The Shear Strength of Bricks and Brickwork

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SUMMARY

This paper describes three different tests employed to determine the shear strength of individual bricks and samples of brickwork made with these bricks, using two mortar mixes. Also investigated is the relationship between the compressive strength and the shear strength of individual bricks.

1. INTRODUCTION

Earlier work by the authors[1] had shown that within the range of brick strengths and types tested a linear relationship appeared to exist between brick shear strength and compressive strength. These tests were carried out using the purpose-made shear test rig[2] illustrated in fig. 13 on bricks with compressive strengths in the 20 - 90 N/mm^2 range.

It was decided to test further samples using this same apparatus and also two other methods so that results could be compared.

In addition small brickwork piers were made using two different mortar mixes combined with bricks of the same type used for the individual tests.

2. MATERIALS

2.1 BRICKS

Eight different clay brick types were tested and their compressive stresses determined in accordance with BS 3921:1974 are given below in Table 1.

Brick Type Code	Compressive stress N/mm^2
A	18.5
B	23.9
C	36.8
D	37.6
E	49.6
F	51.6
G	60.3
H	75.0

Table 1. Brick compressive stresses

3. TESTING

The three test methods applied to individual bricks and the method of testing the small brickwork piers are described below. In each case the test sample comprised five specimens. In tests 1 and 2 the individual bricks were tested across the weakest section i.e. across any perforations present and all results are based on the gross cross sectional area.

3.1 TEST 1 - Single shear tests on single brick specimens

A brick sample was clamped between two steel plates in the test rig, leaving approximately one quarter of the brick cantilevering as shown in fig. 13. The shear force was applied through a section of steel angle at the root of the cantilever and was increased steadily until shear failure occurred.

3.2 TEST 2 - Double shear tests on single brick specimens

The single brick specimens were supported and loaded in a Denison Testing machine as shown in fig. 1. Loading was applied at a machine controlled rate until failure occurred.

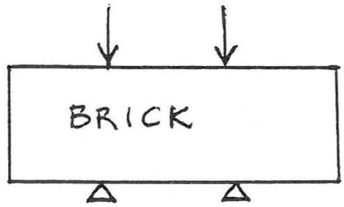


Fig. 1. Double shear test on brick specimen

3.3 TEST 3 - Shear Test on cut brick specimens using a shear box

The shear box used was a Robertson Research Field Shear Box illustrated in fig. 11. The box is designed to measure the shear resistance of bed joints in natural rock material and was thought to be a suitable means of measuring the shear strength of cut brick specimens.

Samples measuring approximately 100 x 65 x 30 mm were sawn from the unbroken ends of bricks used in Test 1. The cross sectional dimensions of these were recorded before casting each sample between two prisms of concrete leaving a 12 mm gap between the two horizontal faces of the prisms. The various stages in the manufacture of the prisms can be seen in fig. 12.

Each sample was then placed in the shear box, an initial vertical load of 2 kN applied and the two prisms sheared horizontally relative to each other using the horizontal jack system. The load indicator connected to the horizontal jack enabled the load at which the trapped brick sheared to be recorded.

3.4 TEST 4 - Shear tests on brickwork piers

For each brick type, sets of ten piers were constructed as shown in fig. 14. Half of these piers were built in 1 : ½ : 4½ mortar and half in 1 : ¼ : 3 mortar.

After curing under polythene for 21 days each pier was supported on timber plattens and loaded as shown in fig. 15. The rollers through which the load was applied were positioned at 10 mm inside the inside faces of the supporting half bricks.

Loading was applied at a constant rate and the loads at which first visible shear cracking and total failure in shear occurred, were recorded.

4. RESULTS

The results of the various tests are presented in Tables 3 to 9 and the mean results have been plotted in Figures 2 to 10. Shear stresses have been calculated based on the gross cross sectional area resisting shear with no allowance for perforation patterns.

4.1 Single shear tests on single brick specimens

Figure 2 shows the mean results of the eight tests plotted against compressive strength. Also shown (as a + sign) are the results from the previous series of tests[1]. The result for brick 'F' seems anomalous and has been discounted.

The results taken together are now suggestive of a curved relationship and the curve shown has been obtained from a computerised regression analysis giving a correlation ratio of 0.85.

Although there are insufficient results in the lower range of brick strengths ($< 25\ N/mm^2$) and in the higher range ($> 65\ N/mm^2$), this curve suggests a larger initial rate of increase of shear strength with compressive strength in the lower range with little or no gain in shear strength once the higher range of compressive strengths has been reached.

In between 25-64 N/mm^2 the plotted points suggest an approximately linear relationship and the lines shown have again been obtained from a regression analysis (a) using the results of bricks A-H and (b) using both sets of results. The correlation coefficients of these lines are 0.76 and 0.74 respectively being statistically significant at the 5% level.

The equation of the 'combined results' line is of the form:-

$$\tau = \frac{\sigma}{31} + 1.45$$

where: τ = shear strength based on gross sectional are (N/mm^2)

σ = compressive strength (N/mm^2)

and is similar to the equation obtained from the original work[1].

4.2 Double shear tests on single brick specimens

Mean results of this test are plotted in Figure 3. Using regression analysis the curve shown (correlation ratio 0.93) and the line shown (correlation coefficient 0.85) have been plotted.

The curve is similar in shape to that of Figure 2 and both straight lines are of identical gradient. The single shear test results however indicate slightly higher strengths than the double shear test results, but both tests indicate the same general relationships between shear and compressive strength.

4.3 Shear tests on cut brick specimens in shear box

Mean results are plotted in Figure 4 indicating much higher shear strengths than those obtained in the other two tests.

This can be attributed to the nature of the test which, whilst using apparently sophisticated apparatus, proved unsatisfactory in operation. As the horizontal shearing load was applied there was a tendency for the test specimen to pivot and rise vertically out of the shear box. This movement was resisted by the vertical jack which applied an increasing downward load as the vertical movement of the sample increased.

The horizontal force required to shear the test specimen therefore not only had to fracture the specimen but overcome the frictional resistance between the two fractured surfaces due to the vertical normal force. The resulting apparent shear stress recorded was therefore considerably higher than the true shear stress.

The second order curve fitted using regression analysis gave a correlation ratio of 0.77 and confirmed the same behavioural trend between shear and compressive strength as indicated by the curves in Figures 2 and 3.

4.4 Shear tests on brickwork piers

"First crack" and failure results are plotted in Figures 5 to 8. All the graphs suggest a curved relationship for all results or possibly a linear relationship if the results for brick 'H' are excluded. Using regression analysis second order curves (including the result for 'H') and straight lines (excluding the results for 'H') have been plotted.

Correlation coefficients and ratios are given in Table 2 which follows.

Figure	Correlation coefficient for line	Correlation Ratio for curve
5	0.66	0.74
6	0.80	0.83
7	0.88	0.88
8	0.90	0.88

Table 2

These results suggest a similar shear/compressive strength relationship to that indicated by the tests on the single brick specimens. The single result for brick 'H' suggests that the shear strength of the brickwork decreases for higher compressive strength bricks. This seems unlikely and it could be that the rate of increase of shear strength decreases as the brick compressive strength increases. More tests on higher strength bricks would confirm this.

The results for the two mortars give identical graphs. If the differences between corresponding pairs of mean results are tested using the statistical 't' test it can be shown that there is no significant difference between the results for the two mortars either at 'first cracking' or failure. It would therefore seem that, for this mode of shear failure, mortar strength is not an important criterion. The 'averaged' equation of the lines of best fit from figures 7 and 8 is of the form

$$\tau^1 = \frac{\sigma}{38} + 1.36$$

where τ^1 = shear strength of the brickwork (N/mm^2)

σ = compressive strength of the bricks (N/mm^2)

The mode of failure for the brick piers was similar in all cases. A typical failed pier can be seen in Figure 14 which shows a single shear crack, although generally cracks formed on both sides of each specimen. First visible cracking occurred at between 80% to 100% of the failure loads and in some cases failure was sudden and explosive. In other cases the shear cracks developed slowly and failure was in a less explosive manner.

The coefficients of variation for the brick pier results were all low indicating a good level of repeatability; somewhat better than the tests on single bricks.

4.5 Relationship between brick shear tests and brickwork shear tests

No attempt has been made to relate the shear box test results to that of the brickwork because of the anomolies indicated earlier.

The averaged results for the brickwork shear strengths at failure for the two mortars have been plotted against the brick shear strengths obtained from shear tests 1 and 2.

The graphs are shown in Figures 9 and 10 with the plotted lines (excluding the result for 'F' in Figure 9) having correlation coefficients of 0.96 and 0.80 respectively. These are indicative of a good level of correlation between the brickwork shear strength and the brick shear strength as measured by the various tests.

A two-way analysis of variance has been carried out on the results of the averaged brickwork shear strengths and the brick shear strengths obtained from Tests 1 and 2. Tested at the 5% significance level, the analysis indicated no significant difference between the mean results of the brickwork shear strengths and Test 2 brick shear strengths. Test 1 results however were on average greater than the results for test 2 and 3. It would therefore appear that the double shear test on single bricks gives a more direct estimate of the brickwork shear strength than the single shear test on single bricks.

5. CONCLUSIONS

1. There is a statistically significant linear relationship between brickwork shear strength and brick shear strength as measured by two of the tests described in this paper.

2. Brickwork shear strength can be related to brick compressive strength by the equation given in paragraph 4.4 for compressive strengths in the approximate range of 25-65 N/mm^2.

3. For low strength bricks (< 25 N/mm^2 approx.) the results of the single shear brick test suggest that the rate of increase of shear strength with compressive strength is greater than indicated in the paragraph above.

4. The results of this work suggest that there is little or no gain in brickwork shear strength for brick compressive strengths greater than approximately 65 N/mm^2. A second order curve gives a good representation of the overall shear/compressive strength relationship.

5. For the shear tests considered in this work the strength of the mortar does not appear to affect the brickwork shear strength.

6. Two of the three brick shear tests realistically model the shear behaviour of brickwork under similar loading conditions. Theses tests therefore offer a simple means of investigating a wider range of brick types and strengths to determine a more exact relationship between brickwork shear strength and

brick compressive strength. The shear box test in its present form is an unsatisfactory method of measuring brick shear strength.

REFERENCES

1. HULSE R. and AMBROSE R.J. Shear Strength of Bricks. Coventry (Lanchester) Polytechnic.

2. POTKINS S.R. Determination of the Shear Strength developed by vertical brickwork joints. Final year project. Coventry (Lanchester) Polytechnic 1980.

Brick	Shear Strength (N/mm^2)		
	Mean	Standard Deviation	Coefficient of Variation
A	1.06	0.13	11.8%
B	2.60	1.01	39.0%
C	2.89	0.76	26.3%
D	3.57	1.13	31.7%
E	3.86	0.75	19.5%
F	6.33	0.60	9.6%
G	4.12	1.47	35.7%
H	3.52	0.84	24.0%

Table 3 - Shear Strength Results

Single Brick Single Shear Test

Brick	Shear Strength (N/mm^2)		
	Mean	Standard Deviation	Coefficient of Variation
A	1.05	0.21	13.0%
B	1.62	0.34	21.1%
C	2.29	0.21	9.0%
D	2.33	0.39	16.7%
E	2.31	0.32	13.6%
F	3.33	0.89	26.7%
G	2.85	0.40	14.0%
H	2.96	0.70	23.4%

Table 4 - Shear Strength Results

Single Brick Double Shear Test

Brick	Shear Strength (N/mm^2)		
	Mean	Standard Deviation	Coefficient of Variation
A	5.47	0.51	9.3%
B	6.80	2.23	32.3%
C	12.82	3.72	29.0%
D	10.62	1.76	16.5%
E	9.52	1.55	16.3%
F	13.66	0.86	6.3%
G	8.85	1.25	14.1%
H	9.76	2.61	26.7%

Table 5 - Shear Strength Results

Shear Box Test

Brick	Shear Strength (N/mm^2)		
	Mean	Standard Deviation	Coefficient of Variation
A	1.67	0.09	5.6%
B	1.92	0.24	12.5%
C	2.07	0.23	11.5%
D	2.70	0.34	12.6%
E	2.03	0.11	5.7%
F	2.66	0.16	6.2%
G	2.43	0.79	32.8%
H	2.11	0.27	13.1%

Table 6 - Shear Strength Results

1:1/4:3 mortar brickwork piers - "First Visible Crack"

Brick	Shear Strength (N/mm^2)		
	Mean	Standard Deviation	Coefficient of Variation
A	1.67	0.19	11.5%
B	1.86	0.28	15.0%
C	2.16	0.15	7.0%
D	1.88	0.45	24.1%
E	2.37	0.29	12.3%
F	2.66	0.44	16.8%
G	2.21	0.39	17.8%
H	1.95	0.22	11.4%

Table 7 - Shear Strength Results

1:½:4½ mortar brickwork piers - "First Visible Crack"

Brick	Shear Strength (N/mm^2)		
	Mean	Standard Deviation	Coefficient of Variation
A	1.67	0.09	5.6%
B	2.22	0.29	13.2%
C	2.09	0.21	10.2%
D	2.71	0.34	12.6%
E	2.84	0.22	8.0%
F	2.68	0.19	7.2%
G	2.92	0.35	12.1%
H	2.44	0.44	18.2%

Table 8 - Shear Strength Results

1:1/4:3 mortar brickwork piers - "Failure"

Brick	Shear Strength (N/mm^2)		
	Mean	Standard Deviation	Coefficient of Variation
A	1.67	0.19	11.5%
B	2.25	0.22	9.6%
C	2.24	0.18	8.3%
D	2.24	0.25	11.3%
E	2.77	0.13	4.7%
F	2.86	0.35	12.3%
G	2.74	0.13	4.6%
H	2.33	0.37	15.8%

Table 9 - Shear Strength Results

1:½:4½ mortar brickwork piers - "Failure"

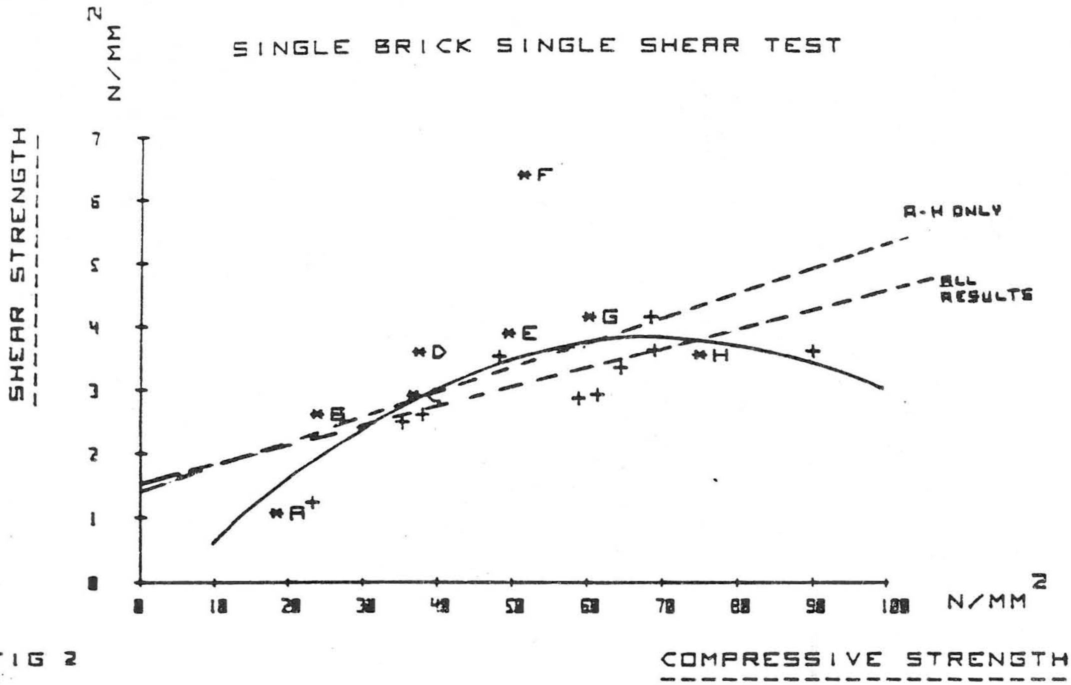

SINGLE BRICK SINGLE SHEAR TEST
SHEAR STRENGTH
N/MM2
A-H ONLY
ALL RESULTS
COMPRESSIVE STRENGTH
N/MM2

FIG 2

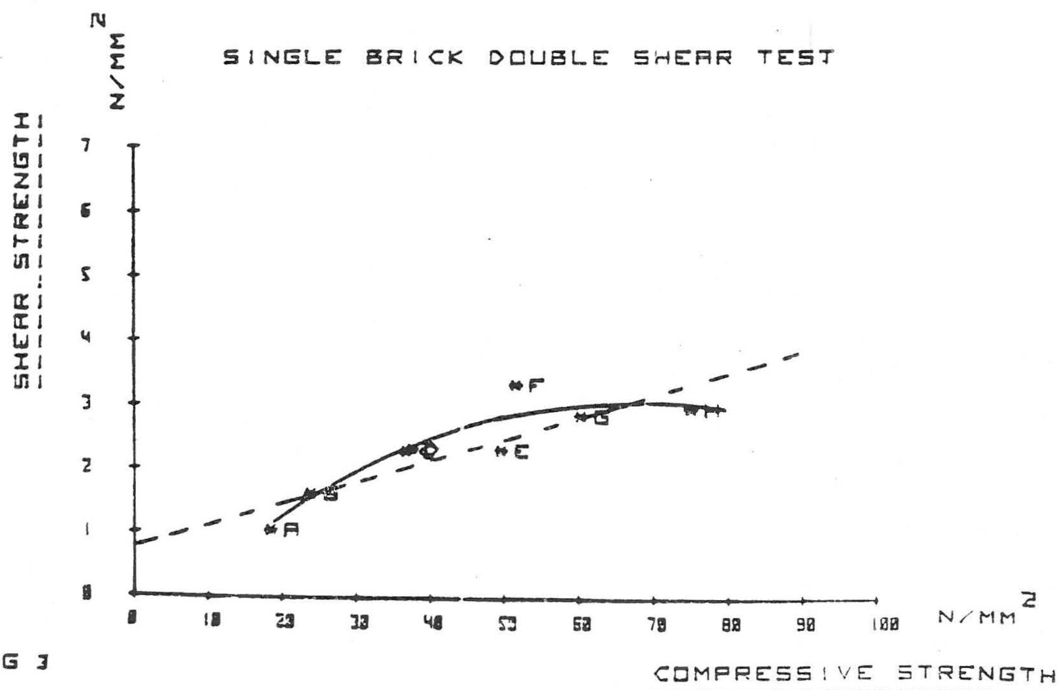

SINGLE BRICK DOUBLE SHEAR TEST
SHEAR STRENGTH
N/MM2
COMPRESSIVE STRENGTH
N/MM2

FIG 3

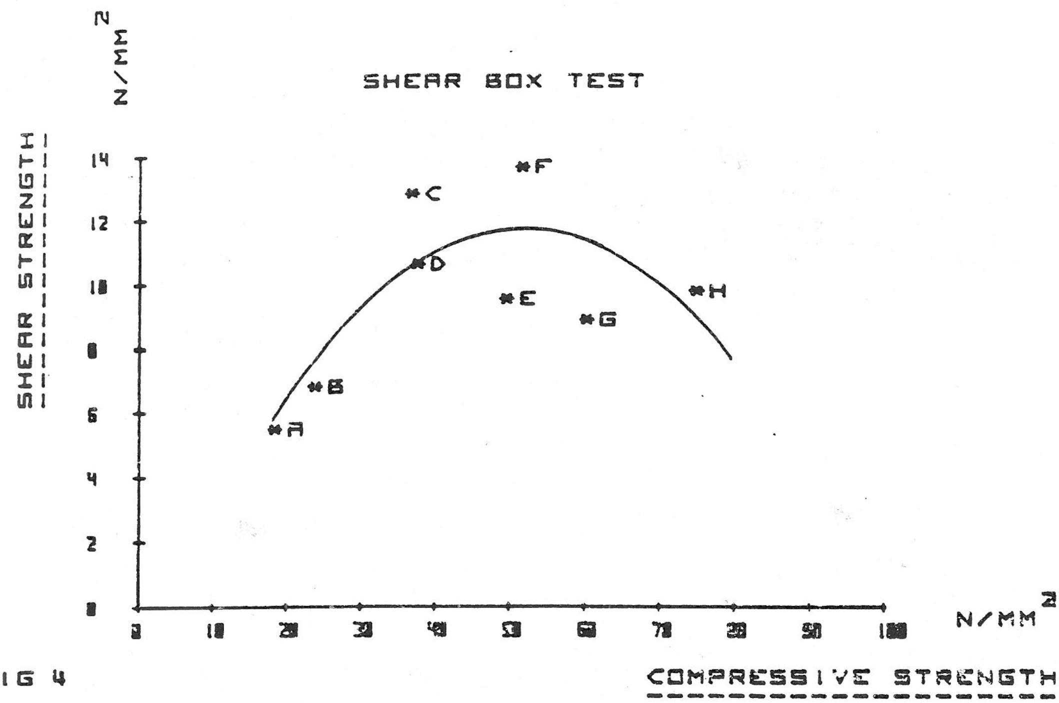

SHEAR BOX TEST
SHEAR STRENGTH
N/MM2
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
N/MM2
COMPRESSIVE STRENGTH
A
B
C
D
E
F
G
H

FIG 4

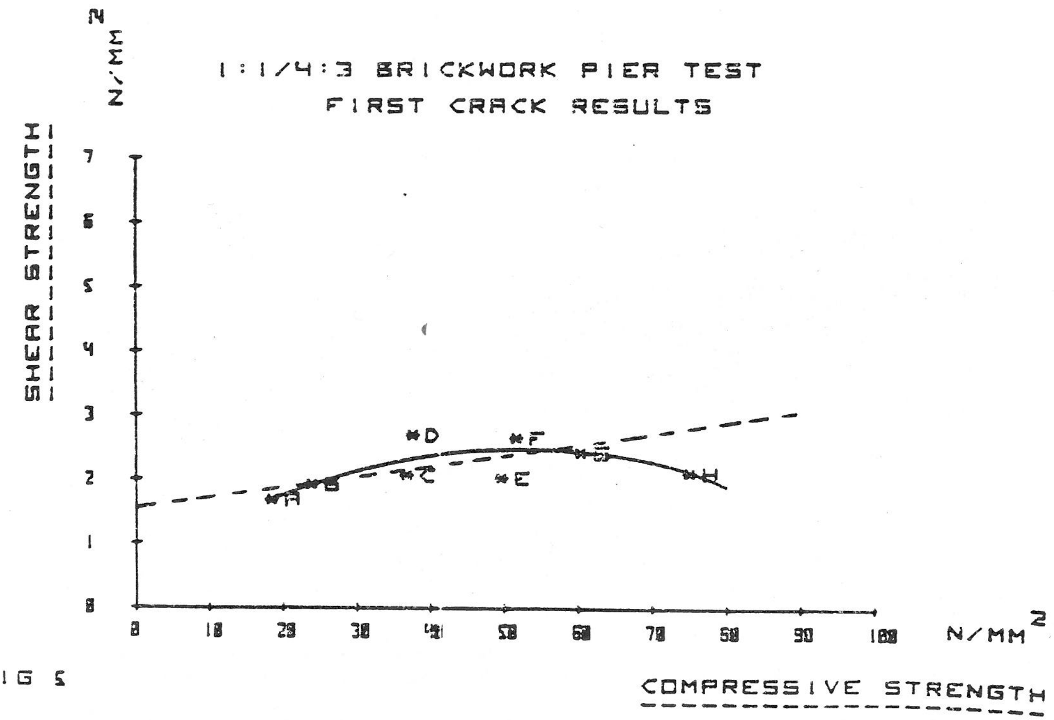
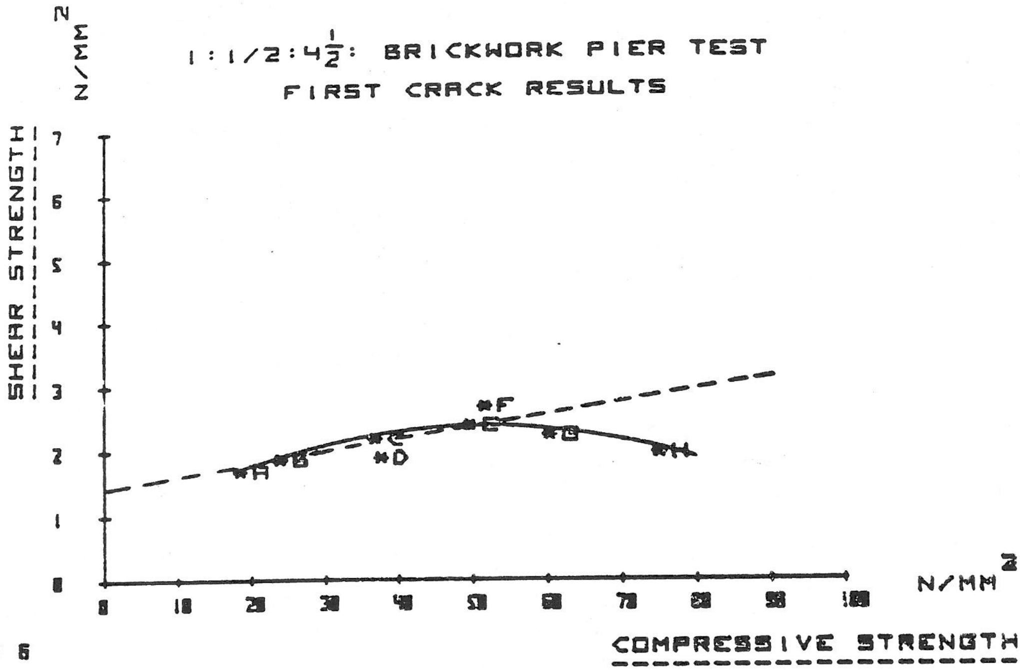
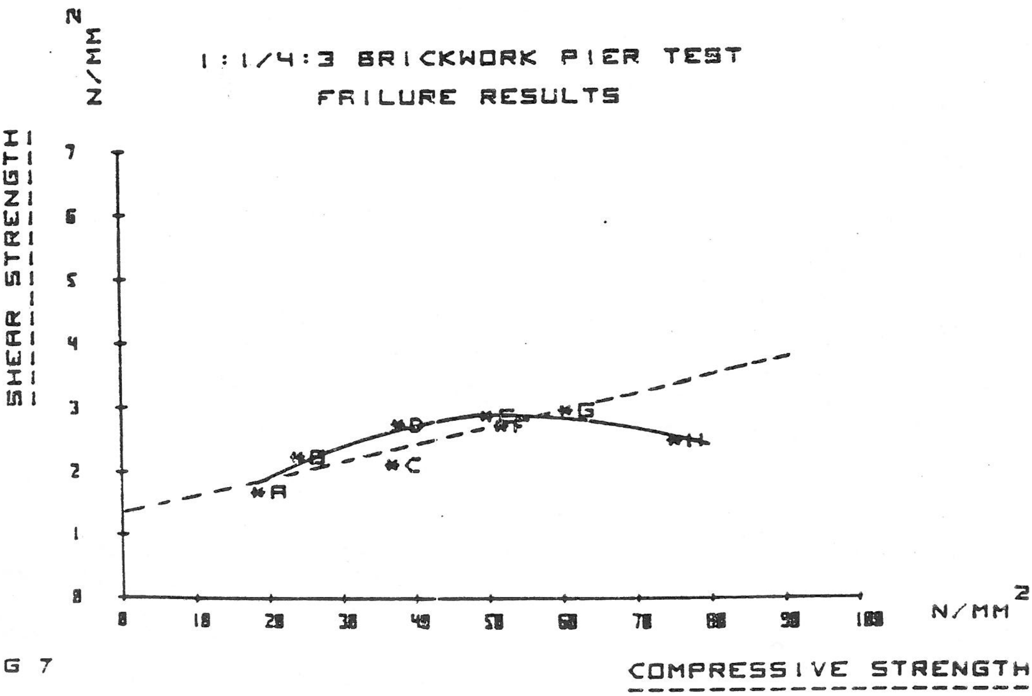

1:1/4:3 BRICKWORK PIER TEST
FIRST CRACK RESULTS
SHEAR STRENGTH
N/MM2
7
6
5
4
3
2
1
0
0
10
20
30
40
50
60
70
80
90
100
N/MM2
COMPRESSIVE STRENGTH
A
B
C
D
E
F
G
H

FIG 5



N/MM²
1:1/2:4½: BRICKWORK PIER TEST
FIRST CRACK RESULTS
SHEAR STRENGTH
7
6
5
4
3
2
1
0
*A
*B
*C
*D
*E
*F
*G
*H
0
10
20
30
40
50
60
70
80
90
100
N/MM²
COMPRESSIVE STRENGTH

FIG 6



N/MM²
1:1/4:3 BRICKWORK PIER TEST
FAILURE RESULTS
SHEAR STRENGTH
7
6
5
4
3
2
1
0
*A
*B
*C
*D
*E
*F
*G
*H
0
10
20
30
40
50
60
70
80
90
100
N/MM²
COMPRESSIVE STRENGTH

FIG 7

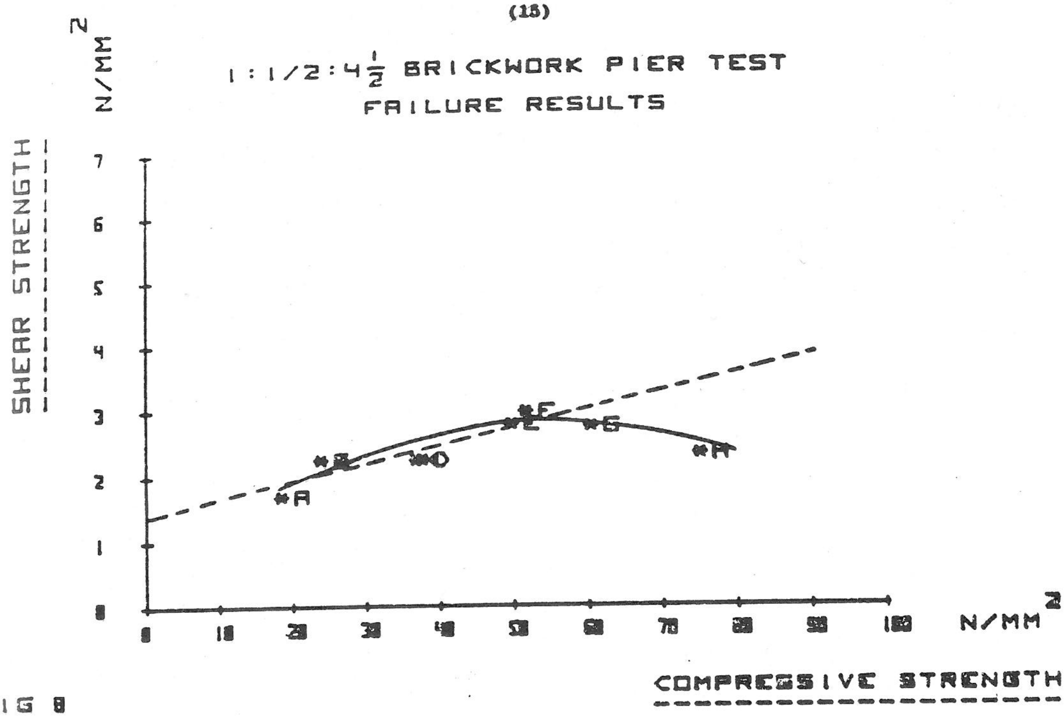

1:1/2:4½ BRICKWORK PIER TEST
FAILURE RESULTS
SHEAR STRENGTH N/MM²
COMPRESSIVE STRENGTH N/MM²

FIG 8

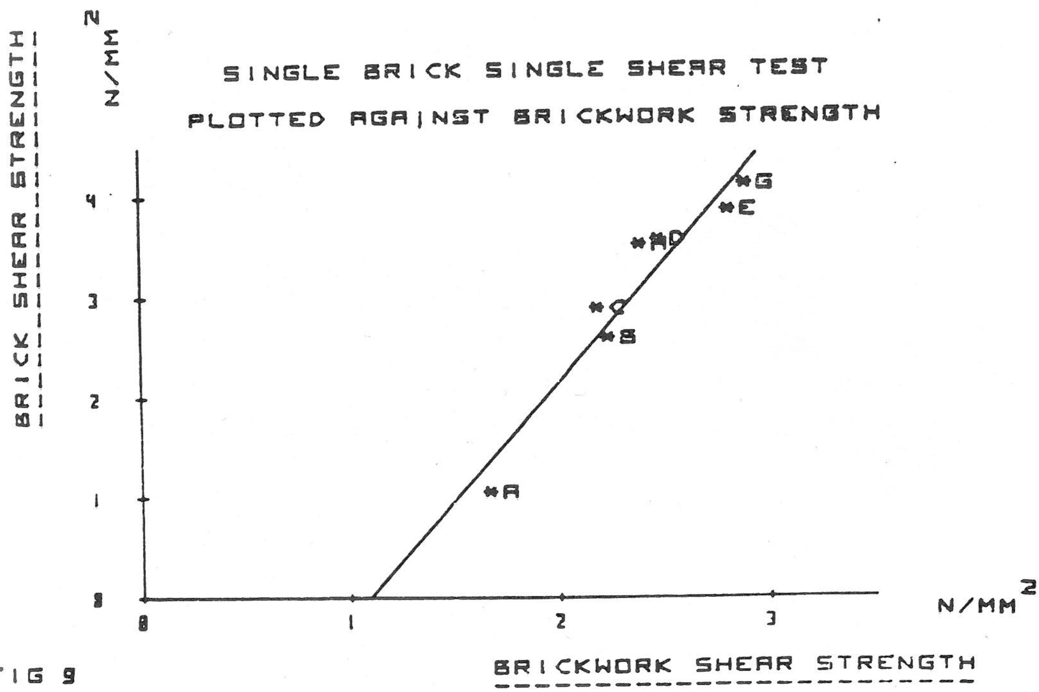

SINGLE BRICK SINGLE SHEAR TEST
PLOTTED AGAINST BRICKWORK STRENGTH
BRICK SHEAR STRENGTH N/MM²
BRICKWORK SHEAR STRENGTH N/MM²

FIG 9

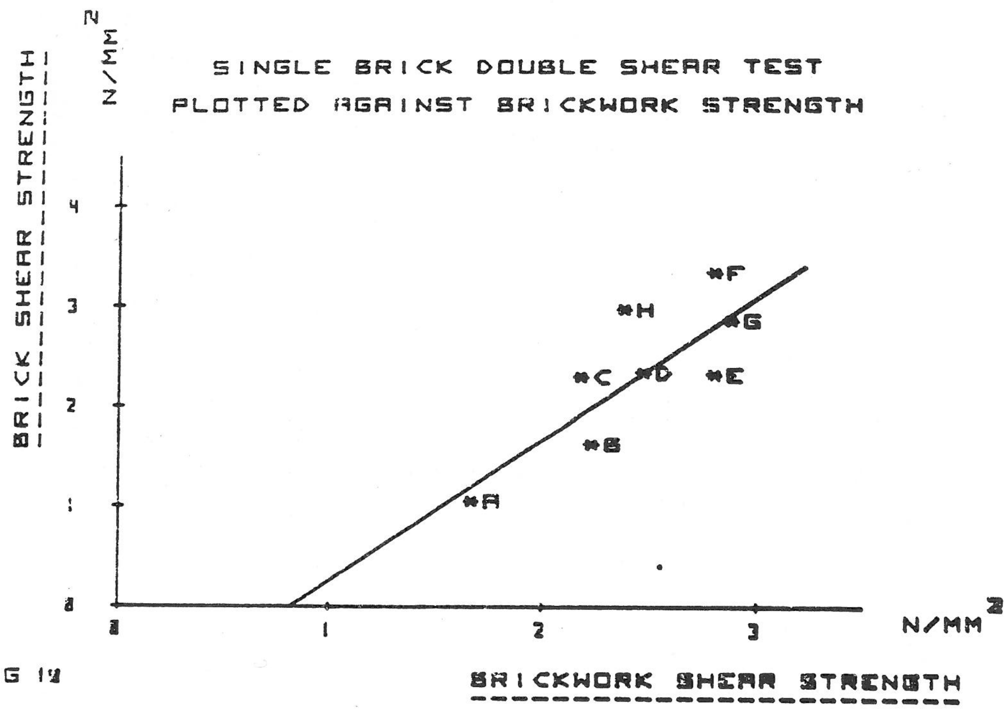


FIG 12

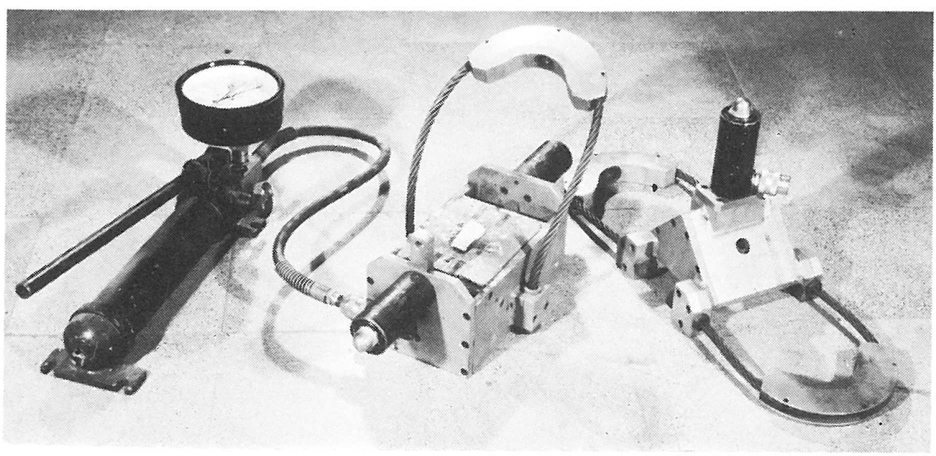


Fig. 11 Robertson Shear Box apparatus

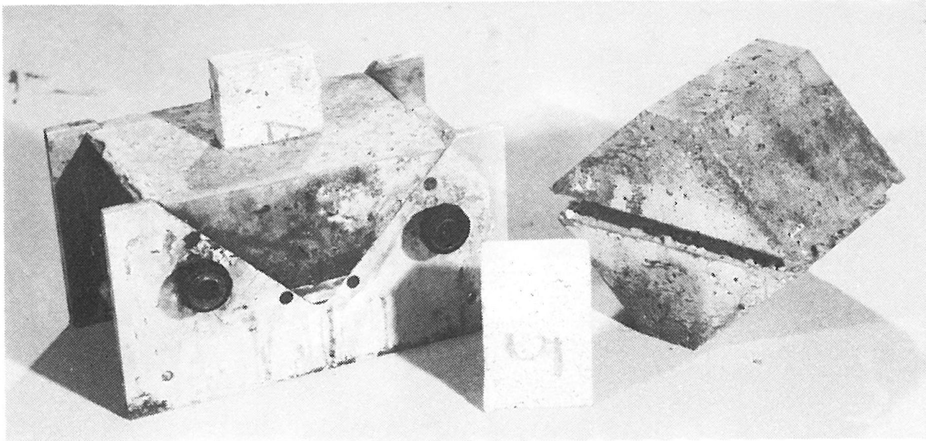


Fig. 12   Brick samples cast in concrete prisms

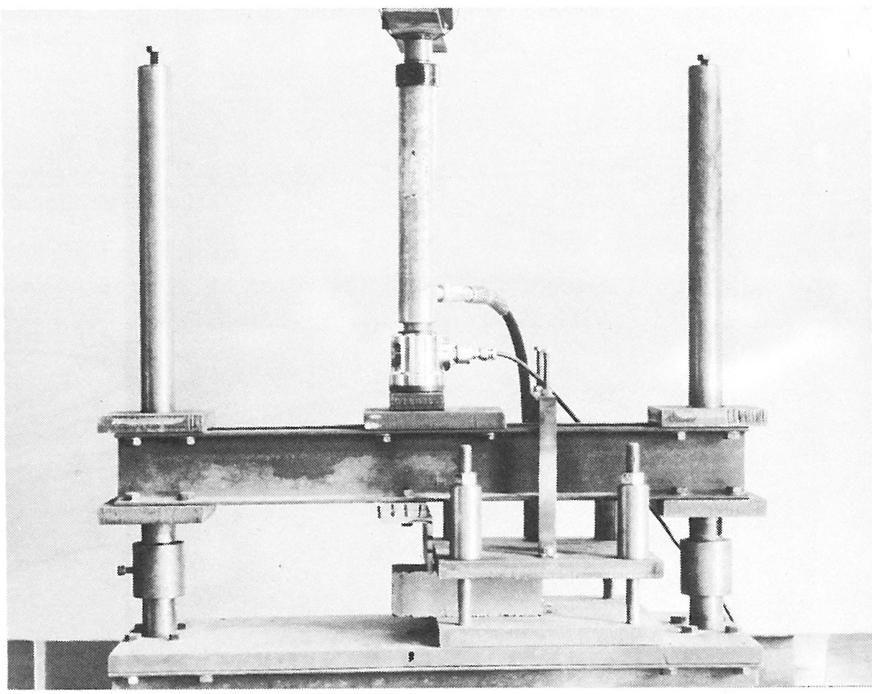


Fig. 13   Shear Test Rig

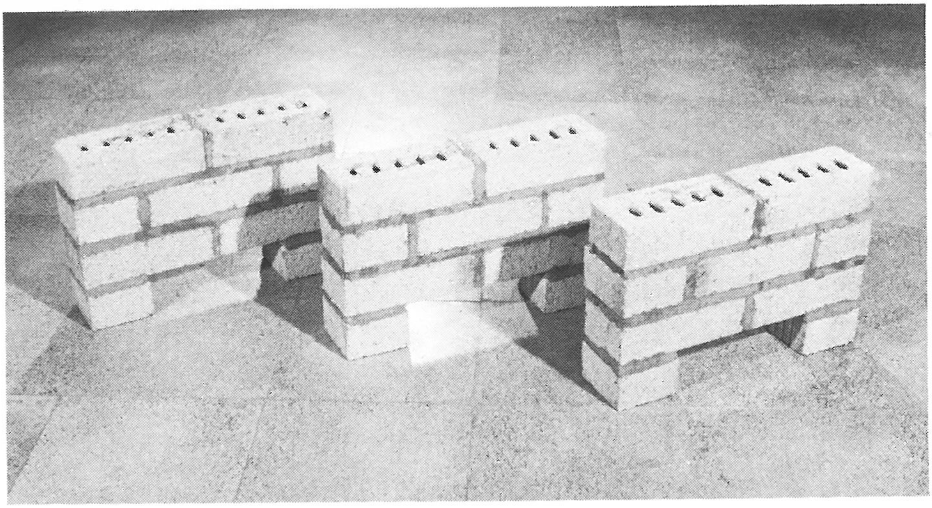


Fig. 14 Brickwork piers

Fig.. 15 Brick pier in test machine