Tests of Tie Reinforcement for Composite and Cavity Masonry Wall Construction

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ABSTRACT

A variety of continuous and individual wall tie systems are available for interconnection of multiple wythe walls. One such system is an adjustable, single unit masonry reinforcement system consisting of a 0.076 cm by 2.54 cm corrugated steel, hot-dipped galvanized, ties which are preattached to the chords of conventional ladder on truss type joint reinforcement.

The paper presents the results of a series of tests to determine basic information on the strength of this tie system in transmitting tension, compression and shear between interconnected masonry wythes.

A total of 45 specimens were tested considering combinations of the following parameters: type of test, (compression, tension, shear) magnitude of space between wythes, (2.2 cm, 7.3 cm, and 9.8 cm), and tie alignment condition, i.e., zero misalignment and maximum misalignment.

Details of the test specimen and method of construction are presented along with a thorough description of the test precedures.

Test results are presented and discussed in detail. Recommended design equations are developed and presented for each failure mechanism.

Introduction:

In both cavity and composite masonry wall construction, it is desirable to interconnect the brick and block wythes with mechanical anchoring devices, referred to as wall ties. A variety of continuous and individual wall tie systems are available for interconnection of multiple wythe walls, including an adjustable, single unit masonry reinforcement system consisting of a 0.076 cm by 2.54 cm corrugated steel, hot-dipped galvanized, ties which are preattached to the chords of conventional ladder or truss type joint reinforcement.

This paper describes a test program designed to provide lower bound values of the capacity of such a tie system in transmitting compression, tension, and shearing forces between wythes of masonry wall construction consisting of concrete block and brick.

Description of Test Specimen

All test specimens consisted of two concrete block units interconnected with two brick units as shown in Figures 1 and 2.

Figure 3 shows the typical placement of the reinforcement system in the concrete block bed joint.

Concrete masonry units were nominal 20 cm x 20 cm x 40 cm expanded shale, lightweight, hollow, load bearing units conforming to ASTM C90, Type N-1 (f'_m = 13.8N/mm^2). Brick used were facing brick, 5.7 cm x 8.9 cm x 20 cm, ASTM C216, grade SW, Type FBS, having an absorption by 5-hr boil of around 4 percent, a saturation coefficient of 0.591, and an average of f'_m = 57.1N/mm^2. Type S mortar, consisting of 1 part portland cement (Type I), 1/2 part hydrated lime, and 4 parts sand, by volume was used for all specimens. All mortar was measured and mixed in a mortar mixer in accordance with ASTM C270.

The major variables in the test program were the magnitude of the cavity and the alignment of the brick and concrete block bed joints.

a) Magnitude of the Cavity.

Three values of overall wall thickness were considered, namely, 30.5 cm, 35.6 cm, and 38 cm. The resulting magnitudes of the cavity separating the two masonry wythes were 2.2 cm, 7.3 cm, and 9.8 cm, respectively. The 2.2 cm cavity represents an upper bound on the gap that can be expected in composite masonry wall construction. Thus, these specimens will be referred to as composite walls.

b) Vertical Misalignment of the Masonry Wythes.

It was considered important, particularly for the compression tests, to investigate the effect of lack of initial straightness of the tie on the tie capacity. The lack of straightness of the tie depends primarily on the misalignment of the bed joints of the masonry wythes.

Two extreme conditions were considered, namely, a zero misalignment producing a straight interconnecting tie, and a maximum misalignment equal to one-half of the brick height. In the latter case, the tie was hand bent down the face of the concrete block and bent again to align with the brick masonry bed joint.

All specimens were prepared by the same mason in a single day. The mortar was retempered as necessary during fabrication of the specimens. Face shell bedding was used for the hollow block wythes. The workmanship was considered excellent throughout. A total of 45 specimens were constructed. Prior to testing all specimens were air cured in the laboratory for 28 days.

Description of Tests

A description of the number of specimens tested and a code for specimen

identification is presented in Table 1.

Details of each of these tests are given below:

a) Compression Tests

All compression tests were performed in a compression testing machine. The specimens were carefully handled to minimize damage to the bond between the tie and mortar. The tie was visually aligned with the upper cross-head of the machine and load was applied until failure occurred. Figure 4 illustrates the test set-up.

b) Tension Tests

All tension tests were performed using the arrangement shown in Figure 5. Load was applied using a 220 KN hydraulic jack. A calibrated load cell was used to measure the applied loading. It should be noted that specimen 2A3T was damaged prior to testing and the failure load for this specimen is not reported herein.

c) Shear Tests

The test set-up for the shear tests is illustrated in Figure 6. Load was applied to the brick wythe using the hydraulic jack and load cell. The concrete block wythe was supported during testing to eliminate horizontal movement of the units. Plywood shims were placed between the brick and block wythes to minimize twisting of the brick wythe and thereby maintain a parallel alignment of the brick and block during the application of load.

Test Results

Failure loads in compression, tension and shear are presented for each specimen in Tables 2, 3, and 4, respectively.

All specimens failed in compression by buckling. For the tension tests, the failure mechanism consisted of a splitting apart of either the brick or block courses. The shearing failure mode consisted of buckling of the tie.

Discussion of Test Results

I. Out-of-Plane Capacity

a) Compression Tests

The average failure loads in compression are summarized in Table 5, along with the standard deviation computed for each of the five tests, and the corresponding coefficients of variation.

With the exception of specimens 2M, the coefficients of variation are relatively large, indicating a significant scatter of the test data. It is believed that this results from the sensitivity of the tie strength to alignment of the compression load along the tie axis.

Slenderness ratios (L/r) for the three cavity sizes considered are 449, 333, and 100.4. Due to the length of embedment of the tie in the brick wythe, this end may be assumed to be fixed. The attachment of the tie to the truss

reinforcement is essentially pinned. The theoretical effective length for these end conditions is 0.7L, in which L = actual unsupported tie length. Using E = 200 GN/m^2, the following estimates of buckling stress may be determined for the 9.8 cm and 7.3 cm cavities, respectively, 20 N/mm^2, and 36.3 N/mm^2.

Corresponding average test values for specimen with zero misalignment are 19.8 N/mm^2 and 39.7 N/mm^2.

For the misaligned specimen, the test results indicate a reduction in buckling strength. Using a theoretical effective length of 0.9L, estimates of buckling sress for 9.8 cm and 7.3 cm cavities, are 12.1 N/mm^2 and 22.0 N/mm^2, respectively. Corresponding average test values are 16.6 N/mm^2 and 21.5 N/mm^2.

Because of the sensitivity of the compression test results to minor variations in actual cavity size, initial straightness of the tie, and alignment of the tie and load, etc., the above agreement between test and theory is considered excellent.

For the composite wall construction, the effective slenderness ratio of the tie is less than 100, and am empirical relationship is needed to determine σ_{cr}. Using a parabolic equation of the form $\sigma_{cr} = \sigma_o - c(KL/r)^2$ and matching results at a 7.3 cm cavity with the Euler buckling stress equation gives:

$$\sigma_{cr} = 77.6 - .00069(kL/r)^2 \text{ for } kL/r \leq 233 \qquad (2)$$

For the composite wall specimen, Eq. (2) gives a value of 74.1 N/mm^2 which is very close to the average test value of 75.4 N/mm^2.

b) <u>Tension Tests</u>

The tension failure loads given in Table 3 indicate that the tie capacity in tension is not strongly dependent on the cavity size or alignment configuration of the tie. The average failure load in tension for all specimens tested is 2763 newtons. The standard deviation is 427 newtons, giving a coefficient of variation of 0.154.

In the 9.8 cm cavity specimens, failure occurred by splitting of the brick courses. In these specimens the larger overall wall thickness resulted in an incomplete penetration of the tie through the brick wythe. This was also true in the specimen series 2M. For specimen series 2A and the composite wall specimens, the failure initiated in the block masonry. It is believed that axial wall stress would tend to prevent the type of failure noted in the tests, so that the capacities obtained in the tests described herein are conservative.

II. In-Plane Capacity

The capacity of the Uni-Tie in shear is 1730 N, based on an average of five (5) tests. The standard deviation of the tests is 96 N, with a coefficient of variation indicates that the shear capacity of the tie may be accurately determined from the average test value.

Recommended Design Procedure

I. Out-of-Plane Loads

Based on the data presented herein, the capacity of the tie in transferring out-of-plane loads between brick and block wythes is governed by compression. Because of the relatively high coefficients of variation obtained in the tests described herein, it is recommended that a factor of safety of 2.0 be used to determine working load values for design.

The following equations are, therefore, recommended for computation of the tie allowable load capacity:

$$P_a = 37.8 - .00034({}^{kL}/_{r})^2 \quad \text{for } {}^{kL}/_{r} \le 233 \qquad (1)$$

$$P_a = \frac{\pi^2 EA}{2({}^{kL}/_{r})^2} \quad \text{for } {}^{kL}/_{r} > 233 \qquad (2)$$

in which

P_a = allowable design load, in newtons; A = cross sectional area of tie, in mm^2; $r = {}^{t}/\sqrt{12}$, in mm; t = thickness of tie, in mm; E = modulus of elasticity, L = actual space between masonry wythes, in mm; k = 0.7 in Eq. (1); 0.9 in Eq. (2).

The amount of load to be transferred through the tie depends on the relative rigidities of the masonry wythes. However, it is recommended herein that each tie be capable of transferring the full loading between wythes.

It is also recommended, herein, that current individual tie spacing requirements contained in Building Code Requirements for Concrete Masonry Structures (ASI 531-79) and Commentary - ACI531R-79, published by the American Concrete Institute be followed.

II. In-Plane Loads

A recommended safe working load value for tie design in transferring in-plane loads between block and brick masonry wythes is 890 newtons. This provides a factor of safety against failure of 1.94.

Table 1 - Description of Test Specimens

Specimen Number	Type of Test	Magnitude of Cavity (cm)	Tie Alignment Condition	No. of Specimen Tested	Wall Type
3M x C	Compression	9.8	maximum	5	3" Cavity
3A x C	Compression	9.8	minimum	5	3" Cavity
2M x C	Compression	7.3	maximum	5	2" Cavity
2A x C	Compression	7.3	minimum	5	2" Cavity
x C	Compression	2.2	minimum	5	Composite
3M x T	Tension	9.8	maximum	3	3" Cavity
3A x T	Tension	9.8	minimum	3	3" Cavity
2M x T	Tension	7.3	maximum	3	2" Cavity
2A x T	Tension	7.3	minimum	3	2" Cavity
x T	Tension	2.2	minimum	3	Composite
x S	Shear	2.2	minimum	5	Composite

Note: Code Descriptions

cavity walls - abxd; composite walls - xd

a = nominal cavity size, 2", 3"

b = alignment condition: M = maximum misalignment; A = zero misalignment

c = specimennumber, 1, 2, 3, etc.

d = Type of test: C = compression, T = tension; S = shear

Table 2 - Compression Failure Loads in Newtons*

Nominal Cavity	Alignment	Specimen Number					Average
		1	2	3	4	5	
3	M	356	200	400	267	378	320
	A	290	378	556	245	445	383
2	M	378	423	378	467	423	414
	A	912	534	801	912	668	765
0	A	1936	1090	1491	1313	1446	1455

*Includes a 20 newtons allowance for the brick weight.

Table 3 - Tension Failure Loads in Newtons

Nominal Cavity	Alignment	Specimen Number			Average
		1	2	3	
3	M	2580*	2780*	3495*	2950
	A	3425*	2915*	2760*	3033
2	M	2315*	1890+	3070*	2425
	A	2490+	2400+	x	2445
0	A	2760+	2800+	3005+	2855

+Denotes splitting failure of the block courses.

*Denotes splitting failure of the brick courses.

Table 4 - Shearing Failure Loads in Newtons

Nominal Cavity	Aligment	Specimen Number					Average
		1	2	3	4	5	
0	A	1869	1646	1785	1705	1647	1730

Table 5 - Summary of Compression Test Results

Nominal Cavity	Alignment	Average Capacity (in newtons)	Standard Deviation	Coefficient of Variation	Average Failure Stress N/mm^2
3	M	320	84	0.263	16.6
	A	383	124	0.325	19.8
2	M	414	37	0.090	21.5
	A	765 -	164	0.214	39.7
0	A	1455	311	0.213	75.4

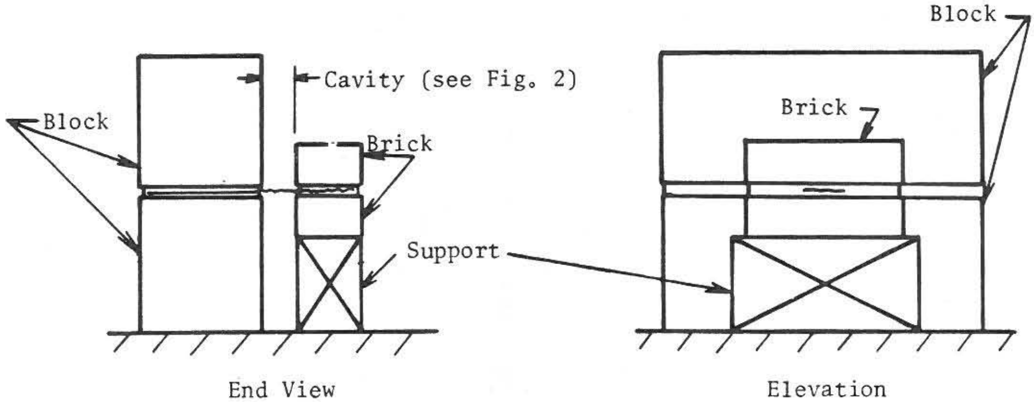


FIGURE 1 ZERO MISALIGNMENT SPECIMEN ('A')

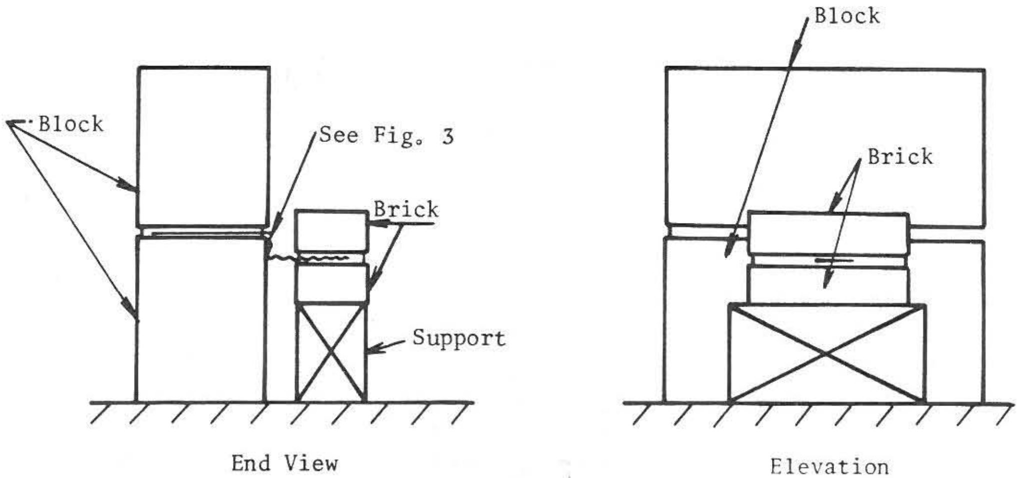


FIGURE 2 MAXIMUM MISALIGNMENT SPECIMEN ('M')

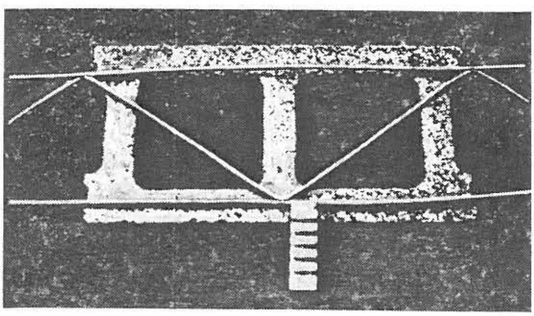
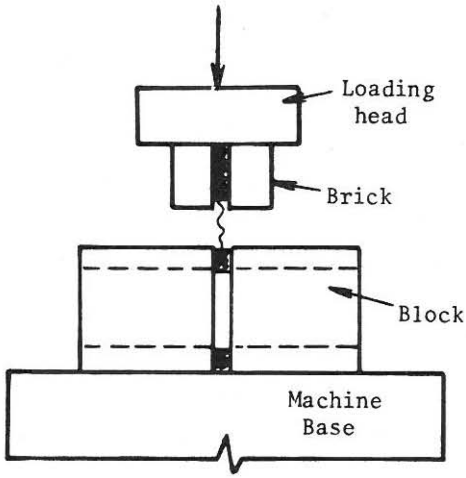
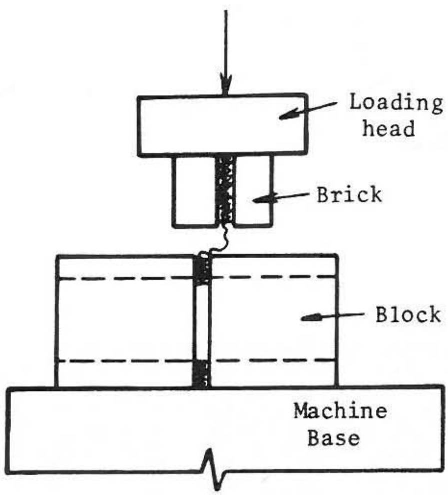


FIGURE 3 DETAIL OF PLACEMENT OF UNI-TIE REINFORCEMENT IN CONCRETE BLOCK BED JOINT



a) 'A" Specimen



b) 'M' Specimen

FIGURE 4 DETAILS OF COMPRESSION TESTS

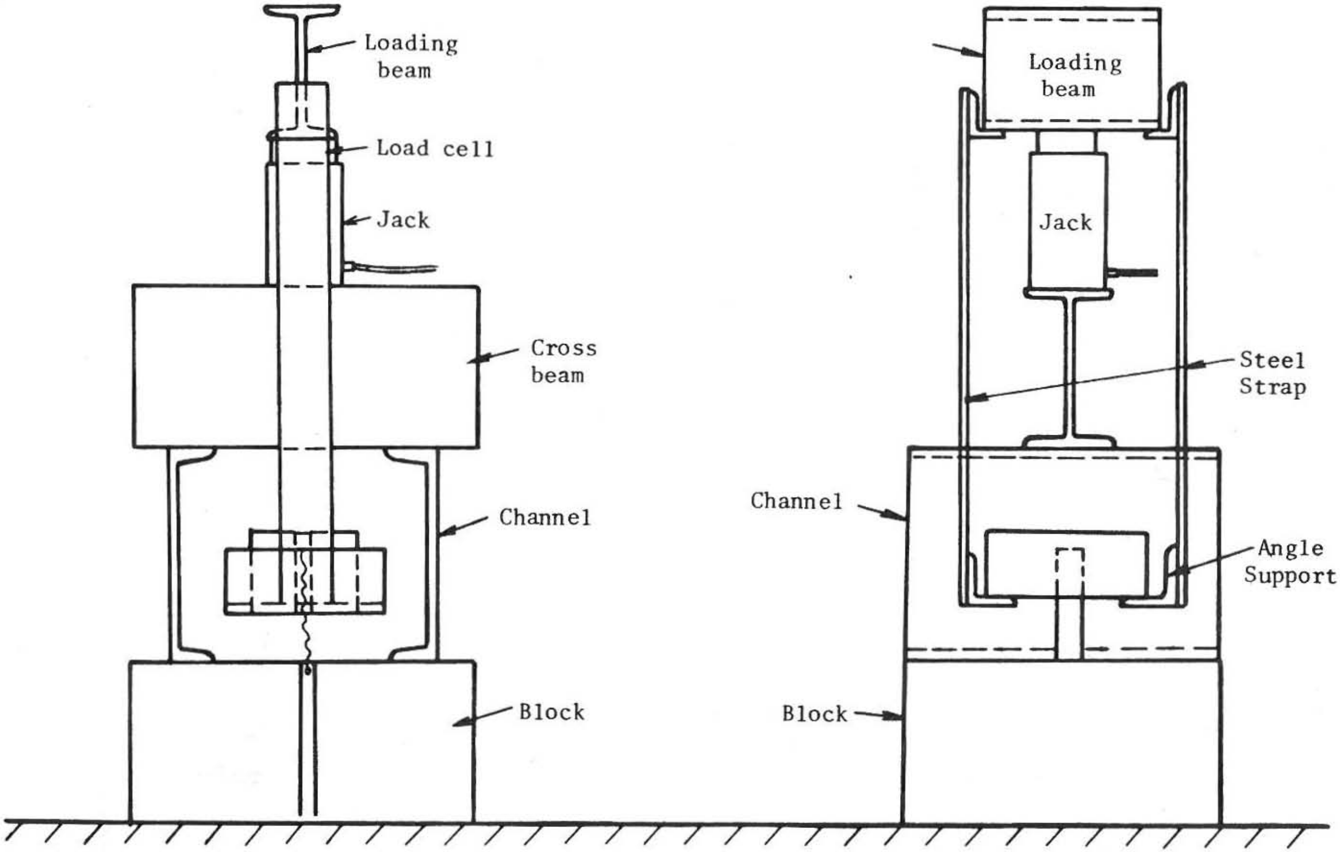
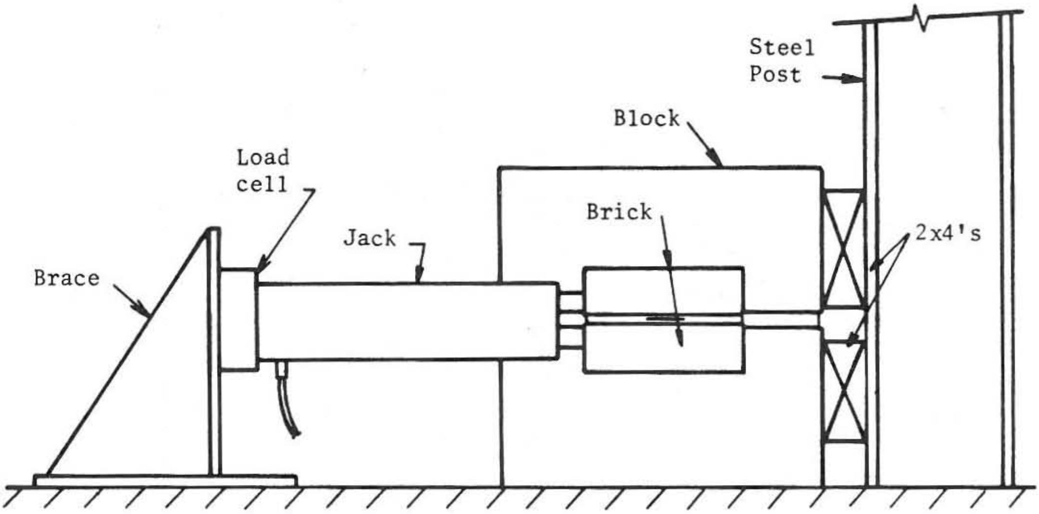
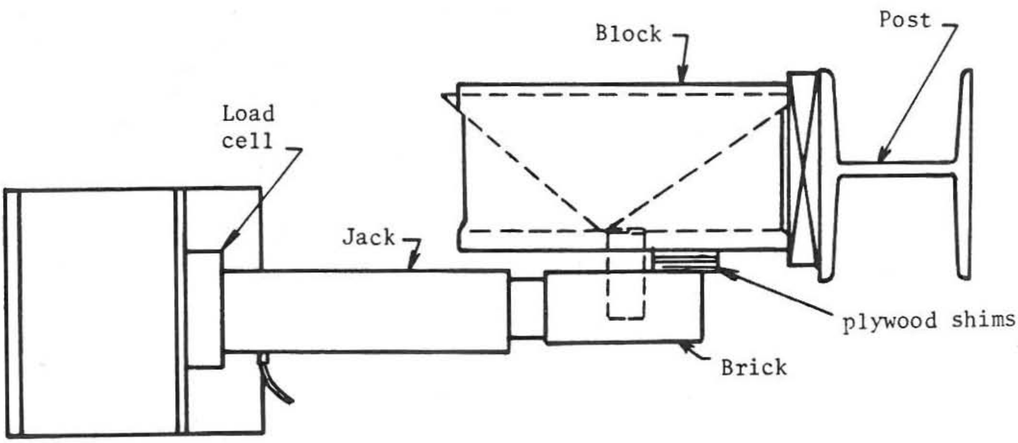


FIGURE 5 DETAILS OF TENSION TEST SET-UP



Elevation



Plan

FIGURE 6 SHEAR TEST SET-UP