IMPACT PERFORMANCE OF FULLY GROUTED CONCRETE MASONRY WALLS

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ABSTRACT

Concrete masonry walls designed as security barriers are fully grouted concrete masonry assemblies. Typically, vertical grouted cells have steel reinforcement in every cell, and reinforced horizontal bond beams may also be specified. This type of construction is found in prisons, secure facilities or other areas where the integrity of the building envelope or wall partition is vital to securing an area. This paper reports on two phases of research into the impact performance of these types of concrete masonry walls. The testing protocol used was based on ASTM F 2322, *Standard Test Methods for Physical Assault on Vertical Fixed Barriers for Detention and Correctional Facilities*. Each wall was subjected to a simulated attack from a sledgehammer and a firefighter's axe. The simulated attack was a series of impacts from a pendulum test apparatus. Failure was considered to be damage to the wall assembly such that forcible egress can be achieved. Forcible egress was defined as an opening created in the wall assembly which allows a 5 inch x 8 inch x 8 inch (127 x 203 x 203 mm) rigid rectangular box to be passed through the wall with no more than 44.5 N (10 lb) of force.

KEYWORDS: concrete masonry, detention facility, impact test, physical security, security barrier

INTRODUCTION

Communities across the United States of America rely on concrete masonry for their prisons and detention centres. In addition to its strength and durability, the layout of concrete masonry walls and cells can be cost-effectively tailored to meet the facility's needs. Concrete masonry is a proven product for correctional facilities, providing secure construction with minimum long-term maintenance.

Concrete masonry walls designed as security barriers are most often fully grouted and reinforced. Typically, vertical grouted cells have steel reinforcement in every cell, and reinforced horizontal bond beams may also be specified. This type of construction is found in prisons, secure facilities or other areas where the integrity of the building envelope or wall partition is vital to securing an area.

Recent testing [2, 3] confirms the impact resistance of concrete masonry construction, and quantifies the performance of various concrete masonry wall systems.

IMPACT TESTING

Standard Test Methods for Physical Assault on Vertical Fixed Barriers for Detention and Correctional Facilities, ASTM F 2322 [1] was developed to help quantify levels of security for walls designed to incarcerate inmates in detention and correctional institutions. The standard is intended to help ensure that detention security walls perform at or above minimum acceptable levels to control unauthorized passage to or from secure areas, to confine inmates, to delay and frustrate escape attempts, and to resist vandalism. The test method is intended to closely simulate a sustained battering ram style attack, using devices such as benches, bunks or tables. It addresses only those threats which would be anticipated based on the limited weapons, tools and resources available to inmates within detention and correctional facilities.

ASTM F 2322 includes provisions to test monolithic wall panels as well as wall panels with a simulated window opening. The standard assigns various security grades for fixed barriers based on the wall's ability to withstand the simulated attack, as shown in Table1.

Table 1 - Security Grades and Impact Load Requirements [1]

Grade No.	Number of Impacts	Representative Barrier Duration Time, Min.
1	600	60
2	400	40
3	200	20
4	100	10

Attack is simulated via a series of impacts from a pendulum testing ram apparatus shown in Figure 1. The testing ram is fitted with two heads: a blunt impactor to simulate a sledgehammer and a sharp impactor simulating a fireman's axe. The testing protocol calls for blows from both the blunt and sharp impactors, applied in sequences of 50 blows each.

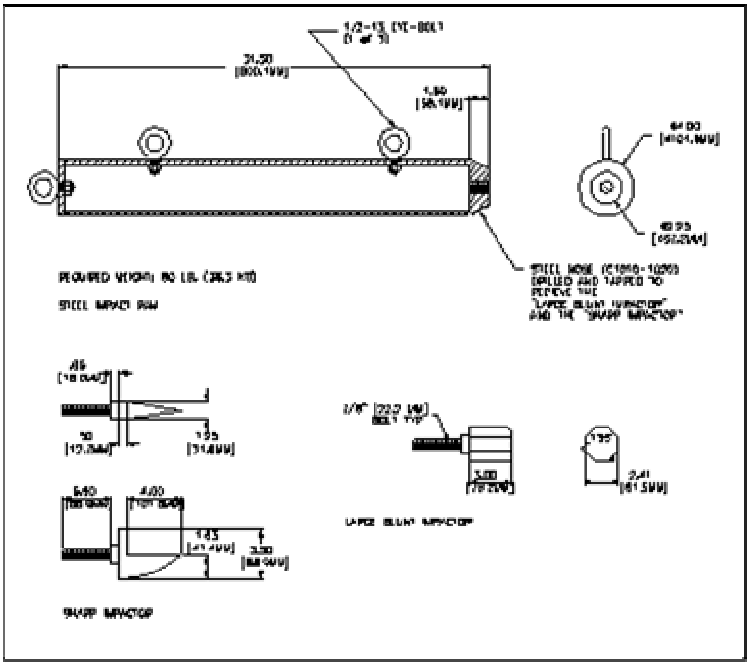

Figure 1 - Pendulum Testing Ram Apparatus

Failure of a wall assembly is defined as an opening through the wall which allows a 127 x 203 x 203 mm (5 in. x 8 in. x 8 in.) rigid rectangular box to be passed through the wall with no more than 44.5 N (10 lb) of force.

The ASTM F 2322 also assigns a representative barrier duration time, based on an historical testing observation that sustained manpower can deliver 400 blows of 271.2 J (200 ft-lb) in 45 minutes. The element of time assigned to the various security grades is adjusted to achieve more manageable time periods than actual calculations provide. The amount of time is estimated and is offered solely as supplementary design information to assist the user in matching security grades with the attack resistance times and staff response times required for each barrier in the facility.

TEST SPECIMENS

Typical wall construction provided stiffness at both the top and bottom of the wall through interconnection with the foundation below and the floor slab above. Rather than constructing individual flat wall panels with a foundation below and a slab above, as well as end returns (simulating stiffness provided by wall intersections), a four-sided closed cell was constructed. Each wall was reinforced vertically with a 13 mm (No.4) Grade 60 (400 MPa) reinforcing bar in each grouted cell of the CMU. Details of the foundation, top slab and individual walls are provided in Figure 2.

All panels were constructed using recommended construction techniques in accordance with ACI 530.1/ASCE 6/TMS 602, *Specification for Masonry Structures* [5].

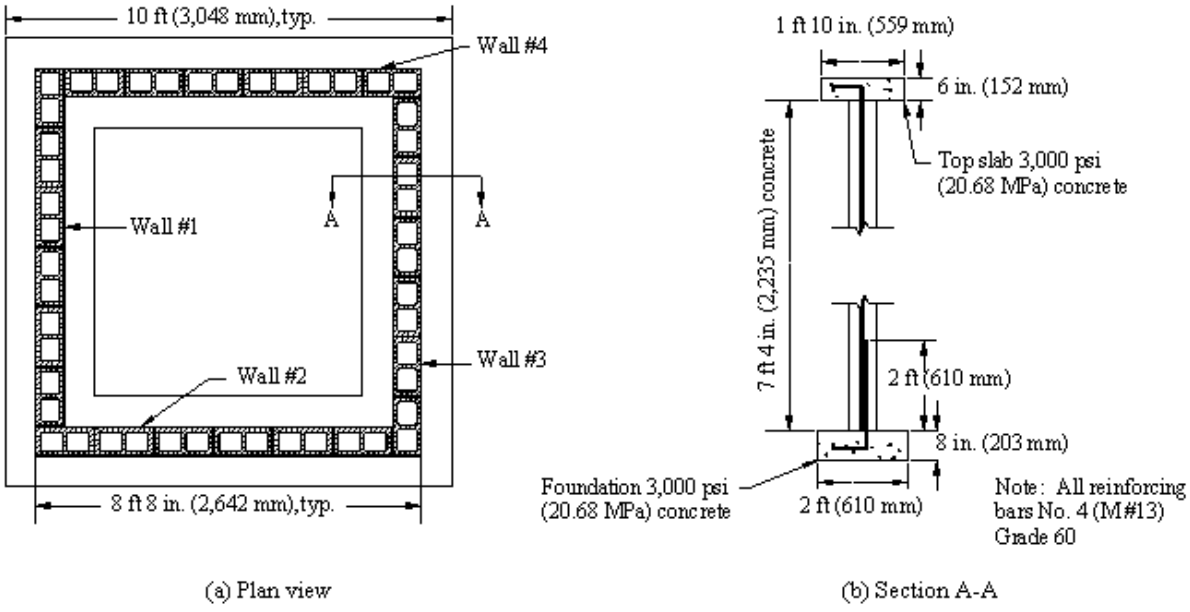

Figure 2 - Details of Prison Wall Test Panels

The foundation was constructed first with 13 mm (No.4) Grade 60 vertical dowels placed at 203 mm (8-inch) spacing and two 13 mm (No.4) Grade 60 horizontal reinforcements around the

entire perimeter of the foundation. Once the foundation concrete was placed and allowed to sufficiently cure, the four individual walls were constructed. Every CMU cell in all four walls was reinforced vertically with a 13 mm (No.4) Grade 60 reinforcing bar. Grout was placed and vibrated using a 19 mm (¾ inch) mechanical vibrator. The entire grouted assembly was cured in ambient conditions for 28 days prior to initiation of impact testing.

The five wall assemblies without openings differed in the types of concrete masonry units used and/or the grout strength used. These differences are fully described in Table 2. Three of the walls used normal weight concrete masonry units (with a concrete density of approximately 2,082 kg/m^3 [130 pcf]), and the fourth used lightweight units (with a concrete density of 1,450 kg/m^3 [90.5 pcf]). A fifth wall was tested with a typical window frame.

Table 2 - Concrete Masonry Wall Assemblies

Wall #	Description [a]	Average Compressive Strength, MPa (psi):		
		Units	Masonry	Grout
1	NW (2,090 kg/m^3, 130.3 pcf), low strength CMU, low strength grout	19.65 (2,850)	16.82 (2,440)	27.85 (4,040)
2	NW (2,110 kg/m^3, 131.6 pcf), high strength CMU, low strength grout	33.23 (4,820)	24.40 (3,540)	23.71 (3,440)
3	NW (2,110 kg/m^3, 131.6 pcf), high strength CMU, high strength grout	33.23 (4,820)	30.27 (4,390)	35.99 (5,220)
4	LW (1,450 kg/m^3, 90.5 pcf), CMU, low strength grout	17.99 (2,610)	17.99 (2,610)	19.85 (2,880)
5	MW (1,720 kg/m^3, 107.3 pcf), CMU, wall with window opening	N/A	N/A	N/A

[a] CMU = concrete masonry unit; NW = normal weight; LW = lightweight per ASTM C 90; mortar used conformed to ASTM C 270 Masonry Cement Type S

When testing the walls without openings, the impacts were applied to the intersection of a bed and head joint at the midpoint of the wall. This location was chosen to be the predicted weak point of the wall assembly. Therefore, using the testing ram, a series of strikes were set against the target area and each strike was within $\pm$ 51 mm (2 in.) horizontally and vertically from the designated target area.

For the panel with the typical prison window frame, the window frame was manufactured to meet *Guide Specifications for Detention Security Hollow Metal Doors and Frames*, ANSI/HMMA 863 [4] as required by ASTM 2322. The nominal dimensions of the frame were 356 mm wide, 965 mm high, with a jamb width of 222 mm (14 x 38 x 8 ¾ in). The window frame was constructed of 6.4 mm (¼ in) thick steel. The frame came equipped with masonry anchors that accommodated the vertical reinforcing bars in the masonry and then were attached to the window frame. Once installed, the hollow area at the jamb was grouted solid. The intent of

this impact testing was to check the integrity of the frame-to-masonry connection by striking at a corner of the window frame. Figure 3 shows the prison impact test walls. Figure 4 shows a detail of the window frame.

Figure 3 – Prison Impact Test Walls

Figure 4 – Detail of Window Frame

RESULTS

For the walls without the window opening, a series of strikes using the testing ram were set against the target area and each strike was within ± 51 mm (2 inches) horizontally and vertically from the designated target area. A target area was determined to be a head-bed joint intersection, representing a weak intersection of the wall assembly.

Starting with the blunt impactor, the target area was hit with a series of 50 blows. The sharp impactor was used for the next series of 50 blows and the blunt and sharp impactors were subsequently alternated in 50 blow increments until an opening large enough to achieve forcible egress was produced. Figure 5 shows the target area and the amount of damage after 50 blows. All wall assemblies showed similar damage after 50 blows.

Figure 5 – Test Wall Assembly after 50 Blows

As noted previously, ASTM F 2322 contains security grades for fixed barriers. Grade #1, the most secure, calls for the wall assembly to withstand 600 blows from the blunt and sharp impactor applied in sequences of 50 blows each. This blow count is also equated to a representative barrier duration time of 60 minutes. Walls #1 through #4 were able to withstand the 600 blows and therefore would be designated as a Grade 1 wall in accordance with the ASTM F 2322. Additionally, the rear of each assembly was monitored after each sequence of 50 blows and no damage, included minor cracks, was observed during the 600 blows. Figure 6 shows typical damage after 600 blows of the wall assembly, and Figure 7 the undamaged backside of the wall.

Figure 6 – Typical Wall Condition After 600 Blows – Front Side

Figure 7 – Typical Wall Condition After 600 Blows – Rear Side

Two of the wall assemblies were taken to failure until a forcible breach was observed. A wall constructed of normal weight concrete masonry units was observed to withstand 1,134 blows. Using the criteria in ASTM F 2322, this wall assembly would have a rating of approximately 2 hours (1.89 hours). One wall constructed with lightweight units allowed a breach after 924 blows, which equates to a security rating of approximately 1 ½ hours (1.54 hours). A typical breach is shown in Figure 8.

Figure 8 - Typical Breach Failure

The impacts for the 203 mm (8 inch) CMU wall/window frame connection were applied to the lower right hand corner of the window frame. This location was chosen based on guidance from ASTM F 2322. As with the other testing, the blunt and sharp impactors were alternated in 50 blow increments, with each strike landing within $\pm$ 51 mm (2 inches) horizontally and vertically from the designated target area.

The window frame connection withstood 935 blows from the impactor, exceeding the highest rating of 600 blows found in ASTM F 2322. The testing was stopped after 935 blows because

the ram apparatus chain connection became disconnected. The frame damage at 935 blows is shown in the Figure 9.

Figure 9- Close-up of Window Frame Damage at 935 Blows

CONCLUSION

Concrete masonry wall specimens were tested using a procedure that simulates attack by a sledgehammer and by a firefighter's axe. This testing is used to model a physical attack by inmates at a correctional facility where a security personnel response has not yet occurred. The test procedure and security requirements are contained in ASTM F2322. The concrete masonry wall specimens in this research were built using solid grouted construction with 13 mm (No.4) reinforcing bars in every cell.

Five concrete masonry wall assemblies were tested [1, 2] and are described in Table 3. All five concrete masonry walls were able to withstand 600 blows and therefore achieve the Grade 1 rating in accordance with ASTM F 2322. Additionally, the rear side of each wall assembly was monitored after each sequence of 50 blows and no penetration or damage, including minor cracks, was observed during the 600 blows.

Table 3 – 203 mm (8 in) Concrete Masonry Wall Test Specimens[a]

Wall #	Description	Average Compressive Strength, MPa (psi):			Number of Blows:	Security Grade:	Representative Barrier Duration Time, Min:
		Units	Masonry	Grout			
1	NW (2,090 kg/m^3, 130.3 pcf), low strength CMU, low strength grout	19.65 (2,850)	16.82 (2,440)	27.85 (4,040)	1,134[b]	1	113[d]
2	NW (2,110 kg/m^3, 131.6 pcf), high strength CMU, low strength grout	33.23 (4,820)	24.40 (3,540)	23.71 (3,440)	600[c]	1	60
3	NW (2,110 kg/m^3, 131.6 pcf), high strength CMU, high strength grout	33.23 (4,820)	30.27 (4,390)	35.99 (5,220)	600[c]	1	60
4	LW (1,450 kg/m^3, 90.5 pcf), CMU, low strength grout	17.99 (2,610)	17.99 (2,610)	19.85 (2,880)	924[b]	1	92[d]
5	MW (1,720 kg/m^3, 107.3 pcf), CMU wall with window opening[a]	N/A	N/A	N/A	935[f]	1	93[d]

[a] CMU = concrete masonry unit; NW = normal weight; LW = lightweight per ASTM C 90 [3]; mortar used conformed to ASTM C 270 Masonry Cement Type S [4]
[b] wall was taken to failure
[c] wall was not taken to failure, testing was terminated at 600 blows
[d] extrapolated from Table 1
[e] phase 2 testing, wall panel with window opening [2]
[f] window frame was not taken to failure, testing was terminated at 935 blows

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