COMPRESSED STABILISED EARTH AS LOAD BEARING INTERLOCKING BLOCK.

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ABSTRACT: The rising costs of construction materials and the need to adhere to sustainability, alternative construction techniques and materials are being sought. Earth as a construction material has been used worldwide since thousands of years. Many methods have been used to produce earth blocks varying according to local climate and environment as well as local traditions and customs. Compressed earth stabilised with cement can be produced by special high compacting pressure machines. Tests have been carried out to get the optimum mix to give the required strength as compressed stabilised soil hollow blocks. The blocks are intended as modular elements in the construction of walls using the load bearing interlocking block technique.

KEYWORDS: load bearing interlocking block, stabilised earth, mortarless building system, IBS.

1. INTRODUCTION

With the increase in material costs in the construction industry, there is a need to find more cost saving alternatives so as to maintain the cost of constructing houses at prices affordable to clients. The potential for using earth as an alternatives construction material have being seriously considered since earth has been used as a brick in house construction throughout the Ages. The methods used from the traditional techniques are being further developed to improve the quality of earth stabilised block hence will broaden the potential for its application. Earth construction is very cost effective, energy efficient (excellent thermal properties and low energy input required for production), environmentally friendly, and safe, these are the qualities which are particularly relevant and important with the ever growing need for increased awareness to reduce energy consumption world wide.

Production techniques had been developed so as to achieve better quality block and reduce production costs. In order to do this the following points need to be considered:
- mix proportions between soil and stabiliser need to be optimised, by considering the specific characteristics of the soil,
- sufficient compaction pressure should be applied to the moist soil mix so as to produce blocks that fit its purpose,
- smooth block surfaces produced will reduce additional surface coating or render.

2. INTERLOCKING BLOCK TECHNIQUE

The block's sizes are modular and rectangular (100 mm high, 125mm to150 mm wide and 300 mm long) in shape. Its dimensions permit multi-dimensional walls making configuration such as buttresses, lintels or columns possible. Corner or junction block is required to maintain right angled corner or a proper T junction.

The interlocking blocks are different from conventional bricks since they do not require mortar to be laid during bricklaying work. Because of this characteristic, the process of building walls is faster and requires less skilled labour as the blocks are laid dry and lock into place.

Compressed stabilised soil blocks (CSSB) may be produced with hollow centres to reduce weight, avoid seepages or improve insulation. The holes inside the blocks allow rebar and concreting (creating reinforced concrete) to run vertically through the block to compensate for the lack of tensile strength. Rebar used can be of mild steel instead of the usual higher grade steel. Once a section of
wall is built, grout holes are filled with a lean cement mixture to seal the wall and making a permanent solid wall. The amount of grout used was calculated to be less than 7.5% of the mortar used in conventional masonry.

The concept of interlocking blocks is based on the following principles:

- The blocks were shaped with protuding parts, which fit exactly into recess parts in the blocks placed above, such that they are automatically aligned horizontally and vertically - thus bricklaying is possible without specialised bricklaying skills.
- Since the blocks can be laid dry, no mortar is required and a considerable amount of cement is saved.
- Each block has vertical holes, which serve four purposes:
  1. to reduce the weight of the block,
  2. to insert steel rods or treated kenaf bar for reinforcement,
  3. to act as conduit for electrical and water piping,
  4. to pour liquid mortar (grout) into the holes, which run through the full height of the wall, thus increasing its stability and providing barrier to seepages.
- The length of each block is exactly double its width, in order to achieve accurate alignment of blocks placed at right angles, else, a junction block is required.

3. **SHAPES AND SIZES**

A variety of interlocking blocks have been developed during the past years, differing in shape and size, depending on the required strengths and uses. The system developed has the following shapes and forms:

- Full blocks (300x125 - 150x100 mm) for all standard walls (single or double block thick)
- Half blocks (150 x 125 - 150 x 100 mm), which can be moulded to size, or made by cutting freshly moulded full blocks in half.
- Channel blocks, same sizes as full and half blocks, but with a channel along the long axis, into which reinforcing steel and concrete can be placed to form lintels or ring beams.
- The vertical sides of the blocks can be flat or have recesses, and the vertical grout holes can be square or round.
- Inserts for electrical switch housing and conduit as well as water piping outlet can be incorporated.
- Special blocks for window sills.

![Figure 1](Shapes of interlocking block)
4. SOIL PROPERTIES

The soil blocks with stabilisers added will show greater resistance to extremes in weather conditions. The experiments to make the block using various quantities of cement as a stabiliser show big variations between the durability of stabilised and un-stabilised compressed earth blocks. From the field tests conducted it is shown that the walls constructed using cement compressed stabilized earth blocks have good weathering and anti seepaging properties.

4.1 Soil Stabilisation Techniques.

The soil properties can be modified by adding another material to improve its durability. This process is called soil stabilisation. Soil stabilisation has been used widely since the 1920s mainly for road construction and slope stability. When a soil is successfully stabilised one or more of the following effects will be evident:

- Increase in the strength and cohesion of the soil.
- Reduction in the permeability of the soil.
- The resulting soil will be made water repellent.
- Increase in the durability of the soil.
- Less shrinkage and expansion of the resulting soil in dry and wet conditions

There are several methods of soil stabilisation commonly used to improve the construction quality. Some of the major stabilisation techniques used are:

- Bitumen stabilisation
- Cement stabilisation
- Gypsum stabilisation
- Lime stabilisation.
- Mechanical stabilisation
- Pozzolanas stabilisation

The research carried out in this study is on using cement as the stabilising agent.

4.2 Soil Tests

Three soil samples from different locations were taken and physically tested for field clarification. Soils were taken from below of the top soil at least 150 mm. The soil samples tested contained a range of soil particles from 53% - 68.9% of gravel 2.4% - 33% of sand, 1.6% of silt and clay for sample A. Meanwhile for sample B, contained 67% - 79% gravel 13.3% - 15% of sand, 9.7% of silt and clay. In addition, for sample C contained 59% - 72% of gravel 1.7% – 40.3% of sand 1.5% of silt and clay. The plastic index for all three samples was low. The sieve analysis shows that over 90% of the soil particles were coarse material and 1.5% to 9.7% were fines than 0.0063µm sieve. Results of the tests are as shown in Tables 1 to 3.

Table 1: Result of the properties of the soil.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Gravel</th>
<th>Sand</th>
<th>Silt &amp; Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample A</td>
<td>52.6-66%</td>
<td>2.4-32.4%</td>
<td>1.60%</td>
</tr>
<tr>
<td>Sample B</td>
<td>66.30-79%</td>
<td>13.20-15.9%</td>
<td>9.70%</td>
</tr>
<tr>
<td>Sample C</td>
<td>56.9-58.2%</td>
<td>1.70-40.3%</td>
<td>1.50%</td>
</tr>
</tbody>
</table>
Table 2: Results of the sieve analysis

<table>
<thead>
<tr>
<th>BS Test sieve size (mm)</th>
<th>Sample A  Percent Finer</th>
<th>Sample B  Percent Finer</th>
<th>Sample C  Percent Finer</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.000</td>
<td>68.90</td>
<td>79</td>
<td>71.80</td>
</tr>
<tr>
<td>3.350</td>
<td>52.60</td>
<td>66.3</td>
<td>59.00</td>
</tr>
<tr>
<td>2.000</td>
<td>32.40</td>
<td>51.9</td>
<td>40.30</td>
</tr>
<tr>
<td>1.180</td>
<td>18.70</td>
<td>39.8</td>
<td>24.10</td>
</tr>
<tr>
<td>0.600</td>
<td>7.90</td>
<td>27.1</td>
<td>10.20</td>
</tr>
<tr>
<td>0.425</td>
<td>5.50</td>
<td>22.7</td>
<td>6.50</td>
</tr>
<tr>
<td>0.300</td>
<td>3.90</td>
<td>17.2</td>
<td>4.00</td>
</tr>
<tr>
<td>0.212</td>
<td>3.00</td>
<td>13.4</td>
<td>2.50</td>
</tr>
<tr>
<td>0.150</td>
<td>2.40</td>
<td>13.2</td>
<td>1.70</td>
</tr>
<tr>
<td>0.063</td>
<td>1.60</td>
<td>9.7</td>
<td>1.50</td>
</tr>
<tr>
<td>Pan</td>
<td>0.10</td>
<td>2.8</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Table 3: Result of plastic and liquid limit test.

<table>
<thead>
<tr>
<th></th>
<th>Sample A</th>
<th>Sample B</th>
<th>Sample C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Moisture Content</td>
<td>45.14</td>
<td>48.28</td>
<td>74.88</td>
</tr>
<tr>
<td>Liquid Limit</td>
<td>44.88</td>
<td>46.4</td>
<td>72.4</td>
</tr>
<tr>
<td>Plastic Index</td>
<td>0.26</td>
<td>1.88</td>
<td>2.48</td>
</tr>
</tbody>
</table>

5. BLOCK STRENGTH

The compressive strength of compressed stabilised soil blocks (CSSB) depends on the soil type, type and amount of stabiliser, and the compaction pressure used to form the block. The maximum compressive strengths of the block are obtained by proper mixing of suitable materials and proper compacting and curing.

In practice the typical wet compressive strengths (7th day) for CSSB may be less than 4MN/m². It also competes favourably, for example, with the minimum British Standard requirements of 2.8MN/m² for precast concrete masonry units (size 4.5 x 9 x 3 ins) and load bearing fired clay bricks, of 5.2N/m². In the case of single storey constructions where building loads are small, a compressive strength of 1–4MN/m² may be sufficient.

The Public Works Department (JKR) recommends values of 2.8 MN/ m² for non load bearing block and 5.2 MN/m² for load bearing block.
5.1 Strength against compaction force

Improved levels of compaction have a significant effect on the compressive strength of the sample and on the effectiveness of the cement as stabiliser added. The following graph presents data collected to indicate the relationships between cement content, compaction energy (defined in MPa pressure) and the resulting bulk density and subsequent 7-day wet compressive strength (cube). This is for laterite soil mixed with 25% sand [Abas 2008]. Other ratios of sand in mix will give different results.

![Image of graph showing relationship between cement content, compaction pressure and 7-day wet compressive strength]

**Figure 2**: Relationship between cement content, compaction pressure and 7-day wet compressive strength.

The above data clearly shows the significant advantages that increased compaction offers. If a CSSB could be compacted to a higher density, then for the same ultimate strength the cement content could be reduced. The trade off is between an increased energy cost and the reduction in chemical additives. What is apparent is the possible mismatch between the moisture contents desired for optimum compaction for a given energy and optimum moisture content for cement curing. This issue of what is the most appropriate moisture content to be used for a given compaction energy needs is part of the whole research project.

5.2 Strength on various mix proportions and different soil types

Mix proportions plays a very important role in determining the strength of the CSSB. Different soils will also give different strengths, hence three soil samples were taken under this study.

![Image of particle size distribution chart]

**Figure 3**  Particle size distribution chart
From the Dry sieve analysis we can relate the relationship between the particles of the soil to produce the required Cement Stabilised Soil Block. Figure 3 shows the percentage of the fine passing from 5 mm to 0.0063 µm. From the literature review, we know that the proportions of various kinds of material in the types of soils that are recommended for the manufacture of compressed soil blocks (Houben 1994) are:

Gravel 0-40%
Sands 25-80%
Silts  10-25%
Clays  8-30%

Comparing it to the results from the three samples, shows that all three samples are below the ideal curve limit for the recommended proportion. Hence to make the mix possible for manufacturing the compressed stabilised soil block, sand was added to the soil samples. The compacting force for all three samples was held at 1 MPa.

Figure 3 Compressed stabilised soil block produced using a hydraulic press

Figure 4 shows the results of the compressive strength of the blocks after 7 days curing. It can be seen that only sample B can be satisfactory and shows promise for use as block construction, exceeding the 2.8MN/m² value. Higher compressive strength could be achieved if the compacting force had been set at 3MPa or above.

Figure 4  
7th day compressive strength vs % of sand in mix for three soil samples
6. DESIGN AND CONSTRUCTION OF BUILDING

6.1 Construction concepts using load bearing blocks

The cavity holes of the interlocking blocks permit the introduction of vertical reinforcement embedded in concrete without the need for any formwork thus eliminating the use of wood in form work. Reinforcement can be introduced to make the building withstand earthquakes and heavy wind loads. Because of the size and resistance of the blocks, load bearing walls can be constructed.

Before placing the first course in a mortar bed, the blocks must be laid dry on the foundation around the entire building, in order to ensure that they fit exactly next to each other (leaving no gaps), and that an exact number of full blocks are used, otherwise the system will not function. When laying the first course in the mortar bed, care must be taken that the blocks are perfectly horizontal, and in a straight line, or at right angles at corners.

Once the base course is properly hardened, the blocks are stacked dry, with the help of a wooden or rubber hammer to knock the blocks gently into place. Up to 10 layers can be placed at a time, before the grout holes are filled with a liquid mortar - 1 part cement to 3 parts sand to 1 part water.

Interlocking blocks are ideally suited for load-bearing wall constructions, even for two or more storey buildings, provided that the height of the wall does not exceed 20 times its thickness, and wall sections without buttresses or cross walls do not exceed 4.5 m length (to prevent buckling).

6.2 Building design using load bearing blocks

Almost any type of building can be constructed with interlocking blocks, the main design constraints being that the plan should be rectangular and all wall dimensions and openings must be multiples of the width of the block type used. All other principles of design and construction, such as dimensioning of foundations, protection against rain and ground moisture, construction of ceilings and roofs, and the like, are the same as for other standard building types.

It is advisable to place channel blocks around the building, at window sill height, to install a ring beam. They should also be placed directly above doors and windows to install lintels, and directly below the roof to finish the walls with a ring beam. To increase structural stability, especially in earthquake regions, steel rods or treated kenaf should be inserted in the vertical grout holes, especially at corners, wall junctions and on either sides of openings.

6.3 Construction of the house using load bearing interlocking blocks

The first completed bungalow house was constructed in FELDA Laka, Kedah in 2008 which took 40 days to complete for a built up area of 1571 sq ft.
Initially the foundation, ground beam and ground slab is laid with the appropriate vertical steel implanted. It takes normally a week for the foundation to set then the first layer of interlocking load bearing blocks is arranged to ensure that the wall is straight and right angle at corners and junctions. After that the crew of six workers can independently stack up the blocks to the required height.

Horizontal bars are placed for the construction of ring beam around the house for added stiffness. Similar process of arranging the block was done up to the roof beam where another two layers of channel blocks was used to simulate the roof ring beam.

This process takes two weeks to complete, then the roofing, plumbing, electrical, sanitary and finishing will take another two to three weeks.

The construction time taken to complete the first bungalow was 40 days. As the workers gained more experience building more houses, the construction time can be reduced further with permitting weather.

7. CONCLUSION

The following conclusions can be derived from the project:

- The strength of the compressed stabilised soil block (CSSB) is dependent on the compaction force during manufacturing,
- The strength of the CSSB is dependent on the type of soil as well as the amount of stabiliser and sand added to the mix.
- Laterite soil has the potential to be used as a compressed stabilised soil load bearing block.
- The materials required for block production and building construction are usually locally available in most regions.
- Compared with conventional masonry, the dry assembly of interlocking blocks saves construction time and a large amount of mortar.
- Additional cost reduction is achieved by building load bearing walls since there is no timber formwork required.
- The structural stability and durability of interlocking block constructions can be enhanced by grout holes and channel blocks that provide means to insert steel reinforcements in vulnerable parts of buildings for increased wind and earthquake resistance.
8. REFERENCES
Mohd Adib bin Abas (2008), *Compression strength of soil cement cube*, Final Year project report, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 2008.


9. ACKNOWLEDGEMENTS
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