



ANCHOR BOLTS IN CLAY MASONRY WALLS

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ABSTRACT

This research project was designed to determine the tensile and shear strengths of anchor bolts extending from the top of clay masonry walls. The test program included 110 anchor bolts in single and double wythe walls with varying load path, wall thickness, and bolt type. Load paths included axial tension, shear parallel to the plane of the wall (in-plane), and shear perpendicular to the plane of the wall (out-of-plane). Two sizes of hollow masonry units, 127 and 152 mm (5 and 6 in), were used to construct single wythe walls. Double wythe walls were built of 103 mm (4 in) solid units. Anchor bolts tested were headed and “L”-shaped, with diameters of 12.7 mm (1/2 in) and 9.53 mm (3/8 in). Each single wythe specimen contained an anchor bolt in the center cell of the specimen embedded in fine grout in that cell only. In the double wythe specimens, an anchor bolt was embedded in the mortar-filled collar joint. Five replications of each combination of parameters were tested. Deformation of the bolts relative to the masonry surface was continuously recorded along with the load. The observed failure mode for tension loading was pullout of the bolt or a wedge-shaped section of masonry that separated from the wall with a depth equal to that of the embedment depth of the bolt. The failure mode for out-of-plane shear loading was splitting of the wall in its plane accompanied by a separation of a triangular shape of masonry, ending at the bolt head or bend and symmetrical about the length of the anchor bolt. In the case of in-plane shear, an unsymmetrical wedge of masonry separated from the wall. Loads in the in-plane tests were significantly higher than those for other loading directions. Analysis of test results shows that the current equations used in the consensus and model building codes significantly underestimate the strength of bolts embedded in the tops of walls. The paper identifies types of loading where modifications in design equations are warranted.

Key Words: Anchor bolts, masonry, clay masonry, hollow clay units, shear, tension, edge distance, headed bolts, bent bolts

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INTRODUCTION

The testing of anchor bolts in masonry walls has been focused primarily on bolts embedded in the wall face (Brown). Such applications are used when attaching a ledger to the face of the wall to allow for the attachment of a floor or other structural element. Few tests have been conducted on brick masonry walls where the anchor bolt is located in the top of the wall. The current equations in the consensus and model codes impose a penalty on the bolt capacity in tension and shear when it is located in close proximity to a wall edge. Bolts in the top of a masonry wall are always close to the edge, and the current equations do not consider the beneficial effects of embedment depth greater than one-half the wall thickness. This test program was designed to determine the tensile and shear strengths of headed and "L"-shaped bolts having diameters of 9.5 mm (3/8 inch) and 12.7 mm (1/2 inch) embedded in the tops of clay walls.

RESEARCH PROGRAM

Scope

The testing program included 110 anchor bolts, 50 in tension and 60 in shear. The larger diameter bolts were not tested in shear perpendicular to the wall because it was anticipated that the capacity would not be increased by a larger bolt diameter.

Materials and Material Properties

The 127 mm (5 inch) and 152 mm (6 inch) hollow clay masonry units used in the research were from commercially available production of brick manufacturers in the southeastern United States. Both hollow units comply with Class H40V of ASTM C 652, with 35% void area for the 127 mm (5 inch) units and 27% void for the 152 mm (6 inch) units. The solid brick comply with ASTM C 216 and were cored less than 25%.

Mortar was made from Type S masonry cement. The mortar was mixed in accordance with the proportion specification of ASTM C 270. The maximum permissible aggregate proportion of three times the volume of the masonry cement was used. Mortar was mixed for approximately five minutes to a consistency judged acceptable by the mason. Mortar cubes were fabricated for each mortar batch and tested in accordance with ASTM C 780. The average cube strength of mortar taken from that prepared for the mason was 5.33 MPa (773 psi) for nine batches, ranging from 4.56 MPa (661 psi) to 6.26 MPa (908 psi). Coefficients of variation for all nine batches averaged 6.34%.

Fine grout was mixed in the laboratory using proportions from ASTM C 476. The maximum permissible aggregate proportion of three times the volume of the cement for fine grout was used. Water was added gradually until a slump of 254-279 mm (10-11 inches) was obtained. Grout strengths were determined in accordance with ASTM C 1019. Two grout pours were necessary for the 152 mm (6 inch) specimens, having mean compressive strengths of 38.5 MPa (5585 psi) and 35.0 MPa (5081 psi). The grout for the 127 mm (5 inch) specimens had a compressive strength of 24.3 MPa (3525 psi).

The bolts were either headed or “L”-shaped having diameters of 9.53 mm (3/8 inch) and 12.7 mm (1/2 inch). The larger headed bolts had hexagonal heads that received a 19.1 mm (3/4 inch) wrench, whereas the smaller bolts had 14.3 mm (9/16 inch) hex heads. The headed bolts were straight, with a total shank length of 203 mm (8 inches). On the smaller bolt, 38.1 mm (1-1/2 inch) was threaded. The larger headed bolts were also 203 mm (8 inch) long, with 44.5 mm (1-3/4 inch) of threads. The smaller “L”-shaped bolts were 191 mm (7-1/2 inch) long with 63.5 mm (2-1/2 inch) of threads, and had a leg 60.3 mm (2-3/8 inch) long. The larger “L” bolts were 210 mm (8-1/4 inch) and 254 mm (10.0 inch) long with 50.8 mm (2 inch) of threads. Each had a leg 50.8 mm (2 inch) long.

Test Specimens

Test specimens are shown schematically in Fig. 1. Anchor bolts were placed in the top, center cell of each hollow brick specimen, and only the cell containing the anchor bolt was grouted. The cross webs on each side of the grouted cell were mortared to retain the grout within the cell containing the anchor bolt. Masons constructed the specimens over a period of 5 days. Anchor bolts were grouted in place at a minimum of 24 hours after wall construction. Grout was placed by hand since the volume of each grouted cell was very small. After the grout was placed the anchor bolt was shoved into the grout and “jiggled” slightly. Then 38.1 mm (1-1/2 inch) thick boards were placed between the extending bolt bearing surface (nut and washer assembly) and the top of the wall to provide a consistent embedment depth. This simulated the sole plate typically used in masonry wall construction and prevented the bolt from creeping into the wet grout.

All bolts in the single wythe specimens were embedded two courses deep which corresponds to 152 mm (6 inch). This embedment depth resulted in all of the threads being outside the masonry except in the case of 9.53 mm (3/8 inch) diameter “L” bolts. When “L” bolts were embedded in cells, the shaft was off-center to accommodate the leg of the bolt. The grout cover in this case reduced from 25.4 mm (1 inch) to approximately 12.7 mm (1/2 inch). When in-plane shear was applied to these bolts, the direction of loading resulted in compression of the grout on the side of greater cover.

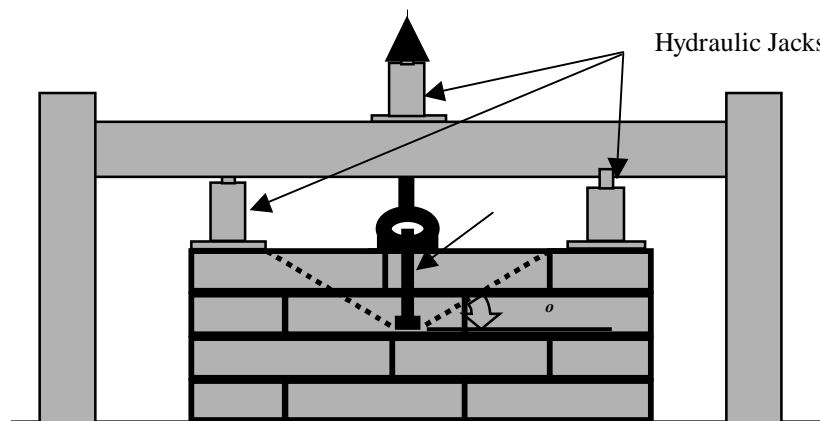


Figure 1- Schematic of Tension Test Setup

Double wythe specimens were similar in length and width to the single wythe tension specimens. They included a mortar-filled collar joint with an embedded anchor bolt. The 19.1 mm (3/4 in) wide collar joint in the double wythe specimens was filled with mortar as the specimens were constructed. The 12.7 mm (1/2 in) anchor bolt was embedded by the mason at the appropriate time during construction. The 254 mm (10 in) long bolts were placed in the five course test specimens with the bent leg in the second bed joint from the bottom, with the bent leg extending into the bed joint between courses. The 203 mm (8 in.) long bolts were also placed in the second bed joint, but the specimens were four courses high. This resulted in embedment lengths of 210 mm (8.25 inch) for the 254 mm (10 inch) bolts and 140 mm (5.5 inch) for the 203 mm (8.0 inch) bolts. Joint reinforcing was placed in the second bed joint from the top of the specimen.

All specimens were covered with plastic and allowed to cure in the laboratory for 28 days. Testing began when the walls were 28 days old, hence the grout may have been only 26 days old when testing first began. However, since testing took longer than wall construction, many of the specimens were older than 28 days when tested.

Test Procedure

The test setup for loading in tension is shown schematically in Fig. 1. The distance between the pair of hydraulic jacks in contact with the top of the wall was wide enough to ensure that the angle shown on Fig. 1 was 35°. The depth of the specimens was relatively small, causing relatively large flexural tensile stresses from beam behavior. Since the purpose of these tests was to measure the strength of the anchors, not the flexural strength of the specimens, an external reinforcing device was added (Fig. 2).



Figure 2- External Reinforcing Apparatus

The apparatus consisted of two steel channels held together by two 19.1 mm (3/4 inch) diameter threaded rods. The threaded rods were tightened to 13.6 Nm (10 ft-lbs) to avoid precompressing the masonry.

Shear tests were conducted using the same test setup but with a different specimen configuration. These are shown schematically in Fig. 3(a) and Fig. 3(b). For out-of plane shear testing, the walls

were placed horizontally under the test frame, supported by spacers. A steel plate was attached to the wall using the test bolt as shown in Fig. 3(a). Test specimens for in-plane shear tests were placed on one end in the test apparatus and the test bolt was fastened to the steel plate as shown in Fig. 3(b). The load was measured with a load cell having a 89.0 kN (20 kip) capacity. A displacement transducer (LVDT) with a stroke of ± 50.8 mm (2 inch) measured the piston travel on the hydraulic jack.

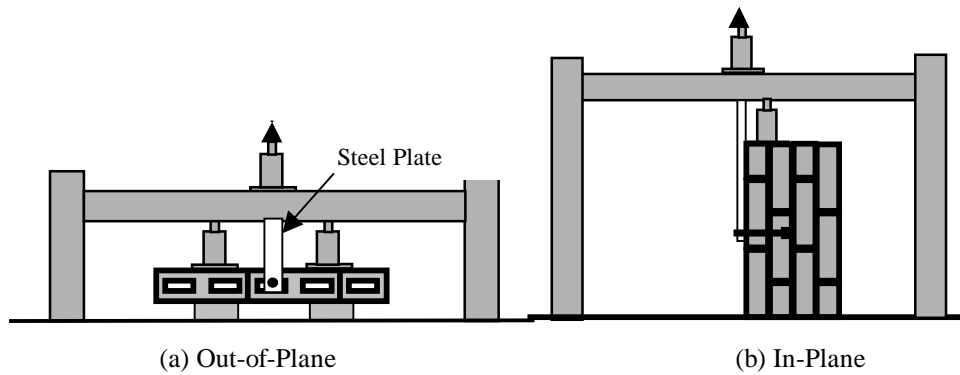


Figure 3 – Schematic of Test Setup

TEST RESULTS

The test results are summarized in Table 1 and Table 2 for each of the anchor bolts tested. The observed failure mode for tension loading in the single wythe walls was a wedge-shaped section of masonry that separated from the wall with a depth equal to that of the embedment depth of the bolt. One angle of the wedge was located at the embedded bolt head or at the bend of the “L”. The other two angles were located at the top of the wall, one on each side of the bolt’s projection out of the top of the wall, each at a distance approximately equal to 1-1/2 times the embedment depth. Hence the wedge was about 152 mm (6 inch) deep and 457 mm (18 inch) wide. The wedge-shaped section is indicated by the dashed line shown in Fig. 1. In some cases the “L”-shaped bolts failed by straightening and pulling out. In those cases it pulled through one course until only one course remained to resist pullout. Then the bolt and the single masonry unit separated from the remainder of the specimen.

Two failure modes were observed in the double wythe walls. With the 254 mm (10.0 in) bolts the failure was a straightening and pull out of the bolt, without apparent damage to the walls, Fig. 4. The specimens with the 203 mm (8 in) bolts experienced masonry failure similar to the tension tests on the single wythe walls. In this case the wythe of masonry into which the “L” of the bolt was directed underwent the damage. The units delaminated from the collar joint. These different failure modes are most likely a result of different specimen configuration. The joint reinforcement for the 254 mm (10.0 in) bolt was located one course above the bend in the bolt. For the 203 m (8.0 in) bolt the joint reinforcement was located in the course with the bend in the bolt.

The failure mode for out-of-plane shear loading was splitting of the single wythe specimen in its plane accompanied by a separation of a triangular shape of masonry. Viewing the failure from the top of the wall, a triangle with a depth equal to half the wall thickness and a width equal to the separation of the jacks (1-1/2 times the wall thickness) separated from the wall. Viewing the wall from the front, a triangle split from the specimen starting at the jacks and converging at the bolt head.

Table 1- Anchor Bolt Test Results, Single Wythe Hollow Clay Masonry

Bolt Type	Load Path	Peak Load, kN					Average		COV
		1	2	3	4	5	kN	lbs	
127 mm (5 inch) Hollow Clay Masonry									
L-9.5mm L-3/8 in	Tension	12.7	11.0	13.1	13.2	13.8	12.8	2868	8.21
	O. P. S. ¹	9.13	12.1	7.83	7.42	9.93	9.28	2085	20.00
	I. P. S. ²	17.8	19.3	20.0	16.0	20.4	18.7	4198	9.63
L-12.7mm L-1/2 in	Tension	14.3	13.5	13.7	12.3	12.3	13.2	2973	6.68
	O. P. S.	-----	-----	-----	-----	-----	-----	-----	-----
	I. P. S.	18.6	19.0	22.7	22.5	21.3	20.8	4679	9.20
H-9.5mm H-3/8 in	Tension	12.9	12.1	13.9	16.7	17.5	14.6	3286	16.14
	O. P. S.	7.58	7.69	9.19	9.84	8.79	8.62	1937	11.29
	I. P. S.	17.7	17.5	17.0	19.8	19.1	18.2	4092	6.47
H-12.7mm H-1/2 in	Tension	13.4	16.5	14.2	16.0	15.9	15.2	3418	8.88
	O. P. S.	-----	-----	-----	-----	-----	-----	-----	-----
	I. P. S.	15.4	13.7	16.6	20.0	16.2	16.4	3684	14.11
152 mm (6 inch) Hollow Clay Masonry									
L-9.5mm L-3/8 in	Tension	10.3	16.5	15.7	16.9	13.3	14.5	3269	18.86
	O. P. S.	10.9	12.0	14.7	12.6	12.4	12.5	2810	11.22
	I. P. S.	23.7 *	23.5 *	23.6	23.1	21.3	23.0	4985	4.35
L-12.7mm L-1/2 in	Tension	15.1	15.3	16.7	15.8	15.9	15.8	3544	4.03
	O. P. S.	-----	-----	-----	-----	-----	-----	-----	-----
	I. P. S.	22.5	26.4	23.6	21.0	23.2	23.3	5243	8.48
H-9.5mm H-3/8 in	Tension	16.5	19.3	17.7	18.7	16.1	17.7	3968	7.92
	O. P. S.	17.3	13.2	11.4	15.3	10.8	13.6	3059	19.98
	I. P. S.	26.0	22.9	29.6	25.5	**	26.0	5846	10.71
H-12.7mm H-1/2 in	Tension	17.9	12.5	16.9	14.7	19.2	16.3	3653	16.43
	O. P. S.	-----	-----	-----	-----	-----	-----	-----	-----
	I. P. S.	23.2	29.6	29.6	29.0	26.6	27.6	6208	10.01

¹ O. P. S. = shear perpendicular to the face of the wall

² I. P. S. = shear parallel to the face of the wall

* Anchor bolt Sheared at Peak Load recorded

** Damaged Specimen Not Tested

---- Not included in test matrix

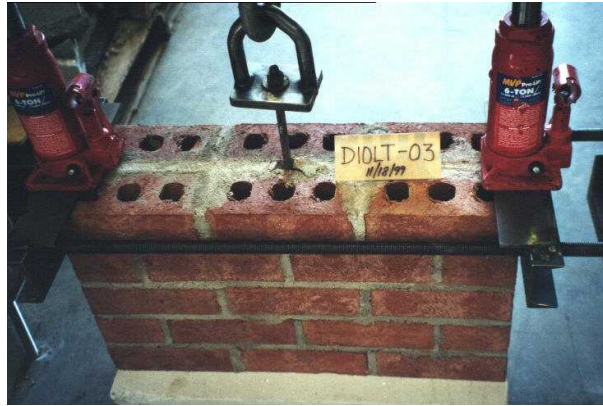


Figure 4. Double Wythe Specimen Pullout Failure

Table 2 – Tension Test Results of Anchor Bolts in Double Wythe Clay Masonry

Bolt Type	Peak Load, kN and lb					Average	MSJC Allow	Ratio: Measured To Allow
	1	2	3	4	5			
L-12.7x203 mm	17.28	12.81	13.14	13.22	13.75	14.04	3.83	3.96
L-1/2 x 8 in.	3885	2879	3032	3429	3813	3408	861	
L-12.7x254 mm	16.60	16.77	17.60	16.96	22.33	18.05	3.83	4.72
L-1/2 x 10 in.	3732	3771	3956	3813	5020	4058	861	

In the case of in-plane shear, loads were significantly higher than those measured for other loading directions. In some cases the grout on the compressive side of the bolt crushed. In other cases the bolts sheared in two. In other cases an unsymmetrical wedge of masonry separated from the wall. Most failures were combinations of all three modes.

OBSERVATIONS AND CONCLUSIONS

Several variables affect the strength of anchor bolts in the tops of clay masonry walls: bolt diameter, bolt geometry, embedment length, wall thickness, and load direction. Each of these will be examined.

Bolt Diameter

The bolt diameters were selected to be relatively small because the authors desired capacities limited by the masonry, not the bolts. This turned out to be true in all but three cases out of one hundred for the single wythe walls. Most of the larger diameter bolts resulted in marginally higher strength, but this was not always the case (Fig. 5 and 6). This small difference between specimens with corresponding loading was not

surprising since masonry governed the failure in so many of the tests.

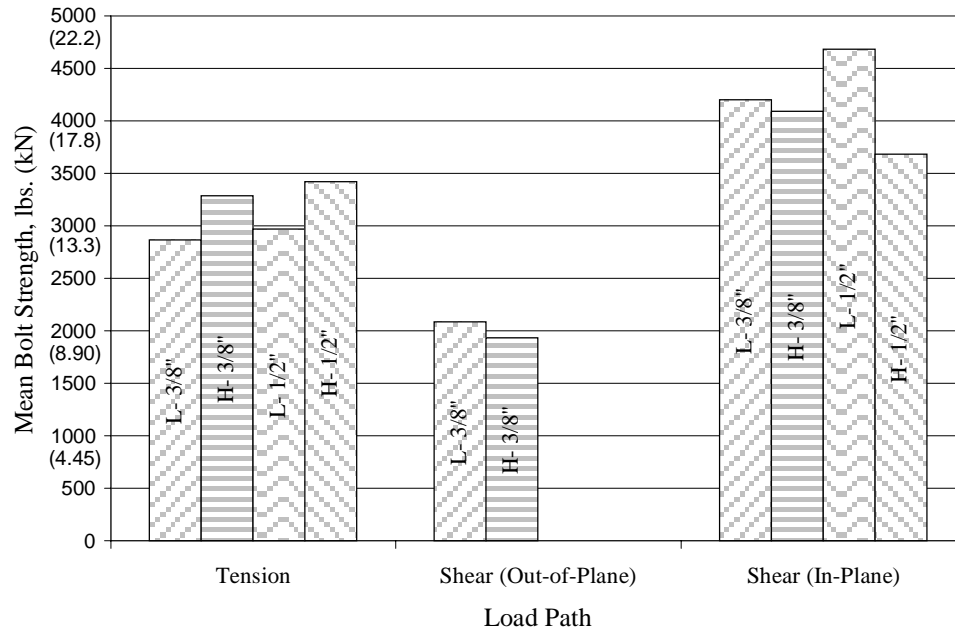


Figure 5- Mean Bolt Strength of All Bolts Tested In 127 mm (5 inch) Hollow Clay Masonry

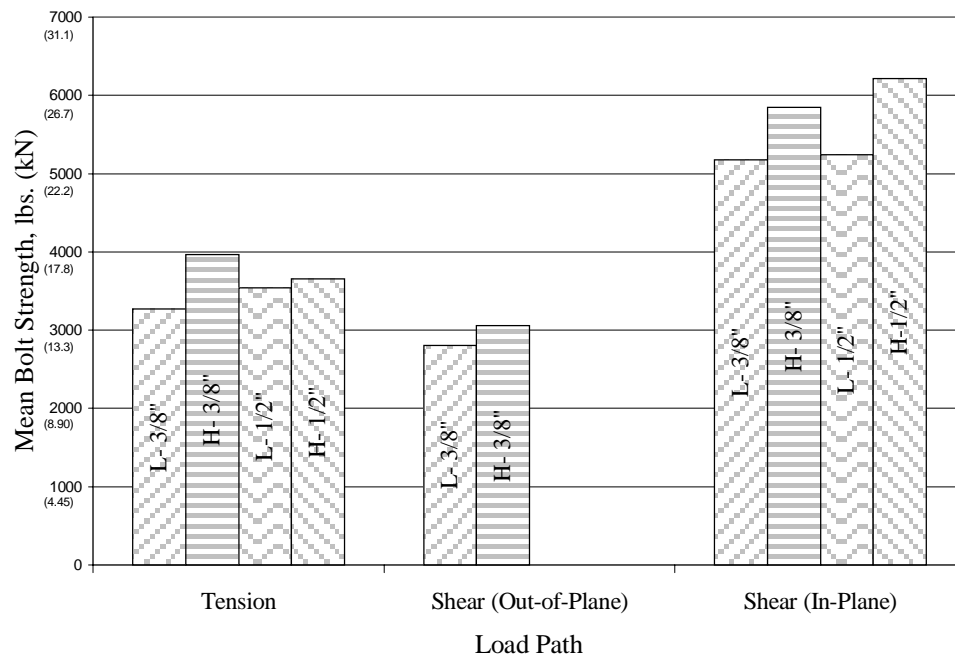


Figure 6- Mean Bolt Strength of All Bolts Tested In 152 mm (6 inch) Hollow Clay Masonry

Bolt Geometry

For tension loading, the headed bolts were stronger in every case. This may be attributable to straightening of the “L” in many of the bent bolts. However, the bolt geometry was much less significant for other loading directions.

Embedment Length

The double wythe specimens were the only walls with bolt embedment length as an independent variable. There was a different failure mode for the two embedment lengths. The walls with shorter bolt embedment length failed in the masonry; the specimens with longer embedment length failed by bolt pullout. However, the specimens were not the same. The joint reinforcement was one course above the bend of the longer bolt whereas it was in the course with the bend for the shorter bolt. Thus the joint reinforcement was more effective in preventing a masonry failure and no conclusion can be attached to bolt embedment length.

Wall Thickness

Test results showed an increase in bolt capacity with increased wall thickness when variables other than wall thickness were eliminated. The greatest increase occurred with out-of-plane load and for the headed bolts loaded in-plane. The wall thickness is an important variable when bolts are placed in the top of walls. The proximity to the nearest edge is no greater than half the wall thickness minus the bolt radius. The current MSJC Code bases bolt capacity on an area defined by either the bolt embedment length, l_b , or bolt edge distance, l_{be} . This research has shown clearly that in certain cases, this reduction is too severe, and that a different rationale should be adopted. The influence of edge distance is discussed further in the following section on load direction.

Load Direction

Comparison of capacities resulting from different directions of loading is not valid. Rather, the values measured are compared to their allowable capacities according to the building code (MSJC). The values of measured and calculated loads are given in Tables 2 and 3. The mean measured values with the allowable values calculated from the MSJC Code are compared in Figs. 7 and 8. The resulting factors of safety vary for different directions of loading. For tension loading in single wythe walls, this ratio is between 6.1 and 10.6, averaging 8.7. For double wythe walls it ranged from 4.0 to 4.7. The allowable capacities, B_a , were calculated from MSJC Code Eq. 2-1 (Eq. 1) using a bolt edge distance, l_{be} , instead of bolt embedment length, l_b , in calculating the area A_p (Eq. 2). Actual, not nominal, brick dimensions are used in determining l_{be} in all equations. For these calculations, the specified compressive strength of the masonry was assumed to be 20.7 MPa (3000 psi).

Clearly, embedment of the bolt deeper than l_{be} results in greater tensile strength, but the Code does not recognize it. The failure modes showed a depth of masonry equal to the actual embedment depth participating in the resistance to tension loading in both the single and double wythe tests. Defining the reduction in B_a due to edge distance as μ_a

(Eq. 3), then the edge distance reduction is isolated. The factors of safety for tension using $\mu_a = 1$ are also plotted in Fig. 7 and 8. These values are much lower, and in some cases less than unity. Clearly a reduction due to edge distance is warranted, however the current reduction appears to be excessive.

$$B_a = 0.5 A_p \sqrt{f'_m} \quad (\text{MSJC Eq. 2-1}) \quad (1 \text{ and } 2)$$

$$A_p = \pi l_{be}^2 \quad (\text{MSJC Eq. 2-3})$$

$$\mu_a = \left[\frac{l_{be}}{l_e} \right]^2 \leq 1 \quad (3)$$

Table 3. Calculated Capacities for Bolts in Hollow Clay Masonry

Units	Bolt Type	Load Path	μ	B		μB		Measured Load, M		Ratio-Measured to	
				lbs.	kN	lbs.	kN	lbs.	kN	M/B	$M/\mu B$
127 cm (5 in) Hollow Clay Masonry Units (4.375 in. actual)	L- 3/8"	Tension	0.111	3097	13.78	344	1.53	2868	12.76	0.93	8.33
		O.P. Shear	0.286	1493	6.64	427	1.90	2085	9.28	1.40	4.89
		I.P. Shear	0.286	1493	6.64	427	1.90	4198	18.68	2.81	9.84
	L- 1/2"	Tension	0.104	3097	13.78	323	1.44	2973	13.22	0.96	9.21
		O.P. Shear	0.188	1724	7.67	323	1.44	-----	-----	-----	-----
		I.P. Shear	0.188	1724	7.67	323	1.44	4679	20.81	2.71	14.47
	H- 3/8"	Tension	0.111	3097	13.78	344	1.53	3286	14.62	1.06	9.55
		O.P. Shear	0.286	1493	6.64	427	1.90	1937	8.62	1.30	4.54
		I.P. Shear	0.286	1493	6.64	427	1.90	4092	18.20	2.74	9.59
	H- 1/2"	Tension	0.104	3097	13.78	323	1.44	3418	15.20	1.10	10.58
		O.P. Shear	0.188	1724	7.67	323	1.44	-----	-----	-----	-----
		I.P. Shear	0.188	1724	7.67	323	1.44	3684	16.39	2.14	11.39
152 mm (6 in) Hollow Clay Masonry Units (5.375 in. actual)	L- 3/8"	Tension	0.174	3097	13.78	538	2.39	3269	14.54	1.06	6.08
		O.P. Shear	0.429	1493	6.64	640	2.85	2810	12.50	1.88	4.39
		I.P. Shear	0.429	1493	6.64	640	2.85	5175	23.02	3.47	8.09
	L- 1/2"	Tension	0.165	3097	13.78	511	2.27	3544	15.77	1.14	6.93
		O.P. Shear	0.288	1724	7.67	496	2.21	-----	-----	-----	-----
		I.P. Shear	0.288	1724	7.67	496	2.21	5243	23.32	3.04	10.58
	H- 3/8"	Tension	0.174	3097	13.78	538	2.39	3968	17.65	1.28	7.38
		O.P. Shear	0.429	1493	6.64	640	2.85	3059	13.61	2.05	4.78
		I.P. Shear	0.429	1493	6.64	640	2.85	5846	26.00	3.91	9.13
	H- 1/2"	Tension	0.165	3097	13.78	511	2.27	3653	16.25	1.18	7.15
		O.P. Shear	0.288	1724	7.67	496	2.21	-----	-----	-----	-----
		I.P. Shear	0.288	1724	7.67	496	2.21	6208	27.62	3.60	12.52

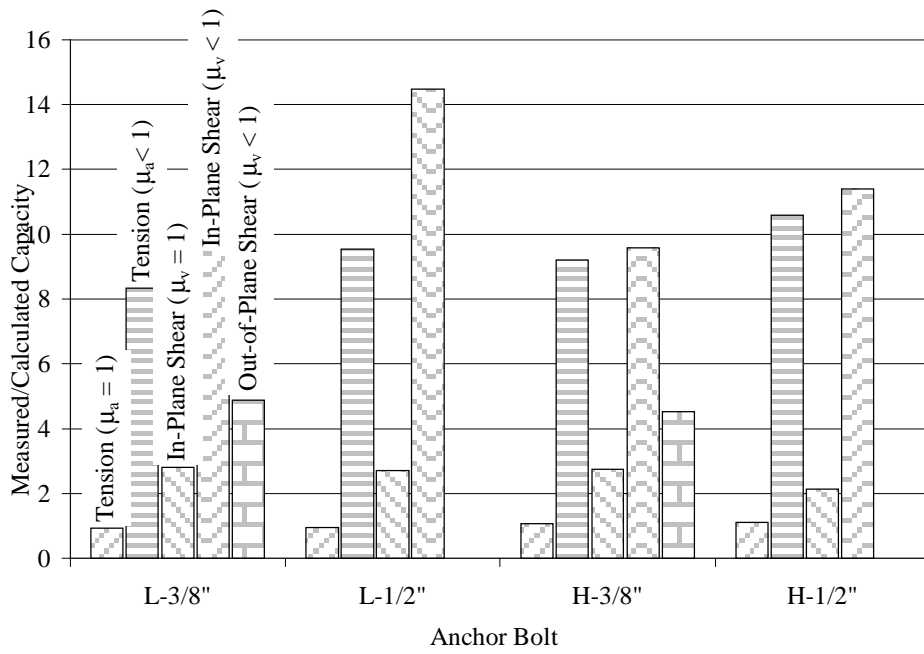


Figure 7- Measured/Calculated Capacities of Anchor Bolts in 127mm (5 inch) Hollow Clay Masonry

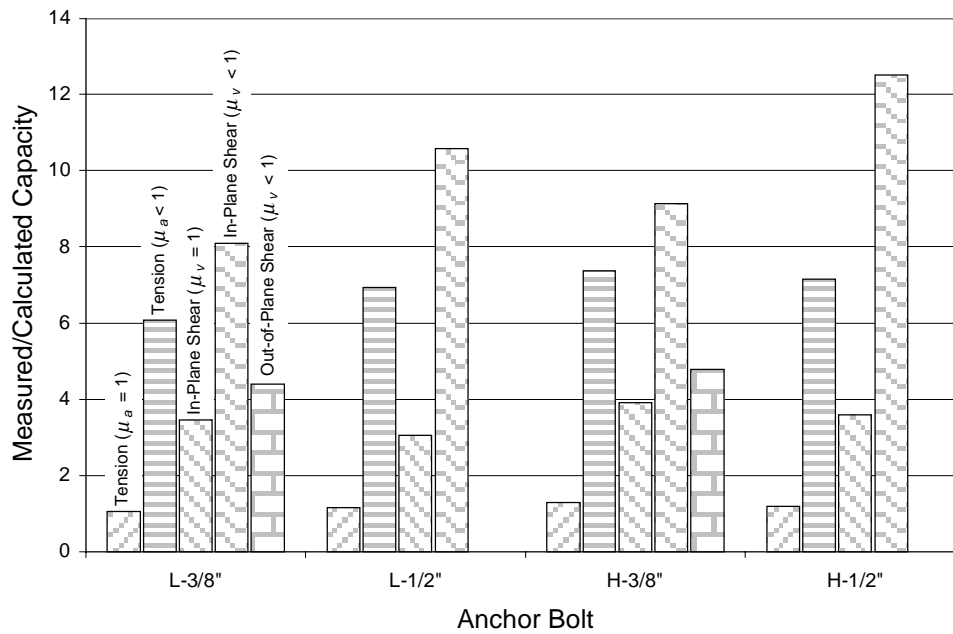


Figure 8- Measured/Calculated Capacities of Anchor Bolts in 152 mm (6 inch) Hollow Clay Masonry

In the case of shear perpendicular to the wall, bolt edge distance is critical. The capacity calculated using MSJC Code Eq. 2-5 (Eq. 4) is modified by a reduction factor μ_v if the edge distance is less than 12 bolt diameters ($12d_b$). The factor μ_v is not a Code equation, but is the mathematical equivalent of Code Sec. 2.1.2.2.3 (Eq. 5). As a result, the factors of safety were between 4.3 and 5.3, averaging 4.8. This is consistent with the intent of the MSJC Code, and use of the edge distance reduction as defined in the code appears fully warranted.

$$B_v = 350 \sqrt[4]{f'_m A_b} \quad (\text{MSJC Eq. 2-5})$$

$$\mu_v = \frac{l_{be} - 1}{12 d_b - 1} \leq 1 \quad (\text{MSJC Sec. 2.1.2.2.3}) \quad (4 \text{ and } 5)$$

In the case of shear parallel to the wall, the factors of safety ranged from 8.1 to 14.5, averaging 11.1. These safety factors, plotted in Fig. 7 and 8, were obtained by calculating the shear capacity using the edge distance reduction factor μ_v . This requirement is imposed in all directions, not just in the direction of the shear load. That is, the reduction is the same for loading parallel or perpendicular to the wall. If the penalty were not imposed ($\mu_v=1$) the safety factors range from 2.14 to 4.33, averaging 3.2. Clearly an edge distance reduction is warranted, but the present rule of imposing the same edge distance reduction regardless of whether or not the edge is in the direction of loading is excessive.

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