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MASONRY PRISM GROUTED COLLAR JOINT SHEAR TESTS

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ABSTRACT

Composite structural action can only be obtained in multiwythe masonry wall construction if the masonry wythes are adequately interconnected and full shear transfer occurs across the collar joint. The filling of a collar joint by pressure injected grout through one of the masonry wythes is one possible method of providing full shear transfer between masonry wythes which were not originally adequately interconnected. Test results on several masonry prisms constructed in the laboratory with open collar joints, which were subsequently grouted using pressure injection, are presented. The test results provide average shear capacity values along the collar joints that compare favorably with existing allowable stress values for grouted collar joints (Building Code Requirements for Masonry Structures, 1992).

INTRODUCTION

The allowable shear stresses on filled collar joints between two wythes of masonry are 35 kPa (5 psi) for mortared joints and 69 kPa (10 psi) for grouted joints (Building Code

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Requirements for Masonry Structures 1992). Although these allowable stresses are relatively low they are adequate to resist the shear forces developed in many practical wall constructions. Although the advantages and disadvantages of composite construction of multiwythe walls are debatable, it is nevertheless beneficial to develop full composite action in many situations by filling of the collar joint with either grout or mortar during construction of the multiwythe wall. In practice it is difficult to fully fill a 19 mm (3/4") or smaller collar joint with mortar, and one reason for the relatively low allowable shear stress on such joints is that the joint usually contains significant voids. Filling such narrow joints with grout is also difficult and grouted collar joints are usually wider than 19 mm (3/4") in size.

As a result, narrow collar joints of 19 mm (3/4") or less are often unfilled in the field and although the two masonry wythes are interconnected with metal ties, they are not interconnected compositely.

In the retrofitting and rehabilitation of masonry, there are situations in practice where the ability to fill or re-fill a narrow collar joint between two wythes of masonry is desirable to provide a solid section and develop beneficial structural composite action. Thus the research results presented herein address the shearing capacity of grouted collar joints in multiwythe construction in which the grouting is accomplished after construction of the masonry wall.

DESCRIPTION OF SPECIMENS

A total of ten multi-wythe masonry prism specimens were constructed. Each specimen consisted of a central wythe of two concrete masonry units bounded on each side by an eight unit high stack bonded clay masonry prism. The specimens were approximately 0.8 m (32") high by 200 mm (8") long by 308 mm (12 1/8") wide.

Each specimen was constructed by laying up each brick wythe in stack bond construction and placing the completed brick wythes on either side of the two unit high concrete masonry wythe. The concrete masonry units were separated by a 10 mm (3/8") thick plywood spacer and after positioning the brick wythes on each side of the concrete masonry units the vertical edges of the collar joints were mortared. The wythes were positioned to create an open 19 mm (3/4") wide collar joint between each of the concrete masonry units and each of the two brick wythes.

The entire assembly was constructed on a thin plywood base. After positioning the masonry wythes as described each of the four open collar joints (one on each side of each concrete masonry unit) was grouted by pressure injecting grout through a small opening drilled through the mortar plug sealing one end of each collar joint. These openings were placed near the bottom of each collar joint. After grouting was completed the specimens were air cured in the laboratory for 88 days at which time they were tested to failure as described below.

The concrete masonry units were nominal 100 mm (4") wide by 200 mm (8") long and 400 mm (16") high solid units. The clay masonry units were 89 mm (3-1/2") wide by 89 mm (3-1/2") high by 190 mm (7-1/2") long.

TEST PROCEDURE

The plywood spacer between the two concrete masonry units was removed prior to testing the specimens to failure. During handling of the specimens, two of the specimens were accidentally separated along the clay brick bed joints at the level of the space between the concrete masonry units, creating four multi-wythe sections, each approximately 0.4 m (15-5/8") high. As a result, two basic specimen types were created; namely eight 0.8 m (32") tall specimens; and four 0.4 m (16") tall specimens. Each specimen type was tested as follows:

Tall Specimens
The eight tall specimens were tested using two different support conditions at the base of the specimens. For six of the tall specimens the lower concrete masonry unit was supported on a plywood strip and a compression load was applied to the top concrete masonry unit until failure occurred in the collar joint grout.

This method of loading and supporting the specimens produced shearing stresses in both upper collar joints as load was transferred from the loaded concrete masonry through the collar joints to the adjoining brick wythes. This loading was then transferred back to the lower concrete masonry unit through the lower two collar joints, thereby producing shearing stresses in the lower collar joints. Figure 1a illustrates the method of loading and support and Fig. 1b illustrates the load transfer mechanism resulting from the test set-up.

For these specimens, failure typically occurred in one of the top collar joints and in one of the lower collar joints on opposite sides of the concrete masonry wythe. However, in one specimen failure occurred through two collar joints in one half of the specimen. Although there was also some shear cracking in one of the other collar joints, half of the specimen was salvaged and retested (described below as short specimens).

The two remaining tall specimens were loaded as described above but were fully supported across the base of the specimen. The objective of this approach was to seek to initiate failure in the upper two collar joints with the intent of salvaging the lower halves of these specimens for retesting along with the four short specimens. However, failure occurred through both an upper and a lower collar joint and it was not possible to salvage the lower halves of these specimens.

Figure 2a illustrates the method of loading and support for these two tall specimens and Fig. 2b illustrates the load transfer mechanism resulting from this test set-up. It should be noted that in the lower half of the specimen the actual load transferred through the lower collar joints is indeterminate, although it is less than that transferred through the

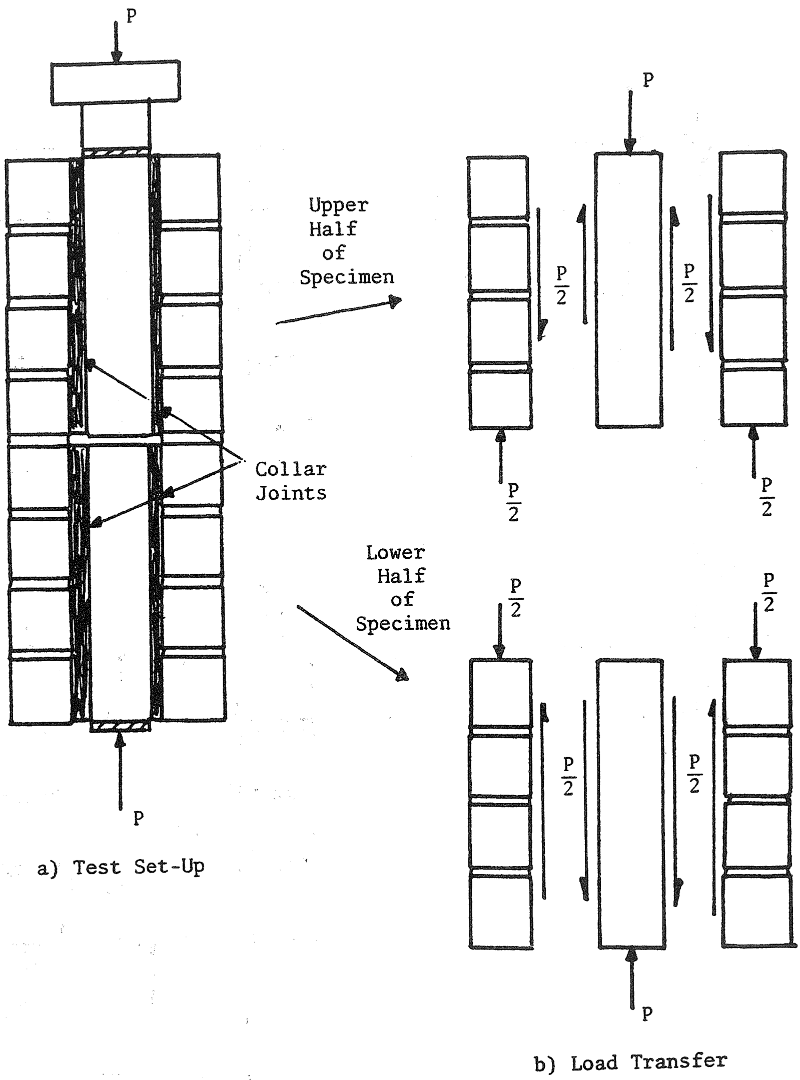


Fig. 1 - Details of 6 Tall Specimens

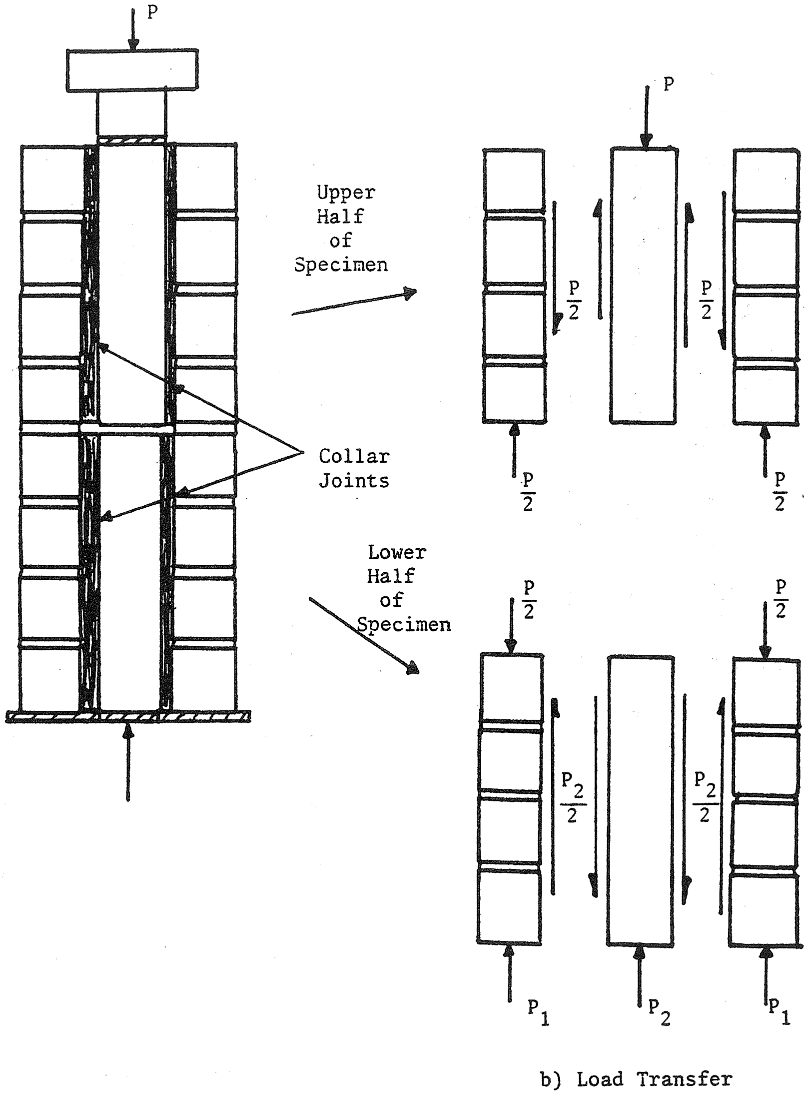


Fig. 2 - Details of 2 Tall Specimens

upper two collar joints.

Short Specimens
The four short specimens along with the salvaged lower half of one of the tall specimens were also loaded through the top of the concrete masonry unit. The two brick wythes were supported on plywood strips and load applied until failure of the collar joints occurred. Figure 3a shows the test set-up and Fig. 3b illustrates the load transfer mechanism.

DISCUSSION OF SPECIMENS AND METHOD OF COMPUTING FAILURE STRESSES

In all of the specimens failure occurred suddenly in the collar joints causing separation or partial separation of the masonry wythes. The failure included the following failure mechanisms.

a) Separation of the grout from the brick units (debonding along the brick-grout interface).

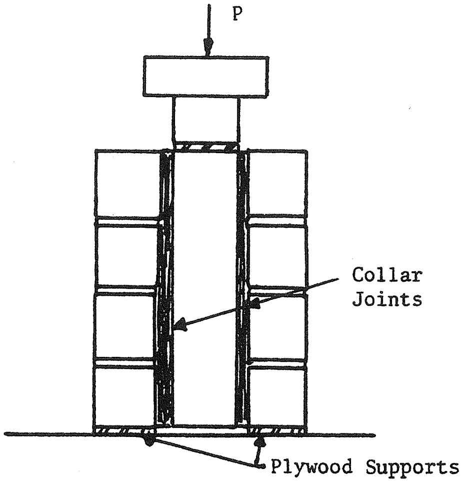
b) Separation of the grout from a portion of the concrete masonry unit with the remaining separation occurring along the brick-grout interface.

c) Separation of part of the grout from the masonry units with a shear failure within the grout along the remainder of the collar joint.

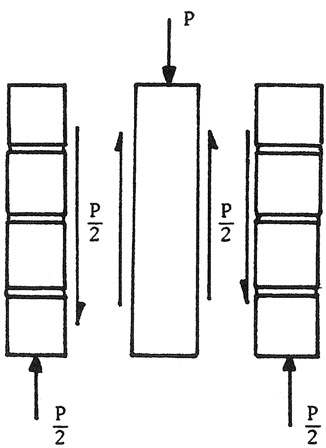
For all specimens the average failure stress was computed by dividing one-half of the load causing failure by the contact area of one collar joint surface. The failure area, therefore, was computed to be .0768 m^2 (119.1 in^2).

This approach assumes that the maximum loading applied to any one collar joint is equal to one-half of the applied loading, which in turn assumes that the load was distributed equally to each brick wythe as shown in Figs. 1b, 2b, and 3b. It also assumes that the shear stress distribution along each collar joint is uniform. Furthermore it is assumed that the failure in the collar joints is the result of shear stress only.

All of these assumptions are conservative with respect to the computed shear stress capacity of the grouted collar joints for the following reasons. Firstly a recent study (Matty et al. 1987) clearly indicates that the shear stress distribution along a collar joint is not uniform. This study which also used triplet specimens, with two wythes of brick masonry constructed around a central wythe of concrete masonry, of similar sizes to those tested herein, revealed that for mortared collar joints the stress on the failed wythe averaged around 13% more than the computed average failure stress. These findings were based on actual load cell measurements of the load distribution to the two brick wythes. In other words in spite of precautions in constructing the specimens and centering them in the test apparatus, variability in the masonry wythes precludes an



a) Test Set-up



b) Load Transfer

Fig. 3 - Short Specimen Tests

equal distribution of the applied loading to each collar joint element.

Also it is practically impossible to apply a pure shear loading to a filled joint between masonry units. In the multi-wythe specimens tested herein and in the other specimens mentioned (Matty, et al. 1987) there is also a flexural stress applied to the collar joints. This creates a tension stress across a portion of the height of the collar joints which is detrimental to the shear bond capacity of the joint. This "peeling action" is more predominant for short specimens since the magnitude of the tension stress is inversely proportional to the square of the height of the specimen.

As a result of these effects, the average shear capacities of the grouted collar joints presented below are considered to be conservative lower bound estimates of the actual shear strengths of the grouted collar joints. It is also important to note that in the case of the six tall specimens, which were supported only along the base of the concrete masonry unit, the probability of failure is greater than for the other specimens, since all four collar joints were highly stressed simultaneously. For the two tall specimens that were fully supported along the base the full transfer of loading is restricted to the upper half of the specimen. Therefore, these specimens, although geometrically similar to the six other tall specimens, are structurally more similar to the short specimens with respect to the full transfer of shear across only two collar joints. For this reason, the results for these two taller specimens are included with the short specimen results.

TEST RESULTS

Failure loads and computed average failure stresses are presented in Tables 1 and 2. Table 1 indicates that the average failure stress for the six tall specimens requiring full transfer of load through all four collar joints was 246 kPa (35.6 psi) with a coefficient of variation of 40.1%. The results in Table 2 indicate that the average failure stress for the two tall specimens in which full load transfer was only required in the upper two collar joints was 405 kPa (59.0 psi). The short specimens had an average failure stress of 315 kPa (45.7 psi) with a coefficient of variation of 24.3%. If specimen 5B is omitted from the short specimen data set, since this specimen was partly damaged as described above, the average failure stress for the remaining four short specimens is 344 kPa (50.0 psi) with a coefficient of variation of 16.5%.

These results are consistent with the discussion presented previously, namely that for tall specimens with essentially two potential failure planes the highest average failure stress of around 405 kPa (59 psi) was obtained. The short specimens which also had only two potential failure planes failed at a lower average stress of around 344 kPa (50 psi) since the "peeling action" effect is more pronounced.

The tall specimens with four potential failure planes yielded the lowest average failure stress of around 246 kPa (36 psi). It is of interest to compare these results with other data obtained in a prior study (Cousins, et al. 1983) in which an average collar joint shear strength of 450 kPa (65 psi) for fine aggregate grouted collar joints based on tests

Table 1 - Test Results for Tall Specimens 1 - 6

Specimen Number	Failure Load kN	Average* Failure Stress kPa
1	57.6	375.0
2	53.2	346.4
3	16.8	109.4
4	26.5	172.5
5	26.9	175.1
6	45.6	296.9
Average	37.8	245.9
Std. Deviation	15.2	98.7
Coefficient of Variation	40.1%	40.1%

$$* \; Ave.\ Failure\ Stress = \frac{Failure\ Load}{2\ (.0768)}$$

Table 2 - Test Results for Tall Specimens 9, 10 and Short Specimens

Specimen Number	Failure Load lbs.	Average Failure Stress psi	Specimen Type
9 10	75.3 49.1	490.2 319.7	Tall Specimens Supported Fully at Base
Average Std. Deviation Coeff. of Variation	62.2 13.1 21.1%	404.8 85.4 21.1%	
5B	30.8	200.5	Short Specimen from Tall Specimen #5
7A	43.3	281.9	Short Specimen from Specimen 7
7B	47.1	306.6	Short Specimen from Specimen 7
8A	66.1	430.3	Short Specimen from Specimen 8
8B	54.9	357.4	Short Specimen from Specimen 8
Average Std. Deviation Coeff. of Variation	48.4 11.8 24.3%	315.3 76.6 24.3%	
Average Std. Deviation Coeff. of Variation	52.4 13.7 26.1%	340.9 88.9 26.1%	All of the above

of 72-0.4 m (16") high by 0.4 m (16") wide composite masonry prisms was reported. In another study (Williams and Geschwindner 1982), an average shear strength of 480 kPa (70 psi) was reported for 50 mm (2") thick collar joints with fine aggregate grout. In this study a three wythe prism similar to that used herein was used.

Results (Matty et al. 1987) for tests of ten 50 mm (2") wide grouted collar joints gave an average failure stress of 230 kPa (33.6 psi) with a coefficient of variation of 32%.

Finally it should be noted that the allowable shear stress on a grouted collar joint is 69 kPa (10 psi) (Building Code Requirements for Masonry Structures 1992).

ANALYSIS OF TEST RESULTS

The test results presented herein indicate that a conservative estimate of the shear capacity of the grouted collar joints is between 246 kPa (36 psi) to 405 kPa (59 psi).

These values exceed values previously obtained (Matty, et al. 1987), and are somewhat lower than other values reported (Cousins, et al. 1983 and William and Geschwindner 1982).

The most reasonable estimate of the capacity of the grouted collar joints reported herein is considered to be the average of the data presented in Table 2 omitting the damaged specimen 5B. These six test values give an average failure stress of 365 kPa (52.8 psi) with a coefficient of variation of 20%. Applying a factor of safety of 4.0 to this average, which is the factor of safety for allowable stresses in masonry in both compression and flexure (Building Code Requirements for Masonry Structures 1992), gives an allowable stress value for the grouted collar joints of 90 kPa (13.2 psi). This exceeds the current allowable stress value of 69 kPa (10 psi) (Building Code Requirements for Masonry Structures 1992) and indicates that the grouting procedure used in constructing the test specimens is able to produce a collar joint which has a design capacity in excess of current values for grouted masonry collar joints.

If the values from Table 1 are used as an extreme lower bond estimate of the shear capacity, a factor of safety of 3.56 will yield an allowable shear stress value of 69 kPa (10 psi). If Matty's factor of 1.13 is applied (Matty et al. 1987) to account for the nonuniform distribution of loading through the collar joints the following allowable shear stress value may be obtained: (using a factor of safety of 4.00).

$$AllowableShearStress = \frac{average\ Shearing\ Strength\ x\ 1.13}{Factor\ of\ Safety}$$

$$= \frac{246(1.13)}{4.00}$$

$$= 69.5\ kPa\ (10.1\ psi)$$

In this case, the design capacity of the grouted collar joints is essentially the same as the current specified value (Building Code Requirements for Masonry Structures 1992).

CONCLUSIONS

The following conclusions are based on the results of the tests described herein.

1) The allowable shearing strength of the grouted collar joints tested herein can conservatively be taken to be at least 69 kPa (10 psi).

2) The method of grouting the collar joints by pressure injecting grout into the open collar joints provides a joint that satisfies existing requirements (Building Code Requirements for Masonry Structures 1992).

3) Full composite action of the brick and concrete masonry wythes may be assumed in design of pressure injected grouted multi-wythe masonry walls provided the collar joint shear stress is less than or equal to 69 kPa (10 psi) under service load conditions.

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THE RESEARCH OF LOAD CARRYING CAPACITY OF REINFORCED CONCRETE-BRICK COMPOSITE WALLS UNDER VERTICAL LOADING CONDITION

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ABSTRACT

In this paper, the research work in the field of composite masonry are reviewed. The formulae of predicting load-carrying capacity of the composite masonry under horizontal or vertial loading condition are summed up. Based on the experimental results and the analysis results of finite element method, the behavior and failure modes of reinforced concrete-brick composite wall under vertial loading are analysed, especially under opening condition. Based on the experimental results of 6 pieces of brick masonry walls and the analysis results of finite element method, discussion is carried out on the relationship between the opening rate and the load-carrying capacity. By analysing results, the formula of calculating the load-carrying capacity of reinforced concrete-birck composite wall under opening condition is proposed. The predicting results are in good agreement with the test results.

Reinforced concrete-brick composite walls are formed by improving the effectiveness of the constructive frames, in which the pillars and beams of the frames are not only constructive elements but also bear some vertical and lateral load respectively. According to the Chinese Design Code for anti-seismic structures,

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