8TH CANADIAN MASONRY SYMPOSIUM

Jasper, Alberta
May 31 - June 3, 1998

MODULUS OF RUPTURE OF CONCRETE MASONRY USING FULL SCALE WALL TESTS AND BOND WRENCH: A COMPARISON STUDY

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ABSTRACT

Development of a limit states design code for masonry is currently underway. A key design parameter is the modulus of rupture of masonry. It is required to determine the cracking load which represents an important serviceability limit state. The bond wrench has been recently used as a convenient way of determining the modulus of rupture of clay brick masonry. However, the applicability and validity of this test to predict the cracking moment of full-scale grouted concrete masonry walls needs to be verified. This paper utilizes the experimental results of the US-Japan Coordinated Program on Masonry Building Research to provide information on the modulus of rupture determined from testing masonry prisms using the bond wrench and from full-scale wall tests. Correlations between the results of the prisms and the full-scale walls are presented. The full-scale wall and bond wrench test results are shown to be comparable. It is concluded that the bond wrench test technique is an appropriate method for determining the modulus of rupture of grouted concrete masonry.

INTRODUCTION

Development of a limit states design code for masonry is currently underway. A key design parameter is the modulus of rupture of masonry that is required to determine the cracking load which represents a serviceability limit state. Pre-cracking and post-cracking behavior are quite different. Therefore, they should be recognized in developing a limit states design code for masonry structures.

The modulus of rupture, f_r, of masonry, synonymously referred to as the flexural tensile strength normal to bed joints, f_t', is affected by the bond strength between the mortar and the masonry unit [Thomas et al. 1995], and the tensile strength of grout for grouted masonry. Typically, the former parameter is influenced by the mortar type and its constituent materials, mortar strength, workmanship and curing [Drysdale et al. 1993, Thomas et al. 1995]. Test data using the bond wrench apparatus indicate a wide range of strengths from 30 to 250 psi (2.1 to 17.2 MPa) [Drysdale et al. 1993].

The bond wrench test has been used as a convenient and efficient way of determining the modulus of rupture of clay brick concrete masonry [ASTM E-518, Sarker & Brown 1987]. Recently, it has also been utilized to determine the modulus of rupture of concrete masonry [Hamid et al. 1987, Thomas et al. 1995]. For hollow masonry construction, Thomas et. al (1995) indicated a close correlation factor of 1.11 existed between the modulus of rupture values of bond wrench tests compared to full-scale wall tests, in spite of the fact that the bond wrench specimens used in the study consisted of a single bed joint compared to the multiple-joint, full-scale wall specimens.

However, the validity of this test to predict the cracking moment of full-scale concrete reinforced masonry walls needs to be verified. This paper utilizes the experimental results of the US-Japan Coordinated Program on Masonry Building Research [Hamid et al. 1989, Abboud et al. 1996] to provide information on the modulus of rupture of fully grouted masonry determined from testing prisms using the bond wrench and from full-scale wall tests. Correlations between the results of the prisms and the full-scale walls are presented.

TEST PROGRAM

Objective

The objective of the test program described herein is to determine the modulus of rupture of fully grouted concrete masonry using the bond wrench test and to correlate the results with those obtained from full-scale wall tests.

Material Properties

Units: Three different size hollow units were used in the test program: 4.5, 6 and 8 in. (114, 152 and 203 mm, respectively). Following ASTM test procedures, the physical and mechanical properties of these units were determined and are listed in Table 1.

Mortar: Type S mortar with volumetric proportions of 1: 0.38: 3.5 (cement: lime: sand) conforming to the proportion requirements of ASTM C270 was used in the construction of prisms and full-scale walls. The average compressive strength of 2 in. (51 mm) mortar cubes was 4,770 psi (32.9 MPa).

Grout: Coarse grout with a maximum aggregate size of $^3/_8$ in. (9.5 mm, pea gravel) conforming to ASTM C476 was used. The volumetric proportion was 1 cement: 3 sand: 2 gravel. The cementitious material and aggregates were batched at a local commercial batching plant. A Grout Aid was premixed in the water that was added to the grout at the laboratory site. This admixture was considered necessary in order to minimize flaws and shrinkage cracks at the block-grout interfaces [Drysdale et al. 1993]. Control specimens were obtained in three forms: 3 in. (76 mm) diameter by 6 in. (152 mm) high non-absorbent cylinders, 3 in. (76 mm) square by 6 in. (152 mm) high block-molded specimens conforming to ASTM E477, and 1.7 in. (43 mm) diameter by 3.5 in. (89 mm) high grout-core specimens. Three test repetitions were used. The average compressive strength of the cylinders, the block-molded prisms and the grout cores were 2,250, 3,450 and 4,040 psi, respectively (15.5, 23.8 and 27.9 MPa, respectively). The low value for the cylinders using non-absorbent molds is attributed to the high water/cement ratio.

Test Specimens

To determine the modulus of rupture of concrete masonry using bond wrench testing, four-course prisms (Fig. 1-a) were used. The half units were saw-cut before construction. A total of six full-scale reinforced concrete block masonry walls, constructed 13 courses high and three units long (Fig. 1-b), were tested under lateral loads. The walls were grouted the day following their construction. Prism specimens were air-cured in the laboratory at an average temperature of 74°F (23.3°C) and an average relative humidity of 70 percent. Compression prisms were capped using high strength gypsum plaster.

Test Setup

A large, stiff bond wrench (Fig. 2) was specially designed to accommodate the full-size concrete block prisms. In principle, the design follows the standard bond wrench test described in ASTM specifications. The load was applied through a double-acting, hydraulic jack with a 21.000 lb. (93.5 kN) load cell to measure the applied load. The load cell reading was measured electronically. The load was applied in equal increments until failure of the bed joint took place.

The full-scale masonry walls were tested in the vertical position as simply supported elements under two horizontal, equal line loads applied to the face of the wall panels at the third points (see Fig. 3). This loading represents lateral wind or earthquake loads.

TEST RESULTS AND DISCUSSION

Bond Wrench Tests

The modulus of rupture was determined by testing a total of seven masonry prisms under flexural tension (bending normal to the bed joints) using the bond wrench. The results including the mean flexural tensile strength are summarized in Table 4. The mode of failure observed for the grouted prisms was cracking at the mortar-block interface followed by tension failure of the grout cores.

Wall Tests

The initial cracking loads, P_{cr}, the corresponding cracking moments, M_{cr}, and the maximum fiber tensile stress at first crack, f'_t, of the wall panels are summarized in Table 5. The initial cracking loads correspond to the first visible crack in the wall panels.

The maximum fiber tensile stress at first crack, f'_t, was calculated using the following relationship:

$$f'_t = \frac{M_{cr} t}{2 I_g} + \frac{W}{A}$$

where M_{cr} = cracking moment;
t = wall thickness;
I_g = moment of inertia of the gross cross-section (ignoring the contribution of the transformed area of reinforcement);
W = weight of wall above the initial crack; and
A = gross cross-sectional area.

The values of maximum fiber tensile stress at first crack, f'_t, are presented in Table 5 for the six walls. The results show that the block size has no significant effect on f'_t values. Additionally, the reinforcement ratio had no effect since the transformed cross-section area of steel was very small and would neither alter the distance from neutral axis to the extreme fiber in tension nor the moment of inertia of the section.

COMPARISON BETWEEN RESULTS OF BOND WRENCH AND WALL TESTS

Comparison of the f'_t values obtained from the tested wall panels to those obtained from the bond wrench test (shown in Fig. 4) indicates that both approaches reveal similar results and that the bond wrench test technique is an appropriate method to determine the modulus of rupture of grouted masonry. In this investigation, the bond wrench test specimens consist of multiple joints and, therefore, are considered by the authors to be further indicative of the suitability and accuracy of the bond wrench test to predict the modulus of rupture of reinforced concrete masonry.

CONCLUSION

Based on the test results presented in this paper it is concluded that the bond wrench test technique is an appropriate method to determine the modulus of rupture of grouted masonry walls.

ACKNOWLEDGMENTS

The test program was made possible through funding from the National Science Foundation under Grant No. ECE-8517019. Materials were made available by Concrete Masonry Association of California and Nevada and Western Clay Products Association. The Delaware Valley Masonry Institute, Plymouth Meetings, PA and J. Sabia and Company, Conshohoken, PA provided the mason to built the test specimens.

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Table 1 Properties of concrete masonry units.

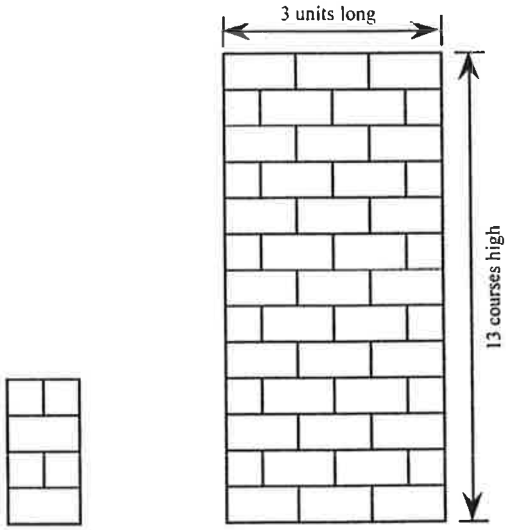
Description	ASTM Standard	Block Size 4.5 in.	6 in.	8 in.
Width (in.)	C140-87	4.52	5.62	7.63
Height (in.)	C140-87	7.60	7.58	7.61
Length (in.)	C140-87	15.56	15.60	15.55
Faceshell Thickness (in.):	C140-87			
Top		1.03	1.20	1.405
Bottom		1.00	1.05	1.291
Gross Area (in^2)	C140-87	70.29	87.50	118.65
Net Area (in^2):	C140-87			
Top		41.33	49.70	62.4
Bottom		39.41	43.00	
Percent Solid:	C140-87			
Top		58.80	56.90	52.6
Bottom		56.10	49.20	
Density (pcf)	C140-87	99.70	102.0	104.50
Absorption:	C140-87			
pcf		12.76	11.00	11.56
%		12.79	10.8	11.18
Moisture content (%)	C140-87	6.27	3.83	7.10
Saturation Coefficient	C67-87	0.73	0.72	0.73
Axial compressive Strength (psi):	C140-87			
Net area		2,430	2,920	2,810
Gross Area		1,390	1,550	1,480
Splitting Tensile Strength (psi)	C1006-87		280	

Note: 1 in.= 25.4 mm, 1 in^2.= 645.2 mm^2, 1 psi= 0.06897 MPa= 6,897 N/m^2, 1pcf= 157.1 N/m^3

Table 2 Wall test specimens.

Wall	Block Size (in.)	Reinforcement
W1	6	2 # 5
W2	6	2 # 4
W3	6	2 # 7
W4	6	6 # 3
W5	4.5	2 # 4
W6	8	2 # 6

Note: 1 in.= 25.4 mm



(a) Prism for bond wrench test. (b) Full-scale wall specimen.

Figure 1 Test specimens.

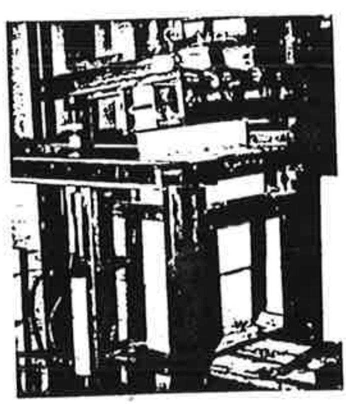


Figure 2 Bond wrench test apparatus.

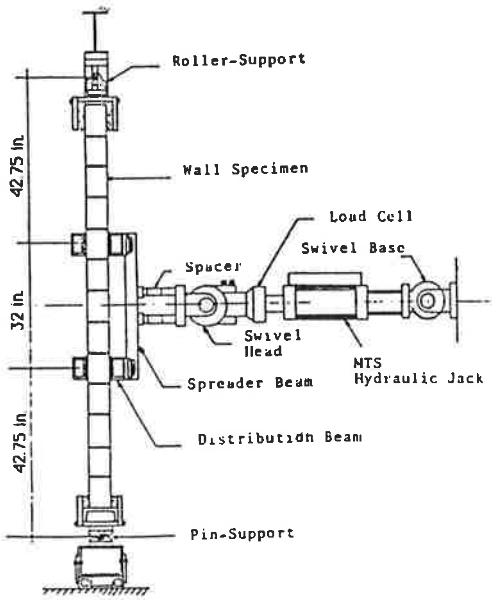


Figure 3 Test setup of full-scale walls.

Table 4 Bond wrench test results.

Prism No.	Nominal Thickness (in.)	Joint	Load (lb)	Moment (lb in.)	Flexural Tension f_t' (psi) Individual	Mean
P1	6	Top	1,040	23,400	265	273
		Middle	1,000	22,590	255	
		Bottom	1,160	26,010	300	
P2	6	Top	1,100	24,750	280	290
		Middle	1,179	26,280	300	
		Bottom	1,140	25,650	290	
P3	6	Top	1,220	27,450	310	310
		Middle	1,240	27,900	320	
		Bottom	1,170	26,280	300	
P4	6	Top	980	22,050	250	280
		Middle	1,200	27,000	310	
		Bottom	1,100	24,750	280	
P5	8	Top	2,100	51,450	310	338
		Middle	2,340	57,330	350	
		Bottom	2,376	58,210	355	
P6	8	Top	2,128	52,140	320	282
		Middle	1,800	44,100	270	
		Bottom	1,700	41,650	255	
P7	4.5	Top	480	9,996	175	240
		Middle	610	12,850	230	
		Bottom	840	17,560	315	

Note: 1 in.= 25.4 mm, 1 lb in.= 0.113 Nm, 1 psi= 0.06897 MPa= 6,897 N/m²

Table 5 Experimental results: cracking moments and maximum tensile stress at first crack.

Wall No.	P_{cr} (lb)	M_{cr} (lb in)	f_t' (psi)
W1	1,830	78,200	319
W2	1,850	79,100	314
W3	1,630	69,800	285
W4	1,330	56,900	234
W5	1,040	44,500	278
W6	3,280	140,130	308

Note: 1 in.= 25.4 mm, 1 lb in.= 0.113 Nm, 1 psi= 0.06897 MPa= 6,897 N/m²

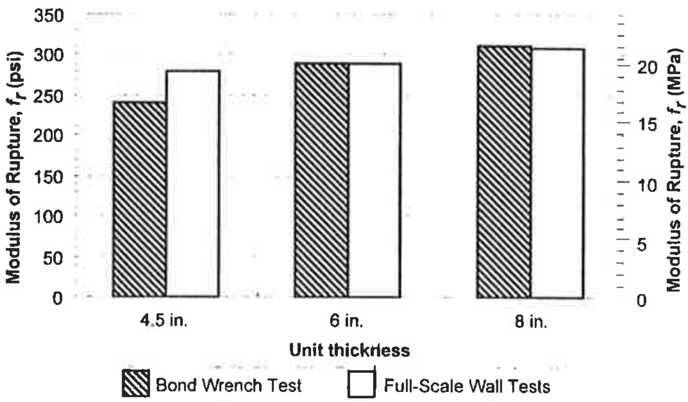


Figure 4 Comparison of results of bond wrench and full-scale wall tests.