THE INFLUENCE OF EDGE DISTANCE ON THE STRENGTH OF CONCRETE MASONRY EMBEDDED ANCHOR BOLTS

Terence A. Weigel[1], J. P. Mohsen[2], Andrew Schad[3] and Karl Erdmann[4]

ABSTRACT

An anchor bolt testing program currently is underway at the University of Louisville. Its purpose is to quantify the effects of edge distance on the strength of anchor bolts embedded in concrete masonry. Both headed and L-shaped anchor bolts embedded in the tops of concrete masonry specimens will be tested in either tension, in-plane or out-of-plane shear. This paper reports the results of the first phase of headed bolts tested in tension.

Three-course-high specimens were constructed using Type S PCL mortar and concrete masonry knock-out web bond beam units. All specimens were fully grouted. Headed bolts were embedded in the "tops" of these specimens, in order to simulate construction in which bolts are embedded in the tops of masonry walls.

Testing was accomplished by loading each anchor bolt using a hydraulic ram. Bolt displacements were measured using an LVDT, and plots of displacement versus load were obtained. A total of five edge distances were used for this phase of the tensile loading program, and will also be used for the in-plane and out-of-plane shear loading programs. At each of these distances, a total of five replicates were tested.

This paper reports the results of the tensile testing program, including average ultimate load achieved by each type of bolt for each edge distance; typical plots of bolt displacement versus applied load; total bolt displacement at both ultimate and final load; a graph of ultimate load versus edge distance; failure mode; and finally, comparison of maximum load achieved with allowable bolt loads calculated using MSJC code provisions.

Key words Anchor bolts, masonry, concrete masonry, tension, edge distance, headed bolts

[1]Associate Professor, Department of Civil and Environmental Engineering, University of Louisville, Louisville, Kentucky USA, 40292 – taw@louisville.edu
[2]Associate Professor, Department of Civil and Environmental Engineering, University of Louisville, Louisville, Kentucky USA, 40292 – jpmohs01@louisville.edu
[3]Graduate Student, Department of Civil and Environmental Engineering, University of Louisville, Louisville, Kentucky USA, 40292 – aschad3983@aol.com
[4]Graduate Student, Department of Civil and Environmental Engineering, University of Louisville, Louisville, Kentucky USA, 40292 – kerdmann@gateway.net

INTRODUCTION

Recently anchor bolt behavior in masonry has received increased attention. Rad (1999) investigated the effect of side cover on post-installed J-bolts. A study at Washington State University (Tubbs, Pollack, McLean and Young 1999) studied embedded and adhesive anchors under shear and tension loading. Both of these studies involved bolts embedded in the sides, not the tops, of the masonry specimens.

Results of these two studies, as well as several earlier investigations are summarized in a Building Seismic Safety Council (BSSC) task group report (Allen, et al 1999). This report also compares existing anchor bolt test data against design provisions such as those of NHERP (FEMA 1997) and the International Building Code 2000 (IBC 2000).

Despite the increased interest, little experimental attention has been given to the influence of edge distance on the capacity of anchor bolts embedded in tops of masonry walls. A recent study at Clemson University (Brown, Borchelt and Burgess 1999) investigated the capacity of both headed and L-shaped bolts embedded along the centerline of the tops clay masonry specimens. An ongoing testing program at NCMA (results yet unpublished) focuses on headed and L-shaped bolts embedded along the centerline of the tops of CMU specimens. This program also includes some bolts positioned off-center, with 50.8 mm (2-in) edge distances.

As Brown indicates, bolts embedded in tops of masonry walls are always “near” an edge, and suffer the penalties imposed by the MSJC capacity equations for bolts so located. Bolts embedded at the centerline of the top of a wall have the maximum edge distance, but still limited to half the wall thickness. Any bolt located off-center has a smaller edge distance and consequently a smaller calculated capacity, when the provisions of MSJC are followed.

PURPOSE

The test program described in this paper was intended to investigate the influence of edge distance on capacities of anchor bolts mounted in the tops of CMU walls. A second aim was to provide additional data to assist in deciding whether alternate fastening design frameworks (for example, the Concrete Capacity method) should be pursued.

In the first phase of the program, described in this paper, 15.9-mm (5/8-in) headed bolts with 102-mm (4-in) embedment in 200-mm wide CMU (8-in nominal width) specimens were tested in tension. A total of five replicates at each of five edge distances were tested. In subsequent phases, behavior of L-shaped bolts, as well as more headed bolts, will be examined in tension and both in-plane and out-of-plane shear.

MSJC BOLT PROVISIONS

Provisions of the MSJC Code (MSJC 1999) require that the tensile capacity of bolts be computed using Equation 1 (MSJC Equation 2-1 – metric versions in parenthesis). When comparing the values generated by these equations with the maximum values obtained by testing, it is worth noting that these provisions of the MSJC are allowable stress values and incorporate a factor of safety.

$$B_a = 0.5\, A_p \sqrt{f'_m}\left(0.042\, A_p \sqrt{f'_m}\right) \qquad (1)$$

$$A_p = \pi\, l_b^2 \qquad (2)$$

$$A_p = \pi\, l_{be}^2 \qquad (3)$$

where:

B_a = allowable axial force on an anchor bolt (lb, N)
A_p = projected area on the masonry surface of a right circular cone for the bolt (in^2, mm^2)
l_b = effective embedment length of the anchor (in, mm)
l_{be} = anchor bolt edge distance from the surface of the anchor to the nearest free edge of masonry (in, mm)
f'_m = specified compressive strength of masonry (psi, MPa)

The value of A_p used in Equation 1 cannot exceed the smaller of the values generated by Equations 2 and 3. For the values of edge distance used in this testing program, the value of A_p generated by Equation 3 always controlled the calculated bolt capacity. That is, the edge distance always controls.

The theoretical basis of Equation 1 assumes that failure occurs on a conical surface originating at the bearing point of the bolt embedment and radiating at a 45^o angle in the direction of the tensile load. When edge distance controls, a modified embedment value (l_{be}) is used. The modified embedment is set so that the right circular cone interests the masonry surface at the free edge that fixes l_{be}.

Equation 1 gives the bolt capacity based on masonry strength. The MSJC Code has a second equation that limits bolt capacity based on the yield strength of the bolt material; but inasmuch as all bolts tested in this program failed in the masonry, it is not relevant in this paper.

SPECIMENS

Masonry

Specimens used in this phase of the program consisted of concrete masonry knock-out web bond beam units laid in a running bond pattern. The units conformed to the ASTM C90 (ASTM C90-99a) specification (when grouted). The purpose of using the knockout units was to improve bond across the head joints in adjacent units in a course. Toward this end, one web (not both webs) at the end of one of two units meeting to form a head joint was removed.

Fig. 1 shows the configuration of the specimens tested. The specimens were built so that all five bolts in a single specimen were at the same nominal edge distance. No bar or joint reinforcing was used in any of the specimens.

Each specimen was built three courses high by a journeyman mason. Type S PCL mortar was used. Twenty-four hours after completion of the specimens the anchor bolts were positioned and the specimens were fully grouted. The grout was consolidated by vibration to insure that the cells of the units were completely filled. In addition to the test specimens, five fully grouted test prisms were built. The specimens and prisms were cured in the laboratory under plastic for 28 days, and then tested. The measured prism compressive strength was 21.9 MPa (3170 psi).

Bolts

Bolts used in this project were 15.9-mm (5/8-in) diameter hex head bolts with length sufficient to give the desired embedment and sufficient extension above the top of the masonry to permit attachment to the loading device.

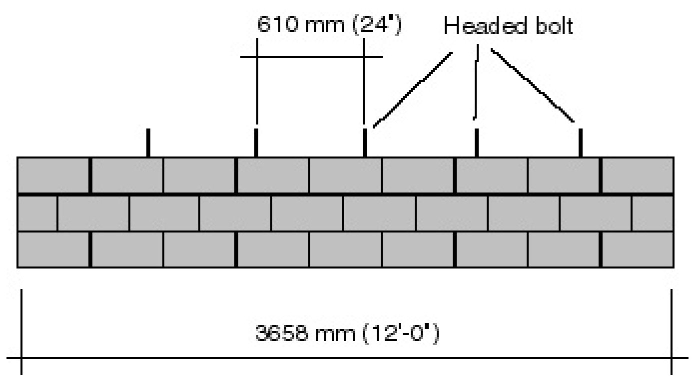

Figure 1. Typical Test Specimen

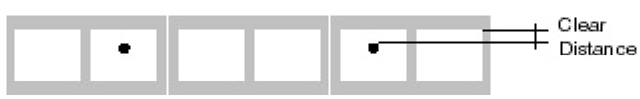

Figure 2. Clear Distance Dimension

Clear Distance and Edge Distance

The edge distances used in the testing program actually were set by the clear distance between the surface of the bolt and the closest of the adjacent face shell, as shown in Fig. 2. Clear distances of 6.4, 12.7, 25.4 and 38.1 mm (0.25, 0.5, 1.0 and 1.5 in) were used. The fifth edge distance was obtained for bolts with centerline collocated with the masonry specimen centerline.

The 6.4-mm (0.25-in) clear distance was chosen to position some bolts as close as possible to the face shell of the unit. In this position, the head of the bolt was almost in contact with the masonry unit. A clear distance of 6.4-mm (0.25-in) gives a thickness of grout between bolt and masonry unit less than that permitted by MSJC Section 1.12.3.5. For course grout, the minimum permitted thickness is 12.7-mm (0.5-in). Technically this provision applies only to reinforcement, but a case can be made that the intent of the provision should also be applied to anchor bolts. It is also worth noting that the new MSJC strength design provisions require no less than 12.7-mm (0.5-in) of grout between the bolt and masonry.

Replicate Designation

The following designation for individual test replicates was used for this project. A typical bolt replicate was designated as followed:

T-8-5H-25-0400-1

The meaning of each part of this designation is as follows:

T - test type (T = tension, VI = in-plane shear, VO = out-of-plane shear)
8 - nominal CMU thickness (in)
5 – bolt diameter (1/8-in increments)
H – type of bolt (H = headed, L = L-shaped)
25 – 100 times the nominal clear distance between the surface of bolt and
    the inside of the face shell (25 = 0.25-in, 50 = 0.50-in, etc.) –
    CL used in this position to indicate a bolt located at the
    centerline of the specimen
0400 – 100 times the nominal embedment
    (quarter inch increments, 0400 = 4-in, 0425 = 4.25-in)
1 – replicate number

TESTING

The testing protocol followed the provisions of ASTM E448 for static testing as closely as practical. A schematic of the test setup for an individual bolt is shown in Fig. 3. The actual testing setup is shown in the photograph in Fig. 4. The testing apparatus and the specimens were oriented so that testing a sequence of five bolts required moving only the hydraulic ram longitudinally along the loading frame. A single loading frame setup thus involved testing one bolt from each of the five specimens (each having a different edge distance). After testing a series of five bolts, the frame was moved to the next line and testing restarted on the next series of five bolts.

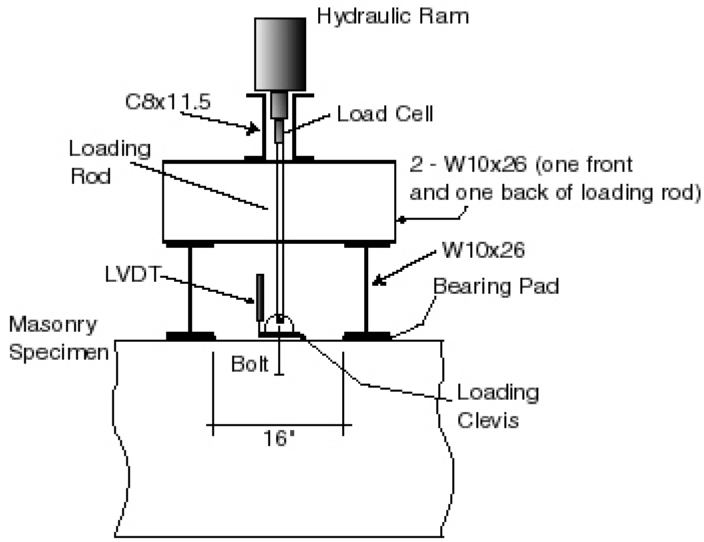

Figure 3. Schematic of Loading Arrangement

RESULTS

Loads

Table 1 summarizes the maximum measured load for each of the specimens tested. The calculated coefficients of variation for these loads for the 6.4-, 12.7-, 25.4- and 38.1-mm and centerline (0.25-, 0.5-, 1.0- and 1.5-in) clear distances were 8.4, 11.9, 8.5, 9.6 and 5.2 percent, respectively. All but one of these values is well within the 12% maximum permitted by ASTM E 448 for a sample size of five. Also shown in the table is the allowable bolt capacity computed using provisions of the MSJC Code, as well as the ratio of the these two values.

Displacements

A load displacement plot for Specimen T-8-5H-50-0400-1 is shown in Fig. 5. This plot is typical of the behavior of all of the specimens tested in this phase of the project.

Failure Modes

Failure modes are shown in Fig. 6 and 7. The typical mode was observed to be that of a wedge-shaped piece of masonry that broke away from the specimen. The “apex” of the wedge was located at the depth of embedment of the bolt, and, in the plane of the specimen, the two sides of the wedge formed angles of approximately 20^{o} with respect to the horizontal. In some cases, when these angled sides encountered a head joint, they propagated vertically to the top of the specimen, rather than continuing at the same angle. In some cases, wedge formation was accompanied by occurrence of a horizontal crack across the top of the specimen and / or a vertical crack, both at the bolt location.

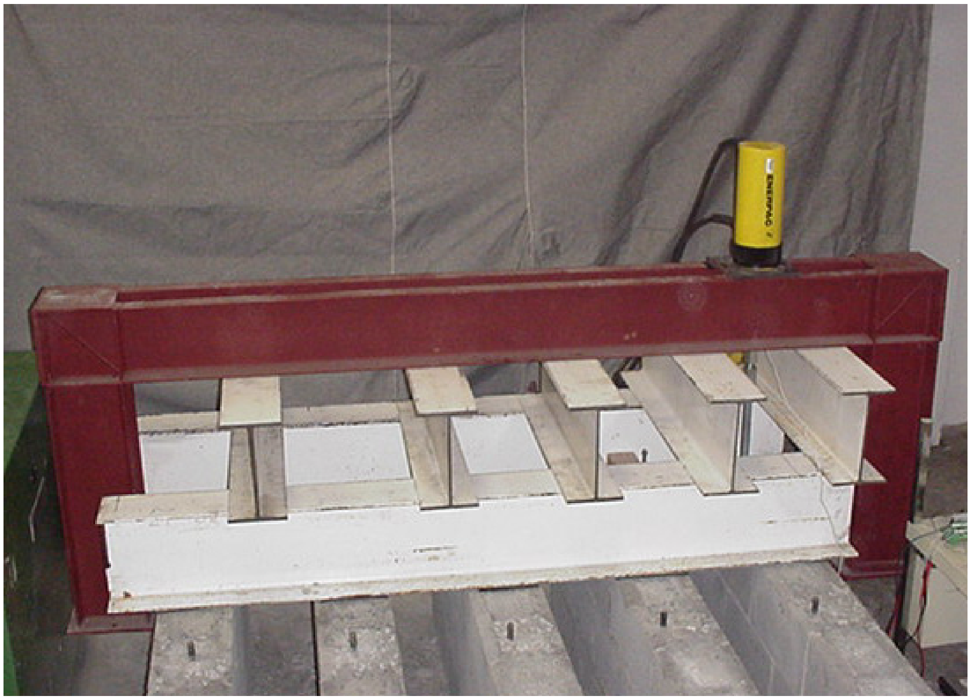

Figure 4. Testing Apparatus and Specimens

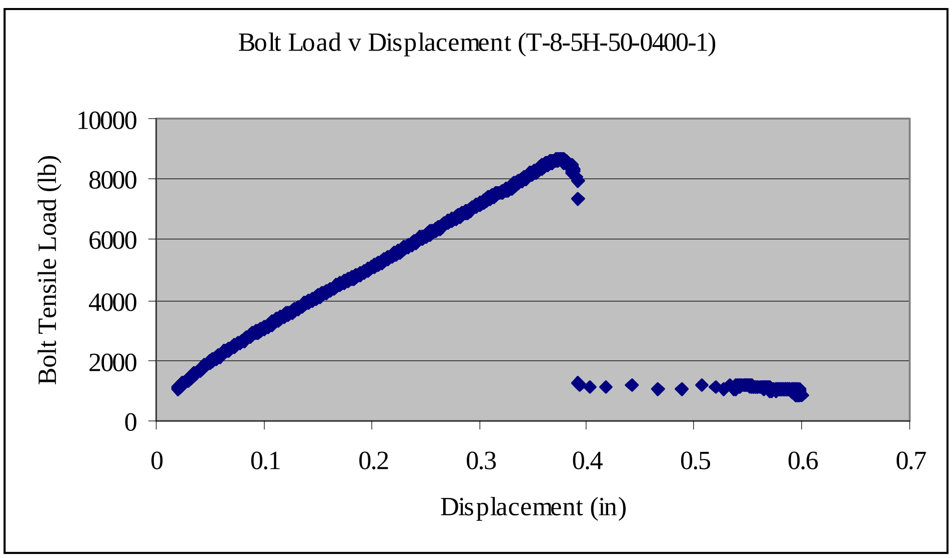

Figure 5. Typical Load Displacement Plot

Figure 6. Failed Specimen T-8-5H-25-0400-1

Figure 7. Failed Specimen T-8-5H-50-0400-2

Table 1. Bolt Capacity Results

Specimen	**Embedment** (mm) (in)	**Edge Distance** (mm) (in)	**Measured Load** (N) (lb) (4)	**MSJC Capacity** (N) (lb) (5)	**Ratio** (4) / (5)
T-8-5H-25-0400-1	99.7	40.3	36 480	991	37.3
	3.92	1.59	8 200	220	
T-8-5H-25-0400-2	99.9	45.6	39 530	1 270	30.7
	3.93	1.80	8 890	290	
T-8-5H-25-0400-3	99.7	44.3	42 520	1 200	35.4
	3.93	1.74	9 560	270	
T-8-5H-25-0400-4	100	42.1	45 640	1 080	42.8
	3.94	1.66	10 260	240	
T-8-5H-25-0400-5	101	45.6	39 990	1 270	31.0
	3.99	1.79	8 990	290	
		Average	40 830		35.4
			9 180		
T-8-5H-50-0400-1	102	47.4	38 700	1 370	28.2
	4.01	1.87	8 700	309	
T-8-5H-50-0400-2	99.4	47.8	42 730	1 390	30.7
	3.91	1.88	9 610	313	
T-8-5H-50-0400-3	101	49.1	47 590	1 470	32.4
	3.97	1.93	10 680	330	
T-8-5H-50-0400-4	100	49.4	37 980	1 490	24.8
	3.95	1.95	8 310	335	
T-8-5H-50-0400-5	99.2	49.7	35 700	1 500	23.8
	3.91	1.96	8 030	338	
		Average	40 320		28.0
			9 070		
T-8-5H-100-0400-1	93.2	64.8	46 700	2 560	18.3
	3.67	2.55	10 500	575	
T-8-5H-100-0400-2	99.7	62.7	43 110	2 400	18.0
	3.93	2.47	9 690	539	
T-8-5H-100-0400-3	101	60.3	49 740	2 220	22.4
	3.96	2.37	11 180	498	
T-8-5H-100-0400-4	101	64.9	42 930	2 570	16.7
	3.97	2.56	9 650	577	
T-8-5H-100-0400-5	98.2	61.8	40 000	2 230	17.0
	3.87	2.43	8 890	524	
		Average	44 500		18.5
			10 000		

T-8-5H-150-0400-1	99.8	75.6	51 330	3 480	14.7
	3.93	2.98	11 540	783	
T-8-5H-150-0400-2	97.4	75.8	53 330	3 500	15.2
	3.84	2.98	11 990	787	
T-8-5H-150-0400-3	98.6	77.3	53 400	3 640	14.7
	3.88	3.04	12 000	819	
T-8-5H-150-0400-4	107	72.8	48 730	3 230	15.1
	4.21	2.87	10 960	726	
T-8-5H-150-0400-5	95.5	75.8	41 890	3 510	12.0
	3.76	2.99	9 420	788	
		Average	49 740		14.3
			11 180		
T-8-5H-CL-0400-1	96.4	89.0	52 900	4 830	10.9
	3.80	3.50	11 900	1 090	
T-8-5H-CL-0400-2	99.2	91.8	48 930	5 140	9.5
	3.91	3.62	11 000	1 160	
T-8-5H-CL-0400-3	99.2	87.7	49 200	4 690	10.5
	3.91	3.45	11 060	1 050	
T-8-5H-CL-0400-4	99.6	88.3	49 360	4 750	10.4
	3.92	3.48	11 100	1 070	
T-8-5H-CL-0400-5	98.2	87.5	45 720	4 660	9.8
	3.87	3.44	10 280	1 050	
		Average	49 230		10.2
			11 070		

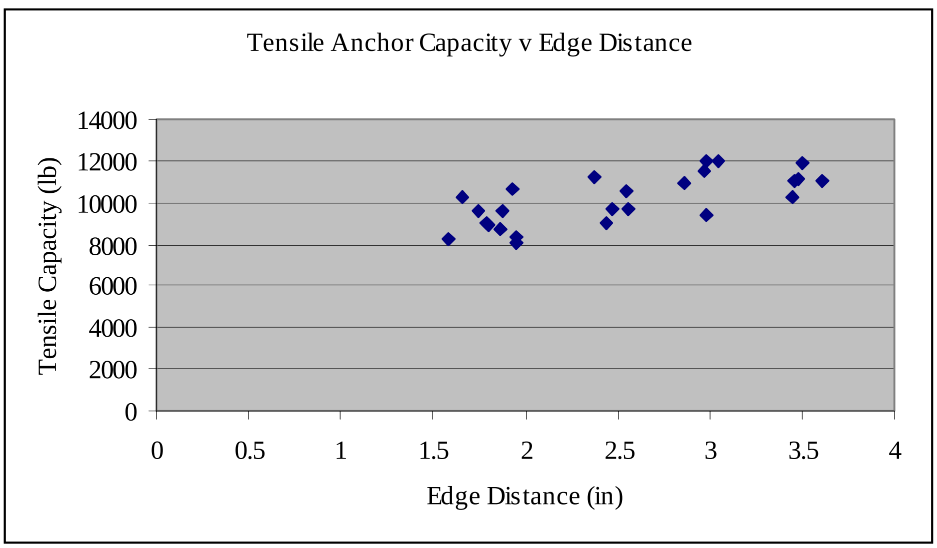

Figure 8. Tensile Anchor Bolt Capacity versus Edge Distance

SUMMARY

Figure 8 shows the variation of tensile capacity with edge distance, for the anchor bolts tested in this phase. The limited results to date from this testing program indicate that the MSJC allowable stress design equations for the tensile capacity anchor bolts with "small" edge distances produce very conservative results. This conservatism becomes less pronounced as edge distance increases.

Much more testing is needed to confirm this result. Furthermore, other types of bolts (different diameter and different shapes) and other loading scenarios (in-plane and out-of-plane loading) need to be tested to generalize this tentative conclusion. Finally, results from this testing program should be compared against existing (other than MSJC) and alternate design frameworks being considered for future use (Allen, et al 1999).

REFERENCES

Allen, R., Zobel, R., Borchelt, J. G., Klingner, R. E. and Shapiro, D. (1999), "Provisions for Design of Fastening to Masonry: A Report to the Joint BSSC Task Group".

ASTM 1999 *Annual Book of ASTM Standards,* 100 Barr Harbor Drive, West Conshohocken, Pennsylvania, PA USA 19428-2959.

- ASTM C 90-99a, *Specification for Loadbearing Concrete Masonry Units*
- ASTM C 270-00, *Specification for Mortar for Unit Masonry*
- ASTM C 476-99, *Specification for Grout for Unit Masonry*
- ASTM C 1019-98a, *Test Method for Sampling and Testing Grout*
- ASTM E 488-96, *Test Methods for Strength of Anchors in Concrete and Masonry Elements*

Brown, R. H., Borchelt, J. G., and Burgess, R. E. (2000), "Strength of Anchor Bolts in the Top of Clay Masonry Walls," *Proceedings of the 12th International Brick/Block Masonry Conference (Supplement),* Madrid, Spain, June 24-27, 2000.

FEMA 302 (1997). *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*, Federal Emergency Management Agency, Washington, D. C.

IBC 2000, International Building Code 2000, International Code Council, BOCA International, Country Club Hills, Illinois, ICBO, Whittier, California, SCCCI, Birmingham, Alabama.

MSJC Code 1999: Masonry Standards Joint Committee, ACI 530-99/ASCE 5-99/TMS 402-99, *Building Code Requirements for Masonry Structures,* American Concrete Institute, Detroit, Michigan, American Society of Civil Engineers, Reston, Virginia, The Masonry Society, Boulder, Colorado.

Rad, F. (1999). "Strength of Grouted Anchors in Masonry Walls", *Proceedings 8th North American Masonry Conference,* Austin, Texas, June 6-9, 1999.

Tubbs, J. B., Pollock, D. G., McLean, D. I., and Young, T. C. (1999). "Performance of

Anchor Bolts in Concrete Block Masonry", *Proceedings 8th North American Masonry Conference*, Austin, Texas, June 6-9, 1999.

ACKNOWLEDGEMENTS

The authors express appreciation to Mr. Mike Sigars of the L. Thorn Company, New Albany, Indiana, and Messrs. John and Paul Clements of Masonomics, Inc., Louisville, Kentucky, for their assistance on this project.