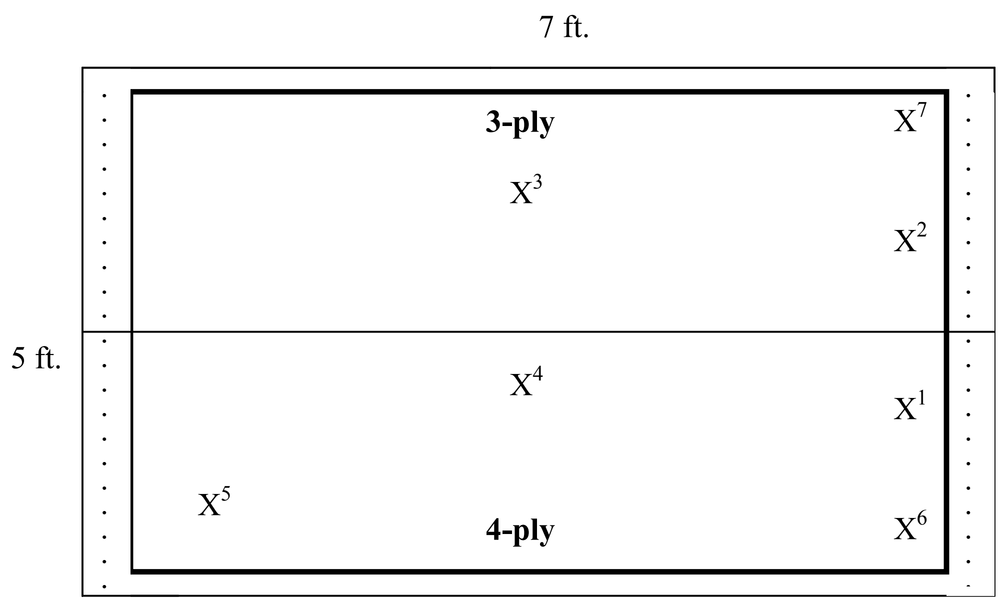
Missile Impact:
___ None
__ 2x4
_X_ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	6.68 lb	46 mph	Punched hole in 4 ply panel
2	6.68 lb	43 mph	Punched hole in 3 ply panel
3	6.62 lb	44 mph	Cracked panel from top to near middle of panel
4	6.64 lb	45 mph	Triple crack in plywood
5	6.64 lb	41 mph	Cracked panel but rejected missile
6			
7			
8			
9			
10			

X# Missile Strike Location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panels 26 and 27

Panel Type: 15/32 Plywood; Two 7'-6" by 2'-9" panels; Top panel is 3-ply and Bottom panel is 4-ply

Panel Layout:
5' x 7' Opening; Two panels with strong axis oriented in 7' direction (2 horizontal panels)

Nailing Schedule and Location:
12d common 3" along each side of the panel

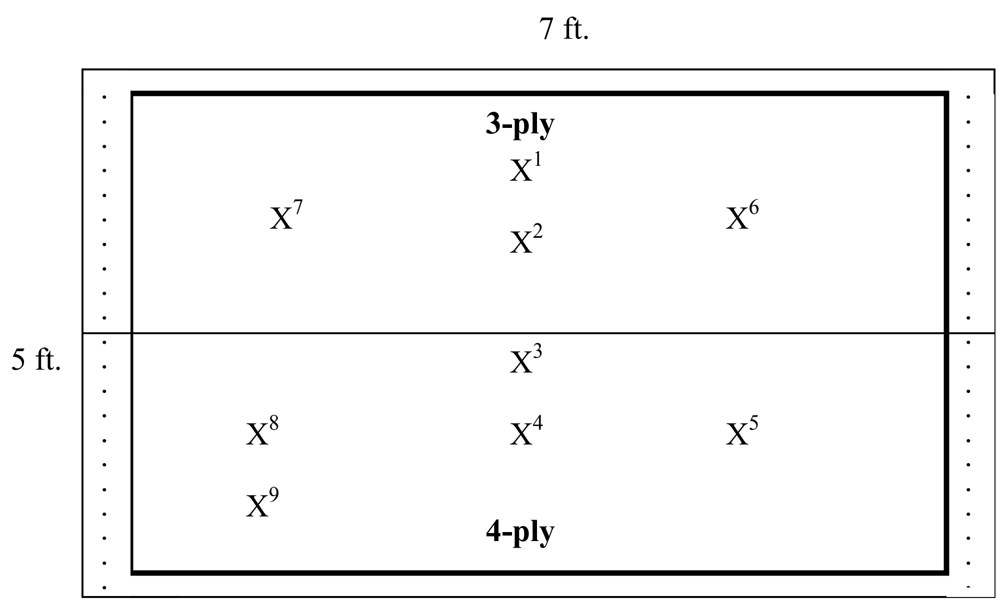
Missile Impact:
___ None
_X_ 2x4
__ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.54 lb	44 mph	Cracked inside ply of 3-ply panel
2	4.54 lb	46 mph	Penetration
3	4.54 lb	NS	Approx 46 mph, penetrated
4	4.54 lb	43 mph	Penetrated panel
5	4.54 lb	40 mph	Punctured panel
6	4.54 lb	39 mph	Punctured panel
7	4.54 lb	38 mph	Cracked panel but bounced off
8	4.54 lb	38 mph	Penetrated
9	4.54 lb	36 mph	Penetrated
10	4.54 lb	34 mph	Cracked back of panel but bounced off

X# Missile Strike Location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panels 28 and 29

Panel Type: 15/32 Plywood; Two 3'-9" by 5'-6" panels; 4-ply on left and 3-ply on right

Panel Layout:
5' x 7' Opening; Two panels with strong axis oriented in 5' direction (2 vertical panels)

Nailing Schedule and Location:
12d common 4" along top and bottom of the panel

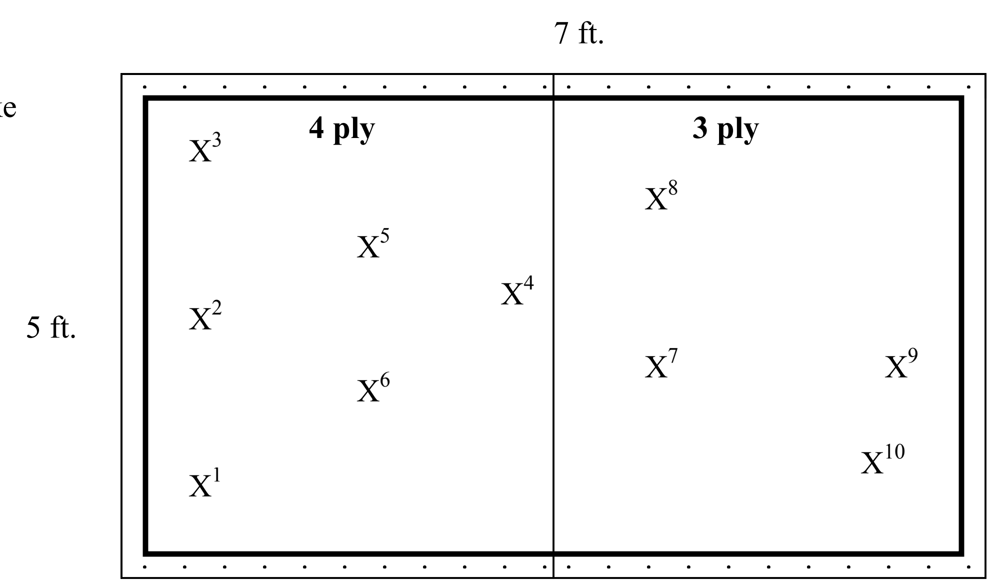
Missile Impact:
___ None
_X_ 2x4
__ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.54 lb	34 mph	Puncture of 4-ply panel
2	4.54 lb	32 mph	Punctured panel
3	4.54 lb	30 mph	Cracked surface and back plys of panel
4	4.54 lb	30 mph	Cracked panel
5	4.54 lb	34 mph	Penetrated panel
6	4.54 lb	34 mph	Penetrated panel
7	4.54 lb	33 mph	Indented panel, cracked interior ply
8	4.54 lb	37 mph	Cracked panel
9	4.54 lb	36 mph	Penetrated panel
10	4.54 lb	33 mph	Indented surfaced and cracked panel

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panels 30 and 31

Panel Type: 7/16 Oriented Strand Board; Two 7'-6" by 2'-9" panels

Panel Layout:
5' x 7' Opening; Two panels with strong axis oriented in 7' direction (2 horizontal panels)

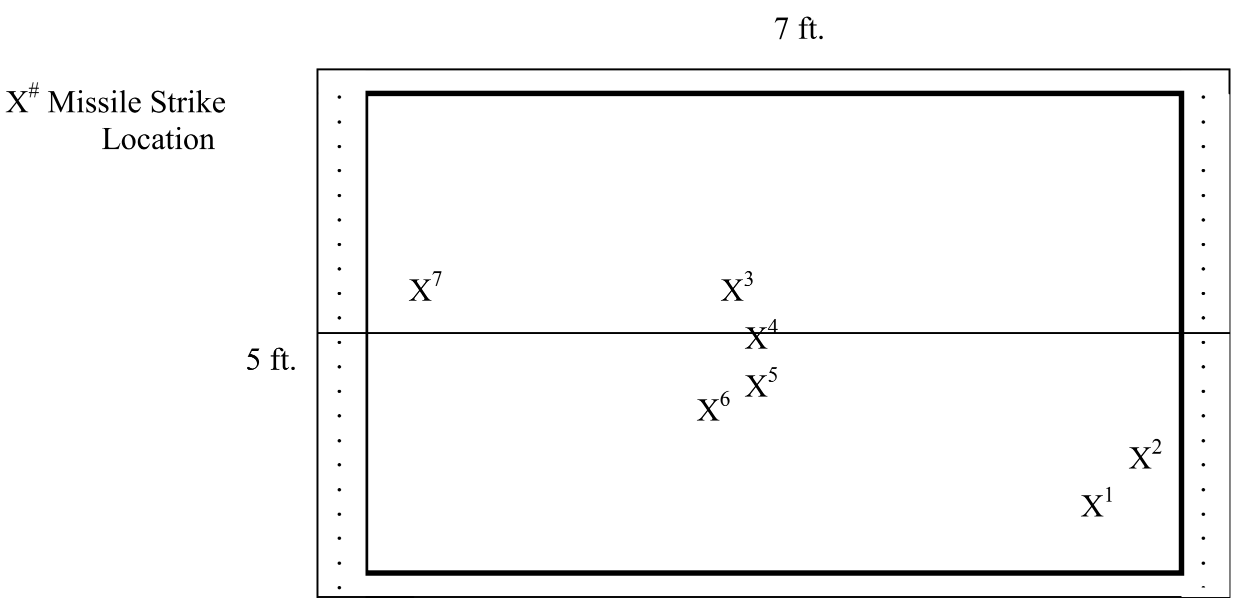
Nailing Schedule and Location:
12d common 3" along each side of the panel

Missile Impact:
___ None
_X_ 2x4
__ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.54 lb	25 mph	Penetration
2	4.54 lb	21 mph	Penetration
3	4.54 lb	23 mph	Cracked back, partial break but did not penetrate
4	4.56 lb	25 mph	Local cracking, impacted on seam between panels
5	4.56 lb	25 mph	Indented panel but did not penetrate
6	4.56 lb	29 mph	Broke panel at previously damaged area
7	4.56 lb	22 mph	Penetration
8			
9			
10			



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panels 32 and 33

Panel Type: 7/16 Oriented Strand Board; Two 3'-9" by 5'-6" panels

Panel Layout:
5' x 7' Opening; Two panels with strong axis oriented in 5' direction (2 vertical panels)

Nailing Schedule and Location:
12d common 4" along top and bottom of the panel

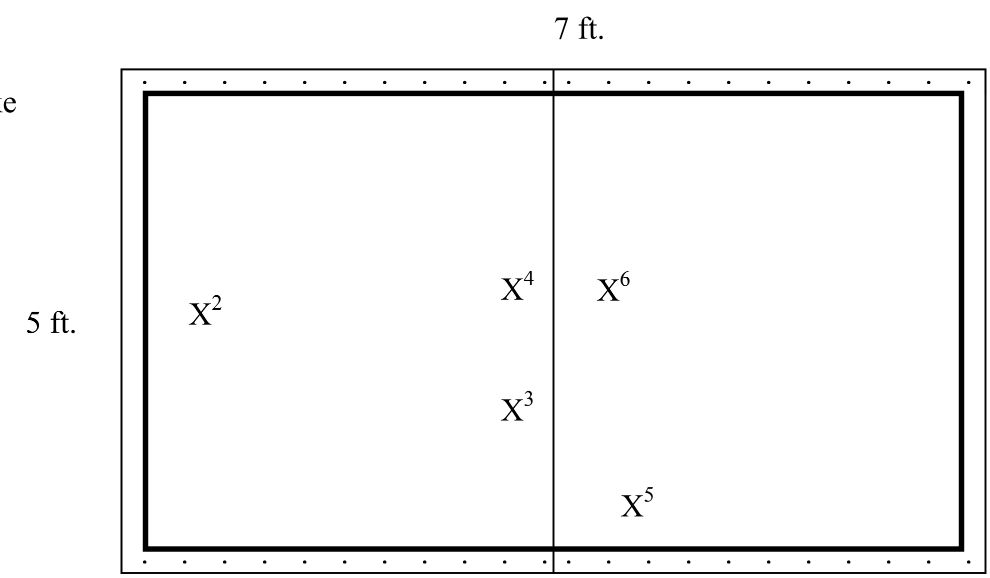
Missile Impact:
___ None
_X_ 2x4
__ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.56 lb	18 mph	Missed low
2	4.56 lb	21 mph	Indented OSB but did not penetrate
3	4.56 lb	24 mph	Scuffed up surface
4	4.56 lb	27 mph	Penetrated panel
5	4.56 lb	26 mph	Penetrated panel
6	4.56 lb	24 mph	Penetrated panel
7			
8			
9			
10			

$X^{\#}$ - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 34

Panel Type: 7/16 Oriented Strand Board – alternating 24 hr. wet and dry cycles over a two week period

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

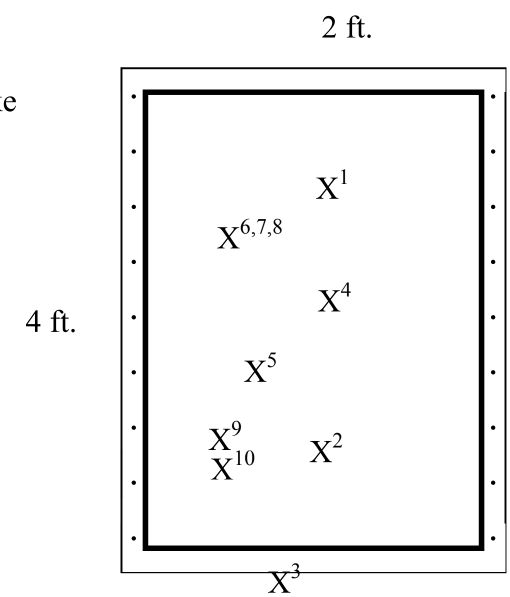
Missile Impact:
___ None
_X_ 2x4
___ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.02 lb	41 mph	Penetration
2	4.02 lb	32 mph	Penetration
3	4.02 lb	21 mph	Missed panel
4	4.02 lb	28 mph	Penetration
5	4.02 lb	25 mph	Dented panel
6	4.02 lb	25 mph	Dent – Full imprint of 2x4
7	4.02 lb	26 mph	Hit same spot as #6
8	4.02 lb	27 mph	Hit same spot as #6
9	4.02 lb	25 mph	Penetration
10	4.02 lb	23 mph	Slightly below #9, penetration

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 35

Panel Type: 7/16 Oriented Strand Board - alternating 24 hr. wet and dry cycles over a two week period

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

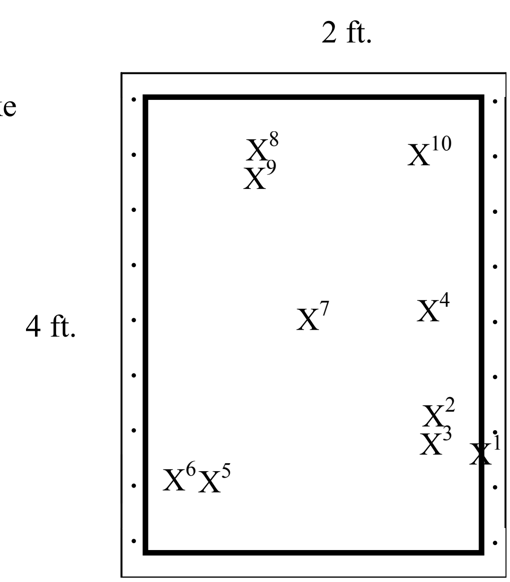
Missile Impact:
___ None
_X_ 2x4
___ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.02 lb	25 mph	Edge
2	4.02 lb	23 mph	Small Dent
3	4.02 lb	25 mph	Penetration
4	4.02 lb	24 mph	Dent
5	4.02 lb	25 mph	Dent
6	4.02 lb	25 mph	Dent
7	4.02 lb	26 mph	Dent
8	4.02 lb	27 mph	Dent
9	4.02 lb	27 mph	Dent
10	4.02 lb	27 mph	Penetration

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 36

Panel Type: 15/32 Plywood 3-ply - alternating 24 hr. wet and dry cycles over a two week period

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

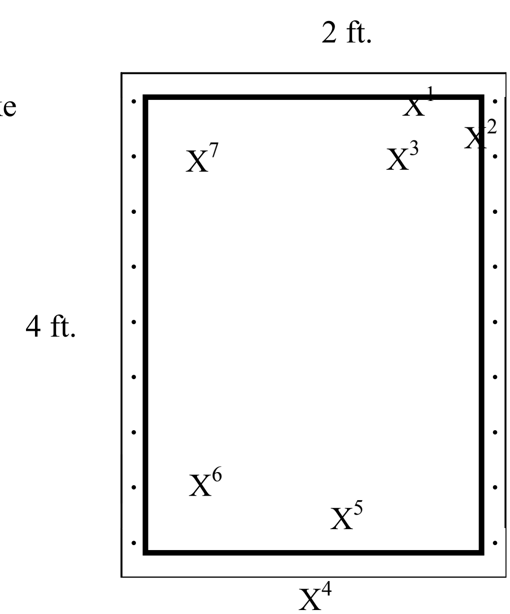
Missile Impact:
___ None
_X_ 2x4
___ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.02 lb	30 mph	None
2	4.02 lb	35 mph	None
3	4.02 lb	33 mph	Light cracking of back
4	4.02 lb	28 mph	Miss
5	4.02 lb	36 mph	Cracking in back
6	4.02 lb	39 mph	Dent
7	4.02 lb	40 mph	Penetration
8			
9			
10			

X# - Missile strike location



ARA / DCA Impact Tests for Code Minimum Shutters

Test Number: Panel 37

Panel Type: 15/32 Plywood 3-ply - alternating 24 hr. wet and dry cycles over a two week period

Panel Layout:
2' x 4' Opening Strong Axis in 4' direction

Nailing Schedule and Location:
12d common 6" along sides of the panel

Missile Impact:
___ None
_X_ 2x4
___ Clay Tile

Pressure Test:
___ None
___ Monontoic to Failure ___ psf failure
___ Cyclic ______ Design Wind Speed
____ Number of Cycles to Failure

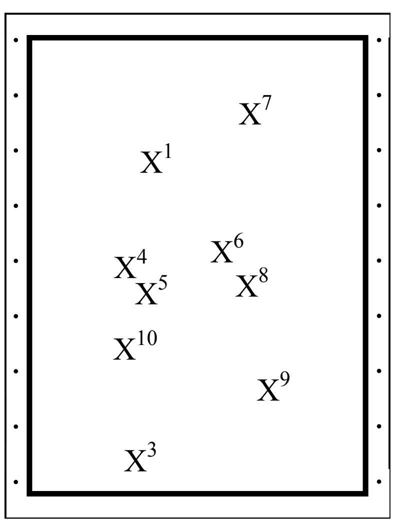
Results of Missile Tests:

Impact #	Missile Weight	Missile Speed	Damage Observation
1	4.02 lb	36 mph	Light cracking in back
2	4.00 lb	25 mph	Miss
3	4.00 lb	25 mph	None
4	4.00 lb	34 mph	Light cracking in back
5	4.00 lb	38 mph	Penetration
6	4.00 lb	37 mph	Moderate cracking in back
7	4.00 lb	39 mph	Penetration
8	4.00 lb	38 mph	Light cracking in back
9	4.00 lb	38 mph	Cracking in back
10	4.00 lb	38 mph	None

2 ft.

X# - Missile strike location

4 ft.



APPENDIX B

Detailed Observations from Cyclic Pressure Tests

Plywood Hurricane Shutter Testing

Shutter Description		
	Test Number	Panel 1 - No Missile Shots
	Panel Type	3 ply 3'x5' Plywood
	Panel Size	42"x66"
	Rough Opening Size	36"x60"
	Test Completion Date	30-Apr-03
	Nail	
	Type	12-D Commons
	Length	3.25"
	Embed Depth	1.75"
	Spacing	6"
	Edge Distance	2.25"
	Location	Left and right sides
Missile Impact		
	Missile	None
Pressures		
	Cycles	Pressures for a Basic Wind Speed of 150 mph, Partially Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	75 psf
	Max Negative	94 psf
	Status	Passed
	Static	
	Status	Failed at 145 psf
	Failure Description	Left side - nails pulled out
Notes		
	Notes	None

Number of Cycles	Pressure	
3500	+37.5 psf	Load 1
300	+45.0 psf	Load 2
600	+60.0 psf	Load 3
100	+75.0 psf	Load 4
50	-94.0 psf	Load 5
1050	-75.2 psf	Load 6
50	-56.4 psf	Load 7
3350	-47.0 psf	Load 8

X	•
X	•
X	•
X	•
X	•
X	•
X	•
X	•
X	•
X	•

Plywood Hurricane Shutter Testing

Shutter Description		
	Test Number	Panel 2 - No Missile Shots
	Panel Type	3'x5' OSB
	Panel Size	42"x66"
	Rough Opening Size	36"x60"
	Test Completion Date	30-Apr-03
	Nail	
	Type	12-D Commons
	Length	3.25"
	Embed Depth	1.75"
	Spacing	6"
	Edge Distance	2.25"
	Location	Left and right sides
Missile Impact		
	Missile	None
Pressures		
	Cycles	Pressures for a Basic Wind Speed of 150 mph, Partially Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	75 psf
	Max Negative	94 psf
	Status	Failed
	Failure Description	Right side – nails pulled out on Load 6
	Static	
	Status	None due to failure during cyclic test
Notes		
	Notes	Several nails were driven into old nail holes

Number of Cycles	Pressure	
3500	+37.5 psf	Load 1
300	+45.0 psf	Load 2
600	+60.0 psf	Load 3
100	+75.0 psf	Load 4
50	-94.0 psf	Load 5
1050	-75.2 psf	Load 6
50	-56.4 psf	Load 7
3350	-47.0 psf	Load 8

•	X
•	X
•	X
•	o
•	X
•	X
•	X
•	X
•	X
•	X
•	X

Plywood Hurricane Shutter Testing

Shutter Description		
	Test Number	Panel 3 - No Missile Shots
	Panel Type	3'x5' OSB
	Panel Size	42"x66"
	Rough Opening Size	36"x60"
	Test Completion Date	1-May-03
	Nail	
	Type	12-D Commons
	Length	3.25"
	Embed Depth	1.75"
	Spacing	6"
	Edge Distance	2.25"
	Location	Left and right sides
Missile Impact		
	Missile	None
Pressures		
	Cycles	Pressures for a Basic Wind Speed of 150 mph, Partially Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	75 psf
	Max Negative	94 psf
	Status	Passed
	Static	
	Status	Failed at 150 psf
	Failure Description	Left side – ½ head pull through & ½ nail withdrawal
Notes		
	Notes	None

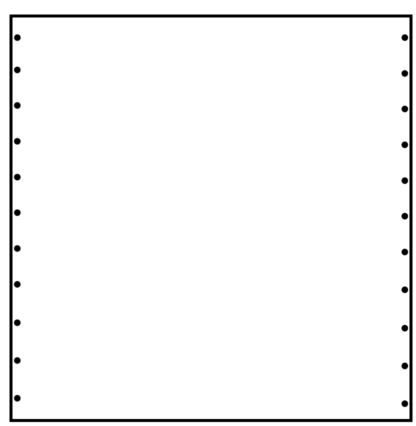
Number of Cycles	Pressure	
3500	+37.5 psf	Load 1
300	+45.0 psf	Load 2
600	+60.0 psf	Load 3
100	+75.0 psf	Load 4
50	-94.0 psf	Load 5
1050	-75.2 psf	Load 6
50	-56.4 psf	Load 7
3350	-47.0 psf	Load 8

X	•
X	•
O	•
O	•
X	•
O	•
X	•
O	•
O	•
X	•
X	•

Plywood Hurricane Shutter Testing

Shutter Description		
	Test Number	Panel 4 - No Missile Shots
	Panel Type	4 ply 3'x5' Plywood
	Panel Size	42"x66"
	Rough Opening Size	36"x60"
	Test Completion Date	5-May-03
	Nail	
	Type	12-D Commons
	Length	3.25"
	Embed Depth	1.75"
	Spacing	6"
	Edge Distance	2.25"
	Location	Left and right sides
Missile Impact		
	Missile	None
Pressures		
	Cycles	Pressures for a Basic Wind Speed of 150 mph, Partially Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	75 psf
	Max Negative	94 psf
	Status	Passed
	Static	
	Status	Sustained 154 psf
		Failed at 209 psf in floor mounted chamber
Notes		
	Notes	Nails backed out about 1/8” to ¼”

Number of Cycles	Pressure	
3500	+37.5 psf	Load 1
300	+45.0 psf	Load 2
600	+60.0 psf	Load 3
100	+75.0 psf	Load 4
50	-94.0 psf	Load 5
1050	-75.2 psf	Load 6
50	-56.4 psf	Load 7
3350	-47.0 psf	Load 8



Plywood Hurricane Shutter Testing

Shutter Description		
	Test Number	Panel 1 - With Missile Shots
	Panel Type	4 ply 3'x5' Plywood
	Panel Size	42"x66"
	Rough Opening Size	36"x60"
	Test Completion Date	20-May-03
	Nail	
	Type	12-D Commons
	Length	3.25"
	Embed Depth	1.75"
	Spacing	6"
	Edge Distance	2.25"
	Location	Left and right sides
Missile Impact		
	Shot 1	Penetrated through center of panel
	Hole Propagated?	No
Pressures		
	Cycles	Pressures for a Basic Wind Speed of 150 mph, Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	56 psf
	Max Negative	77 psf
	Status	Passed
	Static	
	Status	Failed at 145 psf
	Failure Description	Right side - nails pulled out
Notes		
	Notes	None

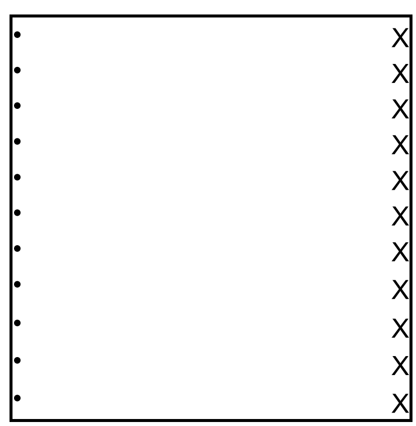
Number of Cycles	Pressure	
3500	+28.0 psf	Load 1
300	+33.6 psf	Load 2
600	+44.8 psf	Load 3
100	+56.0 psf	Load 4
50	-75.6 psf	Load 5
1050	-60.5 psf	Load 6
50	-45.4 psf	Load 7
3350	-37.8 psf	Load 8

•	X
•	X
•	X
•	X
•	X
•	X
•	X
•	X
•	X
•	X
•	X

Plywood Hurricane Shutter Testing

Shutter Description		
	Test Number	Panel 2 - With Missile Shots
	Panel Type	4 ply 3'x5' Plywood
	Panel Size	42"x66"
	Rough Opening Size	36"x60"
	Test Completion Date	20-May-03
	Nail	
	Type	12-D Commons
	Length	3.25"
	Embed Depth	1.75"
	Spacing	6"
	Edge Distance	2.25"
	Location	Left and right sides
Missile Impact		
	Shot 1	Penetrated Top Left
	Shot 2	Penetrated Middle Right
	Shot 3	Penetrated Middle Right
	Holes Propagated?	No
Pressures		
	Cycles	Pressures for a Basic Wind Speed of 150 mph, Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	56 psf
	Max Negative	77 psf
	Status	Passed
	Static	
	Status	Failed at 105 psf
	Failure Description	Right side - nails pulled out
Notes		
	Notes	None

Number of Cycles	Pressure	
3500	+28.0 psf	Load 1
300	+33.6 psf	Load 2
600	+44.8 psf	Load 3
100	+56.0 psf	Load 4
50	-75.6 psf	Load 5
1050	-60.5 psf	Load 6
50	-45.4 psf	Load 7
3350	-37.8 psf	Load 8



Plywood Hurricane Shutter Testing

Shutter Description		
	Test Number	Panel 3 - With Missile Shots
	Panel Type	3'x5' OSB
	Ppanel Size	42"x66"
	Rough Opening Size	36"x60"
	Test Completion Date	20-May-03
	Nail	
	Type	12-D Commons
	Length	3.25"
	Embed Depth	1.75"
	Spacing	6"
	Edge Distance	2.25"
	Location	Left and right sides
Missile Impact		
	Shot 1	Penetrated Middle Left
	Shot 2	Penetrated Bottom Center
	Shot 3	Penetrated Middle Right
	Shot 4	Penetrated Bottom Right
	Holes Propagated?	No
Pressures		
	Cycles	Pressures for a Basic Wind Speed of 150 mph, Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	56 psf
	Max Negative	77 psf
	Status	Passed
	Static	
	Status	Failed at 120 psf
	Failure Description	Both side - nails pulled out
Notes		
	Notes	None

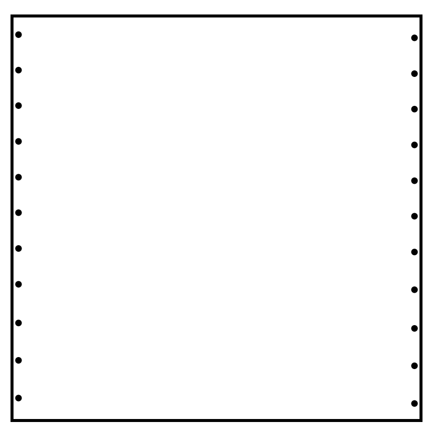
Number of Cycles	Pressure	
3500	+28.0 psf	Load 1
300	+33.6 psf	Load 2
600	+44.8 psf	Load 3
100	+56.0 psf	Load 4
50	-75.6 psf	Load 5
1050	-60.5 psf	Load 6
50	-45.4 psf	Load 7
3350	-37.8 psf	Load 8

X	X
X	X
X	X
X	X
X	X
X	X
X	X
X	X
X	X
X	X
X	X

Plywood Hurricane Shutter Testing

Shutter Description		
	Test Number	Panel 4 - With Missile Shots
	Panel Type	3'x5' OSB
	Panel Size	42"x66"
	Rough Opening Size	36"x60"
	Test Completion Date	20-May-03
	Nail	
	Type	12-D Commons
	Length	3.25"
	Embed Depth	1.75"
	Spacing	6"
	Edge Distance	2.25"
	Location	Left and right sides
Missile Impact		
	Shot 1	Penetrated Center of Panel
	Hole Propagated?	No
Pressures		
	Cycles	Pressures for a Basic Wind Speed of 150 mph, Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	56 psf
	Max Negative	77 psf
	Status	Passed
	Static	
	Status	Sustained 188 psf
Notes		
	Notes	None

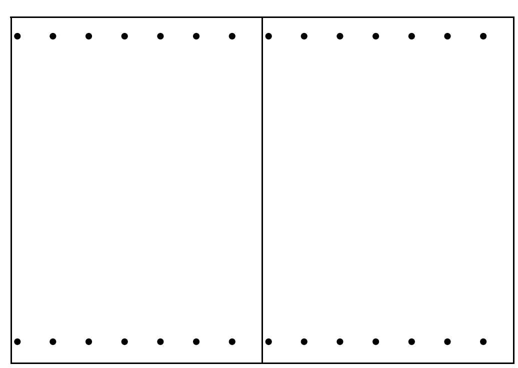
Number of Cycles	Pressure	
3500	+28.0 psf	Load 1
300	+33.6 psf	Load 2
600	+44.8 psf	Load 3
100	+56.0 psf	Load 4
50	-75.6 psf	Load 5
1050	-60.5 psf	Load 6
50	-45.4 psf	Load 7
3350	-37.8 psf	Load 8



Plywood Hurricane Shutter Testing

Shutter Description		
	Test Number	Large Panel 1 - No Missile Shots
	Panel Type	4-Ply Plywood
	Panel Size	2 @ 66"x45" vertically spanning opening
	Rough Opening Size	60"x84"
	Test Completion Date	27-May-03
	Nail	
	Type	12-D Commons
	Length	3.25"
	Embed Depth	1.75"
	Spacing	4"
	Edge Distance	2.25"
	Location	Top and Bottom Edges
Missile Impact		
	None	
Pressures		
	Cycles	Pressures for a Basic Wind Speed of 130 mph, Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	43 psf
	Max Negative	57 psf
	Status	Passed
	Cycles	Pressures for a Basic Wind Speed of 150 mph, Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	56 psf
	Max Negative	77 psf
	Status	Passed
Notes		
	Notes	None

Number of Cycles	Pressure (150 mph)	
3500	+28.0 psf	Load 1
300	+33.6 psf	Load 2
600	+44.8 psf	Load 3
100	+56.0 psf	Load 4
50	-75.6 psf	Load 5
1050	-60.5 psf	Load 6
50	-45.4 psf	Load 7
3350	-37.8 psf	Load 8



Plywood Hurricane Shutter Testing		
Shutter Description		
	Test Number	Large Panel 2 - No Missile Shots
	Plywood Type	3-Ply Plywood
	Plywood Size	2 @ 33"x90" Horizontally Spanning Opening
	Rough Opening Size	60"x84"
	Test Completion Date	27-May-03
	Nail	
	Type	12-D Commons
	Length	3.25"
	Embed Depth	1.75"
	Spacing	3"
	Edge Distance	2.25"
	Location	Left and right sides
Missile Impact		
	None	
Pressures		
	Cycles	Pressures for a Basic Wind Speed of 130 mph, Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	43 psf
	Max Negative	57 psf
	Status	Passed
	Cycles	Pressures for a Basic Wind Speed of 150 mph, Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	56 psf
	Max Negative	77 psf
	Status	Passed
Notes		
	Notes	None

Number of Cycles	Pressure (150 mph)	
3500	+28.0 psf	Load 1
300	+33.6 psf	Load 2
600	+44.8 psf	Load 3
100	+56.0 psf	Load 4
50	-75.6 psf	Load 5
1050	-60.5 psf	Load 6
50	-45.4 psf	Load 7
3350	-37.8 psf	Load 8

Plywood Hurricane Shutter Testing

Shutter Description		
	Test Number	Large Panel 3 - No Missile Shots
	Plywood Type	3-Ply Plywood
	Plywood Size	2 @ 44"x90" Horizontally Spanning Opening
	Rough Opening Size	80"x84"
	Test Completion Date	27-May-03
	Nail	
	Type	12-D Commons
	Length	3.25"
	Embed Depth	1.75"
	Spacing	3"
	Edge Distance	2.25"
	Location	Left and right sides
Missile Impact		
	None	
Pressures		
	Cycles	Pressures for a Basic Wind Speed of 130 mph, Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	43 psf
	Max Negative	57 psf
	Status	Passed
	Cycles	Pressures for a Basic Wind Speed of 150 mph, Enclosed Design, Exposure C, Wall Zone 5
	Max Positive	56 psf
	Max Negative	77 psf
	Status	Passed
Notes		
	Notes	None

Number of Cycles	Pressure (150 mph)	
3500	+28.0 psf	Load 1
300	+33.6 psf	Load 2
600	+44.8 psf	Load 3
100	+56.0 psf	Load 4
50	-75.6 psf	Load 5
1050	-60.5 psf	Load 6
50	-45.4 psf	Load 7
3350	-37.8 psf	Load 8

APPENDIX C

Observations from Constant Amplitude Cyclic Pressure Tests
And
Repeated Single Fastener Withdrawal Tests from the Same Hole

Results of Repeated Constant Amplitude Cyclic Pressure Tests

Frame 1 (OSB)	
Static failure	75 psf Failed
4 cycles -	80 psf Failed
1 cycle -	70 psf Failed
2200 cycles -	60 psf NO FAILURE then taken to static failure at 78 psf
Frame 2 (4 ply plywood)	
Static failure	80 psf Failed
4200 cycles -	65 psf Failed
400 cycles -	70 psf Failed
390 cycles -	75 psf Failed
Frame 3 (4 ply plywood)	
Static Failure	65 psf Failed
50 cycles -	55 psf Failed
1250 cycles -	50 psf Failed
2050 cycles -	45 psf Failed
Frame 4(4 ply plywood*)	
Static Failure	108 psf Failed
50 cycles - ***OSB**	85 psf Failed
10 cycles -	88 psf Failed
500 cycles -	80 psf Failed
220 cycles -	70 psf Failed
2500 cycles -	70 psf Failed

Results of Repeated Nail Withdrawal Tests from the Same Hole

Withdrawal Number	Withdrawal Force - Pounds						Average Ratio
	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	
1	145.5	143.0	173.2	139.2	173.9	165.3	1
2	139.6	153.7	118.8	96.6	182.5	83.9	0.83
3	108.3	163.0	210.5	85.4	179.3	71.6	0.86
4	142.9	114.9	147.7	76.7	162.3	86.7	0.77
5	81.1	78.4	166.8	71.6	128.8	108.7	0.66
6	60.8	80.9	113.7	86.7	120.3	67.2	0.56
7	94.0	74.5	102.6	58.0	110.6	74.3	0.54
8	79.2	60.5	104.2	85.6	165.9	82.8	0.61
9	69.4	89.0	142.5	62.4	85.9	68.1	0.55
10	52.9	54.4	121.2	73.4	72.5	67.7	0.47