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Environmental Water Related Deterioration of Compressed Stabilized Earth Block Structures in Uganda

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Abstract

The provision of shelter for all has not yet been realised. The main challenge is the high cost of building materials. Compressed and stabilised earth blocks (CSEB) are now recognised as low cost materials. While their green properties are well understood, the durability of these materials remain enigmatic. The objective of this research was to investigate the durability of CSEBs as used in the humid tropics. The interplay between the block and the effects of natural exposure conditions, especially the dynamics of rainfall, are examined. Through a methodology involving literature reviews, physical inspections, and exposure condition survey, block behaviour and defects over time are rigorously investigated. Water deterioration modes and their mechanisms of progression are discussed. The sources of water, agents, actions, effects, affected properties, and rate of deterioration are described. Defects were exhibited mainly as surface erosion, and cracking. However, it is still possible to improve the durability and wear resistance of CSEBs for use in the humid tropics. The improvement is achieved via lowered water absorption, and improved design codes, tests and standards. The findings are likely to contribute to the future widespread use of CSEBs. The findings raise a number of questions for further studies.

Keywords: Compressed Earth Blocks, Deterioration, Durability, Rainfall, Soil-Cement, Stabilization, Water

1. Introduction

Cement based building materials like compressed stabilized earth blocks (CSEB's) and concrete were for decades promoted as having an indefinitely long service life. That they would require only minimal maintenance or none at all over time. However, as these structures continue to be left exposed, it is becoming evident over time that even normal exposure conditions are actually more deleterious than originally thought. Occurrences of undesirable, unpredicted premature deterioration where defects are clearly visible even to the casual observer are becoming common. The main cause of deterioration is associated with the action of water on the surface and bulk of the block. The sources of water as an agent of deterioration were: liquid rain, hailstorms, rising damp, condensation and humidity from water vapour. The types of action include; abrasion, wetting, penetration, solvent, and catalytic. The effects include; erosive wear and tear, dampness, swelling, softening, dissolution, and initiation of chemical activity. Both surface and bulk properties are affected, with the former progressing at a higher rate than the latter. Defects in CSEB structures are mainly presented as surface erosion, volume reduction, volumetric changes, mass loss, cracking and crazing, surface pitting and roughening, detachment of render, exposure of mortar, and moulding. These deterioration phenomena have been predominantly witnessed in the wetter humid tropical regions of the world. No similar adverse reports have been documented from the hotter and drier regions.

In this paper, it is noted that while much research has been undertaken in the recent past on initial properties of CSEBs, very little similar research has been done on its durability. Recent advances have however been made in the durability research of comparable materials such as concrete. These are now well documented, and moves to redress identified shortcomings are following. A similar treatment is required in the case of CSEBs. The urgency is more acute. Interest in the durability of CSEBs is likely to become a major concern in the foreseeable future given the potential of the material in alleviating shelter backlogs in developing countries. Durability research is a complex undertaking. This is because in practice several causes of deterioration will occur simultaneously. These are compounded by cumulative as well as synergistic actions (Sjostrom, et al, 1996).

This paper is presented in six sections. After this introductory section, the rest of the paper covers the background, research objectives, methodology, findings and discussions, and conclusion.

2. Background

2.1 Brief

The majority of developing countries are today faced with an ever increasing problem of providing adequate yet affordable housing in sufficient numbers. In the last few decades, shelter conditions have been worsening yet resources remain scarce. Adequate shelter is one of the most important basic human needs, yet 25% of the world's population does not have any fixed abode, while 50% of the urban population live in slums. With the population in developing countries growing at rates of between 2% and 4% per year and the population in their major cities growing by double these figures, demand for low cost housing far outstrips the capacity to supply. No developing country without strategies for low cost materials is likely to meet its shelter targets. Developing countries planning to expand their housing stock for the low-income groups will inevitably need to identify the lowest feasible unit housing costs. The main costs of shelter provision are for building materials (about 60%), machinery, manpower, and loan interest repayments. Strategies are therefore urgently needed to develop low-cost, readily available and durable building materials. A naturally abundant material such as soil that is found on most of the surface of the earth should be a significant resource for building in developing countries. (Abdulrahman, 2009; Patowary, 2015). Research and development of stabilised soil as a building material is not new. The use of CSEBs can be traced back 50 years (Houben & Guillaud, 1994). From the early 1950s attempts were made to develop the material as an alternative walling unit to the modern and more expensive fired bricks and concrete blocks. The widespread promotion of the material was originally introduced via the United Nations. Continued interest in CSEBs will in future evolve around the several merits and attractions associated with its use. Firstly, as the basic raw material is soil, its source will remain abundant. This facilitates direct site-to-service application, thereby lowering costs normally associated with acquisition, transportation and production. Home ownership can then be delivered at comparatively low costs. Secondly, the initial performance characteristics of the material such as the wet compressive strength (WCS), dimensional stability, total water absorption, block dry density and durability are technically acceptable. They are also comparable to those of rival materials (Houben & Guillaud; Kerali, 2001; Debouch & Hakim, 2010; Patowary, et. al 2015). Houses constructed of CSBs also uniquely proffer better internal climatic conditions than other modern materials. Thirdly, promoting the use of CSBs generates more direct and indirect employment opportunities within the local populace than would be the case with other materials. Fourthly, use of the material contributes directly to the social, cultural and educational advancement of the population. Their use also contributes to the training and re-training of artisans and to the provision of new skills. Use of the material through the provision of local infrastructure such as schools, community centers, health centers and administrative units results in the promotion of human interactions and social development. Finally, use of the material is environmentally friendly, appropriate and correct since it utilizes the otherwise unlimited natural resource in its natural state. Moreover, this is achieved with little resultant depletion of other resources, or pollution and requires no excessive energy consumption and wastage as is the case with clamp fired bricks. The elimination of the need for wood fuel resources is seen as a major attraction over such bricks. The use of CSEBs is thus in keeping with current sustainable development strategies. Despite the above advantages however, as with most relatively new materials, shortcomings associated with their use have recently begun to emerge, especially in tropical environments. These regions are characterized by frequent and intense rainfall, high relative humidity and high diurnal temperature changes. CSEBs are produced from soil as the bulk constituent, over 90% (Gooding, 1994). Soil is known to have poor resistance to erosion and to disintegration in water, a low tensile strength, low resistance to abrasion, high water absorption and retention capacity, and is dimensionally unstable during cyclic wetting and drying. The vulnerability of soil has in turn led to blocks showing considerable defects over short periods under conditions of normal and severe exposure in the humid tropics. Whereas the initial building costs might be low, the subsequent high maintenance costs, or even early rebuilding costs are not acceptable to many. Some promoters have also done harm to the image of the material by claiming a high degree of long-term technical performance only to be contradicted by premature deterioration only a few years later. Although the problem is more acute in the humid tropics than in the arid zone, it nevertheless has not been seriously addressed by research. It is the long-term durability of the block, rather than any other factor that will be the key to their widespread acceptance (Gooding, 1994).

2.2 Durability and Deterioration in CSEBs

The terms durability and deterioration are perhaps the two most commonly used words in the field of construction materials. This section attempts to describe the basis of these two terms, and examines their relevance to the performance of CSEBs.

2.2.1 Durability

The word durability originates from the Latin word '*durabilis*' which means 'lasting' (Franklin & Chandra, 1972; Sjostrom et al, 1996). It can be used in the context of most building materials to mean resistance to weakening and disintegration over time. The term has been described in various ways by different authors although the substance remains the same in all cases. According to BS 7543 (1992), durability is defined 'as the ability of a building and its parts to perform its required function over a period of time, and under the influence of agents'. But according to BSI CP3 (1950), 'durability is a measure, albeit in an inverse sense, of the rate of deterioration of a material or component'. More recent definitions state that 'durability may be regarded as a measure of the ability of a material to sustain its distinctive characteristics, and resistance to weathering under conditions of use for the duration of the service lifetime of the structure of which it forms part' (Sjostrom et al, 1996; Abdulrahman Al-Sakkif, 2009). These definitions are too general to be of any practical use with CSEBs. The authors agrees with other scholars who propose that the definition and concept of durability be based on three key parameters, namely: the intended function of the material, the standardised conditions of its use, and the time the material is required to fulfil its functions (Sjostrom et al, 1996).

2.2.2 Deterioration

The term deterioration has been defined by several authors as 'the time-related loss of quality of a material, usually under the influence of environmental agents' (BRE, 1980). Premature deterioration has also been defined as 'failure to achieve the predicted service life' (BS 7543, 1992). The predicted service life of a block can be obtained from recorded performance or from accelerated tests. Unfortunately, such records are not available, as of now. Failure due to the inability of a newly made block to fulfil its functions has to be clearly distinguished from failure brought about by alterations in properties over the service lifetime of a block. Indeed most building materials will have some of their properties altered over time although their durability may not always be called to question. The durability of a block can therefore be regarded as its ability to resist deterioration. It can be treated as the reciprocal of deterioration under pre-defined conditions (Sjostrom et al, 1996).

Due to deterioration however, the durability of a block is unlikely to remain constant. It may in fact change considerably. The implication is that durability of a block and its deterioration are likely to influence each other mutually but negatively. As can be expected, the more a block deteriorates, the less durable it is likely to become over time. For example bulk properties of a block such as water absorption and permeability are related to the type of microstructure and density of the block. However, the microstructure and density of a block may alter appreciably due to weathering (deterioration). This alteration can in turn increase the water absorption and permeability of the block. Such increases are likely to accelerate the rate of deterioration due to softening and dissolution of any unbound soil particles in the block. Further loss of performance can then be expected. The limit at which the loss of performance can be considered unacceptable is not yet well defined in CSEBs. Unfortunately, even if it was, the limit may not be easily applicable without further qualification. This is because depending on the constituent materials used in a block, and on the quality of the processing methods used, no two blocks might be easy to compare. Unacceptable deterioration will therefore vary from block to block, and from property to property. Block properties that diminish over time reflect the past history of the block, both during and after manufacture.

3. Research Objectives

The objectives of this research were four fold, namely to: (a) identify the most critical water deterioration agents, their effects, and severity ranking; (b) understand the main mechanisms involved in water related deterioration, their modes of progression and propagation; (c) suggest measurement techniques to quantify the main outputs of water related deterioration; and (d) recommend selected remedial measures.

4. Research Methodology

There is very limited information available on the long term behavior of CSEBs. This is partly because no prior extensive research has been conducted in the area. It also partly because inspection and maintenance records on the performance of blocks are not available. In view of such circumstances, the use of a combination of various approaches was considered to be inevitable. These approaches included: 1. *Literature review*: to establish the level of current thinking and knowledge, and to provide the intellectual context for the research. 2. *Exposure condition survey in the humid tropics*: done through: (a) inventorisation of CSEB buildings and characterizing their exposure conditions, (b) visual inspection of buildings to identify defect types and their severity rankings, and (c) in-service condition measurement of the main defect types.

5. Findings and Discussions

Deterioration mechanisms in CSEBs are varied and complex. From the literature and experience gained through the use of the material, laboratory tests, building inspection records and the exposure condition surveys, three main deterioration modes can be identified, namely: water related deterioration, temperature related deterioration, and chemical based deterioration. This paper discusses findings from research on water related deterioration. Over seventy-three CSEB structures were visited during the rainy seasons of March to May and September to November (UDIH, 2011). There was a convergence in the findings.

Water related deterioration mechanisms account for most of the observed premature deterioration defects in CSEBs (Kerali, 2001; Obonyo, Exelbirt, & Baskaran, 2010). Water also serves as a common denominator for other deterioration mechanisms occurring in blocks. The main sources of water linked to such deterioration mechanisms are rain, rising damp, condensation and vapour. It was found that the action of water in causing deterioration in blocks occurred in any one or all of the following ways: solvent action, abrasive action, wetting, penetration, swelling action and catalytic action. It was established that the effects of water include: erosive wear and tear, dampness, swelling, softening, dissolution, and catalytic action for chemical activity. The main common defects observed include: volume reduction, mass loss, pitting, roughening, volumetric changes, and moulding. Solvent action and surface abrasion are discussed in this paper. For each action, an attempt is made to describe its nature, where it occurs, when it occurs, why it occurs and how it is likely to occur in a block. Where possible, references to similarities and differences with associated mechanisms in concrete materials are examined.

The *solvent action* of water is one of the most common deterioration mechanisms occurring in many building materials (Sjostrom et al, 1996; Guetala, Abisi &Houari, 2006). It was observed that the ability of a compressed stabilised earth block surface to easily get wet, and the capacity of the block to absorb and retain water for sufficiently long periods of time, are two properties likely to leave the material vulnerable to the solvent action of water. The composition of a block fabric itself might also contribute to its vulnerability. Over 90% of the block bulk consists of soil, with the other 10% or less consisting of cement and/or lime (Thomas, 1994). In a stabilised block matrix, the process of cement-stabilisation is known not to affect all the constituents in the block (Houben & Guillaud, 1994). Moreover, the hydration reaction between OPC and water which is responsible for the binding action in the block also produces soluble by-products such as calcium hydroxide (Young et al, 1998). The microstructure of a block consists of materials which are juxtaposed with capillary pores. The block is therefore able to attract water and retain it. As water permeates the block, any unstabilised soil fraction present, together with the freed calcium hydroxide from the hydration reaction of cement, can be expected to dissolve. Dispersal and subsequent leaching out of these substances can then follow. It was noted that repeated action of this nature over the years led to overall softening of a block fabric. Such action can also have the effect of weakening and altering the microstructure of the hardened cement matrix in a block. The microstructure of a block is therefore likely to continue evolving throughout its service lifetime. This is a detrimental trend since the softening and leaching action is irreversible. It was established that the severity of the action of water increased during the rainy seasons. It was also found to depend on the proportions of materials present in the block which are vulnerable to dissolution and softening. Unfortunately, as this form of deterioration progresses, it has the adverse potential of making the block more vulnerable to other forms of deterioration such as the erosive action of rainwater droplets. It is recommended that the solvent action of water in causing deterioration requires further investigations both experimentally and under in-service conditions.

Surface abrasion by rainwater has been identified as one of the most common deterioration mechanisms associated with water (Walker, 2004). Fortunately however, surface erosion only occurs in areas prone to frequent and intense rainfall such as obtains in the humid tropics. The researchers found that CSEBs remained intact in parts of north east Uganda that are semi-arid. The mechanism of surface erosion in blocks may not yet be well understood but the phenomenon is thought to proceed as follows. When rainwater strikes an exposed block surface, it will directly impact on it, with part of it turning into a spray. While the effect of the impact can be linked to the removal of loose particles, the effect of the spray is more likely to first wet the block surface. It has been estimated that up to 75% of the energy of a raindrop is dissipated on impact (Kirby, 1980). It was found that the erosivity of raindrops depended on the state of bonding of the block surface, its location within the wall, and on the characteristics of the rain. The main characteristics of rain are defined by the drop size, its distribution, fall velocity and impact kinetic energy (Hudson, 1963). It is therefore the interaction between the raindrop size, velocity and shape, storm duration and wind speed that is likely to control the erosive power of the raindrop. It would be reasonable to expect that the higher the impact velocity of a raindrop and the weaker the state of bonding at the block surface, the greater would be the effect of surface erosion. Conversely, the lower the impact velocity of a raindrop, the greater is the effect of the raindrop forming sprays on the surface of the block. Any detached soil particles, (usually assumed to be from the unstabilised fraction of the block surface fabric), can then be easily removed by the resulting wall surface flow. It was found that the effect of surface abrasion was irreversible. The defects linked to this process are discernible even to the casual observer. The observed defects include recessed wall surfaces and volume reduction caused by mass loss. Indirect effects of surface erosion include lowering of surface hardness, lowering of compressive strength, loss of rigidity, lowering of density and increase in permeability. The loss of mass from a block surface can have other more serious consequences. Given the mechanism of quasi-static compression used in forming blocks, their inside core is the part least affected by compaction. The difference in compressive strength between the block surface and its core was found to be between 6 and 15% (Gooding, 1994). The core of the block can therefore be considered to be its weakest region. As can be expected, exposure of the interior due to recessed surfaces can lead to the speeding up of the rate of deterioration. Extra measures are therefore needed to strengthen the block surface in order to protect its bulk from exposure.

Unlike in CSEBs, the phenomenon of surface erosion (to the extent it occurs), has not been widely reported in concrete literature. Given the low amount of OPC used in CSEBs (5-8% by weight) as compared to concrete products (12-14% by weight), weaker inter-particle bonding in the former can be expected. Moreover, even with the low amount of cement used, full hydration of the binder might not be fully achieved. This is because unlike in concrete where the water-cement ratio can be pre-determined accurately, the effective water-cement ratio in CSEBs is still difficult to define. Moreover the water required for the hydration of cement is shared between the cement and the highly hydrophilic clay in the soil. The water is also required to be at an optimum level to fully lubricate the soil particles to achieve maximum densification. The equilibrium between these three requirements for the mix-water are not yet fully understood. Until this is done the incomplete hydration of OPC will continue to lead to weaker block fabrics. A denser, homogeneous and impermeable block surface would probably minimise the effect of surface erosion more than one which is not. It is recommended that the severity of surface erosion be investigated further.

6. Conclusion

It can be concluded that the concept of durability and its expression are not well covered in CSEB literature. It is proposed that expressions of durability in CSEBs should revolve around three factors, namely: intended function of a block, the expected service conditions, and the time taken to satisfactorily fulfil the functions. It was established through building and structural surveys that even under normal service conditions, deterioration agents can still influence the durability of a block. Under more severe conditions of exposure such as in the humid tropics, the effects of deterioration agents can lead to the premature deterioration of blocks. The durability of a block can therefore be regarded as its ability to resist deterioration. It was noted that due to deterioration, the durability of a block is not likely to remain constant, but can vary over time. Performance characteristics which were initially deemed satisfactory at the time of production can alter appreciably for the worse over time. Durability and deterioration therefore influence each other mutually but negatively.

It can be further concluded that the one of the main principal agents likely to influence the performance of a block while in service is the action of water. It was found that water related deterioration mechanisms represented the main forms of deterioration in CSEBs in the humid tropics. Water-related action not only causes loss in mass on the block surface due to wetting and abrasion, but also contributes to the initiation and propagation of otherwise dormant chemical activity. Water related deterioration was found to occur in various forms: solvent action, abrasive action, swelling action, catalytic action and dampness. The main effects were found to be: erosive wear and tear, dampness, swelling, softening, dissolution, and catalytic initiation of chemical reactions. The common defect types included: surface pitting, roughening, mass loss, volume reduction, volumetric changes and moulding. The severity ranking was found to be high and the speed of deterioration relatively fast. It is recommended that total quality management controls be observed during the production of CSEBs. Further that improved building codes and standards are required to protect blocks exposed to rainwater and other forms of moisture. It is recommended that further research be undertaken on all aspects of water-related deterioration mechanisms.

References

Abdulrahman, A. Y. K. (2009). *Durability Properties of Stabilised Earth Blocks.* PhD Thesis. University of Sains, Malaysia

British Standards Institution. (1950). Durability. *BSI, CP3: 1950*, London, England

British Standards Institution. (1992). Guide to Durability of buildings and building elements, products and components. *BS 7543: 1992*, London, England

Deboucha, S; Hashim, R. (2010). A Review of Bricks and Stabilized Compressed Earth Blocks (CSEB). *Scientific Research and Essays*, 6 (3), 499-506

Evans, R. (1980). *Mechanics of water erosion and their spatial and temporary controls: an empirical viewpoint.* Chichester: John Wiley and Sons

Franklin, J. A. & Chandra, R. (1972). The Slake Durability Test. *International Journal of Rock Mechanics,* 9, 325-341, London, England

Guetala, A., Abisi, A. & Houari, H. (2006). Durability Study of Stabilised earth concrete under both laboratory and climatic conditions exposure. *Construction and Building Materials*, 20(3), 119-127

Gooding, D. E. M. (1994). *Improved Processes for the Production Soil-Cement Building Blocks.* PhD Thesis, University of Warwick, Coventry, England

Houben, H., & Guillaud, H. (1994). *Earth Construction: A Comprehensive Guide.* London: Intermediate Technology Publications

Hudson, N. W. (1963). Raindrop Size Distribution in High Intensity Storms. *Rhodesian Journal of Agricultural Research*, 1(1), 6-11

Kerali, A. G (2001). *Durability of Compressed Soil Cement Block*s. PhD Thesis, University of Warwick, Coventry, England

Kirkby, M. J. (1980). *Modelling Water Erosion Processes in Soil Erosion*. Chichester, England: John Wiley & Sons

Laws, O. J. (1941). Measurement of the fall-velocity of water-drops and raindrops. *Transactions-American Geophysical Union*, 22, 709-721, USA

Obonyo, E., Exelbirt, J & Baskaran, M. (2010). *Durability of Compressed Earth Bricks: Assessing Erosion Resistant Using the Modified Spray Testing*. Sustainability, ISSN 2071-1050

Patowary, B. N. et al. (2015). Study of Compressed Stabilized Earth Block. *International Journal of Scientific and Research Publications,* 5(6), ISSN 2250-3153

Walker, P. J. (2004). Strength and Erosion Characteristics of Earth Blocks and Earth Block Masonry. *Journal of Materials in Civil Engineering,* 16 (5), 497-506

Sjostrom, et al. (1996). Durability of Building Materials and Components 7: Prediction, Degradation and Materials. *Proceedings of the 7th International Conference on Durability of Building Materials and Components,* 19-23 May, Stockholm, Sweden

UDIH. (2011). *Uganda Districts Information Handbook*. Kampala: Fountain Publishers Ltd

Young, L. F. et al. (1998). *The Science and Technology of Civil Engineering Materials.* New Jersey, USA: Prentice-Hall