Test Report

INVESTIGATION OF WIND PROJECTILE RESISTANCE OF PRECAST CONCRETE PANELS

Submitted to

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Testing Performed by

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INVESTIGATION OF THE PROJECTILE RESISTANCE OF PRECAST CONCRETE PANELS

Overview of Project

Mr. Jason Hensley of FABCON contacted the Wind Science and Engineering (WISE) Research Center at Texas Tech University to determine debris impact resistance of their concrete panels for the tornado and DOE 1020-02 protocols. Tests were conducted on October 18, 19 & November 1, 2007. The specifics about each test, results, and conclusions follow.

Five series of tests were conducted on various 6-ft. x 6-ft. samples utilizing an extra specimen for series 1-5 for validation of the testing results. The concrete was f'c = 7000 psi at 28 days, but was approximately f'c = 6000 psi at the time of testing. The concrete weighted 138 pcf and used normal weight aggregate. The prestressing reinforcement was 7 wire ½" strand, fy = 270 ksi, with an area of .153 sq. in. and was stressed to 70% fy. Five strands were located across each face of the specimen. The specimens were further reinforced with 3- #3 rebars perpendicular to the strand with one bar located approximately 3-in. from each edge and one rebar located in the center. The specimens were either 8-in. of solid concrete or 12-in. with 2-in. concrete face sandwiching a 2-in. x 2 lbs. density expanded polystyrene with an 8-in. reinforced solid concrete backup. Each series is further described as follows:

Series 1

6-ft. x 6-ft. x 8-in. solid reinforced concrete panel.

Series 2

6-ft. x 6-ft x 12-in. sandwich panel with brick on the 8-in. finish face. Impacts were conducted on the 2-in. concrete face.

Series 3

6-ft. x 6-ft. x 8-in. panel with cast-in place brick veneer tiles. Impacts were conducted on the brick face.

Series 4

6-ft. x 6-ft. x 12-in. sandwich panel with cast-in place brick veneer tiles on the 8-in. concrete face. Impacts were conducted on the brick side of the wall.

Series 5

6-ft. x 6-ft. x 12-in. sandwich panel with cast-in place brick veneer tiles. Impacts were conducted on both faces.

Test Protocol

Introduction

The primary objective in debris impact testing of storm shelters and shelter components is to assure compliance with a high standard of performance in protecting shelter occupants from wind-borne debris. Performance criteria include preventing perforation of the shelter or component by the design missile and preventing deformations which could cause injuries to the occupants.

Debris Impact Test Protocols

The Wind Science and Engineering Research Center performs debris impact tests on storm shelters, shelter components, and building materials to evaluate their ability to resist various types of projectiles propelled at different speeds in accordance to accepted and proposed test protocols as follows:

Protocols for Debris Impact Testing

Protocol 1	Hurricane envelope impact by a 9 lb. wood 2"x4" propelled at 34 mph. In accordance to the Florida Building Code, the International Code Council and the Texas Dept. of Insurance Windstorm Resistant Construction Guide.
Protocol 2	Hurricane shelter low speed impact by a 15 lb. wood 2"x4" propelled at 66 mph. Proposed standard, yet to be adopted.
Protocol 3	Hurricane shelter high speed impact by a 15 lb. wood 2"x4" propelled at 80 mph. Proposed standard, yet to be adopted.
Protocol 4	Tornado impact by a 15 lb. wood 2"x4" propelled at 100 mph. In accordance to The Federal Emergency Management Agency FEMA 320/361Standard and the National Storm Shelter (NSSA) Standard.
Protocol 5	*Reserved :* Department of Energy (DOE) impact standards.

Protocols 2 & 3 will be changed to reflect the new NSSA/ICC Standard (currently under peer review) for shelters in the 2007 International Building Code. This will be a Life Safety Standard and will use a new Extreme Wind Map for Hurricanes with wind speeds starting at 220 mph and with contours along the Atlantic and Gulf Coast stepping back in 10 mph increments. The test projectile will be a 9 lb. missile propelled at 0.40 x the contour wind speed striking the test specimen perpendicularly. The Standard will require 1-2 specimens of each type to be tested. Shelters and shelter components will be impact tested only. Doors without lites (windows) will be proof pressure tested and impact tested. Doors with lites will be proof pressure tested, impact tested and cyclically tested for water intrusion. Refer to www.nssa.cc for the revised standard that is soon to be published by the ICC.

Test Criteria

The testing described is for simulated windborne debris. The primary simulations are impacts of a 2x4-in. wood board traveling along the board's longitudinal axis, striking the test subject perpendicular to the test subject face. Standards that use this type of simulated debris include ASTM E 1886-04 "Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protection Systems Impacted by Missiles and Exposed to Cyclic Pressure Differentials," SSTD 12-99 "SBCII Test Standard for Determining Impact Resistance From Windborne Debris," ANSI A250.13-2003, "Testing and Rating of Severe Windstorm Resistant Components for Swing Door Assemblies," the National Storm Shelter Association (NSSA), "Standard for the Design, Construction, and Performance of Storm Shelters," and Texas Tech University, Wind Science and Engineering's Tornado Test Criterion adopted by the Federal Emergency Management Agency in publication FEMA 320, "Taking Shelter from the Storm," and FEMA 361, " Design and Construction Guidance for Community Shelters." The hurricane test criterion uses a 9-lb. 2x4-in. wood board called a missile, traveling horizontally at 34-mph (50 feet/second), which corresponds to a 110-150-mph wind, and is the criterion used for property protection. The tornado test criterion uses a 15-lb. 2x4-in. wood board traveling horizontally at 100-mph, which corresponds to a 250-mph wind, and is the criterion used in designing vertical surfaces for occupant protection. The criterion for falling debris from a tornado is a 15-lb. 2x4-in. board traveling at 67-mph striking perpendicular to the surface. The 67-mph criterion is used for surfaces horizontal to the ground and inclined less than 30-degrees. Additional factors of safety are inherent in the criterion since there is a very small probability that a missile will be traveling along its axis and will strike perpendicular to the surface.

The Department of Energy Standard for tornado debris impact resistance is contained with the DOE-STD-1020-2002. According to this standard for Performance Category 4, the most extreme category, the missile criteria is a 2x4 timber plank 15 lb propelled at 150 mph (horiz.), max. height 200 ft; 100 mph (vert.); a 3-in. dia. standard.steel pipe, 75 lb propelled at 75 mph (horiz.); max. height 100 ft., 50 mph (vert.); and a 3,000 lb automobile rolling and tumbling at 25 mph.

Test Procedure

The first test on a system is to determine if the basic concept or structural element is capable of resisting the impact. This done by impacting the target in a general field or the area deemed most vulnerable. If the system resists the impact then the testing is concentrated on connections and material support conditions. Shelter walls or test panels are impacted with three test missiles in different and vulnerable locations. Shelter roofs/ceilings constructed differently from the walls are impacted with three test missiles in different and vulnerable locations. Shelter appurtenances, vents, louvers, windows, electrical boxes, shelves, seats, etc., are impacted by a single missile.

Laboratory pressure tests are not conducted on shelters and shelter panels. Numerical analysis of wind pressures is outlined in the above listed standards in the **Test Criteria**.

Pass/Fail Criteria

The criterion for the shelter/shell/panel test pass/fail is as follows:

1) The test subject must be impacted by a minimum three missiles in areas of perceived vulnerability;
2) the missile may penetrate that test subject, but may not perforate the safe side (back face) of the subject;
3) the test subject permanent deflection after impact must be less than 3-in.;
4) segments, spallings or otherwise de-laminated portions of the test subject, though still attached to the subject, may not extend into the safe compartment 3-in. or more; and
5) segments of the test subject or appurtenances attached to the test subject must not be ejected or otherwise released into the safe compartment by the impact force.

Test Equipment

Debris Impact Air Cannon:

1) Air Tank – 30 gallon, Manchester Model Number 301853.

2) Electric Over Air Valve – Matryx Model Number MX200 – 600501.

3) 4-in. aluminum quick coupler to connect barrel to valve.

4) 4-in. x 20-ft. long schedule 40 PVC barrel.

5) Pair Optical Timing Sensors – Keyence Model Number PZ251R and PZ125T 12/24-volt.

6) Signal Conditioner.

7) Pair Precision Timers – BK Precision Timer Model Number 1823 Universal Counter.

8) Control panel with pressure controls, laser sighting and a three stage firing system to eliminate unintentional missile shots.

9) Horizontal articulating cannon carriage with DC motor drive and variable speed controller.

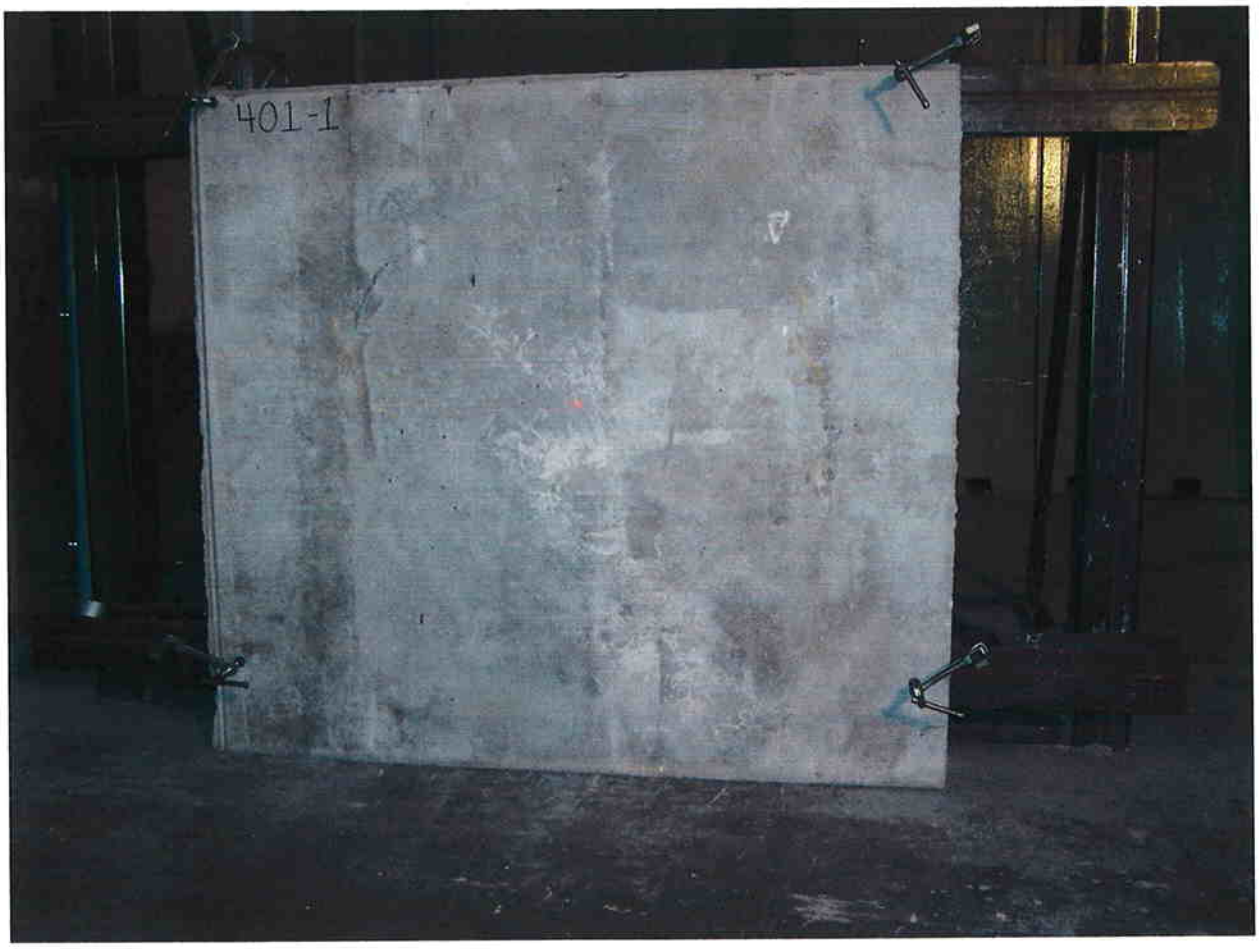
10) Cannon carriage mounted to a hydraulic scissor lift on wheels - Autoquip Model Number 84B16F20.

11) Steel reaction frame made of vertical and horizontal steel beams anchored to the floor to provide simple support at the top and bottom of the test specimen.

Series 1, Specimen 1, October 18, 2007, Test Protocols #4 & #5

Missile Shot I – 15-lb. 100 mph Tornado Test Protocol 4

The Series 1, Specimen 1 panel was installed against the reaction frame and impacted in the center of the panel. There was no remarkable damage to either exterior or interior faces.



Series 1, Specimen 1 Panel impacted by Tornado Wood Missile I

Missile Shot II – 15-lb. 144 mph DOE Tornado Wood Missile Test Protocol #5

The wall sample was impact in the center by the higher speed wood DOE Missile II. There was no remarkable damage produced on either side of the sample.

DOE Wood Missile Impact II of Series 1, Specimen 1 Panel

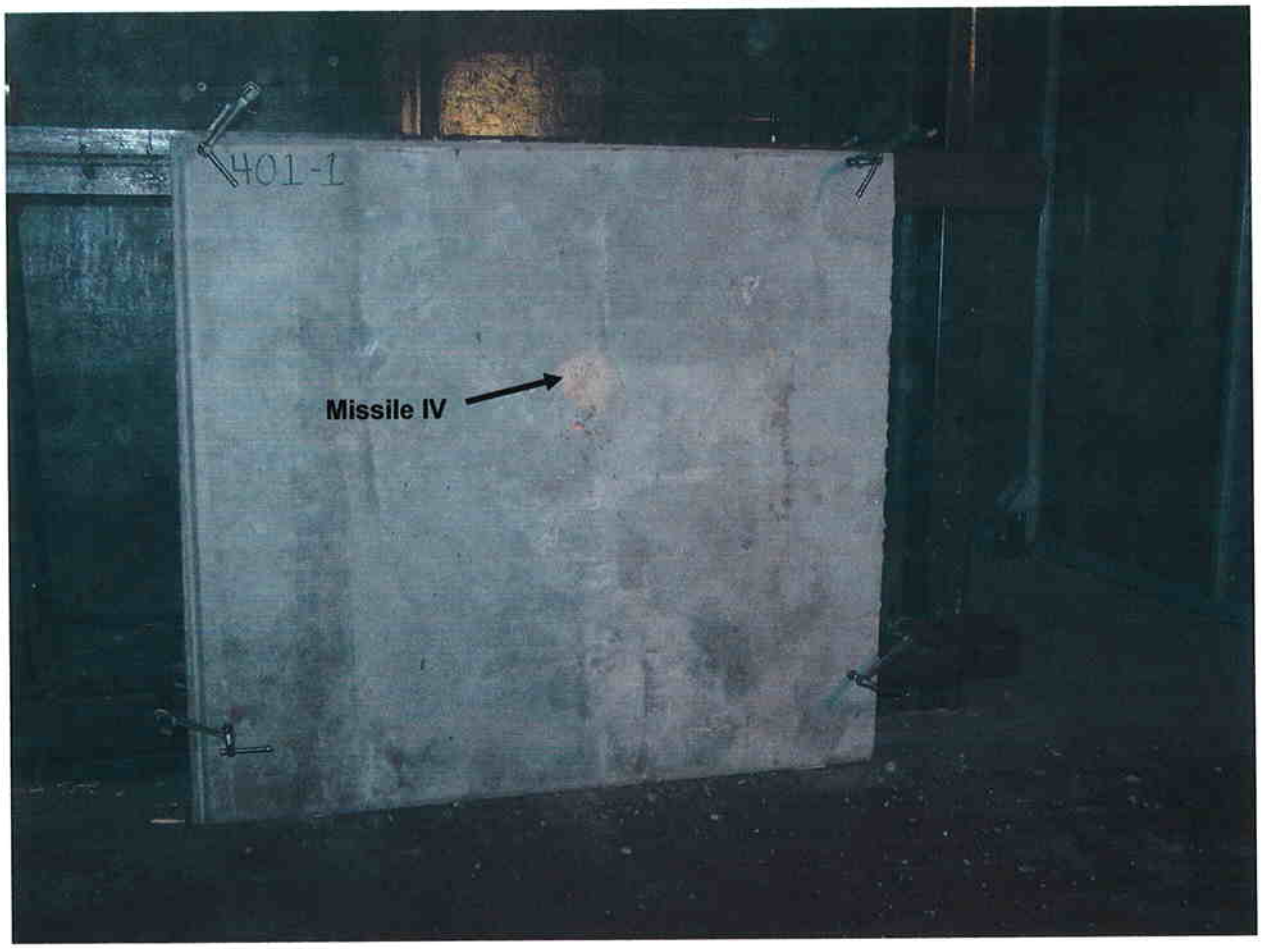
Missile Shot III – 15-lb. 150 mph DOE Wood Missile Test Protocol #5

The Series 1, Specimen 1 panel was impacted in the center by the higher speed wood DOE Missile III. There was no remarkable damage produced on either side of the sample.

Series 1, Specimen 1 Panel impacted by DOE Wood Missile III

Missile Shot IV – 75-lb. 75 mph DOE Pipe Test Protocol #5

The Series 1, Specimen 1 wall sample was impacted in the center by the high pipe DOE Missile IV. The impact produced a rough 7-in. diameter impact crater on the exterior with a maximum penetration of 7/8-in. Radial cracking on the interior surface from the center and extending to each panel corner of the sample was observed. Crack widths measured a maximum of 1/16-in.

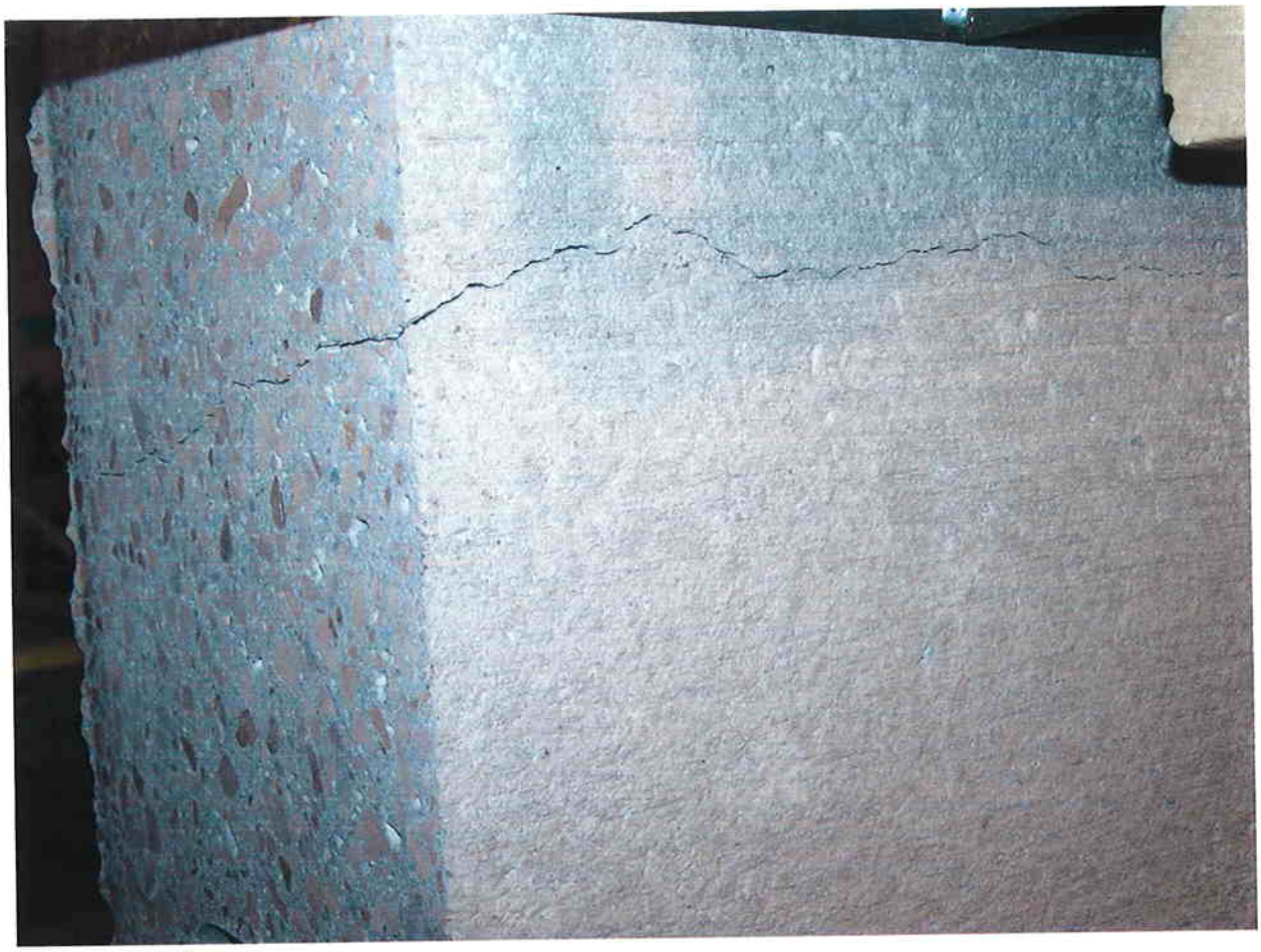


Exterior View of Series 1, Specimen 1 after DOE Pipe Missile IV Impact

Missile IV imprint on Series 1, Specimen 1 Panel

Missile Imprint Depth produced by DOE Pipe Missile IV

End of DOE Pipe Missile after Missile IV Impact

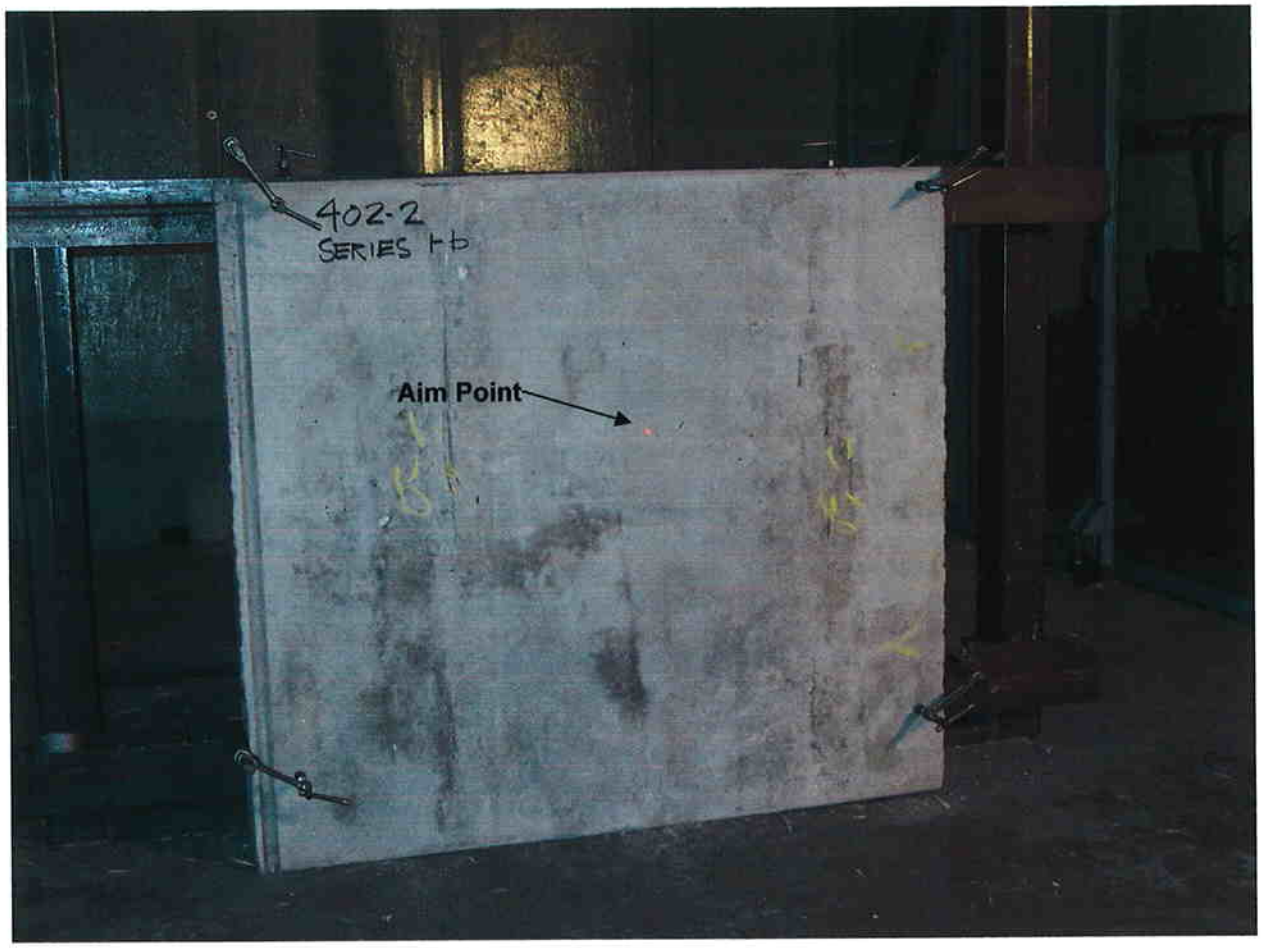


Panel Cracking after Missile IV Pipe Impact

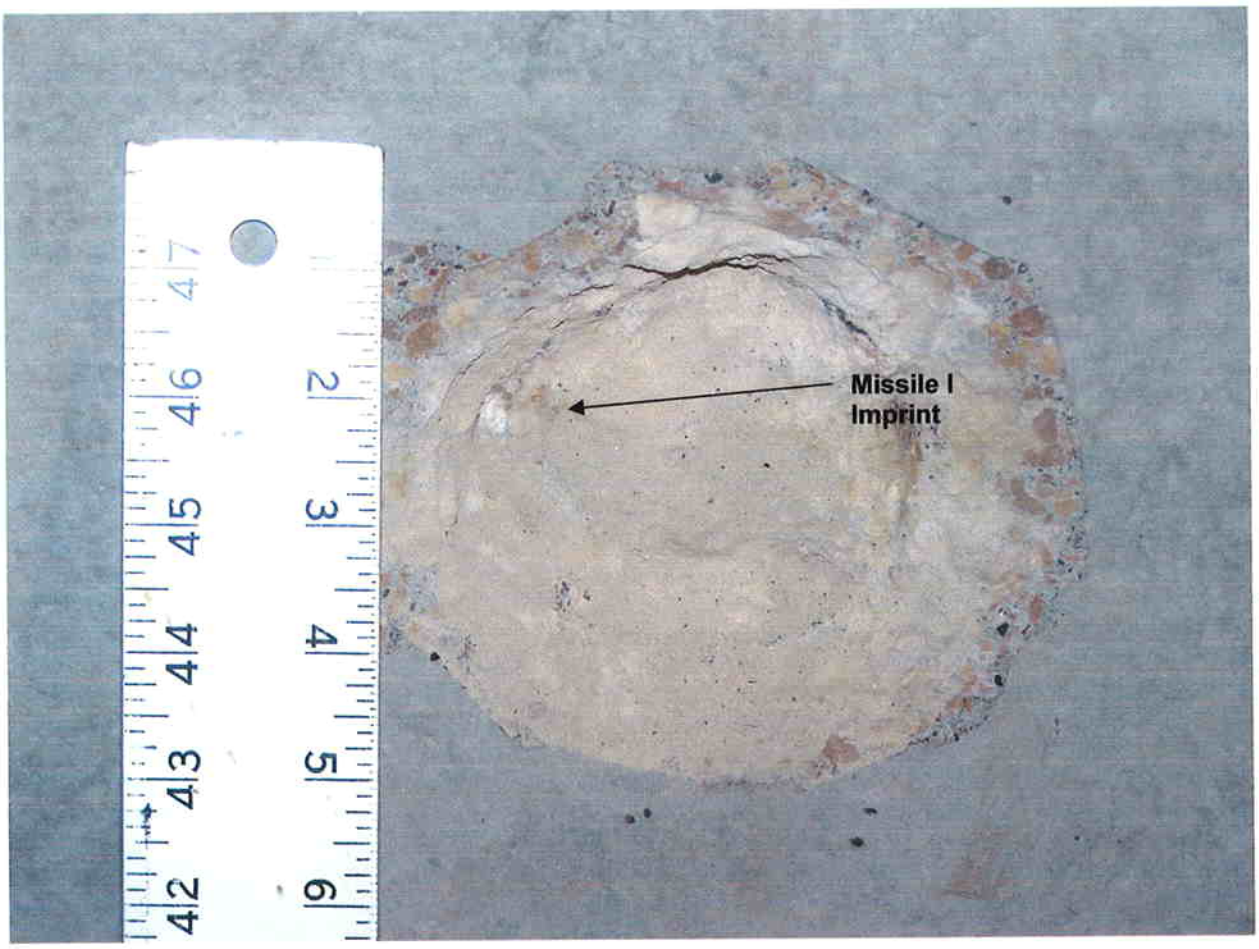
Series 1 – Specimen 2, October 18, 2007, Test Protocol #5

Missile Shot I – 75-lb. 75 mph DOE Pipe Test Protocol

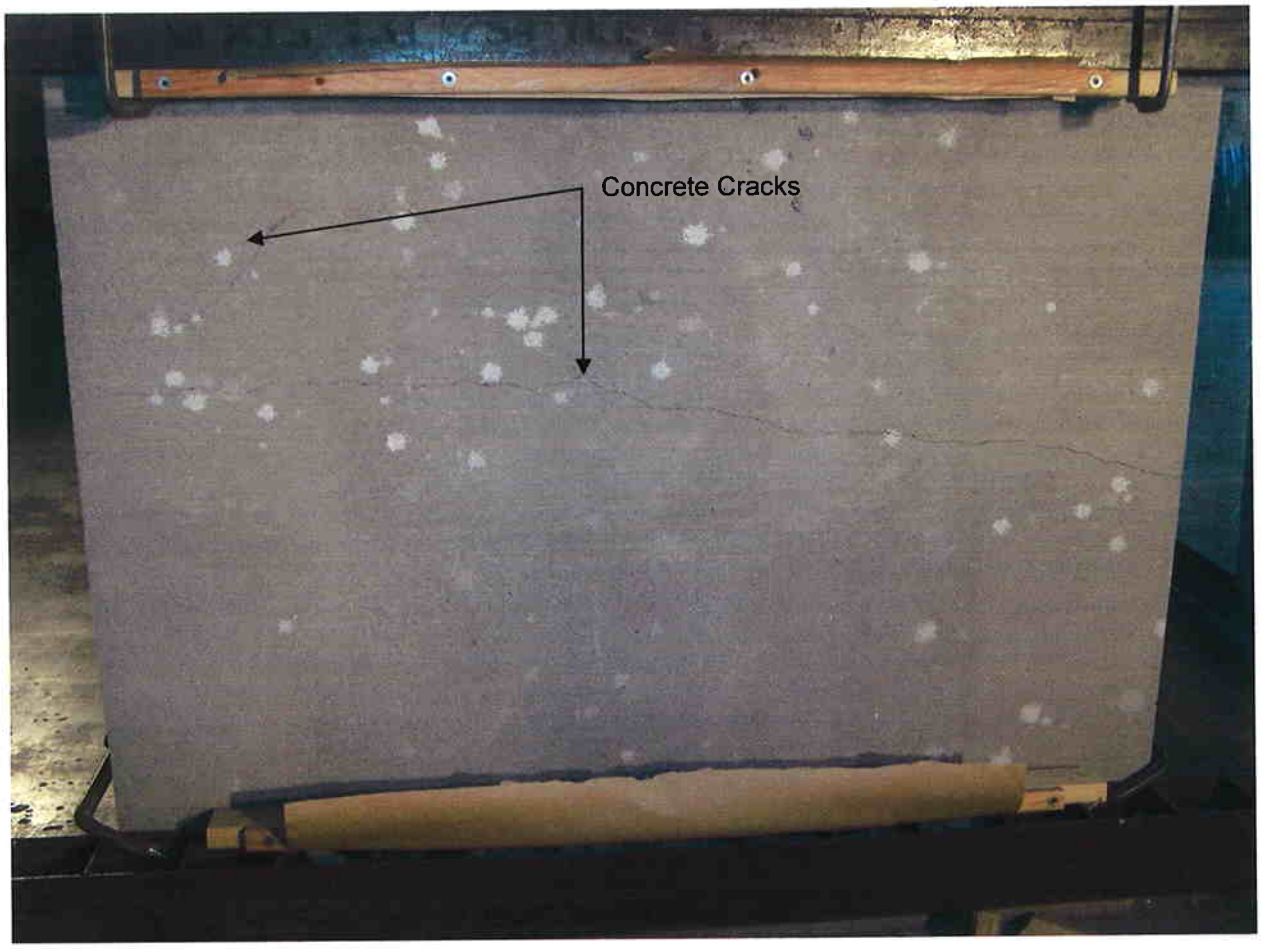
The Series 1, Specimen 2 panel was installed as a validation test of the previous test results observed on Specimen 1. Specimen 2 was impacted in the panel center. The impact produced a rough 5 ½-in. diameter impact crater on the exterior with penetration up to 1 1/8-in. A horizontal crack across the entire wall face was observed. The crack started at the impact point and continued diagonally to the upper left corner. The crack maximum width measured 1/16-in.



Series 1, Specimen 2 Panel erected for Doe Pipe Test



Impact Imprint of Series 2 panel after DOE Pipe Missile I

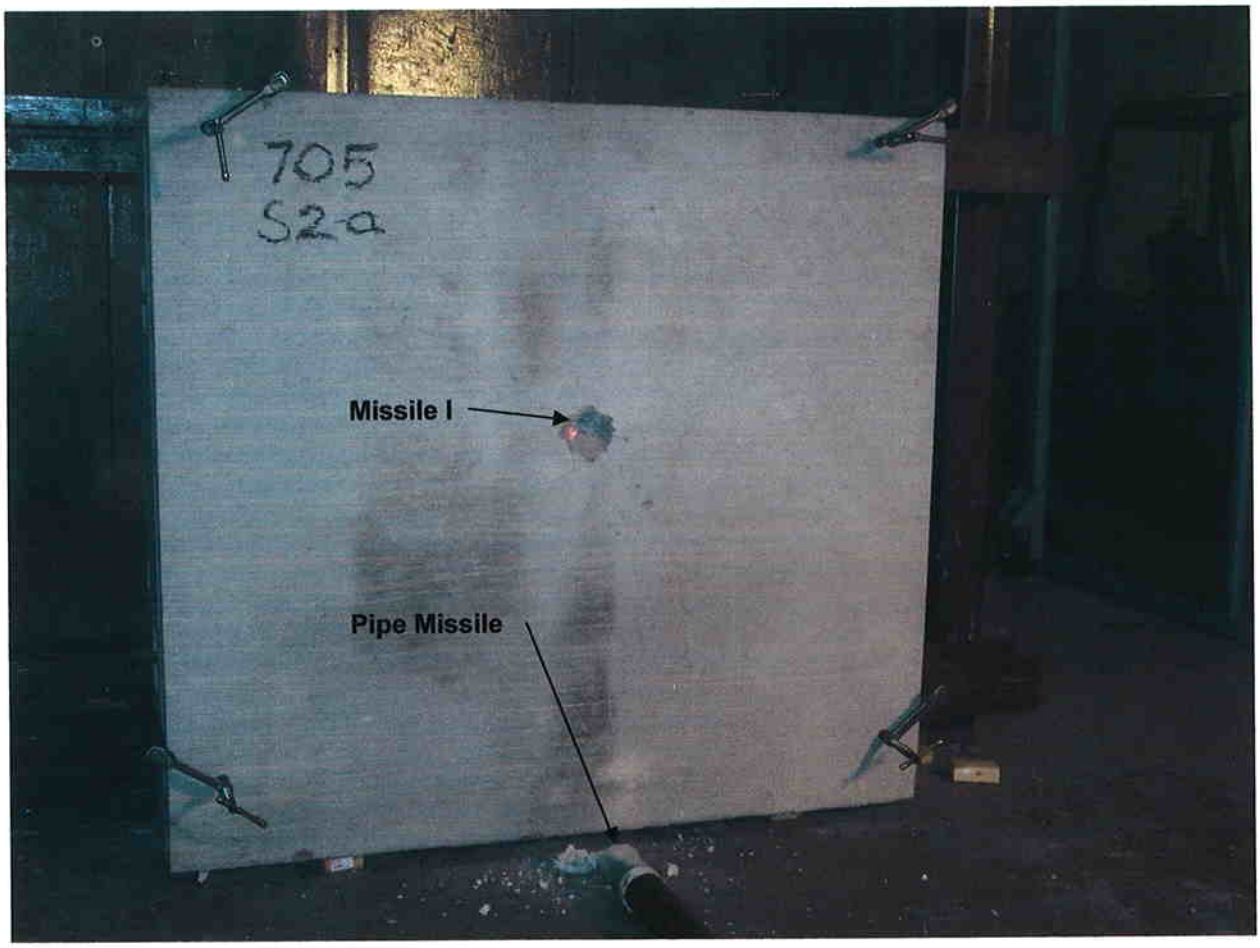


Cracking produced by DOE Pipe Missile on Specimen 2

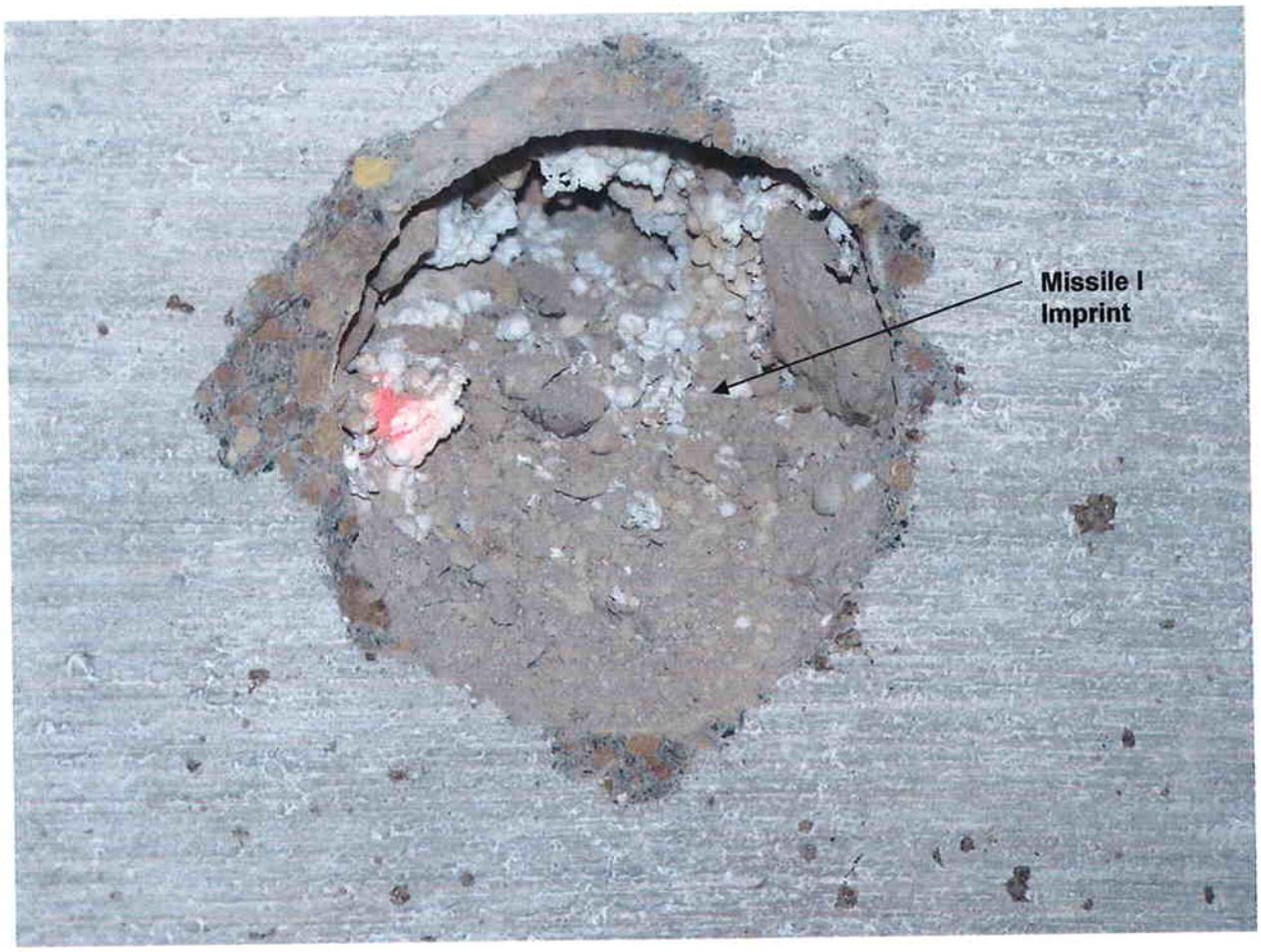
Series 2 – Specimen 1, October 19, 2007, Test Protocol #5

Missile Shot I – 75-lb. 75 mph DOE Pipe Test Protocol

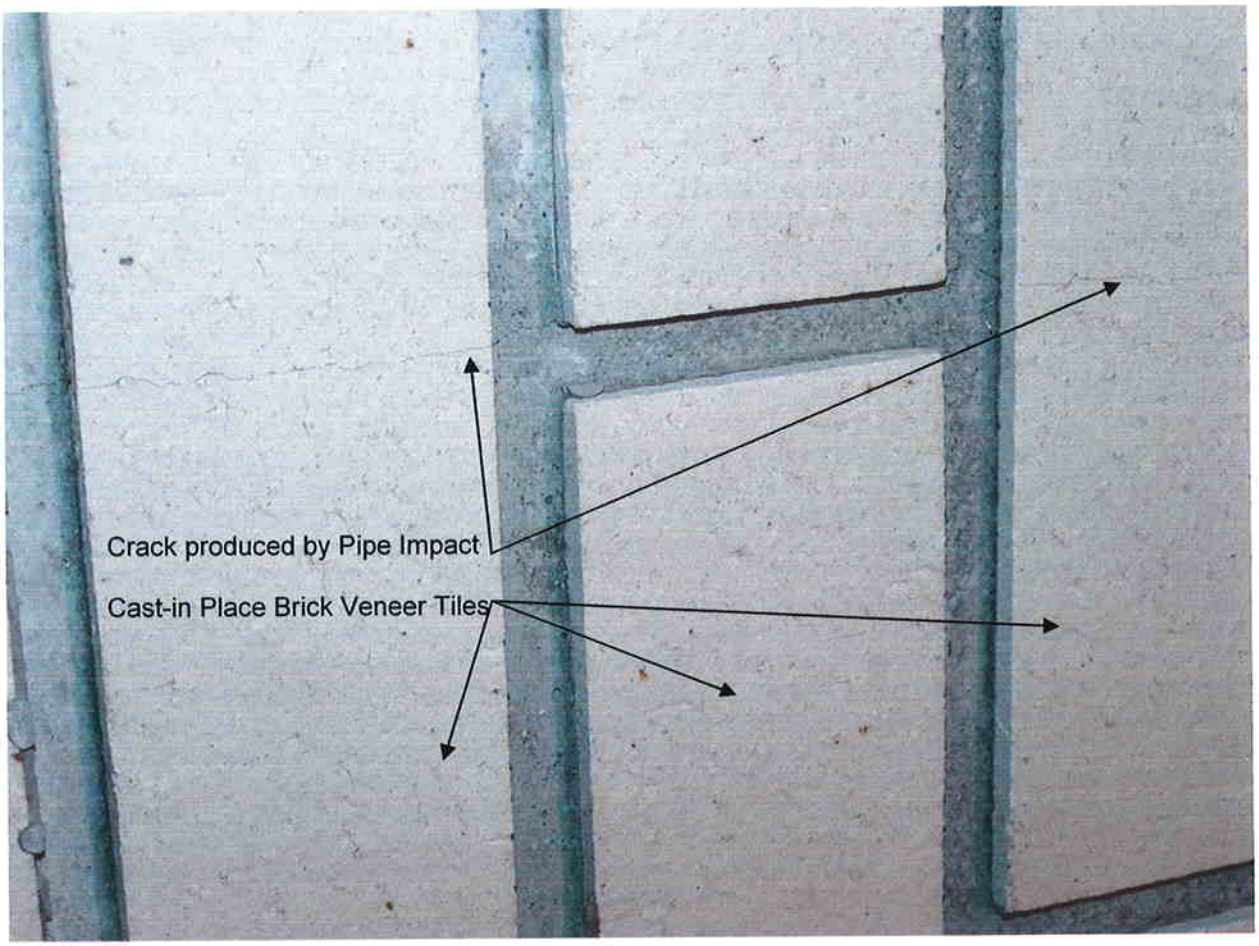
The Series 2 Specimen was a 12-in. sandwich panel with a concrete finish on the 2-in. face and brick veneer tiles cast into the 8-in. face. The panel was erected for impact on the 2-in. concrete face. Missile I impacted the center of the panel. The missile penetrated the concrete 5 ½-in. producing a 4-in. diameter hole. A horizontal crack across the backside of the specimen was produced by the impact. The crack extended from the impact point to each vertical edge of the specimen. The maximum crack width was 1/16-in.



Series 2, Specimen 1 Panel Impacted by DOE Pipe Missile I



Pipe Missile I Imprint

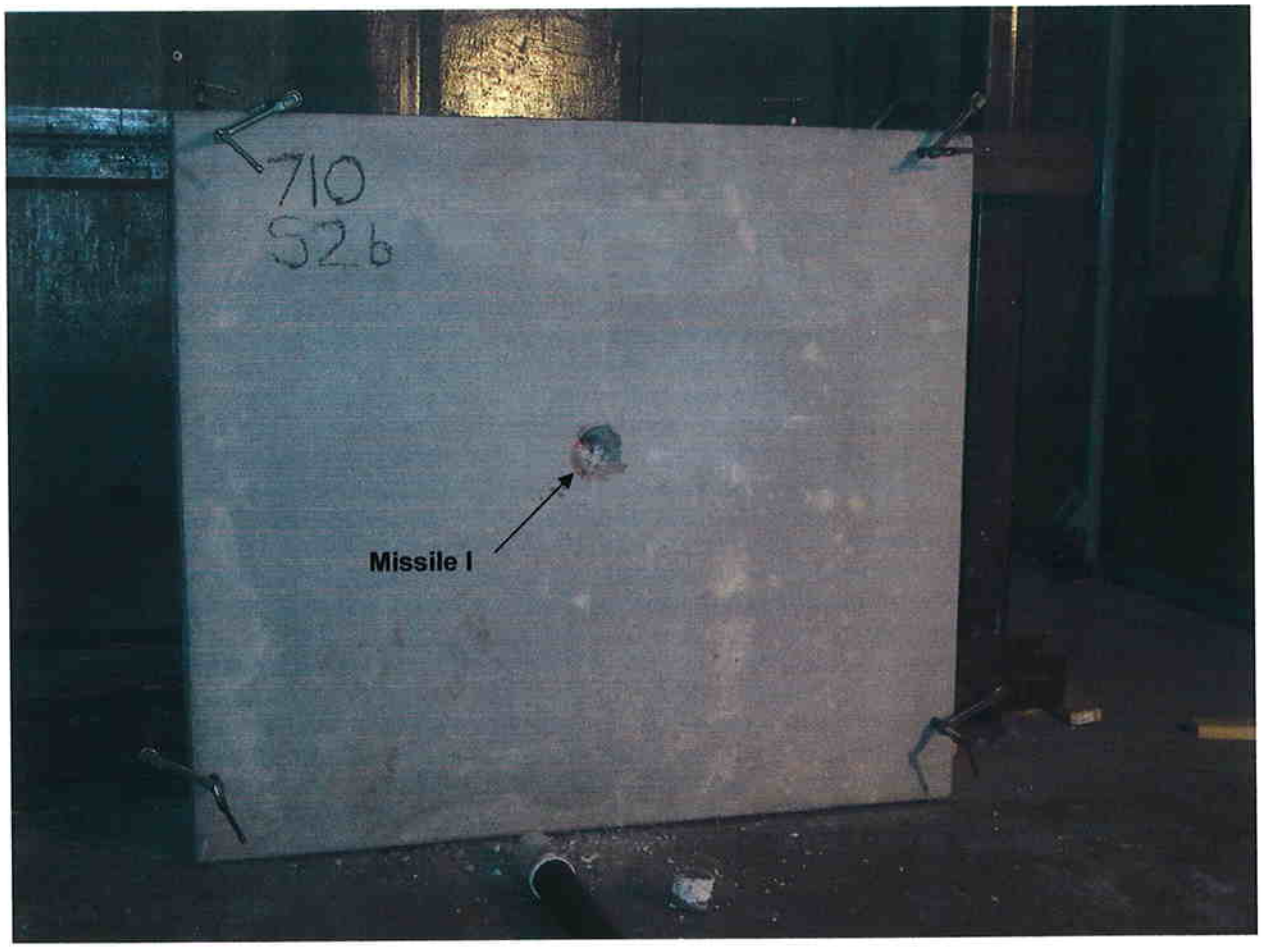


Crack on backside of impacted Series 2 Panel

Series 2 – Specimen 2, October 18, 2007, Test Protocol #5

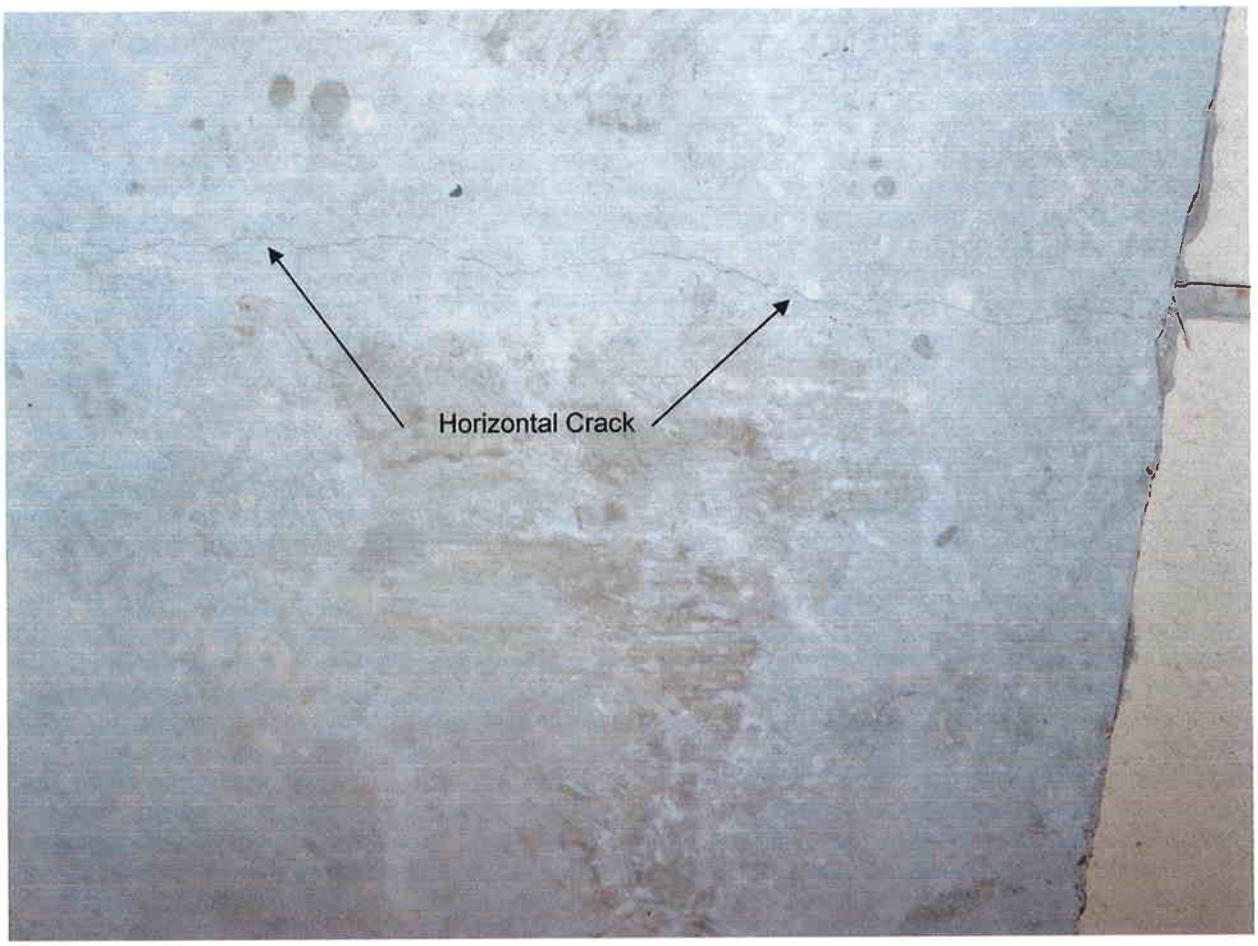
Missile Shot I – 75-lb. 75 mph DOE Pipe Test Protocol

The Series 2, Specimen 2 panel was installed as a validation test of the previous test results observed on Specimen 1. Specimen 2 was impacted in the panel center. The impact produced a rough 5 3/8-in. diameter impact crater and a 4-in. diameter hole in the panel. A horizontal crack across the entire wall face was observed. The crack started at the impact point and continued horizontally to each vertical edge. The crack maximum width measured 1/32-in.



Series 2, Specimen 2 Validation Panel after DOE Pipe Missile I Impact

Pipe Missile Imprint

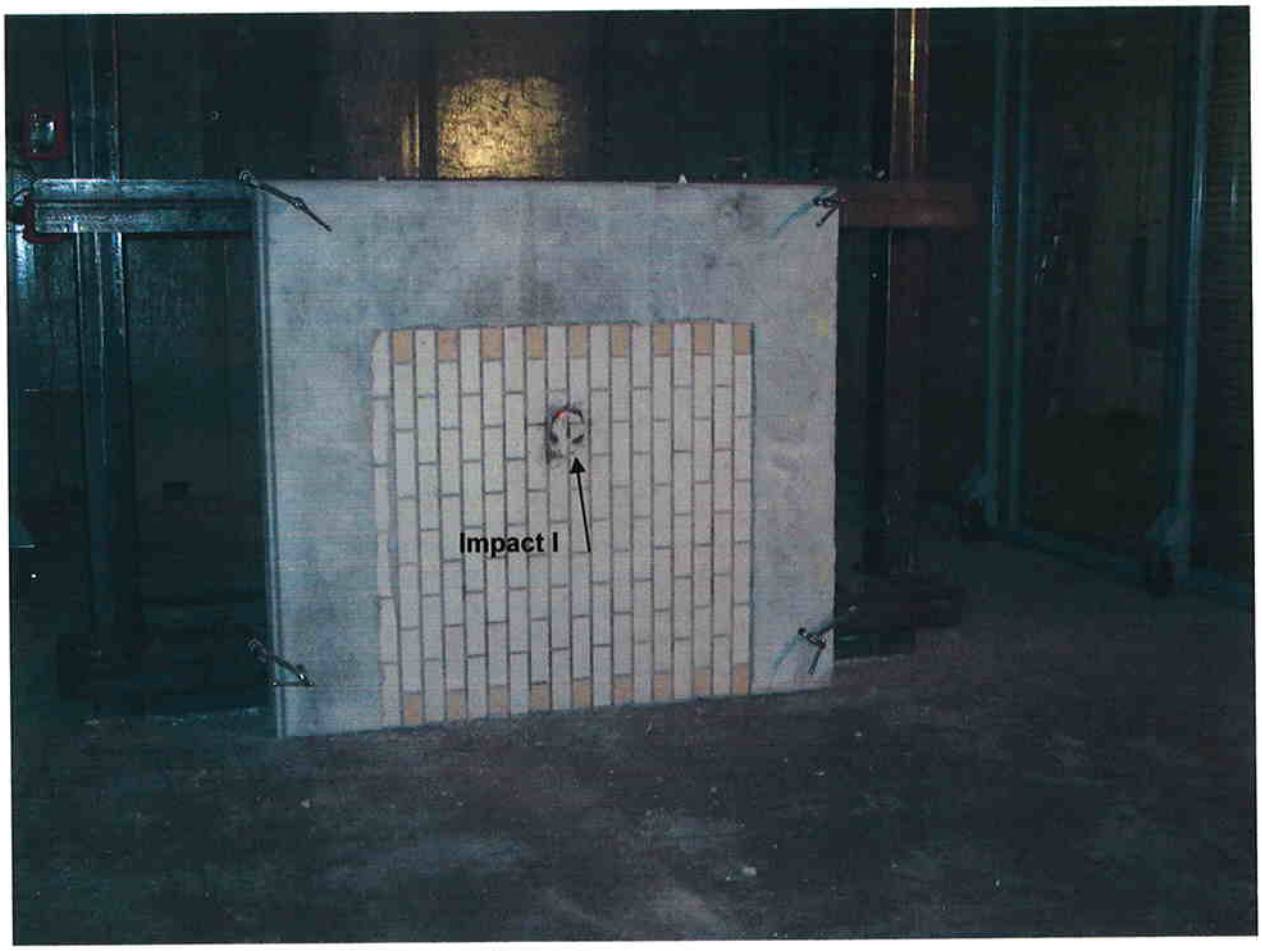


Horizontal Crack in backside of wall after DOE Pipe Impact

Series 3 – Specimen 1, November 1, 2007, Test Protocol #5

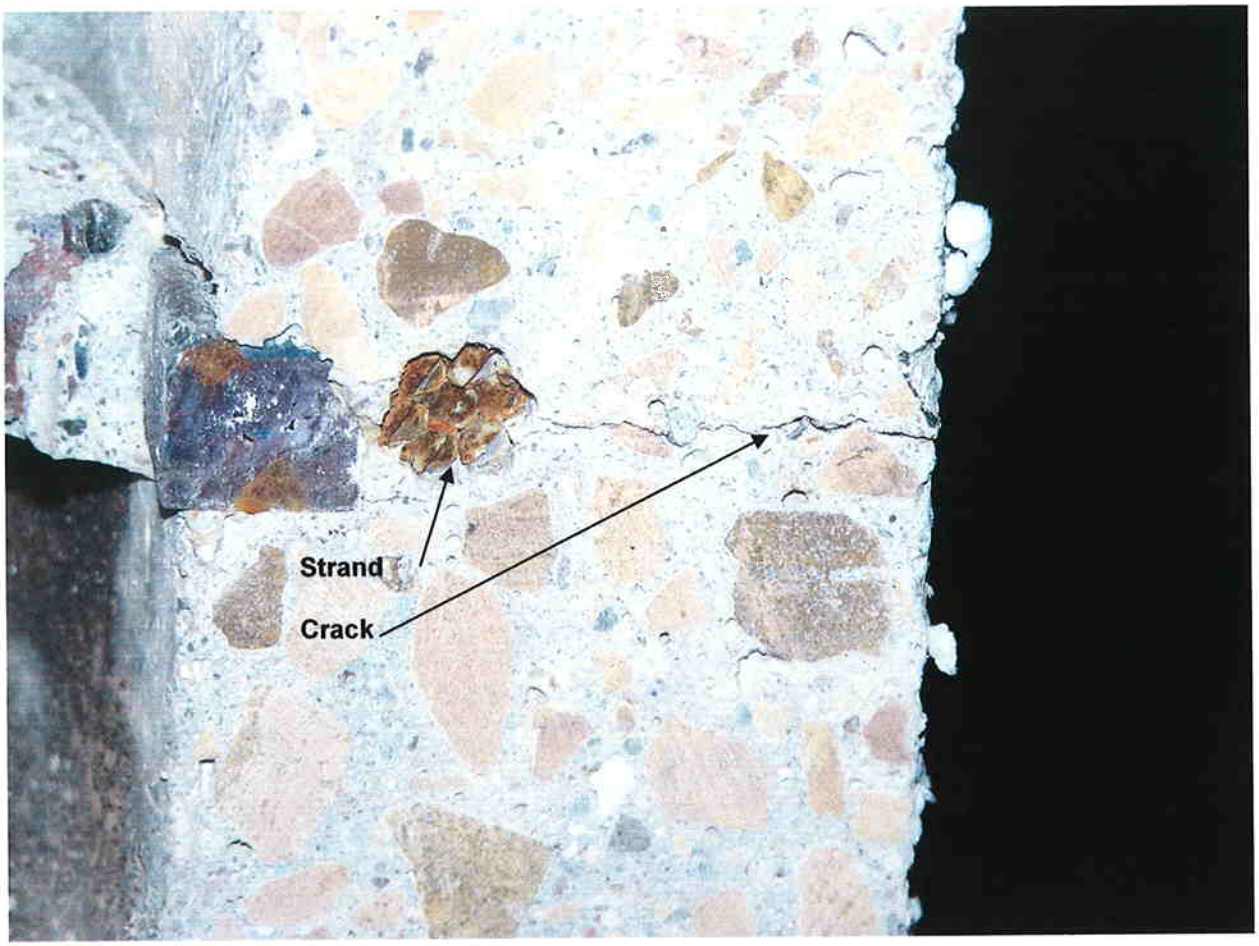
Missile Shot I – 75-lb. 75 mph DOE Pipe Test Protocol

The Series 3, Specimen 1 panel was an 8-in. solid concrete panel with brick veneer tiles cast on the impact face. Specimen 1 was impacted in the panel center. The impact produced a 4-in. pipe imprint with slight fracturing of the edges of the impact face brick. A 16-in. diagonal crack on the exterior top right corner was noted with a maximum width of 1/32-in. Interior face cracking included a horizontal crack 1/8-in. extending from wall edge to wall edge. The horizontal crack appeared to mirror the location of the upper strand. A diagonal crack extending to the left wall edge with a crack width of 1/32-in. was also observed.



Series 3, Specimen 1 Panel impacted by DOE Pipe Missile

Pipe Imprint on Series 3 Panel



Horizontal Crack Occurring at Reinforcing Strand

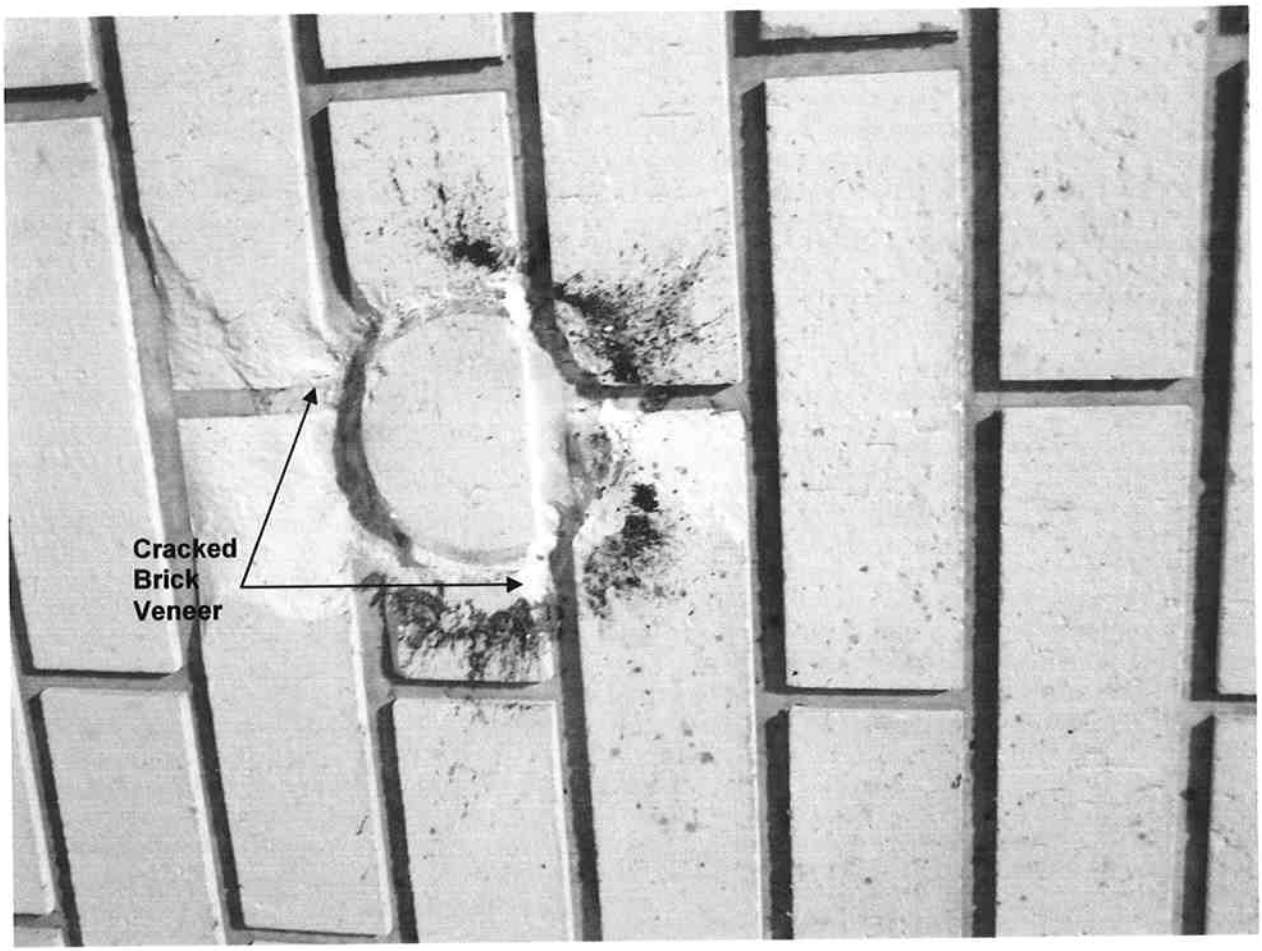
Horizontal Crack produced by DOE Pipe Missile

Series 3 – Specimen 2, November 1, 2007, Test Protocol #5

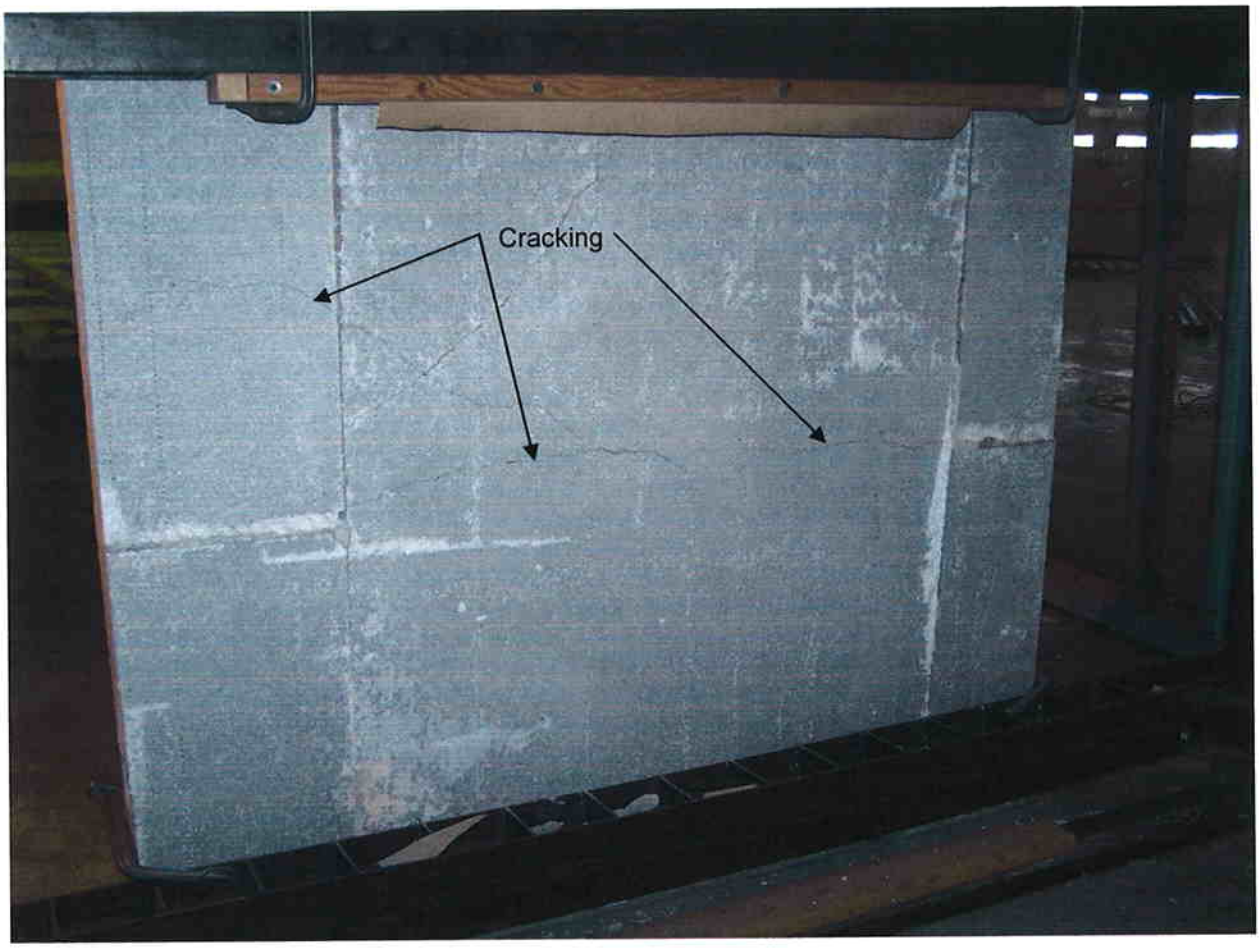
Missile Shot I – 75-lb. 75 mph DOE Pipe Test Protocol

The Series 3, Specimen 2 panel was installed as a validation test of the previous test results observed on Specimen 1. Specimen 2 was impacted in the panel center. The impact produced a rough 5 ½-in. diameter impact crater on the exterior with penetration up to 1 1/8-in. A horizontal crack across the entire wall face was observed. The crack started at the impact point and continued diagonally to the upper left corner. The crack maximum width measured 1/16-in.

Missile Impact I of Series 3, Validation Specimen 2 Panel by DOE Pipe Projectile



Pipe Imprint produced by DOE Missile

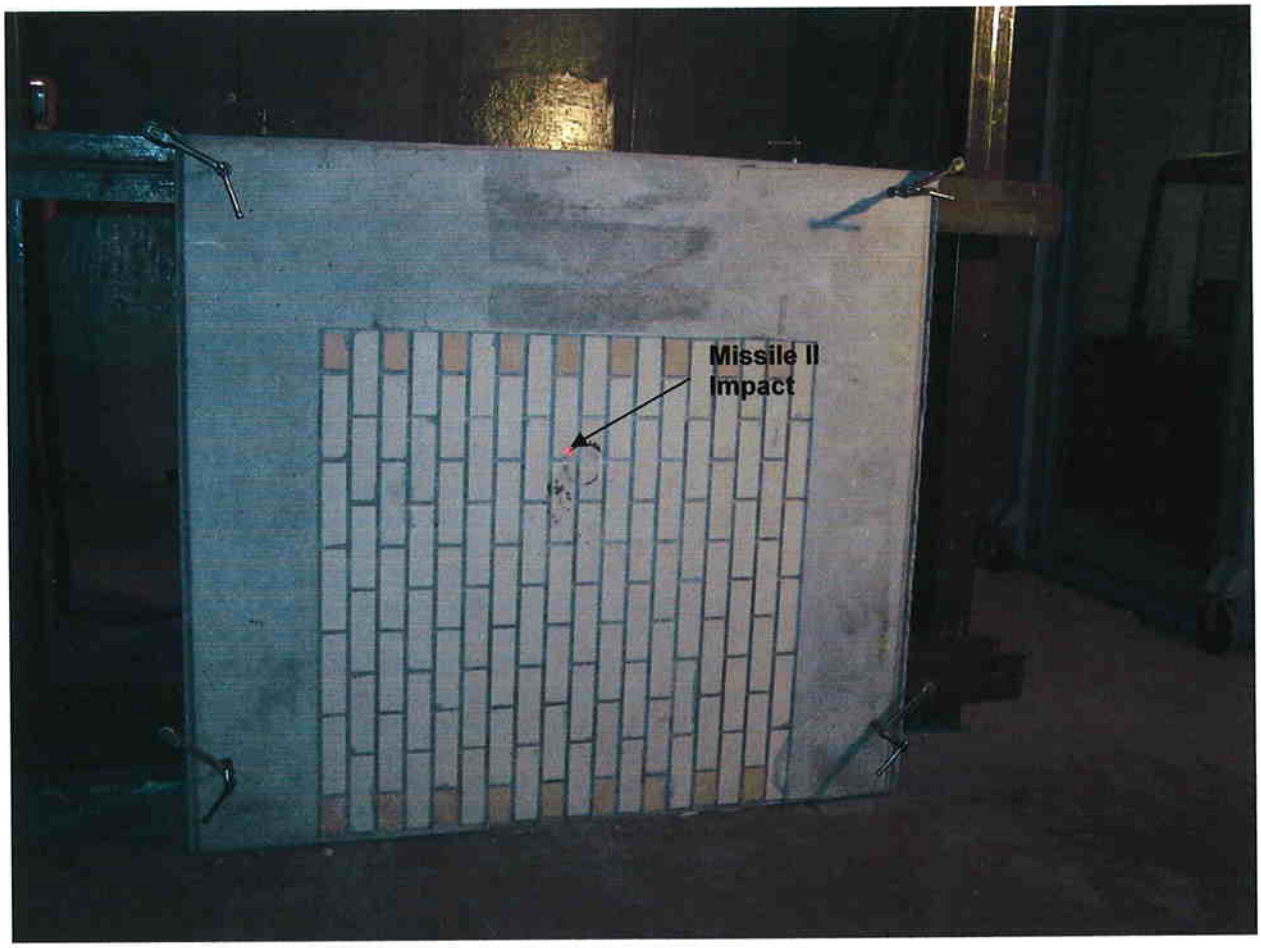


Backside Cracking produced by Pipe Missile

Series 4 – Specimen 1, November 1, 2007, Test Protocol #5

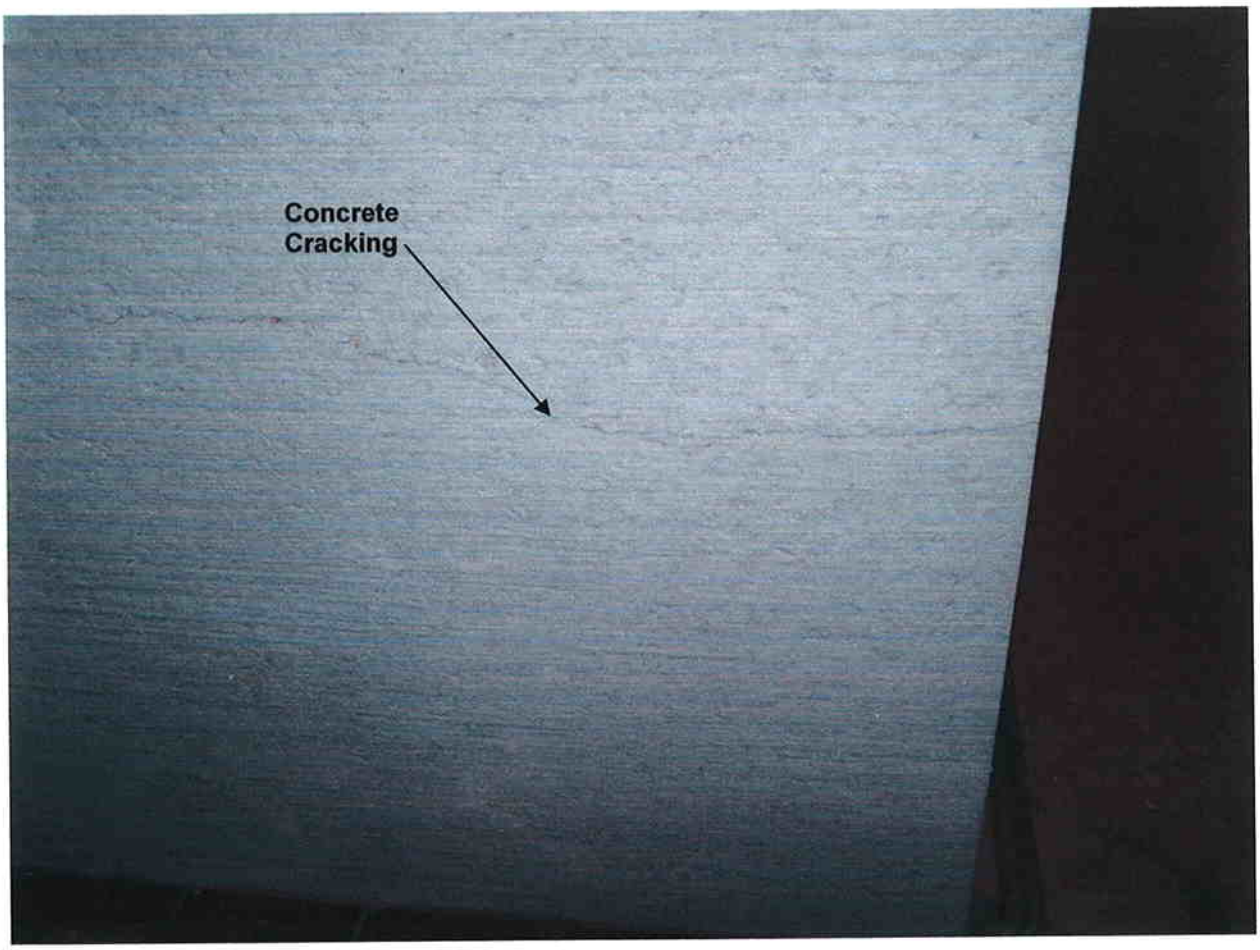
Missile Shot I – 75-lb. 75 mph DOE Pipe Test Protocol

The 12-in. sandwich Series 4, Specimen 1 panel was installed with the brick veneer attached to the 8-in. face of the panel facing the canon. Specimen 1 was impacted in the panel center. The impact produced a rough 5 ½-in. diameter impact crater on the exterior with penetration up to ¼-in. fracturing of the brick edges. A horizontal crack across the entire interior wall face was observed. The crack maximum width measured .017-in.



Series 4, Specimen 1 Panel Impacted by DOE Pipe Missile

Missile Imprint from Missile I

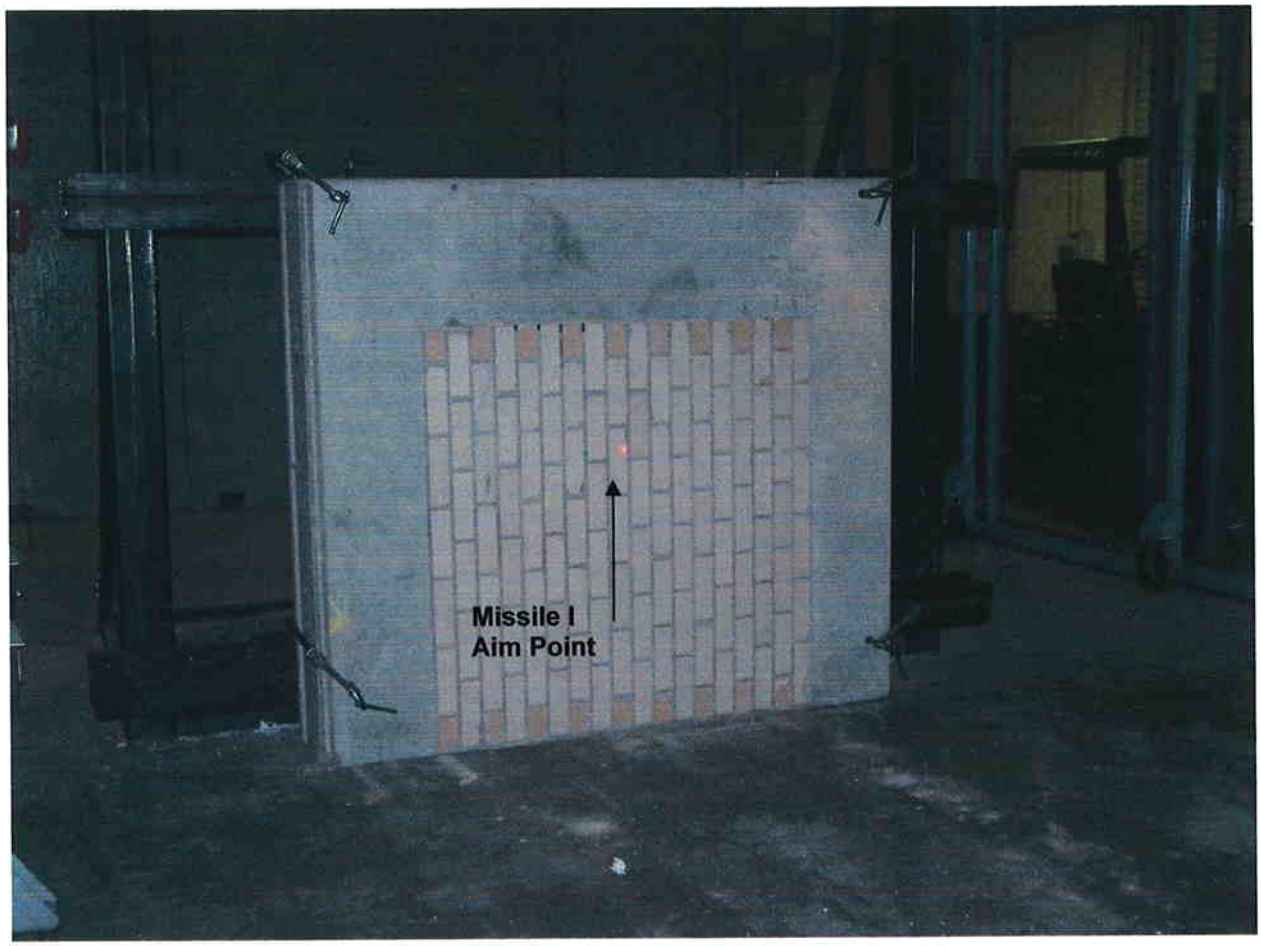


Concrete Cracking produced by Missile I

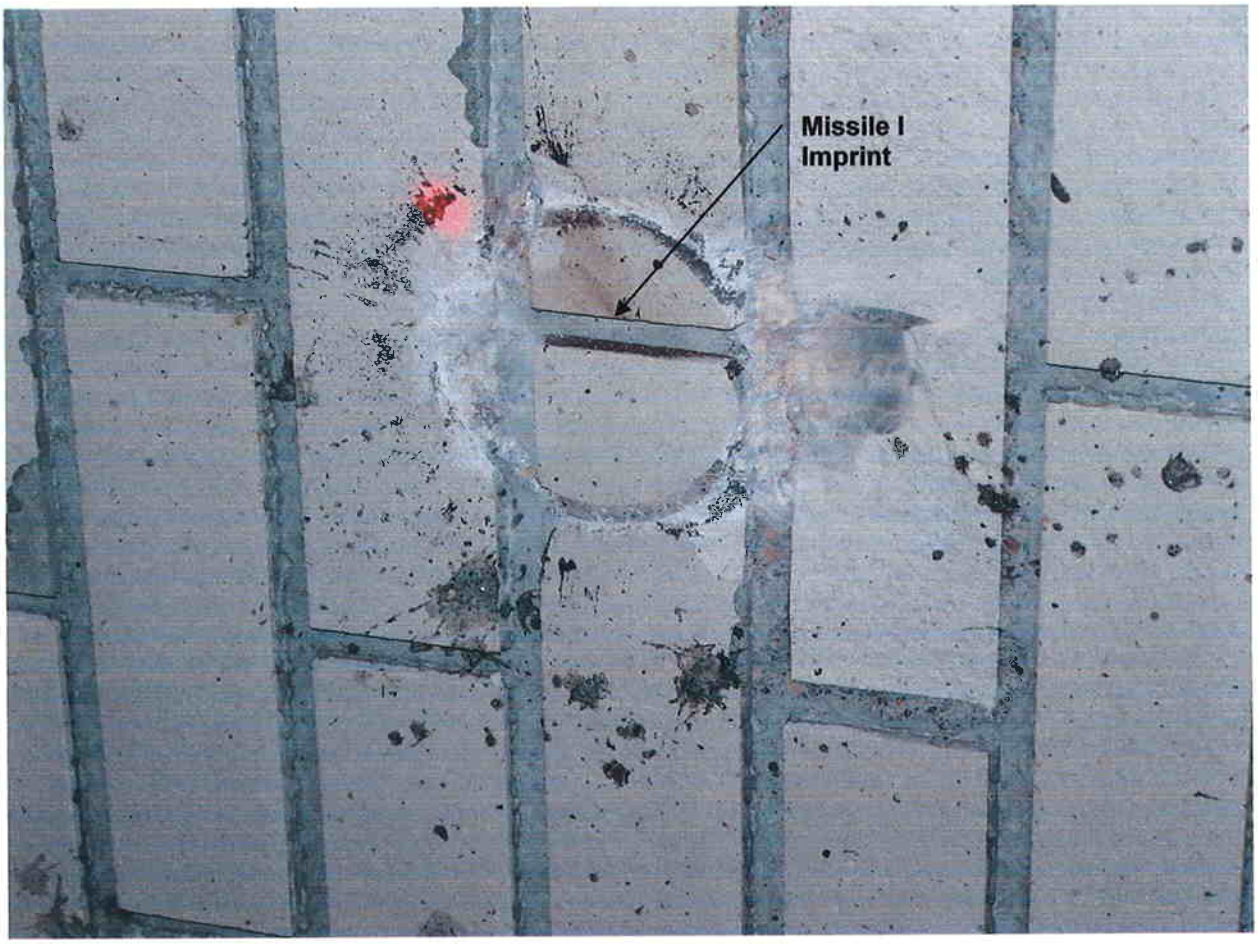
Series 4 – Specimen 2, November 1, 2007, Test Protocol #5

Missile Shot I – 75-lb. 75 mph DOE Pipe Test Protocol

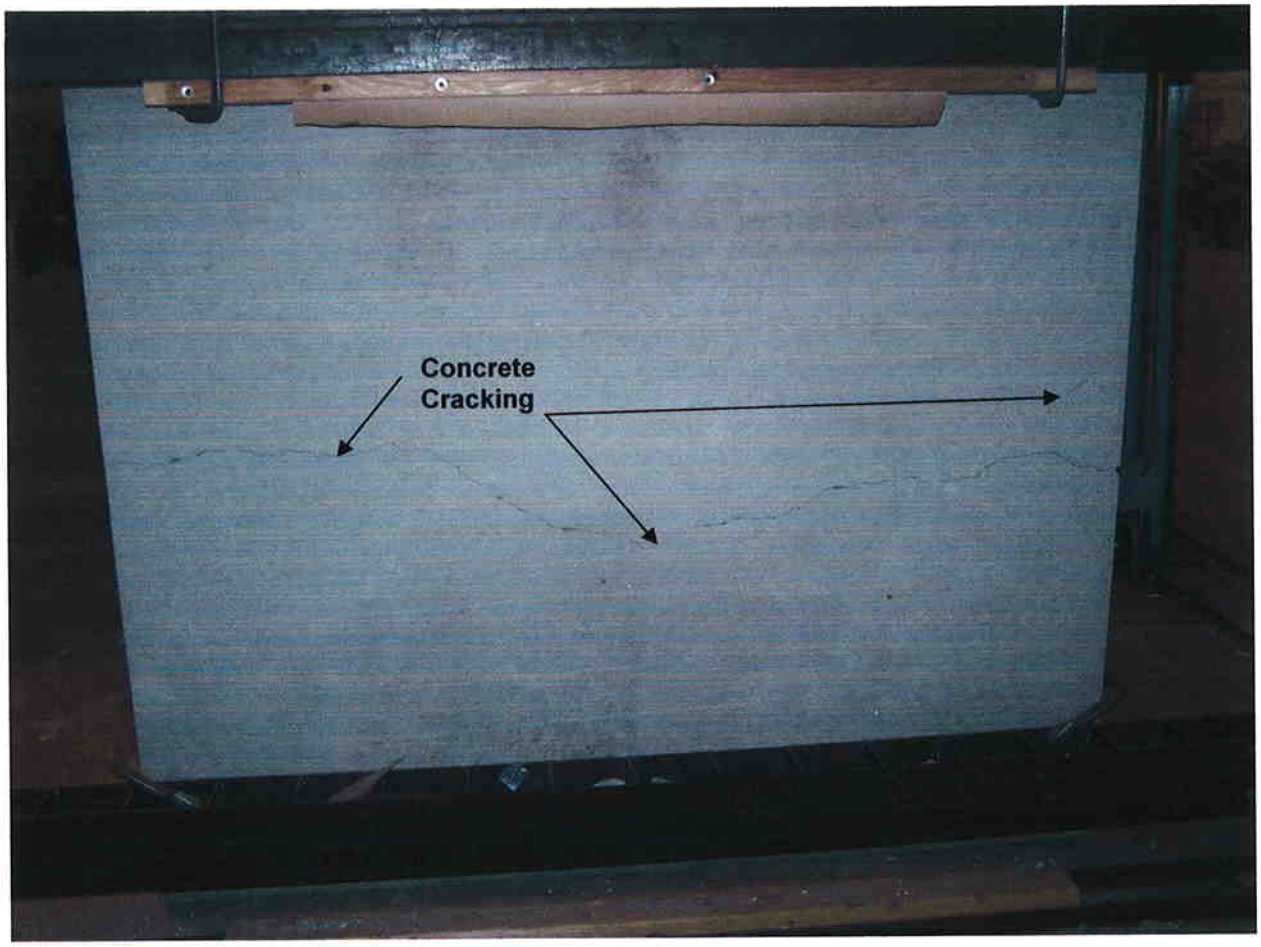
The Series 4, Specimen 2 panel was installed as a validation test of the previous test results observed on Specimen 1. Specimen 2 was impacted in the panel center. The impact produced a rough 5 ½-in. diameter impact crater on the exterior with a fracturing of the brick edges of ¼-in. A horizontal crack across the entire interior wall face was observed. The crack started at the impact point and continued horizontally across the entire panel with a diagonal crack near the right edge.



Series 4, Specimen 2 Panel readied for testing



Missile I Imprint



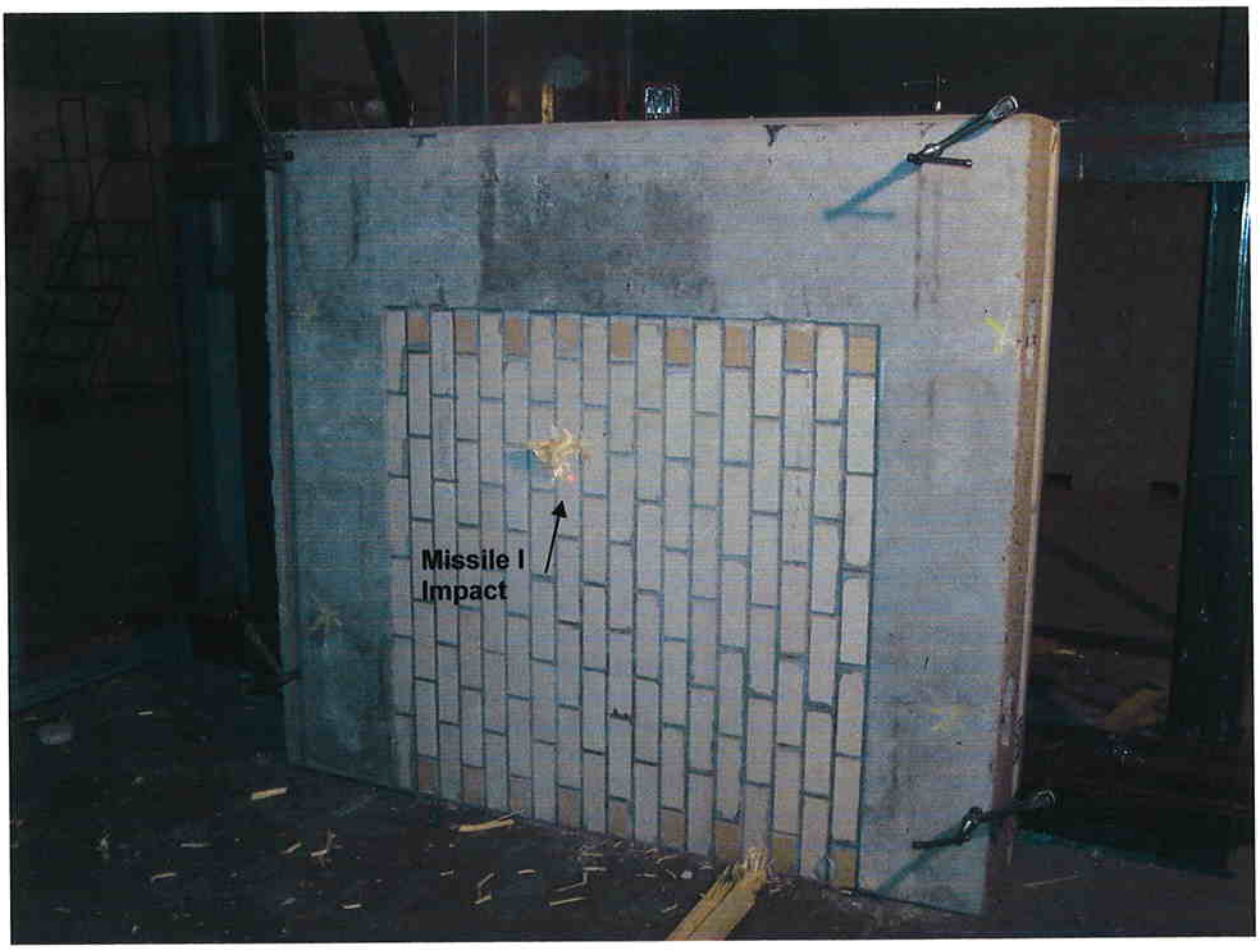
Spalling produced by Impact III

Cracking at right edge of panel backside

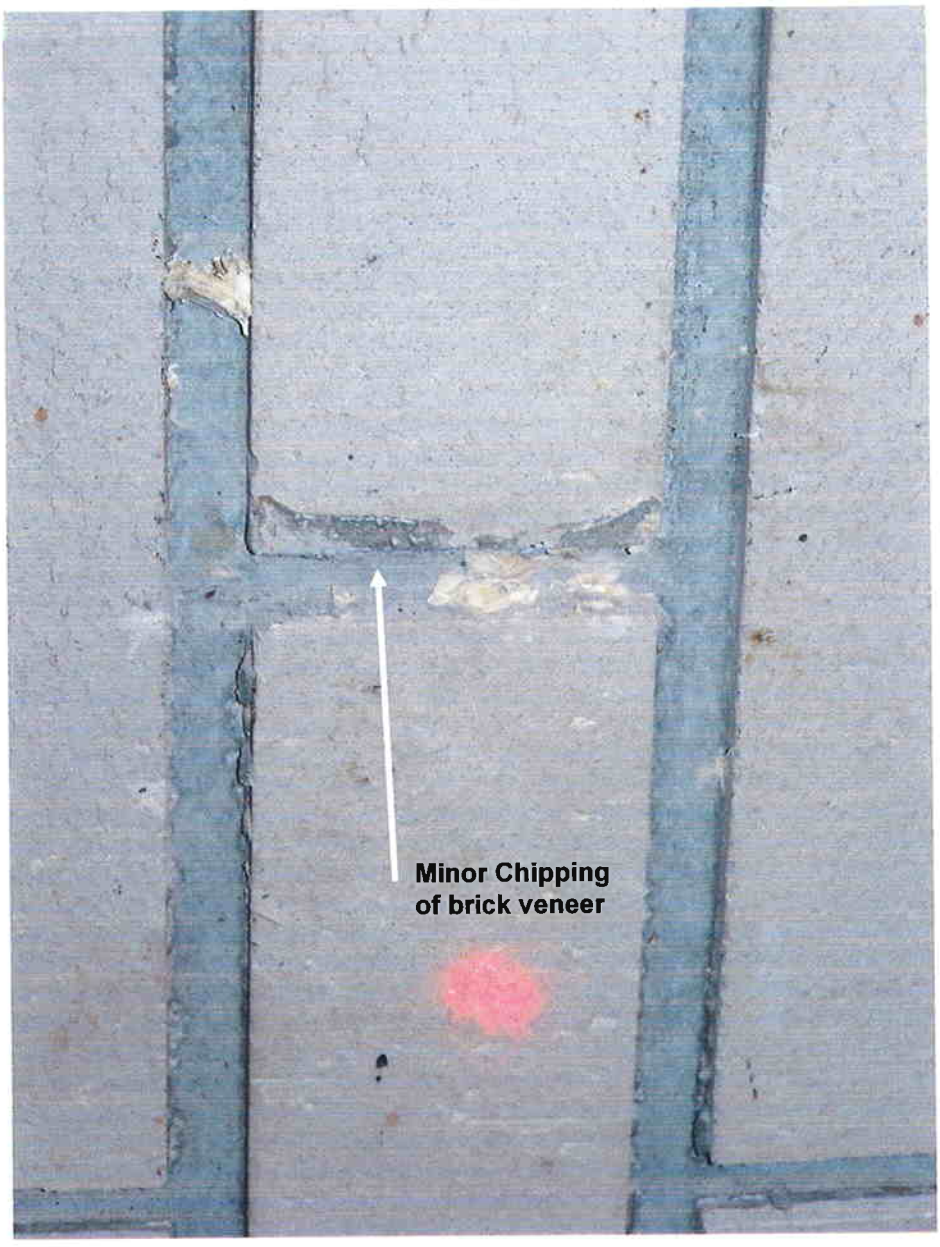
Series 5, Specimen 1 – November 1, 2007, Test Protocol #5

Missile Shot I – 15-lb. 150 mph DOE Wood 2x4 Protocol

The Series 5 sandwich panel was erected with the 8-in. concrete face with the brick veneer facing the canon. The 2x4 wood missile impacted the center of the panel producing no remarkable damage.



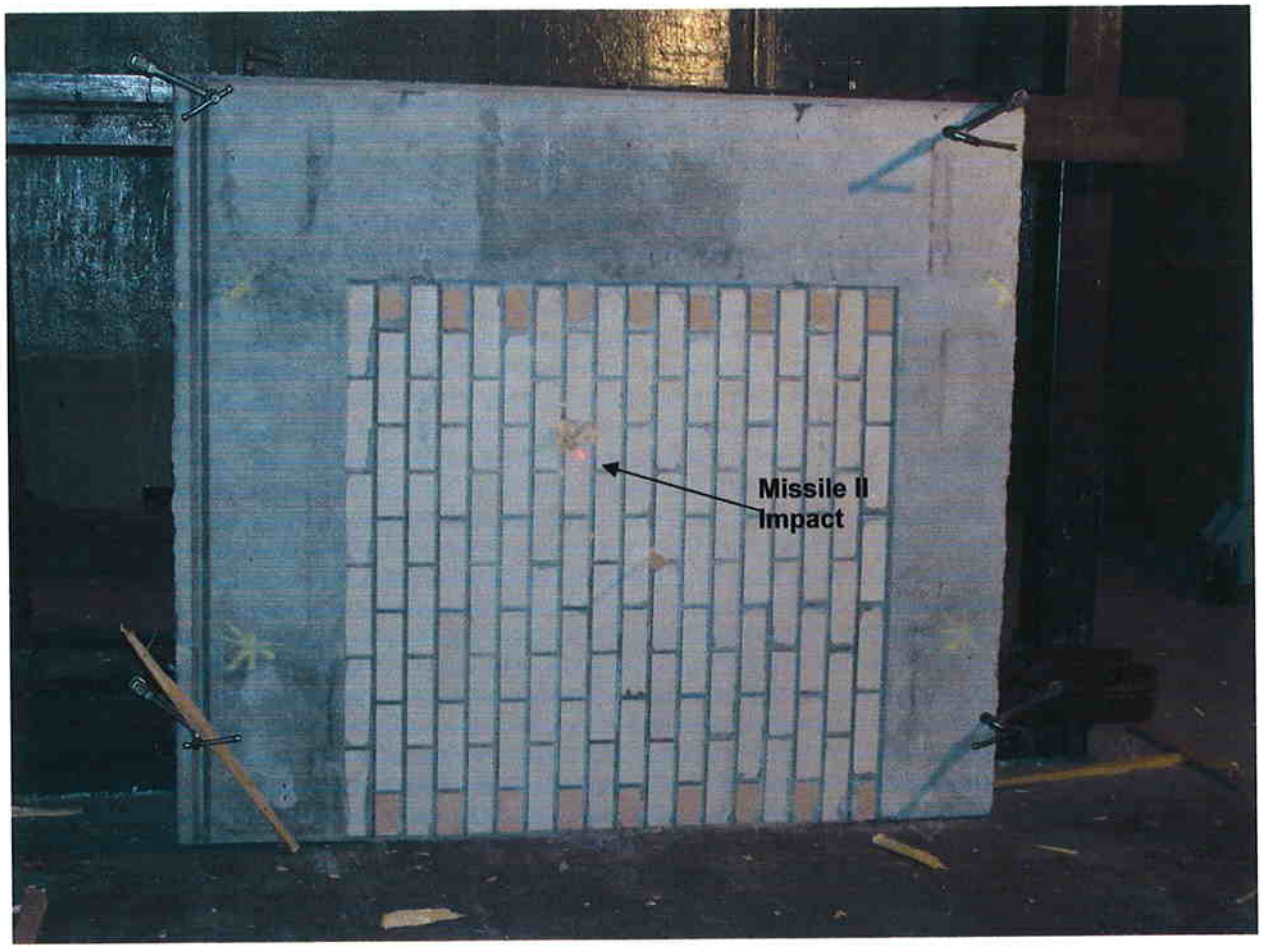
Missile Impact I of Series 5, Specimen 8-in. concrete side



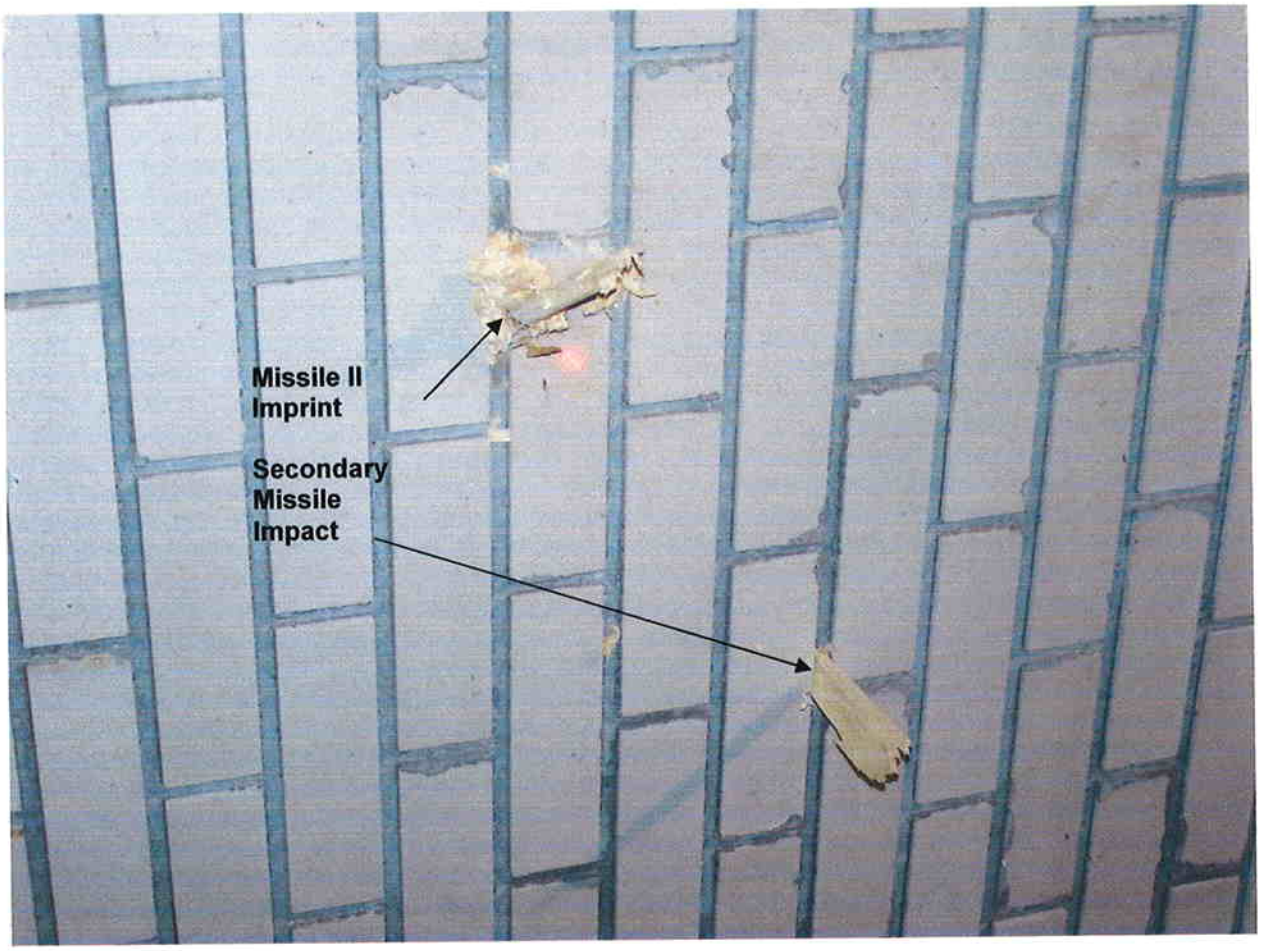
Missile I chipping of brick veneer

Missile Shot II – 15-lb. 150 mph DOE Wood 2x4 Test Protocol

The Series 5 sandwich panel was erected with the 8-in. concrete face with the brick veneer facing the canon. The 2x4 wood missile impacted the center of the panel producing no remarkable damage.



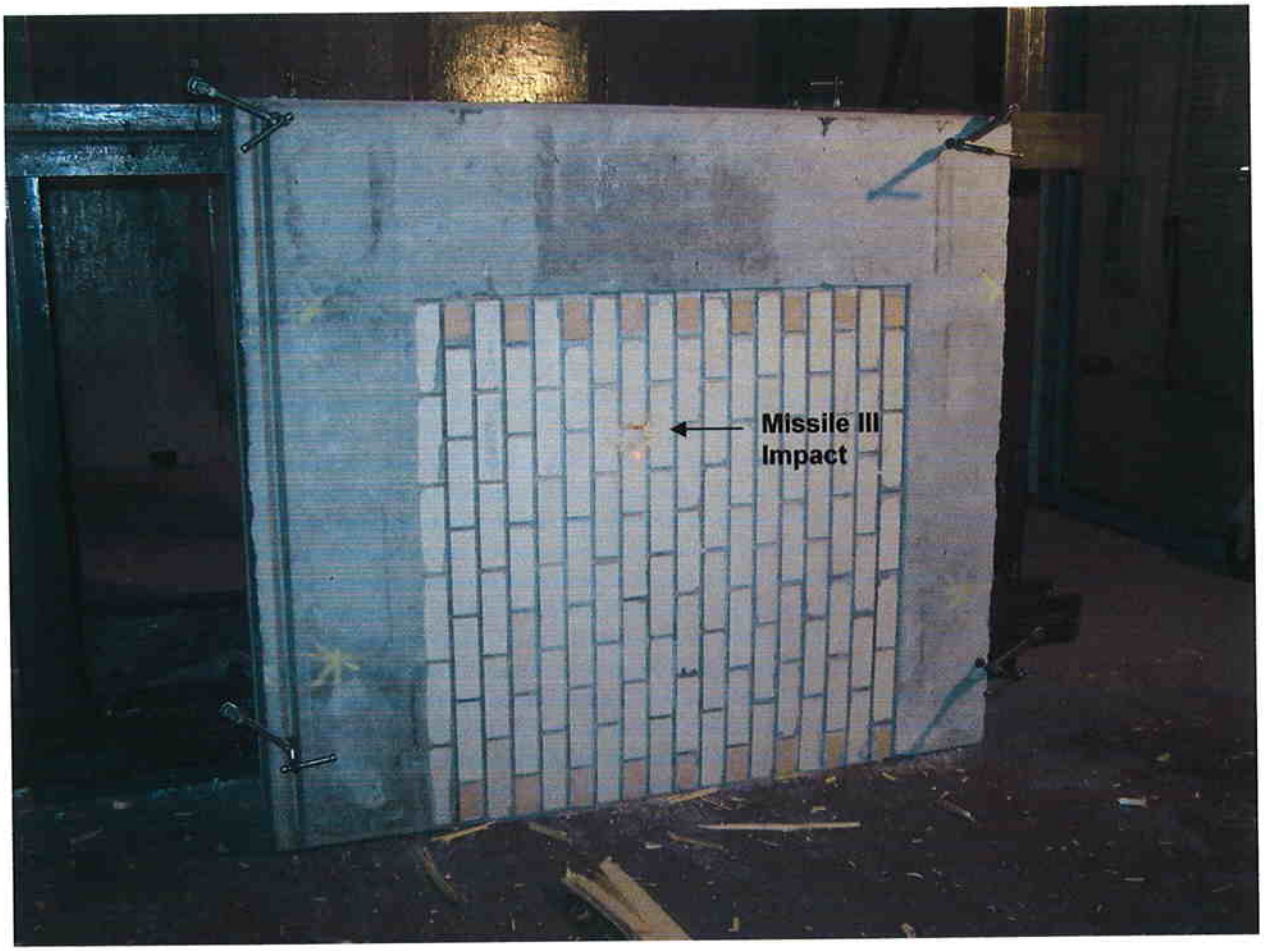
Missile Impact II of Series 5, Specimen 8-in. concrete face



Missile 2 Impact on Series 5 Specimen 8-in. face

Missile Shot III – 15-lb. 150 mph DOE 2x4 Wood Test Protocol

The Series 5 sandwich panel was erected with the 8-in. concrete face with the brick veneer facing the canon. The 2x4 wood missile impacted the center of the panel producing no remarkable damage.



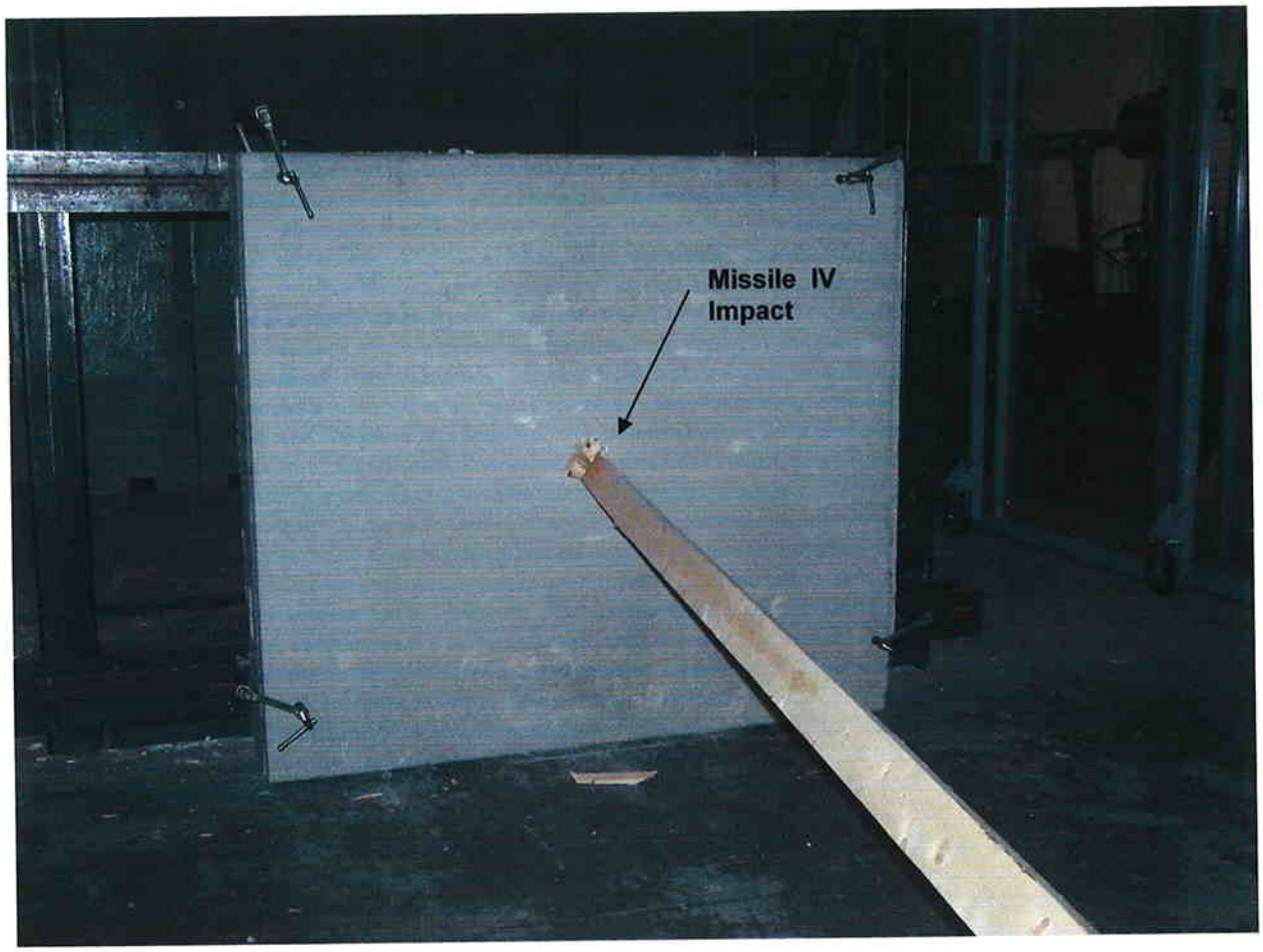
Series 5, Specimen 1 8-in. panel face impacted by Missile III

Missile III Imprint on Series 5, Specimen 1 8-in. panel face

Series 5 – Specimen 2, October 18, 2007, Test Protocol #5

Missile Shot IV – 15-lb. 150 mph DOE Wood 2x4 Test Protocol

The previously tested Series 5 sandwich panel was re-installed with the 2-in. concrete face facing the canon. The 2x4 wood missile impacted the center of the panel. The missile was embedded in the panel up to 4 ½-in extending through the foam insulation. The missile created a rough 4-in. diameter entrance hole.

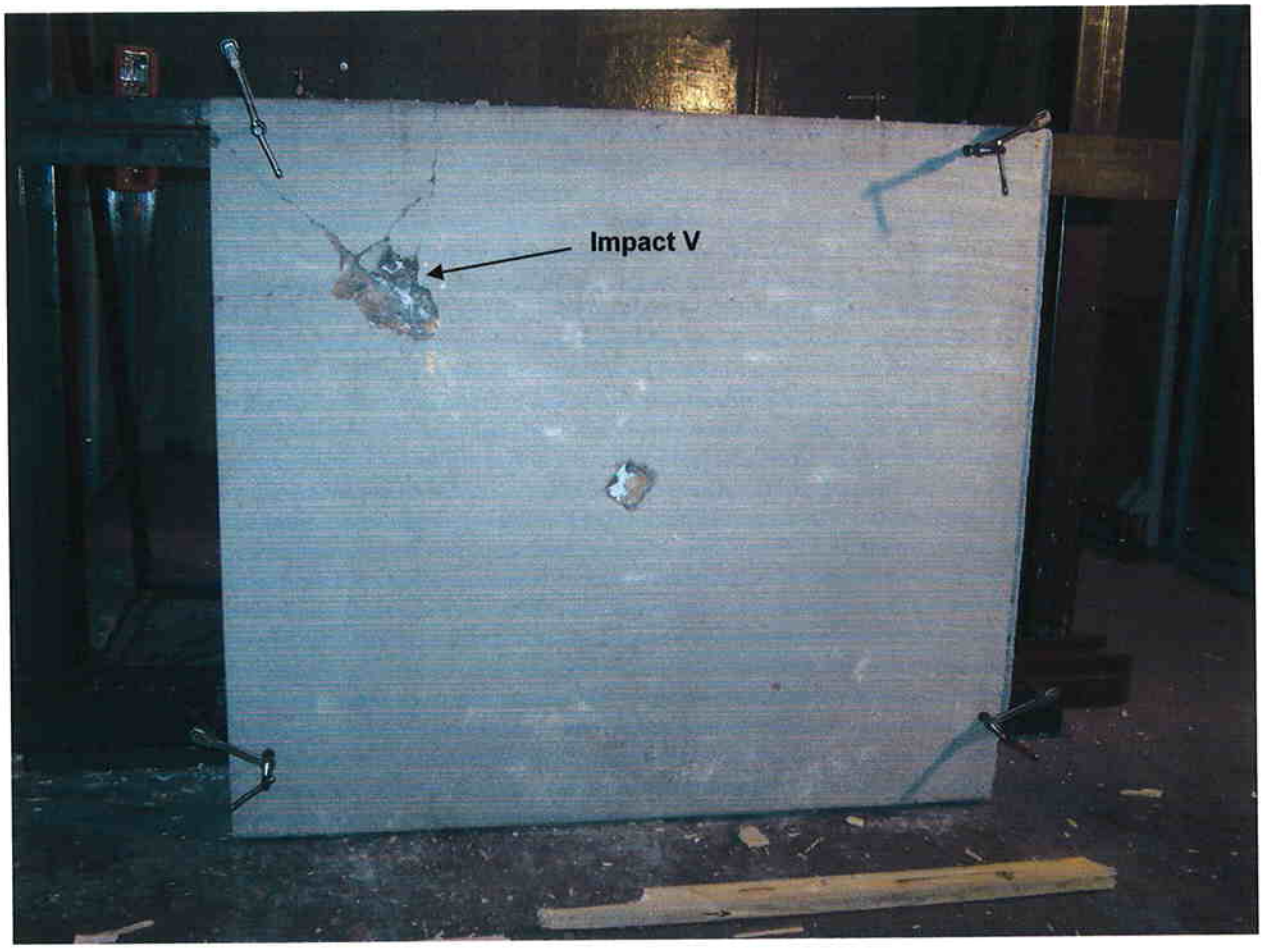


Series 5, Specimen 2-in. panel side impacted by Missile IV

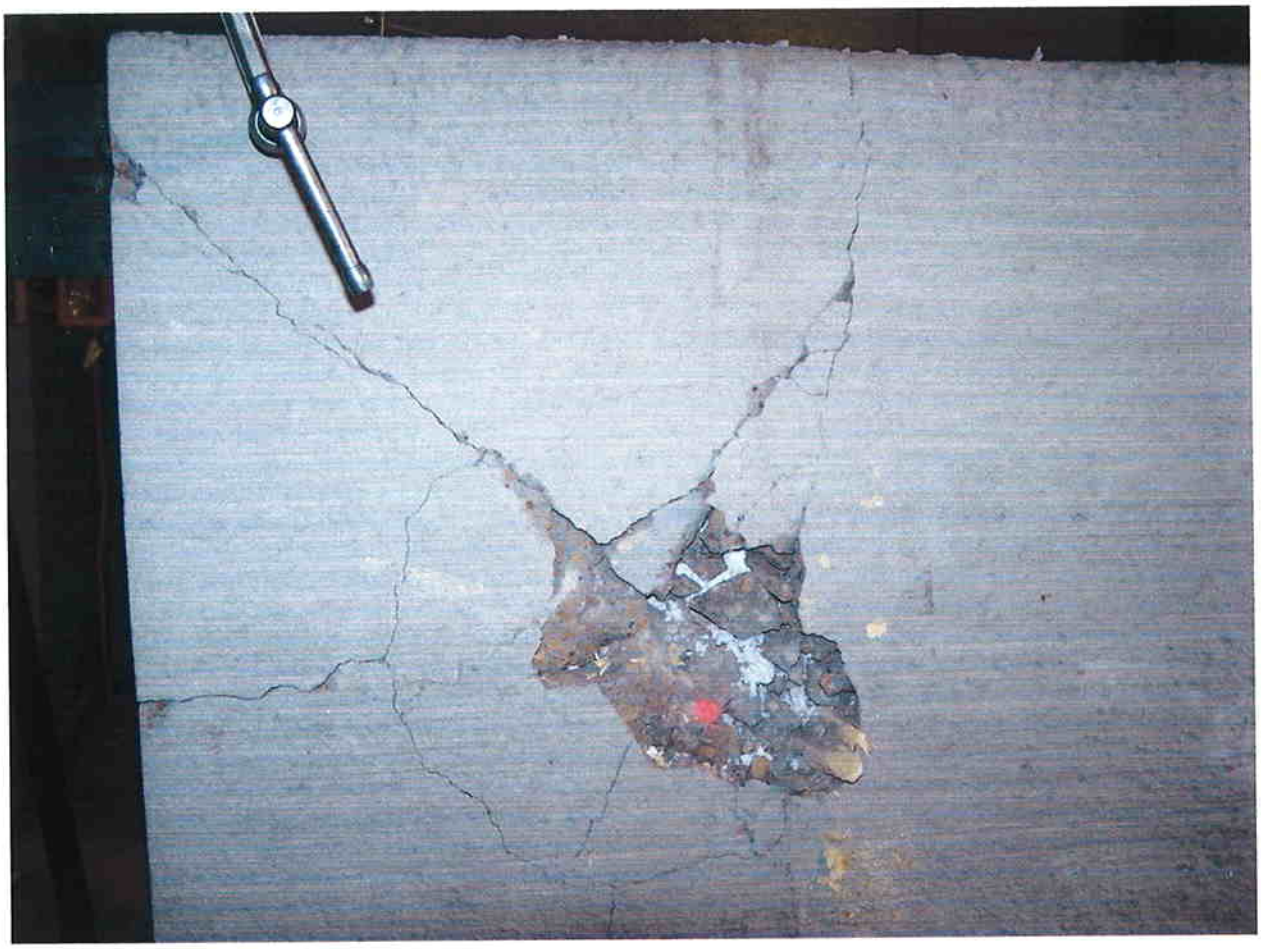
Panel penetration by Missile IV

Missile Shot IV – 15-lb. 150 mph DOE Wood 2x4 Test Protocol

The Series 5, 2-in. concrete face was impacted in the upper left corner of the panel. The missile penetrated the exterior face up to 3-in. with spalling over a rough area of 9-in. x 6-in. A 14-in. radial crack was observed around the penetration point. Diagonal cracking extended up and to the left wall edge, top edge and the bottom edge. No remarkable damage was noted to the backside of the panel.



Series 5, Specimen 2-in. panel face impacted by Missile V

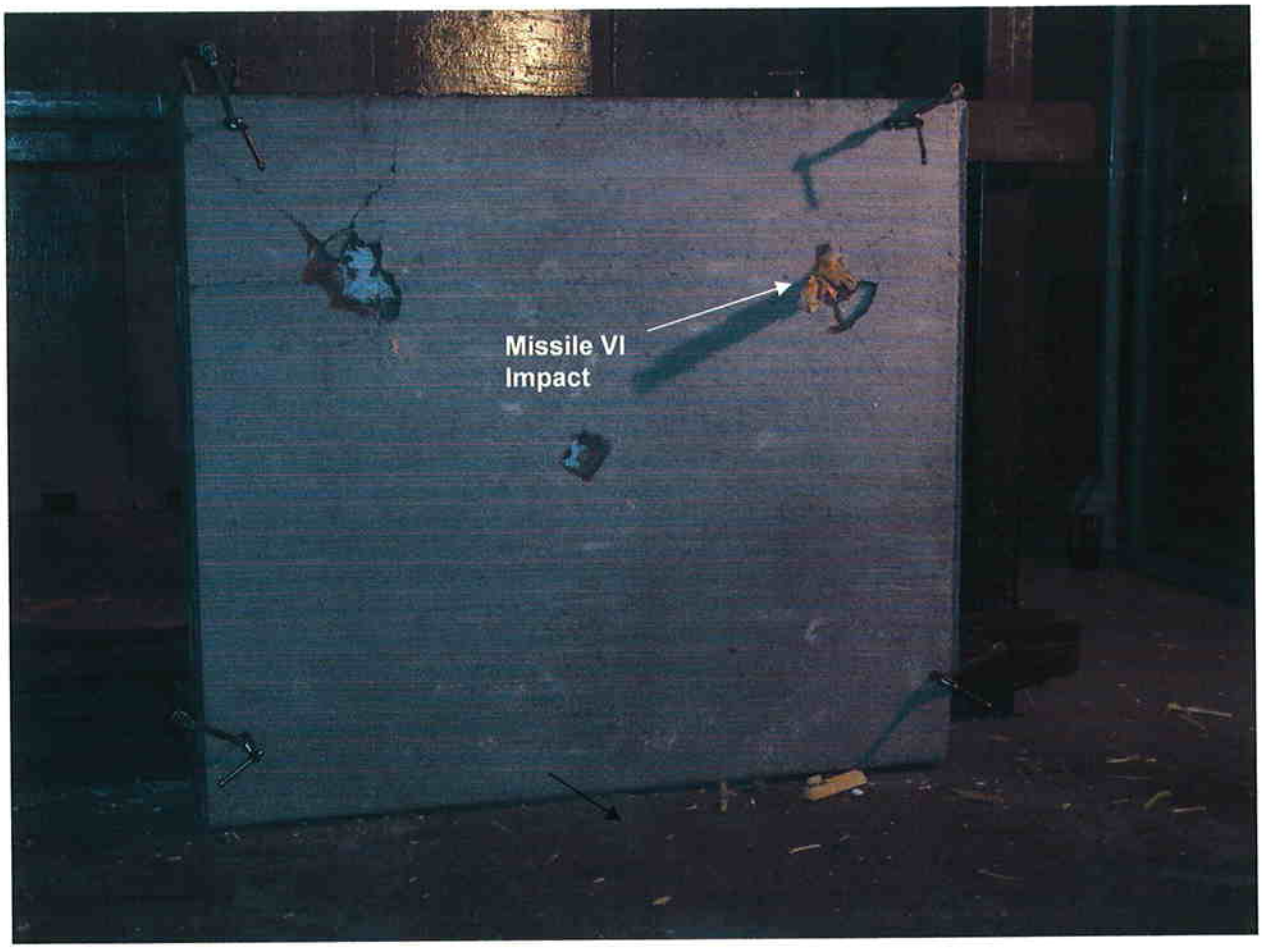


Series 5, panel cracking produced by Missile V

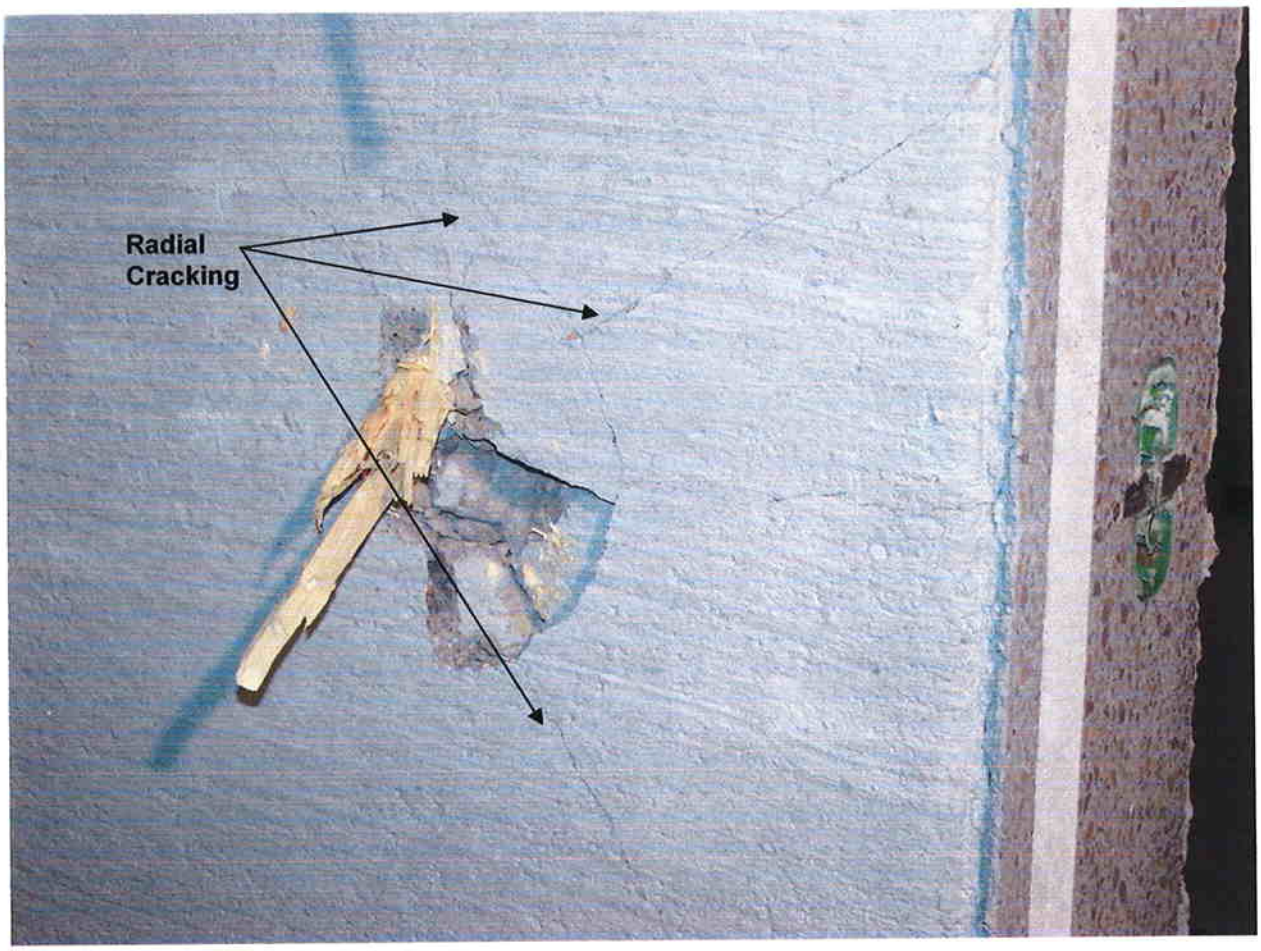
Series 5 Panel Penetrated 3-in. by Missile V

Missile Shot VI – 15-lb. 150 mph DOE Wood 2x4 Test Protocol

The Series 5 sandwich panel with the 2-in. concrete face facing the canon was impacted on the upper right corner of the panel. The missile penetrated the sample 4 ½-in. through the face extending into the foam insulation. 10-in. of radial cracking was produce along the right side of the impact. Four diagonal cracks were observed extending from the impact point to the sample edge, bottom and top right corners. No damage to the panel backside was observed.



Missile Impact VI of Series 5, Specimen 2-in. face of the panel



Series 5 Panel Impacted by Missile VI

Conclusions

Within the bounds of reasonable engineering and technical certainty, and subject to change if additional information becomes available, the following is my professional opinion:

Tests were conducted on October 18, 19 and November 1, 2007 on five series of concrete wall panels for FABCON. Test results are shown in **Table 1**. Tests were conducted to the Tornado Protocol IV for a 15 lb. wood 2x4 at 100 mph, and the DOE-1020-2002 Tornado Protocol V for a 15 lb. 2x4 at 150 mph and a 75 lb. steel pipe at 75 mph.

Table 1

Series	100 mph Wood Missile	150 mph Wood Missile	DOE 75 lb 70 mph Pipe
Series 1	Passed	Passed	Passed
Series 2	Not Tested	Not Tested	Passed
Series 3	Not Tested	Not Tested	Passed
Series 4	Not Tested	Not Tested	Passed
Series 5 – 8-in. side	Not Tested	Passed	Not Tested
Series 5 – 2-in. side	Not Tested	Passed	Not Tested

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The use of the Texas Tech University Wind Engineering logo does not signify that the entire shelter structure was tested at Texas Tech, but rather only [shelter component – name explicitly] was tested and successfully passed missile impact resistance tests at Texas Tech University.

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