INNOVATIONS, APPLICATIONS AND STANDARDS OF COMPRESSED STABILISED EARTH BLOCKS (CSEB)

A.A.D.A.J. Perera,

Senior Lecturer, University of Moratuwa, Sri Lanka

INTRODUCTION

Soil and Timber are the oldest building materials that man has used and probably will in the list of last as well. This is due to fact that soil is the most abundantly available material and while timber is the material that can be harvested by growing. Buildings that had been constructed with soil but more than 4000 years are in existence. Man has learnt the use of soil for building construction by doing and knowledge has passed down to generations. More than twelve construction methods have been documented (Figure 1) for soil and compressed stabilised earth blocks (CSEB) is the most recent. As such, CSEB can be stated as the most innovative of soil based construction.

The application of CSEB for buildings in the environment where regulatory approvals are required faces many obstacles. The first main obstacle is the lack of standards and specifications. Many countries have managed to put up significant number of buildings but comprehensive standards and specifications are yet to be developed and to be approved by relevant authorities. In USA there is an appendix to the building code (1), in India there is very short standard (2), in Australia there is a code of practice (3) and in the New Zealand there is a standard (4). In 2007 and 2008, Sri Lanka Standard Institute developed comprehensive standards for CSEB. In the development of standards, the critical factors that should be included should be established first. Secondly a formal standard required to be written and approved by a relevant authority.

One attractive character of CSEB construction is the use of innovative materials and construction methods. Many buildings have used innovative structures such as domes and vaults. Further the use new materials such as cement:soil:sand plasters, cement:soil:sand mortars, cement:soil:water paints and new wall construction methods such as rat-trap and interlocking methods are common. There were many recorded failures and those have been contributed to create a negative image and have slow down of the applications of CSEB. The objective this study is to establish the critical factors for the application of innovative methods and the factors that should be included in standards and specifications of CSEB.

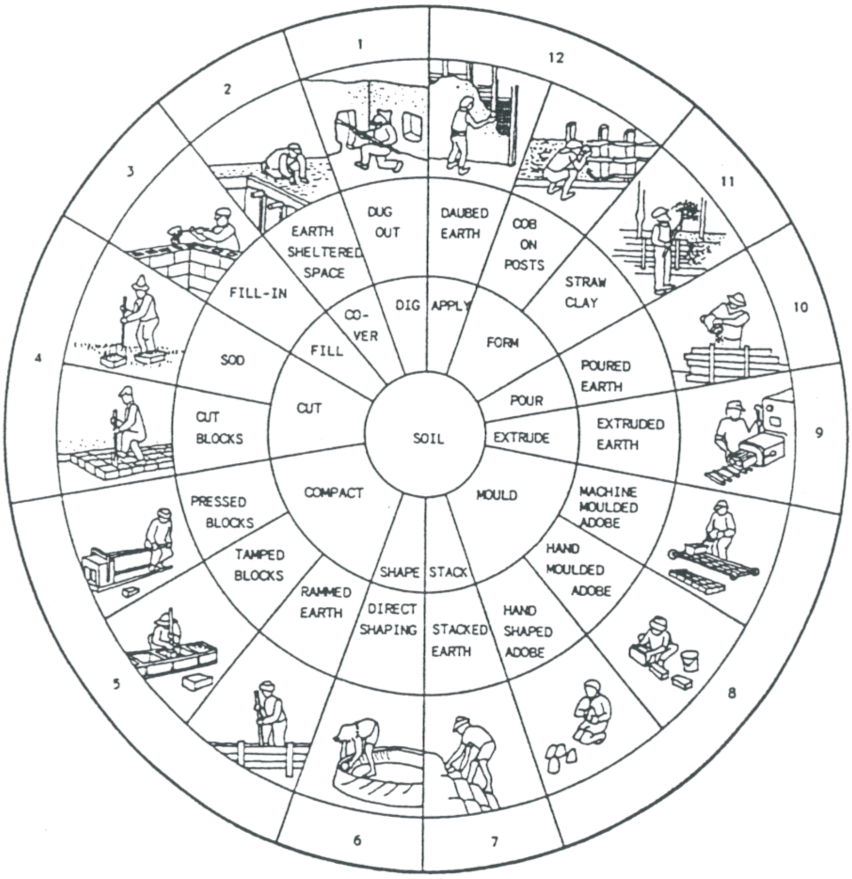

Figure 1 Soil Construction Methods

HISTORICAL REVIEW ON THE APPLICATIONS OF CSEB

Construction with stabilized earth really got off the ground with the development of the CINVA RAM in 1952 in Columbia. There were also a host of technical publications about stabilized earth (5; 6; 7; 8; 9). Several attempts had been made to use CSEB in Sri Lanka. The first recorded attempt was in mid 1950's where government received around 100 CINVA ram machines from abroad. Several building including a workshop of the Technical college in Batticola and one bungalow were built. Little or no information was provided on the selection of soils, production procedure of blocks and construction of walls. There is no evidence of further use CSEB in 1950s. The second recorded attempt was made by State Engineering Corporation(SEC) in 1970s. SEC built their laboratory in Colombo with CSEB and still in use with minor problems. However, many attempts made by SEC ended up in failures particularly housing projects in rural Sri Lanka. The investigations carried out in 1990 reveled that many failures were due bad soils. University of Moratuwa made an attempt for research and development and application from 1991. First, research was carried out to understand the critical parameters of soils and best stabilization methods. Further better press machines (Auram Press 3000) were introduced to produce better CSEB. Construction of houses had been performed together with National Housing Development Authority and some non governmental organizations. This attempt made more than 400 houses by year 2000 where a lot of interest was generated among house builders as well building material producers. From 2002 onwards, commercial block manufacturers started production and blocks are now available in building material market. As per records of private manufacturers, more than 6000 houses have been built in Sri Lanka within the last five years using CSEB.

The recent Sri Lankan experience too recorded with successes and failures. Some reconstruction work of Tsunami of 2004 recorded the most critical failures. Two housing schemes (total of 160 houses) were demolished and rebuilt with traditional walling materials due to failures of CSEB. The failures were due to bad soil selection, non involvement of Engineers, poor block production and poor construction methods. The failures called many professional bodies including Sri Lanka Standard Institution and ICTAD (Institution for Construction Training and Development) to call for standards and specifications for CSEB. Formulation of standards for CSEB was completed in April 2009.

The application of CSEB was first attempt for low cost house construction and faced many additional problems. First, it was difficult to convince the poor the new innovative CSEB is satisfying the requirements to be a wall construction material and method. Many village masons too did not accept it as permanent building materials. Further many attempts were made with non governmental organizations where the technical expertise was not available. On the other hand, when private manufacturers approach middle and upper income groups with CSEB many were attracted to the new features such natural appearance of walls, thermal comfort and environmental considerations. This in turn helped to obtain better acceptance by the low income groups as well. The experiences of other countries too are similar. As such, one could conclude that in the case of innovative building materials first it is necessary to complete the research and development to a satisfactory level, good test applications, development standards and specifications and introduction to the general building industry. Introducing to selected segments such as low income groups should be avoided.

THE INDIAN EXPERIENCE OF CSEB

Some of the early experiments in house building with stabilized earth took place in India. 4000 rammed earth houses using 2.5% cement stabilization were built in Karnal, Haryana, India in 1948 (10). Although this experiment was based on research at Karnal and Lahore, the experiment was not a success. It did not lead to construction of more houses. The main reason is unsatisfactory performance of the stabilized earth. The plastering was peeling off in many walls and the public and the engineers felt the technology was unsatisfactory. About 260 houses were built in Bangalore in 1949 using hand rammed earth blocks with 5% cement stabilization (11). A few of these houses are in use even today although the performance of the walls was not satisfactory. Some of the blocks from demolished buildings had wet compressive strength of the order of 1.5 MPa. Again, the experiment was not successful in that the idea did not spread further.

All these disparate forays into new technology were not mediated by sustained R & D activity. There were no attempts to analyze the causes of the failure of the technology and the means to remedy these causes.

The formation of CRATERRE in France and ASTRA in India in the early seventies represented new initiatives in the use of stabilized earth. These initiatives had a more systematic approach to R & D, information dissemination and technology remediation in the event of local failures of technology. ASTRA (Application of Science and Technology to Rural Areas, Indian Institute of Science) at Bangalore ran a Research and Development Project for about 15 years from 1979. During this period, 3 Manual presses were developed, around 250 Engineers and Architects were trained in Earth Block Construction. More than 100 soil samples were tested to understand their suitability for earth construction. Several research dissertations were produced documenting the relevant information (8, 9, 10). Experimental construction of several stabilized earth buildings also took place in and around Bangalore in the same period and this experience helped in validating the research experience through actual construction. The private sector laboratory MRINMAYEE was set up in the nineties and between MRINMAYEE and Indian Institute of Science more than 500 soil samples were tested from all over India to support the spread of stabilized earth construction.

The contrast between the technology dissemination efforts in the late forties and in the seventies is now clear. Lack of R & D back up led to the infant mortality of the earth technologies in the forties. On the other hand, the efforts at ASTRA in the late seventies involved sustained R & D back up for a couple of decades. The results now show the importance of sustained knowledge support systems in the spread of any new technology.

Today, the stabilized earth block technology is alive and kicking in Bangalore and Mysore districts, Kutch district, Meghalaya and Southern Orissa. The sustenance of spread of technology in Kutch district is mainly due to the Institutional support provided by 'Hunnar Shala'. India can now talk of more than 12,000 buildings using stabilized earth (11). The support of the information back up at Auroville has also been responsible for the spread of earth technology in several locations like Pondicherry and Sivaganga district in Tamil Nadu.

Today, more than 200 earth buildings are built in Bangalore and Mysore every year. In the seventies, there used to be one or two buildings built in Bangalore every year on an experimental basis. In the first few years, most of the buildings were built by ASTRA and Indian Institute of Science for their own use.

In that sense, ASTRA escorted the new technology over a period of 10 years before the technology could mature and grow out of infancy. The slow, measured approach of ASTRA gave lot of time for midstream corrections and technology up gradation.

THE INTERNATIONAL EXPERIENCE

The international scene in stabilized earth construction is also encouraging. The Mayotte experiment, with the support of CRATERRE (12) is a success story. The technology has also taken root in Phillipines (13). The recent efforts of Hunnar Shala of Gujarat and in Indonesia again demonstrates the condition necessary for successful spread of stabilized earth technology.

There is also a considerable interest in Germany in earth construction. The formation of Dach verband Lehm in Weimar (14) is an indication of the active German interest in the use of earth. Germany had produced several DINs for the use of earth in rammed earth and earth block walling in 1956 indicates the survival of earth construction interests in Europe.

The development of Earth Building Standards in New Zealand (15) is again proof of the survival of earth construction interests in the developed world. It is now clear that there is a need for consolidation and networking of earth construction groups all over the world. The way out is not easy since there are several serious barriers that need to be overcome before earth construction becomes more widespread.

CURRENT STANDARDS FOR CSEB

CSEB was first introduced in 1950s and earth construction methods have a very long history. However, the development of standards and specifications related earth construction methods are very poor and Table gives a summary of available standards.

Table 3 Available Standards for CSEB

Publication	Standard or Code of Practice	Critical Parameters
IS 15:1725-1982 Specification for Soil Based Block Used in General Building Construction: First Revision (2)	Standard	Block sizes, Compressive Strength (not less than 20 kgff/cm2), water absorption (not more than 15%)
Australian Handbook of Earth Construction (3)	Handbook	Covers many aspects of earth construction. Defines soil parameters, construction methods including rammed earth.
New Zealand Standard on Earth Construction (4)	Standard	Covers many aspects of earth construction. Defines soil parameters, construction methods including rammed earth.
New Mexico Building Code (1)	Appendix to standard	Brief addition to cover aspects of earth construction.

CRITICAL PARAMETERS FOR A STANDARD FOR CSEB

It is very important to identify the critical parameters that to be included in standard of CSEB. This is the task given to the steering committee, which consisted of 8 practicing engineers and two academics. The steering committee held a joint session with experts from Indian Institute of technology. The following parameters were finally agreed after review of many published literature and discussions on experience.

Table 4 Critical Parameters of CSEB for standards

Parameter		Minimum required value
Critical parameters related to finished CSEB	Dry density	1750 kg/m3
	Water absorption	Less than 15%
	Dry Compressive strength	More than 2.8N/mm2
	Wet Compressive strength	More than 1.2 N/mm2
	Flexural strength (bending strength)	More than 0.5 N/mm^2
	Pitting depth (Erosion resistance)	Less than 10 mm
	Linear expansion of block upon saturation with water	Less than 0.10%
Critical parameters of soil for CSEB block production	Sand and gravel	More than 65%
	Silt	5% to 20%
	Clay	10% to 15%
	Plasticity Index	Less than or equal to 12
	Ph value	Between 6 and 8
Stabilizer	Cement	Not less than 5%

The dry density of blocks depends on soil types, moisture content of time of production and compressive force of block manufacture. Further dry and wet compressive strength too depends on dry density. Many researchers have established the relationship of dry density these parameters. Higher dry densities require higher force for compression and closely related to the cost of block production. Water absorption, pitting depth and linear expansion of block upon saturation with water are close related to each other and all parameters measure the durability. Long term durability is one of the main problems of CSEB, which is not so common with burnt bricks or cement:sand blocks. The requirement of compressive strength depends on the structural application and 1.2N/mm2 wet strength is adequate for buildings up to two storey.

The parameters related soil is probably the most critical for both strength and long term durability. Many buildings have shown problems of surface durability problems. The best way to control the durability is to control the clay content, shall be between 10% to 15%. This very narrow band but is the most critical parameter. The gravel, silt and sand requirements govern the ability to produce good CSEB.

INNOVATIONS OF CSEB

The use of vaults and domes are main characteristics of innovative buildings using CSEB. Yogandara and Jagadish (12) given construction details of 22 vaults and 13 domes in Karanataka and Tamilnadu states. The 22 vaults have been constructed with variety of methods including mobile formwork (3 cases), templates (18 cases) and mud centering (1 case). The spans of 22 vaults varied from 2.3m to 4.5m while lengths varied from 3.3m to 10.6m. Many others have reported the use of vaults and domes for innovative construction. In some buildings vaults were hidden, in some building incorporated to be architectural feature (Figure 3), in some to obtain more living space. The house with a vault roof shown in Figure 2 has first floor accommodated in the vault for additional space. The two houses shown are constructed as model houses for large low income housing project for people to select. This gave a good opportunity to people evaluate the innovative materials, methods of construction and designs. The people selected the new materials, wall finishing methods with mud paints but did not select the innovative design of the house with a vault roof.

Figure 2 Model houses of a housing project

Figure 3 A Chapel with vault with CSEB

Figure 4 Large house with vaults and domes

Figure 5 Two storey house with Vault

INNOVATIVE METHODS AND MATERIALS OF CSEB

Many innovative methods and materials have used with CSEB. It is now a common practice to use cement:soil:sand mortars and plasters with CSEB for wall construction. The mixes specified in CSEB standard of Sri Lanka are 1:2:5 (cement:soil:sand) for mortars and 1:3:6 (cement:soil:sand) for mortars. The innovative rat-trap bond is commonly used with CSEB in India and Sri Lanka. Rat-trap bond is superior with heat and sound insulation as well as generally cost 30% less than English bond.

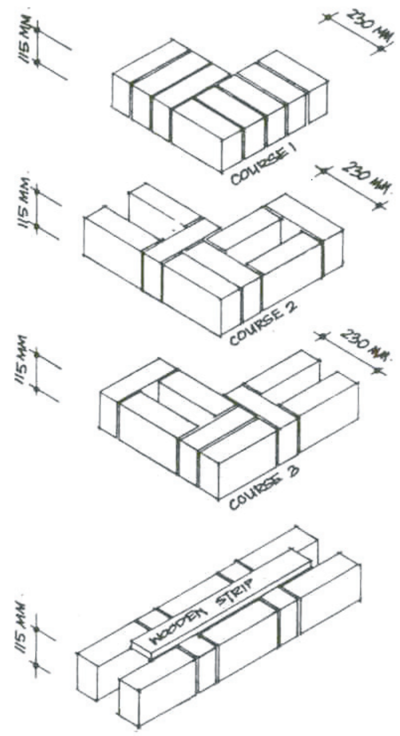

Figure 6 Rat-Trap Bond

CONCLUSIONS AND RECOMMENDATIONS

Soil based construction methods have history of more than 4000 years and CSEB is the latest method. The knowledge and experience on CSEB has come long way and now has the potential for wider applications. The applications of innovative methods good knowledge on critical factors is the most crucial and the applications of CSEB has many evidence. The establishment of standards and specifications are crucial for any innovative application. The use of innovative design and construction related vaults and domes have shown success with CSEB. The main success is the use of dedication of designers and construction personnel. Many failures were reported with building constructed with CSEB mainly due to lack of understanding of critical parameters, absence of standards and specifications and poor quality control.

Any innovative method should complete the development of standard and specifications before the applications. The test applications should not go beyond without proper standards and specifications. This appears is common sense but the history of CSEB applications shows otherwise including many developed countries.

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