BASIC STRESSES FOR STRUCTURAL DESIGN OF LOW STRENGTH BRICK WALLS USING LOCAL MATERIALS

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1. Introduction

Throughout the nineteenth century, bricks were used in every kind of building and for a wide range of engineering structures. From the turn of the century to the present day, despite the challenge from other materials and the demands of new architectural forms, brickwork has maintained its position as a leading structural medium.

Some common applications of bricks where structural design should be considered are :—

(a) External and internal load-bearing walls of multi-storey buildings.
(b) Load-bearing piers and columns in single-storey industrial type or school buildings.
(c) Retaining walls.
(d) Perimeter walls in prisons and high garden walls.
(e) Tall chimneys.
(f) Towers and water tanks.
(g) Walls in single-storey houses with large openings such as windows and grills.
(h) Arches.
(i) Shear walls in concrete framed structures for lateral load resistance.
(j) Abutments for culverts and small span bridges.

Unfortunately in Sri Lanka lack of design data of the local varieties of brick units and mortars seriously hamper the structural designer who wishes to use masonry elements for load-bearing structures.

2. Objectives of the Investigation

The BSCP III[9] which governs masonry design provides guidelines for the design and construction of load-bearing brickwork in terms of strength of brick, type of mortar, type of loading and linear dimensions of the brickwall. Only the strength of units ranging from 400 to 3000 lbf/in^2 is covered in this code.

For the design of load-bearing brickwork the BSCP III[9] cannot be used for bricks having strength below 400 psi. But in Sri Lanka a considerable amount of bricks fall into this category. In this study, this category of brick is termed as Type II bricks. At present this type of brick is not commonly used for structural purposes confidently. Because of this, it is desirable to extend the BSCP III to facilitate the use of low strength bricks.

There are no codes or design charts for cabook blocks. As these are extensively used in Sri Lanka there is a need to formulate design recommendations for cabook blocks.

The mortar (1 cement : 10 sand) and the mortar called lateritic Soil Mortar are two low strength mortars which are widely used and found to perform well in this country. These mortars are viable as severe conditions such as frost action are not important here. The wide application of these mortars makes it worthwhile to extend the Code of Practice to cover these mortars.

This project is aimed at studying the behaviour of brickwork in these areas where no information is available even from other countries, namely strength of walls of cabook units, strength of walls of low strength burnt clay brick (referred as type II bricks in this paper) and strength of medium strength brickwalls (referred as type I bricks of 400 to 700 lbf/in^2 strength)in weak mortars.

The main objectives of this study were as follows:—

(a) Formulation of design recommendations on the same lines as the BSCP III[9].
(b) Determination of the ultimate load capacity.
(c) Distribution of the strains in the brick walls.
(d) Failure mechanisms of the walls.
(e) Evaluation of important material properties of the constituent materials of brick walls.
(f) Study of crack width to determine tolerable limits in walls without endangering structural safety.
(g) Comparison of these results with other published data.

3. Experimental Programme

Brickwork is a composite material with the brick as the building unit and the mortar as the joining material. Its own characteristic properties may bear some resemblance to either of these two elements. The strength of brick walls is usually given as a function of crushing strength of brick and type of mortar used. So to study the property of brickwork, it becomes important to find out the property of these two elements. Therefore tests were done on brick walls as well as on bricks and mortars.

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3.1 Bricks

Dimensions, dry density, water absorption and crushing strength were found according to BS 3921[7]. To find the crushing strength of bricks, bricks should be immersed in water for 72 hours. In the case of Type II bricks, they dissolved in water when they were immersed. So only the dry strength was found and in order to compare these bricks with others, the dry strength of Type I bricks and cabook were also found.

To test the cabook blocks, no code of practice was available. So the same procedure of brick tests were adopted for cabook too.

3.2 Mortar

In this project two types of mortars were used.

a) Lateritic soil mortar (1 cement : 5 sand : 10 lateritic soil).

b) 1 : 10 cement sand mortar.

Mortar tests were carried out as in the BS-4551.(8).

To find out the shear bond strength a three-brick assembly was built in bricks and cabook (see figure 1). Load was applied on the middle brick while outer bricks were supported.

Lateritic soil is the soil directly excavated from the ground where laterite deposits occur. In order to identify this soil in engineering terms and to find its properties, some soil tests were conducted, i.e. liquid limit test, plastic limit test, sieve analysis test and Hydrometer Analysis test.

3.3 Brickwork

To find the compressive strength of brick work, brick cubes, piers and walls have been used by researchers. In brickwork technology, Switzerland is one of the most developed countries, and here brick walls are used for the purpose of testing. Tests on piers and cubes may give the compressive strength. But tests on walls will give overall performance of the brick wall such as compressive strength, cracking pattern, crack width etc. In addition to this, testing of brick walls will represent the actual situation more closely. By considering all the factors, walls were selected for testing strength, and other properties of brickwork.

CP III[9] states that wall panels can be used to find the permissible stresses of brickwork and it gives the dimensions of the wall panels as 4 ft. to 6 ft. in length and 7 ft to 8 ft. in height. Further, to determine basic stress smaller wall units are simpler as they can be designed to eliminate largely the effects of Fa and Fs, these being the reduction factors for area and slenderness respectively in CP III[9]. The size of the wall panels was fixed so as to make Fa and Fs unity or nearly so (ie 2' 9" length and 3' height) and necessary reduction factors were considered in calculating the basic stress.

These wall panels were instrumented with dial gauges and mechanical strain gauges. Dial gauges were fixed to find out the shortening of walls and the bulking out of the wall thickness. Strain gauge points were fixed horizontally at horizontal centre lines of both sides of the wall. The load was applied gradually till it fails (see figures 2 and 3).

The following combinations were used in this project :—

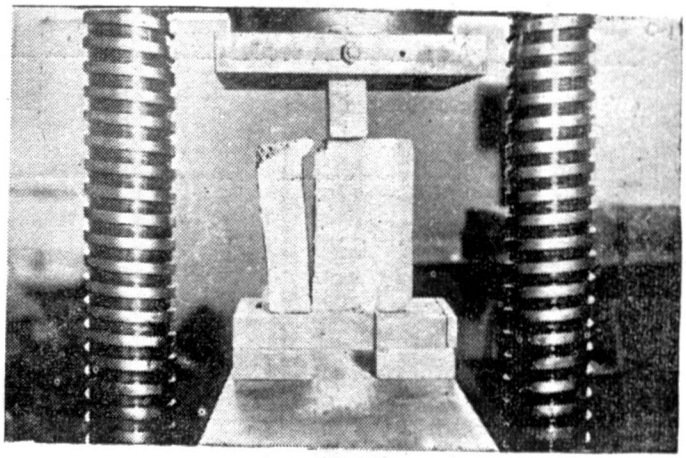
(a) Type I bricks with Lateritic soil mortar—
  9" wall
  4½" wall

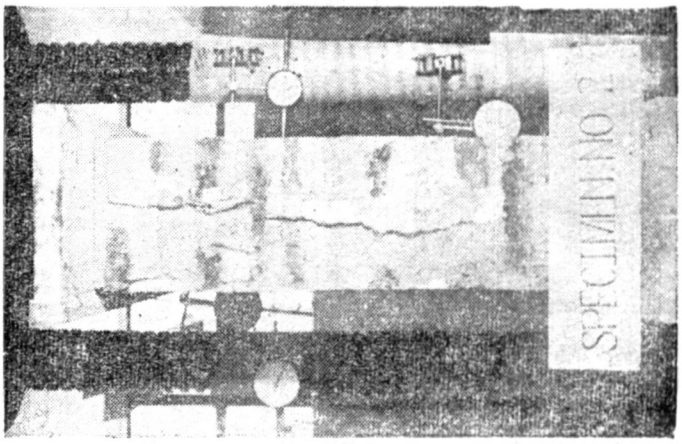
(b) Type II bricks with Lateritic soil mortar—
  9" wall
  4½" wall

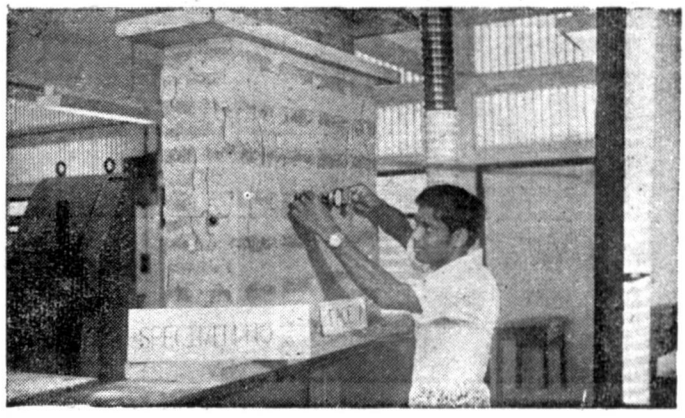
(c) Type II bricks with 1 : 10 cement sand mortar—
  9" wall
  4½" wall

(d) Cabook with lateritic soil mortar—
  6½" wall (½ brick wall)

(e) Cabook with 1 : 10 cement sand mortar
  6½" wall (½ brick wall)







4. Results

4.1 Bricks and Cabook

Type	Dimensions in x in x in (mmxmmxmm)	Crushing Strength lbf/in² (kN/m²) Dry	Crushing Strength lbf/in² (kN/m²) Wet	Water Absorption %	Dry density lbf/ft³ (Kg/m³)
Type I	8.24 x 4.4 x 2.24 (209 x 112 x 57.5)	920.3 (6.35)	633.58 (4.354)	25.42	154.02 (2467.17)
Type II	7.7 x 3.65 x 2.20 (196 x 92.7 x 55.9)	309.8 (2.13)	—	33.1	146.65 (2349.1)
Cabook (with mortar capping)	12.7 x 6.56 x 5.08 (322.9 x 166.6 x 129.0	403.3 (3.79)	178 (1.18)	15.2	123.25 (1974.28)
Cabook (without mortar capping)		106.03 (0.75)	58.11 (0.40)		

Type I and Type II bricks tested do not satisfy the dimensions specified in CS 39 : 1968[1], while no comments can be made on the cabook blocks as regards its dimensions as there is no standard covering cabook blocks.

The wet crushing strength of bricks to CS 39 : 1968[1] should range from 700 lbf/in² (—10%) to 2200 lbf/in2. From the results it is clear that only Type I bricks satisfy this code as regards crushing strength.

The best water absorption is shown by cabook and it compares well with class I bricks of CS 39 : 1968[1] while water absorption of type I bricks is equivalent to Class III bricks of the above standard. Type II bricks do not satisfy CS 39 : 1968[1] as regards water absorption too.

Dry density does not show large variations for the three kinds of bricks. Cabook shows lowest dry density while Type I bricks show the highest.

4.2 Mortar

4.2.1 Compressive Strength in lbf/in² (MN/m²)

	Water/cement ratio	7th day	14th day	28th day
Lat. Soil mortar	1.5 (Minimum workability)	43.6 (0.310)	56.9 (0.405)	—
	4.0	—	—	13.5 (0.093)
1:10 cement sand mortar	0.6 (minimum workability)	46.5 (0.330)	63.75 (0.454)	—
	2.0	—	—	19.9 (0.138)

Compressive strength results show the strength achieved in actual practice at the workability required for brick laying and also at minimum workability. It also shows the large difference in water cement ratio at minimum workability and at workability required for brick laying. In general the strength developed by lateritic soil mortar and 1 : 10 cement sand mortar are of the same order.

4.2.2 Shear Bond Strength

Combination	Shear bond strength lbf/in²	(MN/m²)
1. Type I brick with Lat. Soil mortar	27.1	(0.186)
2. Type II brick with Lat. Soil Mortar	29.5	(0.203)
3. Type II brick with 1:10 cement sand mortar	24.3	(0.167)
4. Cabook and Lat. Soil Mortar	29.3	(0.202)
5. Cabook and 1:10 cement sand Mortar	<0.2 (very weak bond strength)	(<0.0014)

Shear bond strength results show that lateritic soil mortar exhibits better bond strength than 1 : 10 cement sand mortar. Further, higher bond strengths are shown by lateritic soil mortar when used with cabook and Type II bricks.

4.2.3 Lateritic Soil Tests

Liquid limit 49.9% ... Plastic Index 9.5
Plastic limit 38.4% ...

From the appearance of the soil and the high sand content in the particle size distribution curve, the soil can be confirmed as a lateritic soil. Particle size distribution tests also show that both lateritic soil and sand tested were well suited as constituents of mortar.

4.3 Brickwork

Type	Modulus of Elasticity lbf/in² (MN/m²)	Load factor at cracking	Maximum crack width at failure	Factor of safety of CP III interpolated outside its limits where necessary	Ultimate stress after allowing for reduction factors lbf/in² (MN/m²)	Basic stress (lbf/in² (MN/m²
Type I brick with	9" wall 510.0 (3.510)	1.5	4 to 5 mm	5.00	105.5 (0.720)	21.1 (0.144)
Lateritic Soil mortar	4½" wall 343.0 (2.401)	1.3	1.5 mm	5.55	132.0 (0.933)	23.8 (0.168)
Type II brick with	9" wall 371.4 (2.600)	1.31	5 mm	7.00	63.7 (0.448)	9.1 (0.064)
Lateritic soil mortar	4½ wall 164.5 (1.152)	1.77	1 mm	7.62	91.5 (0.633)	12.0 (0.083)
Type II bricks with	9" wall 508.2 (3.557)	1.11	1 mm	7.00	80.5 (0.553)	11.5 (0.079)
1:10 cement sand mortar	4½" wall 414.0 (2.898)	1.3	1 mm	7.62	122.0 (0.846)	16.0 (0.111)
Cabook bricks with Lateritic soil mortar	6½" wall 225.5 (1.579)	1.76	3 mm	9.44	88.0 (0.604)	9.33 (0.064)
Cabook with 1:10 cement sand mortar	6½" wall 116.8 (0.818)	1.63	3.5 mm	9.44	119.0 (0.812)	12.6 (0.086)

For steel structural elements the factor of safety in BS 449 varies from 1.11 to 2.0. For concrete structural elements in effect factor of safety varies from 2.4 to 4.5, in BSCP 114.

For timber structural elements the factor of safety recommended is not available but BSCP 112[4] recommends a factor of safety of 2.5 for strength tests on timber structures. As for timber, the factor of safety for brickwork included in BSCP III[9] is not available, but the load factor recommended in obtaining permissible stress from test panels range from 5 to 12.

Factor of safety in BSCP III[9] is generally considered too high, and Foster[5] has demonstrated the unrealistic nature of these values. In this series of tests too, the load factor at cracking and also the load/shortening graphs[6] show that factor of safety obtained by extending BSCP III[9] are unrealistic. Hence a factor of safety of 5.0 is suggested for all the walls. At the basic stress value obtained using this factor of safety the wall will be free of cracking and also its deformation will be elastic.

5. Conclusions

The following conclusions can be made from this investigation :—

1. As type II bricks have little or no wet strength, these bricks can be used for partition walls and internal load bearing walls (locations where it will be protected from water penetration), when the load coming to the wall is not very large.

2. Lateritic soil mortar gives better overall performance when used with cabooks than the use of cement sand mortar with cabocks, although it is slightly inferior from the point of view of strength.

3. For type II bricks use of lateritic soil mortar gives improved overall behaviour than the use of cement sand mortar in spite of the fact that it is inferior strengthwise.

NOTE:—In each combination 3 specimens were tested and the lowest value was taken as compressive strength.

Type	Wall thickness	Factor of safety by extending CP III	Basic Stress lbf/in²(MN/m²)	Suggested Factor of Safety	Suggested Basic Stress lbf/in²(MN/m²)
Type I brick with	9"	5.00	21.1 (0.144)	5.00	21.1 (0.144)
Lat. Soil mortar	4½"	5.55	23.8 (0.168)	5.00	26.4 (0.186)
Type II brick with	9"	7.00	9.1 (0.064)	5.00	12.7 (0.089)
Lat. Soil mortar	4½"	7.62	12.0 (0.083)	5.00	18.3 (0.126)
Type II brick with	9"	7.00	11.5 (0.079)	5.00	16.1 (0.110)
1:10 cement sand mortar	4½"	7.62	16.0 (0.111)	5.00	24.4 (0.169)
Cabook with Lat. soil mortar	6½"	9.44	9.33 (0.064)	5.00	17.6 (0.121)
Cabook with 1:10 cement sand mortar	6½"	9.44	12.6 (0.086)	5.00	23.8 (0.162)

4. Lateritic soil mortar is not suitable for use with Type I bricks as its load carrying capacity is considerably reduced.
5. Results of this investigation compare well with work by previous researchers as suggested by a comparison of brickwork strength to brick strength.
6. A close examination of load factor at cracking and elastic behaviour of the wall suggests that the factor of safety obtained by using BSCP III[9] and extending by extrapolation when necessary is unrealistic as demonstrated by other researchers. A factor of safety of 5.0 is recommended as suitable.
7. The table of basic stress of CP III[9] can be extended as shown in Table opposite.

6. Acknowledgements

The authors wish to thank Prof. D. S. Wijeyesekara, Head of the Department of Civil Engineering, for the facilities provided at Katubedda Campus where this work was conducted; Dr. M. U. G. Fernando of the Building Research Institute of the State Engineering Corporation for sponsoring this project and for his active support and co-operation at all stages of the work and Mr. S. Rubasingham, Librarian of Katubedda Campus, for providing reference material at very short notice.

References

1. CS 39 : 1968, *Specification for Common Burnt Clay Building Bricks*, Sri Lanka Bureau of Standards.

2. BS 449 : 1970, *Structural Use of Steel in Building.*

3. BSCP 114 : Part 2 : 1962, *Reinforced Concrete in Buildings.*

4. BSCP 112 : 1968, *Structural Use of Timber in Buildings.*

5. D. Foster, *The Use of Structural Brickwork for Frameless High Buildings*, Architectural Review, April and May 1962.

Description of Mortar	Mix (part by Volume)				Hardening time after completion of work (days)	Basic Stress in MN/m²(lbf/in²) corresponding to units whose crushing strength in MN/m²(lbf/in²)					
	Cement	Lime	Lateritic soil	Sand		Cabook	Brick				
						1.40 (200)	2.05 (300) Dry	2.80 (400)	5.6 (600)	7.0 (1000)	96.5 or greater (10,000)
Cement	1	0-$\frac{1}{4}$	—	3	7			(40) 0.28		(100) 0.70	(850) 5.85
	1	$\frac{1}{2}$	—	$4\frac{1}{2}$	14			0.28 (40)		0.70 (100)	4.50 (660)
Cement lime Cement with Plasticizer Masonry Cement	1 1 —	1 — —	— — —	6 6 —	14			0.28 (40)		0.70 (100)	3.80 (550)
Cement lime Cement with Plasticizer Masonry Cement	1 1 —	2 — —	— — —	9 8 —	14			0.28 (40)		0.56 (80)	3.1 (450)
Cement Lime	1	3	—	12	14			0.21 (30)		0.49 (70)	2.40 (350)
Hydraulic Lime	—	1	—	2	14			0.21 (30)		0.49 (70)	2.40 (350)
Non-Hydraulic Lime	—	1	—	3	28			0.21 (30)		0.42 (60)	1.40 (100)
Cement Sand	1	—	—	10	28	0.162 (23.8)	0.110 (16.1)				
Lateritic Soil Mortar	1	—	5	10	28	0.121 (17.6)	0.089 (12.7)		0.144 (21.1)		

6. R. Rajalingam and Miss J Murugesu, *Load Tests on Brickwork*, Final Year Project Thesis, Katubedda Campus, 1976.

7. BS 3921, *Brick and Blocks of Fixed Brick Earth, Clay or Shale.*

8. BS 4551 : 1970, *Methods of Testing Mortars.*

9. BSCP 111 : 1964, *Structural Recommendations for Loadbearing Walls.*

දේශීය අමු ද්‍රව්‍යවලින් තැනිය හැකි ප්‍රබලතාව අඩු ගඩොලු බිත්ති ගැටුම් පිරිමැවුම සඳහා අවශ්‍ය භාෂ්මික ප්‍රත්‍යාබල

සංක්ෂේපය:

කබොක් ගල්, CS 39:1968 පිරිවිතරයේ III ශ්‍රේණියේ ගඩොල් සහ 3 ශ්‍රේණියෙන් පහල ගඩොල්ද, ලාටරයිට් පස් බදම සහ 1:10 සිමෙන්ති වැලි බදමද සමඟ සංයෝජනය කර තැනිය හැකි ගඩොල් බිත්ති CP III හි විෂය පථයට අයත් නොවේ. එහෙත්, මෙම ගඩොල් වර්ග සහ බදම වර්ගවලින් තැනූ ගඩොල් බිත්ති ශ්‍රී ලංකාවේ පාවිච්චි කළ හැකි පමණක් නොව ඇත්තෙන්ම දැනට ඒවා නොයෙක් අවස්ථාවල ඉදිකරද ඇත. මේ පර්යේෂණය අරමුණු වී ඇත්තේ පිරිමැවුම් රීති රෙකමදරු කිරීම සඳහාද ඒවායේ ගැටුම් හැසිරීම අධ්‍යයනය කිරීමටද වේ.

මෙම පර්යේෂණය පිරිමැවුම් රීති රෙකමදරු කිරීමට අමතරව පහත සඳහන් දේ ඉස්මතු කර ඇත:

(අ) 1:10 සිමෙන්ති වැලි බදම, කබොක් ගල්වලට සහ 3 ශ්‍රේණියට වඩා අඩු ප්‍රබලතාව ඇති ගඩොල් සඳහා උචිත නොවේ.

(ආ) ලැටරයිට් පස් බදම, 3 ශ්‍රේණියේ ගඩොල් සමඟ භාවිතය උචිත නොවේ.

(For Tamil summary see page 29)