PRODUCTION OF HAND-CAST SOLID CEMENT-SAND BLOCKS

by

Dr. S. R. De S. Chandrakeerthy, T. Kumarasena & A. Wallooppillai

1.0 Introduction:

As a wall material cement-sand block work is still the leading alternative to brick work. Although machine made cement-sand blocks are superior to hand-cast blocks as regards strength, cost of raw materials consumed, and consistency of the quality, due to high capital cost of such machines, only a few such machines are available in Sri Lanka at present. These hand-cast blocks remain to be the widely used type locally.

BS 2028 (1) specifies suitable crushing strengths of blocks for various applications in buildings, but these values are too high as (a) some blocks are intended for use in load-bearing multi-storey structures, and (b) durability against frost attack is a major consideration in U. K. Hence, much lower crushing strengths can be used in Sri Lanka and it is useful to determine minimum crushing strength suitable for use in single and two-storey buildings where hand-cast blocks are primarily used locally.

A knowledge of important parameters which govern strength of blocks and suitable range of values for those parameters is essential for the manufacture of blocks. This information is not freely available and hence it is useful to establish the values of various parameters that give the required strengths of blocks.

In areas where bricks are freely available and transport costs are not excessive, blocks will be used only if they are cheaper than bricks. The cost of blocks is governed by price fluctuations of cement, sand and labour. Thus at one time blocks will be cheaper while at some other time bricks will be cheaper in the same area. Hence, it is also useful to know under what conditions cement-sand block work can be competitive against brick work.

Thus a need exists to investigate the production of hand-cast cement-sand blocks and this investigation attempts to fulfill that role to some extent.

2.0 The Objectives of the Investigation:

The objectives of the investigation were:

(a) to determine crushing strengths required for single storey and two-storey buildings usually found in Sri Lanka;

(b) to identify the important stages of the production process and the decisions to be made by the prospective block makers;

(c) to identify important parameters that govern strength of blocks;

(d) to determine how to control those important parameters for optimum strength development and to maintain consistent quality;

(e) to study the variation of cost of block work compared to brick work.

3.0 The Investigation

The investigation was carried out in five stages.

Stage 1 - Survey on previous literature on cement-sand blocks.

This survey (1,2,3,4) provided valuable information which enabled (a) to identify areas where information is not available which are applicable to hand-cast blocks; (b) to identify the information which can be applied directly or with some modifications.

Stage 2 - Survey on current practices adopted by block Manufacturers.

Survey proved to be a failure because (a) some manufacturers were reluctant to divulge key information such as mix proportions and method of manufacture; (b) information of some manufacturers was not backed with experimental results such as crushing strength; (c) some manufacturers consider mix proportion as the only parameter to be controlled while paying little attention to parameters such as water-cement ratio and % volume reduction.

Stage 3 - Theoretical work to establish crushing strengths required for single and two-storey buildings.

This was carried out in accordance with BS 5628 (5) and the usual spans and loads encountered locally.

Stage 4 - Experimental Investigation

Experimental investigation was conducted to cover areas where no relevant information was available from earlier stages of the investigation. Starting with the limited information gathered from Stage 1 of the investigation, experimental work commenced with a water-cement ratio of 0.5 (by weight) and
mix proportions of 1 cement: 8 sand (by volume). % volume reduction that can be achieved by hand compaction with reasonable effort without adverse loss of strength and the optimum water-cement ratio for this mix was found.

With water-cement ratio and % volume reduction at near optimum values blocks were tested to achieve the crushing strengths required for single-storey and two-storey buildings. Total of about 125 blocks were cast and tested. Further details of the experimental investigation are under appropriate headings in later sections of this paper.

Stage 5 - Cost analysis of block work.
Cost analysis of block work compared to its main competitor brick work was carried out. As the cost varies with fluctuation of raw material and labour costs formula were derived incorporating those parameters so that at any time relative costs can be easily compared.

4.0 Discussion of results and recommendations.
4.1 General - Although the investigation was originally intended to cover solid, hollow and cellular blocks, soon it was felt that the scope was too large. Hence it was decided to initially investigate
blocks suitable for low load carrying capacities such as those for single-storey and two-storey buildings. Solid blocks of small thickness can only be used for low load carrying situations mentioned above and the results reported here deal with such solid blocks. Investigation on hollow and cellular blocks is currently in progress, and it is hoped to (a) establish whether it is economical to use hollow and cellular blocks for single-storey and two-storey buildings in place of small thickness solid blocks;

(b) determine the range of crushing strengths that can be attained; (c) ascertain for what uses they are best suited.

Results and recommendations are based on the outcome of different stages of the investigation, and presented in the areas in which a prospective block maker is required to decide on various matters as the block making process is evolved.

FIG. 2.
NUMBER OF BLOWS VS.
VOLUME REDUCTION FOR 1:2. 9:1 MIX AND 0.5W/C

The mould was filled in two stages and each layer was given the specified number of blows.
4.2. Size of Blocks

BS 2028 (1) recommends the following sizes for solid blocks:

<table>
<thead>
<tr>
<th>Co-ordinating Size</th>
<th>Work Size</th>
<th>Length x Height</th>
<th>Length x Height</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 x 100 mm</td>
<td>390 x 90 mm</td>
<td>50 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>400 x 200 mm</td>
<td>390 x 190 mm</td>
<td>50, 65, 75, 90, 100 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>450 x 200 mm</td>
<td>440 x 190 mm</td>
<td>- do -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>450 x 225 mm</td>
<td>440 x 215 mm</td>
<td>- do -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 x 200 mm</td>
<td>490 x 190 mm</td>
<td>- do -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>600 x 200 mm</td>
<td>590 x 190 mm</td>
<td>- do -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>600 x 300 mm</td>
<td>590 x 290 mm</td>
<td>75 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Thamotheralingam (3) has recommended the following sizes for solid blocks:
18" x 9" (450 x 225 mm)
17 5/8" x 8 5/8" (440 x 215 mm) x 4" (100 mm)
12 3/8" x 9" (310x225 mm)
12" x 8 5/8" (300 x 215 mm) x 4" (100 mm)

The sizes recommended by BS 2028 are suitable for solid blocks and blocks of work size 17 5/8" x 8 5/8" x 4" (440x215x100mm) weighing approximately 21 kg. was used for the experimental investigation. Coordinating size is obtained by allowing a 10 mm (3/8") mortar bed round the block. Usual tolerances are ±3 mm & -5mm. Solid blocks of non-standard dimensions can also be used provided the following criteria are satisfied:

![Fig. 3. Curves of strength vs. volume reduction for different water cement ratios (7 day strengths)](image)

- o = 0.5 W/C
- o = 0.7 W/C
- o = 0.8 W/C
- o = 0.9 W/C

% Volume Reduction

% Volume Reduction

0.4 0.8 1.2 1.6 2.0 2.4

Strength N/mm²
4.3 Compressive strength of units:

This was obtained from structural calculations according to BS 5628 (5) with the following assumed data:

Span between walls = 7.0 m,     wall thickness = 100 mm;
Wall height = 3.0 m,     imposed load on roof = 0.25 kN/m²;
Imposed load on floor = 1.5 kN/m²;  roof angle 20°;
Density of blocks = 23 kN/m³.

Main values of the calculation are summarised below:

<table>
<thead>
<tr>
<th></th>
<th>Single-Storey</th>
<th>Two-Storey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design load</td>
<td>12.03 KN/m</td>
<td>36.38 kN/m</td>
</tr>
<tr>
<td>Electricity</td>
<td>0</td>
<td>7.6 mm</td>
</tr>
<tr>
<td>½ factor for slenderness</td>
<td>0.53</td>
<td>0.50</td>
</tr>
<tr>
<td>f_k required</td>
<td>0.80 N/mm²</td>
<td>2.55 N/mm²</td>
</tr>
<tr>
<td>ratio of height to thickness</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>compressive strength of units</td>
<td>0.80 N/mm²</td>
<td>2.55 N/mm²</td>
</tr>
</tbody>
</table>
For solid blocks of compressive strength less than 5.0N/mm² having a ratio of height to least horizontal dimension between 2.0 & 4.0, compressive strength of wall is equal to the compressive strength of units for any mortar designation. Thus compressive strength of block should be not less than the above values irrespective of the mortar used in the wall.

4.4. The Mould

Moulds for hand-cast blocks are usually made of timber. Pressure due to fluid mix on the mould is negligible, but to maintain close tolerances of the blocks, warping of the mould should be eliminated. Thus thickness of the mould should be at least 37.5 mm and preferably 50 mm.

It is preferable to make the mould so that demoulding can be done immediately after casting so that, (a) mould will not be in contact with the block during curing, thus eliminating the tendency of the mould to warp under high moisture content; (b) with small number of moulds, a high production rate can be maintained.

The mould shown in figure (1) was developed for the experimental work so that de-moulding can be done immediately after casting, by removing the bolts & tapping lightly to release the chase. This mould or a similar type which can be demoulded easily is recommended.

4.5. Materials

For blocks, the maximum aggregate size is one-fourth the thickness of the block or the web. Although for solid blocks (of 100 mm thickness) this means 20 mm or 25 mm aggregate can be used, normally only sand is used as the aggregate because (a) sand is cheaper than metal aggregate (b) high strength attained using concrete is not needed for blocks.

Some manufacturers use 6 mm to 10 mm quarry waste for blocks in addition to sand and this may be useful when high strengths should be attained by blocks. Thus for manufacture of blocks for up to 2-storey structures use of cement and sand is recommended.

The sand used for experimental work was within the limits specified in BS 882 (6) for zone 2, fine aggregates.
4.6. % Volume Reduction

Percentage volume reduction is a variable as important as the variables such as water/cement ratio and mix proportions, in the manufacture of blocks. In block-making machines this is fixed at a suitable value. Thus in hand-cast blocks, % volume reduction should be controlled to achieve consistent values of strength.

Experimental results in figure (2) shows that a large number of blows are required to achieve a relatively high compaction (i.e. about 40% volume reduction). It is very likely that hand-cast manufacturers do not achieve this degree of compaction because (a) it is practically difficult due to enormous labour effort required; (b) it will consume more materials and increase the cost of blocks. Figure (2) clearly shows that to increase the % volume reduction from 30 to 40, the compactive effort should be increased from 30 to 120 blows, nearly four times.

Figure (3), obtained from experimental work, shows the variation of compressive strength of blocks with the % volume reduction for different water-cement ratios. From Figure (3) it is clear that higher-water-cement ratios produce higher strengths for the same degree of compaction when water-cement ratio was varied from 0.5 to 0.9.

The degree of compaction recommended should be (a) possible to attain with reasonable labour effort; (b) compressive strength obtained is a substantial portion of the maximum compressive strength that can be attained from the mix used with hand compaction.

Hence 30% volume reduction is recommended for hand-cast blocks. It should be noted that maximum % volume reduction possible is about 40% and the recommended value is close to the maximum possible. This required about 28 blows (see Figure (2)) for 1:8 mix with a water-cement ratio of 0.5 and varied between 25 blows for rich mixes to 35 blows for weak mixes.
4.7 Mix Proportions and Water-Cement ratios to be used.

Experimental investigation commenced with a water-cement ratio 0.5 and a mix proportion 1 cement : 8 sand, obtained from the results of stages 1 & 2. The water-cement ratio was found to be unsuitable and hence the optimum water-cement ratio was found to be 0.9 as shown in Figure 4. Maintaining the water-cement ratio at this value, mix was varied from 1:7 to 1:12 and the compressive strength values obtained are as shown in Figure (5).

It was thought that the factor which governs the optimum water-cement ratio for hand compaction to a great extent was the water content of the mix. If the same water content is to be maintained for other mix proportions (same as the water content in 1 cement : 8 sand mix corresponding to a water-cement ratio of 0.9), then the water-cement ratios to be used with other mixes will be as follows:

<table>
<thead>
<tr>
<th>MIX PROPORTION</th>
<th>WATER-CEMENT RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: 7</td>
<td>0.8</td>
</tr>
<tr>
<td>1: 10</td>
<td>1.1</td>
</tr>
<tr>
<td>1: 12</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Tests were carried out for the above mix proportions at the water-cement ratios adjusted as above and the results obtained are as follows and there results are shown in Figure (6).

<table>
<thead>
<tr>
<th>MIX PROPORTIONS</th>
<th>ADJUSTED W/C</th>
<th>STRENGTHS 0.9 W/C ADJUSTED W/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : 7</td>
<td>0.8</td>
<td>2.65</td>
</tr>
<tr>
<td>1 : 10</td>
<td>1.1</td>
<td>1.50</td>
</tr>
<tr>
<td>1 : 12</td>
<td>1.3</td>
<td>0.85</td>
</tr>
</tbody>
</table>
From the results, it is seen that the adjusted water-cement ratios give better strengths except for 1:7 mix. The reduction of strength of 1:7 mix for the adjusted water-cement ratio is small and can be considered to be within the range of variations to be expected in strength prediction of this type of blocks.

It should be noted that the optimum water-cement ratio is in itself a variable which depends on sand grading. Hence what is required is a workable (compactable) water-cement ratio which gives substantial strength development. For this purpose following values may be recommended according to the results that were obtained. (a) 0.9 for 1:7 mix and for 1:8 mix, (b) 1.1 for 1:10 mix, and (c) 1.3 for 1:12 mix.

Mix proportions suitable for single-storey and two-storey construction can be selected from Figure (7) and the water-cement ratios can be obtained from the values given above. In drawing the Figures (6) & (7), 7 day strengths were converted to 28 day strengths using a factor. The ratio of 28 day to 7 day strength varies (7) from 1.3 to 1.7 but the majority of results fall below 1.5, and a mean conservative value of 1.3 was selected. Thus the actual values will be higher than those given. It should be noted that horizontal lines in Figure (7) should be adjusted if wall thickness is different from 100 mm. It is unlikely that wall thickness will be less than 100 mm and when it is greater compressive strength to be attained should be reduced in direct proportion. When height/thickness ratio of blocks is is different from 2.0, crushing strength of unit should be adjusted by a factor, but the effect of this factor (7) for values of ratio between 2.0 and 4.0 can be neglected.

These recommended mix proportions should give consistent results. If large scale manufacture of blocks is envisaged, it is better to test some blocks to achieve the best water-cement ratio as it depends on sand grading, water absorption of timber forms, water lost on the surface used to mix the mortar etc.

4.8. Curing
Several methods of curing can be used as follows:
(a) Steam curing at high pressure;
(b) Steam curing at atmospheric pressure;
(c) Sprinkling water for 7 days;
(d) Immersing in water for 28 days.

Curing should start immediately after final set is achieved. Curing method selected should be economical as well as producing substantial values of compressive strength.

For hard-cast blocks curing by sprinkling water for 7 days is recommended and that is the form of curing used for experimental work.

4.9. Condition of blocks at block laying
Blocks should be dry at the time of block laying. Hence after curing is completed, blocks should be stored in a dry place. Blocks should not be immersed in water before laying and age at block laying should be at least 28 days.

4.10. Cost Analysis
Using standard norms available and observed data while blocks were cast for experimental investigation following cost equations were obtained.

Cost of blocks per square of block work (95 blocks)

\[ C_1 = 95 \left( \frac{2L}{35} + \frac{C + 1.25 \times 10^{-2} \times nS}{2.669 \times n} \right) \]

Labour cost of laying of blocks per square of block work,

\[ C_2 = 0.95 \times (2M + 3L) \]

Cost of square of 4\(\frac{1}{4}\)" brick work (without plaster)

\[ C_3 = (1.5M + 2L) + (0.6B + 1.3C + 0.1S) \]

Cost of plastering per square.

\[ C_4 = (M + 2.5B) + (0.8C + 1.0L) + 0.7S \]

Where \(L = \) Cost of one day labourer
\(M = \) Cost of one day Mason
\(C = \) Cost of 50 kg. of cement
\(n = \) Volumes of sand per volume of cement used in making blocks.
\(S = \) Cost of one cube of sand
\(B = \) Cost of 1000 bricks
\(L = \) Cost of 1 bushel of lime

At present, \(L = Rs. 40, \ M = Rs. 60, \ C = Rs. 100\)
\(S = Rs. 250, \ B = Rs. 350, \) and \(Li = Rs. 40\)

\[ C_1 = Rs. 95 \left( \frac{2.286 + 100 + 3.125 n}{2.669 n} \right) \]
\[ C_2 = Rs. 228 \]
\[ C_3 = Rs. 535 \]
\[ C_4 = Rs. 405 \]

Block work does not need plastering, hence it is appropriate to compare the cost of unplastered block work with the cost of brick work with semi rough finished plaster.
<table>
<thead>
<tr>
<th>Type</th>
<th>Cost of wall per Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. block work in 1:7 with no plaster</td>
<td>... Rs. 1064.88 (C_i + C_j)</td>
</tr>
<tr>
<td>ii. block work in 1:8</td>
<td>... Rs. 1000.32 (C_i + C_j)</td>
</tr>
<tr>
<td>iii. block work in 1:10</td>
<td>... Rs. 912.34 (C_i + C_j)</td>
</tr>
<tr>
<td>iv. block work in 1:12</td>
<td>... Rs. 853.02 (C_i + C_j)</td>
</tr>
<tr>
<td>v. 4½&quot; brick work</td>
<td>... Rs. 535.00 (C_j)</td>
</tr>
<tr>
<td>vi. 4½&quot; brick work with plaster</td>
<td>... Rs. 1345.00 (C_j + 2C_i)</td>
</tr>
</tbody>
</table>

If bricks are not available at the site considered, block work adopted and the cost determined or if brick work is an alternative form of construction, then the economy of the two alternatives could be found using the above cost equation at any time.

5.0. Conclusions

The main information provided by this investigation can be summarised as given below:

(a) Important stages of the block making process were identified and recommendations were made to enable decisions to be taken at each stage.

(b) The most important variables were identified as % volume reduction, water-cement ratio and mix proportions, and suitable values were recommended for single & two-storey constructions for the selected block.

(c) Cost of block work can be easily obtained or can be compared with cost of brick work using cost equations given.

6.0. Acknowledgements

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References


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