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Testing of Storm Shutter Panels

Alexander Borges Irizarry, P.E.
Graduate Student, University of Puerto Rico, Mayagüez Campus

Ricardo López, Ph.D., P.E.
Professor, University of Puerto Rico, Mayagüez Campus

Raúl E. Zapata López, Ph.D., P.E.
Professor, University of Puerto Rico, Mayagüez Campus

Abstract

This paper describes the development of a testing facility for thin-walled folded plate structures. The facility is located at the Structure Laboratory of the University of Puerto Rico at Mayagüez. The research emerges in the context of the assessment of storm shutters used to protect windows and doors during hurricanes. Some testing devices are proposed to verify the capacity of the shutters in order to comply with the Puerto Rico Building Code. The proposed tests are uniform pressure, repetitive uniform pressure and impact load. Results of impact load tests are presented to validate the functionality of the system.

1. Introduction

Every year, we experience the threats of hurricanes that move near Puerto Rico. Historically, these atmospheric phenomena have caused concern at least once every five years, leaving heavily damaged areas and several deaths behind it. Recent events such as: Hurricanes Hugo (1989), Marilyn (1995), Hortense (1996), Georges (1998) and Jeanne (2004) are just remainders of our vulnerabilities and needs for proper preparedness and protection against hurricanes and storms.

The integrity of any structure depends on the structural and deformation capacity of individual areas (walls and roof). Damage usually starts with breakage of weak elements such as doors and windows. These components need additional protection to prevent further damages to the interior of the structure, which can lead to possible complete loss of the property and can endanger lives. Typical hurricane protection available in Puerto Rico includes shutters of different types and materials.

Different type of testing has been presented in the literature to obtain the resistance capacity of the shutters in order to verify if they comply with the Puerto Rico Building Code. The proposed tests are: uniform pressure, repetitive uniform pressure and impact tests. To perform these tests, devices such as a steel rigid frame and air cannon were developed to perform the complete testing program. The devices will permit the measurement of maximum deflections and capacities of the shutter. The measurements will be obtained under the effects of different types of loads and physical condition of the shutters.

2. Pressure Setup

All the testing procedures are performed on the same setup. The setup consists on a steel frame capable of sustaining the applied loads with a minimum displacement of the support. The restriction on displacement was established such that the measurements obtained on the specimens will not be affected. A maximum displacement value of 0.01 inch was established for this purpose.

2.1. Rigid Frame

The frame has been designed to test different types and sizes of specimens. A system of panels or storm shutters covering a possible maximum area of 10' x 15' was established for testing. Based on this pre-established covering area, the size of the frame was determined to be 15' x 15' as shown in Figure 1.

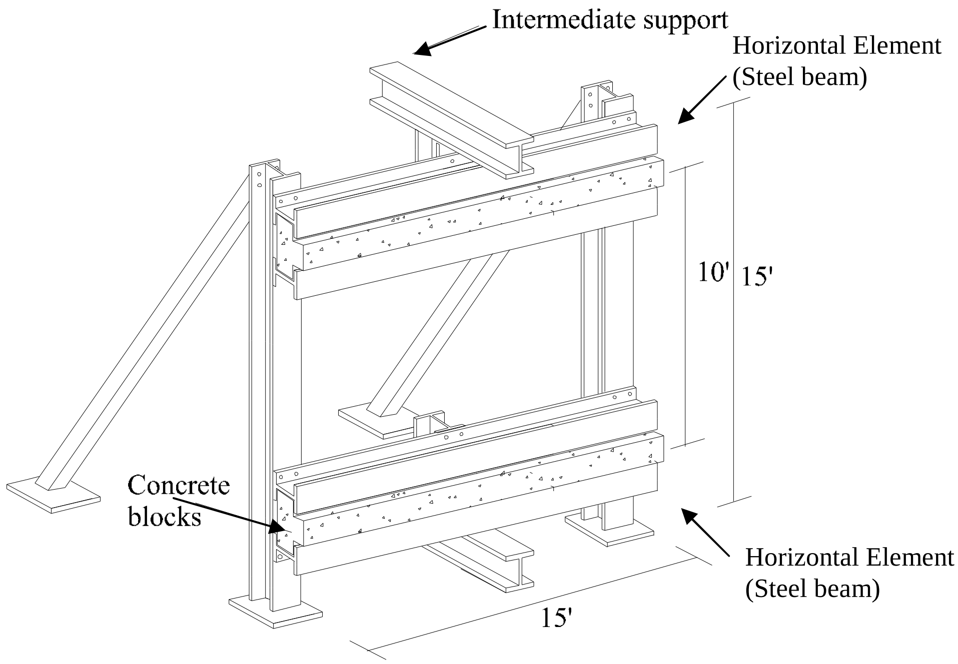


Figure 1. Pressure Setup: Steel Rigid Frame

The horizontal elements of the frame will support the material (concrete, wood) where the panel connections will be attached as shown in Figure 2. Special concrete blocks were designed for this purpose. The objective is to provide a more realistic behavior for testing by allowing the shutters to be connected as typically suggested by manufactures. The horizontal elements can be moved vertically, such that different span length specimens can be placed on the system according to the panel to be tested. The capability of movement is provided by standards holes realized at the frame column flanges. High strength bolt connection provided a simple way to establish the desired location for the horizontal beams.

The beam deflection and the use of lightweight section were the principal criteria for sizing the element of the frame. For this reason an intermediate support for the beams was necessary to obtain a more economical section and control the system displacement. The intermediate support consists of two vertical elements which were perforated and positioned in the setup such that the holes and the ones of the columns will be aligned. In this way the beams of the rigid frame will have an additional bolt connection at its mid span. The two sections were adapted to an existing reaction frame at the Structure Laboratory as shown in Figure 3. Finally, steel W sections (AISC, 1994) were select in the design of the main frame and the mentioned supports as shown in Figure 4.

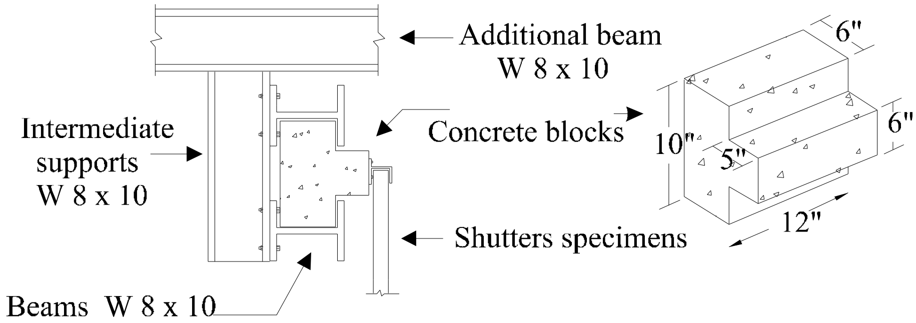


Figure 2. Horizontal beams and Intermediate supports

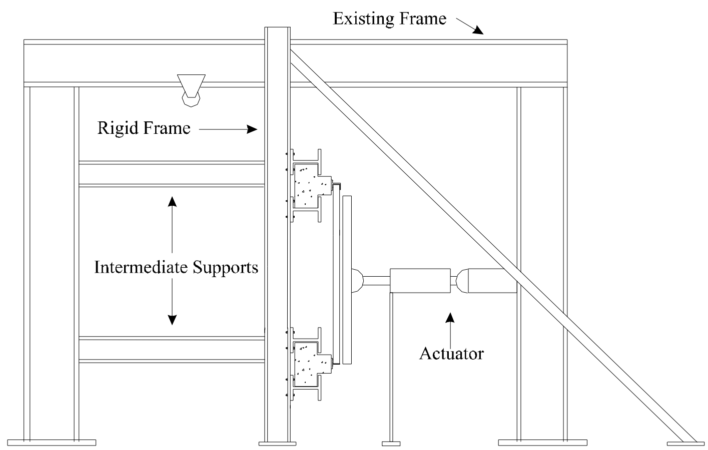


Figure 3. Intermediate support adapted to an existing reaction frame.

Figure 4. Final Assembly: Rigid frame with the shutter

2.2. Load Transfer System

The wind load effects over the specimens are simulated by the use of a hydraulic actuator. This is true if a special system is attached to the actuator such the applied load is modified from a concentrated load to a uniform load. The direction of the applied load depends on the location of the hydraulic actuator and the load transfer system.

The load transfer system consists of steel beams, steel plates and air bags. Same as the steel rigid frame the beam deflection was the principal criteria for sizing the elements. Beams W 10 x 12 were selected. The beams were connected by the use of bolts forming a principal frame as shown in Figure 5. Steel plates were attached to the frame such that a solid surface was obtained. The formed surface area is approximately the same as the area produced by the specimens. Considering that the load transfer system and the specimens do not have the same rigidity the deformation of the surfaces (the one created by the steel plates and the one created by the specimens) are not the same. For this reason it is necessary to add another component to the system such the surface deformation on both sides is not affected. Air bags present the perfect media to transfer the load between surfaces avoiding the effect of different rigidities. The final assembly for the load transfer system is shown in Figure 6.

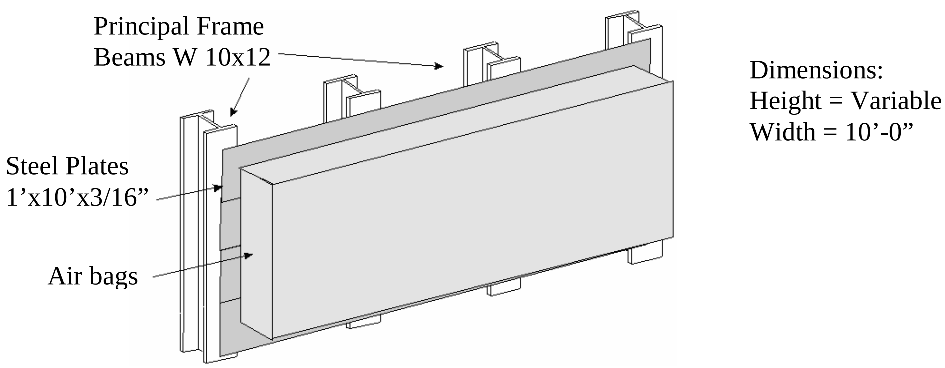


Figure 5. Load Transfer System: Principal Components

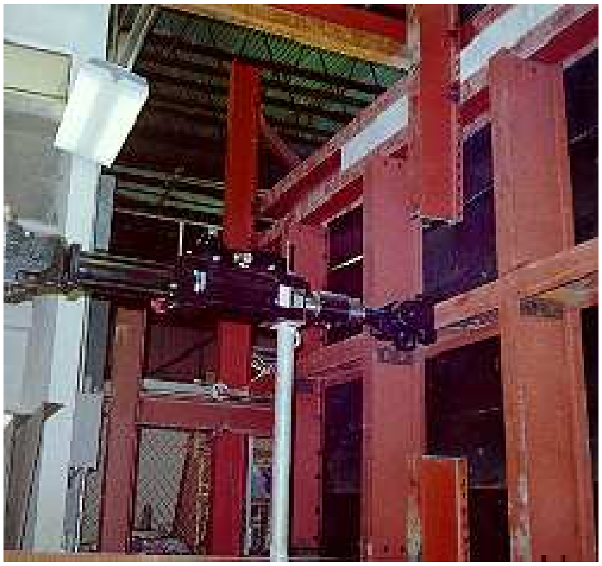


Figure 6. Final Assembly: Load Transfer System

3. Impact setup

One of the most dangerous agents during the pass of a hurricane is the windborne debris; they could produce serious damage to storm shutters and to the elements protected by them. In 1972, (Minor et al., 1972) observed that windows are traditionally designed for wind pressures, but the breakage from impact by windborne debris is the most common failure mechanism during hurricanes. He identified roof gravel as the principal form of small debris that can be carried into all elevations of buildings facades. In residential areas, (Minor, 1994) concluded that the most prevalent type of windborne debris was timber from wood frame houses. Such timber debris has been observed to penetrate walls and roofs during tornadoes. These observations led to the selection of a 9-pounds 2”x 4” timber as the representative object for use (Borges et al., 1997) in defining impact criteria for protection of residences during tornadoes (and now during hurricanes).

3.1. Impact test device: Air Cannon

The impact setup consists of an air cannon capable to shoot large and small missiles against the specimens. For the air cannon system a rigid support table was designed. The support table will be able to sustain the weight of the system, position the air cannon at different heights from the ground and maintain it fixed during the tests. It consists of a steel tube rigid frame as shown in Figure 7. The support table was designed such that its elements can be disconnected for storage or replacement the system. Considering the dimensions of the system, the frame is attached to four wheels to facilitate its movement to the required position of the air cannon. Special PVC tubes are the principal components for the air cannon. These PVC tubes are used to store about eight cubic feet of pressurized air which will be released instantaneously toward the cannon section of the system as shown in Figure 8.

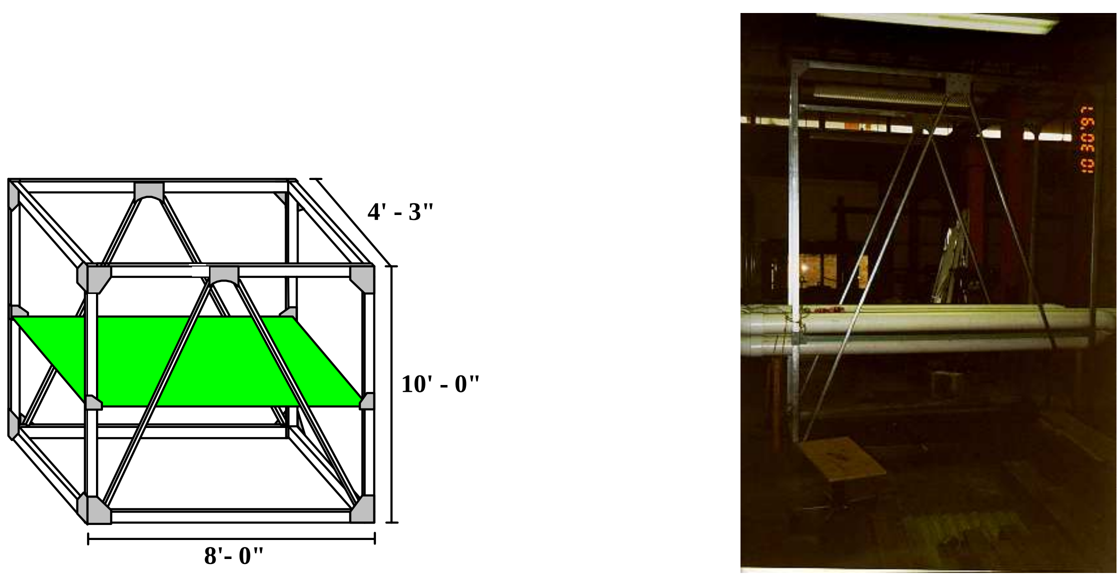


Figure 7. Frame and table support.

Figure 8. Special PVC tubes.

A solenoid valve controls the sudden air flow. This solenoid valve is activated manually by an electronic switch when the established pressure is reached. The kind of missile to be shot (timber or gravel) through the air cannon will be controlled by the use of two balls valves. The valve distribution for the system is shown on Figure 9.

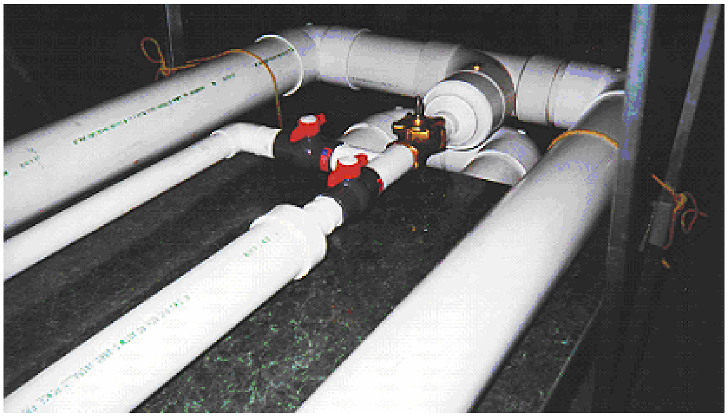


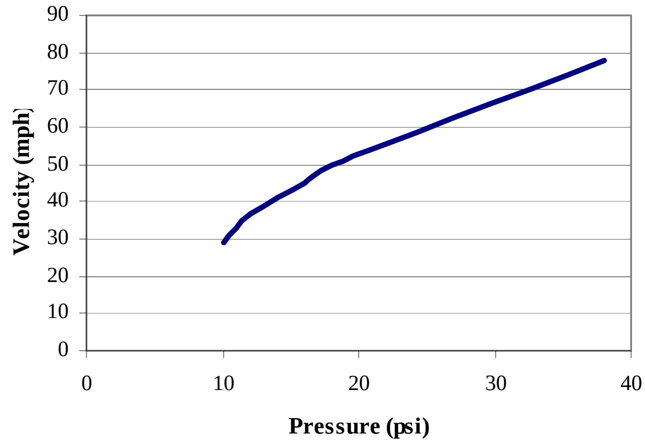
Figure 9. Valves distribution.

3.2. Calibration Values for Air Cannon

As part of the calibration process an infiltration test was performed. This test established the performance of the air cannon joints under compressed air pressure. The results were satisfactory. The air cannon would contain the testing pressure and more.

Once this test was performed the next step was to establish the air pressure needed to obtain the required missile velocity. For this purpose, a series of missile shots was performed to obtain the relationship between the required air pressure injected in the air cannon and the corresponding missile velocity. These results are shown in Figure 10. A 9-pound 2”x4”piece of wood defined as the large missile was used for each trial. A radar gun was used to measure the missile velocity during the test.

(a)



(b)

Figure 10. Missile velocity and air cannon pressure relationship: (a) radar gun used for missile velocity measures and (b) calibration testing results.

3.3. Impact setup performance

Two tests were carried out to validate the functionality of the impact setup. The tests were done on a typical storm shutter panel system in the rigid frame. The air cannon were located at twenty feet in front of the system such the proposed impact will be at the center of the panel system. The storm shutter systems used for each set are described in Table 1.

Material	Aluminum
Gauge	.063 mm
Height	2”
Span	7’- 2”
Number	3 - 5
Cover area*	18 - 30 ft^2
End Support Condition	Clips**

* Area to be protected ** Two or three clips per sheet

Table 1. Storm Shutters tested

Two sets were tested. The main difference between those sets was the arrangement of each sheet in the system.

3.3.1. Test #1: One supported edge

This test was the first one done to measure the behavior of the storm shutters under impact loads. The proposed missile velocity for this test was 50.0 mph using an air cannon pressure of 18.0 psi. However, the velocity obtained during the test was 51.7 mph. It is important to note that the missile used was not the one used in the calibration process of the air cannon. Parameters like weight, length and imperfections are relevant in the velocity of the missile. For that reason a higher velocity was obtained using the required air pressure. The impact location was at the middle span of the center sheet. The storm shutter system was assembled such that each sheet provided some support to the adjacent sheet. One edge of each sheet was placed over the previous sheet as shown in Figure 11.

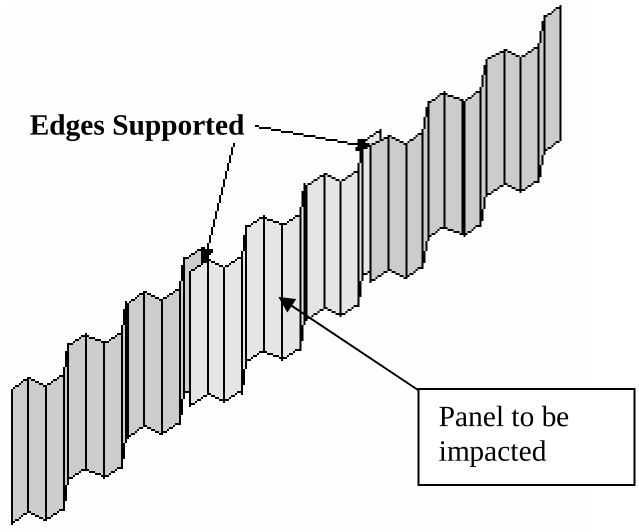


Figure 11. Lateral support at one edge

The results for this test were the following:

a) The impacted sheet lost the clips that were attached to it. The clip deformation was too large so it will not be used again.
b) Other clips of the system lost their original position. The clips rotated approximately 45° (clockwise).
c) The impacted sheet lost it's encasing with the top channel. Each sheet is encased with a channel that acts as provided by the top support of the system.
d) A torsional deformation occurred due to the one edge support. As one edge will be able to have a free displacement the restriction provided by the edge supported produced a torsional effect on the sheet.
e) At middle span the permanent deformation was approximately of 6 ½". That means that under real condition the impact load would damage the protected fenestration.

3.3.2. Test #2: Free edges

This second test was performed using three sheets. As the impacted sheet did not have any lateral support from the others (as it was in the first test), the use of three sheets was enough as shown in Figure 12. This case will represent a condition of wrong panel installation. The manufactures suggest the sequence of install panel used in the previous test.

The conditions of end support were the same as in the previous test. The velocity registered was 49 mph. The impact location was at the middle span of the center sheet.

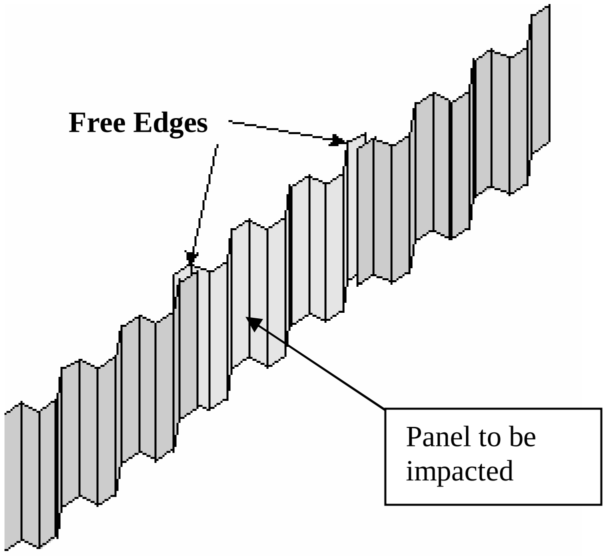


Figure 12. No Lateral support at both panel edges

The results for this test were the following:

a) The impacted sheet did not lose the encasing provided by the top end support.
b) At middle span the permanent deformation ranged between 7 ½ to 8”. That means damages to the protected fenestration.
c) One of the clips attached to it was lost. The others clips were not affected.
d) The permanent deformation of the panel did not present evidence of torsion as was obtained in the previous case.
e) The panel behavior in terms of deflection was similar to a simple beam under a concentrated load at mid span.

4. Conclusion

The main objective of this study was to develop a testing facility such the capacity of storm shutter panels will be evaluated under representative loads during a hurricane event. To attain this objective, some testing devices were design and assembly in the Structural Laboratory of University of Puerto Rico at Mayagüez. The following conclusions can be drawn from this study:

1. The proposed pressure setup can be used to obtain a very good approximation of the capacity of the specimens using a very simple testing device.
2. The use of an hydraulic actuator is a very understood equipment that can be used to apply the required force to recreate the acting pressure on the system. The use of a personal computer connected to the actuator gave the opportunity to control the equipment such that any type of load-time application can be tested.
3. The rigid frame permits a realistic connection behavior of the storm shutter system due to the installation of the exact materials (concrete or wood) where the typical system is attached. This fact will generate a very good source of data about the capacity and behavior of the system connections.
4. Different sizes of panel system can be installed due to the flexibility of the rigid frame to adjust the height of its test base supports (horizontal beams) according to the opening dimensions to be covered.

5. The proposed air cannon can be used to evaluate the effect of windborne debris acting against of storm shutter panels. Parameters like missile velocity, missile characteristics (small or large), and the location and angle of impact can be evaluated with the proposed impact setup.

6. Acknowledgement

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References

AISC (1994), “Manual of Steel Construction”, 2nd Edition, *American Institute of Steel Construction, Inc., Vol.1&2.*

Borges A., López R., and Zapata R. (1997), “Guidelines for testing and Approval of Storm Protection Shutter and Panels”, *Report submitted to Federal Emergency Management Agency, FEMA.*

Minor, J.E. (1994), “Windborne Debris and the Building Envelope,” *Journal of Wind Engineering and Industrial Aerodynamics, Vol. 53*, pp. 207-227.

Minor, J.E., K.C. Metha and J.R. McDonald, (1972), “Failures of structure due to extreme winds.” *ASCE Journal of Structural Engineering, Vol. 98*, pp. 2455-2471.