MECHANICAL PROPERTIES OF UNGROUTED AND GROUTED CONCRETE MASONRY ASSEMBLAGES

A. Hamid[1], M. Bolhassani[2] , A. Turner[2], E. Minaie[3] and F. L. Moon[4]

[1] Professor, Department of Civil, Architectural and Environmental Engineering, Drexel University, Philadelphia, PA, USA, hamidaa@drexel.edu

[2] Graduate students, Department of Civil, Architectural and Environmental Engineering, Drexel University, Philadelphia, PA , USA.

[3] Research Engineer, Intelligent Infrastructure Systems, Philadelphia, PA, USA.

[4] Associate Professor, Department of Civil, Architectural and Environmental Engineering, Drexel University, Philadelphia, PA, USA.

ABSTRACT

The new IBC seismic provisions are particularly harmful to masonry construction, thus passively promoting the use of competing systems. There is little, if any, basis for such claims in the literature, as masonry bearing wall buildings remain one of the least studied structural systems. This is particularly true for partially grouted reinforced masonry buildings which is a common building system in the eastern United States. Past and current component research demonstrates a significant reduction in shear strength and deformation capacity of partially grouted reinforced masonry as compared to fully grouted construction. There is a need for system-level research to accurately predict the seismic response of this system. NSF has awarded Drexel University, University of Minnesota and University of California-San Diego a grant to study seismic performance and design of partially-grouted reinforced masonry buildings. This project will result in economically competitive design details and retrofit methods to enhance the seismic performance and safety of this system. The outcome of the experimental and analytical investigations will be instrumental in improving code's design provisions for new construction and in seismic retrofitting of deficient existing buildings. This paper presents results of tests conducted at Drexel University to determine the physical and mechanical properties of ungrouted (hollow) and fully grouted concrete masonry assemblages under axial compression, bed joint shear and diagonal tension needed to analytically predict building response to loading. This paper clearly demonstrates the distinct difference in behavior between ungrouted and fully grouted concrete masonry.

KEYWORDS: concrete masonry, assemblage, hollow, partially-grouted, fully-grouted, reinforced

INTRODUCTION

The new IBC seismic provisions are particularly harmful to masonry construction, thus passively promoting the use of competing systems. There is little, if any, basis for such provisions in the literature, as masonry bearing wall buildings remain one of the least studied structural systems. This is particularly true for partially grouted reinforced masonry construction a common building system in the eastern United States. Past and current component research [1, 2 and 3] demonstrates a significant reduction in shear strength and deformation capacity of partially grouted reinforced masonry as compared to fully grouted construction. Past and current component research demonstrates a significant reduction in shear strength and deformation capacity of partially grouted reinforced masonry as compared to fully grouted construction. There is a need for system-level research to accurately predict the seismic response of this system. NSF has awarded Drexel University, University of Minnesota and University of California-San Diego a grant to study “Seismic Performance and Design of Partially-Grouted Reinforced Masonry Buildings". This project will result in economically competitive design details and retrofit methods to enhance the seismic performance and safety of partially-grouted reinforced masonry wall systems. The outcome of the experimental and analytical investigations will be instrumental in improving code’s design provisions for new construction and in seismic retrofitting of deficient existing buildings.

This paper presents results of tests conducted at Drexel University in the first phase of this project to determine the physical and mechanical properties of ungoruted (hollow) and fully grouted concrete masonry assemblages under axial compression, bed joint shear and diagonal tension needed to analytically predict building response to loading.

PROPERTIES OF MASONRY MATERIALS

Units

Two types hollow concrete block masonry units; stretcher and regular units (Figure 1) were used in the construction of the masonry assemblages of this study. Figure 1 illustrates the geometric characteristics of the CMU’s. Units were capped and tested under axial compression (Figure 2) to determine compressive strength. The average unit compressive strength was 17.3 MPa (2507 psi). The physical and mechanical properties of the units meet the ASTM C140 [4] requirements for loadbearing concrete masonry units.

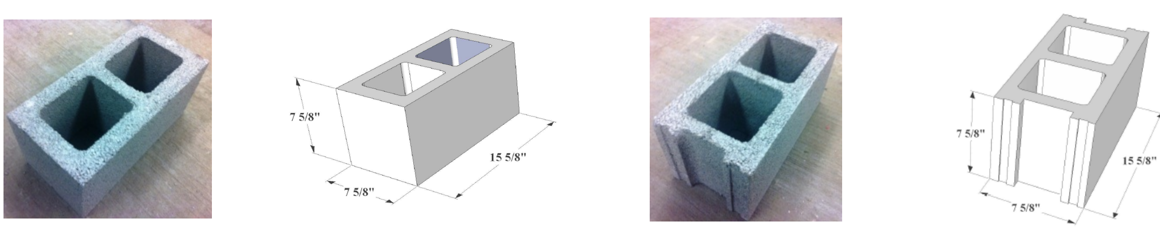


Figure 1: Concrete Masonry Units

Figure 2: Axial Compression Test of Masonry Units

Mortar: Type S Portland Cement-lime mortar was used in construction of the test specimens. Proportions by volume of Portland, lime and masonry sand were 1:0.5:4.5 following ASTM C270 Standard [5] two inch mortar cubes were tested under axial compression (Figure 3) to determine compressive strength. The average compressive strength of mortar was 13.1 MPa (1900 psi).

Figure 3: Axial Compression of Mortar Cubes

Grout: The model masonry grout consisted of 1.0:2.78:0.74 by weight of cement, sand and water, respectively. The water to cement ratio of the grout was chosen to achieve enough workability for good flow of grout into the cells, without any segregation while pouring. Also, during the assemblages' construction, a steel rod was used to get enough compaction of grout and obtain good bond between the grout and the blocks. Block-molded prisms (Figure 4) prepared as per ASTM C1019 Standard [6] were tested under axial compression (Figure 4) to determine compressive strength. The average grout compressive strength was 23.4 MPa (3400 psi) which meets MSJC [7] minimum strength requirement of 13.7 MPa (2000 psi).

Figure 4: Grout Specimen and Test for Axial Compression

AXIAL COMPRESSION TESTS

Three ungrouted full block wide by three courses high were constructed in stack bond and tested under axial compression following ASTM C1314 [8] to determine compressive strength of ungrouted masonry. Two grouted half blocks wide by three courses high were tested under axial compression to determine compressive strength of grouted masonry. Vertical strain was measured using LVDT (Linear Variable Differential Transformer) displacement transducers. Load was applied using MTS hydraulic actuator under force control (Figure 5-a).

Failure mode of the ungrouted was characterized by vertical tensile splitting cracks initiated at the middle web and spread into the top and bottom units (Figure 5-b). For the grouted specimen, failure mode was characterised by diagonal crack as shown in Figure 5-c.

Table 1 contains test results of ungrouted and grouted prisms. For the ungrouted (hollow) prisms compressive strength is presented based on mortar net area. The compressive strength of the grouted prism was higher than that of the ungrouted prisms (based on the net area). The reason can be attributed to the fact that the compressive strength of the grout, occupying 51% of the gross area, was much higher than that of the outer shell (hollow prisms). Therefore, grouting increases the axial load carrying capacity by 2.7 folds [(25.4/19.5)x 2.04 (gross area/net area) = 2.7]. This conclusion is consistent with the past research findings [9].

(a) Test Setup (b) Ungrouted Prism Failure Mode (c) Grouted Prism Failure Mode

Figure 5: Axial Compression Test

Table 1: Compressive Strength of Hollow and Grouted prisms

Results / Specimen	Test Number	Strength		
		Individual MPa (ksi)	Average MPa (ksi)	C.O.V. %
Ungrouted	1 2 3	17.0 (2.5 ksi) 20.7 (3.0 ksi) 20.7 (3.0 ksi)	19.5 (2.8 ksi)	11
Grouted	1 2	21.6 (3.1 ksi) 29.1 (4.2 ksi)	25.4 (3.7 ksi)	-

Figure 6 shows the load-displacement relationship of ungrouted and grouted prisms, respectively. Despite similar strength at ultimate load, axial deformation at peak load of ungrouted and grouted prisms are similar.

BED JOINT SHEAR TESTS

The assemblage shown in Figure 7-a was chosen to determine joint shear slip resistance. Three ungrouted (hollow) and three grouted model bed joint shear assemblages with three units in height were constructed flat-wise using two full blocks at the middle and one full model block at the top and bottom. Vertical load was applied at the top of the middle block as shown in Figure 7-b. This load created pure shear at the mortar joints and resulted in shear slip failure at the block-mortar interfaces, see Figure 7-c.

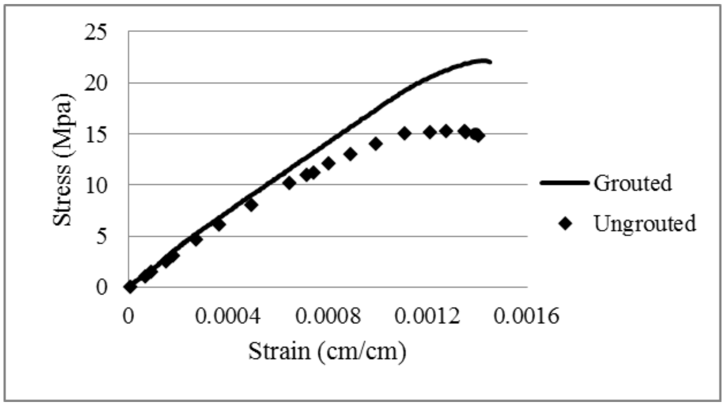
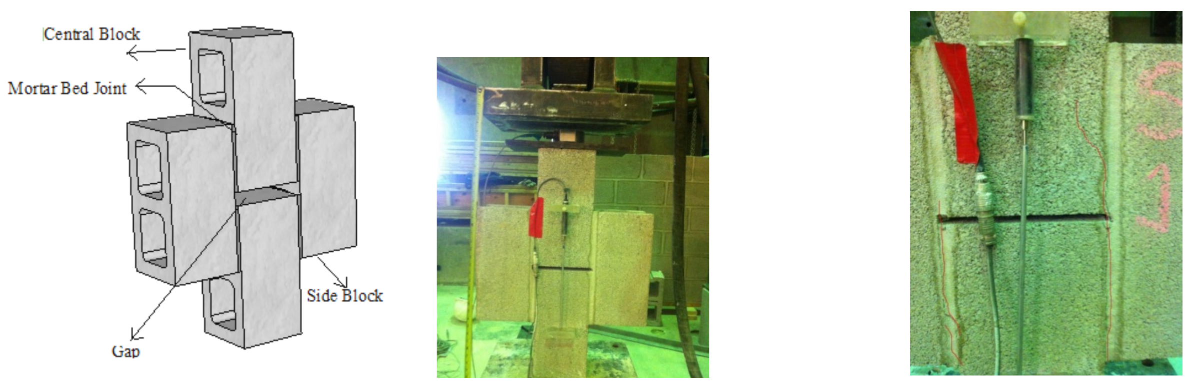


Figure 6: Stress-Strain Curve of Ungrouted and Grouted Prisms

Bed joint shear strength, f_y', is calculated as:

$$f_y' = {}^{P}/_{A} \tag{1}$$

Where P is the applied ultimate load and A is the net and gross contact area between one of the central block and the two end blocks for hollow and grouted specimens, respectively. Table 2 presents shear test results for hollow and grouted specimens. As can be seen shear strength of grouted masonry was 3 times of that of ungrouted masonry. This is attributed to the high shear strength of the grout column compared to the limited mortar bond strength at the block-mortar interface. This conclusion is consistent with the past research findings [9].



(a) (b) (c)

Figure 7: Shear Test Specimens

Figure 8 show stress-strain curves of ungrouted and grouted shear specimens, respectively. As can be clearly seen, the deformation at ultimate load of the grouted specimens was much higher than that of the ungrouted specimens. Adhesion mortar bond at the block-mortar interfaces has very limited deformation indicating high degree of brittleness of this mode of failure. It is to be noted, however, that axial stress normal to bed joints- induced by gravity loads- will maintain large slip deformation after adhesion bond break, and thus creating a ductile mode of deformation and large energy absorption capacity [9].

Table 2: Shear Strength of Ungrouted and Grouted specimens

Results / Specimen	Test Number	Shear Strength		
		Individual MPa (psi)	Average MPa (psi)	C.O.V. %
Ungrouted	1	0.16 (24 psi)	0.20 (30 psi)	23
	2	0.18 (25 psi)		
	3	0.27 (39 psi)		
	4	0.22 (31 psi)		
Grouted	1	0.61 (89 psi)	0.60 (85 psi)	3.5
	2	0.58 (84 psi)		
	3	0.57 (83 psi)		

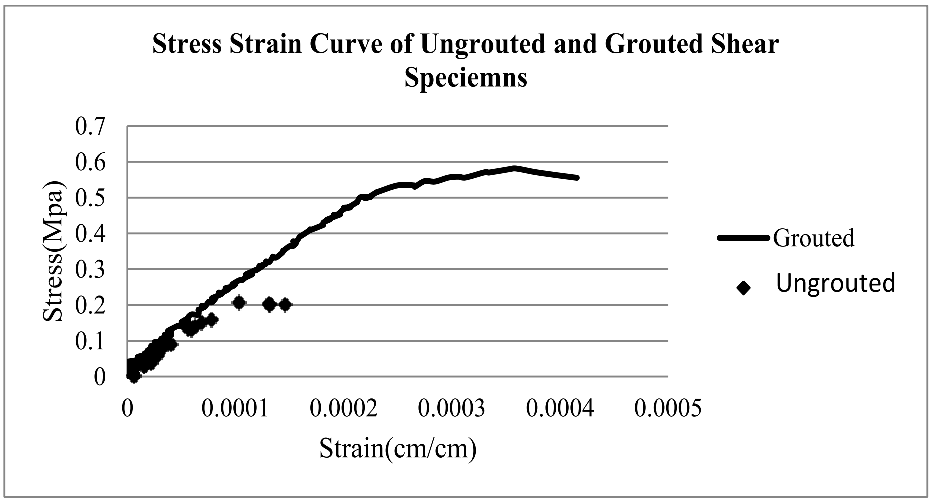
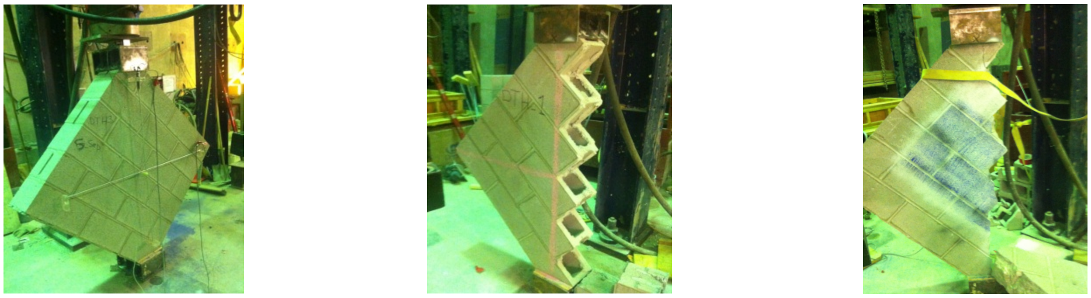


Figure 8: Stress-Strain Curve of Ungrouted and Grouted Shear Specimens

DIAGONAL TENSION TESTS

Hollow (ungrouted) and fully grouted diagonal tension (DT) assemblages with six units height and three units long were constructed in a running bond and tested diagonally (Figure 9-a) following ASTM E519 Standard [10]. The specimens were constructed by a qualified mason and were filled with grout at 24 hours after construction. The load was applied uniformly in constant intervals using vertical MTS hydraulic actuator under force control.

The failure mode of the ungrouted specimens was characterized as step-wise crack at the block-mortar interfaces as shown in Figure 9-b. For the grouted specimens, however, the failure plane followed a straight line through a combination of head joints and masonry units. Grout-filled cells tend to reinforce the mortar joints at those locations and force the crack through the units (Figure 9-c).



(a) Test Setup (b) Failure of Hollow DT (c) Failure of Grouted DT

Figure 9: Diagonal Tension Specimens

Horizontal diagonal tensile strength, f'_d, at the center of the specimen is calculated according to ASTM C1391 as:

$$f'_d = 0.707\, {}^{P}/_{A} \tag{2}$$

Where P is the applied ultimate vertical load and A is the net and gross area of the vertical diagonal section for hollow and grouted specimens, respectively. The net area was calculated as the gross area times the average percent solid of the block which was taken equal to 51%. Table 3 presents test results of ungrouted and grouted specimens. As shown, grouting significantly increased the diagonal tensile strength capacity. The strengthening of the bed joints due to the continuity of the grout results in higher and more uniform strength.

Table 3: Diagonal tension strength of ungrouted and grouted DT specimens

Results / Specimen	Test Number	DT Strength		
		Individual MPa (psi)	Average MPa (psi)	C.O.V. %
Ungrouted	1	0.55 (80 psi)	0.51 (75 psi)	17.8
	2	0.45 (65 psi)		
	3	0.43 (63 psi)		
	4	0.63 (91 psi)		
Grouted	1	0.85 (124.1 psi)	1.00 (145.3 psi)	14.3
	2	1.00 (146.3 psi)		
	3	1.14 (165.5 psi)		

Figure 10 shows load-deflection curves of the opposite diagonals (vertical diagonal in compression and horizontal diagonal in tension). Grouted specimens shows much higher deformation capacity as compared to hollow specimens.

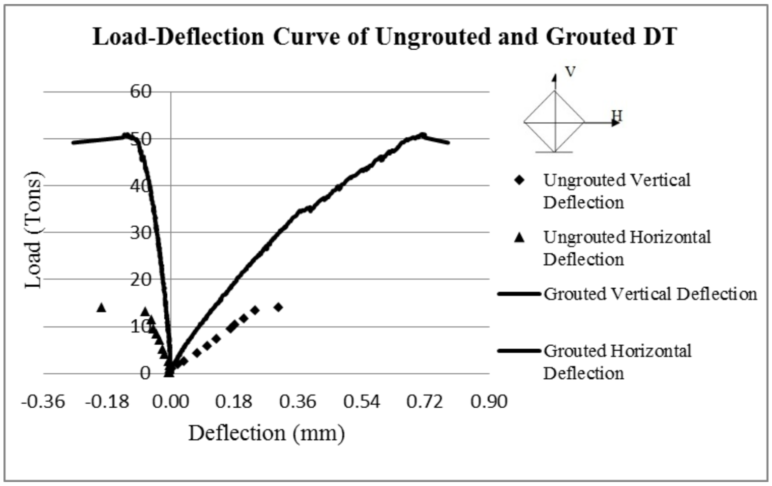


Figure 10: Load-Deflection Curves Hollow and Grouted DT Specimens

CONCLUSIONS

Based on the test results presented in this paper, the following conclusions are drawn:

1) There was a distinct difference in behaviour (failure mode, strength and deformation capacity) between ungrouted concrete and fully grouted concrete masonry.
2) Fully grouting the cells of concrete masonry units increased the compressive strength, shear strength and diagonal tensile strength by 32%, 280% and 168%, respectively.
3) Grouting resulted in a significant increase in deformation capacity under bed joint shear and diagonal tension. No appreciable increase was shown under axial compression.
4) Grout-filled cells tend to reinforce the week mortar bed joints resulting in more continuity and uniformity. Less variability was evident for grouted masonry compared to ungrouted masonry.

ACKNOWLEDGEMENTS

This research is supported by the National Science Foundation under the Network for Earthquake Engineering Simulation program with Award No.CMMI-1208208. Partial support from the National Concrete Masonry Association is also gratefully acknowledged. The support of Delaware Valley Masonry Institute and Sabia Mason Contractors in providing the mason to build the test specimens is acknowledged. However, opinions expressed in this paper are those of the authors and do not necessarily reflect the opinions of the sponsors.

REFERENCES

1. Minaie, E. “Behavior and Vulnerability of Reinforced Masonry Shear Walls,” Ph.D. Dissertation, Department of Civil, Architectural, and Environmental Engineering, Drexel University, Philadelphia, PA, 2009.
2. Minaie E., M. Mota, F. L. Moon, and A. A. Hamid, “In-Plane Behavior of Partially Grouted Reinforced Concrete Masonry Walls,” J. Struct. Engrg. Volume 136, Issue 9 (2010), pp. 1089-1097.

3. Minaie E.; M. Mota; F. L. Moon; and A. A. Hamid (2010), "In-Plane Behavior of Partially Grouted Reinforced ConcreteMasonry Shear Walls", Journal of StructuralEngineering, Vol. 136, No. 9, 2010.

4. American Society for testing and Materials, "Standard Methods for Sampling and Testing Concrete Masonry Units," ASTM C140-03, ASTM, West Conshohocken, PA, 2003

5. American Society for testing and Materials, "Standard Specification for Mortar for Unit Masonry," ASTM C270-03b, ASTM, West Conshohocken, PA, 2003

6. American Society for testing and Materials, "Standard Methods for Sampling and Testing Grout," ASTM C1019-03, ASTM, West Conshohocken, PA, 2003

7.The Masonry Standard Joint Committee, " Building Code Requirements for Masonry Structures," ACI 530/ASCE 5/TMS 402, American Concrete Institute, American Society of Civil Engineers and The Masonry Society, Detroit, New York and Boulder, 2011.

8. American Society for testing and Materials, "Construction and testing Masonry Prisms Used to determine Compliance with Specified Compressive Strength of Masonry," ASTM C1314-03b, ASTM, West Conshohocken, PA, 2003

9. Drysdale, R. and Hamid, A., Masonry Structures: Behavior and Design", 3rd Edition, published by TMS in 2008.

10. American Society for testing and Materials, "Standard test Method for Diagonal Tension (Shear) in Masonry Assemblages," ASTM E519-02, ASTM, West Conshohocken, PA, 2002.