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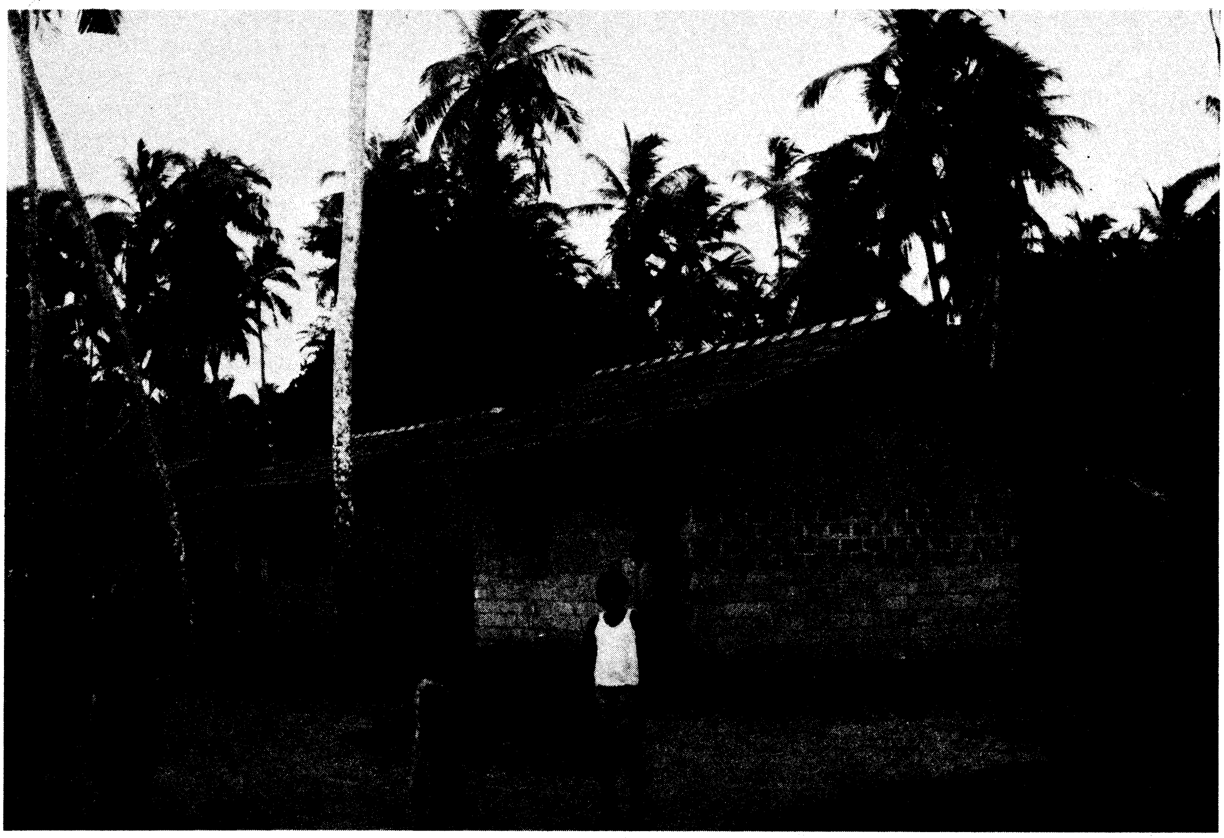
STABILISED SOIL BLOCKS FOR BUILDING

by M G Lunt



Sri Lankan village houses, built from blocks of cement-stabilised soil

Overseas Division
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Department of the Environment

BIOGRAPHICAL NOTE

Michael Lunt graduated in Applied Chemistry from the Liverpool Polytechnic. He joined the Building Research Station in 1971, and worked initially in the Materials Division.

In 1974 he transferred to Overseas Division, where he investigated the use of lime as an economic alternative to cement for stabilising soil building blocks. He made a series of visits to Ghana to carry out field trials on walls made from stabilised soil blocks.

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by M G Lunt, BSc

1 INTRODUCTION

Soil is one of mankind's oldest building materials, and the traditional methods of soil construction such as rammed earth, wattle and daub, and adobe, are still commonly used in many regions of the world. Although soil may be adequately strong for building construction, it is not very durable and has little resistance to moisture. The effects of its poor weathering performance can be seen in many developing countries where rural houses must be maintained regularly or even completely rebuilt at intervals (especially in areas with moderate rainfall).

Methods to improve the natural durability and strength of the soil—commonly referred to as 'soil stabilisation'—have been practised in many countries. These methods are not new since 'stabilisers' such as natural oils, plant juices, animal dung and crushed anthills, have been used for many centuries. In recent years scientific rather than adhoc techniques of soil stabilisation for building have also been introduced, developed largely from methods devised for the stabilisation of earth roads. Tests have been developed to indicate which soils are most suitable for stabilisation and to predict their durability when stabilised. Failure to make adequate use of these tests has sometimes resulted in poor performance and this has led to the unjust belief that stabilised soil can never be a satisfactory building material.

Some of these tests are described in this note together with an outline of the composition and behaviour of soil and of the principles of soil stabilisation. The note also includes descriptions of some soil blockmaking presses specifically designed for low-cost housing in the Third World. Details are also given of an investigation carried out by the Overseas Division of the Building Research Establishment in collaboration with the Building and Road Research Institute in Ghana, on the use of lime as an economical alternative to cement for stabilising soil blocks.

2 SOIL

General classification

Soil consists of disintegrated rock, decomposed organic matter and soluble mineral salts. Under the engineering system of classification which is widely accepted in earth construction a soil is graded into fractions according to the size of particles, as follows:—

Diameter of particle (mm)	Fraction
60 — 20	Coarse gravel
20 — 6.0	Medium gravel
6.0 — 2.0	Fine gravel
2.0 — 0.6	Coarse sand
0.6 — 0.2	Medium sand
0.2 — 0.06	Fine sand
0.06 — 0.02	Coarse silt
0.02 — 0.006	Medium silt
0.006 — 0.002	Fine silt
Less than 0.002	Clay

This classification is also included in British Standard 1377[1]; other classifications are used by other authorities but differences are usually slight.

Generally speaking, soils containing less than 20 percent clay are classed as gravel and sand, loamy sands, sandy loams and loams; soils containing 20-30 percent clay are called clay loams, while those containing over 30 percent clay are classed as clays.

It is the clay fraction which is of major importance in earth construction since it binds the larger particles together thus enabling a soil to be used as a building material. Unfortunately clay readily absorbs moisture, and this is the main cause of soil's instability when wet.

Lateritic soil

A brief mention should be made here of lateritic soils because of their abundance in many developing countries. They are widely distributed throughout the tropical and sub-tropical regions of Africa, South America, Central America, Australia, India and S E Asia. The word laterite (which is derived from the latin word 'later' meaning brick) was first suggested by Buchanan in 1807 to describe a red coloured, iron rich material found in the mountainous regions of Malabar, India. He discovered that this material when freshly dug could be cut easily into blocks which subsequently hardened on exposure to air, thus making them resistant to weathering. Nowadays the term laterite is applied to soils containing iron and aluminium oxides. Because lateritic soils have extremely diverse origins many definitions have been suggested in terms of their morphology, physical characteristics and chemistry[2, 3]. They can best be described however as highly weathered tropical soils containing varying proportions of iron and aluminium oxides which are present in the form of clay minerals. They contain little or no combined silica but, depending on the parent rock, may have large amounts of quartz. Their colour ranges from ochre, through red, brown or violet to black.

3 PRINCIPLES OF SOIL STABILISATION

Because of the clay fraction, walls built of unstabilised soil will swell on taking up water and shrink on drying. This gives rise to severe cracking and often leads to difficulties in getting renderings to adhere to the walls, as well as to their eventual disintegration. The aim of a soil stabiliser is therefore to increase the soil's resistance to the destructive properties of the weather. This can be achieved in one or more of the following ways:

1 By increasing the strength and cohesion of the soil.

2 By reducing the moisture movement of the soil.

3 By making the soil waterproof.

One method of stabilisation is to mix the correct proportions of a sandy soil and a clayey soil. The strength and cohesion of the sandy soil is increased while the movement of the clay soil, as a result of changes in moisture content, is reduced. Mechanical compaction of a natural soil also stabilises it by increasing its strength and cohesion. Both these methods are still used but neither of them stabilises soil to a high degree.

The strength of a soil can be increased and maintained to a reasonable extent when wet by the addition of cementitious materials of which the most widely used is Portland cement[4]. The quantities used are not sufficient to completely fill the pores of the compacted soil, but rather to cement together the soil particles or clusters of particles in a manner similar to that of binding an aggregate in normal concrete. Other cementitious materials which can be used include hydraulic lime and lime-pozzolana mixes[4]. A pozzolanic reaction occurs between lime and certain clay minerals, to form a variety of cement-like compounds which bind the soil particles together. Lime can also reduce the extent to which the clay absorbs water, and so can make the soil less sensitive to changes in moisture content.

Other types of stabilisers act as waterproofing agents by providing a physical barrier to the passage of water. Bitumen, asphalt and certain resins are the most common of these[4].

In practice most stabilisers act in more than one of the ways described. Thus the rigid skeleton formed by Portland cement resists moisture movement, in addition to improving the strength of the soil. Similarly lime, as well as improving the strength, also alters the physical properties of some soils to give improved stability in the presence of water.

Although soils suitable for stabilisation are widely distributed about the world they are far from universal. Some soils may contain so much clay that an uneconomic amount of cement would be needed for stabilisation in which case lime may be necessary, either by itself, or in combination with the cement. Other soils cannot be stabilised with lime as they contain too little clay. Furthermore the presence of organic matter and sulphates can render a soil unsuitable for stabilisation either with cement or lime.

Before going ahead with any soil building project it is therefore important to perform certain tests to determine the suitability of a soil for stabilisation, the best stabiliser to use, and the likely quantities of stabiliser. These tests are now discussed.

4 SOIL TESTS

Particle size analysis

It is the particle size distribution or grading of a soil which determines how effectively it can be compacted and stabilised. A 'well graded' soil will therefore contain the correct proportions of different sizes particles, with all voids between larger particles being filled by smaller ones.

In order to determine the composition of a soil it is necessary to separate and determine the proportions of the different sized particles, fine gravel, coarse sand, fine sand, silt and clay. It is possible to separate the soil down to and including fine sand by the simple method of sieving. The silt and clay fractions cannot however be determined by this method, but only by using lengthy and intricate tests of hydrometry and sedimentation. Field tests have been devised to separate the fines from the rest of the soil. These involve shaking the soil in water and either decanting off the finer material which is in suspension, or allowing the soil to settle into different layers[5]. Although these tests are simple to carry out and are ideal as a preliminary test their main disadvantage is that the silt and clay fractions cannot be determined separately. Because silt behaves differently from clay this could result in wrong conclusions about the soil's suitability for stabilisation.

It is advisable therefore that for all important soil building projects a full laboratory analysis should be carried out on the soil, using the appropriate tests in BS 1377[1], or the equivalent standards issued by other countries.

Plasticity Index

Clays vary greatly in their physical and chemical characteristics, and because of the extremely fine size of the particles it is very difficult to investigate their properties. For the purpose of soil stabilisation the plastic properties of a clay can be conveniently expressed in terms of plasticity using standard tests.

Before discussing these tests it is important to know something about the changes that take place when water is gradually removed from a clay. If sufficient water is present the clay particles will be dispersed and the clay will behave as a liquid. As the water content is reduced a point will be reached when the system no longer behaves like a liquid and below which it possesses shear resistance. This point is called the *liquid limit* and is usually defined as the moisture content at which the soil passes from the plastic to the liquid state when determined in accordance with a standard test procedure (which is described later).

With further drying the clay system will increase in density and it then behaves like a plastic paste, so that it is continuously deformed when a force is applied to it but retains its new shape when the force is removed.

Reducing the moisture content still further eventually causes the clay to crumble under load and not to deform plastically. At this point the clay is at its *plastic limit* which can be defined as the moisture content at which the soil becomes too dry to be plastic when determined by a standard test.

The numerical difference between the liquid limit and plastic limit of a soil is the *plasticity index* and is a measure of the range of moisture content over which the soil will possess plastic properties. Both the liquid limit and plasticity index are affected by the amount of clay present in a soil and the type of clay minerals present.
Sands and sandy soils with negligible clay content have no plastic limit.
Fine-grained soils which have a low degree of plasticity have liquid limits less than 35 percent. The clay content of such soils is generally less than 20 percent.
Fine-grained soils of medium plasticity have liquid limits lying between 35 and 50 percent. Usually these soils contain between 20 and 40 percent of clay.
Soils with high plasticity have liquid limits in excess of 50 percent and their clay content is normally more than 40 percent.

A high liquid limit and plasticity index indicates that a soil has a great affinity for water and will therefore be more susceptible to moisture movement. Such a soil is likely to be difficult to stabilise with cement and would require a larger amount of stabiliser than one with a low liquid limit and plasticity index. On the other hand, soils with high values of liquid limit and plasticity index may be suitable for a lime stabiliser because of its ability to alter the plastic properties of the soil.

Different values for liquid limit and plasticity index have been proposed by different workers for soils to be suitable for stabilisation. Maximum values of 50 for liquid limit and 30 for plasticity index have been suggested, and are probably valid for earth walls rammed in place or made from pressed blocks. In some cases minimum values have been quoted[6].

The procedure for determining the liquid limit of a soil consists of placing the soil-water paste in a standard cup, dividing it into two halves with a grooving tool and determining the moisture content at which the two halves will just flow together when given a standard number of blows. The plastic limit can be determined by rolling a thread of soil to 3 mm in diameter between the palm of the hand and a glass plate. The soil thread is said to be at the plastic limit when its moisture content is such that it crumbles under this rolling action.

Since these tests directly indicate the behaviour of a soil towards water they are considered to be worthwhile. Although field tests[5] have been devised the laboratory tests specified in the standards are easily performed and therefore are best carried out.

Organic matter and soluble salts
The surface layer of the soil usually contains organic material in the form of humus which may seriously impair the setting or hardening of cement or affect the pozzolanic reaction between lime and the soil. In most cases removing the top soil and using only the soil beneath will ensure that no organic matter is present. However in some regions (particularly near rivers) organic matter can be found to a considerable depth. In these localities it is desirable to test the soil to determine whether or not organic impurities are present. One test, given in BS 1924[7] consists of determining the pH of a soil-cement mixture. The pH is measured one hour after mixing in water, and if it is below 12.1 the soil is considered to be unsuitable for stabilisation with 10% or less of cement, since it shows that cement hydration has been affected by the organic impurities. The test, although performed electrometrically, is simple to perform and should if possible be included in the soil survey. If lesser quantities of impurity are present, the soil may be suitable but particular attention should be given to the results of tests on the strength of the stabilised soil blocks.

In other areas (for example arid and semi-arid regions) the presence of soluble inorganic salts, particularly sulphates, may make the soil unsuitable for stabilisation with either cement or lime. This is because any increase in moisture content can lead to chemical reactions which result in expansion and disruption of the soil. Such reactions can occur both between the sulphate and the cement, and between the sulphate and the clay fraction of the soil. The latter reaction occurs at high pH values such as when lime is added to sulphate bearing soils. There is only limited information on this subject, but sulphate contents between 0.5 and

1.0% are said to represent the upper limit for successful stabilisation. The actual value however will depend on the type of sulphate and the amount of clay present in the soil. In areas which are known to contain sulphate-bearing soils, it is therefore important to analyse soil samples in order to determine the amount of sulphate present. If this is greater than 1.0% the soil is unlikely to be suitable for stabilisation and should not be used. If sulphates are present but in lesser concentrations, then particular attention should be given to the effects of immersing the stabilised soil specimens in water and to their subsequent wet strength.

5 TESTS ON STABILISED SOIL

The tests outlined in section 4 are all of value in assessing the relative ease with which different soils may be stabilised. From the results of these tests it should be possible to compile a short list of those soils that are worthy of further consideration. The next step is to decide upon the optimum amount and type of stabiliser to be used. The necessary tests for assessing the performance of stabilised soil specimens are now discussed.

Moisture—density relationship

Natural soil contains pore spaces filled partly with air and partly with water. These spaces can be reduced by compaction, and the degree to which this can be done depends on the soil type, the amount of water present, and the method and force of compaction. A soil which has been well compacted will be stronger and more durable than when poorly compacted. The optimum moisture content, which gives maximum soil density, can be determined by a standard laboratory procedure[1] whereby the soil at various moisture contents is compressed in a mould and its density determined. These tests were designed for use with stabilised soils which would be compacted in dams, embankments and roads, and so they are not necessarily valid for building purposes. Nonetheless they can be used as a guide in preliminary work. Work at BRE and elsewhere has shown that both the optimum moisture content, and the density, are dependant upon the choice of stabiliser. The moisture-density relationship should therefore be determined using the particular soil/stabiliser combination and the method and degree of compaction which will be used in practice. The optimum moisture content found will therefore be the same as that to be used on site and the corresponding density can be a useful quality control against which production blocks may be compared, Figure 1.

Sometimes the 'moisture-density curve' is flat, in which case the optimum point may not be distinct. This will be an advantage in practice since slight changes in the amount of water used for moulding will not result in large changes of density and so of strength.

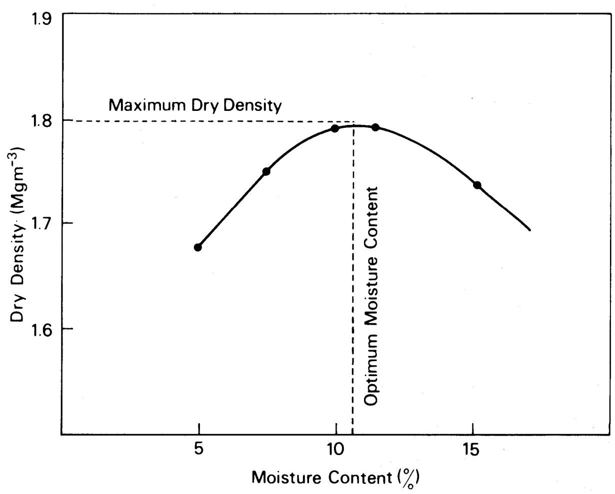

Figure 1 Typical moisture—density curve

Wet strength

A soil wall must possess adequate strength to satisfy loadbearing requirements. In most climates the wall will be wet at various times, and so it is important that the wet compressive strength should be determined. This wet strength of a stabilised soil wall may be only one-third of its dry strength. All strength tests should therefore be carried out on specimens which have been soaked for at least 24 hours after the appropriate curing period—which is normally 28 days during which time the specimens are prevented from drying.

Although these test specimens can be small, so as to economise in materials, yet for a building project of any importance it will be necessary to determine the crushing strength of full sized blocks. The builder then has more information on which to base his decisions on wall heights and thicknesses, following the rules laid down in the appropriate building code. A minimum wet strength of about 1.4 MN/m^2 has been recommended by several building authorities throughout the world. This figure probably takes into account the most economic amount of stabiliser needed to achieve adequate strength and durability. The test procedure for determining wet strength could follow essentially that laid down in the standards for testing precast concrete blocks[8].

Durability

Employing accelerated durability tests to assess the likely weathering performance of building materials is always difficult and this is particularly so with soils. This is borne out by a number of soils which have failed accelerated durability tests but have subsequently performed quite well in practice.

One of the most commonly used durability tests was developed to simulate the weathering of soil-cement road bases. Stabilised soil specimens are soaked in water, dried to constant weight then given a specified number of strokes with a wire brush. This constitutes one cycle. The specimens are weighed after each cycle up to a maximum of twelve cycles unless disintegration occurs before then. The total loss in weight can then be calculated as a percentage of the original dry weight[9].

Some authorities suggest a maximum weight loss above which the soil should not be used, while others quote different limits according to whether the soil houses are to be built in an urban or rural area and the type of climate experienced[6].

Most authorities consider that the cycles of wetting, drying and brushing are too severe a test, and some either omit the brushing or use a brush with nylon or soft hair.

Another test involves the spraying of water from a 100 mm shower head against the face of a specimen 200 mm from and parallel to the shower head. Spraying is continued for two hours at a pressure of 1.5 Kg/cm^2 and the specimen examined visually for erosion and pitting[5]. This test has also been modified in spraying time, rate and pressure.

It is difficult to form an objective opinion of the relative merits of these tests since little correlation is available with their actual weathering performance. Also, the spread of results likely to be obtained with test repetition on identical mixes has not been established. However, some method of directly comparing the likely durability of different soils stabilised to varying degrees is still worthwhile. The most suitable test is likely to be one which involves spraying the specimen, and determining its weight loss, as in this way the specimens would be subjected to an abrasive force similar to that caused by rain. The procedure could be repeated for a number of cycles with the total loss in weight being used as a measure of durability. Any limit of weight loss must initially be somewhat arbitrary until field trials have been conducted on test walls and their behaviour has been correlated with the laboratory results.

Moisture movement

Tests for drying shrinkage and moisture movement should ideally be included in any assessment of the properties of stabilised soils. These tests are necessary because any large movement would lead to cracking of the wall, to failure of applied renderings, or to rain penetration. It was shown earlier that earth walling is inherently sensitive to changes in moisture content, and so, as it loses the water needed for moulding, it must shrink. In the case of pressed or rammed bricks or blocks they can be allowed to dry and shrink before a wall is built. This is not possible when the walls are rammed in place and accordingly it may be necessary to restrict the soils to those which are lower in clay or where it can be shown that shrinkage does not exceed certain limits.

The moisture movement of stabilised soils is still likely to be higher than that of other walling materials. Limits for moisture movement have been proposed but are possibly too restrictive for general application until more data are available[6]. Much can be done by good design to minimise these movements and their effects, and some general principles are set out in section 7.

6 SOIL BLOCKMAKING PRESSES

General principles

Concrete block machines are normally unsuitable for making stabilised soil blocks. This is because concrete mixes are designed to have the right amount of workability for rapid compaction by tamping or vibration, whereas the correct amount of water needed for optimum compaction of a soil would result in an unworkable mix. This unsuitability of concrete block machines has led over the past twenty or so years to a number of simple presses being developed specifically for making soil blocks, and some of the best known presses which are being used for housing construction in the Third World are described below.

There are two main types of press—constant pressure or constant volume. With the first type the ram of the press exerts a constant pressure at every stroke while with the second type the ram moves a fixed distance. Reducing the amount of soil fed into the constant pressure machine will produce a smaller block but with the other type too little soil will cause under-compaction and give a block of low density. In both cases therefore the amount of soil fed into the machine is important and should be controlled with care.

Although it is doubtful whether manually operated presses can produce compaction pressures higher than 4 MN/m^2, they are still popular throughout the developing countries because of their cheapness, simplicity and mobility. Power-driven presses (although capable of producing denser blocks at higher outputs) are likely to be more expensive because of their greater sophistication. Maintenance is also more expensive and it may be difficult to obtain spare parts as readily as for the simpler machines.

Cinva-Ram

One of the most widely known presses is the hand-operated Cinva-Ram which was originally designed by the Inter-American Housing and Planning Centre (CINVA) in Bogota, Colombia. These presses are now manufactured in several countries

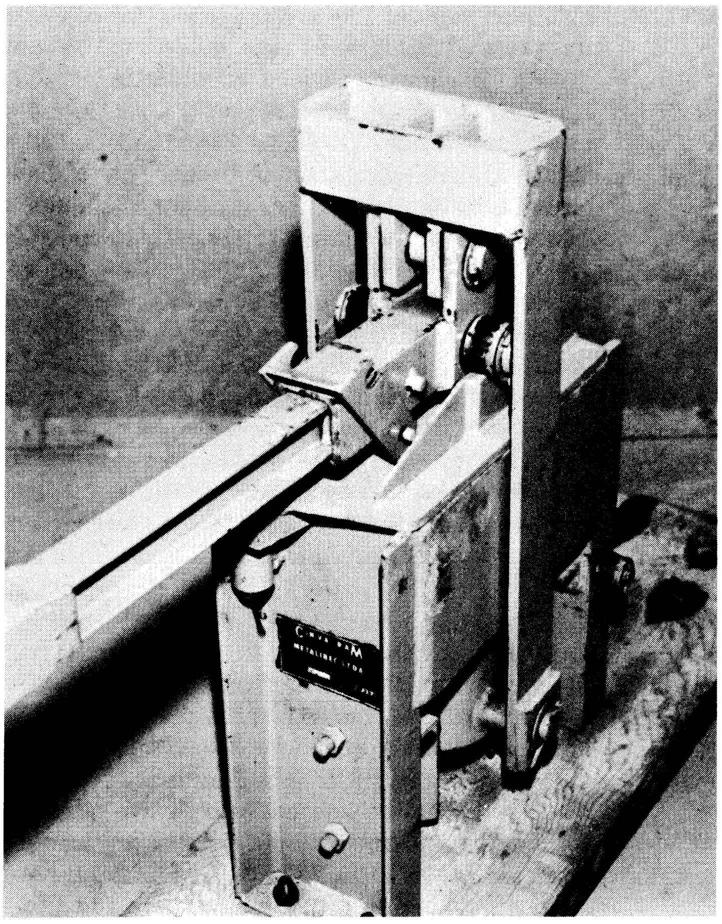

Figure 2 Cinva-Ram at compression

Figure 3 Tek-Block press in use

under licence from the IBEC Housing Corporation in New York, U.S.A.

The machine, which weighs approximately 65 Kg, consists of a metal mould in which a measured quantity of the moist soil mix is compressed by an ascending piston connected via a toggle linkage to a 1.5 m long lever, Figure 2. In order to make well compressed blocks enough mix must be loaded into the mould to require a hard pull on the lever handle. The exact volume of loose soil should always be determined by experiment and a gauge box made to give just this amount. When operated by two men the machine is claimed to produce about 300 blocks daily, this figure could be increased with a larger number of people, some operating the machine, and others preparing the soil mix and stacking the blocks.

Blocks with dimensions 290 x 140 x 90 mm can be produced. They may be plain or if required, frogged, by using a suitable wooden form. It is also possible to make tiles with laid up dimensions of 290 x 140 x 50 mm by using a wooden insert. Some users have further adapted the mould box to make two smaller bricks instead of one standard size block.

Tek-Block

The University of Science and Technology in Kumasi, Ghana has designed the hand-operated Tek-Block press which weighs about 90 Kg, Figure 3. In this case the lever arm is made from timber instead of the three piece metal arm used for the Cinva-Ram. It is intended therefore that overfilling the mould will break the wooden lever before jamming the piston. The number of operations required to press and eject the blocks is less than with the Cinva-Ram because the top of the mould is fixed to the lever arm. After compaction of the soil, movement of the lever from one side of the mould to the other results in the top of the mould being removed and the block being ejected in one single operation. The size of block made by this press is 290 x 215 x 140 mm, with an output claimed at between 200 to 400 blocks per day depending on the number and skill of the workmen.

Landcrete

The South African made Landcrete press is hand-operated and can make blocks of various sizes. However all references to this press are to be found only in old literature and the press may no longer be available.

Ellson

Another South African firm, Ellson Pty, also manufacturers a manually operated press which is claimed to give very dense blocks because of its high lever ratio of 500-1. One significant feature of this press is the height of the mould from the ground (860 mm approximately) which helps reduce back-ache from bending down to remove the ejected blocks. One particular Ellson model—the Universal press—is claimed to produce about 1000 blocks daily at a compaction pressure of about 7 MN/m^2, with two men operating the levers.

Supertor

A range of hydraulically powered soil-cement brick presses is being marketed in Brazil. One version has a four brick mould producing a brick size of either 230 x 110 x 50 mm or 200 x 100 x 50 mm. The Supertor is powered by a 5 HP electric motor, it weighs 1000 Kg and is claimed to have an output of 20 000 bricks per 8 hour day.

Latorex

A Danish firm, Drostholm Products, has developed a plant system for the high speed production of lime-stabilised laterite blocks. The electrically powered plant comprises a soil drier and pulveriser, mixer and presses. A normal size plant is planned for capacities of about 12 000 bricks per 8 hour day (brick size 230 x 110 x 55 mm). The brick presses operate at high pressures and have been designed to deal with a wide range of soils of different gradings and properties. The bricks can be steam cured and are claimed to have compressive strengths of between 15 and 40 MN/m^2.

Manufacturers of Blockmaking Machines

1 Cinva-Ram:
   Richmond Engineering Co, VA, USA;
   Frazer Engineering Co Ltd, 39 Lunns Road, Christchurch 4, New Zealand;
   Metalibec Ltd, Bogota, Colombia.

2 Tek-Block:
   University of Science and Technology, Kumasi, Ghana.

3 Landcrete:
   Landsborough-Findley Ltd, Johannesburg, South Africa.

4 Ellson:
   Ellson Pty, South Africa. Purchased through Blankor Distributors Pty, 15 Hyser Street, PO Box 9584, Johannesburg.

5 Supertor:
   Torsa Maquinas E Equipamentos Ltd, Sao Paulo, Brazil.

6 Latorex:
   Drostholm Products A/S dk—2950 Vedbaek, Denmark.

7 SOIL BLOCKS IN USE

Appearance

It is hardly surprising that the villagers and townspeople of the Third World who normally build with soil would prefer their homes to look like those in the West. With successive generations having experienced the problems of unstabilised soils it is only natural that no matter how much they are improved a certain amount of suspicion will remain. This is especially so when one sees poorly compacted blocks made from stabilised soils which, although possessing better performance, still retain a 'temporary' appearance. In contrast, research workers at BRE have made blocks which are dense and smooth in appearance, and very similar to fired clay bricks. They demonstrate that suitable soil can be compacted quite cheaply to produce blocks which are aesthetically pleasing. (Details of this research study are given in section 8 of this note).

Wastage

The breakage of blocks or bricks during manufacture, in transit, or when building is always a problem in the construction industry. In the more industrialised fired brick and concrete block plants, mechanised handling techniques and higher initial strengths of these products help to reduce wastage. This is not usually the case with soil block manufacture in developing countries because of the high labour involvement and lower block strengths. This high wastage (sometimes as high as 50%) is something which the poorer people can ill afford to bear. The necessity to handle numerous soil blocks in the course of studies at BRE highlighted their vulnerability to damage especially at the edges and corners of the blocks. Those made at 8 MN/m^2 and above could be handled with more confidence although sensible care was still needed.

Soil blocks remain fragile until some strength develops during the curing period due to the action of the stabiliser. Compaction alone will therefore not prevent wastage but with constant care in handling and the use of wooden pallets to carry the blocks, breakages can be kept at a reasonable level.

Design Considerations

Buildings made from stabilised blocks should, whenever possible, be designed in general accordance with the relevant Codes of Practice for concrete blockwork. Concentrated loads on the wall or on part of it should be minimised by using, for example, lintels above door and window openings and by employing a wall plate to distribute load. Wall layout should be simple with few breaks; slender sections of walling between closely set windows and doors should be avoided.

Most stabilised soil buildings are of single storey, although some may be two storeys in height, and the thickness of their walls is often governed by design considerations other than strength—notably by their impermeability to water and by thermal comfort requirements. Walls should be shielded as much as possible from the erosive effects of rain. This is important in areas where high rainfall is accompanied by strong winds. It is advisable to provide generous roof overhangs of at least 1 m, especially in the wet areas.

Rain splashing back from the ground onto the base of the wall is also a frequent cause of erosion. It is good practice to construct the base of the wall with concrete or stone up to a height of at least 250 mm, before laying the lowest course of the soil blockwork. Alternatively it may be worthwhile to lay the soil wall from ground level but protect it to the same height by a rendering.

The corners of buildings are particularly at risk from wind and rain, and blocks in these positions can erode much more quickly than those in the main body of the wall, Figure 4. In wet regions corners should be protected by applying a render; or consideration can be given to the use of more durable corner blocks.

If rainwater downpipes are fitted they should be kept well clear of the walls; any water which overflows as a result of leaks or blockages is thus prevented from causing rapid erosion of the wall

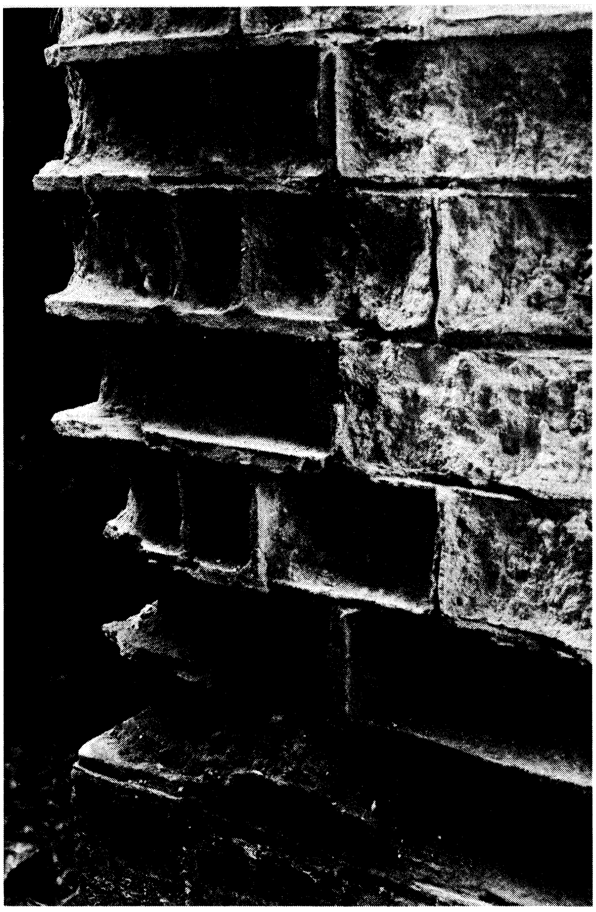

Figure 4 Corner of BRE experimental soil-cement building constructed in 1950[10]

surface. Similarly window cills should project a sufficient distance from the wall to prevent erosion by running water.

If drying shrinkage is found to be high with the particular blocks to be used this must be taken into account in the design of the building. The mortar to be used should not be stronger than the blocks themselves, as a weak mortar accommodates movement and so reduces the possibility of cracking of the blocks. The use of a weak mortar is normal practice for other materials of relatively high shrinkage, such as certain classes of calcium silicate bricks or concrete blocks.

8 EXPERIMENTAL INVESTIGATION AT BRE

This section describes an investigation of blocks made from lime-stabilised Ghanaian soils, which were compacted over a range of pressures most likely to be achieved with a simple and inexpensive press. The properties of these blocks were assessed with a view to possible use as a low-cost building material in developing countries and were compared to other walling materials such as fired clay bricks, calcium silicate bricks and concrete blocks.

Fabrication

Two Ghanaian soils were studied. One was a fine textured micaceous red soil taken from waste ground near the University of Science and Technology campus in Kumasi. The other was a brown soil found near the village of Fumesua several kilometres from Kumasi. Their particle size grading and major chemical constituents are presented in Table 1.

Table 1 Particle size grading and chemical composition of two Ghanaian soils studied

(a) Particle size grading	Kumasi soil Wt%	Fumesua soil Wt%
Fine gravel	9.0	1.5
Coarse sand	23.0	26.5
Medium sand	5.5	14.0
Fine sand	6.5	9.0
Fines	56.0	49.0
(b) Chemical composition oxide	**Kumasi soil Wt%**	**Fumesua soil Wt%**
SiO_2	61.30	81.40
Fe_2O_3	4.55	2.38
Al_2O_3	22.10	9.59
H_2O	9.46	5.02

Blocks measuring 290 × 140 × 90 mm thick were made with a hand-operated Cinva-Ram press. Other blocks were compacted at 4, 8 and 16 MN/m^2 pressure in a reinforced mould, using a concrete testing machine adapted specially for this investigation, Figure 5. Their optimum mix design in terms of lime and water content was obtained from previous strength and density results of cylindrical specimens compacted at different pressures[11]. To make the blocks, sufficient quantities of each soil were passed through a 6 mm sieve and weighed batches then mechanically mixed for ten minutes with 6% of lime by weight of dry soil. The appropriate amount of water, calculated as a weight percentage of the dry lime-soil mix was then added, Table 2. The mix was then stirred for ten minutes to ensure uniform wetting.

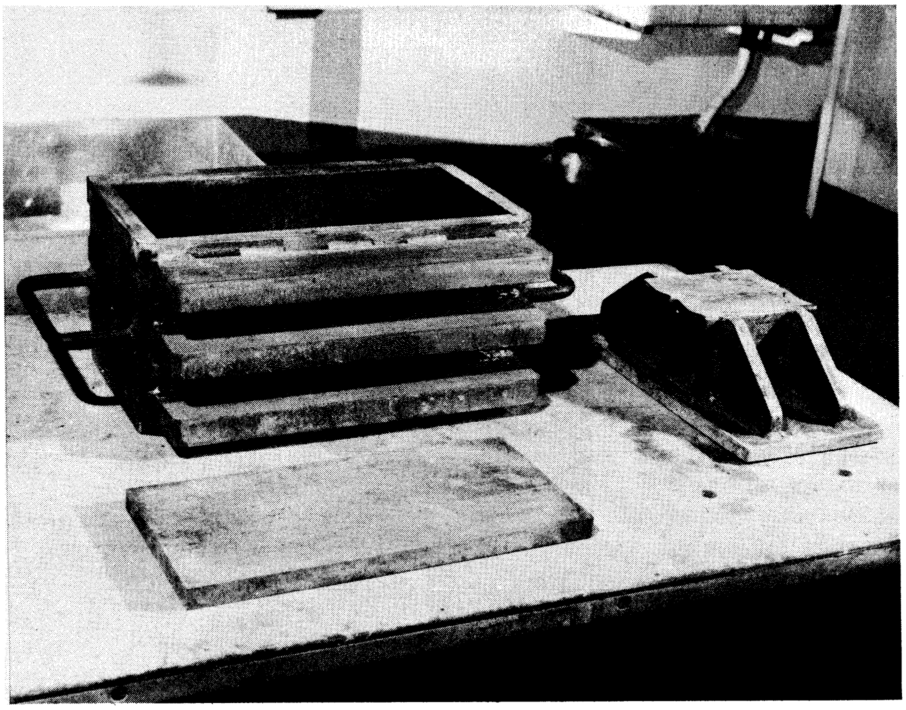

Figure 5 Reinforced mould for making blocks at high compaction pressures

Immediately after demoulding all the blocks were weighed and measured. Some were then placed in large trays, covered with plastic sheeting and then cured for one month in a room at 27°C. This temperature was based on that specified in BS 1924: 1975[7] for testing stabilised soil specimens for tropical and sub-tropical applications. Regular spraying was carried out to ensure that the blocks remained moist during their curing period. Those selected for wet strength tests were completely immersed in water at 27°C for the final 24 hours of the curing period. Those to be used for other tests were allowed to dry in air to constant weight. In order to assess the effects of a higher curing temperature some blocks were cured at 95°C for 24 hours then soaked for 24 hours before testing for wet strength, Figure 6.

The strength, water absorption and moisture movement of the blocks were then determined following the procedures laid down in BS 2028[8]. To assess the blocks' resistance to driving rain a 100 mm diameter shower head was clamped vertically above each block which had its largest faces horizontal. The height of the shower head was selected to produce a fierce spray over the entire surface area of the exposed face and with a force much greater than that expected from tropical rain. Visual observations were made on the blocks after spraying them for six hours.

Experimental observations
Some of the findings from this investigation are presented in Tables 2 and 3 and are now outlined below.

Strength
Figure 7 illustrates the 28 day strengths of the lime-stabilised blocks made from the two Ghanaian soils. Improvements in strength of the Kumasi and Fumesua blocks were observed from 1.05 MN/m^2 to 3.55 MN/m^2 and 0.70 MN/m^2 to 3.05 MN/m^2 respectively as their compaction pressure was increased. These results demonstrate what past research has already indicated, that better compaction of a soil can lead to higher strengths. However one noticeable feature was that the improvement in strength steadily decreased as their compaction pressure increased. Although other stabilised soils might behave differently the strength-compaction relationship raises the question whether there is a cost effective level of compaction pressure which can be applied by a commercially viable block press for producing adequately strong blocks. Certainly both soils evaluated in this investigation when compacted at or above 8 MN/m^2 gave strengths which exceeded the minimum recommended design value of 1.4 MN/m^2. The soil blocks compacted at these higher pressures also exceeded the minimum strength of 2.8 MN/m^2 which is specified in BS 2028 for precast concrete blocks. Although by no means applicable to all soils these results are promising since it appears that very high compaction may not be needed to provide stabilised soil blocks with more than adequate loadbearing capacity and durability.

Table 2 also illustrates the greater block strengths when cured at 95°C for 24 hours. In the case of the Kumasi soil compacted at 8 MN/m^2 and 16 MN/m^2 increasing the curing temperature to 95°C gave strengths of 4.85 MN/m^2 and 5.45 MN/m^2 while for the Fumesua soil, strengths of 4.45 MN/m^2 and 4.60 MN/m^2 were recorded. This effect of temperature on the strength-producing reaction between the lime and a soil goes some way therefore towards eliminating the main disadvantage of lime stabilisation which is its slow strength development compared to cement-stabilised soils. There is a good possibility therefore that even stronger blocks could be made if cured at higher temperatures but not too high to require expensive kilns or autoclaves.

Strengths of up to 40 MN/m^2 have been claimed for lime-stabilised lateritic soils thus making them comparable in strength to the higher quality fired clay bricks and concrete blocks, see Table 4. Unfortunately these strengths seem to require powerful and expensive presses which would be unsuitable for village self help schemes in the developing countries.

Durability
Table 3 records the ability of the lime-stabilised blocks to withstand a six hour water spray. This demonstrates the improvements in weathering resistance which can be achieved with lime-stabilised soil blocks made by simple mixing and curing techniques. Although not all soils would show similar improvements nevertheless the results were a useful means of comparing the effects of fabrication pressure on durability.

With the Cinva-Ram blocks and those made at 4 MN/m^2 pressure some surface damage occurred after spraying them for six hours. Deep pitting was evident where the water jets had struck the face of the block and elsewhere the surface had been roughened due to the water draining off, Figures 8 and 9. The blocks made at higher pressures did not show any signs of erosion, and the exposed surface retained the same smooth appearance as before the test, Figure 10. The performance of all these blocks was in complete contrast to that of the unstabilised blocks which disintegrated very quickly.

This improvement in performance obtained by adding lime to the soils has to some extent been confirmed by field trials carried out in Ghana in collaboration with the Building and Road Research Institute at Kumasi. After three years exposure to the weather, walls made with Cinva-Ram blocks have shown less erosion from rain than similar walls made from unstabilised soils, Figure 11.

Table 2 Properties of Ghanaian soil blocks stabilised with 6% lime

	Kumasi Blocks				Fumesua Blocks			
Compaction pressure (MN/m^2)	2 (Cinva-Ram)*	4	8	16	2 (Cinva-Ram)*	4	8	16
Water content of mix (Wt%)	20.0	19.0	16.0	13.0	17.0	16.0	14.0	13.0
28 day compressive strength (MN/m^2)	1.05	1.85	2.90	3.55	0.70	1.70	2.75	3.05
24 hr compressive strength—cured at 95°C (MN/m^2)			4.85	5.45			4.45	4.60
Water absorption (Wt%)	19.6	19.1	18.4	14.2	15.8	14.7	12.2	12.4
Dry density (Kg/dm^3)	1.51	1.74	1.82	1.84	1.75	1.79	1.86	1.93
Moisture movement (drying shrinkage percent of length)	0.16	0.11	0.06	0.04	0.13	0.07	0.05	0.03

*Compaction pressure obtained from load cell measurements

Table 3 Erosion of blocks

Block pressure	Appearance of blocks after water spray test	
	Kumasi Blocks	Fumesua Blocks
Cinva Ram (2 MN/m^2)	Deep pitting on test surface, some surface roughening, all blocks remained substantially intact	Pitting on exposed surface, some erosion at corners and edges. All blocks remained intact.
4 MN/m^2	Shallower pitting but not much different from above	Some surface roughening on test face
8 MN/m^2	No observed erosion, edges and corners retained sharp appearance	Identical to Kumasi blocks, all surfaces retained smooth appearance
16 MN/m^2	No observed erosion, surfaces smooth and dense	No observed erosion, identical to Kumasi blocks

Table 4 Range of properties of building bricks and blocks

Property	Calcium silicate bricks *	Fired clay bricks *	Concrete bricks (dense) *	Aerated concrete blocks (autoclaved)	Lightweight concrete blocks *	Stabilised soil blocks †
Wet compressive strength (MN/m^2)	10–55	10–60	7–50	2–6	2–20	1–40
Drying shrinkage (percent of length)	0.01–0.035	0.00–0.02	0.02–0.05	0.05–0.10	0.04–0.08	0.02–0.2
Thermal conductivity W/m°C	1.1–1.6	0.7–1.3	1.0–1.7	0.1–0.2	0.15–0.7	0.5–0.7
Durability under severe natural exposure	Good to moderate	Excellent to very poor	Good to poor	Good to moderate	Good to poor	Good to very poor
Properties affecting laying and plastering	Good	Good to poor	Good	Good	Good	Good to very poor
Density (Kg/dm^3)	1.6–2.1	1.4–2.4	1.7–2.2	0.4–0.9	0.6–1.6	1.5–1.9
Aesthetic value of surface†	Good but sensitive to dirt	Good	Poor	Good but sensitive to dirt	Normally rendered	Good to poor

†Properties are based on limited worldwide data of cement- and lime-stabilised soil blocks.
*Properties reproduced from Overseas Building Note 154. Calcium Silicate Bricks.

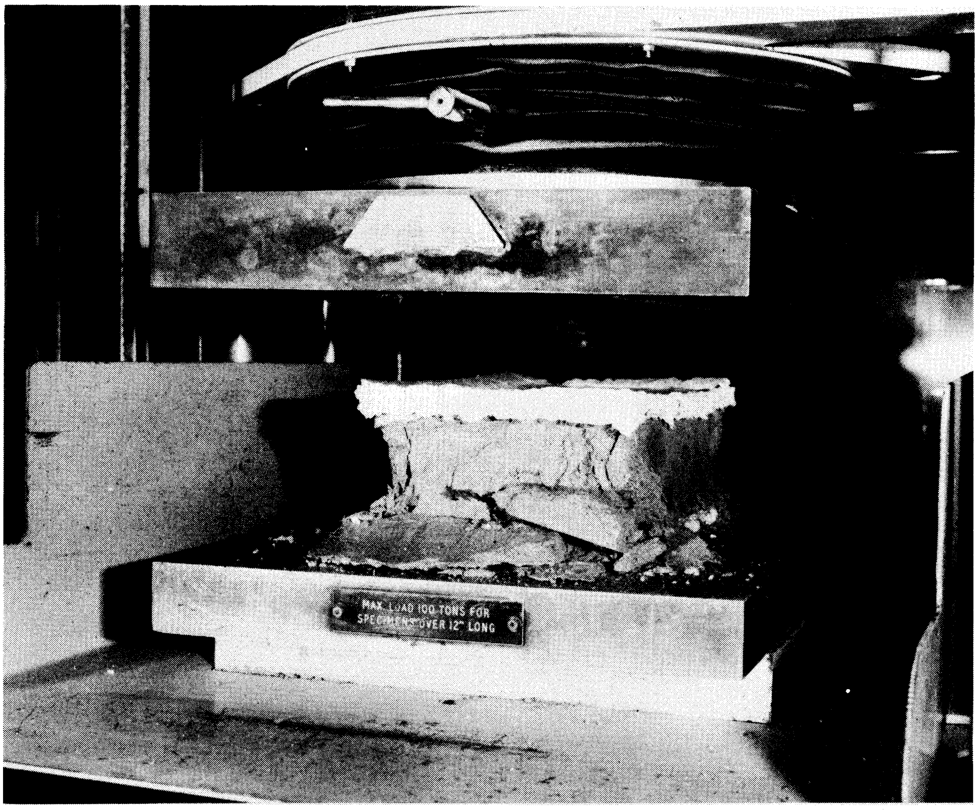

Figure 6 Block after strength test

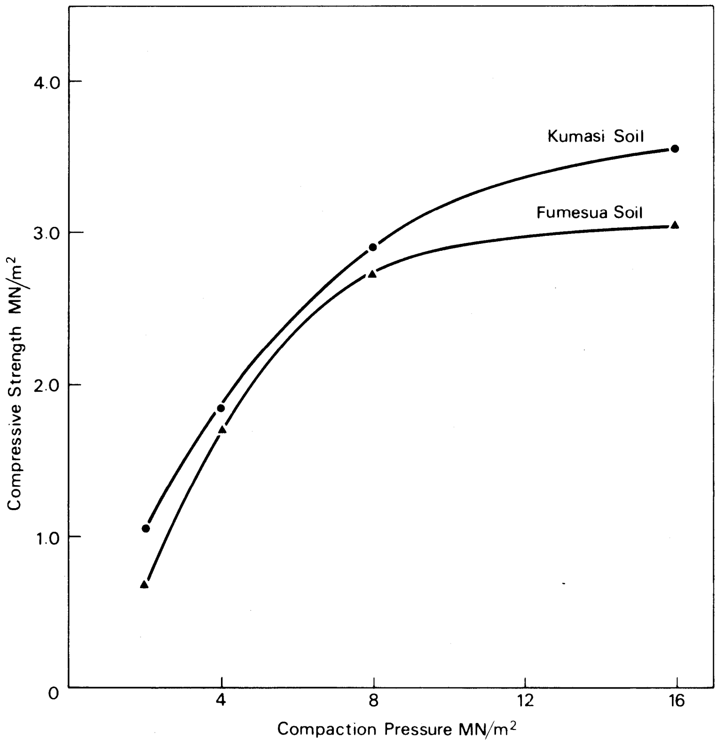

Figure 7 Strength-compaction pressure curves of lime-stabilised soil blocks

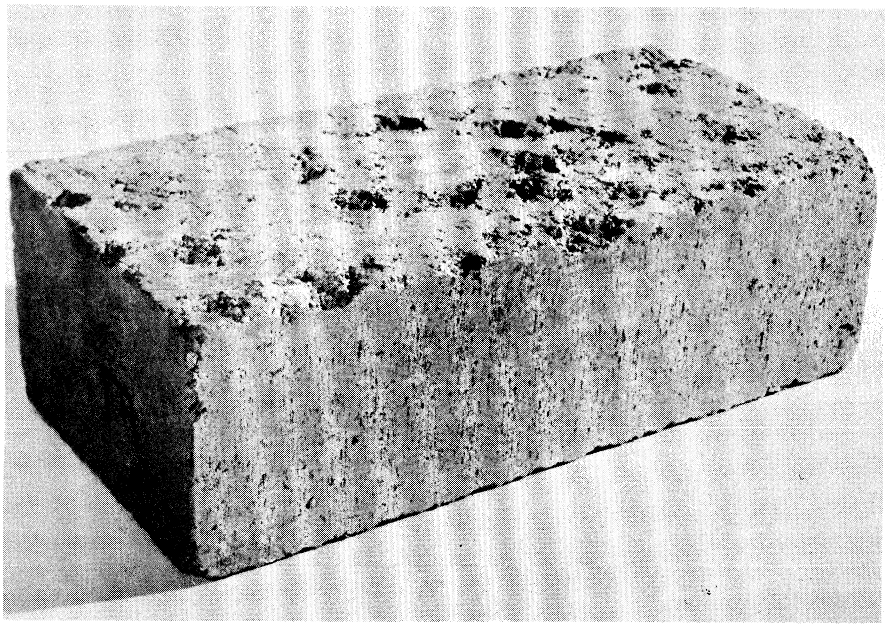

Figure 8 Effect of spray test on Cinva-Ram block made from lime-stabilised Kumasi soil

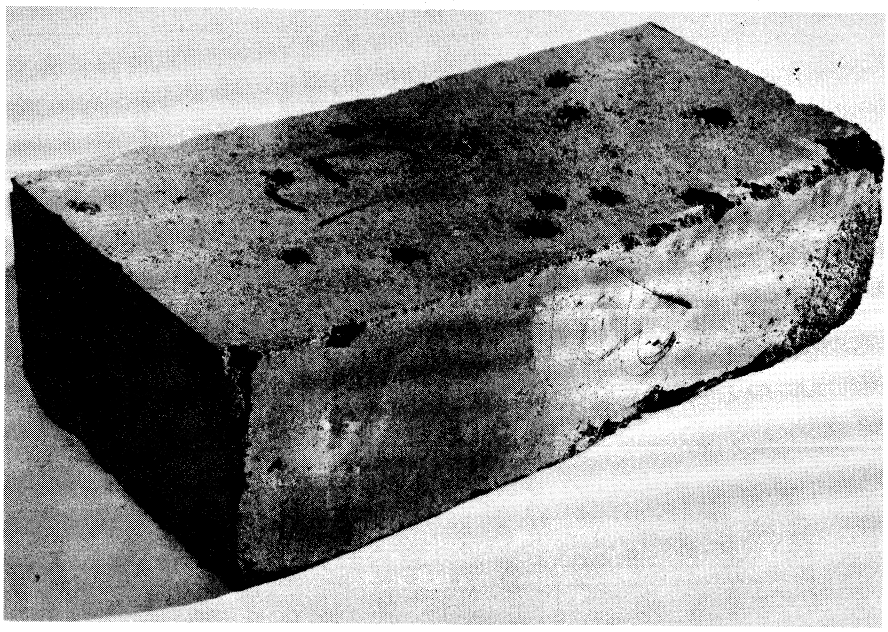

Figure 9 Effect of spray test on Cinva-Ram block made from lime-stabilised Fumesua soil

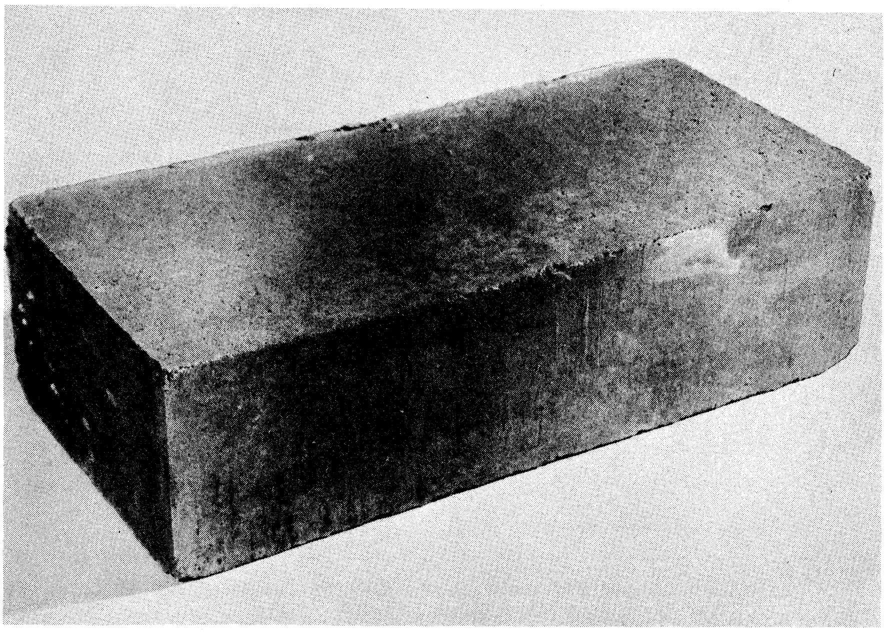

Figure 10 Effect of spray test on block made from lime stabilised Kumasi soil, compacted at 8 MN/m^2 pressure

Figure 11 Walls made from soil blocks, undergoing a weathering trial in Ghana

It is clear that for some soils, higher compaction pressures can reinforce the beneficial effects of stabilisers on weathering resistance. Stabilised soil blocks compacted in excess of 8 MN/m^2 should provide adequate performance especially when shielded from the rain by various design features such as generous roof overhangs and renderings along the lower courses of the walls.

Water absorption

The water absorption of the blocks made from the Ghanaian soils is shown in Table 2. The values are similar to those obtained for fired clay bricks—which have absorptions of about 1% to 30%. All of the Fumesua blocks, and those compacted with the Kumasi soil at 16 MN/m^2 are also comparable to calcium silicate bricks.

These blocks may not be suitable where low absorption and impermeability are essential but this fact does not preclude their use above damp proof course level. Moisture absorption is rarely specified in the UK except where limits are quoted for dense engineering bricks and dpc bricks as a precaution against frost damage[12]. Problems associated with frost are however unlikely to concern many people in the less developed countries.

The possibility of rain penetration through single skin walls always exists. In practice however when a wall permits the passage of rainwater it is seldom through the block or brick itself but rather through cracks in the joints. The more impervious the block therefore, the greater is the risk of rain penetration through the mortar joints. The range of densities from 1.5 Kg/dm^3 to 1.93 Kg/dm^3 quoted in Table 2 and those reported in Table 4 therefore shows that rain penetration of stabilised soil walls is no more of a problem than with any other wall material.

Drying shrinkage

The drying shrinkage of the blocks presented in Table 2 shows that in common with many other building products they are sensitive to changes of moisture content. However with the exception of the manually pressed blocks their drying shrinkages of 0.16% to 0.03% are not excessive compared to some types of calcium silicate bricks or concrete blocks, Table 4. The UK standard BS 2028[8] specifies a maximum drying shrinkage of 0.05% for precast concrete blocks designated for general use. Similar specifications based on this standard have therefore been suggested also for stabilised soil blocks[6]. However these specifications may be too restrictive for soils and a higher limit may have to be tolerated.

CONCLUDING REMARKS

Stabilised soil can be an extremely useful building material for developing countries, provided that an adequate programme of testing is carried out on the raw material.

Soil may be stabilised with cement or with other binders. The experiments carried out at BRE have demonstrated the improvements in strength and durability that can be achieved when lime is used to stabilise tropical lateritic soils.

Blocks suitable for low-cost housing can be produced using a simple press, and many types are available. Improved performance can be achieved by increasing the compaction pressure although the degree of improvement diminishes as this pressure is increased. It is suggested that presses operating in the range 8 to 16 MN/m^2 could give satisfactory and economical results and there is a need for a simple and transportable machine of this type to be developed. With such a machine and with careful selection of materials, soil blocks can be produced which have similar physical properties to some other walling materials, and have the attractive appearance of fired clay bricks. These blocks can be used to build inexpensive durable houses in many parts of the developing world.

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