Earth as an Energy Efficient and Sustainable Building Material

Sangeeta Roy[1], and Swaptik Chowdhury[2]

***Abstract*—**This paper presents the study on components developed of earth as an alternative to conventional building materials like steel and concrete. Earth is the most commonly used building material used by almost 40% of world population. In those areas of the world (e.g. Africa, South America, India) where concrete or steel housing is unaffordable to many of the unprivileged section, building materials developed of earth offer a cheap, energy viable and sustainable alternative. There are several techniques of earth construction like Adobe (CSEB), PISE (Pneumatically impacted stabilized Earth), use as plaster and as an insulating material. This research paper is mainly focused on using building components manufactured from earth as building material. Unlike burnt clay brick, CSEB and other earth products are not burnt but are stabilized by pressure so their carbon foot print and embodied energy is very low as compared to conventional building materials. The embodied energy and carbon emission of an average kiln fired brick of size 22cm*10cm*7cm travelled 150 km is 2247.28MJ/m3 and 202.255 kgCO2 /m3 respectively whereas for an CSEB with 5% cement of size 24cm*24cm*9cm has an energy of 572.58MJ/m3 and carbon emission of 51.531 kgCO2/m3 which is almost one-fourth of the kiln brick [7]. Also, stabilized clay shows thermal insulation. Thus, this simple building material has same capacity for adaption as building material as compared to other building materials with improved energy efficiency and thermal capabilities.

***Keywords*—** Sustainability, efficiency, materials, earth.

I. Introduction

EARTH is the oldest building material known to mankind. Several generations of architects and builders have developed forms ranging from simple mud plaster to complex blocks depending upon varying resources, social implications and place conditions. It is estimated that about 1.7 billion people of the world's population live in earthen houses: About 50 % of the population in the developing countries, and at least 20% of the urban and suburban populations. In India the Toda house Neelgiri hills, Banni house (Kutch), Khidrat house (near Bikaner) [6] etc shows the cultural acceptance of earth as a building material in India.

But its widespread application is hindered due to the following limitations [2]:-

1) Water penetration
2) Erosion of walls at level by splashing of water from ground surfaces
3) Attack by termites and pests
4) High maintenance requirements

With the rising awareness for sustainable development, from past few decades, earthen architecture and construction has witnessed a renaissance of the tradition, which benefits now from scientific researches. All over the world, people have developed this heavy, dark and formless material into a lighter building material. They created their living spaces and they adapted their architectural and constructive needs according to the behavior, and properties of the soil. There are several different techniques of earth:-

Adobe - mud bricks
Pressed earth blocks (e.g. Cinva Ram)
Pise blocks
Pise - monolithic walling of compressed earth.

The first three are considered together as earth masonry. Each construction technique has a special character, with its own advantages and disadvantages. New development of earth construction really started in the nineteen fifties, with the technology of the Compressed Stabilized Earth Blocks (CSEB). A research programme done in Colombia in the 1950's for affordable houses proposed the first manual press: the Cinvaram. India experimented with CSEB technology only in the nineteen eighties/nineties[7]. Since a decade, India sees some wider experimentation and development of CSEB. Also non erodable mud plaster overcomes the limitations by mechanical and chemical treatment with the use of stabilizers[2]. This paper aims to bring out the properties and advantages of these products and shows earth as a good sustainable alternate building material and insulating substance.

II. Compressed Mud Blocks

A. Introduction

The compressed earth block is the developed form of moulded earth block, more commonly known as the adobe block. This technology offers an economic, environment friendly masonry system. The stabilized compressed earth block has a wide spectrum of application in construction starting from walling, roofing, arched openings, corbels etc. Stabilized earth blocks are manufactured by compacting raw material earth mixed with a stabilized such as cement or lime under a pressure of 20 – 40 kg/cm using manual soil press (Dr L Dinachandran Singh, 2007)[2]. The basic principle of all the machines is the compaction of raw earth to attain dense,

[1]Civil Department, Vellore Institute Of Technology (Vellore) (donna.roycutiepie@gmail.com).
[2]Civil Department, Vellore Institute Of Technology (Vellore) (swaptikchowdhury16@gmail.com).

even sized masonry with smooth surfaces. Some of the hydraulic machine can even manufacture interlocking blocks. These interlocking blocks are highly suitable for quick and mortar less construction. Compressed earth blocks are sundried and use cement as stabilization for gaining the required strength.

B. Raw Materials

The primary raw material for the production of SCEB is raw earth or soil. OPC cement in little quantities and water, coarse sand or stone dust may be added depending on soil quality. The physical properties of soil have greater relevance in the manufacture of compressed earth block. They include colour, particle size break-up, structural stability, adhesion, bulk density capillary, porosity, specific heat, moisture content, permeability, linear contraction and dry strength. Soil classified, as clayey sands are excellent for making blocks. The optimum soil composition for compressed soil/mud block is 7% gravel, 53% sand, 20% silt and 20% clay (Dr L Dinachandran Singh, 2007).

C. Role in development

The establishment of compressed earth blocks production unit, whether on a meager-scale or as an industrial base, in rural or urban contexts, is connected to the creation of employment generation at each stage of production, from earth extraction in quarries to building work itself. The wide-spread use of the material for social housing schemes, for educational or cultural and for administrative buildings, helps to build societies' economies. CEB production units need trained and educated personnel well adept in the manufacturing process from both public as well private sector, thus leading to their development. The development which followed the establishment of CEB’s unit and its use for the construction of private as well as governmental residential plans in Mayotte, Comoro Island is an international reference.

D. Social acceptance

CEB show a considerable development over traditional earth construction techniques. When guaranteed by quality control, CEB products can very easily stand its ground with other materials such as the sand-cement block or the fired brick. Hence the confidence it inspires amongst decision-makers, builders and end-users is well earned.

E. Technical performance

Compacting the soil using a mechanical press improves the quality of the material and makes it denser thereby increasing its compressive strength as well as their resistance to erosion and damage from water. The regular shape and sharp edges is very useful feature appreciated by engineers and builders alike.

F. Flexibility of use

The wide categories of presses and production units with variety of moulds available in the current market make the material very versatile to use. With production ranging from small-scale to medium and large-scale semi-industrial or industrial, CEBs can be successfully used to meet any kind of demand whether be it a rural house or an urban sprawling complex.

G. Standards and models

Compressed earth blocks are available in all standard size and have all quality requirements which are needed for an infrastructure programs as per architecture plans. These standard block sizes and shapes, as well as the architectural models, can be defined before the programme begins, at the design stage, with great versatility.

H. Practical nature

The common dimensions of CEBs give architectures and builders a lot of options to use in various building solutions, as load-bearing masonry or as in-fill. CEBs can also be used for arches, vaults and domes, as well as for jack-arch floors.

I. Genuine architectural merit

Very fine masonry work, equal to fired brick building traditions, can be done with compressed earth blocks. The architectural application of CEBs can range from social housing to luxury homes and prestigious public buildings. Much experimentation by architectures and engineers has lent CEB much technical and architectural expertise making it comparable to other conventional construction practices.

J. An alternative to importation

It provides a better alternative for conventional building materials which are imported on the excuse of standard quality. CEBs have the advantage of being produced locally, whilst still meeting the need of quality and standardization.

Some structural properties[1]:-

1) Wet Compressive strength= 1to 4 megapascal
2) Thermal Insulation= 0.81 to1.04 Weber per meter centigrade
3) Density= 1700to 2200 kilogram per meter cube
4) Durability= very good
5) Surface= smooth
6) Visual Aspect= medium to good

K. Main Use of CEB’s

1) As a normal load bearing masonry
2) As infill masonry
3) Special applications such as ventilations. Cable duct, chamfers, vaults and arches etc
4) As reinforced masonry
5) Special building system such as juxtaposed system, dry stacking or interlocking bonding.

L. Advantages of CEBS

The CEB technique has several advantages which are:-

1) The manufacturing of the blocks from mechanical presses provides a consistency in the quality as compared to other hand cured adobe bricks. This helped in social acceptance and renewed this

technology.

2) The CEB production unit is established as per standard norms and quality factors. So they can meet the requirements for constructional material standard as per urban context. It has strength comparable to other building materials which is evident from its crushing strength value in table 1.
3) CEB is versatile and can be used in any context whether urban, rural or industrial with convincing arguments.
4) The structures built from this material present an architectural quality without compromising the durability or strength of the structure.
5) Earthen walls have a different thermal behaviour than any other materials. As clay is just stabilized and not burnt, it can still absorb and release some moisture through evaporation and condensation. Thus if the outside temperature is higher: the wall will evaporate moisture. This will cool down the wall and thus the building inside. And if the temperature is lower outside: the wall will condense moisture. This will create heat in the wall and thus the building inside. This phenomenon is called "latent heat". Thus this saying from France: "Earthen buildings (rammed earth) are cool in summer and hot in winter."
6) The other benefits are Low energy emission, uniform size, high strength and cost effectiveness as depicted in Table 1. It is observed that the energy efficiency of mud brick having way less embodied energy. Also its fire resistance is same as brickworks of concrete and calcium silicate according to Schedule 8 of buildings regulation 1972 of UK.
7) Also extractive industries wastes like Red mud (aluminum plants), Fly ash(Thermal power plants), Stone dust(Stone quarries and processing plants), Coal washery rejects (mines), Siliceous river sediments(water treatments plants) etc can be screened with these bricks to give them superior properties[5].

M. Disadvantage

The quality of CEBs depends on good soil selection and preparation and on the correct proportion of the mix. Also the requirement and design specification must be kept in mind while producing it. This means that professional training must be given to the personnel involved in the process. From an economical point of view, CEBs can sometimes fail to be competitive with other local materials. So a technical survey will ensure its feasibility according to the region Some successful examples of application of CEB in low cost housing:-

1) CEB unit was successfully established and used in the village Leimaram in Bishnupur (Manipur) in India which mainly comprised of the scheduled caste people. It employed the local people for the production thus creating employment and developing the region.
2) In India the technology for stabilized earth block is being promoted by HUDCO' network of Building Centers to build public sector housing and institutional projects as low cost housing schemes.
3) The "DOMAINE DE LA TERRE" project in France was a successful project of providing affordable housing in the Rhodes- Alps region undertaken by its government to address the need of affordable housing.
4) The example of the social housing programme in Mayotte (Comoro) remains still unparallel: 6,000 low-cost houses and nearly 1,000 public buildings (primary and secondary schools, state offices) have been built in the space of 10 years on an island which in 1978 was still using wattle-and-daub and raffia with CEB.

N. Non Erodable Mud Plaster

Central Building Research Institute, India has developed an economical but effective process to protect mud walls by applying non-erodable mud plaster. Non-erodable mud is prepared by mixing bitumen cutback (Bitumen & Kerosene oil mixture) with a specified mud plaster. Soil should consist of clay 20-25%, sand 40-45% and remaining part may be silt, peat, loam etc, but it should be free from organic matter. Bitumen of 80/100 grade penetration and kerosene oil are mixed in the proportion of 5:1 (by weight) for preparing cutback. 64 kg of cutback is required for one cubic meter of soil[3]. Non-erodable mud plastered walls are resistant to water erosion. Also Center for Science for Villages; Wardha, India has developed technique of providing potter made tile lining to mud-walls protecting them from rain and moisture. In place of potter made tiles, Kiln-fired brick or tiles may also be used to protect mud walls from rains. These tiles/bricks can be fixed with mud mortar & pointed with cement mortar.

O. INSULATION

One of the best low cost insulating materials is clay coated straw or any other plant fiber. A light coating of mud acts as both preservative and binder. Clay coated straw has been shown to last for 700 years as a non deteriorating insulation. It is non toxic, renewable and easily available in countries like India and England. A typical 12 inch wall using this material would have an about R-40 insulation factor. As the clay dries, it holds the straw as stiffly and together creates an excellent insulating material. Also suitable finishing can be given to the earth construction in condition of high weathering condition like Solpah oil(most durable), Bituminous paint, silicone sealer, Whitewash, linseed oil, Cow dung render[4] etc

P. Results and Conclusion

Providing affordable housing without compromising durability and strength to the ever increasing rural and urban population had always been a daunting task. Earth products such as CEB or mud plaster can be one of the promising materials that apart from being energy efficient, can meet the overall housing needs in countries like India, Bhutan etc where good quality earth suitable for block formation ids found. If the shortcoming of the earth like water erosion, termites etc is overcome then it can be successfully be used as a building material and living in a good house won't be a limited dream for people. The production unit is environment friendly as no toxic byproducts is developed. The houses built with mud blocks or using plasters is gaining is importance because it has high aesthetic value, high health value. Has versatility, greater strength and most importantly is economical and can be produced by local peoples thus creating employments. So profound research and awareness regarding compressed earth block construction should be enhanced in developing countries who is already facing with an acute housing crisis as earth building material forms a good alternative building material which can be used as a low cost housing. But ultimately for any given condition climate, site and constraints of materials and technology will define the usage of any material.

TABLE I
BASIC DATA OF COMPRESSED STABILISED EARTH

PROPERTIES	SYMBOL	UNIT	DATA
28 day dry compressive crushing strength (+10% after 1 year)	□Cd	MPa	5 to 7
28 day wet compressive crushing strength (after 24 hours immersion)	□Cw	MPa	2 to 4
28 day dry tensile crushing strength (on a core)	□	MPa	0.5 to 1
28 day dry bending crushing strength	□Bd	MPa	0.5 to 1
28 day dry shear crushing strength		MPa	0.5 to 1
Poisson's ratio	□		0.15 to 0.35
Young's Modulus	E	MPa	700 to 1000
Apparent bulk density	□	Kg/m3	1,850 to 2,000
Coefficient of thermal expansion	-	mm/m°C	0.010 to 0.015
Swell after saturation (24 hours immersion)	-	mm/m	0.5 to 1
Shrinkage (due to natural air drying)	-	mm/m	0.2 to 1
Permeability	-	mm/sec	1.10-5
Total water absorption	-	% weight	8 to 12
Specific heat	C	KJ/Kg	0.65 to 0.85
Coefficient of conductivity	L	W/m°C	0.81 to 0.93
Damping coefficient	M	%	5 to 10
Lag time (for 40 cm thick wall)	D	h	10 to 12
Coefficient of acoustic attenuation (for 40 cm thick wall at 500 Hz)	-	dB	50
Fire resistance *	-	-	Good *
Flammability *	-	-	Poor *

Note:
- 1 Mpa = ~ 10 Kg / Cm2
– These Values Are The Result Conducted In Laboratories By Recognized Authorities. They Give An Idea Of What Can Be Reasonably Expected Of A Product Made In Accordance With The Rules Of The Art.
– The Soil Quality, The Nature Of Stabilizer, The Percentage Of Stabilizer And The Compression Pressure Influence A Lot These Values.
– These Value Can Be Obtained With 5 To 8 % Cement Stabilization And A Compression Pressure Of 2 – 4 Mpa.
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– Source: "Earth Construction, A Comprehensive Guide" – Craterre, Hugo Houben And Hubert Guillaud
* No Scientific Tests On Fire Resistance Have Been Conducted Till Now.

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