The Stress Strain Relationships of Brickwork when stressed in Directions other than Normal to the Bed Face

by

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Abstract

The stress-strain relationship of brickwork compressively stressed in the direction normal to the bed face of the bricks has previously been determined. In reinforced brickwork, bricks are frequently subjected to compressive stresses applied in directions other than normal to the bed face, and this paper describes the determination of the secant and tangent moduli of elasticity for brickwork of various bonds and built of several brick and mortar combinations.

1. INTRODUCTION

Information on the stress-strain relationship of brickwork was required for the preparation of the B.C.R.A. Design Guide for Reinforced Brickwork[1]. Results of tests on eight course high prisms built of four different types of clay bricks were reported to the Fourth International Brick Masonry Conference[2]. This work showed that the stress-strain curve approximated to a parabola and had a 'falling branch' beyond the maximum stress. Later work on prisms built of calcium silicate bricks yielded similar results.

In this work the brickwork was compressively loaded in the usual manner, i.e. the applied stress normal to the bed face of the bricks. Reinforced brickwork, however, may be used in such a way that the compressive stress is applied in directions other than normal to the bed face; it may be normal to the stretcher face or to the header (as in a stretcher bonded beam or lintol) or in some bonds to a mixture of two faces of the bricks.

Just as the compressive strength of bricks may be different in the three orthogonal directions so will the compressive strength of brickwork[3]. The magnitude of the ratios of strength in the three directions will depend considerably on the type of brick. Brickwork built of truly solid bricks will have strengths in the three orthogonal directions very roughly equivalent whereas for example brickwork built of highly perforated bricks will be two to three times stronger in the normal to bed joint direction than in the other two orthogonal directions.

The work reported here forms the first stage of an extensive series of tests on various types of bricks and compares the performance of brickwork built of a highly perforated brick with that built of a frogged brick with the frogs fully filled with mortar.

2. EXPERIMENTAL

The earlier work[2] was carried out using eight course high 215mm square piers tested with an elaborate set-up in the B.C.R.A. wall testing machine in an attempt to control the rate of strain. The present work has utilised electronically-controlled servo-hydraulic loading equipment which greatly facilitated the work. A specimen is seen in the crushing apparatus in Figure 1.

Four formats of specimen were tested; these are illustrated in the Figure 2. Two types of clay brick were investigated. They were:-

(a) a sixteen hole perforated wire cut brick having a water absorption of 5.5%.

(b) a deep-frogged semi-dry pressed brick having a water absorption of 21.7%.

The crushing strengths of the two bricks when compressed in three orthogonal directions are given in Table 1.

All the specimens were built in 1:¼:3 Portland Cement:Lime:Sand mortar on a reinforced concrete plinth and capped by a similar concrete block. All the specimens were cured for at least 28 days before testing. The type B bricks had their suction rate adjusted to approximately 1 $kg/m^2/min$ before laying, by wetting.

Four linear variable differential transformer (LVDT) type transducers were mounted one on each face of the specimen. Their outputs were recorded by a data logger with punched tape output from which computer plots of stress-strain could be derived. The output from a fifth LVDT transducer mounted on one face was connected to the control circuit of the loading equipment to control the rate of strain. A continuous plot of stress and strain was displayed on an X-Y plotter on the control equipment to monitor the progress of the test.

3. RESULTS AND DISCUSSION

All the tests were carried out at a rate of strain of 100 microstrain/min. This was a purely arbitrarily chosen rate to yield a test of convenient duration but which also represented a rate of stress increase of the same order as that used for the compression testing of storey-height walls.

Four replicates of each specimen type were tested; the stress-strain curves presented in Figures 3 & 4 are representative examples of the results obtained. The crushing strengths of the prisms are given in Table 2 together with modulus of elasticity values. The modulus of elasticity values have been determined using two methods; the first method, which assumes that the stress strain curve is parabolic up to the point of maximum stress, gives the tangent modulus at the origin based on twice the maximum stress. The second method gives the secant modulus based on two thirds of the maximum stress.

Table 3 contains ratios of the compressive strength of the prisms with those of the bricks in the three orthogonal directions whilst Table 4 contains the ratios of the compressive strengths of the more conventional prism formats with those of prisms tested by compression of bed faces. These results follow the same pattern but differ in detail from the earlier results which were obtained from approximately cubic specimens. That is with Brick A the weakening effect of the perforations when stressed across their diameters is still apparent, whereas the ratios for the solid Brick B are substantially similar.

When testing the prisms built using the frogged bricks the stress/strain relationships were approximately parabolic and had a typical falling branch after the maximum stress had been applied as the specimen yielded before the test ended. However this falling branch was less evident when the prisms built using the perforated bricks were tested, the reason being the perforations within the bricks tended to collapse as the maximum stress was attained, (and the fired clay of this brick was much more brittle than that) of the solid brick.

Table 5 compares the mean values of modulus of elasticity (tangent) for the three other prism formats with those for the values in the stress normal to bed face direction. As was the case of the corresponding ultimate strength ratios, all the values were far below unity. For Brick A they were all approximately two-fifths, while for Brick B they were all approximately three quarter's.

CONCLUSIONS

1. Brickwork of all four bonds, built in a multi-perforated brick and a deep-frogged solid brick exhibited a parabolic stress-strain relationship.

2. The brickwork built of deep-frogged bricks exhibited a falling branch after the ultimate stress value, but this was much less evident in the case of the perforated brick because of the collapse of the perforations at the peak of the curve, and the brittleness of the fired clay.

3. For both bricks, both the values of ultimate stress and Modulus of Elasticity were lower in the other bonds than in the stress normal to bed joint direction. This reduction was less marked with the deep-frogged solid brick than for the perforated brick.

4. Further work is required to establish the broad pattern of relationships for a wide variety of brick types, and this is in progress.

REFERENCES

1. Design Guide for Reinforced and Prestressed Brickwork BCRA Special Publication No. 91

2. Powell B and Hodgkinson H R, Determination of Stress-Strain Relationship of Brickwork. Proc. 4th International Brick Masonry Conference, Bruges.

3. Hodgkinson H R and Powell B, The Compressive Strength of Brickwork Tested in Orthogonal Directions. Private Communication to BDA.

ACKNOWLEDGEMENTS

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TABLE 1

Crushing Strength of Bricks when Compressed in Three Orthogonal Directions

Brick	Mean Crushing Strength N/mm^2			Ratio to Strength Between Bed Faces	
	Between Bed Faces	Between Headers	Between Stretchers	Between Headers	Between Stretchers
A	64.7	8.6	20.2	0.13	0.31
B	25.4	9.1	10.5	0.36	0.41

TABLE 2

Crushing Strength and Modulus of Elasticity Results of Brickwork Prisms Loaded in Different Directions

Prism Format	Crushing Strength * N/mm^2		Modulus of Elasticity N/mm^2			
			Tangent Modulus		Secant Modulus	
	Brick A	Brick B	Brick A	Brick B	Brick A	Brick B
A	25.95	9.69	18216	5197	10570	3838
B	5.23	5.28	7243	3843	4047	2697
C	7.50	5.26	6080	4176	3432	3320
D	9.74	6.00	7120	3961	5034	3763

* Mean of Four

TABLE 3

Ratio of Prism Strength/Brick Strength

Prism Format	Ratio of Compressive Strength of Prism to Crushing Strength of Brick in Corresponding Direction of Stress	
	Brick A	Brick B
A	0.40	0.38
B	0.26	0.50
C	0.87	0.58

TABLE 4

Ratio of Brickwork Strength when Load Applied to Bed Faces

Prism Format	Brick A	Brick B
B	0.20	0.54
C	0.29	0.54
D	0.38	0.62

TABLE 5

Ratio of Modulus of Elasticity (tangent) of Brickwork to Modulus for Specimen Stressed Normal to Bed Face

Prism Format	Brick A	Brick B
B	0.40	0.74
C	0.33	0.80
D	0.39	0.76

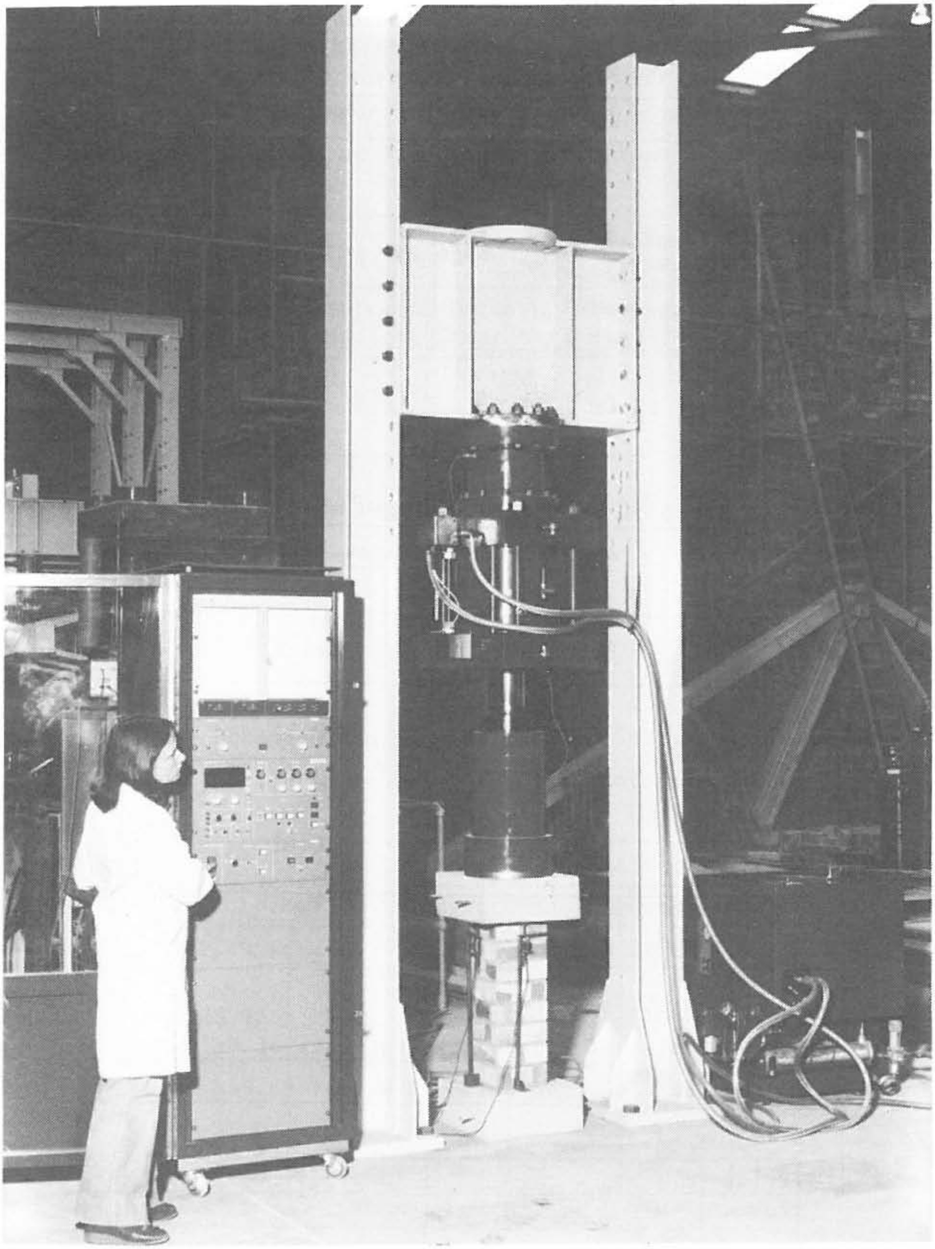

FIGURE 1: Crushing Apparatus

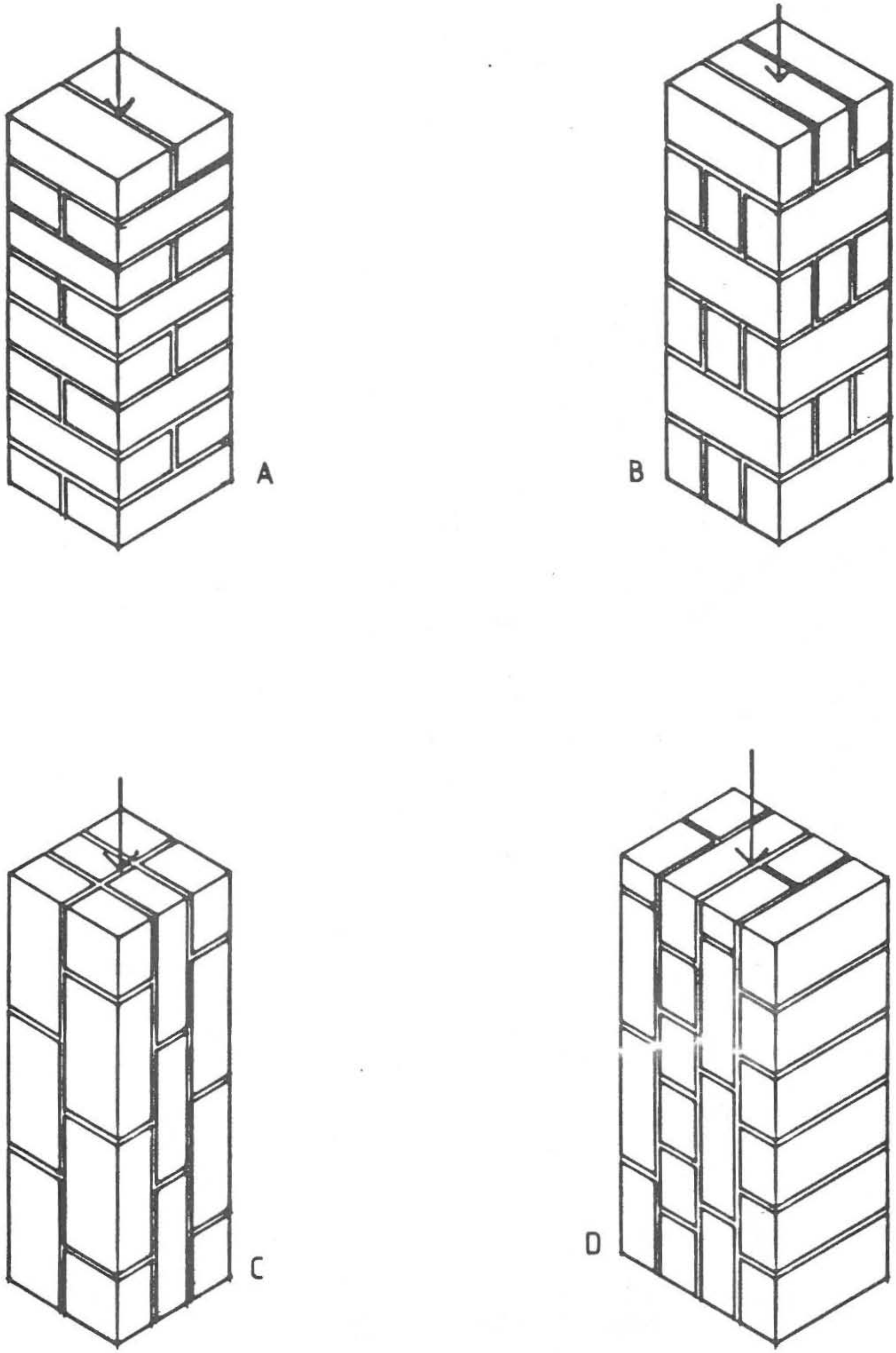

FIGURE 2: Format of Test Specimens

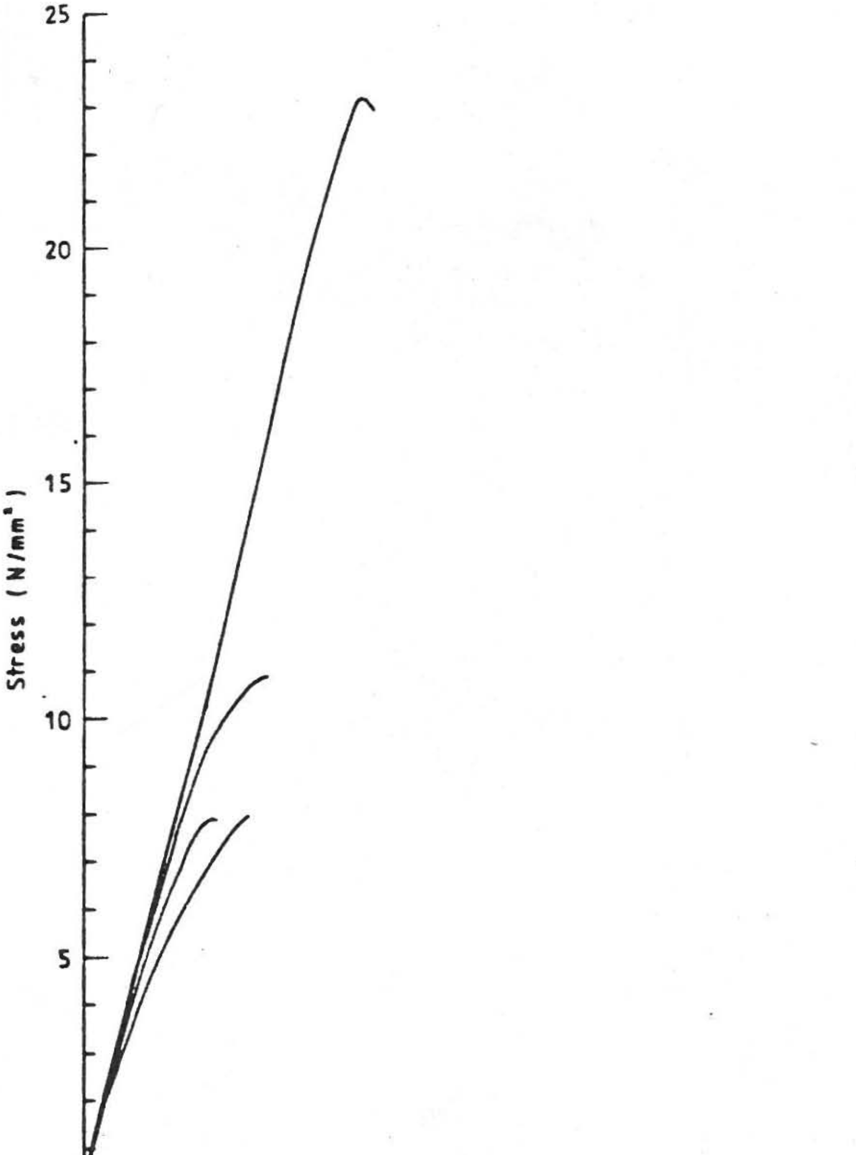

FIGURE 3: Stress/Strain Curves Brick A

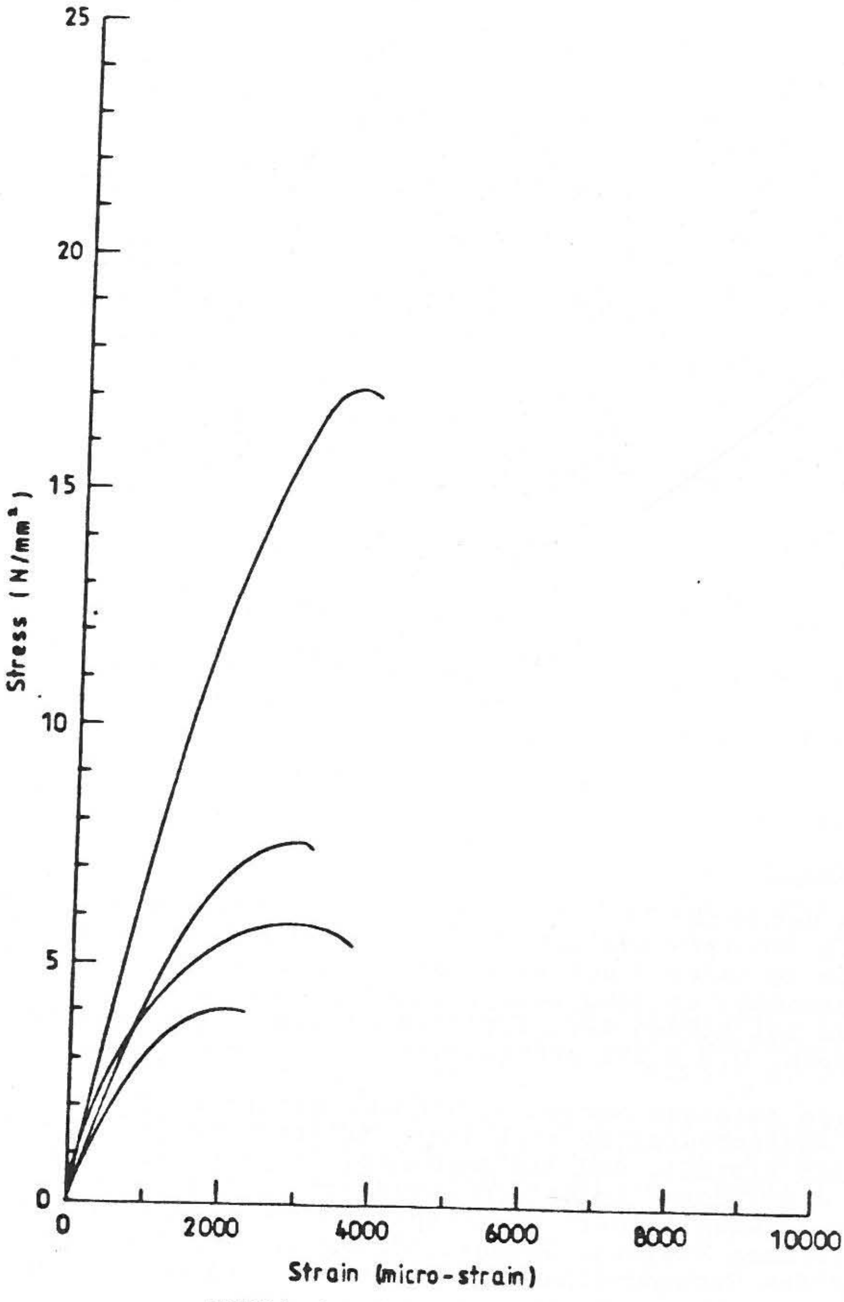

FIGURE 4: Stress/Strain Curves Brick B