Final Report
Missile Impact Resistance of Metal Mesh System

Prepared for:

Florida Department of Community Affairs
Division of Emergency Management
Bureau of Preparedness and Response
Critical Infrastructure and Logistics/Facilities

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SUMMARY

The tests described in this report were performed in my presence. The test results reported are fairly and accurately described, to the best of my knowledge, and observations and conclusions apply only to the specimens tested and under the testing conditions. Tests were performed per ASTM Standard E 1886 (2005). The size of the specimen was determined by the Florida Department of Community Affairs, Division of Emergency Management, Bureau of Preparedness and Response. The missiles used in the tests were representative of Missile Level D. The metal mesh and its welded connection to the test frame resisted penetration of the 2x4 and passed the requirement of a 3 inch diameter solid sphere not passing through after impact. There were signs of distress at the weld points. This was evidenced by breaking of the metal mesh strands adjacent to the welds. Specifics for the welded connections that caused better test performance of the system are noted in the Conclusions section of this report.

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LIST OF MOVIES

1. Movies taken Digitally:

    a) Cannon Testing-Steel Mesh-Hits 1-7.wmv
    b) C1010015 Hit 1.MOV
    c) C1010029 Preparing for Hit 2.MOV
    d) P7250026 Frames before Hit 8.MOV
    e) P7250031 Hit 9.MOV
    f) P7250039 Hit 10.MOV
    g) P7250045 Hit 11.MOV

2. Movies on Tape:

    Additional movies were taken on VHS tape.

ACKNOWLEDGEMENTS

This study was performed under a grant from the Florida Department of Community Affairs, Division of Emergency Management. The air cannon, missiles, and operators were provided by the University of Florida, Gainesville, FL. The design and drawings of the DMS Special Needs Shelters in Appendix C were supplied by Barkley Consulting Engineers, Inc. of Tallahassee, FL.

TEST REPORT

SECTION 1 - INTRODUCTION

The Florida Department of Community Affairs (DCA) Division of Emergency Management (DEM), Bureau of Preparedness and Response, is planning to install generators at several schools in the state of Florida. These generators will provide emergency power during times that the schools are used as special-needs hurricane shelters. Each generator will be housed in a protective structure that is designed for hurricane effects such as winds, rains, flooding, storm surge, and windborne debris impact.

The protective structure was designed by Barkley Consulting Engineers, Inc. (see Appendix C). The walls are to be constructed of 8 in. x 8 in. x 16 in. concrete masonry units, with 16 in. x 16 in. vertical pilasters that are horizontally spaced at 10 ft. The tops of the pilasters are to be braced with a steel frame roof that has, for its perimeter, C8x11.5 or W8x10 with C8x11.5 bolted to the top and bottom flanges. The struts between the pilasters are W8x15. All-thread rod, with a diameter of 5/8", will be used as cross bracing. Effectively, each panel is 10 ft 0 in. x 25 ft 4 in. and has an L3x3x3/16 brace in the middle. The roof is to be covered with metal mesh, which will be welded to the steel frame. The purpose of the roof and walls of the generator housing is to protect the generator from windborne debris impact.

SECTION 2 - PURPOSE OF PROJECT

The purpose of this project is to experimentally test the metal mesh system that will be used as the roof of the protective structure. The tests will be performed using the windborne debris impact criteria from ASTM Standards E-1996 (2006) and E-1886 (2005) for large missiles. These requirements state that the system must resist penetration by a nominal 2”x4” lumber plank weighing nine (9) pounds traveling at 34 miles per hour, striking end-on and normal to the structure’s surface.

Although the system includes the steel frame, the metal mesh, and the welded connections between the two, only the metal mesh is to be tested. Damage to the metal mesh and welded connections will be observed. Failure of the mesh is defined as full penetration beyond the plane of the metal mesh due to wedging between the wires or breaking of the wires.

SECTION 3 - TEST DESCRIPTION

Two steel frames were constructed (see Figure 1), using the same member sizes that will be used in a typical interior panel (two W8x15 on two opposite edges and two C8x11.5 on the other two opposite edges). An L3x3x3/16 brace was placed in the middle of the frame, parallel to the C8x11.5. Each test frame had outside dimensions of 5 ft 4 in. x 9 ft 10 in. All-thread rod, 5/8" diameter, was bolted to the webs of the W8x15 on opposite corners of the frame.

Expanded metal mesh (3/4", 9 gage), with diamond-shaped openings of dimensions ¾ in. x 1 ¼ in., was welded to the frame (see Figure 2). The welds were approximately 1 inch long and were made by stick welding with E70xx welding rods. The weld spacing was an important test parameter, as described below. The mesh was not overlapped in any location; one continuous sheet was used to cover the test frame.

Three series of tests were performed. The 2x4 missiles were fired at the test specimens using an air cannon (Figure 3). For each impact (hit), the speed of the 2x4 was measured with a radar gun, and the results were documented. The approximate location of impact was recorded, based on the markings that were left by the wet paint that was sprayed on the end of the 2x4 prior to release from the air cannon.

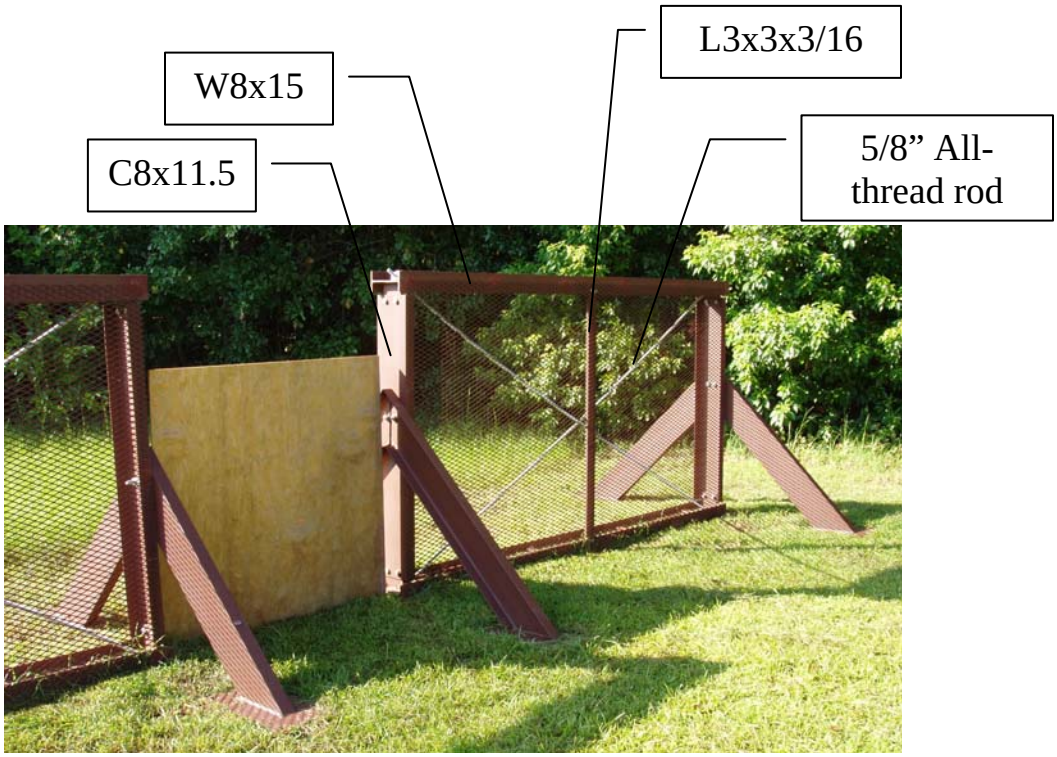


Figure 1 - Test Frames (Frame 1 on left; Frame 2 on right)

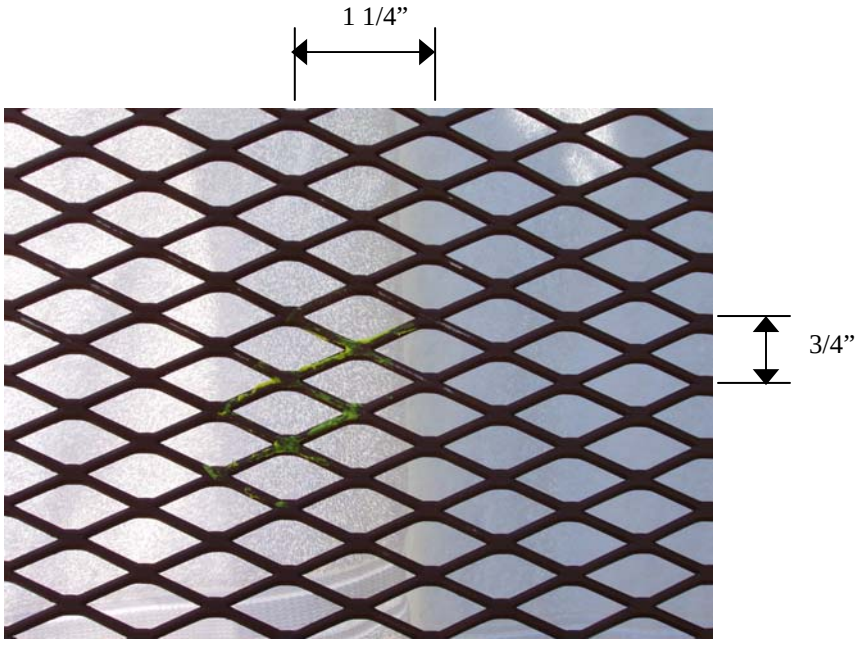


Figure 2 - Expanded Metal Mesh (3/4”, 9 gage)

Figure 3 - Air Cannon used to Fire Missiles

For the tests in Series 1, Frame 1 was impacted one time (Hit 1). This frame had a weld spacing of approximately 38 inches horizontally and 30 inches vertically (Figure 4). After the impact, results were documented.

For the Series 2 tests, Frame 2 was impacted two times (Hits 2 and 3). This frame had a weld spacing of approximately 23 inches horizontally and 20 inches vertically (Figure 5). The frame was modified for Hit 3 by removing the center L3x3x3/16 brace. After each impact, results were documented.

For the tests in Series 3, Frame 1 was impacted eight times (Hits 4 through 11). The weld spacings in Series 2 and 3 were large and resulted in local failure of the mesh material near the welds. Therefore, additional welds were added in the field to this frame, for a weld spacing of approximately 4 to 9 inches horizontally and 6 to 8 inches vertically (Figure 6). Also, for all hits

in this series of tests, this frame was modified by removing the center L3x3x3/16 brace. Results were documented after each impact.

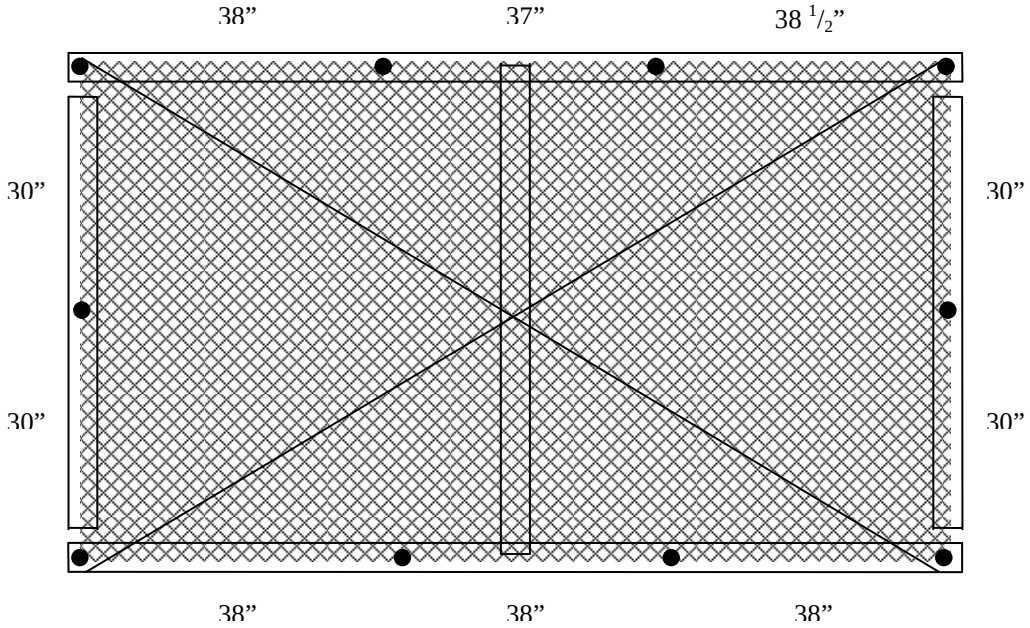


Figure 4 - Weld Spacing for Series 1 Tests on Frame 1

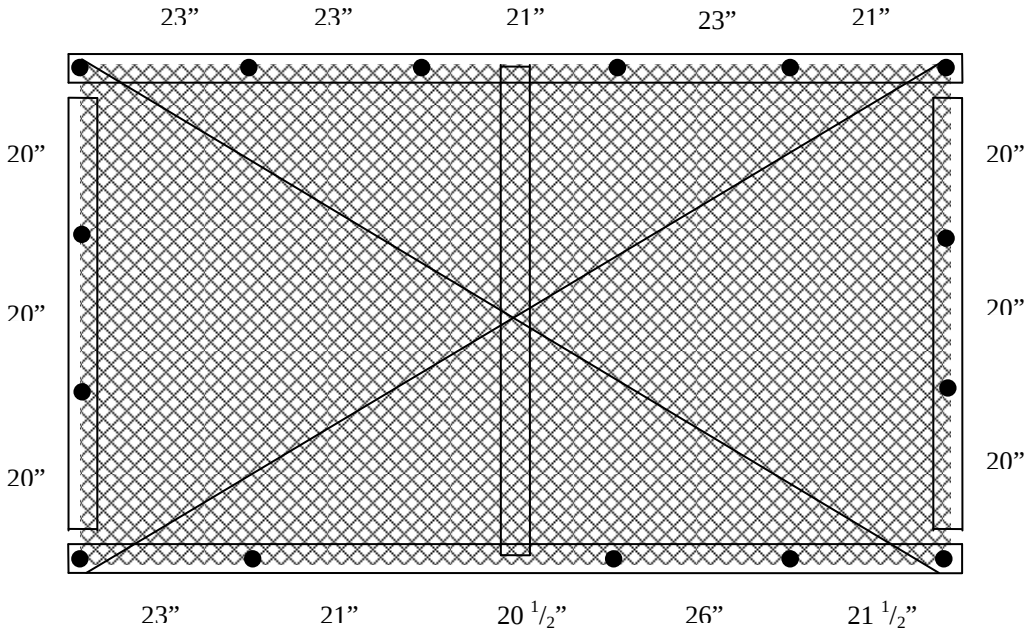
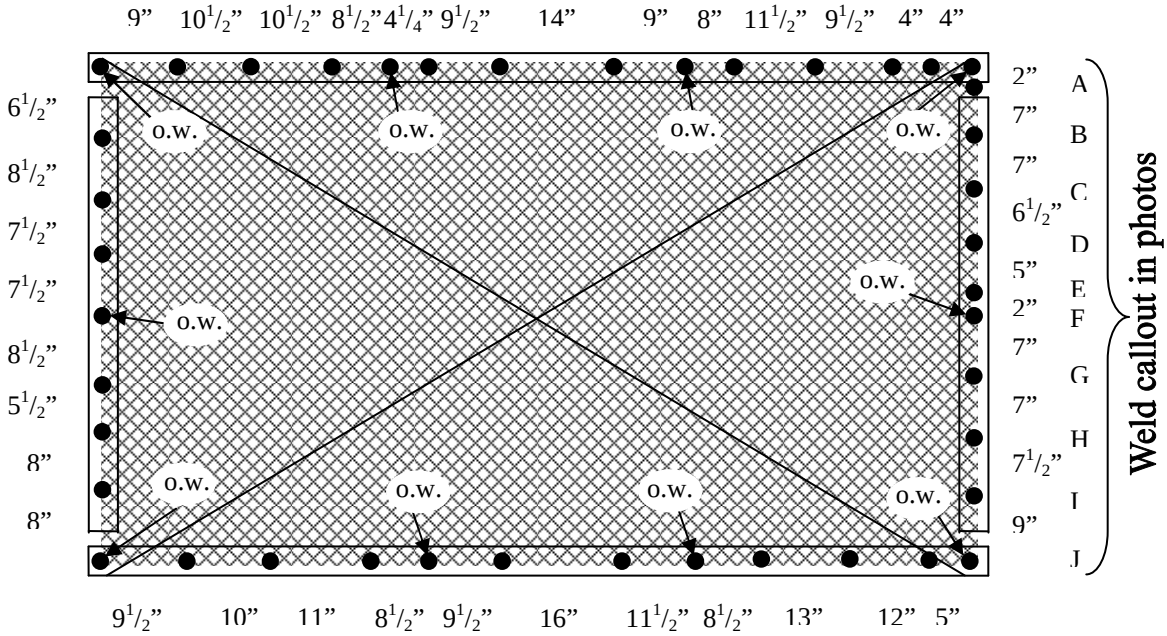


Figure 5 - Weld Spacing for Series 2 Tests on Frame 2



o.w. = original weld

Figure 6 - Weld Spacing for Series 3 Tests on Frame 1

SECTION 4 - TEST RESULTS

For all hits, the speed of the 2x4 was at least 34 mph. Speeds ranged from 34 to 37 mph. Hits 1, 8 and 9 were 37 mph; Hits 2, 3, and 4 were 36 mph; Hit 7 was 35 mph; Hits 5, 6, and 11 were between 34 and 37 mph. Although not required for this project, the speed of the 2x4 was increased to 58 mph for Hit 10 to demonstrate the effect of a higher speed impact.

The locations of the impacts are given in Table 1, relative to the specified corner of the test frame. Also given are notable comments on the results. A schematic of the impact locations is given in Figures 7 through 9.

The metal mesh did not allow penetration of the 2x4. In all tests, the 2x4 rebounded immediately from the test specimen after impact.

Some deformation of the mesh was observed, such as in Hits 3, 5, and 6 where the 2x4 struck near the test frame steel members that supported the mesh. From all of the tests, the most notable damage occurred when the 2x4 struck near the test frame; damage was typically to the mesh in the region directly adjacent to the welds, where the mesh was often broken. Photos taken of the damage after impact are provided in Appendix A. Additional photos, taken after all testing was completed, are in Appendix B.

Minimal, or no observable, damage occurred when the 2x4 struck at the required speed near the center of the specimen, away from the steel frame. An exception to this was for Hit 1 where the corner weld received the most damage. Note, however, that the weld spacing was 30 inches to 38 inches in the Hit 1 test; a much smaller weld spacing was used for subsequent tests. Considerable tearing occurred when the 2x4 struck near the center at an increased speed of 58 mph, as for Hit 10.

Table 1 - Impact Locations and Test Comments

Series	Hit	Missile Speed (mph)	Impact Location			Comments
			Horiz-ontal	Vert-ical	Relative to:	
1 (Frame 1)	1	37	26”	20”	Top right	Mesh broke at top right corner weld.
2 (Frame 2)	2	36	25 ½”	27”	Top right	Mesh broke at 4 welds (1 at top right corner; 1 to left of and 2 below top right corner).
	3	36	8”	10 ½”	Top right	Mesh deformed at impact location.
3 (Frame 1)	4	36	29”	33 ½”	Top left	No observable damage.
	5	**	4”	11”	Top left	Mesh deformed at impact location; mesh broke near one weld.
	6	**	8”	8”	Top left	More deformation at impact location; mesh broke at top left corner.
	7	35	13 ½”	4”	Top right	Impacted steel frame. No observable damage.
	8	37	8”	15”	Top right	Mesh tore at impact location. Some damage near Weld C. 2x4 did not penetrate.
	9	37	7 ½”	24 ½”	Top right	No more observable damage to area of impact. Some damage near Weld D.
	10*	58*	57”	24”	Top right	Mesh tore at impact location and beyond.
	11	**	28”	33”	Top right	No observable damage.

* Missile speed for Hit 10 was 58 mph, much greater than required.

** Missile speed was between 34 and 37 mph.

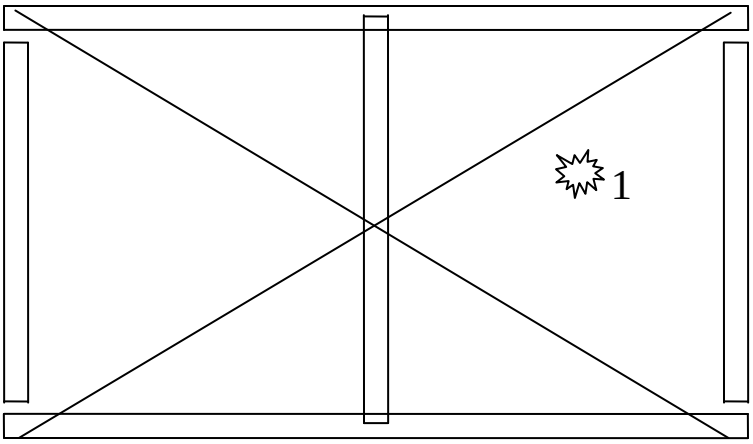


Figure 7 - Series 1 Tests Impact Locations (Hit 1)

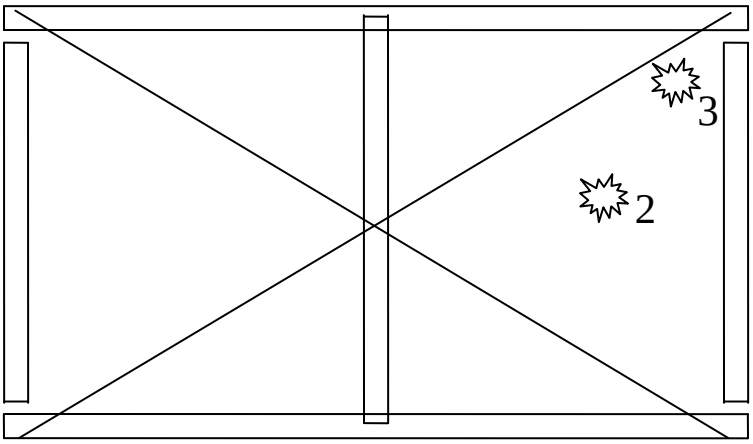


Figure 8 - Series 2 Tests Impact Locations (Hits 2 and 3)

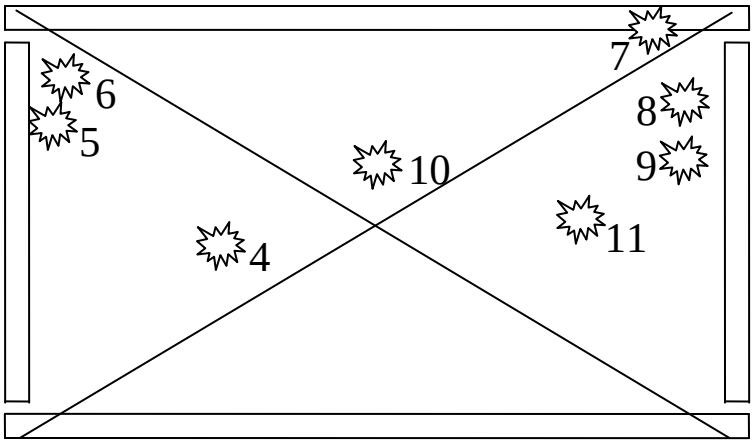


Figure 9 - Series 3 Tests Impact Locations (Hits 4 through 11)

SECTION 5 - CONCLUSIONS

The metal mesh resisted penetration of the 2x4 in all cases that were tested. A comparison of Series 1, 2 and 3 tests shows that the behavior of the system is mainly a function of the weld spacing. A maximum weld spacing of 7 inches around the perimeter, with each weld being at least 1 inch long, produced the best test results. Although not specifically tested in this project, the presence of the 5/8 inch all-thread rods in the corners may not be insignificant. They may have helped resist additional tearing of the metal mesh when the 2x4 struck near the corner of the test frame.

REFERENCES

ASTM Standard E 1996 (2006), “Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors and Impact Protective Systems Impacted by Windborne Debris in Hurricanes.”

ASTM Standard E 1886 (2005), “Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials.”