COMPRESSIVE STRENGTH OF THAI BRICK COLUMNS

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ABSTRACT The physical properties of four popular types of Thai brick have been determined in accordance with the relevant standard specifications of the American Society of Testing and Materials. For its superior properties and size efficiency, Bang Bua Thong (large size) otherwise known as Bo Po Ko bricks are considered the most suitable for structural use.

Ultimate load tests are reported of a total of 32 columns made of Bo Po Ko bricks. The main variables in the tests were the slenderness ratio, mortar strength and age. Graphs are presented summarising the relationships between the critical stress and each of the aforementioned variables. By regression analyses empirical formulae are derived. For computing the strength of masonry prisms, the formula introduced by Grimm is slightly modified. Comparisons of results indicate that the reduction factors given in the British Standard Code of Practice BS 5628 may be used for assessing the column strength in compression.

1. INTRODUCTION

As the numerous ruined pagodas at the ancient cities of Ayudhya and Sukhothai vividly testify, burnt clay bricks as a building material have been used in Thailand for centuries. At present bricks are used in the construction industry for non-load bearing work and for decorative purposes only. There may be some instances where bricks are used as load bearing elements - mainly in the rural areas - but without proper strength and other design considerations.

Considerable efforts are spent on developing low-cost construction materials for introduction to the rural areas. Bricks can be one of the most suitable to be 're-introduced' for they are already available almost everywhere. Similarly, if the strength and rigidity of brick masonry are accounted for in the design of city buildings, savings in costs can be expected.

1.1 Brief Review

The Centre for Thai National Standard Specifications(1) has issued a booklet specifying the sizes of bricks. In a report on the strength of brick in-filled steel frames Malaivongs(2) suggested that the mortar to be used should be in the ratio of 1:0.25:3 for cement:lime:sand by volume with a water/cement ratio of 1.2 by weight. The average thickness of mortar bed joints he adopted was 15 mm; the type of brick used was Morn. A parallel study was also conducted by Tongpatanakul(3) on reinforced concrete frames using the same bricks and mortar specification.

1.2 Scope of Study

To determine the physical properties of Thai bricks, relevant specifications of the American Society of Testing and Materials (ASTM) (4) and the British Standards Institution (BSI)(5) are adopted. The study involves four types of brick, namely Chon Buri, Bang Bua Thong (small size), Bang Bua Thong(large size) or Bo Po Ko and Morn. They are shown in Fig. 1. Comparisons of test results and costs lead to the conclusion that Bo Po Ko is the most suitable type for structural use.

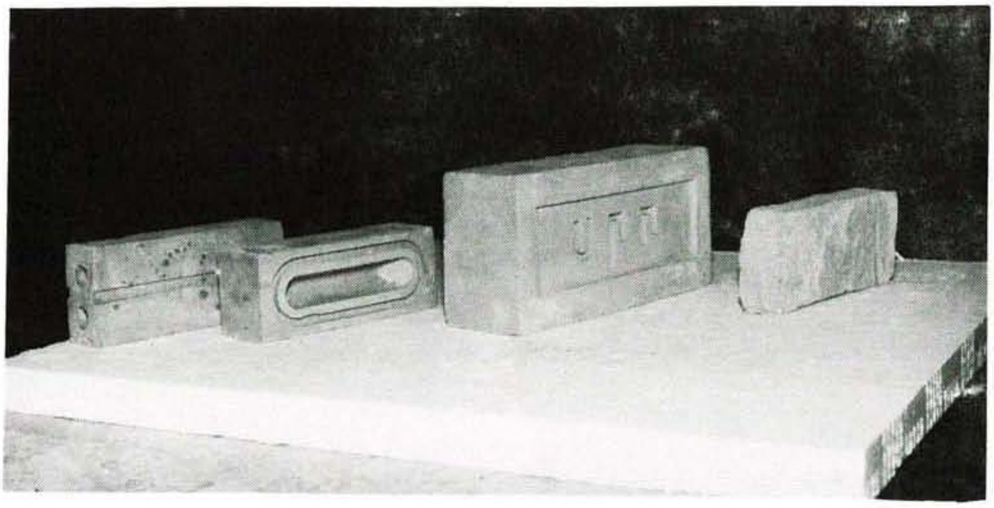

Fig. 1 Types of brick selected for pilot study
(From left to right)
Type-A Chon Buri
Type-B Bang Bua Thong (small size)
Type-C Bang Bua Thong (large size) or Bo Po Ko
Type-D Morn

Experiments have been carried out to investigate the compressive strength of columns laid using Bo Po Ko bricks. The main variables in these tests included age, mortar strength and slenderness ratio. In light of the test results, the applicability of some existing computational procedures is checked.

1.3 Significance of the Research

There appears to be no published experimental data on the properties of Thai bricks and the strengths of masonry made of such bricks. The present work may to some extent help fill this technical information gap.

2. PILOT STUDY

2.1 General

Four commonly available types of brick were used in a pilot test programme. The purpose was to determine the most suitable one which could be used effectively and economically for masonry construction. The bricks were (see Fig. 1),

Type A : Chon Buri (average size - 160 mm x 68 mm x 35 mm);
Type B : Bang Bua Thong (small size) (average size - 160 mm x 58 mm x 46 mm);
Type C : Bo Po Ko (average size -225 mm x 108 mm x 68 mm);
Type D : Morn (average size - 160 mm x 78 mm x 33 mm).

The tests were in accordance with the ASTM Standard Specifications (4a) and included

(a) Compressive strength,
(b) Modulus of rupture,
(c) Initial rate of absorption,
(d) 24-hour (cold water) submersion and
(e) 5-hour (boiling) submersion.

2.2 Summary of Test Results

Results of the pilot tests are summarised in Table 1. Assuming the weathering index as defined by the ASTM(4a:i) to be zero in all parts of Thailand, being in a no frost region, the grade requirement of Thai bricks is grade MW. The corresponding brick properties specified for this grade are also listed in Table 1.

TABLE 1 PHYSICAL PROPERTIES OF THAI BRICKS

Item*	Type-A	Type-B	Type-C	Type-D	ASTM Specs. C62-81
1. Compressive strength (N/mm^2)	9.38	30.8	21.8	9.71	17.2
2. Modulus of Rupture (N/mm^2)	5.28	12.33	5.1	1.84	3.0
3. Initial rate of absorption ($grms/min-194\ cm^2$)	8.46	21.66	16.75	34.34	30.†
4. Absorption % (24 hrs. cold water)	15.49	13.29	16.39	20.29	-
5. Absorption % (5 hrs. boiling)	16.34	14.39	17.08	25.53	22.0
6. Saturation coefficient $(\frac{\text{Item 4}}{\text{Item 5}})$	0.95	0.92	0.96	0.79	0.88

* Average of a minimum of 5 specimens. † Nominal

2.3 Selection of Most Suitable Brick Type

The size of brick is an important factor in determining its suitability for masonry construction. None of the four types of brick complies with the Thai National Standards(1) on size. Only Type C, i.e. Bo Po Ko closely conforms to that specified by the BSI(6) and it is convenient to lay Type C bricks according to the 'English bond' arrangements.

A recent inquiry conducted in Bangkok has indicated that the ex-factory prices per 1000 bricks of the four types are as follows:

Type A: Chon Buri - 290 Baht (A$ 15.30)
Type B: Bang Bua Thong (small size) - 1500 Baht (A$ 78.90)
Type C: Bo Po Ko - 2750 Baht (A$ 144.70)
Type D: Morn - 250 Baht (A$ 13.20)

Mainly because of their low compressive strengths (see Table 1), Types A and D are not considered suitable for load bearing use. On the other hand, the physical properties of Types B and C are satisfactory. Although Type B has a higher compressive strength than Type C, Type C is about 2.85 times larger in volume, but only 85% more costly. The cost per cubic meter of bricks are 3515 Baht and 1665 Baht respectively for the small and large-sized bricks. Further, Type B requires relatively more mortar thus higher labour cost in masonry construction because of its smaller size. The larger bricks would also result in a smaller slenderness ratio.

In view of the above Type C was concluded to be the most economical and effective and was used in the subsequent experiments on columns.

It was found in the course of the study that the wastages were low in Types A, B and C at 5% to 10%; in Type D, it was about 15%. These wastages were for laboratory conditions in which even bricks with minor damages were rejected.

3. COLUMN TESTS

After establishing that Type C or Bo Po Ko was the most suitable for masonry construction, further tests were carried out to quantify the compressive strength and other properties of columns made with such bricks.

3.1 Details of Specimens

The cross-sectional area of all specimens was 227 x 227 mm^2. The average bed joint thickness was kept constant at 12 mm. The dimensions of the 32 columns together with other details are given in Table 2. The specimens were divided into eleven series.

3.2 Variables

In addition to slenderness ratio and age, strength of mortar was included as a major variable. Accordingly three types of mortar (4a:iv) were used:

TABLE 2 DETAILS OF COLUMN SPECIMENS

Cross sectional area of all the columns were kept at
227mm x 227mm with a maximum variation of ± 3mm at either side.

Column No.	Height (mm)	Tested concentrically or eccentrically	Type of mortar	Age at testing (days)	Series
1C18C	480	concentrically	M	7	1
2C18C	477	concentrically	M	14	1
3C18C	477	concentrically	M	28	1
4C18C	472	concentrically	M	28	2
5C18C	470	concentrically	M	28	2
6C18C	465	concentrically	M	28	2
11C18C	465	concentrically	M	28	2
1C27C	685	concentrically	M	28	3
2C27C	668	concentrically	M	28	3
3C27C	700	concentrically	M	28	3
2C51C	1295	concentrically	M	28	4
3C51C	1295	concentrically	M	28	4
7C51C	1305	concentrically	M	28	4
12C18M	462	concentrically	N	28	5
14C18M	450	concentrically	N	28	5
15C18M	465	concentrically	N	28	5
13C18P	460	concentrically	S	28	6
16C18P	470	concentrically	S	28	6
1C39C	990	concentrically	M	28	7
1C72C	1830	concentrically	M	28	7
2C72C	1845	concentrically	M	28	7
7C18E	460	eccentrically *	M	28	8
8C18E	470	eccentrically	M	28	8
9C18E	470	eccentrically	M	28	8
10C18E	470	eccentrically	M	28	8
4C51E	1305	eccentrically	M	28	9
5C51E	1295	eccentrically	M	28	9
4C27E	688	eccentrically	M	28	10
5C27E	700	eccentrically	M	28	10
2C39E	915	eccentrically	M	28	10
18C18C	470	concentrically	M	14	11†
19C18C	480	concentrically	M	7	11

* 42 ± 2 mm. † for 28 days see Series 2.

Type M - cement : lime : sand = 1 : 0.25 : 3 by volume, with a water/cement ratio of 0.75 by weight.
Type S - cement : lime : sand = 1 : 0.5 : 4.5 by volume, with a water/cement ratio of 1.10 by weight.
Type N - cement : lime : sand = 1 : 1 : 6 by volume, with a water/cement ratio of 1.55 by weight.

These are referred to as mortar designations 1, 2 and 3 respectively in the British code of practice (5). Note that mixing of mortar was done manually.

To study their effects on strength, two methods of constructing the columns were adopted:

(a) The bricks were wetted for about 60 seconds, two or three minutes before laying. Series 1 specimens (see Table 2) were laid using this method.
(b) The bricks were soaked for two to three hours before laying and the excess water was wiped off just before laying. All the specimens other than those in Series 1 were constructed by this method which is recommended in many masonry text books for improved adhesion and bond.

3.3 Curing

Each specimen and the corresponding mortar cubes were covered with polyethylene sheets for a period of three days after construction and then left uncovered until tested(5).

3.4 Testing

The specimens which were shorter than 700 mm were tested in a 300-tonne DENISON testing machine. For those taller than 700 mm, tests were carried out in a self-contained steel test rig. Details of the test set-up are shown in Fig. 2.

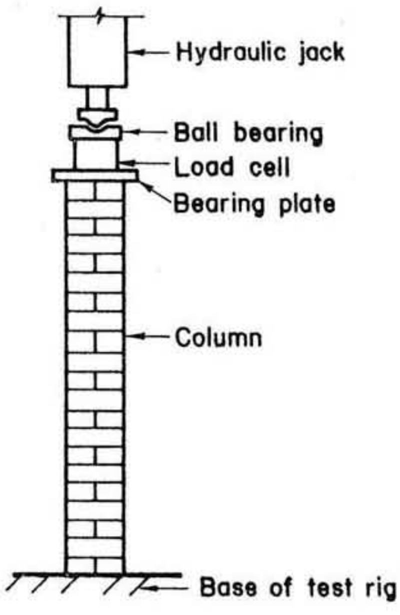

Fig. 2 Test set up

For each test, the load was applied in steps of five tonnes until failure occurred. At each step, the longitudinal strains were measured on all four faces of the column with a 200 mm Demec gauge. A complete record of all measurements have been presented elsewhere (7).

4. RESULTS AND DISCUSSION

4.1 Masonry Strength and Age

By comparing test results of Series 1 and 11 as given in Fig. 3 it is clear that the masonry strength increases with age. The increase from 7 to 28 days was about 30% for the first method of construction (Series 1) and 33% for the second method of construction (Series 11). It appears that the effect of soaking the bricks for prolonged period is negligible. This is no doubt due to Bo Po Ko's low rate of initial absorption (see Table 2).

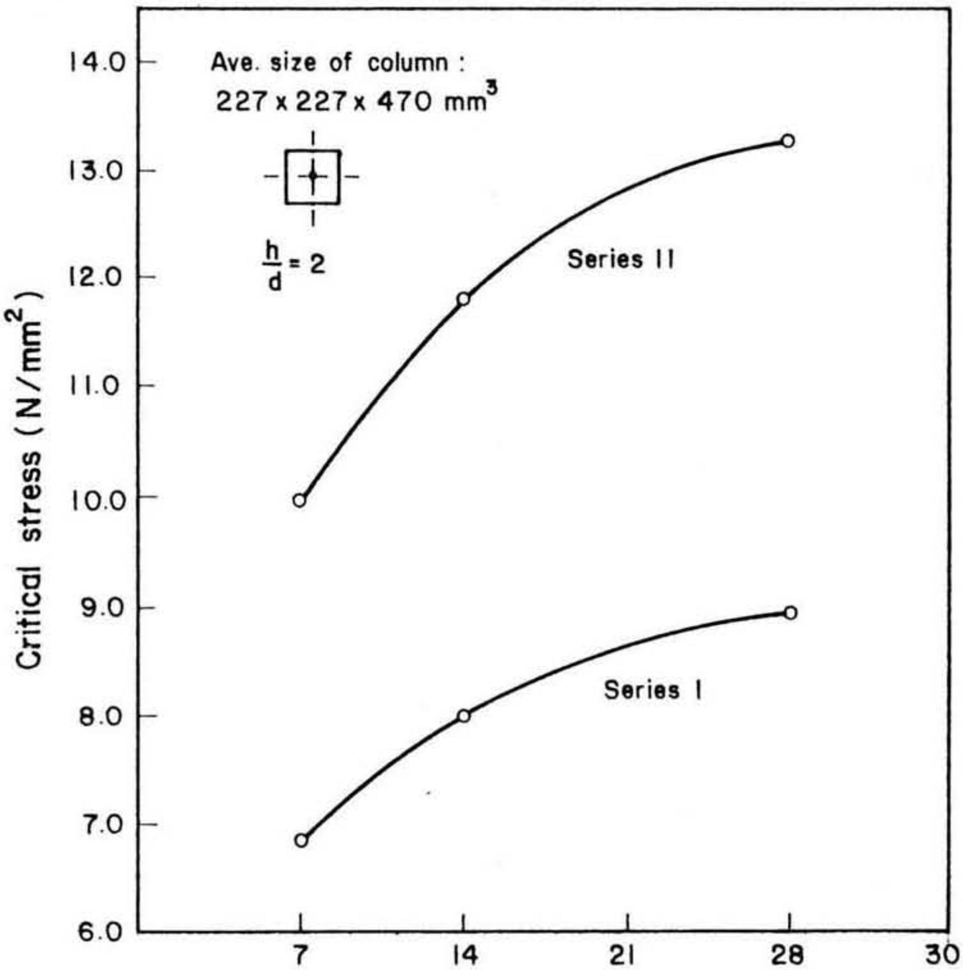

Fig. 3 Critical stress versus age

4.2 Critial Stress and Mortar Strength

The tests in Series 2, 5 and 6 were carried out to determine the variation of masonry compressive strength with the mortar strength. The results are summarized in Fig. 4. As expected an increase in mortar strength yields a higher failure stress. A regression analysis based on these test results gives

$$\sigma_{cr} = -0.02 f_c^2 + 0.83 f_c + 4.7 \quad (1)$$

where σ_{cr} is the stress at failure and f_c is the compressive strength of mortar, both in N/mm^2. Note that the intercept value of 4.7 N/mm^2 is 22% of the brick's compressive strength. This compares favourably with results quoted by Sahlin (8) which give a value of about 20%.

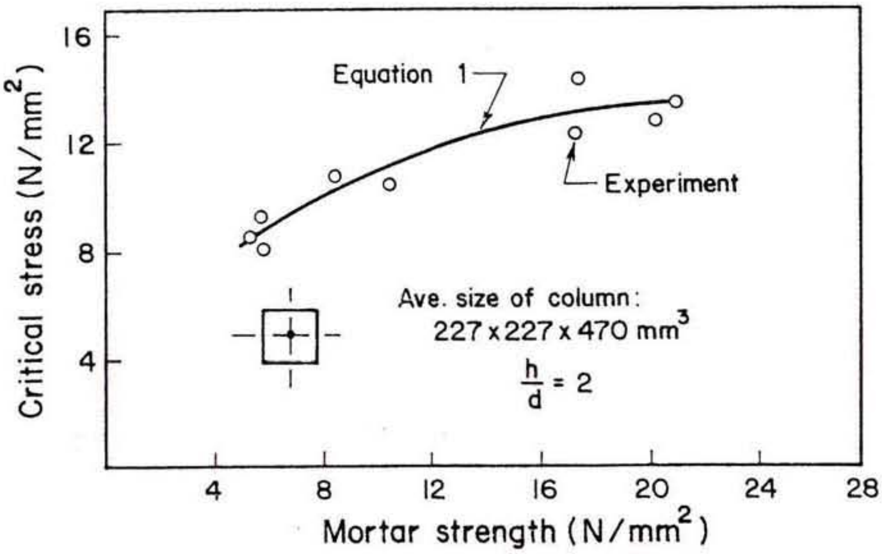

Fig. 4 Critical stress versus mortar strength

4.3 Critical Stress and Slenderness Ratio

4.3.1 Concentrically loaded columns. It was noted in the tests of Series 2,3,4 and 7 that for short columns, failure was due to the development of excessive longitudinal cracking. The longer columns on the other hand failed by splitting in the four faces along the center lines. In some cases, without any prior indication the columns burst and collapsed. But from the debris it was discovered that the specimens still split into four equal parts along the centre lines.

Grimm (9) has developed a formula for the compressive strength of masonry prisms (4c). However the present tests within this range indicated that the strength results were about 70% higher than the predicted values. In view of this, Grimm's formula is slightly modified (which now covers a slenderness ratio of up to 10):

$$\sigma_{cr} = 1.42\ \zeta\eta\ f_b' \times 10^{-8}\ [f_c^2 + 9.45 \times 10^6](1 + \varepsilon)^{-1} \quad (2)$$

where σ_{cr} is in lbf/in^2 and the slenderness factor

$$\zeta = 0.0178\ [57.3 + (\frac{h_s}{t_s} - 10)^2] \quad (2a)$$

All other symbols are as described in Reference 9.

The experimental values are plotted in Fig. 5 together with equation 2. It may be seen that the predicted values are slightly but consistently lower than the lowest test results.

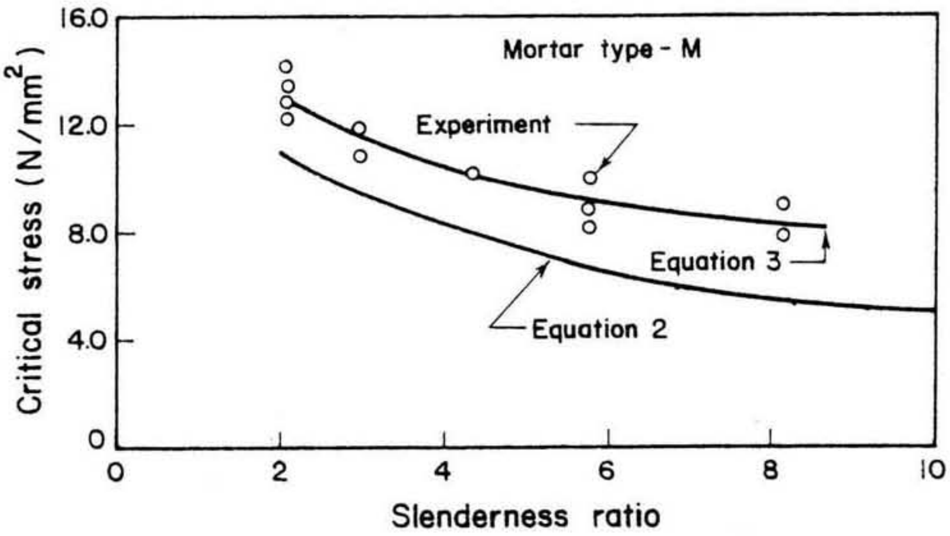

Fig. 5 Critical stress versus slenderness ratio (concentrically loaded)

A regression analysis carried out using the test data presented in Fig. 5 yields,

$$\sigma_{cr} = 16.4\ (h/d)^{-0.34} \quad (3)$$

where σ_{cr} is in N/mm^2 and h/d is the slenderness ratio.

Based on equation 3, the critical stress versus slenderness ratio curve is plotted in Fig. 6. In the same plot are superimposed the values obtained using the reduction factors given in Table 7 of BS 5628: Part 1: 1978 (5). Note that the critical stress of masonry prisms used to obtain the BS curve was derived from equation 3 with a slenderness ratio of 8; this stress value is almost identical to the characteristic strength suggested by BS 5628 for the same brick strength and mortar designation. It can be seen that the two curves are very close to each

other; the BS 5628 recommendation becomes slightly conservative for higher values of slenderness ratio.

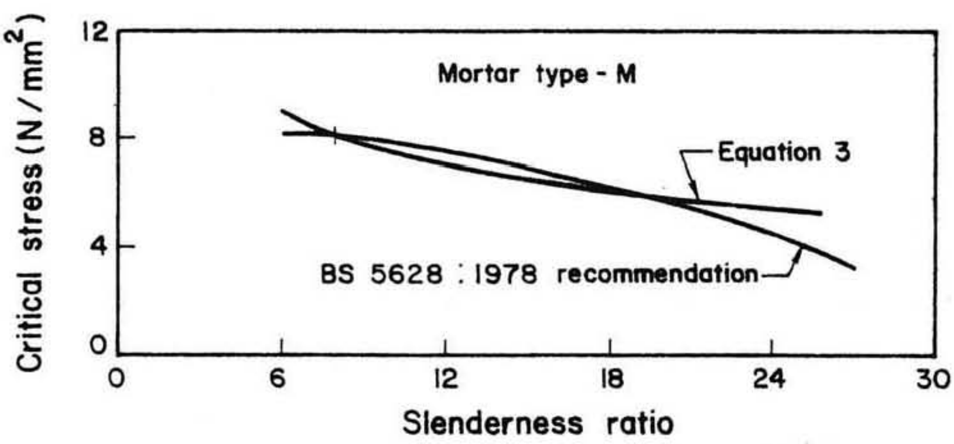

Fig. 6 Critical stress versus slenderness ratio (concentrically loaded)

4.3.2 Eccentrically loaded columns. It was found that under eccentric loading the columns at failure crushed at the compression face coupled with splitting along the bed joints at the tension face. Fig. 7 presents the experimental results on which a regression analysis is carried out. The following relationship is obtained for Type M mortar:

$$\sigma_{cr} = 12.2\ (h/d)^{-0.25} \qquad (4)$$

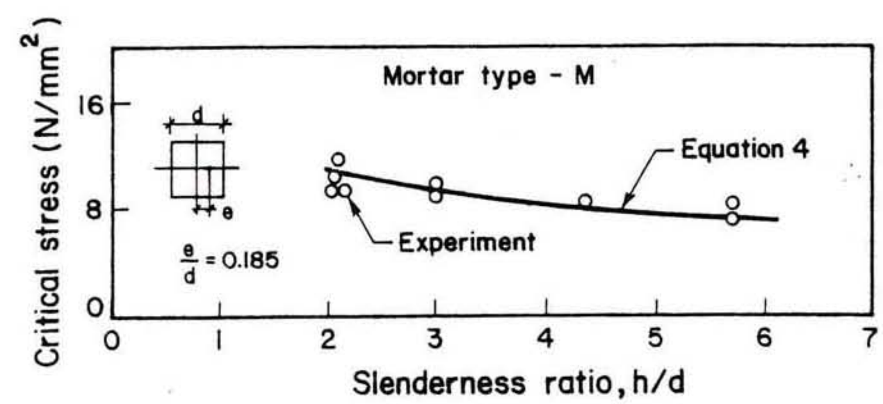

Fig. 7 Critical stress versus slenderness ratio (eccentrically loaded)

Equation 4 is plotted in Fig. 8, together with the values calculated using the eccentricity and slenderness reduction factors given in Table 7 of BS 5628 : Part 1: 1978(5). Again equation 3, with a slender ratio of 8, was used to obtain the reference masonry critical stress. The BS 5628 recommendation is seen to give conservative results. It should be noted that, contrary to the case of concentric loading, the use of the characteristic strength suggested by BS 5628 would considerably overestimate the Bo Po Ko brick column strength under eccentric load.

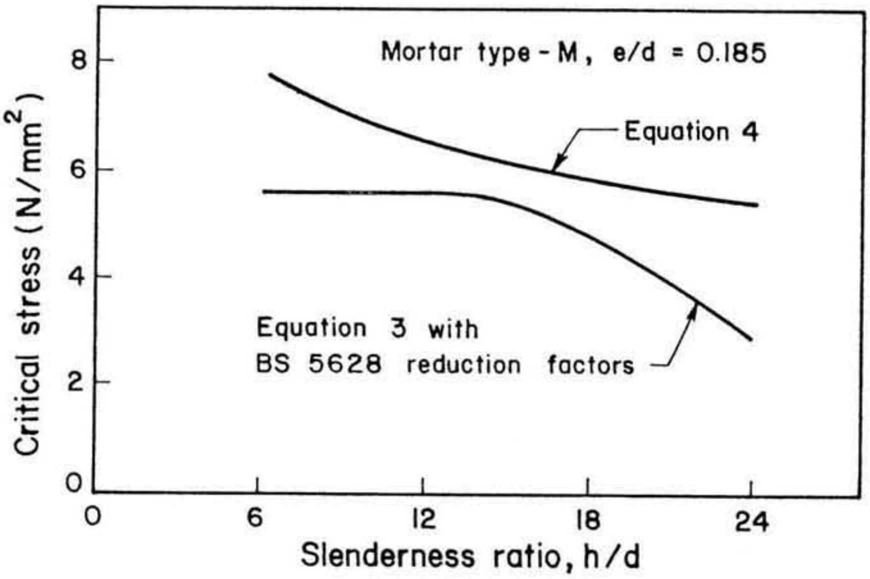

Fig. 8 Critical stress versus slenderness ratio (eccentrically loaded)

4.3.3 Recommendations. The above comparisons indicate that equation 2 may be safely used to compute the strength of short columns made of Bo Po Ko bricks. Thus, with a slenderness ratio of 8, it may also be used in conjunction with the BS 5628 reduction factors for estimating the compressive strength of similarly made columns with a slenderness ratio of up to 24. Needless to say, additional tests should be carried out on full-size specimens before a more sophisticated prediction procedure may be developed.

4.4 Modulus of Elasticity

The initial tangent modulus of elasticity of brick masonry made of Bo Po Ko bricks and Type M mortar was found to be 6000 N/mm^2. It may be recommended that for uniform stress level up to 4.0 N/mm^2,

$$\sigma = 6000\,\varepsilon \tag{5}$$

where the stress σ is in N/mm^2 and ε is the strain.

5. CONCLUSIONS

Out of the four types of brick selected for investigation, Chon Buri and Morn were found to have lower compressive strengths than the value specified by the ASTM (3a:i). Bang Bua Thong (small size) although satisfies all the ASTM specifications, is uneconomical because of its high unit volume costs. Bo Po Ko is the most suitable for structural use.

In light of the column test data, Grimm's formula for masonry strength is slightly modified. In the absence of a more reliable procedure, the modified Grimm's formula may be used in conjunction with the reduction

factors recommended by the British Standard BS 5628, for assessing the compressive strength of Bo Po Ko brick columns.

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