A Preliminary Investigation of the Vertical Shear Strength of Brick Masonry

Tsui, K.Y.[1], Harvey, W.J.[2], Morton, J.M.[3], and Shaw, G.[4]

Synopsis

Guidance on the vertical shear strength of brick masonry is not readily available to British engineers The need is discussed in some detail. Tests for single bricks and for short masonry shear piers are proposed and some typical results presented. Correlation between crushing strength of brick and mortar, and the vertical shear strength are discussed. The effects of stress concentrations are investigated. Some preliminary guidelines for design are presented.

1. Research student, Dundee University

2. Lecturer, Dundee University

3. Senior Structural Engineer, Brick Development Association

4. Partner, W.G. Curtin and Partners (England)

1. INTRODUCTION

Masonry construction, whether of stone or brick, was traditionally massive. The aim of the designer, be he craftsman or, later, engineer, was to carry all loads in compression. This was ensured by the use of buttresses and decorative weights. A deeper understanding of materials and structures has now led to thin wall design.

While the structural engineer is not as fluent in the design of brick masonry as he is with concrete or steel he is beginning to understand the place which masonry holds in the operation of engineering materials. This has been made possible by the use of much thinner sections, with enormous economic pressure to use half brick (102.5 mm) walls wherever possible. The result has been an increased use of the bending and shear strength of masonry. Over the Past twenty years developments in design practise have been restrained by a lack of knowledge in certain areas, or have gone ahead only where engineering judgement indicated a large factor of safety.

In the fourth author's practise, where brick masonry is extensively used, a number of gaps in knowledge have been recognised. The vertical shear strength of brickwork has been of particular concern in a number of their structures. In March 1979 the four authors joined together to study this aspect. The aim was to produce data which would be directly applicable in design. Some of the locations where vertical shear stress might be critical are therefore discussed here.

1.2 Brick Diaphragm Walls

The brick diaphragm wall resists wind forces in bending. It acts as a series of connected I or box beams, of which the diaphragms form the webs. Figure 1 shows the effect of bending and the assumed distribution of shear stress. Since this stress acts in two complementary directions, it might still be assumed, for a fully bonded wall, that shear on the bedding planes remains critical. Architectural considerations, however, may effect the nature of the bond used between the web and the outer leaf. The bending resistance of such a wall may be increased by the application of prestress (fig.2). This will also increase the resistance to shear on the bedding planes, but will increase the shear stress in the vertical direction.

Brick diaphragm walls have been designed in the fourth authors practise for over 14 years. Many use full, alternate course bonding while some have metal ties to provide the shear connection between the diaphragm and the wall panel. In both cases conservative values for strength have been adopted in the absence of test data.

1.3 Cantilevers in Cross Wall Construction

In the detail shown in figure 3 the traditional design approach has been to use a concrete beam to carry the full structural load above the cantilever. A better knowledge of shear strength, particularly at the junction between the outer skin and the cross wall would allow a more economical approach. The concrete may only need to carry the first lift of uncured masonry.

1.4 Vertical Cantilevers for Retaining Structures

The use of stiff geometric shapes (fig.4) for retaining structures may be more confidently approached if reliable figures for shear resistance were available. The use of bricks for retaining walls, tanks and silos may then be more competitive.

1.5 The Prediction of Behaviour at Wall Junctions

Wall junctions are subjected to shear stress in a number of ways. Wind loading on any structure will cause stresses of a similar form to those described above for diaphragm walls (fig.5). Differential settlement, movement or accidental damage may also induce shears which the designer must take into account.

1.6 Requirements

In most of the examples cited above shear develops in combination with bending stresses. For particular applications there will be a need to investigate the interaction of these stresses, but, to give an early indication of available strength to designers, it was decided to study vertical shear as an isolated parameter first.

Since a comprehensive set of tests on all brick types and strength was beyond the scope of this initial investigation, there was a clear need, either to seek correlation between various basic material properties and the strength of finished masonry, or to develop a simple test which would give adequate information on a new brick type. Two groups of tests were therefore performed, one on single bricks and one on masonry piers.

2. TESTS ON SINGLE BRICKS

2.1 Test Method

The application of shear stress without significant bending is very difficult. A study of the methods used for testing other materials showed that the test had to be related to the material. In many cases indirect shear was used, for example in the shear prism used for testing adhesives (ref.2). Since it seemed probable that the properties of bricks were directional, and since most bricks are relatively long and narrow, the use of a double shear test rig (fig.6) was proposed.

Preliminary tests using loose support plates led to bending failure, even when the clearance in the shear zone was reduced to 2 mm. It proved impossible to induce a shear failure without premature flexural failure if the brick were not clamped as shown in figure 7. The value of the clamping force had no effect provided it was sufficient to prevent slipping.

All the bricks tested were slightly miss shapen, and it was necessary to use some form of bedding. Dental plaster provided a very hard bed which set rapidly. The bed was precast on to the brick on a polished and oiled steel plate, so that a set of ten tests could be completed in one session.

2.2 Results

While work is continuing to test the full range of brick strengths and types, the results available indicate that a simple relationship may exist between vertical shear strength and brick crushing strength (table 1 and fig.8).

3. TESTS ON BRICK MASONRY

3.1 Design of Specimens

A test for vertical shear in masonry must be simple. That is the specimens should be robust, easy to build and handle, and easily supported in a standard testing machine. The nature and area of the loading and support plates must be such as to minimise local stresses, and there must be enough courses of brickwork to make the results representative. It is important to be able to prevent premature failure by arch spreading or bending action, and it must be possible to apply direct stress with the shearing force.

An H shaped shear pier five courses high was adopted (fig.9). These were built on 6 mm steel chequer plate for ease of handling, and the bottom brick of the web was removed before the mortar set. Separate clamps were provided for the web and flanges. Thus four bricks were effectively tested in shear.

3.2 Parameters Considered

Many parameters might effect the vertical shear strength of masonry. The effect of brick type and strength, mortar strength, workmanship and coexistent direct stress have been investigated. All the piers tested were constructed in stretcher bond which was broken by the four header bricks under test. Results for piers with unbroken stretcher bond where the shear strength is provided by metal ties are not yet available for publication.

3.3 Results

The results available to date are presented in table 2. Figures 11, 12 and 13 indicate the main relationships which are discussed below.

4. DISCUSSION

4.1 Single Brick Shear

The results presented here show a degree of correlation between shear and crushing strength (fig.8). It is hoped that the work may continue to build up a fuller picture of this relationship.

4.2 Masonry Shear Piers

The validity of the results of tests on only four courses of brickwork might be questioned. The value of failure load for the shear piers and the single bricks were, in some cases, so close that we felt it was necessary to check the results with taller piers (group 12 in table 2). The result is noticeably smaller than that for group 2, which suggests that there is at least some element of stress concentration involved.

A simple computer analysis was made using average elastic properties for the masonry and the results are presented in figures 14 and 15. The values of stresses are deliberately suppressed, but the mean shear stress is the same for the four course and the nine course piers. The shear stress concentration in the tall pier is most marked, but it is likely that principle tensile stress is of more significance.

The peak value of principle tensile stress in the taller column is 1.5 times that in the shorter, and this ratio corresponds exactly with the ratio of

mean shear stress at failure. The reversal of this stress near the ends of the shear plane result from the restraint provided by the loading and supporting steel plates.

The concentration of stress near the ends of the joint relates closely to the long joint effects recently introduced into British codes of practise for structural steelwork (ref.3). It results from the incompatible strains in the web and flanges of the pier when under load (fig.16). Some element of redistribution of stress would be expected in a strong brick, weak mortar combination, but we do not have sufficient results to confirm this.

It is clear that long joints with shear applied directly as in our tests (see figure 3 for example), will need careful analysis. An understanding of the behaviour of diaphragm walls will only be achieved by suitable bending tests, but the mean values of shear strength obtained from our tests should be conservative.

The work of Hendry et al and Curtin et al on principle stresses in brickwork may prove to be applicable to the situation we have studied (ref.1,5). The existing rules for shear in the code of practise BS 5628 effectively limit principle tensile stress, but without a direct application of stress analysis.

REFERENCES

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2. Johnson, R.P. The properties of an epoxy mortar and its use for structural joints. The Structural Engineer, Vol 48, No.6, June 1970.

3. British Standards Institution. Draft British Standard for the Structural Use of Steel in Buildings. BS 5950.

4. Samarasinyhe, W., Page, A.W. and Hendry, A.W. Behaviour of Brick Masonry Shear Walls. The Structural Engineer, Vol 59B, No.3, September 1981.

5. Curtin, W.G. and Phipps. The behaviour of post tensioned diaphragm brick walls. To be published.

BRICK TYPE	Crushing Strength N/mm^2		Shear Strength N/mm^2	
	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
1 PRESSED FROGGED	28	3	5.5	0.3
2) EXTRUDED WIRE CUT (10 hole	51	4	12.6	1.4
3) EXTRUDED WIRE CUT (3 hole	53	4	15.2	1.5
4) EXTRUDED WIRE CUT (3 hole	59	4	13.8	1.2

TABLE 1 TEST RESULTS FOR SINGLE BRICKS

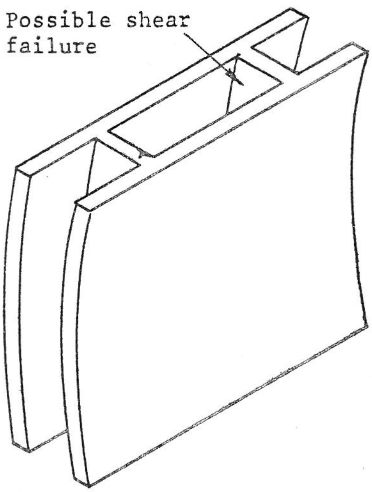
GROUP NO.	BRICK TYPE+	BRICK CRUSHING STRENGTH N/mm^2	MORTAR GRADE (BS 5628)	BRICKLAYER*	PERPENOS FILLED	DIRECT PRESTRESS	ULTIMATE SHEAR SRESS N/mm^2	
							MEAN	STANDARD DEVIATION
1	4	59	3	1	✓	0	2.4	0.5
2	1	28	3	2	✓	0	1.5	0.2
3	3	53	3	3	✓	0	2.5	0.2
4	3	53	1	3	✓	0	3.2	0.4
5	3	53	4	3	✓	0	2.3	0.3
6	4	51	1	3	✓	0	3.2	1.0
7	4	51	1	3	x	0	3.1	0.5
8	4	51	3	3	✓	0	2.9	0.6
9	4	51	3	3	x	0	2.2	0.8
10	3	53	3	2	✓	0.2N/mm^2	2.2	0.3
11	3	53	3	3	✓	0.2N/mm^2	3.1	0.7
12++	1	28	3	3	✓	0	1.0	

\+ See Table 1

* 1 Working Bricklayer
2 Research Student
3 Retired Bricklayer

++ 10 Course high shear pier

TABLE 2 TEST RESULTS FOR MASONRY SHEAR PIERS



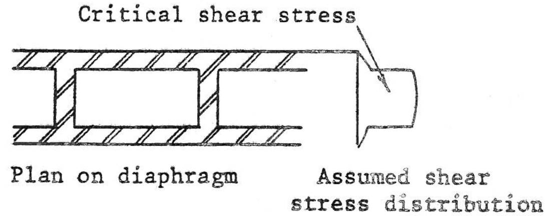


Fig 1 The Diaphragm Wall

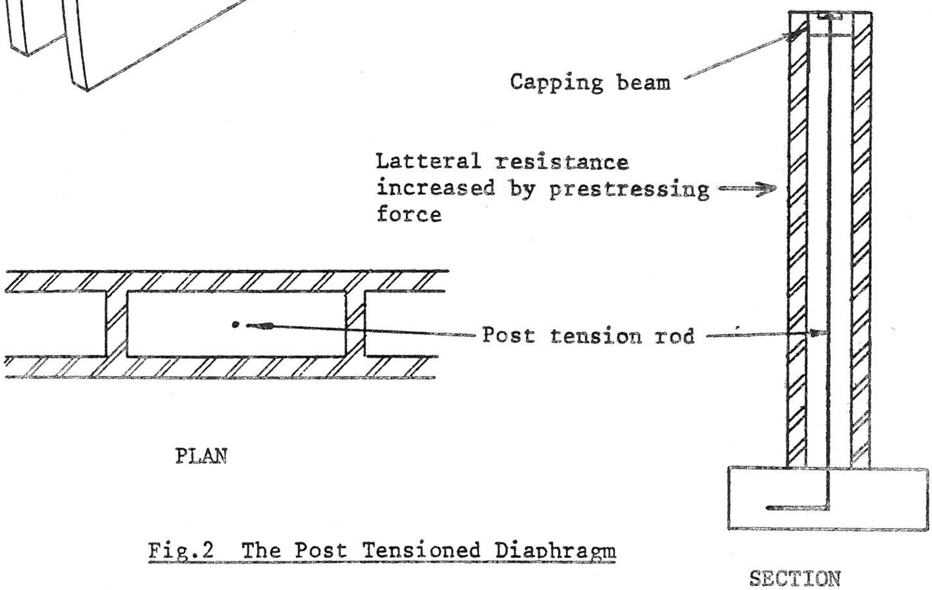


Fig.2 The Post Tensioned Diaphragm

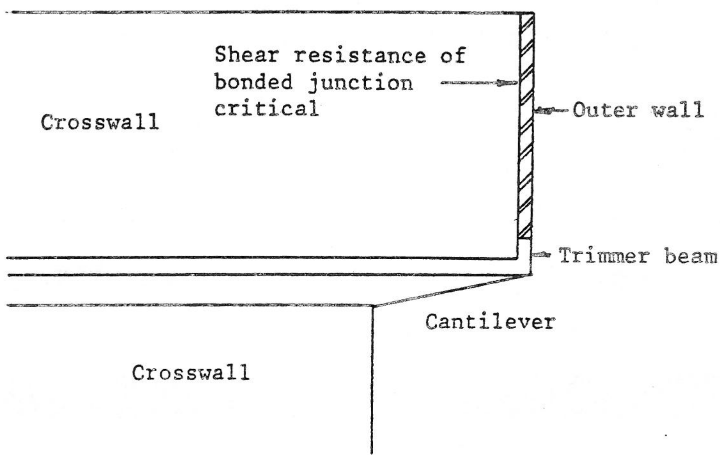


Fig.3 Cantilever in Crosswall Construction

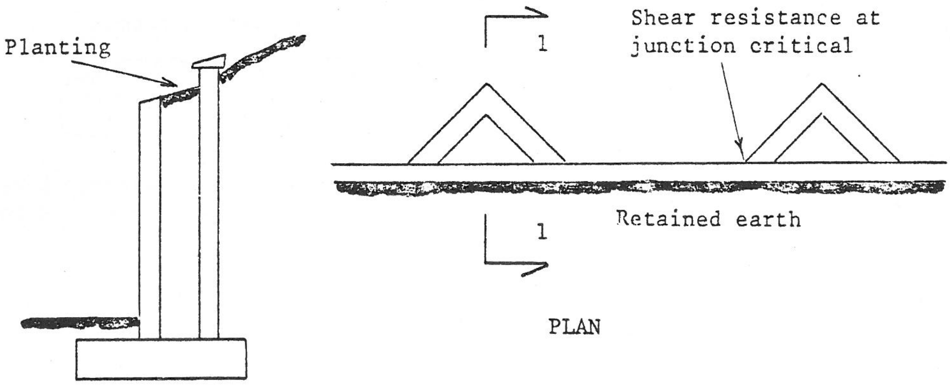


Fig.4 Landscape Retaining Wall

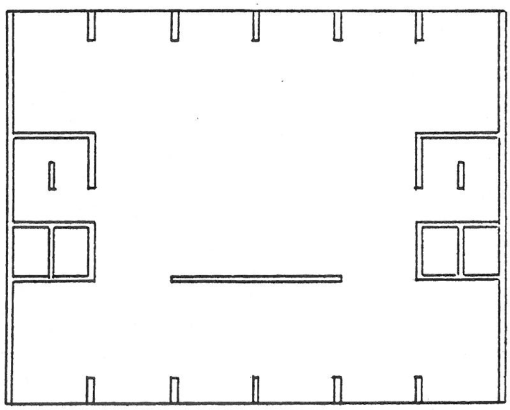


Fig.5 Typical Plan of Multi-storey Building

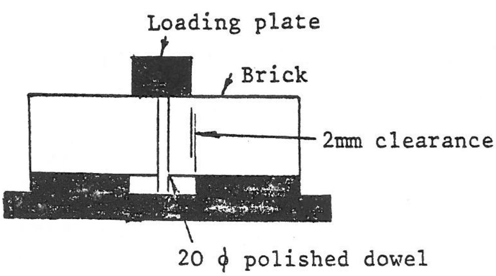


Fig.6 Single Brick Shear Rig

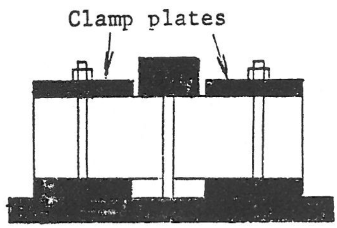


Fig.7 With Clamping Plates

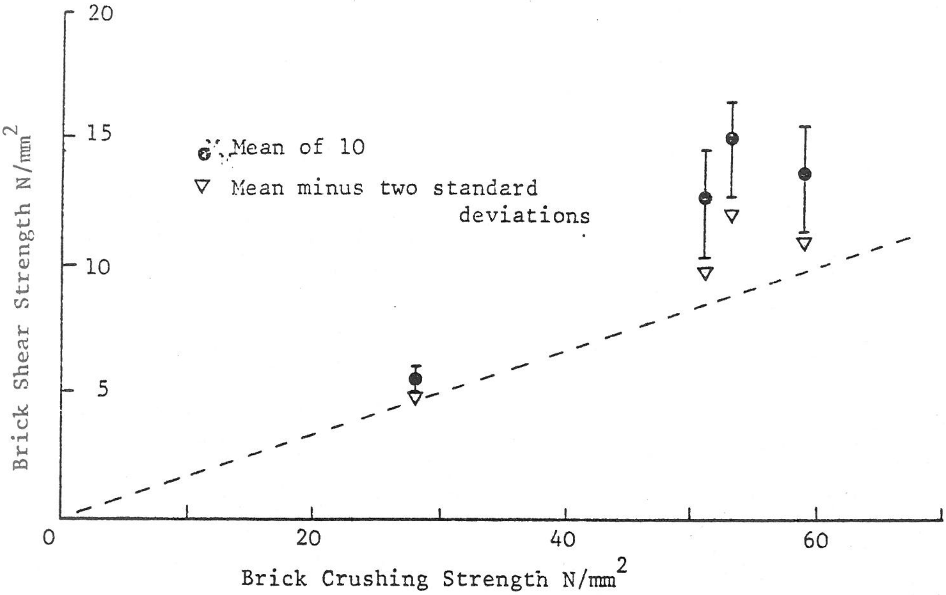


Fig.8 Shear Strength versus Crushing Strength for Single Bricks

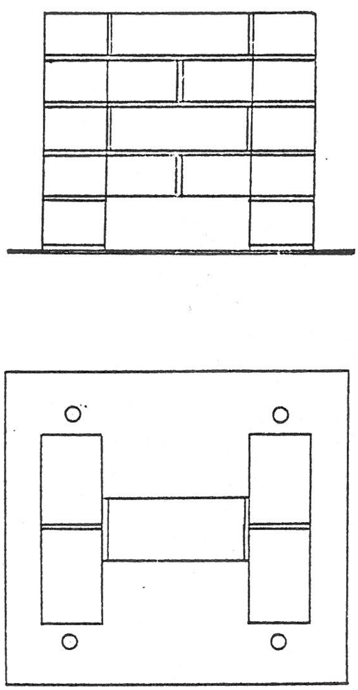


Fig.9

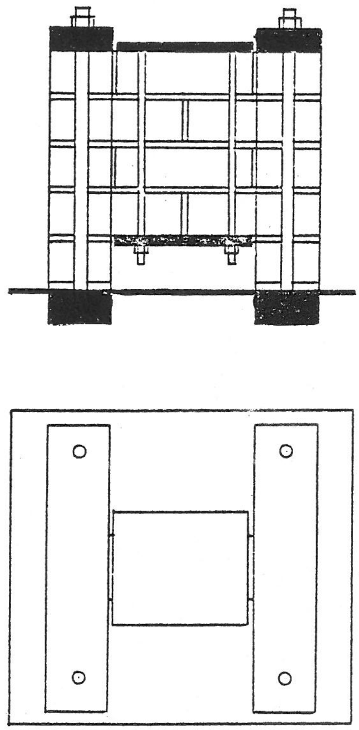


Fig.10

Brick Shear Piers and Associated Clamping Plates

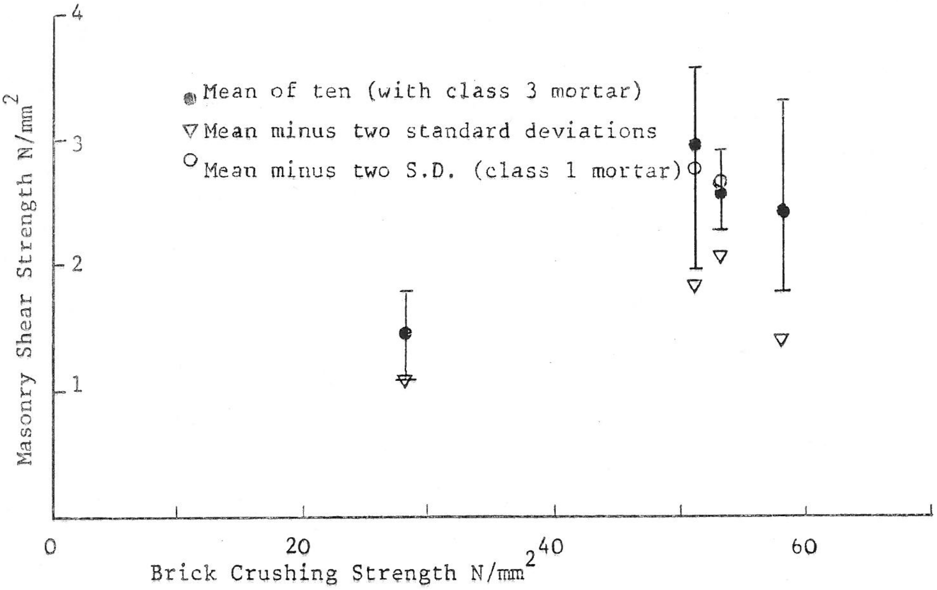


Fig.11 Masonry Shear Strength versus Brick Crushing Strength

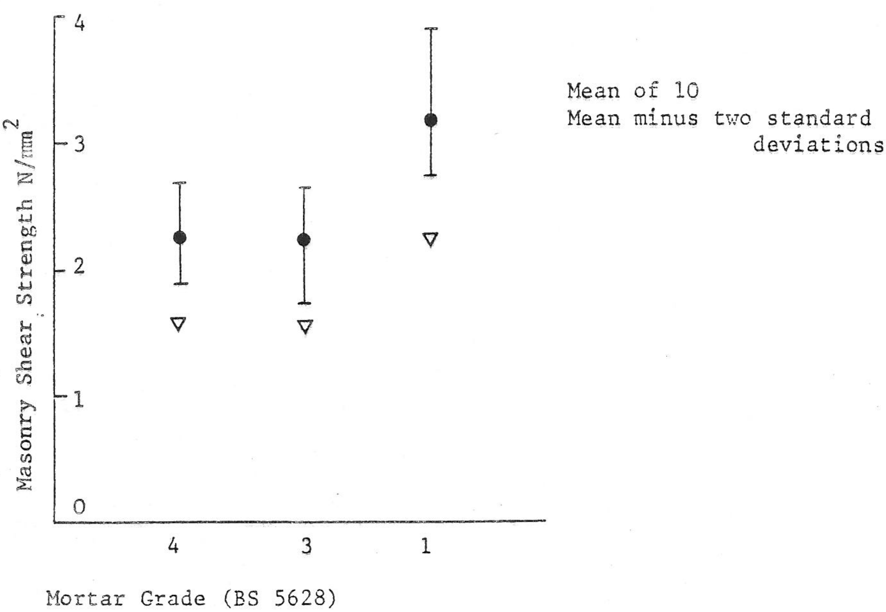


Fig.12 Masonry Shear Strength Variation With Mortar Grade

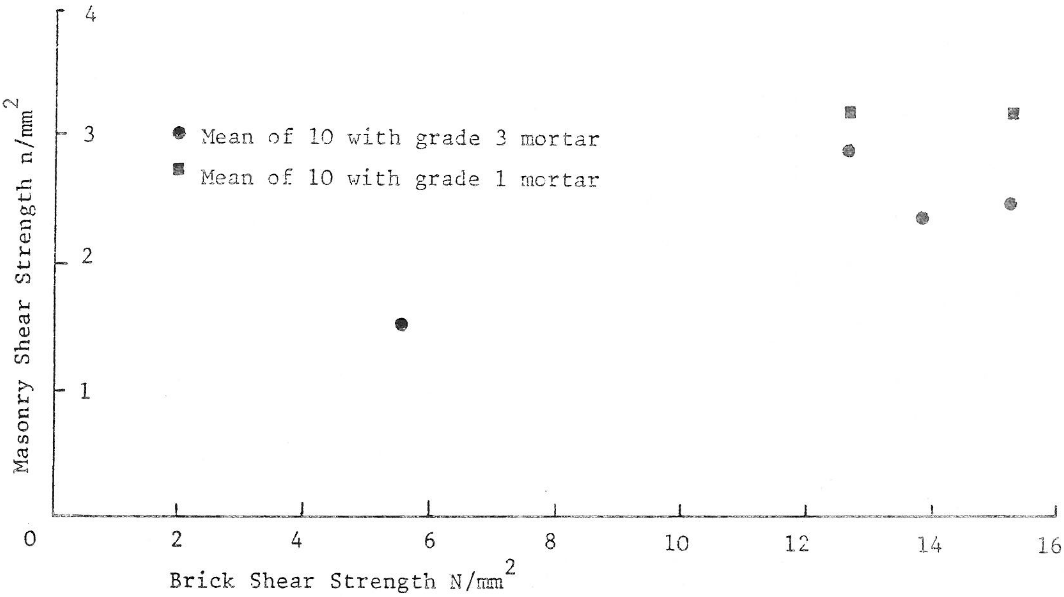


Fig.13 Masonry Shear Strength versus Brick Shear Strength

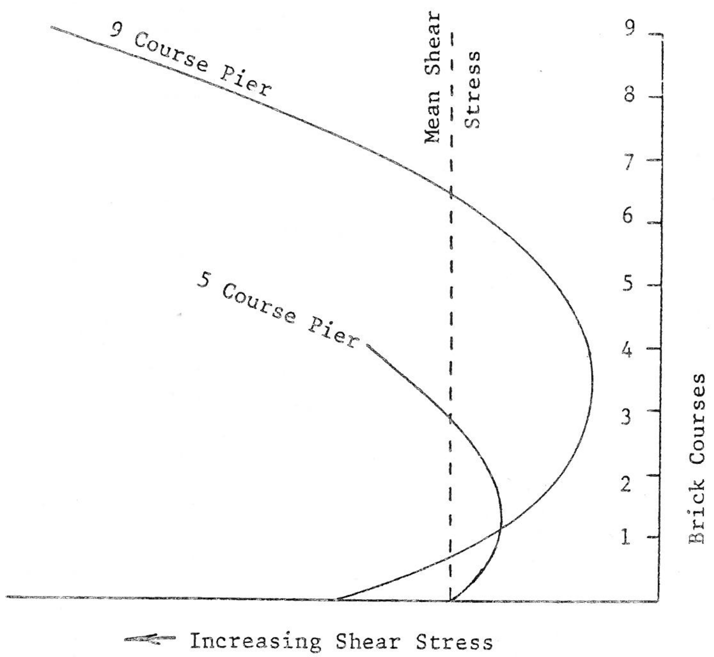


Fig.14 Variation of Shear Stress in Piers of Different Heights

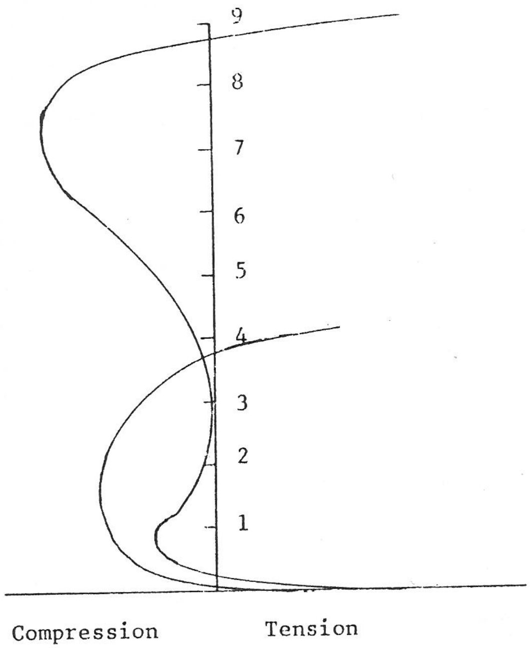


Fig.15 Variation of Minor Principal Stress in Piers of Different Heights

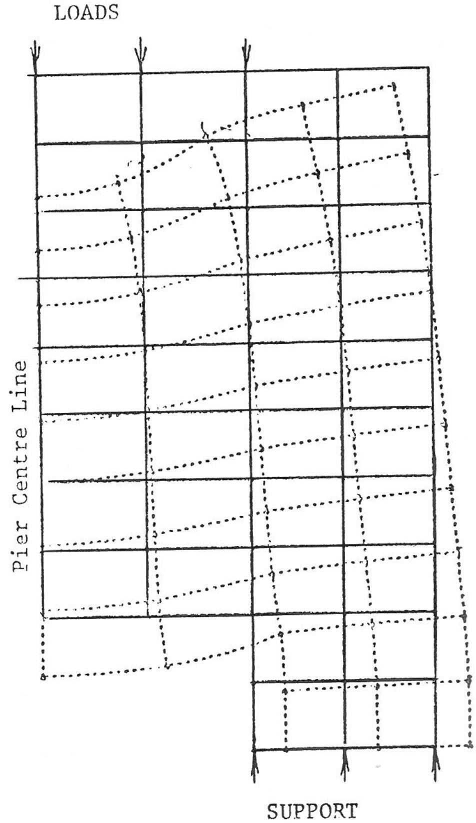


Fig.16 Displacement of Shear Pier Under Load