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Research Evaluation of Single Lift Grouting in Concrete Masonry Wall Panels

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Abstract

The objective of this research was to investigate and document the properties of grouted concrete masonry construction using lift heights that exceed the current 5 foot requirement. Based on the observations stemming from this investigation, appropriate modifications can be proposed to the ACI 530.1/ASCE 6/TMS 602 and other national model codes that govern grout lift requirements. Four CMU wall panels were constructed and tested: Two wall panels were grouted, consolidated, and reconsolidated in 5 foot maximum lifts in accordance with the ACI 530.1/ASCE 6/TMS 602. The other two walls panels, the grout was placed in one continuous lift with mechanical consolidation and reconsolidation only in the top 8 feet of the wall.

Key words

Grouting, compressive strength, grout bond, testing

1 Introduction

A labor intensive and time consuming portion of reinforced concrete masonry construction is grouting the concrete masonry unit (CMU) cores to provide bond between the reinforcing steel and the CMU. The building codes have set a maximum pour height - essentially the distance that grout is allowed to drop - of 24 feet for high lift grouting. However, the maximum grout lift height - the height of grout that can be placed at one time - is stipulated as 5 feet. Each lift must be consolidated and reconsolidated before the next lift can be placed. The *Specification for Masonry Structures* (ACI 530.1/ASCE 6/TMS 602 allows full wall height grouting on an individual case basis provided that it can be shown that a quality end product is provided as permitted by ACI 530.1/ASCE 6/TMS 602. This provision has been successfully utilized on a number of projects to allow increased grout lift heights.

2 Project Scope - General

The objective of this research was to investigate and document the properties of grouted concrete masonry construction using lift heights that exceed the current 5 foot requirement. Based on the observations stemming from this investigation, appropriate modifications can be proposed to the ACI 530.1/ASCE 6/TMS 602 and other national model codes that govern grout lift requirements.

Four CMU wall panels were constructed and tested: two 24 foot tall CMU wall panels were constructed at Allied Block Company Plant in Chesapeake, Virginia and one 18 foot CMU wall panel constructed at the National Block and Ready Mix Plant in Westland, Michigan in which the control panel and the test panel were joined to form a single panel for stability and ease of construction. Test specimens were obtained from these wall panels. Two wall panels – one from Virginia and one from Michigan - were control panels, grouted, consolidated, and reconsolidated in 5 foot maximum lifts in accordance with the ACI 530.1/ASCE 6/TMS 602, herein know as multi-lift. In the other two walls panels, the grout was placed in one continuous

lift with mechanical consolidation and reconsolidation only in the top 8 feet of the wall, known as single lift in this report. The wall panels were allowed to cure 14 days before test specimens were obtained.

In the following report the wall designations are as follows:

- ML - 1: multi-lift constructed at Chesapeake, Virginia
- SL – 1: single lift constructed at Chesapeake, Virginia
- ML - 2: multi-lift constructed at Westland, Michigan
- SL – 2: single lift constructed at Westland, Michigan

Four identical 24 foot tall concrete masonry wall panels (with an 8 inch base course to facilitate the installation of dowels at the bottom of the panels) were constructed at the Allied Block Plant Company in Chesapeake, Virginia, although only two were considered in this research study. One wall was used as the control specimen grouted in 5 foot lifts, consolidated and reconsolidated using a mechanical vibrator in accordance with conventional high lift grouting code requirements. The second test panel was grouted in one continuous 24-foot lift with only the top 8 foot consolidated and reconsolidated using a mechanical vibrator. The wall panels were anchored to an existing steel frame are shown in Figure 1. Reinforcement consisting of No. 5 bars was placed in the middle two cores of each CMU wall panel.

Figure 1. ML – 1 and SL-1 walls laterally supported by steel frame

Figure 2. ML – 2 and SL-2 walls braced with steel supports

One 18 foot high concrete masonry panel shown on Figure 2 was constructed at National Block and Ready Mix in Westland, Michigan. The panel was constructed with 8" squared end lightweight CMU using in Type S masonry cement mortar. The length of the panel constructed was 8 feet with 16" end returns for lateral stability. The panel was doweled into an existing concrete slab and braced for stability in accordance with the *Standard Practice for Bracing Masonry Walls Under Construction*. Four of the vertical cells within the panel were used as the

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control specimen. These cells were grouted in accordance with the minimum code requirements of ACI 530.1/ASCE 6/TMS 602. The grout was placed in 5 foot lifts, consolidated and then reconsolidated. Two of these cells were reinforced with one #5 bar in each cell, and the other two cells were grouted with no steel reinforcement. This wall panel was not constructed with any horizontal steel reinforcement.

3 Test Results

This section describes the testing of specimens taken from the wall panels described above. The three tests performed on the specimens were prism compression, visual inspection of grout-to-reinforcement bonding, and grout bond shear testing. The prism compression test was conducted using the procedures of ASTM C 1314 *Standard Test Method for Compressive Strength of Masonry Prisms*. The grout reinforcement bonding was determined by visual inspection of the saw cut specimens of the flow of the grout around the reinforcement at various heights of the concrete masonry walls. The grout bond shear test was conducted in accordance with *Draft Standard: Standard Test Method for Grout Bond Shear Strength for Masonry* under development at ASTM.

3.1Preparation of Test Specimens

Specimens were removed from the wall panels at 2 foot increments as shown in Figure 3. The specimens were designated by the lift method used and the wall assembly course number starting from the bottom of the wall. Specimens with an "S" represented the single lift concrete masonry wall and specimens with an "M" represented the multiple lift concrete masonry wall. For example an S-14 is the prism at the 14th course from the bottom of the single lift wall panel.

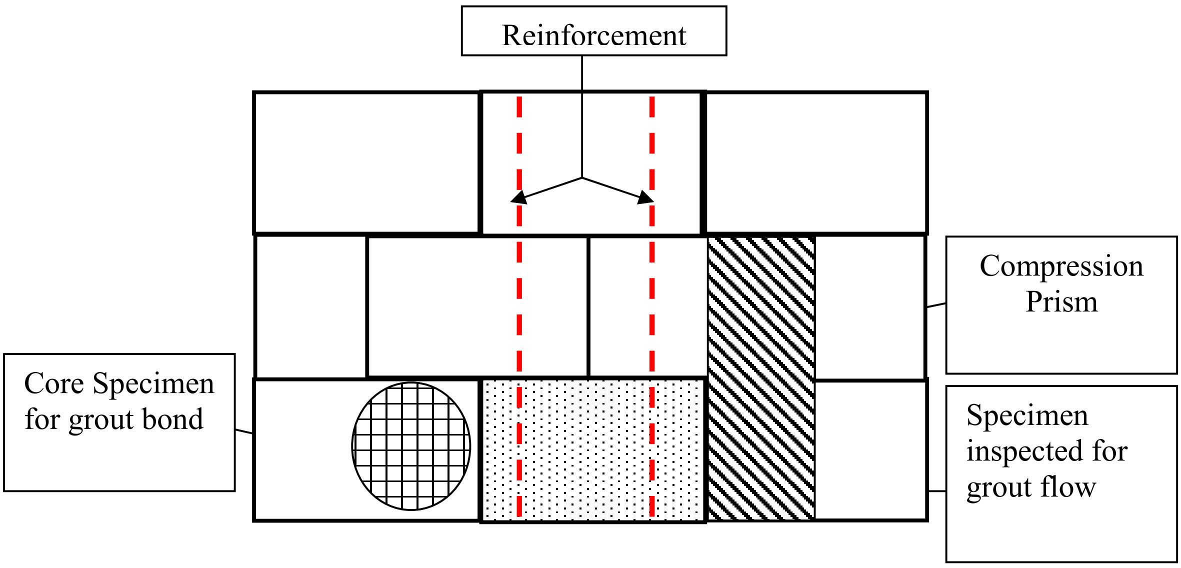


Figure 3. Diagram of a wall panel showing the specimen locations

3.2 Prism Compression Testing

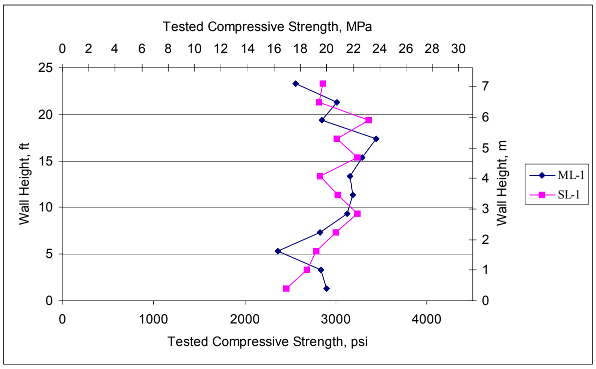
There were a total of 42 compression prisms tested between the single and multiple lift wall panels. Compressive strengths were based on a single prism test for each course under consideration. Descriptive statistics for the prism tests are listed in Table 1. The ranges for the prisms strengths were high with a coefficient of variation from 8 to 10 percent. When testing compressive strength, it is standard practice to perform at least three tests and average the values to obtain a representative result. Only one specimen was tested per wall location, which may have resulted in the large variability of the data.

Prism compression strengths plotted as a function of wall height are shown in Figure 4. Shown are the prism compressive strengths for the wall specimens at different wall heights. For walls ML-2 and SL-2, good agreement is shown for prism compressive strengths at each wall height - within 10 percent – except in two cases. In these two cases, the compressive strengths at approximately 5 feet from the wall bottom differ 10.2 percent, and at about 7 feet, the difference increases to 24.3 percent. Conversely, the comparison between ML-1 and SL-2 shows more varying results at each wall height. This may be a function of the horizontal bond beam installed in these walls.

Table 1. Descriptive Statistics of Prism Test

Value	SL-1	ML-1	SL-2	ML-2
Average (MPa)	20.3	20.5	23.8	25.3
Standard deviation (MPa)	2.0	2.1	2.5	2.2
COV (percent)[1]	8.7	10.2	10.5	8.6
Maximum (MPa)	23.2	23.7	27.5	27.2
Minimum (MPa)	17.0	16.3	19.7	20.5
Range (MPa)	6.2	7.4	7.8	6.7

1) COV = coefficient of variation



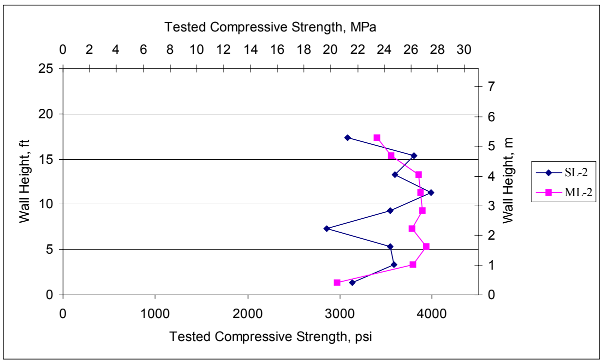


Figure 4. Masonry compressive strength results

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4.2 Grout Flow Inspection

The purpose of the grout flow inspection was to observe the flow of the grout around the reinforcing steel and the presence of any voids. A single reinforced specimen was observed per 2-feet of wall panel and a total of 42 specimens were inspected. There was no noticeable segregation of the aggregate in the grout in either the multiple or single lift test specimens. Further, no voids were observed at any wall height. Photographs were taken of all inspected specimens and these for selected wall heights are shown in Tables 2 and 3.

The grout flow around the reinforcement showed adequate bonding and was observed to be the same for both wall panels. Therefore, the grout lift strategy had no affect on the grout flow around the reinforcement. For example, at course 17 and course 11 the flow of the grout around the reinforcement was the same for the walls SL-1 and ML-1.

Table 2. Grout flow observations – SL-1 and ML-1

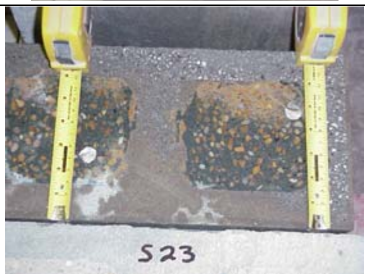
Course #	SL-1	ML-1
36		
26		
11		

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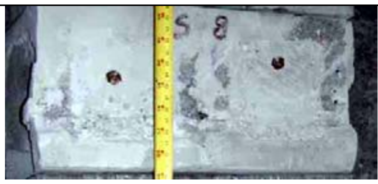
Table 2. Grout flow observations – SL-1 and ML-1

Course #	SL-1	ML-1
2		

Table 3. Grout flow observations – SL-2 and ML-2

Course #	SL-2	ML-2
26		
17		
8		
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4.4 Grout Bond Shear Test

The 6-inch core specimens taken at 2 foot intervals from all the wall panels were tested to determine the grout bond shear strength. The possible failure modes were classified as grout, unit, interface, or combined failure that are shown in Figure 5. A unit failure occurred when the plane of failure was exclusively in the CMU and a grout failure occurred when the plane of failure was exclusively in the grout. When a large portion of the bonding plane in between the unit and the grout was exposed after failure, then the failure mode was called an interface

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failure. A combined failure occurred when the failure was in both the unit and the grout with minimal shearing along the bonding plane.

Unit Failure

Grout Failure

Combined failure

Interface failure

Figure 5. Failure modes for grout bond shear specimens

Table 4 lists the failure modes observed for all the wall specimens. The modes are listed by wall height showing the mode at the designated front and back of the wall panels. The most prevalent type of failure for the single lift walls below the point of consolidation was failure involving grout. For example, approximately 17 feet of SL-1 showed 10 grout and one combined failure out of 16 observations. For SL-2 there were 4 grout and 5 combined failures out of 10 observations below approximately 9 feet. Interface failures were frequent in the zone of vibration: 3 and 4 observations for interface failure for walls SL-1 and SL-2, respectively. Additionally, interface failures were observed for the ML walls: 5 and 8 observed interface failures for ML-1 and ML-2, respectively. Interface failures were not observed below the zone of consolidation, suggesting that grout head pressure is forcing grout against the unit facilitating good bond between the CMU and grout.

Table 4. Failure modes of grout bond shear specimens

Wall height (ft)	**SL-1**		**ML-1**	
	Front	**Back**	**Front**	**Back**
23.33	grout	interface	interface	interface
21.33	interface	interface	interface	interface
19.33	unit	unit	unit	interface

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Table 4. Failure modes of grout bond shear specimens

Wall height (ft)	SL-1		ML-1	
	Front	**Back**	**Front**	**Back**
17.33	unit	grout	unit	grout
15.33(1)	grout	unit	unit	unit
13.33	grout	grout	grout	unit
11.33	unit	grout	unit	unit
9.33	grout	grout	grout	grout
7.33	unit	unit	grout	unit
5.33	combined	grout	grout	grout
3.33	unit	grout	grout	grout
1.33	grout	grout	grout	grout
Wall height (ft)	**SL-2**		**ML-2**	
	Front	**Back**	**Front**	**Back**
17.33	interface	interface	interface	combined
15.33	combined	interface	interface	combined
13.33	combined	interface	interface	combined
11.33	combined	grout	combined	grout
9.33(1)	combined	combined	interface	interface
7.33	Grout	unit	broke in setup	interface
5.33	combined	grout	interface	interface
3.33	grout	grout	combined	Grout
1.33	combined	combined	interface	Grout

1) Shading indicates below consolidation zone

4.5 Observations on prism compressive strength

The prism compressive strengths at each wall elevation reported above can be compared to the masonry compressive strength. Masonry compressive strength can either be calculated using the unit strength method of ACI 530/ASCE 5/TMS 402, *Building Code Requirements for Masonry Structures* or determined by the test method contained in ASTM C 1314, *Standard Test Method for Compressive Strength of Masonry Prisms*. Table 5 lists these compressive strength values for the concrete masonry wall specimens under consideration. Concrete masonry prisms were not constructed at the jobsite for walls SL-1 and ML-1 and therefore are not listed in Table 5.

Table 5. Masonry compressive strength

Walls	Unit Strength (MPa)	Masonry compressive strength - unit strength method (MPa)(1)	Masonry compressive strength – ungrouted prism (MPa)(2)	Masonry compressive strength – grouted prism (MPa)(2)
SL-1 and ML-1	27.2	17.9	[3]	[3]

SL-2 and ML-2	27.8	18.1	21.5	22.8

1) Calculated using unit strength from ACI 530/ASCE 5/TMS 402, *Building Code Requirements for Masonry Structures*.
2) Average of 3 specimens constructed and tested in accordance with ASTM C 1314, *Standard Test Method for Compressive Strength of Masonry Prisms*
3) none constructed at job site

Figure 6 shows the wall prism strength data for walls SL-1 and ML-1 along with the masonry compressive strength determined from the concrete masonry unit strength. Figure 6 also shows this comparison of wall prisms for SL-2 and ML-2 includes the masonry compressive strength determined according to ASTM C 1314. For all the walls, the masonry compressive strength determined using the unit strength method provides a conservative estimate of the wall prisms compressive strengths. In only three cases were the wall prism strengths less than the unit determined masonry compressive strength. Further, for the SL walls, only one case was shown to be greater that the unit determined masonry compressive strength.

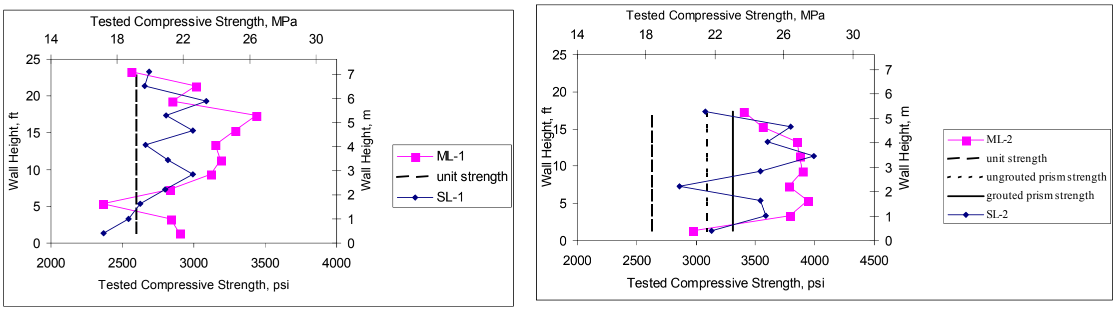

Figure 6 Grout bond shear strength results

5.0 Conclusions

Concrete masonry wall assemblies were constructed and grouted using two different grouting strategies: single-lift and multiple-lift, where in the single lift the grout was placed in a single operation for the full height of the wall and in the multiple lift the grout was placed in five foot wall height increments. Grout consolidation and re-consolidation using mechanical vibration was done to the top 8 feet of the single lift walls and every 5 feet of the multiple lift walls. This study presented a comparison between the performance of these two grouting strategies and performance was measured by testing specimens cut out from all the walls, two single lift walls and two multiple lift walls. Measures of performance were the compressive strength of concrete masonry prisms, visual assessment of the grout's consolidation, and the shear strength of the bond between the concrete masonry and grout.

Concrete masonry prisms were sampled along the height of the wall assemblies and the compressive strength was determined. The results showed that the prism compressive strengths varied along the wall heights for both grouting strategies and, in some cases the differences were large regardless of whether the wall was grouted single lift or multiple lift. Only

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one prism was tested at each wall height location, and consequently could have led to the variation of the compressive strength along the wall height.

The prism compressive strengths at each wall elevation reported was compared to the masonry compressive strength. Masonry compressive strength was calculated using the unit strength method of ACI 530/ASCE 5/TMS 402, *Building Code Requirements for Masonry Structures* or determined by the test method contained in ASTM C 1314, *Standard Test Method for Compressive Strength of Masonry Prisms*. For all the walls, the masonry compressive strength determined using the unit strength method provides a conservative estimate of the wall prisms compressive strengths. In only three cases were the wall prism strengths less than the unit determined masonry compressive strength. Further, for the single lift walls, only one case was shown to be greater that the unit determined masonry compressive strength.

Concrete masonry specimens that contained steel reinforcement were obtained along the wall height for each wall and the grout surrounding the steel was visually inspected. The grout flow around the reinforcement showed adequate bonding without aggregate segregation for all the walls. Therefore, the grout lift strategy had no affect on the grout flow around the reinforcement.

Concrete masonry specimens that were cored from the wall assemblies along the wall height were tested to determine the grout bond shear strength. The results showed that the wall average grout bond shear strengths were similar for the single and multiple lift wall assemblies. Further, it was observed that the common failure mode below the zone of consolidation was grout failure and that above the zone was interface failures, failure along the concrete masonry units and grout interface. This suggests that the head pressure from the grout was the driving mechanism for bonding between the CMU and the grout.

Grout bond shear strength requirements are not found in any national building code. On the other hand, the California State Building Code promulgates that grout bond shear strength is required to be greater than 2 ½ times the square root of the specified compressive strength of masonry. Using the masonry compressive strength results determined from prisms constructed at the jobsite – not prisms sampled along the walls heights –this shear strength was determined to be approximately 1.0 MPa. In every case, the tested grout bond shear strengths were greater than this 1.0 MPa psi requirement.

Based on this research, it can be stated that there was no essential difference in the performance of the concrete masonry walls that were grouted in one single lift compared to CMU walls grouted using five foot increments. Therefore, it is expected that walls grouted continuously in one single lift up to 24 feet would exhibit adequate structural performance.

References

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