STABILISED SOIL BUILDING BLOCKS

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Thesis submitted to the

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by

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ABSTRACT

TITLE: STABILISED SOIL BUILDING BLOCKS

Many countries in the Third World are faced with the grave problem of providing adequate housing in sufficient quantity at a low cost in line with their economies and the resources of the people.

From early ages soil has been used as a major building material for low cost dwellings and more recently, by using cement or lime as a soil stabiliser, reasonable building blocks have been produced.

These blocks have been produced using a relatively low compacting pressure and have proved to be of limited satisfaction. Stabilised blocks are weak in the 'wet state' after demoulding, and prone to damage whilst 'green'; however, after controlled curing, the undamaged blocks are generally usable. From experience it has been observed that the lime stabilised blocks deteriorate rapidly in a hot/wet climate whereas there is hardly any deterioration in a hot/dry climate.

Manually operated block making machines have used a compacting pressure of around 2 MN/m^2 and research has demonstrated that with a machine operating with a compacting pressure of 10 MN/m^2 good quality, durable stabilised soil building elements could be produced.

The thesis includes:

(1) A survey of existing stabilised soil block machines, pointing out the qualities of each machine and the product sizes etc.

(2) A critical review of the research and development work required to formulate the design specifications for an improved block press machine covering the chemical, mechanical and mix design aspects.

The existing CINVA RAM manually operated press, which produces blocks measuring 290 x 140 x 100mm, has been used to obtain the initial data required to start this project at Building Research Station.

(3) Design of an improved press for block making.

(4) A report of field trials in various Third World countries relating to the suitability of a new type of hydraulically assisted manually operated press.

All the initial laboratory work has been conducted at the Building Research Station. Practical site trial investigations have been conducted in numerous Third World countries. The complete study has been funded by the Overseas Development Administration as part of the United Kingdom's technical co-operation programme with developing countries.

The above work forms part of the current research programme that is being conducted at BRS specifically for Third World countries and has benefitted from co-operation with the faculty of Arts at the University of Newcastle-upon-Tyne.

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CHAPTER 1

INTRODUCTION

1.1 Purpose and objectives

The work set out in this thesis broadly comprises three self contained but related parts. The first part is contained in Chapter 2 - 'Types of Soil Houses', which describes the development of the soil and introduces machine formed bricks and blocks. Chapter 3 - 'Soil Selection for Building Products' - describes the various types of soil which can be used for the manufacture of stabilised soil blocks, and Chapter 4 - 'Soil Stabilisation' - which describes the various principles and methods available.

The second part contained in Chapter 5: 'A Review and Appraisal of Recent Research' sets out the preliminary research work conducted at the Building Research Station, together with some overseas trials, and some proposals for developing a new type of block making machine. The third part is contained in Chapter 6 - 'World Survey of soil block making equipment', Chapter 7 - 'A new type of Block Making Machine', Chapter 8 - 'Results of Field Trials', Chapter 9 - 'Soil Block Curing and Testing' and Chapter 10 - 'Economic Considerations'. It describes the concept, design, development and appraisal of a new type of manually operated machine capable of producing superior grade stabilised soil blocks to those hitherto produced in the past.

1.2 Historical Review and Modern Trends

Since time immemorial, man's basic need after food for survival and clothing for protection, has always been to shelter his family from the elements. However in these early ages, nature provided shelter in the form of caves and in flat areas of the world man dug holes in the ground and constructed a simple form of roof over the hole to provide a basic form of shelter.

Primitive man soon realised that a better form of shelter could be built above ground level and early forms of wall construction led to the use of stone, earth or turves piled one upon another. He slowly acquired, by practical experience, a knowledge of building technology, and the need for stability by strutting or buttressing a wall.

After the development of simple cutting tools, stone was the most favoured material for construction purposes in these early ages and proof has been uncovered by archaeologists in Egypt where stone buildings have been uncovered dating from c 3000 BC or earlier, however stonework construction in Egypt was reserved almost entirely for palaces, temples, tombs and monuments.

In the Bible the families of Noah travelled from the east and found a plain in the land of Shinar and they dwelt there. Book of Genesis, Chapter XI states that: 'and they said unto one another. 'Go to, let us make brick from clay, and burn them thoroughly. And they had brick for stone, and slime had they for mortar'. In this context slime refers to bitumen because archaeologists have uncovered some of these early buildings and therefore irrefutable evidence exists that bitumen was

used as a building material mixed with soil or sand to form a waterproof mortar.

The idea of stabilising soils with various admixtures for construction purposes is not new. Several thousand years ago the Romans stabilised road bases with hydrated lime and these appear to have given outstanding service as reported to a Conference on Soil Stabilisation by Woods and Yoder in 1952 (1).

The children of Israel made mud bricks for the Egyptians at the time of Moses. At Chan-Chan, Peru there is an elaborate structure of earth believed by some archaeologists to be of an age comparable to that of the biblical civilisation excavated in Mesopotamia. Many other early types of earth construction are cited in the publication Earth for Homes prepared by the United States Department of Housing and Urban Development in 1955 (2).

It is well documented that over the ages people have lived in houses made of some form of dried mud, and even today it has been estimated that over half of the people of the world still live in houses constructed of earth. With few exceptions, there has been little improvement in the quality of the mud bricks used in the construction of houses or in construction design and techniques. Historically, in wet regions of the world traditional unstabilised earth structures have to periodically be maintained or even rebuilt. Other naturally occurring hazards such as earthquakes and hurricanes cause destruction of houses built of unstabilised soil and more importantly have been responsible for the death of many thousands of people as well as millions of pounds in damage.

Decisions taken by governments to construct new engineering projects will also affect the life style of people living in the rural areas, for example in 1924 the Volta River project was first suggested in Ghana.

After many discussions, this project was started in 1961, which involved the construction of a 60 metre height dam at Akosombo on the Volta river and caused the flooding of some 800 hectares of land and some 80,000 people had to be resettled. The dam was inaugurated in 1966 for the production of hydroelectric power and the power station constructed on this site now provides over 90 per cent of Ghana's electrical power needs.

During the early 1960's over 50 new townships had to be created and by the end of 1964 over 11,000 earthen houses had been constructed with a weekly maximum of some 300 houses being built. Each house consisted of a core room of 15 square metres with a surrounding open verandah area. The majority of soil blocks used for walling construction were made on a Landcrete machine (See section 6.2.15) from a mixture of lateritic soil - See section 3.3.3, cement and cow dung.

The Volta Resettlement Authority were responsible for the rehousing programme and can well be proud of the tremendous achievement that took place in Ghana during the early 1960's.

During the last 30 years engineers and architects have realised that by applying modern technology methods to the treatment of a clay soil by stabilising it could produce good quality durable building products.

Mud may be the only answer to one of the most troublesome questions facing the world today; how to build the half a billion new houses that

developing nations will require between now and the end of the twentieth century.

'Mud, mud, glorius mud, nothing quite like it for cooling the blood!' is a song written by Michael Flanders which brings to light the thoughts of people.

An Earthscan Publication in 1981 entitled Mud, Mud by Anil Agarwal (3) illustrates quite ably the thoughts of the United Nations Centre for Human Settlements (HABITAT) by stating that housing may be the Third World's most intractable problem.

Until the reality of the energy crisis began to bite in the mid 1970's government leaders, architects and peasants all assumed that houses should be built with high proportions of cement, 770 million tonnes of which were produced around the world in 1974-75. Since this date, presidents and peasants alike have become disillusioned with cement. Its production is expensive, both in capital and energy; it consumes ever scarcer natural resources; and it results in houses not suited to many Third World climates.

'The widespread addiction to cement and tin roofs is a kind of mental paralysis', wrote Tanzanian President Julius Nyerere in 1977. 'We are still thinking in terms of international standards instead of what we can afford to do ourselves'.

Prime Minister Indira Gandhi of India, where more than half the houses are built of mud, noted in a 1980 interview that she was born in an ancient mud house which still stands today.

Jomo Kenyatta - 'The father of Kenya', the son of a poor farmer, was born in 1889, in a typical African style earth house. His daughter, Margaret Kenyatta, whom I met in 1981, lives in an earth ro ndavel house in the village of Kabiro in Kenya. This lady informed me that she did not like living in a concrete structure because it was cold in the winter and hot during the summer, she much preferred the circular house constructed of earth and indicated that more people should build their own houses from earth.

Egyptian architect Hasan Fathy tells of the cement villages thrown up to rehouse people as the Aswan High Dam was built: 'The low roofs in the blazing desert turned those stone and cement houses into ovens and reports poured in of increased infant mortality'. Hassan Fathy firmly believes that it is possible to resolve the seemingly overwhelming problem of rehousing the world's poor and his publication Architecture for the Poor (4) published in 1973 was originally published in 1969 under the title of Gourna: A Tale of Two Cities. This publication reports on a practical housing experiment conducted in rural Egypt using local indigenous materials.

Therefore the problem of the world's poor in developing countries who live in mud housing and of their children who will soon want houses was best put by the Hindi newspaper Nai Duniya in India. 'How concrete structures can be strengthened by steel is well documented by engineers, but how mud walling can be strengthened by bamboo is a subject that only those villagers know who suffer from floods every year'.

Looking to the future was the theme of the United Nations Conference on Human Settlements held in Vancouver in 1976 (5); where it was reported that the world's population could be expected to double between 1975 and

the end of the century, and to quadruple by the year 2030. This represents the largest population growth in history, and some fear that today's crisis could well become tomorrow's global catastrophe.

CHAPTER 2

TYPES OF SOIL HOUSES

2.1 Development of soil houses

Since time immemorial man has needed to shelter his family from the elements and in the early ages caves satisfied the need in some areas but in other areas man had to construct simple protective shelters.

In its simplest form the shelter consisted of walls made by placing poles into the ground and weaving between them grass or creepers and laying branches or foliage across the top of the walls to act as a roof, referred to as a roof only starter home.

As added protection, mud was thrown on the outside of the walls and allowed to dry. In fact this method of house building is still used today in all parts of the world and is generally referred to as wattle and daub.

Throughout the ages man has endeavoured to improve the construction of his home within the limitations of minimum income and his natural environment. Soil, being one of the most readily available materials near at hand, was and is widely used for building and five accepted methods of wall construction have evolved through the ages which have stood the test of time.

These are:

2.2 Rammed soil

2.3 Cob

2.4 Wattle and Daub

2.5 Adobe

2.6 Machine made blocks and bricks

2.2 Rammed Soil

By far, the oldest known method of soil wall construction is the rammed soil method (pise de terra).

'Pise': French noun first appearing in Lyon in the 16th Century. Origin: the Latin verb 'pisare' meaning 'to pound'. appearing in many foreign languages including English as 'pise de terre'.

A mixture of sandy clay soil and water of a slightly moist consistency to form a cohesive mix is heaped up and tamped by hand to ensure that the mass of soil is well compacted to produce a soil wall. This method is easily adapted to produce continuous lengths of walling.

To construct a rammed soil wall which has a pleasant smooth appearance on both faces, heavy timber boards have been employed in a shuttering position on each side of the wall. A soil mix is then compacted within the shuttering and after a section of wall has been completed the shuttering can be moved to a new position either sideways or vertically so as to repeat the operation.

The best result obtained by this method is to use soil of varying particle sizes, from very fine to fairly coarse, thus induced stresses developed within a wall are controlled and shrinkage problems are reduced by the homogeneous construction. The strength of a rammed soil wall can be increased by reinforcing the wall with straw, tree branches, plant fibres or hair.

However man has discovered that soil homes last longer in dry arid areas than those constructed in wet tropical zones because a rammed soil wall will be quickly eroded away when water is applied to the surface. It is therefore necessary to protect a rammed soil wall by the application of an external rendering coat of a suitable material that is impervious to the elements.

An example of a rammed soil wall which was being constructed in Kenya in 1980 is shown on Plate 1. This particular wall formed a circular home and had a surface protective layer of cement plaster applied at each layer of rammed soil.

Mohammed A Osman in his paper entitled Laboratory Test Results on Stabilised Soils and Field Studies on Rammed Earth Walls in the Sudan (6) highlights the problem of applying protective weathering coats to rammed earthern walling. It was in 1965 that the Sudanese Building and Road Research Institute (BRRI) Khartoum introduced scientific monitoring of building with rammed earth. Following a detailed research programme they reached a conclusion that when a soil is treated with a stabilising agent for example cement, hydrated or quick lime the soil index properties will change including the optimum moisture content and dry density.

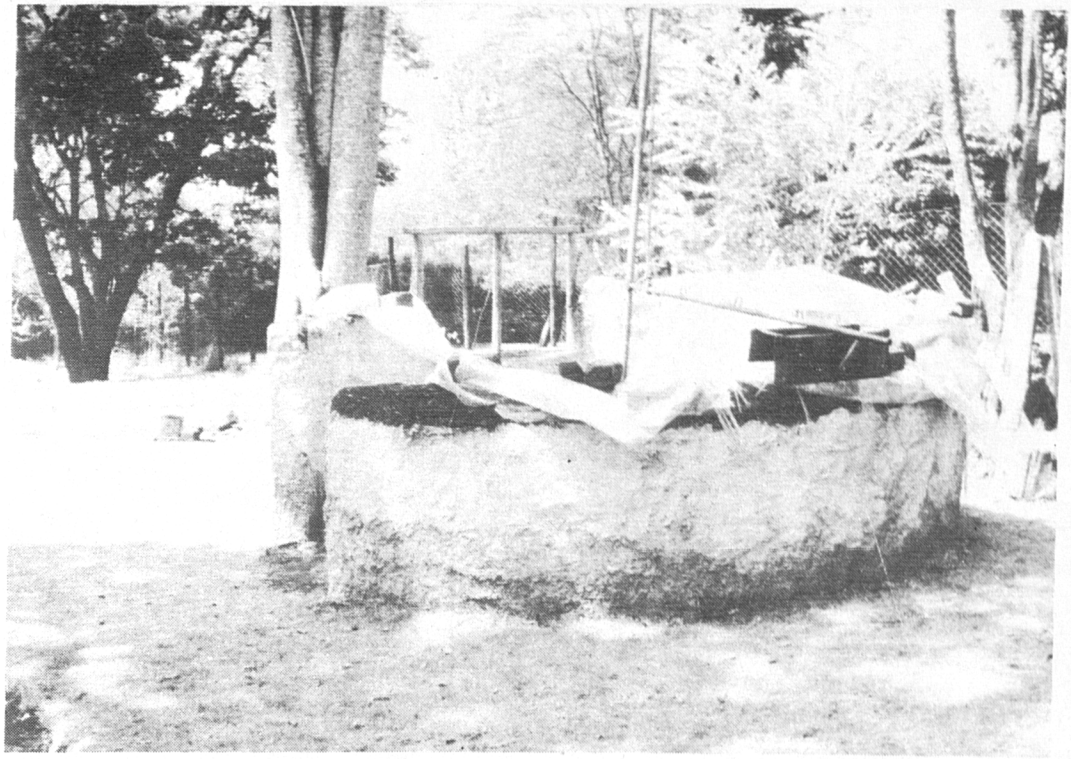


Plate 1 Rammed earth wall forming a circular house

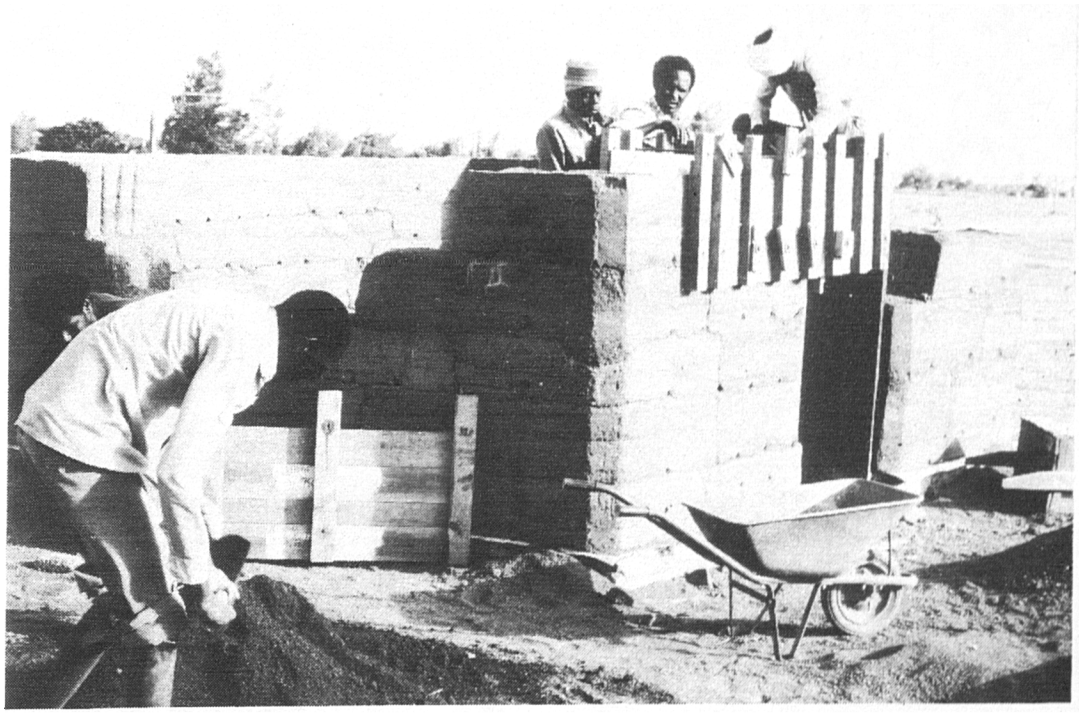


Plate 2 Experimental rammed earth walling in the Sudan

This limited research does not support the use of stabilising soils in rammed earth construction. Time studies have also indicated that the use of raw untreated soils is much quicker, more economic and simpler in rammed earth construction than using stabilised soil.

Plate 2 shows an experimental rammed earthen wall being constructed in the Sudan.

2.3 Cob

This method of wall construction is an extension of the rammed soil technique and the name COB originates from the West of England. Cleam, Clob or Clom are also local names given to the method of Cob construction. In Ghana 'Swish' is the name given to this method of soil wall construction.

The COB method involves mixing soil and small quantities of straw together before the mix is moistened, to a stiff cohesive mud consistency and then shaped into blocks or balls by hand.

These shapes are then piled on top of one another to form a wall of about 150 to 200mm thickness, any pockets being filled with moistened soil or chalk to act as a mortar filler. If any of the moulded shapes protrude from the external line of the wall they are pared away by hand tools. This type of wall has to be constructed slowly so that each one or two layers is allowed to harden off or cure before further layers can be added.

The only real advantage with this method of construction is that minimum hand tools are needed and the method can be used by unskilled labour.

One major disadvantage however is that serious settlement cracks occur as the wall dries out followed by shrinkage cracking because of the inconsistent density of the constructed wall.

When this type of wall has dried out it is usual practice to apply a final external protective coating consisting of animal dung mixed with soil or a more expensive coating of sand and cement. In some parts of Africa, for example, external thatching is often applied to provide extra protection against the elements and will help prevent the formation of fungus on the external earthen face of the building.

2.4 Wattle and Daub

This method of earth wall construction has been used extensively throughout third world countries because it combines the better aspects of both rammed soil and cob construction techniques.

It consists of first erecting a vertical framework of durable timber posts and poles, with the uprights being driven into the ground surface to improve the stability of building.

Thin branches, twigs or reeds are then interwoven into the vertical framework to form a close knitted surface which is plastered or 'chinked' with mud. The mud plaster is usually applied to both faces of the interwoven framework wall and this results in a single skin wall.

If the wall has to be made thicker to improve the internal thermal comfort of the inhabitants, a double thickness framework is first erected and the space between the two frames is filled with the mud plaster at the same time as the internal and external daubing is being

applied. Plates 3 and 4 show two different types of this form of construction in Kenya. This type of wall construction needs constant maintenance because after the mud plaster dries out, many shrinkage cracks will occur and often areas of wall will drop away from the main structure during the rainy season.

Another problem is that the timber used for the framework will often be prone to attack by termites, and those poles imbedded into the ground will soon rot away.

It is therefore again desirable to apply an external protective skin of animal dung mixed with mud or a sand cement rendering but in many instances this treatment is too costly for the family living in the house and it is cheaper to apply a coat of heavy lime wash.

2.5 Adobe

The modern definition of Adobe is a sun-dried brick or block. The name originated in Spain or the Mexican/Californian area of the United States of America, but the method of making the bricks is very ancient, dating back to the construction in Egypt of the 1st Dynasty tomb at Saqqara c 3000 BC; ruins of a complete village at Daeir-el-Medineh c 1600 BC; vaulted storehouses and administrative offices of the Ramasseum of Rameses II c 1300 BC; and an Adobe block pylon of the Temple of Montuemhat c 650 BC.

Plate 3 Circular house using wattle and daub

Plate 4 Rectangular house using wattle and daub

These historical facts together with the properties of adobe bricks were reported in the June 1981 issue of the 'New Scientist' publication pp 678-681 by Dr Ken Games, University of Liverpool(7).

In this method wet mud is slopped into a simple mould compacted and levelled by hand, usually the mould is removed straight away from the formed mud block. Generally the mud or adobe blocks are allowed to atmospherically sun dry or 'cure' for a period of about four weeks before they can be used in the construction of an earth wall.

Slop moulding is the term generally used for this method of brick or block manufacture. Due to the high water content of the original mix, the resultant brick will shrink as it is drying out and is more likely to become distorted which causes further cracking during construction.

An adobe type construction, in Egypt, is shown on Plate 5 with blocks being sun dried in the foreground.

Another type of block or brick manufacture under the general heading of Adobe is referred to as Sand-Moulding. In this case the wetted mud or clay is first rolled in fine clay, or, alternatively sand may be sprinkled around the faces of a dampened mould box. A quantity of mix is then slopped into the mould and any excess mix cut away from the mould by a taut wire. The layer of sand between the mix and mould acts as a release agent by preventing the wet mix from adhering to the mould sides. Demoulding usually means that the mould has to be tapped to ease the brick away from the mould walls before separation is achieved.

In this method the original mix does not need to be as wet and slippery as in the slop moulding technique so several advantages are gained: with

a lower water content the drying or curing period is reduced; more dense bricks are produced which are more durable and less shrinkage cracks occur; and finally the bricks have a more uniform shape which makes building a wall easier.

The main disadvantage of sand-moulding is that the sand has to be obtained involving extra costs and is also another material for the operator to handle.

This method of sand moulding produces the 'Kimberley Brick' which is the name adopted in South Africa to describe a sun dried brick similar to adobe.

Paul McHenry, an American architect, who for the last 25 years has been studying, designing and restoring adobe structures is probably one of the world's foremost experts in this form of earth building technique.

McHenry has been instrumental in the growing world-wide recognition of Adobe as an economical building material as claimed by Shannon A Horst, (staff writer of The Christian Science Monitor) in his papers entitled 'New look at a centuries-old building material' (8) and 'Humble Blocks have a grand potential to house world's poor' (9). McHenry is convinced that 'people just don't have any choice' but to use adobe in meeting low-cost housing needs and is quoted as saying that adobe structures last for centuries. The Taos Pueblo, the oldest continuously inhabited structure in the USA was built more than 900 years ago.

Paul McHenry and Robert Gross (American Engineer) have recently developed mobile equipment to produce adobe blocks and this machine called the 'Terrablock' is described in Section 6.2.29.

2.6 Machine made block and brick housing

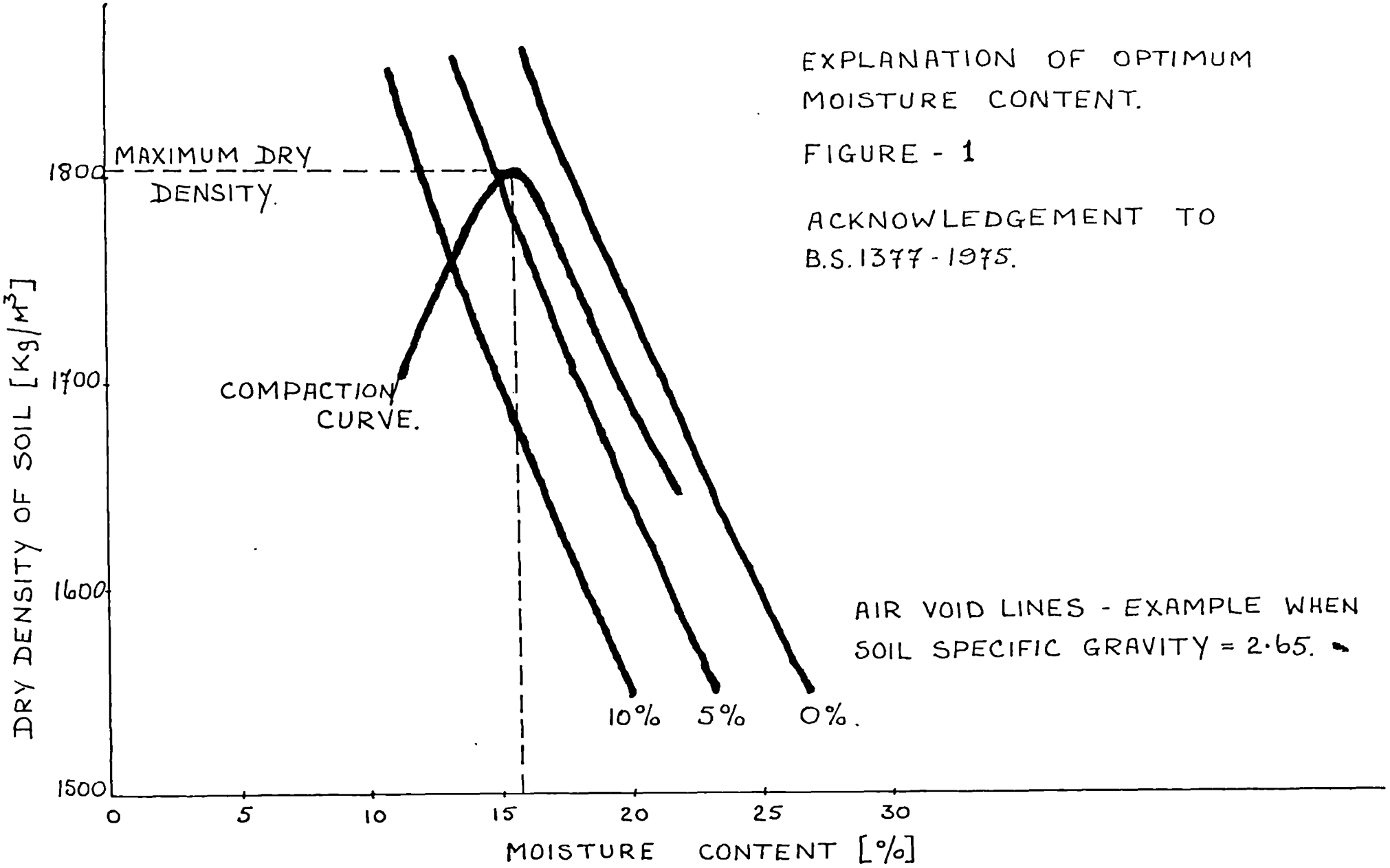
The method of producing soil blocks or bricks by machine is a relatively modern method when compared with the Adobe method of block or brick production.

A machine will provide a uniform compacting pressure on a soil mix contained in a mould and using mechanical methods of compaction higher density products will result. It is a known fact that mechanical ramming will compact a moistened soil mix from two to four times the amount obtained by manual ramming.

However, using higher compacting forces in a machine, will increase the capital cost of the machine and the economics must be evaluated when using a machine made block or brick.

To manufacture a good quality durable soil building block it is advisable to use a minimum quantity of water with the original soil mix. It has been proven that the best density results are obtained when the optimum moisture content (O.M.C.) for a particular soil is used. See Section 3.3.5 and Figure 1 illustrates the O.M.C. for a soil sample.

There are several methods available that could be used to compact soil mixes and these are by direct continuous pressure, impact loading and external vibration coupled with a light continuous pressure. All three methods of mechanical compaction have been used but due to economical considerations manufacturers of block making machines favour the direct continuous pressure method.



EXPLANATION OF OPTIMUM MOISTURE CONTENT.

FIGURE - 1

ACKNOWLEDGEMENT TO B.S.1377 - 1975.

AIR VOID LINES - EXAMPLE WHEN SOIL SPECIFIC GRAVITY = 2·65.

Using a simple, inexpensive manually operated block making machine with mechanical linkages incorporated to increase the manual effort exerted, a relatively high direct continuous pressure can be applied to a soil mix contained within a mould. The soil blocks produced by this method have many advantages over the other methods of block production already discussed.

Durability is improved as a direct result of the increased density; higher block compressive strengths are achieved and a more uniform dimensional acccuracy block obtained which assists the final laying of the blocks to form a wall.

Another advantage is that if suitable stabilisers or chemical admixtures were added to the original soil mix, higher compressive block strengths would be developed and on final construction of a wall no external protective rendering coat would be needed.

One major disadvantage in this type of block production is that the operatives need intial training in selecting the correct soil and using the correct type and quantity of stabiliser, however, if a training programme is implemented, machine produced soil blocks would improve the efficiency in all respects for low cost housing in the third world.

An interesting research project is currently being conducted by the Housing Research and Development Unit of the University of Nairobi in Kenya using unstabilised machine made blocks.

Red Coffee soil is being mixed with about 12 per cent water and compressed in a simple manually operated block making machine at 2 MN/m^2 to form the blocks which are atmospherically cured. The

blocks are atmospherically cured and laid dry, without a mortar joint, but have lengths of sisal fibre distributed over the horizontal block jointing hanging down the inside and outside of the wall.

The quantity of sisal fibre used is 500 gram of sisal fibre, cut into 600mm lengths, per square metre of walling. Each face of the wall receives three separate coats of cement rendering. This technique is illustrated on Plate 6.

Field trials using this method are being conducted by The Katangi Agricultural Project of the Undugu Society of Kenya.

One major problem has emerged from this research work being that the external three coats of cement rendering having little or no shrinkage movement which does not allow for the large moisture shrinkage movement of the compacted soil wall. Uneven stresses have been generated between the surfaces which build up and cause cracking of the external cement rendering as illustrated on a demonstration building (Plate 7). This external cracking showed itself after about one year of the building being completed.

Once the external cracks have appeared maintenance is needed to prevent the ingress of water which would ultimately cause building failure.

2.7 Health Standards of Earthen Housing

The four traditional methods of building with earth mentioned earlier in this chapter all have one common fault - that is shrinkage cracks occur in the walls and floors.

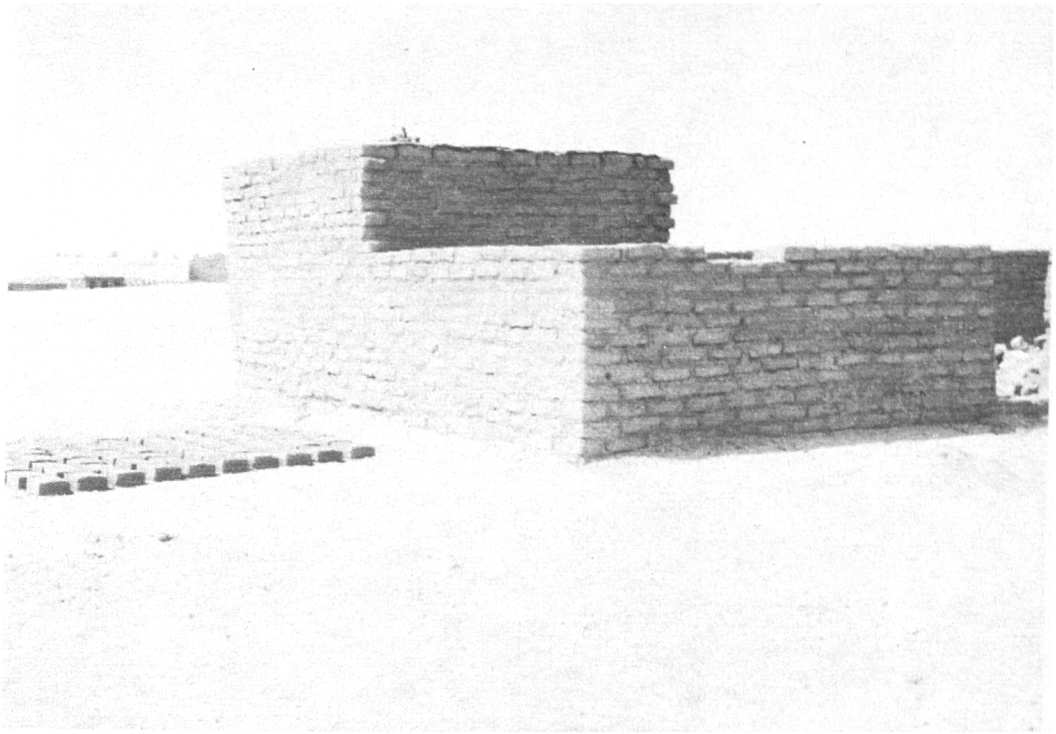


Plate 5 Adobe construction in Egypt

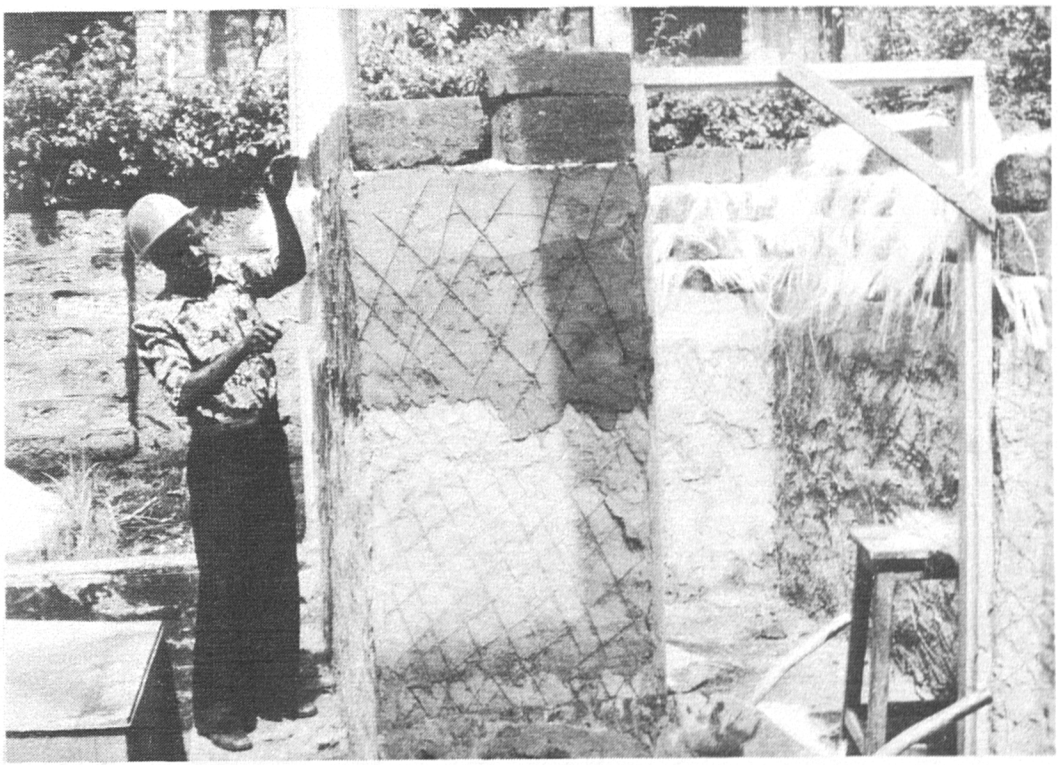


Plate 6 Machine made block construction with sisal fibre in Kenya

The cracks in the earthen floors provide breeding grounds for argasid tick vectors of rickettisial relapsing fevers. Cracks in earthen walls provide breeding sites for bedbugs and triatomine bug vectors of South American Trypanosomiasis. Cockroaches and fleas flourish in the shaded crevices of earthen floors and walls and mosquito vectors of malaria rest on the cool mud surfaces inside earthen houses. One important consideration is health standards of people living in earth constructed dwellings. It was in 1983 that The London School of Hygiene and Tropical Medicine (LSHTM) approached the author with a view to conducting trials on the treatment of stabilised soil blocks to minimise the spread of insect disease carrying vectors. The wattle and daub house illustrated on plate 3 gives a very good example of linear shrinkage cracking where parasite vectors could breed.

In Africa for instance, the female anopheline mosquito is responsible for spreading malaria to an estimated incidence of 150 million new cases each year. As reported by the World Health Organisation in 1980 (10) about 1.25 million deaths per year and some 215 million people are chronically affected in 107 countries by malaria.

The South American triatomine bug vector plate 8 is reported to have infected more than 10 million people annually (10) with Chagas disease and caused some 2 million deaths.

The triatomine bug that transmits Chagas disease are blocksucking vectors which normally live in cracks in walls and earth floors. They feed at night and leave droppings containing parasites. These enter the body through the skin or eye, initially causing an acute fever from which about 10 per cent of sufferers die. Those who recover, continue to carry the parasites, which slowly destroy most of the vital organs in

Plate 7 Cracking of cement rendering on a building constructed from unstabilised soil blocks and sisal fibre

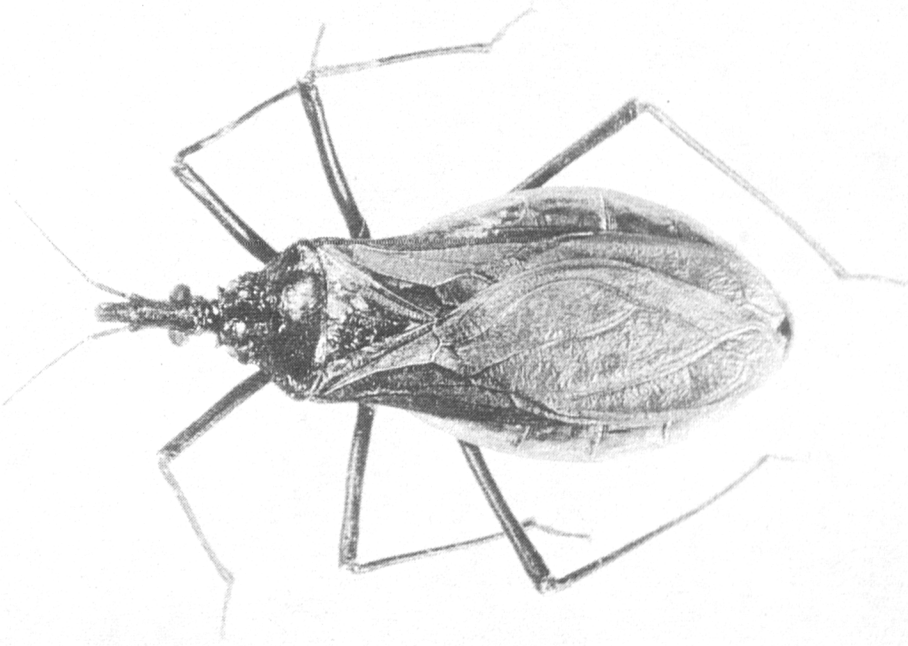


Plate 8 Triatomine bug vector which causes Chagas disease

the body, especially the heart and gut. Many people will die because of heart failure or respiratory collapse.

About 25 million Latin Americans living in earthen constructed dwellings suffer from this debilitating disease. The prescribed drugs are seldom used as a treatment because they are dangerous causing many side effects and expensive.

Bishop in 1983 (11) highlighted the fact that improvements to earthen constructed buildings would have untold benefits for the people living in them. Dr C J Schofield, Department of Entomology, LSHTM a world authority on Chagas disease (12,13), has demonstrated that plastering the walls of a mud brick house in Brazil completely eliminated domestic infestation of Triatoma infestans.

If a suitable machine could be developed that could produce good quality soil building blocks which do not crack then this would assist in raising the health standards of people living in earth constructed buildings.

The author visited the headquarters of the World Health Organisation (WHO) in Geneva, Switzerland during 1985 to discuss the present status of vector control in low-cost housing. In all regions, vector control is largely being achieved through the use of chemical pesticides, with the organochlorine insecticides still playing an important role. Some vector control programmes involving the use of residual insecticides for indoor house spraying, are becoming difficult to manage, owing to opposition by the inhabitants and, in some areas, to diminishing levels of supervision of spraying. The increasing number of cases of insecticide resistance and refactory vector behaviour, the high cost and

increased toxicity of many of the alternative insecticides, and opposition by environmentalists to their use, are additional problems facing pesticide-based programmes. A gradual shift is therefore evident towards reshaping the future policy of vector control within low-cost housing by environmental management and introduction of improved methods of building construction.

It was proposed that a new research project be investigated in the field of improved building construction using good quality stabilised soil blocks. If such a project was initiated at the Building Research Station, WHO would certainly support such an initiative - See Section 11.3.

CHAPTER 3

SOIL SELECTION FOR BUILDING PRODUCTS

3.1 Soil as a Raw Material

Soil or Earth is generally defined as the uppermost layer of the earths crust, consisting of disintegrated rock usually with admixtures of organic remains.

The creation of soil is a continuous and very slow process taking thousands sometimes millions of years. But soil is more than just rock particles, it does not exist without life. Millions of small animals, fungi and microscopic bacteria live in it, breaking down dead and decaying plants and animals.

The decomposition of the earth's surface is caused by four naturally occurring processes - physical weathering - chemical weathering, organic weathering and mechanical disintegration.

Physical weathering is caused by differing climatic conditions, wind and water erosion, freezing and thawing, thermal stresses due to large changes of temperature and friction caused by the earths movement. Chemical weathering follows on from physical weathering where different chemicals within the earths crust are brought together by moisture movement. The reaction of water with the rock minerals, and the atmospheric oxidation in the case of rocks rich in iron oxide.

Organic weathering occurs where bacteria and plant life being activated by moisture causes disintegration of soil particles. Mechanical

disintegration takes place when physical movements are occurring for example during an earthquake, the movement of a river when particles are moved by physical force or similarly by wave action, glacial movements or wind movements.

Accordingly soils are composed of a variety of particle sizes dependent on the soil formation and must greatly vary in chemical composition.

Soil however, is abundant and cheap to obtain and provided it is used in the correct manner can be an excellent building material. If used incorrectly it has inherent failings because a building material must be capable of withstanding the elements. If the soil is not protected, erosion will occur. The best way to prevent this happening is to cement the soil particles together with an admixture and this method is referred to as soil stabilisation.

Not all soils can be used successfully for earth or soil houses due to their differing chemical constituents as the cost of using a high percentage of stabiliser to withstand the elements would be too high.

Certain types of soil would give good results in any type of climate provided that the soil particles are cemented together with the correct grade and quantity of selected stabiliser.

3.2 Types of soil

Soils in general possess a granular skeleton of coarse angular particles, filled out and bound together with clay and fine silts.

A soil sample can be separated into its constituent parts by various methods, the most popular being by mechanical analysis (sieving) or sedimentation.

If the sieving method is used the test sieves employed should conform to British Standard 410: 1969 (14) and BS 1377: 1975 (15) which details the classification of the constituent parts of a soil sample as shown in Table 1

TABLE 1 - SOIL CLASSIFICATION

Constituent Part	Size Range	BS test sieve	Fraction
Coarse Gravel	60mm to 20mm	63mm to 20mm	GRAVEL
Medium Gravel	20mm to 6mm	20mm to 6.3mm	FRACTION
Fine Gravel	6mm to 2mm	6.3mm to 2mm	
Coarse Sand	2.0mm to 0.6mm	2.0mm to 600um	SAND
Medium Sand	0.6mm to 0.2mm	600um to 212um	FRACTION
Fine Sand	0.2mm to 0.06mm	212um to 63um	
Coarse Silt	0.06mm to 0.02mm		SILT
Medium Silt	0.02mm to 0.006mm		FRACTION
Fine Silt	0.006mm to 0.002mm		

The gravel fraction is defined as that portion of a soil sample which passes the 60mm sieve and is retained on the 2mm sieve. The sand fraction of a soil sample is defined as that portion which passes the 2mm sieve and is retained on the 0.06mm or 63 micron sieve. The silt fraction of a soil sample is defined as that portion which passes the 63 micron sieve and is retained on the 0.002mm or 2 micron sieve.

The clay fraction of a soil sample is defined as that portion which passes the 2 micron sieve and is of major importance in the study of soil stabilisation. This size limit of 2 microns is acknowledged as an arbitary figure but has been found to form a useful practical distinction.

With few exceptions natural soils consist of a mixture of two or more different grain size fractions from Sand, Silt and Clay. The designation of soils by names given to the principal constituent is best illustrated by a triangular diagram which was developed by the Public Roads Administration of America, which is shown on Figure 3. This triangular chart is divided into regions to which the names of soil types are assigned. The individual soil types are listed in the publication 'Soil Mechanics in Engineering Practice' (16).

For example a mixed-grained soil composed of 25 per cent sand, 25 per cent silt and 50 per cent clay, represented by point X on the triangular diagram (Fig 2) is classified as a clay type of soil. Casagrande (17) discusses the grain size classification and of methods for representing the results of mechanical analysis.

The gravel fraction of a soil can be classified as either single-sized or graded aggregate and can occur in six different shapes: rounded, irregular, flaky, angular, elongated or elongated and flaky. The sand fraction or fine aggregate fraction of soil can be classified into four main zones 1 to 4 in ascending order or fineness. The zone number is determined by the amount of fine aggregate which passes the 600 micron sieve.

Both the gravel and sand fractions are used extensively for concreting purposes whereas the silt fraction is an undesirable element in the production of good structural concrete.

Loamy soil occurs in the broad band of the silt fraction and should not be used as a building material because of its function as a top soil to act as an agricultural base.

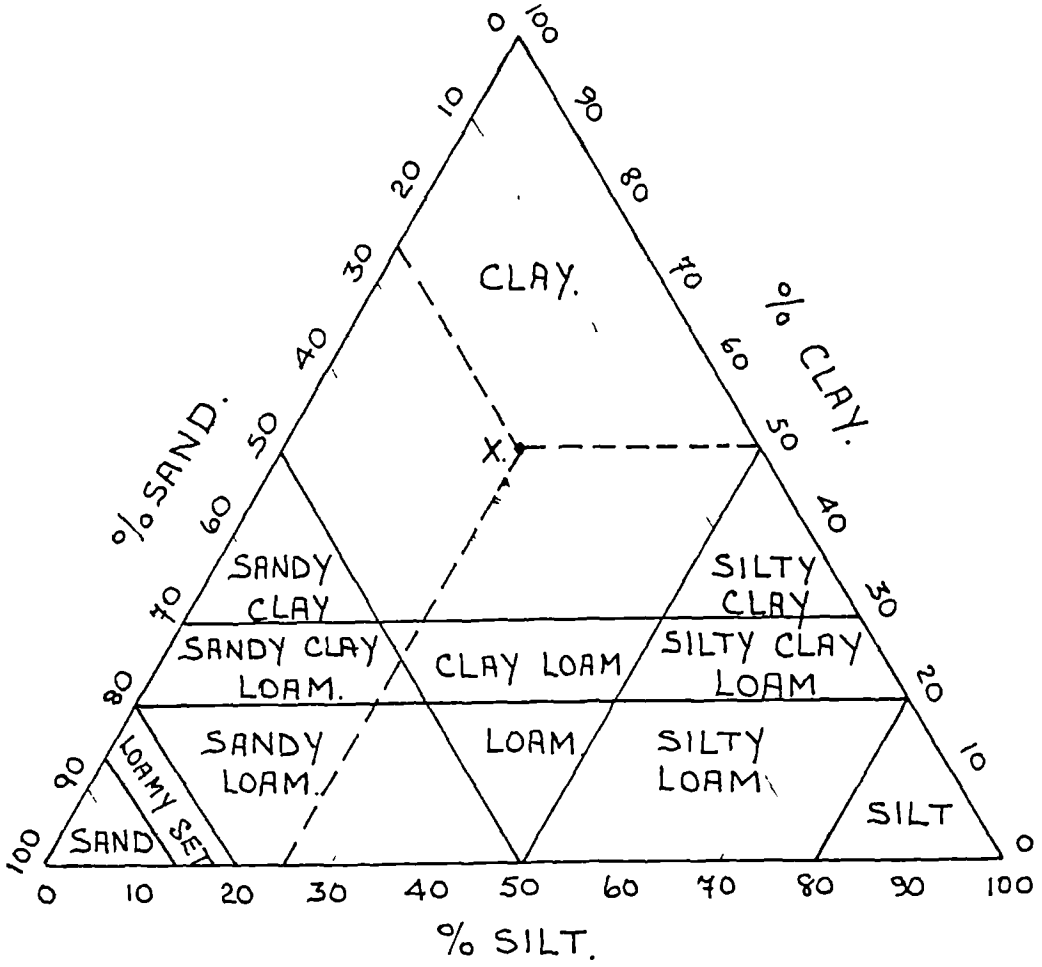


FIGURE - 2.

SOIL CLASSIFICATION CHART DEVELOPED BY THE PUBLIC ROADS ADMINISTRATION OF AMERICA.

EXAMPLE - CLAY SOIL AT 'X' CONSISTS OF :-

25 % SAND.

25 % SILT.

50 % CLAY.

Silt generally consists of many chemical constituents and therefore careful analysis has to be performed before its uses can be determined. As already mentioned the clay fraction is of major importance in the study of soil stabilisation especially in tropical countries.

Depending on the origin of the superficial deposits, soils can be divided into residual soils and transported soils. Residual soils are formed insitu by the weathering of the original rock and consists mainly of gravel clay or sandy silt. These types of soils are usually found on high well drained areas.

Transported soils are usually more abundant and are alluvial, glacial, sea deposits and wind deposited soil which are all transported from high to low ground by wind and moisture movement. During this process, coarser fractions accumulate at the upper reaches of rivers whilst the finer particles are carried to lower ground and then deposited to form the alluvial plains.

Mineralogically and chemically the clay fraction can be divided into five main fractions as shown on Table 2.

TABLE 2 - PROPERTIES OF CLAY MINERAL FRACTIONS

CLAY FRACTION	KAOLINITE	VERMICULITE	ILLITE	CHLORITE	MONTMORIL -LONITE
Cation Exchange Capacity $m^3/100g$	3	150	25	10-40	100
Glycol Retention Mg/g	20	150	80	30	260
Basal Spacing					
Glycol (A)	7	14	10	14	16-18
Dry (A)	7	10	10	14	10
Liquid Limit LL	50	Variable	100-200	Variable	150-700
Plasticity Index P.I.	20	Variable	50-65	Variable	100-650
Activity A_c	0.2av	Variable	0.6av	Variable	1-6

Kaolinite and Montmorillonite represent opposite ends of the spectrum of the clay fractions. The main influence of clay on soil behaviour is its

ability to expand and contract when subjected to changing moisture conditions.

(i) Kaolinite - $Al_2 O_3.2SiO_2.H_2O$ is a well defined mineral which consists of a two layer aluminosilicate with bonding between adjacent particles with sufficient strength to prevent hydration. Kaolinite is chiefly found in highly weathered, well drained soils and is common in tropical countries. This particular mineral has a relatively low liquid limit when comparing it against other clay fractions. Cornish china clay is composed largely of Kaolinite.

(ii) Vermiculite - is a distinct group of minerals within the spectrum of the clay fractions range and consist mainly of hydrated magnesium silicates although considerable amounts of aluminium and iron may be present. An average molecular composition of vermiculite may be $22MgO.5Al_2O_2.Fe_2O_3.22SiO_2.40H_2O$. as stated in The Chemistry and Physics of Clays by R W Grimshaw(18).

(iii) Illite - is a three layer aluminosilicate which together with hydromicas form a middle group within the clay fraction spectruum. This particular mineral is derived from sedimentary rocks and occurs widely in arid and temperate regions. Illite is a general name for a clay group of soils originally found in Illinois, United States of America.

(iv) Chlorite - Hydrated ferrous silicates are usually classified as chlorites and can occur either as a single or double layer

construction. This particular clay fraction has a high capacity for cation exchange.

(v) Montmorillonite - This group covers a wide variety of minerals with Al_2O_3:SiO_2 ratios varying from 1:3 to 1:6 and their isomorphous solid solutions. Similar to Illite, the Montmorillonite group consists of a three layer aluminosilicate derived from weathered volcanic rocks. The individual clay particles are weakly bonded together so that when hydration takes place the individual clay particles will float apart and separate.

Montmorillonite is the name given to a clay group first discovered during exploration work in Montmorillon, France in 1847(18). Some Montmorillonite deposits are thought to be the result of chemical combination of merging water masses. Certain iron and managanese deposits have a similar origin (18).

3.3 Lateritic Soils

Laterite is a general term used by geologists and chemists to define a residual clay which is formed by chemical alteration usually under tropical climatic conditions by the weathering of igneous rocks, usually of basic composition.

Lateritic soils appear to be mixtures of hydroxides, of iron, aluminium, titanium and manganese bonded together. This bond is very weak when first obtained from the ground, but, on exposure to the air, its bond strength increases at the same time as the characteristic hardening of the material.

The word laterite is derived from the Latin, 'later' meaning brick and the word Laterite was first applied by Buchanan in 1807 for describing bricks made of red coloured soils found in the southern parts of India. Here it was found that when the red soil was exposed to the atmosphere the soil hardened off and an excellent building material was discovered. However when the monsoon season occurred the hardened red soil lost some of its strength and partially reverted back to its weak plastic state similar to when it was excavated from the ground.

Lateritic clay soils tend to be strongly coloured due to the presence of iron oxides and generally have a predominance of Kaolinite within the chemical composition.

Lateritic soils occur widely throughout the tropics and can be found in the sub-tropics as far afield as Africa, Central and South America, South East Asia and Australia. Figure 4 shows the world distribution of lateritic soils taken in part from Goodes World Atlas (Rand McNally & Co 1955). In Egypt for example lateritic soil is referred to as 'TUFLA' and after this material has been exposed to the atmosphere for a few days it is extremely difficult to break down the hardened lumps by hand.

Lateritic soils have extremely diverse origins and consequently have a wide range of grain sizes varying from lateritic clay to lateritic gravel and boulders. This physical variation of the grain sizes means that the compaction of lateritic soil to produce building blocks has to be carefully considered at the initial stages and care must be taken to standardise experimental procedures (19).

The dry density of lateritic soils is about 75 per cent of structural concrete and is between 1500 Kg/m^3 and 2000 Kg/m^3 with an optimum

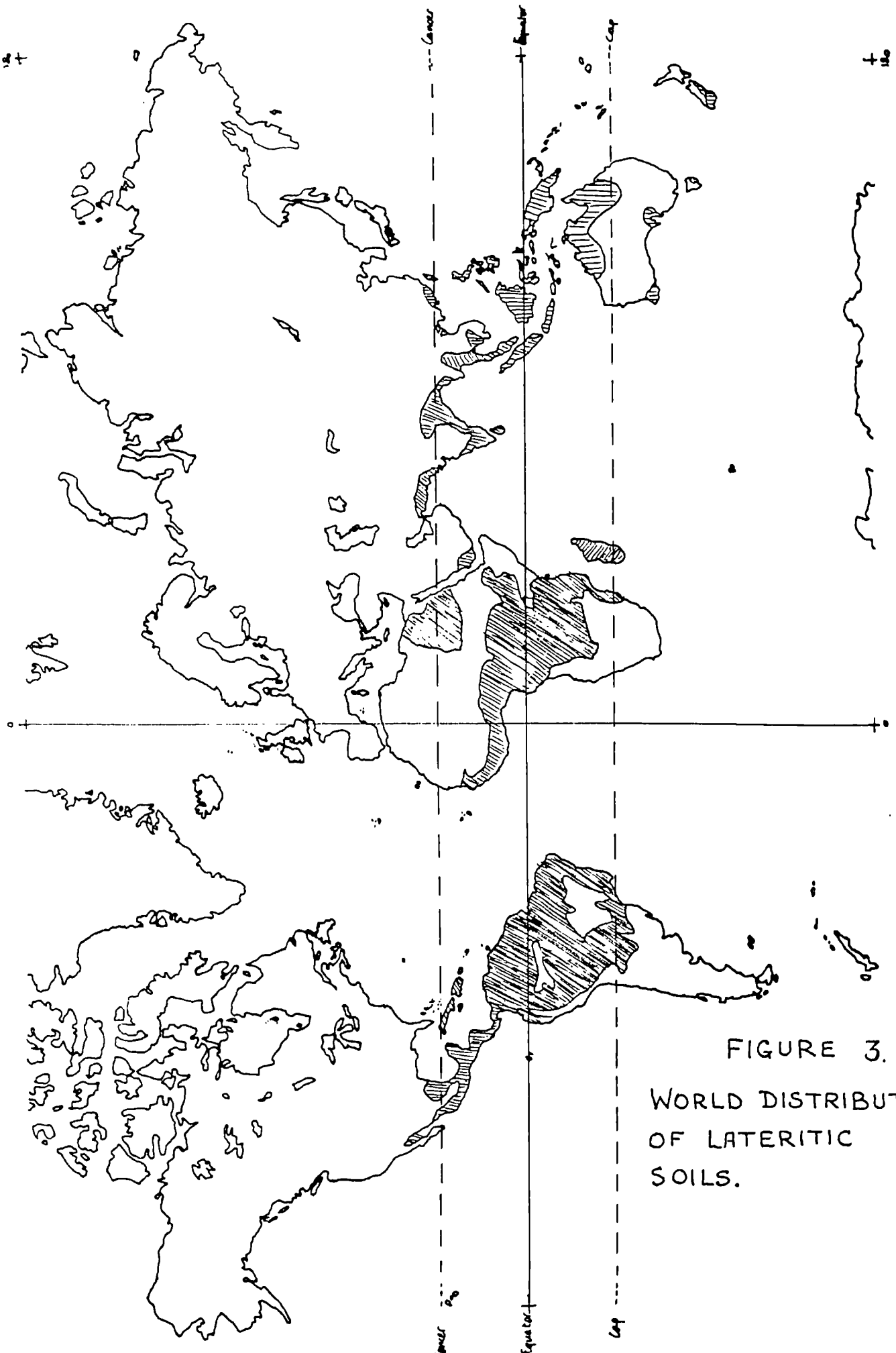


FIGURE 3.

WORLD DISTRIBUTION OF LATERITIC SOILS.

moisture contents range from 8 to 30 per cent. This wide optimum moisture content range indicates that lateritic soils fall within the Kaolinite clay fraction group and gives rise to reasonably high volumetric changes of between 10 to 50 per cent at the liquid limits.

Most loam type soils have a specific gravity in the range 2.50 to 2.75 whilst lateritic soils are significantly higher in the range of 2.60 to 3.40.

Classification methods for temperate soils do not always work reliably for lateritic soils, mainly due to the wide range of parameters that occur with the laterite soils.

Laterites have been found to be suitable subgrades especially for road construction and where black limestone has been weathered in the tropics to form a type of laterite this particular material has been used extensively for airfield runways. Also Lateritic soil has been used for buildings in many different forms predominately in the rural areas of the third world countries.

However with all types of soil construction, including laterites, shrinkage cracking and surface erosion will always take place when the soil is exposed to the natural weathering elements. It is therefore desirable to protect the unstabilised soil construction with a binding agent that may be in the form of cement, hydrated lime, bitumen, animal excrement or plant juices.

When stabilising clay based soils or lateritic soils mechanical compaction is necessary to increase the soil's density which will

produce good quality building blocks due entirely to the variable grain sizing of the silt and clay fractions.

High percentages of ordinary portland cement, in the range of 10 to 20 per cent by weight have been found to give reasonable results but using this amount of cement has proved to significantly increase the cost of the product. Hydrated lime has been used to a lesser degree but only under certain conditions when high temperature curing conditions have existed.

Experimental work conducted at the Technical University of Denmark, Copenhagen by Dr T Ringsholt and Professor T C Hansen in 1977 concluded that when compacted mixtures of lateritic soil and slaked lime are moist cured at tempeatures between 60° and 97° Celsius for various times, a building material having satisfactorily physical properties for structural purposes can be produced.

This experimental research work was reported in the American Ceramic Society Bulletin 1978 and was titled 'Lateritic Soil as a Raw Material for Building Blocks (20). The lateritic soil used for this research work originated from Accra in Ghana and sample mixes of lime and soil were compacted at pressures of about 6 MN/m^2 with resulting compressive strengths of about 5.5 MN/m^2 being achieved.

It is worth noting that the optimum compressive strength results were obtained for a lime content of 17 per cent by weight, and a water content corresponding to 10 per cent by weight of the dry mix. The samples being oven dried at 110° Celsius for a 24 hour period. Bitumen emulsion has been used as a stabiliser for lateritic soils but in this instance the bitumen content has been included as a water-proofer and

only partly assists the strength development. The preparation of a bitumen emulsion usually presents problems and this type of stabilising agent is not often used.

Mechanical compaction of lateritic soils, to achieve good consolidated blocks, was realised as early as 1952 as mentioned in a Colonial Building Note No.8 published by the UK, Department of Scientific and Industrial Research in August 1952 (21). The suggested compaction pressures quoted should be between 10.3 MN/m^2 (1500 lbs/sq.in) to 13.8 MN/m^2 (2000 lbs/sq.in).

The wide spectrum of the differing chemical constituents of a so called lateritic soil has meant that no definite agreement has been reached by soil scientists when defining a standard chemical composition for a lateritic soil.

It was in 1911 that L L Fermor (22) suggested that there should be some line of demarcation between the various chemicals contained within lateritic soils. Fermor, a soils engineer, had been working on soil stabilisation for roads and realised that the silica-alumina ratio (SiO_2/Al_2O_3) was the important consideration when classifying a lateritic soil. Further work was completed by Martin and Doyne in 1927 on the same classification criteria for lateritic soils.

Based on this criterion lateritic soils were classified as follows:

TABLE 3 - LATERITIC SOIL CLASSIFICATION USING THE S_1O_2/Al_2O_3 RATIO

SOIL TYPE	SiO_2/Al_2O_3 RATIO
Laterite	1.33 or less
Lateritic soil	1.33 to 2.00
Non-Lateritic soils	2.00 and over

This classification method was used in the early 1900's as reported by K S Bawa in the Journal of Soil Mechanics and Foundation Division ASCE (23).

Although it was recognised that the iron oxide is an integral part of most laterities, its inclusions in the ratio with respect to silica does not give so clear cut a constant for identification as does the SiO_2/Al_2O_3 ratio.

M S Anderson together with Hardy and Smith in 1931 and later S A Ola from the University of Zaria laid emphasis on the important role played by the iron oxide content; hence the silica/sesquioxide ratio ($SiO_2/Al_2O_3 + Fe_2O_3$) is now used as a criterion for classifying soil types as laterite, lateritic soils and non-lateritic soils (24).

The following Table 4 shows this lateritic soil classification.

TABLE 4 - LATERITIC SOIL CLASSIFICATION USING THE $SiO_2/Al_2O_3 + Fe_2O_3$ RATIO

SOIL TYPE	$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ RATIO
Laterite	1.33 or less
Lateritic soil	1.33 to 2.00
Non-Lateritic Soils	2.00 and over

This method of lateritic soil classification is now used by most soil engineers, chemists and geologists.

The above two tables indicate that there is still some doubt as to the precise chemical definition of a lateritic soil because of the different ways that a lateritic soil is formed.

Nevertheless lateritic soils are still being widely used in third world countries, in Ghana, for example 'Swish' is the most popular form of lateritic soil construction in rural areas as described by Hammond (25) in his article on rural housing.

It should be noted that lateritic soils can be used in the manufacture of Adobe blocks or burnt bricks. As mentioned previously, the laterite hardpan can be cut directly from the ground to form blocks which are allowed to sun dry. This type of block is widely used in Sri Lanka where it is called Kabuk (26).

3.4 Laterite Based Materials Technical Committee

The International Union of Testing and Research Laboratories for Materials and Structures (RILEM) was initiated in 1947 as an association of University laboratories and research institutes with a small number of technical committees. RILEM is a non profit making organisation, headquarters in Paris comprising some 40 active technical committees with members from about 75 countries.

The RILEM General Council, which met in September 1982, officially set up a new international Technical Committee 63-LBM entitled Laterite-based Materials which had the specific object of investigating the experimental study of lateritic soils as a potential building material and possibly introduce an international standard on laterite soil testing.

The author was nominated as the sole UK representative on this international technical working committee and some 14 countries were involved.

The RILEM Technical Committee 63-LBM had its first meeting in Paris early in 1983 and it is hoping to publish an international guidance note standard in 1988 covering the use of laterite based materials.

This proposed standard will comprise the following chapters:

1. Laterites - Definition, availability, mineralogical and geotechnical characteristics.

2. Use of Lateritic soils in buildings in the shape of solid or hollow blocks, stabilised or non stabilised.

3. Determination of the quality of laterite soil blocks including the draft of suitable test methods.

4. Required building arrangements and performance for the use of laterite soil blocks in buildings.

5. Building and manufacturing techniques with laterite soil in the formwork.

6. Drafting a method for monitoring and observation of pilot construction using laterite soils.

3.5 Explanation of Soil Engineering Terminology

Geology is the science of the earth's crust which involves knowledge of soil mechanics, chemistry and geographical physical considerations.

In order to standardise the cross reference of the various terms used in this science, standard definitions and symbols are used some of which are listed in BS 1377 : 1975 (15).

These definitions and symbols will be listed in Appendix (A2) but an explanation of each term now will clarify the text as follows:

1. Soil types - The constituent parts of a soil sample have been fully discussed in Section 3.1 and are not included in this section.

2. Gravel fraction - Is that part of a soil sample of particle size between 60mm and 2mm.

3. Sand fraction - Consists of soil particle sizes between 2mm and 0.06mm.

4. Silt fraction - Is the fines of a soil sample of particle size between 0.06mm and 0.002mm.

5. Clay fraction - Is acknowledged to be an arbitary figure and is classified as any particle size less than 0.002mm in size. (OR that fraction that passes through a 2 micron sieve).

6. Cohesive soil - Is a soil that has an element of silt and clay content so that when moisture is applied a cohesive mass is obtained.

7. Non-Cohesive Soil - This type of soil contains a high content of gravel and is sometimes referred to as a granular soil and when moisture is applied will not form a coherent mass.

8. Particle size distribution - Is a method of describing the distribution of individual particle sizes of a soil sample and can be represented pictorially on an envelope type of graph. The particle size distribution is best determined by either sieving or sedimentation methods.

9. Soil Consolidation - This term applies to the process of applying continued pressure, over a period of time, to a mass of soil. The individual soil particles are packed closer together thus reducing the air voids in the soil mass.

10. Soil Compaction - Is the term applied to a process where a compacting force of short duration is applied to a soil sample. This compacting force will move individual soil particles together thereby increasing the density of the soil mass.

11. Liquid limit (LL) - Is the water content, expressed as a percentage of the dry weight of a soil sample when added to the soil causes the soil to pass from a plastic to a liquid state.

There are two methods generally used to determine the liquid limit of a soil sample, these are the cone penetrometer test and Casagrande's apparatus.

12. Plastic limit (PL) - The plastic limit or lower limit of the plastic state is the moisture content of a soil sample at which stage the sample begins to crumble when rolled out into thin threads.

This test referred to as the Thread Test is essentially a manual test and consists of adding water to a soil sample. The wetted sample is then rolled out into threads of about 3mm diameter and at the plastic limit the resulting thread of soil will begin to crumble.

13. Plasticity Index (PI) - The plasticity index of a soil sample is the numerical difference between the liquid limit and the plastic limit and is determined by the equation

$$PI = LL - PL$$

A granular soil within the non-cohesive range of soils would have a plasticity index of zero.

14. Moisture content - The moisture content of soil refers to the mass of water contained and is measured as a percentage of the dry density of the soil mass. The moisture content is determined by

heating a soil sample to 105 degrees Celsius and weighing the mass of water removed from the soil.

15. Optimum moisture content (OMC) - The optimum moisture content of a soil is of paramount importance when producing soil building products because at this point occurs the maximum 'dry' density of a soil.

British Standard 1377 : 1975 (15) defines the OMC as 'The moisture content at which a specified amount of compaction will produce the maximum 'dry' density'. The relationship between dry density and moisture content is best illustrated by graphical means for a typical soil sample as shown in Figure 2.

The OMC according to the standard Proctor test is the value of moisture content at which the dry density is a maximum.

In both field and laboratory trials the OMC depends not only on particle size distribution but also, to a great extent, on the method and duration of compaction. Hence no standard test of any kind, including the Proctor test, should be expected to produce results of general validity. Conclusive information on the OMC can therefore only be obtained by making large-scale field tests using the compacting methods to be used in production.

3.6 Obtaining Soil Samples

In the preparation of a stabilised soil block making programme consideration must first be given to how much soil is needed and where suitable clayey type soils can be found.

If the proposed production rate warrants a factory-type installation it is probably worthwhile investing in mechanical plant and equipment, if however the proposed production involves small quantities of blocks, simple methods of obtaining soil samples should be adopted and hand tools could well be used.

One major advantage with hand digging over mechanical plant digging is that the labourers who are excavating the soil from the ground would be able to discard unwanted elements, such as large rocks and stones, uncrushable objects, tree roots and any other undesirable elements as they occur.

The spade or shovel will be the most common type of hand tool employed to dig the soil and many types are available as illustrated in Figure 5.

Type (a): a clay digging spade with a slightly rounded blade which can be used to dig both clay and heavy loams.

Type (b): this type of spade has a square ended blade suitable for cutting throgh fibrous materials and skimming weed growth, for example top soil growth and grass.

Type (c): a builder's shovel with upturned edges to prevent spillage, is a most efficient hand tool and ideal for general lifting and mixing duties.

Type (d): this type of shovel is slightly curved with a pointed cutting edge and was originally developed to handle asphalt, has been used in the building industry although not very efficient for digging or mixing materials together.

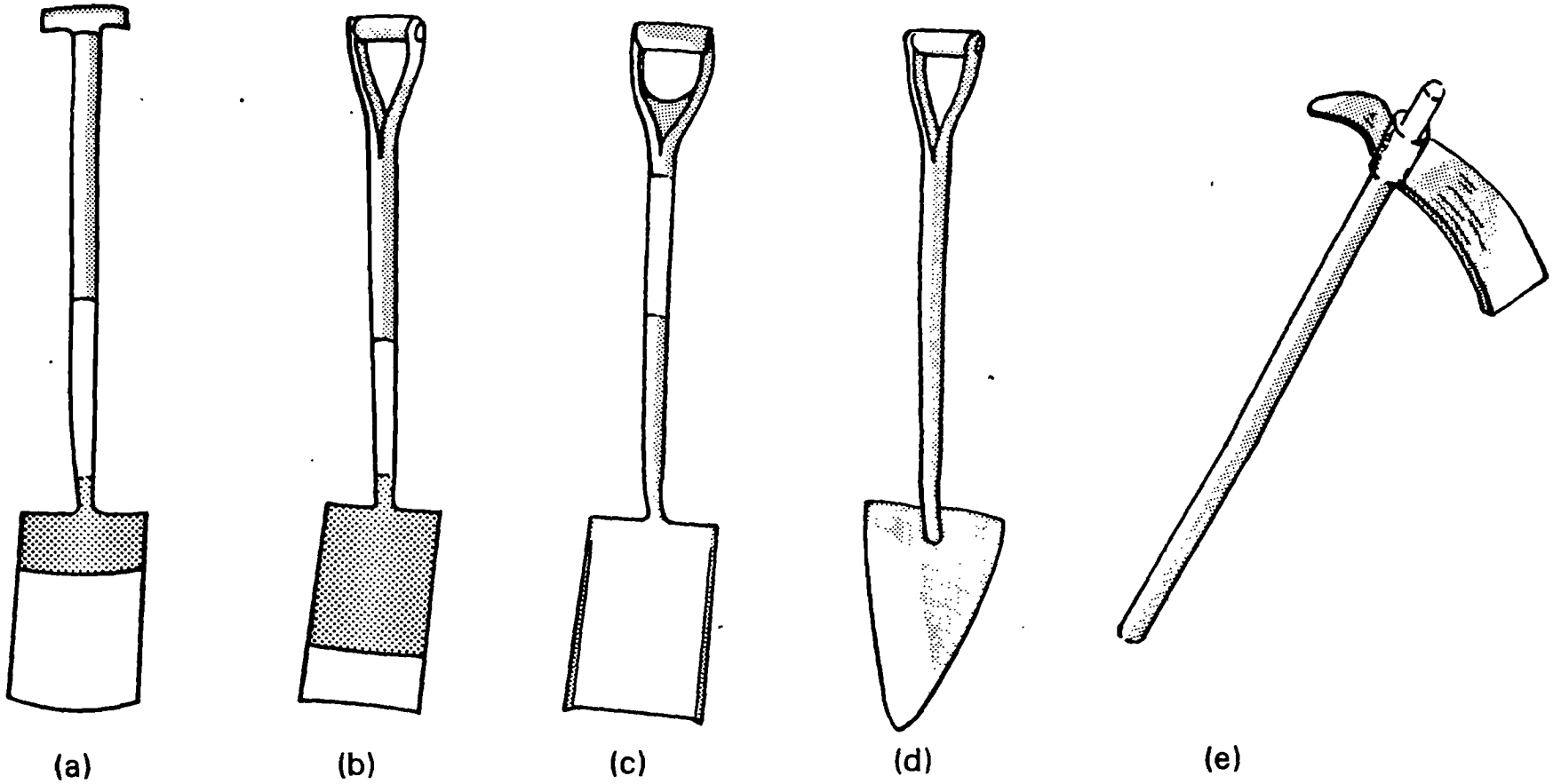


Figure 4 Hand digging tools

Type (e): a pick-hoe which has many uses for digging, breaking up hard ground and lumps and is a most efficient hand tool both for excavating and mixing duties.

Spades or shovels are widely available with shafts of different lengths and blades of different sizes. The standard spade measures 29 x 19cm width whereas the shovel blade measures 29 x 24cm width.

Small test holes will have to be dug in order to investigate the various depths of the clay and sand layers. Again simple hand augers are available, for example the manually operated bucket auger illustrated on plate 9 could be employed to drill pilot test holes up to about 300mm diameter. Alternatively a smaller type of hand auger shown on Figure 5, capable of drilling test holes of 150mm diameter could be manufactured locally in a blacksmith's shop by first cutting annular rings from 6mm thick mild steel plate, these rings are then opened up, to form the auger flights and welded to a centre shaft. The hand operated bucket auger illustrated on plate 9 would be more difficult to manufacture locally.

Soils suitable for stabilisation should meet the following general requirements:

(a) The soil should contain sand, clay and silt properties; the sand proportion to form the body, the clay proportion will improve the cohesion qualities whilst the silt proportion will act as a void filler.

(b) There should be a good even particle size distribution to ensure a uniform homogeneous matrix.

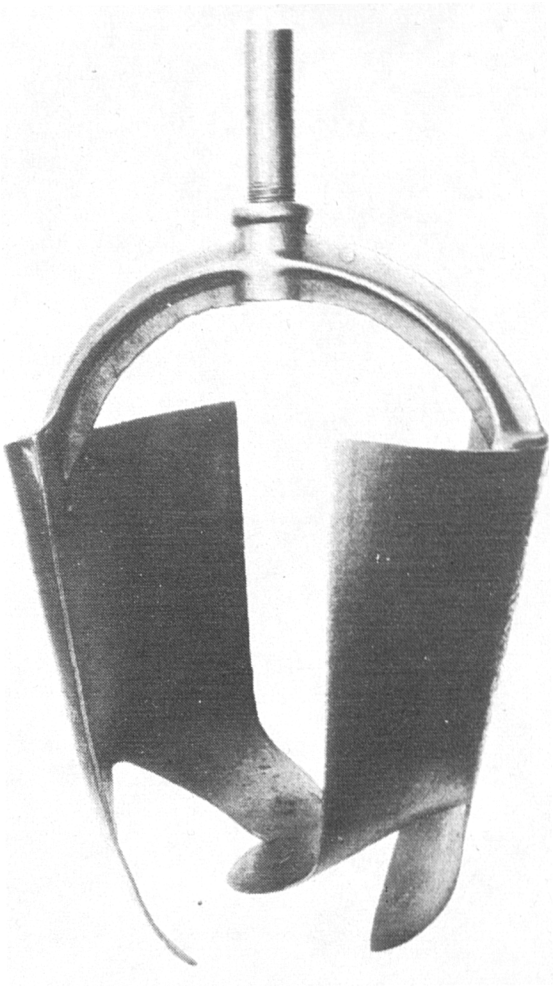


Plate 9 Bucket auger

Plate 10 Clay strata below the sand in Egypt

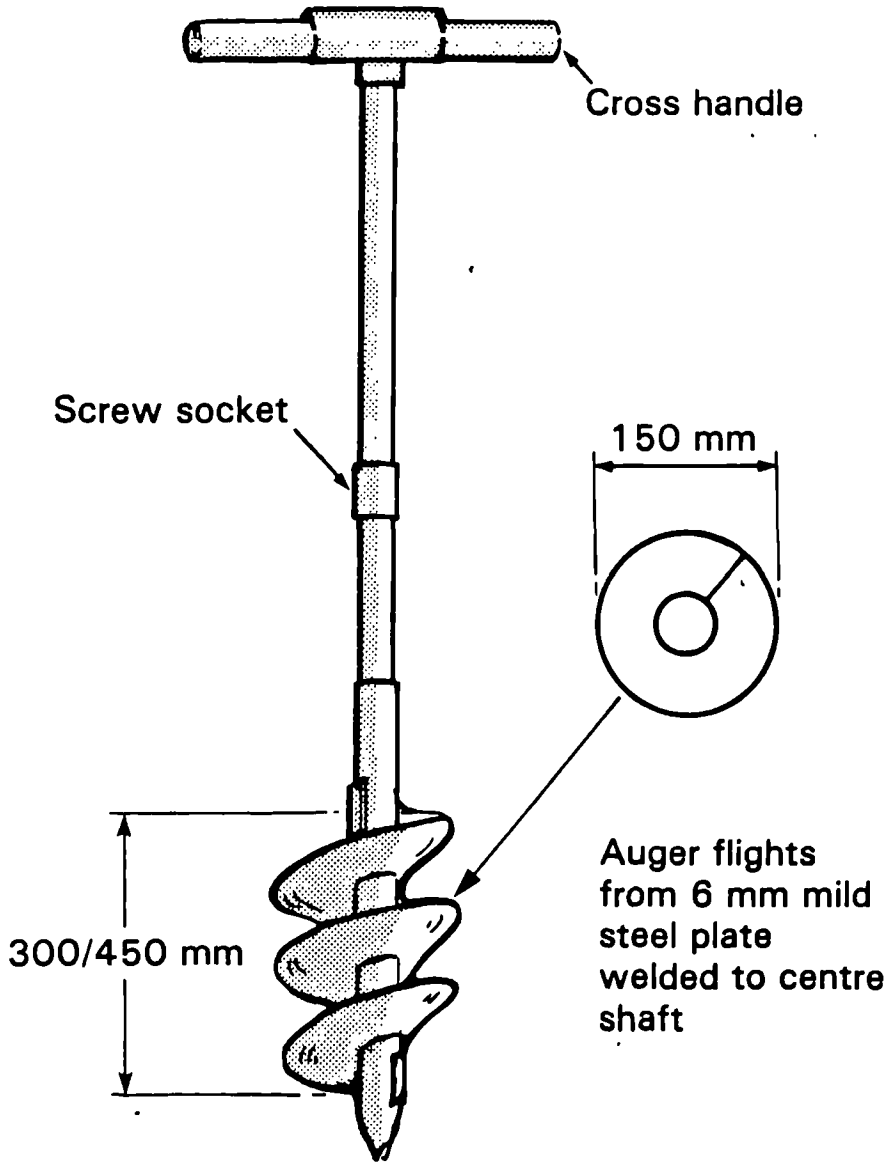


Figure 5 Hand screw auger

(c) After drying the soil should be readily friable, if not, it may indicate too high a clay fraction and sand would possibly have to be added to reduce the clay proportion.

(d) After mixing the soil with water at optimum moisture content, and a selected stabiliser the soil mix should be easily compacted by hand.

(e) After compaction under direct continuous pressure the produced block should be atmospherically cured, under cover and allowed to dry out without any harmful shrinkage, distortion or hair line cracks occurring.

(f) The resultant cured stabilised soil block should be durable against climatic conditions and should meet the basic requirements laid down in local standards.

The above requirements are general but they impose an upper limit to the general suitability of a soil for stabilisation.

A suitable type of clayey soil for a block making programme is nearly always found just below the organic topsoil strata. The top soil strata can consist of loamy soil, which is used for agricultural purposes and sand which could be used as a building material. The best location of clayey soils is on the top of rolling hills (not mountains) or ridges whilst sandy type soils are frequently found in the valleys.

To obtain soil samples first excavate and put aside the organic topsoil strata remembering that it could be on average at least one metre in depth. The test hole should be started after first excavating the

topsoil from an initial hole at least one metre by one metre in plan view.

In wet tropical zones the topsoil strata is usually very shallow of the order of 10cm deep whilst in dry zones for example in desert areas the topsoil strata can vary from a few centimetres to several metres in depth. A shallow topsoil zone is illustrated on Plate 10 taken by the author when he visited Ishmaila in Egypt.

Once the topsoil strata has been cleared the soil colour and texture will change several times, therefore it is important that precise notes are taken of the soil samples extracted. The clay strata, when excavated is easily recognised because the samples obtained would be stickey and adhere to the hand auger or tool being employed.

An operative can conduct simple on-site tests, as described in Section 3.7.1 to determine the suitability of the clay soil excavated for stabilisation purposes.

Due to the wide variation of the soil structure several test holes must be drilled in any specific area dependant on the soil block programme being considered and even with a small programme at least four or five holes must be investigated to obtain full details of the available soil. Therefore the actual number of pilot holes to be dug cannot be specified.

3.7 Soil Testing in the Field

When starting to investigate the suitability of soils for stabilisation, test holes must be dug.

First the organic top soil containing dark soil with roots and plant growth must be removed and put aside.

If digging by hand the sample hole excavated should not be more than about two metres deep. The topsoil strata will vary in depth for example in the desert areas this strata would be very little whilst in wet, tropical areas, the topsoil strata may be at least one metre depth as already mentioned in Section 3.6.

Once the topsoil strata has been cleared a full bucket of soil should be taken from the top of the sample hole. The sample hole is then dug to full depth when a second bucket of soil should be obtained.

The two bucket samples are then tipped onto a dry surface and allowed to dry in the sun after which they are mixed together, during this mixing operation all particles larger than 10mm should be removed either by visual inspection or sieving.

Various tests from simple on-site tests to complicated laboratory tests can now be performed on the soil sample and for clarity the individual tests are listed as follows first starting with the simple site tests.

Soil is a variable and complex building material and it is advisable not to skimp the simple on-site tests because poor soil selection nearly always results in an unsatisfactory product.

The on-site tests have been developed especially to assist people in rural areas who would not have the facilities of a well equipped laboratory at their disposal.

If laboratory facilities are available it is always a wise precaution to repeat the on-site simple tests within the laboratory.

3.7.1 Determination of combined clay and silt content

This test requires the use of a wide mouthed clear glass bottle with a screwed or clip on lid, a small quantity of salt (sodium chloride), clean water and a scale.

This test can be performed as follows:

(a) First fill one third of the clear glass bottle with soil taken from the dried soil sample as shown on Figure 6(a).

(b) Next measure out a quantity of water that will fill the glass bottle one third full and add to this water one to two spoon fulls of salt. This mixture should be well shaken to ensure that the salt has completely dissolved in the water.

The addition of salt will speed up the final settlement of particles within the glass bottle.

This salt/water mixture is then poured into the glass bottle onto the soil sample and the bottle is sealed with its lid as shown in Figure 6(b).

(c) The glass bottle is then shaken vigorously for about two minutes and stood on a level surface for about one hour after which it is again shaken and left for a further five hours for the

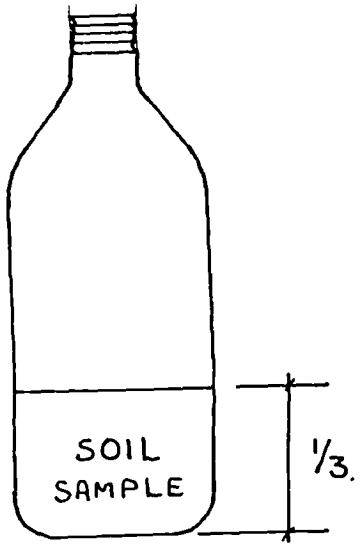


FIG. 6a.

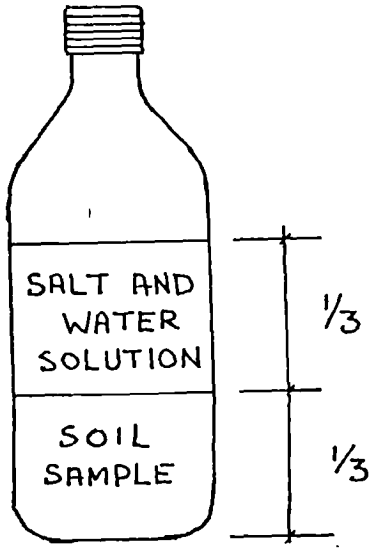


FIG. 6b.

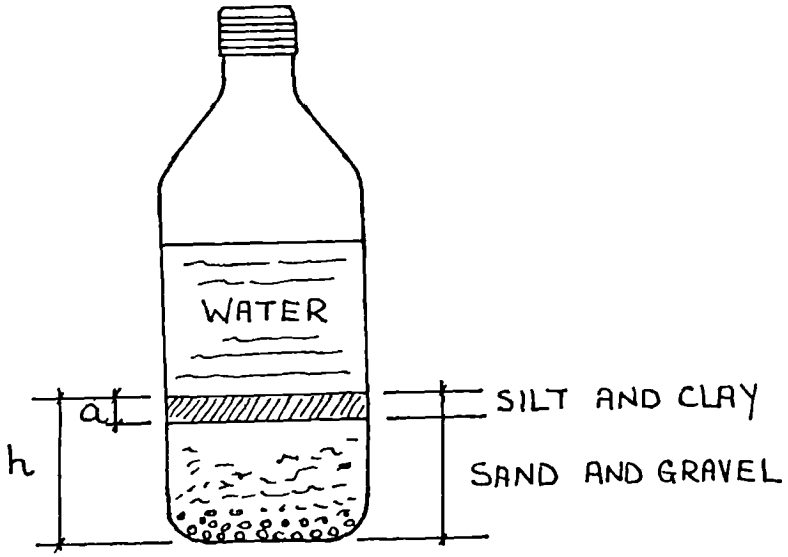


FIG. 6c.

FIGURE 6.
DETERMINATION OF THE COMBINED CLAY AND SILT CONTENT OF A SOIL SAMPLE, USING THE BOTTLE TEST.

individual soil particles to settle out according to their size and constituent fractions of gravel, sand, silt and clay.

(d) The largest particles will be seen at the bottom of the bottle, whilst the smallest particles will be at the top of the sample.

There will be distinct lines of separation because the lower area, occupied by the sand and gravel fraction particles can be seen by the naked eye whereas the silt and clay fraction particles cannot be separated as shown on Figure 6(c).

The percentage of clay and silt fraction can now be obtained from the following equation:

$$\text{Combined Clay and Silt Fraction} = \frac{a}{h} \times 100\%$$

This is not an accurate method but gives an indication of the combined clay and silt percentage within a soil sample. If the combined clay and silt content is larger than 30 per cent, the soil is not a suitable material for cement stabilisation because it would need a high addition of stabiliser to acquire minimum strength requirements. However this soil could be made usable by the addition of sand which in turn would reduce the clay and silt percentage to a value less than 30 per cent and a cement stabiliser could be employed. If a high compression machine is available hydrated lime could be used as a stabilising agent for the original soil.

At the other end of the scale, if the combined clay and silt content is less than 5 per cent, a clay fraction must be added to the sample to increase the combined clay and silt content to make the soil suitable for using in a stabilised soil block production programme.

This test is very important and should be completed at least twice for each test hole to ensure repeatability of the combined clay and silt contents.

3.7.2 Shrinkage Test

The determination of the linear shrinkage of soils is clearly set out in BS 1377 : 1975 (15) and involves the use of an oven for heating a soil sample up to a temperature of 110° Celsius and a special brass mould. This type of equipment would generally not be available and a simple field test has been developed during the current research programme at BRS.

This test will indicate the linear shrinkage properties of a soil sample, this information will help to determine the best type and amount of stabiliser required.

A simple open topped wooden box with internal dimensions of 40mm x 40mm x 600mm length is required for this test as illustrated on Figure 7.

The first step in conducting this test is to lubricate the internal faces of the mould with oil or grease. Ideally silicone grease is preferred but any type of mould release oil or grease could be used

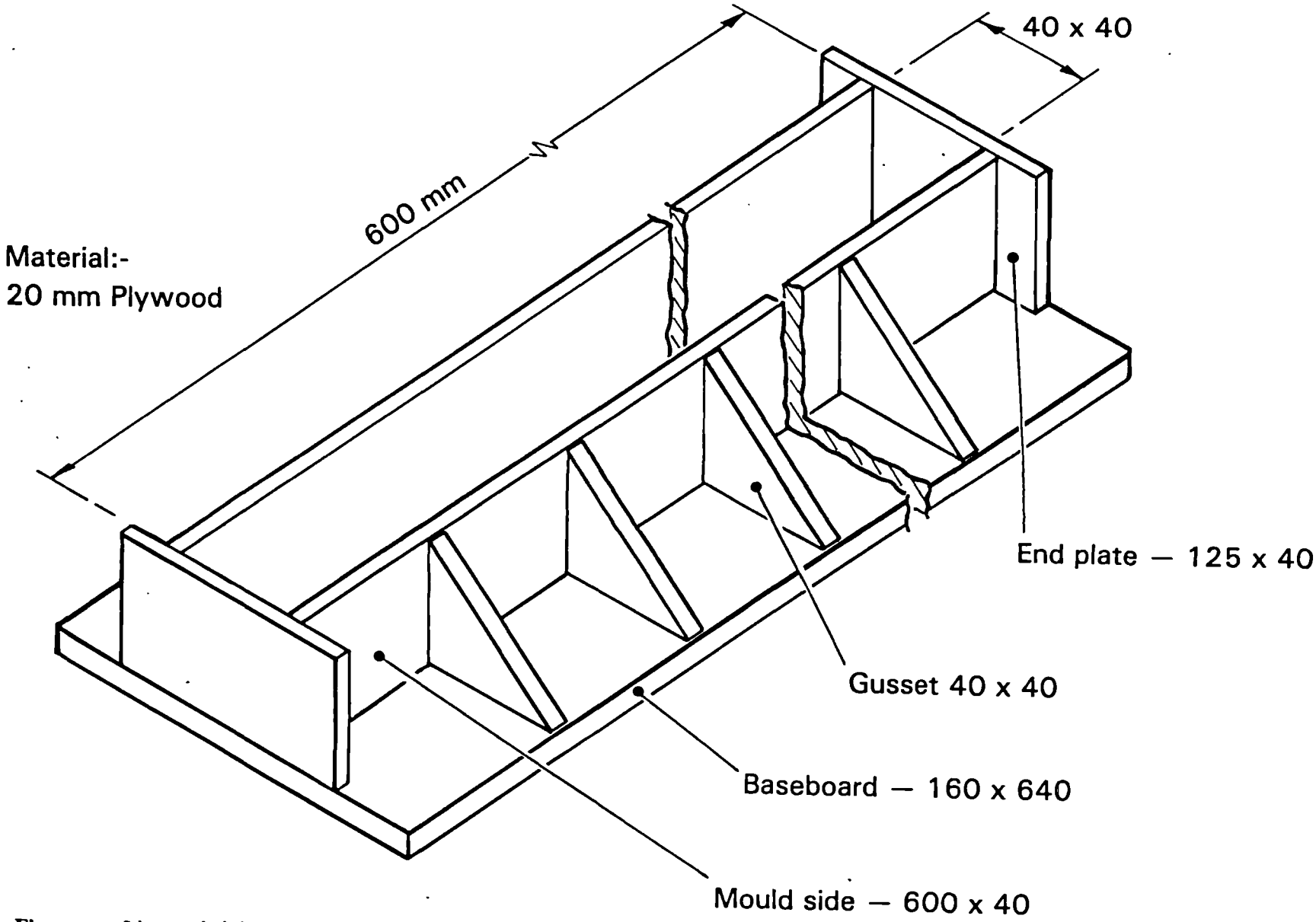


Figure 7 Linear shrinkage mould

which will reduce soil drag on the internal faces of the mould occurring as the soil sample is drying out and shrinking.
The soil sample having been passed through the 6mm sieve is mixed with clear water until a wet puddingey mix is obtained (which occurs near the liquid limit - see Section 3.3.5), which is then packed into the mould cavity ensuring that the mould is completely full, with no air voids and the top open surface is smooth.

The mould is then either placed to dry in the sun for about five days or under shading for about ten days during which time it must be protected from rain.

If the soil sample has a high clay content the sample will shrink and 'hog-up' out of the mould as illustrated in Plate 11 which shows the shrinkage properties of black cotton soil.

A soil sample which shrinks and cracks across the width of the mould as illustrated in Plate 12 indicates a high sand fraction and low silt and clay fraction.

By subtracting the length of the dry soil sample from the length of the mould cavity the linear shrinkage can be determined. This shrinkage is usually expressed as a percentage of the original mould cavity length.

The phenomenon of hogging is brought about by thermal and moisture movements associated with the minerals within a soil during the drying out period which causes internal uneven stresses.

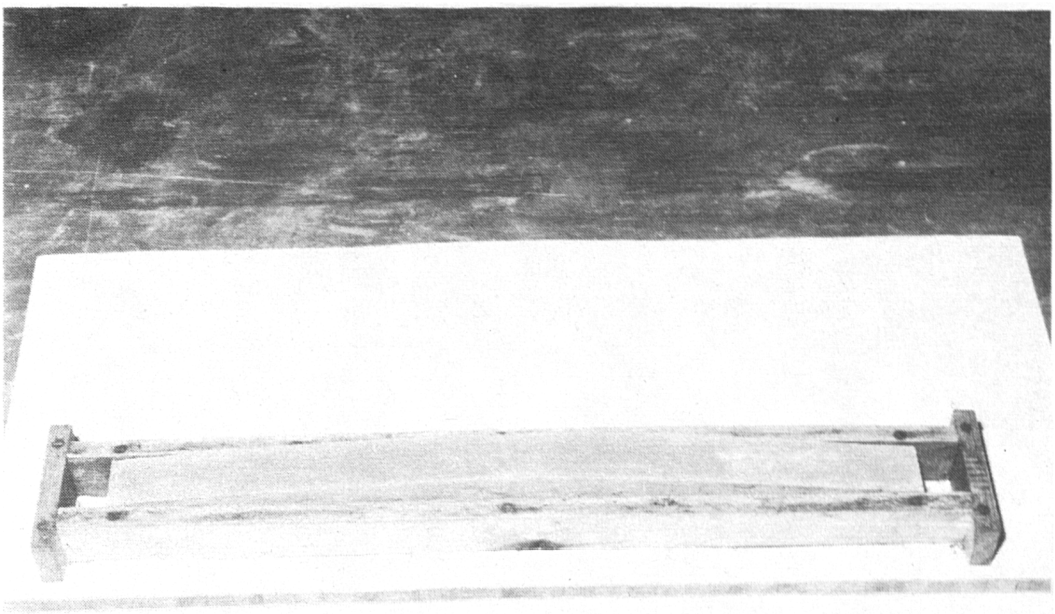


Plate 11 Linear shrinkage of a high clay content soil

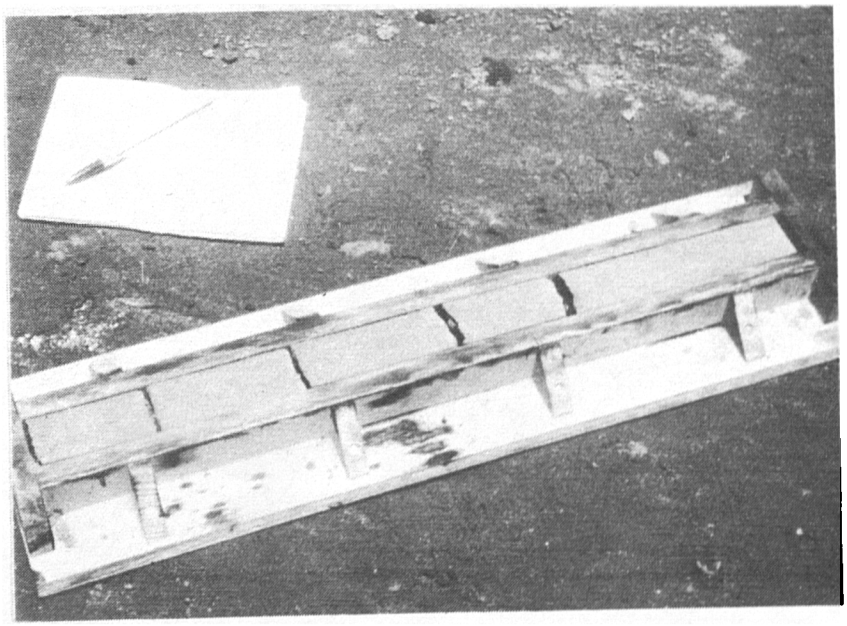


Plate 12 Linear shrinkage of a low clay/high sand content soil

The estimation of thermal and moisture movements is discussed in detail in (31) and is outside the scope of this work.

Percentage of Linear Shrinkage =

$$\left[1 - \frac{\text{Length of cured specimen}}{\text{original specimen length}}\right] \times 100$$

As a general rule knowing the contraction on length that has occurred will give an indication of what type of stabiliser is needed.

A typical linear shrinkage curve against time is illustrated on Figure 8 for a low silt/clay type of soil sample from Pakistan.

The following table 5 has been developed by VITA (Volunteers in Technical Assistance) from material based on the experience of numerous field operatives who have used the CINVA-Ram block making machine. See Section 6.2.3.

TABLE 5 - SHRINKAGE RESULTS - GUIDE FOR CEMENT CONTENT WHEN USING A CINVA-RAM

Specimen Shrinkage (mm)	Cement/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%)
Over 60	Not suitable for direct stabilisation

See page 11C for stabiliser selection for the Brepak machine.

VITA have published a useful booklet entitled 'Making Building Blocks with the CINVA-Ram Block press' (28) which will be referred to in Section 6.2.3.

Note: The CINVA-Ram Machine exerts a compacting pressure of about $2MN/m^2$

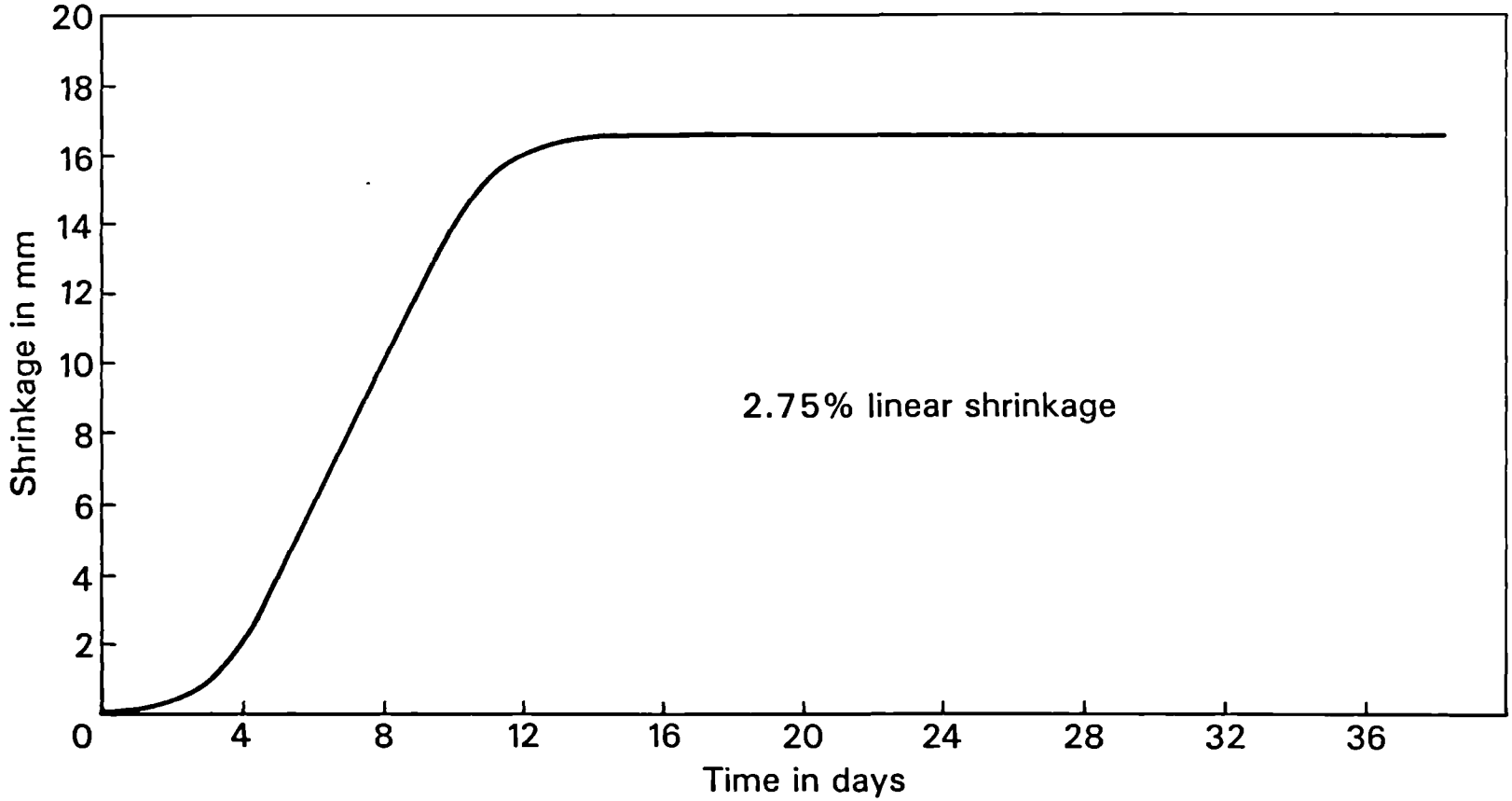


Figure 8 Linear shrinkage curve for Baltit Fort soil from Pakistan

If a soil sample shrinks more than 60mm, generally, the sample will arch up, out of the mould as shown on Plate 11 and this indicates that there is a high percentage clay fraction within the soil and would not be suitable for direct cement stabilisation see Section 4.4.2. See section 4.4.6 Alternative methods must be used to reduce the percentage content of clay by either the addition of sand or of a soil type containing a low clay fraction.

If the compacting pressure is increased from $2MN/m^2$ to $10MN/m^2$ there would be a decrease in the air void ratio of the material pressed, density increases which indicates that a cement dosage rate can also be decreased to that mentioned on Table 5. This aspect is discussed in Chapter 4.

3.7.3 Compaction Test

This simple test will provide the optimum moisture content (see Section 3.3.5) of the soil as well as showing how cohesive the soil sample would be when subjected to moisture.

Enough dried soil to form a ball that could be held in the hand is first weighed and then mixed with a known weight of water. This ball should have just enough water in it so that it will hold together but not stick to the hand or fingers when the ball is grasped.

This ball should be dropped from a height of one metre onto a hard surface and if the soil ball breaks into a few smaller parts, the correct moisture content has been added.

If the ball forms a sluggish heap on the ground this indicates that too much water has been used but at the other extreme, if the ball shatters into many pieces not enough water has been added. This particular test is rather 'ad hoc' but certainly gives a good indication of the cohesive qualities and also the range of the optimum moisture content of a soil sample.

3.7.4 Hand Tests

There are numerous hand tests that can be conducted on a soil sample on site all of which indicate the workability and contents of a soil. The wet shaking test is performed by shaking or jarring the hand against a firm object, if water rises to the surface of the hand held sample it indicates that the sample consists of fine sands and coarse silt.

If the moisture movement is sluggish after hand shaking for about 25 taps of the hand and minimum moisture appears on the surface of the soil sample then this would indicate the presence of some clay fraction. However if no moisture was present after a long period of shaking this would indicate a high percentage clay fraction.

Another method that will give an indication of the clay fraction content is the 'Thread Test' which is described in Section 3.3.5. This method is used to determine the plastic limit (PL) of a soil.

An extension of the Thread Test is the 'Ribbon Test' which follows the same procedure as the Thread Test but gives a better indication of the clay content because the rolled sections formed are usually a smaller diameter than those used in the Thread Test.

3.7.5 Sensory Tests

There are several sensory tests that can be conducted on a soil sample and the most important of these is the 'Odour Test' because organic soils have a musty odour especially when freshly dug. Even dry organic soils when wetted will emit a musty odour and it is therefore advisable to discard this type of soil as being unsuitable for soil stabilisation purposes.

The 'Bite Test' is a quick and useful way of identifying sand, silt or clay. A small pinch of dried soil lightly ground between the teeth would have differing effects dependent on the soil content.

For example sandy soils contain sharp and hard particles which would grate between the teeth and create an objectionable feeling whereas silty soils would feel a lot smoother to the tongue. Clayey type soils do not possess hard particles and would feel smooth and powdery like flour between the teeth. In fact a dry sample with a high clay content would tend to stick when lightly touched by a wetted tongue.

The 'Shine Test' is performed on a moistened soil sample by rubbing a finger tip over the surface of the soil. If the soil contains silt or sand the surface would be abrasive to the touch and would remain dull in colour, whereas, a sample containing a high percentage of clay would quickly shine and be smooth to the touch.

The colour of a soil is also a sensory test. Light brown to black colours indicate organic soils or black cotton soil. Reddish and dark brown colouring is caused by iron oxides being present in the

soil and would indicate clay or lateritic fractions. White to yellow colourings would indicate a chalk or sand content.

When washing, a lot can be learnt about a soil sample by how it washes off of ones hands. Sandy soils would be abrasive to the hands but would rinse off the surface easily with plenty of water, however, clayey soils will always stick to the hand and would require more washing to completely remove from the skins surface.

It therefore follows that a clayey soil is soft and smooth to touch, a sandy soil is abrasive to the touch and soil that has a high percentage of silt would be between the smooth and abrasive zone of touch.

3.7.6 Particle Size Distribution

This test gives a quantitative measure of the individual soil fractions. First obtain or make four sieves and a tray as illustrated in Figure 9; these sieves should nest one on top of another so that a site sieve analysis can be obtained.

The four sieves each have a different size wire mesh for example 6mm, 2mm, 0.2mm and 0.06mm. The 0.06mm size mesh may be difficult to obtain but an open weave cloth could be substituted. The fifth container is a catchment tray.

First weight out 2kg of sun dried soil sample and place it inside the 6mm sieve which must be on top of the nest of sieves. By shaking the nest of sieves simultaneously all the fine particles will pass through this sieve and dependent on the fineness some

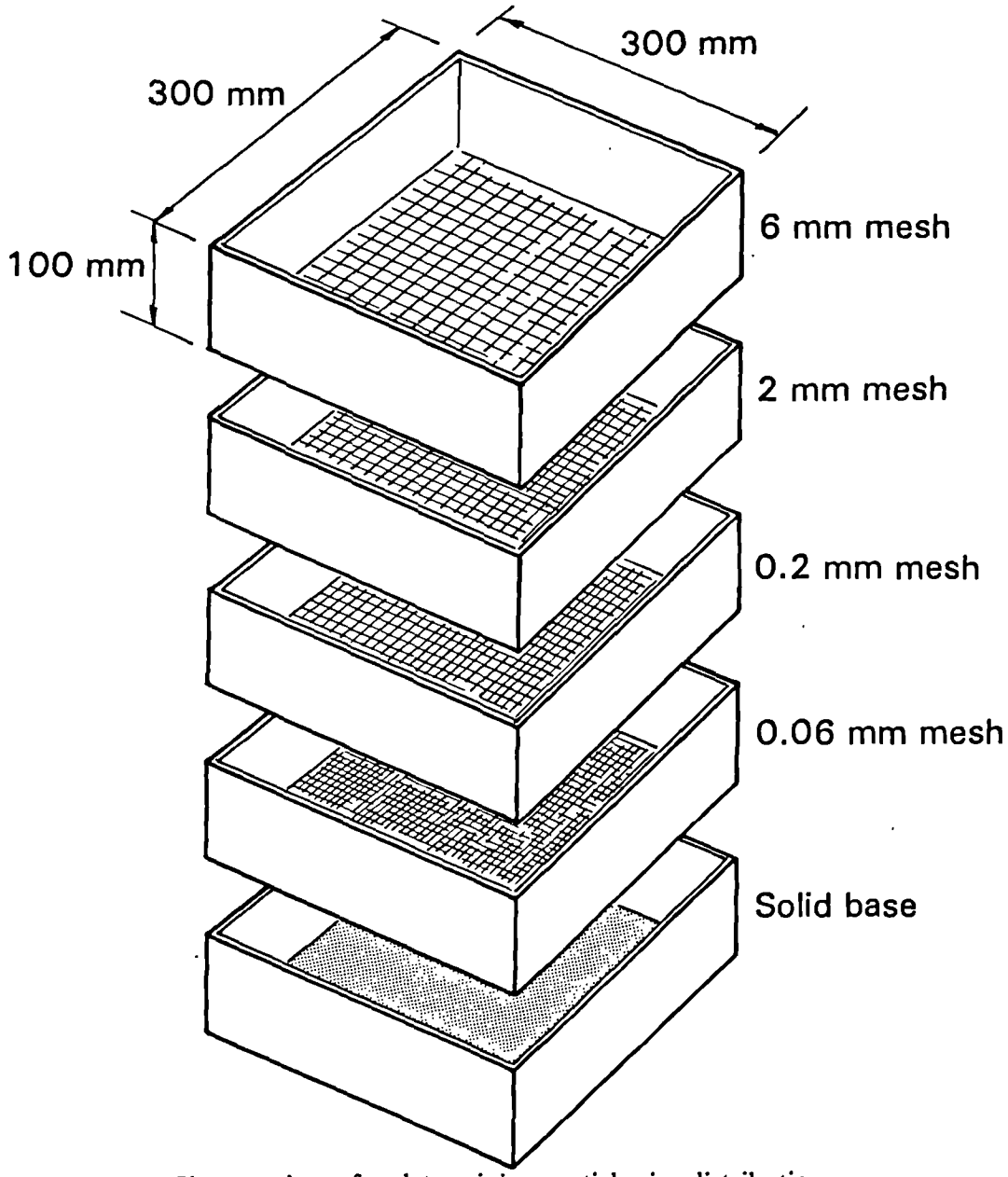


Figure 9 Site test sieves for determining particle size distribution

fractions will rest on intermediate sieves, whilst those passing the 0.06mm sieve will be contained on the lower tray.

When all vertical movement of soil has ceased remove, weigh and record that fraction of soil lying on the top of each sieve and in the tray at the bottom. A simple particle size distribution will then have been obtained for the soil sample.

That fraction retained on the 6mm sieve would be classified as coarse and medium gravel.

That fraction passing the 6mm sieve but retained on the 2mm sieve is fine gravel and that fraction passing the 2mm sieve but retained on the 0.2mm sieve is a mixture of coarse and medium sand.

That fraction passing the 0.2mm sieve but retained on the 0.06mm sieve is fine sand, whilst that fraction passing the 0.06mm sieve is the combined silt and clay fraction.

The results of this sieve analysis will give an indication as to the type of stabilising agent that would be best suited for the soil. Ideally there should be an even distribution of each soil fraction to manufacture good quality stabilised soil building blocks; in this instance about 5 per cent cement would be needed.

In practice, it is generally found that one fraction is greater than the other fractions. For example if there was a higher fraction of coarse and medium sand with a low silt-clay fraction - say less than about 20 per cent - then about 4 to 6 per cent cement should be used to stabilise the soil.

Conversely if the silt-clay fraction is high, above about 30 per cent, about 6-8 per cent lime could be used as the stabilising agent. However there may be a high proportion of silt present which would affect the linear shrinkage properties of the soil and in this case cement may be required.

General Note: There are many on-site tests suitable for testing soil samples which are discussed in a Technical Memorandum No.12 document entitled Small-scale manufacture of stabilised soil blocks published by the International Labour Office of Geneva, Switzerland (29).

3.8 Laboratory Soil Testing

The simple on-site field tests described in Section 3.7 are crude compared with the standards laid down by the relevant British and American Codes of Practice. The results obtained from the 'ad hoc' site testing will give indications of soil suitability for stabilisation purposes but it is advisable to have the site results checked by a soil testing laboratory where equipment can be used to determine more accurately the breakdown of a soil sample.

Many text books have been written covering the procedure of laboratory soil testing and one popular text book often quoted is Laboratory Testing in Soil Engineering by T N W Akroyd (30).

Most of the laboratory tests are extensions of the on-site field tests, but using equipment that would give more accurate results.

The soil moisture content test requires the use of a thermostatically controlled drying oven capable of maintaining a temperature of 105° to 110° Celsius. Using an oven will ensure that the soil sample is dry to start the tests whereas the on-site sun drying will not take into account the relative prevailing humidity. The determination of the liquid limit (LL) can be obtained by either the Cone Penetration Test or the Casagrande apparatus (17).

The Cone Penetration test is the preferred method because the Cone Penetrometer used in this test is simple to use and can be used either on an air dried soil sample or used on a soil in its natural state. Experience has shown that it is difficult to maintain Casegrande's apparatus in accordance with general laboratory standards.

Both laboratory tests to determine the LL are described in (15) and (18) and the results are subject to the judgement of an operator and are outside the subject of this text.

The on-site linear shrinkage test is a fairly accurate and a simple method of determining the clay fraction of a soil sample as compared with the recommended laboratory test as described in (15). The laboratory test involves heating in an oven, up to 110° Celsius, a brass mould which contains the soil sample. The brass mould should be half round, open topped and closed at its ends and should be 140mm long with an internal radius of 12.5mm.

Alternatively the Atterberg apparatus can be employed to determine the linear shrinkage and this involves the use of an open topped mould measuring 19mm x 19mm x 125mm length. In addition to the linear shrinkage test the Atterberg apparatus can be used to determine the liquid limit (LL) and the plastic limit (PL).

Other soil testing apparatus within a laboratory would be used to determine the specific gravity of soil samples, particle size distribution, organic matter content, chemical contents, sedimentation and soil sample compaction tests.

The particle size distribution test covers the quantitative determination of the particle size distribution in a soil down to the fine sand fraction. The combined silt and clay fraction can be obtained by a wet sieving method as described by West and Dumbleton (31) or by a pipette method to determine the individual silt and clay fractions. The procedure given involves the preparation of a soil sample by wet sieving to remove the silt and clay fractions, followed by dry sieving of the remaining coarser material.

The preferred method of determining the presence of organic impurities is given in BS 1924 (32) which consists of determining the pH value (how acid or alkaline the soil might be). A soil rich in lime or chalk is likely to be alkaline whilst a soil which lacks lime or which contains decaying organic matter may be acid. The degree of acidity or alkalinity is measured on the pH scale.

The chief purpose of a full chemical analysis is to reveal all the elements present in a soil. In some instances it may reveal the presence of an unsuspected mineral, which might affect efficient stabilisation, also the chemical analysis results can be used to determine whether the soil can be classified as a true laterite or non-lateritic soil.

A typical chemical analysis is given on Table 6 for two soils used during the project field work and a more extensive list is given on Appendix A6.

TABLE 6 - TYPICAL CHEMICAL ANALYSIS (PERCENTAGE)

Chemical Component		Soil Type	
Name	Symbol	Jamaica Red	Sudan Black Cotton
Aluminium Oxide	Al_2O_3	17.20	9.81
Silica	SiO_2	62.50	61.91
Phosphorus Pentoxide	P_2O_5	<0.01	0.13
Sulphur Trioxide	SO_3	<0.01	<0.01
Potassium Oxide	K_2O	0.25	0.78
Calcium Oxide	CaO	0.35	6.4
Titania	TiO_2	0.93	1.02
Maganese Oxide	Mn_2O_3	0.04	0.31
Iron Oxide	Fe_2O_3	8.39	5.86
Sodium Oxide	Na_2O	1.13	0.68
Magnesia	MgO	0.55	1.95
Loss on Ignition	L.O.I.	9.40	8.90

Note: the chemical analysis normally uses the chemical symbols for identification purposes.

Most of the present day methods for determining the optimum moisture content (OMC) of a soil sample are identical with or derived from a procedure known as the Proctor method (33) which contains the original description of the Proctor method for determining the OMC.

For each laboratory test to be performed satisfactorily a minimum amount of soil must be supplied and in most cases only a few grammes of material is needed therefore it is important that the sample represents the general area of soil that is being considered.
The following table sets out the mass of soil needed for each of the laboratory tests mentioned in the text.

TABLE 7 - LABORATORY TESTING OF SOIL SAMPLES

Type of Test	Soil Group		
	Fine Grained	Medium Grained	Coarse Grained
Moisture content	150g	150g	2-4kg
Liquid Limit LL	500g	1kg	2kg
Plastic Limit PL	50g	100g	200g
Linear Shrinkage	2kg	2kg	3kg
Specific Gravity	300g	600g	600g
Particle Size Distribution	500g	2.5kg	20kg
Organic matter content	150g	600g	3.5kg
Chemical analysis	250g	750g	2.5kg
Compaction test	25kg	25kg	25kg
Sedimentation	200g	300g	-

CHAPTER 4

SOIL STABILISATION

4.1 Object of Soil Stabilisation

The story of the building block begins with the hand formed, sun dried block made many thousands of years ago. Sun dried blocks requiring only labour to make were effective until it was realised that kiln fired blocks, although a luxury, withstood the rigours of the elements much better than the hand made, sun dried block.

The Romans realised that if a soil was mixed with a suitable stabiliser the resultant sun dried block would withstand the elements much better than an unstabilised block. They preferred to use bitumen products which made the soil more waterproof but did not enhance the bearing load or strength of a soil.

So, what is meant by soil stabilisation!

The object of soil stabilisation is to increase the resistance of a soil to the naturally occurring destructive elements and may be achieved by one or more of the following methods:

a. By increasing the strength and cohesive properties of a soil.

b. By reducing the movement of the soil caused by changes in its moisture content.

c. By making the soil less readily wetted.

Various methods to improve the natural durability of a soil have been practised in many couuntries over many centuries usually on an 'ad hoc' basis because the end product justified the means with the manufactured products withstanding the test of time.

Modern day building technology has advanced the use of cementitious materials and chemical compounds to such a degree that the use of a correct stabilisation method might improve the compressive strength of a soil by as much as 400-500 per cent. This improvement greatly increases the soils resistance to erosion and better standards of housing, and living conditions may then be achieved.

Chemical and organic remains present in a soil react in differing ways to standard types of stabiliser therefore the art of soil stabilisation is not a precise topic and is based on experience rather than a text book formula.

4.2 Cement Stabilisation

Cementitious products at present in use can be classified, for convenience, into two main categories: varieties of Portland cement and high alumina cement. All types of cement are classified within British Standards 12 : 1971 (34) and 915 : 1971 (35).

The raw materials used in the production of all types of Portland Cement are calcium carbonate, (which is found in the form of limestone or chalk) and alumina, silica and iron oxide (found combined as clay or shale). The first stage of cement production consists of mixing the clay or shale to a wet slurry and then adding chalk or finely ground limestone.

The second operation is to continuously feed the slurry into the top end of an inclined rotary kiln fired by an ignition source from the kiln's lower end. The slurry is heated to temperatures of about 1500° Celsius and cement clinker is formed which consists of calcium silicates, calcium aluminates and other compounds. The cement clinker is finally cooled and ground to a fine powder resulting in a product called cement.

When cement is mixed with water the cement particles hydrate and unite together to form a hard mass, this process of hardening or hydration is due entirely to the chemical reactions taking place. This unique hardening process is most important when considering soil stabilisation.

Soil consists of gravel, sand, silt and clay fractions and on the application of moisture the clay fraction is the only one that will absorb moisture and swell in three dimensions. It is therefore necessary to reduce this swelling to a minimum by covering each clay particle with a coating of cement so that after cement hydration the clay particles cannot have any further moisture movement.

The action of compressing the soil mix ensures that the individual cement coated clay particles are brought into contact with one another and again as cement hydration takes place a cementitious body is formed. The voids present being filled by the silt fraction.

For economic reasons a minimum amount of cement should be used and this factor is entirely dependent on the total amount of the clay fraction present within a soil mix and it has been found by experimental results that a minimum of 4 per cent of the dry weight of a soil is all that is needed to produce good quality soil stabilised building blocks when produced under a compaction pressure of 10 MN/m^2.

4.3 Lime Stabilisation

Lime has many uses and while its direct use in building work is probably the oldest, it is used today mainly for the manufacture of steel. The 1972 yearbook of the US Bureau of Mines Mineral stated that 5,485,000 tonnes of lime was used in America for the manufacture of steel compared with 1,437,000 tonnes of lime used in the construction industry. It is interesting to note that 802,000 tonnes was used for soil stabilisation purposes mainly in road construction.

The discovery of lime and its useful properties must have been one of the earliest made by man, because at an early stage it was realised that after burning limestone and quenching in water a powder was formed that could be used with water to form a paste that would stick building blocks together.

The modern technique of producing lime is to calcine (burn) some form of calcium carbonate (or mixed calcium and magnesium carbonates) for example limestone shells or coral at a high temperature (900°C to 1100°C) to drive off the carbon dioxide as a gas and quicklime is produced. This product will react quickly with water, forming hydrated lime (calcium hydroxide) in the process of evolution much heat and expansion will occur.

Quicklime, as a product from a kiln will be in a lump form and is either white, grey or yellow. These lumps can be crushed and ground, usually in a tube or ball mill, to form a powder, which is called quicklime. The quicklime powder readily absorbs moisture from the atmosphere and when this happens the process is referred to as air-slaking.

Hydrated lime is formed by sprinkling the quicklime powder with water and this process is referred to as slaking.

The classification of the various types of lime are listed within British Standards 890 : 1972 (36) titled the specification for Building Limes. BS 890 describes the various tests on limes including special reference to lime in tropical climates.

The detailed manufacture of lime in developing countries is discussed in the Overseas Building Note No.161, April 1975 (37).

The principle of lime stabilisation is broadly similar to cement stabilisation with greater chemical reactions but differs in two important aspects.

Firstly the soil moisture content is saturated with calcium ions from the hydrated lime and forms a cementitious compound, calcium silicates which reduces the tendancy for the clay fraction to absorb further water and therefore heavier clayey type soils are better suited to lime stabilisation than those having a higher granular content.

Secondly, as a result of the chemical reaction and the increased electrolyte content of the pure water, the soil and clay particles will flocculate, resulting in an improvement to the clay plasticity and internal texture almost immediately after the application of the hydrated lime.

Both quick and hydrated limes can be used to stabilise soils containing a high clay fraction and during the slow strength development stage four reactions are believed to occur:

(i) Cation exchange which is a chemical exchange of ions, giving the clay particles a lower affinity to water, resulting in a lower moisture movement of the mix.

(ii) Flocculation or agglomeration follows as a result of the cation exchange phenomena and brings together the microscopically small soil particles to form clusters, so making the mix more viscous (or more stiff).

(iii) Carbonation of the lime itself as it reacts with the carbon dioxide from the air which gives rise to the slow hardening effect.

(iv) A Pozzolanic reaction which is a chemical reaction between the clay minerals and the like, yielding hydrated calcium silicate aluminate compounds similar to some of those found in Portland cement. The rate at which this pozzolanic reaction proceeds is temperature dependent, so it is very slow in temperate climates, but usually faster in the tropics.

The chemical phenomenon is well documented and is well presented by Ingles and Metcalf (38) in Soil Stabilisation 1972. The unconfined compressive strength of a lime stabilised clayey type soil can be improved by using various methods as follows:

(i) Finely ground clay material will react better to the chemical changes that occur to a coarser ground clay material.

(ii) Minimising the air void ratio will enable the chemical reaction to occur more vigorously.

(iii) The application of high temperatures will accelerate the internal chemical reaction between the clay fraction and the hydrated lime.

However there are certain disadvantages between these three methods the main one being on economic grounds because it is extremely expensive to grind clay to a fine powder and it has been generally accepted and proven by experimental means that 6mm sieving is sufficient.

To achieve minimum air voids, a lime stabilised soil mix should be subjected to some form of external pressure, ie by a mechanical or manually operated press which will have inherent capital costs.

The early experimental work both at BRS and in Ghana (25,26) suggested that presses operating in the range 8 to 16 MN/m^2 could give satisfactory and economical results. High temperatures will always involve the use of a special type of oven either operated by electricity or solar heating (20). This particular method was patented in 1971 but has not really been successful due to the high capital costs involved.

The author and El Fadil Ali Adam (a Sudanese Architect) (39) studied the effect of lime stabilisation on a typical high clay content Sudanese soil.

Air dried samples of a Sudanese soil obtained from El Hizam, near Khartoum in Sudan were passed through a 6mm BS test sieve and then mixed with 0, 2, 4, 6 and 8 per cent, by weight of hydrated lime with varying moisture contents (8-24 per cent by weight of the dry soil). The engineering properties of this soil are given in Table 8. A series of 3kg batches of soil were mixed dry with hydrated lime for 2 minutes, and

then with water for a further 10 minutes. The mixing was performed in a heavy duty Hobart mixer as illustrated on Plate 13. The mixes were then transferred to air-tight containers and allowed to stand for about 30 minutes before moulding into cylinders.

The author developed a special purpose hydraulic press, shown on Plate 14, that can produce cylindrical test specimens each measuring 50mm diameter by about 100mm length.

Two static compaction pressures, 2 MN/m^2 and 10 MN/m^2 were employed in the special hydraulic press to manufacture a range of cylindrical test specimens from the mixed soil. The cylindrical specimens were demoulded, weighed, measured and sealed in air tight plastic bags for 28 days at 30° $\pm$ 2° Celsius.

Specimens for the wet compressive strength test were removed from their plastic bags 24 hours before the end of the normal 28 day curing period. They were reweighed to determine any loss of moisture content, measured and immersed in water at 30$\pm$2° celsius for 24 hours. Immediately afterwards they were removed from the water bath, carefully wiped with a piece of cloth to remove excess water on the surface and again reweighed to measure the amount of water absorbed on soaking. The specimens were also measured to determine any changes in diameter or length.

Both dry and wet specimens were tested for unconfined compressive strength in a Dension machine, Plate 15 by applying a uniform load at a deformation rate of 1mm/minute. The maximum load exerted by the compression machine at specimen failure was recorded and the dry and wet compressive strengths were computed to the nearest 0.01 MN/m^2, using the equation:

Plate 13 Hobart mixer mixing a soil and lime mix

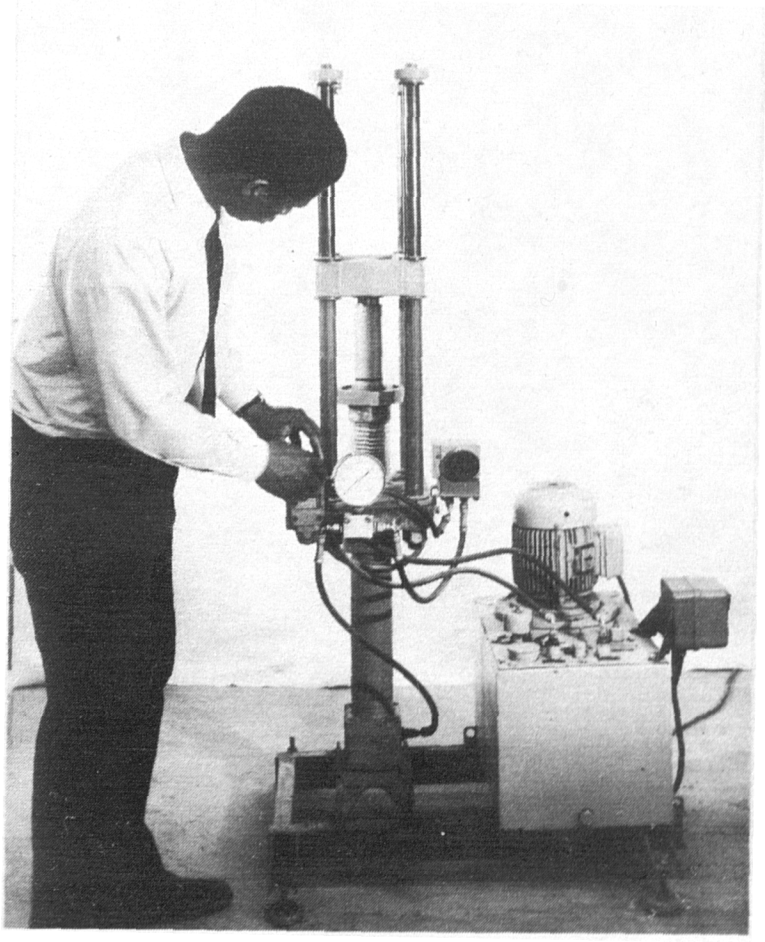


Plate 14 Hydraulic press used to make cylindrical soil specimens

$$P = 5.1 \times 10^{-4} p$$

where P = Maximum recorded load in Newtons

p = Compressive strength in MN/m^2

Constant 5.1×10^{-4} is derived from the overall cross sectional area of the cylindrical specimen.

Sample blocks, 290 x 140 x 100mm deep, were made from the El Hizam soil with 6 per cent lime as the stabiliser and compacted under a pressure of 10 MN/m^2.

Plate 16 illustrates the mode of failure of this type of material when subjected to an unconfined compressive strength test.

TABLE 8 ENGINEERING PROPERTIES AND CHEMICAL ANALYSIS OF THE EL HIZAM SOIL - CLASSIFICATION: CLAY WITH MEDIUM PLASTICITY

Soil Properties %		Chemical Analysis	%
Gravel	6	SiO_2	61.91
Sand	36	Al_2O_3	9.81
Silt and Clay	58	Fe_2O_3	5.86
		CaO	6.40
Liquid Limit	44	MgO	1.95
Plastic Limit	17	P_2O_5	0.13
		SO_3	NIL
Engineering Properties		K_2O	0.78
Linear Shrinkage	11	Na_2O	0.68
Specific Gravity	2.87	TiO_2	1.02
Natural water content	21	Mn_2O_3	0.31
Maximum dry density	1.75 Mg/m^3	Losson ignition	8.90
Optimum moisture content	20%		

Tables 9, 10, 11 and 12 refer to the experimental results obtained from this work.

where w = Moisture content as a % of the dry soil weight

w^1 = % moisture content of cured cylinder

p = Compressive strength in MN/m^2

From these results a series of curves was then plotted of compressive strength against lime content and compaction pressure. Figures 10 and 11 - These curves indicate an optimum lime content of 6% for maximum wet

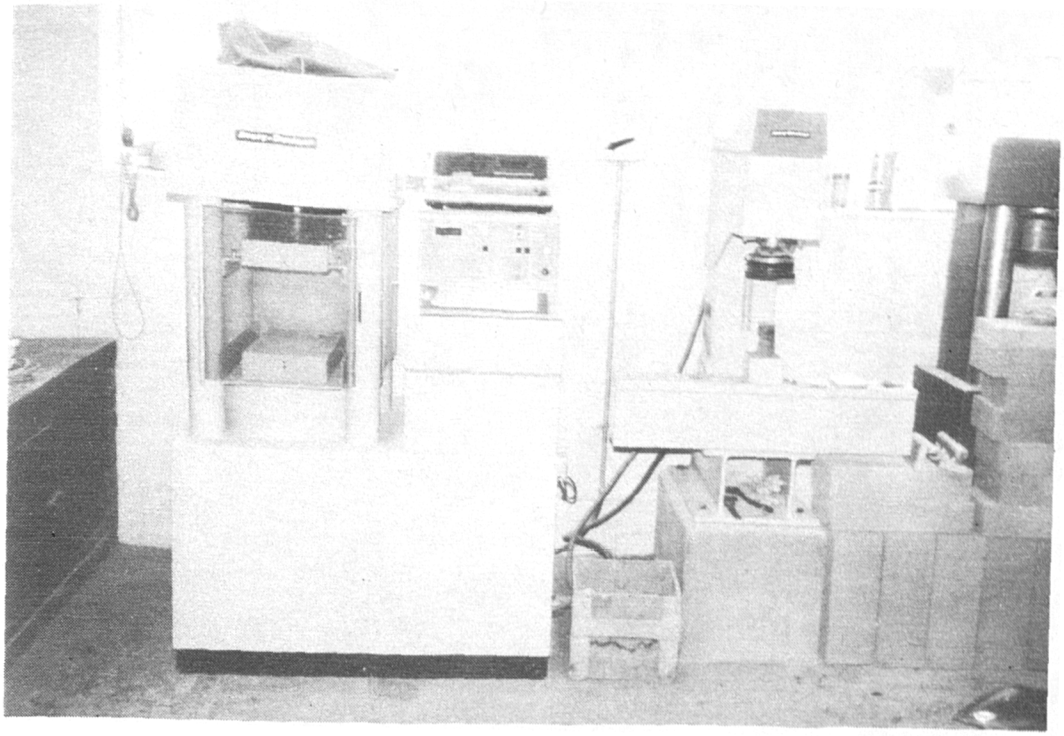


Plate 15 Compression/Transverse load testing machine

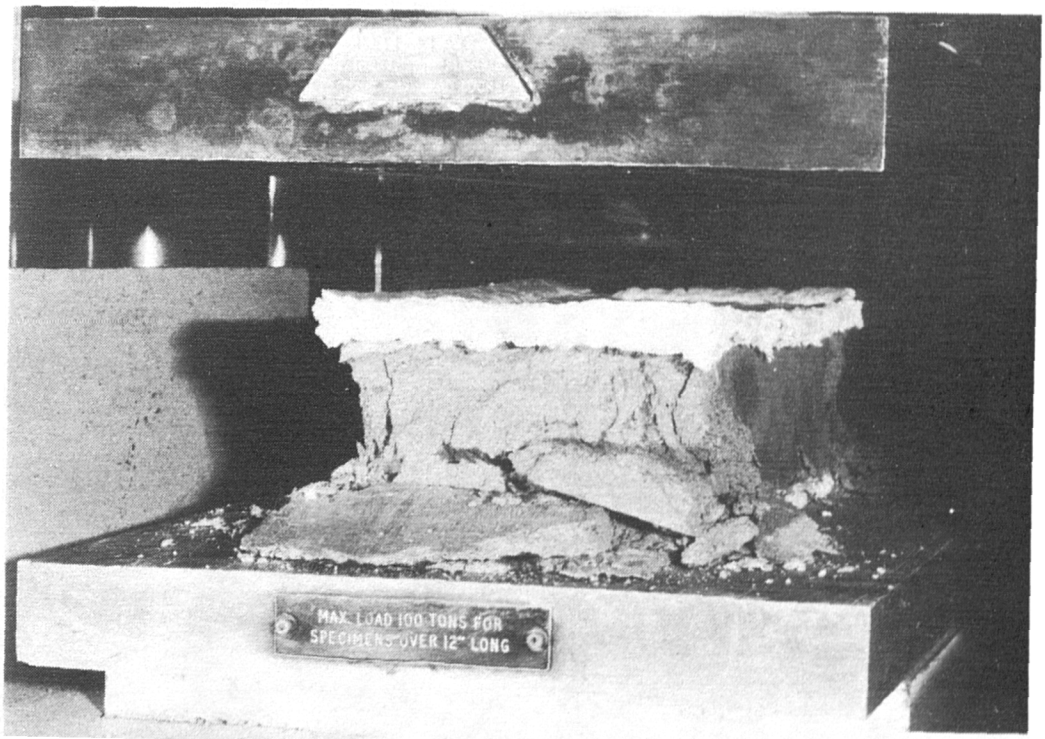


Plate 16 Stabilised soil block after crushing in a test machine

strength. For each lime content, the maximum compressive strengths and corresponding moisture contents are shown in Tables 13 and 14 together with the OMC for each mix.

Once the optimum mix design had been established stabilised soil block specimens were made at both 2 and 10 MN/m^2 compaction pressure to evaluate the effect of curing at 30° Celsius for a period of 6 months. At periodic intervals the blocks were crushed to determine their wet compressive strengths Plate 15 and Figure 12 illustrates the results obtained.

TABLE 9 - DRY COMPRESSIVE STRENGTH, MOISTURE AND LIME CONTENTS FOR SPECIMENS COMPACTED AT 2 MN/M^2 - EL HIZAM SOIL

0% LIME			2% LIME			4% LIME			6% LIME			8% LIME		
W %	P MN/M^2	P'AVER' MN/M^2	W^1 %	P MN/M^2	P'AVER' MN/M^2	W^1 %	P MN/M^2	P'AVER' MN/M^2	W^1 %	P MN/M^2	P'AVER' MN/M^2	W^1 %	P MN/M^2	P'AVER' MN/M^2
12.2	0.69 0.62 0.74	0.68	14.2	1.89 1.89 2.22	2 .00	14.1	2.93 3.52 3.34	3.26	16.4	3.88 3.98 3.90	3.92	16.2	3.34 2.96 3.03	3.11
14.4	0.89 0.82 0.84	0.85	16.0	1.81 2.70 2.27	2 .26	16.4	4.40 4.41 4.51	4.44	18.5	4.05 5.56 4.41	4.67	18.1	4.51 4.05 3.90	4.15
16.3	0.87 0.78 0.78	0.81	18.0	3.08 2.98 2.52	2 .84	17.6	3.95 4.95 4.69	4.53	20.0	5.60 5.55 5.70	5.62	20.0	4.70 4.68 4.72	4.70
17.9	0.63 0.54 0.64	0.60	19.3	2.60 2.56 2.27	2 .51	18.5	4.34 4.16 5.10	4.53	21.0	5.88 5.76 5.81	5.82	22.0	4.44 4.77 4.82	4.68
-	-	-	21.2	1.61 1.89 1.76	1 .75	19.8	4.51 4.87 3.72	4.37	22.8	4.28 4.65 4.95	4.63	23.7	4.18 4.22 4.20	4.20
-	-	-	-	-	-	20.6	4.10 3.98 3.92	4.00	-	-	-	-	-	-

TABLE 10 - DRY COMPRESSIVE STRENGTH, MOISTURE AND LIME CONTENTS FOR SPECIMENS COMPACTED AT 10 MN/M² - EL HIZAM SOIL

0% LIME			2% LIME			4% LIME			6% LIME			8% LIME		
W %	P MN/M²	P'AVER' MN/M²	W' %	P MN/M²	P'AVER' MN/M²	W' %	P MN/M²	P'AVER' MN/M²	W' %	P MN/M²	P'AVER' MN/M²	W' %	P MN/M²	P'AVER' MN/M²
8.4	0.98 1.00 0.99	0.99	11.0	3.20 3.23 3.18	3.20	12.5	6.50 6.60 6.60	6.56	9.5	2.75 2.70 2.65	2.70	14.8	6.80 6.70 6.88	6.79
10.4	1.98 2.02 2.00	2.00	13.0	3.03 3.61 4.36	3.67	14.4	7.47 7.57 6.32	7.12	11.8	4.13 3.86 3.67	3.89	16.0	8.93 8.98 5.62	7.84
11.7	2.48 2.50 2.38	2.45	15.5	4.26 3.94 4.21	4.14	16.5	7.17 7.64 7.52	7.45	15.3	6.66 6.83 5.92	6.47	18.3	8.75 9.10 7.78	8.54
13.1	2.10 2.18 2.08	2.12	18.3	2.98 3.39 3.39	3.25	18.3	6.83 6.83 -	6.85	17.6	7.57 - 7.24	7.41	20.0	6.70 6.72 6.68	6.70
14.1	1.30 1.38 1.32	1.33	20.0	3.14 3.11 -	3.13	19.0	5.41 - 4.46	5.44	19.8	6.76 6.96 6.86	6.86	22.0	7.45 7.55 8.16	7.72
16.3	0.89 0.90 0.89	0.89	-	-	-	-	-	-	23.5	6.20 6.13 6.27	6.20	23.5	6.93 6.73 5.80	6.72
18.1	0.51 0.62 0.55	0.56	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 11 - WET COMPRESSIVE STRENGTH, MOISTURE AND LIME CONTENTS FOR SPECIMENS COMPACTED AT 2 MM/M² - EL HIZAM SOIL

2% LIME			4% LIME			6% LIME			8% LIME		
W¹ %	P MN/M²	P'AVER' MN/M²	W¹ %	P MN/M²	P'AVER' MN/M²	W¹ %	P MN/M²	P'AVER' MN/M²	W¹ %	P MN/MN²	P'AVER' MN/MN²
14.2	1.38 1.15 1.48	1.34	14.1	2.93 3.09 2.58	2 .87	16.4	2.81 2.54 3.32	2.89	16.2	2.07 2.24 2.25	2.19
16.0	1.66 1.66 1.76	1.69	16.4	- 3.49 3.88	3 .69	18.5	4.00 4.26 3.90	4.05	18.1	4.03 4.11 4.08	4.07
18.0	2.04 1.81 1.89	1.91	17.6	5.07 - 4.28	4 .09	20.0	5.00 4.98 5.03	5.00	20.0	3.88 3.90 3.82	3.87
19.3	2.40 2.35 2.17	2.31	18.5	4.64 4.46 4.85	4 .65	21.0	6.53 5.79 5.54	5.62	22.2	4.87 5.25 5.28	5.13
21.2	1.79 1.56 1.61	1.65	19.8	4.79 4.36 4.85	4 .67	22.8	3.77 3.72 3.34	3.61	23.7	4.56 4.80 4.62	4.66
-	-	-	20.6	4.16 4.00 3.88	4 .01	-	-	-	-	-	-

TABLE 12 - WET COMPRESSIVE STRENGTH, MOISTURE AND LIME CONTENTS FOR SPECIMENS COMPACTED AT 10 MN/M² - EL HIZAM SOIL

2% LIME			4% LIME			6% LIME			8% LIME		
W¹ %	P MN/M²	P'AVER' MN/M²	W¹ %	P MN/M²	P'AVER' MN/M²	W¹ %	P MN/M²	P'AVER' MN/M²	W¹ %	P MN/M²	P'AVER' MN/M²
11.0	1.98 1.99 2.05	2.01	12.5	4.90 4.98 5.12	5 .00	11.8	3.63 3.67 3.62	3.64	14.8	4.58 4.60 4.56	4.58
13.0	3.42 3.54 1.97	2.98	14.4	5.37 5.31 5.00	5 .23	15.3	5.80 6.45 5.15	5.80	16.0	5.41 4.46 5.15	5.01
15.5	2.65 2.96 3.90	3.17	16.5	5.74 5.81 5.79	5 .78	17.6	7.37 6.78 6.83	6.99	18.3	6.50 6.04 6.60	6.38
18.3	2.93 2.60 2.81	2.78	18.3	5.03 6.01 5.87	5 .64	19.8	6.73 6.99 7.19	6.97	20.0	6.60 6.58 6.62	6.60
20.0	2.86 2.60 2.81	2.76	19.0	5.31 5.41 5.65	5 .46	23.5	5.80 5.98 5.97	5.88	22.0	6.35 6.48 6.60	6.48
-	-	-	-	-	-	-	-	-	23.5	6.19 6.01 5.80	6.00

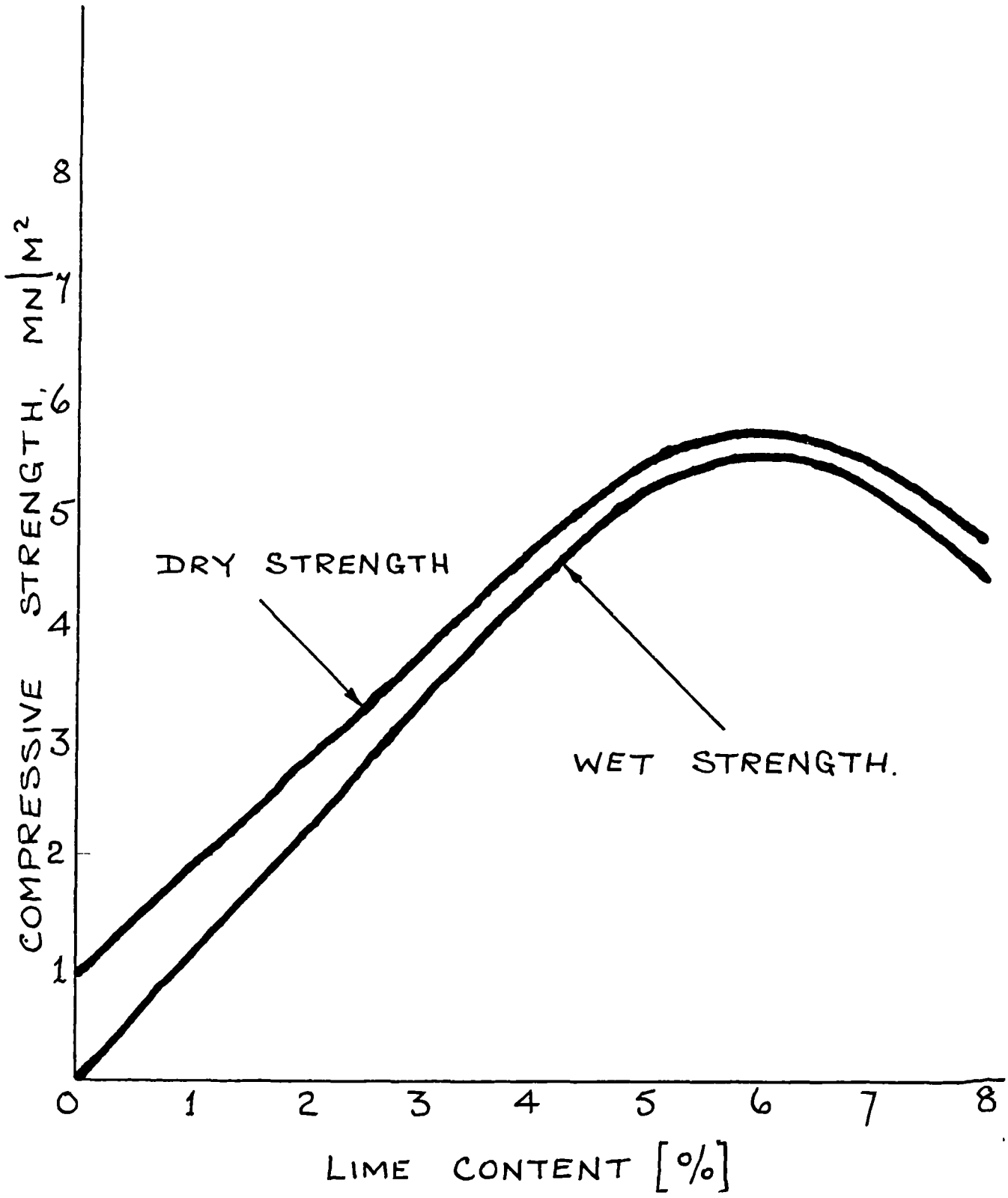


FIGURE 10 :- COMPRESSIVE STRENGTH AGAINST LIME CONTENT, EL HIZAM SOIL COMPACTED AT 2 MN/M²

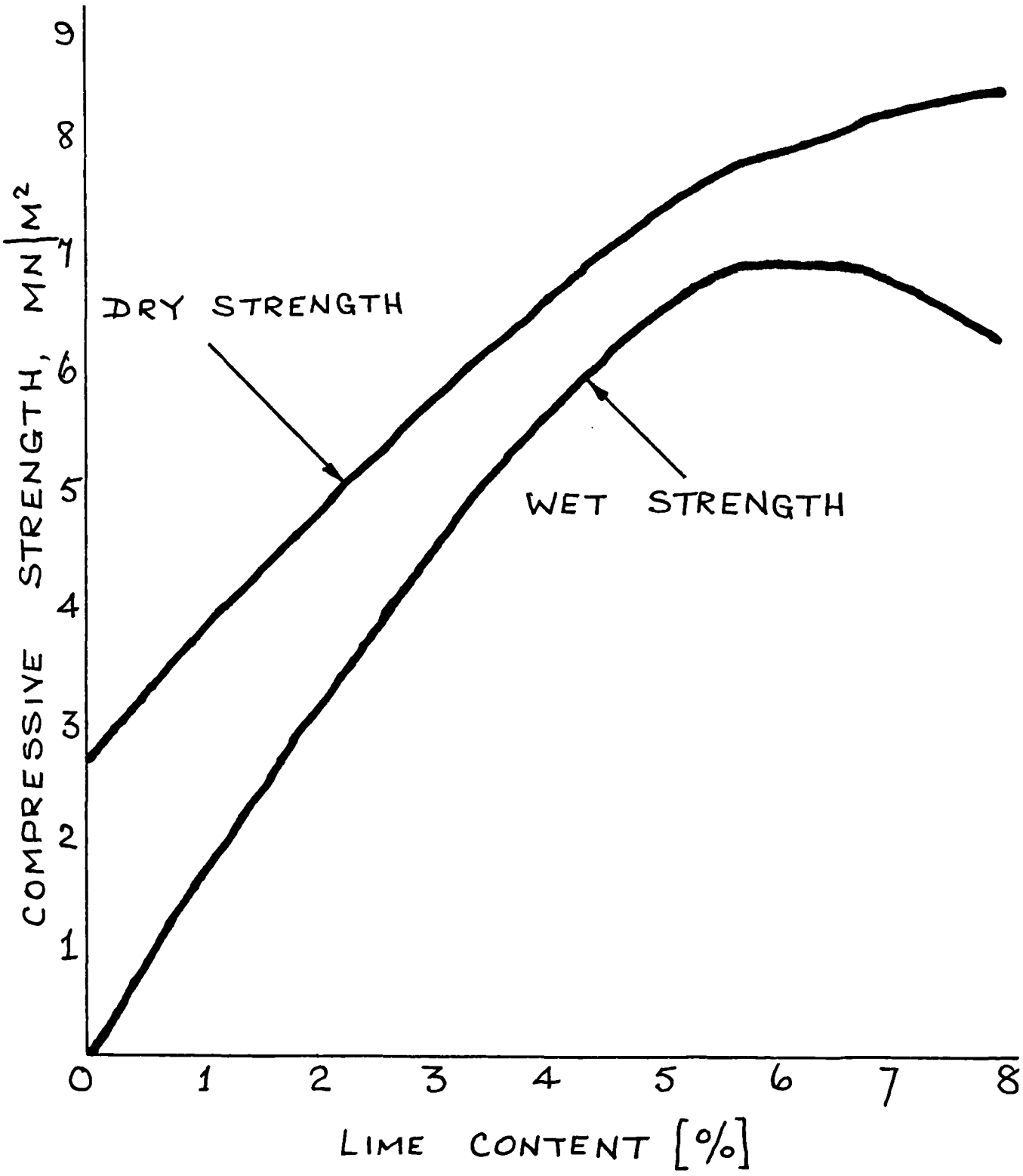


FIGURE 11 :- COMPRESSIVE STRENGTH AGAINST LIME CONTENT, EL HIZAM SOIL COMPACTED AT 10 MN/M²

TABLE 13 LIME CONTENT, DRY AND WET COMPRESSIVE STRENGTH DATA FOR CYLINDRICAL SPECIMENS COMPACTED AT 2 MN/M^2, EL HIZAM SOIL

Lime Content %	Compressive Strength MN/M^2			
	Dry Compressive Strength		Wet Compressive Strength	
	Strength	W,W_1%	Strength MN/M^2	W,W_1%
0	0.85	14.4	0	-
2	2.84	18.0	2.31	19.3
4	4.53	18.5	4.67	19.8
6	5.82	20.8	5.62	20.8
8	5.05	22.2	5.13	22.2

TABLE 14 LIME CONTENT, DRY AND WET COMPRESSIVE STRENGTH DATA FOR CYLINRICAL SPECIMENS COMPACTED AT 10 MN/M^2 EL HIZAM SOIL

Lime Content %	Compressive Strength MN/M^2			
	Strength	W,W_1%	Strength	W,W_1%
0	2.50	13.0	0	12.0
2	4.20	15.5	3.20	15.5
4	7.50	16.5	5.75	17.5
6	7.50	18.0	7.00	18.5
8	8.60	19.0	6.70	20.0

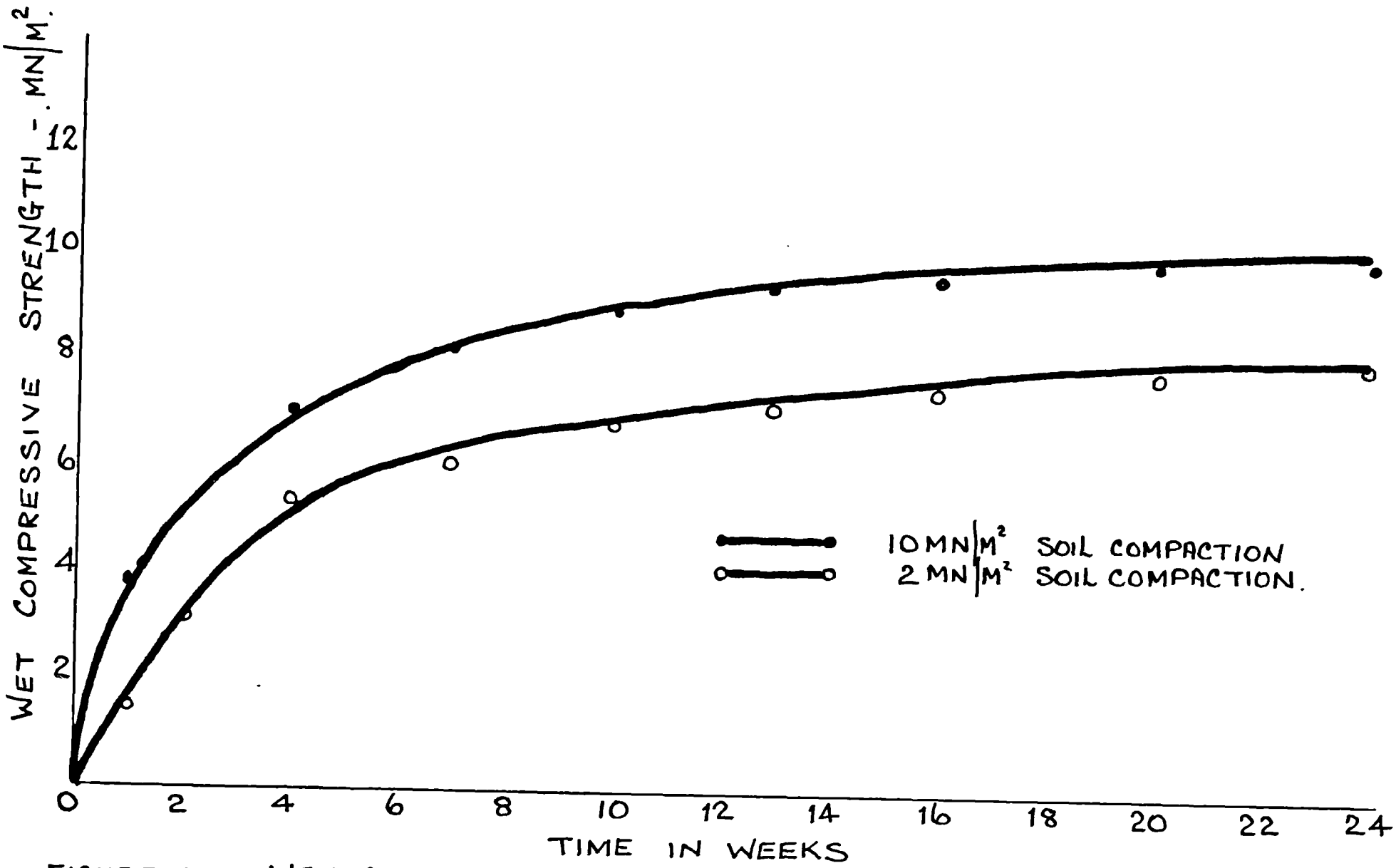


FIGURE 12 :- WET COMPRESSIVE STRENGTH AGAINST TIME FOR EL HIZAM SOIL

Further experimental work was conducted on other Sudanese soils (40) and (41) together with tests on Ghanian soils (42) which have all concluded that good quality building elements can be manufactured with high clay fraction soils using hydrated lime as the stabilising agent.

Improved compressive strength results can be obtained when a lime soil mix is compacted at 10 MN/m^2 containing between 6 and 9 per cent lime.

It has been suggested by several sources that quicklime or lime slurries could also be used for excessively wet or dry high clay fraction soils respectively therefore it can be concluded that lime can be used as a stabilising agent and should not be discarded when considering soil stabilisation methods.

One word of caution should be mentioned that if the lime does contain a high content of impurities this will affect the hardening process, this problem has been encountered in the Yemen Arab Republic by the author and is discussed under section 8.2.7.

It therefore follows that providing the correct soil mix is selected, that there is sufficient clay within the mix and minimum air voids are present, lime can be used as a stabiliser.

4.4 Bitumen Stabilisation

In general usage 'bitumen' refers to natural hydrocarbons and occurs as the non-mineralised substances of coal, crude oil or lignite. Bitumens as a group, are flammable, insoluble in water, but largely soluble in carbon disulfide. Commercially, the term applies to solid and semi-solid hydrocarbons and excludes natural gases.

The use of hot bitumen as a road stabiliser for binding together non-cohesive granual materials is well known but as a soil stabiliser, bitumen is not very popular.

When stabilising a soil with bitumen an emulsion must be made by first breaking down the bitumen in a solvent (diesel fuel or kerosene) and mixing with water so that the bitumen emulsion consists of a fine suspension of bitumen particles.

The addition of bitumen to soil as a stabiliser will affect the properties of the soil in two ways, certainly by waterproofing the soil and possibly by increasing the cohesive strength of the soil dependant on the grain structure of the soil.

In heavy clayey type soils it would be impracticable to coat all the clay particle surfaces mainly because of the high cost involvement.

Asphalt is a type of bituminous deposit formed in an oil-bearing strata by the removal, usually by evaporation, of the volatiles present and occurs as 'tar' pool or 'pitch' lakes.

Natural asphalts were used many thousands of years ago to stabilise soil blocks in Babylon. Similar to bitumen, asphalt would have to be emulsified before it could be used as a soil stabiliser.

Unlike cement or hydrated lime no chemical interaction will take place when a bitumen product is used as a stabiliser. Strength development will occur as an increased friction between the continuous films of bitumen and if this film is too thick the strength will drop away to the shear resistance of the bitumen material.

Some successes have been achieved when using bitumen as a soil stabilising material when granular soils have been used but it is a messy process and the mix design has to be carefully controlled by laboratory testing in the first instance.

Early in 1977 saw the beginning of a pilot project, to provide low cost housing from locally made asphadobe bricks in the suburb of Haj Yousif, 15km north east of Khartoum, Sudan. The equipment used for this project was manufactured in the United States and supplied to the Sudan Government under the US Aid programme.

Asphadobe bricks are made from a mixture of local soil and bunker oil, a petroleum by-product which is 75 per cent asphalt, mixed and compacted in a machine the resulting bricks being sun dried.

Dr Abdel Halim Awad in his article in Sudanow Development (43) clearly regards the asphadobe as a personal challenge and is confident of its eventual success. One tonne of ashphalt residue will make 12,000 bricks when mixed with about 30 cubic metres of soil.

On the economic side a tonne of asphalt cost about £10 in 1978, rising to £16 in 1980 and now costs about £24 per tonne in 1985.

There are two ways why bitumen stabilises soil:

(i) Acts as a binding agent which causes a small increase in strength particularly in granular soils. Generally, small amounts of bitumen (2% to 6%) give the soil increased cohesion properties as discussed by Ola (44). Larger amounts of bitumen tend to act as

a lubricant separating the particles and thus reducing the strength.

(ii) More importantly the bitumen acts as a water repellent and when mixed with a well graded soil could act as a foundation wall provided the soil mix is rammed into position.

High clay fraction soils would require uneconomically larger amounts of bituminous material for reasonable results.

The main disadvantages when considering bituminous material as a soil stabiliser are:

(i) Not a traditional building material for most developing countries.

(ii) Preparation costs are high (heating, storing and mixing) and is certainly a dirty process.

(iii) Bitumen products may be available from an oil refinery otherwise they would be expensive to import into a country.

(iv) Adverse effect of heat on their binding properties.

4.5 Gypsum Stabilisation

Gypsum Plaster (or Plaster of Paris) is a traditional material in many Mediterranean and Middle East countries (45, 46 & 47) especially employed for finishing internal wall surfaces and for the moulding of

decorative shapes. It was used in Egypt over 4000 years ago and gypsum plastering was introduced into England during the 13th Century.

Gypsum or calcium sulphate is produced by heating gypsum rock to about 170° Celsius, at which temperature 75% of the water of crystallisation is driven off leaving a white powder referred to as hemi-hydrate or plaster of paris.

By adding water to plaster of paris, a rapid set takes place making it a most useful material for the moulding of intricate shapes, however, in the solid state it readily absorbs moisture and will eventually soften.

Gypsum plaster has been used occasionally as a soil stabiliser for medium range clay content soils, but blocks made with such a mix are not very durable due to the low water resistance and therefore should only be used for non load bearing internal walls.

In the Yemen Arab Republic, gypsum plaster is used externally on walls and especially for the moulding of curved window frames. This material stands up to the weather conditions quite well because of the low rainfall and high temperature conditions.

Average yearly rainfall of 8.6mm measured over a period of 5 years and an average temperature range of 43° Celsius (max) down to a minimum of 10° Celsius.

Compared with say Kenya, where the average yearly rainfall is 32mm measured over a period of 12 years with an average Max/Min temperature variation of 31°C/12°C.

This information has been taken from the Meteorological Office data tables.

Many countries in the third world produce gypsum and some even export it because it has a wide use in the agricultural and chemical industries. One of its main uses in the building industry is as a retarder in the production of Portland cement.

Little is known of gypsum stabilised soil building elements as an external material although in Australia it has been used for external walling which has a protective covering or cladding of metal sheeting as reported at a New Building Materials Symposium held in Iraq in 1979 (48).

Therefore extreme care must be exercised when considering the use of gypsum as a soil stabiliser especially in areas where dampness will occur.

4.6 Alternative methods of soil stabilisation

So far, we have discussed the three most popular methods of soil stabilisation - Cement (4.2); Lime (4.3); and Bitumen (4.4); however there are many other materials and techniques available which could be used for soil stabilisation. For convenience these can be classified into three main groups; namely:

(i) Mechanical, (ii) Chemical and (iii) Physical.

(i) The man made or naturally occurring 'Mechanical' type of soil stabiliser will not affect the chemical composition of a soil, for example, sisal fibres, flax, steel bar or meshes.

This method of soil stabilisation is an indirect method of improving the overall strength of a soil mix similar to that of using steel reinforcement bars or mesh within a concrete mix. The advantage of using naturally occurring materials would be, that they are cheap and readily available whereas steel bars or mesh would be difficult to obtain and expensive. However using the mechanical method of soil stabilisation has obvious disadvantages. The indigenous materials used would only have a short useful life being prone to attack by ants and termites and the soil mix would not be protected against the rigours of the elements leading to soil erosion and ultimate failure.

(ii) The man made or naturally occurring 'Chemical' stabiliser will alter the basic chemical composition of a soil, some acting with a cementitious property, others as a water proofing agent to increase the wetted strength of a soil.

Man made chemicals that have been used for stabilising purposes would include sodium silicates (sometimes called water glass) which is available in many parts of the world, sodium chloride (common salt), sodium hydroxide (caustic soda) and resins and polymers.

Naturally occurring chemicals would include animal dung, crushed ant heap, cattle urine, juices from various plants, palm oil and molasses.

In Ghana, for example, the seed pod husks of the Dawa-Dawa tree are boiled for about six hours and allowed to stand overnight to cool. The resulting liquid 'Aam' is then applied to the earthen constructed houses and gives added protection to the walls increasing the useful life span of a building by at least another three years. This liquid has also been used as a form of chemical stabiliser in with cob construction - see section 2.2.3.

Chemical stabilisers can be expensive and care must always be exercised when using an acid as a soil stabiliser. Much research is being conducted by the major chemical organisations in the field of soil stabilisation and when a new product is developed it is usual for the organisation to seek patent protection increasing the cost to the final user in the field.

Commercial by-products have been investigated as a possible form of stabiliser for soils, for example mining residue, incinerator ash, settlement sludge from urban waste water purification, fly ash and liquid slag. Various articles have mentioned these by-products from industrial processes but little is known on the end product with regards to durability and strength.

(iii) Soil stabilisation by 'Physical' means comprises the use of thermal, solar, electrical or osmotic methods, the basis being that of heat which affects the chemical constituents within a soil.

It is a well known fact that once a lateritic type of soil has been excavated from the ground and left exposed to the atmosphere the moisture content will evaporate and the soil will 'harden'

off. This particular process will occur under ambient temperature conditions in a tropical climate.

However experimental work has shown that higher soil strengths can be achieved if certain types of soil are autoclaved as previously mentioned in Section 3.3.3.

Microwave methods have been employed to increase the curing temperature of a soil so that with rapid temperature rises strong soil products have been manufactured.

No additives are used in this method so the cured soil products are still subject to erosion by the elements.

Physical curing methods on lime stabilised soil building products are discussed in (20) using temperatures of about 100° Celsius.

In general, soil stabilisation by Physical methods have proved to be just beyond the reach of economic justification and is therefore not widely used however it is an area where research could be conducted in the future.

4.7 International Studies

About twenty students in various countries have written their own dissertations for first and second degrees on the subject of soil stabilisation with reference to the Brepak machine. The first student was A E Fernandes (49) from the University of Nairobi. E F A Adam (39) completed an in depth study of Low Cost Housing in the Sudan again with reference to the Brepak machine (see Chapter 7). As mentioned in

section 6.2.21, Agas Groth sought the views of the author when developing an impact method of making stabilised soil building blocks (50) and compared the results of the Brepak machine with his Ranko-Soil Cement Block Machine (see section 6.2.21). As mentioned in Section 6.2.26 detailed information on soil stabilisation techniques was given to the chief engineer of Zora International Ltd whose company later developed the Zora Hydraulic Press Machine.

A C O Ogolla, an architectural student from the University of Nairobi (51) investigated the thermal response of various earthen buildings in the African continent and compared the thermal properties of several forms of earthen constructed dwellings. He concluded that with stabilised soil blocks made on the CINVA-Ram machine, they would have a density of around 1750 kg/m^3 and a thermal conductivity value of about 0.58 W/m deg C whereas the higher density blocks made on the Brepak machine would have a density of about 2000 kg/m^3 and a thermal conductivity value of about 0.65 W/m deg C.

Note: Due to the earth's low thermal conductivity level most earthen constructed homes are well insulated due to the thickness of walls.

Earth has a thermal conductivity value in the order of 0.5 W/m deg C for mud brick or adobe, compared with about 1.21 W/m deg C for burnt brick, 1.44 W/m deg C for concrete and 1.53 W/m deg C for limestone (52)(53).

The conductivity varies particularly according to the amount of air (which has a conductivity value of 0.26 W/m deg C) contained in the soil. Compacted blocks made on the Brepak machine have a low air void ratio and it follows that the thermal conductivity for a brepak made block would be greater than the value of the adobe block.

Patients visiting the medical clinic at Kawangware (see Section 8.2.1) have often remarked that it was like going into a cool refrigerator even with a hot tropical sun outside the building.

M D Monayem Dad, a Bangladesh student at the University of Newcastle-Upon-Tyne, in his thesis entitled 'The use of cement stabilised soil for low cost housing in developing countries' (54) claims that soil types defined by an upper liquid limit of 34% and a lower limit of 20% can be adequately stabilised with as little as 6 per cent cement resulting in significant cost savings when compared with concrete block built structures.

Several other students at the University of Newcastle are studying different aspects of soil stabilisation ie Abul Khair, a Bangladesh student investigating the production of irrigation channel sections from the Brepak machine; A Shakoor Raji conducting stabilised soil research work in Turkey; Abdi M Sabrie, a Somali student who is completing his thesis entitled 'Local Building Materials in Somali' and M.A.S. Bhuiyan a Bangladesh student is completing a thesis investigating the bonding behaviour of stabilised soil products from the Brepak machine. These students have all approached the author for help and assistance in stabilising various types of local soils.

An Oxford Polytechnic student from Algeria, Bousmala Baiche has been in contact with the author regarding the possibility of combining traditional materials and construction techniques with appropriate modern technology (ie the Brepak Machine, to improve rural housing in Algeria.

An interesting report written by Zulkarnan Aksa from the Indonesian Building Research Institute in 1984 entitled 'Batako for Housing' - (A Lime Stabilised - Soil Building Material)(55). States that a mixture of Batako (soil) and dry slaked lime in the ratio of 4 : 1 by volume (or 2 : 1 by weight) has been used in a CINVA-Ram press to produce blocks which are either atmospherically cured over a period of several weeks or kiln fired which only takes a few days. The resulting costs being higher than the cost of a fired clay brick. A Brepak machine could be used to produce a cheaper and superior type of product being produced.

4.8 Comparisons of Soil Stabilisation Methods

Soil stabilisation is not an exact science because there are so many different kinds and types of soil it is impossible to say whether any one stabiliser will work well on any particular soil. The criteria is that a stabiliser should be economic and easy to use, increase both the dry and wet strengths of a soil, reduce the amount of water absorption and produce an acceptable product that could be utilised to build a home.

Generally a stabiliser would only improve the soil qualities on two or three of the above points and therefore it may be advisable to use more than one stabiliser when improving the qualities of a soil.

Asphalt or bitumen could well decrease the strength of a stabilised soil block but these stabilisers are essentially waterproofers and would certainly decrease the amount of water absorption and should be used on gravelly soil type. Cement or lime used as a soil stabiliser would greatly increase the wet strength of a soil product without much affect on the amount of water absorption.

It is essential that a soil building product is able to withstand compressive loading when built into a wall and it is recommended in BS 6073 - Part 1 1981 (56) Precast Concrete Blocks that the minimum suggested design compressive strength of precast concrete blocks be 2.8 MN/m^2 for adequate strength and durability. BS 3921 : 1974 (57) Fired Clay Bricks also stipulates the minimum compressive strength of fired earth, clay or shale blocks as 2.8 MN/m^2.

The National Housing and Building Research Unit in Dar-Es-Salaam Tanzania has for a number of years been comparing the effect of using different stabilisers (58) on a particular lateritic type of soil and they have published a useful pictorial comparison of where different stabilisers could be used. This comparison chart is shown on Figure 13 and has been partly modified to comply with the standard size of clay particles.

It can be seen from Figure 13 that asphalt and bitumen are best suited for stabilising gravelly/sandy soils Section 4.4.4 but it is expensive and difficult to ensure complete mixing with a soil.

Cement is the most commonly used stabiliser and the best results are obtained when it is used to stabilise sandy type soils whose clay fraction is less than about 30 per cent. The quantity of cement needed to stabilise a soil varies between about 4-20 per cent by weight of dry soil dependent entirely on the distribution of the soil particle sizes and the method of manufacture.

Lime makes a good stabiliser for clayey type soils and is usually used between 4 and 20 per cent of the dry weight of the soil which is again

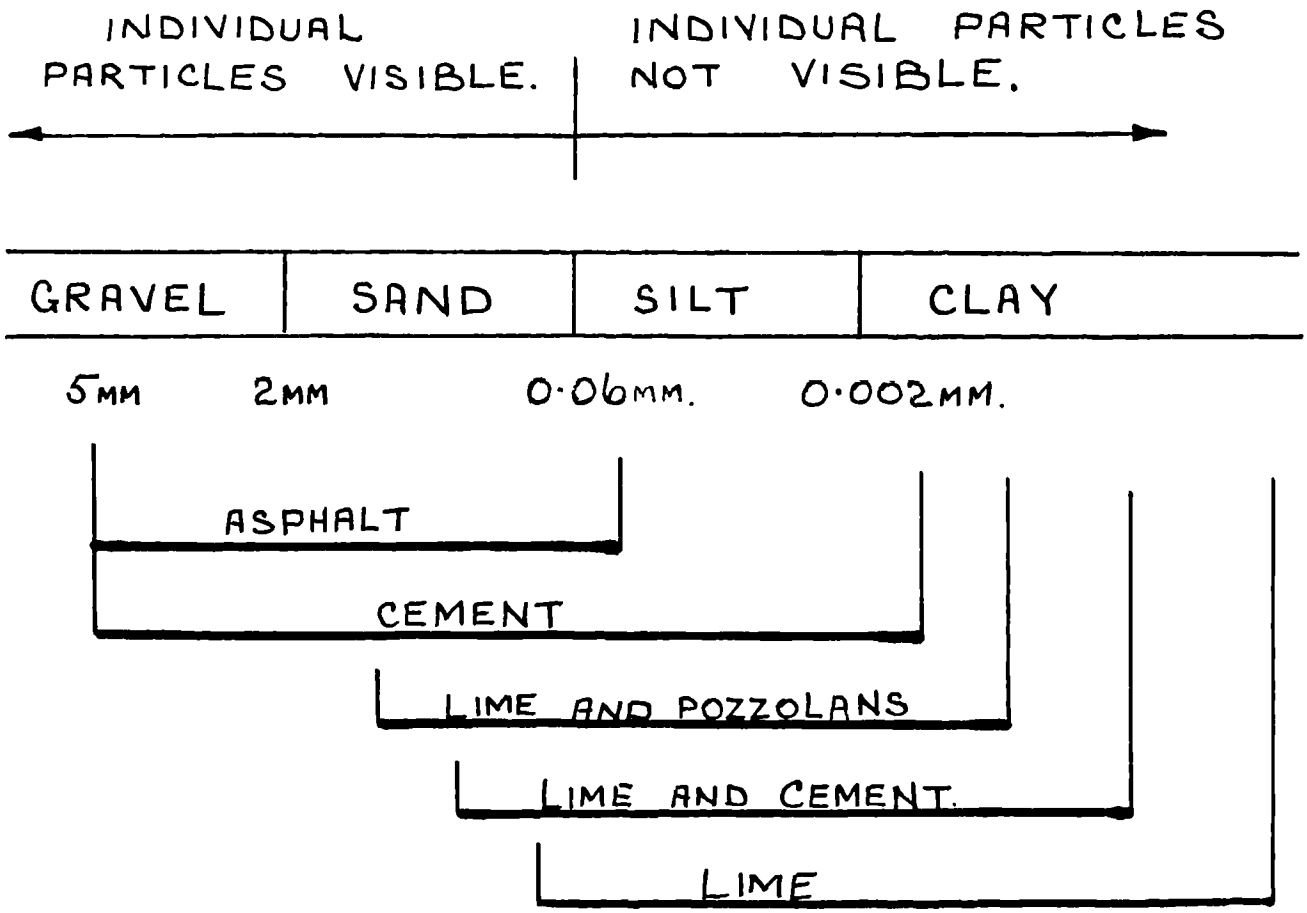


FIGURE 13 :- RECOMMENDED TYPE OF STABILISER IN RELATION TO THE TYPE OF SOIL.

dependent on the soil particle size distribution, and the pressures employed during manufacture.

Pozzolona is another type of stabiliser which is rich in silica and occurs as volcanic ash, pulverised blast furnace slag, pumice or silica flour.

When pozzalana material is mixed with hydrated lime the reaction is similar to the resulting strength when using cement but the strength development takes considerably longer than with cement alone. The combination of lime and pozzolana can be used for both sandy and clayey soils. The field application of different stabilisers will be discussed in Chapter 8.

It is now apparent that the percentage clay content present in a soil is a crucial factor when deciding which type of stabiliser should be used when stabilising a soil. Personal experience over several years coupled with numerous overseas field trials and experiments have proved that if the percentage clay content exceeds 40 per cent ONLY hydrated lime should be used as a stabiliser. If however lime is not available the percentage clay content must be reduced by the addition of sand to a soil mix and Portland cement used as a stabiliser.

For example the average percentage clay and silt content of Egyptian soil is about 60 per cent and to manufacture sun dried, unstabilised blocks a mix of one part sand to two parts clay are used, thus reducing the effective percentage clay content down to about 40 per cent of the mix.

All the preceeding amounts quoted for the various stabilisers for different soils apply to when medium compacting forces are used in the manufacture of a soil building product. This compacting force of about 2 MN/m^2 is generated within the CINVA-Ram block making machine, (see Section 6.2.3) however it has been established within the laboratories at BRS that using a higher compaction force of about 10 MN/m^2 will produce a superior grade soil building product with a lower percentage of stabiliser. Therefore economics must also be evaluated, (discussed in Chapter 10) when considering the suitability of a stabiliser.

In Kenya, good quality blocks have been made from Murram soil containing about 16 per cent clay stabilised with 4 per cent cement by weight under a compacting pressure of 10 MN/M^2 - See section 8.2.1. This compared favourably with blocks being made on a Block press machine - Section 6.2.6, which used 18 per cent cement as a stabiliser. In this case the compacting pressure was 2 MN/M^2.

When using a Brepak machine, (Chapter 7) the following table should be used as a guide for estimating the quantity of cement or lime stabilising agent. Based on the shrinkage test result - Section 3.7.2.

Less than 15mm	- Probably insufficient clay
15mm to 30mm	- 1 part cement to 20 parts soil
30mm to 45mm	- 1 part cement to 15 parts soil, OR
	- 1 part Lime to 7 parts soil.
45mm to 60mm	- 1 part cement to 12 parts soil, OR
	- 1 part Lime to 6 parts soil
More than 60mm	- Insufficient sand - Soil is not recommended for blockmaking unless more sand is added.

Stabiliser to soil ratio is best measured by volume. When considering the use of lime as the stabilising agent, the lime must be of good quality and remember that lime must be handled carefully to prevent injuries to the operator.

CHAPTER 5

A REVIEW AND APPRAISAL OF RESEARCH ON SOIL STABILISATION

5.1 Review of Soil Stabilisation

Soil has been used as a building material for the construction of walls and roofs from the earliest times. Naturally soil is abundant and cheap, but is not very durable when subjected to moisture when being used on its own and therefore has to be protected in some way.

Methods to improve natural durability ie to stabilise the soil have been practised in many countries in the tropics. These methods range from surface protection coatings to the addition of stabilisers to the soil. This method is not new, indeed, stabilisers such as bitumen, plant juices, natural oils, cow dung and crushed ant-hills, have been used for many centuries.

During the early 1960's machine pressed lateritic soil blocks stabilised with cement and cow dung were made on a housing resettlement programme in southern Ghana. The majority of these buildings are still in good serviceable conditions today.

In 1966 Fresno State College, now the California State University, Fresno, USA became interested in better techniques for stabilising soils used for construction purposes and established the International Institute of Housing Technology. This Institute was chiefly concerned with research and developments which increased the weather resistant qualities of blocks made from soil and studied in great depth the effect of stabilising a soil using bitumen emulsions or liquid asphalt.

Promising results were obtained and are discussed in a publication by the International Institute of Housing Technology in 1972 (59). The interesting concluding remarks being that soils containing 2.0 per cent or more of soluble mineral salts are not recommended for use in asphalt or bitumen emulsion stabilised soil blocks.

Indigenous building materials are not permitted by many local urban authorities because they are generally associated with rural areas, except under exceptional conditions in some tourist hotels and lodges. When reluctantly accepted, they are classified as temporary materials this being partly due to the inflexible building by-laws. The majority of the world's poor population live in the rural areas and are generally left to their own devices to provide their own housing.

In the Nyanza province of Kenya for example, traditional round housing varies in size from 4 to 7 metres in diameter and constructed in wattle and mud daubing would last about 7 years. However in more recent years the mud has been stabilised with alternative materials such as plant juices, natural oils, cow dung and crushed ant-hills. This stabiliser addition to the mud has increased the useful life span of buildings to about 10/12 years.

In West Africa, compound houses in common with most traditional building, which is the product of long development, make good use of the limited local materials and techniques available.

For example, in northern Ghana the traditional form of building is a single cell, circular in plan varying in size from 2 to 3.5 metres in diameter. Usually each cell has a removable 'top hat' referred to as a sumpiko which is made from thatch and when moved sideways improves the

ventilation within the cell unit. This single cell unit is repeated numerous times to form a circular compound and the space between each cell unit is filled with a stout timber fence or screen to prevent any unwelcome intruders from entering the main compound area.

The individual cells are used for sleeping, cooking, animal shelter, food and general storage. The size of a compound depends largely on the number of wives that the owner has but the number of cells may often be increased by other members of the owners family including his fathers widows and their dependants.

Generally each individual cell unit is constructed by the COB method - See section 2.2.3, plastered internally and externally with wet mud and cowdung. Further protection against weathering is obtained by spraying with Aam - a liquid obtained from boiling empty Dawa-Daws tree pods or a thatched layer of grass reeds normally held in place by sisal. The thatch cover is also used to prevent fungus growth on the earthen wall.

A series of laboratory trials on soil cement, using a Proctor cylinder were conducted at the Faculty of Engineering, University of Ceylon (Sri Lanka) during the late 1960's which were reported in an article in The State Engineer in 1969 (60). This article states that the properties of natural soils can be improved by stabilising them with cement, lime, bitumen, etc. Cement is probably the most useful stabiliser as it improves both the strength and resistance of the soil to erosion by water. The soil cement product also has the desirable properties of being fire proof and termite free.

Having conducted these laboratory trials, no actual compaction figures were given nor any site trials performed but the article concluded that economic blocks could be made.

In work carried out by Rosenak (61) (1957) on rammed cement stabilised soil walling in Burma, a cement content of only 5 per cent was needed to improve the load carrying property of a clay soil.

In dry arid regions of the world unstabilised soil has been used as a building material and many earth dwellings have survived for centries but in wet humid areas the earth construction rapidly deteriorates, due to surface erosion.

It is generally accepted that the road builders first developed scientific methods for stabilising various soils and they have learnt most about the way many kinds of soils will behave under a wide variety of conditions. However during World War II and the subsequent post war years, civil engineers in Western Europe and the United States made considerable use of local materials with certain binding agents for road construction. It was during this period that an extensive programme of research in the use of soil-cement for road construction was initiated in various parts of the world. This was followed by large scale experimental tests, to understand more fully the limitations of soil-cement as a material of construction.

The United Kingdom's Department of Scientific and Industrial Research (DSIR) was involved in some of this experimental work on road construction and an airfield construction course was held at the Road Research Laboratory during July - August 1943.

Subsequently the Building Research Station (BRS) decided to devote some of its resources to the subject of stabilising soil for building construction and to offer help and assistance to colonial countries on this subject.

In June 1948, DSIR in consultation with the Colonial Office appointed Mr G A Atkinson, B.Arch, ARIBA to act as Colonial Liaison Officer at the Department's Building Research Station. To facilitate the interchange of information on Colonial building and housing matters, Colonial Governments nominated, at the request of the Secretary of State for the Colonies, officers who were able to correspond directly with the Liaison Officer on technical matters.

5.2 Experimental building constructed at Building Research Station using cement stabilised building blocks

This section describes some of the research and experimental work conducted at BRS and abroad on the subject of improving house construction methods using various stabilisers with soil.

After the Colonial Liaison Officer was appointed at BRS considerable knowledge was gained in the use of soil cement construction through field work carried out in the Carribean Islands and East and West Africa. In particular, the work of the Overseas Food Corporation in the field of cement stabilisation had been followed with interest by the UK War Department.

In January 1949, there appeared to be a specific commitment in North Africa, by the Colonial Office, for stabilised soil to be used on a construction project and soil samples from the Cyrenaica region of Libya

were supplied to BRS for examination. BRS reported that the soil from Libya contained 14 per cent content of fine clay and was suited to stabilised soil construction using a 5 per cent cement content of stabiliser by weight.

A similar type of soil was obtained in this country and a quantity of bricks were made in Sheffield using a standard rotary sand lime brick machine. The bricks were made with a moisture content of 11.5 per cent and a 5 per cent cement content under a compaction pressure of 28 MN/m^2 (4000 lbs/in^2).

After pressing, the yellow-coloured bricks were stacked in the open air, under cover, to atmospherically cure for a period of three weeks. During this curing period no attempt was made to moisten down the bricks because of the existing humidity in the atmosphere. When the bricks had been cured they were found to have an average dry compressive crushing strength of 7 MN/m^2 (1000 lbs/in^2).

After the curing period the bricks were transported about 150 miles by road to BRS at Garston, Hertfordshire, UK where the experimental building shown on Plate 17 was erected in 1950. The supervising engineer was Col J L Lishman, research and development engineer to Messrs Taylow Woodrow in consultation with BRS staff and Capt J H F Foster was the War Office engineer in charge of the project.

An article written by Capt J H F Foster appeared in The Builder 181 (5665) 359, 1951 (62), explained the background to this joint experimental house using soil cement construction techniques. The experimental building 9,030m (30ft) by 5.49m (18ft) was erected under entirely normal building conditions such as obtained on any UK building

site and was later used to investigate various external surface treatments.

An article in Building Research and Practice March/April 1974, (63) by R G Smith, Overseas Division, BRS describes the various surface treatments applied to this experimental building.
Plate 18 shows a plan view of this experimental building.
Plate 19 is a photograph of the experimental building taken in 1981 thereby illustrating that the building is now 31 years old, and is still used regularly as a store thus proving that stabilised soil can be used as a good building material provided that the correct production methods are used.

The building is still usable in 1987 although in some parts erosion has occurred due to some of the severe winters that the building has been exposed to especially in the mid 1960's. See Appendix A6 for details of the soil used for this experimental building.

5.3 Laboratory research work on stabilised soils conducted at BRS from 1974

During the twenty-four years between 1950 and 1974 the only research conducted in soil stabilisation was that performed by the various block making machine manufacturers in conjunction with the development of their own machines. Nearly all these manufacturers claimed that cement was the ideal stabiliser that should be used in the production of stabilised soil building blocks.

Many thousands of houses were constructed during the period 1950-1974 using cement stabilised building blocks and these blocks had been

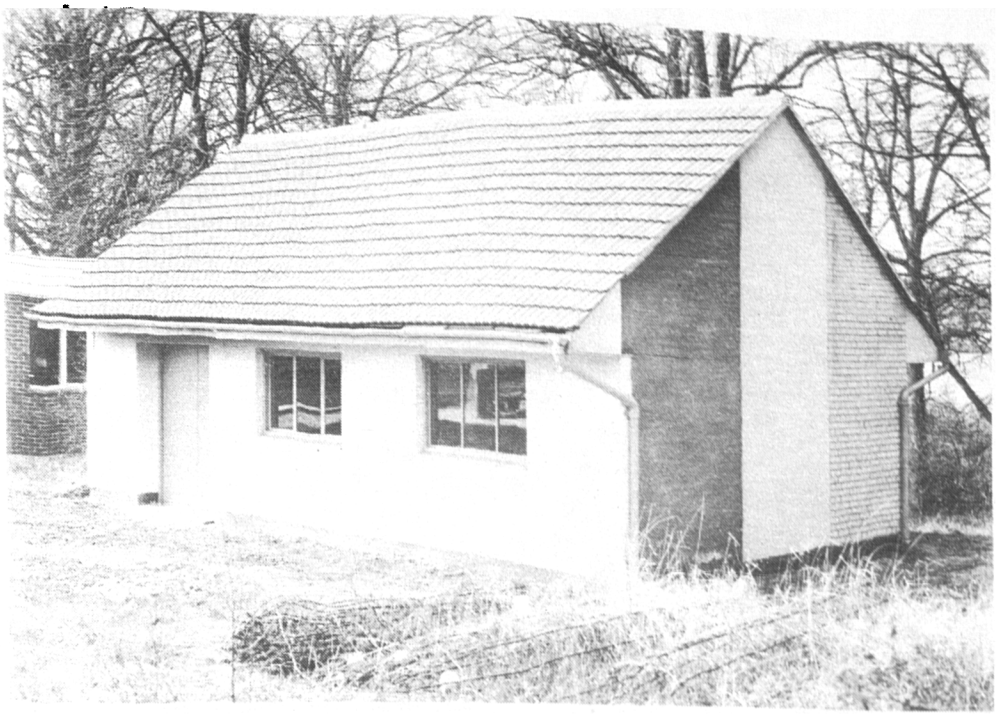


Plate 17 Experimental building constructed from soil/cement bricks at BRS in 1950

Wall facing	Area	Treatment
South	A	Aerated cement (lower 1.2 metres only). Untreated flush-pointed brickwork (upper part).
	B	As A.
	C1	PVA emulsion; followed by 2 coats of cement-based paint mixed with PVA emulsion.
	C2	PVA emulsion (one coat only).
West	D	Rendered 1:2:9 cement:lime:sand; wood float finish.
	E	Rendered 1:3:12 cement:lime:sand; wood float finish.
	F	Untreated flush pointed brickwork.
	G1	Thick coating, white, having appearance of silicate coating.
	G2	Thick coating, yellow, having appearance of a silicate coating.
	H1	Lime/tallow.
	H2	Colourless, wax-based water-repellant liquid treatment.
North	I	Untreated weather-pointed brickwork (lower 2½ metres). Untreated bricks set in minimum of cement slurry (in gable).
	J	1:2 cement:sand, aerated; followed by 1:2 white cement:sand.
	K	1:2 cement:sand, aerated; followed by 2 coats of 1:2 cement:sand.

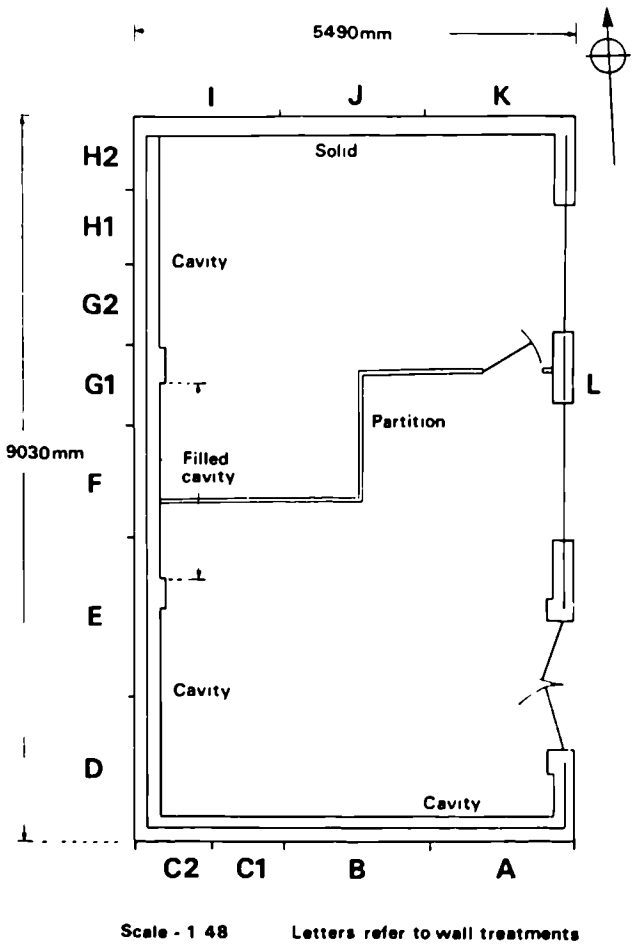


Plate 18 Plan view of experimental building, detailing surface treatments

produced from various types of block making machines each using a cement content of between 10 and 20 per cent. A survey of the machines produced in various countries during this period of time is discussed in Chapter 6.

However the UK Government's Road Research Laboratory did investigate the use of hydrated lime and bituminous materials as suitable soil stabilisers during the early 1940's for road and airfield construction purposes (64).

In all third world countries, without exception, one of the main obstacles to growth is a dire shortage of foreign exchange with an unprecedented boom in the construction industry with all the familiar characteristics - spiralling building costs, shortage of building materials and skilled manpower with unchecked speculation in real estate leading to phenomenal increases in land costs.

The hugh increase in the price of oil, for example, which started in the early 1970's caused a rapid rise in the cost of cement which meant that the low income people in third world countries could not afford to buy concrete blocks because they use a high percentage of cement.

Many research and commercial organisations had stated that cement was the ideal material for soil stabilisation, but due to the high cost of cement it was of paramount importance that an alternative cheaper type of soil stabiliser material be used and hydrated lime was considered such a material. Ideally this alternative stabiliser should be a local indigenous material which is readily available in a third world country.

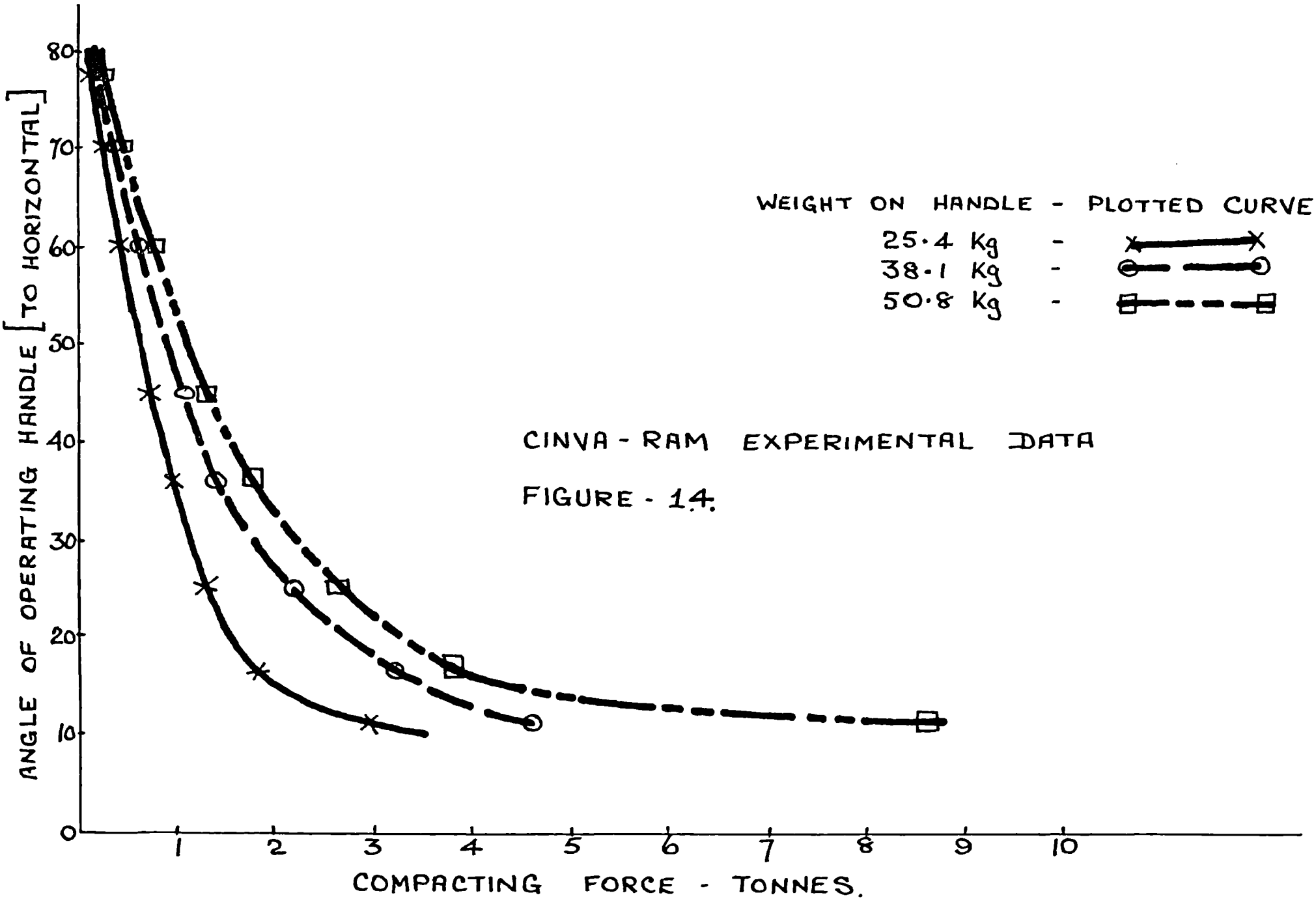
Hydrated lime, although dependent upon chemical reaction with clay materials for its stabilising function appeared to fulfill the requirements of an alternative stabiliser to that of ordinary Portland cement as discovered by Dr J R Coad following his experimental work in Ghana (40) during the late 1970's.

The Ministry of Overseas Development now called the Overseas Development Administration (ODA) decided to finance a research project that was conducted by the Overseas Division of the Building Research Establishment to investigate the use of hydrated lime as a possible stabiliser for soil building blocks and this particular research project was started in 1973/74.

Firstly a 'genuine' CINVA-Ram block making machine was obtained from Colombia, South America so that existing pressing parameters could be studied. The author was made responsible for this particular aspect of the initial research. The CINVA-Ram block making machine, described in detail in Section 6.2.3, produces soil blocks, 290mm x 140mm x 90mm thickness.

To determine the actual pressing forces involved, a 50 tonne capacity electrically operated load cell was introduced into the mould box of the CINVA-Ram machine. A known weight was suspended from the operating handle and the angle of the handle was noted to the corresponding internal compacting force generated within the CINVA-Ram mould box.

Three known weights ie 25.4kg, 38.1kg and 50.8kg (56lb, 84lb, and 112lb) were used for this experiment and curves were plotted of the angle of handle against the compacting force generated through the load cell. These curves are shown on Figure 14.



CINVA - RAM EXPERIMENTAL DATA

FIGURE - 14.

Analysing the results obtained from this initial experiment to determine the compacting forces which are developed within the CINVA-Ram mould box gives a max compacting force of 8.6 tonnes. Converting this force to a compacting pressure gives a value of about $2MN/m^2$ which has been obtained by a manual input of 50.8kg applied to the operating handle of the CINVA-Ram block making machine.

The next step in this research project was to obtain suitable soil from a third world country and this soil was obtained from Ghana.

Dr J Coad and Mr M G Lunt, B.Sc, both chemists were responsible for this research work and their work is described within (40) and (42).

In a support role the author was responsible for the design and development of laboratory equipment needed for this research work which included a special hydraulic press for producing cylindrical test specimens of stabilised soil at compacting pressures up to 43 MN/m^2, Plate 14, and a reinforced mould box from which 290mm x 140mm x 100mm thickness stabilised soil blocks could be produced using compacting pressures up to 36 MN/m^2. Plate 20.

To complete this particular research project, field trials were conducted at the Building and Road Research Institute, Kumasi in Ghana and proved that certain tropical soils rich in iron and alumina - containing minerals could be efficiently stabilised with hydrated lime to increase strength and improve durability.

Further tests were conducted, by the author to validate these findings, using lime to stabilise high silt clay soils obtained from Sudan - see Section 4.4.3.

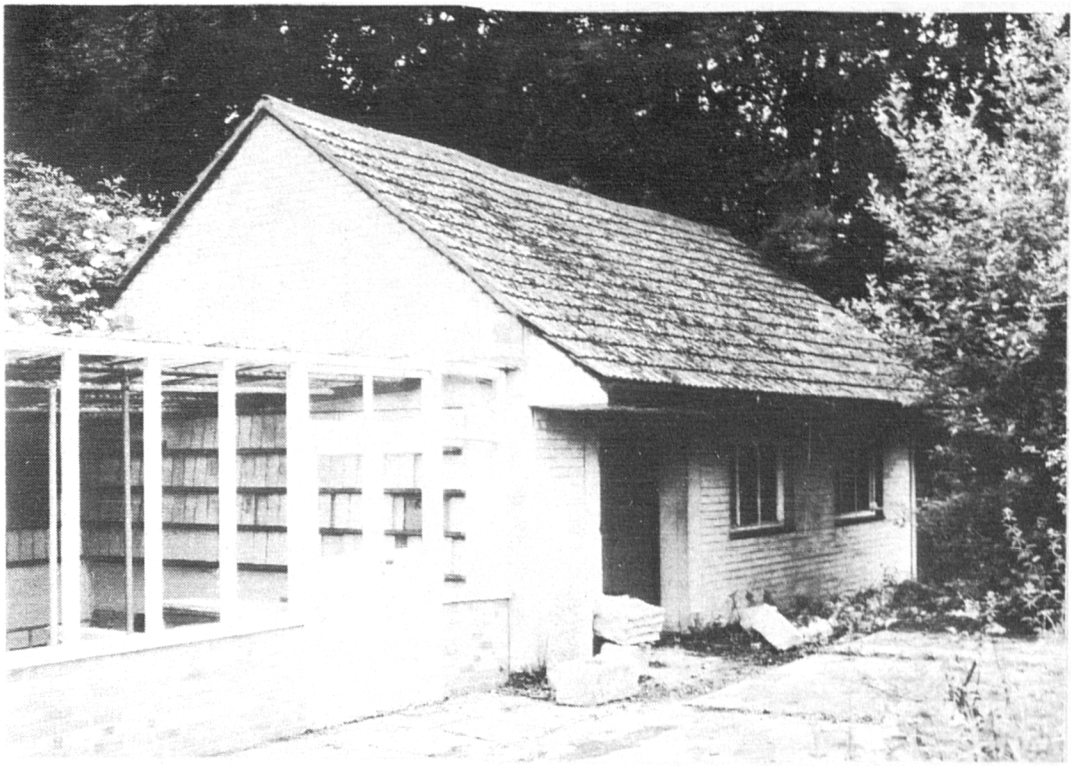


Plate 19 Experimental building in 1981 - 31 years old

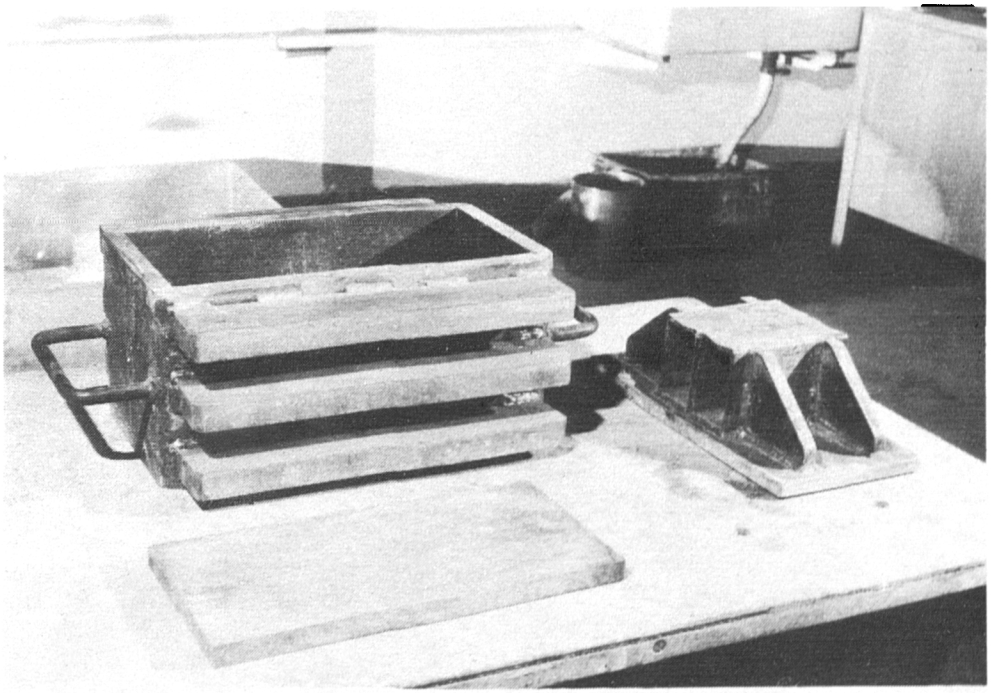


Plate 20 Steel mould for making blocks at high compaction pressures

5.4 Proposal for the development of a new block making machine

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 lime, cement or with other binding agents. The experiments carried out at BRE have demonstrated the improvements in strength and durability that can be achieved when a suitable stabilising agent is used to stabilise tropical soils containing clay particles.

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 compacting pressure although the degree of improvement diminishes as this pressure is increased. it has been suggested (42) that presses operating in the range 8 to 16MN/m^2 could give satisfactory and economical results and there is a need for a simple manually operated machine to be developed. This machine should be light enough so that it could be easily transportable from site to site. With such a machine and with careful selection of the raw materials, good quality stabilised soil blocks could be produced which have similar physical properties to some other walling materials, and have the same attractive appearance of fired clay bricks. These blocks could be used to build inexpensive durable houses in many parts of the developing world.

CHAPTER 6

WORLD SURVEY OF SOIL BLOCK MAKING EQUIPMENT

6.1 Turning soil into a building block

In times of rapid change man often looks back to re-assess the building materials used in the past which are still in existence today - not a case of re-inventing the wheel but seeing how its operation could be improved. This is the case of looking back to see how soil has been utilised within the building industry.

Towards the top of any list of successes in this industry must be the fired clay building brick which has stood the test of time over many centuries of inclement weather conditions.

As mentioned previously the art of firing clay to make bricks is mentioned in the bible but in the early days the hand moulded, sun dried adobe brick must have been the forerunner of the modern oil fired factory installation costing several million pounds sterling to produce millions of bricks.

In the majority of developing countries the fired brick is still considered to be a luxury material and alternative methods of brick and block manufacture are always being investigated.

Brick making in Developing Countries (65) commissioned by Building Research Establishment in 1979, contains a technical review of the brick industries in about 20 different countries which concludes that manual moulding systems should be developed together with simple clay grinding

equipment and small scale continuouis kilns. A review of small-scale brick making methods utilising appropriate technology was published by the International Labour Office in 1984 (66).

A modern day alternative to fired bricks might be concrete blocks but these products generally require a high cement inclusion, however manually operated presses have been developed over the last 30 or 40 years to produce stabilised soil building products. The blocks produced from these machines have been atmospherically cured which saves the much needed energy hitherto used for firing. Simple village brick and block cottage industries have been set up to provide low cost homes which are scattered far and wide within third world countries.

The success of the concrete block making machine has been proved by the many machines now working in the field. They employ a vibration technique to obtain concrete consolidation. Unfortunately these concrete block making machiines cannot normally be used for the production of stabilised soil building elements, because of using a semi dry soil mix it needs direct compaction to improve density.

There has been a variety of pressing machines developed throughout the world during the last 30 or 40 years most of which are described in this chapter. These machines fall into one of two main categories:

(i) Constant volume

(ii) Constant pressure

Constant volume - This type of machine has a compaction ram which moves a fixed distance into a mould.

Constant pressure - This type of machine is governed solely by the pressure within a soil mix and the compaction ram will move a variable distance depending on the internal pressure generation within the soil mix.

Therefore, to produce a constant thickness product a fixed input volume of soil mix must be initially fed into the mould of the machine and constant volume is preferred.

Power driven, soil block making machines, also discussed in this chapter, are capable of higher compacting pressures than those normally produced in a manually operated machine. The power driven machines are capable of producing denser soil blocks with higher outputs over the manual machines. However they are certainly more expensive because of their more detailed construction. It has also been found by experience that the maintenance of a power driven press is expensive and often such a machine falls into disuse because spare parts are difficult to obtain, also trained operators do not have the experience and 'know-how' to repair a broken down machine.

During the research period of this project at BRS the author has established many overseas contacts and representatives from about 90 countries have been seeking advice and help on the subject of soil stabilisation. One organisation from Western Germany, German Appropriate Technology Exchange (GATE) wanted to collate a global survey on manufacturers literature on soil block presses and Kiran Mukerji, responsible for this survey (67) visited BRS on numerous occasions seeking help and assistance from the author.

The individual list of soil block making machines discussed in this chapter features the salient points of each machine and apologies are made to those companies making or supplying equipment, details of which have not been included in this document.

Appendix A3 gives a comprehensive list of soil block making machines, equipment, suppliers names and addresses in both developing and developed countries.

Appendix A4 lists a proposed technical standard for lime stabilised soil products. A library bibliography on soil stabilisation (68) produced in 1973 by Building Research Establishment may be a useful reference for background study on early methods of soil stabilisation methods.

6.2 Soil Block Making Machines

This world survey of soil block making equipment was initiated in 1978 when the author was associated with the design and development of laboratory equipment in support of research being conducted at BRS.

Three methods have been used to gather information:

(i) Bibliographical research
(ii) Extensive correspondence
(iii) Personal visits to institutions both in the UK and numerous overseas organisations.

The survey includes all types of equipment that has been developed within the soil stabilisation industry and in several cases the machines mentioned are no longer available.

6.2.1 Adobe Moulding

Probably the earliest and simplest form of hand press is the adobe moulding technique from which sun dried soil blocks are made.

This method employs a simple wooden or steel box, open at the top and bottom. A sandy clay soil mixed with water to make a mud consistency - generally chopped lengths of straw or fibre are added to the mix for reinforcement purposes to minimise drying out shrinkage cracks that will undoubtably occur.

The mix is 'thrown' into the mould which is tamped or pressed by hand to completely fill the mould space, immediately after filling, the mould is lifted away from the formed block which is allowed to sun dry for about 4 weeks before it can be used in the construction of a wall.

Adobe blocks are commonly made 100 to 150mm thick, between 200 and 500mm in length and 100 to 150mm width. The size of a block generally being governed by the weight of the cured block. For example an adobe block measuring 125 x 250 x 500mm length would weigh about 25kg.

Using mechanical equipment to mix and fill adobe moulds means that multiple cavity moulds are needed to make efficient use of mechanical plant. The multiple moulds could consist of more than 20 cavities so that this number of adobe blocks could be made at a single filling operation. See Sections 6.2.28 and 6.2.29.

There are many variations of adobe mould design from fixed cavity boxes to those having hinged sides also many different types of material have been used from wooden to steel moulds.

The one major drawback with the adobe method of block manufacture is that large areas are needed for curing the blocks and in areas where rain or monsoons occur, a cover must be provided to protect the blocks during the four week curing period.

It is essential that the blocks are cured on a dry clean flat surface so that impurities, example stones and waste material, cannot adhere to the block faces. Plate 21 illustrates unfavourable curing conditions for adobe blocks in West Sudan where some thirty per cent of blocks could not be used after curing because of numerous faults occurring. Incidentally the owner was advised to level out a curing area which was duly completed and resulted in the reduction of faulty blocks to around eight per cent.

Plate 22 illustates a double cavity steel adobe mould which has been damaged due to bad treatment by the operator.

The detailed methods of soil selection and adobe block manufacture are described in the Handbook for Building Homes of Earth (69), which has been produced by the US Department of Housing and Urban Development.

Plate 21 Unfavourable curing conditions for adobe blocks

Plate 22 Double cavity steel adobe mould

6.2.2 Winget Hydraulic Block Making Machine - United Kingdom

The Winget Rotary Table hydraulic making machine has been the only British made, power operated press developed specifically for the manufacture of stabilised soil building blocks on a commercial basis.

Winget Construction Co Ltd manufactured a wide range of building construction equipment both for the home and overseas markets. In 1948 they were asked for their co-operation by the Overseas Food Corporation to develop a machine capable of producing stabilised soil building blocks.

The prototype machine, consisting of a shuttle table mould, was first used in Tanganyika (Tanzania) on a housing project where local native labour, employed on a large ground nut scheme, needed to be housed. This machine produced about 140 bricks per hour, was considered too complicated which often broke down therefore it was decided to develop a rotary table mould which is illustrated on Plate 23. This new machine was capable of producing 180 blocks per hour with a maximum block size of 305 x 150 x 100mm height. About 1.4 cubic metres of mixed soil was required each hour and a trough type mixer was developed for this purpose.

The rotary table press machine is a constant pressure machine and requires five operators. On the rotary table mould, three operations take place simultaneously because there are three mould cavities set into the circular table top. These individual operations are:

(i) Mould filling, (ii) Soil compaction, (iii) Ejection.

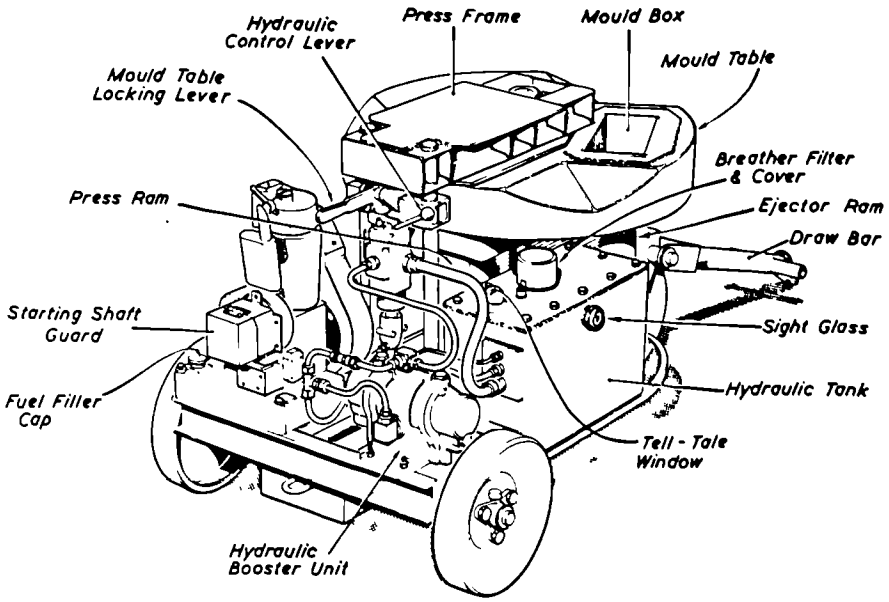


Plate 23 Winget rotary table hydraulic block making machine

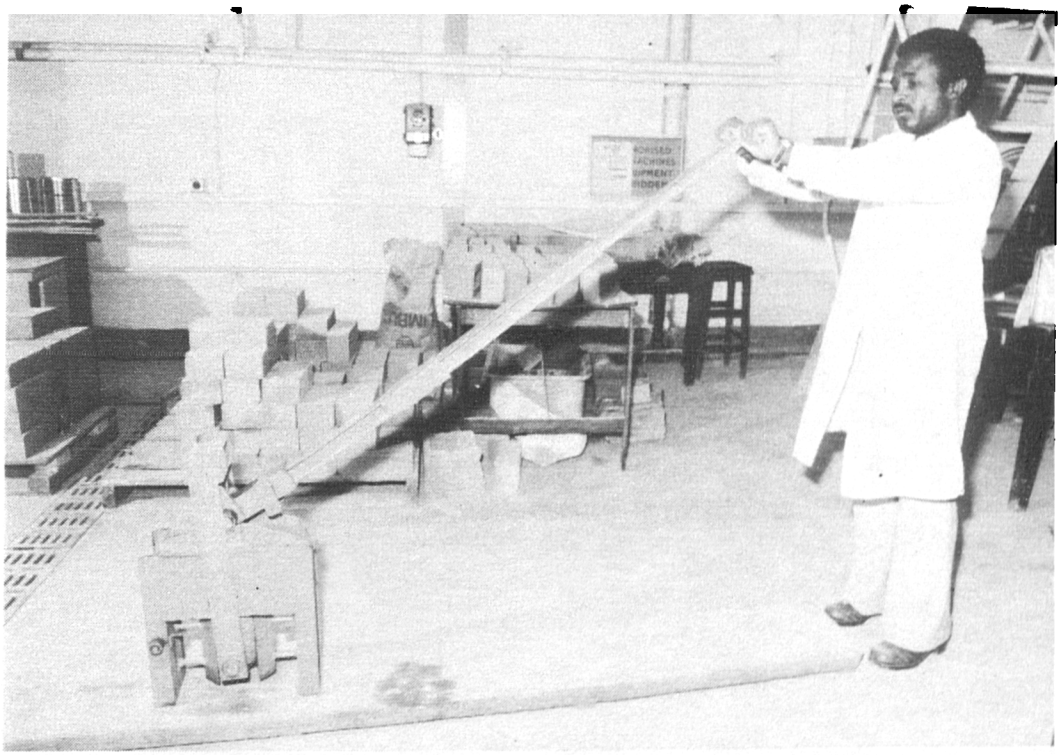


Plate 24 Cinva Ram block making machine

(i) The first operator fills the mould cavity with ready mixed material from the measuring box provided and places a top pallet in position. The table is then rotated 120 degrees.

(ii) The second operator controls the hydraulic operations and table location, by means of two hand levers. An upward stroking ram compacts the soil mix at a pressure of 9.65 MN/m^2 for about 20 secs. The compaction ram retracts and the table mould rotates a further 120 degrees.

(iii) The newly pressed block is ejected from the mould and the third operator carries off the finished block for stacking and curing.

The other two operators in the team are employed on soil mixing, filling the measuring box and block stacking duties.

Referring to Plate 23, it can be seen that this machine is self contained and is powered by a 4 brake horsepower Villiers high speed diesel engine which is mounted on a three wheeled frame which has a tare weight of 1040kg.

The trough mixer is also a self contained unit, powered by a 6 brake horsepower Villiers high speed diesel engine mounted on a four wheeled chassis which has a tare weight of 1300kg.

During the 1950's this type of machine was introduced into about 20 third world countries but due to a decline in sales the production was terminated in 1962 after it had been found that:

(i) Both the trough mixer and rotary table press each weighing over 1 tonne proved to be extremely diffficult to move the equipment from site to site.

(ii) The equipment was too expensive for a third world country to import and it is presumed this is the main reason why only a few machines were sold.

(iii) With many moving parts each machine was susceptable to misuse by inexperienced operators and in the event of a breakdown the mechanism was not always easy to repair. Spare parts were difficult to obtain.

The Winget rotary hydraulic press produced good quality stabilised soil building blocks which were generally stabilised with cement or hydrated lime.

The principle of a rotating table top having three mould cavities is a well proven process in the concrete flagstone industry because this type of machine, in a factory environment, has been in operation since the 1890's. The early types of rotary table presses employed water pressure for compacting concrete to produce 900 x 600 x 50mm concrete flagstones.

A critical assessment of the Winget Rotary Hydraulic Block Press has been published by Robert Fitzmaurice (70) in which it is stated that the machine is too heavy. Using a high compacting pressure good quality stabilised soil blocks are produced inefficiently because of the capital costs involved. Fitzmaurice has quoted the compressive strength of Burmese soil blocks stabilised with 5 per

cent cement and manufactured in a Winget press as 9.5 MN/m^2. The text does not clarify whether this is a dry or wet compressive strength? See Chapter 9 on soil block testing.

6.2.3 Cinva-Ram Press - Colombia

Probably the best known and most used type of manually operated soil block pressing machine is the CINVA-Ram, which was developed in 1952 by the Inter-American Housing and Planning Centre (CINVA) in Bogota, Colombia.

A Chilean engineer, Paul Ramirez, a member of CINVA's staff directed a research project and subsequently invented the CINVA-Ram block making machine. The object of this research was NOT to create a machine to mass produce stabilised soil blocks but to produce a simple machine that could be used by families, with little or no income, to build houses with walls formed from stabilised soil blocks.

A CINVA-Ram machine weighs about 55kg which should be firmly mounted to a wooden baseboard before starting block making operations. Details of subsidiary equipment are listed in the manufacturers operators manual (71).

This machine consists of a fabricated steel mould box, illustrated on Plate 24, into which an organic free soil mix and a suitable stabiliser, slightly moistened, is placed. The soil mix is compacted by an upward movement of the mould baseplate, which is effected via a simple toggle lever mechanism.

The sequence of operating the CINVA-Ram is well documented in many publications and as these operations are described in (32 and 60) it is not necessary to repeat them in this section.

As previously mentioned in Section 2.3, the author established that with a pull down force of about 50kg on the operating handle of the CINVA-Ram machine a compacting force of about 8 tonnes is generated within the mould box. The dimensions of the soil block produced are 290 x 140 x about 100mm depth and the resulting compaction pressure generated in the soil mix is 2 MN/m^2.

The manufacturers claim that three operators working on the various tasks of processing and mixing of soil together with moulding the blocks, should be able to manufacture about 300 blocks per day.

The author has seen CINVA-Rams working in 9 countries and the block production rate has varied from 15 to 30 blocks per hour. Assuming an 8 hour working day this would result in an actual output of between 120 and 240 blocks per day.

To obtain blocks of uniform quality, the mould box must always be filled with the same quantity of mixed soil and stabiliser.

In practice the filling operation is not carefully controlled and the freshly moulded blocks will have a wet density of around 1700 kg/m^3, which is lower than the technical standard proposed by 'Craterre' - See section 6.3 and Appendix A4.

If a higher wet density were to be achieved the effort needed by the operator to eject a block from the mould would be excessive.

The freshly moulded block is usually weak in the 'green' state and can be easily damaged along its arrises. Generally after the curing or hardening process the blocks develop linear shrinkage cracks which substantially reduces the load bearing capacity and allows easy penetration of water when exposed to the elements.

If used as face blockwork sufficient roof overhang must be provided to keep the face work dry from dripping water from the roof and in addition a sand cement rendered plinth must be provided at ground level to stop the water splashing back onto the exposed blockwork. In practice, however, sufficient roof overhangs are not provided and the external faces are protected by a waterproofing coat of rendering or paintwork. This protective coating will add further expense to the building costs but will increase the building's life span by reducing erosion.

The CINVA-Ram manufacturers have appointed various overseas distributors and for reference purposes these names and addresses are listed in Appendix A3.

According to a Reader's Digest article published in July 1974 about 12,000 CINVA-Ram machines had been sold to third world countries.

In May 1980, BRS acquired a CINVA-Ram (machine number 13318) at a cost of about £400 which is illustrated on Plate 24.

The CINVA-Ram has obviously been and is still a popular machine but with the lack of foreign exchange and high import duties many countries have copied the basic design with minimum alterations to

suit their own needs. The author has viewed similar machines in various countries which are discussed later in this section.

6.2.4 TEK-Block Machine - Ghana

The Department of Housing and Planning Research, within the University of Science and Technology in Kumasi, Ghana initiated a programme of research in the late 1960's with the aim of adapting a CINVA-Ram block making machine to produce stabilised soil blocks for use in the rural districts of Ghana.

At an early stage they decided to manufacture soil blocks measuring 290 x 216 x 140mm depth, each block weighing about 16kg.

The operating lever arm of the CINVA-Ram is made of steel which is liable to bend when overloaded which causes damage to the linkage assembly when the machine is misused or the mould box is overfilled.

To overcome this problem, the operating lever of the Tek-Block machine is made of timber so that if any overloading or misuse occurs the timber lever arm breaks thereby protecting the machine linkage.

The remainder of the Tek-Block machine is the same as the CINVA-Ram so with a similar lever arm length and linkage assembly but having a larger block surface area, the resulting compaction pressure on a soil mix is reduced to about 1.5 MN/m^2.

Once the Tek-Block machine, illustrated on Plate 25, was introduced on site it was found that the output varied depending on the keeness of the work force. Generally a labour fore of 5 operators was employed to complete the various tasks from soil preparation, hand mixing, block production and curing and would produce between 150 to 250 blocks each day.

A useful handbook (72) published in 1970 describes various soil selection testing methods and the operation of the Tek-Block machine.

The research project in Ghana was financed by the Department of Social Welfare whose active support promoted the rapid and relatively widespread introduction of the Tek-Block machine to the rural areas of Ghana.

From various information sources it would appear that only few enquiries have been received from other countries in connection with the Tek-Block research project.

According to R Paillon of the Faculty of Architecture at the University of Science and Technology in Kumasi some 400 Tek-Block macchines were purchased by the National Service Corps (NSC) for use by volunteers in the rural areas. After training, the NSC volunteers, organised communal labour projects in the field and numerous building projects have been completed. Paillon claims that the life span of a Tek-Block machine is around 18 months and it would be uneconomical to purchase a machine to build a single house. Assuming a house requires 3000 blocks, at least three

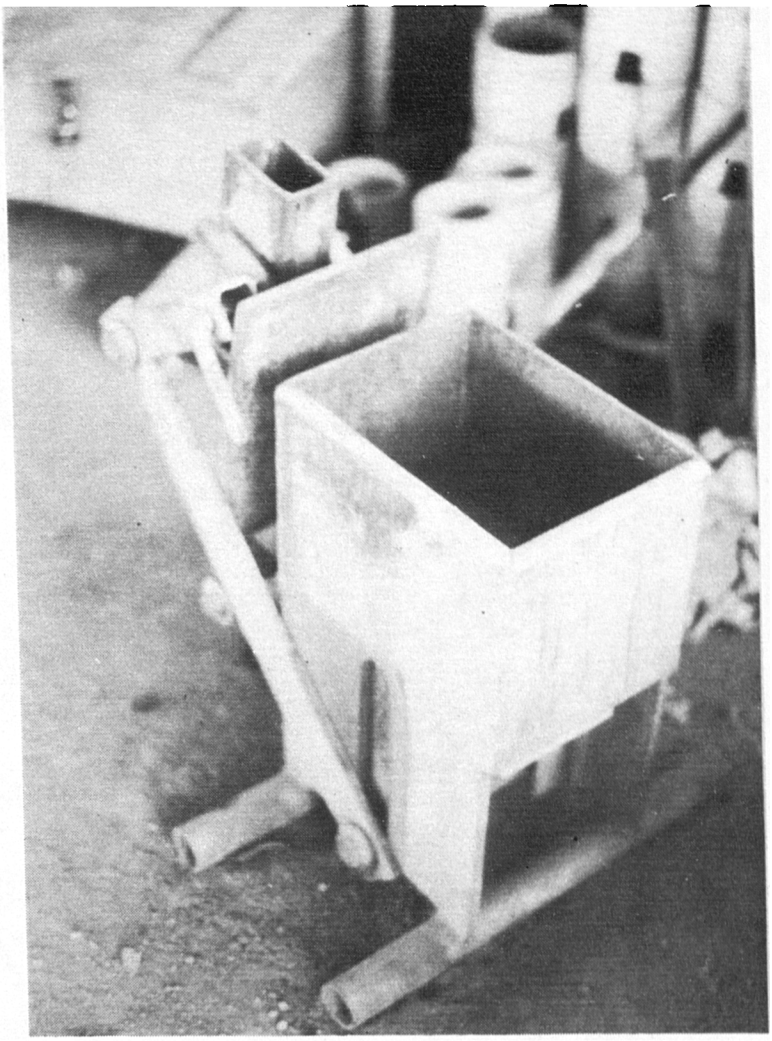


Plate 25 Tek-Block machine

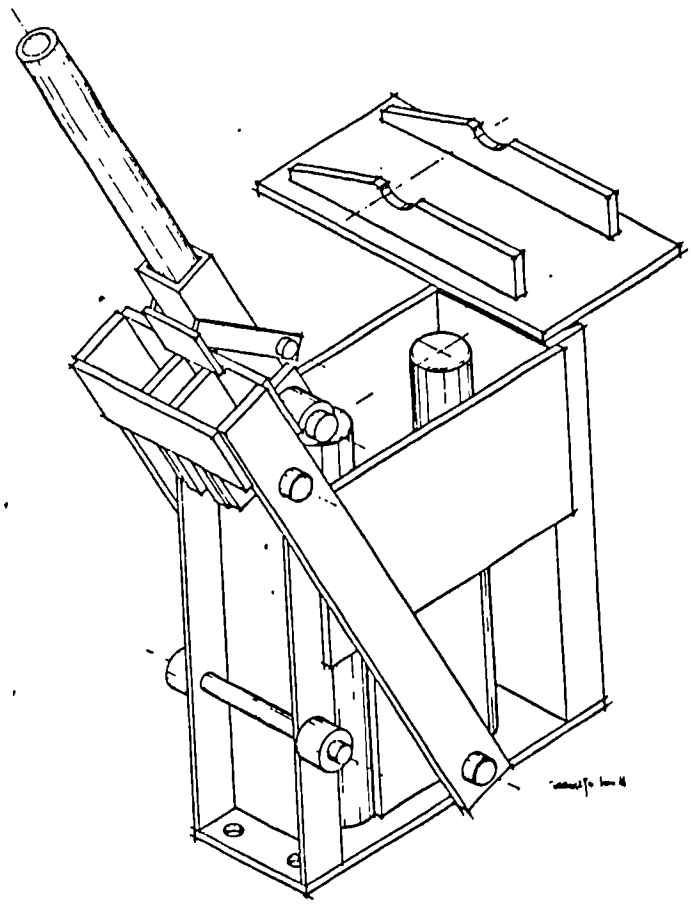


Plate 26 Ceta-Ram press

houses must be built using this machine to make it economically justifiable.

6.2.5 The CETA-Ram Press - Guatemala

Shortly after the earthquake in Guatemala on 4 February 1976 and being involved in reconstruction work a group of engineers and students from the engineering faculty of the San Carlos University were working with the Centre of Appropriate Technical Experimentation (CETA Guatemala). They were using CINVA-Ram machines and wanted to produce stabilised soil building blocks with vertical holes to allow for vertical steel reinforcement to add strength to a soil block constructed wall.

Roberto Lou Ma a Guatemalan Civil Engineer modified a CINVA-Ram Press to manufacture a stabilised soil block 320 x 152 x 110mm depth with two 60mm diameter holes passing through the depth of the block and called this machine the CETA Press as illustrated on Plate 26.

This machine is composed of three principal parts:

(a) A main frame, the upper part forming the walls of the mould with a cover that swivels through 90° used to cover the mould aperture.

(b) A moveable mould baseplate which acts as a piston within the mould body.

(c) The toggle mechanism and hand operating lever.

Ma's manual (73) describes the construction techniques using the soil blocks made by the CETA-Ram Press.

Some prototype CETA-Ram presses have been used extensively on an experimental basis and some rural housing units have been constructed. As an important result of this experience it can be definitely confirmed that in the case of wall constructions that have to be reinforced with steel bars, the use of hollow stabilised soil building blocks has accelerated the erection and lowered the costs.

In Guatemala there is an abundant supply of volcanic material of the pumice type and using cement as the stabilising agent at 1:8 parts of cement to soil by volume, the CETA-Ram has produced blocks with a range of compressive strengths from 2.89 MN/m^2 to 6.8 MN/m^2.

Note that reference (73) does not qualify the above compressive strengths as either 'wet' or 'dry'.

6.2.6 Block Press - Kenya

During the mid 1970's the Rural Industrial Development Centre in Kenya developed a block forming machine referred to as the Block Press.

This machine was modelled on both the CINVA-Ram and Tek-Block machines, and has had limited applications in Kenya. The author has seen this machine operating and due to its flimsy welded construction can be easily damaged. See Plate 39.

This machine will be discussed further in Chapter 9.

The Block Press handbook (74) states that the dimensions of a cement stabilised soil block is 290 x 140 x 215mm depth and the compaction pressure exerted on a soil mix within the mould cavity varies between 1.04 and 2.07 MN/m^2.

6.2.7 Ceneema Press - Cameroon

Following the importation of a CINVA-Ram into Cameroon, the Ceneema organisation developed a block making machine for the manufacture of wall blocks made of loam or earth with an appropriate clay content together with cement as a stabiliser.

The block dimensions are 300 x 140 x 110mm depth.

G.A.T.E, the German Appropriate Technology Exchange featured the Ceneema Press in a publication (75) which gives a list of detail drawings covering the component parts of this machine. Little is known of this machine and further information can be obtained from the manufacturers whose address appears in Appendix A3.

6.2.8 AVM Block Press - West Germany

Following the development of the Ceneema Press, Ausbildungsverband Metall (AVM), West Germany started manufacturing a soil block press referred to as the AVM Block Press.

This machine being similar in all aspects to the Ceneema Press but modified such that only German DIN standard components are used for its construction.

6.2.9 Dirt Cement Brick Press - Thailand

The Southern Institute for Skill Development in Thailand developed a modified CINVA-Ram during the late 70's and called this machine the Dirt Cement Brick Machine.

D W Schippert claims that the maintenance of this machine was taken into consideration when the design was initiated by introducing bolted and pinned connections so that damaged components could be easily replaced.

A useful instruction booklet (76) explains the development and use of this machine.

6.2.10 Ellson Blockmaster Soil Block Press - South Africa/India

The Ellson Soil Block Press was originally developed in South Africa by Ellson Pty and since 1978 is manufactured under licence by Joshi Industries, Rajkot, Gujarat State, India.

This Indian organisation renamed the machine as the Ellson Blockmaster Stabilised Soil Block Press which is illustrated on Plate 27.

The Ellson Blockmaster machine is an all steel welded assembly, manually operated, which can make either block sizes 290 x 190 x 90mm depth or 290 x 140 x 90mm depth and has a tare weight of about 210kg.

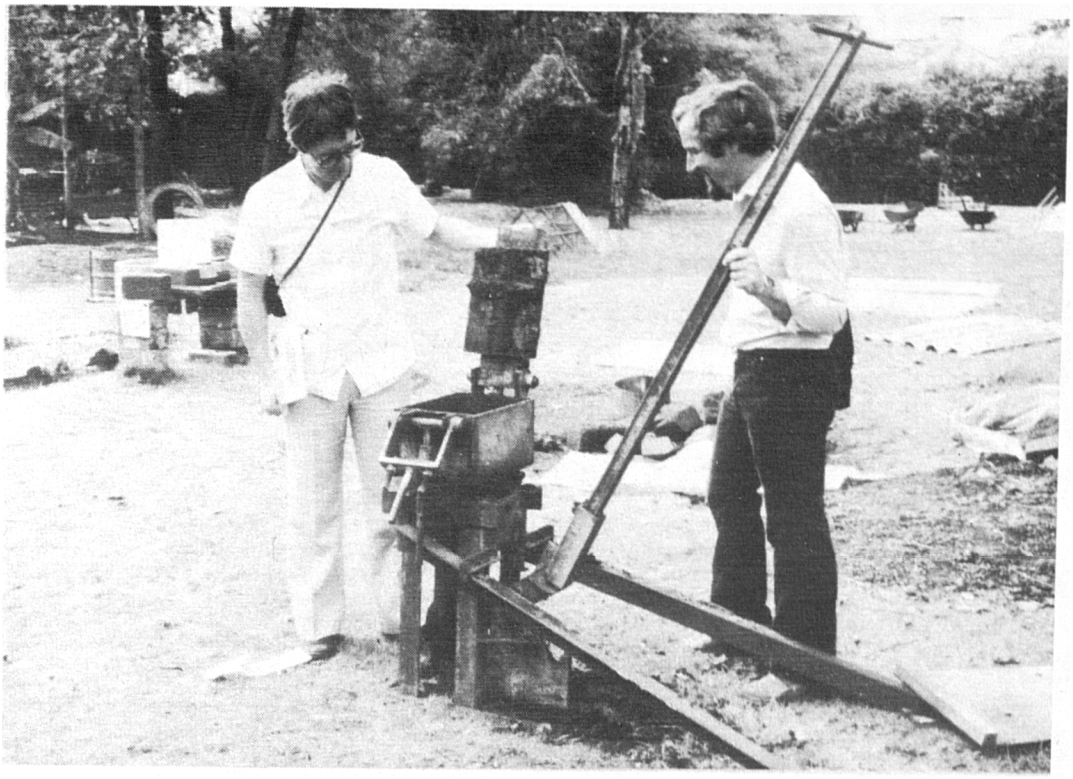


Plate 27 Ellson Block-master soil block press

Plate 28 Astram block making machine

The high lever, ratio of 500:1, is usually operated by two men who stand on the projecting inclined legs ready for the 'pull-down' stroke, these men must experience an evident effort in completing the compacting stroke because a maximum compaction pressure of about 7 MN/m^2 is achieved.

One significant feature of this machine is the height of the mould from ground level, being about 850mm, helps to reduce operator fatigue from bending down too low to remove a freshly made block from the machine.

The manufacturers claim a total labour force of 10 men can produce 750 blocks (290 x 190 x 90mm) per day, this labour force includes digging the soil, spreading out for drying, crushing, sieving, mixing, machine operation and carrying away the freshly made block for curing.

This machine was viewed in the field at the Karen Appropriate Technology Centre in Kenya by the author who witnessed that the daily production rate varied between 200 and 240 blocks. The machine viewed, had been rewelded at the lower end of the main operating lever on several occasions due entirely to the high stresses generated during the compaction stroke.

Depending on the nature of the soil and the stabiliser used, the manufacturers claim, that well stabilised dense blocks can be made having 'DRY' compressive crushing strengths of between 4 and 12 MN/m^2. Moisture absorption is much lower than ordinary burnt clay stock bricks.

6.2.11 Astram Block Making Machine - India

The Centre for Application of Science and Technology for Rural Areas (ASTRA), in India, developed a hand operated soil block making machine in the mid 1970's. This machine referred to as the Astram Block Making machine consists essentially of a mould in which a block is formed, a toggle lever mechanism mounted underneath the mould body and a frame to support the mould and toggle lever mechanism.

The mould is interchangeable and currently moulds of two sizes are being used with this machine and either 300 x 145 x 100mm or 300 x 230 x 100mm depth blocks can be manufactured.

From a design point of view the Astram machine looks like a CINVA-Ram with the tozzle mechanism from the Ellson Blockmaster without the projecting inclined legs and can exert a compaction pressure of about 5 MN/m^2.

The above mentioned machines are compared in a paper presented to the International Conference on Low Cost Housing for Developing Countries at the Central Building Research Institute (77), Roorkee, India in November 1984. The Astram block making machine is illustrated on Plate 28.

The paper (77) states that the Astram machine is superior when compared with the CINVA-Ram and the Ellson Blockmaster Machine.

6.2.12 Meili 60 Manual Soil Block Press - Switzerland

The Meili Engineering Company of Switzerland developed an improved version of the CINVA-Ram machine during the late 1970's.

This particular machine operates according to the principle of the off centre press, is ruggedly built and achieves a compacting force of 20 tons which equates to a compacting pressure of about 5 MN/m^2 when producing a 250 x 125 x 80mm block.

The Meili 60 soil block making machine is detailed in (67) and in the Skat Publication entitled Soil Block making equipment working paper WP 05/84 (78).

The manufacturers of this machine claim that between 60 and 120 blocks per hour can be achieved dependant on the size of the labour force employed.

This organisation also manufacturers an automatic, power driven, soil brick and block making machine which is discussed under Section 6.2.22.

6.2.13 Maro Block Press - Switzerland

During the late 1970's, the Maro enterprise group of Switzerland developed a modified form of a CINVA-Ram machine. The main difference on this machine is that the toggle lever assembly moves as a complete entity when the mould box lid is moved away from the top of the mould cavity.

The machine is basically a bolted steel assembly mounted onto its own steel baseplate and has a tare weight of about 125kg. Block sizes are similar to that of the CINVA-Ram being 290 x 140 x 110mm depth. The sequence of operation is given in (67).

6.2.14 Unata Brick Press - Belgium

This machine is a direct copy of the CINVA-Ram machine with minor modifications. Weighing about 80kg, it can produce between 20 and 60 blocks per hour utilising a labour force of between 2 and 6 operators. The block dimensions being 290 x 140 x 90mm depth.

6.2.15 Landcrete/Presse Terstaram Press - South Africa/Belgium

The Landcrete block making machine was originally developed by Landsborough-Findlay Ltd of South Africa. The manufacturers claimed that during the early 1950's with the development of this machine, cement stabilised soil blocks were introduced into the African continent.

Two main models were introduced, either a hand operated toggle mechanism machine or a power driven version. Both models were sturdy in construction and according to the manufacturers, simple to operate, however all references to these original machines have been found in old literature. Several of these original machines have been viewed by the author in numerous continents and in each case the machines had broken down and were not operational.

During the early 1960's several of these manually operated Landcrete machines were used in Ghana to assist with the Volta Resettlement programme as already mentioned in Section 1.2.

This machine was partly redesigned by Fernand Platbrood and is now available from Belgium under the trade name of Presse Terstaram. It utilises a compacting pressure of about 4 MN/m^2 and can produce various sized stabilised soil building blocks from a mould measuring 295 x 295mm. It weighs about 350kg.

Plate 29 illustrates the Presse Terstaram block making machine showing two operators applying the main compaction force, of 20 tons theoretically, via a lever and beam arrangement, to compact a soil mix.

6.2.16 Ceraman Manual Press - Belgium

The Ceraman Manual Press machine to all outward appearances is identical to the Landcrete/Presse Terstaram machine.

Ceratec is the name of the company that produces a range of equipment, both manual and power operated, that produces both clay bricks for firing and stabilised soil building blocks.

The manufacturers claim the Ceraman manual press is one of the most widely used hand operated mechanical presses in the world today.

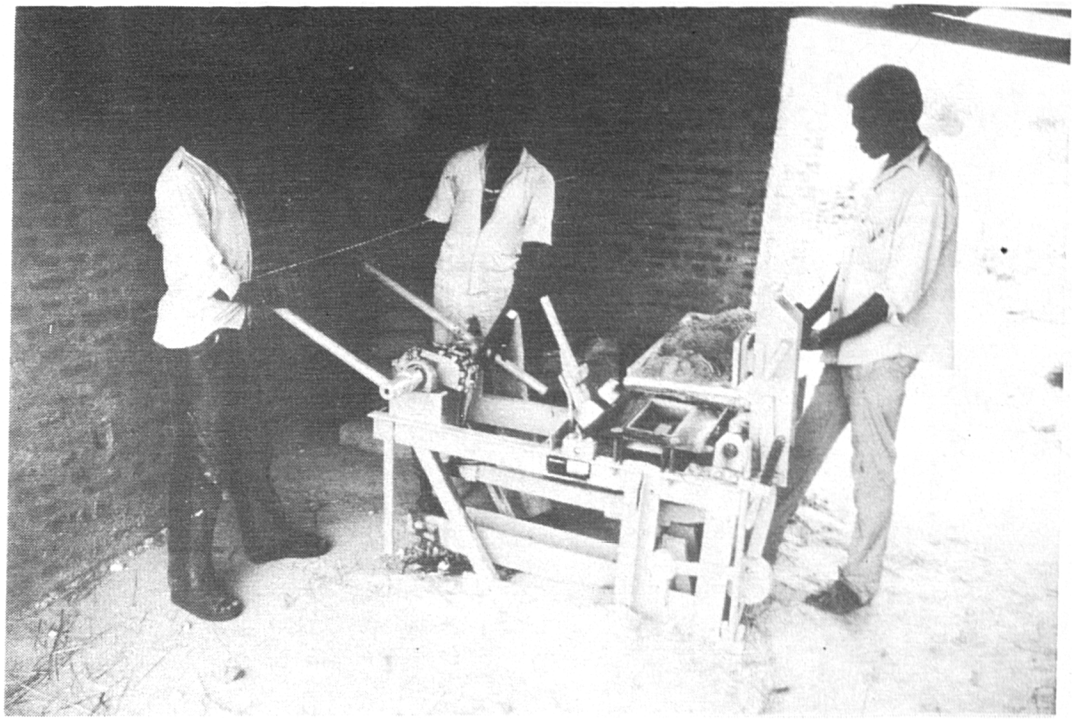


Plate 29 Landcrete/Presse Terstaram press

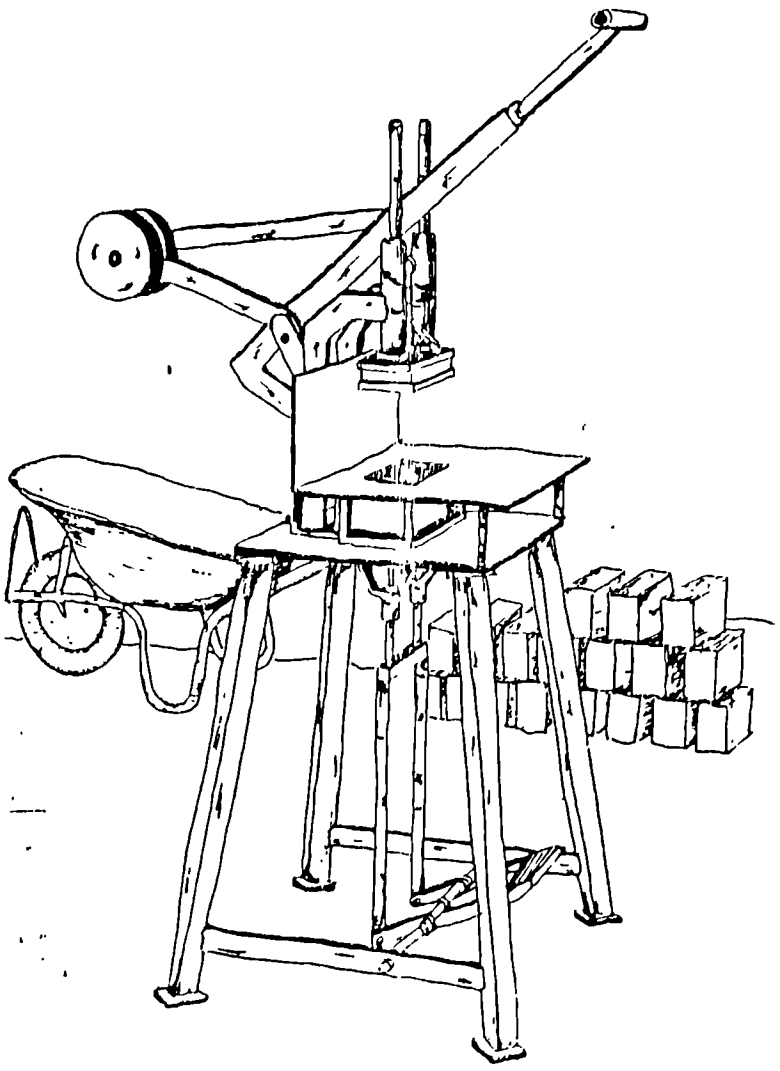


Plate 30 Riffon block press

6.2.17 Jesson Brick Press - South Africa

Developed in the mid 1970's, by Harold Jesson, this brick making machine resembles the CINVA-Ram machine with one or two modifications. This machine incorporates a volume batching box and is operated from only one side. A compacting force of about 1600kg, which equates to a compacting pressure of 0.15 MN/m^2 is used to produce bricks 220 x 104 x 73mm depth.

Jesson Industries of South Africa manufacture this machine and claim that about 1200 bricks can be made daily with a well organised group of operators.

An interesting article describing this machine (79) appeared in the South African Farmers Weekly dated 18 November 1981.

6.2.18 CTA Block Making Machine - Paraguay

This machine was introduced in March 1982 by the Centre for Appropriate Technology at the Catholic University, Asuncion, Paraguay and looks like a much larger version of the CINVA-Ram capable of producing three blocks at each pressing.

The mould cavity measuring 358 x 238 is divided into three parts and stabilised soil blocks can be produced three at a time. In this case the compacting pressure is applied across the 358 x 238mm dimension resulting in a lower compaction pressure to that used on the CINVA-Ram machine.

This machine has been widely used in South American countries and is a truly local, medium to low cost machine as claimed by Roland Stulz (80) in his book on Appropriate Building Materials. This machine operates on the principle of a pull down lever, similar to the CINVA-Ram to exert a compaction pressure on a soil cement mix.

6.2.19 Saturnia Block Press - Switzerland

This machine was developed at ETH-Honggerberg, Zurich by H D Sulzer early in the 1980's. The aim being to improve the productivity of a hand pressing machine as compared to the CINVA-Ram machine. This was achieved by more accurate mould filling methods and the pressing on both sides of a block to achieve homogeneous compaction on both block faces.

Note - H D Sulzer claims that 1 per cent difference in the filling of a mould can lead to 5 per cent variation in strength.

The Saturnia block press has a tare weight of about 200kg and can produce up to 4 blocks per minute. This high output is achieved by the main hand lever, first compacting a soil mix, followed immediately by the ejection of a block BOTH in the same downward movement of the hand lever.

The detailed operational sequence of this machine is given in (67).

6.2.20 Riffon Block Press - Belgium

This machine, developed by J Riffon during the mid 1960's resembles a 'Fly press' in principle. A hand operated press head is brought

down into a mould cavity built into a table. Soil compaction is obtained by impact loading on the soil mix and when sufficient compaction has been achieved a foot mounted pedal is activated which ejects the block from the mould.

The main disadvantage of this type of block press is that uneven depth blocks will result unless accurate mould filling is achieved. Plate 30 illustrates this machine.

6.2.21 Ranko Soil - Cement Block Machine - UK

Agas Groth, an undergraduate at Warwick University, developed the manually operated Ranko-Soil Cement Block Machine as part of his third year project during the 1983/84 academic year. During these studies Agas Groth contacted the author to discuss his ideas on the use of impact blows to compact soil cement blocks eventually producing a paper describing this work (50). Following successful laboratory tests Groth drew up a set of manufacturing drawings and a prototype machine was constructed at the Camphill Community at Otse in Botswana.

This machine is now undergoing site trials in Botswana and good quality soil cement blocks are being manufactured. Plate 31 illustrates this machine and during the trials a daily rate of between 100 and 150 blocks has been reached.

The block sizes being 290 x 140 x 90mm depth, however there has been a wide variation in the block depths so a more accurate method of initial mould filling must be developed.

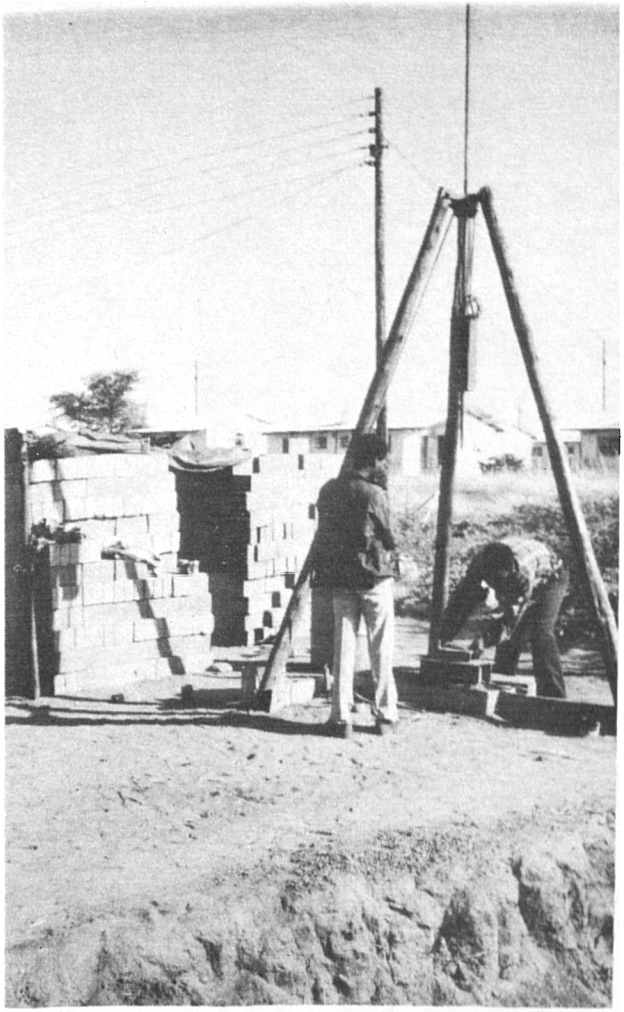


Plate 31 Ranko soil-cement block machine

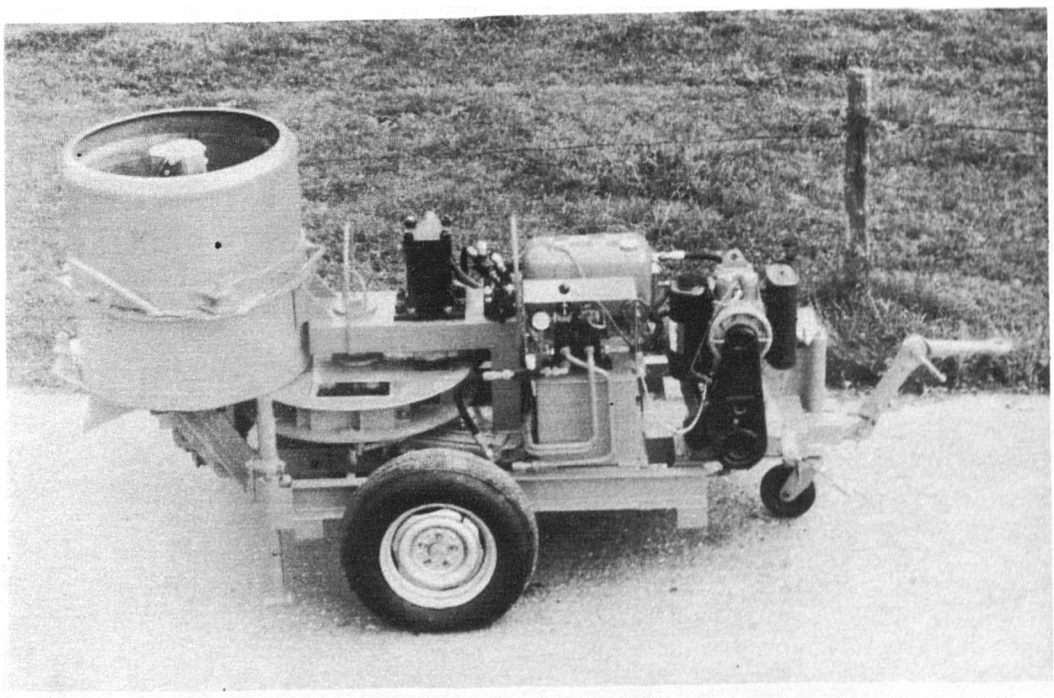


Plate 32 CLU 3000 brick plant machine

This machine works on the principle of a falling weight of about 40kg dropping from a height of about 1.5 metres onto a soil mix contained within a steel mould.

The field trial of this machine is continuing and it is hoped that a few modifications will be introduced before a commercial version of this machine will be offered for sale.

6.2.22 Meili Mechanpress - Switzerland

Following field trials on the Meili 60 Manual soil block press, as described in Section 6.2.12, the Meili organisation developed the Meili Mechanpress which is an automatic soil brick and block making machine powered by an 18.5 horsepower diesel engine.

The machine has a rotary table, similar to the Winget Hydraulic Block making machine, but in this case there are four mould cavities. The mould sizes can be altered from a minimum size of 250 x 125mm to a maximum size of 300 x 150mm and will produce blocks, one every 4 seconds. This machine is then capable of producing about 1000 top quality soil bricks or blocks per hour, as claimed by the manufacturers.

To ensure continuity of production a horizontal pan type mixer of 150 litres capacity is mounted directly above one of the mould cavities, this mixer, together with a batching device between mixer and mould ensures a constant volume supply of mixed soil into a mould cavity.

The complete unit of mixer, press, moulds and power unit weighs about 1700kg and is mounted on three pneumatic tyres for ease of site movement.

The author has not viewed any of the machines manufactured by the Meili organisation but feels that improvements have been incorporated since the Winget machine was developed. No thought has been given to the materials handling side of the operation because some 7 tonnes of mixed materials would be needed to give an output of 1000 blocks per hour as claimed by the manufacturers.

6.2.23 CLU 3000 - Switzerland

During the late 1970's Consolid AG of Switzerland developed a new process of chemical soil stabilisation for use with cohesive soils on road construction projects.

This process involves the use of three stabilising agents (i) Consolid 444, (ii) Conservex and (iii) Solidry.

Consolid 444 is a silicone - copolymer resin solution which is first mixed with a quantity of water dependent on the moisture content of the soil being used. Conservex is a type of bituminous emulsion to enhance the waterproofing properties of Consolid 444. Solidry is a powdered polymer compound producing water resistant properties.

Consolid AG developed a Mobile Stabilised Brick Plant 'CLU 3000' which is powered by a 13 horse power diesel engine as illustrated on Plate 32 which has a tare weight of about 1600kg.

This trailer plant includes a diesel engine, paddle mixer and feed unit, 4 cavity rotary table press, soil mixer and the necessary hydraulic components used for pressing a component.

The pressing of a brick is manually initiated by the operator, the mould table rotates and the soil mix is compacted with a compation force of 15,000kg corresponding to a pressure of 4.8 MN/m^2.

When chemical stabilisers are used the manufacturers claim that the dry compressive strength of such treated bricks will be between 3.9 and 9.7 MN/m^2. If higher strength bricks are needed an addition of 1 to 3 per cent cement to the treated soil would result in compressive strengths greater than 10 MN/m^2.

It is claimed that with a crew of 4 to 5 operators they could produce 3000 to 4000 bricks with one plant per day.

The author viewed one of these machines during a visit to West Germany and feels that if the compaction pressure could be increased then better quality bricks could be made. However there have been favourable comments expressed about this machine from both Ghana and Malaysia.

For example in Ghana, the minimum dry and wet compressive strengths required of stabilised soil bricks as stated in their 1961 standards issued by the Ministry of Construction and Communication for single storey construction is 2.72 and 1.36 MN/m^2 respectively.

The Ministry of Works and Housing Test Laboratory tested bricks made on the CLU 3000 brick plant in 1977 and the following average results were obtained

Dry compressive strength = 3.46 MN/m^2

Wet compressive strength = 1.99 MN/m^2

Note that these strength results are well below those strength figures as claimed by the manufacturers.

A useful publication about the CLU 3000 system has been published in Malaysia by one of the commercial organisations using this system (81).

6.2.24 Ecobrick 1000 - Switzerland

The Ecobrick 1000 is a complete and universal soil brick manufacturing plant, developed by Dieter Schmidheini in Switzerland during the late 1970's. This plant was developed after about ten years of research, design and practical experience in the field.

The complete plant consisting of a 7 Horsepower Hartz diesel engine, paddle mixer and feed unit, a horizontal sliding table mould and a hydrostatic system used for all pressing operations is mounted to a chassis with pneumatic wheels allowing the unit to travel at road speeds up to 2.5 km/hour.

The complete unit has a tare weight of 650kg, which produces stabilised soil bricks 250 x 120 x 75mm depth at a rate of about 100 bricks per hour.

This machine looks very similar to the prototype shuttle type mould originally developed by Winget Construction Co Ltd (See Section 6.2.2).

During the soil compaction stage a compaction pressure of 4.9 MN/m^2 is employed to produce a good standard product and the manufacturers claim that brick compressive strengths of between 3 and 10 MN/m^2 are achieved. Note - It is not clarified whether these results are for 'Wet' or 'Dry' compressive strengths.

6.2.25 Supertor Block/Brick Machines - Brazil

Torsa Maquinas E Equipamentos Ltd, Sao Paulo, Brazil manufacture a range of hyrdraulically operated presses that can be used to produce stabilised soil blocks or bricks. This equipment is normally installed in a factory, because of its tare weight of about 1100kg makes it unsuitable for moving around on a site, in addition a trough type mixer of about 250kg is needed to supply mixed soil to the moulds.

One machine model as described above has a 20 tonne capacity compaction ram which produces 4 bricks at one pressing each brick measuring 230 x 110 x 50mm or 200 x 100 x 50mm. The manufacturers claim an hourly output of 2500 bricks is possible.

A larger machine with a 30 tonne capacity compaction ram is capable of producing 3750 bricks per hour.

Ex works quotations for these two machines in 1981 were £17,500 and £19,500 respectively. In both cases a compacting pressure of

2.07 MN/m^2 is employed which is a similar pressure to that exerted by the CINVA-Ram machine.

From information received, Supertor plants have been installed as factory installations in Brazil, Argentina, Peru, Iraq and Iran. In each case the freshly compacted soil cement bricks are autoclaved in a kiln for a period of time between 24 and 36 hours to accelerate the curing period.

6.2.26 Zora Hydraulic Press - UK

A simple power operated all hydraulic press was developed by Zora International Co Ltd, UK in 1982 which produces a wide range of stabilised soil building units. The all steel welded press has a mould which can produce building blocks 280 x 125 x 100mm depth. This machine was developed after the chief engineer for this company visited BRS and talked in detail with the author on the subject of making stabilised soil building blocks.

The manufacturers claim that this type of press can be operated by unskilled labour and is sturdily built to withstand rigorous outdoor operating conditions with little maintenance. There are three versions available each having a hydraulic power pack receiving power from (i) a one horsepower electric motor, (ii) a 5 horsepower petrol or diesel engine and (iii) for manual power input.

Each model weighs about 450kg and is fitted with the same basic mould components which are all mounted on an identical two wheeled chassis for movement around the site.

An outstanding feature common to all three models is the high compacting pressure of 19 MN/m^2 available at the mould head, resulting in a highly compacted durable product with hardly any wastage during manufacture due to breakages or malformation. The powered machines are capable of producing up to 180 blocks per hour, whereas the manually powered machine can produce about 140 blocks per hour.

This type of machine is undergoing site trials and no actual performance data have been published and all the foregoing information has been taken from sales literature.

6.2.27 The Latorex System - Denmark

A Danish firm, Drostholm Products, developed a plant system in the early 1970's for the high speed production of lime-stabilised laterite soil blocks. This plant will only accept laterite soils for stabilisation - see Section 4.5.3 for the definition of a true laterite soil.

When compacted mixtures of laterite soil and lime are moist cured at temperatures between 60° and 97° Celsius for various periods of time, good quality building products will be produced. Curing at temperatures above 80°C and nearer to 100°C for 24 hours are of practical interest (20). The Latorex Building system was presented at the UNIDO seminar on Prefabrication in Africa and the Middle East, held in Bucharest, Rumania in April 1972 (82).

The electrical powered plant developed by Drostholm Products comprises of a soil drier, pulveriser, mixing machine and presses

with an inbuilt steam oven for curing the manufactured blocks. A normal size plant has a capacity of about 12,000 blocks per 8 hour day with an individual block size of 230 x 110 x 55mm depth. After steam curing it is claimed that the blocks would have compressive strengths of between 15 and 40 MN/m^2.

6.2.28 Ultrabloc - USA

Ultrabloc, an organisation in New Mexico, USA researched the problem of the mechanical production of Adobe style building blocks over a period of 20 years and produced the Ultrabloc machine. The manufacturers claim that the pressed soil blocks are 3-4 times stronger than traditional adobe blocks (see Section 6.2.1), only need 4-6 per cent moisture and can be laid in the wall immediately after manufacture.

Two models have been manufactured:

(i) Powered by a 7 horsepower diesel engine producing 1660 blocks over 8 hours and weighing about 1000kg.

(ii) Powered by a 19 horsepower diesel engine producing 2400 blocks over 8 hours and weighing about 1200kg.

Each machine has a rotary driven soil sieve and produces adobe blocks measuring 90 x 140 x 305mm. Being mounted on pneumatic tyred axles each machine can be towed on the road by a car or small truck.

6.2.29 Terrablock Duplex Machine - USA

A larger version of the Ultrablock machine was developed by the Earth Technology Corporation in Florida during the early 1980's which is referred to as the Terrablock system and is illustrated on Plate 33.

The Terrablock Duplex trailer mounted machine is powered by a 43 horsepower diesel engine and produces 300 x 250 x 100mm adobe soil blocks at a maximum rate of 10 blocks per minute. This process uses wet soil from the ground and a built in computer controls the fully automatic operation of making blocks.

The main hopper holds enough soil for 10 minutes of continuous operation. A heavy duty built in sieve filters out foreign debris and oversize particles, a vibrating device to the hopper head ensures a consistent flow of soil into the two block moulds, located at the lower end of the hopper.

A horizontally mounted double acting hydraulic ram is employed to compact the soil within a mould. After compaction has been completed the block is automatically ejected from the mould onto a simple form of conveyor belt.

The manufacturers claim that starting and operating the machine is a simple one man task. As long as the hopper remains loaded with soil, the machine will automatically produce three to five blocks per minute from each of two moulds, creating enough material in one hour to construct 9 square metres of walling 250mm thickness.

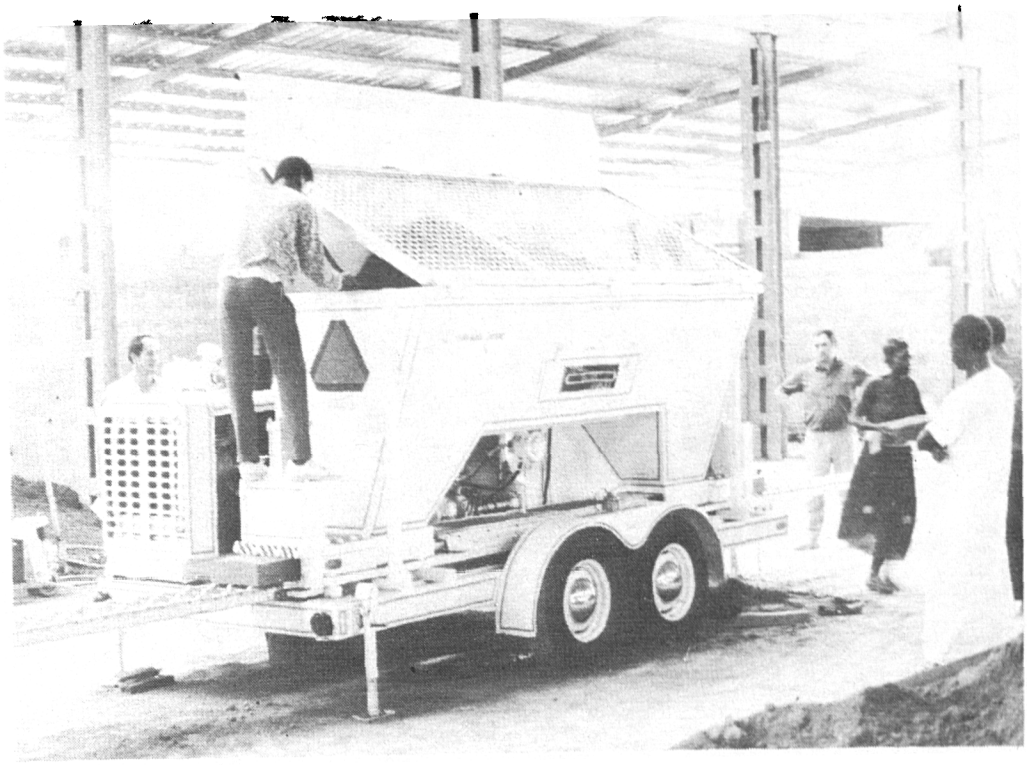


Plate 33 The Terrablock adobe block making machine

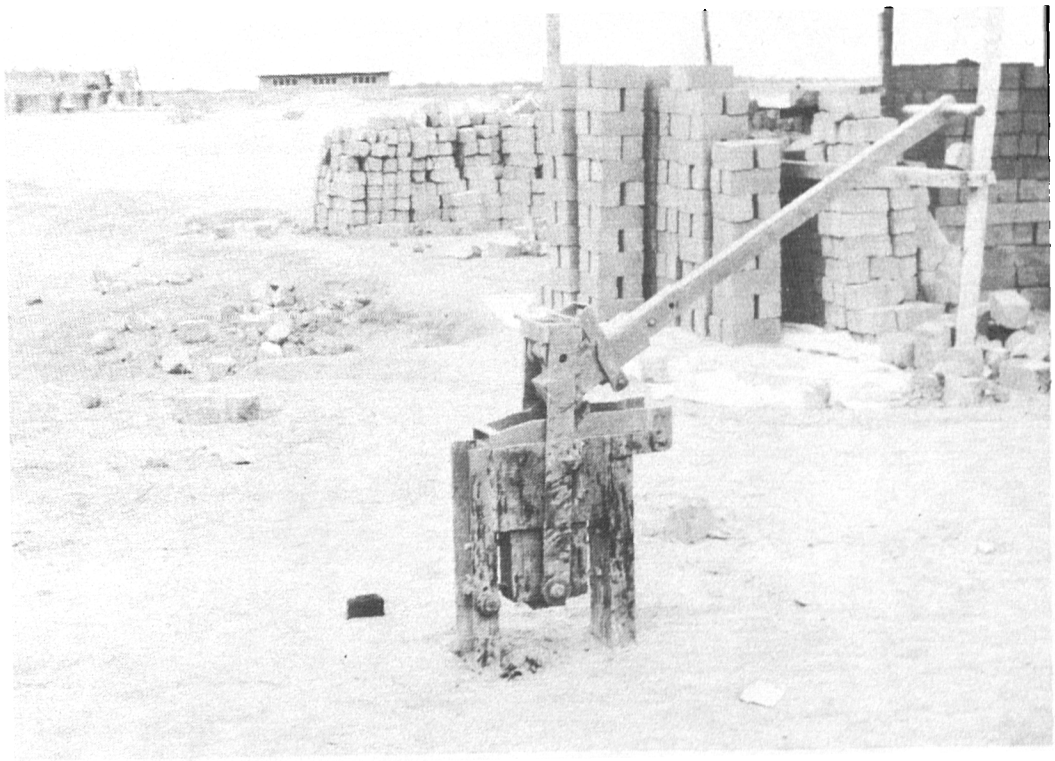


Plate 34 The Bonner block making machine

The soil used in this process is NOT stabilised and the resulting blocks would be called adobe blocks therefore it is essential to treat a Terrablock wall with a fast drying chemical sealant before applying a finish coat of external rendering to prevent erosion from the elements.

6.2.30 Giza Earth Blocks - Italy

The Giza organisation of Bagnolo in Piano (RE) of Italy now produce a range of machines for the production of stabilised soil bricks or blocks of various shapes and dimensions.

Both manual and power operated presses are included in the range of equipment. The pressing machine, mounted inside a reaction frame, consists of a down stroking hydraulic cylinder which compacts a soil mix within a static mould at a compacting pressure of about 6 MN/m^2.

A small production plant weighing about 4000kg is capable of producing 40 bricks or blocks per hour from a single cavity mould. The maximum block dimensions being 250 x 95 x 100mm depth. Two other factory installed plants are capable of producing (i) 2000 blocks per day or (ii) 4000 blocks per day each block measuring 200 x 200 x 40mm deep.

Each plant is similar in appearance with a loading ramp which elevates fresh soil into a screening and mixing unit followed by a conveyor belt which elevates the mixed soil into a holding hopper mounted directly above the pressing machine.

The lower output moulding press machine weighs about 5000kg and is powered by a 15hp motor whilst the mixing and screening unit weighs about 1500kg with a power input requirement of 12hp.

The higher output moulding press machine weighs about 12,000kg and is powered by a 20hp motor whilst the crushing unit weighs about 2500kg with a 13hp motor. The mixing and screening unit weighs 3500kg with a 25hp motor.

The manufacturers claim a wide range of products can be made using this equipment which consist of Walling blocks or bricks, Curtain wall blocks, Partition blocks, Hollow building tiles for floors, Vault blocks, Flues and vent stacks, Waste traps, Slatted floors and floorings and Covering tiles.

The Giza type of equipment is much too large to be used at a rural village level and would best be suited in a factory environment serving the needs of urban development projects.

6.2.31 Tecmor Technology - Brazil

'Make bricks with common earth, without firing' is the claim of Cleto Campels Meireles with equipment manufactured by Equipamentos Mecanicos Ltda of Brazil. The manually operated Tecmor soil cement brick making machine - model MRC-1- is claimed to produce up to 2000 bricks per day with dimensions of 230 x 110 x 50mm or 210 x 100 x 50mm.

The Tecmor machine is similar in appearance to the CINVA-Ram machine but has improved vertical guiding to assist with the

compacting load application by the main lever arm. The compaction pressure of 2.5 MN/m^2 is slightly higher than the CINVA-Ram due entirely to a longer operating level. The tare weight of this machine is about 85kg.

Two other types of hydraulic machines are available under the Tecmor trade name - models HRC-1 and HRC-2 are both powered by 7.5 horse power electric motors and each factory installed machine has a production rate of 1500 units per hour.

Model HRC-1 is used for producing common bricks with dimensions of 230 x 110 x 50mm or 210 x 100 x 50mm.

Model HRC-2 is used for manufacturing common and hollow bricks with dimensions of 230 x 110mm or 210 x 110mm and a solid brick with dimensions of 510 x 230mm. All these structural elements can be produced in various thicknesses from 20 to 90mm.

With the factory installed machines the company will supply a rotating sieve and horizontal pan type mixer which can mix a unit batch of 200kg every three minutes.

This range of machinery will produce a soil cement product and the manufacturers claim that one part of cement to fifteen parts of soil is the most economical mix to be used with about ten to fifteen per cent of water compared to the total volume of the dry and solid raw materials.

However, the manufacturers do recommend that early experimentation should be conducted before a final mix is decided.

6.2.32 Bonner Block Making Machine - Kenya

Action Aid (Kenya) have been working on low cost housing projects in Kenya for several years. They have been using both the Cinva Ram Press - Section 6.2.3 and the Block Press - Section 6.2.6 and in both cases they found that these machines were not strong enough to stand up to the rigours of a building site. They have been engaged in the construction of school classrooms in the most remote parts of Kenya and needed a machine that would not regularly break down and would be capable of producing a good quality block.

Roger Bonner, Head of the Technical Support Unit of Action Aid, developed an improved block making machine during 1982 and called it the Bonner Block Making Machine which is illustrated on Plate 34. Producing blocks 300 x 150 x 120mm deep, this machine resembles the CINVA-Ram Press but uses more robust material, it employs a similar compacting pressure of about 2 MN/m^2 to that of the CINVA-Ram Press. Action Aid are planning to conduct numerous field trials with this new machine and the results obtained so far look promising, however, similar to other low compacting pressure machines the resulting blocks are prone to erosion when subjected to the elements.

The author visited an Action Aid (Kenya) site near the Somali border at Mado Gashi where a large project was nearing completion consisting of 8 classrooms, an administration block, 2 dormitories, 3 double teachers housing, one kitchen store, one ablution block, several latrine blocks and water storage tanks. On this site local sandy soil was obtained and 15% cement was used to make soil blocks from the Bonner Block making machine.

Plate 34 shows this machine with a stock pile of blocks in the background together with a completed ablution block and a kitchen in the course of construction.

The resulting blocks developed wet compressive strengths in excess of $3MN/m^2$ but as they were subject to rapid wear by wind borne sand the completed buildings were finally protected by an external coat of sand cement rendering.

6.3 Block and Brick Standards

Throughout Section 6.2 reference has been made to both bricks and blocks, therefore the question must be answered - When does a brick become a block?

British Standard 3921 : 1985 (83) specifies a brick as a walling unit not exceeding 215mm in length x 102.5mm in width x 65mm in height and with a 10mm mortar joint the co-ordinating size is 225 x 112.5 x 75mm.

A walling unit that exceeds any of these three stated dimensions is referred to as a block.

Numerous standards have been developed covering the use of fired clay bricks and concrete blocks especially in developed countries however in the majority of third world countries, building standards are non-existent especially in the field of soil construction. Many existing practices of using soil construction techniques are inefficient, wasteful of resources with inferior products being produced.

The International Union of Testing and Research Laboratories for Materials and Structures (RILEM) recognised these world wide inefficiencies and in 1983 formed a technical working committee entitled 'Laterite based materials' (LBM 63). The author, as the sole UK representative, was asked to join this international committee with clear cut objectives, to produce an international draft building standard covering the use of stabilised soil building blocks. An international draft standard should be published during late 1988.

Before acceptable standards can be introduced for stabilised soil building elements they first must be proven in the field and as early as the mid 1970's research work at BRS had been initiated.

'Craterre', the International Centre for Research and Application of Earth Construction in France, in 1984 proposed a draft technical standard for lime stabilised compressed soil blocks.

This proposed technical standard - See Appendix A4, was derived from a study of soil block making machines and field experience gained from working in the Sudan.

However the RILEM technical committee would not accept this proposed technical standard because it only applied to an arid region of the Sudan.

As early as 1962 an Indian Standard was introduced as a Code of Practice for the IN-SITU construction of walls in Buildings with Soil-Cement (84). This standard had been derived from the experience gained from the construction of some four thousand single storey houses with 300mm thick walls. The crushing strength of standard test blocks of

cylindrical shape should be 1.4 MN/m^2 in dry conditions and 0.7 MN/m^2 for the saturated condition. This particular standard does however state that walls made from this soil-cement must be protected from the elements due to the very low wet compression strength quoted.

TABLE 15

WORLD SURVEY OF SOIL BLOCK MAKING MACHINES

presented on pages 175 and 176

TABLE 15 – WORLD SURVEY OF SOIL BLOCK MAKING MACHINES

Name	Country of origin	Approx year introduced	Manual (M) or power operation (P)	Gross weight (kg)	Compaction pressure N/mm²	Block size (mm)	Hourly production rate	Number in labour force	Approx Ex-works cost UK Sterling (£)	Illustration plate number	Further information in section number	Reference
A.B.I	Ivory Coast	Mid-1970s	M	120	3.0	200 x 150 x 100	40	Not available	500	N/A	N/A	67
Astram	India	Mid-1970s	M	110	5.0	300 x 230 x 100	Not known	3 - 4	300	28	5-5-11	75
AVM	West Germany	Early 1980s	M	65	2.2	300 x 140 x 110	40	2	120	N/A	5-5-8	67
Block Press	Kenya	Mid-1970s	M	60	2.07	290 x 150 x 100	30	3 - 4	160	39	5-5-6	76
Bonner machine	Kenya	1982	M	85	3	305 x 150 x 140	40	4	350	34	N/A	N/A
BREPAK	United Kingdom	1980	M	140	10	290 x 140 x 100	45	3	1200	35-36-65	Chapters 7 & 8	-
Ceneema	Cameroon	Early 1960s	M	70	2.1	300 x 140 x 110	40	2	100	N/A	5-5-7	67
Ceraman	Belgium	Mid-1970	M	350	2.1	140 x 50 x 100	300	2	1400	N/A	5-5-16	67
C.E.I.A	Guatemala	1977	M	80	2.4	290 x 140 x 90	30	3	300	26	5-5-5	75
Cinva Ram	Colombia	1952	M	60	2.0	290 x 140 x 90	40	3	230	24	5-5-3	75
Consolid AG	Switzerland	Late 1970s	P	1600	4.8	250 x 120 x 75	300/500	6	20,000	32	5-5-23	61
CTA	Colombia	Early 1970s	M	90	1.5	350 x 120 x 75	Not known	Not known	240	N/A	5-5-18	82
Dirt Press	Thailand	Late 1970s	M	55	1.9	N/A	40	3	N/A	N/A	5-5-9	76
Ecobrick 1000	Switzerland	Late 1970s	P	650	4.9	250 x 120 x 75	100	2	7500	N/A	5-5-24	67
Ellson Blockmaster	South Africa/ India	Early 1950s	M	210	6.8	290 x 190 x 90	60	4	450	27	5-5-10	67
G.F.O 50	France	Late 1970s	M	100	1.6	400 x 350 x 100	25	2	600	N/A	N/A	6
Groupe Unipress	France	Mid-1970s	P	2400	3.6	200 x 140 x 60	2000	4	N/A	N/A	N/A	67
Giza	Italy	Early 1970s	Factory	5090 12000	6.0	250 x 95 x 100 200 x 200 x 40	40 250/500	N/A	N/A	N/A	5-5-30	N/A
Jesson Press	South Africa	Mid-1970s	M	85	0.15	220 x 104 x 73	75	4	N/A	N/A	5-5-17	75
La Palafitte	France	Mid-1970s	M	95	2.8	290 x 140 x 90	40	3	120	N/A	N/A	67
Landcrete Terstaran	South Africa Belgium	About 1960	M E P	350/ 2100	4.0	295 x 140 x 90	120/250	4	700 12,000	29	5-5-15	6
Latorex System	Denmark	Mid-1970s	Factory	Not known	5.0	230 x 110 x 55	1500	N/A	N/A	N/A	5-5-27	20 E4
Lescha SBM	West Germany	Late 1970s	P	2300	4.5	250 x 130 x 75	500/700	4	20,000	N A	N/A	6
Lorev	Italy	Mid-1970s	M	150	3.0	300 x 150 x 60	N/A	N/A	N A	N A	N/A	20

TABLE 15 CONTINUED

Name	Country of origin	Approx year introduced	Manual (M) or power operation (P)	Gross weight (kg)	Compacting pressure MN/m²	Block size (mm)	Hourly production rate	Number in labour force	Approx Ex-works cost UK Sterling (£)	Illustration plate number	Further information in section number	Reference
Maquina	Colombia	Early 1970s	M	170	1.8	290 x 150 x 40	80	4	N/A	N/A	N/A	67
Maro	Switzerland	Late 1970s	M	125	2.2	290 x 140 x 110	40	3	350	N/A	6-2-13	77
Meili 60	Switzerland	Late 1970s	M	85	5.0	250 x 125 x 80	60	3	380	N/A	6-2-12	67/78
Meili Mechan Press	Switzerland	Early 1980s	P	1700	5.2	300 x 150 x 80	1000	4	18,000	N/A	6-2-22	67
Pact 500	France	Early 1970s	P	550	9.8	295 x 140 x 90	300	4	7,000	N/A	N/A	67
PPB Sarot	France	Late 1950s	P	9000	8.6	N/A	N/A	N/A	N/A	N/A	N/A	29
Ranko	United Kingdom	1984	M	60	Impact	290 x 140 x 90	20	under trial	N/A	31	6-2-21	50
Riffon	Belgium	Early 1970s	M	150	Impact	220 x 105 x 60	80	3	N/A	30	6-2-20	67
Saturnia	Switzerland	Early 1980s	M	200	3.2	290 x 140 x 70	200	4/5	850	N/A	6-2-19	67
Supertor	Brazil	Mid-1960s	P	1100	4.2	230 x 110 x 50	2500	N/A	18,000	N/A	6-2-25	67
Tecmor	Brazil	1978	M & P	85/ 2000	2.5	230 x 110 x 50	250/1500	N/A	N/A	N/A	6-2-31	29
Tek-Block	Ghana	Late 1960s	M	90	1.5	290 x 215 x 140	20	3	N/A	25	6-2-4	67
Terrablock	USA	1985	P	5350	12.0	300 x 250 x 100	600	4/6	50,000	33	6-2-29	67
Ultrabloc	USA	Late 1970s	P	1000		305 x 140 x 90	300	N/A	N/A	N/A	6-2-28	67
Unata	Belgium	Late 1970s	M	80	1.8	290 x 140 x 90	20	2	300	N/A	6-2-14	67
Winget	United Kingdom	1948	P	1100	9.6	305 x 150 x 100	140	5	N/A	23	6-2-2	70
Zora	United Kingdom	1982	M & P	450/ 850	19	280 x 125 x 100	40/180	3	2500/3500	N/A	6-2-26	67

NOTE: The Latorex blocks are steam cured whilst all the others are atmospherically cured.
The hourly production rate is generally taken from manufacturers' literature.
See Appendix A3 for a comprehensive list of soil block making equipment suppliers.

N/A - Not available

6.4 Comparison of Block Making Machines

The purpose of Chapter 6 is to bring to the readers attention the various types of machines available in the market place that can be used to make soil building products. The individual list presented in Section 6.2 discusses some of the salient features of 32 machines used in the field. However there are several other types of machines available which have been added to the comprehensive list given in Table 15.

Appendix A3 gives a comprehensive list of soil block making equipment, suppliers names and addresses in both developed and developing countries.

42 soil brick/block making machines have been listed in Table 15 of these

(i) 2 are factory installations

(ii) 14 are power operated machines and

(iii) 28 are manually operated machines.

(i) Factory Installations.

The two systems quoted use different techniques to produce stabilised soil products. The GIZA system employs a compacting pressure of $6MN/m^2$ and atmospherically cures the stabilised soil products.

The Latorex system uses a low compacting pressure, as quoted by Dr Torben Hansen, to form lime stabilised laterite soil blocks

which are then moist cured for varying lengths of time at temperatures between 67° and 97° Celsius.

Both these factory systems would be much too large to operate at a rural village level due to the high capital cost.

(ii) Power operated brick/block making machines.

14 machines fall into this category, two of which Ultrabloc 6.2.28 and Terrablock 6.2.29, manufacture unstabilised soil blocks (compacted adobe blocks) from mobile machines with block dimensions of 305 x 140 x 90mm deep and 300 x 250 x 100mm deep respectively. The ex works cost of the Terrablock Duplex Machine has been quoted at £50,000 excluding the mobile earth moving equipment needed to serve the machine with sufficient soil to maintain an output of 600 blocks per hour. The quantity of soil needed to maintain the output of blocks stated by the manufacturers is about 8 tonnes/hour. The Ultrabloc machine has a tare weight of about 1 tonne whilst the Terrablock machine weighs just over 5 tonnes.

Two further machines are factory installations which manufacture stabilised soil products are the Supertor 6.2.25 and the Tecmor 6.2.31. The compacting pressure used by these two machines is 4.2 and 2.5 MN/m^2 respectively each having the same block dimensions of 230 x 110 x 50mm depth. The manufacturers of the Supertor machine claim an hourly output of 2500 blocks which are autoclaved in a kiln to speed up the curing process however the ex-works cost of the press itself in 1981 was about £18,000 which did not include the ancilliary equipment such as mixers, soil

preparation items and the necessary kilns which when added together would make the complete installation similar in cost to the Terrablock machine.

Five of the remaining power operated brick/block making machines are mobile ie Consolid AG (6.2.23), Ecobrick 1000 (6.2.24), Terestaram (6.2.15), Meili Mechan Press (6.2.22) and Winget (6.2.2).

The resulting block sizes range from 250 to 305mm in length x 120 to 150mm in width x 75 to 100mm in depth using a range of compacting pressures from 4 to 5.2 MN/m^2 with the exception of the Winget machine which exerts a compacting pressure of 9.6 MN/m^2.

Nearly all the blocks produced by these machines need surface protection to prevent erosion from the elements however to partially overcome this difficulty higher quantities of stabiliser have been used. In the case of the CLU 3000 machine produced by Consolid AG chemical stabilisers are employed.

The average cost of a machine in this particular range would be about £20,000 making it expensive for a rural site application.

The remaining five power operated brick/block making machines, The Groupe Unipress, Lescha SBM, Pact 500, PPB Sarat and the Zora press (7.2.26).

Very little information has been found about this range of machines. It would appear that they were introduced into the

field and did not come up to the makers specification consequently minimum sales have been made. One example is the Zora machine which was developed in 1982 which utilised a compacting pressure of 19 MN/m^2 and produced good quality stabilised soil blocks measuring 280 x 125 x 100mm deep. The cost of this machine (about £3500) put it out of the market for rural use and an output of about 180 blocks per hour claimed by the manufacturers is low when compared with the mobile powered machines.

In the expressed opinion of Mr Hugo Houben of CRATerre in France, many static site soil block making machines have been introduced into developing countries without conducting suitable market surveys to assess local needs.

(iii) Manually operated soil block making machines.

25 machines mentioned in this thesis fall within this group and of these the CINVA-Ram (6.2.3), developed in 1952 is the best known. Each of these machines works on a linkage device to apply a compacting pressure to a soil mix from a manual input applied to a lever arm. Compacting pressures range from 1.5 to 6.8 MN/m^2 with the Ellson Block master (6.2.10) exerting the maximum pressure. The resulting block sizes range from 140 to 400mm in length x 50 to 350mm in width x 40 to 140mm in depth.

Using a relatively low compacting pressure the resulting blocks have densities in the range of 1400 to 1700kg per cubic metre and are very weak in the newly pressed state with considerable damage occuring to the arrises of each block. They also have an open

texture allowing easy access for water causing erosion to take place. It is usual for these types of blocks to be given a surface protection to prevent erosion of the surface.

These machines are usually poorly constructed and are easily damaged on site.

Two other machines in this range are the Ranko (6.2.21) and the Riffon machine (6.2.20) both of which use impact loading onto a soil mix to obtain soil consolidation. The resulting block dimensions from these two machines are 290 x 140 x 90mm depth and 220 x 105 x 60mm depth respectively.

The Ranko machine was developed locally in Botswana with financial support from the Intermediate Technology Development Group in the UK and so far this machine has produced good blocks but with a wide range of depths. This fault is due entirely to the mix preparation and initial mould filling. However the one main fault of these two machines is that they are unsafe to operate because of the falling weight.

The last machine cited in this thesis is the Jesson Brick Press (6.2.17) which produces stabilised soil bricks 220 x 104 x 73mm depth. Similar in appearance to the CINVA-Ram machine but with a longer operating handle and hardly any offset linkage arrangement it has the low compacting pressure of 0.15 MN/m^2 developed at the pressing stage.

Summarising this Chapter, there would appear to be a need to develop a new type of manually operated block making machine suitable for use in a

rural environment that could produce dense blocks of around 2000kg/m^3 able to stand up to the rigours of the elements. Block sizing of between 250 to 350mm in length with a width of 140mm and a depth of between 85 and 110mm should be acceptable.

One other major consideration is that the cost of such a machine should not exceed £1500 to be within reach of the majority of rural communities. See Chapter 7.

CHAPTER 7

A NEW TYPE OF BLOCK MAKING MACHINE

7.1 Requirements of a new type of block making machine

Techniques employing rammed earth (section 2.2.2), wattle and daub (section 2.2.4) or sun dried adobe blocks (section 2.2.5) can provide durable buildings in many of the drier regions of the world, but in the wetter climates, surface protection of walling is always needed to prevent erosion from taking place. Generally the above methods of building construction give rise to unhealthy living conditions (2.2.7) and a continuous maintenance problem exists. Worse still, in areas subjected to natural hazards, for example, earthquakes, soil constructed buildings can be unsafe (85) or as illustrated on plate 59, where a complete adobe constructed village in the Yemen Arab Republic was demolished as a result of a 12 second duration earthquake tremor in December 1982 - See section 8.2.7.

Earthen buildings have a reputation of being prone to damage and final collapse when subjected to seismic forces. The lack of tensile strength contributes to this risk as generally there is no horizontal or vertical reinforcement, poor building layout and often poor building construction are all contributory factors to the damage sustained from the application of external forces.

It is not surprising, therefore, that attempts have been made over the years to improve the strength, durability and performance of naturally occurring soils in order to produce suitable housing for the low income people of todays world.

The CINVA-Ram press developed in the early 1950's, proved to be a useful machine in providing stronger and more durable stabilised soil building blocks. This machine was analysed by the staff at BRS and the Overseas Building Note 184 - (42) describes this work and concludes that improved block performance could possibly be achieved by increasing the compaction pressure on a dampened soil and stabiliser mix in the range 8 to 16 MN/m^2.

Other parameters should also be considered:

(i) Constant volume or constant pressure operation - See section 6.1.

(ii) Optimum compaction pressure to be employed.

(iii) Product size - Making blocks or bricks - See section 6.3.

(iv) Manual or power operation.

(v) Manufacturing costs and materials for construction.

(vi) Mobility on site or factory installation.

(vii) Who would use the machine.

(viii) Production output potential.

(ix) Acceptability of product.

(x) Operators guide and maintenance procedure.

(xi) Supporting tools and equipment.

(xii) Method of introducing a new type of machine.

(xiii) Site location and proving trials.

(xiv) Compliance with building regulations.

(xv) Economics

The above list of considerations covers several years of research, design and practical field work and answers to all these questions have arisen from many overseas visits by the author when assessing the field

trials conducted with the new machine, referred to as the BREPAK Block making machine.

7.2 BREPAK Machine Design Considerations

At an early stage it was decided to adopt the block size produced by the CINVA-Ram Machine being 290 x 140 x 100mm deep. This would give a 300mm module wall size which includes a 10mm vertical mortar gap as specified in British Standard 3921 (83).

A simple reinforced steel mould was then manufactured - illustrated on plate 20, to allow compaction pressures of up to 40 MN/m^2 to be used to make sample stabilised soil blocks. Hydrated lime was used as the stabilising agent because it was considered at this time to be cheaper than cement in rural areas overseas.

Two Ghanaian soils were then used, both having silt clay fractions greater than 50 per cent, their optimum mix design in terms of lime and water content were obtained from previous strength and density results of cylindrical specimens manufactured on the cylinder press machine illustrated on plate 14. The soil was then passed through a 6mm sieve and weighed batches mixed with 6 per cent lime by weight of dry material were then dry mixed in a mechanical mixer, plate 13 for about two minutes after which time water was slowly added and a further 10 minutes mixing took place to ensure uniform wetting of the soil particles.

Using the steel mould, sample blocks were made in a power driven hydraulic press at compaction pressures of 4, 8, 16, 24 and 36 MN/m^2. Similar blocks were also made in a CINVA-Ram machine using a compaction pressure of 2 MN/m^2 - See section 5.5.3. The sample blocks were

carefully cured for 27 days, then immersed in water for 24 hours after which they were crushed to determine the wet compressive strength.

The results of these tests appear on table 16 and are plotted on figure 15.

TABLE 16 - TEST DATA OF GHANAIAN SOILS STABILISED WITH 6 PER CENT HYDRATED LIME

	SOIL 'A'						SOIL 'B'					
Compaction Pressure MN/m^2	2	4	8	16	24	36	2	4	8	16	24	36
Water content mix (WT %)	20	19	16	13	12	11	17	16	14	13	12	11
28 Day Wet Compressive Strength (MN/m^2)	1.05	1.85	2.90	3.55	3.65	3.70	0.70	1.70	2.75	3.05	3.1	3.15
Water Absorption (WT %)	19.6	19.1	18.4	14.2	13.0	12.6	15.8	14.7	12.2	12.0	11.8	11.75
Dry Density (kg/m^3)	1510	1740	1820	1840	1860	1875	1750	1790	1860	1930	1950	1980

Figure 15 illustrates that the wet compressive strength of lime stabilised soil blocks does not increase very much for compacting pressures greater than about 12 MN/m^2. These results also indicate that the minimum compressive strength, for fired clay bricks (57) and concrete blocks (56), of 2.8 MN/m^2 is achieved when a compacting pressure of about 8 MN/m^2 is employed.

From these test results it was decided to adopt a 10 MN/m^2 compacting pressure for the Brepak block making machine to make blocks 290 x 140 x 100mm deep. Using a compaction pressure of 10 MN/m^2 on a surface area of 290 x 140mm will result in a total compaction force of 40.6 tonnes.

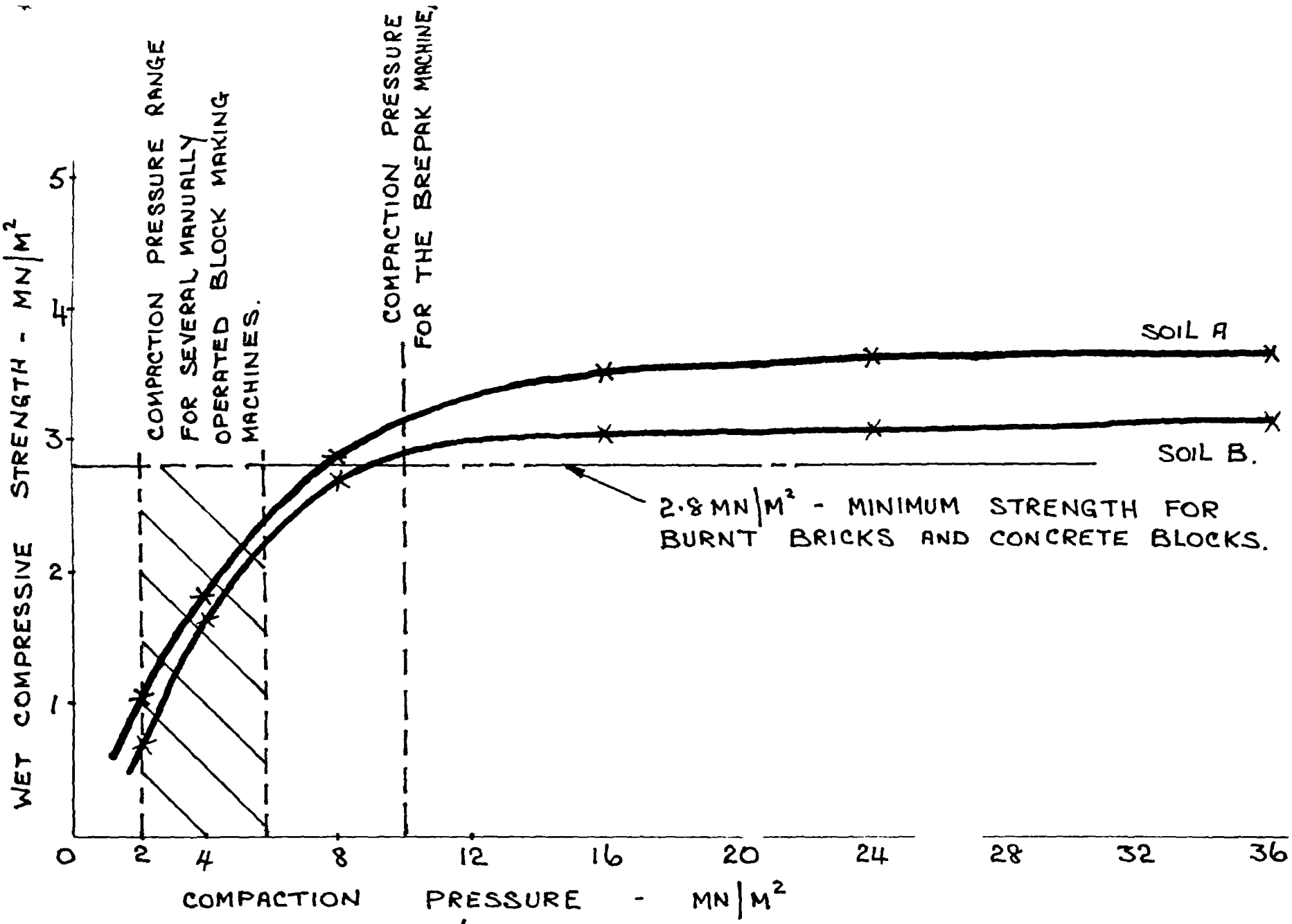


FIGURE 15 - STRENGTH / COMPACTION PRESSURE CURVE FOR TWO GHANAIAN SOILS STABILISED WITH 6% LIME.

It was decided to make the BREPAK machine as light as possible, to be manually operated and simple to operate therefore a simple mechanical linkage could not be employed to generate the total compaction force needed.

A hydraulic system was then designed to provide the compacting force needed and this system is illustrated on Figure 16.

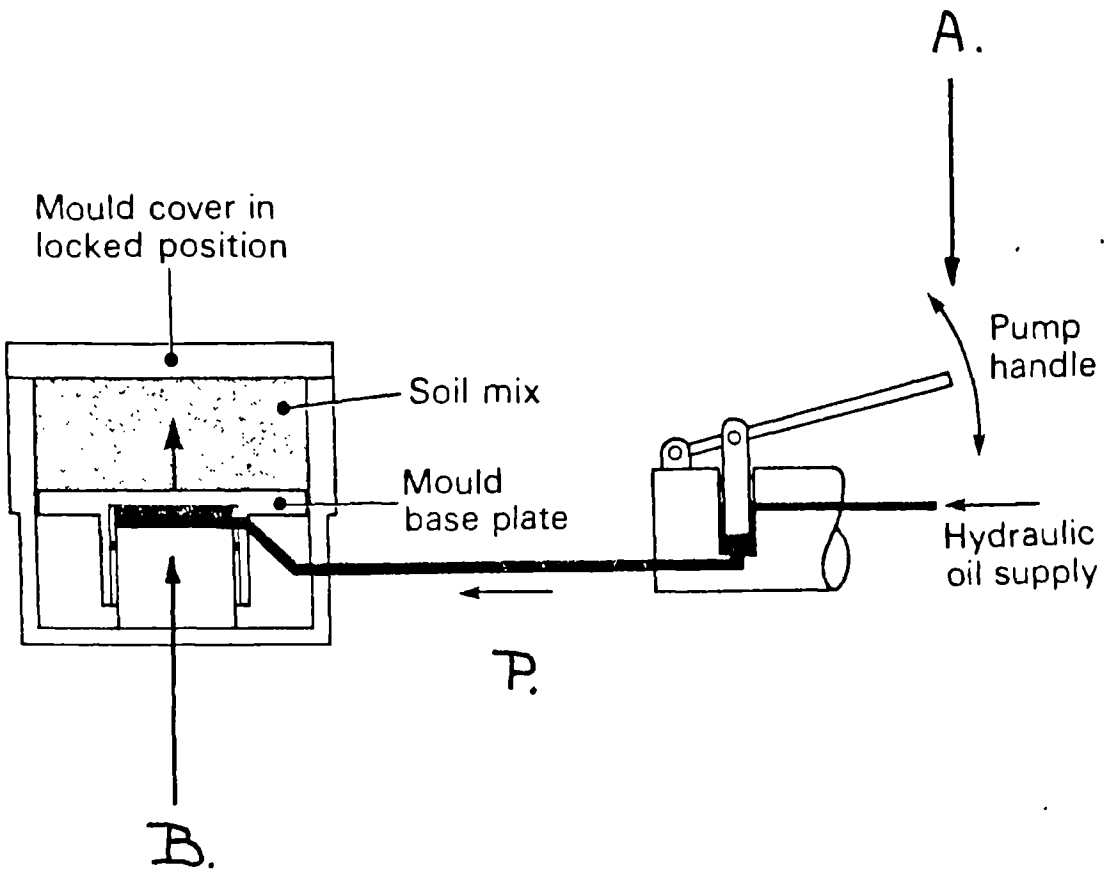


Figure 16: Simplified hydraulic circuit on the Brepak machine

A = Manual input force provided by a manually operated hand pump capable of pressures up to 70 MN/m^2.

B = Required compacting force of 40.6 tonnes. Note that a 100mm diameter plunger has been incorporated at this point.

P = Hydraulic pressure generated by the hand pump.

$$P = \frac{40.6}{\pi \times 50^2} = 51.7 \ MN/m^2$$

Assuming some frictional losses in the system it has been recommended that a hydraulic pressure of 55 MN/m^2 be employed which is within the rated capacity of the hydraulic hand pump. From the earlier experimental data when blocks were being made under a compacting pressure of 10 MN/m^2 it was found that the initial fill depth of the mould should be 155mm thereby giving another dimension for the final machine.

In considering the total movement of a mould component to be activated by the hydraulic system about 430 cubic centimetres of oil must be pumped into a 100mm dia cylinder for movement over 55mm. The hand pump selected for this machine can deliver a maximum of 2.61cm^3 of oil per stroke hence about 165 strokes of the handle would be needed.

This operation would take too long therefore it was decided to achieve the internal mould movement of 55mm by two distinct operations (1) Movement of 35mm through a linkage arrangement similar to the CINVA-Ram machine, forming a reaction frame inside which the hydraulic system would operate and (2) a closed hydraulic cylinder and piston. The piston is held stationary and

hydraulic oil is pumped into the space at the piston head and the cylinder being attached to the underside of the movable mould base plate is moved vertically upwards by 20mm. The hand pump handle then being operated 60 times to complete this operation.

Figure 17 illustrates the main components of the prototype Brepak machine and the list of main components is given inside the operators manual under Appendix A1.

The prototype Brepak machine is illustrated on plate 35 and after about 100 good quality stabilised soil building blocks had been produced a critical assessment of the machine was carried out and reported in an internal BRS report (86).

This prototype machine had achieved the following criteria:

(i) Minimum cost of manufacture.
(ii) Exclusively manual operation.
(iii) Inclusive of a built in device to facilitate ejection of the pressed soil block if manual ejection failed.
(iv) A capability of developing a compacting pressure of 10 MN/m^2.
(v) Capable of producing about 40 blocks per hour.

The prototype machine was then redesigned in certain areas to make it a more compact machine and easier to manufacture and operate. The top linkage alterations are illustrated on plates 36 and 37. The modified Brepak block making machine is illustrated on plate 38.

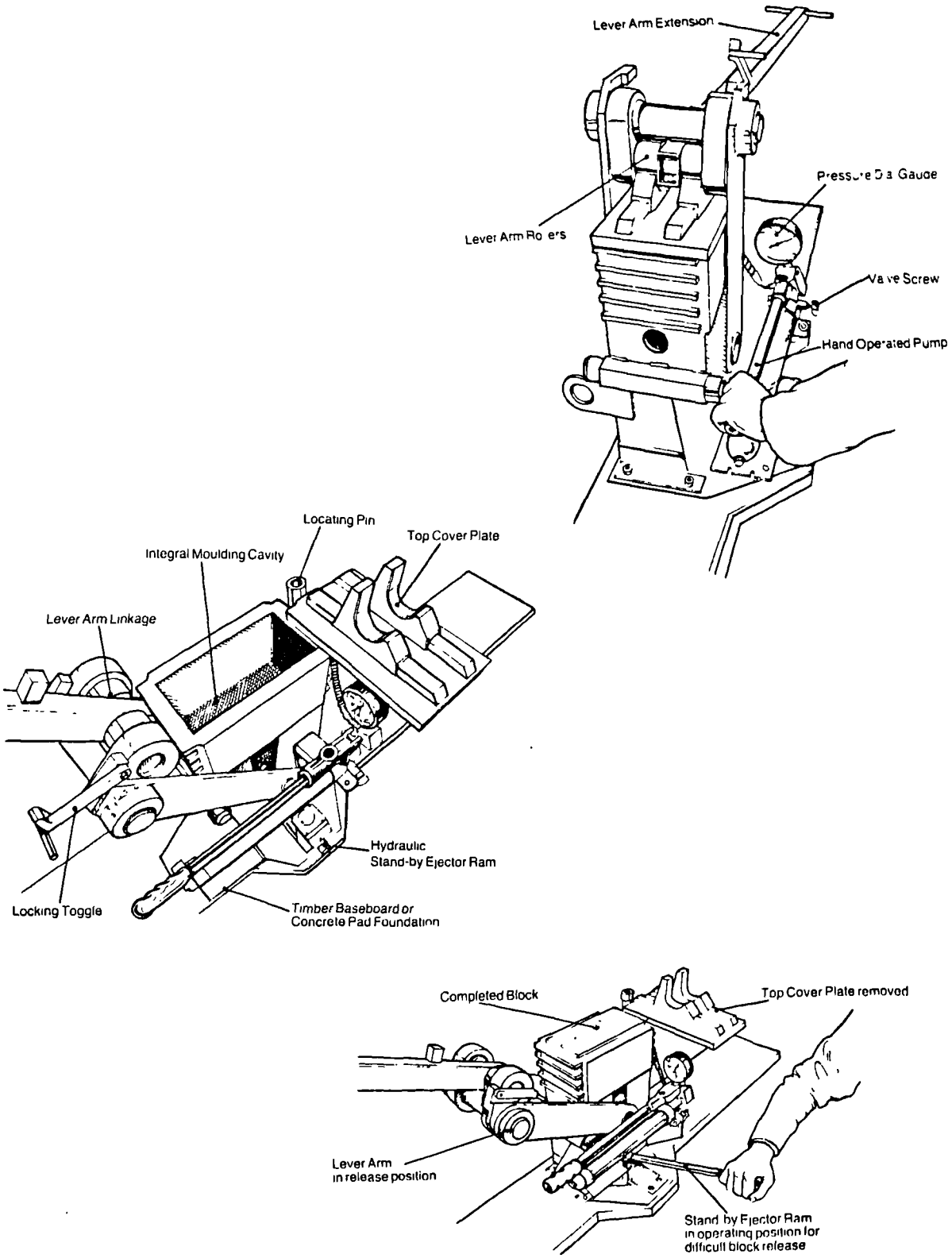


Fig 17 Main components of the Brepak machine

7.3 Brepak Machine Future Developments

The prototype Brepak machine was then modified and to prove this new machine in the field, six machines were constructed and placed in selected areas overseas to undergo exhaustive field trials. Various questions still had to be answered which hopefully would materialise from the field trial results, and decisions should be taken during these trials on the following aspects:

(i) The dimensions/weight of a pressed soil block, 290 x 140 x 95 to 100mm deep, (about 7.5kg) do not make for easy handling on site. If the block size is to remain as it is, a simple block handling device should be developed to enable a mason to place a block with one hand when building a wall - See illustration of a block clamp lifter on Appendix A8 which the author developed.

(ii) The soil preparation and mixing procedure requires further investigation to ensure a uniform mix prior to moulding.

(iii) Clear methods of stabiliser selection should be developed.

(iv) If this new machine is acceptable in a third world situation the production of other sizes of blocks, flooring and roofing tiles, blocks for irrigation channels and hollow blocks, could be usefully investigated.

(v) Acceptance under Building Regulations, (if any exist) would also be desirable.

Plate 35 Prototype Brepak machine

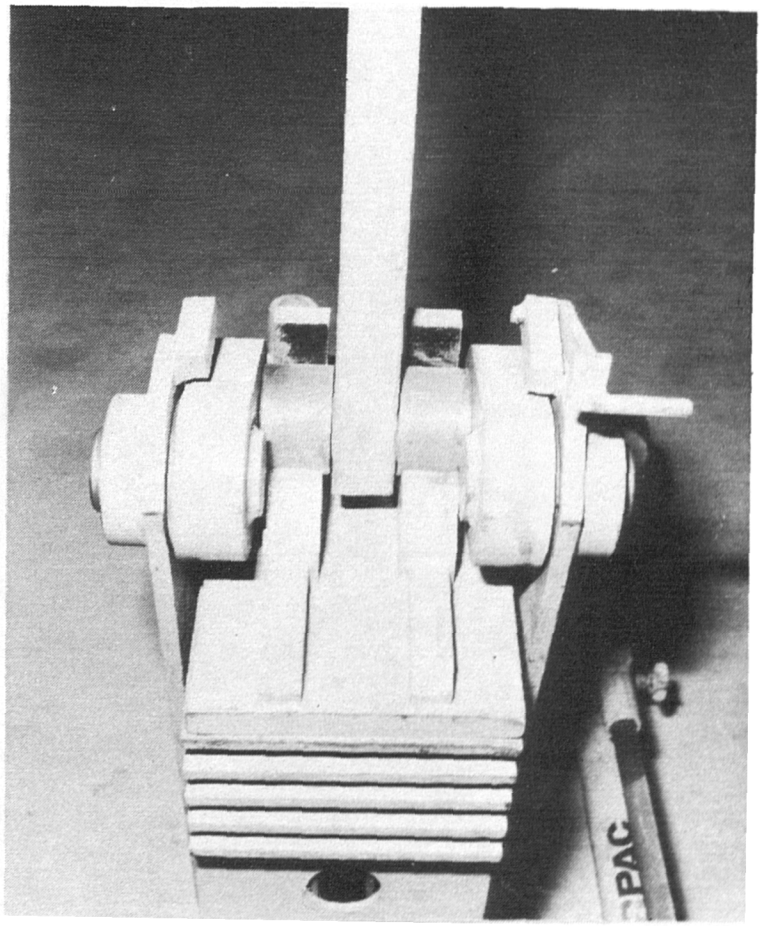


Plate 36 Top linkage on prototype Brepak machine

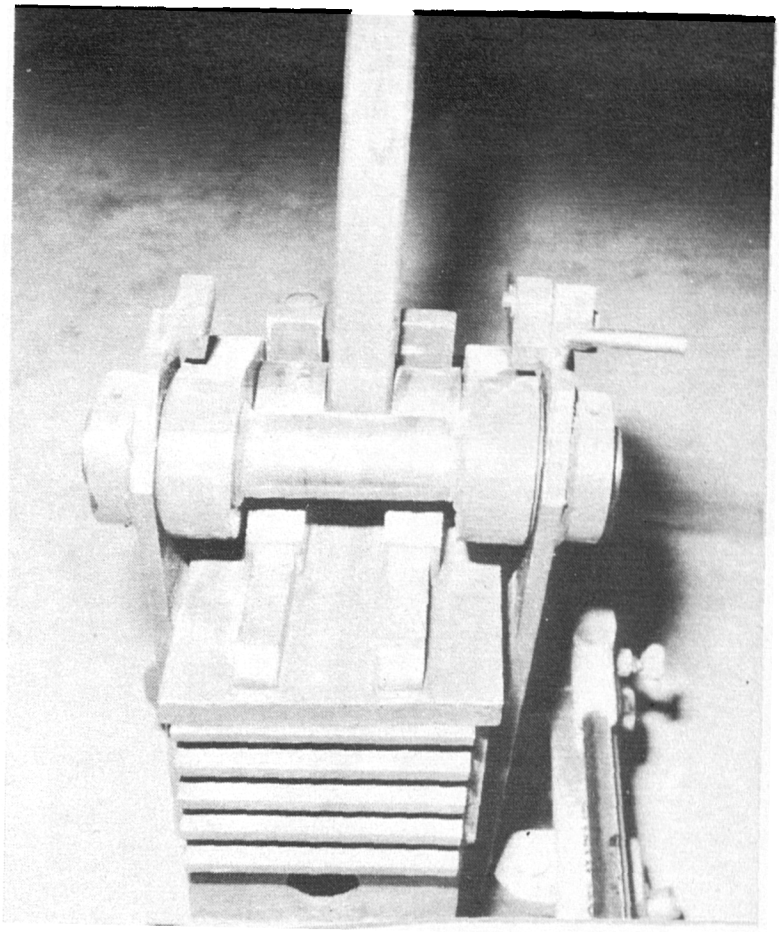


Plate 37 Modified top linkage assembly

Plate 38 Modified Brepak machine

(vi) The use of alternative stabilisers to cement or lime for example indigenous materials could well be studied throughout the period of a specific field trial.

(vii) When the overseas field trials have been completed and any further improvements to the block making process have been incorporated a full operational manual on the subject of hand made soil blocks would be prepared.

(viii) Commercial production of a Brepak block making machine.

Clearly the next step on this project was to initiate overseas field trials for the Brepak block making machine.

7.4 Commercial production of the Brepak machine

Following the successful completion of two Brepak field trials one in Kenya and a second one in Jamaica - See chapter 8, a licensing agreement was awarded to Welding Industries Limited of Blacksworth Road in Bristol, UK. This firm has for many years specialised in the manufacture of equipment for the production of concrete blocks and have sold building equipment into more than 120 overseas countries. The licence agreement was signed in October 1982 for a period of 15 years and a press release issued in February 1983 appears under appendix A7.

After changing design drawings to suit their own style of manufacture, Welding Industries Limited set up an assembly line for making Brepak machines and in the first twelve months about 50 machines were despatched overseas.

To support this sales drive the firm issued a sales brochure which is shown under appendix A8. The block clamp lifting device, is also illustrated on this sales brochure.

The latest development with this company is that with effect from 20 October 1986 this company has been renamed 'MULTIBLOC Limited' and appendix A3 lists the new name and address.

CHAPTER 8

BREPAK MACHINE FIELD TRIALS

8.1 Brepak machine field trial specification

Development projects initiated in the Overseas Division of Building Research Station are usually placed overseas in co-operation with counterpart organisations, for example Building Research Institutes, Universities or Government Public Works Departments or similar types of organisations overseas.

The exact nature of each overseas project application is subject to a specific agreement and in the case of the Brepak block making machine a general specification was initiated a copy of which is included within Appendix A1.

At the commencement of each field trial this general specification was discussed and clauses amended by mutual agreement of the parties concerned.

8.2 Field trial locations

Three countries initially expressed interest in conducting prototype Brepak field trials - these were, Kenya, Jamaica and Sudan. Later on, as the project progressed further field trials were initiated in Iraq, Egypt, Botswana, St Vincent in the Caribbean and the Yemen Arab Republic.

Each country had to be treated differently mainly because of the cultural differences, climatic conditions and certainly the different soil types available in each location. Working relationships with the counterpart

organisations had to be established and in each case the introduction to stabilised soil products had to be slowly introduced via training courses.

The wide variation in climatic conditions together with the problem of natural hazards for example earthquakes and hurricane type winds and health considerations all helped to make each field trial project different. No one field trial was similar to another and therefore I propose to mention each country separately.

8.2.1 Kenya

In the case of Kenya a Memorandum of Understanding had been agreed in 1980 between the governments of Kenya and the United Kingdom which stipulated the counterpart organisations. In Kenya, this was the Housing Research and Development Unit, (HRDU) financed by the Kenyan Ministry of Works Housing and Physical Planning, located in the University of Nairobi. The Overseas Division of the Building Research Establishment was the United Kingdom counterpart organisation.

Two Brepak machines were delivered to HRDU in November 1980 and tests using a local Murram soil stabilised with cement were conducted in their laboratories.

It was decided to commence Brepak field trials in the Kawangware district of Nairobi on a human development upgrading scheme, financed by the Institute of Cultural Affairs (ICA). The Kabiro project, within the Kanangware district, was engaged on the construction of a community building project with an area of about 300 square metres which would be used by about 3500 people living in the Kabiro project area of about 19 acres.

About 50 square metres of the proposed community buildings would be used as a medical clinic which would require about 3500 stabilised soil blocks.

On site, work had already started on the production of stabilised soil building blocks using a locally manufactured 'Block press' - illustrated on plate 39 - See section 6.2.6. About 100 blocks had been made using the local Murram soil with 18 per cent cement as a stabiliser. The Brepak was demonstrated using this local soil with 4 per cent cement used as the stabiliser. The contrasting result of the improved Brepak block to the Block press product can be seen on plate 40. The on-site field trial of the Brepak machine commenced in June 1981 when about 3500 stabilised soil blocks were produced by local voluntary labour under the direction of the HRDU staff.

Sieving was effected by using a static sieve which did not work very well and limited the daily output of blocks to about 250 blocks per day, about 35 blocks per hour. A team of 6 operators were employed to excavate and spread out the soil for drying, sieving, mixing and block manufacture.

The clinic was based on a simple design of load bearing cross walls at 3.30 metre centres. The use of trusses and rafters in the roof construction was avoided by using deep timber purlins spanning the 3.16 metre gaps and supported by the load bearing walls. Jack rafters and fascia boards were used to support a 400mm wide overhang as eaves. The shell construction of this clinic is illustrated on plate 41.

Cement reinforced sisal roofing sheets each one metre square were used to roof this structure and the completed medical clinic is illustrated on plate 42.

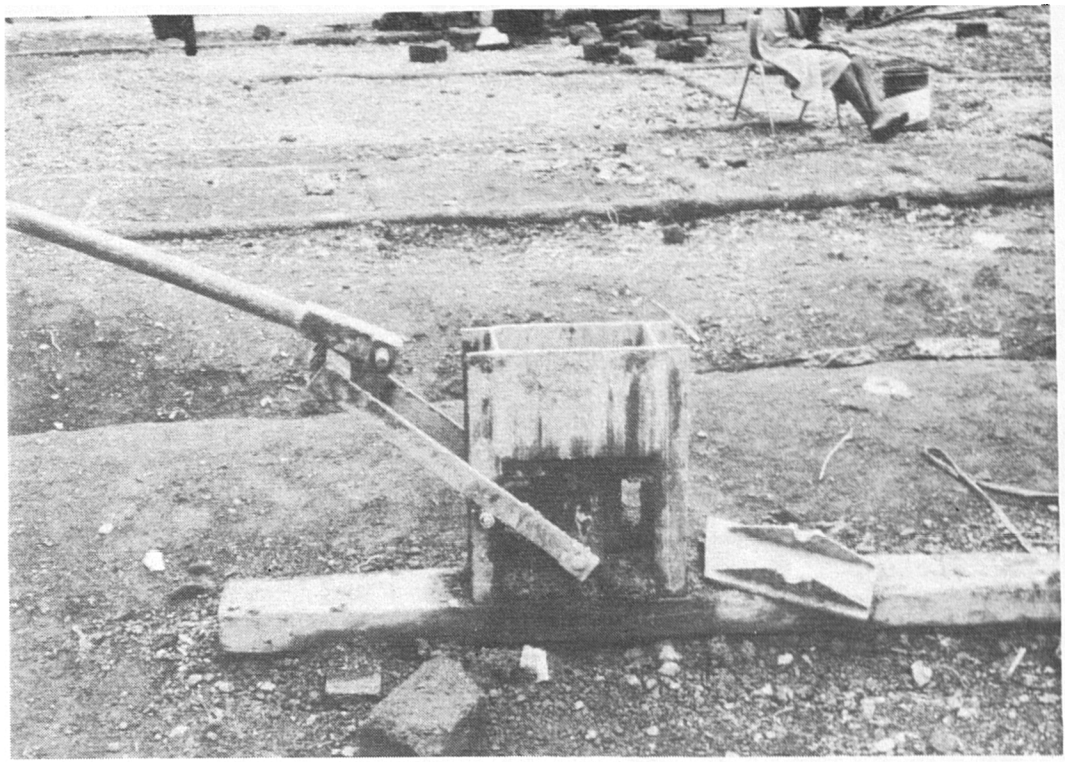


Plate 39 Block press machine manufactured in Kenya

Plate 40 Comparison of blocks made by the block press and Brepak machine

Plate 41 Roof construction at a Medical Clinic at Kawangware

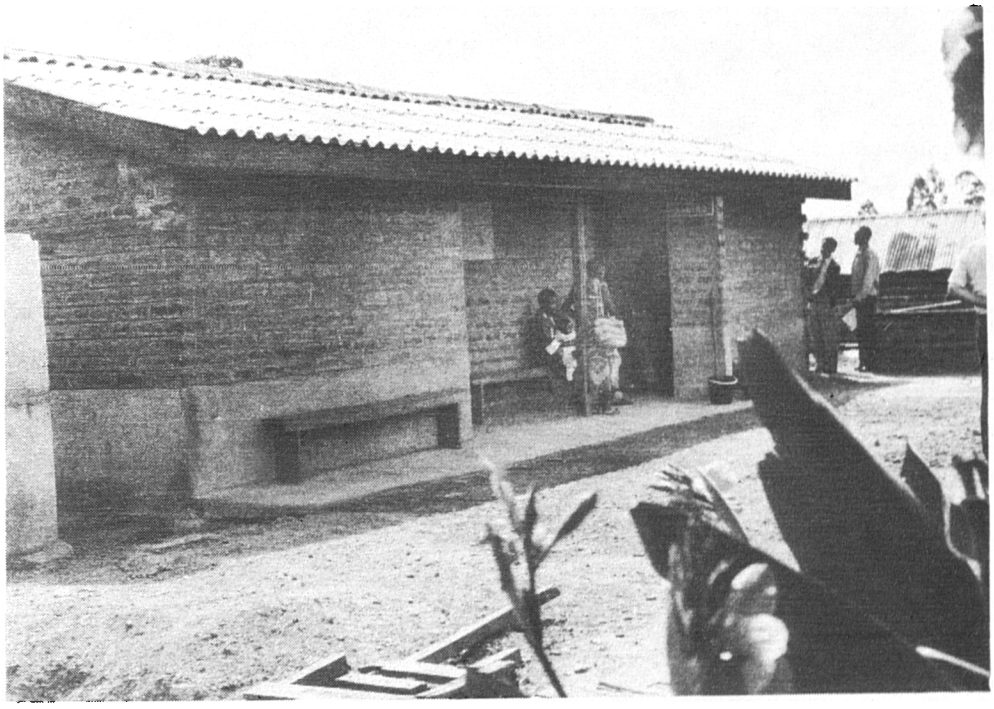


Plate 42 Medical Clinic at Kawangware in use

Mr Charles Rubia, Kenyan Minister of Housing officially opened this medical clinic in February 1982, who stated that the structure could not be approved by the local authorities, it was termed a demonstration structure, but that he would be urging his own Ministry to introduce new building regulations so that structures constructed from good quality stabilised soil blocks could be considered as permanent buildings.

A paper entitled 'Peoples Practical Participation' (87) was prepared by HRDU in 1982 which discusses this project in more detail including the economic aspects - See chapter 10, which indicate a cost saving of about 50 per cent when compared with concrete block work construction.

The local people at Kawangware accepted this method of building construction and progressed with the construction of the community centre which now consists of four main buildings forming a closed quadrangle of about 300 square metres. This complex consists of the following:

(a) A three roomed building used as a medical clinic (plate 42).

(b) Three classrooms, one of which is used by a local ladies group as a handicrafts centre (Plates 43 and 44).

(c) Two small storerooms.

(d) An office/headmasters study - plate 45.

This community centre was completed during 1983, and used by the University of Leuven in Belgium as a project case study document entitled Earth Construction Technology in Kenya (88).

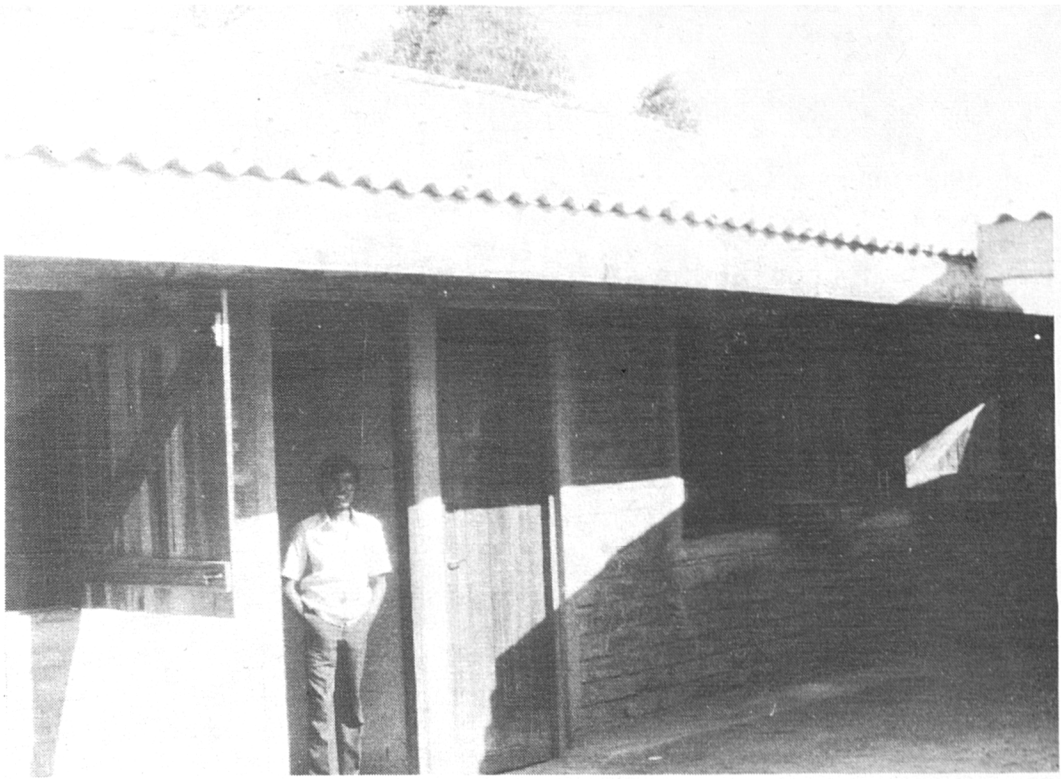


Plate 43 Building with two classrooms

Plate 44 Building with one classroom

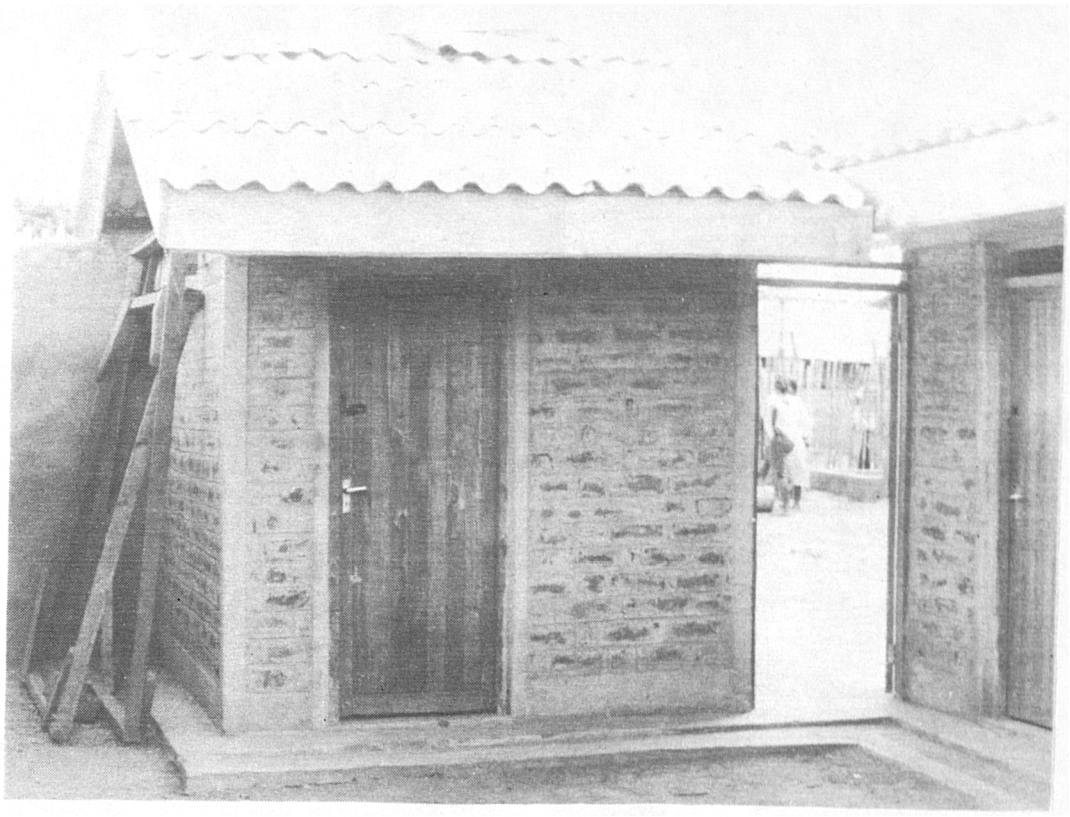


Plate 45 Headmasters study at Kawangware school

Plate 46 Curing Brepak blocks at Ruambwa

Appendix A5 is a single sheet handout prepared by the author in 1982 as a Research for Industry note entitled 'Brepak block making machine for use in developing countries'.

Further research was conducted in Kenya on five sites located around Lake Victoria in Western Province where accommodation has been constructed for 40 teachers. Each site consists of two separated building complex units which accommodates 8 teachers and some 15,000 stabilised soil blocks have been produced for each site complex.

Plate 46 illustrates the curing of Brepak blocks at Ruambwa.
Plate 47 shows a Brepak block building at Ruambwa.
Plate 48 illustrates the completed site at Budalange.
Plate 49 illustrates the Brepak blockwork construction at Makunda.
Plate 50 Site view at Nyamuga.
Plate 51 shows one of the Brepak block buildings at Ogongo.

In addition to the practical site work, several students at the University of Nairobi have worked on a Brepak machine in the University Laboratory and have cited this work within their own degree dissertations. See section 4.5.7.

A document (89) prepared by the Kenyan Ministry of Agriculture details 22 major Kenyan soil types of which about 15 could be used for soil stabilisation. Regarding the joint Anglo/Kenyan research project on soil stabilisation, six general soil types have been successfully used and HRDU is continuing with this research project. The details of the soil types used are listed on Appendix A6 together with the results obtained in the field.

Plate 47 Teachers accommodation at Ruambwa

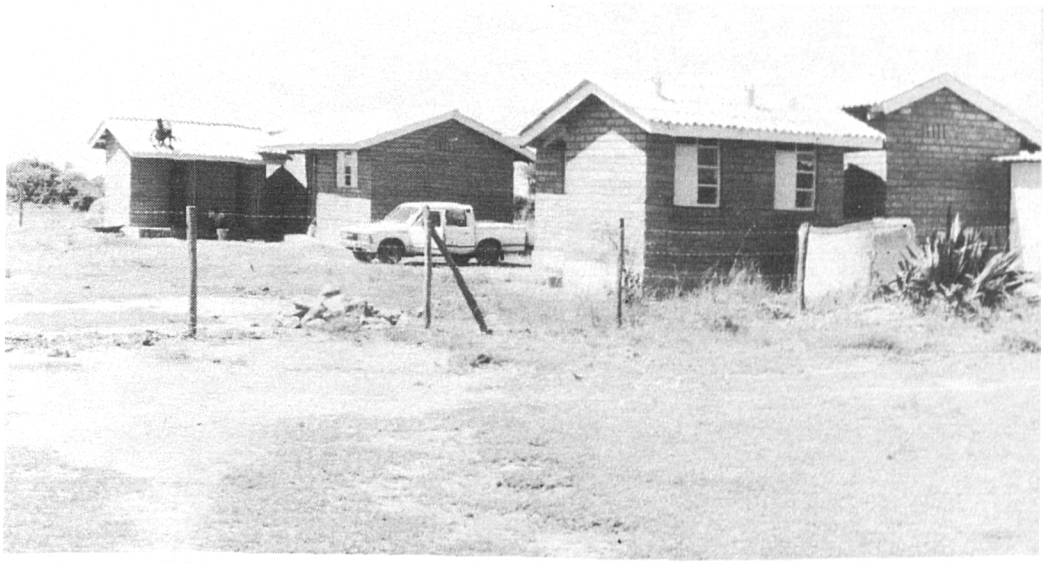


Plate 48 Completed buildings at Budalange

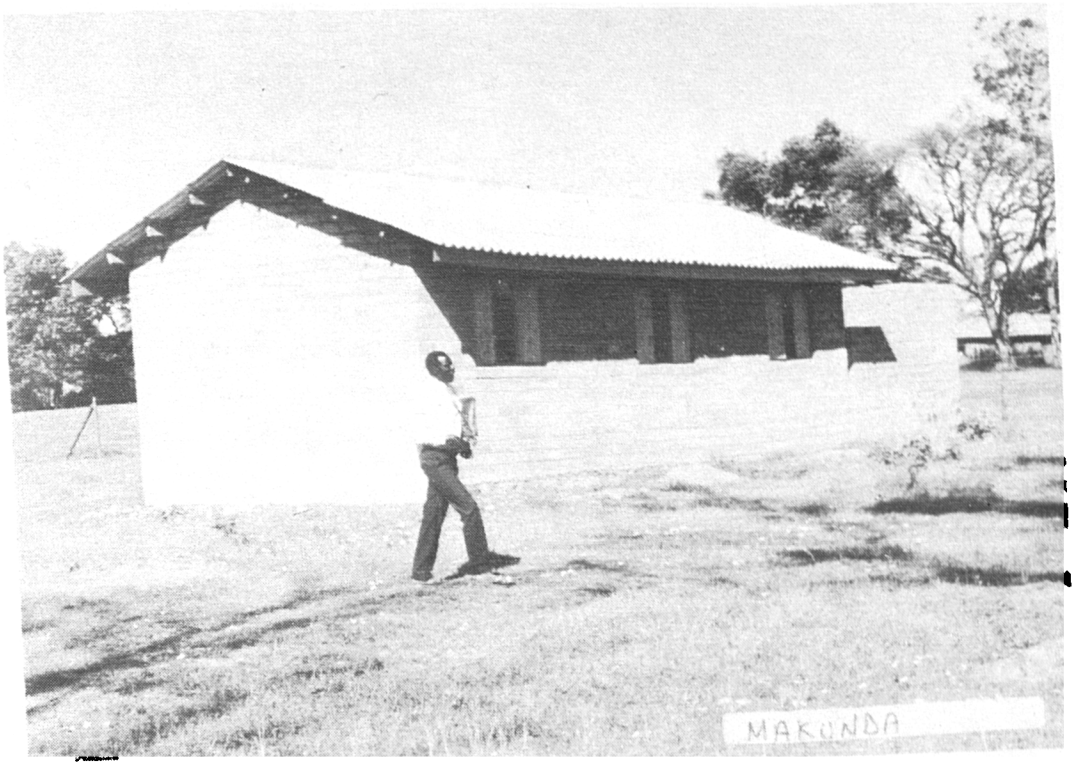


Plate 49 Brepak block construction at Makunda

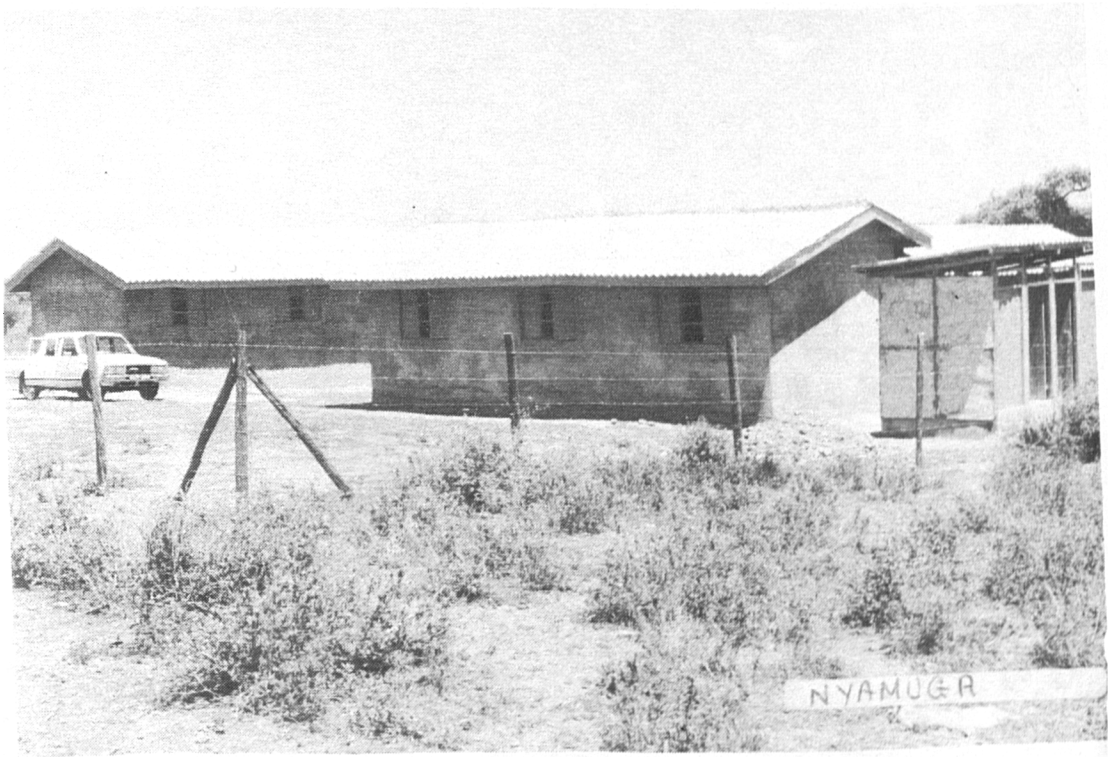


Plate 50 View of site at Nyamuga

Plate 51 Teachers accommodation at Ogongo

Plate 52 Mixture of Brepak blocks and concrete columns in Jamaica

The Brepak field trial in Kenya was reported to an International Conference on Economical Housing in Developing Countries Symposium held in Paris during January 1983 (90).

This report entitled Stabilised Soil Construction in Kenya appears under Appendix A9.

8.2.2 Sudan

The Sudanese research work on soil stabilisation was first initiated in 1980 by the British Council in Khartoum who sponsored El Fadil Ali Adam, a Sudanese architect from the Council for Scientific and Technological Research, National Council for Research, in Khartoum for a study period of two years at Building Research Station.

It has been estimated by Agib (91) of the National Council for Research that 80 per cent of the buildings in the Urban areas of Sudan are constructed with mud (jalous) and in the rural areas the figure is over 90 per cent. This publication also suggests that soil will remain the fundamental building material in the Sudan for the next century. This is certainly due to its availability, its good thermal performance, its low cost and the fact that building with soil in the Sudan is a well established method of construction.

However, the major disadvantage in using soil as a construction material is its lack of durability especially as there is a predominance of black cotton soils in Sudan which have high moisture movement properties. External walls require constant maintenance especially in areas of high rainfall as highlighted by Hammond (92) who quotes the main courses of deterioration of soil buildings as shrinkage cracking, erosion, flaking and mechanical damage.

In its six year National Development Plan (92) (1976-1982) the Sudanese Government has attempted, amongst other things, to provide houses of more durable materials using the black cotton soils.

With the development of the Brepak machine and using lime as the stabilising agent, the object of El Fadil Ali Adam's study tour to BRS was to determine by experiment the significant factors in the production of stabilised soil blocks using selected Sudanese soils.

Three soil samples, each about one cubic metre were obtained from the Sudan and shipped to BRS. These samples were collected from around the Khartoum area from borrow pits which are the usual sources for the traditional jalous construction. These district localities were Fetehab, El Hizam and Deroshab which are in the suburbs of Omdurman, Khartoum and Khartoum North respectively. El Hizam and Deroshab soil samples represent the largest soil group in Sudan ie black cotton soil. The Fetehab soil sample is representative of the second largest soil group ie the red-sand ironstone. Details of these soil types can be seen on Appendix A6. Figure 18 gives the particle size distribution for the three Sudanese soil samples.

Sample blocks were manufactured from these soils using lime as the stabilising agent - see section 4.4.3. However long term durability tests after 2 years on these blocks have indicated that good dry strengths have been maintained but that wet compressive strengths have dropped. It was decided to modify the El Hizam soil with sand to reduce the silt/clay fraction to an acceptable level and then stabilise with 6 per cent cement.

Three linear shrinkage tests were then conducted using the El Hizam soil mixed with proportions of sand as follows:

(i) El Hizam soil, (ii) one part sand and one part soil, (iii) two parts sand and one part soil.

These different linear shrinkage curves were plotted as shown on Figure 19 and it was decided to use the mix of one part sand with one part soil and 6 per cent cement. Good quality strength results were achieved during the durability tests which are reviewed in Chapter 9.

During the research test programme at Building Research Station Professor A R Agib, Director of the Council for Scientific and Technology Research, Khartoum, Sudan visited BRS which is reported on a press notice given under Appendix A10.

Two Brepak machines were sent to Sudan one to the National Council for Research in Khartoum and a second machine to Juba in Southern Sudan where Voluntary Service Overseas operatives planned to use the Brepak machine on a school building programme under the control of the National Council for Research.

The Brepak machine supplied to Khartoum will be used on a pilot project scheme at the village of Rahad in the Blue Nile province some 300 km to the south of Khartoum. When the author visited Sudan in December 1982 this machine was still awaiting customs clearance from the docks and the latest news is that some 40,000 good quality stabilised soil building blocks have been manufactured on site. Building work is progressing slowly.

There has not been very much progress with the Brepak machine in Southern Sudan due entiely to lack of finance and the state of hostilities that exist in this part of the country.

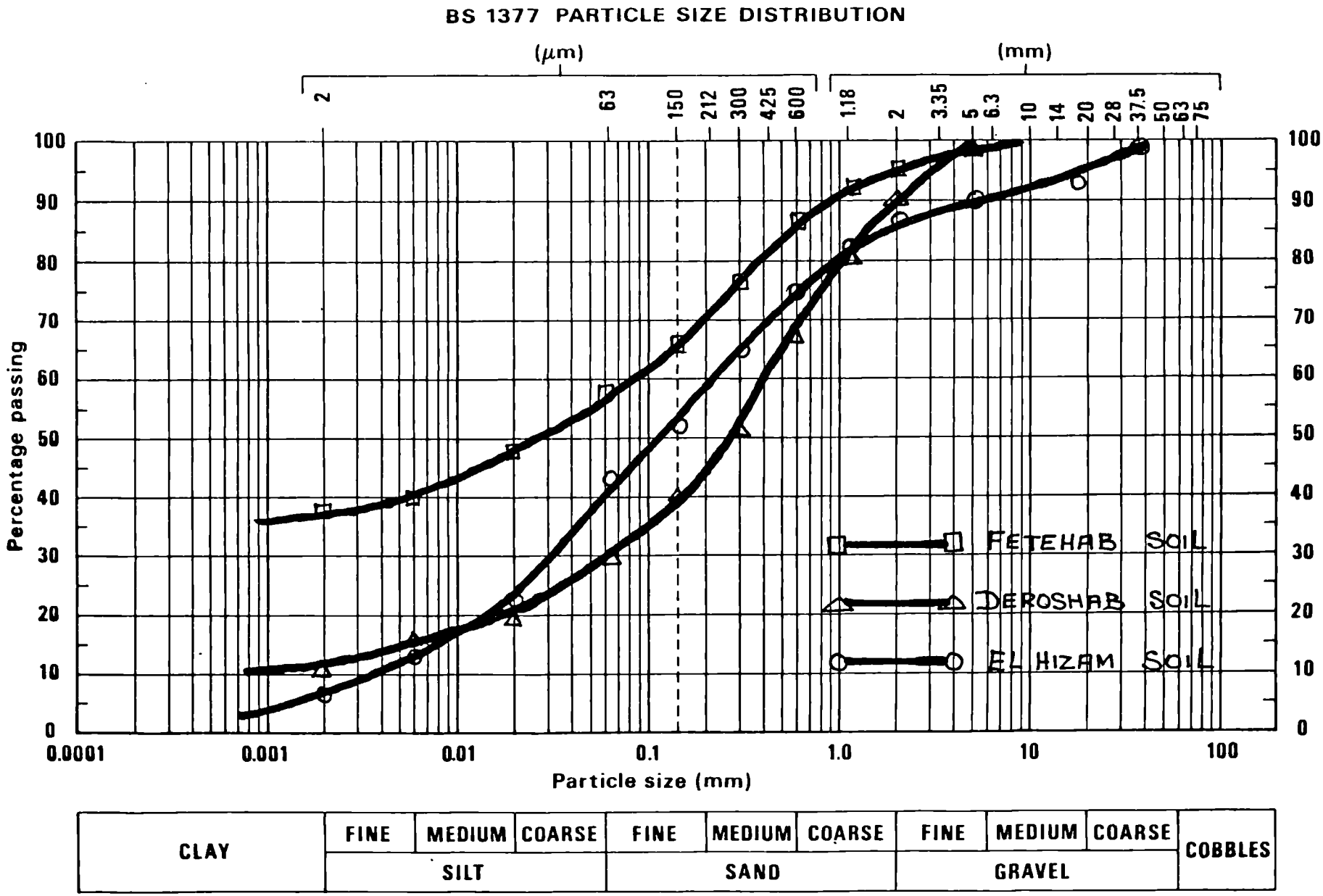


FIGURE 18 - PARTICLE SIZE DISTRIBUTION CURVES FOR THREE SUDANESE SOILS.

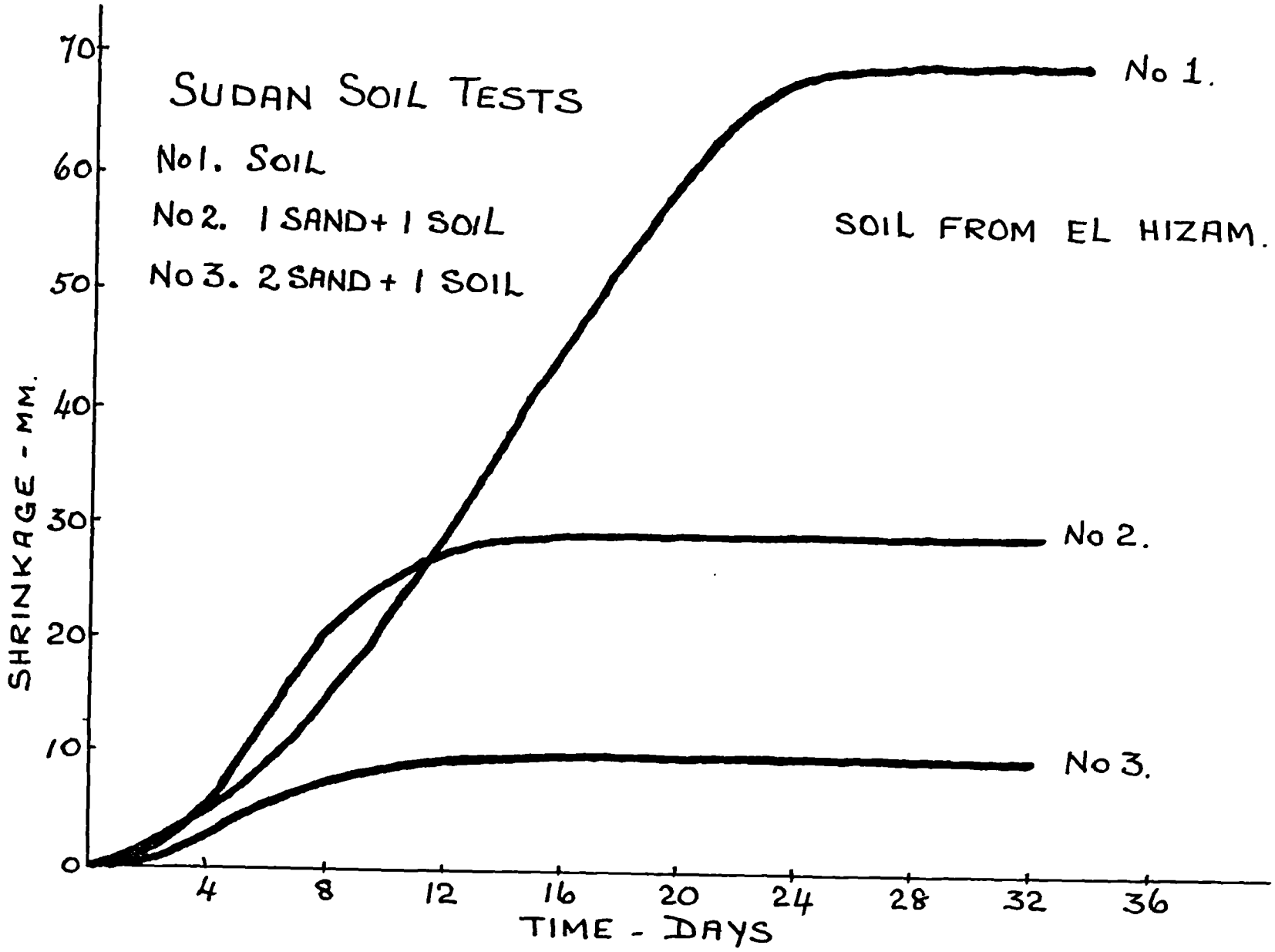


FIGURE 19 - LINER SHRINKAGE CURVES OF MODIFIED SUDAN SOIL.

8.2.3 Jamaica

The Jamaican Brepak field trial was initiated by Senator Bruce Golding, Jamaican Minister of Construction following his visit to Building Research Station on 13 May 1981. On returning home, the Minister submitted a formal request for a Brepak field trial to the British High Commission in Kingston, Jamaica. One Brepak machine together with ancilliary equipment was delivered to the Jamaican Building Research Institute (BRI) during April 1982 when the author was visiting the island.

Jamaica is a mountainous island, some 150 miles long by about 50 miles at its broadest with an area of about 440 square miles. It is situated, rather remotely, to the west of the Commonwealth Caribbean and has a population of approximately 2.2 million.

Buildings erected on this island have to be of strong construction to withstand both hurricane force winds and earthquake tremors. Mainly single storey buildings are constructed using hollow concrete blocks with vertical steel reinforcement passing through the blocks.

At a meeting with the Ministry of Housing it was indicated that some 60,000 houses were urgently needed with an annual requirement of about 16,000 houses but only about 4000 houses were being constructed annually due to the shortage of foreign exchange.

The island of Jamaica has a plentiful supply of indigenous materials generally spread around the island in rather small pockets which includes limestone, clay and aggregates but they do not have the expertise to use this material. There is however an abundant supply of Red Bauxite soil available on the island. It was decided to investigate three possible soils for the

soil stabilisation research project ie Red Bauxite, Knollis clay soil and Denbeigh Clay soil. Details of these soils can be found under Appendix A6.

A 50kg sample of Knollis clay soil was shipped to BRS for experimental purposes and using 8 per cent cement, by weight, as the stabilising agent, good quality building blocks were produced by the Brepak machine. These blocks manufactured at BRS gave wet compressive strengths in excess of 3 MN/m^2 which is above the minimum compressive design strength of concrete blocks.

The Knollis clay soil has a combined silt and clay fraction of 81 per cent and it would probably have been better to stabilise with hydrated lime. However information received from Jamaica stated that the cost of cement is £3.96 for 50kg whilst the cost of hydrated lime is £14.05 for 50kg. Therefore for economic reasons it was decided to use cement as the stabilising agent.

Laboratory trials were conducted by BRI staff at the Soils Testing Laboratory in Kingston on both the Red Bauxite and Denbeigh clay soils where stabilised soil blocks were made from a Brepak machine. These trials indicated that the Red Bauxite soil stabilised with 6 per cent cement would satisfy the strength requirements for single storey building. Twenty sample blocks were made, one mix with 6 per cent cement and a second mix with 10 per cent cement.

The following table gives the test procedure and average results obtained:

Test Procedure	Average Results	
Cement Stabiliser	6 per cent	10 per cent
Block samples	10	10
Dry Density	1944 kg/m^3	1967
Face water absorption after 24 hours immersion	2.37 grm/cm^2	1.74
Standard Deviation	0.31	0.31
24 hours wet strength	2.95 MN/m^2	3.85
72 hours wet strength	1.74 MN/m^2	2.68

The 3 day water immersion prior to crushing is a stringent test and these results should be ignored and accept the normal 24 hour immersion test results.

The Denbeigh clay soil was stabilised with 8 per cent cement which gave favourable wet strength results however the soil block faces were rough and pitted due to the inclusion of fine stones in the soil. This problem would not have shown itself if more care had been exercised with the soil sieving operation which proved to be rather tedious. This operation of manual sieving could be improved if a manual sieve were to be developed.

Senator Golding then agreed to the construction of a 94 square metre demonstration community centre which would be erected inside the agricultural show ground at May Pen.

This demonstration structure would be exposed to some 300,000 visitors during the annual agricultural show which is open to the general public therefore the building must be designed to resist earthquake and hurricane force winds.

Using a design wind speed of 110 MPH (based on a 50 year return period three second record gust) obtained from a Building Code for Jamaica entitled House Construction in Jamaica (93), it was decided to case in-situ, 18 concrete columns each 300 x 140mm around the perimeter of the demonstration structure - see plate 52, and that single frogged Bauxite soil blocks would be employed for the external walls and Denbeigh clay soil blocks used for the internal walls - Plate 53 illustrates the completed building.

There was a delay in the construction of this demonstration structure due to a polio epidemic, however the structure was completed by the end of June 1983 with significant cost savings which are discussed in Chapter 10.

The author would have preferred that the Knollis clay soil be used for this project but transportation costs would have been excessive.

The demonstration structure was subjected to an earthquake tremor of magnitude 4.8 on the Richter scale as recorded by the Seismic Unit of the University of West Indies during mid 1984 with no damaging results.

Plate 53 Community building in Jamaica

Plate 54 Roof only structure in St Vincent

8.2.4 Iraq

Dr Mufid A Samarai, Director of the National Centre for Construction Laboratories (NCCL), Baghdad informed the author at a meeting in Paris during January 1983 that his organisation had ordered six Brepak machines. These machines travelled overland and reached Iraq during the summer of 1983.

From information supplied, NCCL were going to conduct their own field trial studies and hoped to construct low income housing in a marshy area to the south of Iraq.

Due to the hostilities that have existed within the rural areas of Iraq the author has not been able to obtain permission to visit this country and consequently only meagre information has been received.

The Brepak machines did give some problems on operation at the onset of this project and the latest information to hand is that some 120,000 stabilised soil building blocks have been produced but no information as to the type and number of buildings that may have been constructed.

Note: A typical 50 square metre building will need about 3,000 Brepak blocks for the construction of the walls, hence the blocks produced in Iraq represent about 40 single storey detached low income buildings.

8.2.5 Egypt

The author's local supervisor, Dr R F Stevens, visited Egypt in 1980 and on his return made recommendations that a Brepak field trial be conducted in conjunction with the General Organisation for Housing, Building and Planning Research (GOHBPR). This organisation is Egypt's equivalent to the Building Research Establishment in the UK and is located in Cairo within the Ministry of Housing and Reconstruction.

Two Brepak machines were shipped by overland transport, arriving in Cairo during February 1981 and were put into store pending the author's arrival in Egypt during March 1981.

Prior to the period 1960-1970, during which time the Aswan High Dam was constructed, Egypt had a thriving burnt clay brick industry which made use of the daily replenishment of good quality silt deposited along the banks of the River Nile. After the Aswan High Dam was completed the silt deposits ceased because the River Nile was turned into a slower moving mass of water.

Economically the Aswan High Dam improved conditions in Egypt by providing some 10,000 million kW hrs of hydro-electric power annually, irrigation to some 400,000 hectares (1 million acres) of land to improve agricultural output, domestic and industrial water supply improvements and because of water flow control conditions there is no longer a flooding season.

However these improvements have produced problems in other areas with stagnant water in the fields greatly increasing the incidence of schistosomiasis (bilharzia) and with the non availability of suitable materials for turning into burnt bricks the building industry has had to turn its attention to finding other suitable soils.

Egypt has an abundance of naturally occurring shale soils or Marly clay soil formed of consolidated argillaceous sediments. However, shale varieties subjected to heat and pressure are transformed into slates (94) which are metamorphic types of rocks. The clay content of a shale material governs its plastic properties (95).

During the early 1980's research was conducted in Egypt to investigate the production of burnt clay bricks from the Marly clay soil (96) by first extruding the dampened material and forming the bricks by wire cutting. This process proved to be expensive because the Marly clay needed special treatment in mixing, forming and firing at temperatures between 900°C and 1000° Celsius.

GOHBPR wanted to investigate the production of Marly clay soil blocks using the Brepak machine and various stabilising agents mixed with the soil. The details of this soil type are given under Appendix A6.

Many studies have been conducted at GOHBPR on the shale clay deposits obtained from various regions of Egypt and all the sieve analysis results indicate that the silt/clay fractions would be greater than 75 per cent.

It thereby follows that Egyptian clay soil has to be mixed with sand to reduce the clay content followed by the addition of a suitable stabiliser. Cement; Lime; Cement and Lime and Bitumen Emulsion were all used separately as stabilisers.

The bitumen emulsion stabilisation was quickly discontinued because of the messy process involved in breaking down the solid asphalt with a gasoline diesel product and mixing with water. A few blocks were made with no appreciable improvements to the water rejection by a cured soil block.

During the period from 1981 to 1983 numerous trial mixes were investigasted, finally two mixes were used and all the 200 blocks were carefully cured under polythene prior to testing for compressive strength both dry and wet as reported in Table 17.

TABLE 17 - STRENGTH DEVELOPMENT OF EGYPTIAN STABILISED SHALE/CLAY SOIL

Mix 1 - 15% shale clay soil, 75% sand, 10% lime and 9% water.

Mix 2 - 15% shale clay soil, 72% sand, 10% lime 3% cement and 10% water

Age of Block	Compressive strength in MN/m^2			
	Mix 1		Mix 2	
	DRY	WET	DRY	WET
28 days	2.6	0.68	2.35	0.76
31 days	2.12	0.89	2.2	0.8
35 days	2.0	1.43	2.5	1.13
42 days	2.38	1.47	2.07	1.08
2 months	3.1	1.47	1.08	2.05
6 months	0.77	*	0.65	*

*Disintegrated in water.

Before pressing, the mix had been allowed to stand for about half an hour to allow for full water absorption of the clay particles. Since the 2 month period the blocks had been allowed to stand in the open, without any covering within the laboratory. When the blocks were immersed in water at the six month age they completely disintegrated. Dry compressive strength tests were conducted to investigate the reasons for the blocks breaking down when immersed in water.

The dry compressive strengths of these blocks had also dropped from an average of about 2.5 MN/m^2 at 28 days to about 0.7 MN/m^2 at an age of 6

months proving that there is a fundamental fault in the Egyptian shale clay soil used during this research investigation.

The shale clay chemical analysis was then compared with other analyses of satisfactory clay soils used elsewhere in the world and was found to have a higher percentage of Sodium Oxide, Na_2O (soluble salts or sulphate). It was also suggested that Montmorillonite may be present in the Egyptian shale clay soil again affecting the final block strengths.

Concerning the soluble salts problem, a 20 kg sample batch of clay soil was immersed in water for 30 hours after which the excess water was drained off hoping that 'free soluble salts' would be removed with the water.

The moisture content of the saturated shale clay soil was determined as 35%. It was decided to use a mix of 75% sand, 15% clay and water, corrected to compensate for the moisture content and 10% lime. No cement was added because the cement inclusion mix on the previous set of results gave a lower compressive strength.

Further research is therefore in progress at GOHBPR and the results will be passed to BRS when available.

When a suitable mix has been determined, GOHBPR wish to erect on site in Cairo a single room test house measuring 3.3m x 3.3m x 2.7m height from stabilised soil blocks. This test room will be placed with twelve others built with different materials in order to gather data on the internal environment. The data obtained would be valuable information for application in other parts of the world. This inclusion of soluble salts has affected the long term strength of stabilised soil blocks made from the shale clay

soil of Egypt and in addition has influenced the plasticity of the soil as discussed by E C Bloor (95).

From these investigations the soluble salts often being compounds of Potassium and Sodium have indicated that if the combination of K_2O + Na_2O is greater than 2 per cent then an undesirable amount of soluble salts may be present for efficient long term soil stabilisation.

Note that from Appendix A6 the Egyptian shale clay soil has a combination of K_2O + Na_2O equal to 1.17 + 3.32 = 4.49%.

8.2.6 St Vincent

St Vincent and the Grenadines are located in the Eastern Caribbean, 100 miles west of Barbados. One of the Windward Islands group, St Vincent is roughly 18 miles long north to south and 11 miles wide having an area of about 133 square miles.

To the north the interior is mountainous with an active volcano within the Soufriere Mountains rising to over 4000ft. To the south the island is heavily cultivated with banana and coconut plantations and arrowroot fields.

The St Vincent Brepak field trial was initiated by the British Development Division (BDDC) whose headquarters are on the island of Barbados. BDDC have a community development programme with the Caribbean Conference of churches (CCC) who had received favourable reports concerning the Brepak field trial in Jamaica - See section 8.2.3. CCC requested that a field trial should be conducted on the island of St Vincent.

The author visited this island in 1983 and held discussions with representatives of the Christian Action for the Development of the Eastern Caribbean (CADEC) which is the development agency for CCC.

CADEC is a non governmental organisation (NGO) and is one of the few organisations operating at village level that attaches priority to projects promoting agriculture, fishery, small businesses, up grading slum areas and also skill training programmes.

One such project is at the village of Barrouallie (Glebe area) located on the leeward side of St Vincent where some 5500 inhabitants reside and there is a high level of unemployment present.

In the case of the Barrouallie Glebe area, a development strategy was drawn up in 1972 in the form of the Glebe Development Programme, the principal objectives being the improvement, on a self help basis, of the housing and infrastructure and the promotion of income generation and self development.

A first evaluation of the Barrouallic Glebe Development Project was prepared in 1977, entitled 'Lands, Homes and People (97) and in 1982 the German Development Institute in conjunction with CADEC produced a critical assessment of the general progress of this project between 1972 to 1982 (98).

It was agreed that CCC through CADEC would finance the construction of a roof only structure of some 200 square metres and that the UK government would finance a Brepak field trial to produce the necessary stabilised soil blocks for the construction of a trade training centre.

The roof only structure, illustrated on plate 54, was completed during 1984 and provided an ideal covered working area in which to train local people

during a Brepak field trial. Two Brepak block making machines and one pendulum clay crushing machine were shipped out to St Vincent ready for a site trial to commence early in 1985.

Soil samples from the Barrouallic Glebe area had been sent to the UK during 1984 for initial laboratory trials at Building Research Station. These trials had indicated that the local Glebe soil contained about 7 per cent silt and clay with a high sand content. Good blocks were formed in the Brepak machine from this soil using 10 per cent cement content but they broke up when lifted from the machine indicating there was insufficient clay within the sample.

On site it was decided to use a locally available high clay content soil and when mixed with the local sandy Glebe soil and stabilised with cement good quality blocks could be made.

Two high clay content soils were investigated, one was obtained from the Mesopotania area, about 7 miles from Barrouallie and a second sample was obtained from the next valley to Glebe - about one mile away. Both soils produced excellent blocks using an initial mix of one part Glebe sandy soil, one part of the clay soil from Reverscion Valley to 10 per cent cement by weight. Subsequently the cement content was lowered to 7 per cent and the average strength of these blocks were:

Average taken from 10 blocks
Dry Compressive Strength = 5.83 MN/m^2
Wet Compressive Strength = 4.62 MN/m^2 with an average water absorption of 11.8 per cent.

After training ten local people on site, the two Brepak machines and the pendulum clay crushing and sieving machine were used quite sucessfully to produce some 12,000 good quality stabilised soil building blocks.

Plate 55 shows the early results of blocks receiving primary curing and stacking. See sections 9.3.1 and 9.3.2. Plate 56 illustrates the local labour force after the completion of their training course.

Because these blocks were not going to be used as total load bearing elements within the structure they were built on edge and tied to the roof only timber supports giving a decorative finish to the building as illustrated on plate 57.

The Rt Hon Timothy Raison MP, then the Minister of Overseas Development visited this particular site during April 1986 and witnessed a Brepak machine demonstration conducted by the local labour force after which he presented Brepak training certificates. A training certificate appears under appendix A11. Plate 58 illustrates this skill centre almost completed in June 1986. The skill training centre was completed in July 1986 with significant cost savings when compared with concrete blockwork construction and these costings are discussed in chapter 10. It is now planned to construct further low income housing in other parts of St Vincent once an established training course programme has been started on the Glebe site.

Plate 55 Primary and secondary curing of Brepak blocks

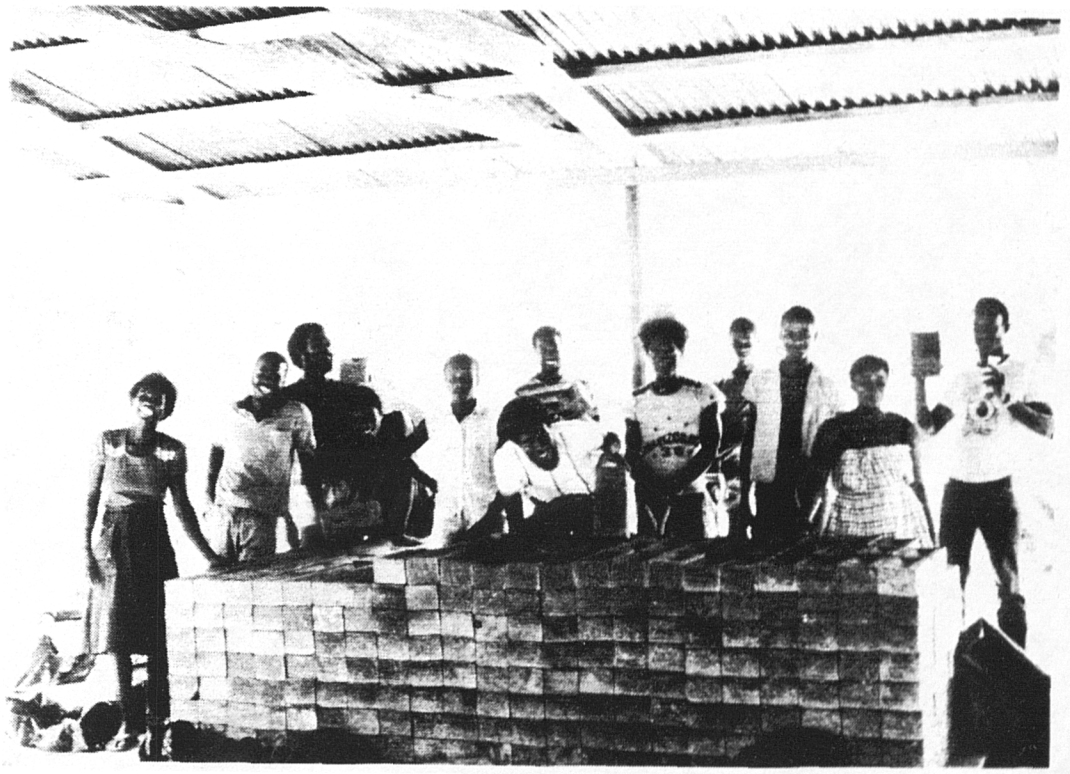


Plate 56 Local labour force in St Vincent

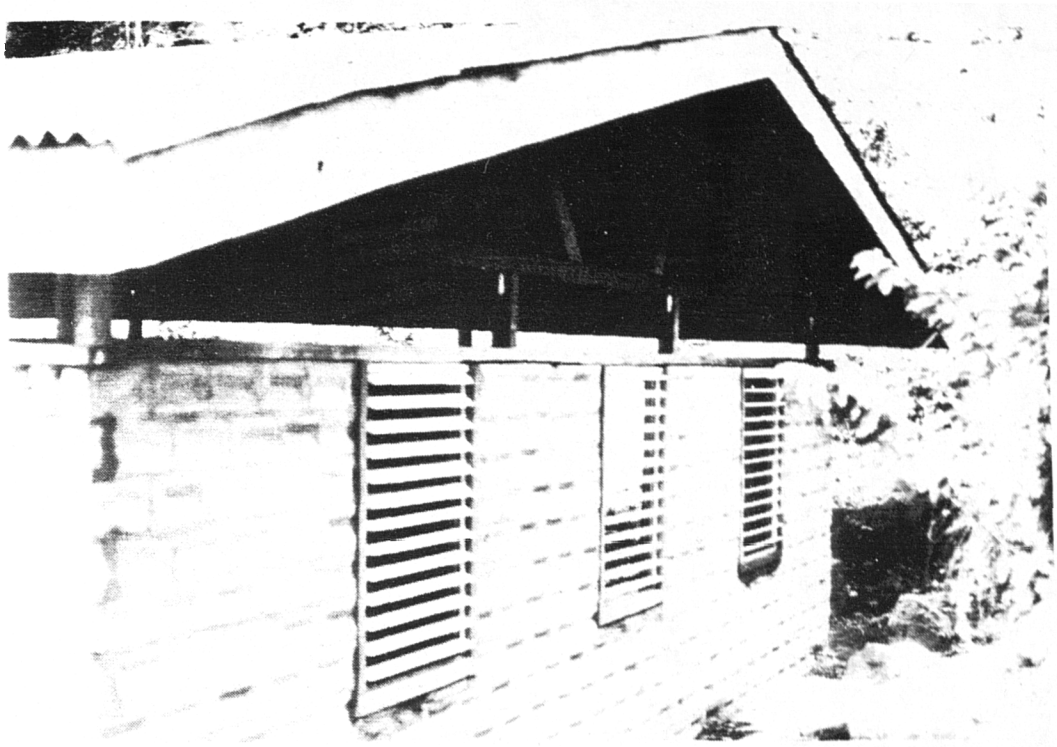


Plate 57 Partially completed skill training centre

Plate 58 Top level view of skill training centre

8.2.7 Yemen Arab Republic

An earthquake of magnitude 5.7 on the Richter scale occurred on 13 December 1982 in the Dhamar district of the Yemen Arab Republic (YAR). Some 280 village settlements were ruined; about 1900 people were killed and about 20 per cent of the district's population was made homeless (99). Material losses amounted to £135 million with most of the destruction being due to the high vulnerability of the local types of dwellings either made from adobe blocks or dressed stone.

Plate 59 illustrates the damaged houses at Al Housoun built with adobe blocks and thick heavy roofs whilst plate 60 illustrates the damaged stone houses at Risabah showing cracks, split walls and heavy roofs.

During September 1983 the Yemeni Government, through its Supreme Council for the Reconstruction of Earthquake Affected Areas, (SCREAA) announced a programme for the construction of some 13000 new homes by commercial contractors on 127 sites within the earthquake affected area. In addition to this, a programme for the repair of 17,000 damaged houses was proposed. A 'self help' programme was also set up later in 1983 to construct model homes from indigenous materials.

It was suggested that the use of Brepak machines for the production of stabilised soil blocks would be of assistance to those villages with supplies of clay for building. This offer was accepted by (SCREAA) and three Brepak machines were delivered to YAR in April 1984.

The local soil was found to have an extremely high clay and silt fraction with an excess of 90 per cent passing the 75um sieve. See Appendix A6 for details of the soil used.

Plate 59 Damaged houses at Al Housoun YAR built with adobe blocks

Plate 60 Earthquake damage to stone houses at Risabah YAR

Chinese hydrated lime was purchased locally and mixed with soil at a rate of 8 per cent by weight. Good blocks were produced from the Brepak machine but when immersed in water some two weeks later the blocks disintegrated. This caused some concern and it was later discovered that the Chinese lime was not lime at all, but consisted mainly of gypsum! Subsequent tests within the laboratory at BRS and changes in mix design were proposed using different soils.

Three alternative readily available local soils were selected for further trials - one highly plastic clay and two sandy clay soils were investigated - and blocks using both ordinary Portland cement and two types of hydrated lime as stabilisers were made from these soils. All the cement stabilised sandy clay specimens subsequentloy withstood immersion in water but those with lime stabilisation crazed to some extent during curing and did not perform well in the immersion tests.

This investigation work was conducted in conjunction with technical staff of SCREAA and to introduce the method of soil stabilisation to the villagers it was decided to join an Oxfam team who had already set up a basic building training course at Dhamar. This course was attended by masons from villages within the earthquake affected area.

It was proposed to construct a three roomed demonstration house covering an area of about 55 square metres which would require some 3100 plain rectangular Brepak blocks and 460 single hollow blocks for vertical reinforcement to pass vertically through the blocks to make the building earthquake resistant.

During November 1984, 3225 plain Brepak blocks were made over a period of nineteen days but as the work force varied between two and five, the resulting daily output was about 45 blocks per man.

Several mechanical breakdowns occurred with the Brepak machine and workers demanded to be paid on piece work rate about half way through the production run. When the piecework bonus incentive scheme was introduced the daily output of blocks more than doubled on site.

Using an ancient hand operated compression test machine, several blocks were tested at varying ages giving a range of compressive strength results between 7.9 and 11.1 MN/m^2 as shown on table 18.

TABLE 18 STRENGTH DEVELOPMENT OF YEMEN STABILISED SOIL BLOCKS

Age-days	% cement	Compressive Strength MN/m^2	Mean dry density (kg/m^3)
14	8	9.88	
14	8	10.43	1749
14	8	10.98	
21	8	9.88	
21	8	9.88	1789
21	8	10.71	
28	8	8.29	
28	8	8.23	2060
28	8	7.20	
35	10	9.88	
35	10	11.25	1719
35	10	12.08	

The results indicate that the strengths are considerably higher than the minimum required strength of 2.8 MN/m^2 and that the cement content of 8 per cent could be reduced in the future. Building of the demonstration structure was controlled by the Oxfam staff and plates 61 and 62 both illustrate the progress of this project.

Plate 61 Brepak blocks being used to construct a house in YAR

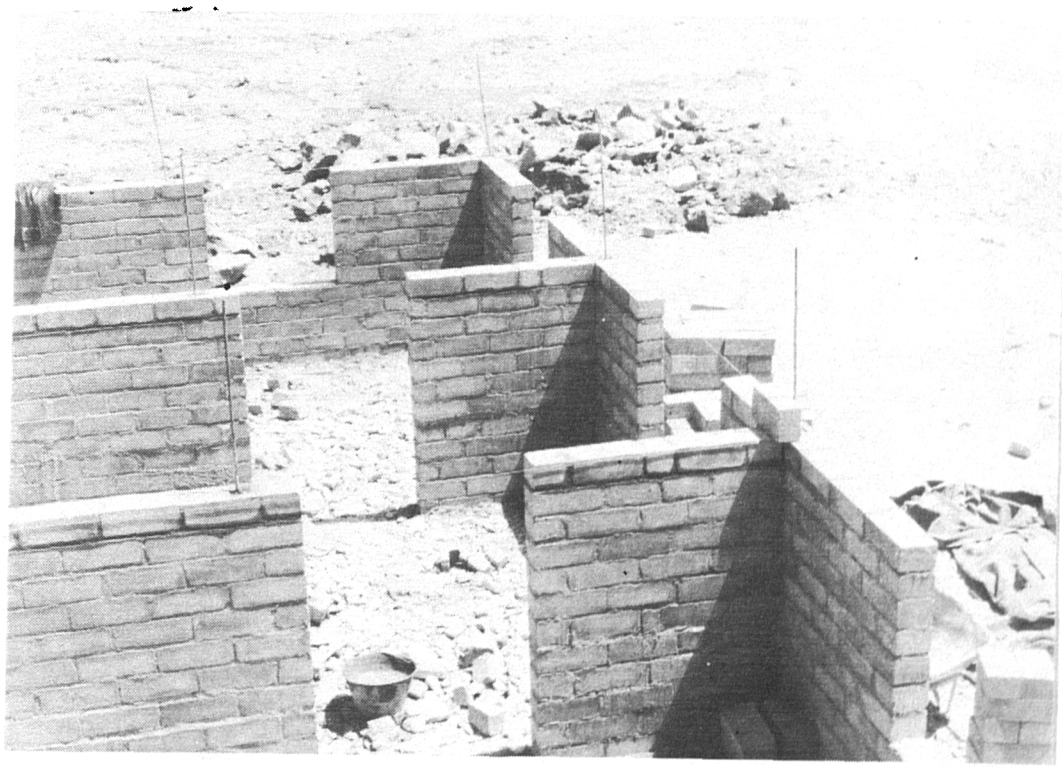


Plate 62 Layout of demonstration house in YAR

This particular Brepak field trial was not really successful because the Yemeni labour force demanded rather high wages in comparison to other countries that the author has worked in and possibly this is a country where a power operated machine may be better suited. See Chapter 11.

The building education programme in YAR has been reported in volume 10 of The International Journal of Disaster Studies and Practice (100).

8.2.8 Botswana

Following a visit to Kenya in 1982, by staff members of the Botswanan Ministry of Finance and Development Planning the Permanent Secretary formerly made contact with the British High Commissioner in Gaborone, capital of Botswana, requesting that a Brepak field trial be conducted in his country. Two Brepak machines were requested one to be sited at the Botswana Polytechnic for the training of technicians and a second machine for a self help housing scheme at Lobatse.

Two Brepak machines together with a clay crushing and sieving machine were sent to Botswana in 1984 and would be working in the field with staff from the Botswana Ministry of Local Government and Lands (MLGL). The field site was located at Lobatse some 90km to the south of Gaborone where a site and services scheme was being set up.

Due to an injury to the author it was not possible for him to visit Botswana to conduct formal training courses for operators in the field and this was completed by a colleague who spent three weeks in this country setting up the equipment, investigating raw materials, demonstrating techniques and instructing personnel how to make stabilised soil blocks.

Five different soil samples were selected and reference was made to Dr Werner Gwosdz of the Geological Survey as to the spread of these soil types in Botswana (101). These soil samples were all taken from the Lobatse area:

Lobatse A - Contained a stripe of white material not soluble in dilute hydrochloric acid, hence not calcite.

Lobatse B - Red soil, not true laterite soil.

Lobatse C - Typical top soil, probably high in silica.

Lobatse D - Shaley soil - even if minerals are finely divided they may be silica.

Lobatse E - A typical washed river deposit, likely to be high in silica.

After various on site tests with these soils it was decided to investigate soil samples Lobatse A and E. Details of these soils are given on Appendix A6.

Using 8 per cent cement as the stabilising agent - lime being 1.55 times the cost of cement, hence lime would have been uneconomic to use - good quality blocks were made which had wet compressive strengths greater than 5 MN/m^2. However information from the field indicated that numerous problems had arisen and that the MLGL staff had difficulty in maintaining a high daily output of blocks for the following reasons:

(i) broken timber baseboard

(ii) Main operating handle too heavy which caused a fracture of the top linkage assembly on the machine.

(iii) general stiffening of the pressing mould in the frame and

(iv) insufficient knowledge of required procedures.

These operational problems necessitated a follow-up visit by a BRS staff member in April 1986 who found that some 2500 blocks had been produced on site at Lobatse and that a 40 square metre demonstration house had been erected as illustrated on plate (63).

The timber baseboard was replaced using steel section as illustrated on Appendix A12 and the top linkage assembly was replaced with a standard assembly. The manufacturers had used a heavier round section without reference to the author. The general stiffening within the pressing mould of the Brepak machine was caused by lack of general maintenance and the use of too wet a mix which had been squeezed into the mould body, dried and acted like a solid packing to prevent the mould baseplate from moving.

The resulting blocks have indicated that the Brepak machine can produce good quality building elements from locally available soil and two further sites are now being considered one at Jwaneng, on the edge of the Kalahari desert in Southern Botswana and the second site at Kasane in Northern Botswana on the border with Zambia.

The CINVA-Ram has been used extensively within Botswana but with limited success and a Mr Jones (102) has conducted a survey on the use of this machine in the Central districts of Botswana.

From the preliminary costings so far obtained it would appear that savings in the region of 35 per cent should be achieved, as a minimum, when compared

with concrete blocks. Two further Mark II Brepak machines and a clay crushing and sieving machine are to be supplied to Botswana to service this particular successful project.

8.3 Countries where the Brepak Machine is being used

Section 8.2 deals exclusively with those countries in which the author has gained first hand experience in using the Brepak block making machine with local people. Several other countries have ordered Brepak machines from the UK manufacturers and little information has come back to the author. To understand the widespread interest that has been generated by this project the following is a comprehensive list of countries where Brepak machines are being used.

Bangladesh	-	Housing for tea plantation workers.
Botswana	-	See section 8.2.8
Egypt	-	See section 8.2.5
Ethiopia	-	Machines being used for the construction of farm buildings and livestock barns.
France	-	Housing accommodation being constructed by local co-operative groups within the southern region of France.
Gambia	-	School buildings being constructed by Action Aid.
Ghana	-	Vocational training centre - No feedback information.
India	-	No information although two machines have been supplied to different locations.
Iraq	-	See section 8.2.4
Jamaica	-	See section 8.2.3
Kenya	-	See section 8.2.1
Liberia	-	No information received

Malaysia	-	A UK contractor is using Brepak machines in this country to construct low income housing.
Nigeria	-	Several machines supplied but no feedback.
St Helena	-	School building project started in 1986.
St Vincent	-	See Section 8.2.6
Solomon Islands	-	Four Brepak machines are being used for the construction of school buildings.
Sierra Leone	-	Experimental housing with stabilised soil floor tiles.
Singapore	-	No information received.
South Africa	-	No information received
Spain	-	No information received
Sudan	-	Brepak machines are being used to construct demonstration buildings on village projects in conjunction with the Council for Scientific and Technological Research, Khartoum - See section 8.2.2.
Tanzania	-	Several machines supplied but no technical feedback information - See plate 64.
Thailand	-	Village community project started in 1984.
Uganda	-	Ten machines supplied to service United Nations Development Programme projects. A further 25 machines have been ordered and are due to delivery early in 1987.
West Germany	-	West German aid programme have purchased about twelve machines for use on their own overseas aid projects.
Yemen Arab Republic	-	See section 8.2.7
Zambia	-	Classrooms being constructed.
Zimbabwe	-	UNDP project on low income housing.

This alphabetical list names 29 countries where Brepak machines are being used on a wide range of differing types of projects.

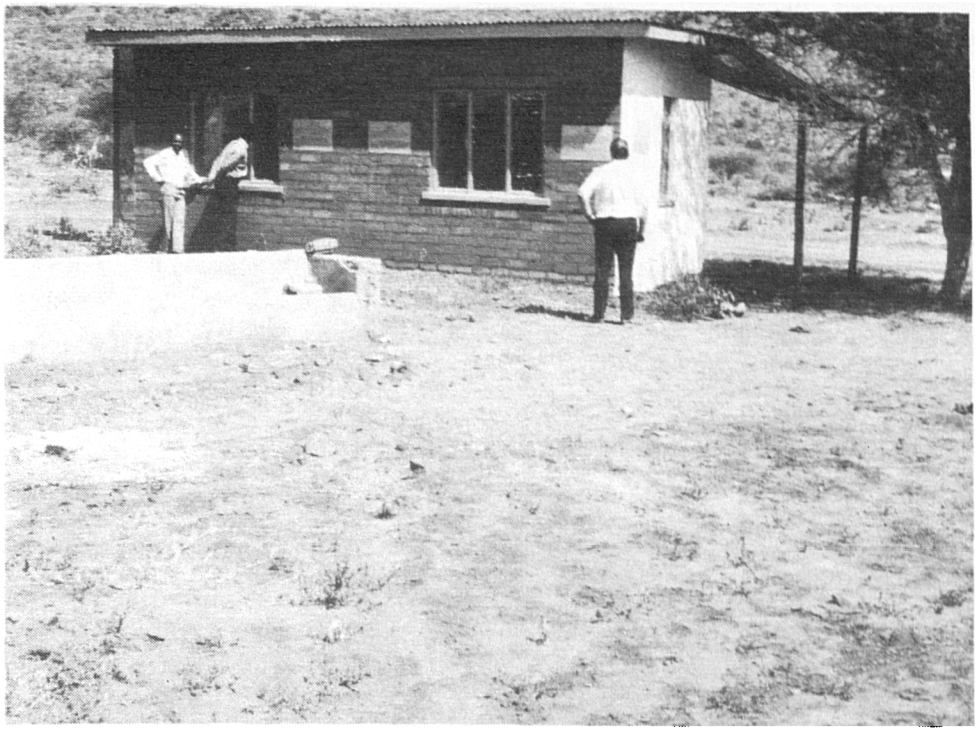


Plate 63 Brepak demonstration house in Botswana

Plate 64 Brepak experimental building in Tanzania

In addition to this list the author has received since 1981 some 600 general enquiries from 96 countries all requesting help and advice on various soil stabilisation problems.

8.4 Ancillary equipment for the Brepak projects

Following practical field trials there has been feedback information which has meant that extra ancilliary equipment needed to be developed so that the output production of stabilised soil blocks would be more efficient on site.

For example the preparation of soil had to be improved because the early methods of breaking down the wet clay soil lumps was most inefficient. The method now employed is to first lay out in the sun the newly won soil from the ground so that it will dry out. Once dry the soil lumps are shovelled into the receiving hopper of a manually operated 'Pendulum Powered' clay crushing and sieving machine which is illustrated on Appendix A13. This machine was a joint development between BRS and the Intermediate Technology Workshops in Cradley Heath, West Midlands, UK. The one man operated clay crushing and sieving machine is compact and portable, weighing 145kg before the pendulum weight is added which could be either local stone or sand. It is capable of producing about 2 tonnes per day of sieved soil.

Another example is the block clamp lifter, illustrated on Appendix A8, which the author developed to assist the mason when constructing a wall of Brepak blocks. This hand operated tool ensures that a block is laid with a 10mm vertical joint between each block.

The original Brepak baseboard, illustrated in appendix A1, was constructed from laminated timber, however when being used in the field the timber had to withstand reverse stressing and often became quite wet causing the board to

fracture. To maintain a longer working life for the Brepak machine a steel baseboard has been developed which is illustrated on appendix A12.

The early form of operators manual given under appendix A1 shows the individual Brepak machine operations but this has proved to be insufficient and needs to be extended. A more detailed manual has been prepared which covers all aspects of soil selection, simple field tests for soils, selection of suitable stabilisers, Brepak-machine operation, block curing and simple building construction methods. This manual entitled 'BREPAK OPERATORS MANUAL (103)' was published in October 1987.

8.5 Mark II Brepak Machine

The original Brepak Machine had been fitted with a stand-by ejector jack which was only used in the event of the mould being overfilled with a soil mix and the resulting block could not be ejected from the mould with the main lever - See Appendix A1. The stand-by ejector jack was then used to eject the block from the mould, however from the feedback information received from the various field trials, this method of block ejection has hardly ever been used. It was therefore decided to discontinue the inclusion of a stand-by ejector jack and offer it as an optimal extra if anyone needed it.

The straight handle fitted to the hand pump on the original Brepak machine as illustrated on plate 37 has been replaced by a swept-up handle as shown on plate 64. This minor alteration has resulted in less fatigue to the operator.

The hydraulic pressure gauge fitted to the hydraulic hand pump, illustrated on Figure 17, was included for an operator to visually check that the correct compacting pressure had been reached during the pressing operation. On

numerous occasions it has been reported that an operator has not bothered to view the dial of this gauge and carried on pumping until the hydraulic pressure relief valve within the hand pump was activated thereby resulting in some damage to the machine caused by internal overloading. The pressure gauge also being rather vulnerable has been subjected to accidental damage on numerous occasions.

With these points in mind, the author has discontinued the use of the hydraulic pressure gauge and has had an audible pressure relief valve fitted internally to the hydraulic hand pump which gives off an audible sound to inform the operator that the correct pressure has been reached. To improve the output of blocks a further modification was made to the hydraulic hand pump by increasing the diameter of the main plunger to give a maximum delivery of $3.3cm^3$ of oil per stroke. See section 7.7.2 - Previous output was $2.61cm^3$ per stroke. This modification has resulted in an increase of about 10 blocks per hour output giving a maximum total of about 53 blocks per hour which has been substantiated during the Brepak field trials in Botswana.

The Mark II Brepak machine is illustrated on plate 65 and although several hundred blocks have been produced within the laboratory at BRS the new modifications have still to be proven in the field and will be used in Botswana during 1987 and in China during 1988.

This particular model of the Brepak machine can be adapted to act as a site compression test machine - See Chapter 9.

8.6 Discussion of Field Trials

Based upon laboratory test results and the feedback of technical information gained from the overseas field trials the following technical conclusions can

be made about stabilised soil building elements produced under a compacting pressure of 10 MN/m^2 as developed in the Brepak block making machine.

8.6.1 Information regarding soil selection

a. A detailed investigation of the raw material is always recommended - Do not use top soil containing organic properties. See Chapter 3.

b. Low Clay Fraction Soil - Cement stabilisation gives the best wet compressive strength results provided the soil being used has a minimum clay and silt content of between 10 and 15 per cent - (Minimum of 2 per cent linear shrinkage) - Up to a maximum of about 30 per cent clay/silt fraction - (Maximum of about 4 per cent linear shrinkage). The range of cement content recommended would be 4-6 per cent by weight. If higher strength blocks are needed then the cement content could be increased to about 8 per cent by weight, for economic results. These higher strength blocks can be used for walling below ground level.

c. High Clay Fraction soil - Above 30 per cent clay and silt fraction (above 5 per cent linear shrinkage) indicates that two methods of stabilising can be used. From this research work the preferred method would be to reduce the clay content with the addition of sand then add about 6% cement by weight or,

With high clay fraction soils greater than 7 per cent linear shrinkage, 6-9 per cent good quality hydrated lime could be used. However a word of caution, when endeavouring to stabilise soils whose linear shrinkage is greater than 10 per cent, the resulting blocks will have good immediate wet strength characteristics but will deteriorate with time and need external protection when exposed to the elements.

Alternatively the high clay fraction soils should be discarded and another soil found. See Chapter 4.

d. Lime stabilisation - The author and El Fadil Adam (39) developed a useful equation from the sedimentation test described in Section 3.7.1 for the optimum lime content which could be used for a high clay fraction soil. This particular equation follows on from the work cited by Hilt and Davidson (104) entitled Lime fixation in Clayey Soils.

$$LOM = \frac{\text{Percentage passing 63um sieve}}{42} + 1.25$$

LOM = Lime Optimum Modification

e. Chemical analysis - If a chemical analysis has been obtained, section 3.5.8, for a particular soil sample three broad assumptions can be made on the suitability of the soil for stabilisation.

(i) The sum of $Al_2O_3 + SiO_2 + Fe_2O_3$ should be greater than 75 per cent of the elements present in the analysis.

(ii) The Loss on Ignition (LOI) figure should be less than 12 per cent, higher figures would indicate the presence of organic matter which would affect the hardening of a stabilised soil block and reduce its durability properties.

(iii) Soluble salts within the soil, especially within the clay fraction, may influence the plasticity of the soil and will affect the long term strength of a stabilised soil block. Soluble salts are often compounds of Potassium and Sodium so that if the combination of $K_2O + Na_2O$ is greater than 2 per cent, an undesirable amount of soluble salts may be present for efficient long term soil stabilisation.

f. Lateritic Soils - From the Silica/Sesquioxide ratio

ie $SiO_2/(Al_2O_2 + Fe_2O_3)$

Ratio of 1.33 or less - Laterite soil

Ratio between 1.33 and 2.0 - Lateritic soil

Ratio of 2.0 and above - Non Lateritic soil

8.6.2 Performance of the Brepak Machine

Chapter 7 describes the design and development stages of the Brepak machine and several field trial locations are discussed earlier in this chapter.

Using a compacting pressure of 10 MN/m^2 a wider range of soils can be used to make good quality stabilised soil blocks as discussed in sections 8.2.1 and 8.2.8.

When site production of soil blocks are under the control of a site supervisor better quality blocks have generally been produced but when a team of operators are left to make blocks on their own the quality drops, this being due to the operators not maintaining a good quality control on site by not filling the Brepak mould with sufficient soil mix at each pressing. This problem should be resolved with the introduction of the Brepak operators Manual (103).

In the early stages the hydraulic hand pump developed faults but these were rectified with the introduction of the audible pressure relief valve as mentioned in section 8.5.

The development of the Brepak block making machine has improved the rural housing stock in many countries. During the various field trials, differing soil types have been used and the author estimates that Brepak Machines have

produced about 2 million good quality building blocks used in the construction of between 400 to 500 new buildings in 30 third world countries.

With the introduction of the Brepak Operators Manual (103) late in 1987 there has been a marked improvement in the hourly production rate of stabilised soil blocks from the machine. Recent feedback information indicates that about 40 blocks per hour are being produced in Botswana, China, Sudan and Uganda.

Following these recommendations, the quality control of block production has also improved by using a cut down bucket for volume batching of the soil and stabiliser mix prior to filling the Brepak mould.

The machine maintenance has also been improved. For example in China, with regular daily cleaning of the machine, some 15000 good quality stabilised soil blocks have been produced, without machine breakdowns, over a two month period of operation. On this particular site a two storey demonstration house is being constructed.

CHAPTER 9

SOIL BLOCK CURING AND TESTING IN FIELD TRIALS

9.1 The Present Housing Situation

In the majority of third world countries, housing elements in the rural areas often use natural materials such as straw, wood, foliage and soil, whilst in the urban areas, minimal housing is constructed from waste material such as sheet metal, plastic, cardboard, rubber etc.

Quite often these types of structures will collapse because of the unsuitability of materials used, and therefore it follows that in the past many governments of the world did not attach very great importance to the sub standard dwellings erected from these materials having only a short span of life: they would be classified as temporary structures.

With the introduction of the Brepak machine which is capable of producing good quality stabilised soil elements from locally available soils several third world governments are now classifying the buildings erected from the Brepak blocks as permanent buildings.

9.2 The Need for Curing and Testing

A building structure is made up of a diverse number of small components which must interact together. A structure would fail at its weakest point.

In its service life a structure will be subjected to various forms of loading which falls into three distinct groups:

(a) Static dead load will always be present and is made up of the self weight of the building components used within the structure plus the internal fixtures and fittings.

(b) Live loading is caused by the vibration effects of moving loads within the structure and is usually taken as an added factor of the induced static or dead loading figure.

(c) Dynamic loading is caused by the application of external forces such as might occur in a natural hazard ie wind and seismic forces that a building structure would be subject to. In this case the dynamic force generated is decided by the architect or designer of the building from local codes of practice which would include a factor of safety.

The above three types of expected loading would then be combined together and detailed analysis would determine the individual strength requirement of each of the different building elements used within a structure.

From British Standards (56) and (57) acceptable compressive strengths of 2.8 MN/m^2 are the minimum requirements for concrete blocks and burnt clay brick products and Section 6.3 discusses the various parameters that are needed for the compressive strength of a stabilised soil building block.

9.3 Methods of Curing the Blocks

A careful procedure should be followed for efficient curing. Much effort has been extended on the correct selection of a suitable soil, mixing with a stabiliser and the moulding of a block. All this effort can easily be destroyed by inefficient curing.

To gain maximum strength, stabilised soil building blocks require a period of damp curing, as is common with all cementitious materials. As already discussed in Chapter 4 various cementitious materials can be employed to stabilise clay-based soils and therefore general guidance can only be given in this chapter to ensure good quality blocks are produced. It has been established from the experience gained from the various Brepak field trials that the curing operation consists of two distinct phases; primary curing and secondary curing.

9.3.1 Primary Curing

When freshly moulded blocks are removed from the Brepak machine they must be handled with care. At this stage they are weak and easily damaged. It is imperative that the moisture of the soil mix is retained in the body of the block in order to generate the best compressive strength. This can be done by simply inserting the block into a plastic bag and leaving for a few days.

If the block is left exposed to ambient conditions the surface material will lose its moisture to the atmosphere, the clay particles will shrink and cause surface cracks to appear on the block faces.
Another method that has been developed successfully in the field is to place about five freshly moulded blocks into a plastic refuse bag or dustbin liner: an example of this is illustrated in the background on plate 55. After the bag has been filled with blocks the open end of the bag should be closed to retain any free moisture.

Alternatively the freshly moulded blocks could be laid out, in a single layer, on a non-absorbent surface, and covered with a protective membrane to retain the moisture content within the blocks.

This primary curing operation can take as little as 2 days or as much as 5; the period depends on the local soil, ambient conditions and choice of stabiliser, it is then a matter of judgement for the site supervisor to decide when the primary curing period has been completed. From experience, if lime is used as a stabiliser then 5 days is indicated and as little as 2 days when cement is used as the stabiliser.

At this stage the blocks may have already started drying out which is indicated by a change of colour to the surface of a block.

9.3.2 Secondary curing

After primary curing the blocks can be removed from their protective cover and stacked in a pile, which is illustrated on the foreground of plate 55. Water should now be sprinkled onto this stack of blocks and a cover placed over the top of the stock. This cover could be a plastic sheet, grass, or reeds to reduce moisture loss to the atmosphere.

Periodically another layer of blocks can be added to the stack, each time water is sprinkled onto the blocks and the stack is recovered. A stack can be built up to about 1500mm in height as illustrated on plate 46.

The importance of retaining the moisture content within a stabilised soil block has been considered an essential part of the manufacturing process for soil blocks for many years, and Spence in his book entitled 'Making Soil-Cement Blocks' (105) concludes the curing section with the statement: 'If these steps are not taken, the block will either not gain full strength, or it will shrink after being built into the building, which will then show cracks'.

The VITA publication (28) devotes several pages to the curing process.

The duration of curing needed will vary from soil to soil, and more essentially with the type of stabilising agent employed.

With cement stabilisation it is advised that a minimum of two to three weeks curing is needed and when using lime the curing period should be a minimum of four weeks.

Generally when stabilised soil blocks are built into a building they should be dry, in which condition they will have minimum dimensions, if wet or moist they would be slightly greater in size and after drying out in the wall there will be a small shrinkage and cracks could either occur in the block or across a joint between the blocks.

9.4 Block Testing

Stabilised soil blocks made in the Brepak machine should be considered as structural elements when built into a building similar to burnt bricks and concrete blocks. They must also be durable to stand up to the abrasive conditions of wind and rain together with the effects of changing temperature conditions.

These questions are linked in that the durability of stabilised soil blocks is improved as the density of the material in the block is increased. It is also true that the density of a block is related to its compressive strength.

In 1958, Fitzmaurice prepared a manual (70) for the United Nations on stabilised soil construction for housing and his experimental results were

based on two different soil types from Burma each stabilised with 5 per cent cement.

The first relationship cited is shown on Figure 20 where the dry compressive strength of a block is plotted against dry density. In this example cylindrical specimens were made of 76mm diameter by 80mm length and crushed dry after 2 months' curing. The relationship between dry strength and density is almost linear.

CONCLUSION 1 - Strength or durability increases as the dry density increases.

The second relationship cited is shown on Figure 21 where the dry density has been plotted against the compaction or moulding pressure for a series of tests at various moisture contents. This set of results is important because various machines and various methods of compaction will yield different results in terms of compressive strength.

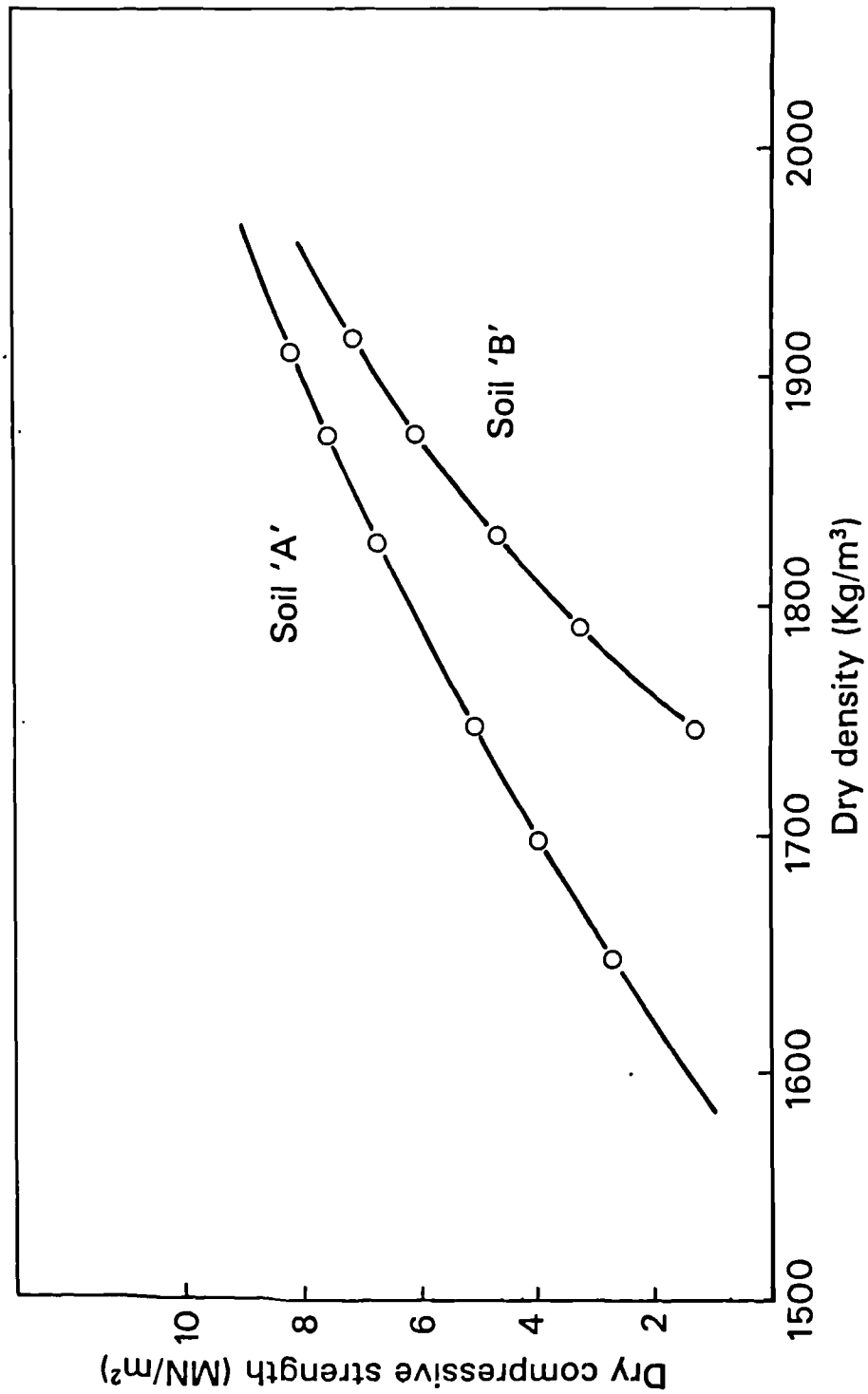


Figure 20 Dry compressive strength: dry density (Reference 59)

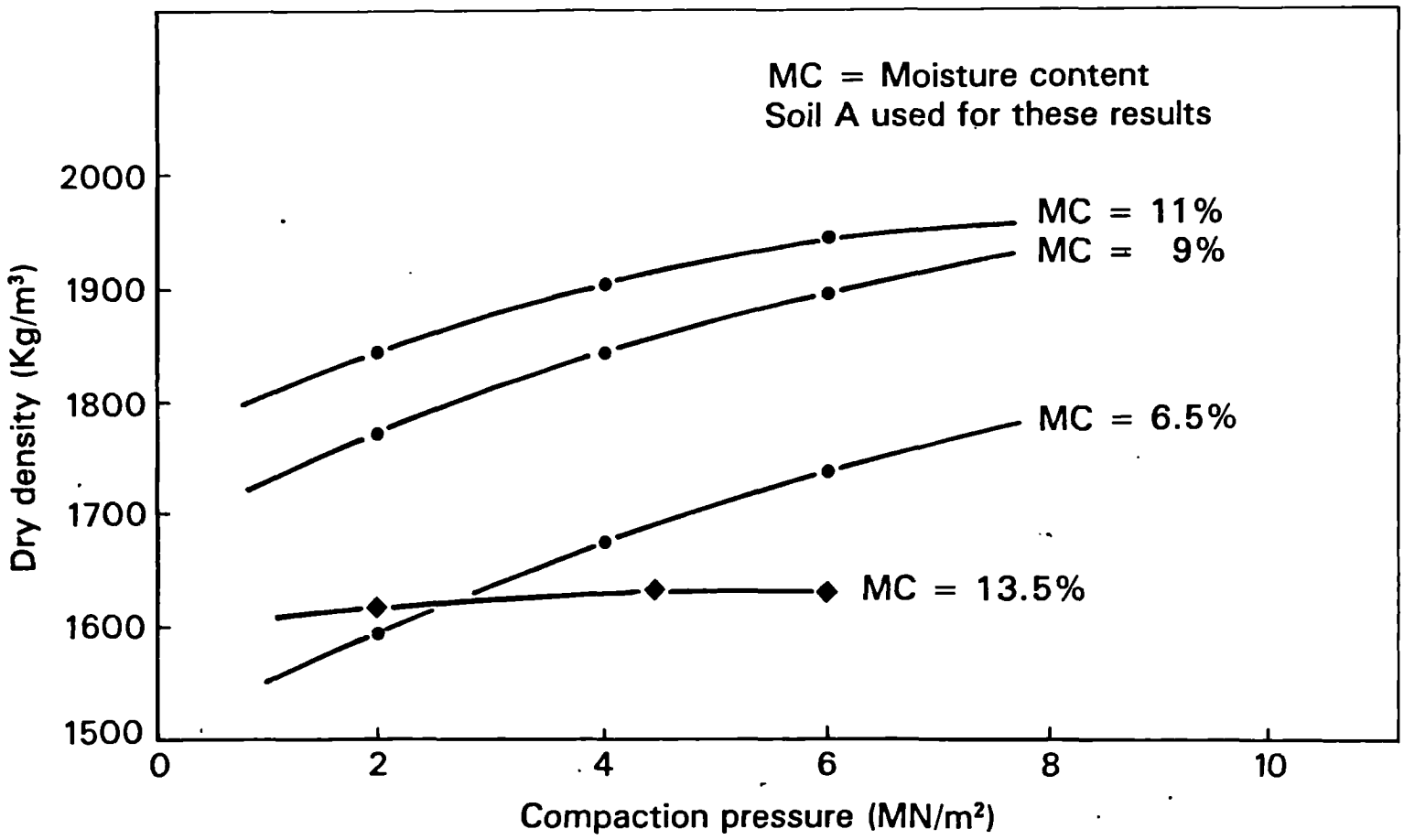


Figure 21 Relation between dry density: compaction pressure and moisture content (Reference 59)

CONCLUSION 2 - Dry density increases as the compacting or moulding pressure increases. Dry density is also dependent upon the moisture content of a mix.

The third relationship cited is shown on Figure 22 where the dry compressive strength of a block has been plotted against the percentage moisture content used in the mix. One set of blocks were made in a hand-operated toggle press which was believed to have a compacting or moulding pressure of about 4 MN/m^2; the second set of blocks made in a hydraulic power-driven press, exerting a compacting pressure of about 7 MN/m^2.

This set of results again indicates that a higher compacting pressure will increase the dry compressive strength.

CONCLUSION 3 - The optimum moisture content (OMC) (see section 3.3.5) decreases with the increase of compaction pressure.

Fitzmaurice (70) laid emphasis to the importance of the moisture content at the time of testing. Stabilised soil in common with other porous building materials is sensitive to moisture content. The wet compressive strength is always considerably less than the dry strength.

It would be very unwise to assume that a wall or pier will never get wet in the whole course of the life of a building and, consequently, the architect should design the building to the wet compressive strength of a stabilised soil block. It was found in tests carried out on the Burmese soils, stabilised with 5 per cent cement, that the wet compressive strength was in the range of 40-50 per cent of the air dry strength.

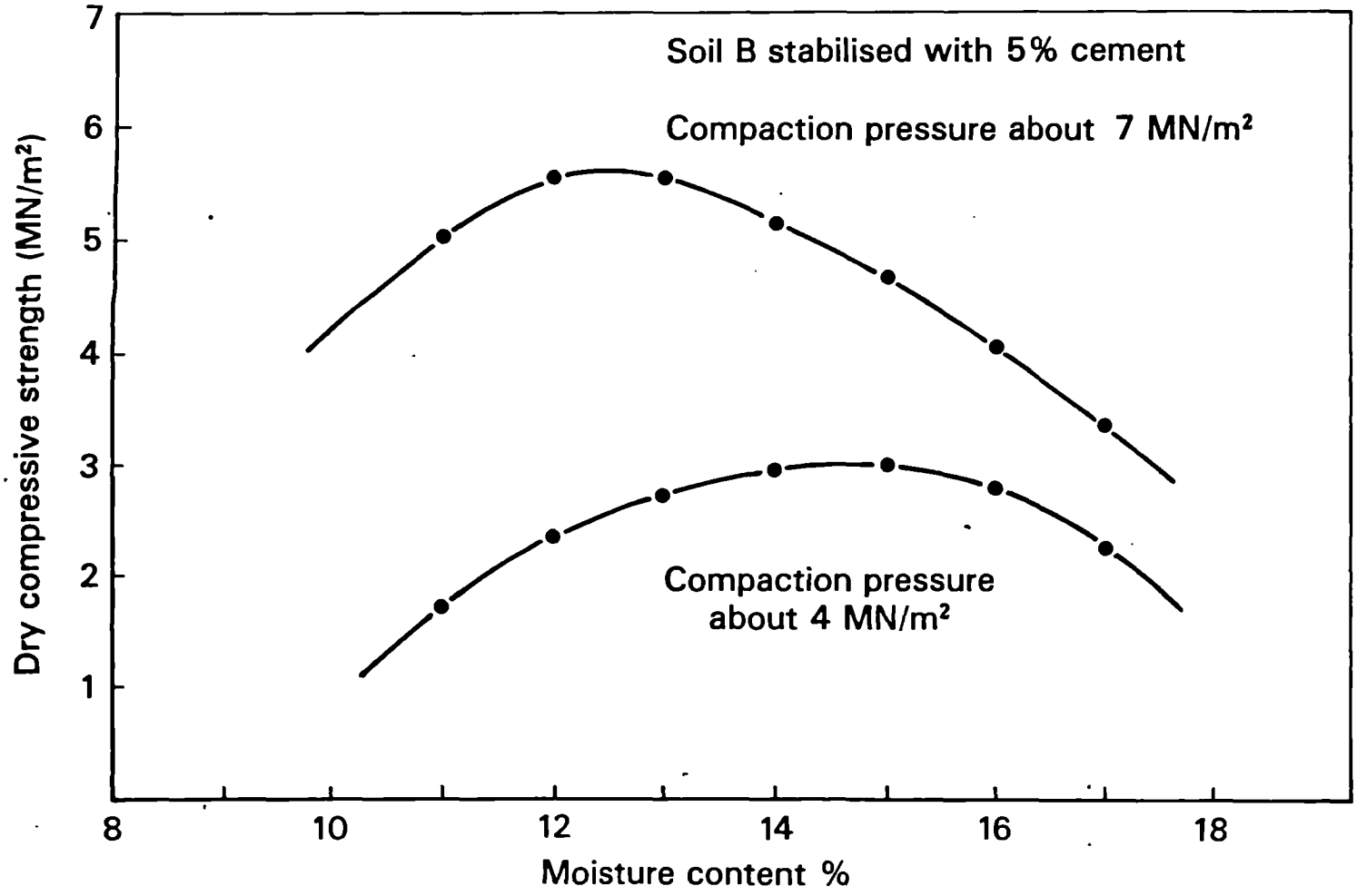


Figure 22 Relation between dry compressive strength, moisture content and compaction pressure (Reference 59)

Referring to the proposed draft technical standard for Lime stabilised soil blocks prepared by 'Craterre' - Appendix A4. This draft recommends a 47.6 per cent maximum drop in compressive strength from dry to wet conditions for a stabilised block. Note the wet strength is obtained when the sample is at the saturated humidification state.

References (57) and (56) are British Standard Specifications which cover the testing requireements for Clay Bricks and Blocks and for Precast Concrete Masonry Units. Reference (32) is also a British Standard Specification which describes the Method of Test for Stabilised Soils but does not include any mention of determining the structural strength of a stabilised soil block.

The method adopted throughout this research has been to cure the blocks through primary and secondary curing stages and at day 27 the blocks are totally immersed in water for 24 hours. After removal from the water the blocks are crushed to obtain their 28 day wet compressive strength. Essentially, the production of stabilised soil building blocks has been a rural activity and therefore it would be wise to consider two aspects of testing (i) Laboratory test methods and (ii) Site testing.

(i) Laboratory test methods

When using the facilities of a laboratory it would be wise to obtain both the dry and wet compressive strengths of a stabilised soil block product. As mentioned previously there will always be a drop of strength from dry to wet conditions so it is advisable to ensure the capacity of a machine is large enough to crush the strongest block.

References (57) and (56) both state that to comply with standards, 10 blocks should be tested for each set of conditions and the time taken to failure

should occur within 0.5 minutes to 1.5 minutes for blocks with an expected strength higher than 7 MN/m^2. For compressive strengths less than 7 MN/m^2 the period of testing may be increased to between 1.0 and 3.0 minutes.

A crushing load must be applied without shock to the sample and continuously applied at a rate of 5.0 $\pm$ 0.5 MN/m^2 per minute on blocks whose expected crushing strength is less than 7 MN/m^2.

For blocks with an expected crushing strength greater than 7 MN/m^2 the loading rate can be increased to 10 $\pm$ 1 MN/m^2.

Both of these standards have been developed for known products ie concrete blocks and burnt clay bricks but because a stabilised soil block falls between the conditions stated it has been found by experience that a load application of between 200 and 300 kN per minute would be acceptable. Ideally this loading application would be automatically controlled. A suitable compression testing machine would have two ranges (i) 3000 kN range with 1 kN increments and (ii) a 750 kN range with 0.1 kN increments.

The upper platen of the machine should be attached to a double ball seat mounting. A suitable machine that would comply with the above specification is illustrated on plate 15.

This machine can be used for a variety of tests, the unit on the left is the main compression test frame whilst the unit to the right is used for transverse testing and the application of small loads. Plate 15 illustrates a 50mm diameter cylindrical stabilised soil specimen prior to crushing on the transverse testing side of the machine.

Plate 16 illustrates how a stabilised soil block 290 x 140 x 100 will fail when subjected to loading in the main compression frame of the machine. It should be noted that compression test specimens should be 'capped' during test and the block shown in plate 16 is capped with fibre board.

After the maximum crushing load has been obtained the crushing strength is determined by dividing the crushing load by the cross sectional area of the block.

Note that $1\ N/mm^2 = 1\ MN/m^2$

Sending stabilised soil building blocks to a laboratory for structural analysis could be both time consuming and expensive, therefore it is wise to use simple on-site tests that would give an indication of the suitability of a block as a structural element.

It is usually accepted that structural components are tested at an age of 28 days, though the same tests could be performed earlier say at 7, 14 and 21 days to indicate the strength - time relationship.

(ii) Site testing methods

With the reasonably low strengths developed by stabilised soil building blocks it is recommended to test at 28 days and the following simple tests could be conducted on site.

(a) Wet - Dry Cycling test: After the curing procedure as detailed earlier in this chapter has been carried out, first select at random five stabilised soil blocks for a wet-dry cycling site test.

Completely immerse the blocks in water after 28 days of cure for a period of 12 twelve hours, or overnight, remove from the water and leave them in the sun during the day. Repeat this procedure for 7 days thus alternatively wetting and drying the samples for 7 cycles.

Inspection of samples should then indicate if anything is wrong with the original soil used or indeed the stabilising agent employed.

For example blocks may slake or fall to pieces, crack, flake or even burst, all of which would indicate that the mix must be modified or as a last resort, a different soil should be found.

It is therefore advisable, in the first instance to make several sets of blocks using different amounts of stabiliser content.

(b) Water Absorption test: This test can be conducted in conjunction with the wet-dry cycling test. Prior to the first water immersion each block is weighed and after overnight immersion, weighed again. A simple calculation can be performed to determine the percentage moisture absorption by weight.

$$\% M_c = \frac{W_W - W_D \times 100}{W_D}$$

where $\% M_c$ = Percentage moisture absorption

W_W = Weight of wetted sample

W_D = Weight of dry sample

From experience, if a block has less than about 15 per cent moisture absorption, the block is likely to have good long term durability characteristics. This would compare favourably with a burnt fletton clay brick which has a water absorbancy of about 22 per cent.

(c) Wet-Dry Density test: Immediately after making a stabilised soil block it should be weighed and its dimensions noted so that the wet or freshly moulded density can be determined.

At day 28, prior to the wet-dry cycling test the block is again weighed and its dimensions noted so that the dry or fully cured block density can be determined. As previously mentioned in appendix A4 a block should have a minimum specific density when freshly moulded of 1870 kg/m^3 although the recommended specific density is 2200 kg/m^3. The dry specific density of a block should be a minimum of 1700 kg/m^3 with a recommended dry density of 2000 kg/m^3.

(d) Ring test: If after the required 28 day cure period, two blocks are knocked together and a good 'ringing' sound is heard, the blocks are reasonably dense and they should be durable if exposed to the weather.

(e) Compressive test: Using a Brepak machine. When making stabilised soil blocks the mould baseplate of the Brepak machine rises and compresses the soil mix. This action is the same as that of any laboratory compression testing machine. Therefore a 28 day cured stabilised soil specimen, of suitable size could if placed in the empty mould cavity, be crushed when a load is applied by the hydraulic hand pump. To measure the applied pressure to a sample block a hydraulic pressure gauge of 10,000 lb/square inch (approx 70 MN/m^2) needs to be fitted to the hydraulic pipeline of the Brepak machine as shown on Figure 15.

First make sample blocks 260 x 110 x 100mm blocks by using a 15mm thick collapsible insert mould inside the main mould frame. If for example a wet compressive strength of 2.8 MN/m^2 is needed to satisfy local regulations - this figure may vary from country to country. Assuming a maximum difference

of 50 per cent drop from dry to wet crushing conditions a total of 5.6 MN/m^2 is needed for the dry compressive strength of a sample block. Maximum load to be applied = 16.325 tonnes.

Note the Brepak machine is capable of exerting a maximum compaction pressure of 10 MN/m^2 over an area of 406 square cms, which is equivalent to a total force of 41.38 tonnes.

The dial gauge reading is a direct measure of the compressive strength of a sample block expressed in pounds per square inch.

Sample Block Strength (MN/m^2) = 0.00214 x Pressure Gauge reading in PSI.

Five sets of blocks should be tested to determine the average dry and wet compressive strengths.

ALTERNATIVELY - a simple lever mechanism as illustrated on figure 23 could be made locally and used to crush 50mm cubes. The United States Department of Housing and Urban Development in their publication 'Earth for Homes' (69) illustrates a similar machine that will crush 2 inch diameter cylinders x 2 inches in height.

A 50mm cube of stabilised soil cut from a solid block will need a force of about 710 kg to crush it if it has a wet compressive strength of 2.8 MN/m^2.

Referring to Figure 23:

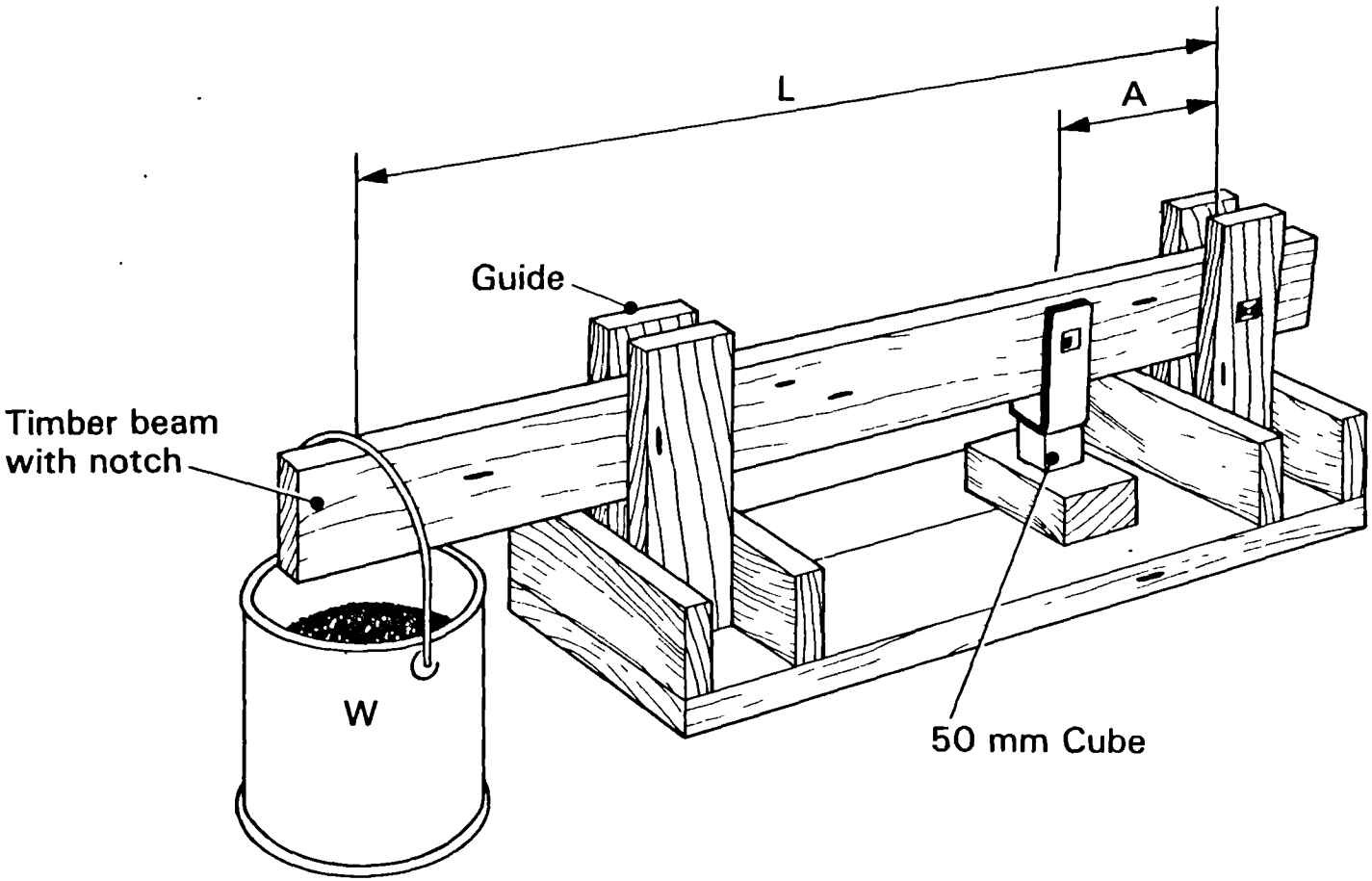
Cube crushing force x 85 = (W x Distance between pivot and bucket suspension point) + (Self weight of beam x distance from pivot to centre of gravity of beam)

$710 \times 85 = (W \times 1676) + (5 \times 838)$

From which $W = 33.5$ kg

The advantage in using a machine of this type is that the applied weight W can be slowly added to the system and using the equation above a more accurate crushing load or stress can be determined for the stabilised soil sample under test.

For example if the resulting blocks are going to be used in a dry climatic condition the wets compressive stress could be lowered from 2.8 MN/m^2 to 2.0 MN/m^2. However this sort of decision must be taken by a qualified engineer who would know the local climatic conditions and possible regulations if any exist.



Timber beam — 100 × 50 × 1800 mm length
A = 85 mm
L = 1676 mm
W = Weight of hanger and contents

Figure 23 Site compression test machine for 50 mm cubes

9.5 Durability Testing

There are two tests that would best be performed in a laboratory that would indicate the long term durability properties of a stabilised soil building component, these are (a) Water spray test and (b) Abrasive wear test.

(a) The water spray test is a visual test only and involves using a horizontal spray of water from a 100mm diameter spray head under a pressure of 1.5 kg/cm^2 (63). A cured stabilised soil block is placed 200mm from and parallel to the face of the spray head. Water is sprayed continuously for a period of 2 hours onto the sample block after which the sample is examined visually for erosion and pitting. Test results are indicative only and slight erosion and pitting of stabilised soil blocks should not be interpreted unfavourably.

Figure 24 shows the effect of a water spray test on a Cinva-Ram manufactured block made from lime stabilised soil. This block was manufactured under a compacting pressure of 2 MN/m^2 and shows considerable erosion and pitting results after the 2 hour spray test.

The same soil, again stabilised with lime but employing a compacting pressure of 8 MN/m^2 will result in a better block, unmarked by 2 hours of spraying as illustrated on figure 25. This block is about 10 per cent heavier than the block shown on figure 24.

Referring back to conclusion 1 under section 9.4 the above simple spray test verifies the statement that the strength or durability increases as the dry density increases.

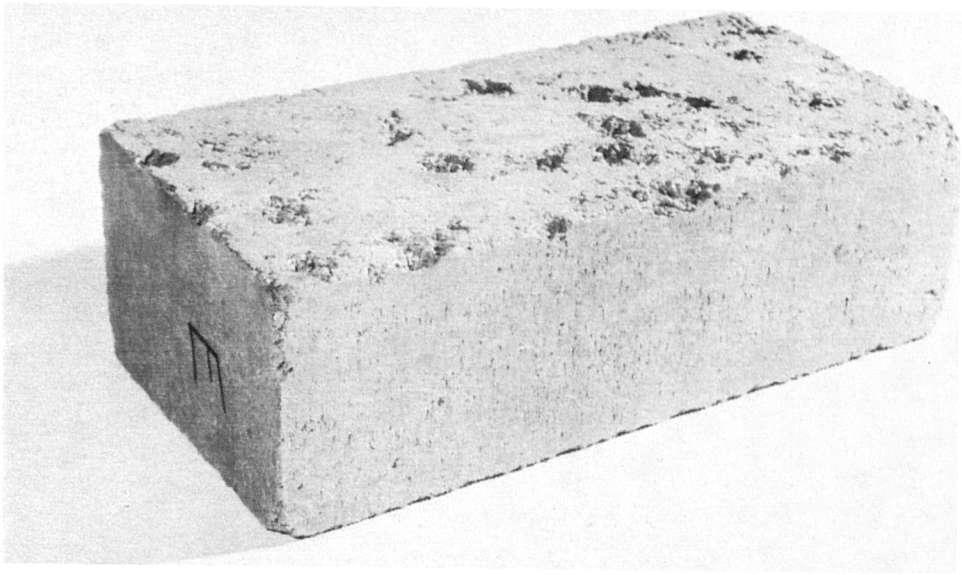


Fig 24 Effect of a spray test on a block compacted at 2 MN/m(2)

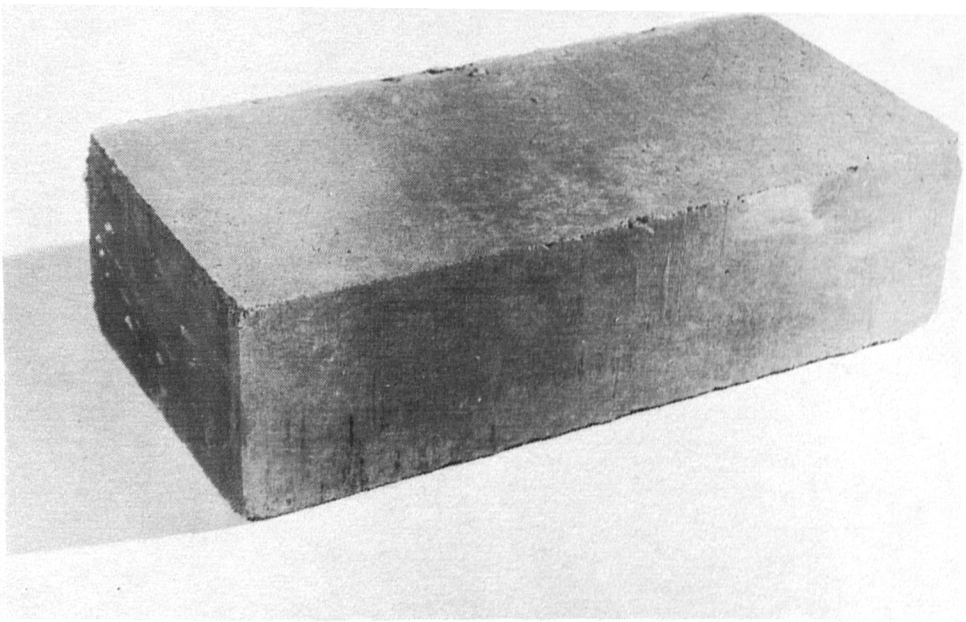


Fig 25 Effect of a spray test on a block compacted at 8 MN/m(2)

(b) The external face of a building will always be subject to the rigours of the weather and various tests described above use water. However in dry arid areas erosion could occur under the abrasive action of wind-borne sand. Several different types of brushing tests have been muted in the past, using a specified number of brushings with a wire brush or using nylon brush heads etc, but no firm recommendations have been specified or established.

It was in the early 1950's that the British Standards Institution introduced BS 784 entitled Methods of Test for Chemical Stoneware (106) which gave details of a method for the determination of resistance to abrasion. This test is based around the A'Court machine in which eight samples each 100 x 150 x 25mm are reciprocated horizontally underneath 8 static hoppers all containing a fine sand. This sand rubs against the upper face of each sample, which is in contact with the lower face of each hopper, giving an abrasive action.

At frequent intervals over a period of 8 hours each sample is weighed to determine the amount of sample abraded away. This weight loss is a good indication of the abrasion resistance of a product.

Plate 66 shows the results of an abrasive test run on various unstabilised and stabilised soil samples, compared with a sand/cement mortar sample. It gives a clear indication of the relative abrasion qualities of different samples, and substantiates the fact that stabilised soil products have good abrasion characteristics.

Figure 26 illustrates the rate of wear of various stabilised soil samples compared with a sharp sand and cement control specimen.

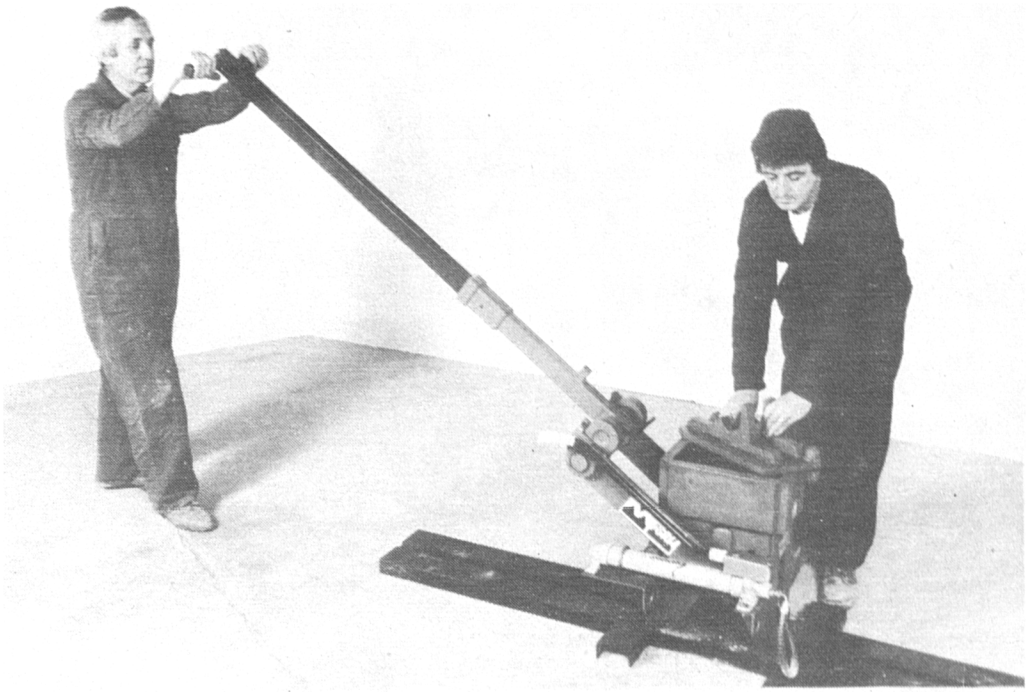


Plate 65 Mark II Brepak block making machine

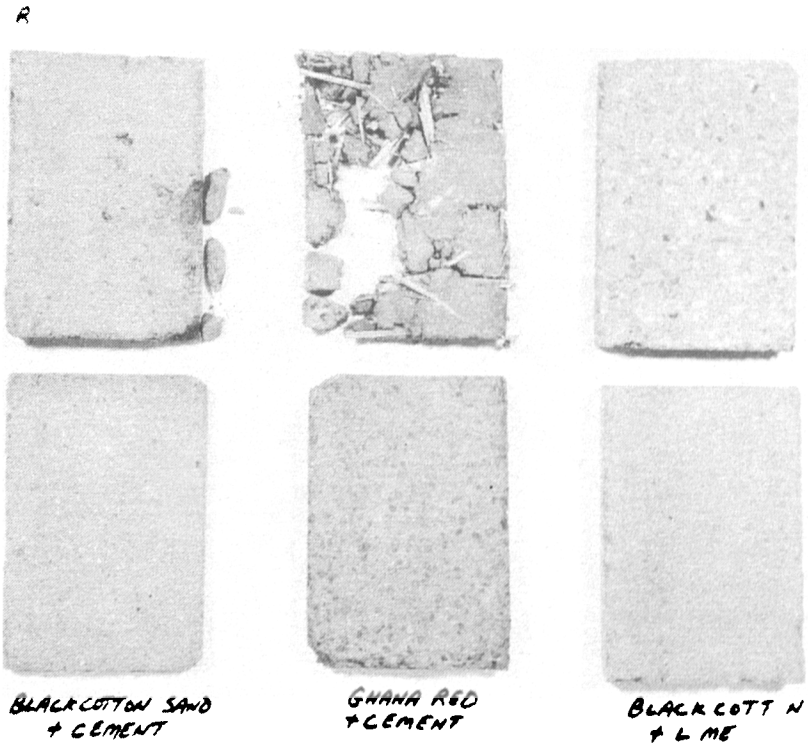


Plate 66 Abrasive test results on stabilised soil samples

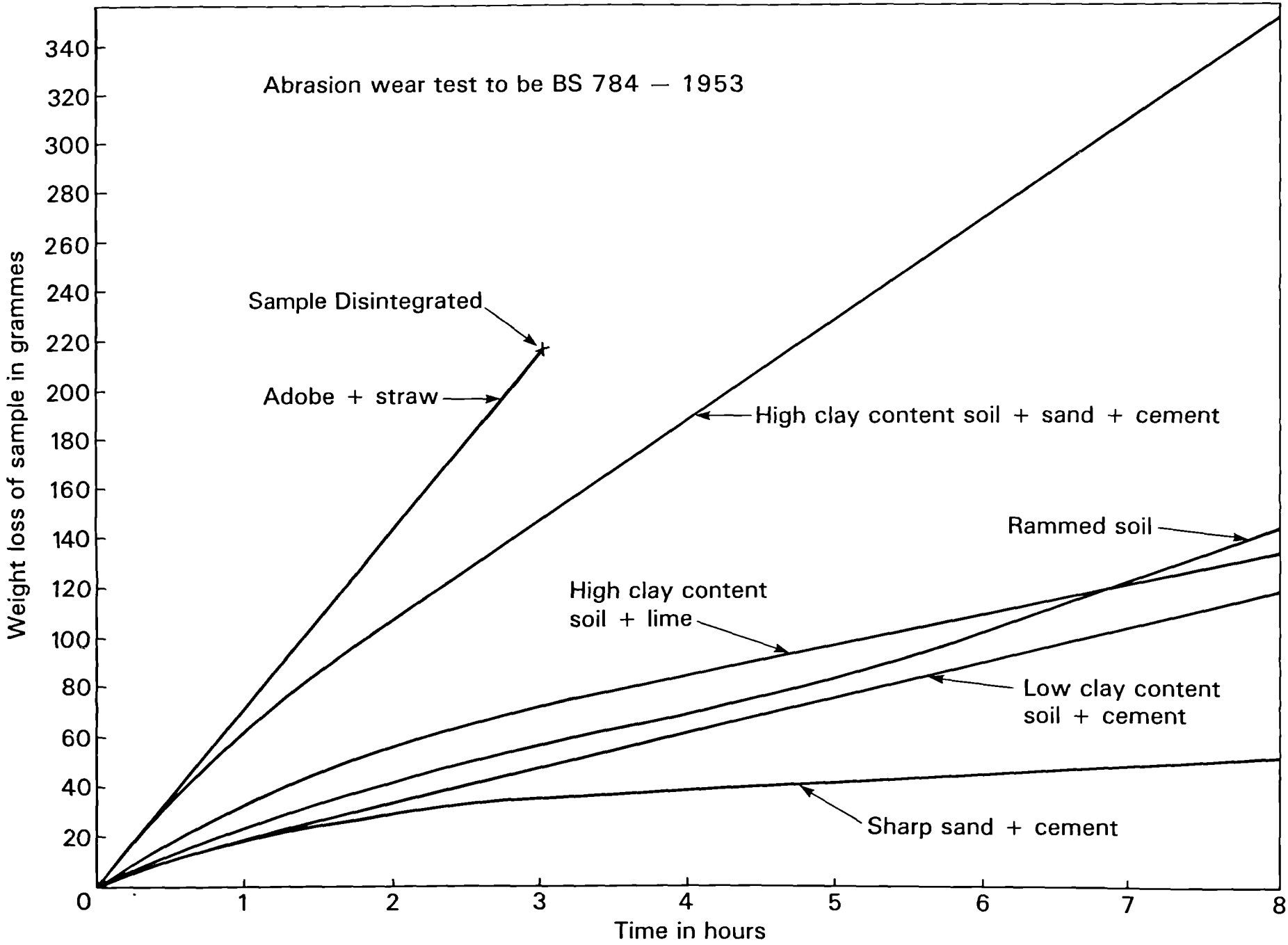


Figure 26 Abrasion test curves for various stabilised soil specimens

Using this information floor tiles between 25 and 30mm thickness have been manufactured in the Brepak machine. When two 20mm thick steel plates are used between layers of a soil stabilised mix, three good quality floor tiles can be produced at a single pressing from the Brepak machine.

The results indicated on Figure 26 clearly shows that those soils stabilised with either cement or lime will have good abrasive properties, however high clay fraction soils modified with sand and stabilised with cement do not perform as well therefore this method should be avoided when considering the production of stabilised soil floor tiles.

9.6 Long Term Strength Testing

As far as the building industry is concerned, good quality stabilised soil building blocks are a reasonably new product and are often introduced into a building project after only short term trials.

Many building materials, including stabilised soil products when exposed out of doors, undergo physical and chemical changes with time. Various short term site and laboratory tests as described earlier in this chapter have been devised to simulate the action of the weather, but long term exposure tests,in which stabilised soil building blocks of known origin and composition are subjected to natural climatic conditions, in the country where they will be used, are a more reliable method for the assessment of the durability of these components.

Long term compression testing of stabilised soil building blocks over a period of three years have indicated that blocks stabilised with either lime or cement retain their dry compressive strengths. However those blocks stabilised with lime have indicated a drop in the wet compressive strength

and from this information it may well be preferable to apply an external protective rendering to a wall construction with this form of block to improve their useful life.

With regards to the cement stabilised soil blocks there has been no significant change in the wet compressive strength over a three year period.

The above comments would apply to walls constructed above ground level.

The National Housing and Building Research Unit in Tanzania has suggested that cement stabilised soil blocks could be used as foundation walling provided that the components are subjected to long term strength and durability testing.

9.7 Building Regulations Overseas

Before building elements are introduced into a building specification or code of practice, the elements have to undergo a series of tests that would demonstrate to the assessment authority that the elements are capable of meeting current building regulations. That is, if any exist in a particular country.

Usually Buiilding Standards in developing countries are adopted from those standards in developed countries.

With regard to earthen constructed dwellings nearly all governments consider this type of dwelling to be substandard and although used in the rural areas, they will not authorise its use in the urban areas. However people have to live somewhere and with the migration of people from the rural to the urban

areas unauthorised slum settlements are built using earth as a building material.

There are some governments that allow earthen construction to be built in the urban areas for example in the Sudan where earthen buildings have always been permitted in the third and fourth class housing areas of Khartoum since condominium days. This is one of the reasons why there has not been such a large squatter problem as compared with, say, Lusaka, Capital of Zambia where concrete building blocks are the only legal means of construction.

The National Housing and Building Research Unit in Dar-Es-Salaam, Tanzania has for a number of years been working in the field of producing stabilised soil building blocks with a view to proposing draft building standards covering the use of sun dried earthen made products. They have produced a series of BRU technical leaflets one of which (58) has been referred to earlier in the text.

When discussing this particular problem with numerous government officials when overseas the author has usually been posed with the following questions:

(i) Durability of stabilised soil blocks
(ii) Soil selection and methods of stabilisation
(iii) Will the blocks have sufficient strengths
(iv) Curing methods to minimise energy resources
(v) Affordability on site by local people
(vi) Quality control on the production of stabilised soil blocks.

All these questions have been answered in the text and with the introduction of the Brepak machine the author seriously believes that draft building

regulations could be introduced into most developing countries of the world today.

By following the general guide lines as specified in the Brepak Operators Manual (103) covering soil selection, and testing, stabiliser selection, mixing, machine operation and stabilised soil block curing methods. Good quality building blocks could be produced on site that would nearly always be superior to locally made concrete blocks or burnt clay bricks.

For example following the official opening of the Medical Clinic at Kawangware in Kenya by Mr Charles Rubia - Section 8.2.1 and the subsequent buildings constructed around Lake Victoria, the Kenyan government issued a document 'Kenya Low Income Housing Report in 1985 (107). This document recommends that practical applied research, including demonstration projects, should be intensified into the technology of stabilised soil blocks for walling and flooring purposes to comply with draft Building Regulations. The author has already instigated much of this work in conjunction with the Housing Research and Development Unit at the University of Nairobi.

The successful Brepak projects conducted in Jamaica (Section 8.2.3) and St Vincent (Section 8.2.6) have resulted in the Caribbean Uniform Building Code Project [CUBIC] proposing to include stabilised soil building blocks into a draft set of Building Regulations now in the course of preparation. Appendix A16 refers to the initial contacts made with the CUBIC organisation.

CHAPTER 10

ECONOMIC CONSIDERATIONS OVERSEAS

10.1 Variations in Costs

Soil stabilisation is not an exact science when compared with concrete or cement mortar type of products. It should be understood that the cost of manufacturing stabilised soil blocks will vary a great deal, depending upon local circumstances, which may well include all the following items.

1. Availability of soil; whether it is on site (eg as dug from foundation trenches etc) or whether it has to be transported to the site.

2. The suitability of the soil for stabilisation, and thus the type, quality and quantity of stabiliser required. Also the possible need for sand to be obtained and added, which might be done if the soil has an excessively high linear shrinkage (section 3.7.2).

3. Current prices for commodities, especially the stabilising agents.

4. Whether the blocks are to be made in rural or urban areas, the size and type of equipment used and the quality which is required.

5. The current wage rates, and the productivity of members of the labour force.

6. It is important to note that blockmaking may be on a 'self help' basis, where labour costs will be reckonable as zero. Also soil is sometimes available at zero cost.

This chapter reviews some of the costing details from actual field trial locations where the Brepak machine has been used. In addition a particular case of cost of production in which both labour and soil had to be paid for. On the other hand low costs were involved in soil preparation and stabilisation because the soil did not need a machine to crush it, and only a low percentage addition of stabiliser was needed. Details of the block production and use have already been published (87). The calculations in this chapter are as an example only, and must be re-worked after the manner shown within the framework for the particular local circumstances prevailing at any other chosen location, using the appropriate inputs of rates, costs etc.

10.2 The Methodological Framework

Before considering individual results from the numerous field trials let us first consider the general methodological freamework of costing which consists of 12 steps split into two main parts:

Part 1 Determination of quantities of various inputs (steps 1 to 6);

Part 2 Estimation of the cost for each input and calculation of the unit production cost (steps 7 to 12).

Part 1

Step 1: Determination of the number of blocks to be produced in a given time. The number will be dictated by market demand, availability of investment funds, the technique of manufacture adopted etc. Table 15 indicates production rates with various equipments.

Step 2: Estimation of the quantities of materials inputs for the scale of production decided in step 1.

The principal materials are suitable soil, sand if soil has high linear shrinkage, stabiliser and water. Some oil, for example used engine oil, will be required as a mould release agent. Guidance on proportions of components is given in Tables 19 and 20.

TABLE 19 USING A BREPAK MACHINE WITH A MINIMUM DAILY OUTPUT OF 300 BLOCKS

Material	Daily requirement of materials	
	8% Hydrated Lime	5% Ordinary Portland Cement
Soil	1.9 tonnes	1.95 tonnes
Stabiliser	150kg	95kg
Water	300 litres	300 litres

In practice however these quantities will vary dependant upon the type of soil and its properties.

An average single-storey house covering an area of 50 square metres will require approximately 3000 blocks, hence an estimate of the materials needed for one house are given in Table 20.

TABLE 20 - EXAMPLE OF THE APPROXIMATE QUANTITIES OF MATERIALS FOR ONE SINGLE STOREY HOUSE OF 50 SQUARE METRES

Material	Materials needed for one house	
	8% Hydrated Lime	5% Ordinary Portland Cement
Soil	19 tonnes	19.5 tonnes
Stabiliser	1500kg	0.95 tonnes
Water	3000 litres	3000 litres

In the above examples, when using a Brepak machine, sufficient blocks for one house could be manufactured within 10 working days. Further reductions in time are envisaged with the improvements now added to the Brepak machine because it is now anticipated that the daily production rate will be increased to about 350 blocks. These new improvements have as yet to be validated in the field. See section 8.5.

Step 3: Listing of equipment required. This will include items for digging and moving soil, preparing soil with crusher or sieving screen, mixing, a device for moulding blocks, and in some cases a covered area for work and in which blocks may be cured, and an office. Provision should also be made for soil investigation and testing equipment.

Step 4: Listing of labour requirements. The productivity of the labour force may vary not just from one country to another, but also from one site to another within the same country. It is necessary 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, all within any conditions agreed between unions, employers etc. The level of skill requirements must also be specified.

Step 5: Other local services or facilities may be required, so they should be listed. They may include:

land for providing the soil for blockmaking,
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, and such security as is deemed necessary locally for the site, on a 24-hour basis, and perhaps including a security fence.

For small scale production, little land will actually be required.

Step 6: Calculation of working capital requirements. In addition to funds for purchase of equipment and land as itemised in the preceding steps, it will be necessary to have sufficient financial resources available for the purchase of raw materials and payment of wages for, it is suggested, a period of one month, since there can be no income at all 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 obtain and stock sufficient for a longer period than one month.

It may well be desirable to utilise some of the first-produced blocks in the construction of the covered area, office etc, to reduce cost of items under Step 3. It will then be necessary to increase slightly the working capital to allow for the number of blocks which are used rather than sold.

Step 7: The annual cost of materials identified in Step 2 must be calculated. Clay, sand and water are often extremely cheap commodities. Often the only significant part of their cost is that incurred in extracting and transporting them. Mould release agent will not be required in very large

quantities, and so the cost will be low: if used engine oil is utilised, it would be free, apart from the minimal cost of collecting it from a nearby garage or service station.

Step 8: Calculation of depreciation on equipment and buildings. Whatever type of equipment is used, it will have a limited life. An estimate must thus be made of the annual depreciation costs for separate equipment items. The depreciation cost of buildings must also be estimated. These costs will depend upon the initial purchase price, the life of equipment and buildings and the prevailing interest rate. Table 21 can be used to estimate these depreciation costs. It gives the discount factors (F) for interest rates up to 40 per cent and expected life periods up to 25 years. Thus, if Z is the purchase price of the equipment or the cost of the building, the annual depreciation cost is equal to Z/F.

Hence, the longer the useful life, the lower the annual depreciation cost, and the higher the prevailing interest rate, the higher this cost.

Step 9: Realistic figures must be obtained for the cost of labour in the actual area where blocks are to be produced. The requirements at different levels will have been identified in Step 4. This step could be ignored in the case of a self help scheme where local labour would be on a voluntary basis.

Year (X)	Interest Rate (I)																	
	5%	6%	8%	10%	12%	14%	15%	16%	18%	20%	22%	24%	25%	26%	28%	30%	35%	40%
1	0.952	0.943	0.926	0.909	0.893	0.877	0.870	0.862	0.847	0.833	0.820	0.806	0.800	0.794	0.781	0.769	0.741	0.714
2	1.859	1.833	1.783	1.736	1.690	1.647	1.626	1.605	1.566	1.528	1.492	1.457	1.440	1.424	1.392	1.361	1.289	1.224
3	2.723	2.673	2.577	2.487	2.402	2.322	2.283	2.246	2.174	2.106	2.042	1.981	1.952	1.923	1.868	1.816	1.696	1.589
4	3.546	3.465	3.312	3.170	3.037	2.914	2.855	2.798	2.690	2.589	2.494	2.404	2.362	2.320	2.241	2.166	1.997	1.849
5	4.330	4.212	3.993	3.791	3.605	3.433	3.352	3.274	3.127	2.991	2.864	2.745	2.689	2.635	2.532	2.436	2.220	2.035
6	5.076	4.917	4.623	4.355	4.111	3.889	3.784	3.685	3.498	3.326	3.167	3.020	2.951	2.885	2.759	2.643	2.385	2.168
7	5.786	5.582	5.206	4.868	4.564	4.288	4.160	4.039	3.812	3.605	3.416	3.242	3.161	3.083	2.937	2.802	2.508	2.263
8	6.463	6.210	5.747	5.335	4.968	4.639	4.487	4.344	4.078	3.837	3.619	3.421	3.329	3.241	3.076	2.925	2.598	2.331
9	7.108	6.802	6.247	5.759	5.328	4.946	4.772	4.607	4.303	4.031	3.786	3.566	3.463	3.366	3.184	3.019	2.665	2.379
10	7.722	7.360	6.710	6.145	5.650	5.216	5.019	4.833	4.494	4.192	3.923	3.682	3.571	3.465	3.269	3.092	2.715	2.414
11	8.306	7.887	7.139	6.495	5.938	5.453	5.234	5.029	4.656	4.327	4.035	3.776	3.656	3.544	3.335	3.147	2.752	2.438
12	8.863	8.384	7.536	6.814	6.194	5.660	5.421	5.197	4.793	4.439	4.127	3.851	3.725	3.606	3.387	3.190	2.779	2.456
13	9.394	8.853	7.904	7.103	6.424	5.842	5.583	5.342	4.910	4.533	4.203	3.912	3.780	3.656	3.427	3.223	2.799	2.468
14	9.899	9.295	8.244	7.367	6.628	6.002	5.724	5.468	5.008	4.611	4.265	3.962	3.824	3.695	3.459	3.249	2.814	2.477
15	10.380	9.712	8.559	7.606	6.811	6.142	5.847	5.575	5.092	4.675	4.315	4.001	3.859	3.726	3.483	3.268	2.825	2.484
16	10.838	10.106	8.851	7.824	6.974	6.265	5.954	5.669	5.162	4.730	4.357	4.033	3.887	3.751	3.503	3.283	2.834	2.489
17	11.274	10.477	9.122	8.022	7.120	6.373	6.047	5.749	5.222	4.775	4.391	4.059	3.910	3.771	3.518	3.295	2.840	2.492
18	11.690	10.828	9.372	8.201	7.250	6.467	6.128	5.818	5.273	4.812	4.419	4.080	3.928	3.786	3.529	3.304	2.844	2.494
19	12.085	11.158	9.604	8.365	7.366	6.550	6.198	5.877	5.316	4.844	4.442	4.097	3.942	3.799	3.539	3.311	2.848	2.496
20	12.462	11.470	9.818	8.514	7.469	6.623	6.259	5.929	5.353	4.870	4.460	4.110	3.954	3.808	3.546	3.316	2.850	2.497
21	12.821	11.764	10.017	8.649	7.562	6.687	6.312	5.973	5.384	4.891	4.476	4.121	3.963	3.816	3.551	3.320	2.852	2.498
22	13.163	12.042	10.201	8.772	7.645	6.743	6.359	6.011	5.410	4.909	4.488	4.130	3.970	3.822	3.556	3.323	2.853	2.498
23	13.489	12.303	10.371	8.883	7.718	6.792	6.399	6.044	5.432	4.925	4.499	4.137	3.976	3.827	3.559	3.325	2.854	2.499
24	13.799	12.550	10.529	8.985	7.784	6.835	6.434	6.073	5.451	4.937	4.507	4.143	3.981	3.831	3.562	3.327	2.855	2.499
25	14.094	12.783	10.675	9.077	7.843	6.873	6.464	6.097	5.467	4.948	4.514	4.147	3.985	3.834	3.564	3.329	2.856	2.499

Table 21 PRESENT WORTH OF AN ANNUITY FACTOR (F)

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 equivalent land. If the land is owned already by the entrepreneur, a hypothetical annual rental rate should be used when estimating the annual land cost, since this is the income he might have obtained by ranting it out instead of using the land himself.

Step 11: Working capital raised on loan for the blockmaking project will require an allowance in the annual costs for interest payments on that capital sum.

Step 12: The unit production cost may then be calculated by summing the separate costs in Steps 7 to 11 to give the total annual cost and then dividing it by the number of blocks produced annually, thus:

Total annual cost = materials + depreciation + labour + land rental + interest on loan,

then Unit production cost = $\frac{\text{Total annual cost}}{\text{Annual output}}$

10.3 Working with the Methodological Framework

The above framework is used to estimate the unit production cost of a stabilised soil block. Some of the following figures are taken from the costing analysis developed during the first Brepak field trial in Kenya (87). See section 8.2.1.

Step 1 - Annual production of blocks = 77,000

Assuming 275 working days per year and 280 blocks were actually produced on a daily basis at Kawangware in Kenya

Step 2 - Annual requirement of materials.

Soil of suitable clay/silt content at 6.5kg per block = 500.5 tonnes. Alternatively if the soil has a high shrinkage, part-replacement of the soil may be made with sand, up to equal volumes of each. With different densities, this would be 249 tonnes of soil and 228 tonnes of sand.

Stabiliser - Ordinary Portland Cement, 4% of soil by weight, used in Kenya = 20.02 tonnes - Murram type soil used contained 15% clay/silt fraction. A different type of soil may have needed a greater percentage of cement.

Water - Uncontaminated, at 1 litre per block = 77,000 litres.

Oil - Waste engine oil at 1 litre per 250 blocks = 308 litres.

Step 3 - Equipment for blockmaking.

Soil selection - 1 Auger, 1 set of sieves, 4 linear shrinkage moulds and bottles.
Winning soil - 2 Wheelbarrows, 2 picks, 4 shovels.
Soil preparation - Either a sieving screen or a manually operated pendulum clay crushing and sieving machine, batching boxes and a watering can with a sprinkler.
Block productioon - One Brepak machine with spare parts and accessories.

Work Area - Covered area, for drying soil, sieving, mixing, block production and primary curing - About 60 square metres.

Note - A completed concrete floor slab for a proposed building could be used as a working area for block production.

Step 4 - Labour requirements for blockmaking

Supervision	1 foreman/technician
Winning soil	1 unskilled
Preparing and mixing	2 unskilled
Block forming	2 unskilled
Curing, stacking	1 unskilled

The team above work 8.5 hours per day, 5.5 days per week and 50 weeks per year, ie 275 working days per year. However the supervisor may be involved in some other projects, so he works 250 days per year on this project.

Step 5 - Land and access requirements

For quarry, material for 15 years, dug 1m deep = 0.3ha
(If blockmaking production site moves frequently, land requirement for quarry is negligible).
Land for access and production, including secondary curing, storage 200 square metres.

Step 6 - Working Capital

Raw materials for one month; one twelfth annual estimate (step 2).
Salaries for one month; one twelfth annual estimate (step 4).

Step 7 - Annual cost of materials Kenyan Shillings

Suitable Murram soil - 500.5 tonnes at 43/- per ton	= 21521/-
Sand, in Kenya, if used as part replacement costs twice as much as soil per tonne.	
Stabiliser - OPC - 20.02 tonnes at 60/- per 50kg	= 24002/-
Water - 77 cubic metres at 0.4/- per cu.ft.	= 31/-
Waste engine oil was free	-
Total annual cost of materials	= 45554/-

Note - These material costs were applicable during 1982 when the first Brepak machine field trial was being conducted. About 16 Kenyan Shillings = 1 Pound Sterling.

Step 8 - Depreciation.

A. Initial Capital Costs

1. Equipment - One Brepak Machine = 15,720/-
   Clay Crushing Machine = 9,600/-
   Ancillary equipment = 5,000/-
   Total = 30,320/-

   Anticipated life of 3 years.

2. Buildings

   Temporary covered area (post and roof)
   60sq.m at 30/- per sq.m = 1800/-

   Anticipated life of 7 years.

B. Annual depreciation costs - see table 21.

1. Equipment; discount factor F_1 for 3 years at 12% interest rate = 2.402, Hence depreciation = $\frac{30320}{2.402}$ = 12,622/-

2. Buildings; discount factor F_2 for 7 years at 12% interest rate = 4.564, Hence depreciation = $\frac{1800}{4.564}$ = 394/-

   Total annual depreciation = 13,016/-

Step 9 - Labour, annual cost

Skilled; 1 man at 55/- per day for 250 days	13750/-
Unskilled; 6 men at 22-50 per day for 275 days	37125/-
	50875/-

Step 10 - Land rental

Land utilised for blockmaking is likely to be situated in areas commanding low land value or rental. Agricultural land rentals can be used in the absence of more reliable information.

Land requirement (step 5) is 0.32 ha, at 1000/- per ha = 320/-

Step 11 - Interest on working capital.

Monthly cost of materials (Step 7)	= 45,554 / 12	= 3796/-
Monthly cost of labour (Step 9)	= 50875 / 12	= 4240/-
Working capital required		= 8036/-
At 12% annual interest on loan = 8036 x 0.12		= 964/-

Step 12 - Unit Production Cost

Annual production cost:	Materials	= 45554/-
	Depreciation	= 13016/-
	Labour	= 50875/-
	Land Rental	= 320/-
	Interest on loan for working capital	= 964/-
	Total annual production cost	= 110729/-

Annual block production = 77,000

Unit block production cost = 110729 / 77000 = 1.44 Kenya Shillings

Using the methodological framework for the Kenyan Brepak field trial has included costings which did not occur because using public land and locally available soil these on costs should not have been considered.

Kateregga (88) has stated that the cost of a Brepak stabilised soil block is around 1.00 Kshs; the block being 290 x 140 x 100mm in size, while the equivalent concrete block is 140 x 190 x 390mm would cost 5.70 Kshs. 2.5 Brepak stabilised soil blocks are equivalent to one concrete block in wall

area; (June 1982 Nairobi prices). This means that one concrete block is more than twice the cost of the equivalent Brepak cement stabiilised soil block.

The final cost of the 50 square metre medical clinic as shown on plate 42 was £31.00 per square metre which compares favourably with a structure built with concrete blocks at a cost of £65.00 per square metre. This comparison of cost figures indicates that at least 50 per cent cost savings can be achieved when setting up a stabilised soil block production programme. The Research for Industry leaflet (Appendix A5) mentions these particular cost comparisons.

Similar costings were achieved during the subsequent buildings erected on the five sites around Lake Victoria. These buildings are illustrated on plates 45 to 49 inclusive.

10.4 Jamaica Costings

As reported in Section 8.2.3, the $90m^2$, community development, demonstration structure, illustrated on plate 53, included both concrete columns and stabilised soil building blocks.

It was therefore not possible to apply the costing framework as developed in section 10.2 although the Building Research Unit in Kingston, Jamaica maintained an accurate record of the various costs involved. When the building was completed the resultant cost savings per square metre of walling was about 30 per cent saving when compared with hollow concrete blockwork walling of a similar thickness.

Appendix A14 quotes these cost saving figures.

10.5 St Vincent Costings

This particular project was controlled by several organisations as discussed in Section 8.2.6 and to obtain true costing comparisons the author had to obtain the detailed costings from different sources - Note that £1 sterling = 4 Eastern Caribbean dollars (E.C.).

The Caribbean Conference of Churches provided an allocation of 16,978 EC dollars to cover the costs of site supervision, materials, labour and erection of a 50ft x 30ft, 'Roof only' building structure which is illustrated on plate 54.

Ms Nelcia Robinson, the project co-ordinator recorded a detailed costing analysis during the period February 85 to June 85 which is given under Appendix A15. this total expenditure of 32,859 EC dollars included salaries for the site team, consumable materials and building erection costs.

Further costs were incurred during the authors last visit to St Vincent when the building was completed.

Therefore summarising these costing figures:

	EC Dollars
'CCC' - Roof only building structure	16,978
Finance from the UK Aid programme	
Training Course and construction (Appendix A15)	32,859
Site supervision and transportation of materials	3,000
Extra costs to complete building	20,000
Total	72,837

To this total must be added the costs incurred by the Community Development Division of the St Vincent Government for supervising this project. An estimate of 8,000 EC dollars has been suggested to cover these costs

including unforeseen contingences not recorded. The total cost for this Skill Training Centre amounted to about 81,000 EC dollars for a total available floor area of about 2225 square feet. This is equivalent to 36.40 EC dollars per square foot for the completed building.

Note: Mr Clem Ballah, Head of the Community Development Division, was extremely pleased with this resultant costing because similar structures constructed from concrete blocks would cost between 65 and 85 EC dollars per square foot depending on the standard of finish required.

This particular costing exercise has again demonstrated that significant cost savings can be achieved when producing good quality stabilised soil building blocks on site from local materials of around 50 per cent cost saving when comparing concrete blockwork costs.

10.6 Bangladesh, The Gambia and Pakistan

During 1986 soil samples were received by the author from Bangladesh, The Gambia and Pakistan. These soils were analysed and good durable stabilised soil products were made on the Brepak machine. Relevant costing data was also supplied to the author from the governments of Bangladesh, The Gambia and Pakistan. This data includes the cost of materials and current wages for skilled and semi-skilled operatives.

From this information the methodological framework has been applied to develop realistic costings for each government and at the time of writing this section it would appear that Brepak machines will be ordered so that field trials will commence in these countries during 1987 and 1988.

10.7 Costing appreciation

The costing of low income housing has been the subject of many methods but the final result must always be - Is the completed building affordable by the occupiers or owners.

In 1968, Vinluan (108) an architect planner in Ghana wrote 'A Study on Low House - Building Costs' which compared the detailed costings of low income housing utilising different materials. This study concluded that substantial reductions in building costs could be achieved by utilising locally available materials and that the use of local soils should result in the best cost savings.

In 1952, Paul Ramirez, Section 6.2.3, developed the CINVA-Ram Press, and demonstrated that substantial cost savings could be achieved by producing cement - stabilised soil blocks when compared with timber framed buildings and traditional material such as fired clay bricks and concrete blocks. The problem of durability of these stabilised soil block buildings was referred to by Vinluan (108).

It is therefore suggested that the minimum useful life of a stabilised soil block building should be at least 30 years as already demonstrated by the demonstration building constructed in 1950 at BRS from soil-cement stabilised blocks (9 and 10).

The methodological framework of costing mentioned earlier in this chapter is maybe lengthy but does incorporate all the possible variations of costs likely to occur when considering the costing aspects of low income housing.

The early model Brepak machine was used in Kenya and the costing analysis (Section 10.3) was based on the actual output of this machine of 33 blocks per hour. In the final costing appraisal by H.R.D.U., they established that the first demonstration building, of 50 square metres, constructed from Brepak made blocks totalled £31 per square metre, compared with an estimated cost of £55 per square metre if the Kenyan style CINVA-Ram had been used, (Plates 39 and 40) and £65 per square metre (A5) for concrete blocks.

Soil experts at the international organisations of CRATerre in France, VITA (28) and the Intermediate Technology Development Group in UK all make similar recommendations for soil-cement stabilisation as the CINVA-Ram, see table 5.

In the case of the Murram soil used on site in Kenya, the CINVA-Ram recommendations would have been to use 5.56 per cent cement whereas the soil blocks produced by the Brepak machine contained 4 per cent cement.

Improvements have been made to the Brepak machine, (Chapter 8) with a confirmed output of 40 blocks per hour - see section 8.6.2. If this output is applied to the costing analysis, the unit block production cost reduces from 1.44 to 1.12 Kenya shillings.

The costing analysis has to include wages and during field trials it has been shown that the best way of keeping labour costs to a minimum is to negotiate an on site bonus scheme at the start of a project.

CHAPTER 11

CONCLUSIONS

11.1 General Conclusions

Having worked on the general concept on soil stabilisation for building construction during the last 10 years, the author has realised the enormous problems that exist with housing people in the third world. After the initial design and development of the Brepak machine and the first successful field trial in Kenya - see Section 8.2.1 some 90 countries have requested further information about this particular development project.

This section on conclusions of this work can best be separated into two distinct parts:

11.1.1 Summary of work

Based upon laboratory test results, world survey of block making machines and practical experience gained from the field trials, the Brepak block making machine has demonstrated that good quality, durable building products can be manufactured on site by local people.

By using simple mould inserts inside the mould cavity of the Brepak machine, a range of different shaped blocks or tiles can be produced which would be suitable for many forms of construction. For example, Plain rectangular blocks with an indent, normally referred to as a 'frog' which improves the shear resistance of a wall against external wind forces. Hollow blocks to enable a simple portal frame to be constructed (Section 8.2.7) within a stabilised soil wall to resist external forces such as those created by

seismic or hurricane type winds. Tile or floor blocks can be produced to improve the floor conditions in buildings or even used as lining for irrigation channels - See Section 9.5.

Shaped blocks can be made, used to line water holes, pit latrines and arches.

The simple site soil testing and selection methods developed during this work Chapter 3, have indicated that when using a compaction pressure of 10 MN/m^2 a wider range of soils can be effiiciently stabilised than when using a low compaction pressure of 2 MN/m^2 similar to that of the CINVA-Ram machine.

11.1.2 Implications of this Work

Throughout this study the author has been aware that there are three quite separate criteria which must be satisfied independently if good quality stabilised soil building blocks are to be used to produce low income housing acceptable and affordable to the people.

Firstly, there is the need for the correct on site selection of a soil, choice of a suitable stabiliser and soil preparation. This particular aspect forms a major part of this study especially in the development of a simple site procedure. From the practical experience gained from the various field trial locations only guidance can be offered on this aspect and for this reason a comprehensive Brepak operators manual has been introduced by the author (103). This will supersede Appendix A1.

Secondly, the use of the Brepak machine under actual site working conditions has meant that modifications have been introduced to make the machine more versatile, improve its productivity and simplify the individual operations needed to manufacture a good quality product.

Thirdly there has been the need to introduce an efficient curing technique for the freshly made blocks on site and achieve better construction techniques when a building is being erected. Using a better quality product the mason on site, has had to learn how to build an acceptable wall with even spaced joints because in most cases there will be no external protective render coat.

The finished product, a single storey dwelling constructed from stabilised soil blocks, should be durable against the elements, aesthetically pleasing and affordable to its occupants. Where the author has worked, in rural locations local people have willingly worked on this work and been proud of their achievements. This proves that the soil blocks produced by the Brepak machine are accceptable especially when savings of up to 50 per cent have resulted when compared with the costs of concrete blockwork. See Section 8.2.1 which refers to a paper entitled 'Peoples Practical Participation' (87). When comparing the stabilised soil blocks with burnt clay bricks, (which are generally more expensive than concrete blocks) the only obvious difference is that the soil blocks are marginally larger than the bricks.

The manufacture of good quality stabilised soil building blocks, using simple manual small scale technologies in the locality where the blocks are needed, is of social benefit in providing gainful employment for local people, improving the quality of shelter and health standards of the occupants. A worthwhile sense of achievement is created for those involved in building their own homes with local materials.

The demonstrated technical, social and economic advantages of stabilised soil block production indicate that assistance and encouragement should be given, where appropriate, to this method of turning locally available soil into a good building product, as a means of helping to alleviate the gigantic

problem of housing and other forms of accommodation that exists in the world today.

In this context the future of stabilised soil blocks looks quite promising especially now that a number of industrialised countries are reviving interest in this and other forms of earthen construction. For example 'Craterre' in France are conducting field work in numerous third world countries as discussed in Section 6.3.

11.2 Concluding Discussion

Robert Fitzmaurice in his publication 'Manual on Stabilised soil Construction for Housing (69) published in 1958 stated that there has already been a very large growth of stabilised soil construction in various parts of the world. Why has this growth not been maintained?

The reasons behind the lack of growth in a number of third world countries is that housing authorities have formulated building standards which often rule out the use of soil as an officially acceptable building material. These standards are normally obtained from industrialised countries and mainly concern medium to high income housing and public buildings which will generally need a building permit. Thus, soil is mostly used for dwellings which are built without formal authorisation, such as rural housing or uncontrolled low-income housing in urban and peri-urban areas. However in the Sudan for example mud or soil buildings have always been permitted in the third and fourth class housing areas of Khartoum since condiminium days. This restrictive building standard often applies to stabilised soil blocks although they may be more suitable than officially accepted building materials when used according to sound technical practice.

With the development of the Brepak block making machine and its introduction into various village communities it has been proved that good quality building blocks can be produced which comply with British standards for both burnt clay bricks and concrete blocks. This machine has also proved advantageous in transferring technology to village people and making use of indigenous materials.

Another possible reason why this growth has not been maintained is that local people do not like living in earthen constructed dwellings, and aspire to live in dwellings constructed from burnt clay bricks or concrete blocks. If they could afford this type of material! One solution is for governments to stamp their mark of approval on the concept of building with stabilised soil building blocks by the introduction of suitable building regulations (already discussed in section 9.7). As a direct result of the successful Brepak machine's field trials the Kenyan government and several Caribbnean countries have taken the first step in introducing suitable building regulations recommending the use of stabilised soil building blocks. One such example is now taking place in St Vincent where low income housing is being constructed from stabilised soil building blocks made on a Brepak machine.

Reflecting on the research activities cited in this thesis and the successful field trials that have been conducted the author is recommending that further Brepak field trials be initiated at village level in many more third world countries. This would give the local population the advantage of learning how to construct their own homes from indigenous materials.

In order to promote the use of stabilised soil building elements, the active involvement of governments and housing authorities will be needed in the following areas:

(a) revision of current building standards and regulations to accommodate soil based materials.

(b) inducements to future home owners to adopt stabilised soil blocks as the main building material, for example, the cost of the building permit may be reduced as an incentive.

(c) initiative taken by local councils to legislate the use of stabilised soil blocks for some types of government buildings, medical clinics and schools etc.

(d) promotion of stabilised soil blocks through advertising, exhibitions and pilot housing schemes.

(e) adjusting duties on imported building materials in order to make these less attractive than locally available materials.

(f) support given to research and development in order to maximise the use of local stabilisers and improve the present quality of stabilised soil blocks and

(g) reorganise the existing training and technology transfer for the production of good quality stabilised soil building blocks.

Decisions must be taken, and if the above measures are implemented they would greatly contribute to making stabilised soil blocks preferable to other building materials in terms of affordability, availability and protection against adverse weather conditions.

The future looks promising because 1987/88 is the International Year of Shelter for the Homeless (IYSH) as declared by the United Nations and the spotlight will be directed towards affordable accommodation for the low income group of the world.

No one country can sponsor a solution for housing the world's homeless, this must lie with the respective governments to take the initiative with assistance from aid donors and charitable organisations throughout the world.

11.3 Proposals for future research

The objective of this thesis was to conduct a review of the use of soil in the construction of low cost housing in the developing world; to study the existing methods of turning soil into acceptable building elements and to develop a new type of manually operated machine capable of producing superior quality stabilised soil blocks to those hitherto produced in the past.

These objectives have been achieved, however, throughout this thesis several questions have arisen which could well form the basis for future research. As already mentioned in Section 4.4.7 a number of students from various countries have written their own dissertations on soil stabilisation.

(i) Power operated block making machine:

When new building regulations allowing the use of stabiilised soil blocks are introduced in a country, it will be necessary to develop a high output soil block making machine capable of producing 200 to 250 good quality blocks each hour for use in an urban or peri-urban situation. This power operated machine could either be mobile for site production of blocks or as a factory

installation. Economics must be considered if the cured building blocks have to be moved from factory to site.

The main design criteria of a power operated machine is that it should consist of a rotating table top with four mould cavities and contain the same compacting parameters as a Brepak machine, resulting block dimensions being 290 x 140 x 100mm maximum depth.

This type of machine would also be suitable for the rural areas of countries such as the Yemen Arab Republic where the high cost of labour, - see section 8.2.7, has proved the Brepak machine uneconomical to use.

(ii) Social studies:

Since the early 1950's numerous soil block making machines have been introduced into third world countries - See Chapter 6 and Fitzmaurice (69) in 1958 stated there had been a large growth of stabilised soil construction in various parts of the world however this growth had not been maintained. This growth rate has been discussed in Section 11.2 and now with the introduction of a low cost machine - Brepak - that has already proven itself in the field for the production of good quality stabilised soil blocks that a useful research project should be conducted by social scientists to investigate the subject of accceptability of stabilised soil construction.

(iii) Improvements to Health Standards:

Improving the health standards of people living in earthen constructed dwellings has already been discussed in Section 2.3.7.

The use of dense stabilised soil building blocks, made on the Brepak machine, which do not crack, will eliminate breeding grounds for vectors and will help prevent the spread of endemic diseases. A further improvement could be made by mixing residual pesticides with the mould release oil used in the manufacture of the Brepak blocks. This method has been used experimentally and the pesticides lasted more than three times longer than on ordinary mud walls or floors; this aspect of the Brepak research project was reported in the New Scientist in April 85 - See Appendix A17.

The author prepared a short article on low-cost housing and Parasite Vectors for Parasitology Today - August 1985 a copy of which appears under appendix A18.

This particular aspect of the Brepak project is still continuing and it is hoped that field trials will eventually take place during 1988 in Brazil, Bolivia and Honduras in South America. The Pan American Health Organisation (PAHO), World Health Organisation (WHO) in Geneva and governments in South America have already shown considerable interest in the proposals.

On a wider basis a research project could be initiated that would study the various methods of insecticide application to earthen constructed buildings, with the immediate affect on the inhabitents and the cost effectiveness of such methods.

(iv) Roofing study

Various materials have been used in the developing world to provide a cover for low income housing. Many of these materials do not last very long and often are a health hazard to the inhabitants. It would therefore be a useful

study to compare these various materials and to conduct a research study covering the possible use of new materials.

For example stabilised soil floor tiles around 20mm thickness have been made on the Brepak machine and a study of their wear qualities have been studied within the work of this thesis - see Section 9.9.5.

Abul Khair, a Bangladesh student studying at the University of Newcastle-upon-Tyne has been using stabilised soil tiles of around 15mm thickness (again made on the Brepak machine) to line experimental irrigation channels. See section 4.7. To study the erosion of these tiles, water has been passed at different velocities over the surface of these tiles and the preliminary results obtained indicate that minimum surface wear occurs.

These two independant studies support a research proposal that stabilised soil roofing tiles could be manufactured on the Brepak machine.

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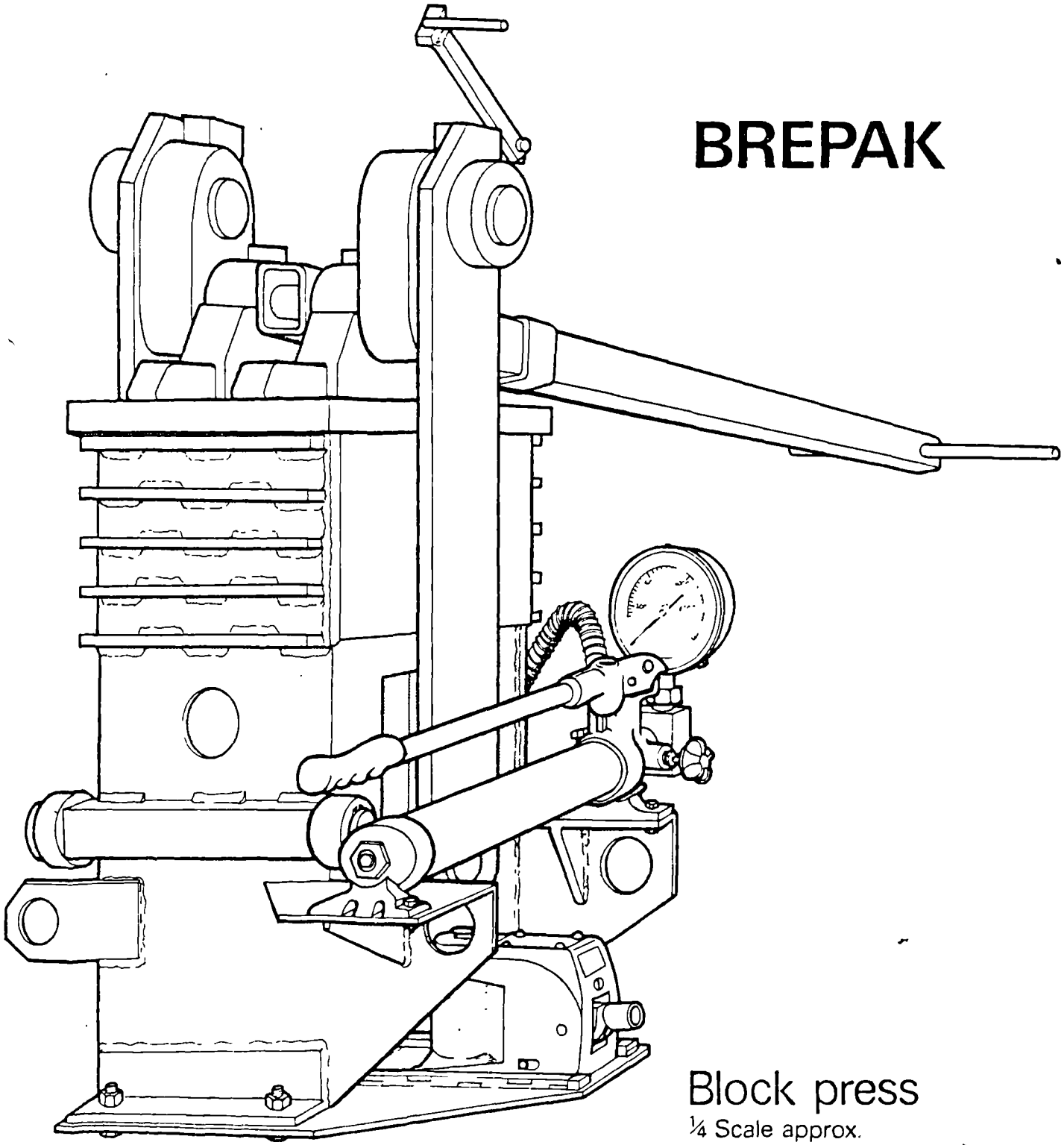


Block press

¼ Scale approx.

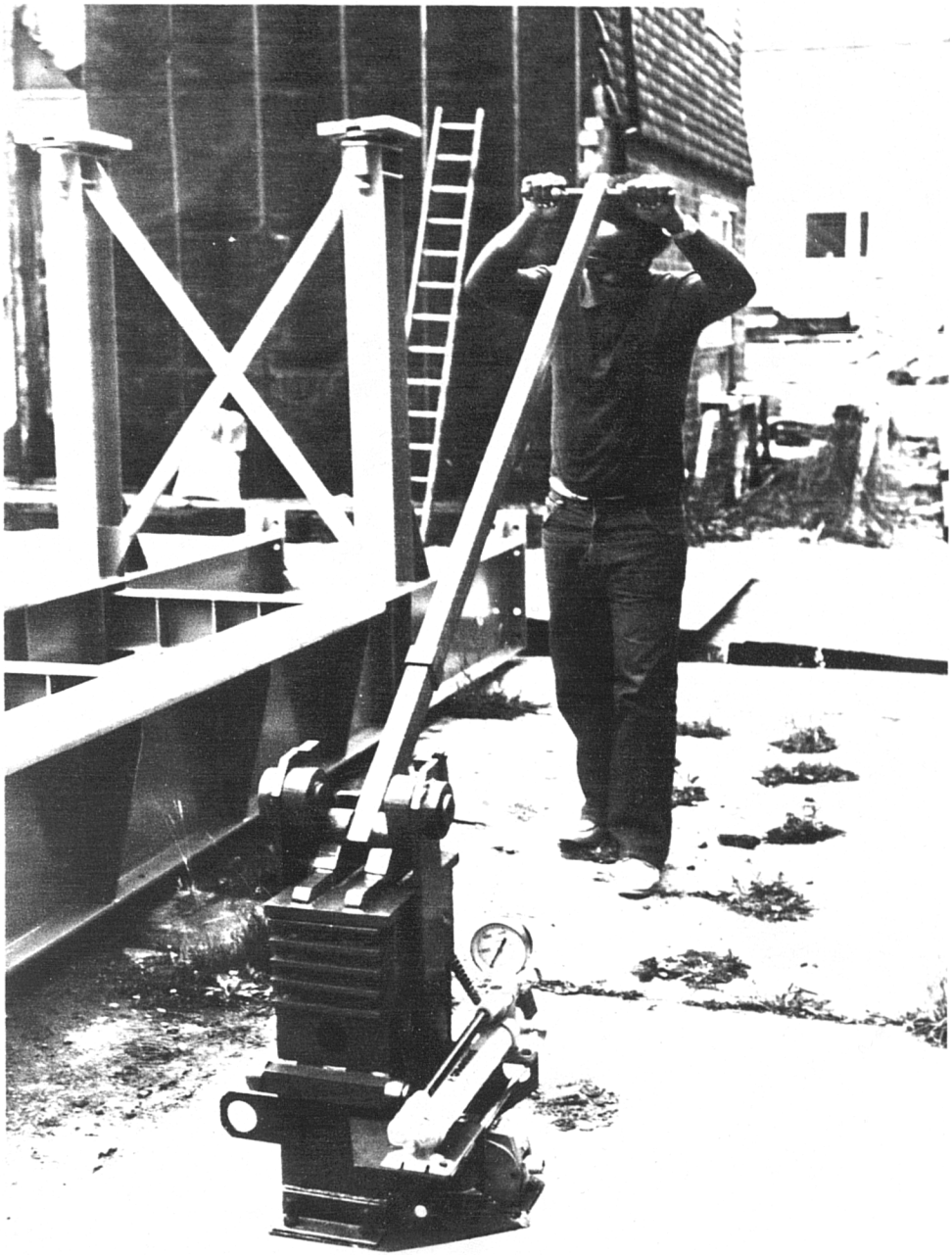


Plate A - 80-215-7

The Protype Brepak Machine

SECTION 2 b

General description of the Brepak machine

The Brepak machine, as shown on plate A, has been designed specifically to produce high quality stabilised soil building blocks and with a secondary use of either producing floor tiles or roof tiles.

The machine is manually operated and does not need any means of external power supply and can produce up to 40 blocks per hour using a team of five men whose duties would be:-

1 man to dig material from the ground and spread for drying

1 man to crush and sieve material also prepare batch quantities for mixing

1 man to mix material and prepare batches for pressing

2 men to operate the machine and stack blocks for curing.

The Brepak machine has an inbuilt manually operated hydraulic system, which when used applies a compaction pressure up to a maximum of 10 MN/m^2 on a moistened mixture of soil and a suitable stabiliser such as cement or hydrated lime.

The dimensions of the produced building block will be 290 mm x 140 mm x 94 mm thick.

A general assembly drawing of the Brepak machine is shown on figure 1 and its leading dimension are:-

Overall height - 760 mm with the main lever in the horizontal position

Overall length - 790 mm which does not include the main lever arm extension of 1500 mm

Overall width - 510 mm which does not include the operating lever for the stand-by ejector ram which is 530 mm long

Gross weight - The total weight of the machine is 159 kg. In addition the main lever arm extension weighs 11 kg and the stand-by ejector ram operating lever weighs 2 kg.

A Brepak machine consists of three principal parts:-

(1) Fabricated steel body

(2) Manually operated hand pump

(3) Stand-by ejector ram

(1) The fabricated steel body comprises a stand complete with carrying brackets, a mould box, operating linkage, swivelling top plate and a main lever arm complete with an extension handle.

The mould box has a fill depth of 154 mm and is strengthened with 20 mm steel plate to resist the internal forces generated during the pressing operation. Built under the mould base plate is the main hydraulic cylinder which is 100 mm in diameter and is incorporated to give a total thrust of 44 tonnes on the soil mixture in the mould.

The main lever arm is incorporated to provide an initial movement of 40 mm to the mould base, this is achieved via the linkage and applies a low compacting force to the soil mixture in the mould box.

(2) The manually operated hand pump is supported on two brackets which are projecting to one side of the Brepak machine; this hand pump is a proprietary item manufactured by Applied Power (UK) Ltd. It is a self contained piston type hand pump consisting of an oil reservoir manually operated pumping unit, a load

release screw and an internal adjustable pressure relief valve.

This unit is a simple, rugged hand operated pump which creates hydraulic pressure with easy strokes of a convenient handle.

The hand pump is connected to the main hydraulic cylinder by a flexible hydraulic pipe which is protected by a spirol winding.

A Budenberg type pressure gauge is incorporated within the hydraulic pipe line to ensure the correct operation of the Brepak machine when being used.

The pressure gauge is fitted with a perspex safety glass.

(3) The stand-by ejector ram is located at ground level beneath the manually operated hand pump and can be moved within fixed slides which are bolted to the machine base plate.

This unit is manufactured by Tangye Ltd, is totally enclosed and suitable for use in very dusty conditions; it is manually operated and can exert an upward force of 6.5 tonnes over a lift of 80 mm.

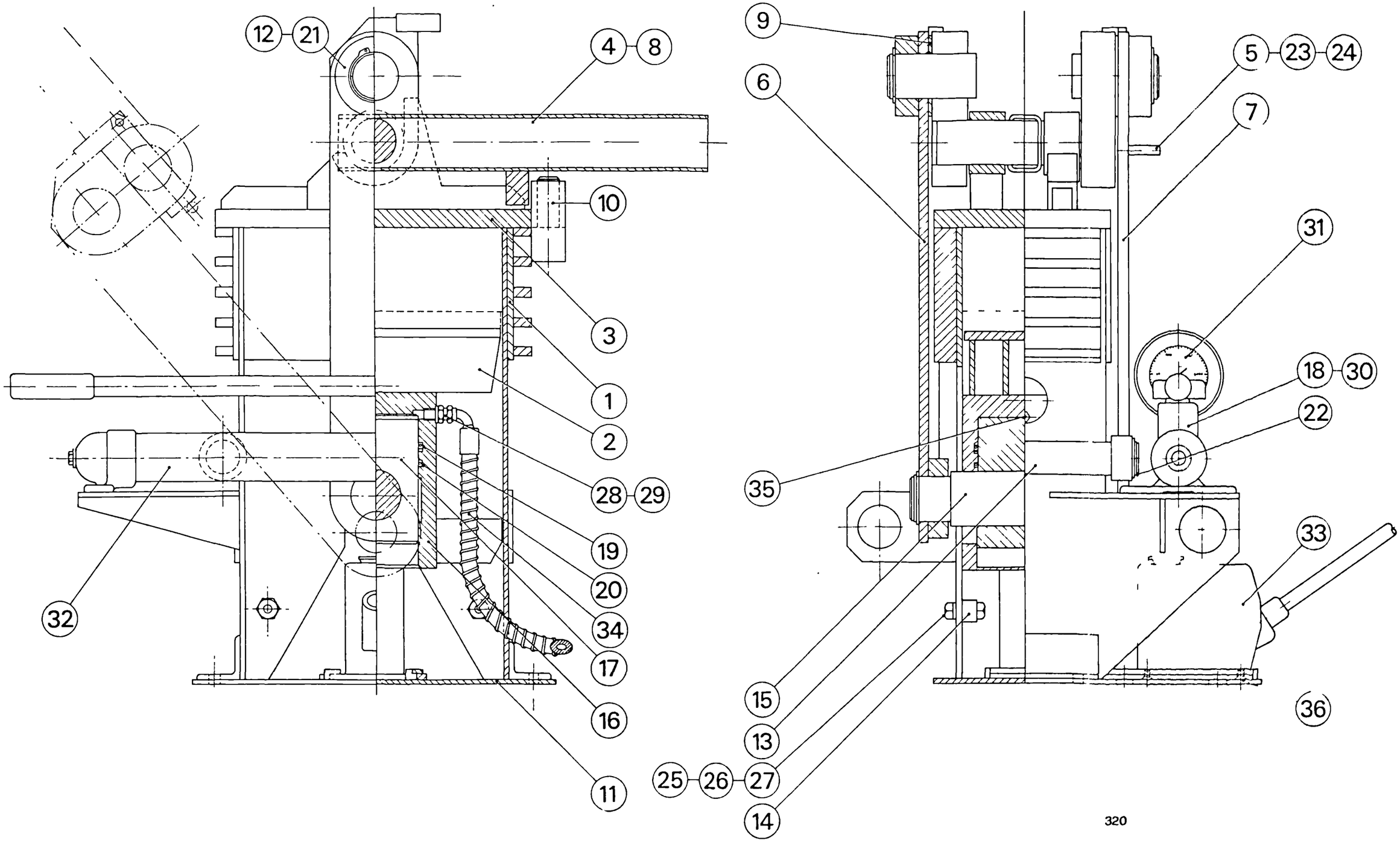
The stand-by ejector ram is not used all the time during the manufacture of a block but should only be used when a pressed block cannot be ejected from the mould box by the normal linkage demould arrangement.

BREPAK

Main components of BREPAK press

Fig. 1

A1



SECTION 2 c

Installation of the Brepak machine

You have now received a Brepak machine and before you start assembling the machine it is adviseable that you first read section 2 of this manual.

Carefully unpack the machine together with its components and check that all the contents agree with the delivery manifesto.

Inspect the various items to ensure that no damage has occured in shipment; if components have been damaged please report the details to Overseas Division, Building Research Station, UK.

The Brepak machine has to be firmly fixed down to either a solid foundation plate A or a wooden base board as shown on figure 2.

During the pressing and demoulding operations upward forces are generated which have to be resisted by whatever method of fixing down is employed.

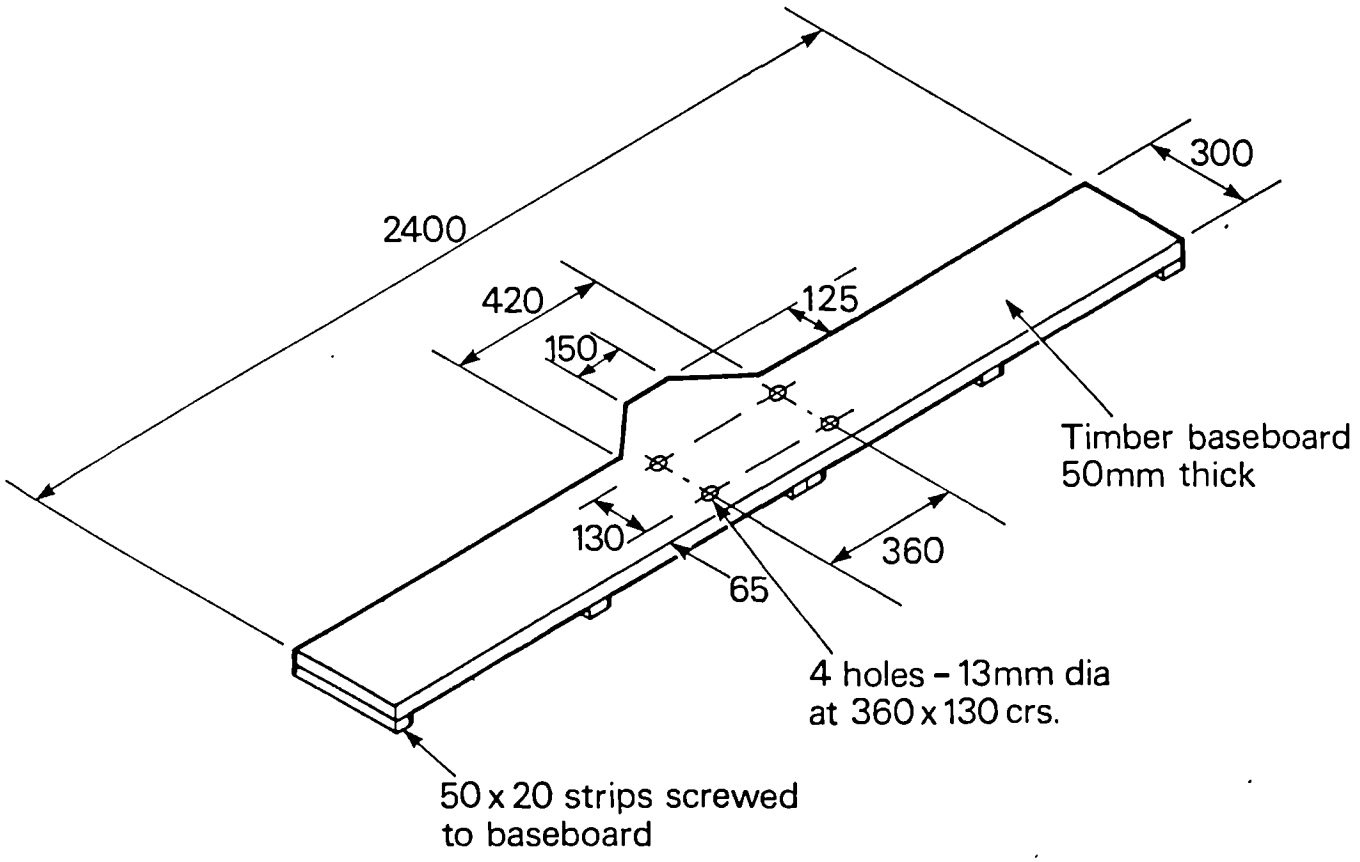
If a concrete base is used the foundation fixings should be M12 bolts positioned at 130 x 360 mm centres and plate illustrates the Brepak machine base plate being lowered into position over the protruding foundation bolts.

The Brepak machine is bolted into its packing case by four M12 x 75 mm long bolts and these bolts can be used to bolt the machine down to a timber base board.

Before final assembly of the Brepak machine the four stop ring assemblies item 14 mounted to the machine body item 1 should be checked for tightness.

BREPAK	Baseboard for press	dims. in mm	Fig. 2.

A1



It is adviseable to check that all moving parts move easily.

Projecting brackets are provided on the sides of the machine body which act as carrying handles, and if convenient bars are inserted into the holes in each bracket the carrying operation will be simplified.

The Brepak machine should now be lifted into position over the projecting foundation bolts onto the top surface of the machine base plate and tightened down into final position; or alternatively onto a timber baseboard.

The next check is to ensure that the stand-by ejector ram is free to slide in and out of the Brepak machine on its own slide carriage. Note that this operation should be performed with no extension on the stand-by ejector ram. See Section 2 d how to operate the stand-by ejector ram.

The mould head plate, item 3, can now be positioned on its swivel and also the extension lever arm, item 8, can be fitted into the socket on the lever arm assembly, item 4.

Finally before the Brepak machine is used, all the moving parts should be lubricated as detailed in Section 2 h.

SECTION 2d - BRAKE MACHINE COMPONENTS

This section to be read in conjunction with figure 1 and the circled numbers are quoted for general identification as follows.

1. Mould body assembly fabricated with items 10 and 13.
2. Mould platform assembly
3. Mould head plate.
4. Lever arm assembly fixed to the link arms.
5. Lever locking assembly incorporating items 23 and 24.
6. Right hand link assembly.
7. Left hand link assembly.
8. Extension lever arm assembly that fits into item 4.
9. Two washers.
10. Head plate hinge assembly.
11. Machine base plate including side plates.
12. Two rollers including item 21.
13. Lever fulcrum bar.
14. Four stop ring assemblies with items 25, 26 and 27.
15. Hydraulic ram pin.
16. Hydraulic cylinder block.
17. Piston rod.
18. Connection block incorporating item 30.
19. Piston seal.
20. Piston wiper 'O' ring.
21. Four - 2 inch external diameter circlip
22. Two - 1.5 inch external diameter circlip.
23. Split pin on the lever locking assembly.

24. Chim washer on the lever locking assembly.

25. Four - 0.5in UNF Hexagon headed bolt 1.5in under head.

26. Four - 0.5in UNF Hexagon headed nut.

27. Four - 0.5in Spring washer.

28. Two - 0.25in BSP Equal hydraulic union.

29. Two - 0.25in Bonded washer.

30. 0.375in - 18 NPT Equal hydraulic union.

31. 4in Budenberg pressure gauge - 10,000 PSI capacity.

32. Hydraulic hand pump - type P39

33. Hydraulic stand-by ejector ram - type Hydramite L.

34. 0.2in Internal diameter hydraulic hose with spirol outer protection.

35. Air bleed screw.

36. Four - M6 CS'K Headed screws - 15m overall length.

Hydraulic hand pump - type P39 item 32.

This unit is manufactured by Enerpac which is a division of Applied Power International, and this organisation distributes its products world wide so any spare parts needed could be obtained locally overseas.

Fig 3 shows an exploded view of item 32 and the following lists a brief description of each component with the manufacturers relevant part number.

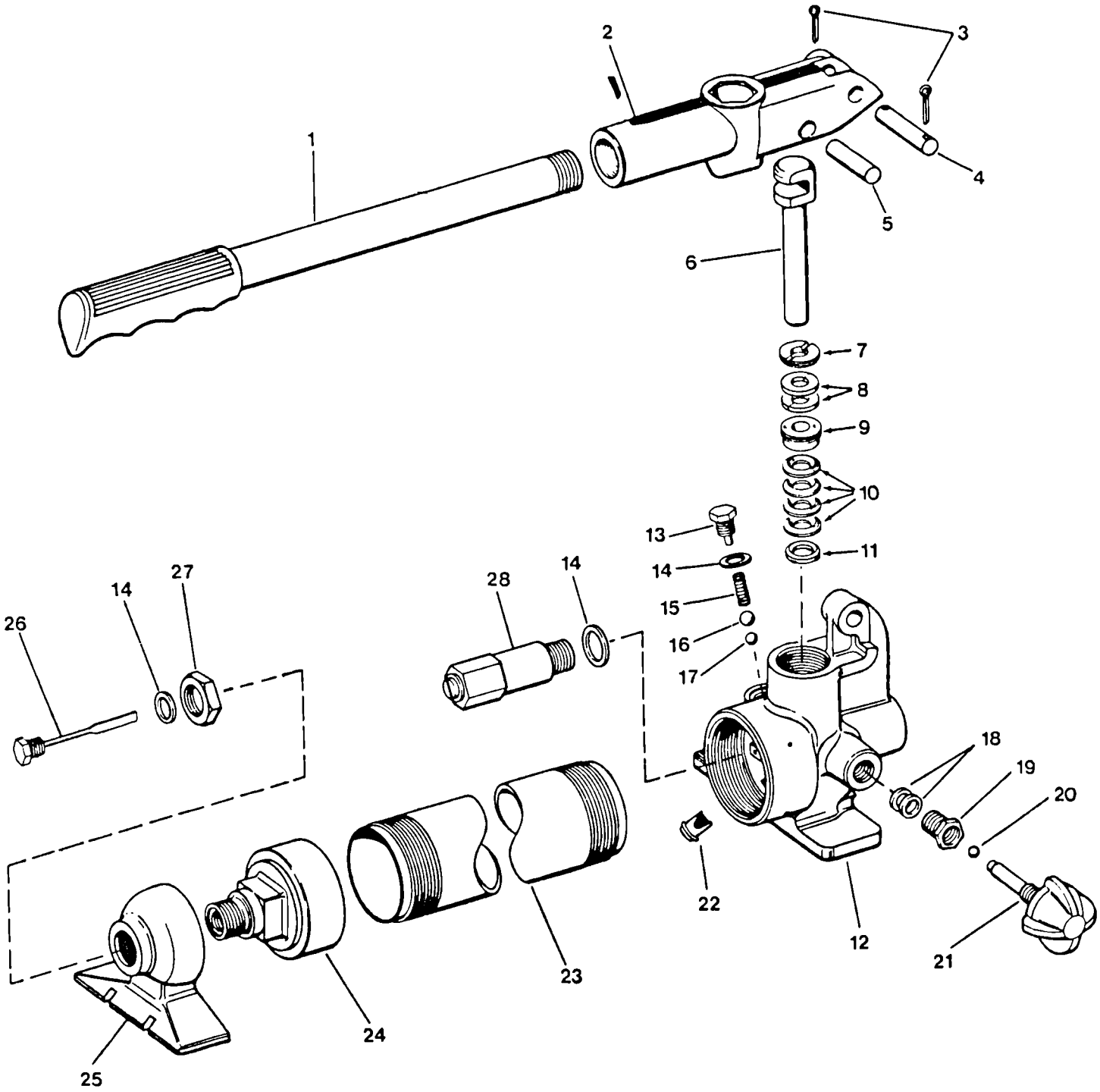
The suffix 32 in front of each part number indicates that it is a comporent of the hydraulic hand-pump item 32.

BREPAK

Hydraulic hand pump

Fig. 3.

A1



Item	Part number	Quantity	Description
321	J7	1	Handle Assembly
322	B113.060-1	1	Beam
323	S1.58	2	Cotter Pin
324	P76.63	1	Beam Pin
325	P75.57	1	Cross Pin
326	P16.51	1	Plunger
327	P16.54	1	Nut
328	P16.75	3	Packing
329	P16.55	1	Nut
3210	S1.53	4	Cup
3211	S1.52-2	1	Spreader
3212	B121.005-1	1	Base
3213	K3.006	1	Plug
3214	B159.167	3	Gasket
3215	S1.183	1	Spring
3216	B1009.016	1	Ball
3217	B1006.016	1	Ball
3218	B217.074	2	Packing
3219	MJ 11-1	1	Nut
3220	B1005.016	1	Ball
3221	J435.900	1	Valve
3222	P307.18	1	Filter
3223	P16.25	1	Reservoir
3224	P75.266-1	1	Cap
3225	P76.267-1	1	Pump rest
3226	B110.900	1	Plug
3227	P75.181	1	Nut
3228	P182.190-2	1	By Pass Valve

Item	Part number	Quantity	Description
3229	R515.245-2	1	Plug
3230	[illegible] 07561	1	Patent Decal
3231	G424.026	1	Decal Enerpac
3232	BSS 14.0780D	1	Decal P39

Note that items 3229, 3230, 3231 and 3232 are not shown on Fig

A repair kit P39K is supplied with each Brepak machine and will contain the following items 323, 328, 3210, 3214, 3215, 3216, 3217, 3218 and 3220.

Hydraulic Stand-by ejector ram - type Hydramite E, item 33.

This unit is manufactured by Tangye Limited, Gough Road, Great Birmingham B11 2NH.

Fig 4 shows views of item 33 and the following lists a brief description of each component with the manufacturers relevant part number.

The suffix 33 in front of each part number indicates that it is a component of the hydraulic stand-by ejector ram item 33.

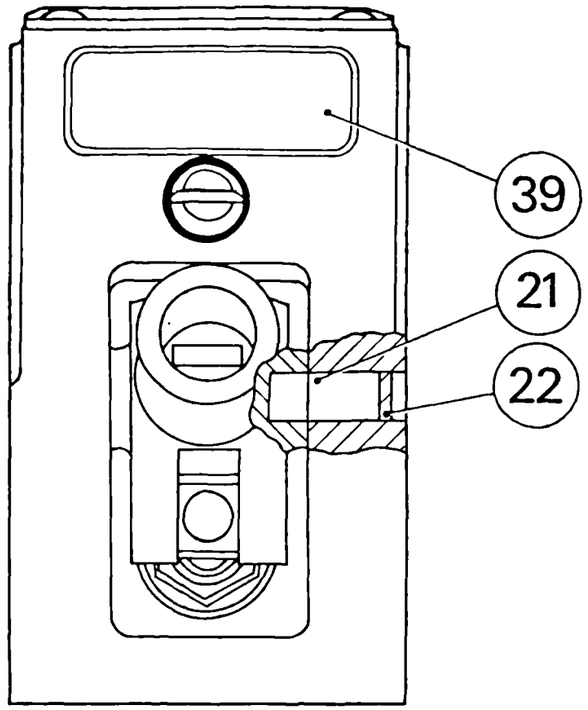
Item	Quantity	Brief Description
331	1	Body
332	1	Ram
333	1	Ram seal
335	1	Ram cap
336	1	Ram cap screw

BREPAK

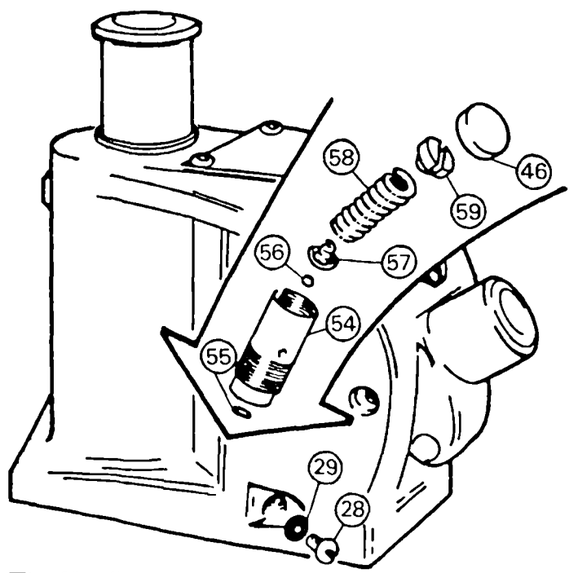
Stand-by ejector ram components

Fig. 4.

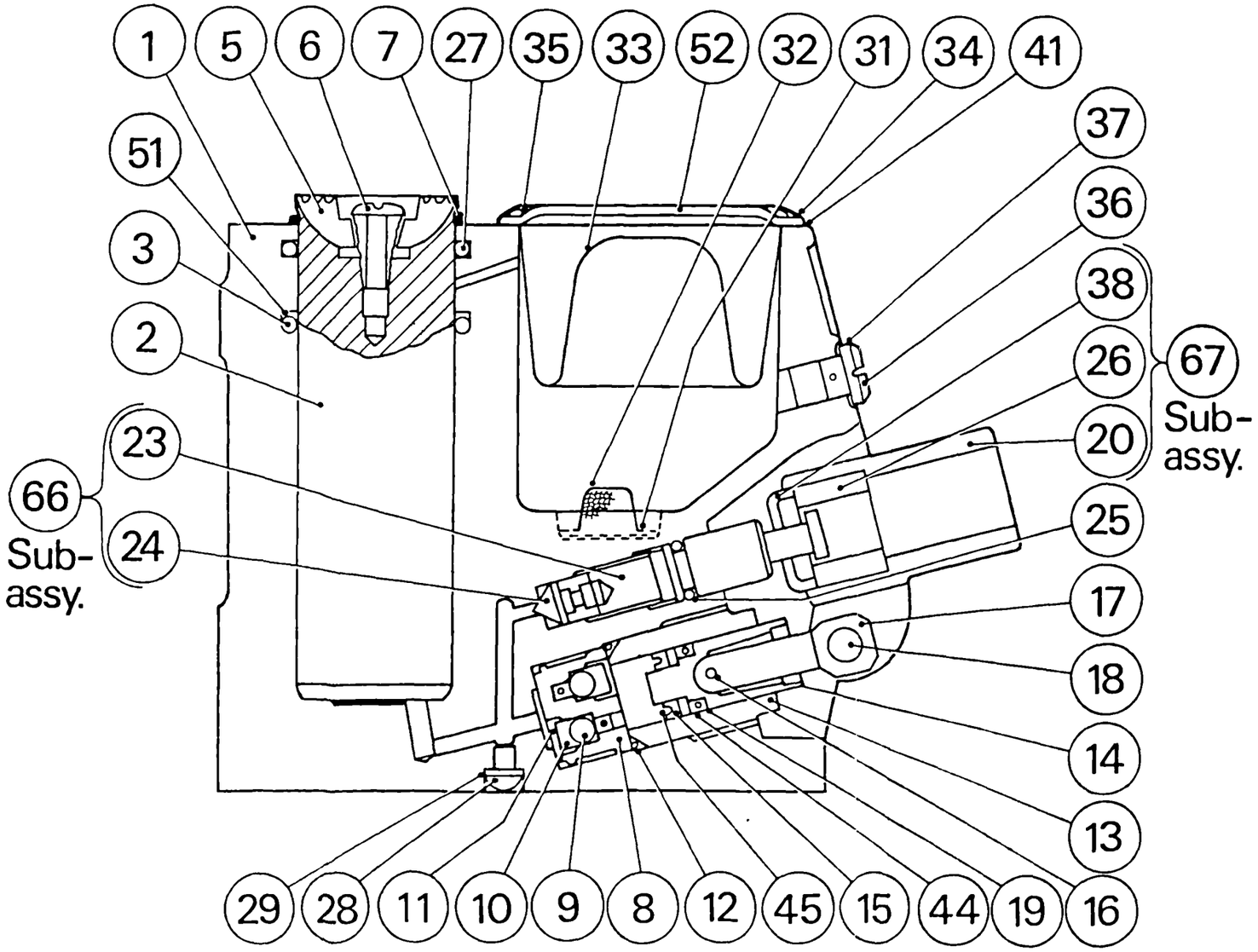
A1



Pump rocker assembly



Relief valve assembly



Item	Quantity	Brief Description
337	1	Ram cap screw washer
338	1	Valve cage
339	2	Suction and delivery valve balls
3310	2	Suction and delivery valve springs
3311	2	Valve spring retainers
3312	2	Valve cage seals.
3313	1	Pump plunger barrel
3314	1	Pump plunger
3315	1	Pump plunger seal
3316	1	Pump plunger gudgeon pin
3317	1	Pump plunger connecting rod
3318	1	Connecting rod pin
3319	1	Pump plunger 'O' ring
3320	1	Pump rocker
3321	2	Pump rocker pivot pin
3322	2	Pivot pin fasteners
3323	1	Release valve screw
3324	1	Release valve screw tip
3325	1	Release valve screw seal
3326	1	Release valve socket
3327	1	Ram wiper ring
3328	2	Passage plug
3329	2	Passage plug joint
3330	1	Operating lever
3331	1	Suction strainer fastener.
3332	1	Suction strainer

Item	Quantity	Brief Description
3333	1	Reservoir diaphragm
3334	1	Reservoir cover
3335	4	Reservoir cover screws
3336	1	Filler plug
3337	1	Filler plug joint
3338	1	Socket retainer
3339	1	Filling instruction plate
3341	1	Diaphragm disc
3342	1	Operating lever grip
3344	1	Anti extrusion ring
3345	1	Packing retaining clip
3346	1	Relief valve protective cap
3351	1	Ram packing anti-extrusion ring
3352	1	Reservoir cover label
3354	1	Relief valve body
3355	1	Relief valve body seal
3356	1	Relief valve ball
3357	1	Relief valve socket
3358	1	Relief valve spring
3359	1	Relief valve adjusting screw
3366	1	Release valve assembly
3367	1	Rocker assembly

Note that items 3342, 3346 and 3354 are not illustrated on Fig

A service repair kit for the model E Hydramite Hydraulic Stand-by ejector ram will be supplied with each Brepak machine and will include one of each of the following part numbers:

333, 339, 3310, 3311, 3312, 3315, 3319, 3322, 3325, 3327, 3329, 3333, 3337, 3341, 3344, 3351 and 3355.

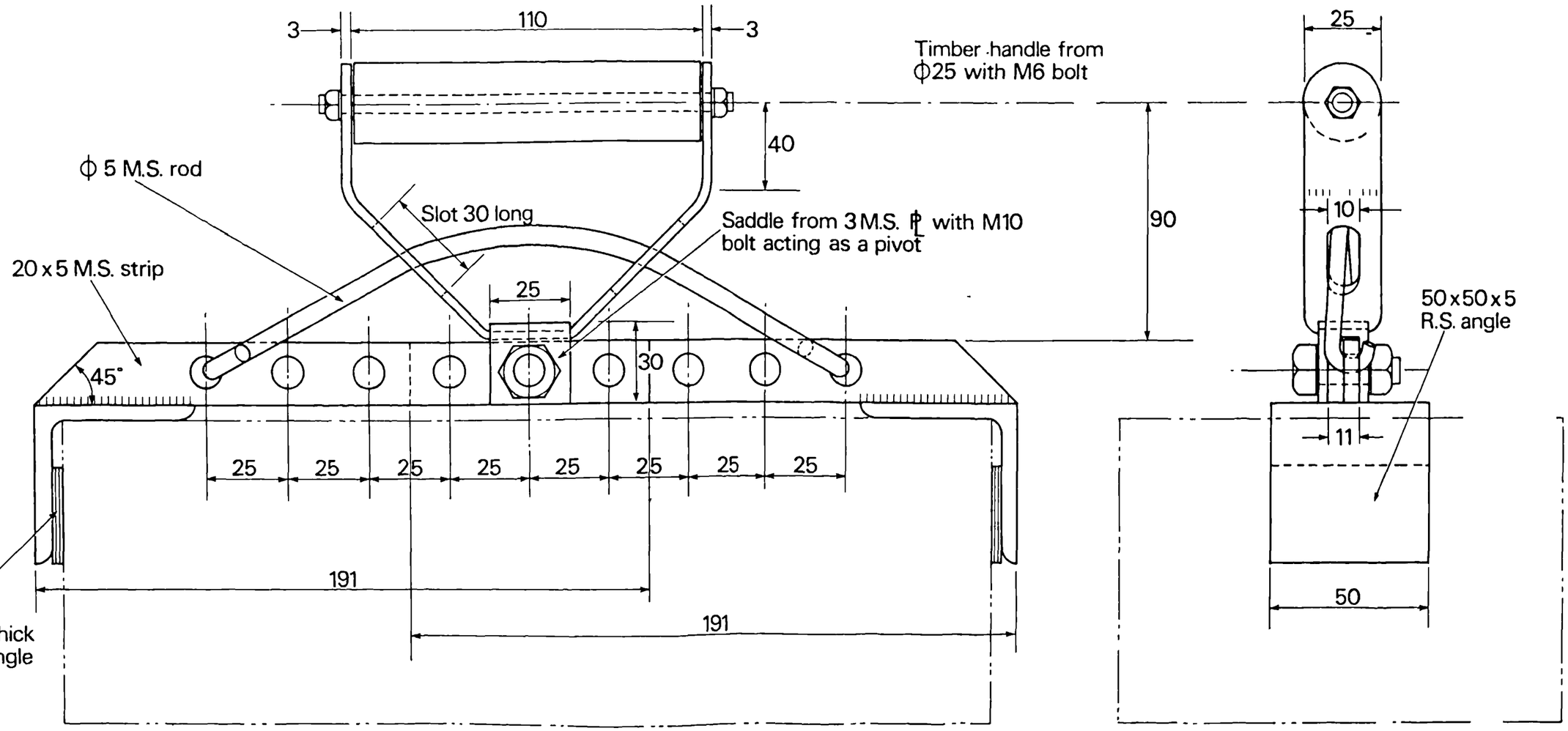
Figure 5 illustrates a soil block carrying clamp developed for the mason who will be constructing a wall.

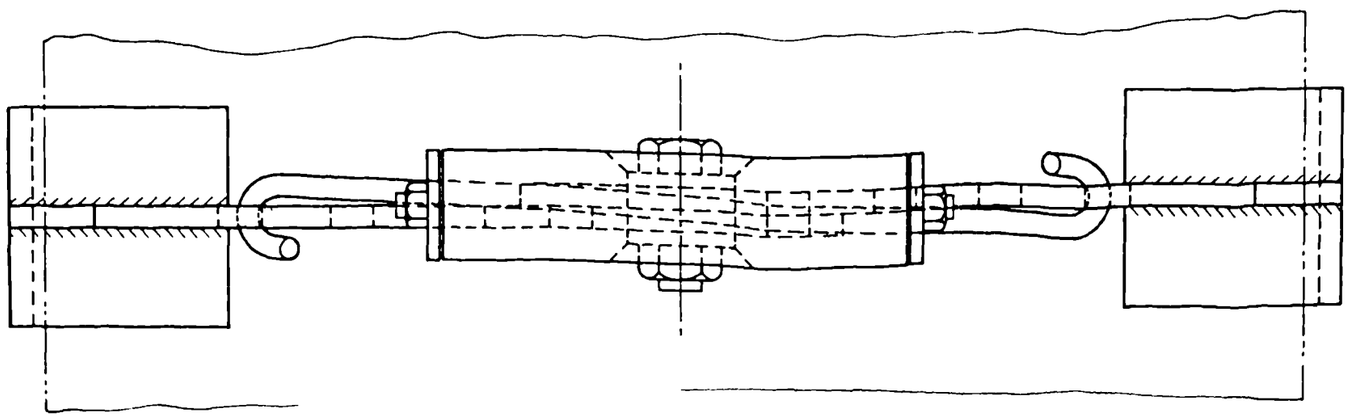
BREPAK | Soil block carrying clamp

Dims. in mm

Fig. 5.

A1





Soil building block 290 x 140 x 95

SECTION 2

Using the Brepak machine

Once a suitable soil has been selected - See Section 3 a - trial mixes can be used to optimise the mix constituents, for example proportions of selected stabiliser, and moisture content added to an amount of soil.

The same method of machine operation will apply whether it is a trial mix or a production run.

To ensure the production of uniform sized blocks each having the same density, special precautions must be taken to fill the mould box of the Brepak machine with the same quantity of mix. To obtain this result it is convenient to pre weigh each mix but if this is not possible a small wooden box or tin scoop to hold the correct amount could be employed.

Initial trials at BRS have indicated that 8.4 kg of mixed soil is sufficient for one pressing operation.

The sequence of operation will be as follows:-

(1) First swing the mould head plate item 3 to one side thus exposing the mould box cavity as show on plate

(2) Ensure that the stand-by ejector ram item 33 has been moved in its slides to its outermost position and that it is clear of the Brepak machine body as shown on plate

(3) The mould base plate should now be at the bottom of the mould box. At the first time of use the filling depth of the mould should be measured and this depth should be 154 mm.

(4) The valve screw item 3221 on the hydraulic hand pump should be unscrewed anticlockwise one revolution. See figure 3 for correct position of this screw.

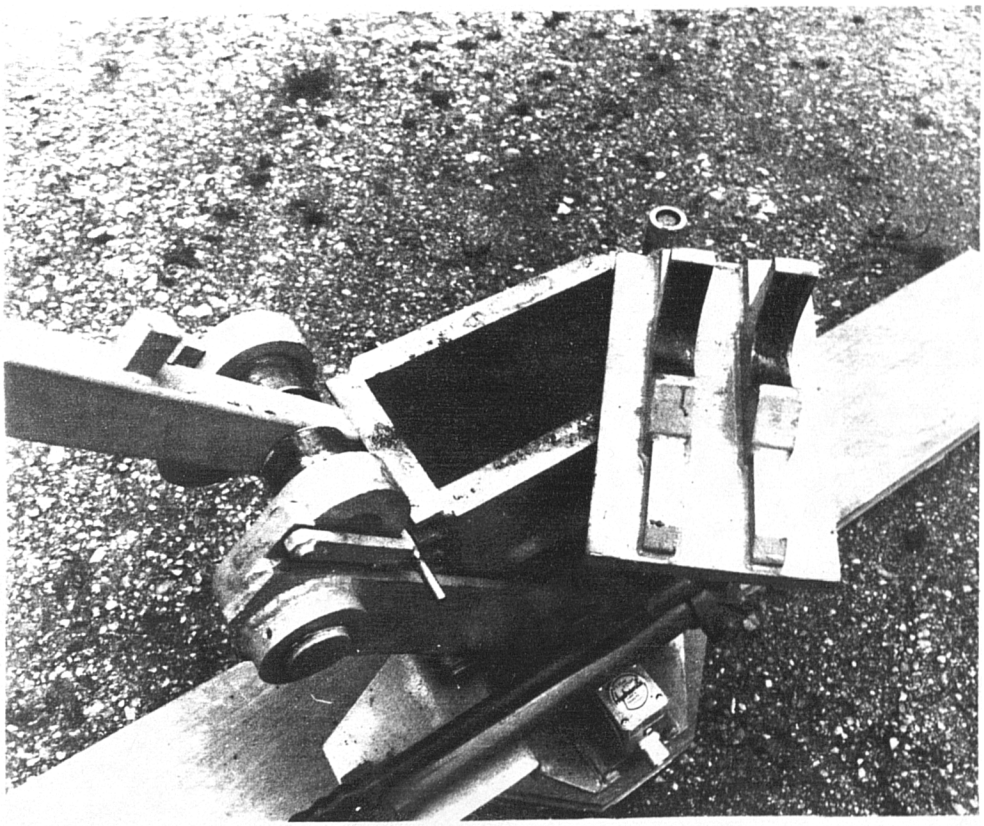
(5) Before filling the mould box with a soil mix the internal walls, base plate and head plate should be slightly moistened with a release oil. Kerosene or old engine oil could be used but may stain the produced block. This operation reduces the sticking of a pressed block to the internal faces of the mould.

(6) The mould box can now be filled with the mixed soil and stabiliser. During this operation ensure that the corners of the mould are filled and lightly compress the soil mix in the mould by hand. See plate illustrating this point.

If the correct quantity of mix has been prepared all the mix should be placed inside the mould box.

(7) The mould plate, item 3, should now be swung back into its original position covering the top of the mould box.

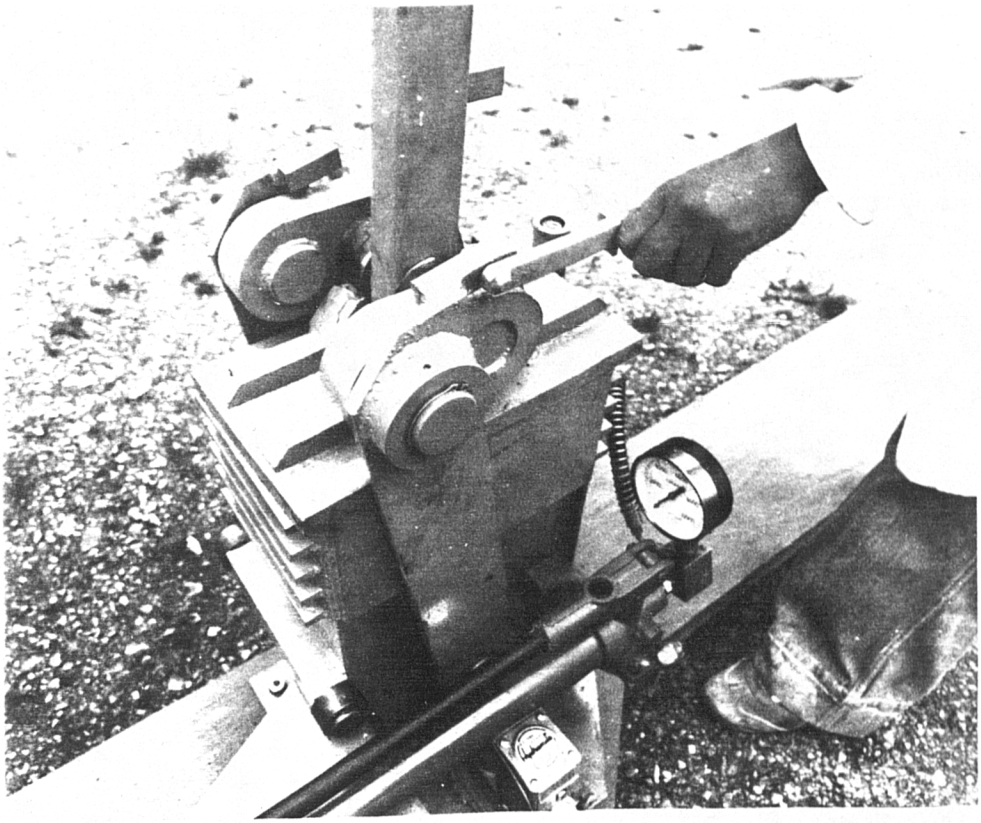
(8) To lock the lever arm joint, the lever locking toggle assembly, item 5, must be rotated about its pivot with its locking stub under the lever arm pivot. See plate



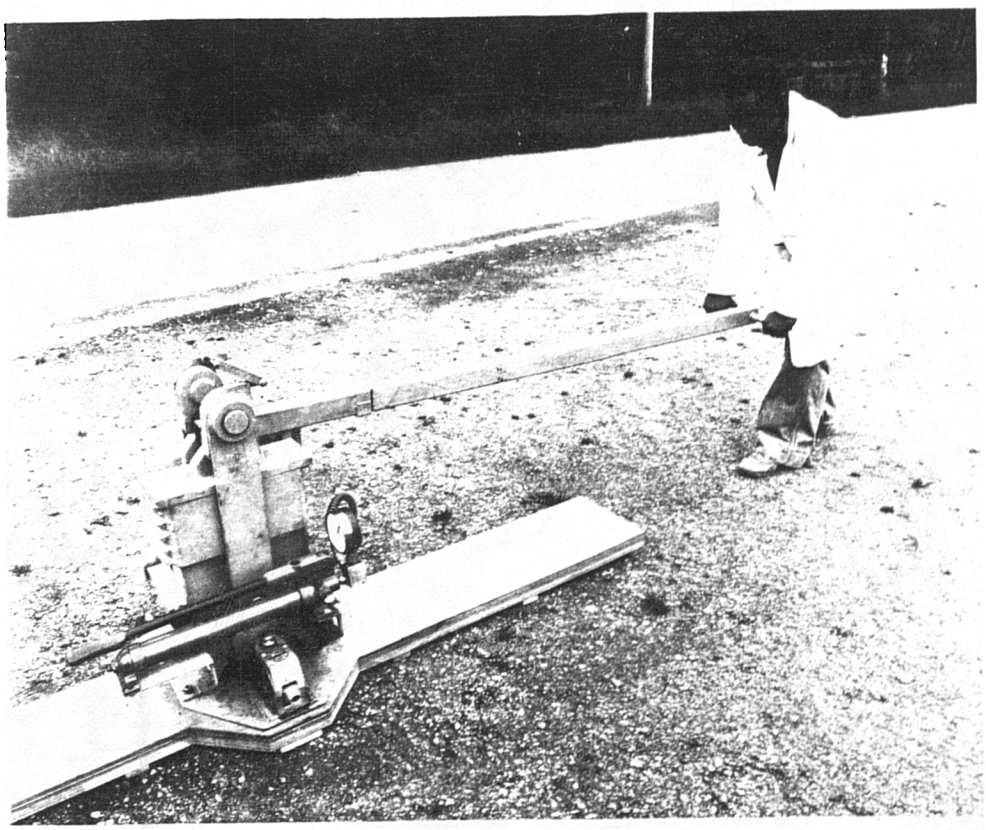
(9) Raise the extension lever arm, item 8, through a small arc until the two rollers, item 12, enter the half round guides fitted to the mould plate, item 3.

(10) Swing the lever locking toggle, item 5, back to its original position.

Plate



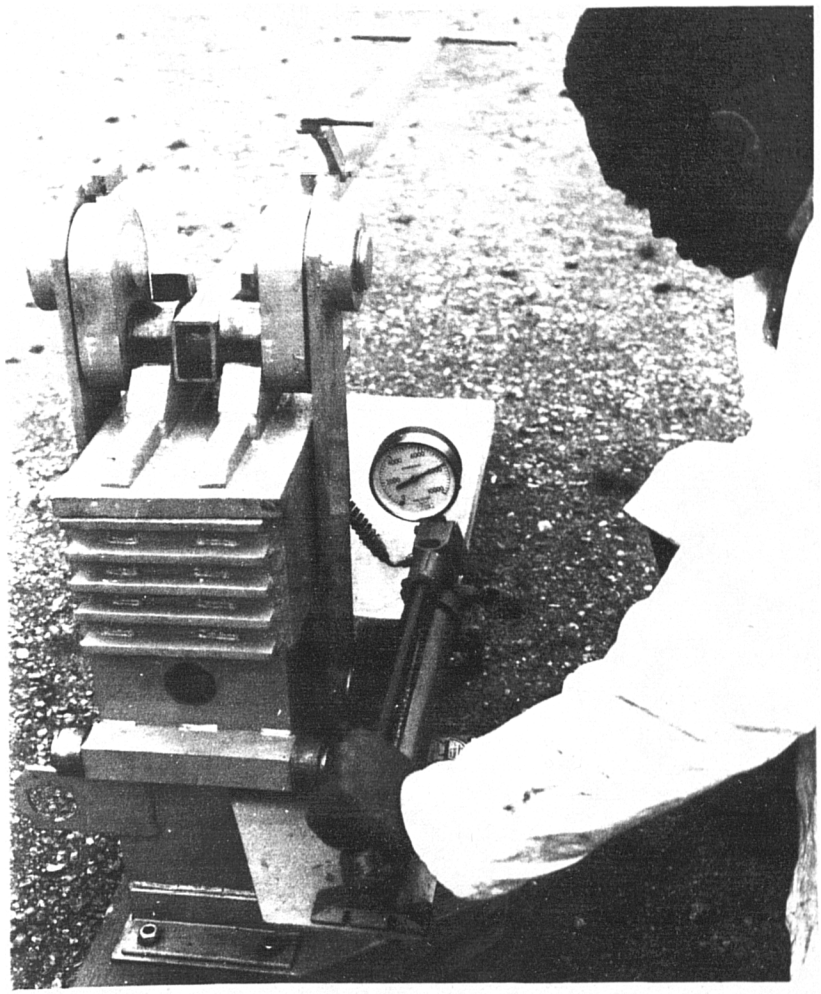
(11) The lever arm, item 8, can now be moved through an angle of about 90 degrees until a stop hits the mould head plate. The lever arm will then be in a horizontal positions. See plate



This particular operation moves the mould base plate about 40 mm and exerts a small compacting force onto the soil mix within the mould body.

(12) Valve screw, item 3221, must now be rotated clockwise until it is hand tight. Plate below shows this valve screw being tightened.

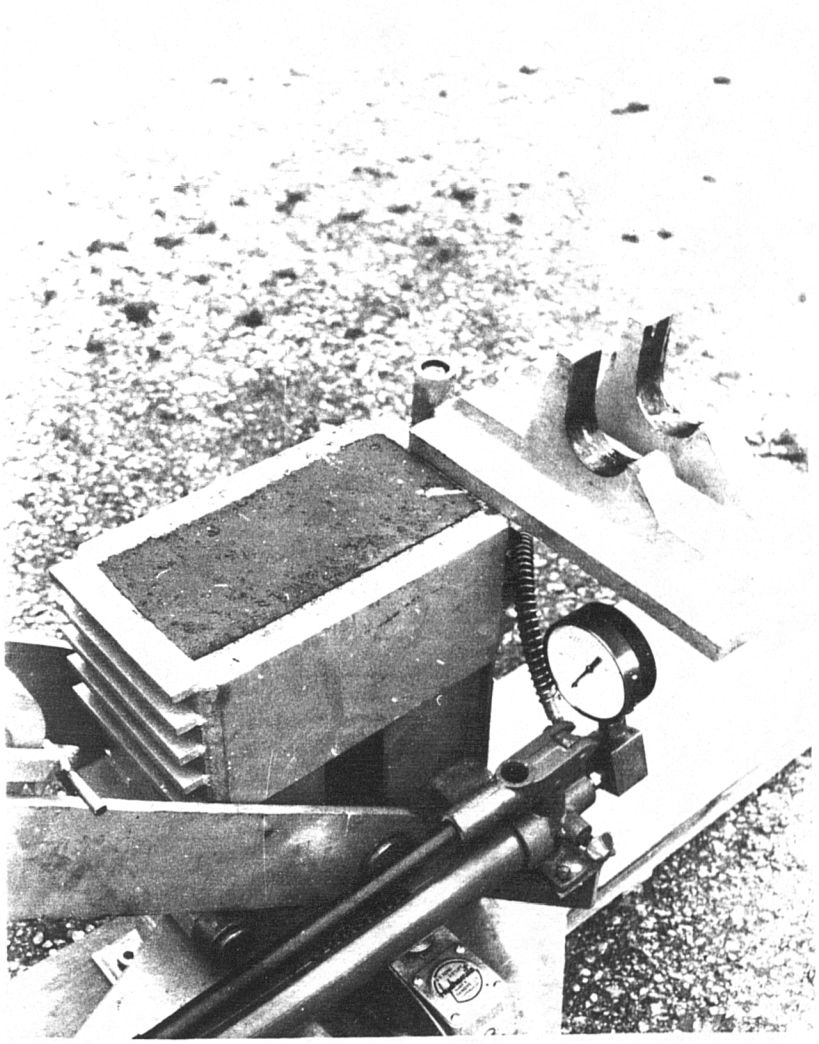
(13) The handle located on the top of the hydraulic hand pump. item 32, should now be pumped until the pointer on the pressure gauge, item 31, registers 8000 lb per sq inch as shown on plate



(14) To release the hydraulic pressure the valve screw, item 3221, should be rotated one revolution in an anticlockwise direction.

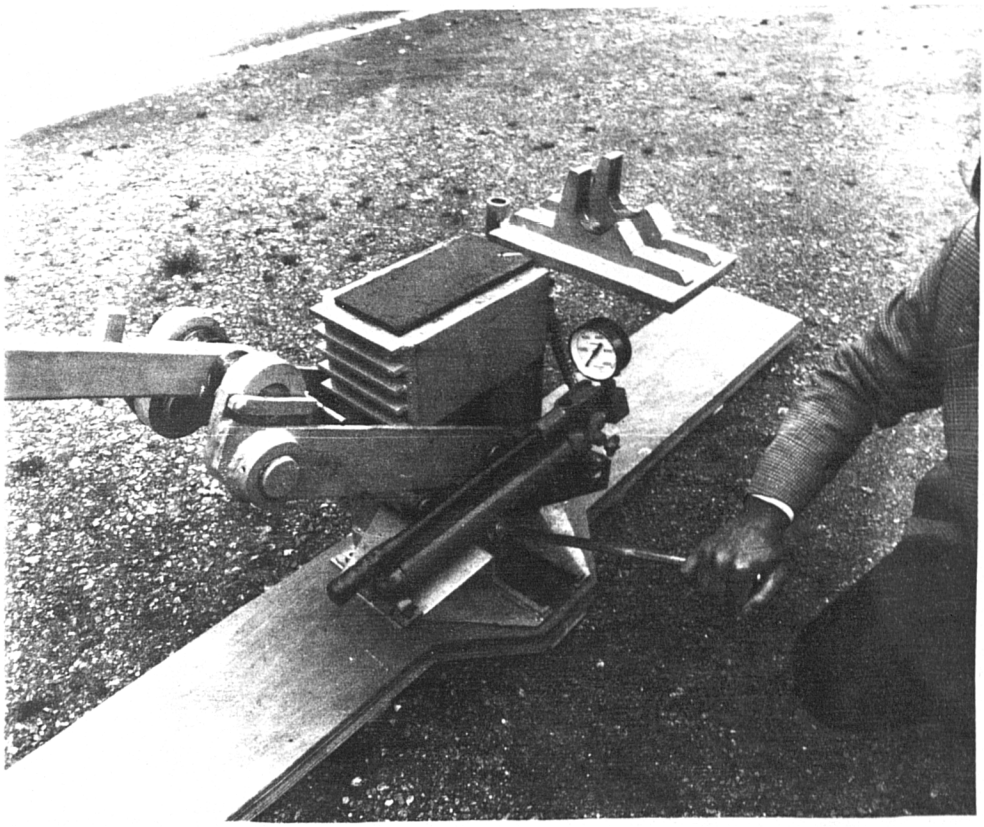
(15) The lever arm, item 8, should now be lifted from its horizontal position and swung over to its original start position.

(16) The mould head plate, item 3, can now be rotated sideways over the top of the pressure gauge to expose the top surface of the newly pressed soil block. As shown on plate



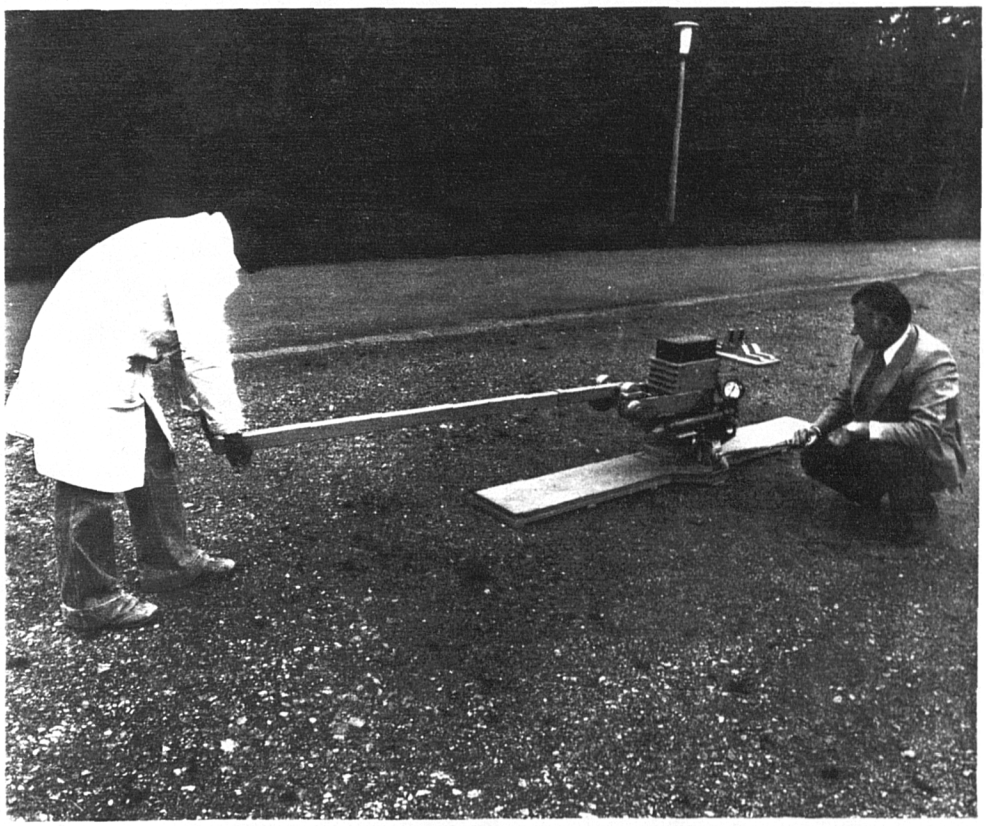
(17) By applying a downward force onto the lever arm, item 8, the newly pressed soil block will be ejected from the mould box; if however the block is not ejected the stand-by ejector ram should be used to start the ejection process.

(16) In ... ejector ram, item 33, should now be moved within its fixed slides into position under the centre of the main press body. Insert the stand-by ejector ram operating lever into the pump rocker socket hole and turn the lever clockwise to close the release valve and start pumping the handle. As shown on plate below.



This action will extend the ram and the newly pressed block will emerge from the mould. After about 10 mm movement of the block the extension lever arm can be pushed downwards and the newly pressed block will be ejected from the mould. See plate below.

(19) If the stand-by ejector ram has been used for block ejection, this unit has to be moved back to its original start position immediately after demould has occured. Its operating lever must be turned anti-clockwise to open the release valve and the hydraulic ram pushed back into the body. Plate shows the stand-by ejector ram being moved to its outermost position. The handle can now be removed for safety purposes.



(20) The soil block can now be lifted from the mould base plate and stored elsewhere for curing.

Section 3

Soil and Stabilizer Selection

Original section removed, please refer to chapters 5 and 6 of the thesis.

SECTION 4a - BREPAK FIELD TRIAL SPECIFICATION

Preamble

In order to prove the 'BREPAK' machine under actual site working conditions, it is proposed to carry out field tests at selected sites in tropical developing countries.

These trials will be undertaken in co-operation with 'counterpart organisations' (eg Building Research Institute, University, Public Works Dept) in the countries concerned. The exact nature of each trial will be subject to specific agreement between BRE and the counterpart organisation, and it is suggested that the following outline agreement should form the basis for discussion. Any other matters (not referred to below) that are agreed between the parties will be included in the final 'terms of reference'.

1. The Building Research Establishment undertakes to make available one or two BREPAK machines for site trials (together with spares) and to arrange for their shipment to the nearest United Kingdom Embassy or High Commission in the country concerned.

2. The counterpart organisation undertakes to collect the machine(s) from the UK representative, and to arrange transportation to the organisation's laboratories and field trial areas.

3. The counterpart organisation undertakes to nominate a 'project leader' who will be responsible for supervising day-to-day operations during the field trials, and for making regular reports of progress to the Building Research Establishment.

4. The Building Research Establishment undertakes to fund the travel and subsistence costs, salaries and necessary incidental expenses of Building Research Establishment staff for a minimum of two visits to the country concerned (at the commencement and at the conclusion of the trials).

5. The counterpart organisation undertakes to arrange local labour as required and to obtain all local materials needed for the trials. The cost of this labour and materials may be shared between the two organisations as agreed at an initial meeting.

6. Building Research Establishment undertakes to supervise the initial laboratory trials of the machine(s) and to provide initial training for operatives, in co-operation with the local 'project leader'.

7. The duration and nature of the trials will be agreed, at an initial meeting of representatives of Building Research Establishment and of the counterpart organisation. Suggested timings for a six month project are as follows:

(a) 2 months at the laboratories of the counterpart organisation in order to gain experience with the machine, to train operatives and to establish satisfactory mix designs. (A number of these trials at the laboratory should make use of soil obtained from the field trial sites.)

(b) 3 months field trials, producing stabilised soil building blocks, and carrying out strength tests on the blocks.

(c) 1 month to erect a demonstration house or health clinic, and to carry out the final assessment of the trials.

8. The counterpart organisation undertakes to record the following details of machine use, block production, and block performance, throughout the period of the field trials.

(a) Mix design, and mixing techniques.

(b) Analyses of soils and of stabilisers used.

(c) Number of operatives employed on mixing the soil, operating the press, and handling the finished blocks.

(d) Hours worked and output rate of blocks produced.

(e) Any operational difficulties encountered.

(f) Any breakdowns, and what remedial action taken.

(g) Any symptoms of machine fatigue (eg slackness, leaks).

(h) Any variations in dimensions of mould box.

(i) Extent of use of stand-by ejector ram.

(j) Methods of curing the blocks.

(k) Any problems with handling raw or cured blocks.

(l) Results of strength tests on a regular sample of blocks (the exact tests to be agreed with BRE).

(m) Costs, wage rates and all other figures needed for an economic assessment of the trials.

(n) Comparisons with performance of alternative blockmaking machines such as CINVA-RAM or ELLSON machine, if this is possible locally.

9. The counterpart organisation undertakes to carry out strength tests and durability tests on the finished blocks, using tests agreed in advance with Building Research Establishment.

10. Results of these trials will be the property jointly of Building Research Establishment and of the counterpart organisation. A joint report on the field trials will be prepared and may be published in accordance with normal scientific practice.

11. On conclusion of the field trials, an assessment will be made of the remedial value of the BREPAK machine(s), prior to a decision on the subsequent location of the machine(s).

12. That BRE will be responsible for the provision of spare parts for the hydraulic equipment in the event of a breakdown. Minor mechanical repairs to be the responsibility of the 'counterpart organisation'.

In the event of a major breakdown of the machine, BRE must be informed, so that a joint decision can be taken as to the best action to get the machine working again.

13. Any of the foregoing clauses may be amended by the mutual agreement of the parties concerned.

Appendix A2

Soil Engineering Terminology

See also section 5.5 which gives the standard definition of terms especially connected with soil stabilisation chemical definitions are given in Table 6.

Absorption	The taking up of water into a solid material. The quantity of water taken up by a stabilised soil block is a measure of the absorption of the block.
Adobe	Mud brick; hand made, dried in the sun, not fired.
Air void ratio	Ratio of volume of air voids to the total volume of the soil.
Alveole	A pit or small depression, as in the surface of a block.
Ambient	The surrounding natural environment, especially with reference to temperature, humidity and wind speed.
Arris	The edge where two external faces of a block meet.
Asphalt	Bituminous deposit.
Asphadobe	Adobe block stabilised with bitumen.
Auger	Tool for boring a hole in the ground, or for taking a sample of soil from the hole so made. It has a screw-like action when boring a hole.
Autoclave	The high pressure steam treatment given to some manufactured cementitious products to hasten the curing of the cement, and attain near maximum strength in a short time.
Bed face	The upper face of a block which is horizontal when laid in a wall.
Binder	The material which binds together separate particles; for example cement binds sand in a mortar, also clay helps to bind together the coarser particles in a soil.
Bitumen	Natural mineral substance, normally black, melted by heat and dissolvable in organic solvents.
Bituminous emulsion	Dispersion of fine particles of bitumen in water.

Block	A rectilinear building unit which usually requires two hands or a special tool to lift it; in contrast to a brick, which may be lifted with one hand. Specific definitions may be found elsewhere (See section 7.7.3).
Bond	The laying of blocks in a regular pattern, in a wall, to obtain good strength and coherence in the wall. The vertical joints between the blocks in one course are not generally in line with those in the courses above and below.
Brick	A rectilinear unit made from clay, concrete etc, with which walls may be built. Its size and weight are such that it can be lifted and laid with one hand. In plan view its length is usually twice its width (if thickness of one mortar joint is added to each direction), so that good bond may be obtained in walling.
Bulking of sand	A given weight of sand will vary in volume, dépending upon the water content of the sand.
Calcine	Heat to elevated temperature. For example limestone is heated to approximately 950 °C to convert it to quicklime.
Calcium silicate	A durable compound formed when lime reacts with silica, as for example during the autoclaving process in making calcium silicate bricks.
Clay	Natural minerals of many different types but consisting of very small particles less than 2 microns (0.002 mm). By reason of their small size, when moist, they have cohesive properties and this permits deformation of a large mass into the desired shape (eg into the shape of a block).
Cleft	Split, such as may be found in a block.
Cob	Wall construction method in which moist clayey soil (and straw) are layed in lumps one upon another in courses without shuttering. The surface is trimmed flat as building proceeds. Also referred to as clean, clob, clom or Swish (Ghana).
Cohesion	The ability of a material to stick together; typically demonstrated by a moist clay.
Compaction	The packing together of particles of soil, under pressure, so forming a more dense material.

Compaction pressure	The pressure applied, usually by a specially designed machine in order to bring soil particles closer and reduce volume of air voids between them.
Compressive strength	The amount of compression or squashing which a block can endure.
Course	A layer of blocks in a wall.
Crevice	A narrow crack.
Cure	Maintain environmental conditions so that a process may continue towards completion. Typically this would involve the maintenance of cement- or lime-containing materials such as stabilised soil blocks under moist conditions so the setting reactions of the cement may proceed or reactions may continue between lime and clay particles.
Dagga Plaster	A mixture of clayey soil, stabiliser and water used as an external rendering. It has medium resistance to rain.
Depreciation	Loss in value of equipment due to wear and tear over a period of time.
Dolomitic lime	Lime with approximately equal contents of calcium oxide and magnesia.
Down time	The amount of time during which equipment is not operating for a variety of reasons.
Dry compressive strength	The compressive strength of a block when it is tested in a dry condition.
Durability	The ability of a material to withstand conditions of service.
Fair-faced	Block walling of an acceptable standard of appearance and quality, without rendering or plastering.
Flash set	The premature setting of a cement, within a short period of time.
Formwork	Shuttering to contain soil etc during wall building.
Frog	Indentation formed during manufacture in one or sometimes both of the bed faces of a block.
Horse Power	A measure of power, as for example the power of an electric motor. One horse power in equivalent to 746 watts at unity power factor.

Hydraulic lime	A lime which sets under water.
Intermediate Technology	A level of technology requiring neither unnecessarily high capital investment, sophistication and back-up services nor on the other hand, an unnecessarily high degree of laborious manual work. It generally utilises fairly simple processes, and simple mechanical aids and it is largely synonymous with 'Appropriate Technology'.
Kabuk	Laterite adobe block in Sri Lanka.
Key	The roughness of a surface which helps mortar to adhere to it.
Kimberley brick	Sand moulded adobe brick.
Laterite	Highly weathered tropical soil, usually red in colour, sometimes containing hard nodules; rich in iron and aluminium oxides.
Lime	Two very different main forms of lime exist. Quicklime is calcium oxide, made by calcining limestone (or coral or shells). Slaked lime is calcium hydroxide, made by careful addition of water to quicklime. They have similar uses in construction and in soil stabilisation but slaked lime is safer to handle and use. (See also Hydraulic, Magnesian and Slake).
Linear shrinkage	The decrease in length of a moist soil specimen as it becomes dry.
Lintel	A beam over a door or window, capable of supporting the wall above.
Liquid Limit	The moisture content of a soil at which it ceases to be plastic and will just flow as a liquid.
Load bearing	A term applied either to the block or the wall built from blocks, indicating that it has to bear the load of all that is built above it; without the benefit of a steel, concrete or wooden frame to take the load.
Loam	Sandy clay, often suitable for moulding into blocks, and having a low shrinkage.
Macro cracks	Large cracks.
Magnesia	Magnesium oxide (MgO).

Magnesium lime	A lime containing 5 to 40 (approx) per cent of magnesia, derived from limestone containing magnesia.
Micro cracks	Very fine cracks.
Mortar	A mix which may contain cement, lime, sand or soil, with water, for laying blocks in; it fills spaces between blocks and helps bond them together.
Mould	The metallic or wooden box in which soil is shaped into blocks. The action of shaping in a mould.
Moulding pressure	The pressure applied to the damp soil to force it into the mould, and compact the soil particles close together, to reduce the air voids ratio.
Optimum moisture content (OMC)	The moisture content of a soil at which it can be compacted under pressure into the most dense block.
Ordinary Portland (OPC)	A cement made by heating clay and limestone in a kiln at 1350 °C (approximately), then grinding to powder the clinker which is formed. It is the material commonly termed 'cement', although this is not a precise description of the material.
Pallet	A small board or platform, usually of wood, upon which one or more blocks may be carried.
Parallelepiped	Solid shape, contained by parallelograms.
Parallelogram	Four-sided rectilinear figure having its opposite sides parallel.
Permeability	A measure of how permeable a solid is.
Perreable	Allowing air or water to pass through, although solid itself.
Perpends	The visible vertical mortar joints between blocks in a wall.
Pisé de terre	Earth rammed between wooden or other formwork to make a wall in situ.
Plaster	The coating of cement/sand, lime, gypsum etc applied to the block surfaces to give a smooth even finish to the wall. Sometimes the term plaster refers exclusively to finishes indoors, especially when gypsum plaster is used.
Plasticity Index	The difference between moisture contents at the Liquid limit and Plastic limit.

Plastic Limit	The moisture content of a soil at which it ceases to be plastic, and behaves more as a solid.
Pointing	A cement-based mortar trowelled into the raked-out joints between blocks after they have been laid.
Power Factor	Efficiency of an electrical circuit.
Pozzolan	A natural or artificial inorganic material which in a wet mix at ambient temperature will react with lime, and set like a cement. Pozzolans do not set by themselves.
Pulverised fuel ash	The fine particle-size ash remaining from burning of coal dust in some modern coal-fired electricity generating plants. It is a pozzolan, often referred to as PFA or flyash.
Pumice	Porous volcanic igneous rock.
Punner	Heavy weight on bottom end of pole, either for dropping on damp soil to compact it within formwork or for breaking up hard lumps or dry soil.
Rammed earth	Construction method for walls, in which earth is rammed down between formwork.
Release agent	A material applied to the surface of a mould to prevent the soil block sticking in the mould.
Render	Coating of durable cement/sand or other mix applied to wall surface.
Retard	Delay the time at which a cement or plaster starts to set.
Rice husk ash cement	A mixture of the ash of rice husks mixed with either lime or ordinary Portland cement.
Ring	The clear bell-like sound obtained when two well-compacted blocks are knocked against each other. Poorly-compacted blocks produce a dull sound.
Rugosity	Roughness of a surface.
Sand	The smaller portion of the coarse material in a soil. Particle sizes from 2 mm down to 0.06 mm (see Section 5.5.2).
Self help	Producing materials such as blocks, or constructing buildings, using one's own labour. This may be by individuals or within small community groups.

Sesquioxides	The oxides of iron Fe_2O_3 and aluminium Al_2O_3.
Shrinkage	Reduction in size of moist soil as it dries (See section 5.7.2).
Shuttering	Temporary structure, usually of wood, to retain soil as it is placed in situ to make a wall.
Silt	Particles of soil finer than sand, coarser than clay. Size 0.06 mm to 0.002 mm (Section section 5.5.2).
Skew	Not in a straight line.
Slake	Disintegrate by combination with water. In the case of a soil block this will constitute the block's failure if it takes place. In the case of quicklime, it is a necessary process in making hydrated lime (also known as slaked lime).
Slop moulding	Method of making adobe bricks or blocks.
Solar gain	Heating up of an object by the radiated heat of the sun.
Spall	To split and splinter, pieces of a block thus becoming detached from the surface.
Specific density.	The mass of a unit volume of material (measured for example in kg/m^3).
Stabilise	Improve properties of a soil by addition of other materials. Commonly this improvement is obtained by making the soil more resistant to slaking and erosion by water.
Strain	Amount by which a body subjected to stress is deformed by that stress.
Strata	Layers of soil, sand etc.
Stress	Amount of a force applied to a body.
Surkhi	Clay fired to temperature insufficient to develop full ceramic properties yet producing changes in the clay which increase its pozzolanicity. Surkhi is a traditional building material in India; the powdered material is used mixed with lime as a cement in mortar etc.
Swish	Mud walling. Swishcrete is mud with some cement added, for walling.

Temper	Leave clay soil in wet condition overnight or longer, to enable moisture to permeate and improve plasticity.
Thermal mass	The property of a structure enabling it to store heat. Heavy building materials have greater thermal mass than lightweight ones.
Tonne	1000 kg.
Tufla	Lateritic soil in Egypt.
Units conversion	1 N/mm^2 = 1 MN/M^2 = 1 MPa = 145 lbs/in^2 $\simeq$ 10 kg/cm^2
Volume shrinkage	Decrease in volume of a moist soil specimen as it dries out.
Wattle and daub	A woven framework of branches and sticks which is smeared and interfilled with a wetted soil, in order to form a wall.
Wet compressive	The compressive strength of a material immediately after it has been soaked in clean cold water for 24 hours.
Win	Obtain soil from the ground.

APPENDIX A3

Manufacturers of Block making equipment.

AUSTRALIA

Australian Adobe Industries
109 Yarra Street
Geelong 3220
- Earth stabilised brick machinery

Ramtec Pty Ltd
105 Forrest Street
Colteshoe
West Australia 6011
- Adobe equipment

BELGIUM

Fernand Platbrood
20 rue de la Rieze
B 6404 Cul-des-Sarts
Couvin
- Terstaram machine
- Clay crushing and sieving
Reference 7-2-15

Ceratec
228 rue du Touquet
7792 Ploegsteert
- Cereman Terstaram Machine with automatic block ejection. Reference 7-2-16

GVD Heuvelstraat 131
3140 Ramsel - Herselt
- UNATA Machine
(Modified CINVA-Ram)
Reference 7-2-14

J Riffon
Rue J Wilgot 6
5220 Andenne
- Riffon impact machine
Reference 7-2-20

BRAZIL

Tecmor Equipamentos, Mecanicos Ltda
Rua da Imprensa
331 - Sao Carlos
Sao Paulo
- Tecmor Machine
- Mixing and sieving
Reference 7-2-31

Industria e Comercio
de Maquinas
- Cinva Ram machine
- Reference 7-2-3

Torsa Maguinas E Equipamentos Ltda
Sao Paulo
- Supertor Machine
Reference 7-2-25

CAMEROON

Ceneema
BP 140
Yaoundé
- Ceneema Machine
(Modified Cinva-Ram)
Reference 7-2-7

COLOMBIA

Metalibec Ltda
Apartado Aereo 11798
Bogota
- Cinva Ram Machine
Reference 7-2-3

S.E.N.A
Direccion General
Careera 31 No 14-20
Apartado Aereo 53329
Bogota

- Maquina Machine

DENMARK

Drostholm Products
A/S dk - 2950 Vedbaek
Nr Copenhagen

- Latorex plant and system equipment Reference 7-2-27

FRANCE

Souen
Centre de Terre
Lavalette
31590 Verfeil

- Modified Cinva Ram GE050 TOB System

Saret - BP 102
Route De Carpentras
84130 Le Pontet

- PPB Saret - Teroc Machine
- Mixing and sieving

I'Unité Pédagogique
d'Architecture de Grenoble
Craterre
Les Rivaux, Haut-Brié
38320 Eybens

- La Palafitte Machine (Modified Tek Bloc Machine)

Hallumeca
37 rue des Ecoles
59780 Baisieux

- Rotary table pressing machine - Unipress

C.T.B.I
Zone Industrielle
51140 Muizon

- CTBI Block Press Machine

RGF Terre 2000
Systéme Constructif
BP 98
13160 Chateaurenard

- Terre 2000 Hydraulic Press
- Mixing

Altech
Rue des Cordeliers
05200 Embrun

- Pact 500 block Press (Modified Winget Machine)

GERMANY

Ausbildungsverbund
Metall (AVM)
Bernhard - Adelung Strasse 42
6090 Russelsheim

- AVM Block Press (Modified Ceneema Machine) Reference 7-2-8

Lescha Maschinenfabrik
Ulmer Strasse 249/251
8900 Augsburg

- Lescha SBM Press improved version of CLU 2000 machine

GHANA

Dept of Housing and Planning Research
Faculty of Architecture
University of Science and Technology
Kumasi
- Tek-Block Machine
Reference 7-2-4

GUATEMALA

Centro de Estudios Mesoamericanos sobre Technologia Apropiada (C.E.M.A.T)
Apartado 1160
Guatemala City
- CETA Machine
(Modified CINVA-Ram to produce hollow blocks)
Reference 7-2-5

INDIA

ASTRA
Indian Institute of Technology
Bangalore 560012
- Astram Machine
Reference 7-2-11

Joshi Industries
Gayatri
Dr Yagnik Road
Jagnath Plot
Rajkot
Gujarat State
- Ellson-Blockmaster Machine
Reference 7-2-10

ITALY

Giza Spa
Sede Amministrativa
42011 Bagnolo in Piano
Reggio Emilia
- Factory installation for production of soil blocks
Reference 7-2-30

IVORY COAST

Abidjan Industrie
Boite Postal 343
45 Rue P et M Curie
Zone 4C
Abidjan
- ABI Block Press
(Modified Cinva-Ram Machine)

KENYA

Christian Industrial Training Centre (C.I.T.C)
Meru Road
Pumwani
PO Box 729935
Nairobi
- Clay Crushing Machine

Western College of Arts and Applied Sciences (W.E.C.O)
PO Box 190
Kakamega
- WECO/Cinva Ram Machine

Kenya Industrial Estates Ltd
Rural Industrial Development Centre
PO Box 275
Machakos

- Modified CINVA-RAM Machine
  Reference 7-2-6

SIHRA Engineering
Lunga Lunga Road
PO Box 16074
Industrial Area
Nairobi

- Bonner Block Making Machine

NETHERLANDS

Centre for Appropriate Technology
C.A.T
Delft University of Technology
PO Box 5048
2600 GA Delft

- Prototype Mechanised Block Press
  (Modified form of Winget Machine)

NEW ZEALAND

Frazer Engineering Co
116 Tuam Street
Christchurch

- CINVA-RAM Machine
  Reference 7-2-3

PARAGUAY

C.T.A
Facultad de Ciencias y Tecnologia
Universidad Catolica
Asuncion

- CTA Block Press
  (Modified Cinva-Ram Machine producing 3 blocks per cycle)
  Reference 7-2-18

PERU

Craterre Perou
Apartado Postal 399
Huancayou

- Craterre Perou Block Press (Modified Ellson Machine)
- Handling equipment

SOUTH AFRICA

Jesson Industries
PO Box 664
Port Elizabeth 6000

- Jesson Block Press
  (Modified Cinva-Ram Machine with filling attachments)
  Reference 7-2-17

SWITZERLAND

Meili Engineering Co
Gewerbe Center Rothaus
8635 Durnten

- Meili Mechanpress Machine
  Reference 7-2-12
  and 7-2-22

Maro Enterprise
Route de Suisse 95B
CH - 1290 Versoix

- Maro Block press
  (Modified Cinva-Ram Machine)
  Reference 7-2-13

Consolid AG
Aechelistrasse 18
CH 9435 Heerbrugg SG

- CLU 3000 Soil Block Plant
  Reference 7-2-23

H D Sulzer
Institut fur Hochbautechnik
ETH Honggerberg
8093 Zurich

- Saturnia soil block press
  (Range of modified Cinva-Ram machines)
  Reference 7-2-19

Dieter Schmidheini
Weinbergstr 29
9436 Balgach

- Ecobrick 1000
  (Modified CLU 3000 Machine)
  Reference 7-2-24

THAILAND

Southern Institute for Skill Development (S.I.S.D)
Thai-German Project
PO Box 5, Kao Seng
Songkhla 90001

- Soil Block Pressure
  (Modified Cinva-Ram Machine)
  Reference 7-2-9

Asian Institute of Technology
Human Settlements Development Division
GPO Box 2754
Bangkok 10501

- Modified Cinva-Ram producing interlocking blocks

UNITED KINGDOM

Multibloc Ltd
Blackswarth Road
Bristol BS5 8AX

- Multibloc Brepak Machine
  chapters 8 and 9

Winget Limited
Rochester
Kent ME2 4AA

- Rotary table pressing Machine
  Reference 7-2-2

Zora International Company Ltd
112 Power Road
London W4 5PY

- Zora Machine
  Reference 7-2-26

Intermediate Technology Workshops
JPM Parry and Associates Ltd
Overend Road
Cradley Heath

- Clay Crushing, sieving and handling equipment

Baird and Tatlock Ltd
Freshwater Road
Chadwell Heath - Romford
Essex

- General laboratory equipment

A Groth
Department of Engineering
University of Warwick
Warickshire

- Ranko impact machine
  Reference 7-2-21

Leonard Farnell and Co Ltd
Station Road
North Mimms
Hatfield
Herts AL9 7SR
- Soil testing equipment and earth augers

G Bopp and Co Ltd
102 Church Lane
East Finchley
- Sieve meshes

ELE International Ltd
Materials Testing Division
Eastman Way
Hemel Hempstead
Herts HP2 7HB
- General laboratory soil testing and compression testing equipment

Avery Denison Ltd
Moor Road
Leeds LS10 2DE
- Compression testing equipment

United Builders Merchants Ltd
Overseas Division
PO Box 78
Avon Works
Winterstoke Road
Bristol BS99 7EW
- General Builders Merchants

UNITED STATES OF AMERICA

Earth Technology Inc
175 Drenen Road
Orlando
Florida 32806
- Terrablock system
Reference 7-2-29

Bellow's Valvair International
200 W Exchange Street
Akron
Ohio 44309
- Cinva-Ram Machine
Reference 7-2-3

Ultrabloc
PO Box 1363
Corrales, NM 87048
- Ultrablock Impact Hydraulic Block Press
Reference 7-2-28

Hans Sumpf Adobe Co
Fresno, California
Via IFEC
3282 Theresa Lane
Lafayette
California 94549
- Hands Sumpf Adobe Block Machine

Design Services
Box 2334
Ruidoso
New Mexico 88345
- Adobemaster hand powered adobe maker

Hugo HOLEBEKE
186 DREEF
B. 1900 OVERIJSE
BELGIQUE

XI TECHNICAL STANDARDS FOR LIME STABILIZED COMPRESSED SOIL BLOCKS

The blocks produced up till now are limited to parallelepipeds with the following maximal dimensions :

length : 40 cm (exceptionally 50)
width : 20 cm (exceptionally 30)
heigth : 20 cm

The most current block-types have the following mold dimensions :

length : 29.50 cm
width : 14.00 cm
heigth : 8.80 cm

A NOMINAL MODULATED DIMENSIONS

L = 29.50 cm
W = 14.00 cm
H = 8.80 cm (see file XI-1)

B DIMENSIONAL TOLERANCES

L = + 1, - 3 mm
W = + 1, - 2 mm
H = + 2, - 1 mm

C SURFACE SMOOTHNESS

Sides : + 1, - 1 mm
Compression surfaces : + 3, - 1 mm

D EDGE SMOOTHNESS

Maximal sweep : 2 mm
A roughness is tolerated as long as it is due to demolding and a very careful manipulation

E CAVERNS, ALVEOLES, HOLES

Tolerated on the same terms as smoothness
Exposed surface : 1 %
Non exposed surface : 15 %

F SPECIFIC WEIGHT

Dry	Minimum	1 700 kg/m³ or 6.178 kg per block
	Recommended	2 000 kg/m³ or 7.268 kg per block
Freshly molded	Minimum	1 870 kg/m³ or 6.796 kg per block
	Recommended	2 200 kg/m³ or 7.995 kg per block

G NOMINAL VOLUME

3 634.40 cm³
3.634 liters
0.003634 m³

H SURFACES

Long side	259.60 cm²
Short side	112.00 cm²
Compaction surface	413.00 cm²
Sides	743.20 cm²
Compaction surfaces	826.00 cm²
Total surface	1 367.60 cm²

I SKEWNESS OF SURFACES

- The exterior faces may be slightly oblique if the prescriptions of dimensions, tolerances and forms are respected.
- The interior surfaces of hollows blocks are preferably oblique.
- The interior spaces of hollow or alveolar blocks may not have sharp edges.

J RUGOSITY OF EXTERIOR FACES

- The exterior faces of the blocks to be coated with mortar or renderings are preferably rugous.
- The exterior faces of the blocks that do not receive a coating must be smooth.

K CLEFTS - SCALING

Are not tolerated on any surface.

L GAPS, CRACKS, CREVICES

- Microcracks : - tolerated on all surfaces.
- Macrocracks : - only on non-exposed surfaces;
  - width and depth may not exceed 1 mm;
  - length may not exceed 10 mm and the total number may not exceed the average value of one per 10 cm rib length, that is 21.

M CHIPPED EDGES

Width and depth may not exceed 10 mm.

N THICKNESS OF ALVEOLAR OR HOLLOW BLOCKS

All faces	: 35 mm for low pressure (20 daN/cm²)
	: 20 mm for very high pressure (100 daN/cm²)
Max. deviation	: unlimited
Min. deviation	: 0 mm

O MINIMAL PROPORTION OF THE LOAD BEARING SURFACE TO THE NOMINAL SURFACE OF HOLLOW BLOCKS

Superior or equal to 0.6 for low pressure.
Superior or equal to 0.4 for high pressure.

P SCRATCHES

Max. depth	10 mm
Max. width	15 mm
Max. surface	100 cm²

Minimal distance between the edge and a deep scratch : 35 mm

Q SPECIAL BLOCKS

Blocks with differential stabilization :
One or more surfaces or parts are more stabilized than the rest of the block.

Blocks with built-in facing tile :
One or more surfaces are decorated with a special facing tile.

Blocks with treated surface :
One or more surfaces are specially treated with :

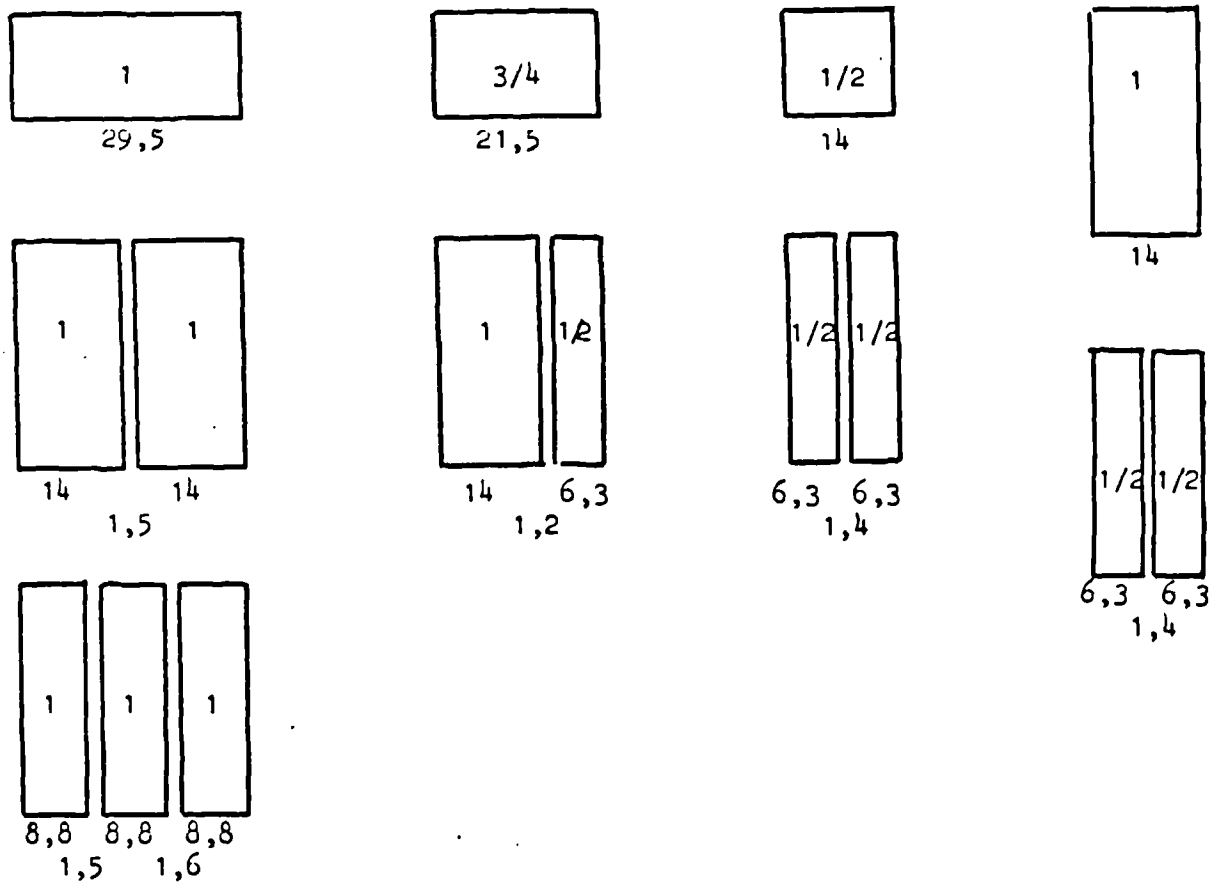
- graphic elements;
- esthetic treatment;
- chemical treatment.

R RESISTANCE

It is generally accepted for stabilized products that :
- the compression resistance (dry) after 28 days is minimum 21 daN/cm²
- the compression resistance (wet) after 28 days and saturated humidification is minimum 10 daN/cm².

TECHNICAL SPECIFICATION	BLOCKS

	THEORETICAL			PRACTICAL		
	H	L	W	H	L	W
1	8,80	29,50	14,00	9	29,5	14
3/4	8,80	21,50	14,00	9	21,5	14
1/2	8,60	29,50	6,30	9	29,5	6,5
1/2	8,80	14,00	14,00	9	14	14



Ref. : Dimensional variations are absorbed in mortar joints.

bre Research for industry

BREPAK block making machine for use in developing countries

A new type of manually operated block making machine has been developed by the Overseas Division of the Building Research Establishment, following research on the stabilisation of clay soils. This machine produces high quality stabilised soil blocks which can be used for building construction in developing countries.

An unstabilised clay soil will swell on taking in small quantities of moisture and shrink on drying. This movement gives rise to severe cracking and often leads to difficulties when soil is used in building construction, to the extent that the soil often disintegrates when subjected to large quantities of water. The addition of a binding agent or stabiliser will prevent this moisture movement and increase the strength and cohesion of the soil. Stabilised soil, if prepared correctly, can be an extremely cheap and useful building material.

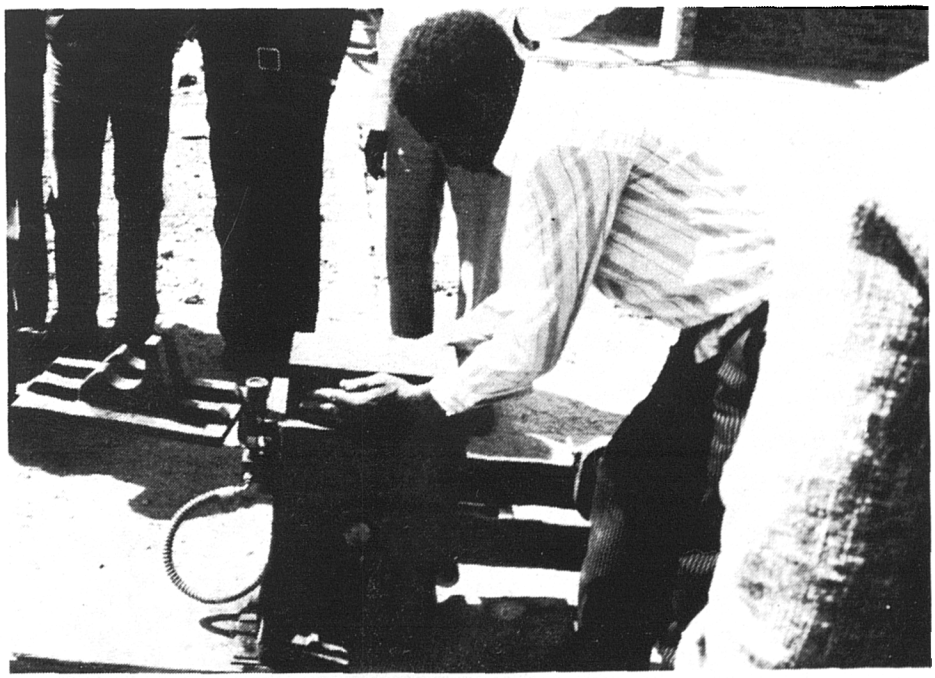
Clay soils may be stabilised with cement or with other binding agents. Research at BRE has demonstrated the improvements in strength and durability that can be achieved when hydrated lime is used to stabilise tropical clay soils. This improved performance has been achieved by compacting a stabilised soil mix at a pressure of about 10 MN/m².

The BREPAK block making machine makes use of a simple hydraulic mechanism added to the final soil compaction operation to obtain a compaction pressure of 10 MN/m². The machine has a tare weight of 150 Kg and produces stabilised soil blocks 290 × 140 × 100 mm.

Six people are needed for an efficient production team, two to dig and prepare the soil, two to prepare the mix by hand and two to operate the machine, producing up to 300 high quality blocks each day.

To prove the BREPAK block making machine, it was decided to conduct on-site field trials overseas. The first field trial of the prototype machine formed part of a collaborative research programme between the Housing and Development Unit (HRDU) of the University of Nairobi and BRE Overseas Division.

During preliminary laboratory trials at the University of Nairobi, the HRDU staff were instructed how to use the BREPAK machine. In Nairobi lime is more



A stabilised soil block being lifted from the BREPAK machine

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Buckinghamshire HP17 9PX
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Building Research Establishment
Scottish Laboratory
Kelvin Road East Kilbride
Glasgow G75 8RZ
Telephone East Kilbride 33001
Telex 778610

expensive than cement, so 4 per cent cement by weight was used as a soil stabiliser. Good quality blocks were produced whose minimum wet compressive strength exceeded 3 MN/m². Some of these blocks were tested by completely immersing them in water and after a period of one month showed no signs of deterioration.

The BREPAK block making machine was then used by a community labour team on a site at Kabiro within the district of Kawangware, Nairobi, to produce the cement stabilised soil blocks required for a 50 m² medical clinic.

With the BREPAK machine and with careful selection of materials, stabilised soil blocks can be produced at low cost and would have the same physical properties of more expensive walling materials. In fact, built as exposed blockwork, they would have the same attractive appearance as the more expensive fired clay bricks.

The BREPAK block making machine has yet to be fully evaluated on site and further trials will be conducted during 1982 in numerous third world countries so that stabilisers and soils can be assessed.

With the completion of the first successful overseas field trial it is hoped that BREPAK machines will soon be manufactured under licence and will be available by export from the United Kingdom. Enquiries should in the first place be directed to D J T Webb, Overseas Division, Building Research Establishment, Garston, Watford WD2 7JR.

The medical clinic partly constructed in Nairobi. This clinic was constructed at a cost of £31 per m² which compares favourably with a structure built with concrete blocks at a cost of £65 per m²

The completed walls of the clinic with the roof partly completed

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DETAILS OF SOILS USED DURING THIS STUDY

N/A - NOT AVAILABLE

Origin of soil / Details	BRS House	JAMAICA			SUDAN			KENYA		KENYA		EGYPT	TANZANIA		ST VINCENT	YEMEN ARAB REP		BOTSWANA			GAMBIA	BANGLA-DESH
		Red Bauxite	Knollis Clay	Denbeigh Clay	Fetehab	EL Hizam	Deroshab	Kawangre Murram	Red Coffee	Makunda	Rurhbwa	Shale Clay	Red	Yellow	Clay	Dhamer	Alulayl	Lobatse A	Lobatse E	Jwaneng	Kotu	
Chemical Analysis % Al_2O_3	N/A	48.89	18.6	17.2	9.51	9.81	4.49	11.72	28.84	12.3	10.76	18.3	18.4	14.7	17.1	14.76	11.18	14.27	10.58	1.87	13.0	16.9
$Si\ O_2$		3.82	57.4	62.5	58.12	61.91	79.95	39.15	39.00	67.93	74.99	51.3	59.3	74.2	48.8	51.10	48.40	69.65	75.77	75.0	73.1	66.7
P_2O_5		Nil	0.05	<0.01	0.16	0.13	0.02	0.07	0.08	0.15	0.07	0.15	0.02	Nil	0.13	0.43	0.31	0.01	0.03	0.07	0.03	0.06
$S\ O_3$		Nil	<0.01	<0.01	Nil	Nil	0.32	Nil	Nil	0.02	<0.01	0.83	0.12	0.04	0.04	0.01	0.09	<0.01	<0.01	0.04	<0.01	<0.01
K_2O		0.12	1.27	0.25	0.52	0.78	0.23	1.10	0.52	2.05	2.55	1.17	0.60	1.58	0.45	2.18	1.81	0.84	2.30	0.38	0.14	1.66
Ca O		2.41	1.06	0.35	6.67	6.40	6.57	0.89	0.13	2.58	1.12	2.59	0.20	0.54	8.71	5.59	11.32	0.08	0.18	7.42	0.12	0.17
TiO_2		1.38	0.73	0.93	1.53	1.02	0.52	1.06	1.40	0.58	0.56	0.98	0.76	0.24	0.93	0.86	1.05	0.45	0.56	0.14	1.04	0.85
Mn_2O_3		Nil	0.15	0.04	0.30	0.31	0.13	2.38	0.44	0.09	0.15	0.05	0.13	0.06	0.15	0.13	0.15	1.71	0.13	Nil	Nil	0.02
Fe_2O_3		15.73	7.73	8.39	7.94	5.86	2.54	30.71	14.43	3.85	3.14	8.19	9.78	1.86	9.41	7.34	6.17	6.09	4.42	0.94	7.26	6.29
Na_2O		0.78	1.82	1.13	0.06	0.68	0.51	0.86	0.14	1.26	1.55	3.32	0.13	4.37	1.30	1.12	1.90	0.03	0.19	0.08	0.04	0.16
Mg O		0.06	1.22	0.55	3.12	1.95	0.89	0.14	0.20	1.06	0.53	1.79	0.29	0.40	5.69	3.40	3.51	0.30	0.37	1.92	0.09	0.51
Loss of Ignition		26.45	8.02	9.40	10.52	8.90	5.43	9.10	12.94	6.53	3.70	11.66	9.80	2.64	7.37	12.19	14.37	0.51	1.11	11.3	6.03	7.65
$Al_2O_3+SiO_2+Fe_2O_3$	N/A	68.44	83.73	88.09	75.57	77.58	86.98	81.58	82.27	84.08	88.89	77.79	87.48	90.76	75.31	73.2	65.75	90.01	90.77	77.81	83.36	69.89
K_2O+Na_2O	N/A	0.9	3.09	1.38	0.58	1.46	0.74	1.96	0.66	3.31	4.10	4.49	0.73	1.98	1.34	3.3	3.71	0.87	2.49	0.46	0.18	1.82
Sieve Analysis																						
Retained on 6.3mm Fine Gravel	0	0	0	0.5	0.8	9.6	0	38.41	0.76	2.2	1.0	<0.1	Nil	1.1	12.48	0.15	10.93	27.9	1.7	5.04	15.04	0.24
Retained on 600µm Coarse Sand	2.0	12.0	1.6	2.8	5.4	10.0	14.2	26.91	20.11	18.2	15.6	0.6	0.6	7.6	21.34	0.41	9.69	11.1	10.3	5.24	9.03	1.47
Retained on 200µm Medium Sand	6.0	26.0	6.6	6.6	13.2	25.4	31.0	11.70	29.81	16.1	19.2	3.6	21.4	23.5	17.99	1.28	9.34	6.8	15.3	17.17	10.41	6.27
Retained on 75µm Fine Sand	54.0	60.0	10.8	14.0	30.1	42.5	56.4	7.36	26.53	15.8	23.0	11.7	41.9	35.6	11.50	1.96	12.10	8.0	21.7	41.6	20.31	8.75
Passing 75 µm Silt & Clay	38.0	28.0	81.0	76.1	43.1	57.8	31.6	15.62	22.79	47.7	41.2	84.1	36.1	32.2	36.69	96.20	57.94	46.2	51.0	30.95	45.21	83.27
% Linear Shrinkage	N/A	N/A	11.0	4.6	12.2	11.3	7.9	3.1	7.4	N/A	N/A	N/A	8.2	7.6	9.1	8.7	N/A	5.1	6.8	4.8	3.0	13.0
Silica-Sequioxide Ratio $\left(\frac{Si\ O_2}{Al_2O_3+Fe_2O_3}\right)$	N/A	0.06	2.18	2.44	3.33	3.95	11.37	0.92	0.88	4.21	5.39	1.94	2.18	4.48	1.84	2.31	2.79	3.42	5.19	26.7	3.61	2.88
Stabiliser Sand/Soil	-	Soil	1.1	1.1	Soil	Soil	Soil	Soil	Soil	1.1	1.1	6.1	Soil	Soil	1.1	1.23	NOT USED	Soil	Soil	Soil	Soil	1.1
% Lime	-	2.0	-	-	6.00	6.00	6.00	-	7.00	-	-	10.00	-	-	-	-		-	7.00	-	-	-
% Cement	5.00	5.00	6.00	8.00	-	-	-	4.00	-	5.00	5.00	3.00	6.00	5.0	7.00	8.00		8.00	-	7.00	6.00	6.00
28 Day Wet Compressive Strength ($MN\ M^2$)	N/A	4.68	2.2	3.4	4.70	6.15	3.30	3.3	2.1	3.8	3.6	1.13	N/A	N/A	4.62	7.20	N/A	5.51	1.06	8.56	6.18	7.58
REFERENCE	N A	9/2/3			9 2/2			9/2/1		9 2 1		9 2 5	N/A		9/2/6	9/2/7		9/2/8			FUTURE PROJECTS	

Appendix A7

press release

Building Research Establishment - Department of the Environment

3 February 1983

BRISTOL COMPANY TO MANUFACTURE BRE BLOCK-MAKING MACHINE

A licence to manufacture BREPAK, the manually operated block-making machine developed by the Building Research Establishment (UK), has been granted to Welding Industries Limited of Blackswarth Road, Bristol. The company will export the machine to countries where it will be used in low-cost building projects, producing high quality durable building blocks from local soils stabilised with a small amount of cement or hydrated lime.

BREPAK was developed as part of a BRE Overseas Division project, financed by the Overseas Development Administration, on the use of indigenous materials in low-cost housing programmes. As well as the development of the machine itself, research was done to establish methods of stabilising clay soils and the compaction pressures required to produce weather resistant durable building blocks.

The BREPAK block-making machine makes use of a simple hydraulic mechanism to obtain a compaction pressure of 10 MN/m². The machine has a tare weight of 150 Kg and produces blocks 290 × 140 × 100 mm. Six people are needed for an efficient production team: two to dig and prepare the soil, two to prepare the mix by hand and two to operate the machine, producing up to 300 high quality blocks a day.

On site field trials have been conducted overseas, including the construction of a 50 sq m medical clinic building at Kabiro village in Kawangware on the outskirts of Nairobi. Kabiro village is one of 16 sites in Kenya where the Institute of Cultural Affairs (ICA) is carrying out self-help housing schemes. Practical field trials are also being conducted in Egypt, Sudan and Jamaica.

Further information on BREPAK can be obtained from Victor Dembo, Head of Licensing, Building Research Establishment, Garston, Watford WD2 7JR (telephone 74040 ext 7221) or Roger Taylor, Director — Group Sales, Welding Industries Limited, Blackswarth Road, Bristol BS5 8AX (telephone Bristol 551951).

10/83

— ends —

Press enquiries to Mrs Lesley James — Garston 74040 ext 7251.

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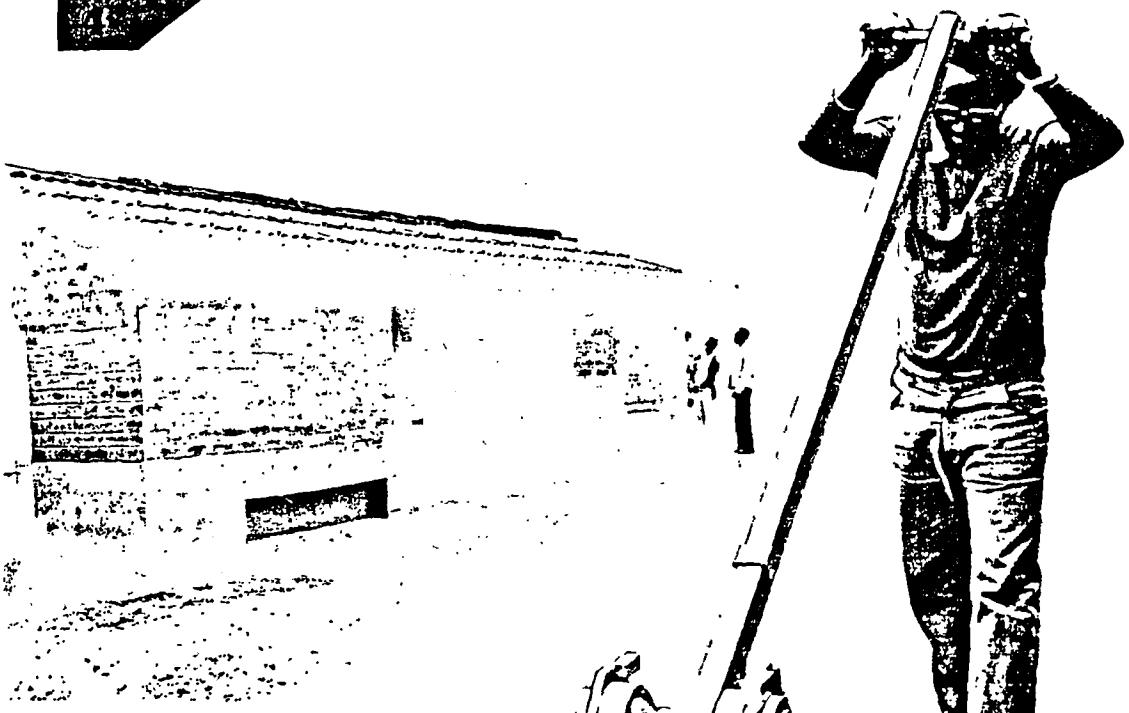
Telex: 8951648

Princes Risborough Laboratory
Princes Risborough
Aylesbury
Buckinghamshire HP27 9PX
Telephone Princes Risborough 3101
Telex 83559

THE MULTIBLOC **BREPAK** BLOCK PRESS

- Producing low cost quality building blocks from stabilised soil.
- Simple to operate with minimal maintenance required.
- Compact and easy to move from site to site.
- Ideal for use in remote areas. No power required.



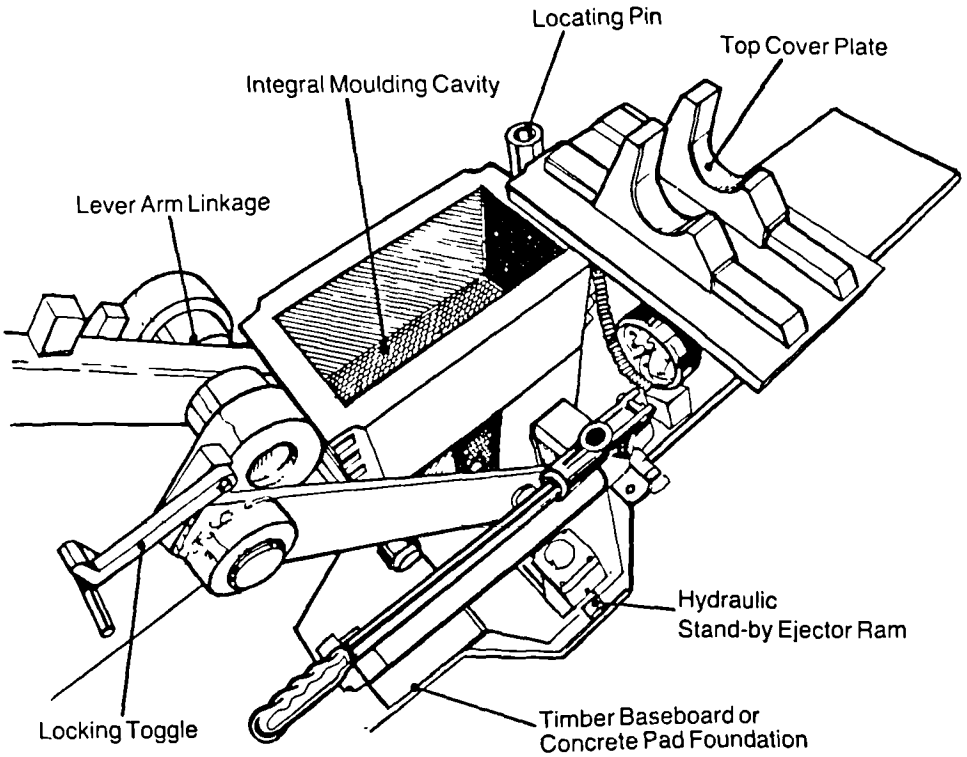
Clinic built at Kabiro, Kenya with 'Brepak' Soil Blocks

MULTIBLOC

MOULDING AROUND THE WORLD

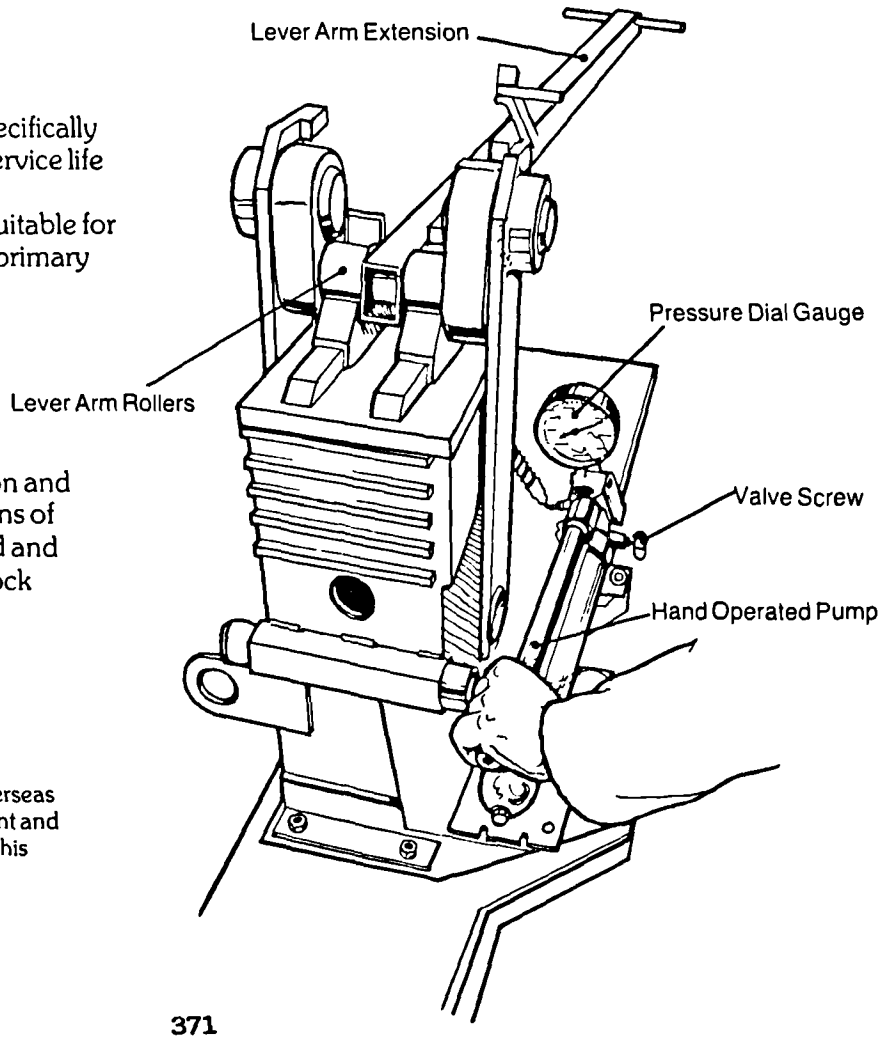
THE MULTIBLOC **BREPAK** BLOCK PRESS

The Multibloc Brepak machine comprises a moulding area of fixed size which, together with the supporting structural frame, forms an integral unit of an all-steel construction. The complete unit should be mounted to a permanent foundation or may be used on a rigid timber baseboard.



Access to the mould area is via a top cover plate pivoting about a corner mounted locating pin, the cover plate may be moved to one side away from the mould opening. The compact design of the unit allows for ease of installation at site and may be used from site to site when mounted to the timber base.

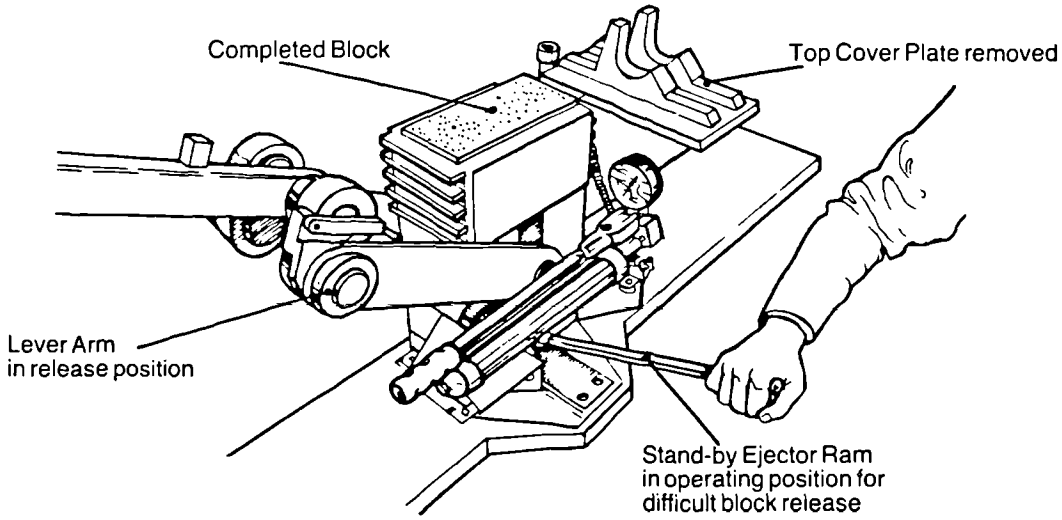
The machine design and manufacture is specifically in keeping with the requirements for long service life with a minimum of spare parts useage and maintenance making the unit particularly suitable for use in areas where rural development is of primary importance.



The press is fitted with a lever arm extension and mechanical linkage which provides a means of locking the top cover plate onto the mould and also allows for initial compaction of the block material within the mould area.

The Brepak block press was developed by the Overseas Division of the UK Building Research Establishment and is being manufactured under licenced granted by this Establishment.

Once the lever arm and cover plate are secured the second stage of block compaction, up to a pressure of 10 MN/m^2 is applied by use of the hand operated hydraulic pump acting through a piston beneath the base plate of the mould.



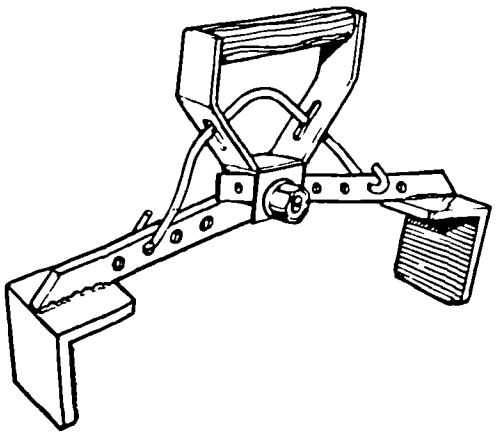
Production Sequence

1. The top cover plate is moved to one side on the locating pivot to gain access to the moulding cavity, it should be ensured that the ejector ram is clear from beneath the base plate of the mould.
2. With the base plate in its lowest position within the mould the screw valve of the hydraulic pump is unscrewed by one turn. The internal surfaces of the mould area should be lightly oiled to aid the release of new blocks.
3. The mould is then manually filled with a measured quantity of the soil mixture and hand pressure is used to ensure complete filling of the mould corners. Once completely filled the top cover plate is moved across the top to its closed position.
4. The lever arm is fitted with a locking toggle which now placed in the locking position, the lever arm assembly may now be raised by approximately 90 degrees until the centre rollers enter the guide locations on the top of the mould cover. At this point the lock toggle is returned to its original position and the lever arm is pulled downward through a further 90 degrees to a horizontal.
5. The screw valve is tightened by hand pressure so that the pump may be manually operated and the mould base plate pushed up into the mould cavity by the piston. The pump is operated until a dial gauge reading of 8,000 lbs./sq. ins. is reached, this ensures complete compaction of the block.
6. By release of the screw valve the hydraulic pressure on the piston is released so that the lever arm may be returned through a full arc back to its original position.
7. The newly pressed block is exposed by sliding the top cover plate to one side and downward pressure on the lever arm will eject the block for removal. If significant resistance is felt the stand-by ejector ram is put beneath the mould base plate and operated until the block is free.

THE MULTIBLOC
BREPAK BLOCK CLAMP

When securely gripped between rubber pads this simple, hand-held clamp permits the easy movement and accurate placing of cured blocks.

Block handling around the site and during laying is reduced to a single-handed operation and results in fewer breakage losses with improved productivity.



Soil Selection

Not all soil types are suitable for block production however 'Lateritic' soils with a clay content as found in the tropical and semi-tropical regions of the world will generally be acceptable. It is the clay content of a soil that is most susceptible to the action of weathering and which will shrink and swell with the addition of water.

This type of soil may be stabilised by the addition of a suitable agent and where the clay content is less than 30% cement would be satisfactory, for higher clay contents stabilisation with hydrated lime would be more appropriate. The addition of the stabilising agent will aid the compressive strength of the block and improve durability under weathering actions.

Compaction of a stabilised material in the BrePak with a pressure approaching 10 MN/m^2 allows the full advantage of the stabilising agent to be realised.

Mixing

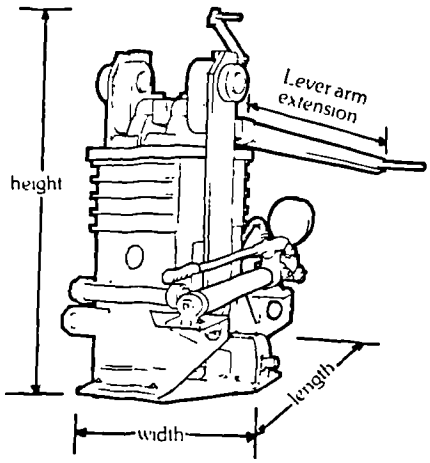
Mixing of the soil should be carried out after the excavated soil has been dried (under the sun), crushed and sieved (5mm) at which time the lime or cement may be added (approx. 6%–10%). The necessary water is required to 'bind' the mix and aid production and also to work with the stabilising agent. the amount of water is approximately 12% by weight.

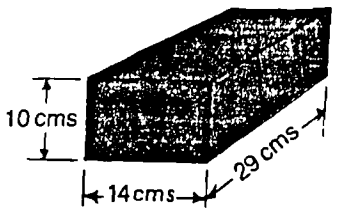
In general 0.3 cu.m. of mixed material will be required per hour to keep the press working equivalent to approximately 8/10 Kgs per block.

Final mix proportions and amount required per block is ultimately found by on-site trials in actual working conditions.

Technical Statistics

1.	Overall length (excluding lever arm)	790 mm
2.	Overall width (excluding ejector ram lever)	510 mm
3.	Overall height	760 mm
4.	Lever arm extension	1500 mm
5.	Press weight	159 Kgs
6.	Lever arm weight	11 Kgs
7.	Ejector ram lever weight	2 Kgs
8.	Effective thrust on mould base plate	44 Tonnes
9.	Effective thrust from ejector ram	6.5 Tonnes
10.	Effective compaction pressure	10 MN/m^2
11.	Average production rate	35/40 blocks/hour
12.	Labour force required	5/6 men
13.	Standard block size	29 × 14 × 10 cms





SHIPPING SPECIFICATIONS

Length	840 mm
Width	620 mm
Height	920 mm
Approx weight	180 Kgs

MULTIBLOC
WELDING INDUSTRIES LTD
Crews Hole Road, off Blackswarth Road, Bristol BS5 8AX.
Tel: Bristol (0272) 551951 Telegrams: Weldwell, Bristol. Telex: 44716.

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WEBB D.J.T.
Building Research Establishment, Great Britain.

Construction en terre stabilisée au Kénya

Stabilised soil construction in Kenya

Construcción de tierra estabilizada en Kenya.

Un nouveau modèle de presse manuelle à blocs, la machine BREPAK, développée par la Division Outremer du Centre de Recherches du Bâtiment du Royaume Uni (Overseas Division, Building Research Establishment, UK), a été soumis à des essais in situ au Kénya. Des blocs de bonne qualité en terre stabilisée au ciment ont été fabriqués sur place en utilisant la main d'oeuvre locale et un dispensaire a pu être construit à un coût très réduit.

A new type of manually operated block making machine, called the BREPAK machine, developed by the Overseas Division of Building Research Establishment UK, was recently subjected to a field trial in Kenya. Good quality cement stabilised soil blocks manufactured on site using local community labour and a low-cost medical clinic was constructed.

Un nuevo tipo de máquina de funcionamiento manual para hacer bloques, que se llama la máquina BREPAK, producida por la División de Ultramar del Establecimiento Británico de Investigación sobre Edificación, de sometió recientemente a una prueba sobre el terreno en Kenia. Se fabricaron sobre el lugar bloques de tierra de buena calidad estabilizados con cemento, utilizando mano de obra local y se construyó una clinica médica de bajo costo.

INTRODUCTION

Millions of new homes will be needed by the turn of the century to house the future population of the developing world. The majority of these homes will be built using traditional building materials such as reeds, grasses, soils, bamboo, woods and animal skins, and hence improved use of local materials could be of major benefit.

Clay based soils have been used by builders for centuries as a basic material for the construction of homes in the form of wattle and daub, rammed soil or adobe blocks. These methods produce a good durable wall in a dry climatic zone, but wet weather conditions produce erosion. It is therefore necessary that these types of construction be protected in some way to withstand the elements. This can be achieved by stabilising the clay soil with a binding agent such as cement or lime. Using cement or lime with any of the above methods will result in higher construction costs due to the large amount of stabiliser required.

Experiments at the Building Research Establishment proved that where a high compacting pressure is applied to a cement stabilised soil, the cement content can be reduced giving rise to substantial financial savings. Many different types of powered or manually operated machines have been developed in the world and the most successful one is the CINVA-Ram machine which was introduced in 1952 by the Inter-American Housing and Planning Centre in Columbo.

The CINVA-Ram block making machine (Figure 1) exerts a low compacting pressure of 2 MN/m^2 on a stabilised soil mix during the production cycle when making a soil block measuring 290 mm x 140 mm x 100 mm. The soil blocks produced usually have a minimum of about 8% cement content and are cured in the open for between 3 and 4 weeks.

Cement, is however, expensive in a third world country and early laboratory trials at BRE have indicated that hydrated lime could also be used as a soil stabilising agent provided the soil mix is compacted at pressures between 8 and 14 MN/m^2. The lime content would be about 6% provided the clay content of the soil is above 35%.

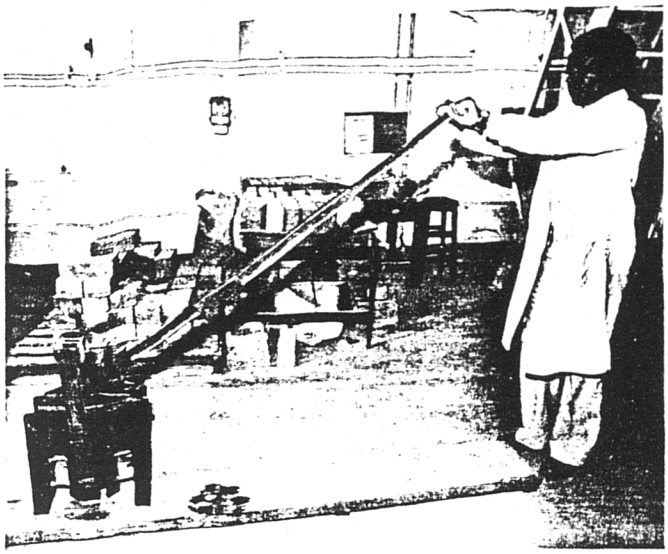

Figure 1 A CINVA-Ram block making machine

The prototype BREPAK machine illustrated on Figure 2, has a tare weight of about 150 kg, employs a 10 MN/m^2 compaction pressure on a stabilised soil mix and produces a soil building block whose dimensions are similar to a block produced by the CINVA-Ram machine. This machine can produce about 40 blocks per hour, each block weighing about 8 kg which is about 20% denser than a CINVA-Ram produced block. A team of 6 people could produce some 3000 stabilised soil blocks needed for a 50 m^2 dwelling in about 10 working days.

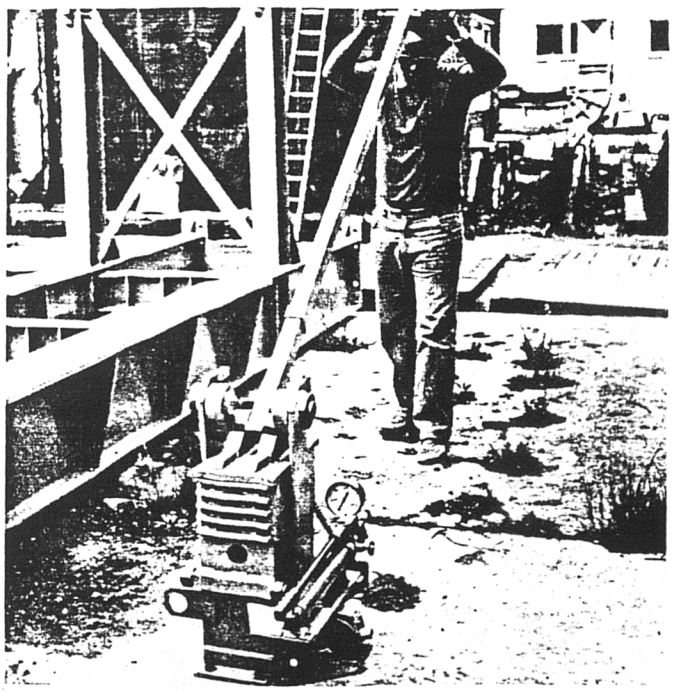

Figure 2 The BREPAK block making machine

Overseas Development Administration (ODA) supported the first overseas field trial in Kenya of the BREPAK block making machine, the object being to evaluate this new machine under actual site working conditions. A joint research project was started in 1981 between BRE and The Housing Research and Development Unit (HRDU) of the University of Nairobi, Kenya.

BRE/HRDU BREPAK SOIL STABILISATION IN KENYA

The joint BRE/HRDU soil stabilisation research project consisted of three main aspects:

(i) Scientific laboratory tests to establish the proportions of materials to be used.
(ii) The on-site field trial preparation of soil mixes and production of stabilised soil blocks using the BREPAK machine.
(iii) The erection of a 50 m^2 demonstration structure (eventually to be used as a medical clinic) using the blocks made on site by village labour.

The site selected for this field trial was located at Kabiro village within the Kawangware district of Nairobi and is some 10 km from Nairobi city centre. Its location, near the headquarters of HRDU made it possible for HRDU staff to regularly visit the site and monitor the progress.

Figure 3 illustrates a stabilised soil block being lifted from the BREPAK machine immediately after pressing.

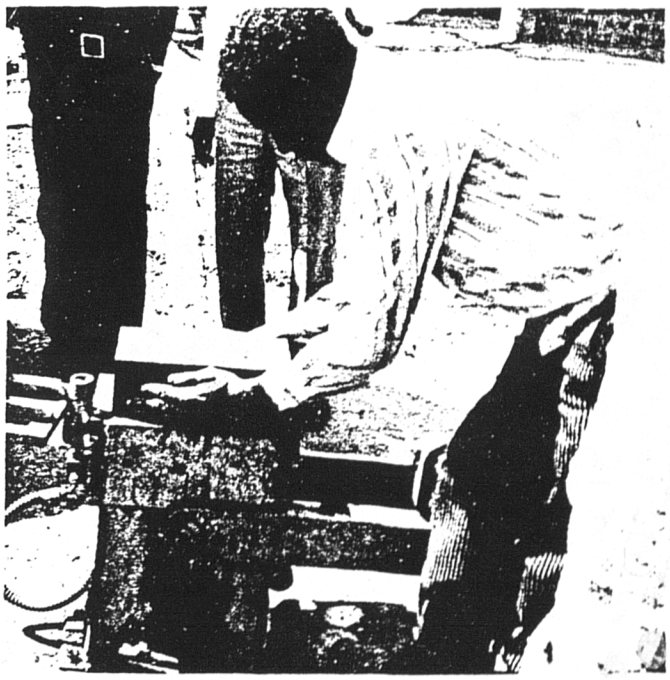

Figure 3 A stabilised soil block being lifted from the BREPAK machine

The first aspect dealt with laboratory tests to identify suitable local soils for stabilisation and to determine the optimum moisture contents for these soils. The most economic proportion of different stabilisers for the various soils was then selected. Sample

blocks were tested to obtain wet compressive strengths, resistance to moisture absorption and durability.

The local soil at Kawangware is called Murram and contains about 15% clay. Because hydrated lime is more expensive than cement in Nairobi it was decided to stabilise the Murram soil with 4% cement and good quality blocks were produced.

The field trial made use of the results of the laboratory tests. These results had to be put in a simplified form for the use of people in the field. The people were able to prepare the soil, measure the required quantities by volume, prepare the mixes by hand and produce blocks on a large scale using the BREPAK block making machine.

The cost of stabilised soil-cement blocks produced by the BREPAK machine compared favourably with conventional concrete blocks of 140 mm thickness. For example, a square metre of walling built with cement stabilised soil blocks resulted in a cost saving of about 46% of the cost of a concrete block wall.

About 3000 stabilised soil-cement blocks produced by the people were used to erect the demonstration structure of over 46 square metre floor area. The completed structure is illustrated in Figure 4.

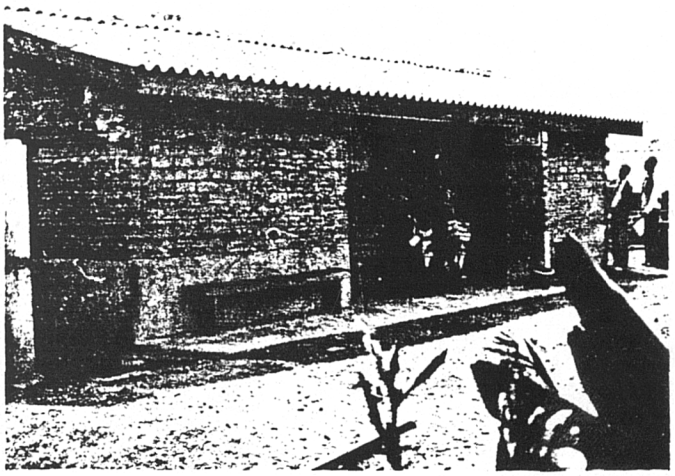

Figure 4 Medical clinic constructed with stabilised soil blocks

The people at the demonstration site, have requested that the machine stays at their site for another three months to produce a further 9000 blocks. These extra blocks are needed to complete a 200 m^2 community centre and to date some 7000 cement stabilised soil blocks have been produced in a period of two months.

This HRDU/BRE research project has many advantages and has already proved successful even before the evaluation period is over as follows:

(i) It has offered opportunities for the HRDU staff and village people to participate, on a self-help basis, with minimum assistance to produce stabilised blocks and to construct a low cost dwelling on site.

(ii) The BREPAK machine produces high quality soil blocks which contain a large portion of a locally available clay soil with a suitable stabiliser. The relative cost of stabilisers determines which should be used and may be, for example, either 4% cement or 6% hydrated lime.

(iii) The whole operation of preparing the soil, mixing and producing the blocks means that it is possible to use the BREPAK machine to produce the blocks on any site without mechanical power or fuel.

(iv) When blocks are produced on a large scale for big projects it maximises the use of human power and at the same time creates employment for the unskilled labour.

The joint BRE/HRDU collaborative research project is being extended to cover the remaining two soil types found in different parts of Kenya and it is hoped that by the end of this research programme the BREPAK block making machine will play its part in housing many families both in Kenya and in other parts of the world.

CONCLUDING REMARKS

The joint Anglo-Kenyan research project at Kabiro has already shown that large numbers of high quality building blocks may be manufactured with the BREPAK machine using stabilised soil. Initial figures suggest that the cost of walling using these stabilised soil blocks is about one half the cost of walling with concrete blocks. Stabilised soil blocks made with the BREPAK machine have the appearance of fired clay bricks and do not need any external rendering to resist the weather.

The BREPAK machine has also proved advantageous with the facility to transfer technology to village people and its ability to make use of indigenous materials.

The BREPAK block making machine has yet to be fully evaluated in the field and in addition to Kenya, field trials are being conducted in Egypt at the General Organisation for Housing Building and Planning Research (GOHBPR) in Cairo, in Jamaica with the newly created Building Research Institute (BRI) and in the Sudan with the mobile building unit of Voluntary Services Overseas working with the Ministry of Education and the National Council for Scientific and Technological Research.

When these various field trials have been completed and the BREPAK block making machine has been fully evaluated, any necessary modifications will be incorporated so that the

proven machines should be available to help with the developing world's housing needs.

ACKNOWLEDGEMENTS

The author is happy to acknowledge the valued help and assistance rendered by Mr Joel Kateregga, Research Fellow (Architect) from HRDU, University of Nairobi, Kenya in the preparation of this article and for his valued work during the BREPAK block making machine field trials at Kawangware.

The work described has been carried out as part of the research programme of the Building Research Establishment of the Department of the Environment and is published by permission of the Director.

FURTHER READING

1 Building Research Establishment Library Bibliography 250 on Soil Stabilisation
2 Lunt, M G. Stabilised Soil Blocks for Building. BRE Overseas Building Note No 184, February 1980
3 Agarwal, A. Mud, mud - The potential of earth-based materials for third world housing. International Institute for Environment and Development 1981. ISBN No 0-905347-18-8

David Webb

Appendix A10

press release

Building Research Establishment - Department of the Environment

7 May 1980

SUDANESE RESEARCH DIRECTOR VISITS THE BUILDING RESEARCH ESTABLISHMENT

Professor A R Agib, Director of the Council for Scientific and Technical Research in the Sudan, visited Overseas Division of the Building Research Establishment, Garston, Herts, on Tuesday 29 April. His visit continued the close liaison on construction research matters which exists between BRE and his organisation.

At BRE Professor Agib met El Fadil Ali Adam, a research assistant from his organisation, who is spending two years in the UK on a scholarship, studying the stabilisation of soil for use as a construction material. El Fadil is combining his course at Hatfield Polytechnic with laboratory studies at BRE. He is pictured (left) demonstrating a press developed by BRE for the production of building blocks from lime stabilised soil. Also shown are (from left to right) Mohamed El Tayeb, David Webb of BRE Overseas Division, Hassan Khitam, Dr R F Stevens, Head of BRE Overseas Division, and Professor Agib. Mohamed El Tayeb and Hassan Khitam, who are also from the Sudan, are spending six months at BRE working on building materials research.

In the second picture Professor Agib is seen (right) examining a building block produced in the press. With him are (from left to right) El Fadil Ali Adam, Mohamed El Tayeb, David Webb and Dr Stevens.

21/80

- ends -

For further information, contact Mrs Lesley James - Garston 74040 Ext 7251

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Telex: 83559

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Building Research Establishment

Overseas Development Research Unit

Training Certificate

Be it known that

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has successfully completed a practical training course on the production of stabilised soil building blocks, using the BREPAK block making machine

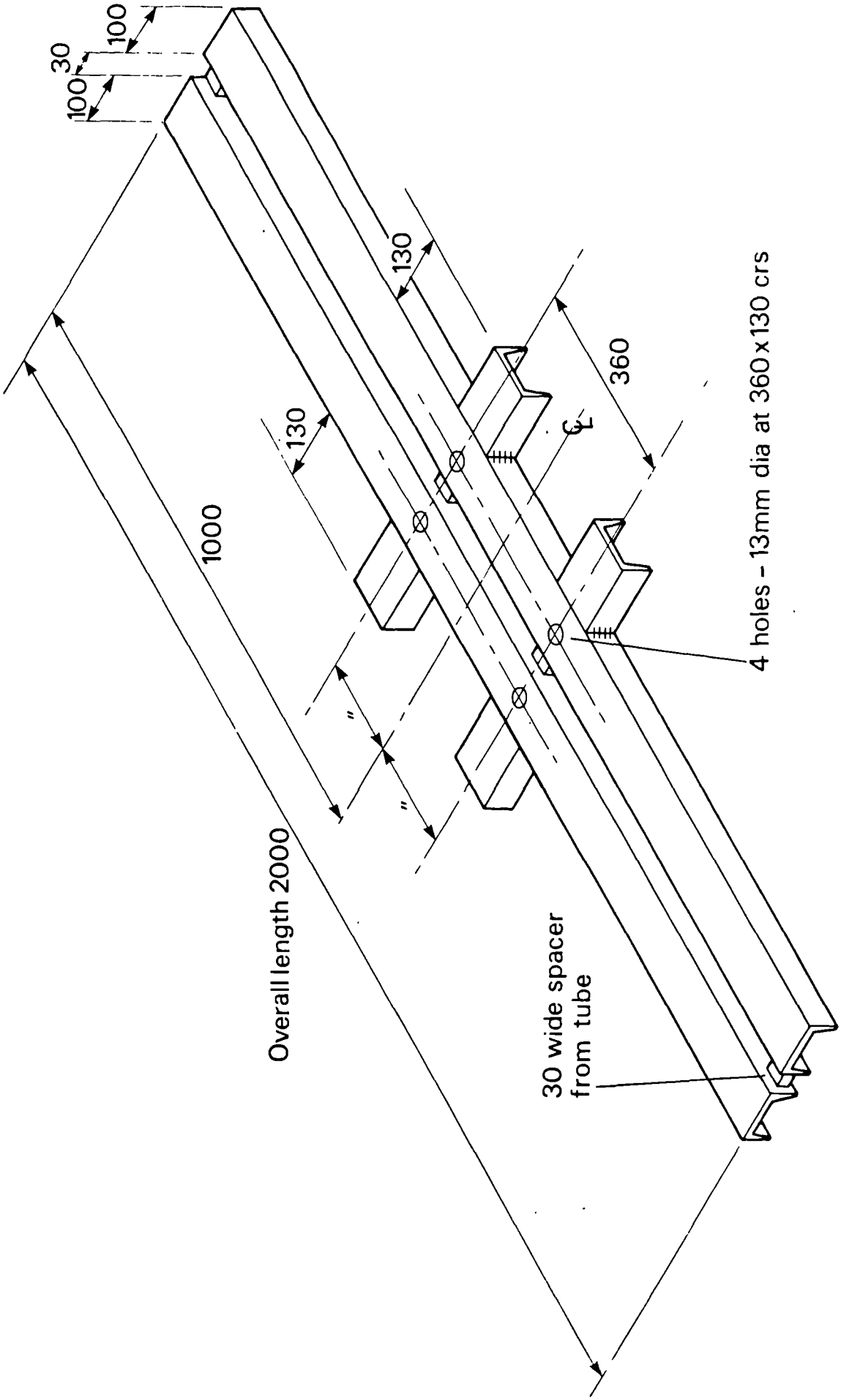
Course location . . . . . .

From . . . . . To . . . . . .

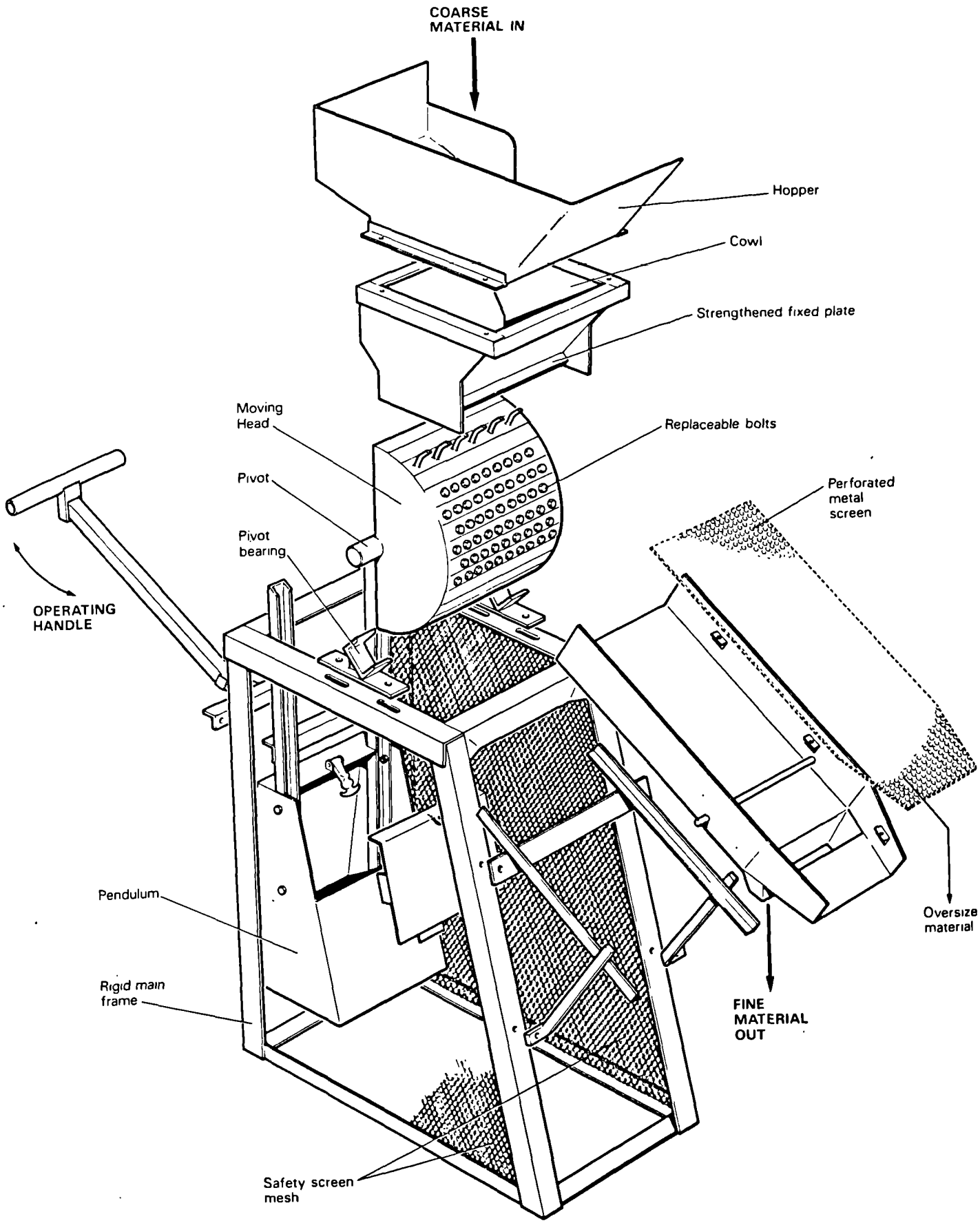
. . . . . Project leader

. . . . . Head of Unit

Department of the Environment
Building Research Establishment
Building Research Station
Garston, Watford WD2 7JR
United Kingdom



(All measurements are in mm)



Appendix A13 Pendulum crusher-exploded view

bre Research for industry

ABR

BREPAK blockmaking machine for use in developing countries

A new type of manually operated blockmaking machine has been developed by the Overseas Division of the Building Research Establishment, following research on the stabilisation of clay soils. This machine produces high quality stabilised soil blocks which can be used for building construction in developing countries.

An unstabilised clay soil will swell on taking in small quantities of moisture and shrink on drying. This movement gives rise to severe cracking and often leads to difficulties when soil is used in building construction, to the extent that the solid often disintegrates when subjected to large quantities of water. The addition of a binding agent or stabiliser will prevent this moisture movement and increase the strength and cohesion of the soil. Stabilised soil, if prepared correctly, can be an extremely cheap and useful building material.

Clay soils may be stabilised with cement or with other binding agents. Research at BRE has demonstrated the improvements in strength and durability that can be achieved when hydrated lime is used to stabilise tropical clay soils. This improved performance has been achieved by compacting a stabilised soil mix at a pressure of about 10 MN/m².

The BREPAK blockmaking machine makes use of a simple hydraulic mechanism added to the final soil compaction operation to obtain a compaction pressure of 10 MN/m². The machine has a tare weight of about 150 Kg and produces stabilised soil blocks 290 × 140 × 100 mm.

Six people are needed for an efficient production team, two to dig and prepare the soil, two to prepare the mix by hand and two to operate the machine, producing up to 300 high quality blocks each day.

To prove the BREPAK blockmaking machine, it was decided to conduct on-site field trials overseas. The first field trial of the prototype machine formed part of a collaborative research programme between the Housing and Development Unit (HRDU) of the University of Nairobi and BRE Overseas Division, financed by the Overseas Development Administration.

During preliminary laboratory trials at the University of Nairobi, the HRDU staff were instructed how to use the BREPAK machine. In Nairobi lime is more expensive than cement, so 4 per cent by weight was used as a soil stabiliser.

Figure 1 The BREPAK blockmaking machine

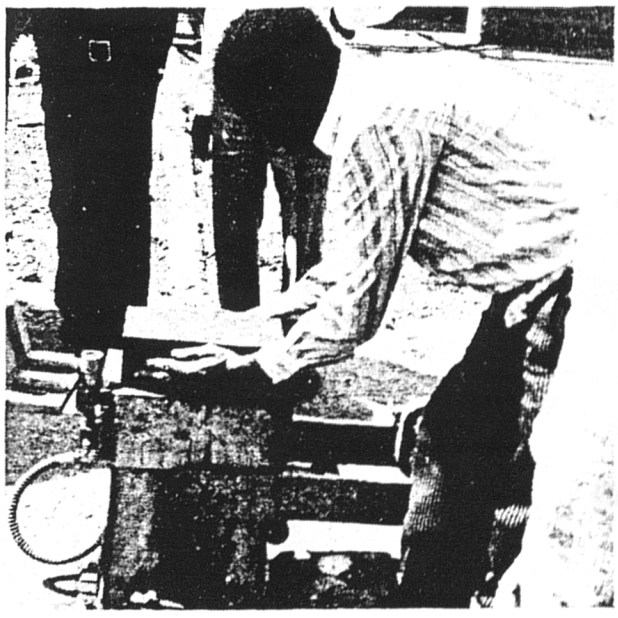


Figure 2 A stabilised soil block being lifted from the BREPAK machine

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Telex 83559

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Glasgow G75 0RZ
Telephone East Kilbride 33001
Telex 778610

Good quality blocks were produced whose minimum wet compressive strength exceeded 3 MN/m². The method adopted to determine the wet compressive strength of a stabilised soil block is to first cure the block atmospherically for 27 days, then completely immerse it in water for 24 hours, finally crushing the block. Some of these blocks were tested by completely immersing them in water and after a period of one month, showed no signs of deterioration with low levels of water absorption.

There is no international standard available which covers the use of stabilised soil building blocks. However, it is worth noting that the soil blocks manufactured by the BREPAK machine exceed the minimum compressive strength of 2.8 MN/m² which is specified in BS 2028 for precast concrete blocks.

The BREPAK blockmaking machine was then used by a community labour team on a site at Kabiro within the district of Kawangware, Nairobi, to produce the cement stabilised soil blocks required for a 50 m² medical clinic.

Figure 3 Medical clinic constructed in Kenya with stabilised soil blocks

Figure 4 Front corner view of 90 m² demonstration constructed in Jamaica

The cost of using stabilised soil-cement blocks for the medical clinic erected in Nairobi compared favourably with conventional concrete blocks of 140 mm thickness. For example, a square metre of walling built with cement stabilised soil blocks resulted in a cost saving of about 46 per cent of the cost of concrete block walling.

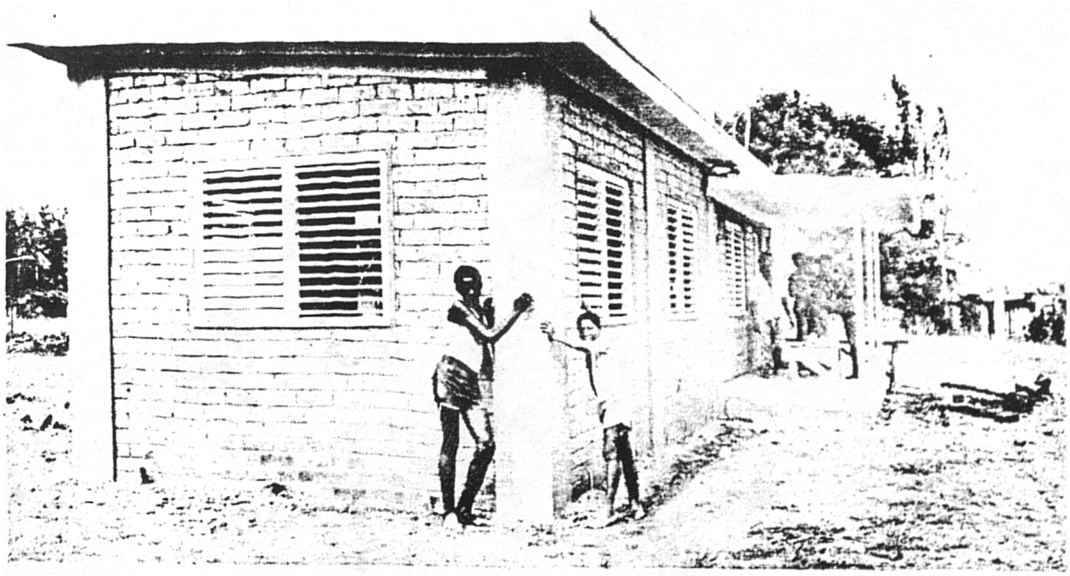
With the BREPAK machine and with careful selection of materials, stabilised soil blocks can be produced at low cost and would have the same physical properties of more expensive walling materials. In fact, built as exposed blockwork, they would have the same attractive appearance as the more expensive fire clay bricks.

The BREPAK blockmaking machine has yet to be fully evaluated in the field and in addition to those in Kenya, field trials are being conducted in Egypt at the General Organisation for Housing, Building and Planning Research (GOHBPR) in Cairo, in Jamaica with the newly created Building Research Institute (BRI) and in the Sudan with the Mobile Building Unit of Voluntary Service Overseas working with the Ministry of Education and the National Council for Scientific and Technological Research.

In Jamaica, a 90 square metre, single-storey building has been constructed from stabilised soil building blocks designed to withstand seismic forces. Again, the resultant cost savings per square metre of walling, are about 30 per cent when compared with hollow concrete blockwork.

The BREPAK blockmaking machine is now being manufactured, under licence, in the UK by Welding Industries Ltd, Blacksworth Road, Bristol BS5 8AX. Telephone (0272) 551951.

Enquiries have been received from about 70 countries and BREPAK machines are now being supplied to various parts of the world indicating that the technology developed at BRE is applicable to other parts of the world.



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EXPENSES - BLOCK-MAKING PROJECT

4/2/85	6 shovels @ $30.65 each) 2 trowels @ 18.75 ") 1 Water Can 72.60 ") 4 lengths board 1x6x10) 1 100 ft water hose)	$	444.03
7/2/85	10 sacks cement @ $8.98		89.90
21/2/85	Wages		1,557.00
4/3/85	Transport		200.00
7/3/85	Wages		1,685.00
8/3/85	Lumber - machine repair		83.02
11/3/85	Hydraulic Oil		117.10
12/3/85	10 sacks cement		89.90
18/3/85	Wages		1,890.00
28/3/85	Oil		9.00
3/4/86	Wages		1,765.00
12/4/85	Transport		240.00
16/4/85	Board		187.54
17/4/85	Building base board for machine		40.00
17/4/85	Wages		1,765.00
30/4/85	Wages		1,750.00
	Sub Total for making of blocks	=	$11,912.49
23/4/85	50 sacks cement		449.50
	60 barrels stone		424.00
	Lumber		1,191.39
14/5/85	Wages		3,516.00
21/5/85	100 barrels stone		265.00
29/5/85	Wages		3,515.00
3/6/85	Materials		85.02
11/6/85	Wages		3,632.00
6/6/85	Diesel		80.60
11/6/85	Materials		389.04
14/6/85	Diesel		85.02
19/6/85	Bamboo		115.50
	Materials		1,262.52
	Galvanise		1,932.00
21/6/85	Materials		384.35
25/6/85	Wages		3,620.00
	TOTAL		$32,859.43

At the time the block production ceased, the amount expended was $11,912.49. The price per block cannot be worked out realistically on these figures, as it was a training programme for ten people, and the bulk of expenses went on wages. Production was 150 blocks per day on both machines. The operation should really be done with four people now they have acquired skill, as a test run for a day, to reach a more accurate price per block.

Nelcia Robinson
Coordinator

CARIBBEAN UNIFORM BUILDING CODE PROJECT

Project Manager: MYRON W CHIN DLC(Hons) PhD MAPE CEng MICE MASCE
Associate Project Managers: ALWYN T WASON OBE BASc MBAPE PEng
TONY GIBBS BSc DCT(Leeds) MBAPE CEng FICE FIStructE MASCE
ALFRICO D ADAMS MJIE CEng MIStructE MASCE

CUBiC

Reply address: 121 Henry Street, Port of Spain. Trinidad

Phone: 623-4956, 0631

1986.07.10.

Mr. D.J.T. Webb,
Building Research Establishment,
Garston,
Watford WD2 7JR,
England.

Dear Mr. Webb,

I recently recieved a copy of a memo from Tony Gibbs re your visit to St Vincent and Barbados in connection with stabilised soil blocks using the "Brepak" press and the possibility of encluding its use in CUBiC. As Project Manager of CUBiC I would be most interested in receiving copies of the publications you left with Tony Gibbs so that I could make an assessment for the Caribbean Community (CARICOM) Secretariat. I should perhaps mention that funding is now being sought for a Phase II of CUBiC. In addition I should be most grateful if you could add my name to your mailing list to receive your publications.

Thank you for your kind attention.

Sincerely,

M. W. Chin
PROJECT MANAGER

New Scientist 11 April 1985

Scientists seek cheap ways to combat parasites

John Newell

SHEETS of black cloth, insecticide, a metal frame and jars of chemicals are proving effective in eliminating tsetse fly from the banks of the Zambesi in Zimbabwe. The work, based on research by Professor Einar Bursell and Dr Glyn Vale, of the Bristol Tsetse Research Centre, was reported to the inaugural meeting of the new Wellcome Tropical Institute.

A team working in Zimbabwe, stretched black cloth impregnated with pyrethrin insecticide over metal frames. Two open jars containing attractant chemicals, isolated from cattle by the Bristol team, were put under the frames. By adding acetone, the chemicals were made more volatile.

One screen was placed per four square kilometres over a 600 square kilometre area next to an infested wooded region. The project began last September. Within a few weeks the numbers of tsetse flies had declined to 0·3 per cent of the original numbers on the border—the most heavily infested area—and to 0·1 per cent of less in the interior of the controlled area. The technique costs less than the cheapest alternative method—ground water spraying (*New Scientist*, 4 April, p 7). But it can be made even cheaper, because results show that the screens do not need to be so closely spaced. Also, chemicals which will increase the screens' "pulling power" have been discovered at Bristol.

In Mali and Tanzania, Chris Curtis, from the London School of Hygiene, has been combating mosquitoes with nets impregnated with the latest pyrethrins. The pyrethrins have a rapid effect. So rapid that the nets keep out mosquitoes even when, as tends to happen, they have small holes which, without insecticide impregnation, let mosquitoes through the netting. The pyrethrin lasts six months before the nets need to be reimpregnated. Impregnation and the tailoring of nets can be done in villages. Curtis has also shown that wrapping 10 centimetre strips of cotton impregnated with pyrethrin round ankles stops 85 per cent of mosquitoe ankle biting. In a separate project, he showed that polystyrene beads floating on latrines prevent mosquitoes from laying eggs. Tests in Dar-es-Salam show the beads are effective for up to three years.

Another success was reported to the meeting by Anthony Sebastian. Sebastian works in Rangoon in Burma. He put out oil drums, the most common form of storage for domestic water supplies, to watch mosquito larvae breed, and found none. A search revealed that the drum contained two dragonfly larvae which ate all the mosquito larvae. Over 90 per cent of mosquitoes responsible for spreading dengue fever breed in domestic water supplies in such drums.

Sebastian got local people to collect dragonfly larvae and put them in pairs in 400 oil drums infested with mosquito larvae. In two weeks no mosquito larvae were left, and six weeks later there were no mosquitoes in the area. The dragonfly larvae went on working because they are able to live without food for several weeks after gorging themselves, and can wait for more eggs to be laid. Dragonfly larvae are easy to collect from known breeding areas, and the dragonflies could be encouraged to breed where required.

At an earlier stage, but with equal potential, is a method of controlling the spread of Chagas disease in Central and South America. It was devised jointly by Chris Schofield of the London School of Hygiene and the Overseas Section of the Building Research Establishment (BRE). The Chagas parasites are spread by bugs which live and breed largely in cracks in the walls of houses built from dried mud.

The BRE developed a hand-operated, hydraulically-assisted machine which compresses earth into hard bricks bound with ordinary lime. Hard bricks made in this way do not shrink or crack, and so eliminate bug breeding places. Residual pesticides spread on these bricks last three times as long as they do on ordinary dried mud floors. The machine costs £1200 and has proved effective in the Yemen. □

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PARASITOLOGY TODAY

ALTERNATIVE ANSWERS

Low-cost housing and Parasite Vectors

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The United Nations (UN) has proclaimed 1987 as the International Year of Shelter for the Homeless*. The aim is to focus attention on the needs of homeless people and the causes of homelessness. The declaration was initiated by the Sri Lankan government in 1980 and now involves planning ministries and charitable trusts in 120 countries.

*Resolution 37/221 adopted by the UN General Assembly at its 37th session 20 December 1982

Table 1. Summary of domestic arthropods of medical importance.

	Cause or carrier of:
Breeding in the house	
fleas	plague, typhus
cockroaches	shigellosis, salmonellosis and other enteric infections
bedbugs	viral hepatitis B?
triatomine bugs	Chagas disease
soft ticks	relapsing fever
dust mites	house-dust allergy
Breeding peridomestica	
Tunga penetrans	jiggers
Culicoides spp.	*Mansonella* spp.
Mosquitoes:	
Aedes spp.	dengue, yellow fever, etc.
Culex spp.	filariasis and arboviruses
Anopheles stephensi	malaria
sandflies	sandfly fever, leishmaniasis
blowflies	dysentery, myiasis
houseflies	dysentery, viruses
latrine flies	dysentery
face flies	yaws, trachoma, speticaemia infectious dermatitis
poisonous spiders	latrodectism, loxoscelism

The provision of adequate shelter for the rural and urban poor is a recognized objective in regional development[1]. The 1976 United Nations Conference on Human Settlements[1] discussed trends in world population, which was expected to double by the end of the 20th century, greatly exacerbating the need for adequate housing.

What is less well recognized is the impact that appropriate housing developments can have on the transmission of parasitic infections. The majority of vector-borne diseases are, or can be, transmitted in the home (see Table 1) but simple modifications to the design and construction of buildings can easily diminish these problems[2]. Improvements to domestic sanitation systems can also restrict the breeding of certain mosquito vectors and reduce the risk of gastroenteric diseases[3].

To meet the targets of adequate housing for poor and disadvantaged peoples by the year 2000, as proposed in the UN resolution, will require imaginative use of local, traditional materials. The western enchantment with concrete and steel is wholly inappropriate, especially for the climate and economic fragility of most developing countries. Earth is a widely-used, and widely available material which offers outstanding characteristics for the construction industry in both temperate and tropical climates. One major advantage in the use of earth is its thermal capacity to 'damp-out' daily and seasonal fluctuations in temperature. Earth has been widely used since early ages but many of the traditional skills in its use have been lost or denigrated by the modern infatuation with energy-intensive brick and concrete[4,5].

Soils for building construction must contain clay for cohesion, sand as a body or filler, and silt to provide the fine particles. However, the clay portion of a soil will swell when taking in moisture and shrink when drying out causing shrinkage cracks to occur.

Cracks in earthen floors provide breeding grounds for argasid tick vectors of rickettsial relapsing fevers. Cracks in earthen walls provide breeding sites for bedbugs and triatomine bug vectors of South American trypanosomiasis. Cockroaches and fleas flourish in the

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Fig. 1 The BREPAK block-making machine.

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shaded crevices of earthen floors and walls, and mosquito vectors of malaria, filariasis and encephalitis rest on the cool mud surfaces inside earthen houses.

It is not necessarily so. The earth used in traditional rural housing can be stabilized against erosion, shrinkage and cracking, by the addition of bitumen (to make waterproof asfadobe), cement (to make soil–cement), or lime. Stabilized earth can be further improved by compaction in a mechanical press[2,6]. Alternatively, earth can be compressed *in situ*, by ramming it firmly with wooden mallets between heavy formers. This is the basis of the French 'pise de terre' which is still widely used in parts of Francophone Africa.

Several types of hand-operated press have been developed for the manufacture of compressed, stabilized building blocks. One of the best known is the CINVA ram, developed in Colombia, which applies a compacting pressure of about 2MN/m^2 (about 8 tons) and produces blocks of a standard size (290 x 140 x 100 mm) that can be used in construction in the same way as adobe blocks. More recently, the UK Building Research Establishment has developed an improved press, known as the BREPAK machine (Fig. 1), in which the compression exerted by the hand-operated lever is hydraulically assisted to produce a pressure of about 10 MN/m^2 (about 40 tons). The resulting blocks, of the same size as adobe blocks, but considerably heavier, are actually superior to the British Standard Specifications for fired bricks in terms of load-bearing strength when wet (Fig. 2).

The superior performance of compressed soil blocks, and their ease of manufacture by local people, could bring about considerable improvements in the quality of rural housing throughout the world at relatively low cost, and extensive field trials are now being conducted in several countries. Moreover, experimental work suggests that by changing the type of mould in the press, blocks could be made of a size and shape suitable for floor and roof tiles, and for the liners of pit latrines. Even if insecticides continue to be required in certain circumstances, the non-porous nature of the compressed blocks appears to offer a greatly improved surface for the action of residual insecticides, compared to adobe blocks made from the same material[7].

Inexpensive mechanical presses such as the BREPAK machine are ideally suited to small-scale business enterprises or to community cooperatives. Their use for rural or suburban house construction could greatly improve housing and make a significant impact on the transmission of a wide range of parasitic diseases.

Joint experiments are being conducted at the London School of Hygiene and Tropical Medicine and the Building Research Establishment on the use of various forms of soil blocks to combat domestic disease vectors. The early results indicate that the denser BREPAK blocks will improve the health standards of people living in houses constructed from these blocks.

The BREPAK machine is now commercially available from Welding Industries Ltd, Blackwarth Road, Bristol, UK.

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Fig. 2 Building blocks of stabilised soil made with the BREPAK machine.

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BOOK REVIEWS

Infectious Diseases

by A.P. Ball and J.A. Gray, Churchill Livingstone, 1985. £4.95 (106 pages) ISBN 0 443 02959 8

A picture can save a thousand words, and with that in mind, Churchill Livingstone have produced a new range of colour atlases, to add to the already well-catered for market. The Colour Aids series is designed for clinical medical students and covers subjects from Infectious Diseases to Rheumatology. Under each heading, a short text is adjacent to colour photographs or radiographs to illustrate particular features. The books are pocket-sized under a sturdy soft cover; the quality of printing is good and the overall appearance is attractive.

The atlas on Infectious Diseases, however, seems to exclude anything tropical or imported except for typhoid. Thus, no parasitoses are included except for toxoplasmosis. Perhaps other widespread diseases, such as giardiasis and amoebiasis, are not easy to illustrate. This is the main weakness of the book, and will continue the artificial separation between Tropical and Infectious diseases that exist in many countries. Other problems in balance and content occur, especially in the section on chest disease. The tuberculosis section, for example, is mainly devoted to primary disease and there is no illustration of an upper-zone cavity. The inclusion of a section on smallpox and its vaccination complications must be both wrong and ill-judged if one is to accept current WHO advice and guidelines.

Other aspects are much more informative, particularly the section on streptococcal disease, and drug side-effects. Generally, the viral diseases are well covered. Within its own limitations, the book is what it sets out to be, a useful and informative student guide, well within their price range. Its usefulness however stops there.

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