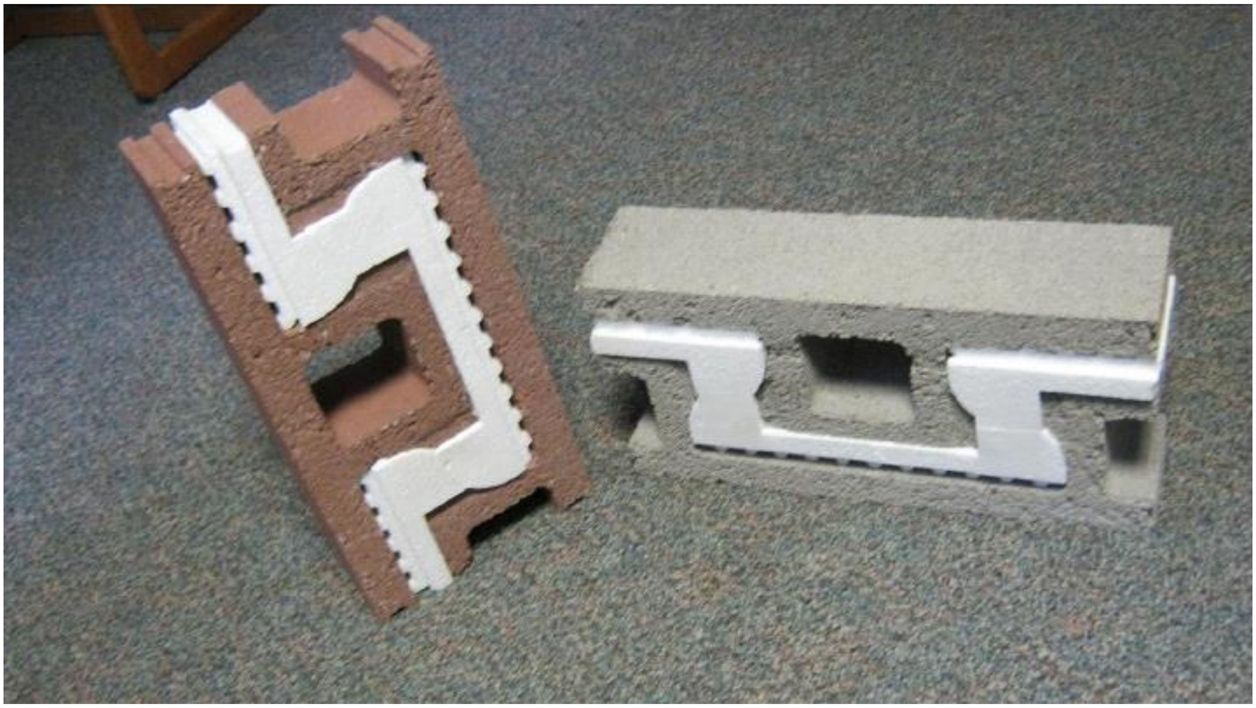


COMPARISON OF CALCULATED DESIGN STRENGTHS TO LABORATORY TESTING RESULTS OF 8-INCH NRG CONTINUOUSLY INSULATED CONCRETE MASONRY UNITS (CICMU)

January 2018

Executive Summary:

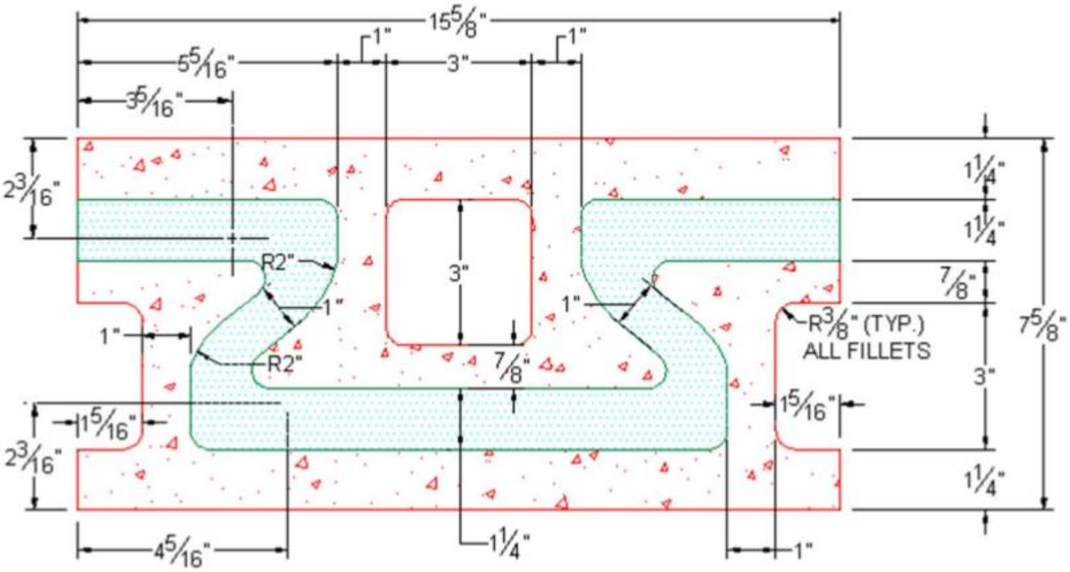
This report summarizes the calculated results of the bending moment capacity of an 8-inch NRG Continuously Insulated Concrete Masonry Unit (CICMU) wall, with the full scale testing results obtained by the Structural Engineering Teaching and Research Laboratory at Villanova University.

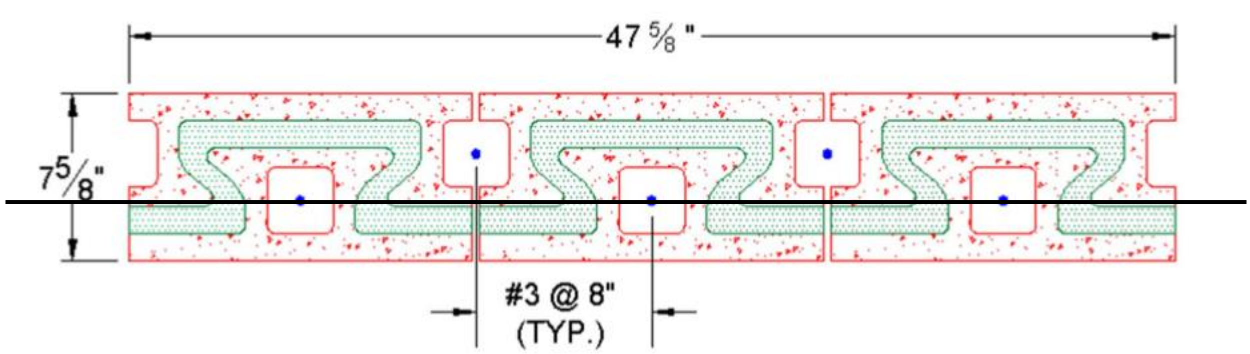
The results obtained using TMS 402 Allowable Strength Design for reinforced masonry, Chapter 8, are conservative as compared to the actual capacities determined by testing.

Several design and detailing considerations are presented for designers using this system.

A. NRG CICMU Wall System:

The NRG CICMU wall system is composed of 8-inch units with 3-inch square cores spaced at 8 inches on-center, staggered on each face of the wall, 1¼-inch face shells, and a continuous insulation layer. The insulation layer keys the inner and outer wythes together to form a continuously insulated block unit.





B. Research Data:

"Structural Performance of 8-inch NRG Concrete Masonry Units" report dated January 28, 2013, prepared by Villanova University is provided in Appendix A of this report.

C. Design Considerations:

The following should be considered when designing with 8-inch NRG CICMU:

TMS 402 Bar Size Limitations:

Reinforcement bar size restrictions are provided in TMS 402, Chapter 6 for Allowable Strength Design. The requirements are modified for Strength Design in Chapter 9.

For the geometry of the NRG CICMU, in accordance with Chapter 6, Section 6.1.2, the maximum bar size is governed by the limit of 6 percent of the area of the grout space. Using a 3-inch by 3-inch cell, the maximum bar size is a #6.

For strength design, this limit is lowered to 4 percent of the area of the grout space (Section 9.3.3.1). Based on this criteria, the maximum bar size is a #5.

Designers may use either method of analysis for the walls, but should be aware of the difference in bar size limitations.

TMS 402 Grouting Limitations:

In accordance with TMS 402 grout space requirements, it should be noted that the code allows for ½-inch mortar protrusions into the grouted cell. Using this allowance, the grout space would be reduced to 2 inches by 2 inches, and grout placement would be limited to 1-foot pour heights of fine grout.

Table 1—Grout Space Requirements (ref. 3)

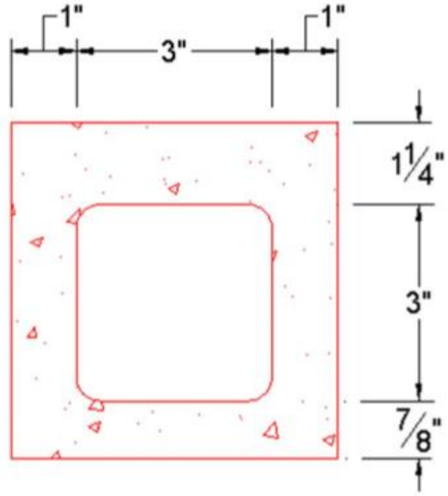
Grout type[1]	Max. grout pour height, ft (m)	Min. width of grout space [2,3], in. (mm)	Min. grout space dimensions for grouting cells of hollow units [3,4] in. x in. (mm x mm)
Fine	1 (0.30)	¾ (19.1)	1½ x 2 (38.1 x 50.8)
Fine	5 (1.52)	2 (50.8)	2 x 3 (50.8 x 76.2)
Fine	12 (3.66)	2½ (63.5)	2½ x 3 (63.5 x 76.2)
Fine	24 (7.32)	3 (76.2)	3 x 3 (76.2 x 76.2)
Coarse	1 (0.30)	1½ (38.1)	1½ x 3 (38.1 x 76.2)
Coarse	5 (1.52)	2 (50.8)	2½ x 3 (63.5 x 76.2)
Coarse	12 (3.66)	2½ (63.5)	3 x 3 (76.2 x 76.2)
Coarse	24 (7.32)	3 (76.2)	3 x 4 (76.2 x 102)

[1] Fine and coarse grouts are defined in ASTM C 476 (ref. 2).
[2] For grouting between masonry wythes.
[3] Grout space dimension is the clear dimension between any masonry protrusion and shall be increased by the diameters of the horizontal bars within the cross section of the grout space.
[4] Area of vertical reinforcement shall not exceed 6 percent of the area of the grout space.

Designers would need to prohibit mortar joint protrusions in order to be permitted to use higher pour heights. This would require special attention by the masons to remove all mortar protrusions from the cells.

<u>Prism Testing</u>:

The prism testing performed by Villanova University was performed on a coupon of block. No full scale testing of the block was performed.



<u>Distribution of Axial Loads</u>:

The testing performed by Villanova University was for pure bending of the wall. No testing has been performed on the wall's ability to resist axial loads or for bending in combination with axial loads. Since the wall consists of split units bonded with insulation, it is unclear how axial loads imposed by structural framing members would distribute within the wall system. If structural members are supported on the inner 'wythe' of the wall system, this eccentricity of load and non-uniform application of compression forces would need to be considered when analyzing the wall system for combined axial and flexural loads.

If the inner wythe of wall is intended to resist axial loads without contribution of the exterior wythe, the typical procedure of using face shell bedding would not be appropriate. The section would need to be fully mortared. As previously noted, prism testing was not performed on the full block profile. If axial loading is to be supported by the full or partial wall system, prism testing is recommended.

Designers may want to consider the use of a standard block at the tops of walls to create a continuous bond beam to help distribute axial loads and act as a diaphragm tie.

<u>Reinforcing Layout:</u>

Due to the eccentricity of the block cores, vertical reinforcing should always be distributed equally on both sides of the wall to ensure the wall has strength to resist both wind pressure and suction loads.

D. Analysis:

The following analysis was performed in accordance with TMS 402-2016 Allowable Strength Design (Chapter 8). In accordance with design assumptions of Section 8.3.2, strain in reinforcement and masonry is directly proportional to the distance from the neutral axis, and stress is linearly proportional to strain. Therefore, the tensile strength contribution of the reinforcing on the compression side of the wall was reduced accordingly.

Design Data:

Based on the Villanova University report, the following design data was utilized in the analysis of the wall system.

Density: 102 psf (unit with insulation)
Unit weight: 65 psf hollow
Type S mortar
2,630 psi grout
Net Area Compressive Strength of Masonry f'm, 4,000 psi based on prism testing of coupon.

Span: 78" (6'6")
Wall panel width = 47.625"
Loading: Two equal point loads applied 27" from supports

Reinforcing: #3 @ 16" o.c. each side of wall, As = .083 m^2 on each side of wall
Distance to reinforcing:
d_1 = 4.875" (tension side of wall)
d_2 = 2.75" (compression side of wall)
d_3 = 3.81" (center of wall)

Using:
Fy = 60,000 psi
Fs = 32,000 psi (Section 8.3.3.1 (b))
Fb = .45 f'b = 1,800 psi (Section 8.3.4.2.2)
Es = 29,000,000 psi
Em = 900 f'm = 3,600,000 psi
n = Es/Em = 8.1
As = 0.55 in2 (5) bars

Design Code:

TMS 402–2016 - Building Code Requirements for Masonry Structures, Chapter 8, Allowable Strength Design.

Analysis Results:

Masonry wall self weight = 102 pcf (7- 5/8/12) + 11 psf for grouted cells = 75.8 psf fully grouted
Self weight moment = (wl^2)/8 = 19,065 in-lb (1588.8 ft-lb)

Determine As_{eq} in center of wall: $As_1 (d_1) + As_2 (d_2/d_1) d_2 = As_{eq} (d_3)$
Equivalent As: 0.083 (4.875) + 0.083 (2.75/4.875) (2.75) = As_{eq} (3.81)
As_{eq} = 0.14 in^2 in center of wall

$p = As_{eq}/bd_3 = 0.14/12(3.81) = 0.003$
np = 0.024
Kd = 0.746 < face shell thickness
2/jk = 10.789
jd = 3.56

Mm = (Fb)bd^2(1/(2/jk)) = 29,101 in-lb/ft

$Ms = (Fs)(As_{eq})(jd)$ = 15,948 in-lb/ft

Steel yielding controls.

Summary of Analysis Results:

Allowable Total Moment Capacity of Panel : 15,948 in-lb/ft (47.625 in/12) = 63,294 in-lb = (5,275 ft-lb) or (1,329 ft-lb/ft)

Allowable Applied Moment: (Ma) = Ms – M(self weight) = 63,294 in-lb – 19,065 in-lb = 44,229 in-lb = (3,685 ft-lb) or (921 ft-lb/ft)

Maximum Allowable Applied Load: P = Ma/27 in = 1,638 lb applied in two locations.
Maximum Total Applied Load Pt = 3,276 lb

E. Comparison with Test Results:

The testing concluded that the wall system failed by steel yielding. This agreed with the analysis results.

The applied total loads at failure ranged from 7,300 pounds to 8,700 pounds. This corresponds to two point loads of 3,650 pounds and 4,350 pounds, respectively.

The moment generated by these applied loads ranged from 8,212.5 ft-lb and 9,787.5 ft-lb on a 4-foot-wide section, or 2,053 ft-lb/ft to 2,447 ft-lb/ft, respectively. In addition to the applied loads, the wall was subject to bending due to its self weight. Using the wall self weight of 75.8 psf for a fully grouted wall, the bending moment due to wall self weight was 19,065 in-lb (1,588.75 ft-lb) or 397 ft-lb/ft.

Therefore the total moment resisted by the wall section ranged from 9,801 ft-lb to 11,376 ft-lb, or 2,450 ft-lb/ft to 2,844 ft-lb/ft.

Summary of Testing Results:

Average Tested Total Moment Capacity of Panel: 127,056 in-lb (10,588 ft-lb) or 2,647 ft-lb/ft

Average Applied Load at Failure: P = 4,000 lb applied in two locations.

Comparison:

Calculated Allowable Moment Total : 1,329 ft-lb/ft
Average Tested Moment Total: 2,647 ft-lb/ft

Calculated Maximum Point Load: 1,638 lb applied in two locations

Average Tested Point Load at Failure: 4,000 lb

Safety Factor ≥ 2

In summary, the predicted capacity of the wall system based on analysis using TMS 402-2016, Allowable Strength Method was conservative compared to the actual capacity of the wall based on testing.

F. **Wall Capacities Based on TMS 402-2016:**

The following tables are provided in Appendix B:

1. Masonry Properties: A summary of properties used for design of the NRG units and standard masonry units.
2. Moment Capacity Tables: These tables provide a graphic of each reinforcing layout, design data, and moment capacities based on TMS 402-2016, Allowable Strength Method.
3. Moment Capacity Comparison Tables: These tables provide a comparison of 8-inch NRG units and standard 8-inch CMU units with equivalent reinforcing.

Appendix A

Structural Performance of 8-inch NRG Concrete Masonry Units

Report Compiled for:

Niagara Regional Group

Date:

January 28, 2013

Report Prepared by:

Dr. Shawn Gross, Associate Professor
Dr. David Dinehart, Professor
Jeffrey Cook, Structural Laboratory Manager
Stephanie Lanno, Graduate Research Assistant

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EXECUTIVE SUMMARY

The structural performance of 8-inch NRG insulated concrete masonry block was evaluated at the Structural Engineering Teaching and Research Laboratory at Villanova University. The goal of the testing was to determine the strength of masonry using 8-inch NRG units and to evaluate the effect of the rigid foam insulation (if any) on structural performance. To achieve this goal, a series of flexural and compressive tests were conducted.

To evaluate flexural capacity, three 48 in. x 96 in. wall panels were constructed from 8-inch nominal NRG concrete masonry units. Vertical reinforcement was provided by placing a No. 3 bar every 8 in. along the length of each panel. Horizontal reinforcement was placed every 16 in. within the mortar joints. All three wall panels were constructed with a running bond pattern and were fully-grouted. The wall panels were loaded with a four-point bending configuration and subjected to out-of-plane loading, in accordance with ASTM E72.

The NRG wall panels demonstrated behavior similar to a conventional 8-inch concrete masonry assembly subjected to flexural loading. All wall panels failed in a ductile manner, experiencing deflections ranging from 7 to 9 inches prior to unloading. The wall panel failures were predictable in that they had maximum loads ranging from 9,700 to 12,000 lb, which exceeds the 9,580 lb predicted using methods outlined in the MSJC Code. Therefore, it was concluded that design methods prescribed in masonry codes for conventional masonry design are applicable to NRG masonry design.

Twelve compressive strength prism tests were also performed in accordance with ASTM C1314. All prisms tested were constructed from partial units and were three units high. Partial units were saw-cut sections of the concrete masonry portion of the block which had the 3 in. x 3 in. void within it. The foam layer and remaining concrete masonry section of the block were removed. Half of these masonry prisms were grouted, and the other half were ungrouted. Results for ungrouted and grouted specimens were very similar, providing an overall average compressive strength of 4,040 psi. These results indicate compressive strength of masonry values well in excess of values typically used in design.

1. MATERIALS

1.1 NRG Concrete Masonry Units

The 8-inch nominal NRG masonry units used for this testing consist of two concrete masonry sections separated by a rigid foam layer. There is a 3 in. x 3 in. void within the unit to accommodate reinforcement. A photograph of the unit is shown in Figure 1 and cross-sectional dimensions are shown in Figure 2.

ASTM C140, *Standard Test Methods of Sampling and Testing Concrete Masonry Units and Related Units,* was followed for compressive strength and absorption testing of the NRG units. The ASTM Standard recommends that full-size units are used for both tests. However, due to limitations on size and capacity of testing equipment, as well as the difficulty in ensuring uniform compressive load distribution between the solid masonry on the two sides of the rigid foam insulation layer, it was established that partial size units would be used for evaluation of compressive strength. A cross section of the reduced unit used for compression tests is shown in Figure 3. Specimens were capped according to ASTM C1552, *Standard Practice for Capping Concrete Masonry Units, Related Units, and Masonry Prisms for Compression Testing,* prior to testing using gypsum cement. A photograph of the compression test setup is shown in Figure 4. Full size units (including the rigid foam insulation layer) were used for the absorption testing.

Test results are summarized in Table 1. A detailed report is provided in Appendix A. The average net compressive strength of the units was 6,090 psi, which exceeds the minimum standard of 1,900 psi set by ASTM C90, *Standard Specification for Loadbearing Concrete Masonry Units*. The average absorption was slightly larger than 4.0 lb/ft^3, which is significantly lower than the maximum permitted value of 13 lb/ft^3 for normal weight units.

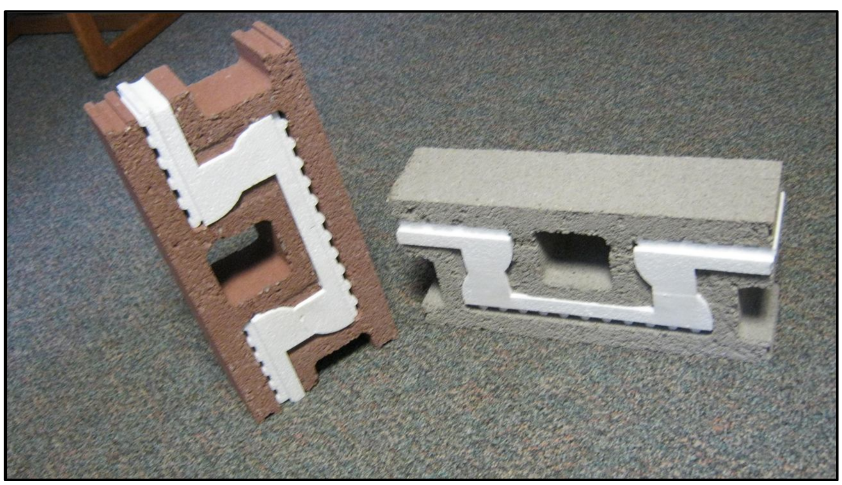

Figure 1 – 8-inch Nominal NRG Concrete Masonry Unit

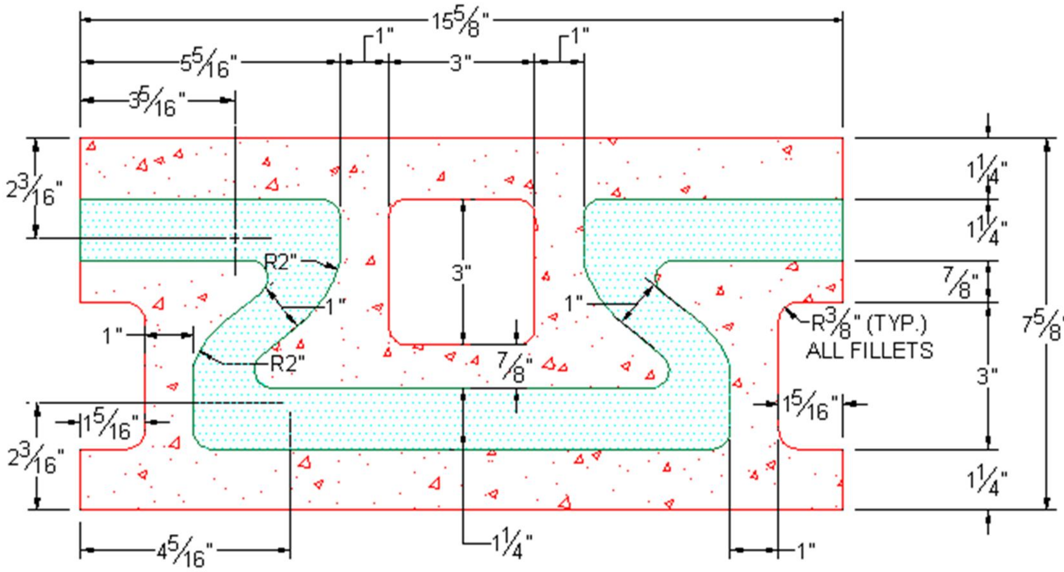

Figure 2 – Cross Section of 8-inch NRG Concrete Masonry Unit

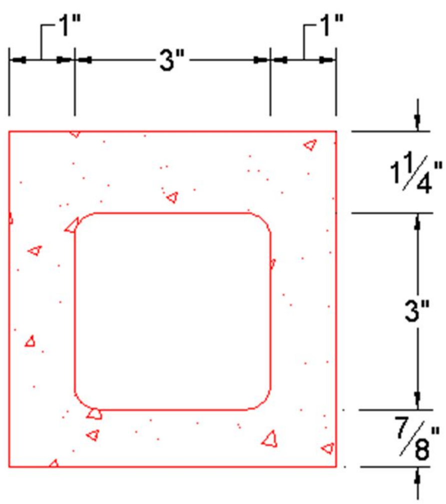

Figure 3 – Reduced Cross Section Used for Compressive Strength Testing

Figure 4 – NRG Compression Test Setup for Individual Masonry Units

Table 1 – NRG Concrete Masonry Unit Tested Properties

Property	Value
Density (pcf) – concrete masonry alone	140
Density (pcf) – concrete masonry with foam layer	102
Absorption (pcf) – concrete masonry alone	4.2
Absorption (pcf) – concrete masonry with foam layer	4.1
Net Area Compressive Strength (psi)	6,090

1.2 Mortar

Type S masonry cement mortar was used for all test specimens involving masonry assemblages. During construction of the flexural wall panels, mortar was sampled from several batches and 2-inch cube specimens and 2 in. x 4 in. cylindrical specimens were prepared. Testing of the mortar cube specimens was conducted in accordance with ASTM C109, *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars.* Mortar cylinder specimens were tested in accordance with ASTM C780, *Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry.*

Test results yielded an average compressive strength of approximately 2,920 psi for the mortar cubes and 2,480 psi for the mortar cylinders. A detailed mortar test report is provided in Appendix B.

1.3 Grout

Grout was sampled and specimens were prepared in accordance with ASTM C1019, *Standard Test Method for Sampling and Testing Grout.* Grout specimens measured approximately 3 in. by 3 in. in cross-section and were formed by placing portions of masonry units in the formation illustrated in Figure 5. Grout specimens were saw-cut to approximately 6 in. in length prior to testing. A total of nine grout specimens were tested in compression, including three samples each from three batches of grout. Two of the batches were grout used in the construction of Wall 1, while the other batch was grout used in Wall 3. Testing was conducted in accordance with ASTM C39, *Standard Compressive Strength of Cylindrical Concrete Specimens.*

The average compressive strengths of the grout specimens were 2,850 psi, 2,510 psi, and 2,520 psi for the three batches tested, respectively. The overall average compressive strength of grout was 2,630 psi. A detailed grout test report is provided in Appendix C.

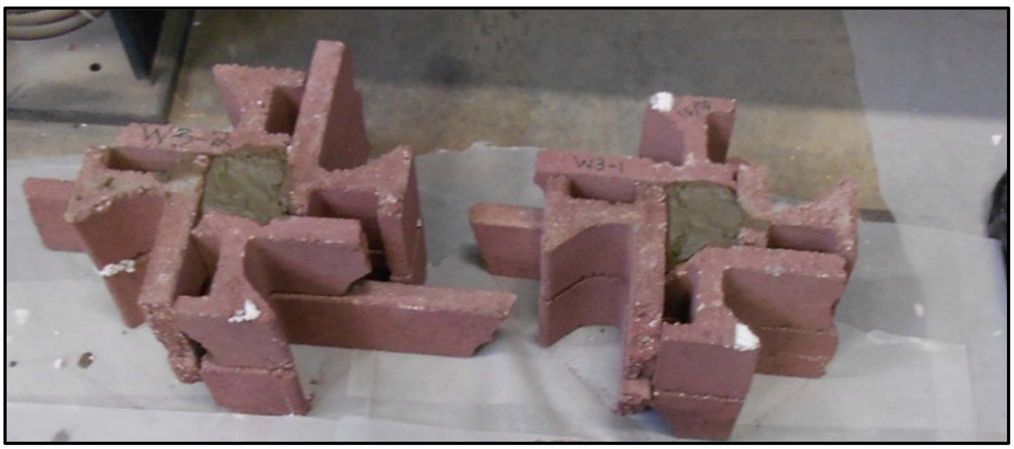

Figure 5 - Grout Specimen Construction

2. PRISM COMPRESSIVE STRENGTH TESTS

Twelve prisms were constructed for evaluation of compressive strength. Partial units were utilized as per the recommendation of ASTM C1314, *Standard Test Method for Compressive Strength of Masonry Prisms,* which eliminated the rigid foam layer from the compressive test specimen. The cross section of the prisms was essentially the same as that shown in Figure 3 used for testing of individual masonry units. Half of the prisms were grouted, and the other half of the prisms were ungrouted (hollow). All prisms tested were three units high. Specimens were capped according to ASTM C1552, *Standard Practice for Capping Concrete Masonry Units, Related Units, and Masonry Prisms for Compression Testing,* prior to testing using gypsum cement. A photograph of the prism compression test setup is provided in Figure 6.

Prism test results are summarized in Table 2 and a detailed report of the prism testing is provided in Appendix D. Test results for ungrouted and grouted prism specimens were very similar. After correction for height-to-thickness ratios of the tested specimens in accordance with ASTM C1314, the average net compressive strengths for ungrouted and grouted specimens were 4,050 psi and 4,030 psi, respectively.

These results indicate compressive strength of masonry values well in excess of values typically used in design. However, it should be noted that the testing on prisms made from partial units did not evaluate the ability to transfer axial compressive loads across the rigid foam layer. In a design situation where the compressive load is applied only to one of the two masonry layers within the wall (i.e. to one side of the rigid foam layer shown in the cross-section of Figure 2), it is recommended that the designer consider only that masonry layer as the effective net cross section resisting the load. Alternatively, the designer would need to ensure that the load path engages both sides of the wall in compression. Given the low axial stress levels typical in most structures, this is not likely to be an issue of major significance.

Figure 6 – Prism Test Setup

Table 2 – Compressive Strength of Masonry Prisms

Prism Configuration	Avg. Gross Compressive Strength of Prisms (psi)	Avg. Net Compressive Strength of Prisms (psi)	Avg. Net Compressive Strength of Masonry (f_{mt}) (psi)
Partial-Size, Grouted	3,910	3,910	4,030
Partial-Size, Ungrouted	2,700	3,940	4,050

Note: The compressive strength of the prisms was calculated by dividing the maximum applied load by the cross-sectional area. The net compressive strength of masonry (f_{mt}) includes a correction factor for prism height-to-thickness ratios that differ from 2.0. For the prims tested, this correction factor was 1.03.

3. FLEXURAL WALL TESTS

3.1 Construction and Curing of Wall Panels

Three wall panels were constructed for flexural testing. Elevation and cross section drawings of the wall panels are shown in Figures 7 and 8, and photographs during construction are provided in Figures 9 and 10. The approximate nominal dimensions of each wall panel were 96 in. high, 48 in. wide, and 8 in. thick. A running bond pattern and half-high (4-inch nominal height) NRG concrete masonry units were used for the construction of each wall panel. All walls were fully-grouted and had faceshell mortar bedding.

The wall panels had both horizontal and vertical reinforcement. Horizontal wire reinforcement was placed every 16 in. within the mortar joints. Vertical reinforcement in each wall panel consisted of five #3 (3/8-in. diameter) steel reinforcing bars, placed in the center of each 3 in. x 3 in. void and spaced at 8 in. along the length of the panel. Due to the staggered arrangement of the voids (see Figure 8), three of the five bars were located to one side relative to middle of the specimen, and the other two bars were located on the opposite side. For testing, all walls were oriented such that three bars were located on the bottom (tension side) of the wall, and two bars were located near the top (compression side) of the wall.

To facilitate construction, reinforcement lap splices were used at mid-height of Wall 1 and Wall 2. That is, two shorter pieces of reinforcement were used within each void in these walls rather than a single 8 ft. length of reinforcement. The masons placed the first vertical reinforcing bars in Wall 1 and Wall 2 when the walls were constructed to a height of approximately 4 ft. The length of the lap splices was 18 in. Lap splices were not used in Wall 3, and instead single reinforcing bars 8 ft. in length ran the full height of the wall.

Walls were constructed on October 9 and 10, 2012. Each wall was constructed following a unique sequence. Wall 1 was grouted as it was constructed, and the wall was built over a two day period. For Wall 2, the masons constructed half of the wall and grouted it, and then constructed and grouted the rest of the wall the following day. Wall 3 was constructed entirely on the second day of construction, and it was constructed to its full height before being grouted.

Threaded rods (3/8-inch diameter) were placed within the third mortar joint from the top and bottom of the wall to facilitate moving and rotating the walls into a horizontal position in the test frame. Figure 9 shows the placement of the threaded rods nearest to the bottom of the wall.

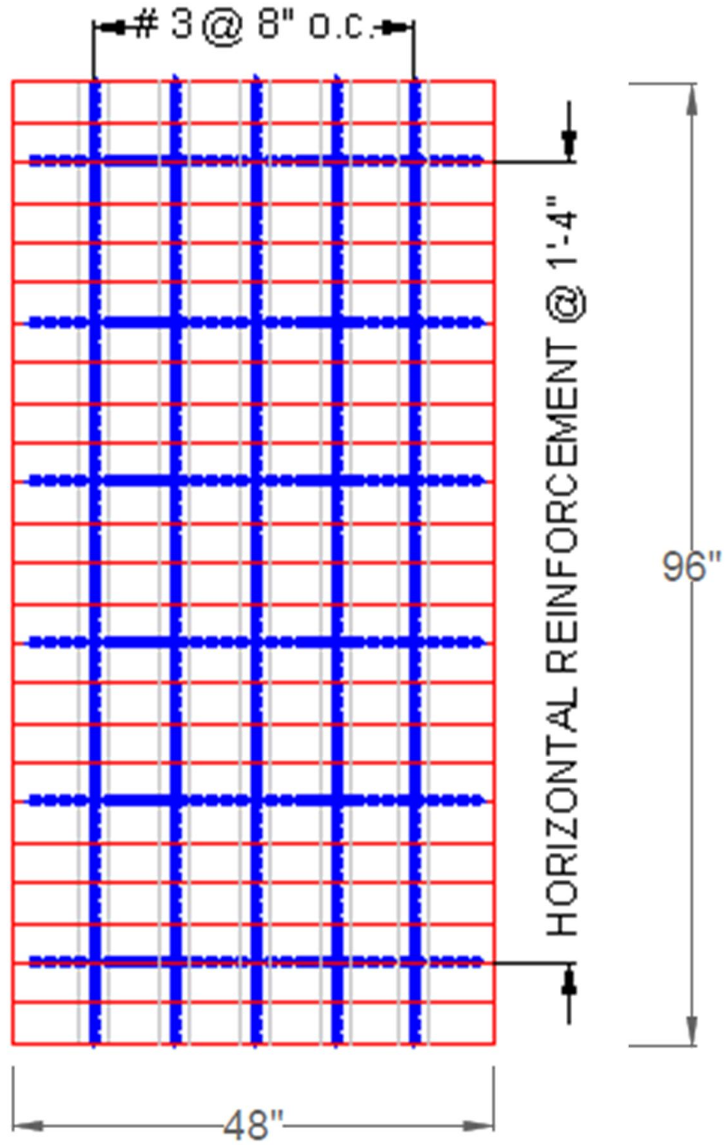

Figure 7 – Flexural Wall Elevation

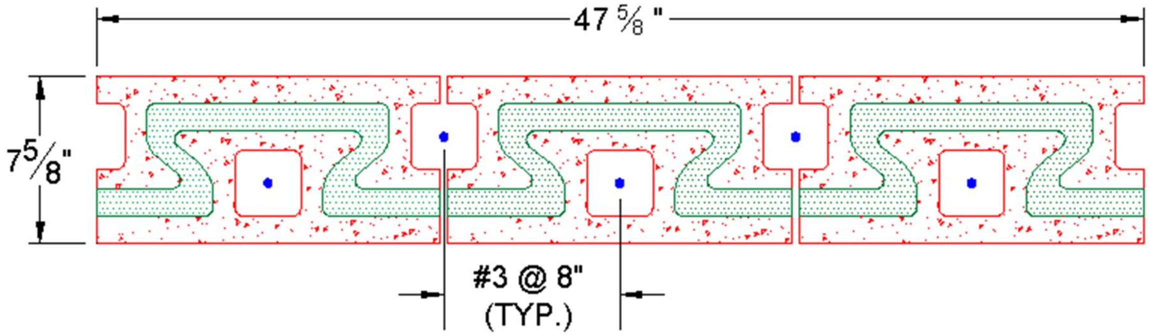

Figure 8 – Flexural Wall Cross Section

Figure 9 – Wall Construction

Figure 10 – Wall Construction Showing Vertical Reinforcement

3.2 Test Procedures

The three flexural tests were conducted in accordance with ASTM E72, *Standard Test Methods of Conducting Strength Tests of Panels for Building Construction.* Each wall panel was transported to the laboratory testing frame, rotated into horizontal position, and placed on supports for testing. Walls 1 and 2 were tested on November 7, 2012 and Wall 3 was tested on November 9, 2012.

The test setup is shown schematically in Figure 11, and photographs are provided in Figures 12 and 13. Walls were tested in four-point bending with a 78 in. span between the supports and 24 in. spacing between the loading points. The loading points were thus positioned 27 in. from each support.

Each specimen was supported in the test frame by a W10 steel section. Above the W10 section was a 1-inch thick steel plate with 2-inch diameter steel round welded to it. Another 1-inch thick steel plate separated the 2-inch steel round from the wall panel. This plate was 4 in. wide and acted to distribute the load evenly across the mortar joints of the wall panel at the support location.

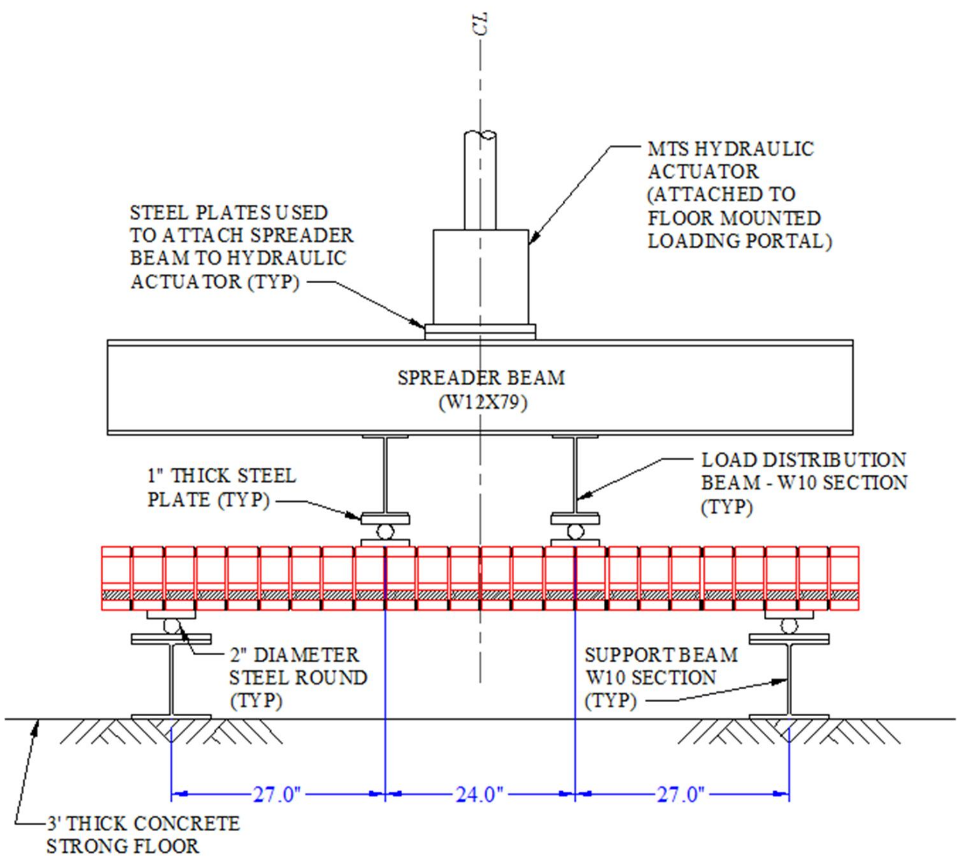

Figure 11 – Test Setup Configuration

Figure 12 – Test Setup Photograph

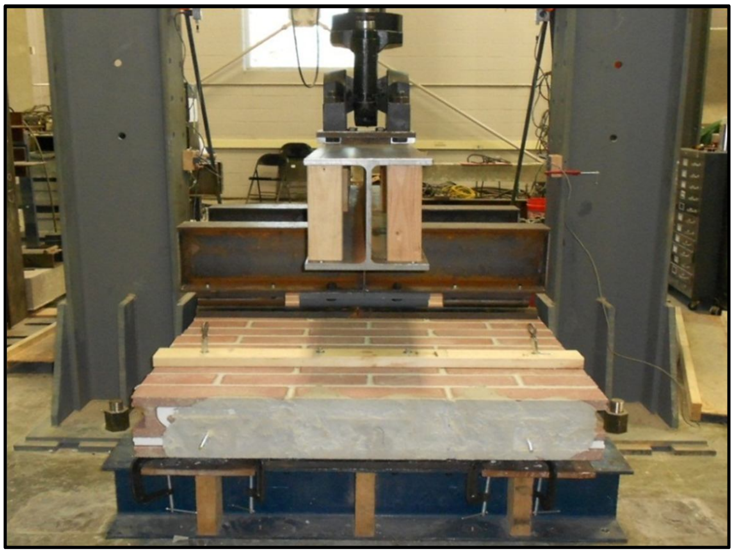

Figure 13 – Test Setup Photograph – Viewed from End of Wall

Load was applied with a servo-controlled hydraulic actuator which acted upon a W12x79 spreader beam. The spreader beam distributed the load to two W10 steel sections which in turn applied the load to the wall panel. The two loading points acting on the top surface of the wall panel were constructed in a similar manner to the roller supports discussed previously, as shown in Figure 11. Load was applied under a displacement-control protocol with a displacement rate of 0.5 in. of deflection per minute.

Load was measured using an integrated load cell and deflection was measured using string potentiometers placed at midspan on either side of the wall panels. Data was recorded continuously for the duration of the test using a data acquisition system.

3.3 Test Results

All three flexural wall specimens exhibited similar behavior when tested. Panels initially cracked at the mortar joints on the tension (bottom) side of the specimen, then continued to deform until the steel reinforcement completely yielded. Crushing was observed along the mortar joints on the compression (top) side of the specimen after yielding of reinforcement. All panels continued to resist load well after yielding of the reinforcement, though there was a noticeable change in panel stiffness. Overall, the panels behaved in a very ductile manner.

Panels were unloaded prior to any significant loss of capacity after excessive deflections had been achieved. Wall 1 was unloaded after achieving a midspan deflection of 9 in., and Walls 2 and 3 were unloaded after achieving a midspan deflection of 7 in. A photograph of Wall 1 at its maximum deflection just before unloading can be seen in Figure 14. All walls exhibited a significant permanent deflection after unloading, as can be seen in Figure 15.

It was observed that as deflections became large the individual masonry and foam layers were shifting relative to one another. This shifting can be seen in the photograph of Figure 16. Despite this shifting, it is clear from the test results that the layers of the wall continue to work together to provide flexural resistance.

During the later stages of testing for Walls 2 and 3, the spreader beam rotated excessively. Unlike for Wall 1, where the yielding of reinforcement was concentrated at midspan of the specimen, the yielding in Walls 2 and 3 occurred closer to one of the spreader beam load points. As seen in Figure 17, this led to an unsymmetric deflection of the specimen, which in turn caused the spreader beam to rotate as it followed the deformation of the specimen. Once this rotation became significant, a larger percentage of the total load applied by the spreader beam probably went to the load point that was deflecting more, and this may have had a slight effect in reducing the measured capacity of these two specimens. The unsymmetric behavior was first observed for Wall 2 at a midspan displacement of approximately 3.0 in, but for Wall 3 was not observed until much later in the test at a midspan displacement of approximately 4.5 in.

Figure 14 – Wall 1 Under Maximum Deflection (Prior to Unloading)

Figure 15 – Wall 1 After Unloading

Figure 16 – Wall 2 After Load is Released (Showing Shifting of Layers)

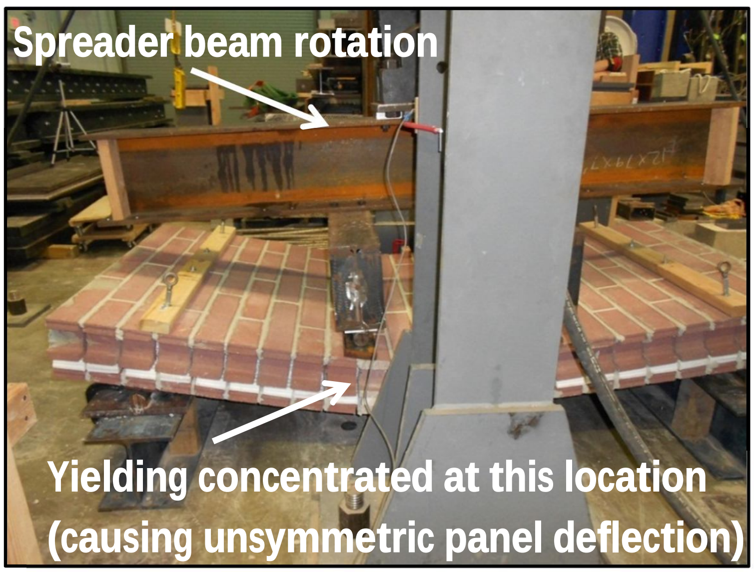

Figure 17 – Unsymmetrical Loading Toward End of Wall 2 Test

Figure 18 shows the load versus midspan displacement plots for each of the three wall panels. The left vertical axis indicates the actual load applied to the specimen, *excluding* the specimen self-weight. The right vertical axis indicates the total load *including* the equivalent self-weight. The equivalent self-weight was defined as the applied (concentrated) load that would cause the same midspan bending moment as the actual (distributed) self-weight of the panel. The use of an equivalent concentrated self-weight allows for direct summation of values in terms of loads rather than bending moments. For the panels in this study, this equivalent load was determined to be approximately 1,200 lb, consistent with a self-weight bending moment of 16,200 lb-in.

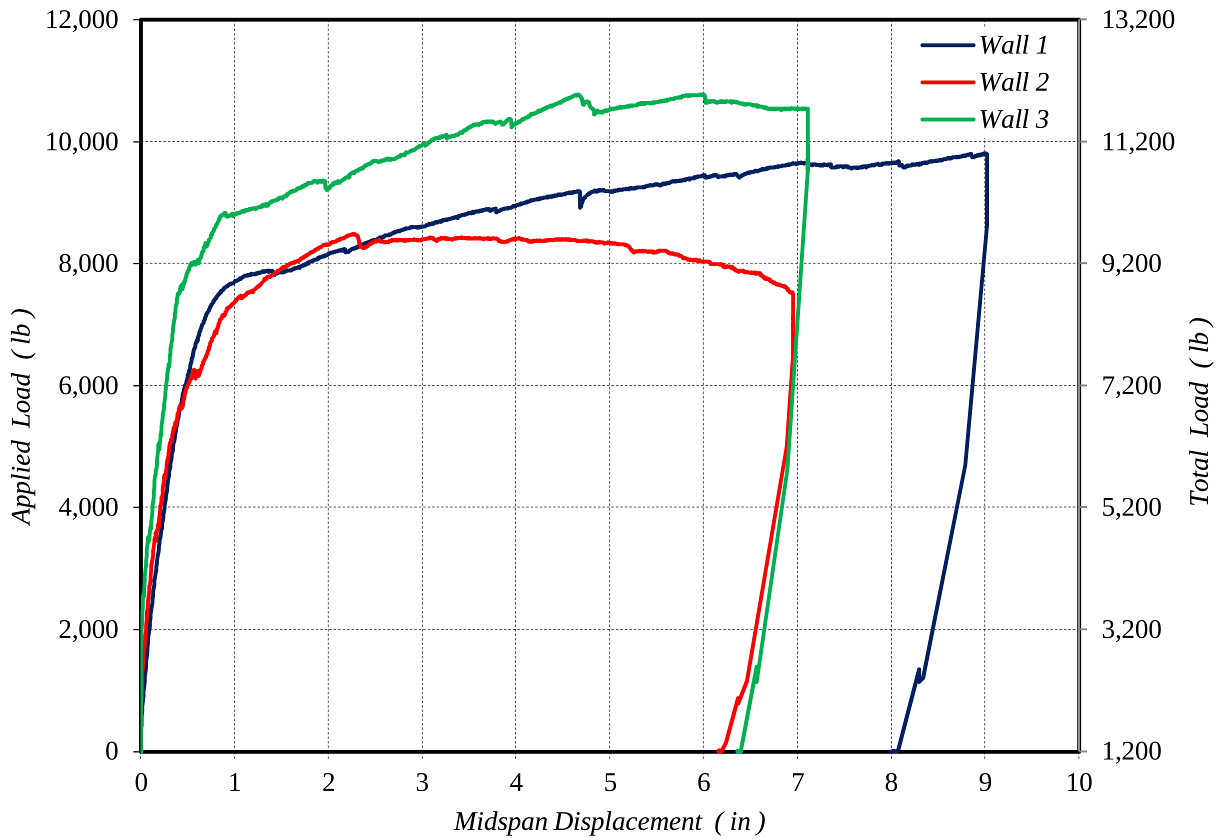

Figure 18 – Load vs. Midspan Displacement Plots for Flexural Wall Tests

Table 3 – Wall Panel Loading Summary

Specimen	Applied Load at Yield (lb)	Maximum Applied Load (lb)	Equivalent Self Weight (lb)	Total Load at Yield (lb)	Maximum Total Load (lb)
Wall 1	7,800	9,800	1,200	9,000	11,000
Wall 2	7,300	8,500	1,200	8,500	9,700
Wall 3	8,700	10,800	1,200	9,900	12,000

Table 3 provides a summary of the loads resisted by each of the wall panels, based on the data shown in Figure 18. As noted previously, applied loads do not include the equivalent self-weight and total loads do include the equivalent self-weight. The yield load is defined as the location where the stabilized linear curve becomes non-linear due to the yielding of the reinforcement. For each of the wall panels, the yield load occurred when deflection was approximately 1 in. Although the yield load is identified for each panel, this load does not have any major significance in the standard design process and is only provided as an indicator of behavior.

The last column in Table 3 identifies the most important value, the maximum total load resisted by each panel including both the actual applied load and the equivalent self-weight load. These loads are compared to the predicted capacities based on the MSJC design code in Section 3.4. The maximum total loads resisted by Walls 1, 2, and 3 were 11,000 lb, 9,700 lb, and 12,000 lb, respectively.

3.4 Predicted Flexural Strength (2011 MSJC Code)

The predicted flexural strength of the wall panels was evaluated based upon standard design equations and principles outlined in the MSJC Code. Equations 3.4.1 through 3.4.4 were developed for standard masonry units and are applied here based upon the expectation that the NRG test specimens behave in a similar manner with the reinforcement yielding prior to failure. All calculations assume that all reinforcement is centered within the 3 in. x 3 in. cells. The value computed below for nominal flexural strength serve as a benchmark value for comparison to actual test results given in Section 3.3.

The equations used to calculate nominal moment strength for reinforcement in a single layer are shown below by Equations 3.4.1 and 3.4.2.

$$M_n = A_s f_y \left(d - \frac{a}{2} \right)$$

Equation 3.4.1

$$a = \frac{A_s f_y}{0.80 f'_m b}$$

Equation 3.4.2

For two layers of reinforcement, the equations above can be modified to produce Equations 3.4.3 and 3.4.4.

$$M_n = A_{s1} f_y \left(d_1 - \frac{a}{2} \right) + A_{s2} f_y \left(d_2 - \frac{a}{2} \right)$$

Equation 3.4.3

$$a = \frac{(A_{s1} + A_{s2}) f_y}{0.80 f'_m b}$$

Equation 3.4.4

where,

M_n = Nominal Moment Capacity of the Section (*lb-in*)

a = Depth of Equivalent Rectangular Stress Block (*in*)

A_{s1} = Area of Longitudinal Steel Reinforcement in top layer (in^2)
= (0.11 in^2 per bar)(2 bars) = 0.22 in^2

A_{s2} = Area of Longitudinal Steel Reinforcement in bottom layer (in^2)
= (0.11 in^2 per bar)(3 bars) = 0.33 in^2

f_y = Specified Yield Strength of Reinforcement (*psi*)
= 60,000 psi

d_1 = Distance from Extreme Compression Fiber to Centroid of Top Layer of Reinforcement (*in*)
= 2.75 in

d_2 = Distance from Extreme Compression Fiber to Centroid of Bottom Layer of Reinforcement (*in*)
= 4.875 in

b = Width of the Compression Face of the Section (*in*)
= 47.625 in

f'_m = Specified Compressive Strength of Masonry (*psi*)
= 4,000 psi (based upon ASTM C1314 prism test results)

Substituting the values above into Equations 3.4.3 and 3.4.4 gives the following values for Depth of Equivalent Rectangular Stress Block (a) and Nominal Moment Capacity (M_n):

$a = 0.217\ in$

$M_n = 129{,}300\ lb - in$

To compare this calculated moment value to the loads applied to the wall panels during testing, M_n was converted to a total load P_n using Equation 3.4.5.

$$P_n = \frac{2M_n}{x}$$

Equation 3.4.5

where,

x = Distance Between the Support and Spreader Beam Load Point (*in*)
= 27 in

Solving Equation 3.4.5 with the computed value of $M_n = 129{,}300\ lb - in$ gives a predicted total load of $P_n = 9{,}580\ lb$.

This predicted load is then compared to the measured total loads for each wall panel presented in Table 3. The tested capacities all exceed the predicted load capacity of 9,580 lb, indicating that the standard MSJC design methodologies developed for standard concrete masonry units can be used to conservatively predict the flexural capacity of the walls constructed using NRG units. When all three walls are considered together, the average total load of 10,900 lb is about 14% higher than the predicted capacity of 9,580 lb.

4. CONCLUSIONS

Both the prism compressive strength tests and flexural wall tests both indicate that the 8-inch nominal NRG unit can be successfully used in place of standard concrete masonry units in typical reinforced masonry construction.

Testing of the compression prisms provided consistent results for both the grouted and ungrouted samples. The average compressive strengths of masonry obtained from testing was 4,030 psi and 4,050 psi for the grouted and ungrouted samples, respectively, which are well in excess of values typically used in design. Although testing of prisms in this study did not evaluate the ability to transfer axial compressive loads across the rigid foam layer, a designer can conservatively consider only the masonry layer to one side of the rigid foam layer for resistance to axial compression, or alternatively the designer can elect to ensure that the load path engages both sides of the wall in compression. Given the low axial stress levels typical in most structures, this is not likely to be an issue of major significance.

Flexural wall panels demonstrated behavior similar to a conventional 8-inch concrete masonry assembly subjected to flexural loading. All wall panels failed in a ductile manner, at maximum total loads ranging from 9,700 to 12,000 lb. The tested capacities all exceed the predicted load capacity of 9,580 lb, indicating that the standard MSJC design methodologies developed for standard concrete masonry units can be used to conservatively predict the flexural capacity of the walls constructed using NRG units.

REFERENCES

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2. ASTM C90-12, *Standard Specification for Loadbearing Concrete Masonry Units,* ASTM International, West Conshohocken, PA, 2012.
3. ASTM C140-12, *Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units,* ASTM International, West Conshohocken, PA, 2012.
4. ASTM C109/C109M-11b, *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)*, ASTM International, West Conshohocken, PA, 2011.
5. ASTM C143-10a, *Standard Test Method for Slump of Hydraulic-Cement Concrete,* ASTM International, West Conshohocken, PA, 2010.
6. ASTM C270-12a, *Standard Specification for Mortar for Unit Masonry,* ASTM International, West Conshohocken, PA, 2012.
7. ASTM C476-10, *Standard Specification for Grout for Masonry,* ASTM International, West Conshohocken, PA, 2010.
8. ASTM C780-11, *Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry,* ASTM International, West Conshohocken, PA, 2011.
9. ASTM C1019-11, *Standard Test Method for Sampling and Testing Grout,* ASTM International, West Conshohocken, PA, 2011.
10. ASTM C1314-11a, *Standard Test Method for Compressive Strength of Masonry Prisms,* ASTM International, West Conshohocken, PA, 2011.
11. ASTM C1552-09a, *Standard Practice for Capping Concrete Masonry Units, Related Units and Masonry Prisms for Compression Testing,* ASTM International, West Conshohocken, PA, 2009.
12. ASTM E72-10, *Standard Test Methods of Conducting Strength Tests of Panels for Building Construction,* ASTM International, West Conshohocken, PA, 2010.

Appendix A – Concrete Masonry Unit Test Report

ASTM C140 Test Report

		Report Date:	1/28/2013
Client:	Niagara Regional Group	Testing Agency:	Villanova University Structural Engineering Teaching & Research Laboratory
Address:	4540 Gentwood Drive Williamsville, NY 14221	Address:	800 Lancaster Avenue Villanova, PA 19085

Unit Specification: ASTM C90-12 Sampling Party: Niagara Regional Group

Unit Designation/Description: NRG Insulated Block (8 in.)

Note: Specimens were saw-cut from full-size units to determine compressive strength. Absorption testing was performed on full-size units *including* the foam layer and full-size units *excluding* the foam layer.

Summary of Test Results – Compressive Strength

Physical Property	Required Values	Tested Values
Net Compressive Strength (psi)	$\geq$1900	6090
Gross Compressive Strength (psi)	N/A	4130
Net Cross-Sectional Area (in^2)	N/A	102

Individual Unit Test Results – Compressive Strength

Properties of Saw-Cut Compression Specimens

	Received Wt, W_R (lb)	Avg. Outer Width (in)	Avg. Inner Width (in)	Avg. Height (in)	Avg. Outer Length (in)	Avg. Inner Length (in)
Unit #1	5.46	5.06	2.93	3.83	5.21	2.94
Unit #2	5.42	5.06	2.91	3.90	5.20	2.93
Unit #3	5.51	5.09	2.90	3.85	5.20	2.91
Unit #4	5.49	5.10	2.90	3.87	5.20	2.93
Unit #5	5.44	5.07	2.93	3.90	5.20	2.92
Unit #6	5.41	5.12	2.91	3.83	5.20	2.92

	Cross-Sectional Area		Max.	Compressive Strength	
	Gross (in^2)	Net (in^2)	Load (lb)	Gross (psi)	Net (psi)
Unit #1	26.37	17.76	112,100	4250	6310
Unit #2	26.32	17.78	117,034	4450	6580
Unit #3	26.47	18.01	94,622	3570	5250
Unit #4	26.58	18.07	114,550	4310	6340
Unit #5	26.34	17.76	100,604	3820	5670
Unit #6	26.64	18.14	116,217	4360	6410

ASTM C140 Test Report

		Report Date:	1/28/2013
Client:	Niagara Regional Group	Testing Agency:	Villanova University Structural Engineering Teaching & Research Laboratory
Address:	4540 Gentwood Drive Williamsville, NY 14221	Address:	800 Lancaster Avenue Villanova, PA 19085

Unit Specification: ASTM C90-12 Sampling Party: Niagara Regional Group

Unit Designation/Description: NRG Insulated Block (8 in.)

Note: Specimens were saw-cut from full-size units to determine compressive strength. Absorption testing was performed on full-size units *including* the foam layer and full-size units *excluding* the foam layer.

Summary of Test Results - Absorption

Physical Property	Required Values	Full-Size *Including* Foam	Full-Size *Excluding* Foam
Density (pcf)	N/A	101.9	140.4
Absorption (pcf)	$\leq$ 13	4.12	4.20
Net Cross-Sectional Area (in^2)	N/A	102	68
Net Volume (ft^3)	N/A	0.21	0.15
Average Net Area (in^2)	N/A	99.27	71.90
Equivalent Thickness (in.)	N/A	6.35	4.60
Percent Solid (ft^3)	N/A	83.32	60.35

Individual Unit Test Results - Absorption

Properties of Full Unit Absorption Specimens – *Including* Rigid Foam Layer

	Received Wt, W_r (lb)	Immersed Wt, W_i (lb)	Saturated Wt, W_s (lb)	Oven-Dry Wt, W_D (lb)	Absorption (pcf)
Unit #7	21.54	9.13	22.14	21.29	4.08
Unit #8	21.44	9.11	22.05	21.23	3.96
Unit #9	21.50	9.14	22.13	21.27	4.13
Unit #10	21.33	8.97	22.02	21.12	4.31

	Density (pcf)	Net Volume (ft^3)	Avg. Net Area, A_n (in^2)	Effective Thickness, T_e (in)	% Solid (%)
Unit #7	102.08	0.21	99.43	6.36	83.46
Unit #8	102.41	0.21	98.80	6.32	82.93
Unit #9	102.20	0.21	99.20	6.35	83.26
Unit #10	101.00	0.21	99.65	6.38	83.64

ASTM C140 Test Report

		Report Date:	1/28/2013
Client:	Niagara Regional Group	Testing Agency:	Villanova University Structural Engineering Teaching & Research Laboratory
Address:	4540 Gentwood Drive Williamsville, NY 14221	Address:	800 Lancaster Avenue Villanova, PA 19085

Unit Specification: ASTM C90-12 Sampling Party: Niagara Regional Group

Unit Designation/Description: NRG Insulated Block (8 in.)

Note: Specimens were saw-cut from full-size units to determine compressive strength. Absorption testing was performed on full-size units *including* the foam layer and full-size units *excluding* the foam layer.

Individual Unit Test Results - Absorption

Properties of Full Unit Absorption Specimens – *Excluding* Rigid Foam Layer

	Received Wt, W_r (lb)	Immersed Wt, W_i (lb)	Saturated Wt, W_s (lb)	Oven-Dry Wt, W_D (lb)	Absorption (pcf)
Unit #11	21.38	12.68	22.04	21.17	5.82
Unit #12	21.28	12.58	22.06	21.08	6.44
Unit #13	21.59	12.79	22.22	21.39	5.50
Unit #14	21.32	12.55	22.93	21.06	5.83

	Density (pcf)	Net Volume (ft^3)	Avg. Net Area, A_n (in^2)	Effective Thickness, T_e (in)	% Solid (%)
Unit #11	141.18	0.15	71.47	4.57	59.99
Unit #12	138.80	0.15	72.40	4.63	60.77
Unit #13	141.56	0.15	72.02	4.61	60.45
Unit #14	139.97	0.15	71.71	4.59	60.19

Comments: All specimens meet ASTM C90 requirements for compressive strength and absorption.

Appendix B – Mortar Test Report

ASTM C780
Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry

		Report Date:	1/28/2013
Client:	Niagara Regional Group	Testing Agency:	Villanova University Structural Engineering Teaching & Research Laboratory
Address:	4540 Gentwood Drive Williamsville, NY 14221	Address:	800 Lancaster Avenue Villanova, PA 19085

Batch Information (ASTM C270)

Corresponding Wall/Specimen: NRG Panels
Mortar Type: S (Masonry Cement)

Material	**Type/Brand/Source**	**Volume Proportions**
Masonry Cement	High Strength for Type S Mortar	1
Masonry Sand	n/a	2.5
Water	Tap Water	Varies

Date Mixed: 10/9/12, 10/10/12

2 in x 4 in Cylinder Compressive Strength (C780)
Cylinder Age: 31 days

Batch #	Cylinder	Load (lb)	Strength (psi)	Batch Average Strength (psi)
1	A	4070	1242	
1	B	8910	2727	
1	C	9015	2757	2740
2	A	8905	2714	
2	B	8983	2744	
2	C	9195	2790	2750
3	A	6445	1972	
3	B	6298	1919	
3	C	6298	1928	1940

Testing by: SNL
Date: 11/09/12

ASTM C780

Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry

		Report Date:	1/28/2013
Client:	Niagara Regional Group	Testing Agency:	Villanova University
Address:	4540 Gentwood Drive		Structural Engineering Teaching
	Williamsville, NY 14221		& Research Laboratory
		Address:	800 Lancaster Avenue
			Villanova, PA 19085

2 in Cube Compressive Strength (C780 / C109)

Cube Age: 31 days

Batch #	Cylinder	Load (lb)	Strength (psi)	Batch Average Strength (psi)
1	D	13320	3330.00	
1	E	12297	3074.25	
1	F	11988	2997.00	3030
2	D	11709	2927.25	
2	E	11932	2983.00	
2	F	11409	2852.25	2920
3	D	9576	2394.00	
3	E	9245	2311.25	
3	F	8863	2215.75	2350
4	D	13171	3292.75	
4	E	14568	3642.00	
4	F	13715	3428.75	3360

Tested by: SNL

Date: 11/09/12

Appendix C – Grout Test Report

ASTM C1019-11: Sampling and Testing Grout

		Report Date:	1/28/2013
Client:	Niagara Regional Group	Testing Agency:	Villanova University Structural Engineering Teaching & Research Laboratory
Address:	4540 Gentwood Drive Williamsville, NY 14221	Address:	800 Lancaster Avenue Villanova, PA 19085

Mix Design:	Wall 1
Date Made:	10/09/12
Date Tested:	11/20/12
Tested By:	SNL

	Specimen 1	Specimen 2	Specimen 3	Average
Height (in)				
1	3.31	5.69	6.19	
2	3.31	5.69	6.19	
3	3.31	5.69	6.13	
4	3.31	5.69	6.13	
Average	3.31	5.69	6.16	5.93 **
Width (in)				
1	2.84	2.72	2.95	
2	2.97	2.97	2.90	
3	2.83	2.70	2.96	
4	2.87	2.96	2.95	
Average	2.88	2.84	2.94	2.89
Compressive Load (lb)	22640	21720	26770	23710
Compressive Strength (psi)	2736	2701	3102	2850

** Value is average of Specimens 2 and 3

Curing Conditions: 1 day in mold
41 days in moist closet

ASTM C1019-11: Sampling and Testing Grout

		Report Date:	1/28/2013
Client:	Niagara Regional Group	Testing Agency:	Villanova University Structural Engineering Teaching & Research Laboratory
Address:	4540 Gentwood Drive Williamsville, NY 14221	Address:	800 Lancaster Avenue Villanova, PA 19085

Mix Design: Wall 3
Date Made: 10/10/12
Date Tested: 11/20/12
Tested By: SNL

	Specimen 1	Specimen 2	Specimen 3	Average
Height (in)				
1	6.31	6.31	6.25	
2	6.31	6.31	6.25	
3	6.31	6.31	6.25	
4	6.31	6.31	6.31	
Average	6.31	6.31	6.27	6.30
Width (in)				
1	3.36	3.16	3.62	
2	3.15	3.33	3.31	
3	3.46	3.18	3.66	
4	3.30	3.26	3.40	
Average	3.32	3.23	3.50	3.35
Compressive Load (lb)	29870	28210	28460	28847
Compressive Strength (psi)	2713	2697	2324	2580

Curing Conditions: 1 day in mold
40 days in moist closet

ASTM C1019-11: Sampling and Testing Grout

		Report Date:	1/28/2013
Client:	Niagara Regional Group	Testing Agency:	Villanova University Structural Engineering Teaching & Research Laboratory
Address:	4540 Gentwood Drive Williamsville, NY 14221	Address:	800 Lancaster Avenue Villanova, PA 19085

Mix Design:	Wall 1
Date Made:	10/10/12
Date Tested:	11/20/12
Tested By:	SNL

	Specimen 1	Specimen 2	Specimen 3	Average
Height (in)				
1	6.44	6.50	6.38	
2	6.44	6.56	6.38	
3	6.44	6.56	6.38	
4	6.44	6.50	6.38	
Average	6.44	6.53	6.38	6.45
Width (in)				
1	3.10	3.32	3.11	
2	3.02	3.05	2.99	
3	3.10	3.33	3.15	
4	3.03	3.03	3.07	
Average	3.06	3.18	3.08	3.11
Compressive Load (lb)	24000	24260	24590	24283
Compressive Strength (psi)	2564	2399	2591	2520

Curing Conditions: 1 day in mold
40 days in moist closet

Appendix D – Prism Test Report

ASTM C1314-11a Test Report
Constructing and Testing Masonry Prisms Used to Determine Compliance with Specified Compressive Strength of Masonry

		Report Date:	1/28/2013
Client:	Niagara Regional Group	Testing Agency:	Villanova University Structural Engineering Teaching & Research Laboratory
Address:	4540 Gentwood Drive Williamsville, NY 14221	Address:	800 Lancaster Avenue Villanova, PA 19085

Prism Identification: Partial Unit, Grouted, Stack Bond, Concrete Masonry Prism
Face shell mortar bedding only

Prism Details:
Number of Mortar Bed Joints: 2
Number of Masonry Units Used: 3
Date Tested: 11/12/12

Masonry Unit Information:
Unit Supplier: Niagara Regional Group
Unit Dimensions: 8 x 4 x 16
Unit Net Area (hollow units): N/A

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

Grout Information:
Grout Supplier / Preparer: Mason
Grout Type / Description: Fine
Grout Slump (ASTM C143): 6 in.
Method of Consolidation: Mechanical

Compression Test Machine Information:
Upper Platen Width: 6.5 in.
Upper Platen Depth: 6.5 in.
Upper Platen Thickness: 2 in.
Lower Platen Width: 12.25 in.
Lower Platen Depth: 18 in.
Lower Platen Thickness: 2 in.

Tested Prism Properties (* Height to Thickness Correction Factor obtained from ASTM C1314-11a Table 1):

Prism No.	Test Age (day)	Avg. Width (in)	Avg. Height (in)	Avg. Length (in)	Gross/Net Area (in^2)	Max Load (lb)	Gross/Net Comp. Strength (psi)	h/t Ratio	h/t CF *	Corrected Gross/Net Strength (psi)
1	33	5.22	11.84	5.00	26.14	107926	4129	2.37	1.03	4250
2	33	5.22	11.80	5.08	26.51	104411	3939	2.36	1.03	4050
3	33	5.20	11.84	5.14	26.76	100614	3761	2.37	1.03	3870
4	33	5.22	11.94	5.07	26.47	101541	3837	2.39	1.03	3950
5	33	5.21	11.88	5.12	26.66	106402	3992	2.37	1.03	4110
6	33	5.21	11.80	5.07	26.39	100767	3819	2.36	1.03	3930
									Average	4030

ASTM C1314-11a Test Report
Constructing and Testing Masonry Prisms Used to Determine Compliance with Specified Compressive Strength of Masonry

		Report Date:	1/28/2013
Client:	Niagara Regional Group	Testing Agency:	Villanova University Structural Engineering Teaching & Research Laboratory
Address:	4540 Gentwood Drive Williamsville, NY 14221	Address:	800 Lancaster Avenue Villanova, PA 19085

Prism Identification: Partial Unit, Hollow, Stack Bond, Concrete Masonry Prism
Face shell mortar bedding only

Prism Details:		Masonry Unit Information:	
Number of Mortar Bed Joints:	2	Unit Supplier:	Niagara Regional Group
Number of Masonry Units Used:	3	Unit Dimensions:	8 x 4 x 16
Date Tested:	11/12/12	Unit Net Area (hollow units):	18.11

Mortar Information:		Grout Information:	
Mortar Supplier / Preparer:	Mason	Grout Supplier / Preparer:	N/A
Mortar Type / Description:	S	Grout Type / Description:	N/A
		Grout Slump (ASTM C143):	N/A
		Method of Consolidation:	N/A

Compression Test Machine Information:

Upper Platen Width:	6.5 in.	Lower Platen Width:	12.25 in.
Upper Platen Depth:	6.5 in.	Lower Platen Depth:	18 in.
Upper Platen Thickness:	2 in.	Lower Platen Thickness:	2 in.

Tested Prism Properties (* Height to Thickness Correction Factor obtained from ASTM C1314-11a Table 1):

Prism No.	**Test Age (day)**	**Avg. Width (in)**	**Avg. Height (in)**	**Avg. Length (in)**	**Gross Area (in^2)**	**Max Load (lb)**	**Gross Comp. Strength (psi)**	**h/t Ratio**	**h/t CF ***	**Corrected Gross Strength (psi)**
7	33	5.16	11.81	5.18	26.72	77508	2900	2.35	1.03	2980
8	33	5.20	11.77	5.03	26.15	71396	2730	2.34	1.03	2810
9	33	5.21	11.81	5.04	26.25	65826	2508	2.35	1.03	2580
10	33	5.20	11.89	5.03	26.14	70344	2691	2.37	1.03	2770
11	33	5.20	11.81	5.16	26.85	67759	2524	2.35	1.03	2600
12	33	5.20	11.77	5.02	26.11	75017	2873	2.34	1.03	2950
									Average	2780

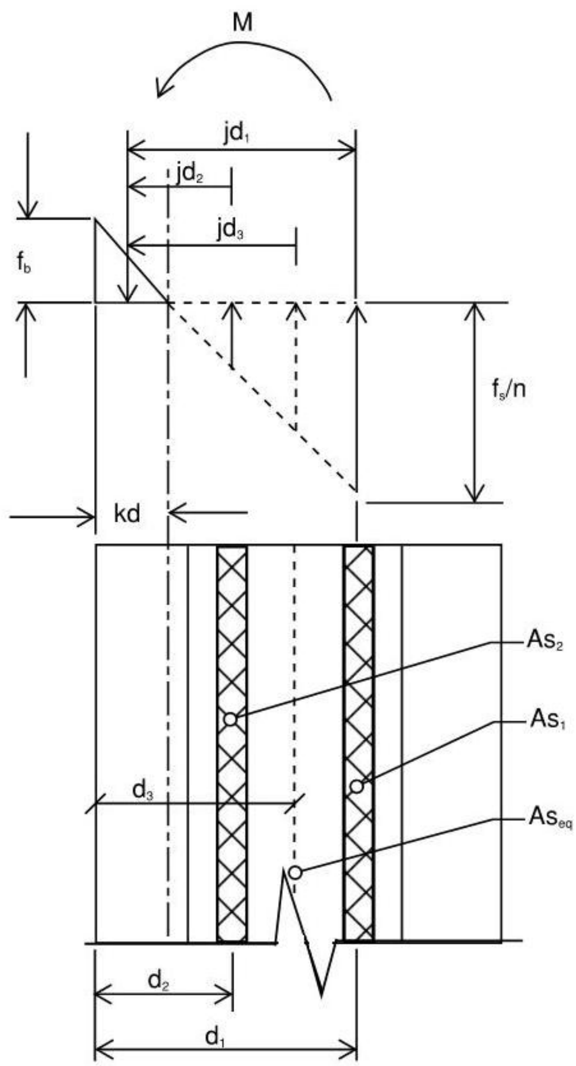
Prism No.	**Net Area (in^2)**	**Max Load (lb)**	**Net Comp. Strength (psi)**	**h/t Ratio**	**h/t CF ***	**Corrected Net Strength (psi)**
7	18.15	77508	4270	2.35	1.03	4390
8	17.47	71396	4088	2.34	1.03	4200
9	18.68	65826	3523	2.35	1.03	3620
10	17.62	70344	3993	2.37	1.03	4110
11	18.23	67759	3717	2.35	1.03	3820
12	18.52	75017	4050	2.34	1.03	4160
					Average	4050

Appendix B

MASONRY PROPERTIES

	NRG 8 BLOCK		STD BLOCK	
ALLOWABLE STEEL STRESS (F_S)	32000	PSI	32000	PSI
MASONRY COMPRESSIVE STRENGTH (f'_m)	4000	PSI	2000	PSI
ALLOWABLE MASONSRY STRESS DUE TO BENDING (f_m)	1800	PSI	900	PSI
STEEL MODULUS OF ELASTICITY (E_S)	29000000	PSI	29000000	PSI
MASONRY MODULUS OF ELASTICITY (E_M)	3600000	PSI	1800000	PSI
n	8.1		16.11	
BLOCK WIDTH	15.625	IN	15.625	IN
BLOCK DEPTH	7.625	IN	7.625	IN
d_1=	4.875			
d_2=	2.75			
d_3=	3.8125	IN	3.8125	IN

Moment Capacities for 8" NRG Units using Allowable Stress Design
f'_m = 4,000 psi, f_y = 60,000 psi, and n = 8.1



DESIGN DATA

f'_m = 4,000 psi
F_b = .45 f'_m = 1,800 psi
E_m = 900 f'_m = 3,600,000 psi
f_y = 60,000 psi
F_s = 32,000 psi
E_s = 29,000,000 psi

DESIGN EQUATIONS

$$n = \frac{E_s}{E_m} = 8.1 \qquad p = \frac{As_{eq}}{bd_3}$$

$$As_{eq} = [As_1 (d_1) + As_2 (d_2/d_1) d_2] / d_3$$

$$k = \sqrt{2np + (np)^2} - np$$

$$M_m = F_b b d_3^2 \left(\frac{1}{2/jk}\right) \qquad j = 1 - \frac{k}{3}$$

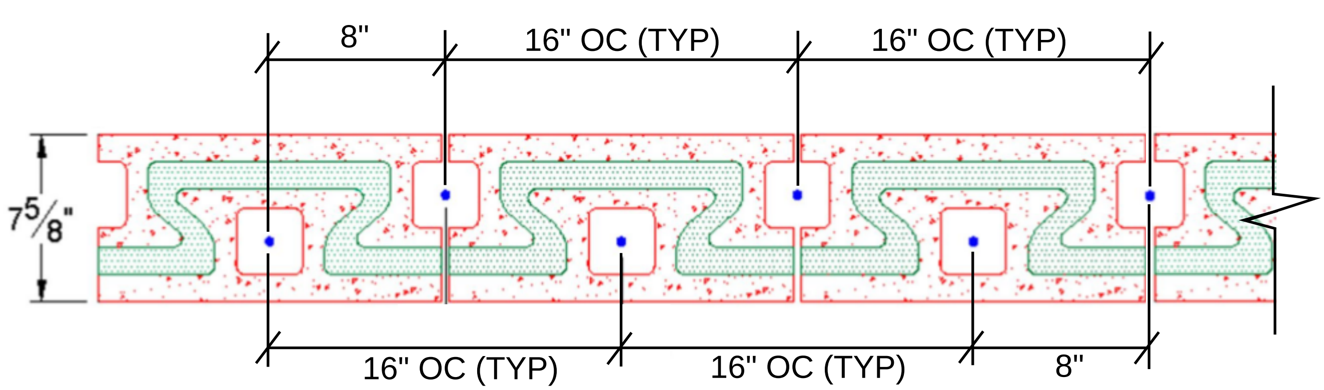
$$M_s = F_s (As_{eq}) (jd_3)$$

d_1 = 4.875"

d_2 = 2.75"

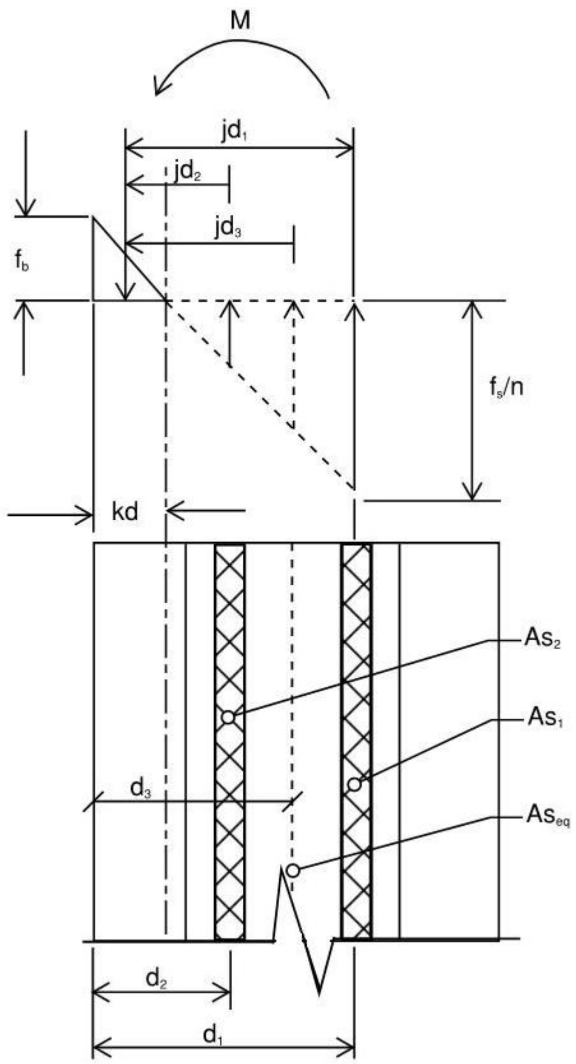
d_3 = 3.8125"

BAR SPACING: 16" OC EA SIDE OF WALL						
Bar Size	As_{eq} (in^2/ft)	np	2/jk	j	k	Controlling Maximum Moment Mm or Ms (ft-lb)
#3	0.140	0.0246	10.79	0.9338	0.1985	Ms = 1326
#4	0.248	0.0437	8.57	0.9149	0.2552	Ms = 2309
#5	0.388	0.0683	7.25	0.8975	0.3075	Ms = 3539
#6	0.559	0.0983	6.38	0.8814	0.3559	Mm = 4104



BAR SPACING: 16" OC EA SIDE OF WALL

Moment Capacities for 8" NRG Units using Allowable Stress Design
f'_m = 4,000 psi, f_y = 60,000 psi, and n = 8.1



DESIGN DATA

$f'_m = 4{,}000$ psi | $f_y = 60{,}000$ psi

$F_b = .45\, f'_m = 1{,}800$ psi | $F_s = 32{,}000$ psi

$E_m = 900\, f'_m = 3{,}600{,}000$ psi | $E_s = 29{,}000{,}000$ psi

DESIGN EQUATIONS

$$n = \frac{E_s}{E_m} = 8.1 \qquad p = \frac{As_{eq}}{bd_3}$$

$$As_{eq} = [As_1\,(d_1) + As_2\,(d_2/d_1)\,d_2]\,/\,d_3$$

$$k = \sqrt{2np + (np)^2} - np$$

$$M_m = F_b b d_3^2 \left(\frac{1}{2/jk}\right) \qquad j = 1 - \frac{k}{3}$$

$$M_s = F_s\,(As_{eq})\,(jd_3)$$

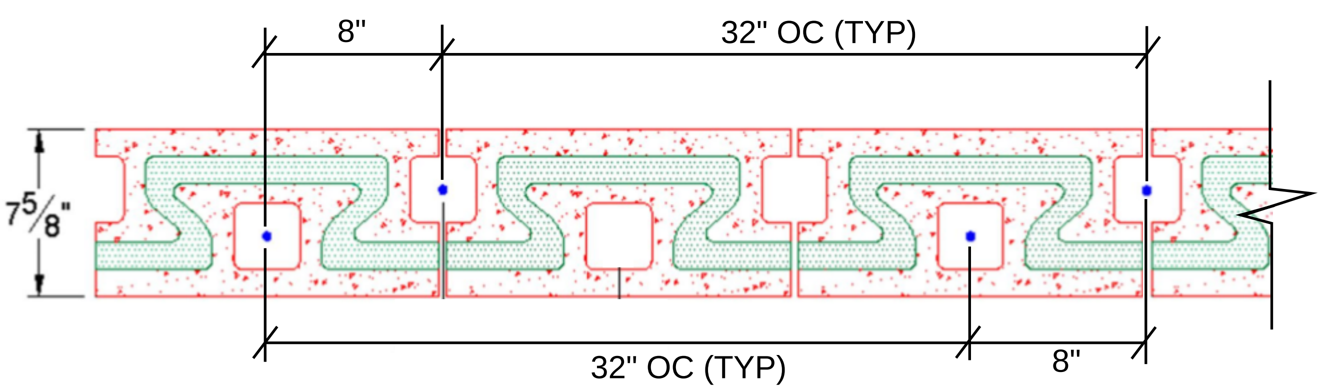
$d_1 = 4.875"$

$d_2 = 2.75"$

$d_3 = 3.8125"$

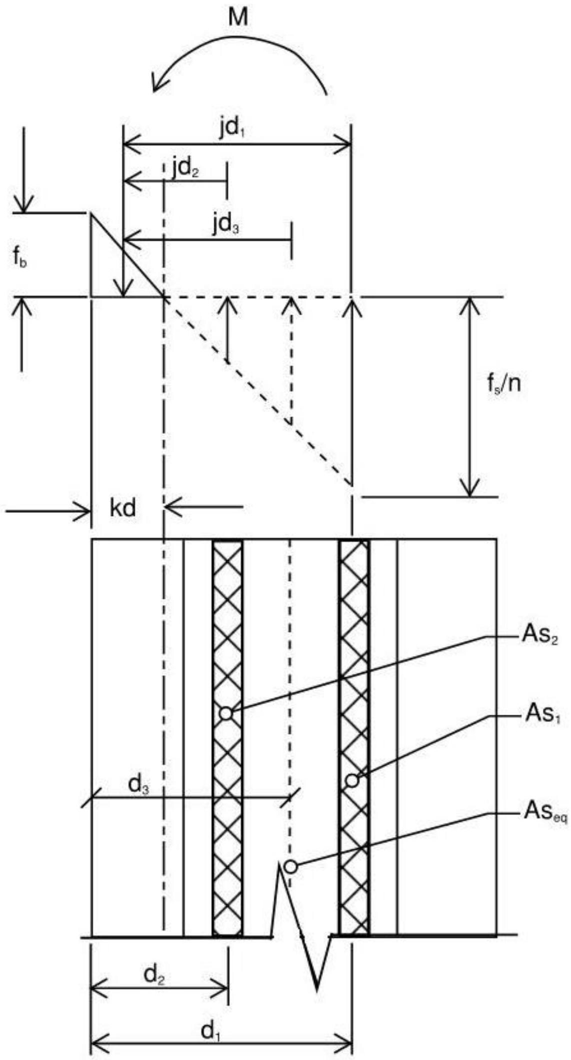
BAR SPACING: 32" OC EA SIDE OF WALL

Bar Size	As_{eq} (in^2/ft)	np	2/jk	j	k	Controlling Maximum Moment Mm or Ms (ft-lb)
#3	0.07	0.0123	14.50	0.9517	0.1450	Ms = 675
#4	0.124	0.0219	11.33	0.9372	0.1883	Ms = 1183
#5	0.194	0.0342	9.44	0.9235	0.2294	Ms = 1821
#6	0.279	0.0492	8.19	0.9106	0.2683	Ms = 2585



BAR SPACING: 32" OC EA SIDE OF WALL

Moment Capacities for 8" NRG Units using Allowable Stress Design
f'_m = 4,000 psi, f_y = 60,000 psi, and n = 8.1



DESIGN DATA

f'_m = 4,000 psi | f_y = 60,000 psi

$F_b = .45 f'_m$ = 1,800 psi | F_s = 32,000 psi

$E_m = 900 f'_m$ = 3,600,000 psi | E_s = 29,000,000 psi

DESIGN EQUATIONS

$$n = \frac{E_s}{E_m} = 8.1 \qquad p = \frac{As_{eq}}{bd_3}$$

$$As_{eq} = [As_1 (d_1) + As_2 (d_2/d_1) d_2] / d_3$$

$$k = \sqrt{2np + (np)^2} - np$$

$$M_m = F_b b d_3^2 \left(\frac{1}{2/jk}\right) \qquad j = 1 - \frac{k}{3}$$

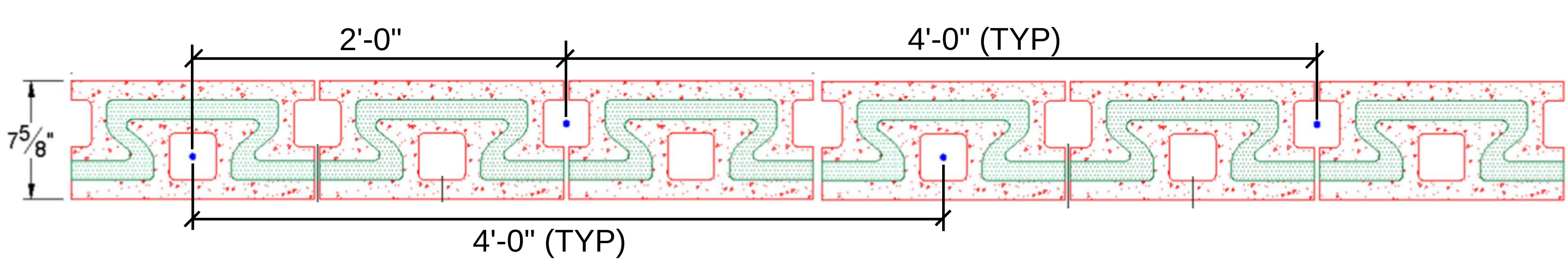
$$M_s = F_s (As_{eq}) (jd_3)$$

d_1 = 4.875"

d_2 = 2.75"

d_3 = 3.8125"

BAR SPACING: 48" OC EA SIDE OF WALL						
Bar Size	As_{eq} (in²/ft)	np	2/jk	j	k	Controlling Maximum Moment Mm or Ms (ft-lb)
#3	0.047	0.0082	17.35	0.9600	0.1201	Ms = 454
#4	0.083	0.0146	13.46	0.9478	0.1567	Ms = 797
#5	0.129	0.0228	11.14	0.9361	0.1918	Ms = 1230
#6	0.186	0.0328	9.60	0.9249	0.2254	Ms = 1751



BAR SPACING: 48" OC EA SIDE OF WALL

Moment Capacity Comparison				
Bar Size		#3		
Bar Spacing (inches)	NRG (ea side of wall)	16	32	48
	STD (centered in wall)	8	10	24
Steel Area (in^2/ft)		.165	.132	.055
Controlling Moment Capacity (ft-lb/ft)	NRG	1326	675	454
	STD	1523	1230	528

Moment Capacity Comparison				
Bar Size		#4		
Bar Spacing (inches)	NRG (ea side of wall)	16	32	48
	STD (centered in wall)	8	10	24
Steel Area (in^2/ft)		.294	.235	.098
Controlling Moment Capacity (ft-lb/ft)	NRG	2309	1183	797
	STD	2089	1935	921

Moment Capacity Comparison				
Bar Size		#5		
Bar Spacing (inches)	NRG (ea side of wall)	16	32	48
	STD (centered in wall)	8	10	24
Steel Area (in^2/ft)		.461	.368	.154
Controlling Moment Capacity (ft-lb/ft)	NRG	3539	1821	1230
	STD	2409	2247	1414

Moment Capacity Comparison				
Bar Size		#6		
Bar Spacing (inches)	NRG (ea side of wall)	16	32	48
	STD (centered in wall)	8	10	24
Steel Area (in^2/ft)		.663	.530	.231
Controlling Moment Capacity (ft-lb/ft)	NRG	4104	2585	1751
	STD	2675	2512	1892