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RESEARCH ARTICLE

Potential of stabilized mud blocks as a sustainable material for building construction

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Abstract: In India, burnt clay brick is the most used building material, which produces a significant amount of greenhouse gasses and destroys a huge amount of topsoil of agricultural land every year. Due to rapid urbanization, the demand for brick as filler material in buildings has been increasing exponentially. Conventional burnt brick puts tremendous pressure on the environment since the burning process results in the production of greenhouse gases. In recent time attention has been turned to sustainable and eco-friendly building materials. However, alternatives such as hollow concrete/fly ash blocks are available, which are costly as compared to burnt clay bricks. The Compressed Stabilized Earth Block (CSEB) gives the opportunity for natural, energy-efficient, eco-friendly, and agricultural-friendly building materials for sustainable development. It does not produce any harmful gasses during production. It is an economic and environment-friendly substitute for conventional materials like brick and cement blocks. In developing countries, earth construction is economical and efficient means of low-rise housing construction, using very less resources. This paper examines the case of stabilized mud blocks as filler material and discusses the engineering viability and properties of such stabilized mud blocks in building construction. The paper concludes that stabilized mud blocks are a viable alternative to conventional bricks with more intangible benefits attached to them.

Keywords: Stabilized mud: Blocks: Sustainable building: Construction materials: Developing countries

1 Introduction

Earth block is a construction material made primarily from soil. The types of earth blocks include Compressed Earth Block (CEB), compressed stabilized earth block (CSEB), and stabilized earth block (SEB). Stabilization is a technique of improving the properties of mud in such a way that it will possess adequate wet strength, durability, and dimensional stability (retains its shape and size both in dry and moist conditions) without burning. Hence, compacting a mixture of sandy soil with 7% cement and small quantities of lime at optimum moisture in press results in Stabilized Mud Blocks (SMB). The overall energy consumption in SMB is quite small (about one-third) in comparison with burnt bricks.

Compaction of the soil-stabilizer mix can be done by using a manually operated or mechanized press. The press should be capable of generating sufficient force to produce a dense block. It is advantageous to use a manually operated press to eliminate additional energy needs in terms of electricity or diesel. The blocks have to be cured for three weeks by keeping the block surfaces moist. Additives like fly ash, quarry dust from crushers, granite fines, stone dust from stone cutting and polishing industries, and various other mine or factory wastes can be used effectively along with the natural soil (Govind, 2015).

Stabilized Mud Block (SMB) or pressed earth block is a building material made primarily from damp soil compressed at high pressure to form blocks. If the blocks are stabilized with a chemical binder such as Portland cement, they are called compressed stabilized earth block (CSEB) or stabilized earth block (SEB). Creating SMBs differs from rammed earth in that the latter uses a larger formwork into which earth is poured and manually tamped down, creating larger forms such as a whole wall or more at one time rather than building blocks and adobe which is not compressed. Stabilized mud block uses a mechanical press to form a block out of an appropriate mix of dry inorganic subsoil, non-expansive clay, aggregate, and sometimes a small amount of cement (Figure 1). Typically, around 3000 psi is applied in compression, and the original soil volume is reduced by about half. The compression strength of a properly made SMB can meet or exceed that of typical cement or adobe brick. Building standards have been developed for SMBs.

Figure 1: Stabilized mud blocks

2 Soil Stabilization Methods with Different Materials

The following are the various soil stabilization methods and materials:

2.1 Soil Stabilization with Cement

The soil stabilized with cement is known as soil cement. The cementing action is believed to be the result of chemical reactions of cement with siliceous soil during the hydration reaction. The important factors affecting the soil cement are the nature of soil content, conditions of mixing, compaction, curing and admixtures used.

The appropriate amounts of cement needed for different types of soils may be as follows:

Gravels	–	5 to 10%
Sands	–	7 to 12%
Silts	–	12 to 15%, and
Clays	–	$12-20\%$

The quantity of cement for compressive strength of 25 to 30 $\mathrm{kg/cm^2}$ should normally be sufficient for tropical climates for soil stabilization.

If the layer of soil having a surface area of A $\left(\mathrm{m}^2\right)$, thickness $\mathrm{H(cm)}$, and dry density r_d (tonnes $/\mathrm{m}^3$), has to be stabilized with p percentage of cement by weight based on dry soil, cement mixture will be

$$\frac{100\times\mathrm{p}}{100+\mathrm{p}}$$

and, the amount of cement required for soil stabilization is given by

$$\text{Amount of cement required, in tonnes } = \left(\frac{\mathrm{AHr_d}}{100}\right)\times\left(\frac{\mathrm{p}}{100+\mathrm{p}}\right)$$

Lime, calcium chloride, sodium carbonate, sodium sulphate, and fly ash are some of the additives commonly used with cement for the cement stabilization of soil.

2.2 Soil Stabilization Using Lime

Slaked lime is very effective in treating heavy plastic clayey soils. Lime may be used alone or in combination with cement, bitumen, or fly ash. Sandy soils can also be stabilized with these combinations. Lime has been mainly used for stabilizing the road bases and the subgrade. Lime changes the nature of the adsorbed layer and provides pozzolanic action. The plasticity index of highly plastic soils is reduced by the addition of lime to the soil. There is an increase in the optimum water content and a decrease in the maximum compacted density and the strength and durability of soil increase. Normally 2 to 8% of lime may be required for coarse-grained soils and 5 to 8% of lime may be required for plastic soils. The amount of fly ash as an admixture may vary from 8 to 20% of the weight of the soil.

2.3 Soil Stabilization with Bitumen

Asphalts and tars are bituminous materials that are used for the stabilization of soil, generally for pavement construction. Bituminous materials when added to soil, imparts both cohesion and reduced water absorption. Depending upon the above actions and the nature of soils, bitumen stabilization is classified into the following four types:

- Sand bitumen stabilization
- Soil Bitumen stabilization
- Waterproofed mechanical stabilization, and
- Oiled earth.

The appeal of soil stabilization with bitumen lies in the fact that the bitumen increases the cohesive and load bearing capacity of the soil. This makes it more resistant to the action of water and enhances the durability of the material for building and construction. Ultimately, the type of bitumen to be used depends on the soil, method of construction, and weather conditions.

2.4 Gypsum Stabilization

Gypsum is a traditional material found in many Mediterranean and Middle Eastern countries. The earliest civilizations used gypsum for building purposes, mainly forplasters and mortars. The advantage that gypsum has over Portland cement and lime is that it requires a low calcinations temperature (about1/7th of that needed for cement and 1/5th of that needed for lime). For developing countries, the use of gypsum as a stabilizing material is relatively less costly and reasonably soluble in water.

2.5 Pozzolanas Stabilisation

Pozzolanas are fine silica and alumina-rich materials which when mixed with hydrated lime produce cementitious materials suitable for stabilization and construction needs. Pozzolanas are found in the irnatural state as volcanic ash or pumice in eastern and western Sudan.

2.6 Chemical Stabilization of Soil

Calcium chloride is hygroscopic and deliquescent is used as a water-retentive additive in mechanically stabilized soil bases and surfacing. The vapor pressure gets lowered, surface tension increases, and the rate of evaporation decreases. The freezing point of pure water gets lowered, and it results in the prevention or reduction of frost heave.

By depressing the electric double layer, the salt reduces the water pick up and thus the loss of strength of fine-grained soils. Calcium chloride acts as a soil flocculent and facilitates compaction. Frequent application of calcium chloride may be necessary to make up for the loss of chemicals by leaching action. For the salt to be effective, the relative humidity of the atmosphere should be above 30%.Sodium chloride is the other chemical that can be used for this purpose with a stabilizing action similar to that of calcium chloride.Sodium silicate is yet another chemical used for this purpose in combination with other chemicals such as calcium chloride, polymers, chrome lignin, alkyl chlorosilanes, siliconites, amines, and quarternary ammonium salts, sodium hexametaphosphate, phosphoric acid combined with a wetting agent (Mishra, 2019).

3 Identification of Soil

Very few laboratories can identify soils for building purposes. But soil identification can be performed by anybody with sensitivity analyses. The main points to examine are:

- Grain size distribution, to know the quantity of each grain size.
- Plasticity characteristics, to know the quality and properties of the binders (clays and silts).

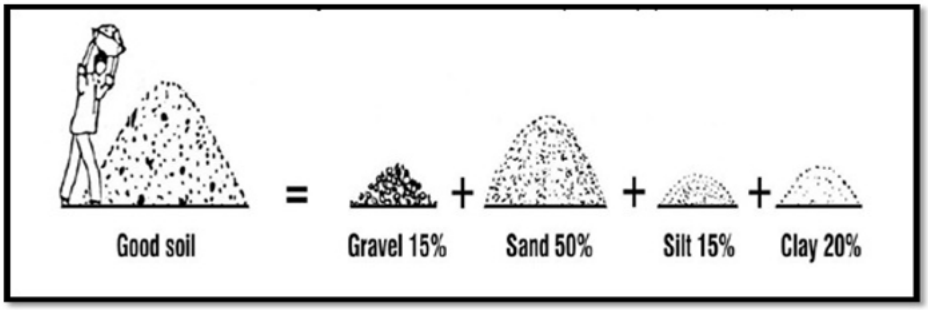

Figure 2: The Proportions of compressed stabilized earth blocks

- Compressibility, to know the optimum moisture content, which will require the minimum of compaction energy for the maximum density.
- Cohesion, to know how the binders bind the inert grains.
- Humus content if there are organic materials that might disturb the mix

3.1 Soil Stabilization

Many stabilizers can be used. Cement and lime are the most common ones. Others, like chemicals, resins, or natural products can be used as well. The selection of a stabilizer will depend upon the soil quality and the project requirements. Cement will be preferable for sandy soils and to achieve quickly a higher strength. Lime will be rather used for very clayey soil but will take a longer time to harden and give strong blocks

3.2 Soil Suitability and Stabilization

Not every soil is suitable for earth construction and CSEB in particular. But with some knowledge and experience, many soils can be used for producing CSEB. Topsoil and organic soils must not be used. Identifying the properties of soil is essential for good quality products. Some simple sensitive analyses can be performed after a short training. Soil is earth concrete and good soil for CSEB is more sandy than clayey. Figure 2 shows the proportions of compressed stabilized earth blocks.

According to the percentage of these 4 components, soil with more gravel will be called gravely, another one with more, sand, sandy, silty or clayey, etc. The field tests aim to identify which of these four categories the soil is. From the simple classification, it will be easy to know what to do with this soil.

3.3 Raw Materials

Soil characteristics and climatic conditions of an area must be evaluated before manufacturing soil building blocks. A dry climate, for example, needs different soil blocks from those used in temperate, rainy, or tropical areas. All soils are not suitable for every building'sneeds. The basic material, however, required to manufacture compressed stabilized earth building blocks is soil containing a minimum quantity of silt and clay to facilitate cohesion. Soils are variable and complex materials, whose properties can be modified to improve performance in building construction by the addition of various stabilizers. All soils consist of disintegrated rock, decomposed organic matter, and soluble mineral salts. Soil types are graded according to particle size using a system of classification widely used in civil engineering. This classification system, based on soil fractions shows that there are 4 principal soil fractions - gravel, sand, silt, and clay.

For soil stabilization, the clay fraction is most important because of its ability to provide cohesion within the soil. The manufacture of good quality, durable compressed stabilized earth blocks require the use of soil containing fine gravel and sand for the body of the block, together with silt and clay to bind the sand particles together. An appropriate type of stabilizer must be added to decrease the linear expansion that takes place when water is added to the soil sample.

4 Preparations of Raw Materials

4.1 The Requirement for Preparation

The basic materials required to produce compressed stabilized earth building blocks are soil, stabilizer, and water. The stabilizer, whether lime or cement or some other material, is usually available in powder or liquid form, ready for use. The soil may be wet or dry when it is first obtained and will probably not be homogeneous. To have uniform soil, it is often necessary to crush it so that it can pass through a 5 to 6-mm mesh sieve. The different soil types may also need to be used together to obtain good-quality products. For instance, heavy clay may be improved by the addition of sandy soil. It is not only important to measure the optimum proportion of ingredients, but also to mix them thoroughly. Mixing brings the stabilizer and soil into direct contact, thus improving the physical interactions as well as the chemical reaction and cementing action. It also reduces the risk of uneven production of low-quality blocks. Various types and sizes of mixing equipment are available on the market.

4.2 Breaking up of Soil

In most developing countries the soil is usually dry when dug out of the borrow pit or it will dry soon after digging. Simple hand tools are available as well as a range of more complicated machinery that can be used to reduce the soil grains to an appropriate size. To obtain a uniform mix of the mineral components, water and stabilizer lump more than 200mm in diameter after excavation must be broken up. Grains with a homogeneous structure, such as gravel and stones, must be left intact, and those having a composite structure (clay binder) broken up so that at least 50 percent of the grains are less than 5mm in diameter. The soil must be dry as wet soil can only be handled by certain mechanized systems.

4.3 Grinding Followed by Screening

The material is pressed between two surfaces - a rather inefficient and tedious process in which bigger stones are broken up, however, only simple machinery is required. The broken-up lumps of soil are then passed through a screen.

4.4 Pulverization of Soil

The material is hit with great force, so it disintegrates. The machinery required is complex but performs satisfactorily. At the delivery end, any large pieces left can be removed utilizing the screen.

4.5 Sieving

Soil contains various sizes of grain, from very fine dust up to pieces that are still too large for use in block production. The oversized material should be removed by sieving, either using a built-in sieve, as with the pendulum crusher, or as a separate operation. The simplest sieving device is a screen made from a wire mesh, nailed to a supporting wooden frame and inclined at approximately 45º to the ground. The material is thrown against the screen, fine material passes through and the coarse, oversized material runs down the front. Alternatively, the screen can be suspended horizontally from a tree or over a pit. The latter method is only suitable in the case where most material can pass through easily otherwise too much coarse material is collected, and the screen becomes blocked and needs frequent emptying.

4.6 Proportioning

Before starting production, tests should be performed to establish the right proportion of soil, stabilizer, and water for the production ofgood-quality blocks. The proportions of these materials and water should then be used throughout the production process. To ensure uniformity in the compressed stabilized earth blocks produced, the weight or volume of each material used in the block-making process should be measured at the same physical state for subsequent batches of blocks. The volume of soil or stabilizer should ideally be measured in dry or slightly damp conditions. After establishing the exact proportion required for each material, it is advisable to build a measuring device for each material. The dimensions of each measuring box should be such that their content, when full, is equivalent to the proportion which should be mixed with other materials measured in other gauge boxes. Alternatively, a simple gauge box could be used for all materials. In this case, the amount of material to produce a given batch of blocks may be measured by filling and emptying the gauge box several times for each separate material. For example, a batch of blocks may require ten gauge boxes of soil for one gauge box of stabilizers. Water may be measured in a small tank or container. It is advisable to mix enough materials to allow the block-making machine to operate for approximately one hour. Thus, the volume of the mixed material will depend on the hourly output of the block-making equipment.

4.7 Mixing

To produce good quality blocks, it is very important that mixing be as thorough as possible. Dry materials should be mixed first until they are a uniform color, then water is added, and mixing continued until a homogeneous mix is obtained. Mixing can be performed by hand on a hard surface, with spades, hoes, or shovels. It is much better to add a little water at a time, sprinkled over the top of the mix from a watering can with a rose spray on the nozzle. The wet mix should be turned over many times with a spade or other suitable tool. A little more water may then be added, and the whole mixture turned over again. This process should be repeated until all the water has been mixed in.

When lime is used as a stabilizer, it is advisable to allow the mix to stand for a short while before molding starts to allow better moistening of soil particles with water. However, if cement is used for stabilization, it is advisable to use the mix as soon as possible because cement starts to hydrate immediately after it is wetted, and delays will result in the production of poor-quality blocks. For this reason, the quantity of cement-sand mix should not exceed what is needed for one hour of operation. Even so, the blocks produced at the end of one hour may be considerably weaker than those produced immediately after the mixing. A concrete mixer, even if available, will not be useful for mixing the wet soil since the latter will tend to stick on the sides of the rotating drum. If machinery is to be used for mixing, it should have paddles or blades that move separately from the container. However, field experience shows that hand-mixing methods are often more satisfactory, more efficient, and cheaper than mechanical mixing, and are less likely to produce small balls of soil that are troublesome at the block molding stage.

4.8 Quantity of Materials Needed

Compressed stabilized earth building blocks are usually larger than traditional burnt bricks. The typical block size is 290 x 140 x 90mm. Its production will need about 7.5 to 8.5kg of materials depending on the compaction pressure. The exact amount of stabilizer necessary must be established for any project. The fraction of lime or cement usually varies between 5% - 8% by weight. Similarly, the optimum water content (OWC) for any soil must be determined experimentally. The moisture level varies widely with the nature of the soil. An approximate estimate of about 15% by weight is often assumed.

5 Molding of Stabilized Mud Blocks

5.1 Standards for Block Production

Many aspects should be taken into consideration before launching an operation to produce compressed stabilized earth building blocks:

- Amount and type of stabilizer required,
- Soil properties and its suitability for stabilization,
- Building standards and hence the quality of blocks required,
- Load-bearing requirements of construction i.e., single storey or more.

One of the purposes of this chapter is to make the reader aware of the problems associated with compressed earth blocks in the construction industry, especially in developing countries where building standards have not yet been developed in the field of earth construction. Generally, there is a wide variety of acceptable standards that vary according to local weather conditions. Blocks with wet compressive strengths in the range of 2.8MN/m2 or more should be adequate for one and two-story buildings. Blocks of this type would probably not require external surface protection against adverse weather conditions. For one-storey buildings, blocks with a compressive strength in the order of 2.0 MN/m2 will probably be strong enough, but where rainfall is high external treatment is necessary. Since the wet strength of a compressed stabilized earth block wall may be less than two-thirds of its dry strength. It should be remembered that all compressive strength tests should be carried out on samples that have been soaked in water for a minimum of 24 hours after the necessary curing period.

The final wet compressive strength of a compressed earth block depends not only on soil type, but also on the type and amount of stabilizer, the molding pressure, and the curing conditions. In 1998, standards for compressed earth blocks were ratified as African Regional Standards (ARS) under the auspices of the African Regional Organization for Standardization (ARSO) technical committee on building and civil engineering (ARSO/TC3) after having satisfied procedures for the approval of regional standards.

5.2 Testing Soil before Block Production

For block production, the soil mix must be checked for each batch of blocks to attain the Optimum Moisture Content (OMC). Two simple field tests can be carried out. These are explained below:

- Take a handful from the soil mix for block production and squeeze it in the hand, the mix should ball together. When the hand is opened, the fingers should be reasonably dry and clean.
- Drop the ball sample onto a hard surface from a height of about one meter. If the sample:- completely shatters, this shows that it is not sufficiently moist,- squashes into a flattened ball or disc on impact with the hard surface, this implies too high a moisture content,- breaks into four or five major lumps, this shows that the moisture contents or the soil mix are close to the Optimum Moisture Content (OMC).

To manufacture blocks of uniform size and density, special precautions must be taken to fill the mold with the same amount of mix for each compaction by using a small wooden box as a measuring device. To facilitate the development of the pressed blocks and to ensure good, neat surfaces it is advisable to moisten the internal faces of the machine mold with a mold-releasing agent (reject oil) which can be applied with either a rag, brush, or spray

5.3 Curing

To achieve maximum strength, compressed stabilized earth blocks need a period of damp curing, where they are kept moist. This is a common requirement for all cementitious materials. What is important is that the moisture of the soil mix is retained within the body of the block for a few days. If the block is left exposed to hot dry weather conditions, the surface material will lose its moisture and the clay particles tend to shrink. This will cause surface cracks on the block faces. In practice, various methods are used to ensure proper curing. Such methods include the use of plastic bags, grass, leaves, etc. to prevent moisture from escaping.

After two or three days, depending on the local temperatures, cement-stabilized blocks complete their primary cure. They can then be removed from their protective cover and stacked in a pile. As the stack of blocks is built up, the top layer should always be wetted and covered, and the lower layer should be allowed to air-dry to achieve maximum strength. Alternatively, freshly molded blocks can be laid out in a single layer, on a non-absorbent surface, and covered with a sheet to prevent loss of moisture. The required duration of curing varies from soil to soil and, more significantly, which type of stabilizer is used. With cement stabilization, it is recommended to cure blocks for a minimum of three weeks. The curing period for lime stabilization should be at least four weeks. The compressed stabilized earth blocks should be fully cured and dry before being used for construction (Adhlakha, 2019).

6 Advantages of Compressed Stabilized Earth Blocks

There are many advantages of Compressed Stabilized Earth Blocks (CSEB). They are summarized as below:

6.1 A Bio-Degradable Material

Well-designed CSEB houses can withstand, with a minimum of maintenance, heavy rains, snowfall, or frost without being damaged. The strength and durability have been proven for half a century. But let's imagine a building falls and that a jungle grows on it: the biochemicals contained in the humus of the topsoil will destroy the soil-cement mix in 10 or 20 years and CSEB will come back to our Mother Earth!

6.2 Limiting Deforestation

Firewood is not needed to produce CSEB. It will save the forests, which are being depleted quickly in the world, due to short view developments and the mismanagement of resources.

6.3 Management of Resources

Each quarry should be planned for various utilizations: water harvesting ponds, wastewater treatment, reservoirs, landscaping, etc. It is crucial to be aware of this point: very profitable if well managed, but disastrous if unplanned.

6.4 An Adapted Material

Being produced locally it is easily adapted to the various needs: technical, social, and cultural habits.

6.5 A Transferable Technology

It is a simple technology requiring semi skills, easy to get. Simple villagers will be able to learn how to do it in a few weeks. An efficient training center will transfer the technology in a week.

6.6 Job Creation Opportunity

CSEB allows unskilled and unemployed people to learn a skill, get a job, and rise in social value.

6.7 Market Opportunity

According to the local context (materials, labor, equipment, etc.), the final price will vary, but in most cases, it will be cheaper than fired bricks.

6.8 Reducing Imports

CSEB is produced locally by semi-skilled people, no need to import from far away expensive materials or transport long distances heavy and costly buildings materials.

6.9 Flexible Production Scale

Equipment for CSEB is available from manual to motorized tools ranging from village to semi-industry scale. The selection of the equipment is crucial, but once

6.10 Energy Efficiency and Environmentally Friendly

Requiring only a little stabilizer the energy consumption in an m3 can be from 5 to 15 times less than an m^3 of fired bricks. The pollution emission will also be 2.4 to 7.8 times less than fired bricks.

6.11 Cost Efficiency

Produced locally, with natural resources and semi-skilled labor, almost without transport, it will be cost-effective. According to each context and one's knowledge, if done properly, it will be easy to use the most adapted equipment for each case.

6.12 Social Acceptance

Demonstrated, for a long, CSEB can adapt itself to various needs: from poor income to well-off people or governments. Its quality, regularity, and style allow a wide range of final house products. To facilitate this acceptance, banish from your language "stabilized mud blocks", for speaking of CSEB as the latter report's research and development done for half a century when mud blocks referred, in the mind of most people, as a poor building material.

7 Disadvantages of Compressed Stabilized Earth Blocks

There are some disadvantages of Compressed Stabilized Earth Blocks (CSEB). They are summarized below:

- Proper soil identification is required or lacks soil.
- Unawareness of the need to manage resources.
- Ignorance of the basics for production use.
- Not suitable for wide spans, high-rise and long buildings are difficult to do.
- Low technical performance compared to concrete.
- Untrained teams producebad-quality products.

- Over-stabilization through fear or ignorance, implying outrageous costs.
- Under-stabilization resulting in low-quality products.
- Bad quality or un-adapted production equipment.
- Low social acceptance due to counterexamples (By unskilled people, or bad soil equipment).
- Requires quality check at every stage of manufacturing to avoid low-quality products.

8 Comparison of Compressed Stabilised Earth Building Blocks with Other Building Materials

This section compares the properties of compressed stabilized earth building blockswith some other walling materials. This comparison is of use for architects, site engineers, and housing authoritiesfor implementing individual housing or larger building programs. The characteristicsof these different materials are given in Table 1.

Table 1. Properties of compressed stabilized earth blocks versus other blocks

Property	Compresseds tabilized earth blocks	Firedclay bricks	Calcium Silicate Bricks	Dense Concrete Blocks	Aerated concrete blocks	Lightweight concrete blocks
Wet compressive Strength(MN/m^2)	1-40	5-60	10-55	7-50	2-6	2-20
Moisture movement (%)	0.02-0.2	0.00-0.02	0.01-0.035	0.02-0.05	0.05-0.10	0.04-0.08
Density(kg/m^3)	1700-2200	1400-2400	1600-2100	1700-2200	400-950	600-1600
Thermal conductivity W/m°C	0.81-1.04	0.70-1.30	1.10-1.60	1.00-1.70	0.10-0.20	0.15-0.70
Durability again strain	Good to very poor	Excellent to very poor	Good to moderate	Good to poor	Good to moderate	Good to poor

9 Implications of CSEB for the construction industry

The type of building materials used in the construction industry has important implications for the global sustainable goal, and local development imperatives of providing adequate low cost housing for the ever increasing populations of the developing countries. Previous research showed that compressed earth bricks demonstrate many advantages compared to conventional fired bricks. Compressed stabilized earth bricks are ultimately greener, eco friendly, comparable in strength, durability, and thermal conductivity. Also, it has shown that compressed earth brick demonstrates comparable durability with that of normal fired clay bricks. Thermal value experiment indicated that thermal conductivity of CSEB showed compliance with the design thermal requirements for clay masonry and building regulations.

Although economic potential may attract more rather than ecological reasons, the full scale production of compressed stabilized earth bricks has demonstrated that this kind of building material have a great potential in the future for low to medium cost housing construction and contribute to sustainable development. It can also be used in hot regions making it a versatile material at the same time not compromising the cost effectiveness. Many techniques can be employed for the construction of low cost housing with the use of CSEB and have proved to be effective in their own means. By using different stabilizing agents and composition, the block required for a particular purpose can be achieved.

Figure 3: . The Realisation Housing at Auroville, India using Compressed Stabilized Earth Blocks

10 Guidelines for Using Compressed Stabilized Earth Blocks

Following are the building construction guidelines (Dash & Pandey, 2020), which can be incorporated while using Compressed Stabilized Earth Blocks:

a) Stabilization of 4% cement and 1% straw by weight should be used in CSEB if the building is 1-2 storeys high as it is the most economic stabilization component composition.If the building needs to be more than 2 storeys high, then a stabilization of $8-9\%$ of cement should be used in the blocks.
b) Laterite soil is well suited for the production of CSEB, requires less quantity of stabilizer to produce a good quality block and thus, should be used for the production if locally available.
c) The blocks should be produced on site with the help of the CSEB block press. If the area for storage is not adequate on site, then they should be transported to the site from the production area within the radius of $2\ \mathrm{km}$.
d) Shelled CSEB blocks should be used in areas which are prone to heavy rains and floods.
e) Stretcher or header bonds should be used for wall construction if the building is only one storey high. External buttresses can be provided if the span of the wall is large.

f) Header bonds can also be used in 2 storey buildings.
g) English and Flemish bonds should be used for construction of building higher than 2 stories.
h) Vaulting earth block techniques should be used when using CSEB for flooring/roofing. If the span is more than $8 - 9\ \mathrm{m}$, then composite CSEB or RCC girders should be used for additional support.
i) CSEB construction in earthquake prone areas should be done with either:
   - With the use of RCC earthquake resistant bands at the plinth beam and lintel level.
   - With the use of hollow interlocking CSEBs.
j) Passive construction techniques should be incorporated when building with CSEB.
   - CSEB itself acts as hydro-cooling agent.
   - Vaulting helps in providing thermal insulation.
   - Planned vaulting in relatively high storey building can help in creating stack effect.
k) CSEB construction helps in the reduction of labor cost. Self-employment policies which help in providing employment to the owner of the house with by constructing their own house should be implemented.

11 Conclusions

This paper discusses the engineering viability and properties of stabilized mud blocks. The clay identification tests are important because they allow defining characteristics of the earth, to situate them concerning the suitability criteria, and therefore orient the choice of the stabilizer. The behavior of the blocks differs depending on the treatment and dosage incorporated. The compressive strengths in dry and wet conditions increase with the dosage of the binder. Mixing cement and lime yielded the best resistance. The different formulations have determined the best treatment. It is the mixture of cement and lime which has proved the best suitable treatment with reference to strength and durability. Twelve percent cement stabilization can be used for outer wall construction and a lower percentage of cement can be used for inner wall construction. CSEB does not produce harmful gases during production as they do not require coal or burning material. So, CSEB is an eco-friendly building material (Patowary et al., 2015). Compressed Stabilized Earth Block (CSEB) could be a great alternative to a mud house in the rural regions of developing countries.

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