

CHAPTER 4

TEST RESULTS

4.1. Introduction

This chapter includes test results for various wall and roof assemblies listed in Tables 3.4 and 3.5. A total of 24 specimens were tested with the basic, enhanced-A and enhanced-B tests.

4.2. Wall Assemblies

Seventeen (17) wall assemblies were tested in this study. Test results for wall assemblies listed in Table 3.4 are described in this section.

4.2.1. Wood Wall Systems: Test results for wood wall framing systems (specimens 1 to 9 from Table 3.4) are presented in Table 4.1. Photographs of the tested specimens are shown in Appendix C (Figs. C.1 through C.11).

The first two test specimens (Items 1 and 2) were built with plywood and OSB siding on stucco. They both failed in the basic test with complete penetration of the missile (Figs. C.1 and C.2). These specimens were impacted in the middle and at the corner of the test assemblies. As these assemblies failed in the basic test for both the impacts, the enhanced-A and enhanced-B tests were not performed. It was observed from these tests that plywood and OSB siding behaved similarly under large missile impact. Test assemblies with stucco on gypsum board and stucco on dingsglass (specimens 3 and 4) also failed the basic test with complete penetration of the

Table 4.1: Test Results for Wood Stud Wall Assemblies

| Specimen No. (Table 3.4) | Assembly | Missile Size and Speed (mph) | Test Type | Impact Location | Damage Summary | Comment |
|-----------------------------|---|---------------------------------|-----------|-----------------|--|---------|
| 1 | Stud wall with stucco on 1/2 in. plywood | 2x4 in. 9 lb 35.0 | Basic | Middle | Missile completely penetrated both the exterior and interior fascia. | Failed |
| | | 2x4 in. 9 lb 35.0 | Basic | Corner | Missile completely penetrated both the exterior and interior fascia. | Failed |
| 2 | Stud wall with stucco on 7/16 in. OSB | 2x4 in. 9 lb 34.7 | Basic | Middle | Missile completely penetrated both the exterior and interior fascia. | Failed |
| | | 2x4 in. 9 lb 35.0 | Basic | Corner | Missile completely penetrated both the exterior and interior fascia. | Failed |
| 3 | Stud wall with stucco on 5/8 in. gypsum board | 2x4 in. 9 lb 35.2 | Basic | Middle | Missile completely penetrated both the exterior and interior fascia. | Failed |
| | | 2x4 in. 9 lb 33.9 | Basic | Corner | Missile completely penetrated both the exterior and interior fascia. | Failed |
| 4 | Stud wall with stucco on 1/2 in. dingsglass | 2x4 in. 9 lb 35.2 | Basic | Middle | Missile completely penetrated both the exterior and interior fascia. | Failed |
| | | 2x4 in. 9 lb 33.9 | Basic | Corner | Missile completely penetrated both the exterior and interior fascia. | Failed |
| 5 | Stud wall with 5/16 in. Hardiboard on 1/2 in. plywood | 2x4 in. 9 lb 35.2 | Basic | Middle | Missile completely penetrated both the exterior and interior fascia. | Failed |
| | | 2x4 in. 9 lb 34.4 | Basic | Corner | Missile completely penetrated both the exterior and interior fascia. | Failed |
| 6 | Stud wall with 5/16 in. Hardiboard on 7/16 in. OSB | 2x4 in. 9 lb 35.0 | Basic | Middle | Missile completely penetrated both the exterior and interior fascia. | Failed |
| | | 2x4 in. 9 lb 35.5 | Basic | Corner | Missile completely penetrated both the exterior and interior fascia. | Failed |
| 7 | Stud wall with 3/4 in. Advantech | 2x4 in. 9 lb 36.4 | Basic | Middle | Missile completely penetrated both the exterior and interior fascia. | Failed |
| | | 2x4 in. 9 lb 37.0 | Basic | Corner | Missile completely penetrated both the exterior and interior fascia. | Failed |
| | | 2x4 in. 9 lb 35.0 | Basic | Corner | Missile completely penetrated both the exterior and interior fascia. | Failed |

Table 4.1: Test Results for Wood Stud Wall Assemblies (contd.)

| Specimen No. (Table 3.4) | Assembly | Missile Size and Speed (mph) | Test Type | Impact Location | Damage Summary | Comment |
|--------------------------|--|------------------------------|------------|-----------------|--|---------|
| 7 (contd.) | Stud wall with 3/4 in. Advantech | 2x4 in. 9 lb 34.4 | Basic | Middle | The impact location was on the stud. Missile rejected without penetration. Impact crushed the Advantech and pushed the stud back into the interior portion of the specimen although no openings were formed. | Failed |
| 8 | Stud wall with brick veneer on 7/16 in. OSB | 2x4 in. 15 lb 51.4 | Enhanced-A | Middle | No penetration. Some minor cracking and spalling near the impact point. | Passed |
| | | 2x4 in. 15 lb 49.7 | Enhanced-A | Corner | No penetration. Impact aggravated existing cracks. | Passed |
| | | 2x4 in. 15 lb 63.9 | Enhanced-B | Middle | Crushing failure of brick at the impact location. Cracks extended vertically throughout specimen. Interior portion of the wall ruptured by stud. | Failed |
| 9 | Stud wall with brick veneer on 1/2 in. plywood | 2x4 in. 15 lb 49.7 | Enhanced-A | Corner | No penetration, only an indentation of missile. Some local crushing of bricks. A vertical crack developed throughout. | Passed |
| | | 2x4 in. 15 lb 49.16 | Enhanced-A | Middle | No penetration, only an indentation of missile. Local brick crushing, and aggravated vertical cracking. | Passed |

missile (Figs. C.3 and C.4). Specimens 5 and 6 were built with Hardiboard on plywood/OSB combination. Both of them failed the basic test as the missiles penetrated the assemblies completely (Figs. C.5 and C.6). Specimen 7 was built with 3/4 in. Advantech siding on wood framing. The specimen failed the basic test for the middle and corner impacts (Figs. C.7). The missile was then impacted intentionally on the stud. The assembly rejected the missile without penetration, but it damaged the assembly considerably (Fig. C.8). The impact crushed the Advantech and pushed the stud back into the interior portion of the specimen. No openings were observed at the front face. Specimens with brick veneer on plywood /OSB (specimens 8 and 9) were tested for the enhanced-A test first. The missile was first impacted on the middle of specimen 8 with brick veneer on OSB siding. The specimen rejected the missile without penetration or spalling. Some minor cracking and crushing of the brick occurred near the impact location (Fig. C.9). The specimen was then impacted in the middle by a 2x4 15 lb missile at a speed of 60 mph. The specimen rejected the missile from penetration. Crushing failure of brick at the impact location occurred (Fig. C.10a). Cracks extended vertically throughout the specimen. A cross stud was detached from the frame and the interior portion of the wall was damaged (Fig. C.10b). As the interior part of the wall was considerably damaged in this test, the assembly was considered as “failed” in the enhanced-B test. The specimen was then subjected to the enhanced-A test with the corner impact. Local brick crushing was observed as shown in Fig. C.9b. The existing cracks were aggravated by the missile impact. There was no penetration or perforation of the missile. According to the failure criteria, this specimen passed the enhanced-A test for both middle and corner impacts. In case of the enhanced-A test on specimen 9 with brick veneer on plywood siding, the specimen was hit at the corner first. The missile did not penetrate

the assembly. Some local crushing of the brick occurred at the impact location (Fig. C.11b). Large cracks developed throughout the specimen. When the missile was impacted in the middle, the existing cracks were aggravated (Fig. C.11a), without missile penetration. These tests also showed the identical behavior of plywood and OSB. As these assemblies passed the enhanced-A test, they must be strong enough to withstand the basic missile impact (2x4 in. 9 lb at 34 mph). It may be inferred that specimen 9 would also have failed in the enhanced-B test as both specimens 8 and 9 were constructed with similar strength materials.

4.2.2. Metal Wall Systems: Three metal wall framing systems (specimens 10 to 12 in Table 3.4) were tested in this study. Results of these tests are presented in Table 4.2. Photographs of the tested specimens are shown in Figs. C.12 through C.15 in Appendix C.

Specimens 10 and 11 had similar sidings as specimens 6 and 7 (Table 4.1). The only difference was their wall framing system. Specimens 6 and 7 had a wood framing system with 2x6 in. studs at 16 in. o.c., whereas specimens 10 and 11 had a metal framing system comprised of 8 in. cold-formed channel. Both specimens 10 and 11 failed the basic tests with complete penetration of the missile (Figs. C.12 and C.13). From these results, it may be inferred that the framing system material has little or no influence on the test result. The siding material controls the test results.

Specimen 12 with 5V Galvalume on plywood siding was tested for the enhanced-A impact first. The missile penetrated the specimen completely in both the middle and the corner impacts (Fig. C.14). It was then impacted with the basic test procedure, twice in the middle and once at the corner. It passed the basic test without any missile penetration for all three impacts.

Table 4.2: Test Results for Metal Stud Wall Assemblies

| Specimen No. (Table 3.4) | Assembly | Missile Size and Speed (mph) | Test Type | Impact Location | Damage Summary | Comment |
|---------------------------------|--|-------------------------------------|------------------|------------------------|--|----------------|
| 10 | Stud wall with 5/16 in. Hardiboard on 1/2 in. plywood | 2x4 in. 9 lb 36.1 | Basic | Middle | Missile completely penetrated both the exterior and interior fascia. | Failed |
| | | 2x4 in. 9 lb 35.1 | Basic | Corner | Missile completely penetrated both the exterior and interior fascia. | Failed |
| 11 | Stud wall with 5/16 in. Hardiboard on 7/16 in. OSB | 2x4 in. 9 lb 35.0 | Basic | Middle | Missile completely penetrated both the exterior and interior fascia. | Failed |
| | | 2x4 in. 9 lb 37.3 | Basic | Corner | Missile completely penetrated both the exterior and interior fascia. | Failed |
| 12 | Stud wall with 26 ga. 5V Galvalume siding on 1/2 in. plywood | 2x4 in. 9 lb 30.0 | Basic | Middle | No penetration. Indentation of missile observed. Local deformation of metal. | Passed |
| | | 2x4 in. 9 lb 34.7 | Basic | Middle | No penetration. Indentation of missile observed. Local deformation of metal. | Passed |
| | | 2x4 in. 9 lb 33.4 | Basic | Corner | No penetration. Indentation of missile observed. Local deformation of metal. | Passed |
| | | 2x4 in. 15 lb 50.4 | Enhanced-A | Middle | Missile completely penetrated both the exterior and interior fascia. | Failed |
| | | 2x4 in. 15 lb 49.2 | Enhanced-A | Corner | Missile completely penetrated both the exterior and interior fascia. | Failed |

Minor deformation at the impact location was observed (Fig. C.15). The specimen was not tested for the enhanced-B test as it failed in the enhanced-A test.

4.2.3. Concrete Wall Panels: Test results for concrete wall panels (specimens 13 to 17 in Table 3.4) are presented in Table 4.3. Photographs of the tested specimens are shown in Figs. C.16 through C.23 in Appendix C.

The 6 in. CMU wall (specimen 13) was impacted first according to the enhanced-A testing criteria. The missile penetrated the front face of the CMU block, but it did not damage the back face of the blocks (Fig. C.16). The missile directly impacted a web, and this is assumed to be the reason why complete penetration did not occur. The assembly was subsequently tested again for the enhanced-A impact. The missile did not cause any damage to the assembly, as shown in Fig. C.17a. The missile was broken into pieces after the impact (Fig. C.17b). At the third enhanced-A impact in the middle, the missile damaged the front face without damaging the back face of the assembly (Fig. C.18). Three missile impacts were performed for the basic test on this specimen. The specimen passed the basic tests without any penetration. The missiles bounced back after the impact in all three tests. In the first test, cracking around the impact location was observed. Two other basic impacts made rectangular openings at the front face of the assemblies (Fig. C.19). The missiles did not damage the back face of the specimens. The 6 in. CMU wall with horizontal reinforcement (specimen 14) passed the basic test without missile penetration, but failed the enhanced-A test with a complete penetration of the missile (Figs. C.20 and C.21).

The AAC wall (specimen 15) was tested using the basic (Fig. C.22), enhanced-A (Fig. C.23), and enhanced-B (Fig. C.24) tests. The specimen passed the basic test by rejecting the

Table 4.3: Test Results for Concrete Wall Panels

| Specimen No. (Table 3.4) | Assembly | Missile Size and Speed (mph) | Test Type | Impact Location | Damage Description | Comment |
|-----------------------------|--|---------------------------------|------------|-----------------|---|---------|
| 13 | 8 in. CMU wall | 2x4 in. 9 lb 31.3 | Basic | Middle | No penetration. Impact point at center of a cell. A crack developed around impact location. | Passed |
| | | 2x4 in. 9 lb 31.1 | Basic | Middle | Impact point at corner of a cell. Missile repelled, but made a rectangular hole on impact face. No damage to back face. | Passed |
| | | 2x4 in. 9 lb 37.6 | Basic | Middle | Impact point at corner of a cell. Missile repelled, but made a rectangular hole on impact face. No damage to back face. | Passed |
| | | 2x4 in. 15 lb 50.3 | Enhanced-A | Middle | Missile impacted at a web and penetrated exterior fascia. No damage to back face. | Passed |
| | | 2x4 in. 15 lb 50.3 | Enhanced-A | Middle | Impact point at corner of a cell. Missile rejected without penetration. No damage to the panel. | Passed |
| | | 2x4 in. 15 lb 50.8 | Enhanced-A | Middle | Missile impacted at a web and penetrated exterior fascia. No damage to back face. | Passed |
| 14 | 8 in. CMU wall with horizontal reinforcement | 2x4 in. 9 lb 33.9 | Basic | Middle | Impact point at corner of a cell. Missile rejected without penetration, spalling, or cracking. | Passed |
| | | 2x4 in. 9 lb 31.5 | Basic | Corner | Impact point at corner of a cell on horizontal reinforcement. Missile repelled, but made a rectangular hole on impact face. No damage at back face. | Passed |
| | | 2x4 in. 15 lb 50.3 | Enhanced-A | Middle | Impact point at middle of a cell. Missile completely penetrated both exterior and interior fascia. Massive spalling of interior fascia. | Failed |
| 15 | AAC blocks | 2x4 in. 9 lbs 34.7 | Basic | Middle | Impact point at the center of the block. Missile rejected without penetration. Cracking throughout specimen. | Passed |
| 15 (contd.) | AAC blocks | 2x4 in. 15 lbs 50.6 | Enhanced-A | Middle | Impact Point at the center of the block. Missile rejected without penetration. Massive cracking of specimen. | Failed |

Table 4.3: Test Results for Concrete Wall Panels (contd.)

| Specimen No. (Table 3.4) | Assembly | Missile Size and Speed (mph) | Test Type | Impact Location | Damage Description | Comment |
|-------------------------------------|---|---|------------------|------------------------|---|----------------|
| | | 2x4 in. 15 lbs 59.8 | Enhanced-B | Middle | Impact point at the center of the block. Missile completely penetrated the specimen. Massive spalling and cracking of the specimen. | Failed |
| 16 | 6 in. ICF wall panels with 7120 psi concrete compressive strength | 2x4 in. 15 lb 49.2 | Enhanced-A | Middle | Missile rejected without penetration. | Passed |
| | | 2x4 in. 15 lb 59.6 | Enhanced-B | Middle | Missile rejected without penetration. | Passed |
| 17 | 5 in. tilt-up wall with #5 bar @ 12 in. o.c. longitudinal and #3 bar @ 12 in. o.c. temperature and shrinkage reinforcement. Concrete compressive strength was 4250 psi. | 2x4 in. 15 lb 49.7 | Enhanced-A | Middle | Missile rejected without penetration. | Passed |
| | | 2x4 in. 15 lb 59.6 | Enhanced-B | Middle | Missile rejected without penetration. | Passed |

sustained massive amounts of cracking during the enhanced-A test. Finally, during the enhanced-B test, the missile completely penetrated the specimen and cause severe cracking throughout.

The ICF wall (specimen 16) was first impacted with the enhanced-A test. The specimen rejected the missile without penetration or spalling of the concrete. Only the ICF form was damaged at the impact location (Fig. C.25a). Similar results were observed for the enhanced-B test (Fig. C.25b). The tilt-up wall (specimen 17) passed both the enhanced-A and the enhanced-B tests without penetration or spalling of concrete (Fig. C.26). Therefore, no basic test was performed on specimens 16 and 17.

4.3. Roof Assemblies

Seven (7) roof assemblies were tested in this study. Test results for roof assemblies listed in Table 3.5 are described in this section.

4.3.1. Metal Framing Systems: The large missile impact test results for the metal framing systems are presented in Table 4.4.

The roof assembly with 26 ga. 5V Galvalume on 1/2 in. plywood (specimen 1 from Table 3.5) was tested with the enhanced-A impact. The missile completely penetrated the assembly (Fig. C.27). It was then impacted for the basic test, which it passed without the missile penetration. Some minor local deformation was occurred at the impact location (Fig. C.28). No enhanced-B test was needed for this specimen.

The roof assembly with 26 ga. Standing Seam on 7/16 in. OSB (specimen 2) passed the basic missile impact test without penetration. The specimen was impacted twice at the corner and once in the middle with the basic set-up. The first corner impact produced minor deformation at

Table 4.4: Test Results for Metal Roof Framing Systems

| Specimen No. (Table 3.5) | Assembly | Missile Size and Speed (mph) | Test Type | Impact Location | Damage Description | Comment |
|--------------------------|---|------------------------------|------------|-----------------|---|---|
| 1 | 26 ga. 5V Galvalume on 1/2 in. plywood | 2x4 in. 9 lb 29.4 | Basic | Middle | Missile rejected without penetration. Some local deformation occurred. | Passed |
| | | 2x4 in. 9 lb 28.0 | Basic | Middle | Missile rejected without penetration. Some local deformation occurred. | Passed |
| | | 2x4 in. 9 lb 34.9 | Basic | Middle | Missile rejected without penetration. Some local deformation occurred. | Passed |
| | | 2x4 in. 15 lb 50.3 | Enhanced-A | Middle | Missile completely penetrated both the exterior and interior fascia. | Failed |
| 2 | 26 ga. Standing Seam on 1/2 in. plywood | 2x4 in. 9 lb 31.7 | Basic | Corner | Missile rejected without penetration. Minor deformation near impact point. | Passed |
| | | 2x4 in. 9 lb 34.4 | Basic | Corner | Second impact almost at same location. Missile rejected without penetration. Panel separation on left side, large deformations in material. Plywood cracked. | Damages influenced by previous test. Considered as Passed |
| | | 2x4 in. 9 lb 32.9 | Basic | Middle | Missile rejected without penetration. Panel separation on left side, large deformations in material. Plywood cracked. | Damages influenced by previous test. Considered as Passed |
| | | 2x4 in. 15 lb 49.2 | Enhanced-A | Middle | Missile rejected without penetration. Panel separation on left side, large deformations in material. Plywood cracked. Tore free from fasteners on the right side. | Failed |
| | | 2x4 in. 15 lb 46.6 | Enhanced-A | Corner | Missile rejected without penetration. Severe deformations in metal and pulled some fasteners from plywood. Severe cracking of plywood. | Failed |

Table 4.4: Test Results for Metal Roof Framing Systems (contd.)

| Specimen No. (Table 3.5) | Assembly | Missile Size and Speed (mph) | Test Type | Impact Location | Damage Description | Comment |
|-----------------------------|---|---------------------------------|------------|-----------------|--|---------|
| 2 (contd.) | 26 ga. Standing Seam on 1/2 in. plywood | 2x4 in. 15 lb 60.5 | Enhanced-B | Middle | Missile completely penetrated both the exterior and interior fascia. | Failed |
| 3 | Metal deck with 5V Galvalume on 1-1/2 in. structural deck | 2x4 in. 9 lb 36.7 | Basic | Middle | Missile rejected without penetration. Some local deformation occurred. | Passed |
| | | 2x4 in. 15 lb 51.4 | Enhanced-A | Middle | Missile rejected without penetration. Some local deformation occurred. | Passed |
| | | 2x4 in. 15 lb 50.3 | Enhanced-A | Corner | Missile rejected without penetration. Some local deformation occurred. | Passed |
| | | 2x4 in. 15 lb 61.3 | Enhanced-B | Corner | Missile rejected without penetration. Large deformation in deck, as well as, a tear in 5V. Center stud ripped from bottom track and edge studs buckled. | Passed |
| 4 | Asphalt tiles on 7/16 in. OSB | 2x4 in. 9 lb 29.4 | Basic | Middle | Missile completely penetrated both the exterior and interior fascia. | Failed |
| | | 2x4 in. 9 lb 33.4 | Basic | Corner | Missile completely penetrated both the exterior and interior fascia. | Failed |
| 5 | 3 in. metal deck | 2x4 in. 15 lb 48.6 | Enhanced-A | Middle | Missile rejected without penetration. Missile hit corner of a rib and caused some local deformation. Lap joint between panels opened slightly. | Passed |
| | | 2x4 in. 15 lb 47.6 | Enhanced-A | Corner | Previously damaged specimen rejected the missile without penetration. The impact did, however, cause large deformations in the material and failure of the puddle welds. | Passed |
| | | 2x4 in. 15 lb 59.6 | Enhanced-B | Middle | Missile rejected without penetration. Impact caused large deformations and tore decking across rib and at weld. | Failed |
| | | 2x4 in. 15 lb 59.6 | Enhanced-B | Corner | Missile penetrated lap joint, which was targeted intentionally. | Failed |

Table 4.4: Test Results for Metal Roof Framing Systems (contd.)

| Specimen No. (Table 3.5) | Assembly | Missile Size and Speed (mph) | Test Type | Impact Location | Damage Description | Comment |
|-------------------------------------|------------------|---|------------------|------------------------|---|----------------|
| 5 (contd.) | 3 in. metal deck | 2x4 in. 15 lb 59.6 | Enhanced-B | Corner | Missile rejected without penetration. Large deformation at impact point. Tore decking across rib and at weld. | Failed |
| | | 2x4 in. 15 lb 58.9 | Enhanced-B | Middle | Missile rejected without penetration. Some local deformation occurred. | Passed |
| | | 2x4 in. 15 lb 58.9 | Enhanced-B | Corner | Missile penetrated joint, which was targeted intentionally, and tore two of adjacent screws from deck. | Failed |

the impact location (Fig. C.29). The second corner impact was made at the same location. The specimen rejected the missile without penetration. The missile impact separated the panels on the left side and caused large deformations in the material (Fig. C.30a). The impact slightly damaged the plywood (Fig. C.30b). The damages on the assembly from this impact were aggravated by the previous impact. The test failure criteria does not recognize double impacts at the same location. The middle impact separated the panels on the left side, caused large deformations in the material and cracked the plywood (Fig. C.31). This impact occurred on a panel adjacent to a damaged panel from the previous basic corner impact. This assembly was recorded as “Passed” in the basic test, as the missile did not penetrate the assembly. No missile penetration was observed in the enhanced-A test. The left seam was torn off from the middle impact (Fig. C.32a). The right seam was separated from the previous impacts. The backside of the assembly was damaged with considerable amount of cracking, as shown in Fig C.32b. Although the missile did not completely penetrate, the assembly was considerably damaged at the front and back sides of the panel. The assembly was, therefore, considered to be failed in the enhanced-A missile impact test. As the missile did not penetrate the assembly in the enhanced-A test, it was further tested for the enhanced-B impact. The missile completely penetrated the assembly under the enhanced-B impact (Fig. C.33).

The roof assembly with 5V Galvalume on 1-1/2 in. structural deck (specimen 3) passed the enhanced-A test without missile penetration for both middle and corner impacts. Minor local deformation at the impact location occurred, as shown in Figs. C.34 and C.35. The missile also did not penetrate under the enhanced-B impact; however a large deformation in the deck as well as a tear in the 5V Galvalume was observed (Fig. C.36a). The missile did not penetrate the

structural deck. The impact caused the center stud to rip from the bottom track and the edge studs to buckle (Fig. C.36b). This assembly was recorded as “Passed” in the basic, enhanced-A and enhanced-B tests, according to the failure criteria.

The roof assembly with 7/16 in. asphalt shingles on OSB siding (specimen 4) failed in the basic test with complete missile penetration, as shown in Fig. C.37.

The 3 in. metal roof deck (specimen 5) passed the enhanced-A test without any penetration. The impact caused local deformation of the panel (Fig. C.38). The lap joint between panels opened slightly under the impact. The specimen was then subjected to the enhanced-B test, which caused extensive deformations (Fig. C.39). The impact tore the decking across the rib and at the weld. Under the enhanced-A corner impact, the missile did not penetrate the assembly (Fig. C.40), but the welding at the support was torn off the steel column support structure. It is to be noted that the corner impact was performed on the damaged specimen. The missile penetrated the joint due to the enhanced-B corner impacts (C.41a). It was understood from these tests that the vertically welded roof panel configuration caused the welds to be weak because the material ran to the bottom of the weld area and therefore a solid 3/4 in. puddle weld was not produced. Also, screws were not included in the lap connections. The lack of lap screws and the failure of the welds during testing produced marginal results. Due to the performance of the welds and lack of screws, it was deemed necessary to rebuild the specimen in the horizontal position so that the desired welds could be produced and the lap screws could be included. To accomplish this, new 3 in. deck sections were welded to the channels and lap screws applied while the specimen was lying on the floor. Another channel was welded across the top of the assembly, which allowed it to be lifted without damaging the deck. Lifting bolts were attached and the assembly was lifted

into place using the overhead crane. Once in place, the specimen was again clamped to the columns using wrench clamps. This modified roof panel was then tested for the enhanced-B impact in the middle. It caused minor local deformation without penetration (Fig. C.42). When the missile was impacted at the joint with the enhanced-B criteria, it penetrated the assembly (Fig. C.41b). Based on the failure criteria, 3 in. metal deck was considered as “Passed” in the enhanced-A test. Although, it passed for the enhanced-B middle impact, it failed the enhanced-B impact at the lap joint. The assembly was, therefore, considered to be “Failed” in the enhanced-B test.

1.3.2. Concrete Panels: The large missile impact test results for the concrete roof panels are presented in Table 4.5.

Tests were performed on 6 in. and 8 in. hollow core slabs (specimens 6 and 7). The 6 in. hollow core slab was first impacted at the midpoint. The missile did not perforate or penetrate the specimen. A large crack formed at the front and back face of the specimen due to the impact, as shown in Fig. C.43. The 6 in. hollow core slab passed the enhanced-A test, according to the failure criteria. The specimen was not tested with a corner impact as it was heavily damaged by the first impact. The 8 in. hollow core slab passed the enhanced-A test without any damage. The enhanced-B 60 mph impact did not damage the 8 in. hollow core slab. Figure C.44 shows the enhanced-A and enhanced-B missile impacts and the damaged missile after the impact.

Table 4.5: Test Results for Concrete Roof Panels

| Item No. (Table 3.5) | Assembly | Missile Size and Speed (mph) | Test Type | Impact Location | Damage Description | Comment |
|---------------------------------|------------------------|---|------------------|----------------------------|--|----------------|
| 6 | 6 in. hollow core slab | 2x4 in. 15 lb 50.3 | Enhanced- A | Middle | No penetration. A vertical crack from top to bottom occurred at front face. No damage at back face except a small amount of concrete spalling. | Passed |
| 7 | 8 in. hollow core slab | 2x4 in. 15 lb 52.0 | Enhanced- A | Middle | No penetration or damage | Passed |
| | | 2x4 in. 15 lb 47.6 | Enhanced- A | Middle | No penetration or damage | Passed |
| | | 2x4 in. 15 lb 60.5 | Enhanced- B | Middle | No penetration or damage | Passed |