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Evaluation of
Tension Capacity of Masonry Splices at Early Ages

for the

Council for Masonry Research

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1.0 INTRODUCTION

1.1 Background

The development of bond between reinforcing steel and grout is normally of concern after the grout has cured for a substantial period of time. However, for purposes of bracing masonry during construction, the strength of the wall at very early ages is an important issue. One technique for wall bracing is the use of strong backs, or braces that provide a stiff, strong vertical member against the wall that is laterally supported at the top by either compression struts or tension cables. The horizontal distance, which may be safely allowed between such braces, depends on the flexural strength of the wall spanning in the horizontal direction. Bond beams are often provided in masonry walls, even if the walls are otherwise unreinforced. The ability of these bond beams to provide significant flexural strength between braces during the construction process will depend on the rate at which the grout and reinforcing steel develop bond strength. Further complicating this issue is the likelihood that the reinforcing steel in the bond beams will be spliced. Previous research on splices in grouted masonry construction has shown that splices, when designed and constructed properly, can develop the full strength of the reinforcing steel. But this ability may not be developed at the early ages of grout during the bracing operation.

1.2 Purpose

The purpose of the test program was to investigate the pullout strength of splices in bond beams in both clay and concrete masonry when tested at early ages. Although the original purpose was to investigate the strength of splices at 24 hours and older, the project was revised to include tests on splices 12 hours old. The results of the tests were to be used to assist in the development of a masonry wall bracing methodology.

1.3 Scope of Research

The testing program included the pullout testing of 45 wall specimens. The specimens included 21 clay specimens and 27 CMU specimens. Figure 4.2 and 4.3 depict the typical test specimens for clay and CMUunits, respectively. Table 1.1 summarizes the relevant information concerning the test series.

2.0 MATERIALS AND MATERIAL PROPERITES

2.1 Masonry Units

The concrete masonry units in the research were virtually the same as those used in Phase 2 of a recent NCMA study[2] evaluating the minimum reinforcing bar splice criteria. Similarly the hollow clay units were virtually the same as the 6-in. units used in the NCMA study. Results of unit tests from the NCMA study are repeated below.

2.1.1 Hollow Clay Bricks

Hollow clay bricks of 6-in. thickness were used to construct clay brick panels. The specified dimensions of these bricks were 5½ x 3½ x 15½ in. (6 x 4 x 16-in. nominal dimensions). The face shell thickness was 1.28 in. The hollow clay bricks complied with the applicable requirements of ASTM C 652[3a], Type HBX and Grade SW.

2.1.2 Concrete Masonry Units

The specified dimensions for concrete masonry units were 7-5/8 x 7-5/8 x 15-5/8 in. (8 x 8 x 16-in. nominal dimensions). The units had square corners on both ends and had square cores. The face shell thickness at the top of the units as laid was approximately 1½ in. and decreased to approximately 1¼ in. in a straight taper to the bottom of the unit as laid.

The concrete masonry units were tested in accordance with ASTM C 140[3c]. Unit test results are summarized in Table 2.2. The concrete masonry units complied with applicable requirements of ASTM C 90[3b], although drying shrinkage was not evaluated.

Table 2.1: Average Tested Properties of Hollow Clay Brick

Unit Property	6 x 4 x 16 in. Hollow Clay Brick
Net Area Compressive Strength	17950 psi
Gross Area Compressive Strength	11,810 psi
Cold Water Absorption	5.3 %
5-Hour Boil Water Absorption	7.4 %
Saturation Coefficient	0.72
Initial Rate of Absorption	2.5 g/30 in.^{2}/min.
Dimensions	
• Width	5.45 in.
• Height	3.54 in.
• Length	15.42 in.
• Minimum Face Shell Thickness	1.28 in.
• Minimum End Shell Thickness	1.35 in.
• Minimum Web Thickness	1.14 in.
Void Area	36.1 %

Table 2.2: Average Tested Properties of CMU

Unit Property	Phase 2 8 x 8 x 16 Hollow CMU
Net Area Compressive Strength	2240 psi
Oven-Dry Density	97.1 pcf
Absorption	12.9 pcf
Dimensions	
• Width	7.63 in.
• Height	7.61 in.
• Length	15.60 in.
• Minimum Faceshell Thickness	1.29 in.
• Minimum Web Thickness	1.02 in.
Percent Solid	51.2 %

2.2 Mortar

The mortar used was a type S masonry cement mortar obtained from a local commercial distributor. The mortar was mixed by proportion in accordance with ASTM C 270[3d].The maximum permissible aggregate proportion[3] of three times the volume of the masonry cement was chosen. Mortar was mixed in a commercial mortar mixer with neoprene blades in good condition to insure good dispersion of cementitious materials. Mortar was mixed for approximately five minutes to a consistency judged acceptable by the mason. Tests were not conducted on the mortar.

2.3 Reinforcing Steel

The reinforcing steel was furnished by a local commercial steel supplier and was delivered to the laboratory in twenty- foot lengths. The reinforcing steel was cut to the desired lengths in the laboratory. A short length of each size of rebar was tested in tension in order to anticipate the maximum possible force, which could be developed in the splice. Strain was not measured, hence yield stress is not known. The mean value of ultimate force (not stress) was 19.95 kips for #4 bars and 44.95 kips for #6 bars. The bars were marked as grade sixty and with the bar size designation of either 4 or 6 for ½ in and ¾ in. diameter bars, respectively.

Table 1.1 Test Matrix

Panel Designation	Type of Masonry Unit	Replication Number	Phase Number	Grout Age at Testing, days	Reinforcing Bar Size	Splice Length, inches	Full or Partial Grout
B-1-F-1	brick	1	I	1	#4	24	full
B-1-F-2	brick	2	I	1	#4	24	full
B-1-F-3	brick	3	I	1	#4	24	full
B-3-F-1	brick	1	I	3	#4	24	full
B-3-F-2	brick	2	I	3	#4	24	full
B-3-F-3	brick	3	I	3	#4	24	full
B-7-F-1	brick	1	I	7	#4	24	full
B-7-F-2	brick	2	I	7	#4	24	full
B-7-F-3	brick	3	I	7	#4	24	full
B-28-F-1	brick	1	I	28	#4	24	full
B-28-F-2	brick	2	I	28	#4	24	full
B-28-F-3	brick	3	I	28	#4	24	full
B-½-F-1	brick	1	II	½	#4	24	full
B-½-F-2	brick	2	II	½	#4	24	full
B-½-F-3	brick	3	II	½	#4	24	full
B-½-P-1	brick	1	II	½	#4	24	partial
B-½-P-2	brick	2	II	½	#4	24	partial
B-½-P-3	brick	3	II	½	#4	24	partial
B-1-P-1	brick	1	II	1	#4	24	partial
B-1-P-2	brick	2	II	1	#4	24	partial
B-1-P-3	brick	3	II	1	#4	24	partial
C-1-F-1	concrete	1	I	1	#6	36	full
C-1-F-2	concrete	2	I	1	#6	36	full
C-1-F-3	concrete	3	I	1	#6	36	full
C-1-F-4	concrete	4	II	1	#6	36	full
C-1-F-5	concrete	5	II	1	#6	36	full
C-1-F-6	concrete	6	II	1	#6	36	full
C-3-F-1	concrete	1	I	3	#6	36	full
C-3-F-2	concrete	2	I	3	#6	36	full
C-3-F-3	concrete	3	I	3	#6	36	full
C-7-F-1	concrete	1	I	7	#6	36	full
C-7-F-2	concrete	2	I	7	#6	36	full
C-7-F-3	concrete	3	I	7	#6	36	full
C-28-F-1	concrete	1	I	28	#6	36	full
C-28-F-2	concrete	2	I	28	#6	36	full
C-28-F-3	concrete	3	I	28	#6	36	full
C-28-F-4	concrete	4	I	28	#6	36	full
C-28-F-5	concrete	5	I	28	#6	36	full
C-28-F-6	concrete	6	I	28	#6	36	full
C-½-F-1	concrete	1	II	½	#6	36	full
C-½-F-2	concrete	2	II	½	#6	36	full
C-½-F-3	concrete	3	II	½	#6	36	full
C-½-P-1	concrete	1	II	½	#6	36	partial
C-½-P-2	concrete	2	II	½	#6	36	partial
C-½-P-3	concrete	3	II	½	#6	36	partial
C-1-P-1	concrete	1	II	1	#6	36	partial
C-1-P-2	concrete	2	II	1	#6	36	partial
C-1-P-3	concrete	3	II	1	#6	36	partial

2.4 Grout

Grout[3e] was supplied by a local ready-mix concrete supplier with one exception. The supplier no longer produced fine grout when the Phase II grout was ordered. Hence, the grout was mixed in a mortar mixer in the lab using the proportions provided by the producer. When grout was delivered to the job site, water was added to obtain the desired slump[3f] of 9-11in. Coarse grout was used for all CMU specimens, and fine grout was necessary to accommodate the smaller cells in the hollow clay test specimens. In Phase I, slump of the coarse grout was 9 ½ in, and for fine grout, 11 in. Phase II slumps were 10 in. for coarse, 10 in. for fine. Grout proportions reported by the producer were as follows:

Table 2.3.1 Grout Proportions

	Grout Component	Weight, lbs/yd^3
coarse	cement	750
	sand	2018
	coarse aggregate (#89 stone)	765
fine	cement	846
	sand	2387
	coarse aggregate (#89 stone)	0

Grout strengths were determined in accordance with ASTM C-1019[3g] at early ages as well as at 28 days. Results of the grout tests and mix proportions are included in Table 2.3.2.

Table 2.3.2 Grout Strength

(a) Phase I	Fine Grout for Brick Walls			Coarse Grout for CMU Walls		
Age, days	force, kips	stress, ksi	mean stress	force	stress, ksi	mean stress
1	7	0.778	0.800	13.3	1.086	1.102
	7.4	0.822		13.7	1.118	
	*			*		
3	7.85	0.872	1.043	23.4	1.910	2.136
	9.7	1.078		28	2.286	
	10.6	1.178		27.1	2.212	
7	18.3	2.033	2.033	30.2	2.465	2.955
	21	2.333		45.1	3.682	
	15.6	1.733		33.3	2.718	
28	18.2	2.022	2.063	51.6	4.212	3.818
	20.6	2.289		46.7	3.812	
	16.9	1.878		42	3.429	

*damaged during demolding

(b) Phase II	Fine Grout for Brick Walls			Coarse Grout for CMU Walls		
Age, days	force	stress, ksi	mean stress	force	stress, ksi	mean stress
1*	8.3	0.922	0.959	24.8	2.024	2.193
	8.6	0.956		27	2.204	
	9	1.000		28.8	2.351	
28	49	5.444	5.456	87.5	7.143	7.483
	48.3	5.367		90	7.347	
	50	5.556		97.5	7.959	

*fine grout prisms tested @ 26 hrs, coarse grout prisms tested @ 27 hrs

Phase II grout strengths were higher than those of Phase I. The grout in Phase I was furnished by a ready-mix concrete producer, but the Phase II fine grout was produced in the lab using mix proportions provided by the suppliers of Phase I grout. Such a difference was certainly not expected, and may indicate that the mix proportions supplied by the producer were not, in fact, those actually supplied in Phase I. The supplier changed its quality control procedures during the short period between Phase I and Phase II which may explain the variation between coarse grout strengths.

2.5 Test Specimens

The concrete masonry unit (CMU) specimens were constructed from 8-in. units in running bond laid three courses high. Hence the specimens had nominal dimensions of 40 in. long, 24 in. high and 8 in. thick. The middle course included a bond beam that was manufactured in the lab by saw-cutting the webs of the units to a prescribed depth. These webs were knocked out with a hammer to provide a depression 2 3/8 in. deep. This dimension ensured that no more than 1½ in. of grout cover was provided on the top of the spliced rebar when only the bond beam was grouted. All concrete masonry units were reinforced with #6 (¾ in. diameter) deformed Grade 60 reinforcing steel bars. The splice length was in accordance with ACI 530/ASCE 5/TMS 402, *Building Code Requirements for Masonry Structures*[1] equation (8-2) which requires:

$$l_d = 0.002\ d_b\ F_s$$

Since an allowable steel stress of 24,000 psi is typically used in design, this equation requires l_d to be at least 48 d_b (forty-eight bar diameters) or 36 in. for a #6 bar. The test specimens were slightly longer than 36 in. and the portion of the reinforcing steel that was not lapped was covered with insulating tape. This "bond-breaker" prevented the transfer of stress from the rebar to the grout in the zone outside of the actual lap splice.

Specimens made from hollow clay units were seven courses high and two units in length resulting in nominal wall dimensions of 32 in. long, 28 in. high and 6 in. thick. Bond beams were constructed in the middle course by saw-cutting the webs to the depth of 2-1/8 in., again for the purpose for providing the minimum cover of 1½ in. for partially grouted specimens. Grade 60 deformed #4 (½ in. diameter) reinforcing steel bars were lap spliced forty-eight diameters (24 in.). The portion of the reinforcing steel that was embedded in grout but not part of the lap splice was wrapped in insulating tape to serve as a bond breaker.

For both clay and concrete masonry, all tests included three replications. A series was conducted at ages of 12 hours, 1 day, 3 days, 7 days and 28 days. Partially grouted walls were tested at 12 hours and 1 day. The full scope of the project is shown in Table 1.1.

The testing was conducted in two phases. The first phase was intended to examine the pullout strength at 1 day, 3 days, 7 days and 28 days using fully grouted construction. After the first few tests, the early strength was found to be higher that expected, hence a second phase of tests was proposed at an age of ½ day (12 hrs.). The second phase also included partially grouted specimens tested at both 12 and 24 hrs. Finally, the second phase included a repeat of the one-day tests on CMU specimens. During the first phase, when the CMU walls were tested at 24 hrs, the hydraulic jack had insufficient capacity to test to ultimate. This was remedied before the 3-day tests, but the one-day test results were lost. Hence, the one-day series for CMU walls was repeated in Phase II.

3.0 CONSTRUCTION AND CURING OF TEST SPECIMENS

The test specimens were constructed by experienced masons. Construction techniques were observed to ensure compliance with good workmanship practices. All specimens were constructed on a sheet of polyethylene placed on the concrete laboratory floor. The masonry units were placed directly on the polyethylene without a bed of mortar. Masons were instructed to use 3/8-in. mortar joint thicknesses, and they adhered closely to that instruction. For partially grouted masonry construction, a nylon mesh (Grout Stop™) was placed in the mortar joint below the bond beam. After the masons completed all of the walls, the walls were allowed to cure in laboratory approximately one-day before being grouted. During that interval, the reinforcing steel splices were placed in the bond beams that had been provided for in the masonry panels. Each end of the wall panel was fitted with a sheet of plywood provided with a hole through which one rebar protruded. This plywood ensured that the spliced rebar was located at exactly the right height and that the splice was centered in the specimen.

Grout placement in Phase I involved filling of all cells. The grout was placed by hand, not pumped, and consolidated with a vibrator. The grout was reconsolidate in approximately 15 minutes, and grout was added to the tops of the cells to replace grout that had subsided. The small core sizes in the hollow clay units did not provide sufficient space for the vibrator to pass below the reinforcing steel. Hence, the grout below the reinforcing steel was not consolidated with the vibrator. However, since the vibrator was able to pass to the level of the steel, its zone of influence probably provided sufficient consolidation of the grout in the vicinity of the reinforcing steel.

In Phase II only the bond beams were grouted. In this case, that grout was also placed by hand. Grout was placed in the cells and vibrated until the desired depth was achieved. A "dipstick" was fabricated to measure the depth of the grout in the bond beam to ensure that the beams were not over or under filled. Grout prisms in accordance with ASTM 1019[3g] were cast as the grout was placed in the specimens. They were covered with moist paper towels initially and moved to the moist curing room one day after casting.

Figure 4.2: Schematic Elevation View of CMU Test Specimen

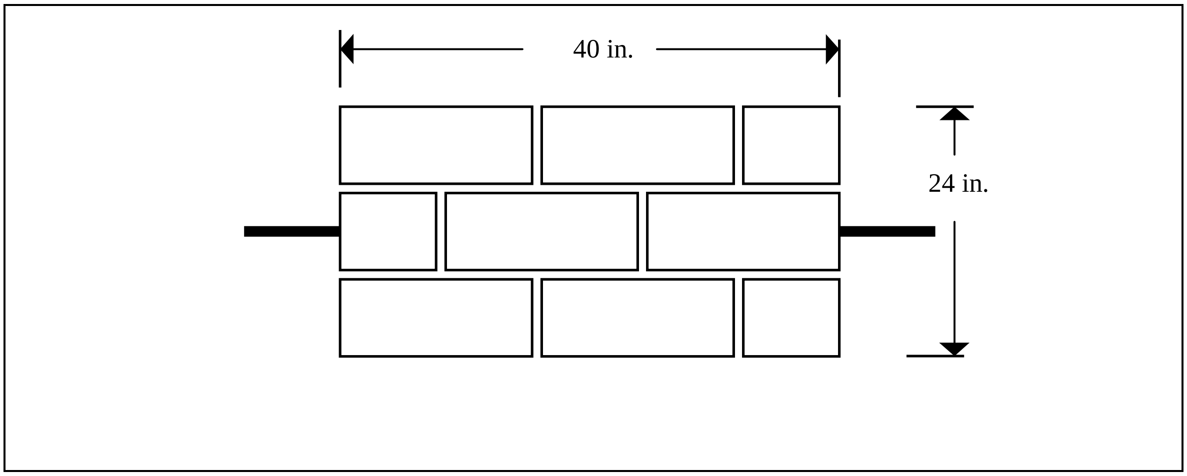
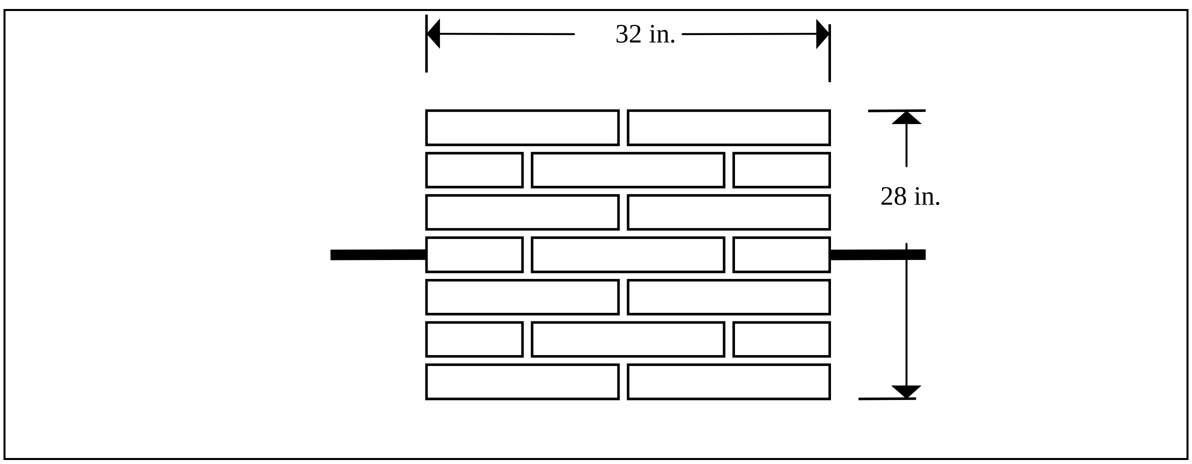


Figure 4.3 - Schematic Elevation View of Hollow Clay Unit Specimens



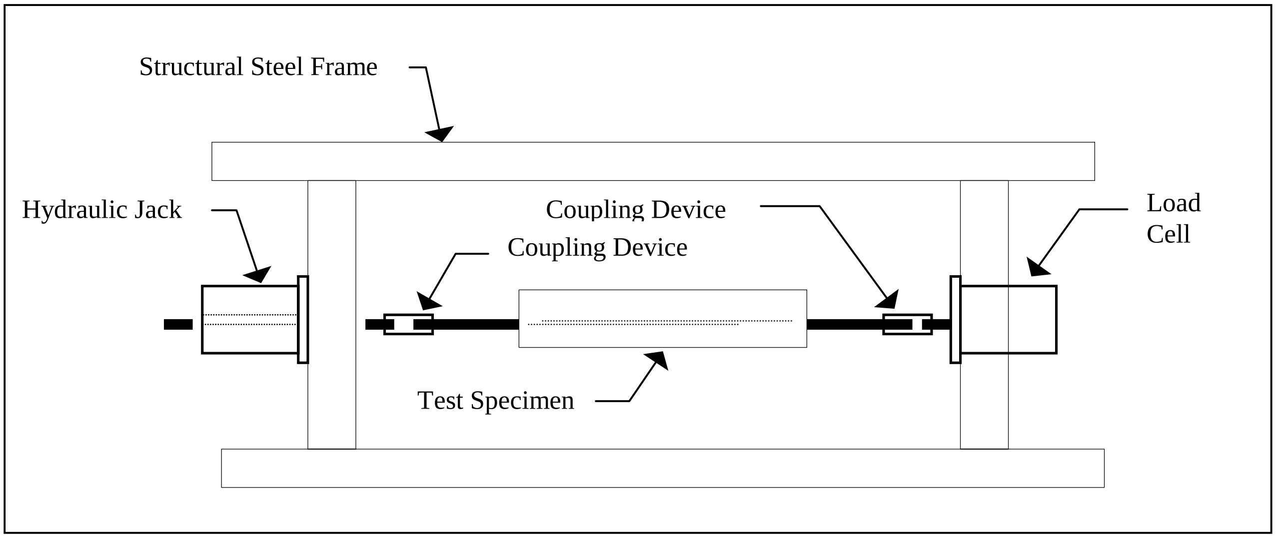
The panels were cured in laboratory air until testing. Temperature and humidity was monitored in the lab, but were found not to vary measurably. The temperature was 68 ^{o} F ^{and} the relative humidity, 72%. The specimens were not moved from the time that the mason constructed them until after the tests were completed. It was not necessary to move the test specimens to conduct the rebar pull out tests since the test apparatus was portable.

4.0 TEST PROCEDURES

A test frame was constructed for this project using structural steel sections as shown in Figure 4.0. The frame was fitted with a load cell at one end and a hydraulic jack at the other. Special fittings were fabricated in the machine shop to provide connections between the hydraulic jack, the load cell and the reinforcing bars. A commercial reinforcing bar-coupling device manufactured by Bar-Lock (MBT) Coupler systems in Bellingham, WA was used to connect the jack and the load cell to the reinforcing bars. These couplers consisted of a steel sleeve that fit over two end-butted reinforcing bars intended to be connected. In this research, one of the reinforcing bars was actually a length of hardened steel connected to the hydraulic jack or the load cell. The reinforcing bar from the splice specimen was butted against this length of hardened steel and induction-hardened steel pointed conical bolts were then tightened into the sides of the reinforcing bar and the connecting device. A torque wrench was used to tighten each bolt to a predetermined value. In field applications, the bolts are intended to be sheared off during tightening.

In this research, the shearing torque was measured for several bolts and the bolts were tightened to approximately 80% of this value to prevent their shearing off and to allow for their reuse. This scheme worked very well and was able to produce forces in the rebar which were sufficiently high to fail the splice. In some cases, this force approached the ultimate capacity of the reinforcing bar.

Figure 4.0: Schematic of Test Frame Set-up (plan view)



5.0 TEST RESULTS

Results of the pull out test are shown in Table 5.1 for all of the test specimens. On the first day of testing, the hydraulic jack was found to have insufficient capacity to load the splice for #6 bars to failure. Hence, these specimens were essentially "proof tested", although this was not the intent. The apparatus had sufficient capacity to "fail" the smaller #4 bars embedded in clay masonry, hence there was no "proof test" for clay masonry. In order to fill in the missing data, these specimens were reconstructed during the second phase of the project in which the twelve-hour and the partially grouted specimens were constructed. Furthermore, the proof tested specimens were retested at 28 days.

Table 5.1 Test Results

Panel Designation	Force, kips	Stress, ksi	Mean Stress, ksi
B-1-F-1	12.38	63.05	
B-1-F-2	14.73	75.02	65.32
B-1-F-3	11.37	57.91	
B-3-F-1	8.93	45.48	
B-3-F-2	18.41	93.76	69.36
B-3-F-3	13.52	68.86	
B-7-F-1	12.77	65.04	
B-7-F-2	10.2	51.95	64.93
B-7-F-3	15.28	77.82	
B-28-F-1	9.6	48.89	
B-28-F-2	17.14	87.29	76.92
B-28-F-3	18.57	94.58	
B-½-F-1	9.709	49.45	
B-½-F-2	7.558	38.49	44.46
B-½-F-3	8.927	45.46	
B-½-P-1	7.559	38.50	
B-½-P-2	10.17	51.80	47.46
B-½-P-3	10.23	52.10	
B-1-P-1	14.01	71.35	
B-1-P-2	13.1	66.72	68.87

B-1-P-3	13.46	68.55	
C-1-F-1	24.11	54.57	
C-1-F-2	24.47	55.39	54.72
C-1-F-3	23.95	54.21	
C-1-F-4	40.06	90.68	
C-1-F-5	40.04	90.63	93.12
C-1-F-6	43.33	98.08	
C-3-F-1	34.67	78.48	
C-3-F-2	39.29	88.93	85.10
C-3-F-3	38.84	87.92	
C-7-F-1	43.27	97.94	
C-7-F-2	42.62	96.47	97.82
C-7-F-3	43.76	99.05	
C-28-F-1	42.32	95.79	
C-28-F-2	42.62	96.47	94.57
C-28-F-3	40.4	91.45	
C-28-F-4	42.55	96.31	
C-28-F-5	38.77	87.76	93.48
C-28-F-6	42.58	96.38	
C-½-F-1	30.92	69.99	
C-½-F-2	27.82	62.97	64.72
C-½-F-3	27.04	61.21	
C-½-P-1	25.38	57.45	
C-½-P-2	22.94	51.93	53.39
C-½-P-3	22.45	50.82	
C-1-P-1	33.09	74.90	
C-1-P-2	33.75	76.39	77.66
C-1-P-3	36.1	81.71	

5.1 Observations

Several observations are particularly of interest:

1) At a grout age of 24 hrs. the mean value of pullout strength exceeded the specified yield strength in every case. This was true for both clay and concrete masonry, and for fully and partially grouted construction.
2) At a grout age of 12 hrs. failure occurred at approximately 75% of specified yield for clay masonry. The concrete masonry values were higher, even exceeding specified yield for the fully grouted specimens.
3) The fine grout used in Phase I had significantly lower compressive strength because the slump was 11 in. The head of the vibrator could not pass below the level of the rebar in the bond beam; hence a very high slump was needed to ensure placement. There was a trade-off in grout strength versus workability; a result which may have been reduced bond strength.
4) At ages beyond one day, an occasional test result was below specified yield. In every case these were clay masonry walls. Examination of the grout surrounding the reinforcing steel revealed poor consolidation below the rebar. Hence, these occasional low values, though not significantly low, appear to be related to the grout placement and consolidation.
5) Partial grouting appears to provide comparable strength to that obtained by fully grouting. Because the vibrator could not pass below the rebar in the clay specimens, it appeared that the grout below the rebar had a better chance of being consolidated than in the fully grouted case. Furthermore, because there was less grout below the rebar in partially grouted cases, there was less bleed water below the rebar to become trapped under the rebar while moving upward in the normal consolidation process. Air bubbles and bleed water are known to reduce the bond strength between concrete and reinforcing steel and hence would be expected to have a similar effect in this testing.
6) Specimens proof tested to an average stress of 55 ksi (92% of specified yield) when they were only 24 hrs. old had a failure strength at 28 days of approximately 94 ksi. This was virtually the same as the 28-day strength of comparable specimens that were not proof tested (95 ksi). Although anecdotal, this comparison illustrates that

loading to a high stress level at a grout age of 24 hrs. did not appear to reduce the ultimate splice strength at 28 days. This would imply that a wall that relied on reinforcing steel in a bond beam to resist wind loads at early ages would not suffer from a reduction in bond strength in the long term.

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