IMPACT RESISTANCE OF BRICK VENEER STRUCTURES TO HURRICANE DEBRIS

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ABSTRACT

Typical residential brick veneer wall construction consisting of brick veneer, oriented strandboard sheathing, wood studs, batt insulation, and gypsum wallboard was tested for the impact resistance to hurricane wind-blown debris. Tests were performed by impacting the wall with a 40 N (9 lb) 50 mm x 100 mm (2 in. x 4 in.) timber at various speeds. The Florida building code requires wall assemblies up to 9.1 m (30 ft) in height in high velocity hurricane zones to resist an impact from a 40 N (9 lb) 50 mm x 100 mm (2 in. x 4 in.) timber travelling at 55 km/hr (34 mph). ASTM E 1996 has an identical requirement for basic protection in high wind zones. ASTM E 1996 requires essential facilities to resist a 40 N (9 lb) 50 mm x 100 mm (2 in. x 4 in.) timber travelling at 88 km/hr (55 mph). In these tests, there was slight cracking of the veneer at a missile speed of 55 km/hr (34 mph). At 88 km/hr (55 mph), there was cracking of the veneer and a 10 mm (3/8 in.) penetration of the veneer. There was no damage to the sheathing or gypsum wallboard. When the missile was shot at 109 km/hr (68 mph), there was a 38 mm (1-1/2 in.) penetration of the missile, but again there was no damage to the sheathing or gypsum wallboard. A test at 127 km/hr (79 mph) on a wall panel with only half the ties resulted in a 6 mm (1/4 in.) penetration of the brick veneer and failure of the timber missile. These tests show that conventional brick veneer construction clearly exceeds the Florida Building Code and ASTM E 1996 requirements for impact resistance of hurricane debris.

KEYWORDS: brick veneer, hurricane, missile, impact resistance, windborne debris

INTRODUCTION

In addition to their devastating winds, hurricanes are known to generate airborne missiles. These missiles can perforate the walls and roofs of buildings, putting the occupants at risk of injury and death. With respect to residential and light commercial structures, impact resistance is usually quantified based on the ability of a wall system to withstand the impact of a 50 mm x 100 mm (2 in. x 4 in.) wood stud. The Florida Building Code [1] requires assemblies and materials in high velocity hurricane zones (Broward and Dade counties) up to and including 9.1 m (30 ft) in height to be able to resist a missile impact of a 40 N (9 lb) 50 mm x 100 mm (2 in. x 4 in.) timber travelling at 54.7 km/hr (34 mph). ASTM E 1996 [2] is a standard specification for performance of exterior windows, curtain walls, doors and impact protective systems impacted by windborne debris in hurricanes. For basic protection in high wind zones, it requires the assembly to withstand the impact of a 40 N (9 lb) 50 mm x 100 mm (2 in. x 4 in.) timber travelling at 54.7 km/hr (34 mph). Enhanced protection requires the assembly to withstand the impact of a 40 N (9 lb) 50 mm x 100 mm (2 in. x 4 in.) timber travelling at 87.8 km/hr (55 mph). For tornado shelters, FEMA [3] requires a wall assembly to resist the impact of a 67 N (15 lb) 50 mm x 100 mm (2 in. x 4 in.) timber travelling at 161 km/hr (100 mph).

Little testing has been performed on the impact resistance of brick veneer walls, with most of the previous testing focusing on tornado shelters. McDonald and Bailey [4] tested 92 mm (3-5/8 in.) brick veneer over a wood stud wall. The assembly was impacted with a 56 N (12.5 lb) 50 mm x 100 mm (2 in. x 4 in.) timber missile travelling at 193 km/hr (120 mph). The missile punched a hole approximately 150 mm (6 in.) high by 125 mm (5 in.) wide through the brick veneer. The missile did not perforate the gypsum wallboard on the back side of the studs. Kiesling and Carter [5] tested 75 mm (3 in.) brick veneer over a wood stud wall. A 67 N (15 lb) missile traveling at 111 km/hr (69 mph) perforated the wall, but remained imbedded in the wall. There was minor damage to the missile.

This paper reports the results of impact testing of brick veneer walls using a 40 N (9 lb) 50 mm x 100 mm (2 in. x 4 in.) missile. The purpose of the testing was to determine the resistance of typically constructed brick veneer walls to hurricane-generated missiles.

SPECIMEN CONSTRUCTION AND TEST SETUP

Typical residential wall sections were constructed for this research. The specimens were 1.2 m (4 ft) wide x 1.2 m (4 ft) tall constructed with 50 mm x 100 mm (2 in. x 4 in.) studs at 406 mm (16 in.) on center. The sheathing was 13 mm (1/2 in.) oriented strandboard (OSB) with a weather-resistant barrier and the interior finish was 13 mm (1/2 in.) gypsum wallboard. Fiberglass batt insulation with a kraft paper face was placed between the gypsum wallboard and the sheathing. The specimens were built on a metal base to facilitate handling.

The brick were standard modular face brick with dimensions of 92.9 mm (3-21/32 in.) wide by 57.9 mm (2-9/32 in.) high by 197 mm (7-3/4 in.) long. The brick conformed to ASTM C 216 [6], Grade SW, Type FBA. They had three cores holes, 25% coring, and a minimum face shell thickness of 22 mm. The average unit compressive strength was 40.5 MPa (5870 psi). The brick veneer was constructed with ASTM C 270 [7] Type N masonry cement mortar mixed to a volumetric proportion. The average brick prism compressive strength based on three brick high prisms ($h/t = 2.2$) was 26.6 MPa (3870 psi).

Brick veneer was attached to the backing with 22 mm (7/8 in.) wide by 0.8 mm (22 gauge) thick corrugated sheet metal ties that were screwed to the studs. Nailing the ties produced an undesirable movement of the assembly. There was a 25 mm (1 in.) air space. Post-inspection of the walls indicated the ties were well embedded, with mortar both below and above the tie. There were some mortar droppings and bridging, typical of veneer construction. The distance between the screw anchorage and the tie varied from 32 mm (1-1/4 in.) to 44 mm (1-3/4 in.). This is significantly greater than the 12.7 mm (1/2 in.) maximum distance allowed by the MSJC code [8]. Ties were spaced at 406 mm (16 in.) horizontally, or on each stud. Three specimens had ties placed at 406 mm (16 in.) vertically, or third points, corresponding to a tie frequency of 1 tie per 0.186 m^2 (2.0 ft^2) of wall area. One specimen had ties at 610 mm (24 in.) vertically, or at mid-height, corresponding to a tie frequency of 1 tie per 0.372 m^2 (4.0 ft^2) per tie.

The specimens were moved into position for testing by a wheeled hoist and clamped top and bottom to a structural steel reaction frame. An air cannon was used to propel the timber missile. Speed was measured with two electronic timers that measured the time of the trailing edge of the missile to travel 0.61 m (2.0 ft) as it exited from the air cannon.

TEST RESULTS

The testing program started with the hurricane missile of a 40 N (9 lb) 50 mm x 100 mm (2 in. x 4 in.) timber traveling at 55 km/hr (34 mph). The speed of the missile was gradually increased in an attempt to determine the assembly perforation velocity. The results of the brick veneer testing are summarized in Table 1.

Table 1 - Results of Impact Testing of Brick Veneer Specimens

Speci-men	Missile Characteristics				Result	
	Weight, N (lb)	Speed, km/hr (mph)	Momentum, N-s (lb-s)	Energy, J (ft-lb)	Exterior Damage	Interior Damage
1	40 (9)	55 (34)	62 (13.9)	471 (348)	Small vertical crack	None
	40 (9)	56 (35)	64 (14.3)	499 (368)	Impact at same place; 19 mm (3/4 in.) penetration	None
2	40 (9)	88 (55)	100 (22.5)	1230 (909)	Cracking of veneer; minor tearing of weather-resistant barrier; no damage to sheathing	None
	40 (9)	108 (67)	122 (27.5)	1830 (1350)	Shot at corner; brick knocked off; sheathing pushed in	2.4 mm (3/32 in.) wide crack
3	40 (9)	109 (68)	124 (27.9)	1880 (1390)	38 mm (1-1/2 in.) penetration; minor damage to weather-resistant barrier	None
	40 (9)	122 (76)	138 (31.2)	2350 (1740)	Shot at corner; brick knocked off; missile split; penetration of sheathing	None
4	40 (9)	127 (79)	144 (32.4)	2540 (1880)	Large vertical crack; missile broke; 6 mm (1/4 in.) penetration; scuffing of weather-resistant barrier	None

The first specimen was impacted at the center of the panel with a 40 N (9 lb) missile traveling at 55 km/hr (34 mph). This missile rebounded from the brick veneer and caused a vertical crack in the masonry that went from 0.8 mm (1/32 in.) wide at the top to hairline at the bottom of the wall. There was no other visible damage. A second shot at 56 km/hr (35 mph) at the same impact location caused the vertical crack to open to 10 mm (3/8 in.) at the top and 1.6 mm (1/16 in.) at the bottom. There were additional horizontal and diagonal hairline cracks. The missile penetrated about 19 mm (3/4 in.) into the brick veneer, causing an indention about the same size as the end of the 50 mm x 100 mm (2 in. x 4 in.) stud (Figure 1). No further tests were performed on this panel. The brick veneer was removed, and it was determined that there was no damage to either the weather-resistant barrier or the sheathing (Figure 2). Thus, it is clear that brick veneer is very capable of resisting a hurricane missile of 40 N (9 lb) at 55 km/hr (34 mph).

Figure 1 - Missile Penetration, 2nd Shot of 40 N (9 lb) 56 km/hr (35 mph) Missile

Figure 2 - Weather-resistant Barrier After 2nd Shot of 40 N (9 lb) 56 km/hr (35 mph) Missile

The second specimen had a band of mortar approximately 75-100 mm (3-4 in.) around the sides and top that filled the air space. This mortar band was not specified, but was mistakenly put in by the mason. The effect of the presence of this mortar is unclear. It could be argued that the additional mortar helped the panel behavior by providing more support for the brick veneer. It could also be argued that the mortar hindered the performance of the brick veneer by adding stiffness. The increased stiffness would increase the natural frequency of the brick veneer. Impact loads will cause a greater force on stiffer structures than they will on more flexible structures.

The first shot on this panel was a 40 N (9 lb) missile at 88 km/hr (55 mph) in the center of the panel. There was 9.5 mm (3/8 in.) penetration into the veneer, with the penetration being almost exactly the size of the 50 mm x 100 mm (2in. x 4 in.) missile (Figure 3). There was a vertical crack similar to that of the first specimen, being 0.8 mm (1/32 in.) wide at the bottom and hairline at the top. There was also a hairline horizontal crack. After all the testing on this panel was completed, the brick veneer was removed to examine the sheathing and weather-resistant barrier. Small holes and abrasions were visible in the weather-resistant barrier at the point of impact (Figure 4) apparently caused by flying debris or impact from mortar bridging. There was no damage to the sheathing.

The second shot on this panel was in the upper right, unrestrained corner, with the 40 N (9 lb) missile traveling at 108 km/hr (67 mph). This missile shot caused a triangular area to be knocked off the corner of the brick veneer, about 0.46 m (18 in.) wide x 0.43 m (17 in.) high (Figure 5). There was a 0.30 m (12 in.) wide x 0.25 m (10 in.) high damaged area of the sheathing, with the sheathing being knocked in about 50 mm (2 in.). The gypsum wallboard had a 2.4 mm (3/32 in.) wide crack that extended from the location of the first impact to the second impact.

Figure 3 - Penetration of 40 N (9 lb) 88 km/hr (55 mph) Missile

Figure 4 - Weather-resistant Barrier After 40 N (9 lb) 88 km/hr (55 mph) Missile

Figure 5 - Brick Veneer Cracking and Failure from 40 N (9 Lb) 108 km/hr (67 Mph) Missile Shot at Corner of Previously Tested Panel

The third brick specimen was of identical construction to the first specimen. It did not have any mortar around the sides and top, as the second specimen did. The first shot on this panel was a 40 N (9 lb) missile at 109 km/hr (68 mph) in the center of the panel. There was significant cracking of the brick veneer and a 38 mm (1-1/2 in.) penetration of the missile into the brick veneer (Figure 6). There was a vertical crack that went from 3.2 mm (1/8 in.) wide at the top to 0.8 mm (1/32 in.) wide just above the point of impact. The brick face texture, including the head joint, was visible in the end of the missile (Figure 7). After this test, the top portion of the panel was torn down so the impact area could be examined. There was minor scuffing of the weather-resistant barrier and no damage to the sheathing. A shear crack was visible through the thickness of the brick below the point of impact. The crack appeared to be at about 45º to the face of the veneer.

Figure 6 - Missile Penetration and Panel Cracking, 40 N (9 lb) 109 km/hr (68 mph) Missile

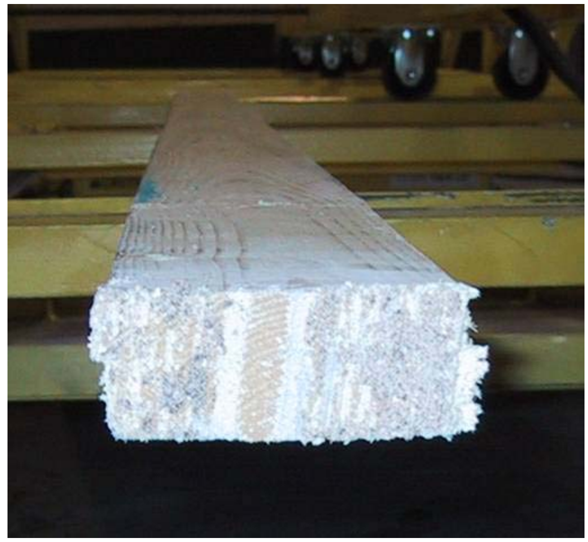

Figure 7 - Impact End of Missile After 109 km/hr (68 mph) Shot

The remaining lower portion of the panel was impacted with a second missile traveling at 122 km/hr (76 mph) in the lower left hand corner. The point of impact was one course above the lower row of ties. The brick corner was shattered, and there was a large vertical crack in the veneer. The missile split upon impact, with one piece penetrating about 25 mm (1 in.) into the sheathing, Figure 8. No cracks were present in the gypsum wallboard.

The fourth specimen had only one row of ties 660 mm (24 in.) from the bottom, conforming to normal brick construction. The specimen was impacted with a 40 N (9 lb) 127 km/hr (79 mph) missile between the center studs, two courses below the row of ties. A vertical crack formed in the veneer, with the crack being 14 mm (9/16 in.) wide at the top and 8 mm (5/16 in.) wide at the bottom (Figure 9). There was also extensive diagonal cracking, and an approximate 50 mm x 100 mm x 6 mm (2 in. x 4 in. x ¼ in.) deep penetration of the brick. The missile broke at a knot. The brick above the ties rocked upon the impact. The top portion maintained position approximately 38 mm (1.5 in.) out at the top, leaving a 64 mm (2.5 in.) air space (Figure 10). There was no permanent movement at the tie level. Upon removal of the brick and examination of the specimen, it was determined there was no substantial damage to the weather-resistant barrier; there was a little scuffing, but no holes or tears (Figure 11).

Figure 8 - Damage from 40 N (9 lb) 122 km/hr Missile

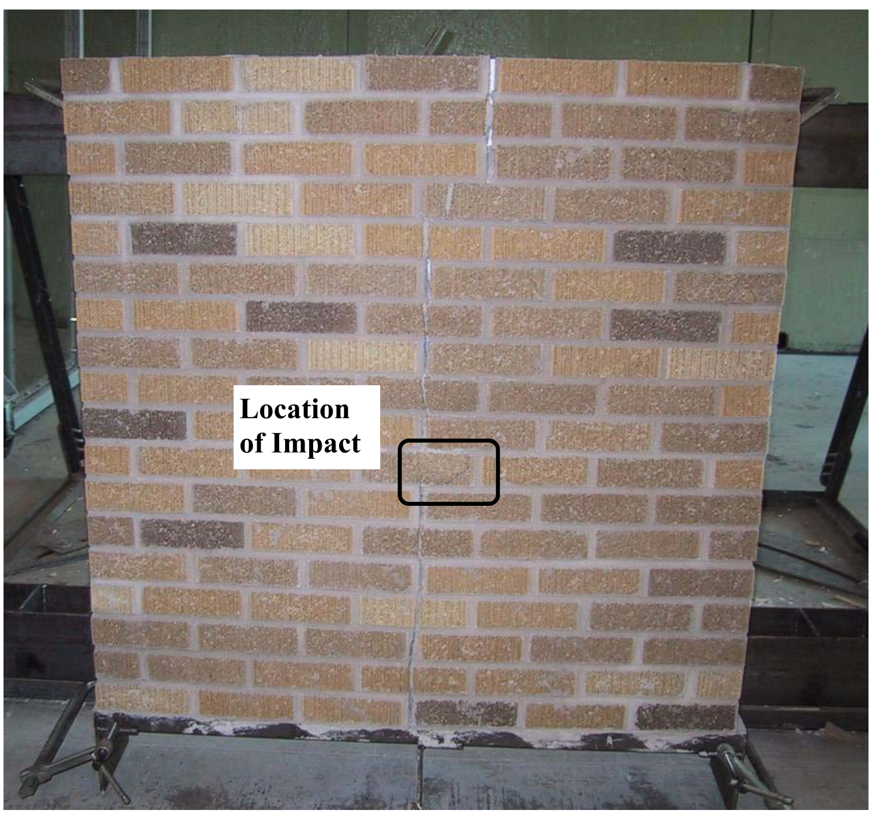

Figure 9 - Damage from 40 N (9 lb) 127 km/hr (79 mph) Missile

Figure 10 - Side View of Veneer after Impact with a 40 N (9 lb) 127 km/hr (79 mph) Missile

Figure 11 - Weather-resistant Barrier after 40 N (9 lb) 127 km/hr (79 mph) Missile Impact

CONCLUSIONS

Typical brick veneer residential and light commercial walls constructed according to current codes and specifications inherently have more than sufficient capacity to resist hurricane-generated missiles. The perforation speed of a 100 mm (4 in.) nominal brick veneer wall is in excess of 127 km/hr (79 mph) for a 40 N (9 lb) hurricane design missile. This value exceeds the 55 km/hr (34 mph) required for high velocity hurricane zones in the Florida building code [1], and the basic protection in ASTM E 1996 [2]. This also exceeds the 88 km/hr (55 mph) required for enhanced protection of ASTM E 1996 [2]. Thus brick, as currently constructed, provides impact resistance even for essential facilities. In terms of energy, brick veneer can resist the hurricane design missile with 5.5 times the kinetic energy required for basic protection and 2.1 times the kinetic energy required for enhanced protection. The tie spacing did not appear to affect the behavior of the brick walls.

ACKNOWLEDGEMENTS

The tests were performed at the Wind Science and Engineering Research Center, Texas Tech University, Lubbock, Texas.

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