

A summary report on

Debris Impact Testing at Texas Tech University

Prepared by

Wind Science and Engineering Research Center



Texas Tech University

Lubbock, TX 79409-1023



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Table of Contents

Forward

| | |
|---------------------------|-----|
| Overview..... | iii |
| Facility Development..... | iii |
| Definitions..... | iv |

Section A - 15 lbf, 2×4 Board missiles

| | |
|--|----|
| A1 Reinforced Concrete Slabs..... | 1 |
| A2 Reinforced Concrete Walls Constructed using Insulating Concrete Forms (ICF) | 2 |
| A3 Reinforced Concrete Masonry Unit (CMU) Walls | 3 |
| A4 Reinforced Brick Cavity Walls with Concrete Infill | 5 |
| A5 Stud Walls with Concrete Block Infill..... | 5 |
| A6 Stud Walls with Concrete Infill | 7 |
| A7 Stud Walls with Plywood..... | 8 |
| A8 Stud Walls with Plywood and Steel Plate..... | 10 |
| A9 Stud Walls with Plywood and Expanded Metal | 12 |
| A10 Stud Walls with Inserts between Studs | 12 |
| A11 Stud Walls with Infill and Siding Materials | 13 |
| A12 Stud Walls with Polystyrene Infill..... | 15 |
| A13 Stud Walls with Corrugated Infill Materials..... | 15 |
| A14 Brick Veneer Walls..... | 15 |
| A15 Doors..... | 16 |

Section B - 2×4 Board missiles of various weights

| | |
|--|----|
| B1 Reinforced Concrete Masonry Unit (CMU) Walls..... | 17 |
| B2 Reinforced Concrete Slabs..... | 19 |
| B3 Brick Veneer Walls..... | 19 |
| B4 Plywood layers..... | 19 |
| B5 OSB layers | 19 |

Table of Contents

| | |
|---|----|
| Section C - 10 ft. length, 3 inch diameter PVC pipe missiles | |
| C1 Reinforced Concrete Masonry Unit (CMU) Walls..... | 20 |
| Section D - EMT Conduit missiles | |
| D1 Reinforced Concrete Masonry Unit (CMU) Walls..... | 20 |
| D2 Reinforced Brick Cavity Walls with Concrete Infill | 20 |
| D3 Stud Walls with Plywood and Steel Plate..... | 20 |
| Section E - 3 inch diameter Steel Pipe (Schedule 40) missiles | |
| E1 Reinforced Concrete Slabs..... | 21 |
| E2 Reinforced Concrete Masonry Units (CMU)..... | 22 |
| E3 Reinforced Brick Cavity Walls with Concrete Infill | 22 |
| Section F - 15 lbf, 3 inch diameter Pressure-treated Fence Post missiles | |
| F1 Stud Walls with Plywood and Steel Plate..... | 22 |
| Section G - 15 lbf, 2×6 Board missiles | |
| G1 Stud Walls with Plywood and Steel Plate..... | 22 |
| Section H - 22.5 lbf, 2×6 Board missiles | |
| H1 Stud Walls with Plywood and Steel Plate..... | 23 |
| Section I - Clay Brick missiles | |
| I1 Stud Walls with Plywood and Steel Plate..... | 23 |
| Section J - 2×4 Board missile Drop tests (65 mph) | |
| J1 Wall Sections | 24 |
| J2 Doors..... | 24 |
| References | |

A summary report on

Debris Impact Testing at Texas Tech University

Overview

Since the early 1970's, Texas Tech University has been deeply involved in wind engineering research conducted through the Institute for Disaster Research and the Wind Engineering Research Center. One very important aspect of the wind engineering research is the effect of wind-generated debris on structures. In violent wind storms and tornadoes, windborne debris causes considerable damage to buildings and poses a threat to life, even to building occupants. Texas Tech University has lead in this field of research. Hundreds of tests have been conducted in the Debris Impact Test Facility. Test results on products that are not proprietary are reported herein. Testing was divided into sections based on missile types and subsections based on target configurations. The data is presented in a tabular format to facilitate comparison of missile type, weight, speed, momentum, energy, and description of damage for the various types of targets.

While this report is not complete in terms of considering all types of debris or all types of impacted surfaces, it is considered a significant contribution to a database for resistance by the most commonly used shelter components to windborne debris. This report is presented with the expectation that it will be useful in future wind engineering research and in product development.

Facility Development

Facilities were developed with funds from: the State of Texas, the Federal Emergency Management Agency (FEMA), Texas Tech University, companies involved in product development, and others. Funding for upgrading launch facilities and relocating the main facility to Reese Technology Center was provided, in part, by the National Institute for Standards and Technology (NIST) and Texas Tech.

This facility includes a pneumatic cannon that can accelerate a 15-lb (6.8-kg), nominal 2 x 4-in. (actual 1.5 x 3.5

in. or 3.8 x 8.9 cm) timber plank from rest to a speed of 150 mi/hr (67 m/s). The cannon can also project a 75-lb (34 kg), 3-in. (7.6 cm) diameter Schedule 40 steel pipe at speeds up to 75 mi/hr (34 m/s). Other types of simulated debris, or “missiles,” include: nominal 2 x 6-in. (actual 1.5 x 5.5 in. or 3.8 x 14 cm) timber planks, fence posts, bricks, PVC pipe, and steel conduit.

Different types of building components, or targets, are tested in this facility including: concrete masonry unit (CMU) wall sections, reinforced concrete slabs, plywood and metal combinations, doors, and others.

A brochure titled *Debris Impact Testing—Wind Science and Engineering*, Texas Tech University more fully describes the facility.

Definitions

Failure is defined as behavior that might cause injury to occupants of a shelter using the component. Perforation by the missile, scabbing of target material that would create debris or large deformations of the target would constitute *failure*.

In this report, *repercussed* denotes that the missile was repelled or failed to inflict sufficient damage to the target to endanger a person on the non-impact side.

The *threshold speed*, usually given as a range of speeds, is the speed, above which, perforation or failure was shown to occur or would likely occur.

Perforation implies that the missile passed through the barrier so that it could be seen from the non-impact (back) side.

Penetration implies that the missile made an indentation or embedded itself in the target but did not perforate the target.

Missile Momentum (p) is calculated as:

$$p = m \cdot v = \frac{w}{g} \cdot v \quad (1)$$






where w is the weight of the missile in pounds-force (lbf), g is the acceleration of gravity (32.2 ft/s²), and v is the speed of the missile in feet per second (ft/s). Thus, the units for Missile Momentum are pounds-force times seconds (lbf-s).

Missile Energy (T) is calculated as:

$$T = \frac{1}{2} \cdot m \cdot v^2 = \frac{1}{2} \cdot \frac{w}{g} \cdot v^2 \quad (2)$$

where w is the weight of the missile in pounds-force, g is the acceleration of gravity (32.2 ft/s²), and v is the speed of the missile in feet per second (ft/s). Thus, the units for Missile Energy are feet times pounds-force (ft-lbf).

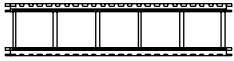
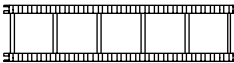

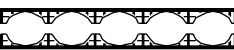
SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|---|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|---|-------------------|
| A1 - REINFORCED CONCRETE SLABS | | | | | | | | |
| 2 in. thick pea-gravel concrete with #4 rebar reinforcement 12 in. o.c. each way. |  | 2 x 4 Board | 15 | < 26.0 | < 18 | < 339 | The missile repercussed. (1 shot) | S & C (2001) P.T. |
| | | 2 x 4 Board | | 26.0 - 30.0 | 18 - 20 | 339 - 451 | Threshold was observed. (2 shots) | |
| | | 2 x 4 Board | | > 30.0 | > 20 | > 451 | The missiles perforated the barrier. (7shots) | |
| 3 in. thick pea-gravel concrete with #4 rebar reinforcement 12 in. o.c. each way. |  | 2 x 4 Board | 15 | < 102.0 | < 70 | < 5213 | The missiles repercussed. (4 shots) | S & C (2001) P.T. |
| | | 2 x 4 Board | | 102.0 - 106.0 | 70 - 72 | 5213 - 5630 | Threshold was observed. (3 shots) | |
| | | 2 x 4 Board | | > 106.0 | > 72 | > 5630 | The missile perforated the barrier. (1 shot) | |
| 4 in. thick pea-gravel concrete with #4 rebar reinforcement 12 in. o.c. each way. |  | 2 x 4 Board | 15 | 104.0 - 162.0 | 71 - 111 | 5419 - 13149 | The missiles repercussed. (5 shots) | S & C (2001) P.T. |
| 6 in. thick pea-gravel concrete with #4 rebar reinforcement 12 in. o.c. vertically. |  | 2 x 4 Board | 15 | 102.4 | 70 | 5254 | No cracking, front face spalling, or back face scabbing was observed. | K & C (1997) |
| 6 in. thick pea-gravel concrete with #4 rebar reinforcement 24 in. o.c. vertically. |  | 2 x 4 Board | 15 | 102.4 | 70 | 5254 | No cracking, front face spalling, or back face scabbing was observed. | K & C (1997) |



Missile Direction







SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|--|--------------|
| A2 - REINFORCED CONCRETE WALLS CONSTRUCTED USING INSULATING CONCRETE FORMS (ICF) | | | | | | | | |
| 6 in. thick GREENBLOCK ICF (Exterior finish consists of vinyl siding attached to ICF fastening strips.) |  | 2 x 4 Board | 15 | 103.8 - 119.9 | 71 - 82 | 5398 - 7203 | No cracking, front face spalling, or back face scabbing of the concrete core was observed. The missile penetrated the vinyl siding and the Green block form. | K & C (1997) |
| 6 in. thick BLUE MAXX ICF (Interior finish consists of 5/8 in gypsum board attached directly to ICF fastening strips. Exterior finish consists of 3 in. brick veneer attached to ICF fastening strips with brick ties 12 in o.c.) |  | 2 x 4 Board | 15 | 99.0 | 68 | 4911 | No cracking, front face scabbing, or back face spalling of the concrete core was observed. The missile penetrated the brick veneer, cracking it from the point of impact to the top of the sample. The Blue Mix ICF was indented but the missile never made direct contact with the concrete core. | K & C (1997) |
| 4 in. thick LITE FORM ICF (Interior finish consists of 5/8 in gypsum board attached directly to ICF fastening strips. Exterior finish consists of vinyl siding attached to ICF fastening strips.) |  | 2 x 4 Board | 15 | 96.7 | 66 | 4685 | No cracking, front face scabbing, or back face spalling of the concrete core was observed. The missile penetrated the vinyl siding and the Late Form ICF form. The missile made contact with the concrete core. | K & C (1997) |
| 6 in. thick POLYSTEEL (WAFFLE) ICF (Exterior finish consists of 1/4 in thick Exterior Insulation Finish System (EIFS) applied directly to ICF.) |  | 2 x 4 Board | 15 | 100.2 - 103.8 | 68 - 71 | 5030 - 5398 | No cracking, front face scabbing, or back face spalling of the concrete core was observed. The missile penetrated the EIFS siding and the Polyester ICF. The missile made contact with the concrete core. The missile hit the target at the side of the thicker column. | K & C (1997) |



Missile Direction





SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|---|---------------|
| A3 - REINFORCED CONCRETE MASONRY UNIT (CMU) WALLS | | | | | | | | |
| 8 in. CMU reinforced with concrete and #4 rebar in every cell; truss type horizontal reinforcement was placed every 16 in. |  | 2 x 4 Board | 15 | > 100.0 | > 68 | > 5010 | The target was impacted over thirty times with the design missile. This was done for demonstration purposes only the first (verification) test was conducted as part of G&O contract. | Carter (1998) |
| 8 in. CMU reinforced with concrete and #4 rebar in every cell; truss type horizontal reinforcement was placed every 16 in. |  | 2 x 4 Board | 15 | 116.0 | 79 | 6742 | Wall remained intact; no stress cracks in block nor joints could be found. Missile splintered on impact. | TTU (1990) |
| 8 in. CMU reinforced with concrete and #4 rebar in every cell; truss type horizontal reinforcement was placed every 16 in. |  | 2 x 4 Board | 15 | 121.0 | 83 | 7336 | Minor surface indentation (1/8"). | White (1986) |
| 6 in. CMU reinforced with concrete and #4 rebar in every cell; truss type horizontal reinforcement was placed every 16 in. |  | 2 x 4 Board | 15 | 101.6 - 106.7 | 69 - 73 | 5172 - 5704 | No visible damage was observed. 1/8 to 3/16 in. indentation on impact side. | Carter (1998) |
| 6 in. CMU reinforced with concrete and #4 rebar in every cell; truss type horizontal reinforcement was placed every 16 in. |  | 2 x 4 Board | 15 | 98.5 - 103.4 | 67 - 71 | 4861 - 5357 | The missile impacted the target at a mortar joint. The target was cracked from the point of impact to the top of the target both in the front and in back. The mortar spalled out of the joint on the back of the target. | Carter (1998) |
| 6 in. CMU reinforced with concrete and #4 rebar in every cell; truss type horizontal reinforcement was placed every 16 in. |  | 2 x 4 Board | 15 | 92.4 - 97.0 | 63 - 66 | 4278 - 4714 | The missile impacted the target at a mortar joint. The cracking of the wall was extended into the base. A new crack appeared in the next joint 8 in. away and extended to the top of the target. The missile perforated the target and spilled the concrete fill out of the back of the target. | Carter (1998) |



Missile Direction

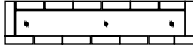








SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

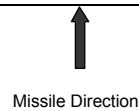
| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|--|-------------------|
| A3 - REINFORCED CONCRETE MASONRY UNIT (CMU) WALLS | | | | | | | | |
| 6 in. CMU reinforced with concrete and #4 rebar in every cell; truss type horizontal reinforcement was placed every 16 in. |  | 2 x 4 Board | 15 | NA | NA | NA | No penetration of the target occurred. The target was cracked from the point of impact to the top of the target. | Carter (1998) |
| 6 in. CMU reinforced with concrete and #4 rebar in every cell; truss type horizontal reinforcement was placed every 16 in. |  | 2 x 4 Board | 15 | 106.1 - 111.3 | 72 - 76 | 5640 - 6207 | The target was impacted at a vertical mortar joint. There was a 1/16 in. indentation on the impact face but no visible damage to either side of the target. | Carter (1998) |
| 6 in. CMU reinforced with concrete and #4 rebar in every cell; truss type horizontal reinforcement was placed every 16 in. |  | 2 x 4 Board | 15 | 101.8 - 106.9 | 70 - 73 | 5192 - 5726 | The target was impacted at a vertical mortar joint. There was a 1/16 in. indentation on the impact face. The joint spalled slightly on the non-impact side of the target. A small crack was detected at the impact point terminating at the top of the target. | Carter (1998) |
| 6 in. CMU reinforced with concrete and #4 rebar in every cell; 8-gage truss horizontal reinforcement every other course |  | 2 x 4 Board | 15 | < 130.0 | < 89 | < 8467 | The missiles repercussed. | S & C (2001) P.T. |
| | | | | 130.0 - 137.0 | 89 - 94 | 8467 - 9404 | Threshold was observed. (2 shots) | |
| | | | | > 137.0 | > 0 | > 0 | The missiles perforated the barrier. (2 shots) | |



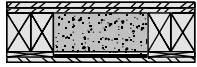

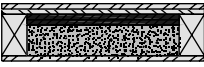

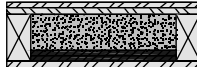

Missile Direction

SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|---|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|---|---------------|
| A4 - REINFORCED BRICK CAVITY WALLS WITH CONCRETE INFILL | | | | | | | | |
| Brick cavity wall reinforced with #4 rebar every 12 in. and concrete infill. |  | 2 x 4 Board | 15 | > 100.0 | > 68 | > 5010 | The target has been proven successful in previous tests. | Carter (1998) |
| A5 - STUD WALLS WITH CONCRETE BLOCK INFILL | | | | | | | | |
| 4x4 stud wall, containing 4 in. concrete block, and one layer of 3/8 in. CD grade plywood on the impact and two layers 3/4 in. CD grade plywood non-impact faces. |  | 2 x 4 Board | 15 | 110.1 - 115.7 | 75 - 79 | 6074 - 6707 | There was no missile penetration. | K & C (1998) |
| 4x4 stud wall, containing 4 in. concrete block, and one layer of 3/8 in. CD grade plywood on the impact and two layers 3/4 in. CD grade plywood non-impact faces. |  | 2 x 4 Board | 15 | 103.8 - 109.0 | 71 - 74 | 5398 - 5953 | The missile impacted the interface between the block and the 4x4 stud perforating the target 3 ft. | K & C (1998) |
| 4in. concrete block in a 2X4in. stud wall with two layers of 3/4 in CD grade plywood. |  | 2 x 4 Board | 15 | 103.9 - 109.1 | 71 - 75 | 5409 - 5964 | The missile impacted the stud and perforated the target 18 in. | Carter (1998) |
| 4 in. concrete block in a 2x4 in. stud wall with two layers of 3/4 in. CD grade plywood one the non-impact side, one layer of plywood on the impact side, and 14 ga. 1/2 in. expanded metal. |  | 2 x 4 Board | 15 | 101.6 - 106.7 | 69 - 73 | 5172 - 5704 | 3/4 in. of penetration. No evident damage to the non-impact side. | Carter (1998) |
| 4 in. concrete block in a 2x4 in. stud wall with two layers of 3/4 in. CD grade plywood one the non-impact side, one layer of plywood on the impact side, and 14 ga. 1/2 in. expanded metal. |  | 2 x 4 Board | 15 | 101.0 - 106.1 | 69 - 72 | 5111 - 5640 | The missile impacted the stud and sheared it in two. The non-impact side showed no damage. | Carter (1998) |
| 4x4 stud wall with 1x4's on the studs, containing 4 in. concrete block, gypsum board infill, and one layer of 3/4 in. CD grade plywood on the impact face and two layers on the non-impact face. |  | 2 x 4 Board | 15 | 101.4 - 106.5 | 69 - 73 | 5152 - 5683 | Missile penetrated the target, but did not perforate when impacted at the interface between the block and the 4x4 stud. | K & C (1998) |
| 4x4 stud wall with 1x4's on the studs, containing 4 in. concrete block, gypsum board infill, and one layer of 3/4 in. CD grade plywood on the impact face and two layers on non-impact face. |  | 2 x 4 Board | 15 | 105.9 - 111.2 | 72 - 76 | 5619 - 6196 | The missile impacted the stud and 1/2 in. of deflection occurred on the non-impact face. | K & C (1998) |
| Double studded 2x4 wall with furring. Two layers of 3/4 in. CD grade plywood on the non-impact face, one layer on the impact face, and a layer of 3/8 in. gyp. board. The wall is filled with 4 in. concrete block. |  | 2 x 4 Board | 15 | 103.0 | 70 | 5315 | The missile impacted 1/2 in. on the stud and 1/2 in. on the concrete block infill. There was 1/2 in. of deformation on the non-impact side. | K & C (1998) |



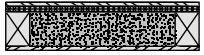
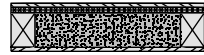





SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference | |
|---|--|--|----------------------|---------------------|--------------------------|-------------------------|--------------------|--|---------------|
| A5 - STUD WALLS WITH CONCRETE BLOCK INFILL | | | | | | | | | |
| | Double studded 2x4 wall with furring. Two layers of ¼ in. CD grade plywood on the non-impact face, one layer on the impact face, and a layer of 3/8 in. gyp. board. The wall is filled with 4 in. concrete block. |  | 2 x 4 Board | 15 | 100.7 | 69 | 5081 | The missile impacted next to the stud. There was ½ in. of deformation and cracking on the non-impact side. | K & C (1998) |
| | Double studded 2x4 wall with furring. Two layers of ¼ in. CD grade plywood on the non-impact face, one layer on the impact face, and a layer of 3/8 in. gyp. board. The wall is filled with 4 in. concrete block place vertically in the cell. |  | 2 x 4 Board | 15 | 101.9 | 70 | 5203 | The missile perforated the target 3 in. | K & C (1998) |
| | 4 in. concrete block in a 2x6 in. wall with 1 ½ in. of polystyrene between block and one layer of ¼ in. CD grade plywood |  | 2 x 4 Board | 15 | 81.0 - 85.1 | 55 - 58 | 3287 - 3629 | The missile penetrated the target. The non-impact plywood was punched out in the area of impact. | Carter (1998) |
| | 4 in. concrete block in a 2x6 in. wall with 1 ½ in. of polystyrene between the block and two layers of ¼ in. CD grade plywood. |  | 2 x 4 Board | 15 | 106.0 - 111.3 | 72 - 76 | 5630 - 6207 | The missile penetrated the target. There was no damage to the back side of the target. | Carter (1998) |
| | 4 in. concrete block in a 2x6 in. stud wall with 1 ½ in. of polystyrene between the block and the impact face of ¼ in. CD grade plywood. There is also two layers of plywood on the non-impact face. |  | 2 x 4 Board | 15 | 100.7 - 105.4 | 69 - 72 | 5081 - 5566 | The missile penetrated the target but did not perforate it. The back face plywood pulled from the studs and the studs were torn in half. There was catastrophic damage to the structure. | Carter (1998) |
| | 4 in. concrete block in a 2x6 in. wall with 1 ½ in. of polystyrene on each side of the block, one layer of ¼ in. CD grade plywood on the impact side, and two layers on the non-impact face. |  | 2 x 4 Board | 15 | 99.0 - 104.0 | 68 - 71 | 4911 - 5419 | The missile penetrated the target but did not perforate it. The back face plywood pulled from the studs and the studs were torn in half. There was catastrophic damage to the structure. | Carter (1998) |



Missile Direction










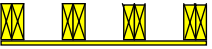
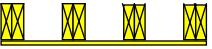
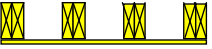
SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|--|---------------|
| A6 - STUD WALLS WITH CONCRETE INFILL | | | | | | | | |
| Stud wall with CD grade plywood, 14 ga. ½ in. expanded metal, and concrete infill. |  | 2 x 4 Board | 15 | 101.0 - 106.1 | 69 - 72 | 5111 - 5640 | The missile impacted 1 ½ in. to the left of a stud. No damage was visible on the back of the target. | Carter (1998) |
| Stud wall with CD grade plywood, 14 ga. ½ in. expanded metal, and concrete infill. |  | 2 x 4 Board | 15 | 100.4 - 105.4 | 69 - 72 | 5051 - 5566 | The missile impacted 1 in. to the right of a stud. No damage was visible on the back of the target. | Carter (1998) |
| Stud wall with CD grade plywood, 14 ga. ½ in. expanded metal, and concrete infill. |  | 2 x 4 Board | 15 | 100.0 - 105.0 | 68 - 72 | 5010 - 5524 | The missile impacted 4 in. to the left of a stud. No damage was visible on the back of the target. | Carter (1998) |
| Stud wall filled with concrete with no plywood and 14 ga. ½ in. expanded metal on the non-impact face. |  | 2 x 4 Board | 15 | 102.6 - 107.7 | 70 - 74 | 5274 - 5812 | The missile made partial contact with the stud. The concrete was cracked around the impact area. | Carter (1998) |
| Stud wall filled with concrete with no plywood and 14 ga. ½ in. expanded metal on the non-impact face. |  | 2 x 4 Board | 15 | 102.1 - 107.2 | 70 - 73 | 5223 - 5758 | The missile made partial contact with the stud. The concrete was severely damaged and a 4 in. deflection on the back of the target was observed. | Carter (1998) |
| Stud wall filled with concrete with no plywood and 14 ga. ½ in. expanded metal on the non-impact face. |  | 2 x 4 Board | 15 | 102.0 - 107.1 | 70 - 73 | 5213 - 5747 | The missile impacted the concrete. No visible damage was observed. | Carter (1998) |
| Stud wall filled with concrete with no plywood and 14 ga. ½ in. expanded metal on the non-impact face. |  | 2 x 4 Board | 15 | 99.5 - 104.5 | 68 - 71 | 4960 - 5471 | The missile hit the stud fully. There was 3 in. of deflection to the back of the target but no perforation. | Carter (1998) |



Missile Direction





SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|---|---------------|
| A7 - STUD WALLS WITH PLYWOOD | | | | | | | | |
| 2x8 in. stud wall with ¼ in. CD grade plywood inserts. |  | 2 x 4 Board | 15 | 101.3 - 106.4 | 69 - 73 | 5141 - 5672 | The full length of the missile perforated the target. | Carter (1998) |
| 4 layers of ¼ in. CD grade plywood. |  | 2 x 4 Board | 15 | 96.0 - 100.8 | 66 - 69 | 4618 - 5091 | The missile perforated the target 4 ft. | Carter (1998) |
| 4 layers of ¼ in. CD grade plywood. |  | 2 x 4 Board | 15 | 93.0 - 97.7 | 64 - 67 | 4333 - 4783 | The missile perforated the target 2 ft. | Carter (1998) |
| 4 layers of ¼ in. CD grade plywood. |  | 2 x 4 Board | 15 | 85.4 - 89.7 | 58 - 61 | 3654 - 4031 | The missile perforated the target 2 ft. | Carter (1998) |
| 4 layers of ¼ in. CD grade plywood. |  | 2 x 4 Board | 15 | 86.7 - 91.0 | 59 - 62 | 3766 - 4149 | The missile perforated the target 1 ft. | Carter (1998) |
| 4 layers of ¼ in. CD grade plywood glued together and attached to the frame with screws. |  | 2 x 4 Board | 15 | 82.0 - 86.1 | 56 - 59 | 3369 - 3714 | The missile perforated the target 3 ft. | Carter (1998) |
| 4 layers of ¼ in. BC grade plywood glued together and attached to the frame with screws. |  | 2 x 4 Board | 15 | 98.2 - 103.1 | 67 - 70 | 4832 - 5326 | The missile perforated the target 7 ft. | Carter (1998) |
| 4 layers of ¼ in. BC grade plywood glued together and attached to the frame with screws. |  | 2 x 4 Board | 15 | 86.3 - 90.6 | 59 - 62 | 3732 - 4113 | The missile perforated the target 3 ft. | Carter (1998) |
| 4 layers of ¼ in. BC grade plywood glued together and attached to the frame with screws. |  | 2 x 4 Board | 15 | 78.9 - 82.8 | 54 - 57 | 3119 - 3435 | The missile perforated the target 1 ft. | Carter (1998) |
| 1 layer of 1/2 inch Plywood |  | 2 x 4 Board | 15 | 52.0 | 36 | 1355 | The missile perforated the target. | Bailey (1984) |
| 1 layer of 1/2 inch Plywood with Masonite Siding |  | 2 x 4 Board | 15 | 52.0 | 36 | 1355 | The missile perforated the target. | Bailey (1984) |
| 1 layer of 3/4 inch Plywood |  | 2 x 4 Board | 15 | 53.0 | 36 | 1407 | The missile perforated the target. | Bailey (1984) |



Missile Direction


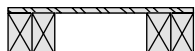

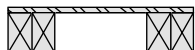


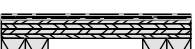
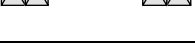




SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|--|-------------------|
| A7 - STUD WALLS WITH PLYWOOD | | | | | | | | |
| 1 layer of ¼ in. plywood mounted with 3 in. #8 wood deck screws spaced 6 in on center to the double stud 4X4 ft. frame. |  | 2 x 4 Board | 15 | < 29.0 | < 20 | < 421 | The missiles repercussed. (4 shots) | S & C (2001) P.T. |
| | | | | 29.0 - 31.0 | 20 - 21 | 421 - 481 | Threshold was observed. (1 shot) | |
| | | | | > 31.0 | > 21 | > 481 | The missiles perforated the barrier. (3 shots) | |
| 2 layer of ¼ in. plywood mounted with 3 in. #8 wood deck screws spaced 6 in on center to the double stud 4X4 ft. frame. |  | 2 x 4 Board | 15 | < 41.0 | < 28 | < 842 | The missile repercussed. (1 shot) | S & C (2001) P.T. |
| | | | | 41.0 - 44.0 | 28 - 30 | 842 - 970 | Threshold was observed. (1 shot) | |
| | | | | > 44.0 | > 30 | > 970 | The missiles perforated the barrier. (4 shots) | |
| 3 layer of ¼ in. plywood mounted with 3 in. #8 wood deck screws spaced 6 in on center to the double stud 4X4 ft. frame. |  | 2 x 4 Board | 15 | < 59.0 | < 40 | < 1744 | The missiles repercussed. (2 shots) | S & C (2001) P.T. |
| | | | | 59.0 - 61.0 | 40 - 42 | 1744 - 1864 | Threshold was observed. (1 shot) | |
| | | | | > 61.0 | > 42 | > 1864 | The missiles perforated the barrier. (4 shots) | |
| 4 layer of ¼ in. plywood mounted with 3 in. #8 wood deck screws spaced 6 in on center to the double stud 4X4 ft. frame. All plywood layers are rotated 90 degrees from the previous layer. |  | 2 x 4 Board | 15 | < 71.0 | < 49 | < 2526 | The missiles repercussed. | S & C (2001) P.T. |
| | | | | 71.0 - 74.0 | 49 - 51 | 2526 - 2744 | Threshold was observed. (4 shots) | |
| | | | | > 74.0 | > 51 | > 2744 | The missiles perforated the barrier. (3 shots) | |




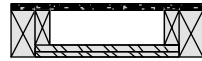
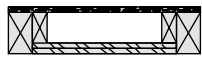
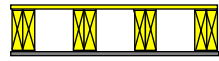
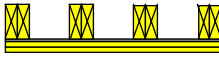

Missile Direction

SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|---|---------------|
| A8 - STUD WALLS WITH PLYWOOD AND STEEL PLATE | | | | | | | | |
| Double 2x4 stud wall with one layer of 12 ga. steel on the impact side and one layer of ¼ in. CD grade plywood on the non-impact side. |  | 2 x 4 Board | 15 | NA | NA | NA | The missile impacted near the stud and was deflected. | K & C (1998) |
| Double 2x4 stud wall with one layer of 12 ga. steel on the impact side and one layer of ¼ in. CD grade plywood on the non-impact side. |  | 2 x 4 Board | 15 | NA | NA | NA | The missile impacted the stud and was deflected, there was some damage to the non-impact face. | K & C (1998) |
| Double 2x4 stud wall with one layer of 12 ga. steel on the impact side and one layer of ¼ in. CD grade plywood on the non-impact side. |  | 2 x 4 Board | 15 | 105.2 | 72 | 5545 | The missile impacted next to the stud and was destroyed. | K & C (1998) |
| Double 2x4 stud wall with one layer of 12 ga. steel on the impact side and one layer of ¼ in. CD grade plywood on the non-impact side. |  | 2 x 4 Board | 15 | 103.6 | 71 | 5378 | The missile impacted next to the stud and was destroyed. | K & C (1998) |
| 2x8 stud wall with two layers of ¼ in. plywood and one layer of 14 ga. steel. |  | 2 x 4 Board | 15 | 100.9 | 69 | 5101 | The missile impacted the stud and broke it, but did not perforate the target. | Carter (1998) |
| Double stud wall with 4 layers of ¼ in. CD grade plywood and 14 ga. steel on the back face of the target. |  | 2 x 4 Board | 15 | 99.0 - 107.0 | 68 - 73 | 4911 - 5736 | 1 in. of deformation on the back face of the steel but no perforation. | Carter (1998) |
| Double stud wall with 4 layers of ¼ in. CD grade plywood and 14 ga. steel on the back face of the target. |  | 2 x 4 Board | 15 | 101.5 - 106.6 | 69 - 73 | 5162 - 5694 | The target was impacted next to a stud. Several heads of screws were popped off the back of the target. The steel had 1 in. of deformation. No perforation. | Carter (1998) |
| Double stud wall with 4 layers of ¼ in. CD grade plywood and 14 ga. steel on the back face of the target. |  | 2 x 4 Board | 15 | 99.9 - 104.9 | 68 - 72 | 5000 - 5513 | The target was impacted on the stud line. The stud was cut in two. No deformation was observed on the back side. No perforation. | Carter (1998) |
| Stud wall with 2 layers of ¼ in. CD grade plywood with 16 ga. metal on non-impact side. |  | 2 x 4 Board | 15 | 100.7 - 105.7 | 69 - 72 | 5081 - 5598 | 1 in. deformation of 16 Ga. metal on non-impact side of target. No perforation. | Carter (1998) |
| Stud wall with 2 layers of ¼ in. CD grade plywood with 16 ga. metal on non-impact side. |  | 2 x 4 Board | 15 | 99.7 - 104.7 | 68 - 72 | 4980 - 5492 | Wood screws pulled out of studs and 16 Ga. metal had 3 ½ in. of deformation. No perforation. | Carter (1998) |
| Stud wall with 2 layers of ¼ in. CD grade plywood with 16 ga. metal on non-impact side. |  | 2 x 4 Board | 15 | 100.1 - 105.1 | 68 - 72 | 5020 - 5534 | Wood screws pulled through metal and 1 in. of deformation of 16 Ga. Metal. No perforation. | Carter (1998) |
| Stud wall with 3 layers of ¼ in. CD grade plywood inserts with 14 ga. metal on the non-impact side. |  | 2 x 4 Board | 15 | 100.7 - 105.7 | 69 - 72 | 5081 - 5598 | The first insert of plywood failed in shear while the interior two failed in bending. The studs started to be torn in half and there was 3 in. of deformation in the steel. | Carter (1998) |

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Missile Direction

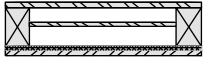
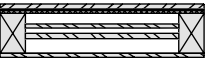
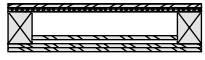





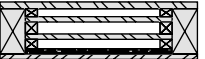
SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|--|-------------------|
| A8 - STUD WALLS WITH PLYWOOD AND STEEL PLATE | | | | | | | | |
| 2 layers of 3/4 in. CD grade plywood with 14 ga. steel on the non-impact side, and gypsum board on both the impact and non-impact faces. |  | 2 x 4 Board | 15 | 92.6 - 97.2 | 63 - 66 | 4296 - 4734 | 4 in. of deformation on the non-impact side. The wood screws were pulled from the studs and the studs were torn in half. The inserts were sheared through with no bending action. | Carter (1998) |
| 2 layers of 3/4 in. CD grade plywood with 14 ga. steel on the non-impact side, and gypsum board on both the impact and non-impact faces. |  | 2 x 4 Board | 15 | 99.6 - 104.6 | 68 - 71 | 4970 - 5482 | 4 in. of deformation on the non-impact side. The wood screws were pulled from the studs and the studs were torn in half. The inserts were sheared through with no bending action. | Carter (1998) |
| 2 layers of 3/4 in. CD grade plywood with 14 ga. steel on the non-impact side, and gypsum board on both the impact and non-impact faces. |  | 2 x 4 Board | 15 | 103.2 - 108.4 | 71 - 74 | 5336 - 5887 | The metal screws were pulled from the studs 6 in. | Carter (1998) |
| 1 layer of 12 ga. steel that was hot rolled A569 Grade 33 on impact side of the double stud frame; a layer of 3/4 in. plywood on the non-impact side |  | 2 x 4 Board | 15 | < 145.0 | < 99 | < 10534 | The missiles reperculated. (3 shots) | S & C (2001) P.T. |
| | | | | 145.0 - 148.0 | 99 - 101 | 10534 - 10975 | Threshold was observed. (4shots) | |
| | | | | > 148.0 | > 101 | > 10975 | The missiles perforated the barrier. (3 shots) | |
| 2 layers of 3/4 in. plywood, one layer of 14 ga. steel. |  | 2 x 4 Board | 15 | < 130.0 | < 89 | < 8467 | The missile reperculated. (1 shot) | S & C (2001) P.T. |
| | | | | 130.0 - 133.0 | 89 - 91 | 8467 - 8863 | Threshold was observed. (3 shots) | |
| | | | | > 133.0 | > 91 | > 8863 | The missiles perforated the barrier. (4 shots) | |
| 2 layers of 3/4 in. plywood, one layer of 14 ga. steel and the 4x4 ft, double stud frame. |  | 2 x 4 Board | 15 | 112.8 - 117.8 | 77 - 80 | 6375 - 6953 | The missile ricochets at 15°, 12.5° and at 11.25° and perforated at any angle lower than 10°. Repeat shots were fired at 12.5°, 10° and 0° resulting in confirmed conclusions that the critical angle lay within 11° and 13°. Although the missile does not perforate the target, permanent deflection and some structural damage were recorded. | C & S (2001) C.A. |



Missile Direction

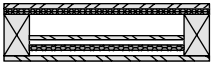
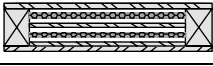

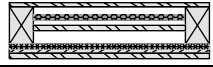
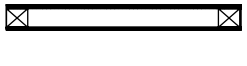
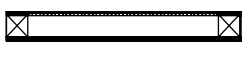
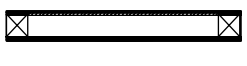
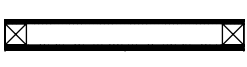
SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference | |
|--|---|---|----------------------|---------------------|--------------------------|-------------------------|--------------------|--|---------------|
| A9 - STUD WALLS WITH PLYWOOD AND EXPANDED METAL | | | | | | | | | |
| | 3 layers of ¼ in. CD grade plywood with 14 ga. ½ in. expanded metal on the impact side. |  | 2 x 4 Board | 15 | 103.8 - 109.0 | 71 - 74 | 5398 - 5953 | The missile perforated the target 12 ft. | Carter (1998) |
| | 4 layers of ¼ in. CD grade plywood with 14 ga. ½ in. expanded metal on the non-impact side. |  | 2 x 4 Board | 15 | 99.2 - 104.2 | 68 - 71 | 4931 - 5440 | The missile perforated the target 7 ft. | Carter (1998) |
| | 4 layers of ¼ in. CD grade plywood with 14 ga. ½ in. expanded metal on the non-impact side. |  | 2 x 4 Board | 15 | 102.7 - 107.8 | 70 - 74 | 5285 - 5822 | The missile perforated the target 3 ft. | Carter (1998) |
| | 3 layers of ¼ in. CD grade plywood with 14 ga. ½ in. expanded metal on the non-impact side. |  | 2 x 4 Board | 15 | 100.9 - 105.9 | 69 - 72 | 5101 - 5619 | The full length of the missile perforated the target. | Carter (1998) |
| | 5 layers of ¼ in. CD grade plywood with 14 ga. ½ in. expanded metal on the impact side. |  | 2 x 4 Board | 15 | NA | NA | NA | The missile perforated the target 3 ft. | Carter (1998) |
| | 4 layers of ¼ in. CD grade plywood with 14 ga. ½ in. expanded metal on the impact side. |  | 2 x 4 Board | 15 | 98.7 - 103.6 | 67 - 71 | 4881 - 5378 | The missile perforated the target 10 ft. | Carter (1998) |
| A10 - STUD WALLS WITH INSERTS BETWEEN STUDS | | | | | | | | | |
| | 4 layers of ¼ in. plywood with 14 Ga. steel insert with spacers between inserts and the back face of the target. |  | 2 x 4 Board | 15 | 104.2 - 109.4 | 71 - 75 | 5440 - 5997 | The missile penetrated the target 1 ½ - 2 in. There was a crack in the plywood on the back face caused bending, but total separation did not occur. | Carter (1998) |
| | 14 ga. steel insert with spacers between all the inserts and the back face has two layers of ¼ in CD grade plywood. |  | 2 x 4 Board | 15 | 103.0 - 110.0 | 70 - 75 | 5315 - 6063 | The missile penetrated the target 1 ½ - 2 in. There was a crack in the plywood on the back face caused by bending, but total separation did not occur. | Carter (1998) |
| | 4 layers of ¼ in. CD grade plywood with 14 ga. steel insert and spacers between all inserts. |  | 2 x 4 Board | 15 | 99.6 - 104.6 | 68 - 71 | 4970 - 5482 | All plywood inserts failed in bending. The top third of the inserts were shot out the non-impact side of the target. | Carter (1998) |



Missile Direction






SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|--|---------------------|----------------------|---------------------|--------------------------|-------------------------|--|---------------|
| A1.1 - STUD WALLS WITH INFILL AND SIDING MATERIALS | | | | | | | | |
| 3 layers of 3/4 in. CD grade plywood with 14 ga. 1/2 in. expanded metal on the non-impact side and bead-board infill. |  | 2 x 4 Board | 15 | 90.8 - 95.3 | 62 - 65 | 4131 - 4550 | The full length of the missile perforated the target. | Carter (1998) |
| 4 layers of 3/4 in. CD grade plywood with two layers of energy absorbing bead board as inserts. |  | 2 x 4 Board | 15 | 102.2 - 107.3 | 70 - 73 | 5233 - 5769 | The missile perforated the target 7 ft. | Carter (1998) |
| 3 layers of 3/4 in. CD grade plywood with 14 ga. 1/2 in. expanded metal on the impact side and bead-board infill. |  | 2 x 4 Board | 15 | 104.8 - 110.0 | 72 - 75 | 5503 - 6063 | The full length of the missile perforated the target. | Carter (1998) |
| 4 layers of 3/4 in. CD grade plywood with 14 ga. 1/2 in. expanded metal on the impact side and bead-board infill. |  | 2 x 4 Board | 15 | 103.3 - 108.5 | 71 - 74 | 5346 - 5898 | The missile perforated the target 3 ft. | Carter (1998) |
| Masonite siding wall; 7/16 in. masonite siding (rough finish) on the front face and 1/2 in. gypsum wallboard on the back face. |  | 2 x 4 Board | 15 | 54.0 | 37 | 1461 | The missile perforated the target. | Bailey (1984) |
| Insulation Board / Masonite siding wall; 1/2 in. insulating board and 7/16 in. masonite siding (rough finish) on the front face and 1/2 in. gypsum wallboard on the back face. |  | 2 x 4 Board | 15 | 54.0 | 37 | 1461 | The missile perforated the target. | Bailey (1984) |
| 5/8 in gypsum board attached directly to steel studs 16 in o.c.; 3 1/2 in fiberglass batt insulation; Vinyl siding over 3/4 in plywood sheathing on exterior face |  | 2 x 4 Board | 15 | 103.5 | 71 | 5367 | The missile completely perforated the target; little or no damage to the missile | K & C (1997) |
| Plywood / Masonite siding wall; 1/2-in. plywood sheathing and 7/16-in. masonite siding (rough finish) in the front face and 1/2-in. gypsum wallboard in the back face. |  | 2 x 4 Board | 15 | 52.0 | 36 | 1355 | The missile perforated the target. | Bailey (1984) |



Missile Direction





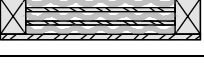
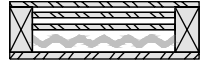
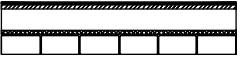
SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|------------------------------------|---------------|
| A1.1 - STUD WALLS WITH INFILL AND SIDING MATERIALS | | | | | | | | |
| Plywood wall; 1/2-in. plywood sheeting on the front face and 1/2-in. gypsum wallboard on the back face. |  | 2 x 4 Board | 15 | 52.0 | 36 | 1355 | The missile perforated the target. | Bailey (1984) |
| Plywood wall; 3/4-in. plywood sheeting on the front face and 1/2-in. gypsum wallboard on the back face. |  | 2 x 4 Board | 15 | 53.0 | 36 | 1407 | The missile perforated the target. | Bailey (1984) |
| Stucco wall; 1/2-in. plywood sheeting topped by 3 course stucco exterior on the front face and 1/2-in. gypsum wallboard on the back face. |  | 2 x 4 Board | 15 | 53.0 | 36 | 1407 | The missile perforated the target. | Bailey (1984) |
| Lapboard siding wall; 3/4-in. plain lapboard siding on the front face and 1/2-in. gypsum wallboard on the back face. |  | 2 x 4 Board | 15 | 53.0 | 36 | 1407 | The missile perforated the target. | Bailey (1984) |
| Insulation Board / Lapboard siding wall; 1/2-in. insulation board and 3/4-in. plain lapboard siding on the front face and 1/2-in. gypsum wallboard on the back face. |  | 2 x 4 Board | 15 | 52.0 | 36 | 1355 | The missile perforated the target. | Bailey (1984) |



Missile Direction





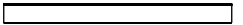

SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference | |
|---|---|---|----------------------|---------------------|--------------------------|-------------------------|--------------------|---|---------------|
| A1.2 - STUD WALLS WITH POLYSTYRENE INFILL | | | | | | | | | |
| | 4 layers of 3/4 in. CD grade plywood with two layers of energy absorbing polystyrene as inserts. |  | 2 x 4 Board | 15 | 100.4 - 105.4 | 69 - 72 | 5051 - 5566 | The missile penetrated the target but did not perforate it. The back of the target had 6 in. of deformation and the back layer of plywood was pulled from the frame. | Carter (1998) |
| | 4 layers of 3/4 in. CD grade plywood with two layers of energy absorbing polystyrene as inserts. |  | 2 x 4 Board | 15 | 104.1 - 109.3 | 71 - 75 | 5430 - 5986 | The missile perforated the target 4 ft. | Carter (1998) |
| | 4 layers of 3/4 in. CD grade plywood with two layers of energy absorbing polystyrene as inserts. |  | 2 x 4 Board | 15 | > 100.0 | > 68 | > 5010 | The full length of the missile perforated the target. | Carter (1998) |
| A1.3 - STUD WALLS WITH CORRUGATED INFILL MATERIALS | | | | | | | | | |
| | 3 layers of corrugated tin with four layers of 3/4 in. CD grade plywood. |  | 2 x 4 Board | 15 | 104.1 - 109.3 | 71 - 75 | 5430 - 5986 | The missile perforated the target 8 ft. | Carter (1998) |
| | 3 layers of corrugated tin with four layers of 3/4 in. CD grade plywood. |  | 2 x 4 Board | 15 | 100.9 - 105.9 | 69 - 72 | 5101 - 5619 | The missile perforated the target 7 ft. | Carter (1998) |
| | 1 layer of corrugated tin with four layers of 3/4 in. CD grade plywood. |  | 2 x 4 Board | 15 | 104.8 - 110.0 | 72 - 75 | 5503 - 6063 | The missile perforated the target 7 ft. The missile also broke the interior layers of plywood and pushed the pieces and the corrugated tin out the back of the target. | Carter (1998) |
| A1.4 - BRICK VENEER WALLS | | | | | | | | | |
| | (Interior finish consists of 5/8-in. gypsum board attached directly to the wood studs. 3 1/2-in. fiberglass batt insulation was placed between 2x4 studs. Exterior finish consists of 3/4-in. plywood sheathing attached to the studs with a 3-in. brick veneer.) |  | 2 x 4 Board | 15 | 69.4 | 47 | 2413 | The missile perforated completely through the brick veneer, exterior and interior sheathing. The brick veneer was cracked horizontally and vertically from the point of impact. | K & C (1997) |



Missile Direction

SECTION A - 15 LBF, 2 X 4 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|---|--------------|
| A15 - DOORS | | | | | | | | |
| Curries 14 ga. Steel door with 20 ga. Metal ribs. The door was installed and tested as a swing out door. (Sargent mortise lock with deadbolt function) |  | 2 x 4 Board | 15 | 82.0 - 106.6 | 56 - 73 | 3368 - 5690 | The door withstood several impacts at the midpoint of the door next to the hardware and at the upper and lower corners next to the hinges and on the lock side respectively. | K & C (1998) |
| Republic 14 ga. Door with a polystyrene infill. The door was mounted and tested as a swing in door. (Yale mortise lock set with dead bolt function) |  | 2 x 4 Board | 15 | 81.3 | 56 | 3312 | The door failed the impact test due to hardware failure. When modified with three slide dead bolt locks, mounted opposite the hinges, the door is successful. | K & C (1998) |
| Republic 20 ga. Door, a honeycomb infill, with a 14 ga. Steel plate mounted on the non-impact side. The door was mounted and tested as a swing in door. (Standard heavy duty lock with three 1/2 inch slide bolts mounted opposite the hinges) |  | 2 x 4 Board | 15 | 103.9 | 71 | 5407 | There was a local failure of the hardware, but the redundancies in the hardware held the door in place. The missile penetrated the impact skin, but did not perforate the non-impact side or the 14 ga. Steel plate. There was permanent deformation. | K & C (1998) |
| Republic 20 ga. Door, a honeycomb infill, with a 14 ga. Steel plate mounted on the impact side. The door was mounted and tested as a swing in door. (Standard heavy duty lock with three 1/2 inch slide bolts mounted opposite the hinges) |  | 2 x 4 Board | 15 | 104.1 | 71 | 5429 | The missile did not penetrate the door, but it caused permanent deformation in the internal door frame. (The door buckled around the standard lock set.) | K & C (1998) |
| Hollow core door (wooden door). |  | 2 x 4 Board | 15 | 54.0 | 37 | 1461 | The missile perforated the target. | |
| Solid-core door (particle board fill). |  | 2 x 4 Board | 15 | 53.0 | 36 | 1407 | The missile perforated the target. | |

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Missile Direction

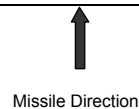
SECTION B - 2X4 BOARD MISSILES OF VARIOUS WEIGHTS

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|--------------------|---------------------|----------------------|---------------------|--------------------------|-------------------------|---|--------------|
| B.1 - REINFORCED CONCRETE MASONRY UNIT (CMU) WALLS | | | | | | | | |
| 8 in. CMU reinforced with #4 rebar at 24 in. on center cells with rebar filled with grout. | | 2 x 4 Board | 13.75 | 92.0 | 58 | 3887 | 45 degree impact angle, No damage was observed. The impact point was at the joint between cells. | TTU (1990) |
| 8 in. CMU reinforced with #4 rebar at 24-in. on center cells with rebar filled with grout. | | 2 x 4 Board | 11.5 | 116.0 | 61 | 5169 | 45 degree impact angle, No damage was observed. The impact point was at the joint between cells. | TTU (1990) |
| 8 in. CMU with no reinforcement. | | 2 x 4 Board | 13 | 60.0 | 36 | 1563 | The missile perforated the barrier. The impact point was at the center of the cell. | White (1986) |
| 8 in. CMU with no reinforcement. | | 2 x 4 Board | 11 | 131.0 | 66 | 6305 | The missile perforated the barrier. The impact point was at the joint between cells. | TTU (1990) |
| 8 in. CMU reinforced with #4 rebar at 16 in. on center cells with rebar filled with grout. | | 2 x 4 Board | 11 | 135.0 | 68 | 6696 | No penetration of the target occurred. One big crack was observed. The impact point was at the joint between cells. | TTU (1990) |
| 8 in. CMU reinforced with #4 rebar at 16 in. on center cells with rebar filled with grout. | | 2 x 4 Board | 11.25 | 104.0 | 53 | 4064 | The missile perforated the barrier. The impact point was at the center of the cell. | TTU (1990) |
| 8 in. CMU reinforced with #4 rebar at 16 in. on center cells with rebar filled with grout. | | 2 x 4 Board | 11 | 49.0 | 25 | 882 | No damage was observed. The impact point was at the center of the cell where the rebar and the grout are located. | TTU (1990) |
| 8 in. CMU reinforced with #4 rebar at 16 in. on center cells with rebar filled with grout. | | 2 x 4 Board | 12 | 120.0 | 66 | 5772 | No damage was observed. The impact point was at the center of the cell where the rebar and the grout are located. | TTU (1990) |
| 8 in. CMU reinforced with grout filled in every cell. | | 2 x 4 Board | 12.5 | 98.0 | 56 | 4010 | No damage was observed. The impact point was at the joint between cells. | TTU (1990) |
| 8 in. CMU with no reinforcement. | | 2 x 4 Board | 13.75 | 71.0 | 44 | 2315 | The missile perforated the barrier. The impact point was at the center of the cell; the missile had pointed end. | TTU (1990) |
| 8 in. CMU with no reinforcement. | | 2 x 4 Board | 13.75 | 100.0 | 63 | 4593 | The missile perforated the barrier. The impact point was at the joint between the CMU's; the missile had pointed end. | TTU (1990) |


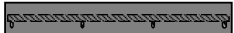

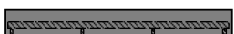
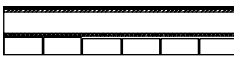
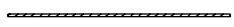
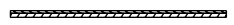
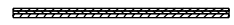

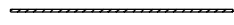
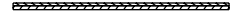
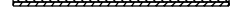
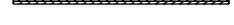
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Missile Direction

SECTION B - 2X4 BOARD MISSILES OF VARIOUS WEIGHTS

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|---|--------------------|---------------------|----------------------|---------------------|--------------------------|-------------------------|--|------------|
| B.1 - REINFORCED CONCRETE MASONRY UNIT (CMU) WALLS | | | | | | | | |
| 8 in. CMU with steel trusses in horizontal joints. | | 2 x 4 Board | 12.5 | 104.0 | 59 | 4516 | The missile perforated the barrier. The impact point was at the joint between the cells. | TTU (1990) |
| 8 in. CMU with steel trusses in horizontal joints. | | 2 x 4 Board | 12.5 | 89.0 | 51 | 3307 | The missile perforated the barrier. The impact point was at the center of the cell. | TTU (1990) |
| 12 in. CMU with no reinforcement. | | 2 x 4 Board | 11.75 | 120.0 | 64 | 5652 | The missile perforated the barrier. The impact point was at the center of the cell. | TTU (1990) |
| 12 in. CMU with no reinforcement. | | 2 x 4 Board | 12 | 85.0 | 46 | 2896 | The missile perforated the barrier. The impact point was at the joint between the CMU's. | TTU (1990) |
| 12 in. CMU with steel trusses in horizontal joints. | | 2 x 4 Board | 11.75 | 125.0 | 67 | 6132 | No penetration of the target occurred. Small cracks were observed. The impact point was at the joint between cells. | TTU (1990) |
| 12 in. CMU with steel trusses in horizontal joints. | | 2 x 4 Board | 11.75 | 124.0 | 66 | 6035 | The missile perforated the barrier. The impact point was at the center of the cell. | TTU (1990) |
| 12 in. CMU with steel trusses in horizontal joints. | | 2 x 4 Board | 12.75 | 86.0 | 50 | 3150 | The missile perforated the barrier. The impact point was at the center of the cell. | TTU (1990) |
| 12 in. CMU with steel trusses in horizontal joints. | | 2 x 4 Board | 12 | 76.0 | 42 | 2315 | The missile penetrated the barrier by 2.5 in. The impact point was at the center of the cell, the missile had pointed end. | TTU (1990) |
| 12 in. CMU with steel trusses in horizontal joints. | | 2 x 4 Board | 12.25 | 72.0 | 40 | 2121 | The missile perforated the barrier. The impact point was at the center of the cell, the missile had pointed end. | TTU (1990) |
| 12 in. CMU with steel trusses in horizontal joints. | | 2 x 4 Board | 13 | 85.0 | 50 | 3137 | The missile perforated the barrier. The impact point was at the center of the cell. | TTU (1990) |






SECTION B - 2X4 BOARD MISSILES OF VARIOUS WEIGHTS

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|---|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|---|----------------|
| B2 - REINFORCED CONCRETE SLABS | | | | | | | | |
| 4 in. thick reinforced concrete; #3 rebar at 6 inch o.c. each way in the middle of the slab |  | 2 x 4 Board | 13.5 | 121.0 | 74 | 6602 | No damage; the missile was reduced to splinters | TTU (1989) |
| 4 in. thick reinforced concrete; #3 rebar at 6 inch o.c. each way in the middle of the slab |  | 2 x 4 Board | 14 | 147.0 | 94 | 10105 | Hairline cracks on the back face; missile was reduced to splinters | TTU (1989) |
| 4 in. thick concrete - NO Reinforcement |  | 2 x 4 Board | 14.25 | 122.0 | 79 | 7085 | No penetration, 0.24 in vertical crack propagated through the panel | TTU (1989) |
| 6 in. thick reinforced concrete; #3 rebar at 6 inch o.c. each way in the middle of the slab |  | 2 x 4 Board | 13.75 | 140.0 | 88 | 9002 | No damage; the missile was reduced to splinters | TTU (1989) |
| B3 - BRICK VENEER WALLS | | | | | | | | |
| Brick veneer wall with 1/2-in. insulation board and 1/2 in. gypsum wallboard. |  | 2 x 4 Board | 12.5 | 120.0 | 68 | 6012 | The missile penetrated the target and the brick veneer crushed into small pieces. The backside wallboard remained intact. | Bailey (1984) |
| B4 - PLYWOOD LAYERS | | | | | | | | |
| 1 layer of 3/4 inch Plywood |  | 2 x 4 Board | 14 | 48.4 - 54.2 | 31 - 35 | 1095 - 1374 | Interior deformation - Total Failure | Robbins (1995) |
| 2 layers of 3/4 inch Plywood |  | 2 x 4 Board | 14 | 63.0 - 66.9 | 40 - 43 | 1856 - 2093 | Interior deformation - Total Failure | Robbins (1995) |
| 3 layers of 3/4 inch Plywood |  | 2 x 4 Board | 14 | 76.6 - 84.5 | 49 - 54 | 2744 - 3339 | Interior deformation - Total Failure | Robbins (1995) |
| 4 layers of 3/4 inch Plywood |  | 2 x 4 Board | 14 | 110.2 - 120.8 | 70 - 77 | 5679 - 6824 | Interior deformation - Total Failure | Robbins (1995) |
| B5 - OSB LAYERS | | | | | | | | |
| 1 layer of 3/4 inch OSB |  | 2 x 4 Board | 14 | NA | NA | NA | No lower bound could be established | Robbins (1995) |
| 2 layers of 3/4 inch OSB |  | 2 x 4 Board | 14 | NA | NA | NA | No lower bound could be established | Robbins (1995) |
| 3 layers of 3/4 inch OSB |  | 2 x 4 Board | 14 | 62.3 - 67.4 | 40 - 43 | 1815 - 2124 | Interior deformation - Total Failure | Robbins (1995) |
| 4 layers of 3/4 inch OSB |  | 2 x 4 Board | 14 | 74.3 - 90.9 | 47 - 58 | 2582 - 3864 | Interior deformation - Total Failure | Robbins (1995) |


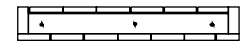
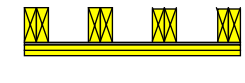


Missile Direction

SECTION C - 10 FT. LENGTH, 3 IN. DIAMETER PVC PIPE MISSILES

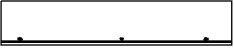


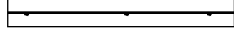
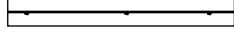
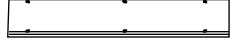
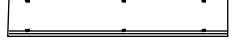
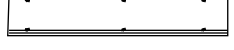
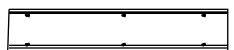
| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|---|------------------------|----------------------|---------------------|--------------------------|-------------------------|---|------------|
| C1 - REINFORCED CONCRETE MASONRY UNIT (CMU) WALLS | | | | | | | | |
| 8 in. CMU reinforced with #4 rebar at 24-in. on center cells with rebar filled with grout. |  | 10 ft Length, 3 in PVC | 14.25 | 92.0 | 60 | 4029 | No Damage was observed. The impact point was at the center of the cell where the grout and the rebar are located. | TTU (1990) |
| 8 in. CMU reinforced with #4 rebar at 24-in. on center cells with rebar filled with grout. |  | 10 ft Length, 3 in PVC | 14 | 93.0 | 59 | 4045 | No Damage was observed. The impact point was at the center of the cell where the grout and the rebar are located. | TTU (1990) |
| 8 in. CMU reinforced with grout filled in every cell. |  | 10 ft Length, 3 in PVC | 14.25 | 102.0 | 66 | 4952 | No penetration of the target occurred. Small cracks were observed. The impact point was at the joint between cells. | TTU (1990) |

SECTION D - EMT CONDUIT MISSILES

| | | | | | | | | |
|--|---|--|-------|---------------|---------|-------------|--|-------------------|
| D1 - REINFORCED CONCRETE MASONRY UNIT (CMU) WALLS | | | | | | | | |
| 8 in. CMU reinforced with #4 rebar at 24-in. on center cells with rebar filled with grout. |  | EMT Conduit | 14.75 | 67.0 | 45 | 2212 | The missile penetrated the target. The impact point was at the center of the cell where the grout and the rebar are located. | TTU (1990) |
| D2 - REINFORCED BRICK CAVITY WALLS WITH CONCRETE INFILL | | | | | | | | |
| Brick wall with concrete interior wall and #4 rebar reinforcement. |  | 10 ft; 1 in. EMT Conduit | 7.45 | 116.9 - 190.0 | 40 - 64 | 3401 - 8983 | Missile failed with very little damage to the target. | C & S (2001) I.W. |
| D3 - STUD WALLS WITH PLYWOOD AND STEEL PLATE | | | | | | | | |
| 2 layers of 3/4-in. plywood, one layer of 14 ga. steel and the 4x4 ft, double stud frame. |  | 10 ft Length; 1 in. diameter EMT Conduit | 7.45 | < 48.0 | < 16 | < 573 | The missiles repercussed. | C & S (2001) I.W. |
| | | | | 48.0 - 50.0 | 16 - 17 | 573 - 622 | Threshold was observed. | |
| | | | | > 50.0 | > 17 | > 622 | The missiles perforated the barrier. (The impacts resulted in a hole punching effect.) (5 shots) | |

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Missile Direction

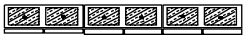


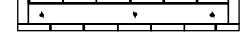
SECTION E - 3 IN. DIAMETER STEEL PIPE (SCHEDULE 40) MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|--|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|--|---------------|
| E1 - REINFORCED CONCRETE SLABS | | | | | | | | |
| 6-in. slab with # 3' s 9 in. o.c. each way, 1.5-in. from the front face. |  | 3 inch Steel Pipe | 73 | 36.0 | 120 | 3160 | The missile penetrated the target by 0.25 in. Radial cracks with a 0.19 in. maximum width propagated through slab. | Nevins (1993) |
| 6-in. slab with # 4' s 12 in. o.c. each way, 1.5-in. from the back face. |  | 3 inch Steel Pipe | 73.25 | 37.0 | 123 | 3350 | The missile penetrated the target by 0.38 in. Radial cracks with a 0.06 in. maximum width propagated through slab. | Nevins (1993) |
| 6-in. slab with # 3' s 6 in. o.c. each way, 1.5-in. from the back face. |  | 3 inch Steel Pipe | 73 | 38.0 | 126 | 3521 | The missile penetrated the target by 0.38 in. Radial cracks with a 0.06 in. maximum width propagated through slab. | Nevins (1993) |
| 8-in. slab with # 4' s 9 in. o.c. each way, placed in the middle of the slab. |  | 3 inch Steel Pipe | 72.5 | 44.0 | 145 | 4688 | The missile penetrated the target by 0.38 in. Radial cracks with a 0.06 in. maximum width propagated through slab. | Nevins (1993) |
| 8 in. slab with # 4' s 12 in. o.c. each way, placed in the middle of the slab. |  | 3 inch Steel Pipe | 79.5 | 44.0 | 159 | 5141 | The missile penetrated the target by 0.63 in. Radial cracks with a 0.06 in. maximum width propagated through slab. | Nevins (1993) |
| 8 in. slab with # 3' s 12 in. o.c. each way, placed 1.5 in. from each face. |  | 3 inch Steel Pipe | 79.5 | 50.0 | 181 | 6639 | The missile penetrated the target by 0.69 in. Radial cracks with a 0.09 in. maximum width propagated through 3/4 of slab width. | Nevins (1993) |
| 9 in. slab with # 4' s 12 in o.c. each way, placed 1.5 in. from each face. |  | 3 inch Steel Pipe | 79 | 50.0 | 180 | 6597 | The missile penetrated the target by 0.44 in. Hairline radial cracks propagated through half the slab thickness. | Nevins (1993) |
| 9 in. slab with # 4' s 12 in. o.c. each way, placed 1.5 in. from each face. |  | 3 inch Steel Pipe | 76.5 | 78.0 | 272 | 15546 | The missile penetrated the target by 1.5 in. Radial cracks propagated with scabbing, scab fragments had dimensions of 1.0 in x 0.5 in. | Nevins (1993) |
| 10 in. slab with # 4' s 12 in. o.c. each way, placed 1.5 in. from each face. |  | 3 inch Steel Pipe | 73.5 | 74.0 | 248 | 13444 | The missile penetrated the target by 0.81 in. Radial cracks with hairline width, cracks did not propagate through slab. | Nevins (1993) |




Missile Direction


SECTION E - 3 IN. DIAMETER STEEL PIPE (SCHEDULE 40) MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|---|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|--|---------------|
| E2 - REINFORCED CONCRETE MASONRY UNIT (CMU) WALLS | | | | | | | | |
| 8 in. grouted CMU wall with # 4 bars 8 in. o. c. and horizontal ties 16 in. o.c., single brick wythe on front face. |  | 3 inch Steel Pipe | 77 | 50.0 | 175 | 6430 | The missile penetrated the target by 2.13 in. Vertical cracks with a 0.38 in. maximum width propagated through wall. | Nevins (1993) |
| 8 in. grouted CMU wall with # 4 bars 8 in. o. c. and horizontal ties 16 in. o.c. |  | 3 inch Steel Pipe | 77.5 | 51.0 | 180 | 6733 | The missile perforated the target. Pieces of scabbing weighing between 7 and 14 lbs. were found. | Nevins (1993) |
| 12 in. grouted CMU wall with # 4 bars 12 in. o. c. and horizontal ties 16 in. o.c. |  | 3 inch Steel Pipe | 73.5 | 59.0 | 198 | 8546 | The missile penetrated the target by 1.38 in. Threshold of scabbing reached. | Nevins (1993) |
| E3 - REINFORCED BRICK CAVITY WALLS WITH CONCRETE INFILL | | | | | | | | |
| 9.5 in. brick cavity wall (grouted) with # 4 bars 8 in. o.c. and horizontal ties 16 in. o.c. |  | 3 inch Steel Pipe | 79 | 50.0 | 180 | 6597 | The missile penetrated the target by 1.13 in. Vertical cracks with a 0.25 in. maximum width propagated through wall. | Nevins (1993) |

SECTION F - 15 LBF, 3 INCH DIAMETER PRESSURE-TREATED FENCE POST MISSILES

| | | | | | | | | |
|---|---|----------------------------|----|---------------|---------|-------------|---|-------------------|
| F1 - STUD WALLS WITH PLYWOOD AND STEEL PLATE | | | | | | | | |
| 2 layers of ¼ in. plywood, one layer of 14 ga. steel and the 4x4 ft, double stud frame. |  | 3 in Pretreated Fence Post | 15 | < 133.0 | < 91 | < 8863 | The missiles reperculated. (5 shots) | C & S (2001) I.W. |
| | | | | 133.0 - 136.0 | 91 - 93 | 8863 - 9267 | Threshold was observed. (3 shots) | |
| | | | | > 136.0 | > 93 | > 9267 | The missiles perforated the barrier. (1 shot) | |

SECTION G - 15 LBF, 2X6 BOARD MISSILES

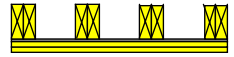
| | | | | | | | | |
|---|---|-------------|----|---------|-------|---------|--|-------------------|
| G1 - STUD WALLS WITH PLYWOOD AND STEEL PLATE | | | | | | | | |
| 2 layers of ¼ in. plywood, one layer of 14 ga. steel and the 4x4 ft, double stud frame. |  | 2 x 6 Board | 15 | < 165.0 | < 113 | < 13641 | The missiles reperculated. (5 shots) | C & S (2001) I.W. |
| | | | | NA | NA | NA | The speed necessary to perforate the target is beyond the capacity of the canon. Testing the missile configuration at higher speeds was abandoned. | |



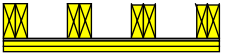




Missile Direction



SECTION H - 22.5 LBF, 2X6 BOARD MISSILES

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|---|---|---------------------|----------------------|---------------------|--------------------------|-------------------------|--|-------------------|
| H 1 - STUD WALLS WITH PLYWOOD AND STEEL PLATE | | | | | | | | |
| 2 layers of ¼ in. plywood, one layer of 14 ga. steel and the 4x4 ft, double stud frame. |  | 2 x 6 Board | 22.5 | < 165.0 | < 169 | < 20461 | The missiles repercussed. (5 shots) | C & S (2001) I.W. |
| | | | | NA | NA | NA | The speed necessary to perforate the target is beyond the capacity of the canon. Testing the missile configuration at higher speeds was abandoned. | |

SECTION I - CLAY BRICK MISSILES

| I 1 - STUD WALLS WITH PLYWOOD AND STEEL PLATE | | | | | | | | |
|---|---|---------------------------------------|------|-------|----|------|---|-------------------|
| 2 layers of ¼ in. plywood, one layer of 14 ga. steel and the 4x4 ft, double stud frame. |  | 2 5/8 in x 3 in x 8 5/8 in Clay Brick | 4.05 | 131.9 | 24 | 2354 | Missile impacted and rebounded. Penetrated target 1/2 inch causing very slight deflection in steel of non-impact side. | C & S (2001) I.W. |
| 2 layers of ¼ in. plywood, one layer of 14 ga. steel and the 4x4 ft, double stud frame. |  | 2 5/8 in x 3 in x 8 5/8 in Clay Brick | 4.05 | 225.9 | 42 | 6903 | Missile reduced to powder; penetration 1 inch and permanent deflection in steel of 1/2 inch | C & S (2001) I.W. |
| 2 layers of ¼ in. plywood, one layer of 14 ga. steel and the 4x4 ft, double stud frame. |  | 2 5/8 in x 3 in x 8 5/8 in Clay Brick | 4.05 | 231.4 | 43 | 7244 | Missile penetrated 1.75 inch then turned into powder. Deflected steel on non-impact side of 1 inch. Cracked outside stud. | C & S (2001) I.W. |
| 2 layers of ¼ in. plywood, one layer of 14 ga. steel and the 4x4 ft, double stud frame. |  | 2 5/8 in x 3 in x 8 5/8 in Clay Brick | 4.05 | 232.6 | 43 | 7319 | Missile perforated target causing 3.5 inch petaling and deflection to non-impact side. Brick remained lodged in the target. | C & S (2001) I.W. |
| 2 layers of ¼ in. plywood, one layer of 14 ga. steel and the 4x4 ft, double stud frame. |  | 2 5/8 in x 3 in x 8 5/8 in Clay Brick | 4.05 | 270.3 | 50 | 9884 | Missile penetrated 2.5 inch causing 1.5 in deflection in steel on non-impact side. Both studs cracked. Brick disintegrated. | C & S (2001) I.W. |

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Missile Direction

SECTION J - 2 X 4 BOARD MISSILE DROP TESTS (65 MPH)

| Target Name | Target Description | Missile Description | Missile Weight (lbf) | Missile Speed (MPH) | Missile Momentum (lbf-s) | Missile Energy (ft-lbf) | Damage Description | Reference |
|---|--------------------|---------------------|----------------------|---------------------|--------------------------|-------------------------|--|-----------------|
| J1 - WALL SECTIONS | | | | | | | | |
| 3/4 inch plywood | NA | 2 x 4 Board | 15.8 | 65.0 | 47 | 481 | Missile passed through | Thompson (1973) |
| Expanded metal (1/4 inch) over 3/4 inch plywood | NA | 2 x 4 Board | 46.3 | 65.0 | 137 | 1411 | Missile passed through | Thompson (1973) |
| 3/4 inch plywood over expanded metal | NA | 2 x 4 Board | 86.9 | 65.0 | 257 | 2650 | Plywood was penetrated, several wires broken | Thompson (1973) |
| 3/4 inch plywood-lightweight concrete - 3/4 inch plywood | NA | 2 x 4 Board | 86.9 | 65.0 | 257 | 2650 | Plywood was penetrated, concrete broke in cone shaped hole, bottom plywood cracked | Thompson (1973) |
| 3/4 inch plywood - expanded metal - lightweight concrete - 3/4 inch concrete | NA | 2 x 4 Board | 185.1 | 65.0 | 548 | 5645 | Plywood was penetrated, several wires broken, concrete broke in cone shaped hole, bottom plywood had 1 inch deep bulge | Thompson (1973) |
| 3/4 inch plywood - lightweight concrete - expanded metal - 3/4 inch plywood | NA | 2 x 4 Board | 185.1 | 65.0 | 548 | 5645 | Plywood was penetrated, concrete broke in cone shaped hole, 3 inch deep bulge in wire, bottom plywood cracked | Thompson (1973) |
| Concrete block beam filled with lightweight concrete | NA | 2 x 4 Board | 92.5 | 65.0 | 274 | 2822 | Block beam destroyed | Thompson (1973) |
| Concrete block beam filled with lightweight concrete with #3 rebar in each cavity | NA | 2 x 4 Board | 185.1 | 65.0 | 548 | 5645 | No penetration or cracks | Thompson (1973) |
| Preformed, steel reinforced masonry wall panel, about 4 inch thick | NA | 2 x 4 Board | 185.1 | 65.0 | 548 | 5645 | No penetration, one horizontal mortar joint cracked, allowing about 1 inch lateral deformation in 4 ft span, impacted brick did not crack, missile shattered | Thompson (1973) |
| 1 3/4 inch solid wood | NA | 2 x 4 Board | 74.0 | 65.0 | 219 | 2258 | Wall section destroyed | Thompson (1973) |
| J2 - DOORS | | | | | | | | |
| Solid (filled) door | NA | 2 x 4 Board | 86.9 | 65.0 | 257 | 2650 | Missile passed through | Thompson (1973) |
| 16 gage steel over hollow-core door | NA | 2 x 4 Board | 86.9 | 65.0 | 257 | 2650 | Metal deformed, door destroyed | Thompson (1973) |
| Expanded metal over filled door | NA | 2 x 4 Board | 74.0 | 65.0 | 219 | 2258 | Missile passed through | Thompson (1973) |
| Filled door over expanded metal | NA | 2 x 4 Board | 74.0 | 65.0 | 219 | 2258 | Missile passed through door, large deformation in wire | Thompson (1973) |
| Hollow core door over 16-gage steel | NA | 2 x 4 Board | 74.0 | 65.0 | 219 | 2258 | Door destroyed, large deformations in metal | Thompson (1973) |
| 14 gage steel over 1 1/2 inch solid wood door | NA | 2 x 4 Board | 175.8 | 65.0 | 521 | 5362 | Large deflection of metal door cracked | Thompson (1973) |



Missile Direction

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