Flexural Testing of NRG Concrete Masonry Units

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Northfield Block Co.

Research Conducted by:

NATIONAL CONCRETE MASONRY ASSOCIATION
RESEARCH & DEVELOPMENT LABORATORY

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RESEARCH AND DEVELOPMENT LABORATORY

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EXECUTIVE SUMMARY

Research was conducted at the NCMA Research and Development Laboratory to investigate the structural performance of NRG block manufactured with rigid foam-in-place insulation subjected to flexural out-of-plane loading. The goal of the research was to ascertain the contribution, if any, of the rigid insulation on the measured flexural strength and performance of the tested assemblies.

Six concrete masonry panels were constructed using 12-inch (305 mm) nominal NRG units. Each specimen was reinforced with one No. 4 (M#13) reinforcing bars at a spacing of 40 inches (1,016 mm). To evaluate the influence the effective depth of the reinforcement has on the strength and performance of the specimens, three panels were tested such that the effective depth to the reinforcement was nominally 3 inches (76 mm) while the remaining three panels were tested with a nominal effective depth of 8.625 inches (219 mm).

The results show that the NRG panels tested perform similarly to conventional 12-inch (305 mm) concrete masonry assemblies in flexure for both strength and failure mode. Based upon these results, the flexural strength of the NRG system can be estimated using conventional code-prescribed design models assuming the full cross-section of the assembly was structurally resisting loads. This conclusion appears valid only if the compressive strength of the masonry assembly is based on prisms constructed using the full unit cross-section (that is, with the outside face shell and insulation).

Based on the results of this research, preliminary conclusions would support the flexural design of the NRG system as a full 12-inch (305 mm) wide assembly (including the outside veneer and insulation) if the masonry design flexural strength was based on the full unit cross-section (that is, prisms were constructed and tested with the outside face shell veneer and insulation). Alternatively, if the solid masonry ‘back-up’ portion of the assembly is used for determining the compressive strength (that is, prisms were constructed and tested without the outside veneer face shell and insulation), then an assessment of the assembly flexural strength should be determined using the reduced ‘back-up’ width of the unit.

The compressive strength and shear strength of the NRG assembly was not directly evaluated in this research project and as such, any conclusions on these properties would be speculative. It would reason, however, that the solid masonry ‘back-up’ portion of the NRG unit could reasonably be assumed to resist compressive and shear loads. Further research and testing would be needed to more accurately quantify the shear and compressive strength properties of assemblies constructed with NRG units assuming that the full cross-section of the unit was assumed to be effective in resisting applied design loads.

Flexural Testing of NRG Concrete Masonry Units

1.0 INTRODUCTION

This report describes the results of out-of-plane flexural testing performed on assemblies constructed using proprietary concrete masonry units, NRG block, manufactured with a foam-in-place insulation. The Research and Development Laboratory of the National Concrete Masonry Association conducted the testing and analysis.

Six wall assemblies, consisting of two sets of three panels, were constructed from lightweight NRG concrete masonry units and tested for their resistance to out-of-plane flexure under third-point loading. The nominal thickness of all the concrete masonry units was 12 inches (305 mm), which included a nominal 2-inch (51 mm) rigid foam-in-place insulation between two thermally isolated concrete masonry segments. The out-of-plane flexural testing was conducted in accordance with ASTM E 72, *Standard Test Methods of Conducting Strength Tests of Panels for Building Construction* (Ref. 1) through the application of third-point loading as illustrated in Figure 1. The third point loading configuration creates a region of relatively constant bending moment over the mid-span of specimen between the points of applied load. The resulting constant moment region spread over a larger area helps to reduce anomalous results stemming from isolated or discrete assembly properties.

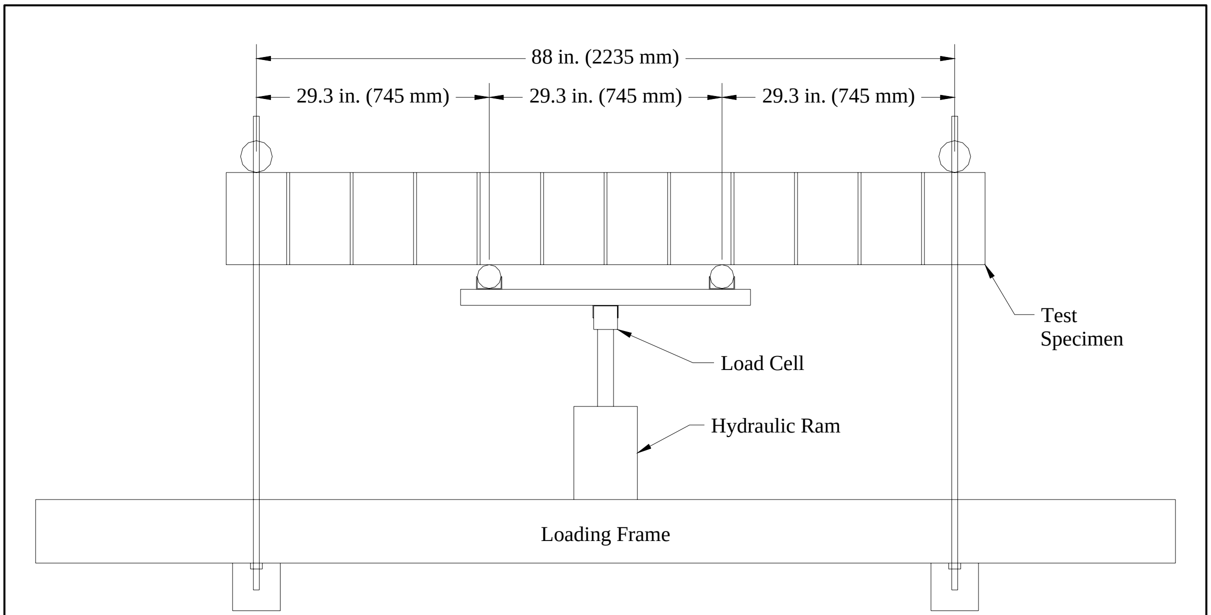

Figure 1 – Typical Loading Configuration

2.0 MATERIALS

2.1 NRG Concrete Masonry Units

The concrete masonry units used in this research program are a unique proprietary configuration consisting of two thermally isolated sections of concrete masonry bonded together by rigid foam-in-place insulation as shown in Figure 2. Commercially, these units are known as NRG block.

Due to their configuration, ASTM C 140, *Standard Test Methods of Sampling and Testing Concrete Masonry Units and Related Units* (Ref. 2) requires that compression coupons be removed from the face shells of the units for measuring the compressive strength of the concrete used to manufacture the units. Further, due to the presence of the foam insulation, which would influence the tested properties, coupons were also saw-cut from the full-size specimen to determine the absorption and density characteristics of the concrete within the units. A summary of the unit testing results is provided in Table 1. A full report of the unit testing results is provided in Appendix A. As tested, the units met the minimum compressive strength requirement for concrete masonry units according to ASTM C 90, *Standard Specification for Loadbearing Concrete Masonry Units* (Ref. 3). Due to the unique configuration of the units, specifically the presence of the rigid insulation, the minimum web thicknesses and equivalent web thicknesses were not determined.

Table 1—Physical Properties of Coupons from Concrete Masonry Units (Average of Three Units)

Density, lb/ft^3 (kg/m^3)	79.7 (1,277)
Absorption, lb/ft^3 (kg/m^3)	11.8 (189)
Net compressive strength of unit, lb/in.^{2} (MPa)	4,220 (29.1)

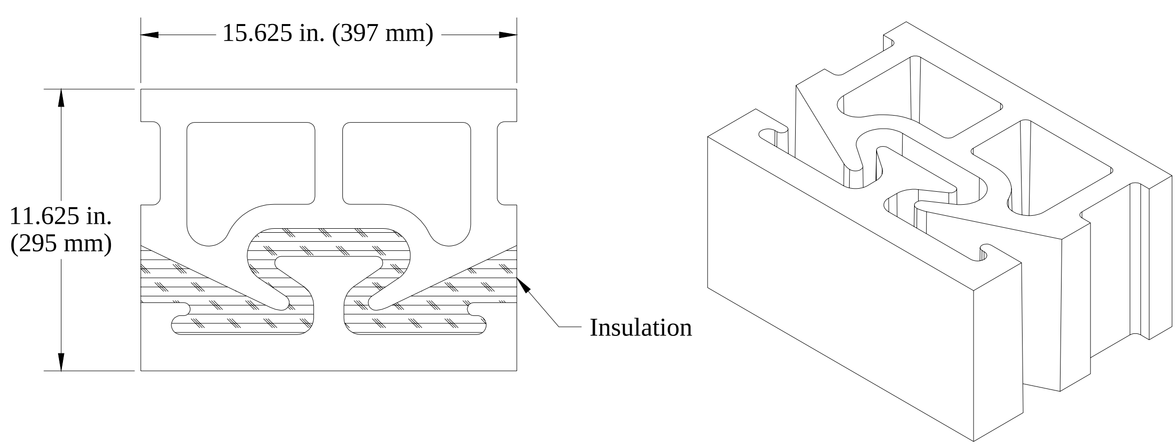

Figure 2 – NRG Block Cross-Section and Isometric View

Based upon the dimensions of the full-size units as tested in this project, the net cross-sectional properties of the NRG units are summarized in Table 2. These values may be used for the purposes of designing and proportioning ungrouted masonry assemblies constructed with NRG block. Grouted section properties will vary based on spacing between grouted cells.

Table 2 – Net Cross-Sectional Properties[A]

Cross-Sectional Property		Per Unit	Per Unit Length
12 in. (305 mm) NRG Units	Area	95.7 in.^{2} (61,740 mm^2)	73.5 in.^{2}/ft (155,580 mm^2/m)
	Moment of Inertia About Weak Axis	1,483 in.^{4} (61,730 cm^4)	1,139 in.^{4}/ft (155,540 cm^4/m)
Conventional 12 in. (305 mm) Concrete Masonry Units[B]	Area	76.4 in.^{2} (49,290 mm^2)	58.7 in.^{2}/ft (124,250 mm^2/m)
	Moment of Inertia About Weak Axis	1,398 in.^{4} (58,190 cm^4)	1,074 in.^{4}/ft (146,660 cm^4/m)

[A]Based upon the full, net cross-sectional area of the unit. For design application, the actual net cross-sectional properties will be a function of mortar bedding area (face shell or full) and percentage of grouting, if applicable.
[B]Based upon 1.5 inch (38.1 mm) face shell thickness units.

2.2 Mortar

Type S masonry cement mortar supplied by the laboratory was used in the construction of all test specimens. The mortar was batched in accordance to the proportion specification of ASTM C 270, *Standard Specification for Mortar for Unit Masonry* (Ref. 4). The average compressive strength of the mortar when tested in accordance with ASTM C 780, *Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry* (Ref. 5), was 2,590 psi (17.9 MPa) following 28 days of curing. A detailed mortar test report is provided in Appendix B.

2.3 Grout

Grout used to construct the test specimens conformed to ASTM C 476, *Standard Specification for Grout for Masonry* (Ref. 6). The average compressive strength of the grout tested in accordance with ASTM C 1019, *Standard Test Method for Sampling and Testing Grout* (Ref. 7), was 2,670 psi (18.4 MPa). The grout was allowed to cure an equal amount as the panel specimens prior to testing in compression. Detailed grout test reports are provided in Appendix C.

2.4 Prisms

Due to the unique configuration of the units, several different prism configurations were constructed and tested in compression to evaluate the influence of the unit shape on the measured compressive strength of assemblies constructed with such units. These tests could also serve as baseline comparisons for field quality control measures to evaluate the compressive strength of prisms constructed using different methods. Detailed results for each prism set are provided in Appendix D.

Five different prism sets were constructed and tested as follows:

- Full-size units (including insulation), hollow, stack bond, face shell mortar bedding only.
- Full-size units (including insulation), hollow, stack bond, full mortar bedding
- Full-size units (including insulation), grouted, stack bond, full mortar bedding
- Reduced size units (without insulation), hollow, stack bond, full mortar bedding
- Reduced size units (without insulation), grouted, stack bond, full mortar bedding (See Figure 3.)

Table 3 summarizes the gross area and net area compressive strength results from each of the five different prism sets.

Table 3 – Compressive Strength of Masonry Prisms

Prism Configuration	Prism Description	Gross Area Compressive Strength, lb/in.^{2} (MPa)	Net Area Compressive Strength, lb/in.^{2} (MPa)
Full-Size Prisms with Insulation Intact	Hollow Prism with Face Shell Mortar Bedding Only	510 (3.5)	2,050 (14.1)
	Hollow Prism with Full Mortar Bedding	1,040 (7.2)	1,980 (13.7)
	Solid Grouted	1,640 (11.3)	2,150 (14.8)
Reduced Size Prisms with Insulation and Exposed Face Shell Removed	Hollow Prism with Full Mortar Bedding	1,970 (13.6)	3,140 (21.6)
	Solid Grouted	2,970 (20.5)	2,970 (20.5)

Figure 3 – Reduced Size Solid Grouted NRG Prisms

As seen in Table 3, the net compressive strength of the prisms containing insulation was consistent for each mortar bedding area and grouting configuration. Likewise, the net compressive strength of the reduced length prisms without insulation were equally consistent, but approximately one-third higher than the corresponding prisms containing insulation. This observation would likely mean that if the full cross-section of the NRG unit (including the insulation and outside veneer face shell) were to be used in determining the strength of the assembly, the corresponding masonry prisms should likewise be constructed and tested with the insulation and face shell. Alternatively, if the solid masonry 'back-up' portion of the assembly is used for determining the structural strength (that is, neglecting the outside veneer face shell and insulation), then an accurate assessment of the assembly compressive strength could be determined using only the reduced size prisms.

3.0 CONSTRUCTION AND CURING OF WALL PANELS

Two sets of three flexural specimens were constructed as part of this research investigation. All six wall assemblies were constructed using good techniques as defined in ACI 530.1/ASCE 6/TMS 602 *Specification for Masonry Structures* (Ref. 8). The overall nominal dimensions of the finished wall assemblies were 96 inches (2,438 mm) in height, 48 inches (1,219 mm) in length, and 12 inches (305 mm) in thickness. Each wall assembly was constructed using a running bond pattern. The concrete masonry units were laid using face shell bedding except at the ends of each panel where mortar was also placed on the end webs of the units and around the cells designated to be reinforced and grouted as shown in Figure 4. All mortar joints were struck and tooled concave when the mortar became thumbprint hard. One No. 4 (M# 13) reinforcing bar was placed in the end cells of each panel to simulate a reinforcement spacing of 40 inches (1,016 mm). Additional reinforcement was placed in the top and bottom courses to provide development for the vertical reinforcement and facilitate moving and testing the panels in the laboratory. This reinforcement was intentionally located away from the mid-span of the specimens to ensure that its presence did not influence the measured strength and performance of the panels. A typical wall elevation is shown in Figure 5.

Figure 4 – Wall Construction

To provide a solid bearing surface to apply load to the specimens, the top and bottom courses were constructed with conventional 12 inch (305 mm) concrete masonry units, which were grouted solid. Likewise, because one set of specimens (three panels) were to be loaded by applying load directly to the insulated side of the assemblies, the NRG units in the walls of Panel Set A were replaced with solid grouted conventional 12 inch (305 mm) units in those courses where loading was applied as illustrated in Figure 6. This configuration is not felt to have a significant impact on the measured flexural strength of the assemblies.

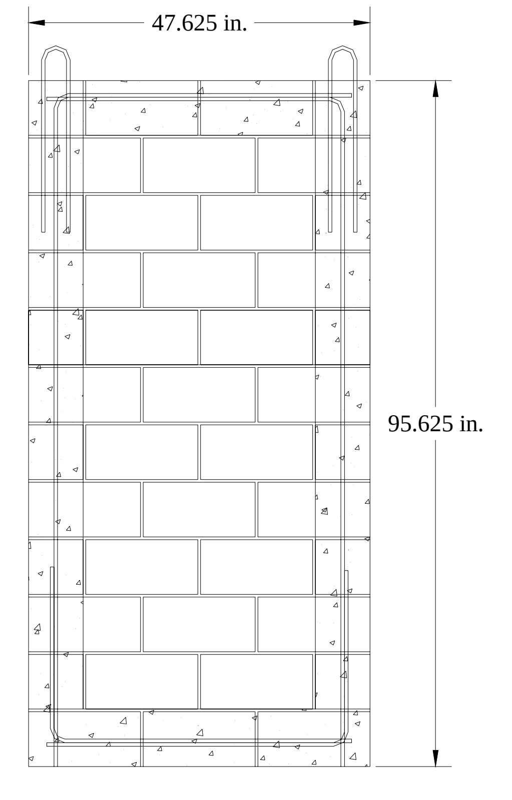

Figure 5 – Typical Wall Elevation

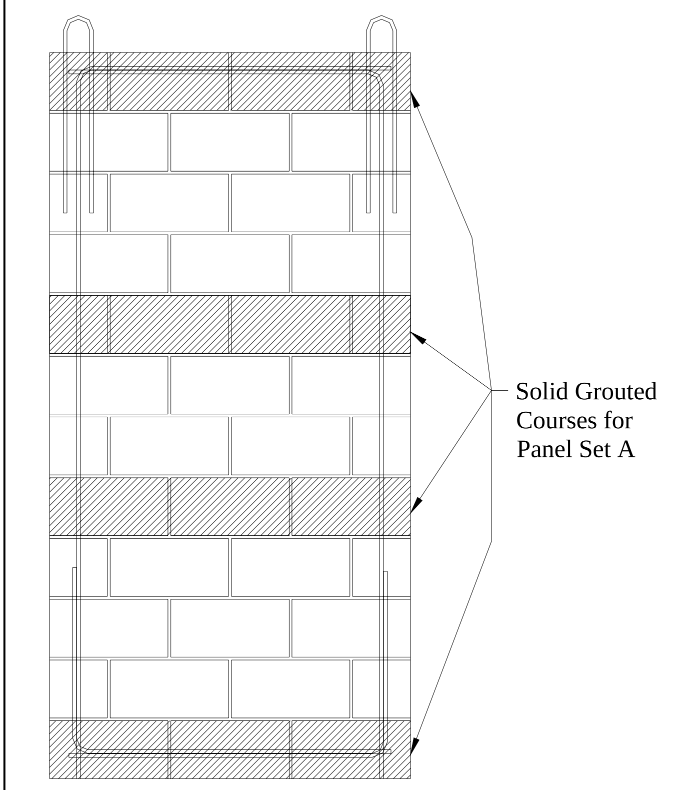

Figure 6 – Solid Grouted Support Courses

Exterior above-grade walls are subjected to both positive and negative wind pressures. Further, when the cross-section of the wall assembly is not symmetrical due to unit configuration or reinforcement placement, the negative and positive flexural strength would be expected to differ. To evaluate the impact of such alternating loads, the two sets of panels were loaded in opposite directions. For each panel, the reinforcement was placed in the same location within the cells of the units. For panel Set A, the specimens were loaded in flexure such that the reinforcement was closer to the tension side of the panel, providing an effective depth to the reinforcement of nominally 8.625 inches (219 mm). For Panel Set B, the specimens were loaded in the opposite direction such that the reinforcement was closer to the compression side of the panel, providing an effective depth to the reinforcement of 3 inches (76 mm). A cross-section of a typical flexural specimen is shown in Figure 7. The result of this alternating loading direction and the influence of the effective depth of the reinforcement becomes clear in the measured capacity of the specimens as discussed later in this report.

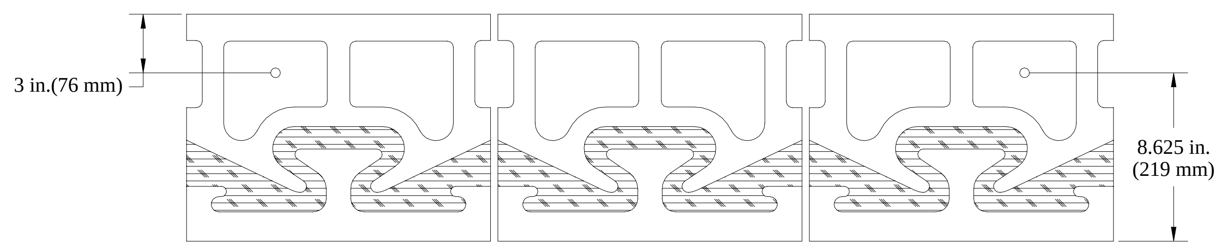

Figure 7 – Effective Depth to Reinforcement for Panel Set A (8.625 in.) and B (3 in.)

4.0 TEST PROCEDURES AND RESULTS

All panels were subjected to third-point loading in accordance with ASTM E 72 (Ref. 1). A general schematic of the loading configuration is illustrated in Figure 1. To provide a quantitative assessment of the test specimens' performance under load, mid-span deflection was measured on each side of each panel. The two deflection measurements for each panel were in turn averaged to minimize the effect of panel warping during testing.

4.1 Design Strength in Accordance with Current Code Requirements

For comparison purposes, the strength of conventional masonry assemblies is evaluated for the defined variables (masonry strength, reinforcement size and spacing, and loading conditions) used in the construction and testing of the NRG panels. Based upon the 2005 MSJC *Building Code Requirements for Masonry Structures* (Ref. 9), the following design equations are used to determine the nominal flexural strength of a masonry assemblage using the strength design requirements:

In accordance with the strength design provisions of the 2005 MSJC Code (Ref. 9), the nominal flexural strength of a masonry assembly is determined in accordance with Equation 1.

$$M_n = A_s f_y \left(d - a/2\right) \quad \text{Eqn. 1}$$

Where:
M_n = nominal flexural strength of assembly, in-lb (mm-kN)
A_s = nominal area of reinforcement, in.^{2} (mm^2)
f_y = nominal yield strength of reinforcement, lb/in.^{2} (MPa)
d = effective depth to reinforcement, in. (mm)
b = width of section, in. (mm)
f'_m = specified compressive strength of masonry, lb/in.^{2} (MPa)
a = depth of equivalent compression zone as defined by Equation 2, in. (mm)

$$a = \frac{A_s f_y}{0.8 f'_m b} \quad \text{Eqn. 2}$$

Applying the following test variables used in this research project:

A_s = 0.2 in.^{2} (129 mm^2)
f_y = 60,000 lb/in.^{2} (414 MPa)
b = 40 in. (1,016 mm)
f'_m = 2,150 lb/in.^{2} (14.8 MPa) – The specified masonry compressive strength was assumed equal to the compressive strength of the solid grouted prisms containing insulation and the outside veneer face shell. Since the difference in the measured compressive strength of the prisms containing the insulation was minor, the choice of the composite masonry compressive strength (including insulation) would not affect the calculated assembly flexural strengths significantly.

Then, for an effective depth to the reinforcement (d) equal to 8.625 inches (219 mm), the nominal flexural strength (M_n) is:
M_n = 30,730 in-lb/ft (11,480 mm-kN/m)

For an effective depth to the reinforcement (d) equal to 3.0 inches (76 mm), the nominal flexural strength (M_n) is:
M_n = 10,480 in-lb/ft (3,910 mm-kN/m)

To determine the design strength, the nominal strength is multiplied by a strength reduction factor (ϕ) equal to 0.90 per the requirements of the 2005 MSJC *Building Code Requirements for Masonry Structures* (Ref. 9). Hence:

For an effective depth to the reinforcement (d) equal to 8.625 inches (219 mm), the design flexural strength (ϕM_n) is:
ϕM_n = 27,660 in-lb/ft (10,330 mm-kN/m)

For an effective depth to the reinforcement (d) equal to 3.0 inches (76 mm), the design flexural strength (ϕM_n) is:
ϕM_n = 9,430 in-lb/ft (3,520 mm-kN/m)

4.2 Tested Strength of NRG Panels

Each of the six NRG test panels were subjected to third-point flexural loading in accordance with ASTM E 72 as previously described. Table 4 provides a summary of the measured wall weights, yield loads, and maximum loads for each specimen. For all specimens, except Panel A-3, the failure mode was due to yielding of the reinforcement resulting in excessive deflection of the panel and loss of load-carrying capacity. For Panel A-3, failure resulted from one of the vertical reinforcing bars losing its anchorage from the end bearing course and ultimately pulling-out of the specimen. The load-deflection curves for each panel set are shown in Figures 7 and 8. Note that due to equipment failure, the deflection history and maximum displacement of Panel B-1 was not determined.

Table 4 – Summary of Tested Properties			
Specimen	**Wall Weight, lb (kN)[A]**	**Ram Load at Yield, lb (kN)[B, C]**	**Maximum Ram Load, lb (kN)[B]**
Panel A-1	3,300 (14.7)	14,400 (64.1)	19,390 (86.3)
Panel A-2	3,400 (15.1)	16,500 (73.4)	20,490 (91.1)
Panel A-3	3,000 (13.3)	12,800 (56.9)	16,060 (71.4)[D]
Panel B-1	NA[E]	NA[E]	8,700 (38.7)
Panel B-2	2,600 (11.6)	6,600 (29.4)	8,730 (38.8)
Panel B-3	2,500 (11.1)	7,300 (32.5)	9,890 (44.0)

[A]The wall weight is the total weight of each specimen as measured by the hydraulic ram.
[B]The measured load is the load applied by the hydraulic ram.
[C]The yield load was estimated as the point in the load-deflection plot where the load-deflection curve changes slope.
[D]The failure mode was the result of reinforcement pull-out.
[E]Data not available due to equipment malfunction.

Due to the loading configuration used, the specimens were subjected to a combined uniform load from the self-weight of the specimen and the third-point load applied through the hydraulic ram. Although not significant, the self-weight of the panels was measurable and was therefore accounted for in determining the maximum flexural capacity of the specimens in the tested configurations. The equation for determining the maximum bending moment (flexural strength) each test panel was subjected to was derived using standard engineering mechanics and is shown in Equation 3.

$$M_{total} = (1.222)(P_{\max} - P_w) + (0.374)(P_w) \qquad \text{Eqn. 3}$$

Where:
M_{total} = total bending moment, ft-lb (m-kN)
P_W = total wall weight, lb (kN)
P_{max} = total applied load to specimen, lb (kN)

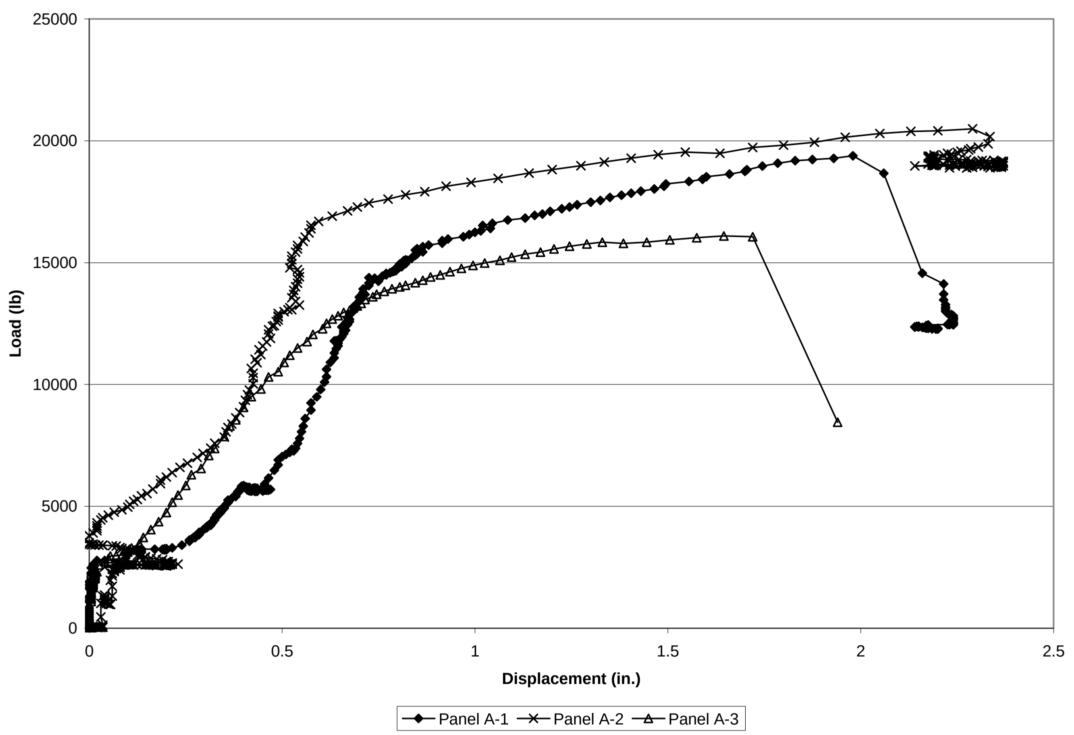

Figure 7 – Load-Deflection Curves for Panel Set A

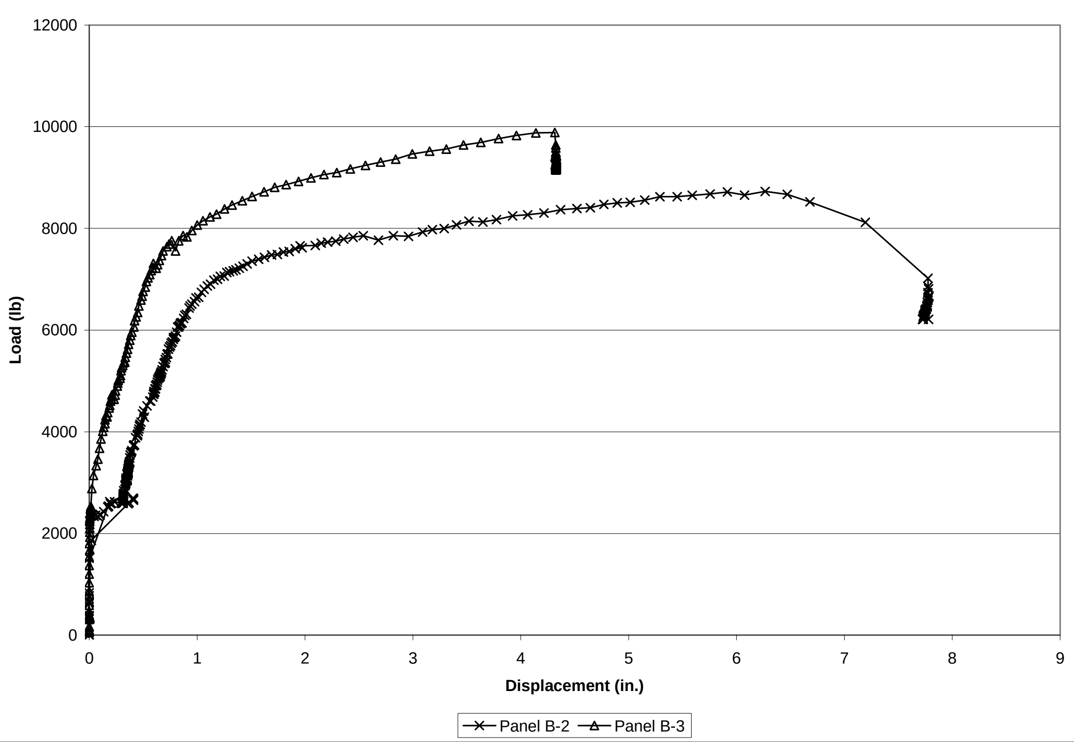

Figure 8 – Load-Deflection Curves for Panel Set B

Using Equation 3, the total bending moment (for the entire specimen) at yield and the maximum bending moment for each test specimen are summarized in Table 5.

Table 5 – Measured Flexural Strength of NRG Panels

Specimen	Bending Moment at Yield, ft-lb (mm-kN)	Maximum Bending Moment, ft-lb (mm-kN)
Panel A-1	14,800 (20,060)	20,900 (28,330)
Panel A-2	17,280 (23,430)	22,160 (30,040)
Panel A-3	13,100 (17,760)	17,080 (23,160)
Panel B-1	NA	8,510 (11,540)
Panel B-2	5,860 (7,940)	8,460 (11,470)
Panel B-3	6,800 (9,220)	9,970 (13,510)

For comparison to the design flexural strengths determined earlier, the tested flexural strengths shown in Table 4 are converted to a per unit length value as shown in Table 6.

<table>
<tr><th colspan="4">Table 6 – Comparison to Codified Design Flexural Strength</th></tr>
<tr><th>Specimen</th><th>Nominal Flexural Strength, ft-lb/ft (mm-kN/m)[A, B]</th><th>Measured Bending Moment at Yield, ft-lb/ft (mm-kN/m)[B]</th><th>Measured Maximum Bending Moment, ft-lb/ft (mm-kN/m)</th></tr>
<tr><td>Panel A-1</td><td rowspan="4">2,560 (11,480)</td><td>3,700 (16,460)</td><td>5,220 (23,220)</td></tr>
<tr><td>Panel A-2</td><td>4,320 (19,220)</td><td>5,540 (24,640)</td></tr>
<tr><td>Panel A-3</td><td>3,270 (14,550)</td><td>4,270 (18,990)</td></tr>
<tr><td>Average</td><td>3,760 (16,730)</td><td>5,010 (22,290)</td></tr>
<tr><td>Panel B-1</td><td rowspan="4">870 (3,910)</td><td>NA</td><td>2,130 (9,470)</td></tr>
<tr><td>Panel B-2</td><td>1,470 (6,540)</td><td>2,120 (9,430)</td></tr>
<tr><td>Panel B-3</td><td>1,700 (7,560)</td><td>2,490 (11,080)</td></tr>
<tr><td>Average</td><td>1,590 (7,070)</td><td>2,250 (10,010)</td></tr>
</table>

[A]Based upon Equation 1 for the material properties used to construct the test specimens.
[B]For comparison purposes, the design strength should be compared to the measured bending moment at yield as these values would be the controlling limit state for design.

Using the average flexural strength at yield for the tested NRG panels, Table 7 was developed to conceptually illustrate the maximum height for an NRG wall system using a prescribed service-level load applied uniformly over the height of the wall. While this table is based solely on the measured flexural yield strength as determined in this research project and does not take into consideration all the design variables required by current building codes (including appropriate safety factors), it does illustrate the relative effectiveness of the NRG system in resisting simulated applied loads.

Table 7 – Maximum Wall Heights for a Given Service-Level Pressure[A]		
Uniform Pressure lb/ft^2 (kN/m^2)	Maximum Wall Height for Panel Set A, ft (m)	Maximum Wall Height for Panel Set B, ft (m)
5 (0.24)	77.6 (23.6)	50.4 (15.4)
10 (0.47)	54.8 (16.7)	35.7 (10.9)
15 (0.72)	44.8 (13.6)	29.1 (8.9)
20 (0.96)	38.8 (11.8)	25.2 (7.7)
25 (1.20)	34.7 (10.6)	22.6 (6.9)
30 (1.44)	31.7 (9.7)	20.6 (6.3)
35 (1.68)	29.3 (8.9)	19.1 (5.8)
40 (1.92)	27.4 (8.4)	17.8 (5.4)
45 (2.15)	25.9 (7.9)	16.8 (5.1)

[A]These values are based upon the variables tested in this research project, including material strength, reinforcement spacing and location, and unit cross-sectional properties and may not take into consideration all project-specific design variables.

5.0—CONCLUSIONS

Due to the measured differences in the tested masonry prism compressive strength between the full-size units (containing both the outside veneer face shell and insulation) relative to the prisms constructed and tested without the outside veneer face shell and insulation, if the full assembly cross-section were used in estimating an element strength, the assembly compressive strength should be correspondingly based on the prism compressive strength using the full units (including the outside face shell and insulation). Alternatively, if the solid masonry 'back-up' portion of the assembly is used for determining the structural strength (that is, neglecting the outside veneer face shell and insulation), then a more realistic estimate of the element strength would likely be determined by using prisms constructed solely of the masonry 'back-up' without the outside face shell and insulation.

Based upon the testing of the NRG system using rigid foam-in-place insulation, the flexural strength of this system can conservatively be estimated using conventional code-prescribed design models assuming the full cross-section of the assembly was effective in structurally resisting loads if the masonry design flexural strength was based on the full unit cross-section (that is, prisms were constructed and tested with the outside face shell veneer and insulation). Alternatively, if the solid masonry 'back-up' portion of the assembly is used for determining the compressive strength (that is, prisms were constructed and tested without the outside veneer face shell and insulation), then an assessment of the assembly flexural strength could be determined using reduced 'back-up' width of the unit. Additional flexural strength in the NRG system could be realized with the inclusion of additional flexural reinforcement.

The code-prescribed design models would be applicable for common masonry applications, approved material properties, and bond patterns (including both running bond and stack bond). This research project focused solely on the performance of the NRG system in simple flexure only. The compressive strength and shear strength of the NRG assembly was not directly assessed in this research project and as such, and conclusions on these properties would be speculative. It would reason, however, that the solid masonry 'back-up' portion of the NRG unit could reasonably be assumed to resist such applied compressive and shear loads. Further research and testing would be needed to more accurately quantify the shear and compressive strength properties of assemblies constructed with NRG units.

References

1. ASTM E 72-05, *Standard Test Methods of Conducting Strength Tests of Panels for Building Construction*, ASTM International, West Conshohocken, PA, 2005.
2. ASTM C 140-05a, *Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units*, ASTM International, West Conshohocken, PA, 2005.
3. ASTM C 90-05a, *Standard Specification for Loadbearing Concrete Masonry Units*, ASTM International, West Conshohocken, PA, 2005.
4. ASTM C 270-05a, *Standard Specification for Mortar for Unit Masonry*, ASTM International, West Conshohocken, PA, 2005.
5. ASTM C 780-05, *Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry*, ASTM International, West Conshohocken, PA, 2005.
6. ASTM C 476-02, *Standard Specification for Grout for Masonry*, ASTM International, West Conshohocken, PA, 2002.
7. ASTM C 1019-05, *Standard Test Method for Sampling and Testing Grout*, ASTM International, West Conshohocken, PA, 2005.
8. ACI 530.1-05/ASCE 6-05/TMS 602-05 *Specification for Masonry Structures*, Reported by the Masonry Standards Joint Committee, The Masonry Society, Boulder, CO, 2005.
9. ACI 530-05/ASCE 5-05/TMS 402-05 *Building Code Requirements for Masonry Structures*, Reported by the Masonry Standards Joint Committee, The Masonry Society, Boulder, CO, 2005.

Appendix A – Concrete Masonry Unit Test Report

ASTM C 140 Test Report
From Saw-Cut Specimens

Job No.: 05-520
Report Date: 2/14/2006

Client: Oldcastle Architectural/Northfield Block
Address: One Hunt Court
Mundelein, IL 60060

Testing Agency: National Concrete Masonry Association
Research and Development Laboratory
Address: 13750 Sunrise Valley Drive
Herndon, Virginia 20171-4662

Unit Specification: ASTM C90-05

Sampling Party: Oldcastle Architectural/Northfield Block

Unit Designation/Description:
NRG Insulated Block
Compression Coupon from Face Shell

Note: Due to the unique configuration of the units, coupon specimens were saw-cut from full-size units in accordance with the requirements of ASTM C 140 to determine unit compressive strength, absorption, and density characteristics.

Summary of Test Results

Physical Property	Required Values	Tested Values[1]	
Net Compressive Strength	1900 min	4220	psi
Gross Compressive Strength	****	4220	psi
Density	****	79.7	pcf
Absorption	18 max	11.8	pcf

Physical Property	Required Values	Tested Values	
Net Cross-Sectional Area	****	9.3	in^2

[1] Reported values are based on the properties of saw cut absorption and compression specimens.

Individual Unit Test Results

Properties of Saw-Cut Compression Specimens	Received Wt, W_R	Avg Width	Avg Height	Avg Length	Cross-Sectional Area Gross	Cross-Sectional Area Net	Max. Load	Compressive Strength Gross	Compressive Strength Net
	lb	in.	in.	in.	in^2	in^2	lb	psi	psi
Unit #1	1.30	1.53	3.02	6.10	9.30	9.30	36210	3890	3890
Unit #2	1.29	1.53	3.02	6.09	9.31	9.31	39540	4250	4250
Unit #3	1.32	1.53	3.01	6.08	9.30	9.30	42050	4520	4520
Average	1.30	1.53	3.01	6.09	9.30	9.30	39270	4220	4220

Properties of Saw-Cut Absorption Specimens	Received Wt, W_R	Immersed Wt, W_I	Saturated Wt, W_S	Oven-Dry Wt, W_D	Absorp	Density	Net Volume
	lb	lb	lb	lb	pcf	pcf	ft^3
Unit #4	5.06	1.86	5.64	4.78	14.2	78.9	0.0606
Unit #5	5.04	1.73	5.51	4.84	11.2	79.9	0.0605
Unit #6	5.02	1.68	5.47	4.87	10.0	80.2	0.0607
Average	5.04	1.76	5.54	4.83	11.8	79.7	0.0606

Comments: These tested properties meet or exceed the applicable requirements of ASTM C 90-05.

Robert Thomas
Vice President ofEngineering

Appendix B – Mortar Test Results

NCMA Research and Development Laboratory
ASTM C 780
Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry

Job No.: 05-520

Client: Oldcastle Architectural/Northfield Block
Address: One Hunt Court
Mundelein, IL 60060

Corresponding Wall/Specimen: NRG Panels
Mortar Type: S MC

NCMA Lab Aggregate Unit Weight = 80 pcf
Weight of Cement Bag = 75 lb.

Batch Information (C270)

Batch Factor = Agg Wt /(Agg Unit Wt x Agg. Vol. Proportion) = 100 / (80 x 3) = 0.416
Cement Weight = Cmt Prop x Bag Weight x Batch Factor = 1 x 75 x 0.416 = 31.2 lb.

Material	Type/Brand/Source	Volume Proportions	Weight (lb.)
Portland Cement	None		
Lime	None		
Masonry Cement	LAFARGE		31.2
Masonry Sand	Lab C 144		100
Water Added to Mix	Tap Water	Varies	
Admixture	None		
		Total Wt. =	131.2

Mixed By: DL
Date: 2/6/06

2-inch Cube Compressive Strength (C 780 / C 109)

Cube Age: 28 days

Cube #	Cube Wt (g)	Load (lbs)	Cube Strength (psi)
1	263.5	10380	2595
2	261.1	10140	2535
3	261.5	10530	2633
Average	262.0	10350.0	2590

Testing by: DL Date: 2/6/06

Cone Penetration (C 780)

Initial Penetration = 62.0 mm

Tested By: DL
Date: 12/6/05

Robert Thomas
Vice President of Engineering

Appendix C – Grout Test Report

NCMA Research and Development Laboratory
ASTM C 1019-05: Sampling and Testing Grout

Project No.: 05-520
Report Date: 2/14/2006

Client: Oldcastle Architectural/Northfield Block
Address: One Hunt Court
Mundelein, IL 60060

Testing Agency: National Concrete Masonry Association
Research and Development Laboratory
Address: 13750 Sunrise Valley Drive
Herndon VA, 20171-4662

Project /Description: NRG Flexural Testing

Sampling Party: NCMA

Mix Design: Bulk Sack Mix - Set 1

Date Made: 1/27/2006
Date Rec'd: NA
Date Tested: 2/6/2006
Tested By: DL

		Specimen 1	Specimen 2	Specimen 3	Average
Height (in.)	1	7.50	7.40	7.50	
(H = 2W)	2	7.50	7.50	7.50	
	3	7.50	7.40	7.50	
	4	7.60	7.50	7.50	
Average		**7.53**	**7.45**	**7.50**	**7.492**
Width (in.)	1	3.60	3.80	4.00	
(> 3 inches)	2	3.70	3.80	4.00	
	3	3.60	3.90	3.90	
	4	3.70	4.00	3.80	
Average		**3.65**	**3.88**	**3.93**	**3.817**
Weight (lb.)		7.87	8.11	8.70	**8.227**
Plumb (in.)		0.125	0.125	0.125	**0.125**
Plumb (%)		2	2	2	**2**
Compressive Load (lb.)		32450	32700	38700	**34617**
Compressive Strength (psi)		**2436**	**2178**	**2512**	**2380**

Curing Conditions: 2 days in mold
7 days in curing cabinet

Robert Thomas
Vice President of Engineering

NCMA Research and Development Laboratory
ASTM C 1019-05: Sampling and Testing Grout

Project No.: 05-520
Report Date: 2/14/2006

Client: Oldcastle Architectural/Northfield Block
Address: One Hunt Court
Mundelein, IL 60060

Testing Agency: National Concrete Masonry Association
Research and Development Laboratory
Address: 13750 Sunrise Valley Drive
Herndon VA, 20171-4662

Project /Description: NRG Flexural Testing

Sampling Party: NCMA

Mix Design: Laboratory Mix - Set 2

Date Made: 1/31/2006
Date Rec'd: NA
Date Tested: 2/6/2006
Tested By: DL

		Specimen 1	Specimen 2	Specimen 3	Average
Height (in.)	1	7.80	7.60	7.70	
(H = 2W)	2	7.80	7.60	7.70	
	3	7.80	7.60	7.70	
	4	7.80	7.60	7.70	
Average		**7.80**	**7.60**	**7.70**	**7.70**
Width (in.)	1	3.50	3.60	4.00	
(> 3 inches)	2	3.50	3.50	4.00	
	3	3.50	3.50	3.60	
	4	3.50	3.50	3.60	
Average		**3.50**	**3.53**	**3.80**	**3.61**
Weight (lb.)		7.52	7.61	8.59	**7.91**
Plumb (in.)		0.125	0.125	0.125	**0.125**
Plumb (%)		2	2	2	**2**
Compressive Load (lb.)		37990	35910	41110	**38337**
Compressive Strength (psi)		**3101**	**2890**	**2847**	**2950**

Curing Conditions: 2 days in mold
5 days in curing cabinet

Robert Thomas
Vice President of Engineering

Appendix D – Prism Test Reports

ASTM C 1314-03b Test Report:
Constructing and Testing Masonry Prisms Used to Determine Compliance with Specified Compressive Strength of Masonry

Project No.: 05-520-01
Report Date: 02/17/06

Client: Oldcastle Architectural/Northfield Block
Address: One Hunt Court
Mundelein, IL 60060

Testing Lab: National Concrete Masonry Association
Research and Development Laboratory
13750 Sunrise Valley Drive
Herdon VA, 20171-4662

Project Identification: 05-520-01
Prism Identification: 12 x 16 x 16, Hollow, Stack Bond, Concrete Masonry Prism
Face shell mortar bedding only
Specified Compressive Strength of Masonry NA

Prism Details:
Number of Mortar Bed Joints: 1
Number of Masonry Units Used: 2
Date Retrieved from Site: NA
Date Delivered to Lab: NA
Date Tested: 2/6/2006

Masonry Unit Information:
Unit Supplier: Oldcastle Arch
Unit Dimensions: 12 x 8 x 16
Unit Net Area (hollow units): 95.71

Mortar Information
Mortar Supplier / Preparer: NCMA
Mortar Type / Description: S

Grout Information
Grout Supplier / Preparer: NA
Grout Type / Description NA
Grout Slump (ASTM C 143): NA
Method of Consolidation: NA

Compression Test Machine Information
Diameter of Spherical Seat: 10 in.
Required Upper Bearing Plate Thickness: 4.8 in.
Required Lower Bearing Plate Thickness: 1.0 in.
Provided Upper Bearing Plate Thickness: 5.1 in.
Provided Lower Bearing Plate Thickness: 2.5 in.

Tested Prism Properties:

Prism No.	Age at Test (days)	Avg. Width (in.)	Avg. Height (in.)	Avg. Length (in.)	Gross Area (in^2)	Max Load (lb.)	Gross Compr. Strength (psi)	h/t Ratio	h/t CF*	Corrected Gross Strength (psi)
1	62	11.65	15.78	15.68	182.61	116000	635	1.35	0.78	500
2	62	11.60	15.65	15.65	181.54	114540	631	1.35	0.78	490
3	62	11.60	15.65	15.60	180.96	125460	693	1.35	0.78	540
									Average	510

Prism No.	Net Area (in2)	Max Load (lb.)	Net Compr. Strength (psi)	h/t Ratio	h/t CF*	Corrected Net Strength (psi)
1	44.9	116000	2582	1.35	0.78	2010
2	44.9	114540	2550	1.35	0.78	1980
3	44.9	125460	2793	1.35	0.78	2170
					Average	**2050**

Net cross-section area of units based upon the minimum net face shell bedded surface of the prisms using

* Height to thickness correction factor from Table 1 of ASTM C 1314-03b. Values have been linearly interpolated as necessary.

Robert Thomas
Vice President of Engineering

ASTM C 1314-03b Test Report:
Constructing and Testing Masonry Prisms Used to Determine Compliance with Specified Compressive Strength of Masonry

Project No.: 05-520-02
Report Date: 02/17/06

Client: Oldcastle Architectural/Northfield Block
Address: One Hunt Court
Mundelein, IL 60060

Testing Lab: National Concrete Masonry Association
Research and Development Laboratory
13750 Sunrise Valley Drive
Herdon VA, 20171-4662

Project Identification: 05-520-02
Prism Identification: 12 x 16 x 16, Hollow, Stack Bond, Concrete Masonry Prism
Full mortar bedding only
Specified Compressive Strength of Masonry NA

Prism Details:
Number of Mortar Bed Joints: 1
Number of Masonry Units Used: 2
Date Retrieved from Site: NA
Date Delivered to Lab: NA
Date Tested: 2/6/2006

Masonry Unit Information:
Unit Supplier: Oldcastle Arch
Unit Dimensions: 12 x 8 x 16
Unit Net Area (hollow units): 95.71

Mortar Information
Mortar Supplier / Preparer: NCMA
Mortar Type / Description: S

Grout Information
Grout Supplier / Preparer: NA
Grout Type / Description NA
Grout Slump (ASTM C 143): NA
Method of Consolidation: NA

Compression Test Machine Information
Diameter of Spherical Seat: 10 in.
Required Upper Bearing Plate Thickness: 4.8 in.
Required Lower Bearing Plate Thickness: 1.0 in.
in.
in.

Provided Upper Bearing Plate Thickness: 5.1 in.
Provided Lower Bearing Plate Thickness: 2.5 in.

Tested Prism Properties:

Prism No.	Age at Test (days)	Avg. Width (in.)	Avg. Height (in.)	Avg. Length (in.)	Gross Area (in^2)	Max Load (lb.)	Gross Compr. Strength (psi)	h/t Ratio	h/t CF*	Corrected Gross Strength (psi)
1	62	11.60	15.70	15.70	182.12	216490	1189	1.35	0.78	930
2	62	11.60	15.70	15.70	182.12	228780	1256	1.35	0.78	980
3	62	11.60	15.65	15.60	180.96	284970	1575	1.35	0.78	1220
									Average	1040

Net cross-section area of units based upon the mortared surface area using minimum specified dimensions.

Prism No.	Net Area (in2)	Max Load (lb.)	Net Compr. Strength (psi)	h/t Ratio	h/t CF*	Corrected Net Strength (psi)
1	95.7	216490	2262	1.35	0.78	1760
2	95.7	228780	2390	1.35	0.78	1860
3	95.7	284970	2977	1.35	0.78	2310
					Average	**1980**

* Height to thickness correction factor from Table 1 of ASTM C 1314-03b. Values have been linearly interpolated as necessary.

Robert Thomas
Vice President of Engineering

ASTM C 1314-03b Test Report:
Constructing and Testing Masonry Prisms Used to Determine Compliance with Specified Compressive Strength of Masonry

Project No.: 05-520-03
Report Date: 02/17/06

Client: Oldcastle Architectural/Northfield Block
Address: One Hunt Court
Mundelein, IL 60060

Testing Lab: National Concrete Masonry Association
Research and Development Laboratory
13750 Sunrise Valley Drive
Herdon VA, 20171-4662

Project Identification: 05-520-03
Prism Identification: 12 x 16 x 16, Grouted, Stack Bond, Concrete Masonry Prism
Solid Grouted Prism
Specified Compressive Strength of Masonry NA

Prism Details:
Number of Mortar Bed Joints: 1
Number of Masonry Units Used: 2
Date Retrieved from Site: NA
Date Delivered to Lab: NA
Date Tested: 2/6/2006

Masonry Unit Information:
Unit Supplier: Oldcastle Arch
Unit Dimensions: 12 x 8 x 16
Unit Net Area (hollow units): 95.71

Mortar Information
Mortar Supplier / Preparer: NCMA
Mortar Type / Description: S

Grout Information
Grout Supplier / Preparer: NCMA
Grout Type / Description: Course
Grout Slump (ASTM C 143): 8 in. +
Method of Consolidation: Mechanical

Compression Test Machine Information
Diameter of Spherical Seat: 10 in.
Required Upper Bearing Plate Thickness: 4.7 in.
Required Lower Bearing Plate Thickness: 1.0 in.
in.
in.

Provided Upper Bearing Plate Thickness: 5.1 in.
Provided Lower Bearing Plate Thickness: 2.5 in.

Tested Prism Properties:

Prism No.	Age at Test (days)	Avg. Width (in.)	Avg. Height (in.)	Avg. Length (in.)	Gross Area (in^2)	Max Load (lb.)	Gross Compr. Strength (psi)	h/t Ratio	h/t CF*	Corrected Gross Strength (psi)
1	7	11.60	16.00	15.60	180.96	365710	2021	1.38	0.79	1600
2	7	11.58	16.08	15.65	181.15	378670	2090	1.39	0.80	1670
3	7	11.55	16.05	15.65	180.76	371300	2054	1.39	0.80	1640
									Average	1640

Net cross-section area of units based upon the mortared surface area using minimum specified dimensions.

Prism No.	Net Area (in2)	Max Load (lb.)	Net Compr. Strength (psi)	h/t Ratio	h/t CF*	Corrected Net Strength (psi)
1	138.0	365710	2650	1.38	0.79	2100
2	138.0	378670	2744	1.39	0.80	2190
3	138.0	371300	2691	1.39	0.80	2150
					Average	**2150**

* Height to thickness correction factor from Table 1 of ASTM C 1314-03b. Values have been linearly interpolated as necessary.

Robert Thomas
Vice President of Engineering

ASTM C 1314-03b Test Report:
Constructing and Testing Masonry Prisms Used to Determine Compliance with Specified Compressive Strength of Masonry

Project No.: 05-520-04
Report Date: 02/17/06

Client: Oldcastle Architectural/Northfield Block
Address: One Hunt Court
Mundelein, IL 60060

Testing Lab: National Concrete Masonry Association
Research and Development Laboratory
13750 Sunrise Valley Drive
Herdon VA, 20171-4662

Project Identification: 05-520-04
Prism Identification: 6 x 16 x 8, Grouted, Stack Bond, Concrete Masonry Prism
Half-Length, Solid Grouted Prism with Insulation and Veneer Removed
Specified Compressive Strength of Masonry NA

Prism Details:
Number of Mortar Bed Joints: 1
Number of Masonry Units Used: 2
Date Retrieved from Site: NA
Date Delivered to Lab: NA
Date Tested: 4/7/2006

Masonry Unit Information:
Unit Supplier: Oldcastle Arch
Unit Dimensions: 12 x 8 x 16
Unit Net Area (hollow units): 95.71

Mortar Information
Mortar Supplier / Preparer: NCMA
Mortar Type / Description: S

Grout Information
Grout Supplier / Preparer: NCMA
Grout Type / Description: Course
Grout Slump (ASTM C 143): 8 in. +
Method of Consolidation: Mechanical

Compression Test Machine Information
Diameter of Spherical Seat: 10 in.
Required Upper Bearing Plate Thickness: 0.5 in.
Required Lower Bearing Plate Thickness: 1.0 in.

Provided Upper Bearing Plate Thickness: 5.1 in.
Provided Lower Bearing Plate Thickness: 2.5 in.

Tested Prism Properties:

Prism No.	Age at Test (days)	Avg. Width (in.)	Avg. Height (in.)	Avg. Length (in.)	Gross Area (in^2)	Max Load (lb.)	Gross Compr. Strength (psi)	h/t Ratio	h/t CF*	Corrected Gross Strength (psi)
1	9	6.20	15.80	9.20	56.8	161900	2851	2.55	1.04	2970
2	9	6.25	15.80	9.20	56.8	161460	2843	2.53	1.04	2960
3	9	6.25	15.80	9.20	56.8	163210	2874	2.53	1.04	2990
									Average	2970

Net cross-section area of units based upon the total cross-sectional area using minimum specified dimensions.

Prism No.	Net Area (in2)	Max Load (lb.)	Net Compr. Strength (psi)	h/t Ratio	h/t CF*	Corrected Net Strength (psi)
1	56.8	161900	2851	2.55	1.04	2970
2	56.8	161460	2843	2.53	1.04	2960
3	56.8	163210	2874	2.53	1.04	2990
					Average	**2970**

* Height to thickness correction factor from Table 1 of ASTM C 1314-03b. Values have been linearly interpolated as necessary.

Robert Thomas
Vice President of Engineering

ASTM C 1314-03b Test Report:
Constructing and Testing Masonry Prisms Used to Determine Compliance with Specified Compressive Strength of Masonry

Project No.: 05-520-05
Report Date: 02/17/06

Client: Oldcastle Architectural/Northfield Block
Address: One Hunt Court
Mundelein, IL 60060

Testing Lab: National Concrete Masonry Association
Research and Development Laboratory
13750 Sunrise Valley Drive
Herdon VA, 20171-4662

Project Identification: 05-520-05
Prism Identification: 6 x 16 x 8, Hollow, Stack Bond, Concrete Masonry Prism
Half-Length, Hollow Prism with Insulation and Veneer Removed
Specified Compressive Strength of Masonry NA

Prism Details:
Number of Mortar Bed Joints: 1
Number of Masonry Units Used: 2
Date Retrieved from Site: NA
Date Delivered to Lab: NA
Date Tested: 4/7/2006

Masonry Unit Information:
Unit Supplier: Oldcastle Arch
Unit Dimensions: 12 x 8 x 16
Unit Net Area (hollow units): 95.71

Mortar Information
Mortar Supplier / Preparer: NCMA
Mortar Type / Description: S

Grout Information
Grout Supplier / Preparer: NCMA
Grout Type / Description: Course
Grout Slump (ASTM C 143): 8 in. +
Method of Consolidation: Mechanical

Compression Test Machine Information
Diameter of Spherical Seat: 10 in.
Required Upper Bearing Plate Thickness: 0.6 in.
Required Lower Bearing Plate Thickness: 1.0 in.
in.
in.

Provided Upper Bearing Plate Thickness: 5.1 in.
Provided Lower Bearing Plate Thickness: 2.5 in.

Tested Prism Properties:

Prism No.	Age at Test (days)	Avg. Width (in.)	Avg. Height (in.)	Avg. Length (in.)	Gross Area (in^2)	Max Load (lb.)	Gross Compr. Strength (psi)	h/t Ratio	h/t CF*	Corrected Gross Strength (psi)
1	24	6.30	15.80	9.20	56.8	107920	1900	2.51	1.04	1980
2	24	6.30	15.85	9.20	56.8	120090	2115	2.52	1.04	2200
3	24	6.28	15.85	9.20	56.8	94680	1667	2.53	1.04	1740
									Average	1970

Prism No.	Net Area (in2)	Max Load (lb.)	Net Compr. Strength (psi)	h/t Ratio	h/t CF*	Corrected Net Strength (psi)
1	35.6	107920	3028	2.51	1.04	3150
2	35.6	120090	3370	2.52	1.04	3510
3	35.6	94680	2657	2.53	1.04	2770
					Average	**3140**

Net cross-section area of units based upon the mortared surface area using minimum specified dimensions.

* Height to thickness correction factor from Table 1 of ASTM C 1314-03b. Values have been linearly interpolated as necessary.

Robert Thomas
Vice President of Engineering