PRODUCTION INFORMATION ON HAND CAST CEMENT-SAND HOLLOW BLOCKS

by

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Abstract

As a wall material cement-sand blockwork is still the leading alternative to brickwork. Due to high initial cost of blockmaking machines, only few such machines are available in Sri Lanka and the availability of machine cast blocks is restricted to a few urban areas only. Hens hand cast blocks have considerable scope. Unlike machine cast blocks, hand cast blocks are not produced using reliable engineering information and this leads to high variability and uncertainty in strength of blocks. This study was directed to provide production information for hand cast hollow blocks for use up to two-storeyed buildings.

A literature survey was conducted to identify the available knowledge and based on it, a test programme was conducted involving casting and testing of about 100 hollow blocks. The required target crushing strengths were obtained from structural calculations performed on a typical building. A cost analysis was also conducted so that user can ascertain costs depending on current market prices.

In addition to recommending production information for hollow blocks up to two-storeyed buildings, the investigation revealed that at current prices of building materials and wages, hollow blockwork is not economical for up to two-storeyed buildings as compared to brickwork or solid blockwork.

Introduction

Of the durable materials, ordinary brickwork is the most widely used walling material in Sri Lanka, while blockwork is the leading alternative ahead of its closest rivals, rubble masonry and wire-cut brickwork. The advantages of blockwork are :-

(a) Blockwork can be used for low strength single-storey walls as well as high strength walls of multi-storey loadbearing masonry buildings;
(b) The time saved in construction is higher, because of the bigger size of the block covering a larger area, simplicity of the stretching bond used, and lesser mortar joints;
(c) Blocks can be manufactured as a high capacity commercial venture or as a cottage industry in anyone's back-yard;
(d) Strength of a block can be varied (by varying mix proportions and water/cement ratio) to suit the desired application thus minimising the cost;
(e) The dimensional tolerances of a block are better than those of a brick;
(f) As blockwork is durable without a plaster, it can be left unplastered;
(g) Blocks are not easily broken, thus resulting in less wastage;
(h) Cracks, most frequently, occur at mortar joints rather than across the blocks making repair easy;

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(i) Various surface finishes can be easily incorporated to block during casting. The disadvantages of blockwork are:-

(i) The installation of services is difficult;
(ii) It is difficult to drive nails without installing timber plugs;
(iii) As blocks are difficult to break special blocks needed should be produced seperately;
(iv) Subsequent alterations to a blockwork wall are difficult;
(v) Shrinkage cracks can occur due to the use of inadequately cured blocks and cracks at block-mortar interface can occur due to use of blocks without proper dusting. The significant demand and popularity prevalent for blockwork can be attributed to the advantages offered by blockwork overcoming its disadvantages.

Blocks can be machine cast or hand cast. Machine cast blocks are superior because high degree of compaction, higher output, better finish and consistent structural properties can be achieved. The need for large capital investments to install these machines, transporting and marketing difficulties restrict the availability of machine cast blocks to a handful of urban areas only. Thus hand cast blocks will continue to retain its importance in Sri Lanka. Further, hand cast block is more amenable to applying decorative finishes at the casting stage and hence its demand should grow in the future.

Use of hand cast cement-sand solid blocks for single and two-storeyed buildings was studied by Chandrakeerthy et al (1) and the necessary production information is available. No such information, compatible with construction practices used in Sri Lanka, is available for hand cast hollow blocks for single and two-storeyed buildings, and this study was directed towards that goal.

The objectives of the investigation

The objectives of the investigation were:-

(a) To determine crushing strengths of hollow blocks for single-storey and tow-storey typical buildings;
(b) To recommend suitable mix proportions and other controllable data (such as water/cement ratio, degree of compaction) for the above applications;
(c) To study the economy of hollow blocks with other alternatives;
(d) To study the typical strengths of machine cast/hollow blocks currently marketed by the leading blockmakers.

The investigation

The investigation consisted of a literature survey, an experimental study, determination of target strengths of hollow blocks for single and two-storeyed buildings, and a cost analysis.

The literature survey (2) helped to identify the main parameters which govern the performance of blocks as method of curing, size of blocks, grading of aggregate, degree of compaction, water/cement ratio, mix proportions and type of cement. It also provided information on scope of work and methodology adopted by previous researchers as well as information on specifications applicable to hollow blocks.

As mix proportions and water/cement ratio are the most influential parameters, these were selected as control variables while other parameters were kept constant during the experimental study. The experimental programme consisted of testing hollow blocks with varying values of water/cement ratio and mix proportions to achieve the required target strengths. As a starting point the optimum water/cement ratio of 0.9 and 1 cement : 8 sand mix recommended by Chandrakeerthy et al (1) were selected. Starting value of water/cement ratio for each mix was obtained by the method recommended by Chandrakeerthy et al (1),

$$\frac{\text{Predicted optimum water/cement ratio for mix A}}{\text{Optimum water/cement ratio for mix B}} = \frac{\text{Sand in mix A}}{\text{Sand in mix B}}$$

This method, which maintains the same water content and ignores the volume occupied by cement particles, was found to predict the optimum water/cement ratio reasonably well but always less than the actual optimum. The mix proportions, predicted optimum water/cement ratios and water/cement ratios tested are given in Table 1. As the method for determination of transverse breaking load in BS 2028(3) and BS 6073(4) uses only five repetitions, it was considered adequate. For each condition defined by a set of variables five blocks were cast to allow for variability to be expected in practice. Further, the casting sequence was arranged so that each mix was cast on different days so that variation that may occur in practice can be simulated in the laboratory without use of a large sample.

Target strengths of hollow blocks for use in single and two-storeyed buildings were computed in accordance with BS 5628(3) using the block size and the usual spans and loads encountered locally.

Cost analysis was carried out using currently accepted worknorms in Sri Lanka. Formulae developed for blockwork and brickwork, can be used to obtain cost, while cost of building materials and cost of labour undergo variations.

Analysis of results and recommendations

General

Recommendations were made based on analysis of results and the information collected from all the sections of the investigation. These were presented under appropriate headings, in such a sequence, to facilitate systematic decision making by the prospective blockmaker, as the hand cast blockmaking process to be adopted is evolved.

Sizes of hollow blocks

Sizes of hollow blocks should satisfy (3, 4) the following criteria :-

(a) Hollow block should be greater than the size of bricks;

(b) Height of the block should not exceed its length or six times its thickness;

(c) Thickness should be not less than 100mm;

(d) Width of cavity, as measured at right angles to the face of the block as laid in the wall, should not exceed 65% of the thickness of the block;

(e) Volume of cavity or cavities should not be greater than 50% or less than 75% of the gross volume of the block;

(f) Density should not be less than 1500 kg/m^3;

(g) Hollow blocks should be as large as possible so that maximum possible wall area can be covered per given thickness, but should not be heavier than 9 kg for single handed laying and 32 kg for two handed laying;

(h) Main dimensions of the structure should be a multiple of coordinating size of the block to minimise breaking or cutting of blocks;

(i) Minimum thickness of the external shell of hollow blocks should be not less than 15mm or 1.75 times the nominal maximum size of the aggregate (not applicable for cement-sand blocks), whichever is greater;

(j) Whenever possible external sizes should satisfy the specifications of BS 2028(3) and BS 6073: Part 2 (5).

It was possible to select the thickness from 100, 140, 190 and 215mm (metric sizes) or 102, 152 and 219mm (imperial sizes). Selection of a small thickness will increase the stresses on the wall and also makes shell wall thinner which in turn reduces crushing strength. Hence a greater thickness was assumed and the block size adopted was 448mm (17 5/8") long x 219mm (8 5/8") thick x 219mm (8 5/8") high with two cavities 140mm (parallel to length side of block) x 120mm symmetrically placed at a X-section parallel to the bedface of the block.

Target crushing strength of blocks

This was obtained from structural calculations according to BS 5628(8) with the following assumed data:-

(i) Span between walls = 7.0m;
(ii) Wall thickness = 219mm;
(iii) Wall height = 3.0m;
(iv) Roof angle = 20^{o};
(v) Imposed load on roof = 0.25 kN/m²;
(vi) Imposed load on floor = 1.5 kN/m²;
(vii) Density of cement-sand mortar = 23 kN/M³;
(viii) Dead load from roof on plan area = 0.85 kN/m²;
(ix) Dead load of the first floor = 3.6 kN/m².

Main steps of the calculation are summarised in Table 2 and the required crushing strength (28 days) of block for single-storey work was 0.689 N/mm² and that for two-storey work was 1.828 N/mm². Crushing strength was found to be independent of the mortar designation and hence the mortar designation (iv) (1 cement : 8 sand mix) was recommended.

The mould

The mould used should be capable of producing blocks to the following tolerances:-

(i) +3 and -5mm for length and height;
(ii) +2 and -2mm for thickness. The mould developed by Chandrakeerthy et al (6) is recommended for use with hollow blocks so that a higher production rate can be attained.

Materials

Sand used should satisfy BS 882(7). The sand used for experimental work was within the limits specified in BS 882 (7) for zone 2, fine aggregate.

In Sri Lanka, only O.P.C. is used and hence type of cement is not a variable.

% Volume reduction

Percentage volume reduction is a very important variable in block manufacture. In blockmaking machines this is fixed at a suitable value, and to obtain blocks of consistent quality using hand casting, this variable should be carefully controlled.

The volume reduction recommended

(a) should be attainable with reasonable compactive effort;
(b) should not reduce crushing strength of the block appreciably from the optimum attainable. Hence a volume reduction of 30% is recommended(1). Compaction should be done in two layers and each layer should be compacted to attain this volume reduction.

Mix proportion and water/cement ratio to be used

The experimental results are presented in Figure 1. The seven day crushing strengths of blocks were converted to 28 day strengths using a factor. This factor, which is considered to vary from 1.3 to 1.7, was taken as 1.3 as recommended (1) so that actual strengths will be higher than those given. This will ensure greater factor of safety.

Recommended mix proportions and water/cement ratios are :

(i) for single-storey loadbearing walls, hollow blocks to be cast out of 1 cement : 8 sand mix with a water/cement ratio of 0.9 to 1.0; and
(ii) for two-storey loadbearing walls, hollow blocks to be cast out of 1 cement : 4 sand mix with a water/cement ratio of 0.45 to 0.55.

In using Figure 1 following considerations should be noted :-

(a) Target strengths are given for general guidance only and if building details are available actual target strengths should be obtained by structural calculations;
(b) For buildings larger than the typical building considered, target strengths should be found;
(c) Eccentricity of two-storey wall and ratio of strength of wall to strength of block change for other block sizes;
(d) Crushing strength of blocks for different water/cement ratios should be adjusted for different block sizes using data in Tables 2b & 2c of BS

5628 (8) for 1:8 mix/mortar designation (iv).

Casting process

The mould (6) was assembled on a flat surface preferably with an overlay of polythene, to make dismantling easy, and mould oil was applied inside the mould. Spacer blocks were used to correctly position the hollows.

Cement, sand and water were mixed to correct proportions. The volume needed to fill half the mould after 30% volume reduction was found. This quantity was placed in the mould and compacted with a compacting tool till mortar half fills the mould. Next layer was placed and compacted and earlier ensuring that 30% volume reduction was attained.

As soon as the casting was completed, two hollows were removed. Demoulding was done after 24 hours from completion of casting.

The above method is recommended for use.

Curing

Curing was commenced 24 hours after the completion of casting. Water was sprinkled daily for 7 days (till tested). The top and side faces of the blocks were protected with gunny bags, which were removed when watered.

The above method of curing is recommended with water sprinkled for at least 21 days. This curing period is necessary

(a) to obtain the highest crushing strength;
(b) to minimise cracking due to drying shrinkage for which hollow blocks are vulnerable, due to its thin shell.

Costs analysis

Cost equations were developed using standard worknorms and observed output during casting of hollow blocks. Cost of 9" brickwork was expressed per square instead of cube for ease of comparison.

Notations used in the formulae and the assumed current rates are given below:-

M = Wage of a mason for an 8 hour shift (Rs.75/-); L = Wage of a labourer for an 8 hour shift (Rs.45/-); C = Cost of a 50kg bag of cement (Rs.120/-); S = Cost of a cube of sand (Rs.285/-); B = Cost of 1000 bricks (Rs.600/-); Li = Cost of a bushel of lime (Rs.45/-); n = 1 cement : n sand mix of block; W_b = water/cement ratio of block; W_m = Water/Cement ratio of mortar layer; m = 1 cement : m sand mix of mortar bed.

Cost of casting hollow blocks per square (C_1)

$$C_1 = 132\left[\frac{2L}{24} + \frac{C + 1.225n\, S \times 10^{-2}}{1.13+1.49n + 3.56W_b}\right]$$

Cost of mortar for laying hollow blocks per square (C_2)

$$C_2 = \frac{6.56\ (C + 1.225m\ S \times 10^{-2})}{(0.56 + 0.739m + 1.76\ W_m)}$$

Cost of labour for laying hollow blocks per square (C_3)

$$C_3 = 1.32\ (2M + 3L)$$

Cost of unplastered 9" brickwork per square at ground floor (C_4)

$$C_4 = 0.75(3M+5L) + 1.09B + 0.278\ S + 1.74\ C$$

Cost of unplastered 9" brickwork per square at first floor (C_5)

$$C_5 = 0.75\ (3M+7L) + 1.09B + 0.278\ S + 1.74\ C$$

Cost of internal plaster (C_6)

Internal plaster consists of 1 lime : 2½ sand plaster 15mm thick finished smooth with lime putty.

$$C_6 = (0.75\ M + 1.5L) + 0.07\ S + 3.25\ Li$$

Cost of external plaster (C_7)

External plaster consists of 1:1:5 plaster 15mm thick.

$$C_7 = (0.67M + 1.33L) + 0.07S + Li + 0.8C$$

Formula by Chandrakeerthy et al (1) was used to obtain cost of solid blockwork per square.

Following data were also obtained :-

(i) $n = 8$ for ground floor and 4 for first floor; $m = 8$; $W_m = 1.5$; $W_b = 0.95$; for ground floor and 0.5 for first floor.

Costs of different walls are presented in Table 3 and the following conclusions can be made from the cost analysis at current rates :-

(a) Hollow block walls are expensive than brick walls;
(b) Hollow block walls are expensive than solid block walls upto two-storeyed buildings;
(c) Although the above results are related to the size of blocks considered, it is unlikely that other block sizes may significantly alter the results.

Comparison with machine Cast hollow blocks

Machine cast blocks of three manufacturers were found to be popular and freely available in the market. These three types of machine cast blocks (all of coordinating size 400mm long x 200mm thick x 200mm height) were tested and their crushing strengths were:- 1.95, 2.50 and 4.40 N/mm^2. These blocks have excess strength for single-storey construction and more than adequate strength for two-storey construction.

Conclusions

The following conclusions can be made from this investigation :-

(a) Recommendations made for various important aspects of the hollow block-making process should help to produce hollow blocks adequate for up to two-storeyed buildings and of consistent quality;

(b) For single-storey loadbearing walls, hollow blocks of the size specified cast out of 1:8 mix with a water/cement ratio of 0.9 to 1.0 are recommended;

(c) For two-storey loadbearing walls, hollow blocks of the size specified cast out of 1:4 mix with a water/cement ratio of 0.45 to 0.55 are recommended;

(d) Method adopted for obtaining a trial value of water/cement ratio for cement-sand mixes seems to be reasonably close to the optimal value but always lesser than the optimal value;

(e) Cost analysis at current rates indicated that hollow block walls are expensive than solid block walls or 9" brick walls, for use in up to two-storeyed buildings;

(f) Machine cast hollow blocks of leading manufacturers have more than adequate strength for two-storeyed loadbearing walls.

References

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(4) BS 6073: Part 1: 1981, "Precast concrete masonry units - Part 1 - specification for precast concrete masonry units", B.S.I., London.

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(7) BS 882: Part 2: 1973, "Aggregate from natural sources for concrete", B.S.I., London.

(8) BS 5628: Part 1: 1978, "Code of practice for the structural use of masonry - Unreinforced masonry", B.S.I., London.

Table 1 - Cement-sand mixes and water/cement ratios tested

The mix tested	Predicted optimum water/cement ratio	Water/cement ratio tested		
1 cement : 14 sand	1.575	1.575	1.675	1.775
1 cement : 12 sand	1.35	1.35	1.45	1.55
1 cement : 10 sand	1.125	1.125	1.225	1.325
1 cement : 8 sand	0.9	0.9	1.0	1.1
1 cement : 6 sand	0.675	0.675	0.775	0.875
1 cement : 4 sand	0.45	0.45	0.55	0.65

Table 2 - Determination of crushing strength of blocks

Description	Single-storey	Two-storey
Design load ($1.4G_k + 1.6\ Q_k$)	19.642 kN/m	59.47 kN/m
Eccentricity (t = thickness of wall)	0.167t	0.095t
β factor for slenderness	0.7128	0.887
f_k required	0.442 N/mm²	1.172
Ratio of height/thickness of block	1.0	1.0
Mortar designation in the wall	(iv) = (1:8)	(iv) = (1:8)
Required crushing strength of units	0.689 N/mm²	1.828 N/mm²

Table 3 - Summary of cost analysis results

Description		Cost in rupees
Unplastered hollow block wall per square -		
$(C_1+C_2+C_3)$	Single-storey	2166.04
	Two-storey	2971 32
Unplastered solid block wall per square -		
(Reference 1)	Single-storey	997.78
	Two-storey	1252.02
Unplastered brick wall (9") per square -		
	Single-storey (C_4)	1279.53
	Two-storey (C_5)	1347.03
Plastered internal brick wall (9") per square -		
Single-storey (C_4+2C_6)		1859.43
Two-storey (C_5+2C_6)		1926.93)
Plastered external brick (9") per square -		
Single-storey $(C_4+C_6+C_7)$		1840.53
Two-storey $(C_5+C_6+C_7)$		1908.03
Plastered internal hollow block wall per square -		
$(C_1+C_2+C_3+2C_6)$	Single-storey	2745.94
	Two-storey	3551.22
Plastered external hollow block wall per square -		
$(C_1+C_2+C_3+C_6+C_7)$	Single-storey	2727.04
	Two-storey	3532.32

FIGURE 1 - RELATIONSHIP OF MIX PROPORTIONS, WATER/CEMENT RATIO AND TARGET CRUSHING STRENGTH OF HOLLOW BLOCKS