

Compressed Stabilised Earth Block Manufacture in Sudan

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in collaboration with
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United Nations Educational, Scientific and Cultural Organization

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Appendix II - extracts from Centre for the development of Enterprise (CDE) guides:

- “*Compressed Earth Blocks - Standards*”. ‘Technologies Series’ No.11. A joint Center for Development of Enterprise (CDE) and CRATerre-EAG publication, 1998.
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Preface

This publication has been prepared within the framework of the UNESCO project '*Improvement of Educational Facilities in the Least Developed Countries of the Arab States*', 522/RAB/II.

Co-financed by AGFUND and AFESD, the main component of the project was to construct the El Haj Yousif School in the Khartoum area using compressed stabilised earth block building technology, a practical way of demonstrating the potential of earth as a viable and desirable construction material.

In order to make the knowledge acquired during the construction process of El Haj Yousif school widely available, this publication '*Compressed Stabilised Earth Block Manufacture in Sudan*' and a twin publication '*Roofing Systems in Sudan*' have been prepared.

Earth as a construction material has been used for thousands of years by civilisations all over the world. Many different techniques have been developed, the methods used vary according to the local climate and environment as well as local traditions and customs. As a modest estimate it is thought that as many as 30% of the world's population live in a home constructed in earth (Houben & Guillaud, 1994: p6).

Despite these very significant figures, earth construction in many parts of the world particularly in developing countries, is considered to be a construction material for the poor and hence undesirable. Loss of traditional knowledge resulting in a deterioration in the quality of recent earth constructions has, in many cases, compounded these beliefs.

In recent years, however, the potential for earth as a valuable and desirable construction material is being rediscovered. Methods derived from the traditional techniques are being developed to improve the quality of earth construction and 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, qualities which are particularly relevant and important with the ever growing need for increased awareness to reduce energy consumption world wide.

Governments, international and national organisations who are involved in the domain of construction all have a responsibility to recognise earth's potential as a construction material and promote its use through research and practical applications so as to help re-integrate it into common construction practices.

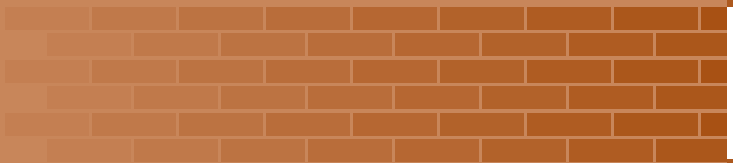
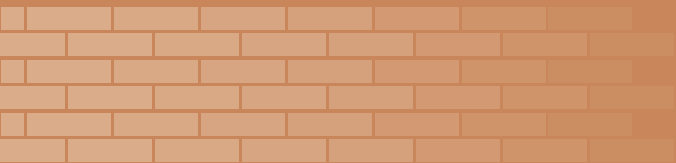
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Preview



1.1 Aims and Objectives of the Handbook

Provision of housing for developing countries is one of the most important basic needs of low-income groups. It is a very difficult requirement to meet, however, since land and construction costs are mostly beyond the means of both the rural and urban poor. In order to address this issue various governments have undertaken housing schemes that aim to facilitate some form of housing ownership by low-income groups. These ideas include self-help housing schemes which provide housing subsidies, provision of credit, and/or low interest rates etc.

Due to limited means within developing countries, it is necessary to seek ways to reduce construction costs, especially for low-income housing, as well as adopting easy and effective solutions for their repair and maintenance. Such objectives can be achieved partially through the production and use of cheap yet durable locally available building materials. Ideally the production of these building materials will contribute to improving development objectives of Sudan by generating local employment, rural development and a reduction of imports.

Various traditional construction materials exist in Sudan which have proved to be suitable for a wide range of buildings and which have a great potential for increased use in the future. One such material is the compressed stabilised earth block, an improved form of one of the oldest materials used in building construction.

Soil is one of the primary materials used for construction of traditional low-cost dwellings in Sudan and is well suited to local weather conditions and occupancy patterns. Soil construction methods are used in 80% of urban buildings in Sudan while this figure exceeds 90% in rural areas. Buildings are constructed entirely, or partially of soil, depending on location, climate, available skills, cost, building use and local tradition.

The purpose of this handbook is to provide detailed technical and economic information on the production of compressed stabilised earth blocks with a view to making available our experience in this field to those who produce or plan to manufacture blocks so as to improve production techniques and quality of output. This includes information on soil types in the Sudan, local stabilisers, stabilisation techniques, production of compressed stabilised earth blocks, quality of the blocks, and their economical value and potential.

1.2 Contents of the Handbook

Following the introductory **Chapter 1**, **Chapter 2** provides information on the different soil types in Sudan and the materials used in the manufacture of compressed stabilised earth building blocks, including the necessary field tests needed to determine their suitability for block making. Attention is given to techniques that measure the optimum amounts of materials as well as the processing conditions required for the manufacture of good quality blocks.

The various production stages described in **Chapters 3** and **4** include soil preparation prior to stabilisation, block-making equipment for forming the blocks, and curing.

Chapter 5 describes properties of mortars as well as plastering and rendering techniques for block wall surfaces.

Simple procedures for estimating the unit production cost and the socio-economic aspects are considered in **Chapters 6** and **7**.

The handbook concludes with four Appendixes which include **Appendix I** - a bibliography, **Appendix II** - African Regional Standards (ARS) for compressed earth blocks, **Appendix III** - useful addresses for block making machinery and equipment, and **Appendix IV** - a glossary of terms.

1.3 Earth in Building Construction

Recently, traditional earth construction technology has undergone considerable developments that enhance earth's durability and quality as a construction material for low-cost buildings. Such methods include rammed earth and machine pressed compressed stabilised earth blocks.

Application and uses in Sudan

Soil construction techniques are used in 80% of urban buildings in Sudan. This figure exceeds 90% in rural areas. Buildings can be made entirely or partially of soil, depending on their location, the climate, available skills, cost, and building use and requirements.

There are three traditional soil construction methods used in Sudan;

- cob (jalous) - mixture of straw, gravel and clay,
- wattle and daub - coarse basket work of twigs woven between upright poles and plastered with earth,
- adobe - roughly moulded, sundried clay bricks of varying sizes.

The main drawback of these types of earth construction is their lack of durability, further research is required so as to improve their quality.

1.4 Advantages and Limitations

There are many advantages and disadvantages of using soil for construction purposes, these are briefly discussed in Figure 1.1.

Figure 1.1 - Advantages and limitations of compressed earth block construction

Advantages	Limitations
<ul style="list-style-type: none"> ● Soil is available in large quantities in most regions. ● Cheap and affordable - in most parts of the world soil is easily accessible to low-income groups. In some locations it is the only material available. ● Ease of use - usually no very specialised equipment is required. ● Suitable as a construction material for most parts of the building. ● Fire resistant - non-combustible with excellent fire resistance properties. ● Beneficial climatic performance in most regions due to its high thermal capacity, low thermal conductivity and porosity, thus it can moderate extreme outdoor temperatures and maintain a satisfactory internal temperature balance. ● Low energy input in processing and handling soil - only about 1% of the energy required to manufacture and process the same volume of cement concrete. This aspect was investigated by the Desert Architecture Unit which has discovered that the energy needed to manufacture and process one cubic metre of soil is about 36 MJ (10 kwh), while that required for the manufacture of the same volume of concrete is about 3000 MJ (833 kwh). Similar findings were also reported by Habitat (UNCHS), Technical Note No. 12 comparing adobe with fired clay bricks. ● Environmental appropriateness - the use of this almost unlimited resource in its natural state involves no pollution and negligible energy consumption thus further benefiting the environment by saving biomass fuel. 	<ul style="list-style-type: none"> ● Reduced durability - if not regularly maintained and properly protected, particularly in areas affected by medium to high rainfall. ● Low tensile strength - poor resistance to bending moments, to be used only in compression e.g. bearing walls, domes and vaults. ● Low resistance to abrasion and impact - if not sufficiently reinforced or protected. ● Low acceptability amongst most social groups - considered by many to be a second class and generally inferior building material. ● On account of these problems - earth as a building material lacks institutional acceptability in most countries and as a result building codes and performance standards have not been fully developed.

1.5 Need to Develop New Techniques

Traditional earth construction techniques such as wattle and daub, cob (jalous) and adobe need continuous maintenance in order to keep them in good condition. Current research, carried out by research institutions in the Khartoum area, aims to increase the durability of earth as a construction material. Their work has led to the improvement of rammed earth and compressed stabilised earth blocks as building techniques.

Unfortunately the quality of compressed stabilised earth blocks in some construction schemes is far from adequate and often materials are wasted in the production process.

To extend the use of compressed stabilised earth building blocks to all types of housing e.g. low-cost housing in rural and urban areas and middle income housing in urban areas, production techniques need to be further improved so as to achieve better quality and reduce production costs. In order to do this the following points need to be considered carefully:

- proportions between soil and stabiliser need to be optimised, taking into consideration the specific characteristics of the soil,
- compaction pressure applied to the moist soil mix needs to be sufficient so as to produce blocks that are dense and strong with regular surfaces and edges.
- block surfaces need to be smooth so that they have the potential to be used without an additional surface coating or render.

Good quality compressed stabilised earth blocks improve hygiene (e.g. there will be less surface cracks for insects to lodge in), reduce maintenance and repair costs and, in general, prolong the life span of a building.

The following chapters provide technical information that will help improve and reduce costs of small-scale compressed stabilised earth block production through use of appropriate techniques.

1.6 Compressed Stabilised Earth Building Blocks versus other Building Materials

This section compares the properties of compressed stabilised earth building blocks with some other walling materials. This comparison is of use for housing authorities implementing individual housing or larger building programmes. The characteristics of these different materials are given in Figure 1.2.

Figure 1.2 - Properties of compressed stabilised earth blocks versus other walling materials

Property	Compressed stabilised earth blocks	Fired clay bricks	Calcium silicate bricks	Dense concrete blocks	Aerated concrete blocks	Lightweight concrete blocks
Wet compressive strength (MN/m ²)	1 - 40	5 - 60	10 - 55	7 - 50	2 - 6	2 - 20
Moisture movement (%)	0.02 - 0.2	0.00 - 0.02	0.01 - 0.035	0.02 - 0.05	0.05 - 0.10	0.04 - 0.08
Density (kg/m ³)	1700 - 2200	1400 - 2400	1600 - 2100	1700 - 2200	400 - 950	600 - 1600
Thermal conductivity W/m°C	0.81 - 1.04	0.70 - 1.30	1.10 - 1.60	1.00 - 1.70	0.10 - 0.20	0.15 - 0.70
Durability against rain	good to very poor	excellent to very poor	good to moderate	good to poor	good to moderate	good to poor

Compressive strength

The compressive strength of compressed stabilised earth building blocks (i.e. the amount of pressure they can resist without collapsing) depends upon the soil type, type and amount of stabiliser, and the compaction pressure used to form the block. Maximum strengths (described in MN/m²) are obtained by proper mixing of suitable materials and proper compacting and curing. In practice, typical wet compressive strengths for compressed stabilised earth building blocks may be less than 4MN/m². However, some Sudanese black cotton soil when stabilised with hydrated high calcium lime give wet compressive strengths in the range of 6-8MN/m², a strength suitable for many building purposes. It also competes favourably, for example, with the minimum British Standard requirements of 2.8MN/m² for precast concrete masonry units and load bearing fired clay blocks, and of 5.2N/m² for bricks. Where building loads are small (e.g. in the case of single-storey constructions), a compressive strength of 1-4MN/m² may be sufficient. Many building authorities around the world recommend values within this range.

Density and thermal properties

Normally compressed stabilised earth blocks are denser than a number of concrete masonry products such as aerated and lightweight concrete blocks. While having densities within the range of various types of bricks e.g. clay, calcium silicate and concrete bricks (see Figure 1.2). The high density of compressed stabilised earth blocks may be considered as a disadvantage when the blocks have to be transported over long distances, however, it is of little consequence when they are produced at or near the construction site. Low density compressed stabilised earth blocks have an advantage over high density ones of acting as better thermal insulators. This is particularly advantageous in hot dry climates where extreme temperatures can be moderated inside buildings made of compressed stabilised earth blocks.

Moisture movement

Building materials with high porosity when used for wall construction may expand slightly in wet and dry conditions. Such movements may result in cracking and other defects to the building.

Expansion of compressed stabilised earth blocks may vary according to the properties of the soil, some soils expand or shrink more than others. The addition of a stabiliser will reduce this expansion. In general, however, there may be greater movement in structures built with compressed stabilised earth blocks than those using alternative construction materials (see Figure 1.2). Proper block manufacture and construction methods, however, will reduce such movement. Moisture movement is denoted in terms of linear per cent change.

It is worth mentioning that moisture movement becomes especially important when two materials with different movement properties are used in a building. Differential movement results in stress which may break the bond between the materials, or cause other damage. For example, cement renderings often peel off earth walls or poorly compressed stabilised earth blocks because of their different expansion properties.

Durability, maintenance and appearance

As a rule soil blocks containing stabilisers show greater resistance to extreme weather conditions. Block making experiments in Sudan using various quantities of lime as a stabiliser showed marked variations between the durability of stabilised and un-stabilised compressed earth blocks. Field tests at El Haj Yousif experimental school (see Figure 1.3) have shown that walls constructed with cement compressed stabilised earth blocks demonstrated good weathering properties.

Figure 1.3 - El Haj Yousif experimental school



Blocks of the same size, when made of a sufficiently good quality and shape with a high quality finish, can be used for fair-faced walling. Their appearance depends upon soil colours, particle size, and degree of compaction used. With good high quality blocks external or even internal rendering should not be necessary. A white wash finish applied directly to the blocks as a render coat could be used to reduce solar gain.

It should be noted that compressed stabilised earth blocks, in common with other types of blocks and bricks, will need adequate steel reinforcement if used in areas prone to earthquakes or cyclones etc.

Termites, bacteria, fungi and fire do not present a particular hazard for compressed stabilised earth blocks. However, organic material in the soil may weaken the strength of the block.

1.7 Scale of Manufacture

The potential scale for compressed stabilised earth block production depends on the degree of mechanisation of the manufacturing process used. Manually operated equipment may produce a few hundred units a day, while mechanised equipment has the capacity to produce several thousand units per day. Figure 1.4 shows the range of productivity for both small and large scale manufacture.

Figure 1.4 - Scale of production

Scale of production	No. of blocks produced/day	Type of production	Time required to produce blocks for a small house
Small	up to 400	manual	1 week
Large	400 to 4000	machine	1 day to 1 week

Small-scale production is suitable for isolated communities and has the advantage that it can generate employment, reduce transportation costs, and only requires the use of simple tools and equipment. This is in contrast with large-scale production which may need expensive, rather sophisticated equipment that usually will have to be updated on a regular basis.

The block making machines used for the experimental school building at El Haj Yousif are of the small-scale variety with both motorised and manual operation.

1.8 Target Groups

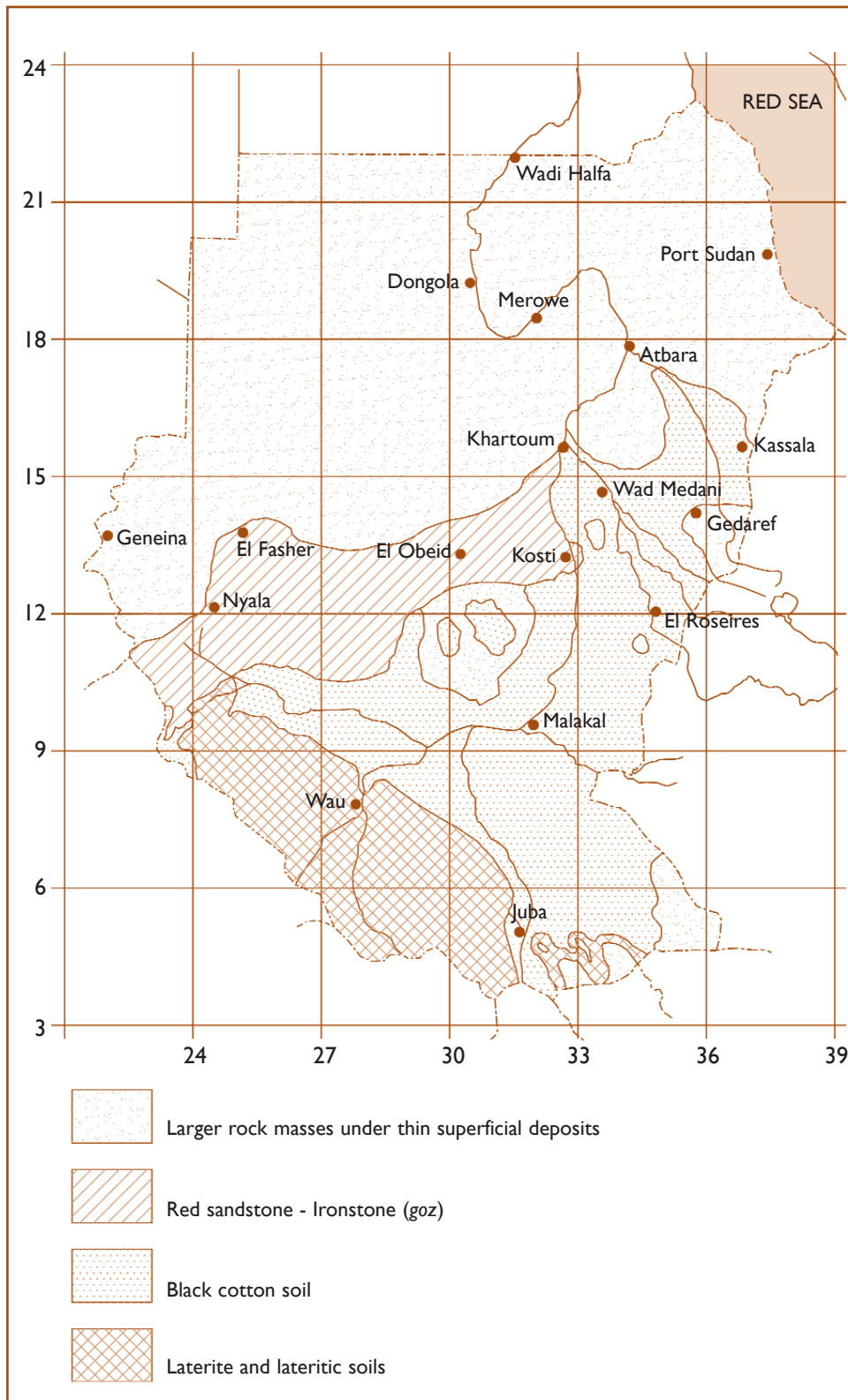
This handbook is meant to make available information to different groups of individuals or institutions concerned with building and construction in developing countries. For example housing authorities, building research organisations, government officers, financial institutions, builders, architects, and voluntary organisations.

Materials for
Compressed Stabilised
Earth Block Production

2.1 Soils of Sudan

In Sudan the main soil types are identified as black cotton soils, red sand ironstone soils, and laterite and lateritic soils. Brief information on these soil types is given in Figure 2.1 below.

Figure 2.1 - Distribution of main soil types across Sudan



Black cotton soil - badobe

The term 'black cotton soil', otherwise known as badobe, is derived from the soil's dark or black colour and the fact that it was originally used for growing cotton. In general, black cotton soils are formed in areas where the parent material is a basic such as basalt. In Sudan, black cotton soil or badobe is formed by one of the following processes: to the east of the Blue Nile badobe is a residual soil derived from its parent basalt rock. Between the two Niles (the Gezeria clay plain) the black cotton soil is a transported alluvial deposit from the Ethiopian mountains to the east. To the south and south-west, badobe occurs as a transported soil derived from the volcanic tuffs. Despite differences in origin, the black cotton soils of Sudan have the following common characteristics:

- the colour ranges from dark grey to dark brown,
- pronounced volume change upon wetting and drying, i.e. extreme expansion and shrinkage properties,
- high (35%) clay content (clay is defined as soil fraction containing particle sizes less than 0.002mm). This clay fraction is composed mainly of montmorillonite, a group of soils often found in drier tropics. Its structure allows water molecules to enter between the layers causing expansion or shrinkage,
- the liquid limit (LL) ranges between 47% and 93%,
- the plastic limit (PL) ranges between 26% and 50%,
- the plasticity index (PI) ranges between 13% and 58%,
- the linear shrinkage ranges between 8% and 18%.

Due to the high plasticity of these soils they can be difficult materials to handle when mixed with water. Nevertheless, black cotton soil is a popular building material since it covers large areas in central Sudan where more than two thirds of the country's population live. However, due to the high clay content and the presence of expandable clay minerals in this soil type, the life span of buildings made from black cotton soils is normally short (approximately 15 years on average), and so there is continuous need for repair. In recent years it has been recognised that further study of the properties and characteristics of black cotton soils and their potential for use in the building industry is necessary since it is so prevalent and easily available in Sudan. Black cotton soils constitute ~16% of the total land area of Sudan where more than two-thirds of the Sudanese population live.

Red sand - ironstone soils (goz)

To the west of the main Nile and the White Nile, extend the red sand-ironstone Goz soils, see Figure 2.1. These soils are formed from the breakdown of the Nubian sandstone rock that underlies soils of western Sudan. This soil type also occupies

large expanses of land area in Sudan (~7%). In general, however, knowledge of the engineering properties of these soils is limited. They are mainly red or brown ironstone soils formed in dry arid conditions. Attempts have been made to relate them to the laterite and lateritic soils of West Africa, but they possess different properties to those soils. Goz soils include wind blown sands, silt and clays that have accumulated in depths of up to 5m, where the lower layers have become consolidated with time.

Many villagers in these areas have built dwellings from Goz soils that demonstrate greater durability properties than those buildings made from badobe soils. A possible reason for this is that Goz soils tend to have a lower clay content so they expand and shrink less on wetting and drying, making them more stable through periods of climatic fluctuation.

Laterite soils

The term 'Laterite', which is derived from the Latin word *later* meaning brick, was first used by Buchanan in 1807 for describing a red iron-rich material found in southern parts of India. Laterites are highly weathered soils which contain large, though extremely variable, proportions of iron and aluminium oxides, as well as quartz and other minerals. They are found in abundance in the tropics and sub-tropics, where they generally occur just below the surface of grasslands or forest clearings in regions with high rainfall. The soil colour can vary from red, brown, and violet to black, depending on the concentration of iron oxides.

2.2 Raw Materials

Soil characteristics and climatic conditions of an area must be evaluated before manufacturing soil building blocks. A dry climate, for example, needs different soil blocks from those used in temperate, rainy or tropical areas. All soils are not suitable for every building need. The basic material, however, required to manufacture compressed stabilised earth building blocks is a soil containing a minimum quantity of silt and clay so as to facilitate cohesion.

Soils are variable and complex materials, whose properties can be modified to improve performance in building construction by the addition of various stabilisers.

All soils consist of disintegrated rock, decomposed organic matter and soluble mineral salts. Soil types are graded according to particle size using a system of classification widely used in civil engineering. This classification system, based on soil fractions (see Figure 2.2) shows that there are 4 principal soil fractions - gravel, sand, silt and clay.

Figure 2.2 - Soil classification according to particle size

Name of fraction		Diameter size ranges of particles (mm)
GRAVEL	Coarse gravel	20.000 - 60.000
	Medium gravel	6.000 - 20.000
	Fine gravel	2.000 - 6.000
SAND	Coarse sand	0.600 - 2.000
	Medium sand	0.200 - 0.600
	Fine sand	0.060 - 0.200
SILT	Coarse silt	0.020 - 0.060
	Medium silt	0.006 - 0.020
	Fine silt	0.002 - 0.006
CLAY	Clay	less than 0.002

For soil stabilisation, the clay fraction is most important because of its ability to provide cohesion within a soil.

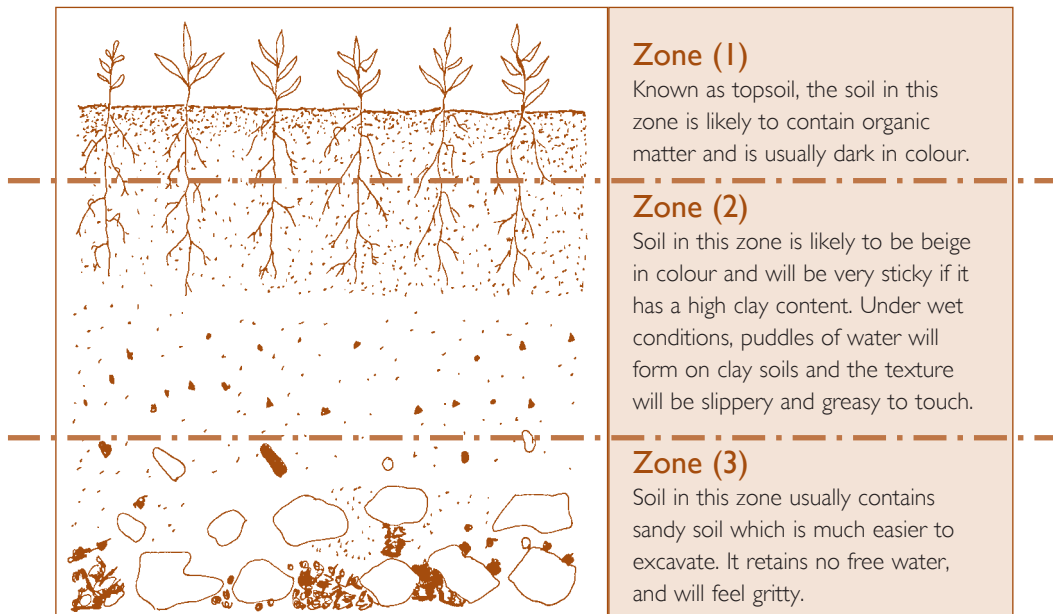
The manufacture of good quality, durable compressed stabilised earth blocks requires the use of soil containing fine gravel and sand for the body of the block, together with silt and clay to bind the sand particles together. An appropriate type of stabiliser must be added to decrease the linear expansion that takes place when water is added to the soil sample. The stabiliser has further benefits that are described in a later section.

2.3 Sampling Soil for Compressed Stabilised Earth Block Production

For small-scale, on-site production of compressed stabilised earth building blocks a minimum of about 500m³ of suitable soil per year is needed for each block-making machine. The borrow pit should not be too far from the production site in order to reduce transportation costs of the raw material. Sufficient soil must be available from the borrow pit to satisfy the proposed scale of manufacture.

Before any major action takes place, soil samples from trial holes must always be taken to check the adequacy of the soil and to be able estimate available amounts. A cross section of the soil layers and zones, known as the soil profile, is given in Figure 2.3. Soil composition can vary greatly even within a small area so several test holes should be dug to give a full picture of the type of the soil within a borrow pit.

Various types of excavating tools can be used in a quarry depending on the size of the proposed project. For large projects heavy earth moving equipment can be used. For small-scale projects simple tools can be employed for digging and handling earth in preparation for stabilisation.

Figure 2.3 - Typical soil profile

2.4 Soil Testing Methods

Laboratory analysis of the raw material is always necessary for large-scale production of compressed stabilised earth blocks. For small-scale production, however, it is not essential to employ sophisticated tests to establish the suitability of a soil. Simple field tests can be performed to get an indication of the composition of the soil sample. Such tests are discussed briefly below.

Smell test

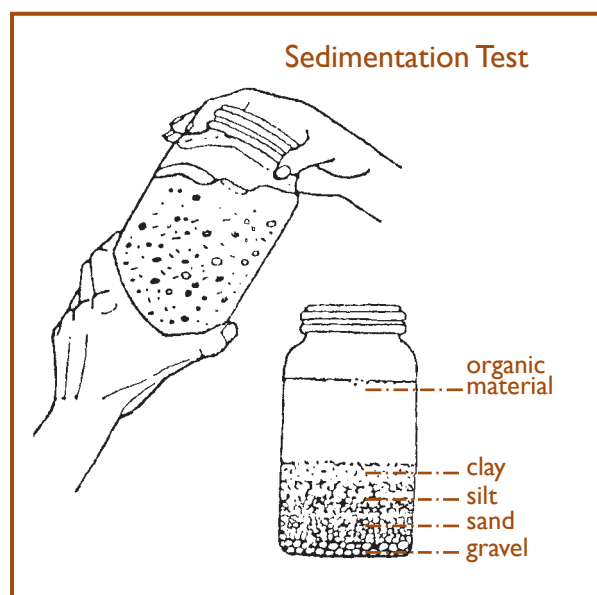
Smell the soil immediately after it has been sampled. If it smells musty it contains organic matter. This smell will become stronger if the soil is heated or wetted. Soil containing organic matter is not suitable for production of compressed stabilised earth blocks (Houben & Guillaud, 1994: p 48).

Nibble test

Care should be taken to ensure that it is safe to place any samples in the mouth. Nibble a pinch of soil, crushing it lightly between the teeth. If it grinds between the teeth with a disagreeable sensation, the soil is sandy. If it can be ground between the teeth, without a disagreeable sensation the soil is silty. If it has a smooth or floury texture and if when a small piece is applied to the tongue it sticks, the soil is clayey (Houben & Guillaud, 1994: p 48).

Touch test

Remove the largest grains and crumble the soil by rubbing the sample between the fingers and the palm of the hand. If it feels rough and has no cohesion when moist the soil is sandy. If it feels slightly rough and is moderately cohesive when moistened the soil is silty. If, when dry, it contains lumps or concretions which resist crushing, and if it becomes plastic and sticky when moistened the soil is clayey (Houben & Guillaud, 1994: p 48).



Sedimentation test

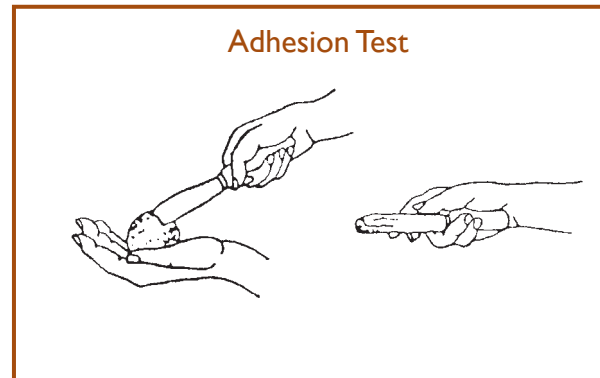
The tests mentioned previously make it possible to form a general idea of the texture of the soil and the relative particle sizes of the different fractions. To obtain a more precise idea of the nature of each soil fraction, a simplified sedimentation test can be carried out in the field. The apparatus required is straight forward: a transparent cylindrical glass bottle with a flat bottom and a capacity of at least one litre, with a neck wide enough to get a hand in and a lid to allow for shaking.

Fill the bottle to one-third with clean water. Add approximately the same volume of dry soil passed through a 6mm sieve and add a teaspoonful of common salt.

Firmly close the lid of the bottle and shake until the soil and water are well mixed. Allow the bottle to stand on a flat surface for about half an hour. Shake the bottle again for two minutes and stand on level surface for a further 45 minutes until the water starts to clear. The finer particles fall more slowly and as result will be deposited on top of the larger size particles. Two or three layers will emerge, with the lowest layer containing fine gravel, the central layer containing the sand fraction and the top layer containing silt and clay. The relative proportions, and hence percentages, of each fraction can be determined by measuring the depth of each layer (Houben & Guillaud, 1994: p 48).

Adhesion test

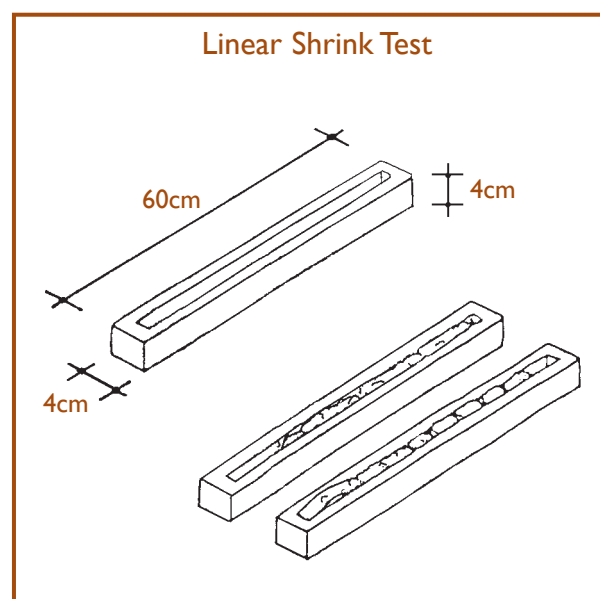
Compact a ball of moist soil so that it does not stick to the fingers and insert a spatula or knife. If the spatula penetrates it with difficulty, and soil sticks to it upon withdrawal the soil is extremely clayey. If the spatula can be pushed into it without great difficulty but a bit of soil remains on the knife upon withdrawal the soil is moderately clayey. If the spatula can be pushed into the mass without encountering any resistance at all, even if the spatula is dirty upon withdrawal the soil contains only a little clay (Houben & Guillaud, 1994: p 48).

**Washing test**

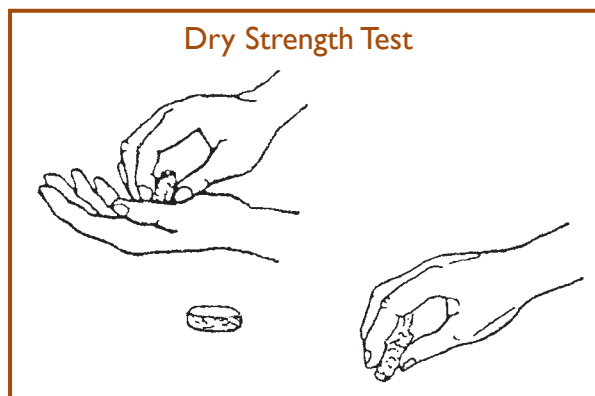
Rub the hands with some slightly moistened soil. If the hands are easy to rinse clean this implies that the soil is sandy. If the soil appears to be powdery and the hands can be rinsed clean fairly easily the soil is silty. If the soil has a soapy feel and the hands cannot be rinsed easily the soil is clayey (Houben & Guillaud, 1994: p 48).

Linear shrinkage mould test

The linear shrink test, or Alcock's test, is performed using a wooden box, 60cm long, 4cm wide and 4cm deep. Grease the inside surfaces of the box before filling it with moist soil with an optimum moisture content (OMC). Ensure that the soil is pressed into all corners of the box using a small wooden spatula that can also be used to smooth the surface. Expose the filled box to the sun for a period of three days or in the shade for seven days. After this period measure the length of the hardened and dried soil as compared to the length of the box and calculate the shrinkage length of the soil (Houben & Guillaud, 1994: p 48).



Materials for Compressed Stabilised Block Production



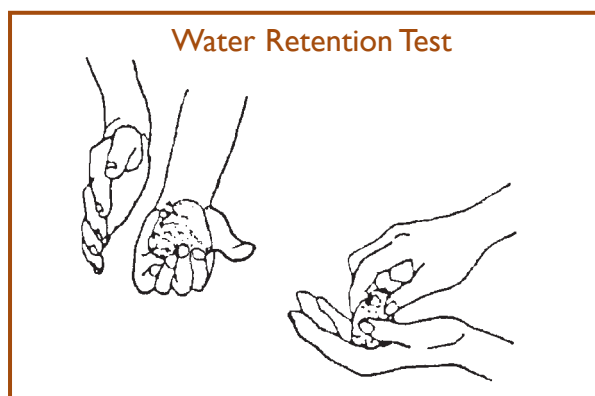
Dry strength test

- Form two or three pats of soft soil,
- Place the pats in the sun or in an oven until they have completely dried,
- Break a soil pat and attempt to pulverise it between thumb and index finger,
- Observe how easy the pat is to pulverise.

Implications

- If the pat pulverises easily, the soil is silty or fine sand and has a low clay content,
- If the pat can be crushed to a powder with a little effort, the soil is silty or sandy clay,
- If the pat is hard to break and will not pulverise, the soil has a high clay content.

(Houben & Guillaud, 1994: p 52).



Water retention test

- Form a ball of fine soil, 2 or 3cm in diameter,
- Moisten the ball so that it sticks together but does not stick to the fingers,
- Slightly flatten the ball and hold it in the palm of the extended hand,
- Vigorously tap the ball with the other hand so that the water is brought to the surface. The ball will appear smooth, shiny or greasy,
- Press the ball flat between thumb and index finger,
- Observe the number of taps required for a reaction as well as the consistency of the soil.

Implications

- If a rapid reaction is achieved (5-10 taps) and the flattened ball crumbles, the soil is very fine or a coarse silt,
- If a slow reaction is achieved (20-30 taps) and the flattened ball does not crumble but flattens, the soil is slightly plastic silt or silty clay,
- If a very slow reaction is achieved (over 30 taps) and the flattened ball does not change appearance on pressing, the soil has a high clay content.

Consistency test

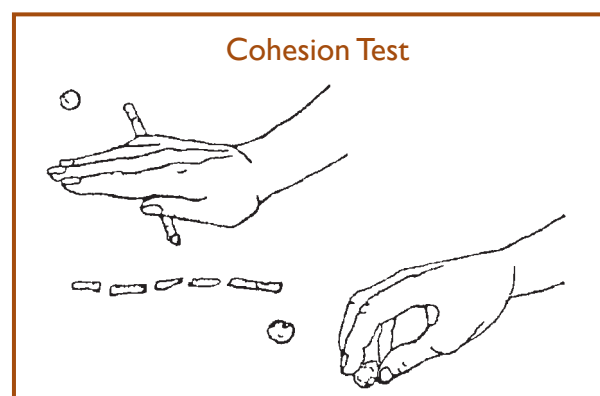
- Prepare a ball of fine soil approximately 3cm in diameter,
- Moisten the ball so that it can be modelled but does not stick to the fingers,
- Roll the ball on a flat clean surface to form a thread,
- If the thread breaks when it is thicker than 3mm, the soil is too dry - add water,
- The thread should break when approximately 3mm thick,
- When the thread breaks, make it into a small ball again and crush it between the thumb and index finger,
- Observe what happens when the ball is crushed.

**Implications**

- If soil crumbles before forming a ball it has a high silt or sand content,
 - If the ball cracks and crumbles, it has a low clay content,
 - If the ball is hard to crush and does not crack or crumble, it has a high clay content,
 - If ball feels spongy, it contains organic matter.
- (Houben & Guillaud, 1994: p 52).

Cohesion test

- Roll soil into a sausage with a diameter of approximately 12mm,
- The soil should not be sticky and it should be possible to roll it into a continuous thread, 3mm in diameter,
- Place the thread in the palm of the hand,
- Starting at one end, carefully flatten it between index finger and thumb to form a ribbon of between 3 and 6mm wide,
- Measure the length of ribbon before it breaks.

**Implications**

- No ribbon, shows a negligible clay content,
- 5-10cm ribbon, shows a low clay content,
- 25-30cm ribbon, shows a high clay content.

2.5 Soil Stabilisers

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

- strength and cohesion of the soil will increase,
- permeability of the soil will be reduced,
- the soil will be made water repellent,
- the durability of the soil will increase,
- the soil will shrink and expand less in dry and wet conditions.

Natural soil construction techniques such as cob, adobe, wattle and daub, or rammed earth are still widely used throughout the developing world by low-income groups. This is mainly because of their low cost and the abundance of easily available soil.

The principal soil fraction which enables a soil to be used as a construction material is clay because it provides cohesion and binds together the other fractions. Unfortunately, because clay usually swells on absorbing water and shrinks on drying, this can give rise to severe cracking and in extreme cases eventual disintegration. It can also give rise to difficulties in getting rendering to adhere to the walls. In order to enable soil to serve as a better and more durable construction material an additional material should be added to the soil mix to strengthen it. Traditionally, animal dung and straw have been used and are still used in many areas. Although they have the advantage of being low in cost, they are not very durable and need to be renewed after every rainy season.

Techniques to enhance the natural durability and strength of a soil - commonly defined as soil stabilisation - are practiced in many countries. The concept of soil stabilisation is not new, since natural stabilisers e.g. natural oil and plant extracts, animal dung, and crushed ant-hill materials have been used for many centuries. Recently, more rigorous scientific rather than adhoc methods of soil stabilisation have also been introduced, developed mainly from early techniques devised for the stabilisation of earth roads.

Many stabilisers have been tried, including manufactured ones such as Portland cement, lime, bitumen, gypsum, alkalis, sodium chloride, calcium chloride, aluminium compounds, silicates, resins, ammonium compounds, polymers, and agricultural and industrial wastes. The most widely used stabilisers in developing countries, are Portland cement, lime and bitumen because they are inexpensive and readily

available. Gypsum and agricultural wastes are used to a lesser extent. The properties, availability, production and consumption of the most popular stabilisers are discussed in this chapter.

2.6 Principles of Soil Stabilisation

As mentioned previously silt and clay within a soil sample react to moisture, swelling when water is absorbed, and shrinking when the soil dries out. Such movement can result in surface cracking of walls and consequently accelerate erosion, which may eventually lead to structural failures. Movement often causes the crumbling of surface coatings. The main objective of soil stabilisation is to enhance soil resistance to the erosive effects of the local weather conditions, including variations in temperature, humidity and rainwater.

The use and adoption of the right stabilisation method can improve the compressive strength of a soil by as much as 400 to 500% and increase its resistance to erosion and mechanical damage.

Good resistance to erosion can be obtained in one or more of the following ways:

- increasing the density of the soil,
- adding a stabilising agent that either reacts with, or binds the soil grains together,
- adding a stabilising agent which acts as a waterproofing medium.

2.7 Soil Stabilisation Techniques

There are several methods of soil stabilisation widely used to improve construction quality. Some of the major stabilisation techniques are described in this section.

Mechanical stabilisation

This involves tamping or compacting the soil by using a heavy weight to bring about a reduction in the air void volume, thus leading to an increase in the density of the soil. The main effects of compaction on the soil are to increase its strength and reduce its permeability. The degree of compaction possible, however, is affected greatly by the type of soil used, the moisture content during compaction and the compression effort applied. Best results can be obtained by mixing the correct proportions of sand and clay in a soil. More recent developments for roads and embankment construction have led to compacting soil with vibrating rollers and tampers. Tampers and block-making presses are also used for single storey constructions. The major drawback of mechanically compressed stabilised earth blocks is their lack of durability especially in places of moderate to high rainfall.

Materials for Compressed Stabilised Block Production

Manual stabilisation or compaction methods vary from foot treading to hand tamping equipment, with compacting pressures varying between 0.05 to about 4MN/m². Mechanical equipment may achieve compacting pressures of several thousand MN/m².

Cement stabilisation

Ordinary Portland cement hydrates when water is added, the reaction produces a cementitious gel that is independent of the soil. This gel is made up of calcium silicate hydrates, calcium aluminate hydrates and hydrated lime. The first two compounds form the main bulk of the cementitious gel, whereas the lime is deposited as a separate crystalline solid phase. The cementation process results in deposition between the soil particles of an insoluble binder capable of embedding soil particles in a matrix of cementitious gel. Penetration of the gel throughout the soil hydration process is dependent on time, temperature and cement type. The lime released during hydration of the cement reacts further with the clay fraction forming additional cementitious bonds. Soil-cement mixes should be compacted immediately after mixing in order not to break down the newly created gel and therefore reduce strengthening. The basic function of cementation is to make the soil water-resistant by reducing swelling and increasing its compressive strength.

With respect to the general processes of cementation, penetration and binding mentioned above, many factors must be considered. Processes may also vary between different types of soils. Cement is considered a good stabiliser for granular soils but unsatisfactory for clays. Generally cement can be used with any soil type, but with clays it is uneconomical because more cement is required. The range of cement content needed for good stabilisation is between 3% and 18% by weight according to soil type.

Findings have shown that there is a relationship between linear shrinkage and cement content need for stabilisation. Figure 2.3 shows that the cement to soil ratio ranges between 5.56% and 8.33% for measured shrinkage variations of between 15mm to 60mm.

Figure 2.4 - Cement to soil ratio

Measured shrinkage (mm)	Cement to soil ratio
Under 15	1:18 parts (5.56%)
15 - 30	1:16 parts (6.25%)
30 - 45	1:14 parts (7.14%)
45 - 60	1:12 parts (8.33%)

It may be noted that for a given shrinkage the cement to soil ratio is function of the compaction effort exerted. For example, a CINVA Ram machine exerts a compaction pressure of about 2MN/m^2 (see Chapter 4) by increasing this pressure to about 10MN/m^2 the cement content can be reduced to between 4% and 6% for soil with a shrinkage of up to 25mm. Over this shrinkage value, 6% to 8% cement would need to be used for effective stabilisation

Lime stabilisation

By adding lime to the soil for stabilisation, four basic reactions are believed to occur: cation exchange, flocculation and agglomeration, carbonation, and pozzolanic reactions. The pozzolanic reaction is believed to be the most important and it occurs between lime and certain clay minerals to form a variety of cementitious compounds which bind the soil particles together. Lime can also reduce the degree to which the clay absorbs water, and so can make the soil less sensitive to changes in moisture content and improve its workability. Lime is a suitable stabiliser for clay soils. Lime is more widely available than Portland cement in Sudan and is produced locally in traditional kilns. However, some improvements still need to be made in its production and processing.

The advantages that lime has over Portland cement are that it requires less fuel to manufacture and requires relatively simple equipment to make. It is therefore more suitable for village scale production and use.

It has been reported that when lime is used as a stabiliser instead of cement, the quantity needs to be doubled. However, research by the author, Dr. E.A. Adam, at the United Kingdom Building Research Establishment shows that such doubling is not necessary if a sufficiently high compacting effort is applied on a high clay content soil. The reduction in the volume of air voids brings the lime and soil particles into closer contact and the stabilising reactions can take place more easily. Tests show that wet compressive strengths of between 3MN/m^2 and 3.5MN/m^2 may be achieved with compacting efforts in the range of 8 to 14MN/m^2 . Blocks made from Sudanese black cotton soils are tested using wide range of compaction pressures. A 6% lime content is used for stabilising black cotton soil from Sudan with a silt and clay content of 58% and a linear shrinkage of 11%.

Bitumen stabilisation

There are two ways whereby bitumen can stabilise soil. The first way is a binding process that increases soil strength particularly in granular soils. Generally, small amounts of bitumen (2% to 6%) give the soil cohesion. When these percentages are exceeded the bitumen tends to act as a lubricant separating the particles and thus reducing the strength. The second way is when the bitumen acts as a water

Materials for Compressed Stabilised Block Production

repellent. The two mechanisms usually occur together in any soil but to different degrees, depending on the type of soil.

Soils suitable for bituminous stabilisation are sandy soils. Clays need large amounts for good results.

The main disadvantages of bituminous materials as stabilisers are:

- they are not a traditional building material in most developing countries,
- bituminous materials are expensive to import,
- preparation costs are high (heating, storing and mixing),
- heat can have an adverse effect on their binding properties, particularly in hot countries.

In Sudan asphalt has been used for making adobe bricks called asfadobe. Asfadobe have been used to build experimental houses in Khartoum North. A new plant was constructed to produce asfadobe bricks that cost half as much as fired bricks. If this technique is transferred to the remote parts of the country, however, asfadobe bricks are likely to become very expensive due to high transportation costs and as well as the high cost of importing materials.

Gypsum stabilisation

Gypsum is a traditional material found in many Mediterranean and Middle Eastern countries. The earliest civilisations used gypsum for building purposes, mainly for plasters and mortars. The advantage that gypsum has over Portland cement and lime is that it requires a low calcination temperature (about 1/7th of that needed for cement and 1/5th of that needed for lime). Besides its agricultural and chemical uses, the main use of gypsum in Sudan is in the production of Portland cement where it retards the setting of the cement. Gypsum is a good stabiliser for sandy soils.

Pozzolanas stabilisation

Pozzolanas are fine silica and alumina rich materials which when mixed with hydrated lime produce cementitious materials suitable for stabilisation and construction needs. Pozzolanas are found in their natural state as volcanic ash or pumice in eastern and western Sudan. Pozzolanas can also be manufactured from finely ground recycled fired clay bricks and mudstone which is available in the Khartoum province. Such pozzolanas are used extensively in western Sudan for building plasters and stabilisers with excellent results.



Other stabilisers

Traditionally, many stabilisers such as animal dung, ant hill materials, bird droppings, plant extracts and animal blood, have been used for the manufacture of compressed stabilised earth building blocks. These waste materials generally consist of nitrogenous organic compounds which help bind together soil grains.

Chopped straw, grasses and natural organic fibres, although not active stabilisers, are used as reinforcement materials to reduce linear shrinkage problems which occur with soil that has a high clay content.



Preparation of
Raw Materials

3.1 The Requirements for Preparation

The basic materials required for the production of compressed stabilised earth building blocks are soil, stabiliser, and water. The stabiliser, whether lime or cement or some other material, is usually available in powder or liquid form, ready for use. The soil may be wet or dry when it is first obtained, and will probably not be homogeneous. In order to have uniform soil, it is often necessary to crush it so that it can pass through a 5 to 6mm mesh sieve.

Different soil types may also need to be used together so as to obtain good quality products. For instance, a heavy clay may be improved by addition of a sandy soil. It is not only important to measure the optimum proportion of ingredients, but also to mix them thoroughly. Mixing brings the stabiliser and soil into direct contact, thus improving the physical interactions as well as the chemical reaction and cementing action. It also reduces the risk of uneven production of low quality blocks. Various types and sizes of mixing equipment are available on the market.

3.2 Breaking up Soil

In most developing countries the soil is usually dry when dug out of the borrow pit or it will dry soon after digging. Simple hand tools are available as well as a range of more complicated machinery which can be used to reduce the soil grains to an appropriate size.

In order to obtain a uniform mix of the mineral components, water and stabiliser, lumps more than 200mm in diameter after excavation must be broken up. Grains with a homogeneous structure, such as gravel and stones, must be left intact, and those having a composite structure (clay binder) broken up so that at least 50 per cent of the grains are less than 5mm in diameter. The soil must be dry as wet soil can only be handled by certain mechanised systems.

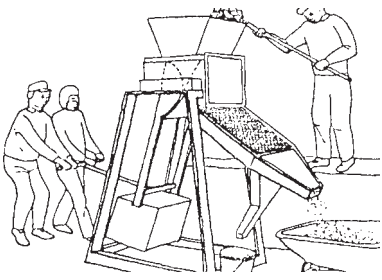
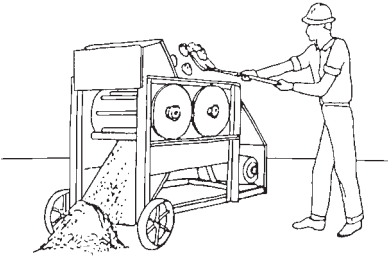
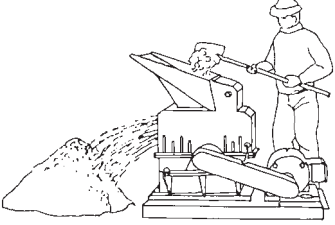
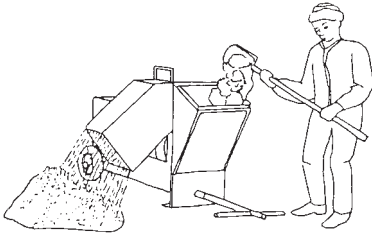
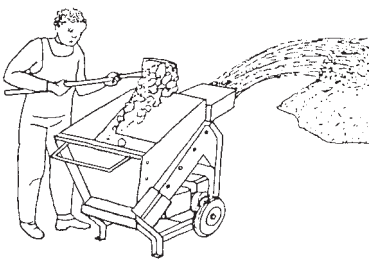
Grinding followed by screening

The material is pressed between two surfaces - a rather inefficient and tedious process in which bigger stones are broken up, however, only simple machinery is required. The broken up lumps of soil are then passed through a screen.

Pulverisation of soil

The material is hit with great force so it disintegrates. The machinery required is complex but performs satisfactorily. At the delivery end, any large pieces left can be removed by means of screen.

Preparation
of Raw Materials*Figure 3.1 - Some techniques used for pulverising soil*

Pounding	A manual process that is very slow. Approximately 1 m ³ can be pounded per day per man, screening afterwards is absolutely essential.	
Jaws	An elementary mechanism of reciprocating motion. With the manual version an output of 3 to 4 m ³ /day, with a weight of 150kg can be expected.	
Squirrel cage	A very rapid rotation of 600 rpm, a 3hp or 2.25kW electric motor. An output of 15 to 20 m ³ /day, with a weight of 150kg can be expected.	
Hammers	Several spring-mounted hammers on a central axle beat the earth at a high frequency, with a 10hp or 7.5kW electric motor. An output of 40 m ³ /day, with a weight of 200kg can be expected.	
Screw	The same system as that used in conventional composting machines. Such machines can be used if care is taken to avoid excess wear. Using a single screw or set of screws, with a 5hp or 3.75kW diesel motor, an output of 15 m ³ /day, with a weight of 200kg can be expected.	
Toothed belt	The only machine with a hopper. It is highly efficient. Using a 3hp or 2.25kW petrol run motor, an output of 30 m ³ /day, with a weight of 100kg can be expected.	

3.3 Sieving

Soil contains various sizes of grain, from very fine dust up to pieces that are still too large for use in block production. The oversized material should be removed by sieving, either using a built-in sieve, as with the pendulum crusher, or as a separate operation.

The simplest sieving device is a screen made from a wire mesh, nailed to a supporting wooden frame and inclined at approximately 45° to the ground. The material is thrown against the screen, fine material passes through and the coarse, oversized material runs down the front. Alternatively, the screen can be suspended horizontally from a tree or over a pit. The latter method is only suitable in the case where most material can pass through easily otherwise too much coarse material is collected, and the screen becomes blocked and needs frequent emptying.

3.4 Proportioning

Before starting production, tests should be performed to establish the right proportion of soil, stabiliser and water for the production of good quality blocks. The proportions of these materials and water should then be used throughout the production process. To ensure uniformity in the compressed stabilised earth blocks produced, the weight or volume of each material used in the block making process should be measured at the same physical state for subsequent batches of blocks. The volume of soil or stabiliser should ideally be measured in dry or slightly damp conditions.

After establishing the exact proportion required of each material, it is advisable to build a measuring device for each material. The dimensions of each measuring box should be such that their content, when full, is equivalent to the proportion which should be mixed with other materials measured in other gauge boxes. Alternatively, a simple gauge box may be used for all materials. In this case, the amount of material for the production of a given batch of blocks may be measured by filling and emptying the gauge box a number of times for each separate material. For example, a batch of blocks may require ten gauge boxes of soil for one gauge box of stabiliser. Water may be measured in a small tank or container.

It is advisable to mix enough materials to allow the block-making machine to operate for approximately one hour. Thus, the volume of the mixed material will depend on the hourly output of the block making equipment.

3.5 Mixing

In order to produce good quality blocks, it is very important that mixing be as thorough as possible. Dry materials should be mixed first until they are a uniform colour, then water is added and mixing continued until a homogeneous mix is

obtained. Mixing can be performed by hand on a hard surface, with spades, hoes, or shovels.

It is much better to add a little water at a time, sprinkled over the top of the mix from a watering can with a rose spray on the nozzle. The wet mix should be turned over many times with a spade or other suitable tool. A little more water may then be added, and the whole mixture turned over again. This process should be repeated until all the water has been mixed in.

When lime is used as a stabiliser, it is advisable to allow the mix to stand for a short while before moulding starts to allow better moistening of soil particles with water. However, if cement is used for stabilisation, it is advisable to use the mix as soon as possible because cement starts to hydrate immediately after it is wetted and delays will result in the production of poor quality blocks. For this reason the quantity of cement-sand mix should not exceed what is needed for one hour of operation. Even so, the blocks produced at the end of one hour may be considerably weaker than those produced immediately after the mixing.

A concrete mixer, even if available, will not be useful for mixing the wet soil, since the latter will tend to stick on the sides of the rotating drum. If machinery is to be used for mixing, it should have paddles or blades that move separately from the container. However, field experience shows that hand-mixing methods are often more satisfactory, more efficient and cheaper than mechanical mixing, and are less likely to produce small balls of soil that are troublesome at the block moulding stage.

3.6 Quantity of Materials Needed

Compressed stabilised earth building blocks are usually larger in size than traditional burnt bricks. A typical block size is 290 × 140 × 90mm. Its production will need about 7.5 to 8.5kg of materials depending on the compaction pressure. The exact amount of stabiliser necessary must be established for any particular project. The fraction of lime or cement usually varies between 5% to 8% by weight. Similarly, the optimum water content (OMC) for any particular soil must be determined experimentally. The moisture level varies widely with the nature of the soil. An approximate estimate of about 15% by weight is often assumed.

The amount of material required for a typical block press producing 300 blocks per day is shown in Figure 3.1.



Figure 3.2 - Approximate quantity of materials required for producing 300 blocks per day

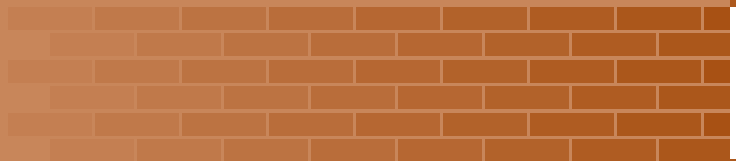
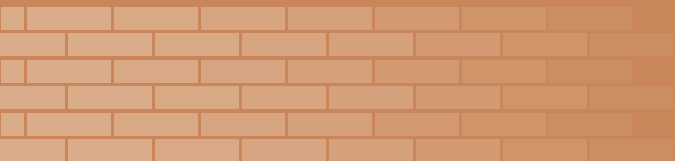
Material	Quantity Required / Day	
	8% hydrated lime	5% cement
Soil	1.9 tonnes	1.95 tonnes
Stabiliser	0.150 tonnes	0.095 tonnes
Water	300 litres	300 litres
Total (after mixing)	2.350 tonnes	2.345 tonnes

In practice, the above quantities of soil, stabiliser, and water will vary depending upon the type and properties of the soil. A single storey building with a floor area of 50m² will require about 3000 blocks. The estimated amount of soil, stabiliser, and water needed for building such a house is given in Figure 3.3. In this example, the blocks for the house could be produced in ten days.

Figure 3.3 - Approximate quantity of materials required for a single story house

Material	Quantity Required / House	
	8% hydrated lime	5% cement
Soil	19 tonnes	19.5 tonnes
Stabiliser	1.5 tonnes	0.95 tonnes
Water	3000 litres	3000 litres

Moulding Compressed Stabilised Earth Blocks



4.1 Standards for Block Production

Many aspects should be taken into consideration before launching an operation to produce compressed stabilised earth building blocks:

- amount and type of stabiliser required,
- soil properties and its suitability for stabilisation,
- building standards and hence quality of blocks required,
- load bearing requirements of construction i.e. single storey or more.

One of the purposes of this handbook is to make the reader aware of the problems associated with compressed earth blocks in the construction industry especially in developing countries where building standards have not yet been developed in the field of earth construction.

Generally, there is a wide variation of acceptable standards that vary according to local weather conditions. Blocks with wet compressive strengths in the range or 2.8 MN/m^2 or more should be adequate for one and two-story buildings. Blocks of this type would probably not require external surface protection against adverse weather conditions. For one-storey buildings, blocks with a compressive strength in the order of 2.0 MN/m^2 will probably be strong enough, but where rainfall is high an external treatment is necessary. Since the wet strength of a compressed stabilised earth block wall may be less than two-thirds of its dry strength. It should be remembered that all compressive strength tests should be carried out on samples which have been soaked in water for a minimum of 24 hours after the necessary curing period.

The final wet compressive strength of a compressed earth block depends not only on soil type, but also on the type and amount of stabiliser, the moulding pressure, and the curing conditions.

In 1998, standards for compressed earth blocks were ratified as African Regional Standards (ARS) under the auspices of the African Regional Organisation for Standardisation (ARSO) technical committee on building and civil engineering (ARSO/TC3) after having satisfied procedures for the approval of regional standards (see [Appendix II](#)).

4.2 Testing Soil Prior to Block Production

Various soil-testing methods are described in Chapter 2 which are used to determine the suitability of different soils for block making and the type of stabiliser required. For block production, the soil mix must be checked for each batch of blocks so as to attain the optimum moisture content (OMC).

Two simple field tests can be carried out. These are explained below:

- Take a handful from the soil mix for block production and squeeze it in the hand, the mix should ball together. When the hand is opened, the fingers should be reasonably dry and clean.



Moulding Compressed Stabilised Earth Blocks

- Drop the ball sample onto a hard surface from a height of about one metre. If the sample:
 - completely shatters, this shows that it is not sufficiently moist,
 - squashes into a flattened ball or disc on impact with the hard surface, this implies too high a moisture content,
 - breaks into four or five major lumps, this shows that the moisture contents or the soil mix is close to the optimum moisture content (OMC).

To manufacture blocks of uniform size and density, special precautions must be taken to fill the mould with the same amount of mix for each compaction by using a small wooden box as a measuring device.

To facilitate development of the pressed blocks and to ensure good neat surfaces it is advisable to moisten the internal faces of the machine mould with a mould releasing agent (reject oil) which can be applied with either a rag, brush or spray.

4.3 Curing

To achieve maximum strength, compressed stabilised earth blocks need a period of damp curing, where they are kept moist. This is a common requirement for all cementitious materials. What is important is that the moisture of the soil mix is retained within the body of the block for a few days. If the block is left exposed to hot dry weather conditions, the surface material will lose its moisture and the clay particles tend to shrink. This will cause surface cracks on the block faces.

In practice, various methods are used to ensure proper curing. Such methods include the use of plastic bags, grass, leaves, etc. to prevent moisture from escaping.

Figure 4.1 - Brick curing



After two or three days, depending, on the local temperatures, cement stabilised blocks complete their primary cure. They can then be removed from their protective cover and stacked in a pile, as shown in Figure 4.1. As the stack of blocks is built up, the top layer should always be wetted and covered, and the lower layer should be allowed to air-dry to achieve maximum strength. Alternatively, freshly moulded blocks can be laid out in a single layer, on a non-absorbent surface, and covered with a sheet to prevent loss of moisture.

The required duration of curing varies from soil to soil and, more significantly, which type of stabiliser is used. With cement stabilisation, it is recommended to cure blocks for a minimum of three weeks. The curing period for lime stabilisation should be at least four weeks. Compressed stabilised earth blocks should be fully cured and dry before being used for construction.

4.4 Sizes of Compressed Stabilised Earth Blocks

Most countries currently use concrete blocks that are 400mm long and 200mm high, with varying thickness of up to 200mm. Such dimensions are not suitable for compressed stabilised earth blocks because the production of high quality blocks of this size would need relatively high compacting forces. It is therefore necessary to adopt smaller overall dimensions.

A soil building block 290mm long, 140mm thick and 90-100mm high is considered to be an acceptable size. In this case a mortar joint of 10mm should be used creating a module length of 300mm. A double block wall thickness of 290mm with a minimum wet compressive strength of 2.8MN/m² is suitable for a building of more than one storey. A single skin wall thickness of 140mm would be sufficient to carry the vertical and lateral loads in a single storey building and probably a two storey building provided the foundations are sufficient.

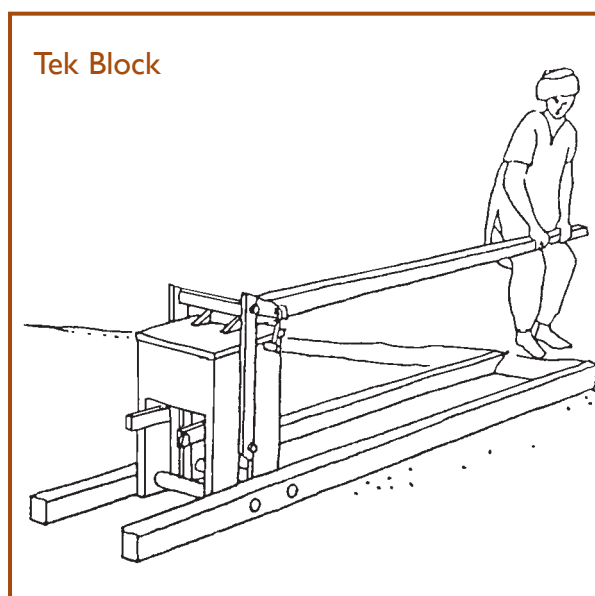
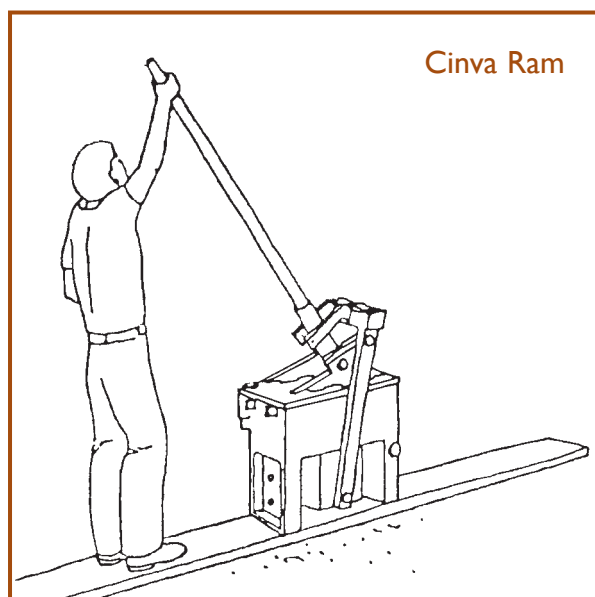
A good durable construction with a wall density of about 2,000kg/m³ can be achieved without the need for costly external protective rendering to resist weathering problems. Each individual block will have a dry weight of about 7kg which is easy for the mason to handle. A wall thickness of 140mm with a density of 2000kg/m³ should provide adequate thermal insulation even when external wall temperatures fluctuate, thus helping to reduce temperature variations inside a building.

4.5 Compressed Earth Block-Making Machines

There are a wide range of block machines in operation throughout the world produced in both developed and developing countries. **Appendix III** gives some useful addresses for block making machinery and equipment

Available machines vary from simple manual operated machines to industrialised units. Some detailed description is given in the following sections of the various block making machines and their mechanisms.





4.6 Types of Presses

1. Manual presses

(a) Light mechanical presses

The advantage of Cinva-Ram type presses are that they are light, sturdy, low cost, and simple to manufacture and repair. Their main disadvantages are that they can wear out quickly (the coupling rings), they only have a single moulding module that can exert low pressures, and have a low output. Nevertheless, they are one of the best presses of their type on the market, and it is usually the copies which wear out prematurely.

The skills that go into producing Cinva-Ram presses are not always very well understood, nevertheless, this press has potential for improvement. The following are some of the improvements designers have come up with:

- joining the cover to the lever (Tek-Block),
- better ejection (Steven, Ceneema),
- greater moulding depth (Ait Ourir),
- better transmission of energy (Dart-Ram),
- fold-down cover (Meili),
- standard steel profile (Unata),
- dual compaction section (C+BI),
- compartmentalised mould (MRCI),
- production of perforated blocks (Ceta-Ram).

These technical improvements aim to refine the production process of the press.

Production capacity is determined to a large extent by the way the work is organised, the way the crew are paid and the prevailing working conditions. The average output of a Cinva-Ram or similar press is 300 blocks/day, though this can be increased to 1200 blocks/day.

These presses are produced in many countries including Belgium, Burkina Faso, Cameroon, Colombia, France, Morocco, New Zealand, Switzerland, United Republic of Tanzania, United States of America, Zambia.

(Houben & Guillaud, 1994: p 230)

(b) Light Hydraulic Presses

The Brepak is a small press which is considerably more productive than the Cinva-Ram. Pressures of up to 10MN/m^2 can be achieved by replacing the swivel and rod system of the Cinva-Ram with a hydraulic piston. The resulting blocks have identical dimensions to those made using the Cinva-Ram but are approximately 20% denser. This hyper-compression means that they can be used for compacting highly expansive soils such as black cotton soil (Houben & Guillaud, 1994: p 230).

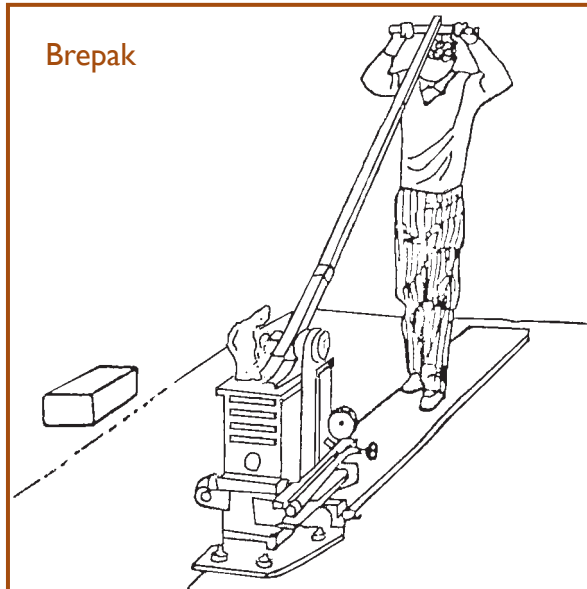
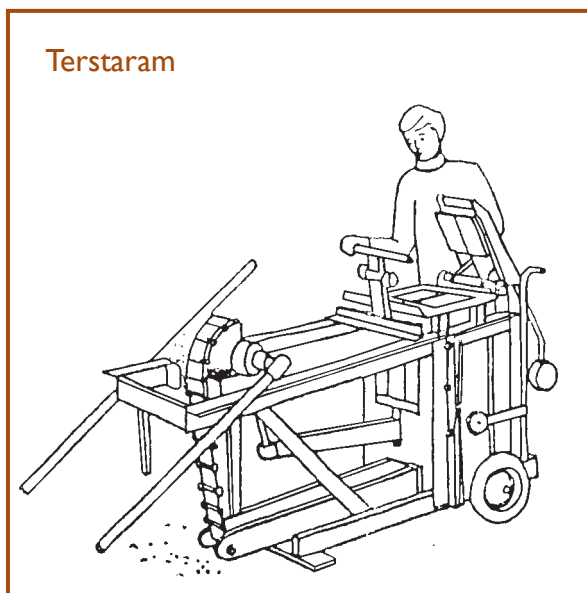
(c) Heavy Mechanical Presses

These presses (e.g. Terstaram) are sturdy and do not wear out easily. They can produce pressures greater than the minimum threshold of 2MN/m^2 . They are easy to use and maintain and have interchangeable moulds. Their design allows for more efficient organisation of work carried out around the press. The fold down cover of these machines allows the soil to be pre-compacted and the back and fourth motion from one side of the press to the other is avoided (Houben & Guillaud, 1994: p 231).

2. Motorised Presses**(a) Mechanical Presses**

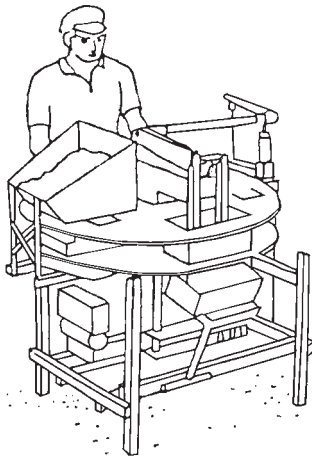
Some of these presses, such as the Semi-Terstamique, are direct descendants of the heavy manual presses and have benefited from lessons learned using the previous models. They represent a new generation of presses currently available on the market and appear destined for a bright future. Their economic viability is excellent despite the fact they cost between 4 - 7 times more to run than heavy manual presses. At one time the Semi-Terstamique was on the market under the trade name Major and LP9 (Landcrete).

Motorised mechanical presses belong to one of two groups: those that are simple and sturdy and have a fixed table and single mould, and those with a rotating plate and 3 or 4 multiple moulds which can raise productivity rates. With the single mould model the mould can be changed quickly and cheaply, whereas with the rotating plate

Brepak**Terstaram****Semi Terstamatique**

Moulding Compressed Stabilised Earth Blocks

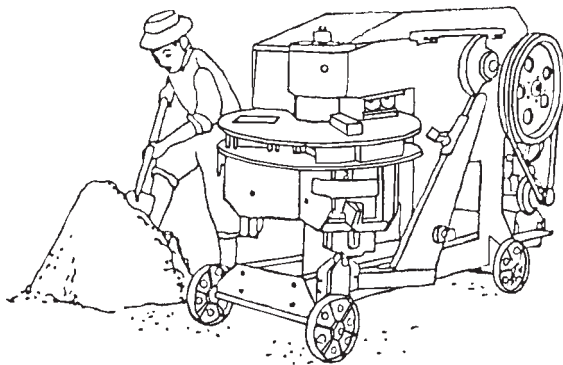
Pact 500



model, changing the mould takes more time and is more expensive. With some models (e.g. Pact 500) the tables can be turned by hand or mechanically. This system requires a more sophisticated mechanism and more energy.

Dynamic pre-compaction, achieved by lowering the cover, becomes possible when using a single mould and has significant advantages. Pre-compaction using a rotating table press can be achieved by using a feed hopper to ensure that the level of earth is slightly above the sides of the mould. The tapered pre-compacting roller located between the feeding and compacting position must also be adjusted.

Ceramic



The designers of the Ceramic press have encountered several problems which had still not been resolved when the presses were brought onto the market. The soil has a tendency to get into sensitive areas of the machine disturbing the functioning of the machine. To ensure safe operation of these machines they should not be allowed to operate in reverse, which happens if the electric motor is installed backwards. Poorly compacted blocks will be produced if too much earth is put in the mould as it is impossible to exert the required pressure. To avoid this the press ought to be provided with a compensating spring and motor release system that regulates the quantity of soil. Finally, these presses should be designed to give the user the option of using an electric motor, a combustion engine, or another type of motor. These presses are very largely dependent on good upstream production operation of screening, proportioning and mixing. (Houben & Guillaud, 1994: p 230).

(b) Hydraulic Presses

These are stand-alone presses capable of medium output. Hydraulic presses were very popular in the 1950s but rapidly disappeared from the market.

These presses function well in a technologically advanced environment, but they often perform

poorly in rural areas or even in the suburbs of cities in developing countries where access to spare parts etc. may be limited.

New presses of the same type were launched in the 1970s (e.g. Tob System, Quixote and Supertor). Owing to the functioning of the piston and their compact design hydraulic systems have the advantage of allowing a long stroke with resulting compression ratios equal to or greater than 2. These systems can easily be adjusted to match the composition of the soil, as a first step towards automation they can be equipped with a hopper.

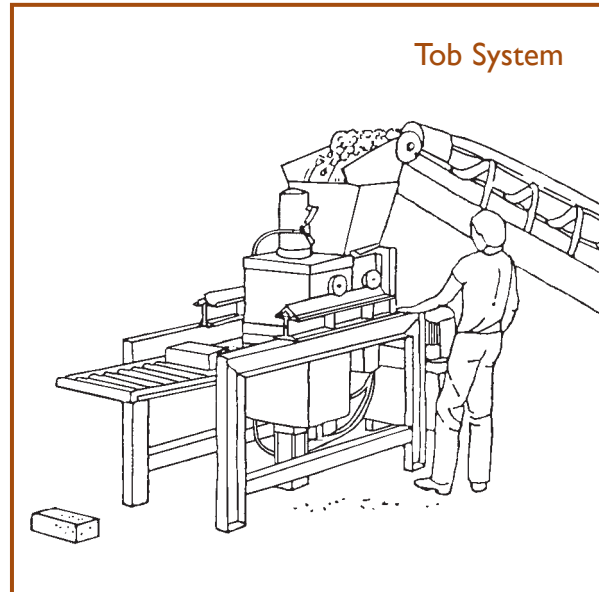
It is also true, however, that hydraulic presses can give rise to several specific problems. The hydraulic pump is delicate and susceptible to damage. If the press is running in a tropical climate and the rotating plate is hydraulically driven the oil reservoir should have a volume of at least 200 litres so as to avoid sudden temperature rises of the lubricating fluid. Any rise in temperature over 70°C, especially in tropical climates, will prevent the hydraulic components from functioning properly. Some presses can tolerate a temperature of 120°C but parts are difficult to replace if they break down. The alternative is an oil cooling system which complicates the plant as the oil must be changed regularly and may not always be available.

Many models of this type of press have been built and the market has seen the steady appearance and disappearance of models. Rarely have they been known to be fully reliable (Houben & Guillaud, 1994: p 233).

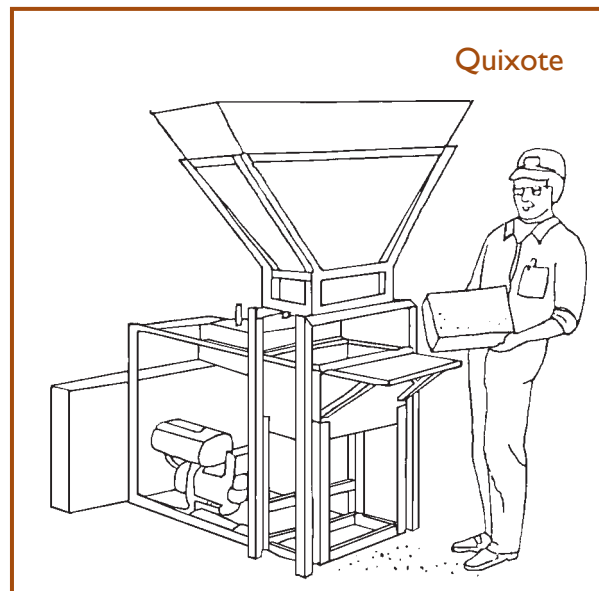
(c) Mobile production units

Designers and researchers have tried with some difficulty to integrate all the equipment required to make compressed earth blocks into self-contained units i.e. the mixer, pulveriser and press. The components do not, however, all operate in the same way and it is hard to maintain the ideal conditions for each component. Even in industrialised countries these machines require

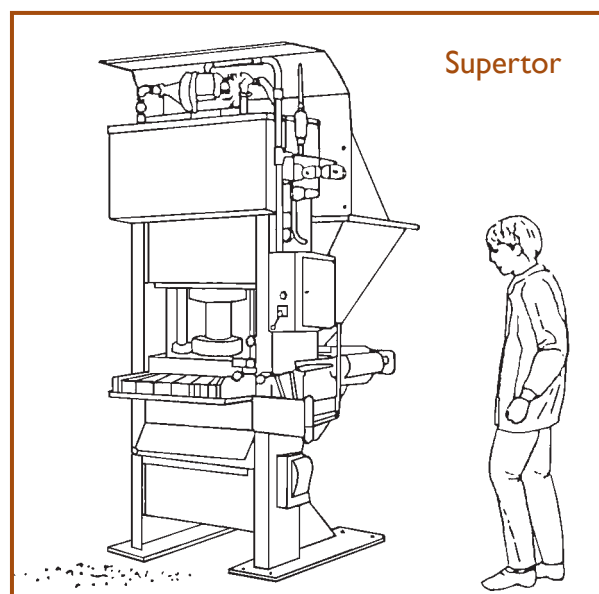
Tob System



Quixote



Supertor

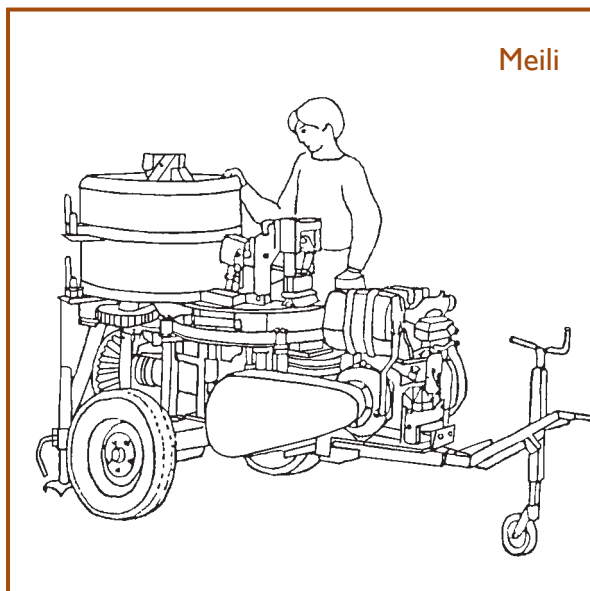


Moulding Compressed Stabilised Earth Blocks

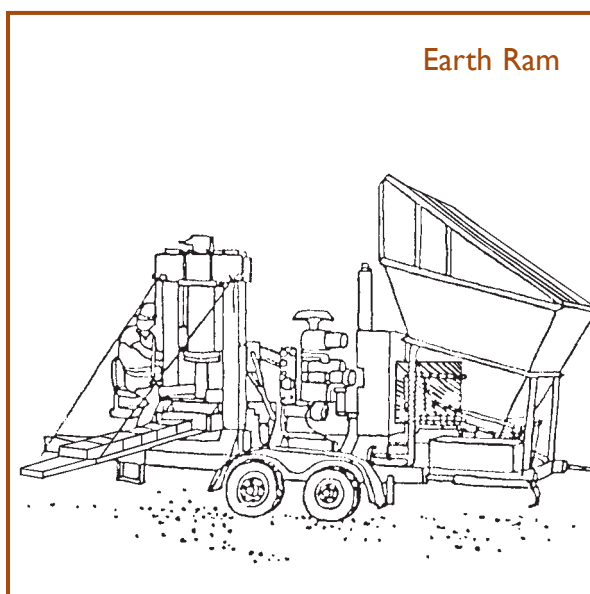
considerable financial input to operate. In developing countries they are often uneconomical. There are two main types of mobile production units:

(i) *Light units*

The advantage light units offer is that they open up the potential for new marketing strategies in both industrialised countries and in urban areas of developing countries by enabling 'do-it-yourself' builders to lease equipment out. These machines can be rented for the entire block production period at a relatively low price. Even so, this type of machine still suffers from a few defects, mainly because of a lack of integration between all the components.



Light units can operate with mechanical presses. At present the Swiss manufactured Meili unit, is the only example of this type of press on the market. There is not a very wide range of this type of unit but so far there is no totally integrated unit on the market, the pulveriser still suffers from defects. Light units can also operate with hydraulic presses. The Earth Ram, the Clu 2000 and Clu 3000 are a few of the many examples of this type of unit. The machines are sometimes adapted from standing units. In principle the design is attractive, but calculations of overall costs show that on large construction sites it is more economic to purchase the production materials (pulveriser, mixer, press) separately. Un-integrated plants are not less efficient and it is not clear that integrated equipment when working well is more convenient (Houben & Guillaud, 1994: p 234).



(ii) *Heavy Units*

Some larger manufacturers have proposed mobile units which can, in principal, be transported anywhere but are very large and heavy. The annual production capacities of these machines are very high. Broadly speaking the plants correspond to the light units described in the previous paragraph but at present there is a tendency towards using hyper-compression units. Few units of this type have been manufactured and as a result the the economic viability of these

presses has yet to be demonstrated. A thorough survey of market should be undertaken before acquiring them.

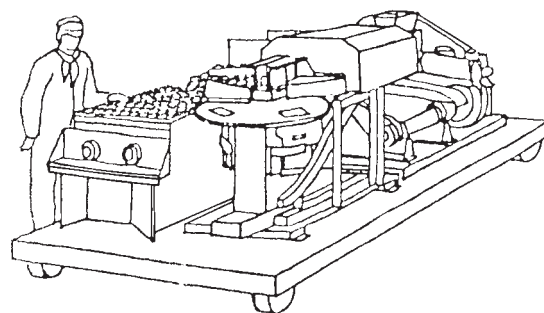
To date there is only one known unit that operates with mechanical presses, the 'Unipress'. Its design is based on the concept of combining and mounting several single units onto a single chassis. The resulting plant is very sturdy. This plant is ordinarily used for the production of burnt bricks but attempts, in Egypt, to adapt it so that it can be used to make compressed earth blocks have met with some difficulties.

Hydraulic presses are presented as a being all-purpose machines, but models found on the market (e.g. Teroc) have a fairly limited range of applications. As they are expensive and have only moderate output, their future appears to be limited. These units are not equipped with pulverisers or screens. The earth, which is deposited in a hopper, is premixed by gravity with a stabiliser by means of an integrated proportioning system. It is then moved by a conveyor belt to the mixer where dry and wet mixing are carried out. A strong hopper distributes the earth within the mould where it is hyper-compressed and then automatically ejected in the form of blocks. These units dispose of a system of slide moulds which cannot be used to produce hollow or cellular blocks (Houben & Guillaud, 1994: p.235).

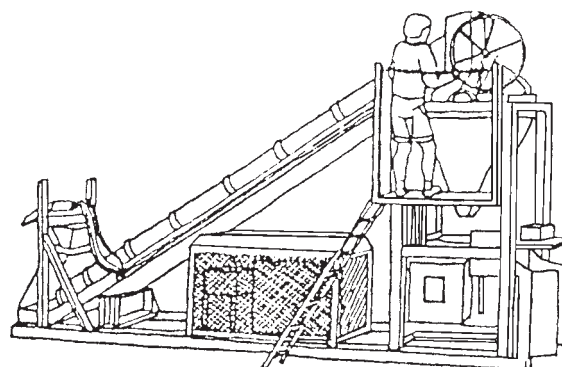
(d) Industrial production units

For several years the market has seen the arrival of a whole range of fully equipped standing industrial production units that operate on single or double, static compression or dynamic compression, principles. The list of products that can be manufactured by them is not limited to basic soil blocks but includes hollow stabilised earth blocks, perforated bricks, and all forms of concrete block and burned brick. As yet this manufacturing equipment is only intended for a limited market. Only massive construction programmes can ensure that the investments involved will be recovered.

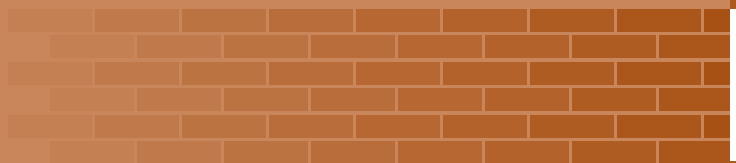
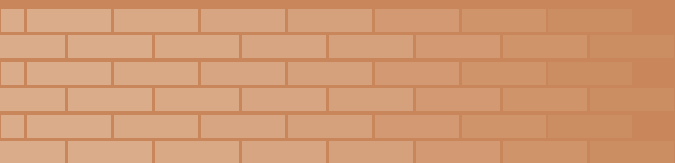
Unipress



Teroc



Mortars and
Surface Protection



5.1 Purpose of Mortars and Renders

Mortars are used primarily to accommodate slight irregularities in size, shape and surface finish of blocks thus providing uniformity and stability to a wall. In doing so any gaps between blocks are also closed, preventing wind and rain from passing through the wall. Mortar has a further purpose in that it improves both the shear and compressive strengths of the wall. Mortars have some binding characteristics which improve the shear resistance but do not add significantly to the tensile strength of a wall.

Renders applied to the external surface of walls can help prevent erosion and are often used to cover uneven block laying. However, if blocks are of good quality and excellent block-laying techniques are used, rendering is usually unnecessary. Rendering is preferred in some countries mainly for aesthetic reasons while bare, fair-faced work is preferred in others.

For compressed stabilised earth block construction there are various types of mortars that can be used for bonding the blockwork. Such mortars include mud, lime and sand mixes, pozzolana, cement sand mixes, pulverised fuel ash, and gypsum plaster. There are also many types of renders that can be used as an external finish for compressed stabilised earth block walls. Most of material types used for the production of mortars may also be used to produce renders. However, gypsum is not suitable for external rendering in wet climates. Traditionally, mud render is made more durable by adding cow dung.

Strong renders are more likely to shrink and crack than weaker ones. Cracks in rendering result in the moistening of blocks by rain. Damp walls will dry more slowly as moisture gets trapped between the render and blocks.

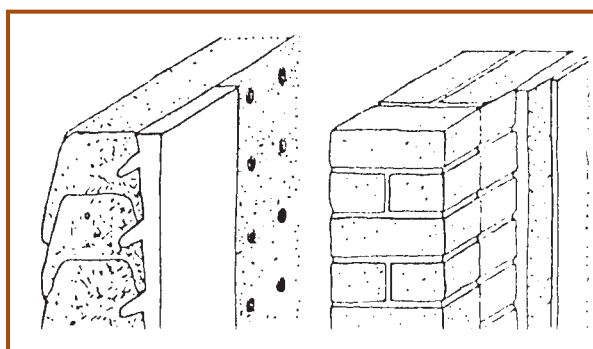
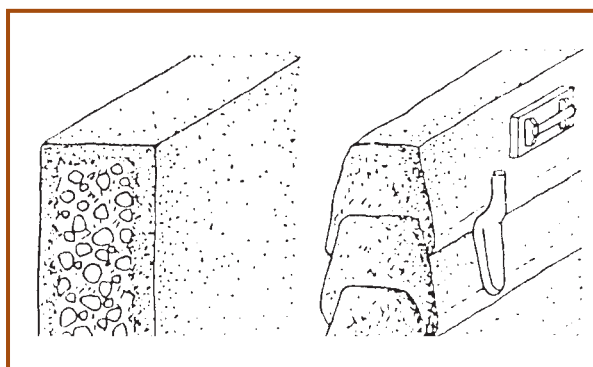
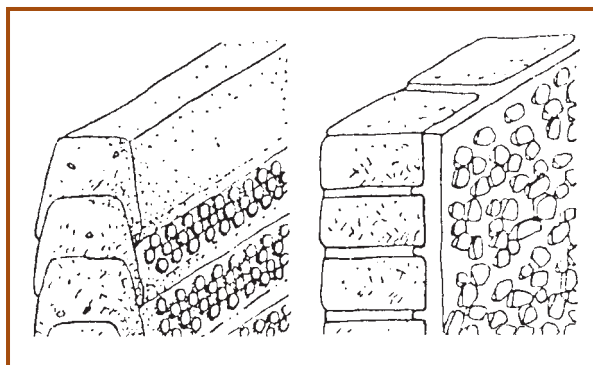
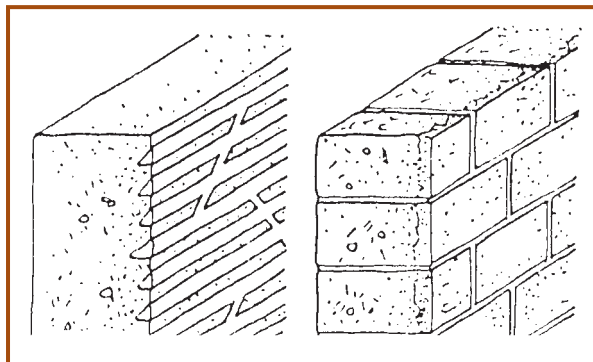
Renders may be applied after the wall surface has been prepared and cleaned from dust to provide a good base. Renders may be applied in one or three coats, depending upon the required quality of surface finish. The second coat can be used to fill any cracks in the dried first coat, and to improve the finished quality of work.

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Figure 5.1 - Different support systems

Supports					
Monolithic			Blockwork		
smooth i.e. rammed earth	porus i.e. cob	very porous i.e. straw-clay	smooth i.e. blocks	porus i.e. adobe	very porous i.e. sod
1	2	3	4	5	6

(Houben & Guillaud, 1994: p 350)



5.2 Surface Protection - types

Twin layers

This is a surface stabilisation system where two layers of render are applied to the wall surface. The twin layer system has also been developed for soil blocks (Burundi 1952, and EIER at Ouagadougou) and gives excellent results but is slow to do. With rammed earth walls the layers are applied to the outer surface while still in the form-work. Partial stabilisation is achieved where layers of mortar or lime are applied as render coats. The effect of this type of surface stabilisation is limited to a depth of 2 to 3cm (Houben & Guillaud, 1994: p334).

Inlay

Elements inlaid into the outer surface of the wall can create a weather resistant layer. Examples of elements often used are pebbles or flakes of stones, potsherds or brick flakes, shells, bottle tops (seen in Mexico), bottoms of bottles and tin lids (seen in Khartoum). As a large supply of elements is required and the work is labour intensive usually only the most exposed walls are inlaid (Houben & Guillaud, 1994: p334).

Surface treatment

This is a treatment where the exposed surface is carefully treated by ramming the outer surface with extremely fine soil. Another surface treatment, practiced in Morocco, involves ramming the wall with a wooden paddle. Such external tamping is also carried out in Yemen on cob structures. In some cases the surface of the wall can also be rubbed down with a stone for example. Such treatments are quite effective but should not be carried out when a rendering is going to be applied (Houben & Guillaud, 1994: p335).

Renders

Rendering can be applied in a single thick or thin layer, or in several thinner layers of earth, stabilised earth, or a sand-based mortar to which a hydraulic binder has been added i.e. cement or lime, or some other additive such as bitumen, resin, etc. Multi-layer renderings perform extremely well but take longer to apply (Houben & Guillaud, 1994: p334).

Paint

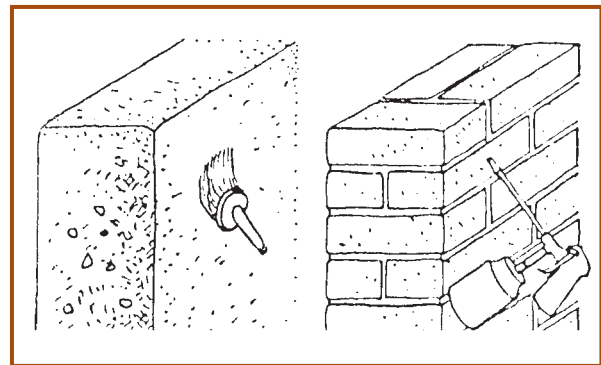
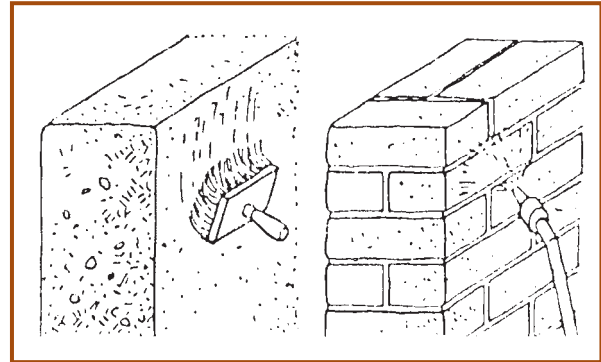
The coatings mentioned under this heading include conventional paints as well as distempers and washes. The latter are cement or lime slurries applied with a brush on walls that have been properly prepared and hydrated in advance. Bitumen may also be applied in liquid form using a spray-gun (Houben & Guillaud, 1994: p335).

Impregnation

The soil is impregnated with a natural (e.g. linseed oil) or chemical (e.g. silicon) product which gives the following properties to the wall:

- waterproofing,
- mixing of fine grains and particles to the surface thus hardening of the exposed wall surface,
- colouring.

The impregnation product can be applied with either a brush or a spray-gun (Houben & Guillaud, 1994: p335).



5.3 Detailed Aspects of Surface Protection

Latching and anchoring glue

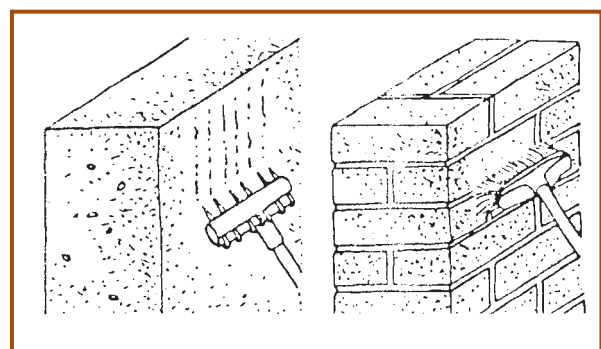
(Supports 1, 2, 4, 5 - see Figure 5.1)

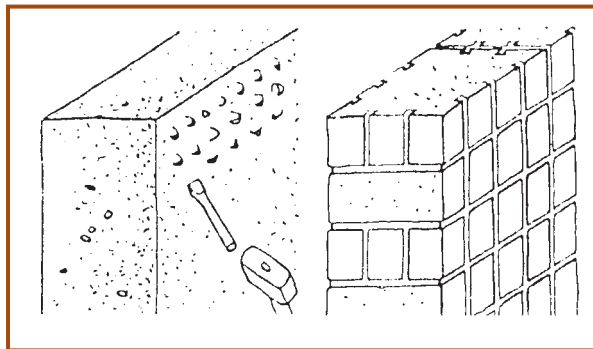
The use of white joinery glue (e.g. dilute polyvinyl acetate), diluted in water and applied in two layers using a brush has been tested in Egypt, Nigeria, Sri Lanka and Sudan. Dust is fixed to the surface and the mortar adheres to the rendering more easily. Glue surface treatments should preferably be used in conjunction with a fibre reinforced render. Other dust fixatives can be used if they are compatible with the render (Houben & Guillaud, 1994: p335).

Scraping and dust removal

(Supports 1, 2, 4, 5 - see Figure 5.1)

Scraping the supports is particularly important if they are at all crumbly, as it removes any materials/particles which are not well fixed to the surface. The sand and gravel skeleton is exposed and will hold the rendering. Dust removal is imperative on most earth supports and can be done with a dry or moist brush, being careful not to saturate the wall, or using compressors or blowers (Houben & Guillaud, 1994: p350).

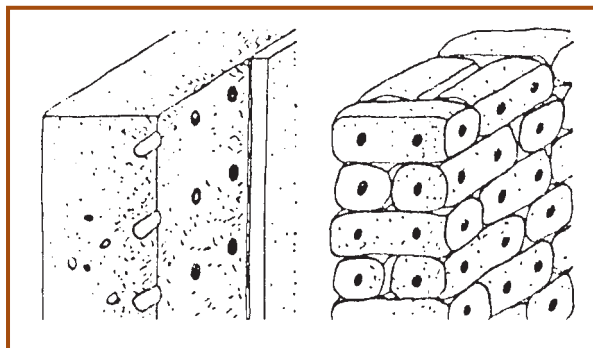




Grooving

(Supports 1, 2, 4, 5 - see Figure 5.1)

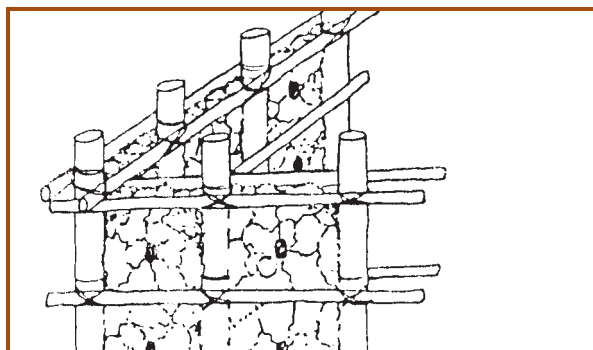
By scraping the joints, to a depth of 2-3cm, on walls built with compressed blocks and adobes, the hollowed out joint will anchor the rendering. A variation of this process is to groove or chisel the blocks themselves. Grooving is particularly good for anchoring render onto rammed earth and cob. The grooved surface can also be prefabricated using special moulds for blocks, or nailing dovetailed battens onto rammed earth formwork (Houben & Guillaud, 1994: p 350).



Holes

(Supports 1, 2, 3, 4, 5, 6 - see Figure 5.1)

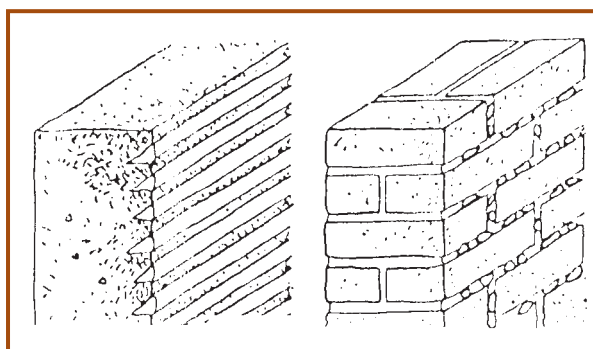
This anchoring technique is particularly useful for rammed earth, cob and straw-clay supports. It involves making slanting holes of at least 3cm depth or preferably 6cm, in the wall when the earth is still moist or the formwork has just been removed. If building in balls or loaves of soil, the holes are made when the blocks have just been moulded (Houben & Guillaud, 1994: p 350).



Piercing walls

(Supports 2, 3 - see Figure 5.1)

This technique is used in Gabon on houses built in cob between posts. Using a sharp tool the masses of a clayey soil covering the frame are pierced through the thickness of the support. Render is applied on both the inside and the outside forming a bridge of rendering (Houben & Guillaud, 1994: p 350).



Anchor points

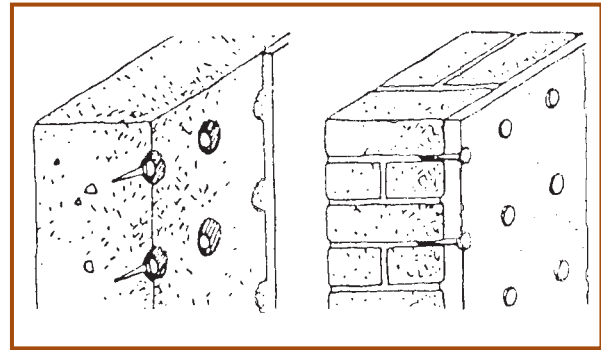
(Supports 1, 2, 3, 4, 5, 6 - see Figure 5.1)

This procedure of encrusting the wall with solid fragments, flakes of stone or broken pottery can easily be carried out on fresh cob or daub. The fragments are set at an angle. When inserted into blockwork or adobe walls, the fragments are set directly into the fresh mortar. Anchoring points of the same composition as the rendering e.g. strips of lime included in the outer thickness of the rammed earth can also be used (Houben & Guillaud, 1994: p351).

Nailing

(Supports 1, 2, 4, 5 - see Figure 5.1)

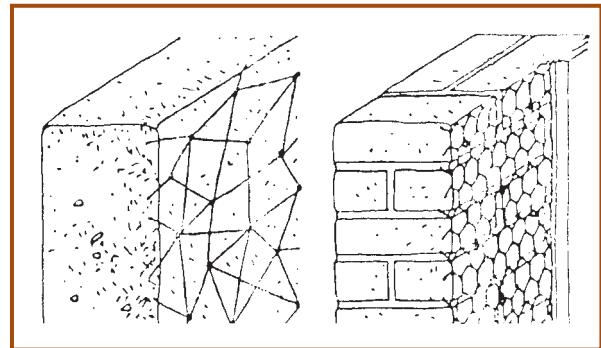
This technique involves inserting nails into the wall in a regular pattern, at intervals of about 10 to 15cm. The nails should preferably be galvanised and at least 8cm long with wide flat heads. As the nails can hinder application of the rendering another method is to make holes on the surface of the support and insert the nails at these points. Alternatively the nails can be inserted after applying the floating coat. (Houben & Guillaud, 1994: p 351).



Lattice work

(Supports 1, 2, 3, 4, 5, 6 - see Figure 5.1)

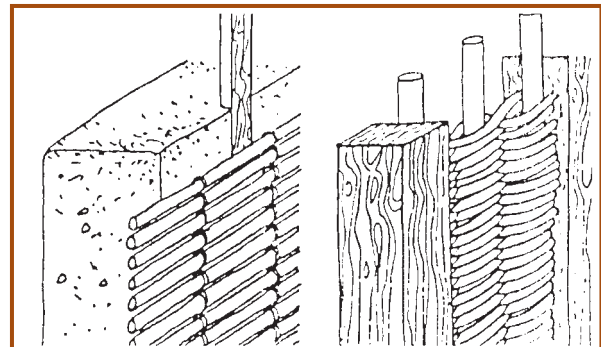
This process involves fixing a metal lattice onto the support using nails. It is best if the mesh is galvanised particularly for walls exposed to moisture, although non-galvanised mesh sticks better. Conventional chicken wire can be used with its hexagonal holes or alternatively simple steel wire (Houben & Guillaud, 1994: p 351).



Wattle

(Supports 1, 2, 3 - see Figure 5.1)

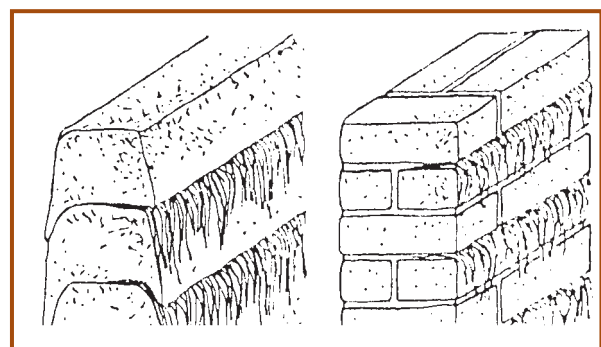
Some construction techniques leave the wattle exposed providing an ideal surface for anchoring the rendering. Examples of this include daub or cob on posts, rammed earth between a reed formwork or heavy clay-straw covered with plaited canes or woven reeds (Houben & Guillaud, 1994: p 351).



Fibres

(Supports 2, 4, 5 - Figure 5.1)

The University of Nairobi has tested a wall protection that combines cement and sisal fibres. The mixture is applied as a first coat. The short sisal fibres remain visible, facilitating adhesion of the subsequent coats. Instead of sisal, other fibres such as hemp, synthetic fibres (i.e. polypropylene), animal hair or fibrous materials (i.e. jute sacking) can be used (Houben & Guillaud, 1994: p 351).



Costing

6.1 Cost Variations

The data presented in this chapter is meant to help entrepreneurs, staff of financial institutions, business people and government officials to estimate the production cost of compressed stabilised earth blocks with a view to identifying the lowest costing technology and size of production. A methodological framework for the estimation of production costs is described in the following sections.

It should be noted that the cost of producing compressed stabilised earth blocks will vary a great deal from country to country and even from one area to another within the same country. Unit production costs will differ in relation to local conditions.

Causes for cost variations include:

- availability of soil, whether it is available on site or has to be transported to the site,
- suitability of the soil for stabilisation, and thus the type, quality and quantity of stabiliser needed. It may also be necessary to buy sand if the soil has an excessively high linear shrinkage,
- current prices of materials, especially stabilisers,
- whether the blocks are to be made in rural or urban areas, size and type of equipment used, and quality required,
- current wage rates, and productivity of the labour force.

It is important to note that block making can be carried out on a 'self-help' basis, where labour costs are eliminated. Furthermore, soil is often available at no cost.

6.2 Methodological Costing Techniques

The methodological costing technique consists of 12 steps that may be sub-divided into two main parts:

- (a) determining quantities of the various inputs (*Steps 1 to 6*),
- (b) estimation of the cost of each input and computation of unit production costs (*Steps 7 to 12*). These steps are briefly described in the remaining part of this section.

Step 1 - Determine the quantity of blocks to be produced in a given period of time. The number will be a function of market demand, availability of finance, acquired production techniques, etc.

Step 2 - Calculate amount of material inputs required for the chosen scale of production. The basic materials are suitable soil, sand (if needed for linear shrinkage modification), stabiliser and water. Some oil, for example used engine oil, will be needed as a mould release agent.

Step 3 - List of equipment required. This will include items for digging and moving soil, preparing soil with a crusher or sieving screen, mixing, a device for moulding the blocks, a covered yard for curing the blocks and an office. Provision should also be made for soil investigation and testing equipment. Chapters 2 to 4 provide information on the type of materials, equipment and infrastructure needed.

The cost of industrial pieces of equipment may be acquired from equipment suppliers and manufacturers, (see **Appendix III**), or from local workshops in cases where the equipment is produced locally.

Step 4 - List of labour requirements. The productivity of the labour force may not only vary from one country to another, but also from one site to another within the same country. It is important to specify the length of the working day, the number of days worked per week and the number of working weeks per year, taking into account an allocation of time for leave of absence during the year. The level of skill requirements must also be determined.

Step 5 - Other local services and facilities may be required, such needs may include:

- land for quarrying soil for block making,
- land for production area,
- land for curing area and storage of raw materials,
- provision of access to working area for delivery of materials and dispatch of products.

Step 6 - Computation of working capital requirements. In addition to funds required for purchase of equipment and land as itemised in the preceding steps, it will be necessary to have sufficient financial resources for the purchase of raw materials and payment of wages for a period of one month, since there can be no income from the sale of blocks until they have been made and cured. If difficulties are anticipated in obtaining any particular commodity, it might be necessary to maintain enough stocks for a period longer than one month.

It may also be desirable to use some of the first products in the construction of the covered area, offices, etc., in order to reduce the cost of items under **Step 3**. It will then be necessary to slightly increase the working capital to allow for the number of blocks that will be used for this purpose, rather than sold.

Step 7 - Annual cost of materials identified in **Step 2** must be calculated. Clay, sand and water are often extremely cheap items. The mould-releasing agent will not be needed in large amounts so should cost very little. Reject engine oil may be acquired at a very low price or obtained free in some cases.

Step 8 - Computation of depreciation costs of equipment and buildings. Whatever type of equipment used, it will have a limited life-span. An estimate must be made of the annual depreciation costs for separate equipment items. The depreciation cost of buildings must also be estimated. These costs will depend on the original purchase cost, the life-span of equipment and buildings and the prevailing interest rate. It should be noted that the longer the useful life of equipment or building the lower the annual depreciation cost.

Step 9 - Reasonable value must be given for the cost of labour in the area where blocks are to be produced. Local wage levels for different skills must be applied and fringe benefits included in the estimation of labour costs.

Step 10 - Land has an infinite life, and the area from which soil is obtained may be restored to its original use in some instances. Thus the annual cost of land may be assumed to be equal to the annual rent of the same or equivalent piece of land. If the land is already owned by the investor, a hypothetical annual rental rate should be used when estimating the annual land cost, since this is the income the investor might have obtained by renting it out instead of using the land themselves.

Step 11 - Working capital raised on loan for the block-making project will need to be accounted for in the annual cost for interest payments on borrowed capital.

Step 12 - The unit production cost may be calculated by summing up the separate cost items from **Steps 7** to **11** in order to get the total annual cost. The latter is then divided by the number of blocks manufactured annually to obtain the unit production cost. Therefore:

+ material costs	(7)
+ depreciation	(8)
+ labour cost	(9)
+ land rental	(10)
+ interest on loan	(11)

= Total annual production cost

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Unit production cost = Total annual production costs ÷ annual output

Socio-Economic
Considerations

7.1 General

The previous chapters are mostly technical and they are of particular interest to small contractors, and government staff or government agencies concerned with low-cost housing schemes. This chapter is essentially directed towards government planners, housing authorities and officials from industrial development agencies who are in a position to develop the necessary legislation and programmes for the promotion of production of compressed stabilised earth building blocks along with that of other building materials. The technical chapters are meant to promote successful production of high quality compressed stabilised earth building blocks. However, some socio-economic constraints may prevent or delay the wide adoption of this building material especially in low-cost housing programmes. The aim of this chapter is therefore to highlight the various socio-economic effects that may result from expansion of the production of compressed stabilised earth blocks with a view to encouraging the formulation of policies and measures in favour of such production.

7.2 Acceptance and Applications

Soil has been, and continues to be, the most widely used building material throughout most developing countries. It is cheap, available in abundance, simple to form into building elements. It provides adequate shelter against hot and cold weather conditions due to its high thermal capacity and insulating properties. Despite its long proven applications, earth is sometimes looked upon with scepticism and mistrust, and is often not recognised by authorities as an acceptable, durable building material. Its main technical disadvantage is the lack of resistance to extreme weather conditions, in particular rain.

In many developing countries building standards, which often rule out applications of soil as an acceptable building material, have been formulated. Earth is mostly used for buildings that are built without formal authorisation, such as rural housing or squatter settlements around urban centres.

Although there are some signs of change whereby compressed stabilised earth may be permitted for construction, it will first be necessary in many countries to convince the authorities of the potential of this material, especially when compared to unstabilised methods of soil construction. In practice, it is advisable to build some community buildings first so that the local people can see for themselves the quality and durability of the material, and experience, first hand, the quality of construction which this method of construction can offer (i.e. El Haj Yousif prototype model school - see Figure 7.1). Kenya offers an example, among others, of a country that has modified its building code to include compressed stabilised earth as a recognised and approved building material (see **Appendix II**). Following successful research and development work and the erection of a number of experimental buildings, including El Haj Yousif model school, the use of good quality compressed stabilised earth blocks for wall and flooring is now practiced by the housing authority in Khartoum.

Figure 7.1 - El Haj Yousif school under construction

It is worth noting that a number of developed countries are reviving the use of compressed stabilised earth blocks and other forms of earth construction. For example, an international centre for the study and promotion of soil-based construction has been established in France (CRATerre-EAG). Surprisingly while the use of earth as a building material concerns mostly low-income groups in developing countries, it is mostly associated with middle to high income housing in industrialised countries such as France or the United States. This shows that the adoption of compressed stabilised earth blocks for high income housing in developing countries could be achieved through effective promotion. For example, housing authorities could help finance houses made from compressed stabilised earth blocks for rent to government officials in order to demonstrate the quality, durability and versatility of the material. Such a project would also show that soil-based housing need not be limited to simple one-storey buildings.

The El Haj Yousif prototype model school has had a direct impact on housing in Khartoum area. The research findings of the project were used and a programme for the construction of 800 houses was launched using local building materials and building techniques developed while constructing the prototype.

7.3 Creation of Employment Opportunities

The creation of productive employment is one of the most important aims of national development plans in developing countries. Hence, technologies which need more labour per unit of output than other technologies are preferable, providing that labour is used in an efficient and economical way.

Experience has shown that in general, the small scale production of compressed stabilised earth blocks is much more labour intensive than that of other similar building materials such as fired clay bricks or concrete blocks. Figure 7.2 compares

labour requirements for the production of equivalent numbers of compressed stabilised earth blocks and fired bricks. Because the sizes of blocks are different from that of fired bricks, and since the comparison should apply to the same volume of walling, it is assumed that one compressed stabilised earth block is equal, in terms of volume, to 3.6 bricks. Four brick making technologies are compared with one block making technology (using the Brepak press). Figure 7.2 shows that the production of compressed stabilised earth blocks is 2 to 18 times more labour intensive than that of fired bricks, depending on the technique being compared.

It can also be shown that the production of compressed stabilised earth blocks is more labour intensive than that of other competing materials, such as concrete blocks.

compressed stabilised earth building block production has other benefits apart from creating direct employment. Most developing countries can produce the tools and equipment required for the production of compressed stabilised earth blocks using some of the soil preparation equipment and block presses described in previous chapters. Thus, the manufacture of compressed stabilised earth blocks could create a great deal of both direct and indirect employment, more so than for other building materials.

Figure 7.2 - Comparative labour requirements

Products	Production method	Labour needed to make volume equivalent to 240 blocks/day
Compressed stabilised earth blocks	Brepak press	6.00
Fired clay bricks	Traditional manual	2.50
	Intermediate technology	3.00
	Soft mud machine manual	1.00
	Moderately mechanised	0.33

7.4 Investment Cost and Foreign Exchange Savings

The local manufacture and processing of building materials that require the import of expensive equipment can sharply affect the limited foreign reserves of developing countries. Thus, production of building materials which do not require such imports should be encouraged. This is the case for compressed stabilised earth blocks which, in terms of foreign exchange savings, compare very favourably with sun-dried bricks or building stones. Equipment and tools needed for the manufacture of compressed stabilised earth blocks can be made locally and in most cases under license. Stabilisers may also be produced locally, especially if lime is used. In comparison with other building materials, the production of compressed stabilised earth blocks does not need energy for drying or firing. Thus, it is not necessary to use imported fuel or to aggravate deforestation by using local wood for firing the bricks.

The manufacture of compressed stabilised earth blocks does not require large

capital investments which, in a developing country like Sudan will usually incur very high interest rates. Thus, the establishment of a small plant may be affordable by an investor who cannot obtain or afford relatively large loans from banks or other sources. The area of land needed is usually small compared with that required for brick production. Furthermore, no land is needed if blocks are made at the construction site. The cost of block making equipment can also be very low. In some cases it need not exceed 1,000 US\$ for a production capacity of 350 blocks per day.

In conclusion both in terms of capital investment and foreign exchange utilisation, production of compressed stabilised earth blocks compare very favourably with that of other building materials, especially fired clay bricks and concrete blocks.

7.5 Production Cost of Compressed Stabilised Earth Blocks

The Al Haj Yousif experimental prototype school, constructed in compressed stabilised earth blocks, was found to be very cost effective by Sudanese standards. The total savings made, in cost per square metre, were approximately 40%. Reduction of the cost of blocks was approximately 70% and of the roofing sheets 48%. Similar findings were also reported in Kenya where the average unit cost of compressed stabilised earth blocks is approximately 20% to 70% that of concrete blocks, depending on the method of production followed.

The production cost of compressed stabilised earth blocks, should not be the only basis for comparison with other building materials. For example, the large block size results in less labour and a lower amount of mortar needed for block laying. Furthermore, good quality compressed stabilised earth blocks do not require external renderings which will result in additional savings being made.

7.6 Conclusions and Recommendations

The previous sections have demonstrated that in general, the utilisation of compressed stabilised earth buildings blocks in building construction can provide a great number of advantages, especially to the Sudanese building industry and developing countries in general. The development and promotion of good quality building blocks can also improve the standard of living for low-income groups in developing countries. Soil blocks are the only building material that can be produced in-situ if the proper equipment and optimum amount of stabiliser is available. For example, housing authorities may organise for the transport of a block making machine and supporting equipment to the building site and assist in training of the work-force. Alternatively, the equipment can be owned by a contractor within the urban areas, and/or by co-operatives in rural areas operating on a self-help basis.

From our experience in the construction of EL Haj Yousif school, the promotion of compressed stabilised earth building blocks can be achieved through:

- advertisements, exhibits and pilot-projects,
- recommending the use of compressed stabilised earth building blocks for public or government buildings such as schools, etc.,
- promotion, of research and development in this area so as to maximise the use of local stabilisers and improve the quality of compressed stabilised earth buildings blocks,
- organisation of training programmes for the production and use of compressed stabilised earth building blocks,
- encouragement of future home owners to use compressed stabilised earth building blocks as the primary building material by, for example, reducing the cost of building permits to serve as an incentive.

The adoption of the above measures could greatly contribute to making compressed stabilised earth blocks preferable to other building materials in terms desirability, cost, availability, use and durability.

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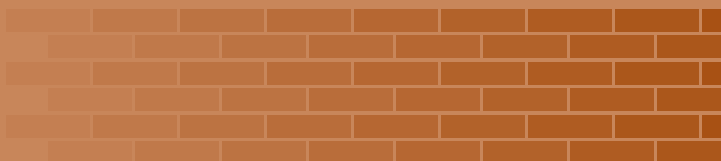
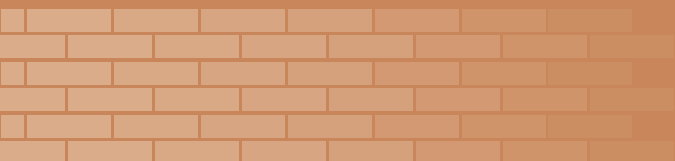
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African Regional
Standards for
Compressed Earth Blocks



II.a - ARS 670: 1996 - Compressed Earth Blocks Standard for Terminology

(CDE Guides 'Technologies Series' No. 11, Compressed Earth Blocks - Standards, 1998, p.21)

1. General

1.1 Object

The aim of the present standard is to define the principle terms applying to compressed earth block technology (CEB).

1.2 Fields of application

The terms defined by the present standard are applicable in drawing up all technical, administrative and contractual documents relating to compressed earth block technology and relate both to public and to private contracts.

2. Terms applicable to compressed earth blocks

2.1 Definition

Compressed earth blocks (CEBs) are masonry elements, which are small in size and which have regular and verified characteristics obtained by the static or dynamic compression of earth in a humid state followed by immediate demoulding.

Compressed earth blocks generally have a rectangular parallelepiped format and are full or perforated with vertical and/or horizontal indentations.

Compressed earth blocks are principally made of raw earth and owe their cohesion in a humid state and in a dry state essentially to the clay fraction within the earth; an additive can, however, be added to the earth to improve or enhance particular characteristics of the product (see p.82, 3.1.2).

The final characteristics of CEBs depend on the quality of the raw materials used (earth, additive) and on the quality of the execution of the various manufacturing stages (preparation, mixing, compression, curing).

Note: this definition therefore excludes blocks obtained by extrusion, as well as agglomerated products where the chemical binder plays an essential part in ensuring cohesion when dry.

2.2 Description

The most common type of CEB can be described geometrically stating its format. The format of the product described consists of its general shape, its principal dimensions and the nature of any indentations (hollows, perforations etc.) incorporated into the product.

The most common format is a rectangular parallelepiped (or prismatic) format with a length (l), a width (w) and a height (h). Giving these three dimensions in this order (l, w, h) is sufficient for their use.

African Regional Standards for Compressed Earth Blocks

Non parallelepiped rectangular formats require a fuller description (cylindrical, conical, hexagonal, wedge-shaped, in the form of a truncated cone, etc.). The format used for the description is the nominal format which takes into account the manufacturing dimensions.

The format may be principal or secondary. The principal format or common format corresponds to the basic format from which secondary formats are obtained, these being merely fractions or multiples of the basic format in relation to its length. The most frequently found secondary formats are the "3/4", the "1/2", and the "1/4" the respective lengths of which are:

- $l_{3/4} = (l_{4/4} - tm/3) \cdot 3/4$
- $l_{1/2} = (l_{4/4} - tm) \cdot 1/2$
- $l_{1/4} = (l_{4/4} - 3tm) \cdot 1/4$

where tm is the thickness of the vertical joint. There are also CEBs reduced by half in height.

Secondary format CEBs are required to ensure bonding continuity throughout the built structure, for example at wall corners, and at the intersections of walls and partitions.


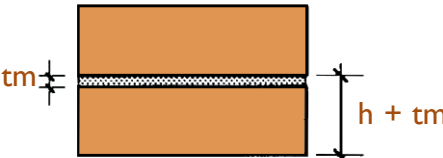
Secondary format CEBs are obtained either directly by manufacturing, or cut at the moment of use.

The "nominal format" should not be confused with the "work format" which corresponds to a description using real dimensions to which a corresponding joint thickness has been added.

The work format is therefore a unit of measurement for practical use enabling the dimensions of a built structure to be rapidly calculated. To recapitulate:

- nominal format: (l, w, h)
- work format: $(l + tm, w + tm, h + tm)$

Figure II.a.1 - Example relating to the height of blocks

NOMINAL FORMAT	WORK FORMAT
 <p>Ex: $h = 9\text{cm}$</p>	 <p>Ex: $h + tm = 9 + 1,5 = 10,5\text{cm}$</p>

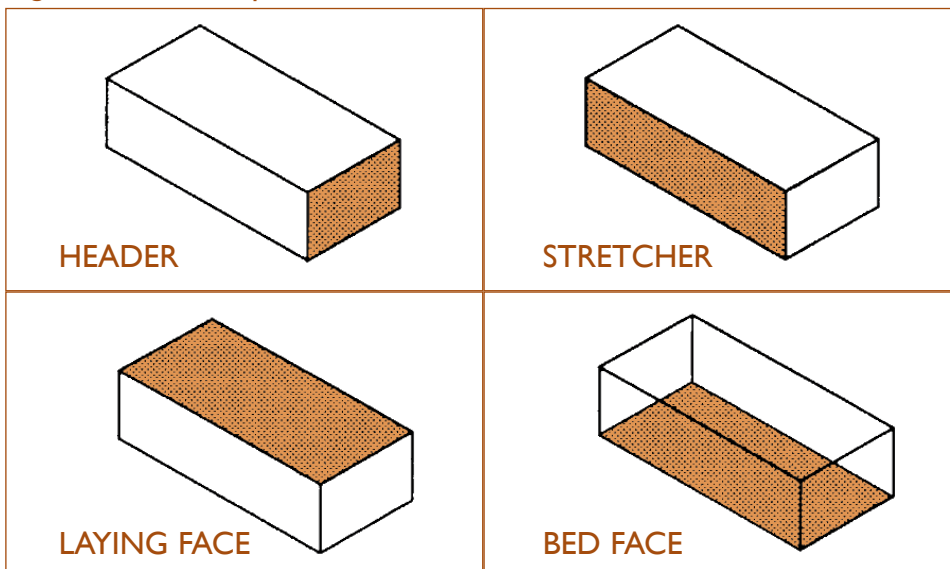
The nominal format is the one normally used and in the event of any danger of confusion it is recommended that the nature of the format being used should be specified.

2.3 Description of the parts of CEBs

The prismatic block has 6 faces, each of which has a name:

- 2 faces are known as surface "stretchers" ($l \times h$);
- 2 faces are known as surface "headers" ($w \times h$);
- 1 face is known as the "laying face" ($l \times w$), being the upper face of the CEB when laid;
- 1 face is known as the "bed face" ($l \times w$), being the lower face of the CEB when laid.

Figure II.a.2 - Compressed earth block faces



The details describing a CEB should include the following values:

- Gross section: $l \times w$ (l and w measured on the same plane);
- net section: gross section less any hollow;
- bed section: surface common to the laying and the bed faces when superimposed in contact with the mortar joints and capable of transmitting the load.

3. Terms applicable to compressed earth block production and production equipment

3.1 Terms applicable to CEB constituents

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3.1.1 Earth

Earth intended for CEB construction designates the basic material made up essentially and in carefully controlled proportions of the following components, before any mixing with an additive or with water: gravel, sand, silt and clay. These components can be defined using a metric classification, or with regard to the fines, by their mineralogical nature.

The metric classification is as follows:

gravel fraction:	coarse gravel	-	60mm to 20mm
	medium gravel	-	20mm to 6mm
	fine gravel	-	6mm to 2mm
sand fraction:	coarse sand	-	2mm to 0.6mm
	medium sand	-	0,6mm to 0,2mm
	fine sand	-	0,2mm to 0,06mm

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silt fraction:	coarse silt	-	0.06mm to 0.02mm
	medium silt	-	0,02mm to 0,006mm
	fine silt	-	0,006mm to 0,002mm
clay fraction:	passes the	-	0.002mm sieve

There are other classifications which are also acceptable.

Coarse material (gravel and part of the sand fraction) consists of components with a diameter in excess of 0.08mm. Coarse material provides the stable "skeleton" of CEBs thanks to its internal friction and its inertia.

Fine material (a part of the fine sand fraction, silt and clay) consists of components the diameter of which is less than or equal to 0.08mm. From a mineralogical point of view, the notions of clay and of silt are not restricted to the metric values given above. Understanding the mineralogical nature of fines may be vital when selecting types of earth.

Fines fill in the voids in the "skeleton". Clay and part of the silt fraction provide the cohesion of CEBs because they act as binders.

3.1.2 Additive

An additive is a substance added during manufacture, intended to improve the final characteristics of the CEB or to enhance particular characteristics.

The most common additives are stabilisation products, know as stabilisers, such as cement, lime, pozzolonas, etc. intended to neutralise the sensitivity to water of the fine fraction and thus to maintain cohesion at an acceptable level even in a humid state. But other additives can also be used to modify other characteristics such as colour (colouring agents), tensile strength and reducing shrinkage cracks (fibres), etc.

3.1.3 Filler

A filler is a granular material, generally of a sandy type, employed as an additive in types of earth which contain too great or too active a silt and/or clay fraction.

3.1.4 Mix

The mix is the material obtained by adding additives and/or filler and water to the earth, preparatory to being introduced into the press for the manufacture of the CEB.

3.2 Terms applicable to the production of compressed earth blocks

3.2.1 Preparing the earth

This consists of the following operations:

- drying;
- screening;
- pulverising.

3.2.1.1 Screening

This operation is intended to eliminate all undesirable components (roots, leaves, etc.) together with any components with a diameter greater or lesser than that required. This operation also enables the earth to be loosened in a uniform manner.

3.2.1.2 Pulverising

This operation is intended to break down lumps made up of coarse material and/or fines. It can also be used to split coarse material to reduce it to smaller diameter aggregates.

3.2.2 Mixing

This is a series of technical operations aimed at making the prepared earth, to which additives and/or a filler may have been added, homogeneous. Mixing most often takes place in two stages: dry mixing before adding water and wet mixing after adding water. There may also be a third stage, after a given reaction time, which consists in subjecting the mix to a further phase of stirring.

3.2.3 Retention time

Retention time is the delay between the start of wet mixing and the compression of the earth.

3.2.4 Compression

Compression is the operation which consists in compressing the material in a confined space known as a mould using a static or dynamic mode; compression is followed by immediate demoulding, freeing the shaped block.

3.2.5 Curing

Curing is the period following compression during which two types of phenomena principally occur. These can be differentiated as follows:

- physicochemical reactions between the various components of the mix and above all between the earth and the additives resulting in the stabilisation of the block; during this phase, conditions of relative hygrometry and of heat are crucial and require careful attention;
- drying which consists in the gradual removal of manufacturing humidity by evaporation.

3.3 Terms applicable to production equipment

3.3.1 Preliminary note

All production operations can be carried out manually with simple tools or using manual or motorised mechanical equipment.

3.3.2 Earth preparation equipment

Preparation equipment includes:

- screens, to remove components with too large a diameter;
- pulverisers, which allow the particle size of coarse components to be reduced or silt and clay aggregates to be broken down without affecting the particle size distribution.

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3.3.3 Mixing equipment

Mixing is carried out using a mixer. Mixers can be planetary, where the mixing system is mounted on a vertical axis, or linear, where the mixing system is driven by a horizontal axis.

3.3.4 Presses

Presses are classified using several criteria:

- a) the **energy source**: manual or motorised (with a distinction between thermal and electric motors);
- b) the **system by which the energy is transmitted to the moulding system**: mechanical, hydraulic, or combined.

3.3.5 Specific characteristics of presses

In describing presses, certain specific criteria are used:

- a) **Compression action**: this is the very principle of the operation of the compression system. Compression may be static, dynamic by vibration or dynamic by impact;
- b) **Usable force**: the force potentially available to compact the earth;
- c) **Compression pressure**: the pressure theoretically applied to the mix and which expresses the ratio of usable force to the surface to which it is applied; compression pressure is classified as follows:

● very low pressure	=	1 to 2 N/mm ²
● low pressure	=	2 to 4 N/mm ²
● medium pressure	=	4 to 6 N/mm ²
● high pressure	=	6 to 10 N/mm ²
● hyperpressure	=	10 to 20 N/mm ²
● megapressure	=	20 N/mm ² and over.

It should be noted that the highest compression pressures are not necessarily the most efficient.

- d) **Pressure at the end of compression**: the pressure actually applied to the mix at the end of compression.
- e) **Dynamic effect coefficient**: the effect, on static compression presses, due to the inertia of the lever movement of the machine, which increases the pressure at the end of compression.
- f) **Compression mode**: the principle of spreading the pressure across the mix. In simple compression, pressure is transmitted by displacing a single plate onto the laying or the bed face. In double compression, pressure is applied by displacing both plates onto the laying and the bed face simultaneously or alternatively.
- g) **Compression ratio**: the ratio between the depth of the press mould before compression and the depth at the end of compression (which corresponds to the height of the CEB product).
- h) **Output**: theoretical output corresponds to the sum of the number of CEBs produced per cycle, by number of cycles (filling, compression, demoulding) per hour; practical output corresponds to the theoretical output adjusted for estimated down time (machine maintenance etc.); actual output is the output measured in the context of normal activity.

3.4 Terms applicable to delivery conditions

3.4.1 Order

3.4.1.1 Ordering earth

The order specifies the designation of the earth (gravely earth, sandy earth, clayey earth, etc.), the quantity, the place of delivery, and the procedure for accepting or rejecting delivery. The order may also specify the location of the quarry and the depth of the quarrying operation.

3.4.1.2 Order for CEBs

The order specifies the designation of the CEBs, the quantity, the delivery location, and the procedure for accepting or rejecting delivery.

3.4.2 Supply

The quantity of merchandise corresponding to one and the same order.

3.4.3 Delivery

The quantity of merchandise delivered or intended to be delivered on one single occasion, whatever the number and the nature of the means of transport used.

3.4.4 Lot

The quantity of merchandise serving as a basis for determining samples for testing.

3.4.5 Taking delivery

A series of operations enabling the conformity of the merchandise to be checked against the specifications of the standard.

4. Terms applicable to construction with CEBs

Compressed earth blocks being masonry elements, when referring to their use, one therefore applies the common terminology of traditional masonry with thick mortar joints (around 15mm).

4.1 Earth mortar

An earth mortar (EM) is a mortar used for compressed earth block masonry of a traditional type using thick mortar joints.

An earth mortar consists principally of raw earth and water and owes its cohesion in a humid or a dry state essentially to the clay fraction of the earth; an additive and/or a filler can, however, be added to the earth to improve or enhance particular characteristics of the mortar.

4.2 Compressed earth block masonry

Compressed earth block masonry (CEBM) is masonry of a traditional type using thick earth mortar joints.



5. Terms applicable to assessing the characteristics, performance and suitability for use of CEBs

To assess the characteristics, performance and suitability for use of compressed earth blocks, one should use the terminology commonly used for other small masonry elements, excluding the elements provided in the present standard relating to terminology.

6. Symbols and units

6.1 Units of measurements

Figure II.a.3 - Symbols and basic units of measurement

Symbols	English	French	SI Units		Units used in the building sector
L	Length	Longueur	metre	m	m, cm, mm
F	Force	Force	newton	N	MN, kN, N
σ	Pressure, Stress	Pression, Contrainte	pascal	N/m ²	MPa = N/mm ² = MNm ⁻²
m	Mass	Masse	kilogramme	Kg	t, kg, g
t	Temperature	Température	degrees Celsius	°C	°C
L	Time	Temps	seconds	s	h, min, s

II.b - ARS 674: 1996 - Compressed Earth Blocks Technical Specifications for Ordinary Compressed Earth Blocks

(CDE Guides 'Technologies Series' No. 11, Compressed Earth Blocks - Standards, 1998, p.47)

1. General

1.1 Object

The aim of the present standard is to define the requirements applicable to ordinary compressed earth blocks (CEB O).

1.2 Field of application

The field of application is that defined by the standard "ARS 671: 1996 Compressed earth blocks - Definition, classification and designation of compressed earth blocks".

1.3 Definition

The definition of ordinary compressed earth blocks is specified by the standard "ARS 671: 1996 - Compressed earth blocks - Definition, classification and designation of compressed earth blocks". (Compressed Earth Blocks - Standards, 1998, p.31)

1.4 Classification

The classification of ordinary compressed earth blocks is specified by the standard, "ARS 671: 1996 - Compressed earth blocks - Definition, classification and designation of compressed earth blocks". (Compressed Earth Blocks - Standards, 1998, p.31)

1.5 Designation

The designation of ordinary compressed earth blocks is specified by the standard "ARS 671: 1996 - Compressed earth blocks - Definition, classification and designation of compressed earth blocks". (Compressed Earth Blocks - Standards, 1998, p.31)

1.6 Reference

Standard "ARS 671: 1996 - Compressed earth blocks - Definition, classification and designation of compressed earth blocks".

2. Specifications

2.1 Textural characteristics

The earth should not contain any particles with a diameter greater than 20mm. To obtain an optimal result, the diameter of the largest particles will be restricted to 5mm.

2.2 Dimensional characteristics

2.2.1 Dimensions

The most commonly employed full compressed earth blocks have the following theoretical moulding dimensions and nominal dimensions:

- length: 29.50cm
- width: 14.00cm
- height: 9.00cm to 9.50cm

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These blocks are used as a reference here for the terms of the specifications which follow. For CEBs of different dimensions, tolerances should be adjusted using a linear mathematical relationship.

The measurements given are the net block dimensions, not counting any hollows or indentations.

Special blocks can be developed using other main formats.

Dimensional tolerances are as follows:

- length: + 2 to - 3mm;
- width: + 2 to - 3mm;
- height: + 3 to - 3mm.

In addition, the difference between the corresponding dimension of two CEBs of any kind from the same supply must not exceed 4mm for the length, 3mm for the width and 5mm for the height.

2.2.2 Thickness of sides of indented or hollow blocks

For all faces: minimum 25mm or 3 times the diameter of the largest particle if the diameter of the largest particle exceeds 8mm.

2.3 Geometric characteristics

2.3.1 Irregular geometry

CEBs which have a deliberately irregular geometrical form are not subject to the specifications of this article. However, the flatness of the bed faces must meet the conditions which follow.

2.3.2 Parallelism

Defects of parallelism or of right angles, and also the acceptable sweep of a face, cannot exceed the tolerance for the dimension affected.

2.3.3 Surface smoothness

- Sides: the sweep must not exceed 2mm.
- Compression surfaces: the sweep must not exceed 3mm.

2.3.4 Edge smoothness

- The sweep must not exceed 3mm.
- Some roughness on the edges can be tolerated, whether it is due to demoulding or caused by mishandling.

2.3.5 Surface obliquity

- For exterior faces, form and dimensional tolerances must be respected.
- Interior faces and the hollows of hollow or indented blocks must be oblique and must have no sharp corners.



2.4 Appearance characteristics

2.4.1 Damage

A distinction is made between mechanical damage caused by impact when handling CEBs and cracks or other defects which result from an imperfect production process.

For mechanical damage, the following rule is to be respected: damage which has no effect on the appearance of the masonry (such as chips on the side of the CEB which are not visible) will not be taken into account.

The following are regarded as damaged:

- any broken CEB;
- any CEB displaying chipped edges or corners the overall volume of which exceed 5% of the volume of the CEB.

For cracks and other manufacturing defects, the prescriptions which follow are applicable.

2.4.2 General appearance

The CEBs should display no systematic defects such as cracks or significant chips of a kind likely to jeopardise correct execution and the stability of the masonry.

2.4.3 Holes, punctures and scratches

For exposed faces, these must affect no more than 20% of the surface and not exceed 5mm in depth.

2.4.4 Roughness

The exposed faces can have a grainy and rough appearance.

2.4.5 Chipped corners

Chipped corners and edges which do not extend over more than 10mm and which do not exceed 10mm in depth are tolerated on all surfaces.

2.4.6 Flaking, splitting

These are tolerated provided mechanical performance is not affected.

2.4.7 Cracks, crazing, fissures

Micro-cracks:

- are tolerated on all faces.

Macro-cracks:

Conditions of acceptability for all faces:

- they must not exceed 1mm in width;
- they must not exceed 40mm in length;
- they must not exceed 10mm in depth;
- they must not exceed 3 in number on any one surface.



2.5 Physicochemical characteristics

2.5.1 Pitting

No pitting due to the bursting of expansive materials is tolerated.

2.5.2 Efflorescence

CEBs must not display any significant and lasting efflorescence covering more than 1/3 for the total surface of the CEBs. A faint whitish film or a thin band are not taken into account.

2.6 Mechanical, hygrometric and physical characteristics

Mechanical, hygrometric and physical characteristics are determined by the values shown in the following table.

Figure II.b.1 - Mechanical, hygrometric and physical characteristics required for ordinary CEBs

Designation	Environmental constraint category	Mechanical constraint category	f_b dry N/mm ²	f_b wet N/mm ²	Water absorption %	Abrasion loss of matter %
CEB O 1 D	Dry Environment (D)	1	≥ 2	N/A	N/A	N/A
CEB O 2 D		2	≥ 4	N/A	N/A	N/A
CEB O 3 D		3	≥ 6	N/A	N/A	N/A
CEB O 1 R	Effect of water by lateral spraying (R)	1	≥ 2	≥ 1	N/A	N/A
CEB O 2 R		2	≥ 4	≥ 2	N/A	N/A
CEB O 3 R		3	≥ 6	≥ 3	N/A	N/A
CEB O 1 C	Effect of water by vertical penetration (C)	1	≥ 2	≥ 1	≤ 15	N/A
CEB O 2 C		2	≥ 4	≥ 2	≤ 10	N/A
CEB O 3 C		3	≥ 6	≥ 3	≤ 5	N/A

Note:

- 1) N/A = not applicable;
- 2) The use of CEBs in R and C category environments requires using a stabiliser if the protection provided is not guaranteed. If the protection provided against water damage is guaranteed, the environment is regarded a category D;
- 3) If tests to establish water absorption or abrasion are not feasible, or if the results are not available, this deficiency can be compensated by increasing the requirements for the dry and/or wet compressive strength by one category;
- 4) The values given are the average values obtained from tests carried out on a set of samples.

II.c - Dimensions, Mass, Apparent Density

(CDE Guides 'Technologies Series' No. 16, Compressed Earth Blocks - Testing Procedures, 2000, p.87)

1. General

1.1. Object of the test

To determine the physical characteristics of a block.

1.2. Principle of the test

Dimensions

The size of a block does not correspond exactly to the nominal dimensions of the mould box of the press. On removal of the block, a "slumping" effect occurs, followed by some shrinkage on drying.

The mould box may buckle and the press compression plates may tip. Thus the length, width and height of the block may not be constant. Each face of the block therefore needs to be measured.

Mass

A block always contains water which is in equilibrium with the ambient environment as the material is hygroscopic. The block must therefore be weighed after oven-drying when it has attained its equilibrium and when its mass is constant.

Density

The apparent density will give us an indication of the extent of compaction of the block. This requires accurate measurements of its volume and mass.

2. Apparatus

- Ventilated drying oven capable of maintaining a temperature of 105°C,
- a precision ruler,
- a calipers,
- a balance readable to 10kg and accurate to 1 gram. For masses > 10kg accuracy to $\pm 5g$ is permissible,
- a non-absorbent cloth or chamois leather.

3. Preparing the sample

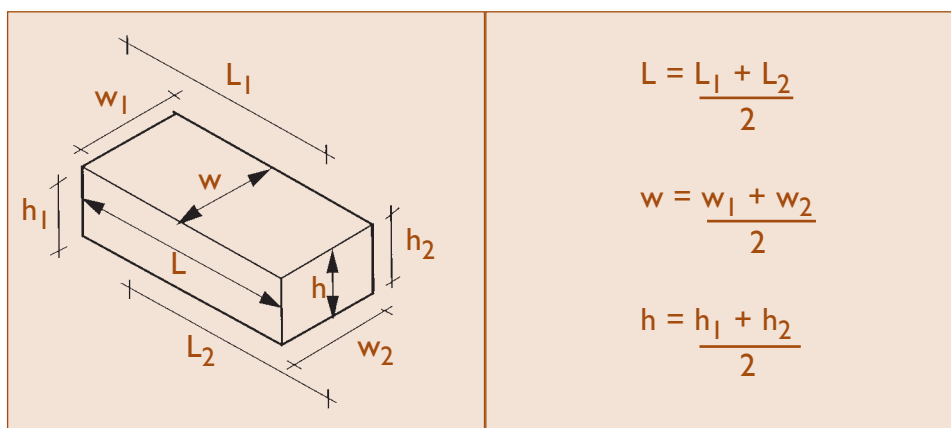
- The blocks must be at least 3 weeks old,
- Wipe the block using a non-absorbent cloth in order to remove any dust or loose matter stuck to it,
- Note the appearance of the block.

4. Test procedure and calculations

Dimensions

- Identify the direction in which the blocks would be laid,
- Note if this corresponds to the direction in which the blocks were compressed,
- Define the dimensions: Length (L), width (w), height (h),
- Length (L): the largest dimension of the block,
- Width (w): the block dimension corresponding to the width of the laying face,
- Height (h): the dimension of the block measured in the direction of the compression or in more general terms, the smallest dimension of the block,
- Measure to the nearest millimetre each dimension of the block in the middle of each face and calculate the averages.

Calculate the volume of the block: $V = L \times w \times h$ (in cm^3).



Mass

- The block is oven-dried until a constant mass is obtained. The mass of the block is considered to be constant when the difference in mass between 2 weighings at a 24 h interval is $< 0.1\%$ of the initial mass.
- On removal from the oven the block is left open to ambient air for 2 hours.
- After this interval, weigh the block mass m (in g, to the nearest g).

Density

- The dry density is given as the ratio of the mass of the block to its volume, thus
- $\rho_d \text{ (in g/cm}^3\text{)} = \rho_d = \frac{m}{V}$

5. Reporting the results

Calculate and record results.

II.d - Dry Compressive Strength

(CDE Guides 'Technologies Series' No. 16, Compressed Earth Blocks - Testing Procedures, 2000, p.63)

1. General

For the past twenty years or so, compressed earth blocks have provided a new alternative to building materials such as concrete or fired bricks.

Although the methodology of block production is now well understood and materials have been designed to enable one to obtain a reliable, high performance material, there is not yet a universally recognised test standard to assess the compressive and the tensile strength of these blocks.

The objective of the present section is to suggest an operational method for carrying out mechanical compression tests on parallelepiped blocks of compressed unfired earth. The tests have been devised to be carried out on cylindrical test samples.

1.1. Object of the test

To determine the dry compressive strength of blocks intended for masonry in order to obtain comparative results regardless of the configuration of the block.

1.2. Principle of the test

The test consists in subjecting a sample to simple compression until failure, the sample being made up of two half-blocks placed one on top of the other and stuck together using a mortar made of earth or alternatively of sand cement, in the case of stabilised CBEs.

The half-blocks, which shall be full, are crushed in the direction in which they are laid by the effect of a constant displacement or a constantly increasing load provided by a press.

The crushing is considered to be complete at the moment of complete failure. One can thus calculate the compressive strength of the block (fb dry).

To avoid problems relating to uneven contact points, both faces of the specimen are faced with a cement paste or sheets of cardboard or plywood.

The minimum height of the block shall be 6cm.

2. Apparatus

2.1. Special apparatus

- A calibrated crushing press for hard materials (in particular the flatness of the loading plates and the centre of application of loads must have been checked). It is preferable to be able to adjust the speed of displacement of the plates so that the block does not fail in the first fifteen seconds of the test, and the power should be compatible with the strength of the blocks* (see p.94).

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* Minimal capacity of the press assuming the following data:

- standard half-block measuring approximately $14.7 \times 14 \times 10\text{cm}$,
- compressed surface area: approximately 200cm^2 ,
- the press shall allow compression at a pressure in the range 1 MPa et 20MPa,
- the block shall not fail in the first fifteen seconds.

Thus the capacity of the press will fall in the range 20 to 400 kN and the dial should enable precise readings to be taken between these two margins.

The rhythm of the press should enable the set displacement to be adjusted to the nearest 0.02mm/sec.

The press should enable the increase in load to be adjusted to between 0.15 et 0.25MPa/s. Mechanical data: tempered steel: 55 [RC] (Rockwell); depth of tempering: 5mm; French standard NFP 18 412.

2.2. Apparatus in common use

- Ventilated drying oven capable of maintaining a temperature of $40^\circ\text{C} \pm 5^\circ\text{C}$,
- precision rule graduated in mm,
- a balance readable to 10kg and accurate to 1 gram. For masses $> 10\text{kg}$ accuracy of $\pm 5\text{g}$ is permissible,
- a mallet and a knife or blade to make two half-blocks,
- 0/3mm sand, high alumina melted cement (CA) and artificial Portland cement (CPA-CEM I),
- if necessary two sheets of smooth cardboard or plywood, 3 or 4mm thick,
- a flat surface: a sheet of metal or of glass, which has been checked beforehand for flatness (deviation from flat when loaded less than 0.30mm),
- oil to assist removal from the mould or film of plastic material which does not stick to the cement paste (polythene for example).

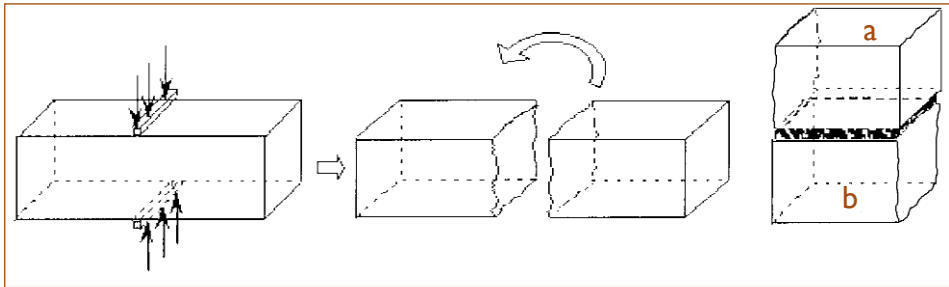
3. Preparing the sample and making the specimen

3.1 Preparing the sample

- The blocks are of a homogenous structure and shall have no cracks visible to the naked eye,
- dry compressive strength tests are carried out on dry blocks. Oven-dry the block to 40°C until a constant mass is obtained (the mass of the block is constant when the difference in mass does not exceed 0.1% between 2 weighings at a 24h interval),
- remove the block from the oven and leave it to stand for approximately 2 hours. Wipe the block to remove any dust or loose matter stuck to the block,
- the samples selected from the blocks should each have an identical dry density, only a variation of maximum 1% is permissible between blocks of the same sample group.

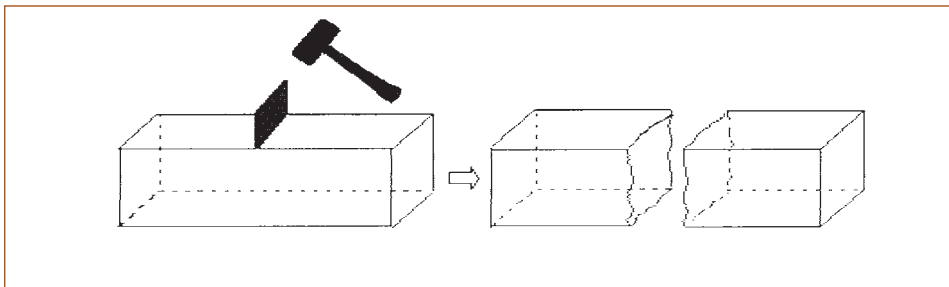
3.2 Making the specimen

- Cut the blocks in two. To do this, a tensile strength test can be carried out beforehand.



Alternatively, cut each block across the middle by sawing it into two equal pieces or break the blocks as follows:

- Place the block on a bed of fine sand, make a groove on the four sides showing where it should break. Place a steel blade on one of the grooves and hit it with a mallet to obtain the two half-blocks.



- Wet the laying face of the two half-blocks, and place the two corresponding halves of each block one on top of the other, taking care that the header of one should be on the same side as the cut section of the other, with an intermediate layer of mortar no more than 10mm thick. The mortar is made of a mix of 0/3mm sand and of Portland cement dosed at 1 volume of cement for 5 volumes of sand, so that the test can be carried out after 48 hours curing.

Note

It is also possible to use an interface mortar made of a material similar to that used to produce the CEBs (soil, if necessary with added sand) for unstabilised blocks intended for use in a dry environment.

For stabilised blocks intended to be used in a wet environment, the mortar will also be made of a material similar to that used for the production of the CEBs, consisting of soil, if necessary with added gravel and cement, so that the compressive strength of the mortar is the same as that of the blocks.

The following procedure is recommended:

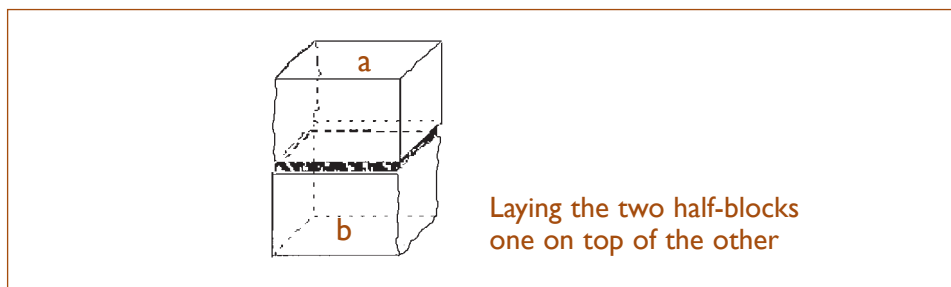
- Remove all loose material from the laying face and the bed face,
- partially immerse the laying face in 1 to 2cm of water for a quarter of an hour. Repeat the same operation for the bed face,
- spread the mortar to a thickness of approximately one centimetre on the laying face of the first half-block,

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- lay the bed face of the second half-block as if building the wall, taking care that the entire surface of the laying face is loaded with mortar,
- check that the two half blocks are parallel using the materials testing press to apply a very slight load to the specimen before the interface mortar sets,
- leave to harden or to cure for at least 48 h before the compression test.

Note

For unstabilised blocks, the mortar is simply left to dry and harden. For stabilised blocks, the specimen should be hermetically sealed and left to cure for 48 h.



- Once the mortar has set and hardened, measure the dimensions of the upper and lower surfaces of the resulting specimens and calculate for each of them the average of the two surfaces.

3.3. Coating the specimen

- Coat the upper and lower faces of each specimen using a pure mortar paste. The mortar is made of a mix of high alumina melted cement (CA) and Portland cement (CPA-CEM I) in a proportion at which it sets within a maximum time of 10 to 15 min.

The pure paste is generally made up of 2/3 Portland cement and 1/3 high alumina melted cement to a maximum thickness of 3mm.

The following procedure is recommended:

- Remove all loose material from the laying face and the bed face,
- partially immerse the laying face in 1 cm to 2 cm of water for a quarter of an hour,
- spread the paste on the flat surface (to which a product to assist removal from the mould has first been applied),
- place the block as it would be in the wall being built, taking care that the entire laying face is loaded with paste, and check that the free surface is parallel to the flat surface,
- leave to harden for approximately 15 min and repeat the same operation by turning the block over onto the opposite face, so that the bed face is coated following partial immersion as described above,
- coating should occur at least 12 h before the compression test.

Note

It is possible to use another type of surface coating (sheets of smooth cardboard or of plywood, 3 or 4 mm thick) but in this event this should be recorded in the results.

4. Test procedure and calculations

4.1. Test procedure

- Centre the complete specimen between the plates of the press, so that the geometric centre of the loaded surface is located on the axis of the plate to the nearest ± 1 mm:

Monitor that it is centred by checking on all four sides the distances between the edges of the specimen and the sides of the plates using a ruler,

- Apply the load in a continuous manner, with no sudden jolts, at a regular speed of 0.02mm/s, or corresponding to an increase in pressure of between 0.15 and 0.25MPa/s until complete failure of the specimen. No adjustment should be made to the test machine controls immediately before the failure,
- record the maximum load borne by the specimen during the test.

4.2. Calculations

The compressive strength of the blocks is shown by the formula $f_{b \text{ dry}} = 10 \times \frac{F}{S}$

in which:

- $f_{b \text{ dry}}$ = dry compressive strength of the blocks in Mega Pascals (MPa) or (MN/m²) or (N/mm²),
- F = maximum load borne by the two half-blocks in kilo Newtons, (kN),
- S = average surface area of the test faces in square centimetres (cm²) (as the surfaces are not always regular, the common surface in contact is used).

The average compressive strength of the blocks is the arithmetic average of the compressive strengths of at least three tests carried out on specimens from the same lot.

5. Reporting the results

Calculate and record results.

6. References

- NBN/B 24-301 *Projet de norme Belge concernant l'approche et le calcul de maçonnerie*, 1976.
- ENTPE geomaterials laboratory: A. Mesbah, Z. El Gharbi, M. Olivier, *Proposition d'une norme pour la réalisation d'essais de résistance sur BTC*. Vaulx-en-Velin, France, September 1995.

II.e - Wet Compressive Strength

(CDE Guides 'Technologies Series' No. 16, Compressed Earth Blocks - Testing Procedures, 2000, p.69)

1. General

Buildings are often exposed to the effects of water, particularly as a result of capillarity and of spraying. By contrast they are rarely submerged.

The mechanical characteristics (tensile and compressive strength) of wet blocks are weaker than those of dry blocks. It is therefore useful to test them in a wet state in order to be aware of their minimum characteristics in worst case circumstances. If the characteristics of the wet blocks prove unsatisfactory, they can be improved, e.g. by increasing the proportion of binder, or by selecting the soil and/or the type of hydraulic binder used more carefully.

The blocks can be made wet as a result of immersion or capillarity. The test for capillary absorption (described below in this section) is a reasonable approximation of what happens in reality, but immersion has the advantage of being quick and simple to carry out.

The object of the present section is to suggest an operational method for carrying out mechanical compression tests on wet CEBs. These tests have been adapted from the operational methods for dry compressive strength tests.

1.1. Object of the test

To determine the wet compressive strength of blocks intended for masonry subject to a wet environment in order to obtain comparative results regardless of the configuration of the block.

1.2. Principle of the test

This test is identical to the dry compressive strength test, except that the specimen is wet by complete immersion for 2 hours.

The crushing is considered to be complete at the moment of complete failure. One can thus calculate the wet compressive strength of the block (f_b wet).

The minimum height of the block shall be 6cm.

2. Apparatus

The apparatus is identical to that used for the dry compressive strength test, apart from an additional tray enabling the specimens to be completely immersed, and a watch to monitor the time of submersion (2 h.).

3. Preparing the sample, wetting and making the specimen

3.1. Preparing the sample

- Prepare the sample in exactly the same way as for the dry compressive strength test (see p. 94, § 3.1.),

- Cut the blocks in two as described for the dry compressive strength test (see pp. 95, § 3.2.).

3.2. *Wetting the specimen*

- Place the half-blocks in a tray of clean water for two hours, ensuring that there is at least 5cm of water above the upper faces of the blocks,
- 2 hours later remove the half-blocks and dry them with a sponge, a cloth or a chamois-leather.

3.3. *Making the specimen*

- Place the two corresponding halves of the half-blocks one on top of the other as described for the dry compressive strength test (see p. 95, § 3.2.),
- Check that the two half blocks are parallel using the materials testing press to apply a very slight load to the specimen before the interface mortar sets,
- If necessary, coat the specimen using a cement paste as described for the dry compressive strength test. Alternatively, use sheets of cardboard or of plywood when carrying out the test (see p. 96, § 3.3.),
- Wrap the specimens prepared in this way in a hermetically sealed bag for at least 48 hours.
- After 48 hours, measure the dimensions of the upper and lower surfaces of the specimens and calculate - for each specimen - the average of these two surfaces.

4. *Test procedure and calculations*

Use the same procedure as for dry compressive strength (see p. 97, § 4.)

5. *Reporting the results*

Calculate and record results.

6. *References*

- NBN/B 24-301 *Projet de norme Belge concernant l'approche et le calcul de maçonnerie*, 1976.
- ENTPE Geomaterials laboratory: A. Mesbah, Z. El Gharbi, M. Olivier, *Proposition d'une norme pour la réalisation d'essais de résistance sur BTC*. Vaulx-en-Velin, France, September 1995.

II.f - Abrasive Strength

(CDE Guides 'Technologies Series' No. 16, Compressed Earth Blocks - Testing Procedures, 2000, p.79)

1. General

1.1. Object of the test

To determine the abrasive strength of CEBs used in facing masonry. This value is not directly linked to mechanical strengths, but is generally closely linked to the nature of soils and to the rates of stabilisation of the material.

1.2. Principle of the test

A CEB is subjected to mechanical erosion applied by brushing with a metal brush at a constant pressure over a given number of cycles.

The brushing is applied to the sides of the block which are actually used as facing, i.e. usually the header or the stretcher.

The abrasion coefficient can then be calculated; this expresses the ratio of the surface to the quantity of the material removed by brushing and is proportional to the abrasive strength.

Standards ARS 674, 675, 676, 677 give the abrasive strength values in percentage mass (mass of lost matter / mass of the block before abrasion), this value being one of the standardised classifications for CEBs to be taken into account. However, the abrasion coefficient gives a more significant value which is also easier to compare, regardless of the configuration of the CEBs.

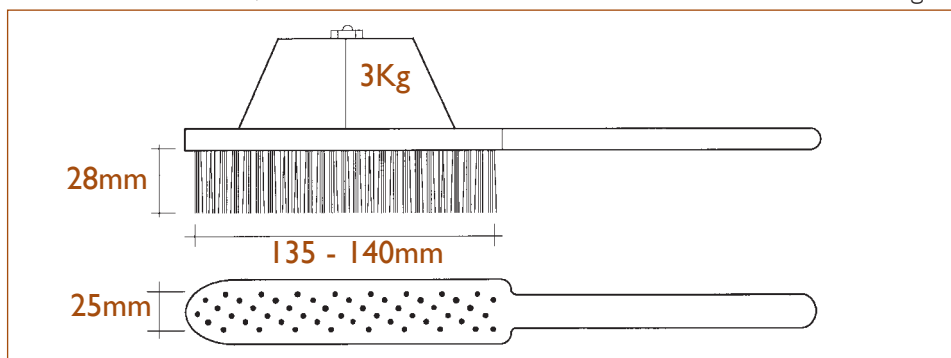
2. Apparatus

2.1. Apparatus in common use

- a rule,
- a balance readable to 10kg and accurate to 1 gram. For masses > 10kg accuracy of $\pm 5g$ is permissible.

2.2. Special apparatus

- 1 steel wire brush, of the kind shown below and loaded with a mass of 3kg.



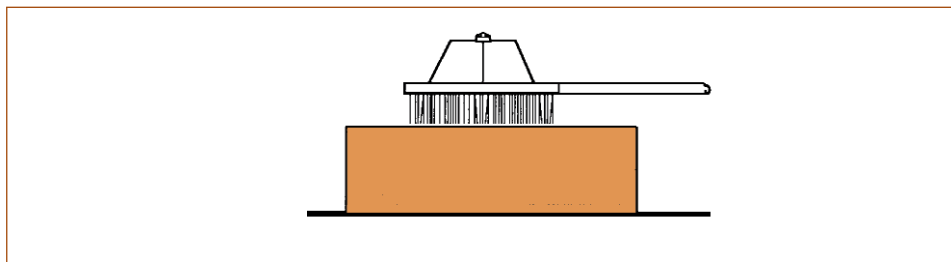
3. Preparing the sample

The CEBs are all produced in the same way at the optimum water content of the mix of which they are made (depending on the equipment used) and from a sample of soil which is representative of the material tested.

4. Test procedure and calculations

4.1. Test procedure

- Weigh and number each block from 1 to 5 (or 6), from the lightest to the heaviest, i.e. m_1 .
- Place the block on a horizontal work surface for brushing; the brush shall be laid on the block (so that its mass is vertically applied to the latter),

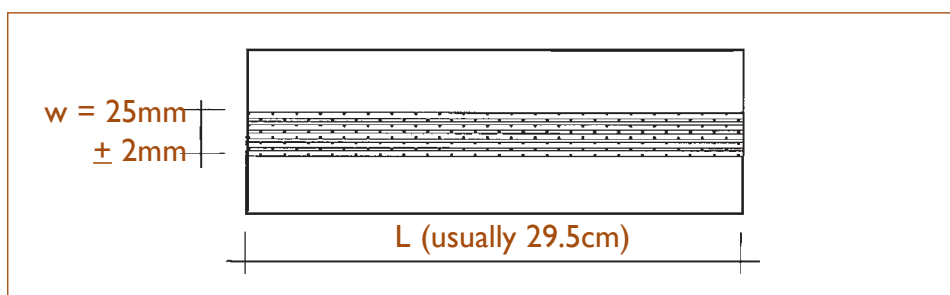


- The facing side of the block (depending on how it is to be used) should be brushed; failing this, for preference, the stretcher should be selected,
- Brush the surface of the CEB using the wire brush to the middle of which a 3kg mass has been correctly attached. Brushing should consist in one forward and backward motion per second for one minute (i.e. 60 cycles). The operator should apply no vertical pressure to the brush when handling it. The brushed area of the CEB should not exceed the width of the brush by more than 2mm.,
- Brushing should take place along the whole length of the block and at least half the surface of the brush should remain permanently in contact with the surface of the CEB for the whole duration of the test. This is to avoid any angling of the brush which would put greater pressure on the edges of the block,
- When brushing is complete, all loose matter is removed from the CEB and weighed (m_1). The mass of detached matter, i.e. $m_1 - m_2$, is recorded,
- Calculate the brushed surface area $S = L \times w$ (in mm),

where:

L = length of the brushed face of the block,

w = width of the brush (in principle 25mm).



African Regional Standards for Compressed Earth Blocks

4.2. Calculations

By definition, the abrasion coefficient (C_a) expresses the ratio of the brushed surface S (in cm^2) to the mass of the material detached by the brushing ($m_1 - m_2$, in grams).

$$\text{Abrasion Coefficient: } C_a (\text{cm}^2 / \text{g}) = \frac{S}{m_1 - m_2}$$

5. Reporting the results

Calculate and record results.

6. References

- R. Sperling, U.D.C. 691.327, Soil-cement blocks "A field test for suitable mix proportions"; September 1961; West African Building Research Institute, ACCRA, GHANA.
- Amina FADLI, "Protection de murs en terre non stabilisée, cas des enduits en terre", Dissertation for post-graduate degree in building with earth, CEAA-Terre 1993-1994, French Ministry of Works, Transport and Tourism, Department of Architecture and of Urban planning, Grenoble, France.

II.g - Capillary Absorption

(CDE Guides 'Technologies Series' No. 16, Compressed Earth Blocks - Testing Procedures, 2000, p.83)

1. General

1.1. Object of the test

CEBs used in a structure may be subject to alternating phenomena of absorption and desorption. In most cases this is because of a "capillary environment" in which capillary rise occurs.

1.2. Principle of the test

In this test, the material is partially immersed to a height of 5mm. Conditions must therefore be such that the block is always immersed to the same height. The absorption coefficient of water corresponds to the speed of absorption. This value is more representative of the behaviour of masonry subjected to a violent storm than its absorption capacity measured at saturation.

Standards ARS 674, 675, 676, 677 give absorption values in percentage mass (mass of water absorbed/mass of the block before wetting), this value being one of the standardised classifications for CEBs to be taken into account. It corresponds to the absorption capacity to saturation of a block in a capillary absorption situation after several days. However, the absorption coefficient as it is given here indicates the speed of absorption of a block after 10 minutes. This value is more representative than what could be measured on actual CEB masonry subjected to a violent storm. The absorption coefficient measured after 10 minutes is a way of characterising a material which is already in use for other small masonry elements. It will therefore be possible to compare the specific values obtained for CEBs with those of other similar materials depending on progress in research in this field.

2. Apparatus

2.1. Special apparatus

- A tray containing drinking water,
- 4 wedges adjustable in height.

2.2. Apparatus in common use

- Ventilated drying oven capable of maintaining a temperature of 40°C,
- a balance readable to 10kg and accurate to 1 gram. For masses > 10kg accuracy to ± 5 g is permissible,
- a 250 ml flask for constantly maintaining the correct water level,
- a precision ruler graduated in mm,
- a stop watch,
- a non-absorbent cloth or chamois leather.

3. Preparing the sample

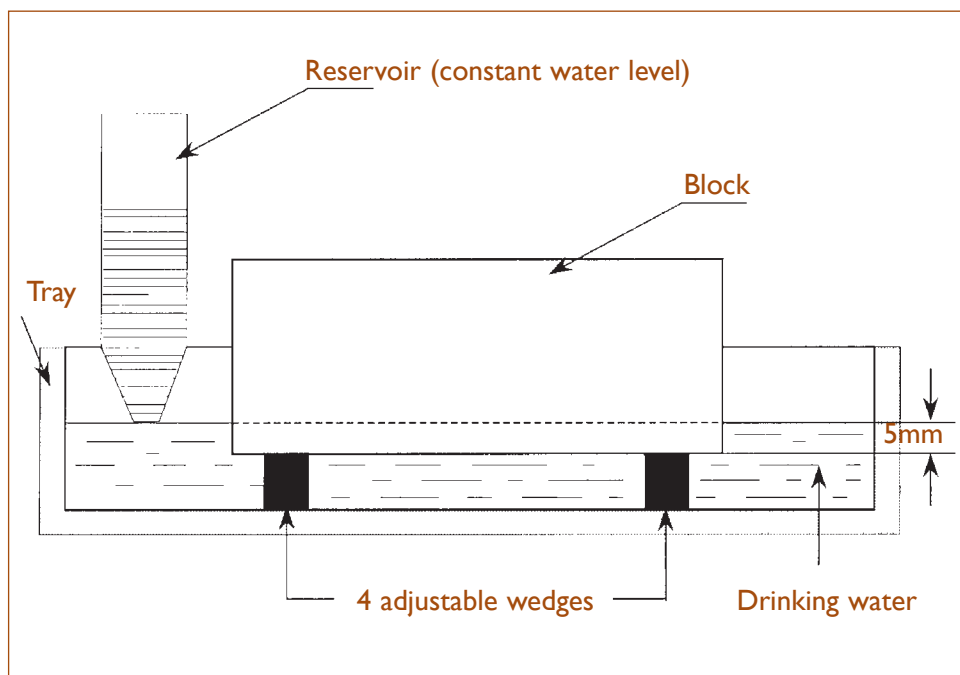
Dry the blocks in a ventilated oven-dry at 40°C until a constant mass is obtained. The mass of the block is constant when the difference in mass between 2 weighings at a 24 h interval is < 0.1% of the initial mass.

- Weigh each block to the nearest 2 g and number them,
- Place the blocks in the oven in the position in which they would be when in actual use, in such a way that the hot air can circulate over all the faces,
- Dry the blocks out until a constant mass is obtained. The mass is considered constant when the difference in mass between 2 weighings at a 24 h interval is < 0.1 % of the initial mass,
- Leave the blocks to stabilise in the laboratory for 6 h,
- Weigh each block, thus: m_{d1} , m_{d2} , m_{dn} mass of the dry block (in grams),
- Measure the dimensions of the surface to be immersed in cm.

4. Test procedure and calculations

4.1. Test procedure

- Immerse a smooth facing side so that it is 5mm beneath the surface of the water. The immersion should be carried out by resting the products on wedges placed at the bottom of the tray and allowing water to circulate all round the immersed face,
- Position the flask (or reservoir) filled with water so that the water level remains constant,
- After 10 min, remove the block from the water and dry it with a damp cloth or chamois leather,
- Weigh the block, thus: m_{d1} , m_{d2} , m_{dn} mass of the wet block in the course of the test (in grams).



4.2. Calculations

The water absorption coefficient C_b of each block is by convention expressed by the formula:

$$C_b = \frac{100 \times (m_h - m_d)}{s\sqrt{t}} = \frac{100 \times (m_h - m_d)}{s\sqrt{10}}$$

in which:

$m_h - m_d$ = is the mass of water, in grams, absorbed by the block during the test,

s = is the surface area of the submerged face, in square centimetres,

t = is the duration of time of the immersion of the block, in minutes.

5. Reporting the results

Calculate and record results.



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Source - derived from Stulz & Mukerji, 1993: pp 343-352

Glossary

Glossary

Adobe brick	Large, roughly moulded, sun-dried clay brick of varying sizes.
Agglomeration	The collecting together of tiny suspended particles into a mass of a larger size, one which will settle more rapidly.
Aggregate	An inert granular material such as natural sand, manufactured sand, gravel, crushed gravel, crushed stone, etc. which when bound together into a conglomerate mass by a matrix forms concrete or mortar.
Badobe	Black cotton soil.
Basalt	A dark, fine-grained, igneous rock used extensively for paving stones, but rarely for building stone.
Borrow pit	A bank or pit from which earth is taken for use as fill elsewhere.
Cation exchange	The exchange of positively and negatively charged ions that results in a hardening process by the formation of bridges that hold particles together. Clay particles have an over all negative charge and therefore attract positive ions forming such a hardening bridge.
CEB	Compressed Earth Block.
Cement	A material or mixture of materials (without aggregate) which, when in a plastic state, possesses adhesive and cohesive properties and hardens in place.
Cement (Portland)	The cementitious binder for most structural concrete; obtained by pulverising clinker (a partly fused product of a kiln, which is ground for use in cement) consisting essentially of hydraulic calcium silicates.
Cement gel	A gelatinous substance so finely divided that it remains in suspension when dispersed in liquid, comprising the largest part of the porous mass of mature hydrated cement paste.
Cementitious	Having cementing properties.
Cob	A mixture of straw, gravel and unburned clay. Cob method of construction is to stack earth balls and tamp to form monolithic wall.
Curing	Maintaining the humidity and temperature of freshly cast soil blocks (or freshly placed concrete, or similar) during some definite period following casting or placing or finishing to assure satisfactory hydration of the cementitious materials and proper hardening of the soil (concrete, or similar).
Flocculation	A process in which particles in a colloid aggregate into larger clumps.
Goz	Red sandstone.

Hopper	A funnel shaped bin or chute, used to store loose construction materials such as crushed stone or sand.
Later	A brick, formed in a mould and dried in the sun or baked in a kiln by the early Greeks and Romans, much larger than a modern brick.
Laterite	Soil that is rich in iron oxide and typically porous and clay like. It forms in tropical and subtropical regions where the climate is humid.
Montmorillonite	One of the common clay materials which typically swells upon wetting and becomes soft and greasy.
Pozzolanas	Siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.
Stabilisation	The action of modifying the properties of soil by adding another material that improves its strength and durability for construction purposes.
Stabiliser	A substance (i.e. lime, cement, bitumen, gypsum, pozzolana, organic fibres etc) that when added to a soil mix will increase its strength and durability.
Tamp	To compact a material or surface, such as earth or freshly placed concrete, by repeated blows.
Volcanic tuff	A low density, high porosity rock, composed of volcanic particles, ranging from ash size to small pebble size, which are compacted or cemented together, sometimes used as building stone or as a thermal insulation material.
Wattle and daub	A very common form of primitive construction, consisting of a sort of a coarse basket work of twigs woven between upright poles, then plastered with mud.



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