The Stress/Strain Relationship of Brickwork

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Abstract

Normally the stress/strain relationship of brickwork is determined by testing specimens under compressive loads perpendicular to the bed joint. In flexural members, however the compressive force is usually parallel to the bedjoint. Tests were carried out on brickwork specimens to determine the stress/strain relationship and compressive strength parallel to bedjoint. Four different strengths of brick an two types of prism, built to represent the top course and top three courses of the compression zone of reinforced or prestressed brickwork flexural members were used. The stress/strain relationship for the four different strengths of brick are illustrated and it is shown that the compressive strength of brickwork can vary considerably depending on the type of prism tested.

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1.1 Introduction

It has been recognised for a long time that brickwork is an anisotropic material with different elastic and strength properties in different directions.

In the past (1,2,3) most attention has been given to measuring the properties of brickwork in the direction normal to the bedjoint, mainly to gain insight into the behaviour of load bearing wall systems.

However, with the ongoing development of reinforced and prestressed brickwork as flexural members it becomes increasingly important to consider the stress/strain and strength properties of brickwork loaded in the direction parallel to the bedjoint, as would occur in the compression zone of a reinforced brickwork beam.

During tests on prestressed brickwork beams (4) carried out by the authors it was observed that splitting along the uppermost bed joints occurs in the compression zone prior to failure. This implies that at high levels of load the compressive forces are carried by the brickwork acting as individual courses rather than a monolithic homogenous brickwork section. It was decided, therefor to consider two types of prism in the test programme, one to represent the upper three and the other to represent the top course of the compression zone of a reinforced brickwork beam.

The results of the tests on prisms under axial compression are presented and the stress/strain relationships for four different strengths of brick using the two types of prism are also given. It is shown that the compressive strength of brickwork is influenced by the type of prism used.

A stress/strain relationship is proposed and it is also shown that this represents well the stress/strain relationship for the four strengths of brick.

2.0 Materials and test specimens

2.1 Bricks

Four different strengths of brick were considered. The first three types were three hole bricks of high (82.03 N/mm^2), medium (67.58 N/mm^2) and low (34.18 N/mm^2) strengths. The fourth type was a single frogged brick (22.72 N/mm^2). Compressive tests were carried out on random samples of 10 bricks in each of the three possible directions and the results are given in table 1. All bricks were tested between 6mm thick plywood sheets and in the case of the frogged bricks the frogs were filled with a mortar mix to give a flat surface for testing. The average 24 hours absorption for each type of brick is also given in table 1.

2.2 Mortar

A $1:\frac{1}{4}:3$ (cement:lime:sand) mix by volume was used throughout. Control cubes were taken and the average compressive strength was 19.1 N/mm^2.

2.3 Test specimens

The two types of prisms used are illustrated in fig. 1. The three course (type A) prism Fig. 1(a) has a ratio of height to least lateral dimension (h/t) of 2.1 and the single course prism (Type B) has a h/t ratio of 5.0. All specimens were built on wooden battens on the floor of the laboratory by an experienced bricklayer. Each prism was then allowed to cure under polythene

for 28 days before testing.

3.0 Experimental procedure

Each prism was capped and levelled using a mix similar to the mortar used in their construction. The prisms were placed in a hydraulic testing machine with a capacity of 2500 kN. Six mm thick plywood sheets were placed between the prisms and the platens of the testing machine to help distribute the load and reduce and platen friction effects.

The strain was measured at six points on the three course prisms and four points on the single course prism using a 'demec gauge' (fig. 1) over a length of 150mm across the central horizontal axis of each prism. The prisms were then tested in axial compression. The load was applied in equal increments the magnitude of which depended on the type of brick and prism being tested. At each increment the load was held constant to enable strain readings to be taken. At between 60 and 70% of the expected failure load of the prisms the load increment was halved. Strain measurements were then taken up to approximately 95% of the ultimate load.

3.1 Experimental Results and Discussion

The experimental stress/strain relationships are presented graphically for both types of prism, in fig. 2 for low strength bricks, fig. 3 frogged brick, fig. 4 medium strength and fig. 5 high strength. The compressive strengths of the prisms are given in table 2. The compressive strengths of the brick on end and on edge (table 1) are considerably lower than the compressive strength in the bedjoint direction.

For all types of brick and prism the stress/strain relationship is initially linear after which the strain increases more rapidly than the stress. During the tests on the three course prisms it was observed that vertical splitting of the bedjoints occurred at approximately 60% of the ultimate load in the case of the high strength brick, 80% for the medium strength, 90% for the low strength and 59% for the frogged brick. Up to the point of splitting the strain readings for each prism has been very uniform indicating that axial strain was occurring, after splitting had occurred there was a redistribution of load indicated by the strain measurements and it appeared that each course was acting individually and carrying a different proportion of the applied load. The strain measurements at particular points on the prisms showed considerable variation with some indicating strains of similar magnitude to those obtained in the single course prisms, as failure approached. Failure usually occurred by crushing of one or two of the courses, simultaneous crushing of all three courses was not observed. Strain readings taken on the single courses indicated axial compression up to higher levels of load. Failure of the single course prisms was initiated by vertical splitting through the brick followed by crushing.

Comparison of the results obtained from both types of prism for the high and medium strength bricks show that although the stress/strain relationships have the same general characteristics the compressive strengths are 40 and 50% higher for the single course prism for the high and medium strengths respectively. The ultimate strains are approximately 40% higher for the single course prisms.

The three course frogged brick prisms showed a slightly greater compressive strength than the single course prisms and the ultimate strains were very similar. The compressive strengths for both types of prism built of the low strength brick are almost identical and only slightly less than the compressive strength of the brick tested on edge (table 1), although much higher strains were experienced in the single course prisms.

It appears therefore, that when splitting occurs in the three course prisms built of the high and medium strength bricks the redistribution of load causes premature failure of one or two of the courses and that if splitting could be prevented the average compressive strength would be considerably higher.

4.0 Analysis of Results

To obtain a more general picture of the behaviour of the brickwork the stress/strain results were plotted in non dimensional form for each of the two types of prism (Figs. 6 and 7). A least square approximation using polynomials of degree 2, 3, 4 and 8 were used to obtain relationships to fit the experimental results.

A comparison of the results of the regression analysis are presented in table 3. The area under the curve and the centroid are not greatly influenced by the degree of the polynomial chosen for both types of prism. The standard deviation for both types of prism is less for the three degree polynomial and it would appear that the three degree or cubic equation is best suited, and they are shown in figs. 6 and 7.

The two equations obtained are, for three course prisms

$$\sigma/\sigma_m = -0.00407 + 2.1043\,(\epsilon/\epsilon_m) - 2.0252\,(\epsilon/\epsilon_m)^2 + 0.9234\,(\epsilon/\epsilon_m)^3$$

for the single course prisms,

$$\sigma/\sigma_m = -0.005756 + 2.3961\,(\epsilon/\epsilon_m) - 2.2567\,(\epsilon/\epsilon_m)^2 + 0.8664\,(\epsilon/\epsilon_m)^3$$

4.1 Conclusions

1. The use of three course prisms to obtain the compressive strength of brickwork parallel to the bedjoint may result in a reduced estimate of the compressive strength when using high or medium strength bricks.

2. The compressive strength of the low strength and frogged brick is not great: influenced, by using one or three course prisms as the compressive strength of the brickwork is very close to the compressive strength of the brick.

3. The stress/strain relationship of brickwork parallel to the bedjoint may be well represented by a 3 degree polynomial based on results obtained from tests on single course prisms.

Acknowledgements

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Notation

σ stress in brickwork

σ_m compressive strength of brickwork

ϵ strain in brickwork

ϵ_m ultimate strain in brickwork

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TABLE 1 COMPRESSIVE STRENGTH & ABSORPTION OF BRICKS

	HIGH	MEDIUM	LOW	FROGGED
COMPRESSIVE STRENGTH IN BED JOINT				
ave N/mm^2	82.03	67.58	34.18	22.72
RANGE "	64.80-96.70	44.16-91.08	30.70-40.88	15.47-28.84
std. deviation N/mm^2	5.85	12.20	2.79	3.36
coef. of variance %	7.13	18.06	8.16	14.81
Compressive strength on edge				
ave N/mm^2	53.17	26.36	11.48	16.95
Range	33.54-68.03	19.32-39.36	7.51-20.21	12.52-20.21
std. deviation	9.43	5.71	3.54	2.237
coef. of variance	17.73	21.66	30.84	13.20
Compressive strength on end				
ave N/mm^2	40.23	23.23	10.67	15.81
Range	30.00-50.76	10.79-33.80	7.54-18.76	12.62-21.54
std. deviation	6.94	5.90	3.24	2.33
coef. of variance	17.25	25.40	30.37	14.71
24 hrs absorption %	4.17	5.71	7.20	23.85
Range	3.21-4.71	4.62-8.07	6.82-7.74	23.41-24.19
std. deviation	0.461	0.90	0.303	0.244
coef. of variance	11.06	15.80	4.21	1.02

TABLE 2 COMPRESSIVE STRENGTH OF PRISMS

BRICK TYPE	HIGH STRENGTH		MEDIUM STRENGTH		LOW STRENGTH		FROGGED BRICK	
	THREE COURSE	SINGLE COURSE	THREE COURSE	SINGLE COURSE	THREE COURSE	SINGLE COURSE	THREE COURSE	SINGLE COURSE
COMPRESSIVE STRENGTH N/mm^2	22.15	33.17	9.82	19.85	10.05	9.53	8.98	5.56
	19.44	29.30	14.4	18.86	9.26	10.73	8.25	5.82
	18.17	47.63	10.2	29.3	9.75	8.94	9.23	8.07
	22.21	29.70	12.17	28.20	8.25	8.59	14.15	7.87
	20.30	25.92	14.4	25.09	9.23	8.23	13.20	5.80
	20.60	29.58	12.94	21.10	9.64	10.20	12.11	8.35
AVERAGE	20.48	32.56	12.36	23.70	9.36	9.37	10.99	6.91
std. dev.	1.43	7.06	1.82	4.05	0.57	0.88	2.26	1.20
coefficient of variance	6.97	21.69	14.70	17.10	6.06	9.40	20.61	17.30

TABLE 3 Comparison of Regression Analysis

Degree of polynomial		2	3	4	5
Std. deviation	three (A)	0.0943	0.0903	0.0920	0.0917
	single (B)	0.0643	0.0589	0.0609	0.0606
Area under curve	three (A)	0.605	0.604	0.604	0.603
	single (B)	0.660	0.656	0.656	0.658
Centroid	three (A)	0.402	0.374	0.374	0.374
	single (B)	0.381	0.374	0.383	0.382

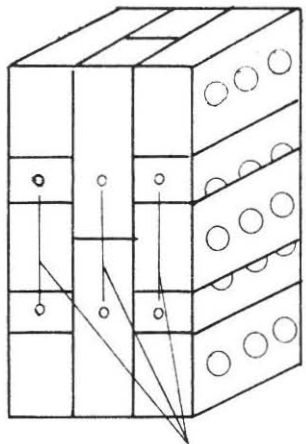


Fig.1(a) type A

strain measuring points

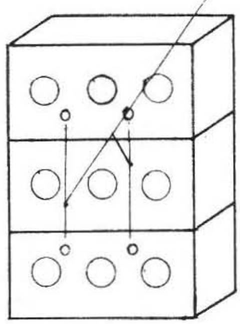
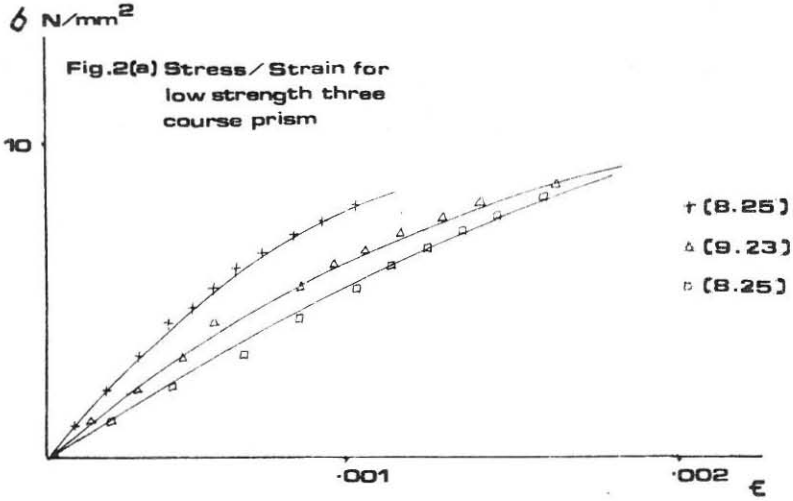
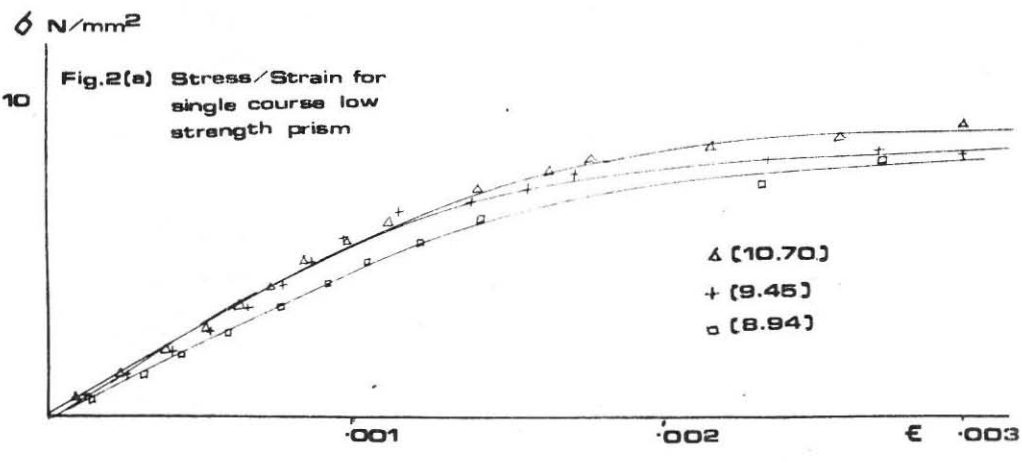


Fig.1(b) type (b)

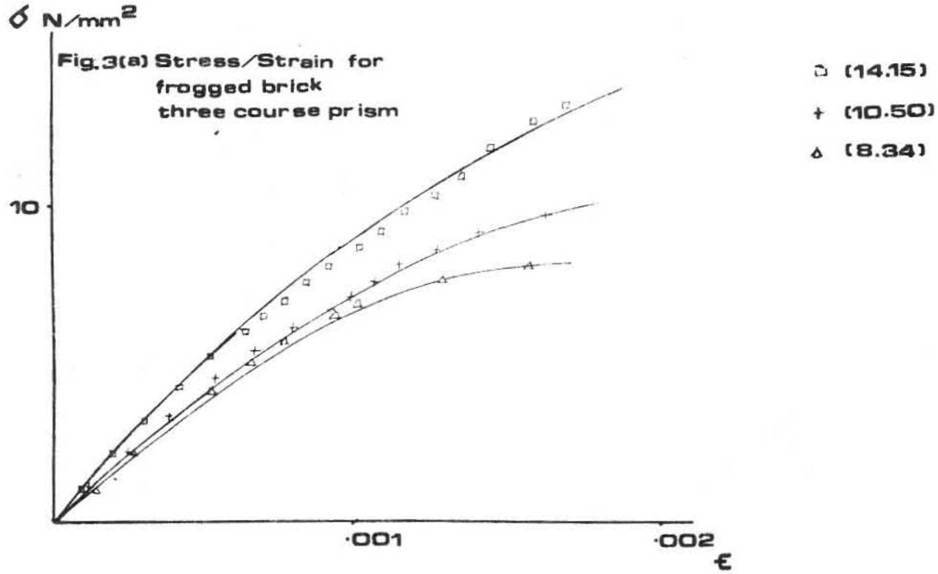
Fig.1 Test Prisms

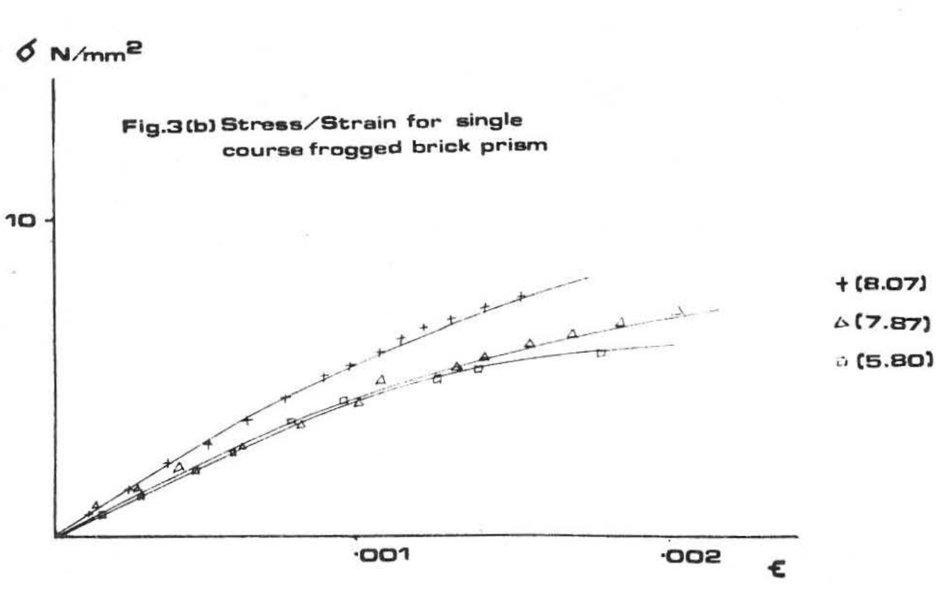


σ N/mm²
Fig.2(a) Stress/Strain for low strength three course prism
10
·001
·002
ε
+ (8.25)
△ (9.23)
□ (8.25)



σ N/mm²
Fig.2(a) Stress/Strain for single course low strength prism
10
·001
·002
ε
·003
△ (10.70)
+ (9.45)
□ (8.94)


σ N/mm²
Fig.3(a) Stress/Strain for
frogged brick
three course prism
□ (14.15)
+ (10.50)
Δ (8.34)
10
·001
·002
ε


σ N/mm²
Fig.3(b) Stress/Strain for single
course frogged brick prism
10
+ (8.07)
Δ (7.87)
□ (5.80)
·001
·002
ε

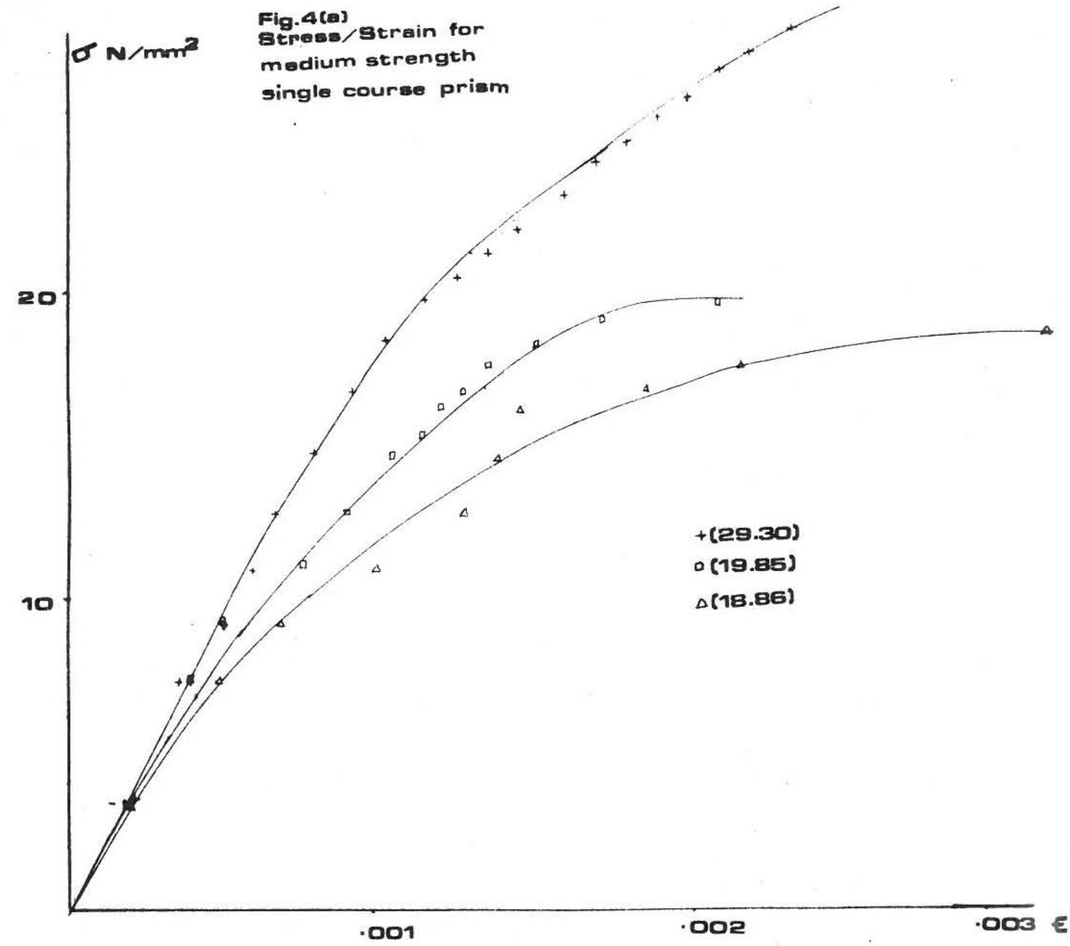
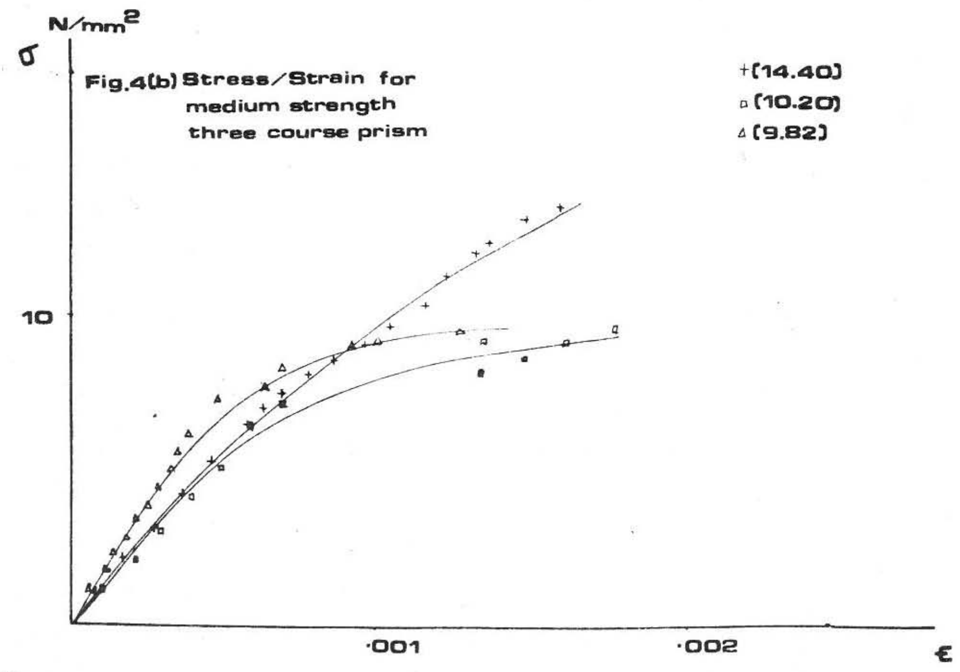
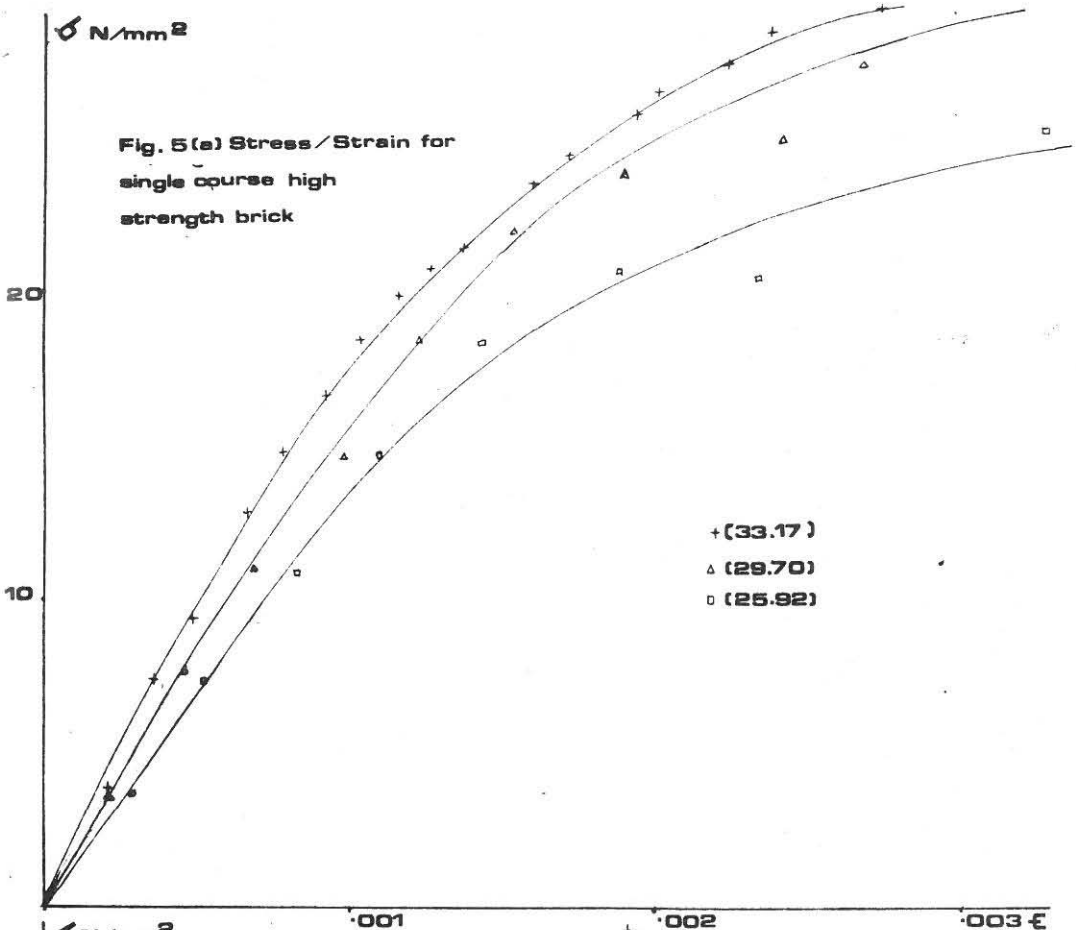
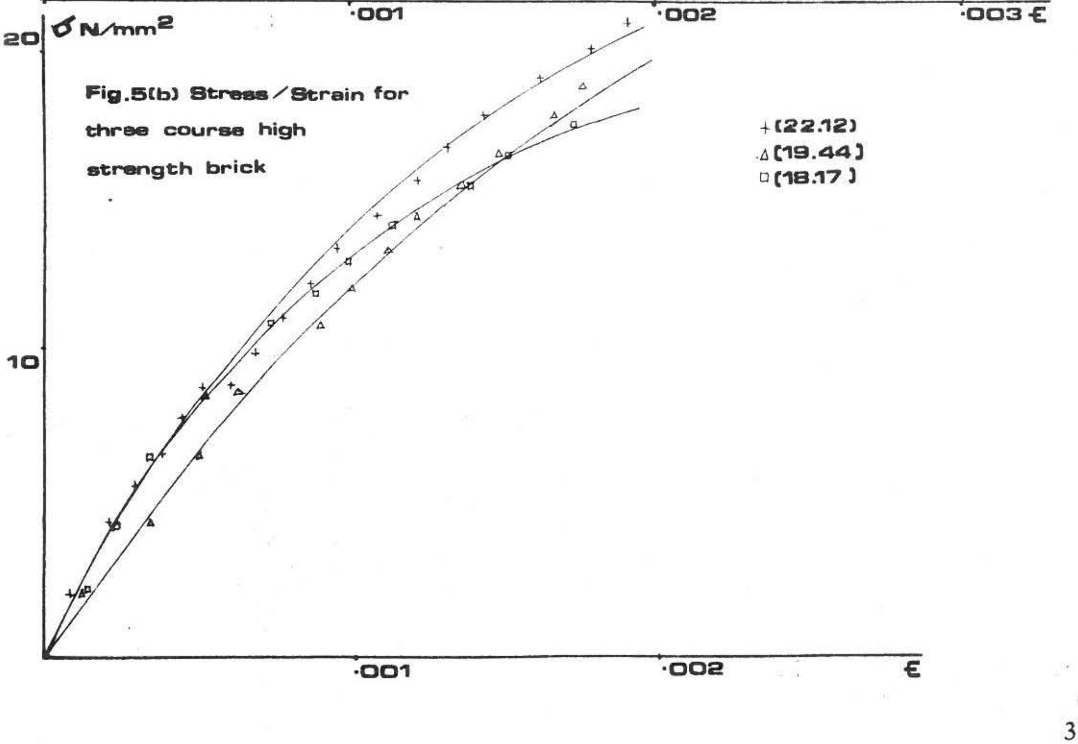


Fig.4(a)
Stress/Strain for
medium strength
single course prism
σ N/mm²
20
10
·001
·002
·003 ε
+(29.30)
□(19.85)
△(18.86)


N/mm²
σ
Fig.4(b) Stress/Strain for
medium strength
three course prism
+(14.40)
□(10.20)
△(9.82)
10
·001
·002
ε


σ N/mm²
Fig. 5(a) Stress/Strain for single course high strength brick
20
10
+(33.17)
Δ (29.70)
□ (25.92)
·001
·002
·003 ε


σ N/mm²
20
Fig.5(b) Stress/Strain for three course high strength brick
+(22.12)
Δ(19.44)
□(18.17)
10
·001
·002
ε

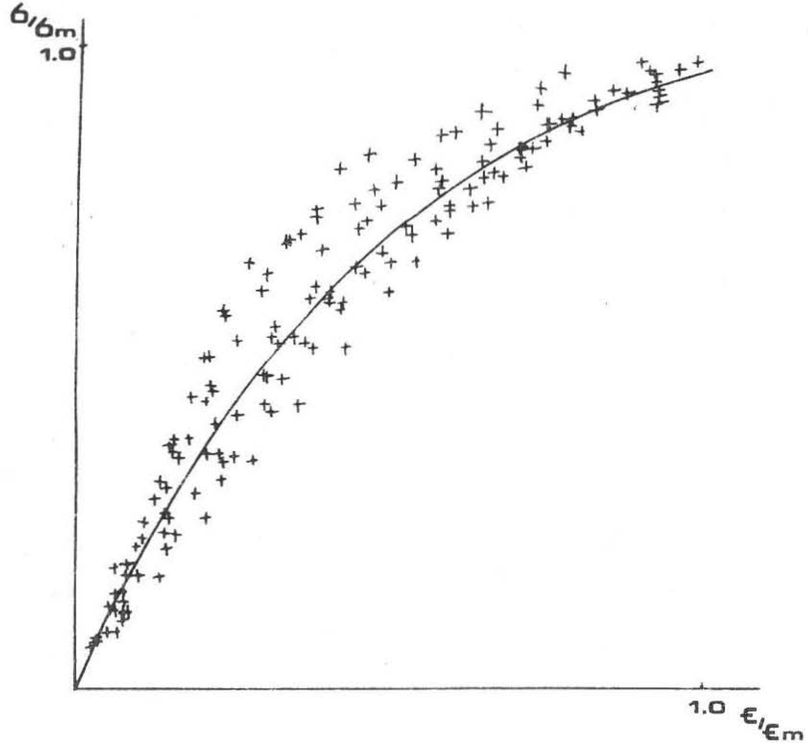


Fig. 6 Non-dimensional stress/ strain relationship based on single course prisms.

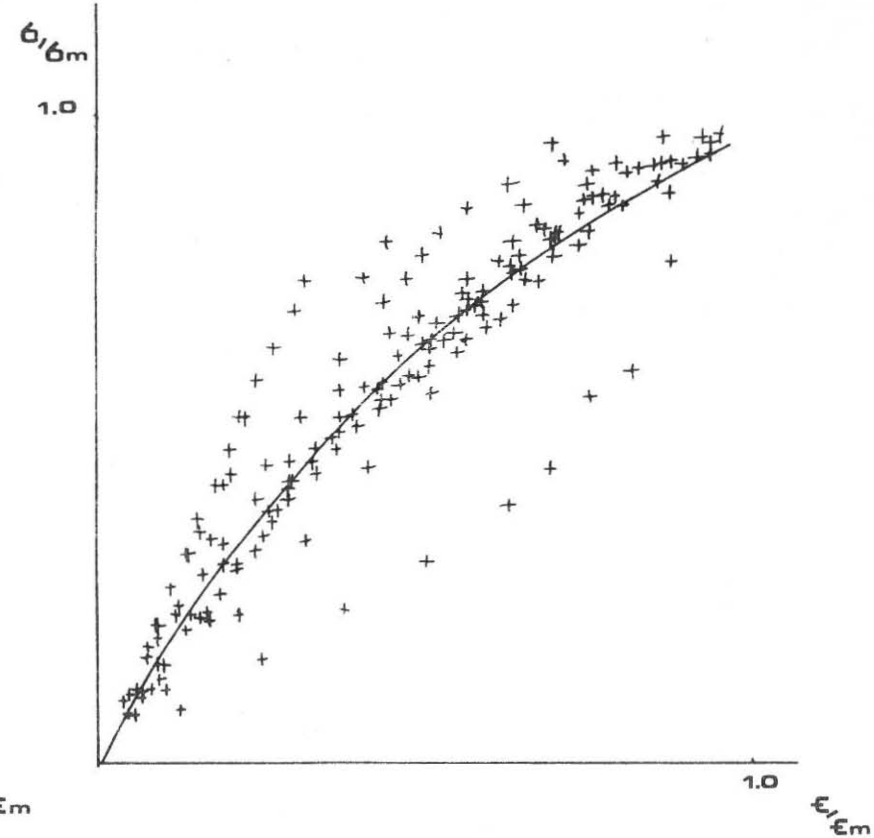


Fig. 7 Non-dimensional stress/ strain relationship based on three course prisms.