HAND CAST BLOCKS FOR THREE-STOREY TO FIVE-STOREY LOADBEARING STRUCTURES

by

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Abstract

Although machine cast blocks are now popular in Sri Lanka for low strength applications for buildings of up to 2-storeys, these blocks are still not widely used for high strength applications due to the availability of only a few manufacturers who can produce medium to high strength blocks, and fluctuating demand as well as a small market, discouraging new manufacturers from entering this field. Hence, it is likely that the present practice of using blocks hand cast at the construction site will continue. Previous of using blocks hand cast at the construction site will continue. Previous research has established economical blocks for 1 to 2-storeyed buildings and 6 to 8-storeyed buildings, but scope exists to find economical blocks for 3 to 5-storeyed buildings. This study addresses this issue.

The study consisted of selection of suitable sizes for blocks, determination of target compressive strengths, experiments to evolve production information, and costings covering blockwork and alternative types of walling.

The study resulted in recommending: dimensions of a suitable block for hand casting; target strengths of the solid block for different applications; production information; mortar suited for blocklaying; and the most economical walling types for different applications.

1.0 Introduction

Blockwork is economical in Sri Lanka for tall loadbearing masonry structures(1) such as 7 to 8-storeyed buildings, while for 1 to 3-storeyed and 4 to 6-storeyed buildings economical solutions are found in ordinary brickwork and wirecut brickwork respectively. However, there is a possibility that if hollow blocks and solid blocks of 1 cement : 3 sand : 6 coarse aggregate mix are used, application of blockwork can be made economical even for buildings 3 to 5-storeys high.

For high strength applications, machine cast blocks are unlikely to be used widely in Sri Lanka in the near future as : (a) the market available is too small and variable to import suitable blockmaking machines required for this purpose; (b) demoulding of the block should be done at least within a minute for such a machine to be viable. This need for quick demoulding will require the use of high cement contents, low water-cement ratios and suitable admixtures, which in turn will increase the cost; (c) the use of high cement contents and low water-cement ratios will require a greater degree of curing such as low pressure steam curing and this will also increase the cost; and (d) the lack of steam curing facilities does not allow effective utilisation of faster demoulding of machine cast blocks to produce blocks much faster than hand cast blocks. Thus, for high strength applications, hand cast blocks can exploit the above adverse factors affecting machine cast blocks to become a viable alternative provided weaknesses of hand cast blocks are overcome by improving the slow production rate by use of an efficient mould as suggested by Chandrakeerthy et al (1) and also using good construction planning to commence casting of blocks ahead of actual commencement of construction. Indeed, blocks for high strength applications in Sri Lanka, have been mostly hand cast so far, and this trend is expected to persist.

One of the main obstacles to the use of hand cast blocks in Sri Lanka is the inadequacy of production information, confirmed with experimental evidence, available to the designer. Information is available for solid and hollow cement-sand blocks(2,3) but these blocks are not suited for 3 to 5-storeys high loadbearing structures.

This investigation[16] was directed at: (a) studying the viability of hand cast solid and hollow blocks in 3 to 5-storeys high loadbearing structures; (b) evolving production information on viable blocks; (c) selecting suitable mortar mixes for blocklaying; and (d) recommending the most economical walling type for loadbearing structures 3, 4 and 5-storeys high.

2.0 Selection of a Suitable Size for the Blocks

2.1 Hollow blocks

The dimensions of the selected hollow block should satisfy the requirements of British Standard specifications[4,5] and Sri Lanka specifications[6,7] which are: (a) solid material should be between 50 to 75% of the total volume; (b) total width of cavities measured at right angles to the surface $\not>$ 65% of the thickness of the block; (c) a cavity volume $\not>$ 50% of the gross volume; (d) dimensions should conform to specified work sizes of blocks; (e) minimum thickness of external shell of hollow should not be less than 25mm or 1.75 times the nominal maximum size of the aggregate whichever is the greater; (f) webs should be of a minimum height of 70mm, or the full height of the block less 50mm,whichever is the greater; and (g) face shell and web thicknesses should be not less than those specified[7] to prevent premature local buckling of face shells and webs. In addition, the weight of the block should satisfy the approximate requirement for two handed laying (9Kg $\leq$ weight $\leq$ 32Kg).

Size of the block selected was 440x215x215mm (length x width x height) with two cavities of 140mm (measured along the length of block) x 115mm (along width of the block) x 215mm (height) giving an outer wall thickness of 50mm and a central wall thickness of 60mm. Webs extended through the full height of the block.

2.2 Solid blocks

The dimensions of the selected solid block should satisfy the following requirements: (a) size should be greater than that of a brick;(b) height $\not>$ 6xwidth; (c) height $\not>$ length; (d) width $\not>$ 100mm as blocks with a greater width should be made hollow or cellular; (e) size as large as possible so that weight is between 9 Kg and 32 Kg for two handed laying; (f) height/width ratio between 2 and 4 to allow for enhancement of strength; (g) should comply with recommended sizes in the standards[4,5,6,7]; and (h) density $\not<$ 1500 Kg/m^3, if lightweight aggregate is used.

Sizes of solid blocks considered and how they fare with respect to the above requirements are shown in Table 1. The density was taken as 2390 Kg/m^3.

Block 1 (see Table 1) satisfied all the criteria. However, considering the workmanship prevalent in Sri Lanka, it was thought unsafe to use 100mm wide blocks for 3 to 5-storey high walls as slight variations from verticality can reduce the wall strength appreciably. Hence, block 1 was not selected. Blocks 5 and 9 were rejected as they did not satisfy the weight criteria (e) (see Table 1) for two handed laying. Blocks 2 and 3 were rejected as they did not conform to the sizes (g) specified in the standards. Block 6 was rejected as it was lighter and smaller than Block 4. Block 4 was rejected as it was lighter and smaller than Block 7. Finally, Block 7 was rejected as it was lighter and smaller than Block 8. Block 8, which was left, did not satisfy the requirement as regards hollows. This may be uneconomic use of material but cannot be ruled out on structural considerations. Block 8 also does not satisfy the height/width requirement, but still achieves enhancement of strength over concrete bricks. Thus, Block 8 (440mm long x 140mm wide x 215mm high) was selected for further study.

3.0 Determination of Target Compressive Strength of Blocks

It is not possible to derive the target compressive strength of block units applicable to any building, since: (a) wind loads depend on the geometry and shape of the building and its location; (b) stresses due to loads on floors and roof also depend on plan geometry; and (c) loads on floors depend on the intended use. Hence, a typical building was considered for computations and its main details are: (a) 7.0m long crosswalls spaced at 3.0m intervals; (b) Plan dimensions of the building - 7.0m wide x 9.0m long; (c) gabled crosswalls at topmost storey; (d) eaves and verges overhang of the roof - 1.0m measured in plan; (e) timber roof structure of 100mm wide x 150mm deep beams placed on gabled crosswalls which support 75mm wide x 150mm deep purlins spaced at 1.0m measured on slope length, which in turn support corrugated asbestos sheets; (f) roof slope of 12^0 to the horizon; (g) concrete floor slab 150mm thick spanning one way to crosswalls; (h) crosswall thickness of 215mm for hollow blocks and 140mm for solid blocks; (i) wall height of each storey (excluding slab thickness) of 3.0m,; and (j) number of storeys from 3 to 8.

The following loads were considered to act on the typical building: (a) dead load of asbestos corrugated roofing sheets of 0.16 KN/m^2; (b) dead load of concrete of 23.6 KN/m^3; (c) imposed load on the roof of 0.25 KN/m^2; (d) imposed load on floors of 3.0 KN/m^2; (e) dead load of timber of 8.2 KN/m^3; (f) dead load of hollow blockwork - 15 KN/m^3 and that of solid blockwork - 24.4 KN/m^3; (g) basic wind speed[10] of 33.5m/sec and ground roughness 1.

The design process adopted conformed to CP3: Chapter V:Part 1[9] and Part 2[10], and BS 5628[11]. Calculations for hollow blocks (with cavities filled or empty) were not done in this study and values given were those of Chandrakeerthy et al[1]. Calculations for solid blocks were carried out and presented (see Table 2) with some useful information at different stages of the design process. The values in Table 2 are meant to help the designer to anticipate the compressive strength of blocks needed for a particular application. The values are approximate as (a) the typical building considered may be different from the actual building; (b) the use of the building and, hence, the imposed load may be different; (c) as same coefficients of wind pressure are used, wind loads on shorter buildings may be lower; (d) the building may be at a location less severe than assumed. As these tall buildings will be designed by structural engineers, it is expected that detailed calculations will be carried out by them to obtain the compressive strength of block units required. Production information can then be obtained to match the required strengths as detailed later in this paper.

Results of Table 2 indicate that (a) for 3 to 5-storeys high structures, there is no advantage in filling cavities of hollow blocks; and (b) solid blocks are not viable for 6 to 8-storey high buildings due to very high compressive strengths required for solid blocks compared to those of hollow blocks.

4.0 Experimental Study

4.1 Formulation

4.1.1. General

Having found the target compressive strengths of blocks, the next stage is to develop production of blocks satisfying those compressive strength requirements. In the succeeding sections, variables that affect compressive strength of blocks were identified and either varied appropriately or held constant at suitable values.

4.1.2. Mix proportion

A previous study[1] indicated that, for hollow blocks, 1:2:4 (12mm) volume batched concrete mix was not economical for 2 to 5-storeyed structures as strength developed was far in excess of what is required. It was also established[3] that cement-sand mixes cannot develop the strengths needed for hollow blocks for the above structures economically. Thus, it was decided to study the viability of 1:3:6 (12mm) volume batched concrete for hand cast hollow blocks.

Compressive strength of solid blocks in excess of 5 N/mm^2 cannot be attained economically using cement-stand mixes[2]. Further, grade 20 concrete (1:2:4 (20mm) volume batched) may be too strong. Hence, grade 10 concrete was considered to be adequate and 1:3:6 (20mm) volume batched concrete mix was selected for hand cast solid blocks.

4.1.3. Water-cement ratio

The importance of this variable is well known. To determine the most beneficial range, the information given in Sri Lanka specification for building works[6] for grade 10 nominal mix was considered. Thus, for solid blocks of 1:3:6 (20mm) mix, water-cement ratio was varied from 0.55 to 0.8 in steps of 0.05. It was not possible to use the same range for 1:3:6 (12mm) mix due to the higher water requirement of the smaller size aggregate. Hence, for hollow blocks, the water-cement ratio was varied from 0.75 to 1.0 in steps of 0.05.

4.1.4. Degree of compaction

Full compaction is required to reduce the voids present and achieve the highest strength that can be attained. As there are no reinforcements embedded in the block, a lower degree of compaction can also be used in the production of blocks. Full compaction will increase the cost of a block by consuming more concrete and increasing labour or compaction effort. However, a lower degree of compaction may also increase cost because a richer mix is needed to achieve the same strength. For low strength blocks, it was found that[2] a degree of compaction of 30% volume reduction gives best results. For high strength blocks, it is advantageous to attain full compaction. Hence, in this investigation full compaction was attained for each test.

4.1.5. Method of compaction

Hand compaction (rodding), poker vibrators, external (shutter) vibrators, vibrating tables, forcing under pressure and combinations of the above are the commonly used methods of compaction.

The method of compaction was not found to be significant for high cement content mixes[1]. However, it was considered worthwhile to study the effect of the method of compaction on very low cement mixes used in this study.

Compaction of the block was carried out in two layers. The main method of compaction used was by poker vibration as it is freely available. Hand compaction by rodding was also carried out to a limited extent (for water-cement ratio of 0.65 which is a middle value in the range) to identify whether the method of compaction is significant.

4.1.6. Curing

Sri Lanka specification for building works[6] specifies that curing shall be carried out for 14 days with units immersed in water (not earlier than 16 hours after casting) for the first 7 days, and thereafter kept wet by stack curing (stack not higher than 1.2m) for the next 7 days. Additionally, cavities of hollow blocks should be filled with sand (in wet stack) and cured as above.

In selecting a method of curing, the following methods were also considered: (i) low pressure steam curing; (ii) covering with gunny bags, not earlier than 16 hours after casting, and sprinkling water intermittently to keep the block continuously wet for 14 days; (iii) immersion of block, not earlier than 16 hours after casting, in water for 28 days; and (iv) immersion of block, not earlier than 16 hours after casting, in water for 7 days and sprinkling water for the next 21 days after placing in a stack not higher than 1.2m.

Factors considered in selection of a suitable curing method were: (a) testing of blocks was to be carried out after 7 days of casting to enable alterations to the experimental programme depending on available results and also to compress the study period; (b) in order to keep any errors of investigation on the conservative side, a slightly inferior method of curing was preferred; (c) it is important to select a method that can be adopted at any site with minimum effort and cost; and (d) blocks in this study (with low cement content and high water-cement ratio) are different from high cement content and low water-cement ratio blocks produced by machine casting, and require higher priority for prevention of evaporation than provision of a supply of water from the outside to sustain the chemical reactions of cement.

Covering with gunny bags, not earlier than 16 hours after casting, and sprinkling water intermittently to keep it moist for 7 days from casting was the method adopted.

4.1.7. Maximum size of aggregate

Selection of the maximum size of aggregate will depend on the following considerations: (i) CP 110[13] and BS 882[14] specify it to be 40, 20,14, or 10mm; (ii) as specified in BS 5337[12], maximum size of coarse aggregate should not be greater than one-quarter of the minimum thickness of the member, where minimum thickness is taken as width for solid blocks, and web or shell thickness for hollow blocks; (iii) minimum thickness of external shell or webs of hollow blocks shall not be less than 25mm or 1.75 times the nominal maximum size of the aggregate[7].

Considering that width of the solid block selected was 140mm and that shell or web thickness of the hollow block selected was 50mm, it was decided to use a maximum aggregate size of 20mm for solid blocks and 12mm for hollow blocks. Adoption of 12mm size was influenced by the difficulty of obtaining 10mm size locally.

4.1.8. Method of mixing

This is likely to affect the very dry mixes used in machine cast block production. As wet mixes are used for hand cast block production, this is unlikely to be significant.

4.1.9.Type of cement

Type of cement may affect strength of blocks, as for instance masonry cement cannot be used economically for the production of blocks. As only ordinary Portland cement is used in Sri Lanka, this variable did not change. The cement was bought at the same time from one source and it belonged to a leading brand in Sri Lanka.

4.1.10. Mould

The mould used for casting blocks influences production greatly and contributes to the viability of hand casting as a means of block production by maintaining close dimensional tolerances of the blocks cast, and by enhancing production with quick demoulding capacity. This aspect was studied earlier[1] and the timber moulds used were inexpensive and could be easily demoulded without damaging the green block after only the initial set (approximately 1 hour) of cement. The mould used has hinges on three sides and opens up leaving the block in position as shown in Figure 1. In the case of hollow blocks, timber pieces defining the cavities are removed immediately after casting and side mould removed after initial set of cement.

4.2. Test programme

Mix proportion and water-cement ratio were the two variables most effective in influencing the properties of blocks. For each block type, mix proportion was maintained at 1:3:6 proportion as a richer mix will be uneconomical and a leaner mix may not provide the required strength. However, water-cement ratio was varied. The other variables were held constant at appropriate values or conditions as stated in the preceding sections.

The compressive strength of blocks was determined at 7 days. Testing was confined to compressive strength since effects of durability tests, namely drying shrinkage and wetting expansion, are at safe levels due to low cement contents and can be further minimised by proper curing and suitable detailing. Ten blocks were cast to study the behaviour of a block represented by a certain combination of variables and this was in accordance with BS 2028[4] and SLS 855[7]. Those ten blocks were done over several days, using several separate batches of concrete, to simulate incidental variations that can affect the casting operation. For each group of two blocks representing a certain combination of variables, one cube was cast and tested to note any variations in cement properties within a bag of cement or in different bags of cement. Cubes also helped to assess the influence of poker vibration and hand compaction.

All measurements such as dimensions, density, width of cavity, volume of cavity, compressive strength etc. and reduction of results were carried out in accordance with SLS855[7]. The test programme consisted of production and testing of 30 hollow blocks, 70 solid blocks, 48 cubes, and other tests such as aggregate grading and density.

4.3. Experimental results

Since blocks were tested at 7 days, it was necessary to use a relation between 28-day and 7-day compressive strengths. In CP 110[13] this ratio (28-day compressive strength/7-day compressive strength) varied from 1.389 to 1.515, depending on grade of concrete. According to Neville[15] this ratio varies between 1.3 and 1.7 but the majority of results fall above 1.5. As a conservative value, it was decided to use 1.3 which was also used by previous investigators[1,2,3].

From the test results, compressive strengths of blocks were calculated as follows: (a) for solid blocks compressive strength was based on bed area of blocks; (b) for hollow blocks for use in hollows unfilled condition, compressive strength was based on gross bed area, while those for use in hollows filled condition, compressive strength was based on net bed area after deducting area of cavities as specified in BS 5628[11].

The following conclusions were made from the experimental results: (a) There is a very close correlation between strength of block and density, and this can be used in selection of blocks for purchase from a batch; (b) Optimum water-cement ratio for 1:3:6 (20mm) mix is in the range 0.7 to 0.8, while that for 1:3:6 (12mm) mix is in the range 0.9 to 1.0, (c) The 1:3:6 (20mm) mix can attain grade 20 concrete strength (10N/mm^2), while 1:3:6 (12mm) mix cannot attain the grade 10 concrete strength; (d) As shown in Figure 2, the following blocks can be recommended for the lowermost storey of buildings of the stated number of storeys:

(i) 3-storeys - Solid block (440mm long x 140mm wide x 215mm high); 1:3:6 (20mm); water-cement ratio 0.7 to 0.8 Mortar equivalent to designation IV.

(ii) 4-storeys Solid block (dimensions as above); 1:3:6 (20mm); water-cement ratio 0.7 to 0.8; Mortar equivalent to designation IV.

(iii) 5-storeys - Solid block (dimensions as above); 1:3:6 (20mm); water-cement ratio 0.7 to 0.8; Mortar equivalent to designation II;

(e) As shown in Figure 3, hollow blocks with 1:3:6 (12mm) mix cannot be used for the lowermost storey of 4 and 5-storeyed buildings. However, if hollows are filled, it is possible to use hollow blocks with 1:3:6 (12mm) mix for the lowermost storey of 3-storeyed buildings, but this is not recommended since the cost study indicated that blocks with hollows filled are expensive; (f) The surface finish of the blocks cast with 1:3:6 mix was rough. Hence, either plastering should be carried out or the rough finish should be boldly exhibited as an architectural feature; and (g) As shown in Figure 2, for a water-cement ratio of 0.65, a mid-value in the range 0.55 to 0.80, there was no significant difference between hand compaction and poker vibration. This confirms earlier findings[1] for reasonably wet mixes.

5.0. Cost Study

5.1. General

This was undertaken to decide on: (a) a suitable type of block when hollow blocks and solid blocks are both suitable for a particular application; (b) the mortar mix to be used for blocklaying when several mixes are available for the same block to attain the required wall strength; (c) whether blockwork is economical compared to alternative types of walling available for the same application.

Cost formulae were developed using standard worknorms in Sri Lanka and observed output during casting of blocks. These cost formulae will help the user to update the cost information as rates and prices vary.

Notations used in the formulae are given below with the assumed current prices or rates (as at 31st May 1993) given inside brackets: a proportion of lime in the mortar mix; AI - cost of one cube of coarse aggregate 20mm or 12mm (Rs.2400.00); b - proportion of sand in the mortar mix; B - Cost of one brick (ordinary - Rs.1.00 and wirecut - Rs.5.50) C - Cost of 50Kg of cement (Rs.240.00); L - Labour cost per 8 hour day (Rs.150.00); Li - Cost of lime per Kg (Rs.3.75); M - Wage for a mason per 8 hour day (Rs.250.00); p - Water-cement ratio; S - Cost of one cube of sand (Rs.800.00); t - wall thickness in mm; W - Cost of one litre of water (Rs.0.0025); X - Bamboo scaffolding cost per metre of plan length (Rs.22.50).

5.2. Formulae for solid blockwork

<u>Material cost per solid block 1:3:6 (20mm) (F1)</u>

$$F1 = \frac{[0.61C + 0.22S + 0.045(AI) + 30.401(p)W]}{(7.39 + 1.765p)}$$

Note: See 5.1. for the notation used.

<u>Material cost per square of blockwork in bed joints (F2)</u>

$$F2 = \frac{[3.01C + 58.9(a)(Li) + 0.037(b)S + 90.3W]}{(1.62 + 0.251a + 0.849b)}$$

<u>Note:</u> p varies from 0.6 (for 1:0:3 mix) to 1.5 (for 1:0:8 mix). Lower value was taken so that cost will be highest.

<u>Labour cost of casting blocks per square (F3)</u>

F3 = 12.5L

Labour cost of laying blocks per square (F4)

$F4 = 1.15\,(2M + 5L)$

Labour cost of plastering per square (Internal plaster - F51; external plaster - F52)

$F51 = 0.75M + 1.5L$
$F52 = M + 3L$

Note: Internal plaster (2 lime : 5 sand) and external plaster (1 cement : 1 lime : 5 sand).

Material cost of plastering per square (Internal plaster - f61; external plaster-f62)

$F61 = 77.557(Li) + 0.07S$
$F62 = 0.8C + 23.864(Li) + 0.07S$

Scaffolding cost (F7)

$F7 = 71.7x$

Total cost of 1:3:6 blockwork per square (nternal and external plaster - C1; internal plaster on one side only - C2)

$C1 = 100F1 + F2 + F3 + F4 + F51 + F52 + F61 + F62 + F7$

$C2 = C1 - F52 - F62$

5.3. Formulae for hollow blocwork

Material cost per hollow block 1:3:6 (12mm) (F1)

$$F1 = \frac{[0.475C + 0.0175S + 0.0351(A1) + 23.759(p)W]}{(7.39 + 1.765p)}$$

Material cost per square of blockwork in bed joints (F2)

$$F2 = \frac{[4.64C + 90.796(a)(Li) + 0.057(b)S + 139.2W]}{(1.62 + 0.251a + 0.849b)}$$

Note : p taken to be 0.6 as in the earlier case.

Labour cost of casting blocks per square (F3)

$F3 = 12.5L$

Labour cost of laying blocks per square (F4)

$F4 = 1.15\,(2M + 5L)$

Labour cost of plastering per square (Internal plaster-F51; external plaster - F52)

$F51 - (0.75M + 5L)$

$F52 = (M + 3L)$

Note : Internal plaster and external plaster as stated earlier.

Material cost of plastering per square (internal plaster - F61; external plaster - F52)

$F51 = (0.75M + 1.5L)$

$F52 = (M + 3L)$

Note : Internal plaster and external plaster as stated earlier.

Material cost of plastering per square (internal plaster - F61; external plaster - F62)

$F61 = 77.557(Li) + 0.07S$

$F62 = 0.8C + 23.864(Li)\ 0.07S$

Scaffolding cost (F7)

$F7 = 71.7x$

Material cost of filling hollows per square with 1:3:6 concrete

$$F8 = \frac{[22.434C + 0.8278S + 1.6556(AI) + 1121.7(p)W]}{(7.39 + 1.765(p))}$$

Labour cost of filling hollows per square with 1:3:6 concrete

$F9 = 6.25L$

Total cost of 1:3:6 (12mm) hollow blockwork per square (internal and external plaster - C1; internal plaster on one side only - C2)

$C1 = 100F1 + F2 + F3 + F4 + F51 + F52 + F61 + F62 + F7$

$C2 = C1 - F52 - F62$

Note: For case with hollows filled add (F8 + F9) to C1 and C2

5.4. Formulae for ordinary brickwork

Labour cost of bricklaying per square (F1)

$$F1 = 0.003281(t)\,(3M + 9L)$$

Material cost per square (F2)

$$F2 = 0.003281(t)\,(1450B + 0.37S + 2.32C)$$

Note: Mortar mix is 1 cement : 8 sand.

Labour cost of plastering per square internally and externally (F3)

$$F3 = 1.42M + 2.83L$$

Note: Internal plaster and external plaster as stated earlier.

Material cost of plastering per square internally and externally (F4)

$$F4 = 0.8C + 101.421(Li) + 0.14S$$

Cost of scaffolding and cost of water (F5)

$$F5 = 71.7X + 50W$$

Total cost of ordinary brickwork in 1 cement : 8 sand mortar(C1)

$$C1 = F1 + F2 + F3 + F4 + F5$$

5.5. Formulae for wirecut brickwork

The formulae are the same as for ordinary brickwork with F2 changed to permit the use of 1 cement : 5 sand mortar. Amended F2 is given below.

$$F2 = 0.003281(t)\,(1450B + 0.23S + 3.7C)$$

Also, delete F3 and F4 terms so that brickwork is unplastered.

5.6. Cost Analysis

Table 3 gives material cost of mortar while Table 4 gives comparable walling types. Table 5 gives a summary of wall costs. The following conclusions were reached from the cost study: (a) The extent of cost reduction possible by selecting a particular mortar from a given mortar designation is insignificant; (b) Cost reduces as mortar designation changes from I to IV but the extent of reduction is small; and (c) Most economical walling types for the lowermost storey of 3 to 5-storeyed building are: (i) 3-storeyed ordinary brickwork; (ii) 4-storeyed - external surface unplastered solid blockwork; and (iii) 5-storeyed - external surface unplastered solid blockwork.

6. Main Conclusions

The following main conclusions can be made from this study:

(a) The blocks recommended for the lowermost storey of typical buildings are:

(i) 3-storeys- Solid block (440mm long x 140mm wide x 215mm high); 1:3:6 (20mm) mix; water-cement ratio of 0.7 to 0.8; mortar equivalent to designation IV;

(ii) 4-storeys - Solid block (dimensions as above); 1:3:6(20mm) mix; mortar equivalent to designation IV;

(iii) 5-storeys - Solid block (dimensions as above); 1:3:6(20mm) mix; water-cement ratio of 0.7 to 0.8; mortar equivalent to designation II;

(b) Surface finish of the blocks cast with the above mix is rough. Hence, either plastering should be done or the rough finish exhibited as an architectural feature;

(c) Most economical walling type for the lowermost storey of 3 to 5-storeyed buildings are:- (i) 3-storeyed - ordinary brickwork; (ii) 4-storeyed - external surface unplastered solid blockwork; (iii) 5-storeyed - external surface unplastered solid blockwork; and

(d) selection of good blocks from a lot can be done by choosing heavier, distortion-free and crack-free blocks which possess bedding surfaces perpendicular to block faces, sharp edges, uniform surface finish and freedom from broken edges, honey-combing or visually noticeable dimensional variations.

7.0. References

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Serial Number	Size (mm) length x width x height	a	b	c	d	e	f	g	h
1	440 x 100 x 125	Y	Y	Y	Y	Y	Y	Y	Y
2	440 x 215 x 130	Y	Y	Y	N	Y	N	N	Y
2	275 x 215 x 215	Y	Y	Y	N	Y	N	N	Y
4	390 x 140 x 190	Y	Y	Y	N	Y	N	Y	Y
5	390 x 190 x 190	Y	Y	Y	N	N	N	Y	Y
6	390 x 140 x 90	Y	Y	Y	N	Y	N	Y	Y
7	440 x 140 x 190	Y	Y	Y	N	Y	N	Y	Y
8	440 x 140 x 215	Y	Y	Y	N	Y	N	Y	Y
9	440 x 190 x 190	Y	Y	Y	N	N	N	Y	Y

Note 1: Y denotes compliance with a requirement, while N denotes non-compliance

Note 2: Requirements a to h are defined in the first paragraph of 2.2.

Table 1 - Compliance with necessary requirements by different solid blocks

Description	3-Storeys			4-Storeys			5-Storeys			6-Storeys			7-Storeys			8-Storeys		
	Solid	Hollow (empty cavity)	Hollow (filled cavity)	Solid	Hollow (empty cavity)	Hollow (filled cavity)	Solid	Hollow (empty cavity)	Hollow (filled cavity)	Solid	Hollow (empty cavity)	Hollow (filled cavity)	Solid	Hollow (empty cavity)	Hollow filled cavity)	Solid	Hollow (empty cavity)	Hollow(filled cavity)
Critical stress condition	a	a	a	a	a	a	a	a	a	a	b	b	b	b	b	b	b	b
Critical wall	IW	IW	IW	IW	IW	IW	IW	IW	IW	IW	IW	IW	IW	IW	IW	IW	IW	IW
Critical stress (N/mm^2)	0.718	0.443	0.443	0.977	0.604	0.604	1.215	0.753	0.753	1.486	0.922	0.922	1.815	1.333	1.333	2.172	1.356	1.356
f_k required (N/mm^2)	3.03	1.6	1.6	4.12	2.19	2.19	5.13	2.72	2.72	6.27	3.33	3.33	7.66	4.09	4.09	9.17	4.90	4.90
Compressive strength(N/mm^2) of block with mortar designation I	5.0	2.8	2.8	5.0	3.5	3.5	10.0	4.3	4.3	15.0	5.3	5.2	35.0	7.0	6.5	35.0	10.0	8.2
Compressive strength(N/mm^2) of block with mortar designation II	5.0	2.8	2.8	5.0	3.5	3.5	10.0	4.3	4.3	20.0	5.4	5.3	35.0	7.8	7.0	35.0	11.7	8.8
Compressive strength(N/mm^2) of block with mortar designation III	5.0	2.8	2.8	5.0	3.5	3.5	15.0	4.3	4.3	35.0	5.4	5.3	35.0	8.2	7.0	35.0	12.9	9.0
Compressive strength(N/mm^2) of block with mortar designation IV	5.0	2.8	2.8	7.0	3.5	3.5	20.0	4.8	4.8	35.0	6.8	6.3	35.0	11.4	8.6	35.0	17.5	11.7

Note 1 : $a = 1.4G_k + 1.6Q_k$; $b = 1.2G_k + 1.2Q_k + 1.2W_k$

Note 2 : IW = interior crosswall ; EW = exterior crosswall

Note 3 : Hollow block size (mm) = 440 long x 215 wide x 215 high ; Solid block size (mm) = 440 long x 140 wide x 215 high

Table 2 - Compressive strength of blocks for different number of storeys

	Cement:lime:sand	Cost in Rupees
Mortar designation I	1:0:3 1:0:3	194.73 -do-
Mortar designation II	1:½:4 1:0:3	185.06 194.73
Mortar designation III	1:1:5 1:0:5	178.47 148.44
Mortar designation IV	1:2:9 1:0:8	146.55 114.05

Note 1: BS 5628 mix proportions are given first and Sri Lanka building specification mix proportions are given below for each mortar designation.

Note 2: Total cost of blockwork per square varies from Rs.8953.20 to Rs.10071.37.

Note 3: Costs with prices and rates as at 31st May 1993.

Table 3 - Material cost of mortar in bed joints per square of blockwork

	Number of storeys		
Description	3	4	5
Solid blockwork 1:3:6 (20mm)	With mortar of designation IV	With mortar of designation IV	With mortar of designation II
Hollow blockwork 1:3:6 (12mm) with unfilled cavities	Not suitable	Not suitable	Not suitable
Hollow blockwork 1:3:6 (12mm) with filled cavities	With mortar of designation IV	Not suitable	Not suitable
Ordinary brickwork in mortar of designation IV	225 mm thick wall	450 mm thick wall	675 mm thick wall
Wirecut brickwork in mortar of designation III	225 mm thick wall	225mm thick wall	225 mm thick wall

Note: All blockwork walls are in Stretching bond, while brickwork walls are in English bond.

Table 4 - Comparable walling types

Description of wall construction		Number of storeys 3	4	5
Solid blocks (1:3:6 (20mm))	Plastered	9990.69 (1:0:8 mix)	9990.69 (1:0:8 mix)	10071.37 (1:0:3 mix)
	Unplastered	8953.20 (1:0:8 mix)	8953.20 (1:0:8 mix)	9033.88 (1:0:3 mix)
Hollow blocks (1:3:6 (12mm)) with unfilled cavities	Plastered	Not suitable	Not suitable	Not suitable
	Unplastered	-do-	-do-	-do-
Hollow blocks (1:3:6(12mm)) with filled cavities	Plastered	11317.24 (1:0:8 mix)	Not suitable	Not suitable
	Unplastered	10279.75 (1:0:8 mix)	-do-	-do-
Ordinary bricks (1:0:8 mix)	Plastered	6327.46 (225mm thick)	9577.72 (450mm thick)	12827.97 (675mm thick)
Wirecut bricks (1:0:5 mix)	Both sides unplastered	9842.37 (225mm thick)	9842.37 (225mm thick)	9842.37 (225mm thick)

Note 1: Costs as at 31st May 1993 prices and rates.

Note 2: Plastered refers to a wall with both external and internal faces plastered. Unplastered refers to a wall with external face exposed but internal face plastered.

Table 5 - Cost (in Rupees) per square of comparable walling types