**DTU Working Paper No.44** **December 1995**

# The Potential of Cement-Stabilised Building Blocks as an Urban Building Material in Developing Countries

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## Statement

This Working Paper comprises the *Overview* part of a Report (TDR Project No.D141) to the Overseas Development Administration (ODA) of the British Government which wholly funded the study on which the Paper is based. The Contents List also shows the *Appendices* to the Report which for reasons of economy have been omitted from this Working Paper. Appendices A to I contain the raw survey data acquired during visits to 7 African, 1 Asian and 1 Latin American countries. Individual appendices are obtainable on request from the DTU.

The responsibility for opinions expressed in this Paper rests with the authors and are not necessarily endorsed by ODA. Moreover reference to the names of firms, commercial products and processes does not imply their endorsement by ODA, nor does failure to mention a particular firm, commercial product or process indicate any sign of disapproval.

## Abstract

This Paper examines the level of technical achievement in production and the level of social acceptance of cement-stabilised building blocks (alias ‘soil-cement’) currently displayed in 9 developing countries surveyed in early 1995. The survey established that these blocks are currently in common use and are likely to be more widely used in the future. Several technical problems or deficiencies were however identified across the whole area visited, as were new developments pertinent to the advancement of this building technology. These deficiencies and developments are analysed and used to define the research, design and training needed to significantly improve the effectiveness of cement-stabilised blocks as a low-cost walling material in urban areas of developing countries.

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# SUMMARY

There is a widespread shortage of permanent housing in urban and peri-urban areas of Africa. This shortage is increasing both because of high rural-to-urban migration rates and because of the relatively high cost of permanent urban building materials. The poorest sector of the community is most affected by this housing shortage as it is least able to afford construction materials classified as permanent under prevailing building regulations. This project has focused on building materials for this sector of the population and in particular on cement-stabilised blocks.

*Review of objectives*

The project leading to this Working Paper falls into ODA’s TDR theme objective U1, "Improving the quality and accessibility of low cost housing and other infrastructure provision in poor urban areas". It forms a preliminary survey to asses the current cost, quality and potential for improvement of cement block making and the viability and value of accelerating the extension of this technology in poor urban and peri-urban areas through the implementation of subsequent programmes of research and design, and of producer training.

It was intended to measure the scale of cement block use, the social acceptability or otherwise of such blocks, whether there is a need for improvement in quality (if so potential interventions were to be identified) and whether it is possible to reduce costs significantly. Using the data gathered it would then be possible to determine whether in combination these factors form sufficient justification for further research to facilitate any potential interventions identified or whether other building materials are more suited to these circumstances and consequently cement block production should not be pursued further. See also Figure 1, "Logical Framework" (overleaf).

*Summary of work carried out*

Major surveys were carried out in Kenya, Tanzania, Botswana, and Ghana while minor survey were conducted in Sri Lanka Uganda and Mexico. Predominantly urban and peri-urban areas were visited. Discussions were held with governmental and non-governmental organisations involved with building material production, housing construction, planning and building regulation. Poor urban and peri-urban residential locations were visited to assess the current levels of use of cement blocks. Block manufacturers were visited to determine the current quality and cost of the blocks produced and to observe the production methodology in use. Alternative competing building materials were also examined to compare their cost and quality with that for cement blocks. Data was gathered to enable economic predictions to be made to determine the potential block cost reductions which could be made if the process methodology and production equipment were improved. Table 1 summarises this economic modelling overleaf. Potential building material purchasers, private individuals and developers were also visited to determine the acceptability of the available building materials in terms of their cost, quality and social acceptance and the likely acceptability of improved blocks.

Based on observation of the production methodology in use, economic analysis and discussions with local experts, potentially appropriate interventions to improve cement blocks were identified.

*Technical results*

Cement blocks were found to be a major construction material in both urban and peri-urban areas and are increasingly becoming the basic walling material in these areas. The block quality obtained for a given production cost is much below that which could be achieved. Problems were observed with raw material testing, cement optimisation, mixing, batching, mould filling, compaction and curing. These problems could be reduced if producers were more informed, better skilled, equipped with better production and testing equipment and more diligent in quality control.

It was found that micro-enterprise production of soil-cement can offer cost savings over sandcrete walling. The cost advantage is small (0 to 30%) for built-up walling using current soil-cement block production systems. Soil-cement blocks are usually smaller than sandcrete blocks and consequently are more costly to lay because of the increased laying time and additional mortar required per square meter. Using local cost data for predictions it was found that further savings, in the order of 50%, are potentially possible if impact compaction of larger size soil-cement blocks (equivalent to the size of current sandcrete blocks) were instigated. However it was found that at present soil-cement is disadvantaged by the incorrect perception that it is not a "permanent" building material; it is strongly associated with traditional unstabilised soil construction in the minds of many. It was found that nomenclature was the prime reason for this association and that this may be remedied through the removal of "soil" from the material's name.

The manual equipment used for block production was found to be often poorly designed and its purchasers appeared generally unable to distinguish good design from bad. There was an absence of quality control procedures and in particular of testing equipment to monitor quality.

*Implications of results*

The implications of these findings for future R&D or training interventions are covered in the last section of this Executive Summary.

This survey found that cement blocks are a major building material for the poor (and the more well off) in the areas of study and that they are increasing in importance as competing materials continue to increase in cost. It is feasible to substantially improve block quality and reduce block costs both for soil-cement and sandcrete. If such improvements were successfully implemented then it is likely that blocks could become both more accessible and more desirable to the urban and peri-urban poor. Consequently it is likely that they could contribute to alleviating the current housing shortage.

Research is required to determine why the present level of process understanding displayed by manufacturers is so low and what improvements could be obtained under current market conditions if operators/owners were better informed and possessed the ancillary equipment to support better quality control.

Current manual compaction machine design is often poor. A wide range of machines are available globally but generally only one machine is available within one country. There is a need to assess the available machines, make public the assessment findings and feed back recommended machine developments to manufacturers and purchasers.

There is sufficient justification for the development, field testing and promotion of the impact moulding process as it offers considerable potential savings in cost and improvements in quality over pressure-moulding.

# OVERVIEW

## INTRODUCTION

The following report gives details of the result of a four month survey into the use of cement-stabilised[1] building blocks in urban and peri-urban areas of eastern, southern and western Africa, Southern Asia and Central America. The countries of focus for this report were: Kenya, Tanzania, Uganda, Zimbabwe, Botswana, South Africa and Ghana. Sri Lanka and Mexico were also visited to identify practices with potential for future use in Africa. In these countries the building materials used in poorer urban and peri-urban areas were surveyed to determine their price, quality and social acceptance. Particular attention was paid to cement-stabilised building materials and the level of improvement in quality and reduction in cost which could result if a programme to assist block producers were instigated. The data presented in this report was gathered from the field by Dr D.Gooding and Dr T.Thomas[2] between February and May 1995. All prices given are current at this time unless otherwise stated.

*Report structure*

This report has been arranged so that the central themes and patterns which extend beyond a single country are presented together as an "Overview" which comprises the body of the report. Country specific information is presented in a set of four appendices. In this way repetition of common factors has been minimised.

The Overview has been split into three parts introduction, survey and interventions. The introduction part gives a brief explanation of the differences and similarities between soil-cement and sandcrete blocks, provides the definitions which will be used in this report and outlines the importance of compaction and densification to cement-stabilisation. The second part presents the findings of the survey conducted to establish the current patterns of use, levels of technical production skill and levels of understanding in the 9 countries visited. Also in this part the most commonly observed problems with cement-stabilised building materials are presented. This part finishes with a consideration of the economic value resulting from the use of soil-cement compared to alternative building materials in urban areas. In the third part recent developments in the theory of cement-stabilisation of building blocks are presented and both immediate simple interventions and longer term remedies to the problems observed in part two are suggested. Factors which may affect the advancement of this technology are noted. Research, design and training needs are discussed.

## THE TECHNOLOGY

### 1 THE CURRENT UTILISATION AND QUALITY OF CEMENT-STABILISED BUILDING BLOCKS

#### 1.1 Definition of cement-stabilised building blocks

In this report the term "cement-stabilised building blocks" is used as a generic name to cover a wide range of building materials. A cement-stabilised building block is defined here as one formed from a loose mixture of soil and/or sand and/or aggregate, cement and water (a damp mix), which is compacted to form a dense block before the cement hydrates. After hydration the stabilised block should demonstrate higher compressive strength, dimensional stability on wetting and improved durability compared to a block produced in the same manner but without the addition of cement. This definition includes a range from hand-tamped soil blocks containing only enough cement to enhance their dry strength a little (but not to achieve any long term wet strength) to close-tolerance high-density concrete blocks, mechanically mass produced and suitable for multi-storey construction without a render. The spectrum of cement-stabilised building blocks has been split traditionally into two distinct fractions, sandcrete and soil-cement. Although the terms "soil-cement" and sandcrete/ sandcement/concrete have very different images in

1 covering the spectrum of materials from soil-cement to sand-cement or "sandcrete".

2 Both from the Development Technology Unit, a research centre of the University of Warwick.

the public mind in Developing Countries, there is no clear boundary between them. Good soil-cement may be stronger than poor concrete and use "soil" no different in particle size distribution from the so called "sand" used in sandcrete. Provided that the mixtures are "damp" rather than liquid[3] then there is no practical reason to discriminate between soil and sand cement, the production process being the same.

Sandcrete use is widespread and increasing: it has a good popular image. Soil-cement by contrast carries an association or stigma linking it with unstabilised soil and simple adobe construction which has much limited its popularity. However in areas where demonstration production has been undertaken (Arusha, Dar Es Salaam, Nairobi, Taita, Otse, Francistown, Kumasi to mention a few locations) the public has been impressed with soil-cement and the opinion has been repeatedly voiced that it appeared better than the prevailing low quality sandcrete blocks. It is therefore suggested that it is primarily the association of soil-cement with rural adobe building that has restrained its propagation.

It seems appropriate to acknowledge the spectrum of possible cost and quality which cement stabilisation encompasses but to counter the public perception that "sand-cement" blocks are high quality, durable building components, while "soil-cement" blocks are low quality and not as durable. In the country-specific appendices a differentiation has been made between soil-cement and sandcrete because at present, with the exception of South Africa, manufacturers either produce soil-cement or sandcement blocks and identify the materials as separate.

For the purpose of this report soil-cement is defined as a permanent durable material which is produced from a natural or modified soil containing sufficient fines to provide cohesion on densification, sufficient to allow unsupported handling of the freshly moulded block. Good soil-cement blocks may thus be stacked for curing. Quasi-static compaction is usually employed and block depth is typically restricted to 120mm. Using depths greater than this leads to excessive variation in density within the block as a result of high internal friction. Ideally block depth should be 100mm or less.

Sandcrete/sandcement is here defined as a permanent and durable material formed from a washed sand, a natural sandy soil or a modified sandy soil such that cohesion of the freshly moulded block is insufficient to allow unsupported handling or stack curing. Block depth may be greater than 100mm and is typically 230mm. Dynamic compaction is commonly used which produces more uniform compaction resulting in sufficient strength for the block to retain its moulded shape, though not enough for unsupported handling or stack curing.

The key differentiating factors between soil-cement and sandcrete are then cohesion/strength of the freshly demoulded block and the block size. During the course of the survey it was found that block size effectively determined the marketed name, large blocks were sold as sandcrete while smaller blocks were sold as soil-cement. The exceptions to this were in South Africa and Botswana where cement stock bricks are common. However these are typically smaller than soil-cement blocks, 100x225x87.5mm (width x length x depth) compared to 140x290x100mm for soil-cement and 150x460x230mm for sandcrete.

Stabilisation is also possible with alternative cementitious binders such as lime. The following report deals only with ordinary portland cement. At present this is the most widely available and quality-consistent stabiliser and is likely to remain so for at least the next ten years. Even if lime were to become widely available with assured quality, lime stabilisation requires at least twice as long for initial curing. As quick curing has a significant economic value in block production, lime use is likely to remain less common than ordinary portland cement (hereafter cement).

### 1.2 Methods of forming cement-stabilised building blocks

In all cases blocks are formed by the application of energy to a loose soil/sand-cement-water mix in a mould that determines all but one of the final block's dimensions. The commonest forming processes are

(i) hand-tamping of a moist mix into a wooden mould with no top or bottom, placed on a flat surface; the mould is removed prior to curing the block in situ on that surface. This process was seen in all of the surveyed countries, primarily used for the production of decorative ventilation blocks. Research into the use of this process for labour intensive methods of soil-cement block production has been carried out in South Africa but it is not currently used in the field.

(ii) pressing in a rigid steel mould with a force of up to 10 tonnes (pressure up to 2 MPa) onto the bottom face of the block; the force is obtained by using levers to amplify the pull (say 500N) of an operator; the best

[3] Poured concrete requires compaction to remove air entrained in a viscous liquid which is a different operation to the compression of a damp powder. Moreover such concrete must be contained within a mould until it has hydrated sufficiently to retain its cast shape on removal from the mould.

known machine type operating in this way is the Cinva Ram press. This process was seen in all countries and used exclusively for the production of soil-cement or unstabilised soil blocks.

(iii) pressing with a force greater than 10 tonnes (pressures typically between 2 MPa and 10 MPa) using hydraulic cylinders such as in the Brepack machine. This process has been used in Botswana, Tanzania and Ghana for the production of soil-cement but is no longer in use.

(iv) slamming a hinged and weighty lid onto the exposed top of a mix that has been hand-tamped into a mould. This process was seen in all countries surveyed for the production of sandcrete blocks and also for the production of soil-cement blocks at Camartec in Tanzania.

(v) vibrating a mix in a mould to which some modest pressure or shock impulse is applied towards the end of the process: the vibrator may be powered by electricity or an engine; the blocks may be moulded onto the ground directly by a mobile machine and left to cure there or they may be carried on pallets from a stationary machine to a curing area. This process is used exclusively for sandcrete and was seen in all of the countries surveyed.

### 1.3 Compaction and Densification

It was shown by Lunt (1980) that higher compaction pressure up to 10 MPa, generated quasi-statically, has beneficial effects on compacted density and cured strength (research conducted on lime-stabilised soil). Subsequently several machines were produced, eg the Brepack, which used a hydraulic circuit to achieve compaction pressures up to 10 MPa. Higher density blocks are easier to handle between moulding and curing, have a higher compressive strength after curing and also an improved surface hardness. The first is important to reduce the incidence of damage during handling and to permit the stacking of green blocks during curing (thereby facilitating good curing and reducing the size of any curing yard). The second is important because standards for building materials are usually expressed in terms of bulk compressive strength. Surface hardness is important as lack of it results in rapid rain or wind erosion or requires a render to be applied to protect the blocks.

By increasing the compacted density of the block, whether soil-cement or sandcrete, the stabiliser content may be reduced for a given strength, thus reducing the cost of the block. However experimental research[4] conducted by the DTU has shown that the cement saving resulting from higher compaction pressures is not enough to offset the increased capital cost of a quasi-static high pressure machine, unless production output is dramatically increased. Additional advantages of high density production were noted by the DTU, namely an increase in the allowable range of particle grading for the material to be stabilised and improved resistance to poor curing as a result of reduced block porosity. These factors do counteract the greater cost of high density compaction but not sufficiently to encourage the use of manual quasi-static high pressure machines.

Block density is not solely determined by the maximum compaction pressure that the forming process could exert. In the case of fixed-volume compaction the amount of soil placed in the mould is highly significant. Too little material and a low density block is produced, while too much material and the machine is over-stressed and liable to jam. Moreover if the material is not compacted at its optimum moisture content, lower density will result. If too little water is present, internal friction is high and densification prematurely ceases. If too much water is added then hydrostatic conditions may be generated where the applied compaction force increases the pressure of the material's pore water but does not result in particle rearrangement and densification. Variable water content causes a further complication as the volume occupied by a damp soil also depends on its moisture content. A dry soil initially expands as water is absorbed, up to a point known as the fluff point, more than this amount of water and the soil volume again decreases.

[4] The relationship between applied compaction pressure, cement content and cured strength was determined empirically in a laboratory setting. This work is described in DTU Working Paper No.40 "Quasi-Static Compression Forming of Stabilised Soil-Cement Building Blocks" (1993).

# SURVEY

## 2 THE TREND TOWARDS INCREASED USE OF CEMENT-STABILISED BUILDING BLOCKS

The traditional building materials common in Developing Countries may be considered to fall into four broad groups; unstabilised soil, fired brick, wood and stone.

Unstabilised soil construction is a widespread construction material in rural areas but is generally seen as undesirable being the bottom rung of the materials ladder. This view is pronounced in South Africa, Kenya and Zimbabwe. Unstabilised soil is not classified as a permanent material under current building regulations which prevents its legal use in urban districts, leaving the home occupier vulnerable to dispossession and the dwelling vulnerable to demolition. None of the survey countries define urban unstabilised soil construction as permanent. Finance organisations are highly unlikely to lend money for the construction of any property built from material not classified as permanent.

Use of unstabilised soil is likely to continue in rural areas where it is freely available (dug on site) and the cost of construction is primarily determined by the cost of labour (which is considered free in a self-build situation). A French organisation, CRATerre has been involved in the promotion of improved architecture to extend the life of unstabilised soil structures, however despite the existence of some admirable demonstration houses unstabilised soil remains firmly fixed in the minds of Developing Countries residents as being second rate. The overwhelming demand in all of the countries surveyed is for "something better than soil". In areas where soil walling is common it is seen as a temporary structure, built because no other alternative material could be afforded. It seems likely that unstabilised soil will remain associated with poor quality and will always be chosen as a last resort by those with limited means. In consequence its use will continue for the foreseeable future in rural areas but not in urban ones.

Fired brick is one of the cheapest building materials where supplies of suitable soil and firewood are present. The quality of burnt bricks was found to be highly variable. In Kampala the soil used has a low clay content and high amount of sand. This is an unsuitable soil for fired brick production, the bricks produced are low quality being porous and even liable to collapse in the rain. These bricks were observed to be highly fissured and bent even before firing. The cost of fuel for a single clamp of bricks in Arusha, Tanzania is 300,000 Tsh (£400). This alone contributes 25% of the final cost of the bricks. Traditionally wood has been the most common source of fuel for brick firing but supplies are rapidly diminishing and have already been exhausted in many areas, in desperation dried cattle dung is now being used by Kenyan artisans south of Nairobi. Work is under way to find alternative sources of fuel; waste wood shavings (Ghana), furnace slag (Botswana and Zimbabwe) and coffee husks (Kenya), all of these are being used with varying degrees of success. In areas where the price of firewood is high, brick production falls in to two categories: high cost bricks produced using adequate quantities of firewood and poor quality bricks using inadequate quantities of firewood with consequent under-burning. It is likely that the use of fired brick will decline in the lower income groups. This trend may be delayed in areas with suitable soil and current reserves of wood but unless the deforestation process is reversed quickly these areas too will see an escalation in cost.

In many areas sawn timber is now one of the most expensive construction materials and consequently one of the least popular, particularly as ongoing preservative treatment to counter the termite threat is expensive. Many squatter settlements are built with waste wood, as seen to some extent in all of the countries surveyed, but this is classified as non-permanent housing and is always vulnerable to demolition by the town authorities. Split bamboo although still widely used in parts of the humid tropics is not an important building material in any of the nine countries visited. Wood will continue to be used for roof support but unless sustainable forest husbandry is successfully promoted its use as a permanent walling material will continue to decline.

Stone is a common building material in areas where soft easily quarried deposits are found. The cost of the material is determined by the labour costs of extraction and dressing and the transport cost of supply to the construction site. Suitable stone is mainly found in Eastern Africa, most notably Nairobi, Kenya where volcanic tuff has been quarried since the 1940s. The early local quarry sites are now becoming worked out and the cost of the material is increasing because the transport costs are escalating as the quarries become more remote. In areas where accessible supplies exist its use is likely to continue, as it is seen as a highly durable material with a low initial purchase price. Stone housing construction by individual home owners has been following an ***extending*** pattern. This pattern of construction has been noted in all of the countries surveyed and is discussed in more detail below in section 2.1.

In all the countries surveyed except Uganda cement-stabilised blocks are becoming the most common urban walling material, despite the increasing cost of cement (a result of internal economic difficulty and structural adjustment programmes). They are steadily displacing the many forms of unstabilised soil, fired brick, wood and stone that have been traditionally used. These blocks owe their popularity to their image of modernity, strength and durability, although at present many of the blocks do not live up to these expectations. They are easy to produce with very little equipment, generally relying more on labour than machinery. Their large unit size compared to stock bricks offsets their higher purchase cost per piece as fewer are required per meter of walling. The large unit size and regularity speeds construction, reducing labour costs and requires less mortar. In all of the countries surveyed current methods for producing soil-cement were found to be capable of producing less expensive block-walling than sandcrete. However soil-cement is currently much less popular than sandcrete because of its stigmatising associations.

At present the majority of these blocks, both soil-cement and sandcrete are not reaching their potential strength or durability, defined by the quantity of cement used in their production. There is great potential for reducing the cost of these materials *and* increasing their quality. Although cement is an expensive industrial product, it is made on a large scale and is widely available, exceptions are remote rural areas such as the Kalahari in Botswana where the price rises dramatically with the distance from supply centres and Ghana where, until recently, supply has been largely restricted to government contracts. With improved production methodology the quantity of cement used in blockmaking and hence the cost of the blocks may be reduced. In contrast, the traditional materials although indigenous are becoming more scarce, particularly firewood, and in consequence more expensive.

There are many possible options for improving the provision of housing, one is to fight against public opinion and promote more traditional building methods, for example improved soil architecture. Another is to promote sustainable forestry to supply wood both for direct use in construction and for fuel for brick firing. A third is to improve the efficiency of cement use in cement-stabilised building blocks. With improved soil/sand selection, more efficient compaction and in particular well controlled curing (see below), the cost of these blocks may be reduced substantially, significantly reducing the quantity of cement consumed per unit of walling, while at the same time maintaining or improving strength and durability.

In the short term at least, it seems likely that cement-stabilised materials will continue to increase their market share. It is generally easier to improve a popular product with an established and expanding market than to revive one with a failing reputation. Moreover it is possible to improve the efficiency of cement-stabilisation through only minor modifications of current production practices. Following the recent rapid increase in cement price in many of the areas visited (the Kenyan price rose from 170 Ksh to 370 Ksh in a matter of months, while the Tanzanian price rose from 1400 Tsh to 4000 Tsh in one year), methods of reducing the cement content per block will be welcomed by the existing manufacturers. It is a more complex proposition to find widespread alternative fuel supplies for brick firing or to implement widespread sustainable forestry practice. As the need for improved affordable housing is current and very pressing it seems preferable to promote methods of reducing the cost of cement-stabilised material now.

### 2.1 The *Extending* pattern of house construction

In this section the *extending* pattern of construction, common in urban areas of the countries visited, is explained and its influence on materials choice is explored.

Typically a house is built on a grand scale as the owner's "ideal" house. It is not uncommon to let its construction take ten years, divided into many stages of construction and payment, rather than to build an immediately affordable smaller house. Initially a site is obtained and no construction work takes place until the site has been paid for. Then blocks are purchased and stockpiled until enough have been acquired to construct a section of wall whereupon a mason is employed. The stockpiling and block-laying phases are then repeated until the house is ready for roofing. In this way the home owner may use a higher quality material than could otherwise be afforded.

In the particular case of Nairobi where stone is believed to be the highest quality construction material, rough hewn stone is purchased very cheaply and a mason employed to provide the final dressing as and when finance is available. Once enough stone has been purchased and dressed the mason is then employed to lay the blocks and so on. Stone is suited to this pattern of construction as each stage of construction is cheap, even though in total the final cost of the wall may be higher than one constructed from sandcrete blocks.

While the house is under construction the eventual owner is usually renting accommodation elsewhere. The rapidly increasing urban population in many areas is causing the price of rented accommodation to increase rapidly, in Botswana the urban population is increasing at 6.9% per year. Similarly the population of Nairobi is increasing at 7% p.a. In Arusha rent for a 10' by 12' room is currently 7000 Tsh a month, payable for one year in advance (the minimum wage is 15000 Tsh a month). Such high rents are discouraging the *extending* pattern of house building described above. As rent rises so it becomes more attractive to speed up the construction process even if this means a smaller house; the quicker the owner can occupy the house the quicker he/she stops paying rent. Once construction speed becomes an issue then the total cost of the house is considered rather than the cost of its components. For example although undressed stone is cheap to purchase, the cost of subsequent processing and construction is high. Because the stones are irregular, a thick layer of mortar is required and consequently a substantial quantity of cement is used. Similarly a substantial quantity of cement is required for the render. In contrast cement-stabilised building blocks although marginally more expensive to purchase initially, do not require final dressing and are regularly sized using less cement both for mortar and render. As general awareness of the financial drawbacks to *extending* construction increase it is likely that it will become less popular, perhaps becoming replaced by a *core-extension* pattern.

### 2.2 The *Core-extension* pattern of housing construction

Core-extension housing was observed in the redeveloped squatter settlement of Old Naladie in Gaborone, Botswana. The situation is slightly different in Old Naladie as the future home owner already owns the plot of land and usually occupies a temporary structure on the site. In this case the drive for rapid construction is to allow income to be generated by renting space in the house to third parties. Small twin room houses are initially constructed (using sandcrete), one is occupied by the house owner while the other is rented out. The rental income is then used to provide finance for further extensions to the house which are used either by the home owner or also rented out to generate further income.

Once the advantages of faster construction become more generally appreciated it is likely that both a reduction in the size of the initial construction and an increase in the use of more affordable materials will be seen.

## 3 CURRENT PRODUCTION OF CEMENT-STABILISED BUILDING BLOCKS: PRACTICES AND PROBLEMS

### 3.1 Process methodology

#### *3.1.1 Curing procedures*

The most detrimental practice seen in all of the countries surveyed was poor curing of the formed cement-stabilised block. Once formed the blocks are frequently left out in the sun to "dry", large areas of sun-dried "curing" blocks were observed in every country surveyed. Cement relies on the presence of water to hydrate, forming an interlocking skeleton of calcium silicate hydrate which gives the material its strength. If the block is allowed to prematurely dry then full hydration of the cement does not occur and consequently only part of the cement used contributes to the strength of the block. Experiments conducted by the DTU at the University of Warwick have shown that the strength lost due to poor curing can easily reduce the final block bulk strength by 20%. As the block surfaces lose water first, strength loss in these regions is still higher. The loss of surface strength reduces both the handleability (edge and corner chipping during transport) and the durability of the blocks. If proper curing were implemented, maintaining the moulding water content for at least seven days, then both strength and durability improvements would be seen. Good curing practice is not followed for one of two reasons. Either the producer is not aware of the need for curing (instances in all countries surveyed) or it is felt that the cost of constructing a suitable curing area is not worth the potential increase in quality. In Kampala where sandcrete blocks are produced by "egg-laying" vibrating machines, producers observed that wet weather, provided heavy rain did not pit the newly moulded blocks, gave better curing. However they were reluctant to use cloths to increase humidity during curing and also indicated that shading the blocks would be unacceptably expensive, given the large area which would have to be covered.

With conventional moulding methods the strength of the green blocks is not sufficient to allow stacking of the fresh blocks and hence a large sheltered curing area is required. Improved compaction produces higher density green blocks which may be stack cured, greatly reducing the area needed. Furthermore a higher density block loses water more slowly as a result of its reduced porosity and consequently is less susceptible to poor curing practice.

#### *3.1.2 Batching*

Cement hydration begins as soon as the cement comes into contact with water. In consequence the batch-time, the length of time between addition of water to a cement mix and the use of the last part of a batch, is important. Ingles and Metcalf (1972) suggest that as much as 50% of the final cured strength of cement-stabilised soil may be lost by a delay of two hours before compaction. Experiments conducted by the DTU confirmed a strength loss due to compaction delay but found it to be less pronounced, namely 20% loss after a two hour delay. The significance of batch time was not understood by field producers and consequently batch times of two hours or more were common, in isolated instances batch times up to six hours were found (St Joseph's Mission, Nairobi) which would result in at least a 50% strength loss for blocks produced at the end of a batch. Batch times of 30 minutes are recommended and it is advisable that times do not exceed 1 hour.

*3.1.3 Optimum water content*

The amount of water added to the cement mix is also important for good compaction during moulding. Moulding at the optimum water content results in the most dense block yielding the greatest strength. If too much or too little water is added the formed block will be less dense. This fact was not fully appreciated by any of the block manufacturers visited and consequently variable moisture contents were used at moulding. This fact also contributes to the argument for shortening batch-times, as water is progressively lost from the mix both in the hydration of cement and also by evaporation.

*3.1.4 Raw materials testing*

The material, either "soil" or "sand" to be stabilised is not adequately tested and the importance of the fines content is not understood. Thorough soil testing has always been advocated for soil-stabilisation but not for sand stabilisation. It has been found in the field that what is sold as sand, which should contain minimal quantities of material finer than fine sand (0.063mm) frequently contains high quantities of such fines. CSIR in Pretoria, South Africa have found supplies of "building sand" composed of over 50% clay. More commonly contamination is in the order of 25% fines, as observed in Zimbabwe, Kenya, Botswana and Ghana for unwashed pit sand. The proportion of silt and clay (the fines) present in the material to be stabilised plays an important role in determining the amount of cement needed for a given degree of stabilisation. It is the fines, particularly the clay fraction, which expand and contract on wetting and drying and consequently affect the durability of the cured block. Without an understanding of both the effect of the fines and the quantity present it is unlikely that the optimum use of cement will be made.

Although testing is advocated for soil stabilisation it has been found that this rarely happens. In fact in Tanzania the training given by Camartec to purchasers of their block press (Cinva Ram type) does not include how to test the soil. Instead Camartec technicians conduct soil tests on site and report to the producer the quantity of cement required. This is only a very short term solution to the testing problem as the composition of soil is highly variable and unlikely to remain at the tested composition once soil extraction extends from the immediate vicinity of the soil samples taken. Once the composition has changed significantly, the recommended cement content should also change. At present this does not happen and consequently cement use is not optimised.

The soil testing methods reported in the literature have been found to be lacking (see DTU working paper No 38 "Soil Testing for Soil-cement Block Production"), yet these publications usually form the basis for NGO organisations' knowledge. Hence where soil-testing information has been disseminated to block manufacturers by such organisations the information was found to be incomplete, faulty or misunderstood. High quality blocks may be produced with no soil testing whatsoever if adequate trial block production takes place. However without some form of testing and understanding, this process is extremely lengthy and was not observed in any of the countries surveyed.

*3.1.5 Quality control*

Quality control is usually not appreciated by the block manufacturer, in consequence there is a large degree of variation in quality, both between manufacturers and within the stock of a single manufacturer. Neither testing of the green compact nor testing of the cured blocks was observed. Most NGO projects had tested blocks at the start of production to determine the optimum cement content for the required strength but had not continued testing subsequently. Blocks produced by St Joseph's Mission (Kenya) were recently tested for compressive strength by the Kenyan Standards office and found to be only half of the value expected, 0.7 MPa compared to 1.5MPa. This is not surprising as the production of blocks had begun 12 years earlier, methodology was passed from operator to operator, degenerating over the years, and no quality testing had been implemented to monitor gradual changes.

Testing of the green blocks' density would identify production problems at an early stage, allowing quick remedial action to be taken. Testing of representative sample blocks for cured strength would serve as both an overall check on the production system and a useful marketing tool, namely the adherence of the block to the local building regulations. However although building regulations exist in nearly all urban areas, defining the minimum allowable compressive strengths of walling materials, they are not effectively enforced for low rise construction. Botswanan site inspectors rely on a purely visual assessment of the blocks (source Mr Maititing, Acting Director of the Department of Architecture and Building Services). Moreover the only one of the surveyed countries to have passed a standard relating specifically to soil-cement was Kenya (KS02-1070, 1992), in the other countries either no standard or only an unadopted draft standard exists.

Although the cement-stabilised production process is a simple one, it relies very heavily on tight quality control to achieve good results. The following is a summary of the factors which can cause block defects if not adequately monitored;

- soil/sand composition may vary considerably even if dug from a single pit
- inadequate mixing can produce a highly uneven distribution of cement
- mixing too large a batch of stabilised material at one time can reduce strength due to premature cement hydration

- incorrect moisture content at the time of moulding adversely affects the efficiency of compaction
- variations in the volume of mix placed in the mould for compaction affects the final density of the block and can seriously damage the machine
- inappropriate curing will allow the block, in particular the block surface, to lose the water required for full hydration of the cement, causing low strength blocks with poor surface durability

## 3.2 Compaction systems

### *3.2.1 Hand tamping*

This method of production was only observed for small, but relatively high value decorative ventilation blocks, carried out exclusively in the informal sector. These are particularly common in Arusha and Dar Es Salaam (Tanzania). It was not observed for larger sized building blocks except in one small Tanzania town and for an experimental investigation conducted by CSIR in South Africa, as the labour cost becomes excessive compared to mechanical compaction.

### *3.2.2 Low-pressure compaction*

The most common compaction equipment used for "soil" stabilisation is based on the Cinva Ram machine, invented in the 1950's. This slowly applies a pressure (usually less than 2 MPa) to the mix. These machines are generally produced in the informal sector although formal production does also occur. Table 3.2.2 details the most common type of machines observed in the African countries surveyed. Machine cost varies significantly with country of manufacture and quality of construction from £63 for a machine produced in Ghana under the supervision of the University of Science and Technology (UST) to £526 for a high quality machine incorporating sealed bearings, the Shelter Press made in Zimbabwe, commissioned by Intermediate Technology (Zimbabwe). The compaction pressure is applied mechanically by transmitting the force exerted by the operator to the contained mix through an over-centre toggle lever arrangement. There are a number of common problems both with the manufacture and use of these machines.

**TABLE 3.2.2 Cinva Ram type machines observed in Africa**

| Organisation | Country | Block size | Compaction Ratio | Novel features | Cost /£ |
|---|---|---|---|---|---|
| Camartec | Tanzania | 140x290 x100mm | 1.65:1 | none, has poorly aligned mould box | 92 |
| Approtec | Kenya | 140x290 x115mm | 1.7/1.9:1 | variable compaction ratio, secondary pivot to ease block ejection, slam-shut lid | 321 |
| IT (Zimbabwe) | Zimbabwe | 140x295 x120mm | 1.6:1 | Sealed bearings, sliding mould lid to automate removal and strike off after filling | 526 |
| RIIC | Botswana | 150x300 x115mm | 1.6:1 | none, has piston guidance problems | 159 |
| UST | Ghana | 200x290 x150mm | 1.5:1 | mould top linked to compaction handle so that removal is automatic | 63 |

The construction quality of these machines was found to be highly variable, some machines are manufactured using jigs to ensure correct alignment of parts (Approtec, IT Zimbabwe and UST) while others are not (RIIC and Camartec). Non-parallel mould boxes and misaligned compaction pistons were the most serious common faults, producing sub-standard blocks and quickly jamming and breaking down, sometimes after only weeks of use (experience of Habitat for Humanity, Botswana). Some of these machines have been modified from the original Cinva Ram design to include useful innovative improvements. A significantly improved machine could be produced by amalgamating the useful features seen individually world wide in many of these machines. However this is unlikely to happen without external assistance as the manufacturers/designers are not aware of machines outside their own locality. Several organisations are currently working separately to improve Cinva Ram type machines, including RIIC, Botswana Technology Centre (BTC) and IT Zimbabwe. If these organisations could effectively liaise then progress would be much faster and duplication of mistakes minimised. Both RIIC and BTC are working independently on interlocking block designs. The organisations are within the same country and less than two hours drive apart but are not currently collaborating.

Most of the machines operate on a fixed compaction ratio (typically 1.6:1), this determines the volume of the mould box at the time of filling. Different soils have different densities at the time of moulding and require different degrees of compaction in terms of the ratio of loose to compacted volume. This necessitates some form of batching to place the correct amount of mix in to the mould; too little and the block is under-compacted and weak, too much and the machine is over-stressed and liable to break. Batch-box filling was not observed in the field, both under-compacted blocks and machine breakdown were common. Overloading of the mould box was by far the most common cause of breakdown yet Approtec were the only organisation to have included the ability to vary the compaction ratio in their machine.

The significance of mould friction is not appreciated by block manufacturers. Research conducted by the DTU has shown that mould wall friction can significantly reduce the effectiveness of any applied pressure. To minimise this the mould should be lubricated with a release oil. This not only improves the compacted density of the block but also improves the block's surface finish and eases ejection. Mould lubrication is not currently common in any of the countries surveyed.

*3.2.3 Manual high pressure quasi-static compaction*

This type of machine uses the Cinva Ram toggle lever to first provide the majority of the compaction; final compaction to high pressure is then achieved by operating a hydraulic ram which acts on the moving piston. This type of machine is produced only in the formal sector. It is no longer in current use as it is very costly to purchase and has a reduced production speed since the hydraulic ram must be operated in addition to the toggle lever for each cycle. Although savings may be made in the cement used for a given degree of stabilisation the increased capital cost of a high pressure slow-squeeze machine (£ 3000-£4000) outweighs these savings. (See section 5.1 for new developments in the field of alternative high pressure compaction). Powered high-pressure compaction machines are also available but these are much more expensive eg the Ceratec machine seen in Botswana which costs £24,000, excluding ancillary powered mixing and sieving equipment.

*3.2.4 Slam-shut low-pressure compaction*

The slam-shut compaction machine was found in all of the countries surveyed. The compaction ratio of these machines is very low, a maximum of 1.3:1 if the mix heaped above the top of the mould is included. Consequently the mix is heavily pre-compacted by hand-tamping before repeatedly slamming the mould lid to achieve final compaction. This machine is made cheaply in the informal sector and its origins are unknown. It is less complex than the Cinva Ram and less prone to manufacturing problems. It generally costs slightly more than the cheapest Cinva Ram machine, eg £110 compared to £93 (cost comparison for Tanzania). In Ghana a slam-shut machine costs less than a Cinva style machine, 60,000 C compared to 111,000 C, but 300 wooden pallets are also required at an additional cost of 400 C per piece, increasing the effective cost to 120,000 C. This machine applies a variable compaction energy to the mix, depending on the degree of hand-tamping employed, the amount of mix contained in the mould and the number of blows applied by the lid. Consequently quality and consistency are dependant on the degree of care exercised by the operator. One informed Tanzanian manufacturer, Kunda Co Hardware in Arusha, attempted to ensure quality consistency by closely supervising production, always using the same operators for the same task and ceasing production if one of the team became ill, rather than hire a temporary replacement. Again batch-box mould filling was never observed.

Typically six blows are applied which equates to an applied energy of approximately 1kJ/block[5] (assuming an effective drop height of 30cm, for a mould lid weighing 15kg which is thrown down onto the mix by the operator applying a force of 400N, repeating the operation six times). The energy applied per block falls to 0.5kJ when two blocks are formed at once as is the case for some machines observed in Tanzania. 1kJ is a low level of applied energy. The DTU has found that slow compaction to the low pressure of 2 MPa requires an applied energy of approximately 2kJ (calculated for a block 290x460x100mm).

The low compaction achieved with slam-shut machines results in low density blocks with little green strength. In order to allow transportation from the compaction machine to the curing area the blocks are moulded on a wooden pallet which is then used to carry them. They are too weak to allow stack curing and consequently curing normally follows the "sun dried" pattern. Improving machine design to increase the amount of energy applied

[5] The standard size of block produced by these machines is either 290x460x100mm (4") or 290x460x150mm (6").

would allow the quantity of cement used to be reduced and also increase the green block strength, allowing further savings to be made by facilitating stack curing.

*3.2.5 Powered vibro-compaction*

In this process machines powered either by electric or internal combustion motors utilise vibration coupled with a very low confinement pressure to compact the mix; some machines finish the compaction cycle with an impact blow of moderate energy. Two types of these machines are common. The moving "egg-laying" type compacts several blocks at once; these are laid directly onto the ground where they are cured without moving (sun dried). The stationary machine produces one or two blocks per cycle which are ejected from the mould on a pallet (a pallet is placed in the bottom of the mould prior to filling) and carried to a separate curing area (sun dried). These machines are produced in the formal sector and are expensive, costing £6000 in Zimbabwe. They require a wetter mix for successful compaction than the impact machines and blocks are prone to slump. The size of the final block is dependant on the wetness and amount of mix placed in the mould and the length of time for which vibration is applied. The mould is filled and scraped off flush. However only volume and not weight of the charge is fixed; block heights were observed to vary as much as 10mm in Harare.

## 4 ECONOMIC ANALYSIS OF BUILDING MATERIALS COMPETING FOR THE URBAN AND PERI-URBAN MARKETS

Table 4.1 (below) shows the raw data, labour rates, cement costs etc which were gathered in the field and subsequently used to perform the economic analysis contained in the relevant country appendix. It also shows the best case for the costs of built-up walling using respectively, standard-size blocks made by conventional quasi-static compaction of soil-cement to low pressure, large-size blocks made by impact compaction of soil-cement to high pressure, sandcrete blocks, burnt bricks and quarry stone. In the Appendix J four methods of soil-cement production were modelled (using Kenyan costs). The most efficient of these methods, peri-urban micro-enterprise production, was the only method to be used in the subsequent analysis conducted for other countries. The full methodology is detailed in Appendix J and used for the remaining countries examined.

The ratio of labour wage to cement cost, row 14 in table 4.1, was thought to provide a good indicator of the economic viability of soil-stabilisation; however this has proved to be incorrect. Although this labour/cement ratio varies strongly from country to country, the cost ratios of standard block soil-cement walling to sandcrete walling (row 15) and of large block impact formed soil-cement walling to sandcrete walling (row 16) vary little. The results of the economic analyses show that using current low-pressure production, switching from sandcrete to soil-cement will reduce walling costs by between 11 % and 35 %. This is significantly less than the figure of 50% which has been quoted in the past. In previous studies only the cost of the individual walling elements have been compared, whereas in our study the cost of a built-up wall has been used for comparison. Consequently small blocks are disadvantaged. A larger number must be used per square meter of walling (usually considered in earlier analysis), more mortar is required (not normally considered) and they take more time to lay (not normally considered). Although this type of production method is less expensive than sandcrete, a cost advantage of 30% or less is unlikely to encourage the uptake of the technology in areas where social stigma is a factor. It should be noted that for this analysis the two production figures used (200 and 400 blocks per day for low pressure compaction) define the range generally achieved by self help and NGO projects, while the prices quoted for sandcrete are those charged by commercial yards where the production rate is much higher, even if quality is low. For example although 200 and 400 blocks per day was used as the basis for the Action Pack block press output, Approtec believe that with a suitably trained and motivated workforce the daily output could easily reach 800. If such outputs were seen in practice, as should be the case for micro-enterprise rather than self-help production, then this method becomes more attractive.

However with production rates of only 160 and 320 blocks per day, the hypothesised large-size, impact compacted block would cost significantly less than any other available durable walling material. The cost efficiency seen for this type of walling is principally a result of the method of compaction. Impact compaction, resulting in high uniform densification allows a deeper block to be produced which has enough strength to allow hollowing. The hollowing of the block reduces the mass of stabilised material used per square meter of walling. The high block density allows the percentage of cement to be reduced for a given strength. The larger size of the block allows further savings to be made in laying time and the amount of mortar required. Research conducted by the DTU has also shown that impact compaction, by virtue of its superior densification, will also be more tolerant of poor production methodology. It has also shown than a wider range of soils may be economically stabilised and that reduced porosity reduces the rate at which water is lost from the compacted block during curing.

**TABLE 1 COSTS FOR LABOUR, CONSTRUCTION MATERIALS AND BUILT UP WALLING IN THE PRINCIPAL COUNTRIES OF FOCUS** (figures given are in local currency)

| | KENYA | TANZANIA | BOTSWANA | GHANA |
|---|---|---|---|---|
| 1 exchange rate | 68.5 (£1) | 865 (£1) | 4.22 (£1) | 1780 (1) |
| 2 unskilled daily labour wage | 70 (£1.02) | 1000 (£1.16) | 5 (£1.18) | 1500 (0.84) |
| 3 foreman wage /day | 250 (£3.65) | 2000 (£2.31) | 35 (£8.29) | 3500 (1.97) |
| 4 skilled construction labour /day | 200 (£2.92) | 2500 (£2.89) | 35 (£8.29) | 3500 (1.97) |
| 5 cement cost /50 kg | 370 (£5.40) | 4000 (£4.62) | 10.95 (£2.59) | 6000 (3.37) |
| 6 sand cost /tonne | 1000 (£14.60) | 4286 (£4.95) | 22.6 (£5.35) | 7600 (4.27) |
| 7 soil cost /tonne | 429 (£6.26) | 1714 (£1.98) | 1.7 (£0.40) | 517 (0.29) |
| 8 machine cost (Cinva Ram type) | 22000 (£321) | 80000 (£92) | 670 (£159) | 111625 (63) |
| 9 cost /m$^2$ for internally rendered wall built with std size soil-cement block | 327 (£4.78) | 2970 (£3.43) | 16.45 (£3.90) | 4360 (2.45) |
| 10 cost /m$^2$ for internally rendered wall built with large size soil-cement block produced by impact | 213 (£3.11) | 1866 (£2.16) | 11.36 (£2.69) | 2551 (1.43) |
| 11 cost /m$^2$ for internally rendered wall built with sandcrete blocks | 457 (£6.67) | 3341 (£3.86) | 25.21 (£5.97) | 4880 (2.74) |
| 12 cost /m$^2$ for internally rendered wall built with burnt bricks | n/a | 3454 (£3.99) | 19.79 (£4.69) | 4796 (2.69) |
| 13 cost /m$^2$ for internally rendered wall built with quarry stone | 418 (£6.10) | n/a | n/a | n/a |
| 14 ratio of labour wage to cement cost | 5.29 | 4.00 | 2.19 | 4.00 |
| 15 ratio of soil-cement to sandcrete cost std size | 0.72 | 0.89 | 0.65 | 0.89 |
| 16 ratio of soil-cement to sandcrete cost large size | 0.56 | 0.56 | 0.45 | 0.52 |

# INTERVENTIONS

## 5 RECENT DEVELOPMENTS IN THE THEORY OF CEMENT-STABILISATION OF BUILDING BLOCKS AND PERTINENT INTERVENTIONS

### 5.1 Compaction, the effects of density on block quality and the superior densification of impact compaction

Research over many years, including that undertaken since 1990 by the DTU, has shown that block quality depends upon three main factors. These are materials selection, densification during moulding and curing. The effectiveness of the first and last of these depends upon the block-maker's skill and the expenditure on cement. Densification depends on the moulding machinery used as well as the moulder's skill. New knowledge in this field relates particularly to the densification process and its consequences: the most recent findings are summarised as follows.

The advantages of increasing the pressure of conventional quasi-static compaction were presented in section 1.3. An alternative method of generating high but transitory forces is through the use of a dynamic lever. A weight lifted slowly through a height gains potential energy. Once the weight is dropped its potential energy is transferred to kinetic energy. When the weight strikes a stationary object all of the stored kinetic energy is released in a very short distance, generating a large force. With quasi-static mechanical machinery the full compaction force must be transmitted through elements which move relative to each other, leading to high bearing wear rates and a short machine life, moreover this force must be transmitted through the body of the machine hence requiring it to be relatively massive. Impact machinery does not suffer these drawbacks nor does it suffer from the complexity associated with the inclusion of the hydraulic circuitry required to achieve compaction pressures above 2 MPa.

Recent research conducted by the DTU has found dynamic methods of compaction, utilising impact blows are also capable of producing high density blocks. Such blocks have a more uniform distribution of density and require lower levels of applied energy than do slowly pressed blocks. For example compaction to a mean density equivalent to that resulting from a quasi-statically applied compaction pressure of about 10 MPa was found to require 43% less energy. Moreover the improved density distribution seen with impact compaction was found to equate to a 24% increase in compressive strength for a given mean density. In combination these factors result in a 50-75% overall saving in the energy required to achieve a given compressive strength. In addition one of the main problems with quasi-static compaction, difficulty of block ejection, is overcome with optimised impact compaction. The dilation and subsequent contraction of the impacted material (which allows the more uniform density distribution to develop) also reduces the final lateral pressure exerted by the mix on the mould walls and consequently greatly eases ejection.

### 5.2 Possible interventions, immediate

There are thus four prime areas in which improvement may be made to the production of cement-stabilised building blocks; curing practice, production methodology, soil/sand selection and processing/compaction equipment. Crucial to the process of improvement is increased understanding of the pertinent factors both by NGOs engaged in promotional and support activities and the block producers themselves.

The prevalent poor curing practices observed in the field cause a significant under-attainment of compressive strength and durability. This is typically 20% but depends on the degree of adversity experienced by the blocks during curing, the amount of exposure to direct sun, air temperature, relative humidity and wind speed. Improved curing practice to maintain the moulding moisture content for at least seven days is very simple to implement, requiring no additional equipment other than a covering for the blocks. The intervention identified here would be to provide training to block makers, demonstrating the improvement in block quality resulting from good curing practice. Good curing resulting in either a stronger more marketable block or alternatively a cheaper block as a result of the cost saving resulting from cement optimisation if strength was maintained at the current level. Strength is approximately proportional to cement content, so a process-related 20% improvement in strength for a block where cement cost comprises 60% of the total cost could reduce the block cost by 12 % (the cement content may be reduced by 20%).

Similarly immediate improvements, either reductions in cost or increase in quality, will result from improved understanding, used to implement better production practice. Reduced batch times, optimum water content used for moulding, consistent mould filling (batch-box filling) and consistent compaction all increase the quality of the cured blocks.

Correct use of simple soil/sand testing procedures will enable the most appropriate use of the available material to be made, identifying unsuitable soil/sand which should not be used and allowing discrimination between alternative materials. Proper initial use of soil/sand testing can greatly speed the setting up of production while occasional subsequent monitoring can identify changes likely to lead to substandard production.

Improvements to current low-pressure compaction equipment are possible by amalgamating the various refinements seen in individual Cinva Ram type machines. These refinements will increase the production capacity of the individual machines by streamlining their operation and improving compaction consistency. For example a machine with a variable compaction ratio (as is the case for Approtec's Action Pack Block Press, Kenya), once its purpose, adjustment and operation are understood, will result in reduced variation of compacted block density and remove the risk of over-stressing the machine without resorting to batch-box filling.

### 5.3 Possible interventions, medium term

There are significant advantages in producing blocks of higher density than those obtainable from low-pressure, slam-shut or vibration machines. High-pressure quasi-static compression does not seem to be the answer; as argued earlier it is too slow and the machines are too costly. Impact appears to offer a more economic route to obtaining high and uniform density. Any refined impact machine should find a ready market in competition with the existing slam-shut machines and displace the vibration based machines.

The development of an impact-based machine capable of generating densities equivalent to 10 MPa quasi-static compaction should allow the benefits of high density mentioned above to be achieved in addition to the separate benefits of impact compaction. Any such optimised machine will compact with a much lower energy input than say a hydraulic machine, resulting in less operator fatigue if the machine is manually powered and less fuel consumption if motor driven. The robust simplicity of the slam shut compaction machine and its current popularity with block producers is a good indication that any improvement to this type of machine should find a ready market. A short life and high incidence of mechanical breakdown were the most commonly cited dissatisfactions with the Cinva Ram type machines. The fundamental problems with this type of machine (see section 5.1) are overcome by impact force application. Consequently provided an impact machine's mould box is designed to withstand the fatigue of small repeated shock loading, the machines life and reliability should be superior to the Cinva Ram.

A high-pressure prototype impact machine, the Ranko Block Maker (cost £120), was designed and successfully used by Agas Groth in Botswana in 1985 to produce blocks which were used in the construction of several houses. These houses have now been standing for ten years with no maintenance and are still in excellent condition. They should be compared with neighbouring houses recently built with high density blocks produced using mechanically sieved and mixed soil, compacted with the Belgium Ceratec and South African Hydraform machines which cost £24000 and £14000 respectively. These houses are already suffering from erosion.

## 6. FACTORS LIKELY TO AFFECT THE UPTAKE OF THE IDENTIFIED INTERVENTIONS

Sandcrete is an established material. The only barrier to extension of its use is its cost. The cost may be reduced through implementing the interventions mentioned. Operators are generally keen to reduce production cost and consequently the uptake of the interventions is likely to be high in this field.

If soil-cement is specifically promoted then there are factors likely to hinder advancement, those mentioned below are the dominant ones which will have to be contended with;

- Soil-cement has frequently been promoted as a low-cost walling material, which it is. However this ignores the social status associated with permanent housing. Namely the owners are prepared to spend ten years building a house rather than use "low-cost" materials because of the social stigma (see below).
- Standards dealing with soil-cement are not yet widespread, consequently soil-cement is not officially recognised as a permanent building material. Therefore planning permission cannot be given for dwellings built from it. Moreover the passing of national standards frequently requires local ratification. Kenya is the only surveyed country where a national standard relating to soil-cement has been adopted (KS02-1070, 1992). Local Kenyan building by-laws are changing but only slowly as these are modified on a district by district basis, frequently hampered by "personal conflict of interest". It should be noted that although standards do exist for sandcrete blocks these are infrequently enforced.
- The need for quality is often not appreciated in the informal manufacturing sector (neither in the soil-cement nor the sandcrete fields) where the majority of block production has taken place. It is one thing to demonstrate a cost reduction resulting from an improvement to a manufacturer's existing production method, which can be appreciated and another to generate interest in training from new manufacturers who believe the process to be simple. Recently a five day course run by Approtec (Kenya) on the proper use of its Action Pack block press machine has had to be shortened to two days in an attempt to increase participation by machine purchasers. The cost of the training course is included in the purchase cost of the

machine so that participants incur no additional fees. The non-attendance of purchasers must therefore be attributed to a lack of appreciation of its importance.

- The literature dealing with soil-cement production methodology is not adequate. Soil-cement is often presented as a simple process while in fact it relies on a significant degree of understanding coupled with a rigorous pre-production testing programme. While the labour force will have been trained in the mechanical operation of the machines which is a simple task, other aspects, such as detailed soil-testing and determining the optimum moisture content have been less rigorously taught and less well understood.
- The field training of existing block producers (both soil-cement and sandcrete) has frequently been conducted by technicians whose knowledge has been gained from the available published literature. This literature is not adequate and consequently the training given to block producers is frequently inadequate. In particular the coverage of methods of soil testing and final block quality are generally not adequate and not sufficiently emphasised.

The soil-cement block must be treated like any other commercial product and subjected to a coordinated marketing strategy. The prime aim of this strategy should be to de-stigmatise the product. Pronounced anti soil-cement stigma was observed in Kenya, Zimbabwe and South Africa. Stigma was also observed in the other countries surveyed but was found to be less pronounced. It is stressed here that at the moment a number of the criticisms which are sustaining the stigma associated with the technology are deserved. The soil-cement blocks currently produced frequently do display poor quality and vary greatly within batches. Although these deficiencies are also commonly shared with informal sandcrete block production it is the blocks marketed as soil-cement which are identified by both the general public and builders as poor.

If soil-cement can be demonstrated to existing sandcrete manufacturers in suitable locations and offered to them as a diversification product to be marketed as a cement-stabilised block, then the uptake of the technology is likely to be sustained (providing that the block quality is maintained). Soil stigma will be averted and the cost of building materials will be reduced. It is recommended that future promotion of both "soil-cement" and sandcrete be combined under the title "cement-stabilised building blocks".

## 7 TRAINING AND RESEARCH & DESIGN NEEDS IDENTIFIED

Further research is required to determine the most successful method of implementing training and the usefulness of additional ancillary equipment to promote quality control. It is envisaged that three types of training are required, one to provide a proper grounding for employees of NGOs and city councils involved in promoting low-cost housing and two for end users. Of the end user courses one should focus on the practical detail of correct soil preparation and machine operation for foremen/fundis and the other should be for machine owners interested in quality control, cost reduction and marketing.

This training should be fully supported with permanent reference material. The available literature has been reviewed by the DTU and it has been concluded that at present good reference material specifically concerned with cement stabilisation is not available, either to NGO technicians or more importantly to end users. Such literature as there is oversimplifies cement stabilisation: the production process is mechanically a simple one but it requires skill if it is to be cost effective. The soil/sand testing procedures reported in the literature have been found to be misleading and on occasion incorrect. No adequate explanation of the mechanisms underlying stabilisation have been found and in particular the field remains firmly split into separate soil-stabilisation and sand-stabilisation parts.

At present the only NGO/city council orientated training course is run by CRATerre in Grenoble France. This course places an emphasis on CRATerre's own field of focus namely unstabilised soil and improved soil architecture. There is a need for courses focused specifically on cement-stabilisation to be conducted within the developing countries. It is envisaged that a small number of such courses would be well subscribed and have a significant impact, provided that the information presented can be taken away in a permanent reference format.

At present there are almost no end user training courses and those which are available are under attended. The reasons given for the poor attendances were the length of the course and the financial impact to the participant of not working for the course duration. Such courses also have to contend with the additional difficulty of a highly mixed audiences. In Approtec's case (Kenyan NGO) although most of the participants were end users, some of these were foremen/fundis whose prime interest was the machine operation, others were owners whose interest was in optimisation of cost and quality and marketing, while still others were interested in construction methods.

Manual equipment for block production is often poorly designed and purchasers are unable to distinguish good design from bad. To further improve the production process the existing compaction equipment may be improved. The many various designs of machine available worldwide need to be quantitatively assessed. Bad machines must be improved or publicised as being deficient. Generally there is only one common design of machine in each country even if it is produced by several organisations. A competent external agency with no vested interest should be responsible for any such assessment, one outcome of this would be recommendations on simple improvements to individual machines and also if suitable a new amalgamated machine combining the useful features noted on individual machines. The design of any new machine should be circulated to all machine manufacturers.

This survey has indicated that dynamic compaction (impact) can potentially reduce block walling costs by 50%. Hence it appears worthwhile to undertake field testing and promotion of this moulding process. Research is required to develop a commercial "high-pressure" impact machine. Such a design would be based on the experimental research already conducted by the DTU into optimisation of impact compaction and the practical experience gained by Agas Groth with the Ranko Block Maker in Botswana.

# REFERENCES


1 ApproTEC.: A Sub Sectoral Analysis of Walling and Roofing Materials in Nairobi and the Environs. (ApproTEC, P.O.Box 10973, Nairobi. December 1993).

2 Botswana Technology Centre (BTC).: BTC Experimental Staff Housing Project Design and Construction Assessment Report. (Botswana Technology Centre, Architectural and Civil Engineering Units, Botswana, April 1995).

3 British Standards Institution: Methods of Testing Soils for Civil Engineering Purposes. doc. BS1377 (London, BSI, 1991).

4 British Standard Institution: Methods of Test for Stabilised Soil. doc. BS1924 (London, BSI, 1975).

5 Building Research Establishment.: Building in Hot Climates, A Selection of Overseas Building Notes. (London, H.M.S.O., 1980).

6 CRATerre.: Earth Building Materials and Techniques, Select Bibliography. (Eschborn, Federal Republic of Germany, German Appropriate Technology Exchange, 1991).

7 Doat, P. et al.: Construire en Terre. (Paris, CRATerre, 1979).

8 Enyatseng, G.R.: Research into the Application of the Ranko Block Machine. (Botswana Technology Centre, Gaborone, Botswana, Sep 1987).

9 Fitzmaurice, R.: Manual on Stabilised Soil Construction for Housing. (New York, United Nations, 1958).

10 Gooding, D.E.M.:Soil Testing for Soil-Cement Block Production - Working Paper No.38. (Coventry, Development Technology Unit, University of Warwick, 1992).

11 Gooding, D.E.M.:Quasi-Static Compression Forming of Stabilised Soil-Cement Building Blocks - Working Paper No.40. (Coventry, Development Technology Unit, University of Warwick, 1993).

12 Groth, A.: The Use of Impact Blows to Compact Soil-Cement Blocks. (Third-year undergraduate engineering project conducted at the University of Warwick, 1984).

13 Groth, A.: The Ranko Soil-cement Block Machine, Design, Manufacture and Testing of Prototype. (Motheo (Pty) Ltd, P.O.Box 2224, Gaborone, Botswana, 1984).

14 Groth, A.: CORDE Shelter Study, Final Report. (CORDE, Co-operation. Development and Education, P.O.Box 1895, Gaborone, Botswana, March 1994).

15 Gurusamy-Naidu, K.: Housing in Botswana, A Case for Soil Block Construction. (Botswana Technology Centre, Gaborone, Botswana, 1993).

16 Handbook For Building Homes of Earth. Department of Housing and Urban Development, Office of International Affairs, Washington, D.C. 20410 (undated).

17 Hawkins, A.M.: Soil Stabilised with Cement. (Third-year undergraduate engineering project conducted at the University of Warwick, 1988).

18 Haavaldsen, T.: Plaster for Soil and Soil-cement Walls. Basic requirements, materials and test results. (Building Research Unit, Ministry of Lands, Housing and Urban Development, Dar Es Salaam, May 1981).

19 Head, K.H.: Manual of Soil Laboratory Testing. (London, Pentech Press, 1980).

20 Ingles, O.G. & Metcalf, J.B.: Soil Stabilization Principles and Practice. (London, Butterworths, 1972).

21 Hoek-Smit, M.C.: Housing Demand and Preferences Study for Urban Areas. (Ministry of Local Government and Lands, Botswana, 1989).

22 International Labour Office.: Small-scale Manufacture of Stabilised Soil Blocks. (Geneva, Switzerland, Technology Series, Technical Memorandum No.12, ILO Publications 1987).

23 Intermediate Technology Development Group (Zimbabwe).: How to Make Stabilised Soil Blocks - Technical Advice Notes Number 2. (Harare, ITDG, undated).

24 Lawson, W.: Materials for Low-Cost Building in North East Nigeria - Working Paper No.35. (Coventry, Development Technology Unit, University of Warwick, 1991).
25 Lunt, M.G.: Stabilised Soil Blocks for Building in Building Research Establishment.: Building in hot climates, A Selection of Overseas Building Notes. (London, H.M.S.O., 1980).
26 Mason, K.: Sedimentation Jar and Linear Shrinkage Mould Tests - Suffix to Interim Report. (Report outlining results of Dr Peter Walker at the University of Zimbabwe, ITDG Zimbabwe, 1992).
27 Moriarty, J.P. & Therkildsen O.: Lateritic Soil-cement as a Building Material. (National Housing and Building Research Unit, Housing Division, Ministry of Lands and Urban Development, Dar Es Salaam. 1973).
28 Moriarty, J.P.: Earth Wall Construction in Tanzania. (Building Research Unit, Ministry of Lands, Housing and Urban Development, Dar Es Salaam, March 1976).
29 Mukerji, K.:Soil Block Presses. (Eschborn, Federal Republic of Germany, German Appropriate Technology Exchange, 1988).
30 Mukerji, K & Worner, H.: Soil Preparation Equipment. (Eschborn, Federal Republic of Germany, German Appropriate Technology Exchange, 1991).
31 Mwafongo, F.G.: Alternative Building Materials, Iringa Demonstration House. (Building Research Unit, Prime Ministers Office, P.O.Box 1964, Dar Es Salaam, 1984).
32 NBRI.: Low-cost Housing. (NBRI, National Building Research Institute, Council for Scientific and Industrial Research, Pretoria, South Africa, 1987).
33 Norton, J.: Building With Earth: A Handbook. (London, Intermediate Technology Publications Ltd, 1986).
34 Ola, S.A. & Mbata, A.: Durability of Soil-cement for Building Purposes - Rain Erosion Resistance Test. (Butterworth-Heinemann Ltd, Construction & Building Materials Vol. 4 No.4, Dec 1990).
35 Ophoven, P.: Compressive Strength of Walls built up of Mudblocks and Soil-cement Blocks. (Building Research Unit, Ministry of Lands, Housing and Urban Development, Dar Es Salaam, Jan 1977).
36 Parsons, A.W.: Compaction of Soils and Granular Materials: A Review of the Research Performed at the Transport Research Laboratory. (London, HMSO, 1992).
37 Perera, A.: Landcrete Blocks (Cement Stabilized Laterite Soil Blocks). (Department of Civil Engineering, University of Moratuwa, Sri Lanka, 1993).
38 Perera, A.: Low Cost House Using Cement Stabilised Blocks and Timber Poles. (Department of Civil Engineering, University of Moratuwa, Sri Lanka, 1993).
39 Petersen, J.: Experiments with Sample Testing Procedures for Stabilised Soil Blocks. (Rural Industries Innovation Centre, Kanye, Botswana, 1991).
40 Petersen, J.: Material Options & Cost Computations for Building Elements in Botswana. (Rural Industries Innovation Centre, Kanye, Botswana, 1992).
41 Spence, R.J.S. & Cook,D.J.: Building Materials in Developing Countries. (Chichester, Wiley, 1983).
42 Spence, R.J.S.: Predicting the Performance of Soil-cement as a Building Material in Tropical Countries. (Building Science, **10**, 1975)
43 Stulz, R.: Appropriate Building Materials. (London, U.K / SKAT. St.Gallen, Switzerland, Intermediate Technology Publications Ltd, 1983).
44 Sutcliff, J.: Quality Assurance of Stabilised Soil-Cement Blocks. (Third-year undergraduate engineering project conducted at the University of Warwick, 1994).
45 United Nations.: Soil-Cement its Use in Building. (United Nations Publication, Sales No.: 64.IV.6, 1964).
46 United Nations Centre for Human Settlements (UNCHS, Habitat).: Development of National Technological Capacity for Environmentally Sound Construction. (UNCHS, Habitat, Nairobi, Kenya, 1993).
47 United Nations Centre for Human Settlements (UNCHS, Habitat).: Report of the Workshop on the Network of African Countries on Local Building Materials and Technologies. (UNCHS, Habitat, Nairobi, Kenya, 1994).
48 Volunteers in Technical Assistance: Making Building Blocks with the Cinva-Ram Block Press. (Mt. Rainier, Maryland, VITA, 1977).
49 Walker, P.: STABILISED SOIL BLOCKS, The influence of Constituent Materials on Physical Properties. (Department of Civil Engineering, University of Zimbabwe, Mt Pleasant, Harare, Zimbabwe. Draft report September 1994)
50 Webb, D.J.T.: Stabilised Soil Building Blocks. (University of Newcastle-upon-Tyne, Ph.D. Thesis, 1988).
51 Williams, F.H.P. & Maclean, D.J.: The Compaction of Soil. A Study of the Performance of Plant. Transport & Road Research Technical Paper No. 17. (London, H.M.S.O., 1950).