EFFECT OF TEST TECHNIQUE ON MASONRY SHEAR STRENGTH

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ABSTRACT

The paper presents a comparison between the critical tensile strengths of concrete block masonry panels obtained by three different test techniques. The first two methods consist of simple diagonal tests on 32"x32" square panels. The test set up used in the third method was designed to simulate insofar as possible the boundary conditions the pier would experience in a perforated shear wall of a complete building. Each test specimen of the third method was a full scale panel about 15 feet square consisting of two piers and a top and bottom spandrel. Theoretical formulations are used in an attempt to correlate the experimental results. Good correlation of shear strength was achieved when an appropriate theoretical formula was used.

I. Introduction

One of the more important parameters required for the design of masonry structures is the shear strength of masonry walls. In order to determine the shear strength of masonry assemblages, a limited amount of both experimental and theoretical research has been performed. Many different test techniques have been used to investigate the shear strength of masonry assemblages and the diversity of methods has arisen because of the difficulty in simulating experimentally, the actual load and boundary conditions of a structural masonry component in a building.

The aim of this paper is first to survey the different types of test techniques; and the second to compare the results of the critical tensile strengths obtained by two different tests and the cyclic horizontal load tests recently performed at the Earthquake Engineering Research Center, University of California, Berkeley.

II. Test Techniques for Masonry Shear Strength

The rapid development of mechanical and electrical test equipment over recent years has lead to an increase in sophistication of apparatus available for use in experimental investigations. The scope and aim of many programs have consequently been broadened, resulting in the determination of more detailed and relevant information.

One of the first methods used in the determination of the shear strength of masonry walls was that shown in Figure 1(a). The external hold down force P_v was applied to resist the overturning moment of the panel. This method was used by Schneider(2), Scrivener et al. (3.4) and

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in the test programs of the Structural Clay Products Research Foundation(5,6). It also formed the basis of the standard racking tests described in ASTM E 72-61.

The above method was modified by Schneider(7) in a second series of tests performed in 1959, and the modified procedure was also utilized by Scrivener(8) in a series of three tests. Instead of using the external force to resist the overturning moment, an internal hold down anchor was used, as shown in Figure 1(b). Here the objection of the large external compressive stress applied by the overturning constraint at the edge of the panel is eliminated. However, since overturning resistance depends upon the development of bond between the jamb steel and the grout, a certain flexibility in the types and arrangement of jamb steel is lost, although a more realistic boundary condition is obtained.

Probably one of the most frequent techniques used to determine the relative shear strengths of walls is that shown in Figure 1(c). This method was used in the extensive program performed by Blume and Associates (9) and Degenkolb and Associates(II). Borchelt(10) and Yokel and Fattal (III) also used the diagonal test method but added a compressive load as shown in Figure 1(d).

Schneider(11) in 1967 performed a series of tests on concrete masonry piers. The test set up he used is shown in Figure 1(e). The geometry of the system was maintained by the struts at the end of the openings and the axial and shear loads were applied by a system of jacks and tie rods.

Cyclic loading tests were performed by Williams(12), Meli(13) and Priestley and Bridgeman(14), utilizing the cantilever pier shown in Figure 1(f). Resistance to overturning moment was provided by whatever internal reinforcement was in the piers. This is a variation of the internal hold down method used by Scrivener and Schneider.

Recently, Mayes and Clough(15,IV) carried out an extensive test program which attempts to approximate as closely as possible the boundary conditions of the piers in a complete structure - Figure 1(g). Results of this test procedure are compared with results obtained by other methods in the present paper.

III. Test Program

The test arrangement depicted in Figure 1(g) was developed to carry out a major part of an experimental study of the earthquake behavior of masonry structures at the Earthquake Engineering Research Center. This test specimen was chosen because of the realistic manner in which the boundary conditions of the piers are simulated. Results of these experiments are reported in EERC Report No. 76-8 (V). However, it was recognized that these results should be correlated with those obtained from a simple test procedure such as could be used in commercial test laboratories for obtaining the shear strength of masonry components. The method most commonly used to date is the diagonal compression test shown in Figure 1(c).

Some of the theoretical formulations associated with this test (9) assume that the compressive load P can be represented by a shear force of $P/\sqrt{2}$ applied on each side of the panel. To investigate the validity of this assumption, a modified form of the test set-up was designed (Figure 3 which ensured that the components ($P/\sqrt{2}$) of the compressive force P were transferred to the panel as shear forces. In order to compare results obtained by the three different test procedures, test specimens of each type were constructed at the same with the same mortar and grout. In total eight sets of two identical double pier test specimen were constructed and for each set of large panels at least two "32 x 32" (81 cm x 81 cm) square shear panels were constructed. All test specimens were constructed from 6" (15.2 cm) wide x 8" (20.3 cm) high x 16" (40.6 cm) long hollow concrete block units. A short description of each test set up and a comparison of the results follows.

III-1. Diagonal Compression Tests

An overall view of the diagonal compression test set up is shown in Figure 2. Top and bottom shoes to apply the loading were fabricated from 1" (2-5 cm) thick steel angles to form a 90 degree bearing corner which transferred the vertical compressive force to the panel. A four million pound University Testing Machine applied the load at a rate of approximately 8000 pounds per minute until failure. The critical tensile strength σ_{tcr}, was calculated by two methods. The first employed a formula used by Blume$^{(9)}$ which was based on analytic and photoelastic studies performed by Frocht$^{(24)}$ on a homogeneous square panel.

$$\sigma_{tcr} = \sqrt{2.422\tau^2 + (\sigma_c/2)^2} - (\sigma_c/2 + 0.832\tau) \qquad -1.$$

where σ_c is the applied compressive stress and τ is the assumed shear stress. $\tau = P/\sqrt{2}\cdot A$. Here, P is the applied compressive load and A is the area of one side of the square - Figure 4. The second formula was used by Borchelt$^{(10)}$ and is based on the simple Mohr's circle approach

$$\sigma_{tcr} = \sqrt{\tau^2 + (\sigma_c/2)^2} - \sigma_c/2. \qquad -2.$$

III-2. Modified Diagonal Compression Test (Simple Shear Test)

In the initial stages of the test program the diagonal compressive test was the only simple test used to correlate results with the double pier tests. However, because certain theoretical formulations associated with the diagonal compression test$^{(10)}$ assumed that the vertical compressive load (P) had shear force components, $P/\sqrt{2}$, acting on each side of the panel, a modified test set up was developed to satisfy this assumed boundary condition. The test set up is shown in Figure 3 and is described in more detail in EERC Report No. 76-16$^{(VI)}$. Because of the time required to develop the modified test set up, only one set of double piered test results has been used for correlation with these results. The critical tensile strength at failure was calculated by the formula developed by Borchelt$^{(10)}$

III-3. Cyclic Shear Tests

Each test specimen was a full scale panel about 15 feet (4.6m) square consisting of a top and bottom spandrel and two piers as shown in Figure 5. The details of this test program are discussed in a paper presented at Session II-64 of this conference $^{(IV)}$. A typical shear mode of failure in the piers is shown in Figure 6.

In order to estimate the critical tensile stress of the piers, a point of inflexion is assumed at the mid-height of the pier (Figure 7) and each pier is assumed to resist half of the applied shear load. The compressive load in each pier is modified by the axial forces induced by the overturning moment, acting on the panel, as shown in the Figure 7. The shear force across the width of the panel is assumed to have a parabolic distribution (18). With these assumptions the critical tensile strength of the double piers is calculated by the same formula used by Turnsek and Cacovic(18) which is based on a Mohrs Circle approach at the center of the pier, as follows

$$\sigma_{tcr} = \sqrt{(1.5\tau)^2 + (\sigma'_c/2)^2} - \sigma'_c/2 \qquad -3.$$

where τ is the average shear stress and σ'_c is the modified compressive stress.

IV. Discussion of Test Results

A comparison of the critical tensile strengths obtained from five sets of double pier tests with the corresponding critical tensile strengths obtained from both the diagonal and modified diagonal (simple shear) compression tests is shown in Figure 8. The critical tensile strengths obtained from the diagonal compression test are calculated from both Equations 1 and 2. Also included in the results are double piers that failed in a combination of the shear and flexural modes of failure.

For the simple diagonal compressive test the more exact formulation of Equation 1 gives the best correlation with the double pier results. The results obtained from Equation 2 are approximately 1·36 times greater than Equation 1 values, and therefore show corresponding poorer correlation. This indicates the inappropriatness in the theoretical model of the assumption that, the compressive load P can be considered to have shear force components $P/\sqrt{2}$. The only two pier results that can be used for correlation with the modified diagonal (simple shear) compressive test were from a double pier that failed in a combination of the shear and flexural modes. Before any conclusions can be drawn about the value of this method, further tests should be performed to correlate the results with double or single piers failing in the pure shear mode of failure.

Although this series of tests is limited in number it appears that a reasonable correlation exists between the critical tensile strengths obtained from the simple diagonal compressive test (Equation 1) and the more realistically loaded piers. In masonry research "reasonable correlation" is difficult to define because of the variability of the material. However, to further evaluate the test methods, it is the authors intention to continue determining the correlation between the results of the three test methods in an extensive (80) single pier test program. It is hoped that when completed the results can be used to recommend a more realistic test method for determining the allowable shear strength of masonry. At present the Uniform Building Code uses a proportion of the uniaxial compressive prism strength (f'_m) to estimate the shear strength of masonry.

Acknowledgement and References

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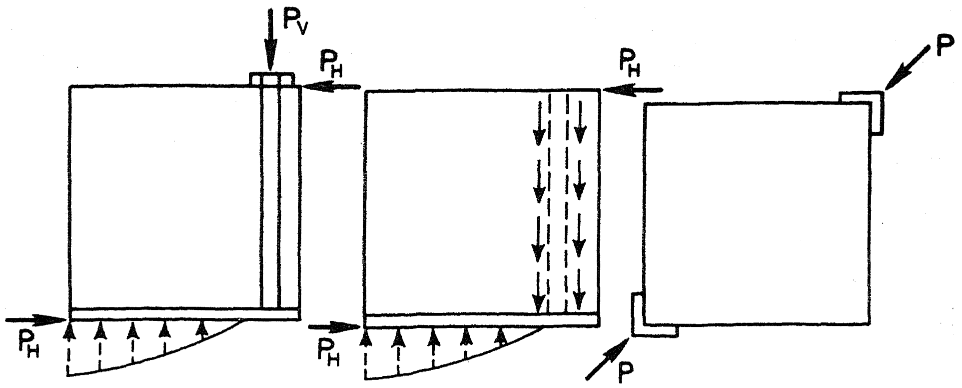
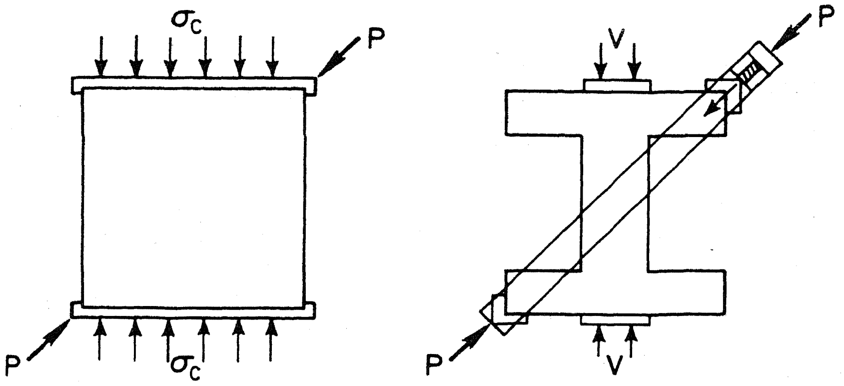


(a) EXTERNAL HOLD DOWN

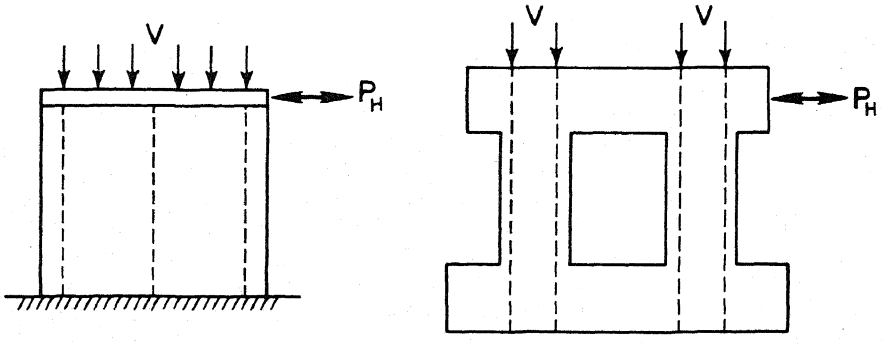
(b) INTERNAL HOLD DOWN

(c) DIAGONAL COMPRESSION



(d) EDGE LOAD WITH RACKING

(e) DIAGONAL LOAD FRAME



(f) CANTILEVER LOAD TEST

(g) FIXED ENDED PIER TEST

Fig.1 Test Techniques on Masonry Shear Strength

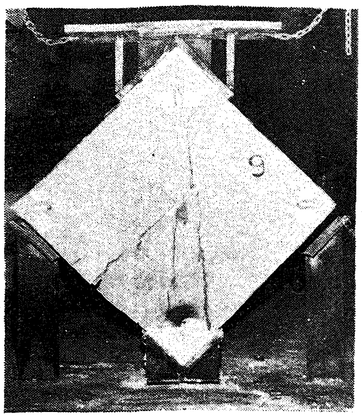


Fig.2 Diagonal Compression Test

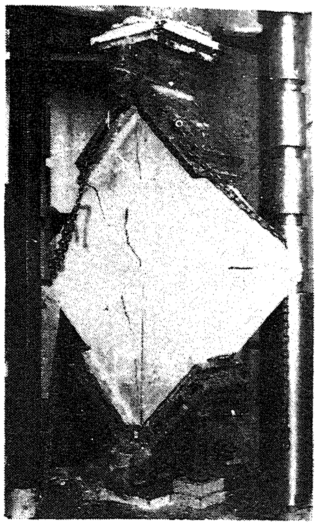


Fig.3 Modified Diagonal Test

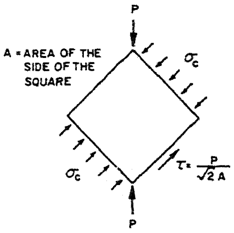


Fig.4 Stress Distribution

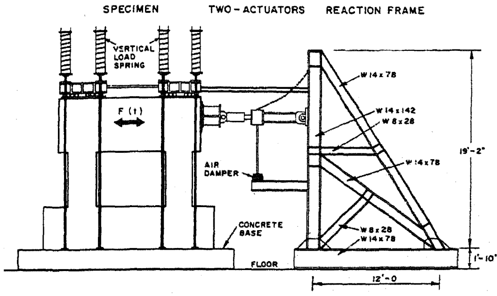


Fig.5 Cyclic Shear Test

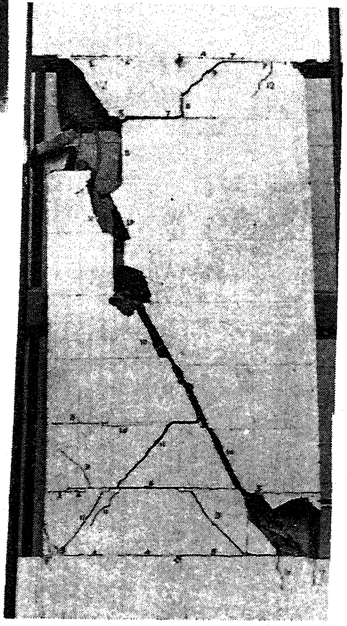


Fig.6 Shear Mode of Failure on Pier

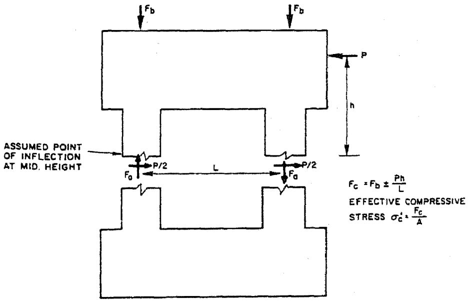


Fig.7 Assumed Force Distribution in Double Pier

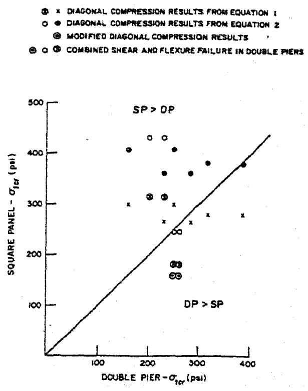


Fig.8 Test Results of Critical Tensile Strength