STRENGTH AND BEHAVIOUR OF ANCHOR BOLTS EMBEDDED IN CONCRETE MASONRY

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ABSTRACT

Anchor bolts are commonly used in masonry to support roof decks, overhead doors, crane brackets, elevator guide rails, etc. The most common type of load carried by bolts is shear, although as a result of fastening pro-cedures, a combination of shear and tension is often present.

The present design procedure in the Canadian masonry code limits the allowable stress on a bolt to 5000 psi with no regard for the effects of the strength of the masonry or the strength and behaviour of the bolt-masonry assembly. Also absent from this design procedure are consider-ations of loaded edge distance such as encountered when an anchor bolt
is located in a lintel beam.

In this study the results from an experimental project are reported and design procedures found to give consistent safety factors, are proposed.

INTRODUCTION

This paper presents the results of tests made on anchor bolts embedded in concrete masonry specimens. In masonry structures anchor bolts are common-ly used to support roof decks, overhead doors, cranes, brackets, elevator guide rails, etc. Current design requirements included in CSA Standard S304 (1), contain a statement "anchors shall be. solidly embedded in mortar or grout to develop adequate resistance to the design forces". There is no differentiation between the type of masonry, i.e. clay bricks or concrete blocks, nor is the effect of the masonry strength considered in the capa-city of the anchor bolt. Consequently, in design of anchor bolts, the allowable load is increased with increasing bolt diameter without explicit consideration of the limiting capacity of the masonry.

Current design procedures are examined in this paper and compared to results of the tests described. From the results of these tests and of others, design recommendations are proposed. In this test series the important variables studied included the type of loading, the support conditions, the size of bolt and the distance of the bolt from the support.

EXPERIMENTAL PROGRAM

Materials

Two core 8 x 8 x 16 inch light-weight concrete blocks were used in manu-facturing the test specimens. The compressive strength of the units was 2350 psi based on tests on 4 x 8 x 16 inch solid blocks tested with h/t ratio of 4.31.

Type S mortar mixed in volume proportions, in accordance with CSA S304(1), was used by an experienced mason to prepare the specimens. The compressive strength of the grout based on an average of 5 specimens was 2120 psi.

Four sizes of bolts were used, namely 1/2, 3/4, 5/8 and l". Two 1/2 dia. bolts which were tested in direct tension failed at 16900 and 15600 lb., and a 5/8" dia. bolt tested in a similar manner failed at 33450 lb.

Specimens

Figure 1 shows the general dimensions and bolt location for one type of specimen tested. The specimens varied in height from one block to 6 blocks. Holes for the bolts were made either by punching or drilling at the mid-height of a block and the center of one of the cores. Position of a bolt other than at the center of one of the cores, was not a variable. The bolts were inserted in these holes and then embedded in mortar or grout at the embeddrnent lengths given in Table 4.4.3.H of Ref. 3. The l" dia-meter bolts were embedded only 6" instead of the recommended 7" because of the dimensional limitations of the blocks used. In accordance with usual practice, a washer was fitted on the end of the bolt in order to increase the end bearing area. Figure 2 shows a section through a grouted core of a test specimen.

Test Procedure

All specimens were tested using a closed loop testing frame shown in Photo 1. As shown in Photo 2 a hydraulic jack.applied a shearing load through a rod and fitting to an embedded bolt. Reaction to the jack load was furnished by an assembly consisting of plates and bolts shown in Photo 1.

Basically two support conditions were investigated: a uniform support to simulate a continuous wall or pilaster, and, a partial support to simulate situations where bolts would be embedded above openings such as doors. Uniform support was achieved using heavy plates and a plaster of paris bedding as shown in Photos 1 and 2. Partial support conditions were achieved using wood and steel plates as shown in Photo 3.

Measurements of bolt deflection with increased load were made using a dial gage as illustrated in Photo 3.

In a small number of tests direct tension was applied to the bolts. For these specimens support reactions were placed at the exterior cross webs of the concrete blocks.

TEST RESULTS

The failure mode of most of the specimens was cracking of the grouted masonry; a typical pattern of cracking is shown in Photo 4. Continued application of loading beyond cracking caused large deflections in the bolts and cracking of the grouted core. Photo 5 illustrates a cracked grouted core. Several bolts removed from the specimens after completion of testing, are shown in Photo 6. Only one specimen failed by 'snapping off' of the bolt end after considerable deformation.

The test failure loads are presented in Tables 1, 2 and 3 together with other pertinent information. The results for the specimens tested with full uniform support conditions are given in Table 1. Table 2 presents test information for specimens partially supported. Results from direct tension tests are given in Table 3.

Typical information obtained from measurements of bolt deflection, when loaded, is presented in Figures 3 and 4.

ANALYSIS OF TEST RESULTS

The results obtained from single block specimens indicate that the method of producing the holes and the type of fill have no significant effect on the capacity of the assembly. For these specimens the effect of bolt size on the shear strength is very small and inconsistent.

From Table 1 it is seen that there is a significant increase in capacity with increasing bolt size but only a very small increase as the distance from the loaded edge to the bolt is increased. Figure 5 shows the results from Table 1 together with the allowable .shear load as given by Ref. 1. From Table 1 and Figure 5 it is seen that the factor of safety for this type of bolt assembly based on allowable loads from Ref. 1 ranges from 8.7 for the 1/2" bolts to 3.1 for the l" bolts:-

For.partially supported specimens composed of two or more blocks the results obtained are not significantly different from those for uniformly supported specimens. .For single block specimens however,. a dramatic reduction in capacity was observed; capacity reductions of the order of 50 percent are noted.

From Figures 3 and 4 it can be seen that the bolt deflection increased as the diameter decreased. Such deformations indicate that the bolts may fail when their strength under combined bending and tension is reached. This mode of failure may occur after the masonry adjacent to the bolt has failed by crushing and providing there is no other form of failure. The bolt load capacity will then be its strength in tension. The results obtained

indicated that the shear capacity of the bolts in masonry reported here is governed by the strength of the masonry and limited by the strength of the bolt.

The shear capacity in kips of an anchor bolt embedded in masonry, having at least 12 inches from a bolt to the loaded edge, can be predicted by the following empirical relation.

$$V = 2 \sqrt[4]{f'_m A_s} \tag{1}$$

f'_m = Compressive strength of the masonry in psi as obtained from Table 3, Ref. 1.

A_s = Cross-sectional area of bolt in sq. in.

Equation 1 was used to predict the strength of the specimens tested with uniform support and is plotted in Figure 5. The compressive strength of the masonry used in conjunction with Eq. 1 was 1350 psi (2080 psi comp-ressive strength of units on the net area and type S mortar). For design purposes the shearing load on the bolt assembly should also be limited to the shear strength of the bolt material.

The shear strength of the bolt based on shear yield of the material is:

$$V = \frac{F_y}{\sqrt{3}} A_s \tag{2}$$

where F_y = yield strength

By introducing safety factors, Eqs. 1 and 2 can be converted into design equations.

Partially supported specimens in which the distance from the loaded edge to the bolt was at least 12 inches failed at load levels very comparable to similar specimens which had full support; here edge effects are considered insigificant. In partially supported specimens where the distance from the loaded edge to the bolt was only 4 inches the results shown in Table 2 indicate capacities of the order of only 50% of those in which the distance from loaded edge to the bolt is 12 inches or larger. Although no test data is available for distances from loaded edge to bolt -between 4 and 12 inches it is reasonable to assume a linear variation in capacity.

The capacity of the bolt masonry assembly in direct tension is found to be relatively small and thus care should be taken when fastening in order to avoid tensile failure.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of tests reported herein, the design of anchor bolts embedded in masonry as recommended by the Canadian Standard S304 (1) should be reassessed.

The factors of safety obtained with using the CSA S3O4 recommendations decrease It increased bolt diameter. CSA S3O4 is suggested that article 4.5.4.1 of (1) be replaced by: anchors shall "The allowable shear on steel bolts and of: be the smaller

$$V = \frac{2}{FS} \sqrt[4]{f'_m A_s} \qquad (3)$$

$$V = \frac{1}{FS} \frac{F_y}{\sqrt{3}} A_s \qquad (4)$$

It is recommended that the minimum distance from the loaded edge to a bolt be 4 inches, and, for this case a factor of safety of 8 be used in Eq. 3.

For distances from a loaded edge to bolt of 12 inches or more a factor of safety of 4 is recommended. Factors of safety for Eq. 3 for intermediate distances between 4 and 12 inches can be obtained readily by linear inter-polation.

It is recommended a factor of safety of 2 be used in Equation 4.

ACKNOWLEDGEMENTS

REFERENCES

1. CSA Standard S3O4 - "Masonry design qnd construction for buildings". Canadian Standard Association, 178 Rexdale Boulevard, Rexdale, Ontario, Canada, M9W 1R3.

2. CSA Standard Al79-1975 - "Mortar and grout for unit masonry". Canadian Standard Association, 178 Rexdale Boulevard, Rexdale, Ontario, Canada M9W 1R3.

3. Commentaries on Part 4 (including Requirements for Plain and Rein-forced Masonry) of the National Building Code of Canada 1975, Sup-plement No. 4 to the National Building Code of Canada. Issued by the Associate Committee on the National Building Code National Research Council of Canada, Ottawa, Ontario, NRCC No. 13489.

4. Schneider, Robert R., "Grouted Brick Masonry - Test Analyze Diagonal Tension Beams, and Wall Panels, also other properties". Southwest Builder and Contractor. Dec. 28, 1951.

TABLE 1 – SHEAR STRENGTH OF BOLTS EMBEDDED IN GROUT, UNIFORMLY SUPPORTED

Number of Blocks	Bolt Diameter in.	Embedment in.	Ultimate Shear Strength kips	Average kips
3	1/2	4	7.8	7.9
3	1/2	4	8.0	
3	1/2	4	8.1	
3	5/8	4	11.2	10.8
3	5/8	4	10.4	
3	5/8	4	11.0	
3	3/4	5	11.3	11.1
3	3/4	5	11.0	
3	3/4	5	11.2	
3	1	6	12.0	12.3
3	1	6	13.0	
3	1	6	12.1	
4	1/2	4	9.0	9.5
4	1/2	4	10.0	
4	5/8	4	9.0	9.5
4	5/8	4	10.0	
4	3/4	5	9.3	10.4
4	3/4	5	11.5	
4	1	6	10.0	10.5
4	1	6	11.0	
5	1/2	4	8.7	8.4
5	1/2	4	8.0	
5	5/8	4	8.7	7.4
5	5/8	4	6.0*	
5	3/4	5	11.5	10.8
5	3/4	5	10.2	
5	1	6	13.5	14.4
5	1	6	15.3	

* Cavity improperly filled

TABLE 2 - SHEAR STRENGTH TEST RESULTS, PARTIALLY SUPPORTED

Number of Blocks	Bolt Diameter in.	Minimum Embedment in.	Type of Fill	Block Penetration Procedure	Failure Load kips	Average Failure Load kips
1	1/2	4	Mortar	Drilled	3.7	
1	1/2	4	Mortar	Drilled	3.2	
1	1/2	4	Mortar	Drilled	3.0	
1	1/2	4	Mortar	Drilled	4.4	3.4
1	1/2	4	Mortar	Drilled	2.8	
1	1/2	4	Mortar	Punched	3.5	
1	1/2	4	Grout	Drilled	2.5	
1	1/2	4	Grout	Drilled	3.5	3.5
1	1/2	4	Grout	Punched	4.0	
1	5/8	4	Mortar	Drilled	3.8	
1	5/8	4	Mortar	Drilled	3.6	
1	5/8	4	Mortar	Punched	2.5	3.4
1	5/8	4	Mortar	Punched	3.3	
1	5/8	4	Mortar	Punched	3.6	
1	5/8	4	Grout	Drilled	5.3	
1	5/8	4	Grout	Drilled	4.4	4.6
1	5/8	4	Grout	Drilled	4.1	
1	5/8	4	Grout	Drilled	4.4	
1	3/4	5	Mortar	Drilled	4.5	
1	3/4	5	Mortar	Drilled	6.0	5.1
1	3/4	5	Mortar	Drilled	4.7	
1	3/4	5	Mortar	Punched	3.7	
1	3/4	5	Mortar	Punched	4.4	
1	3/4	5	Mortar	Punched	3.7	4.4
1	3/4	5	Mortar	Punched	4.5	
1	3/4	5	Mortar	Punched	4.1	
1	3/4	5	Mortar	Punched	6.2	
1	3/4	5	Grout	Drilled	4.2	
1	3/4	5	Grout	Drilled	4.6	4.7
1	3/4	5	Grout	Drilled	5.2	
1	3/4	5	Grout	Punched	4.0	
1	3/4	5	Grout	Punched	3.6	4.0
1	3/4	5	Grout	Punched	4.4	
2	1/2	4	Grout	Drilled	7.4	
2	1/2	4	Grout	Drilled	8.1	7.8
2	5/8	4	Grout	Drilled	7.9	7.5
2	5/8	4	Grout	Drilled	7.0	
2	3/4	5	Grout	Drilled	7.3	7.3
2	3/4	5	Grout	Drilled	7.2	
2	1	6	Grout	Drilled	9.3	9.1
2	1	6	Grout	Drilled	8.9	

8.

TABLE 2 - SHEAR STRENGTH TEST RESULTS, PARTIALLY SUPPORTED (cont'd.)

Number of Blocks	Bolt Diameter in.	Minimum Embedment in.	Type of Fill	Block Penetration Procedure	Failure Load kips	Average Failure Load kips
3	1/2	4	Grout	Drilled	7.6	8.6
3	1/2	4	Grout	Drilled	9.6	
3	5/8	4	Grout	Drilled	7.4	7.7
3	5/8	4	Grout	Drilled	8.0	
3	3/4	5	Grout	Drilled	7.4	7.9
3	3/4	5	Grout	Drilled	8.3	
3	1	6	Grout	Drilled	10.7	10.0
3	1	6	Grout	Drilled	9.3	
4	1/2	4	Grout	Drilled	7.2	7.1
4	1/2	4	Grout	Drilled	7.0	
4	5/8	4	Grout	Drilled	8.6	8.3
4	5/8	4	Grout	Drilled	8.0	
4	3/4	5	Grout	Drilled	10.0	9.7
4	3/4	5	Grout	Drilled	9.3	
4	1	6	Grout	Drilled	11.5	11.7
4	1	6	Grout	Drilled	11.9	

TABLE 3 - TEST RESULTS FROM DIRECT TENSION

Bolt Size in.	Minimum Embedment in.	Type of Fill	Block Penetration Procedure	Failure Load kips	Average Failure Load
1/2	4	Grout	Punched	3.8	
1/2	4	Grout	Punched	2.8	3.5
1/2	4	Grout	Drilled	3.9	
5/8	4	Grout	Punched	2.9	
5/8	4	Grout	Punched	4.3	3.8
5/8	4	Grout	Drilled	4.0	
5/8	4	Mortar	Drilled	3.8	
3/4	5	Grout	Drilled	4.8	
3/4	5	Grout	Drilled	4.2	4.2
3/4	5	Grout	Punched	3.6	
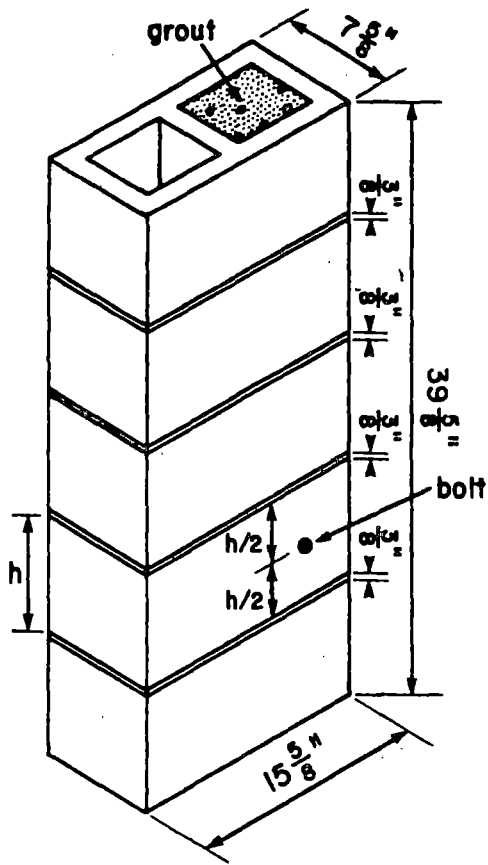
Figure 1   Dimensions of specimen showing
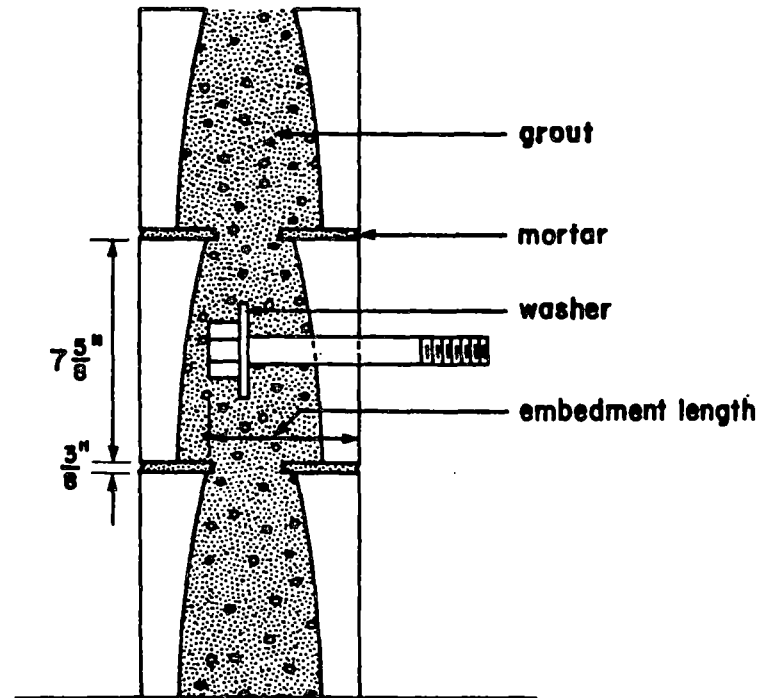the position of the bolt.

Figure 2   Section through a specimen showing
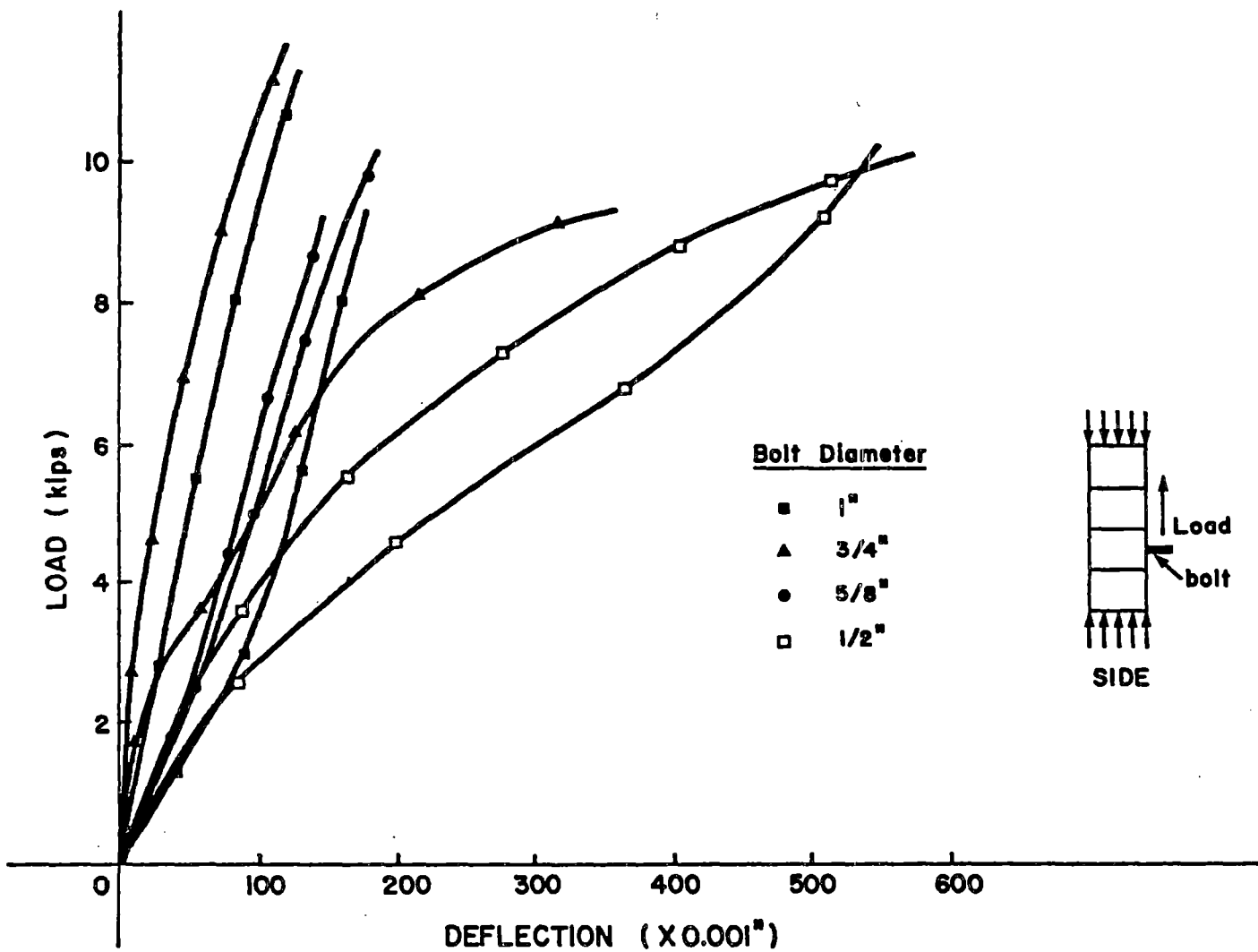embedment length and washer.
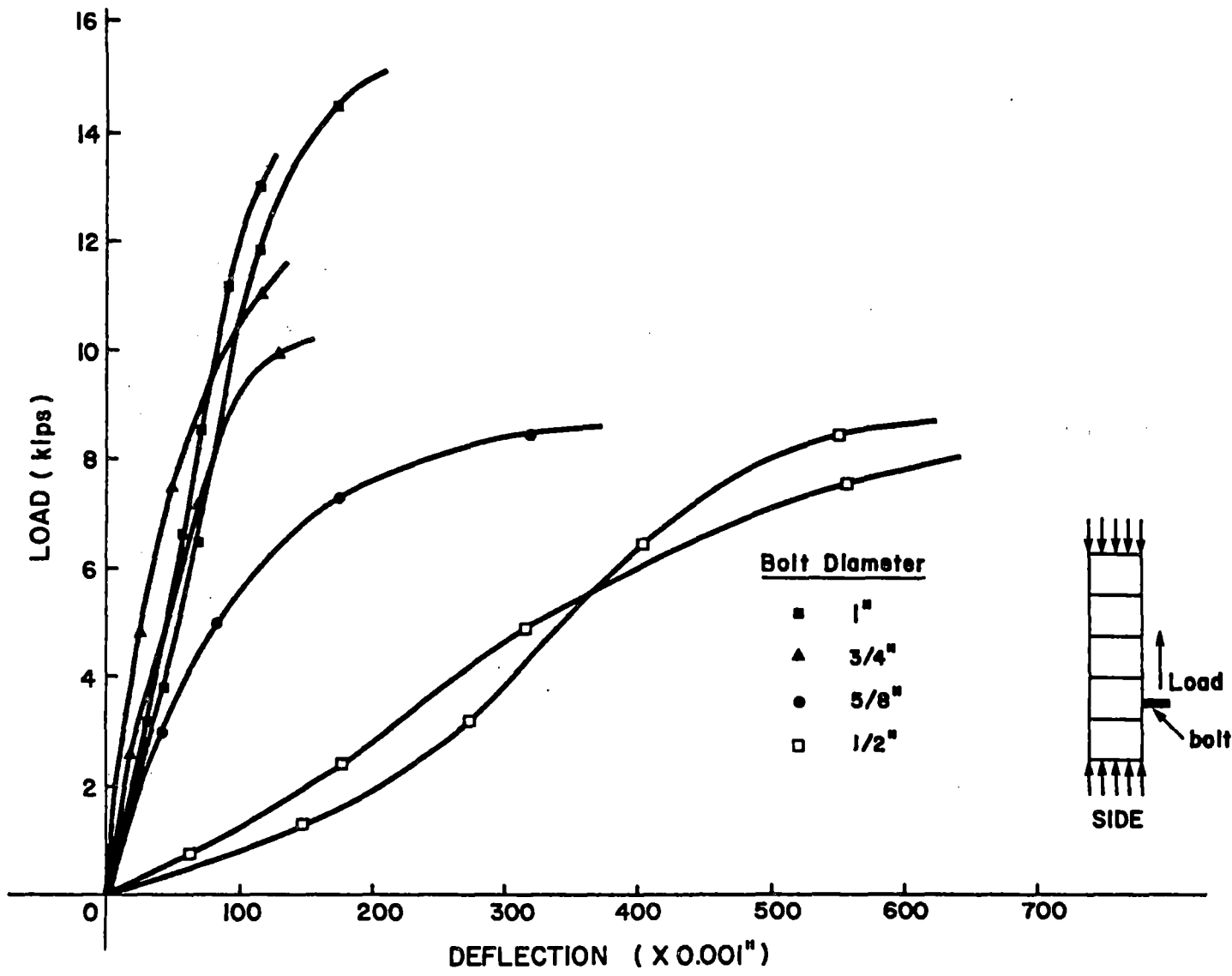
Figure 3   Load vs bolt deflection

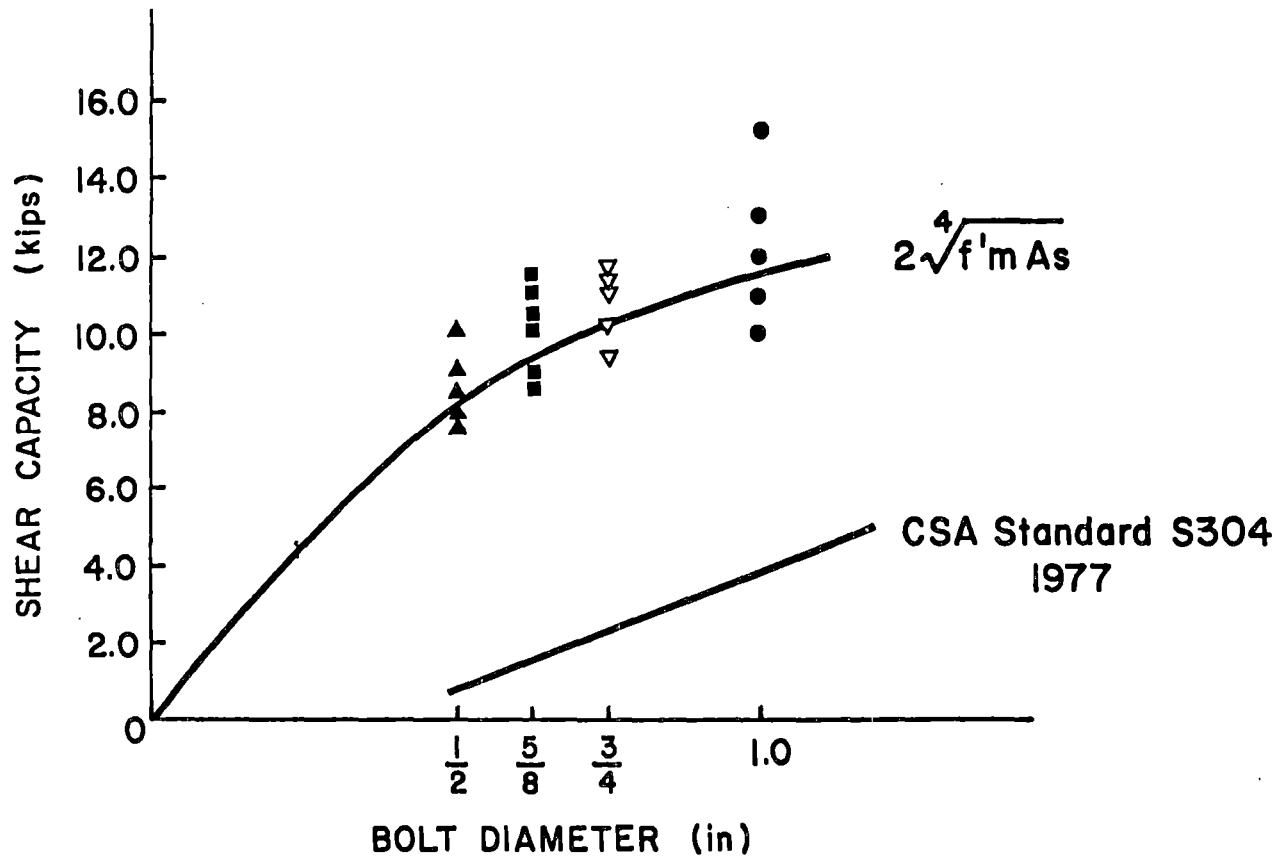Figure 4 Load vs bolt deflection

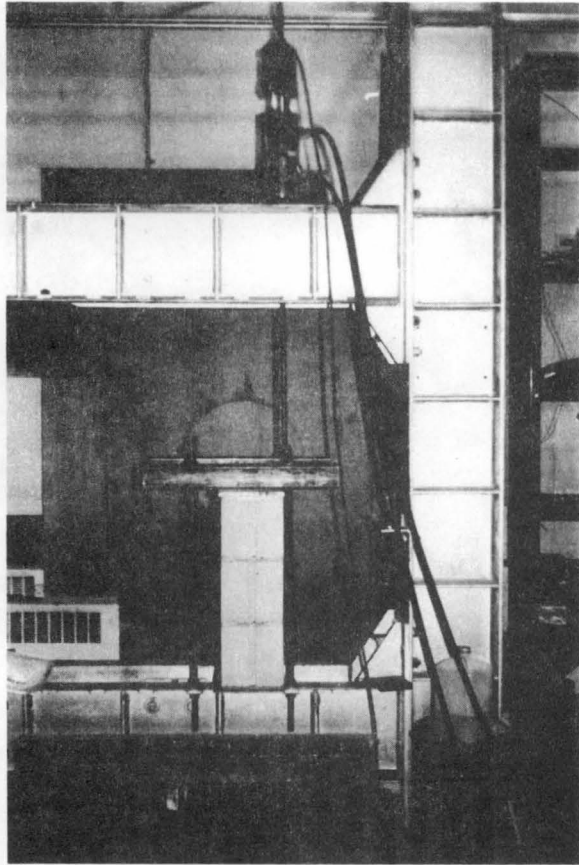Figure 5   Strength of anchor bolts embedded in concrete masonry

Photo 1 Three block specimen prior
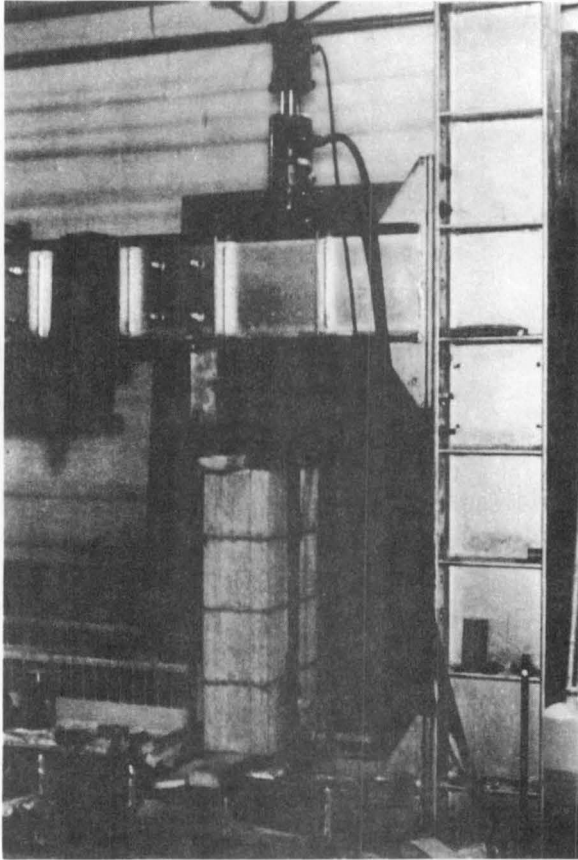to testing

Photo 2 Detail of load application

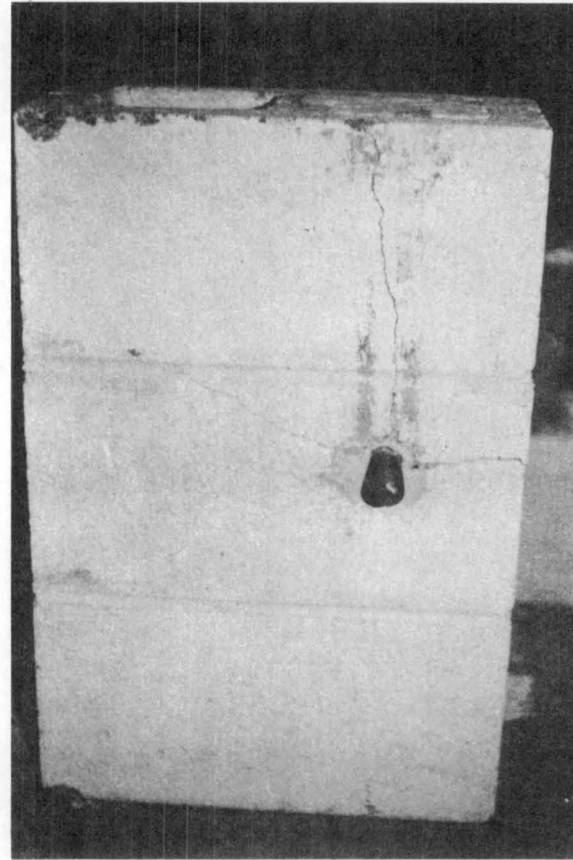Photo 3   Partially supported specimen
[ready to be tested]

Photo 4   Typical failure of anchor bolt
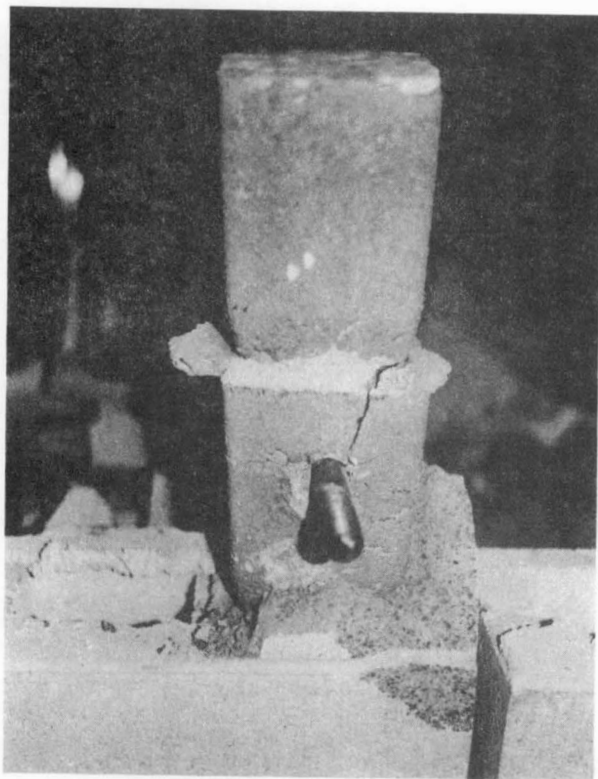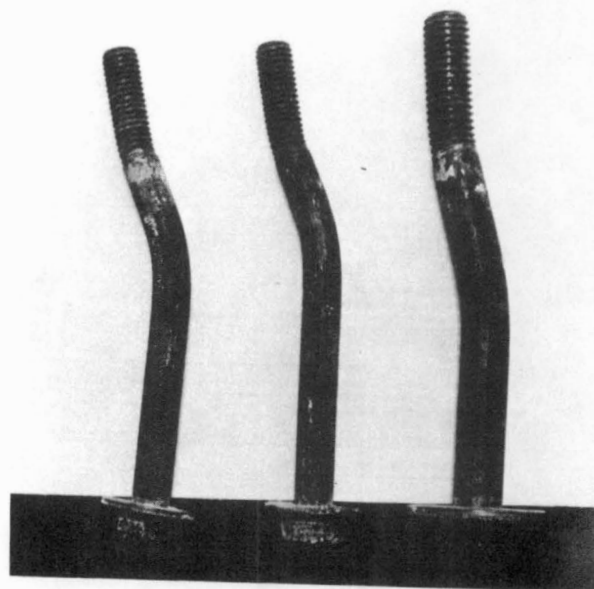[embedded in concrete block]

Photo 5 Failure of grout

Photo 6 Deformed bolts recovered
after testing

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