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LATERITE IN CONSTRUCTION: A REVIEW OF APPLICATIONS, PROPERTIES, AND SUSTAINABILITY

Abstract

Laterite, a soil and rock type rich in iron and aluminium oxides, has been widely used in construction across tropical regions due to its abundance, workability, and durability. This review consolidates historical, engineering, and modern perspectives on laterite as a building material. Traditional applications include monumental architecture, vernacular housing, and colonial structures, while contemporary uses extend to blocks and bricks, road bases, stabilised earth blocks, and decorative facades. The review examines laterite's physical and chemical properties, moderate strength, high plasticity, porosity, and oxide-rich composition, which underpin its performance in construction. Stabilisation techniques with lime, cement, and bitumen are discussed as essential for enhancing durability and water resistance. Laterite's sustainability potential is emphasised, as it is locally available, low-carbon, and thermally efficient, aligning with global goals for eco-friendly housing and infrastructure. Challenges such as variability in composition, susceptibility to weathering, and strength limitations are also addressed. Overall, this review highlights laterite's enduring relevance as a construction material, bridging traditional practices with modern sustainable solutions.

***Keywords**: stabilisation, compressed earth soil, water absorption, compressive strength, sustainability*

1. Introduction

In the life of every human race, even from ancient times, shelter has been ranked one of the most basic three needs (in addition to food and clothing) of man to be able to function effectively in a given society. In effect, the provision of good housing, accommodation or shelter for the members of a given community is an essential duty of government (or individuals or groups so charged) for the well-being of the people in every part of the world. However, durable shelter is an essential need of man economically and socially, though realistically, many developing countries are having problems providing enough affordable and durable housing for their citizenry (Kerali, 2001). The unpredictably increasing cost of building materials has been a disturbing topic for almost every private establishment and government at all levels in developing countries. But then specialists have observed that the high cost of construction and building materials is not the only factor that influences the cost of building houses, since the cost of transporting materials from urban areas to the remote rural areas and the lack of access to the building material factories in the urban areas immensely increase building costs (Caiola & Davenport, 1985). These issues could only be addressed by the use of available materials in a given area or region to reduce or eliminate transportation costs.

Notably, an increase in population in Malaysia and some Asian countries has impaired access to good and affordable housing for those living in rural areas.

In effect, this increase in population and attendant increase in demand for good and affordable shelter have been a great challenge to the citizens. "However, in less developed Asian and African countries where urbanisation is still low, they are expected to be 54 per cent urban by 2025" (Fadairo & Ogunmakinde, 2011).

But then, it has been observed in different research that housing is an issue for the low income group in Malaysia and this challenge increases by day due to increased urbanization caused by immigration from the rural region to the urban centres, and most of these people are the "Bumiputera" who are from a low income group (villages) and cannot afford houses due to high costs and this has become a problem to the urban regions that can only be fixed by government contribution to reduce the housing challenges (Ahmad & Hasmah, 2012). Noor Sharipah & Sultan Sidi (2011) reported on the issue of housing in Malaysia and further explained that "an increase in housing demand will result in high costs which will affect the low-income group. It has been established by experts that the problem house buyers are facing generally in Malaysia is the high price of houses due to the high cost of the materials used to build them, which makes the houses unaffordable to low-income earners.

In effect, notwithstanding the highlighting of improved housing by the government and private house developers. Housing is still a contentious issue which has changed from ordinary accessibility to obvious affordability (Salfarina, Normalina, & Azrina, 2010). According to the "Third Malaysian Plan (TMP)", which stated that "provision of house is a key component of a program to eradicate poverty", there is thus a convincing need to address this challenge through the proper implementation of affordable housing programmes due to its link to income level.

Some developing countries like Nigeria still face serious housing problems in the urban centres. Sandcrete blocks are commonly used as a material for walling for most buildings, and the high demand for these blocks has made this essential material scarce, relatively expensive, and thus difficult for most citizens to have their own comfortable home (Isiwu, 2012). From past researchers, suggestions have been made to the government and other private housing developers to encourage the use of local construction materials to guarantee durable, available and affordable materials for the building and construction industry (Tamakloe, 2012). A Housing Policy was also developed in Malaysia by the British in 1957, and with the influence of the colonial masters, such a policy aimed at providing public shelter for the poor citizens and quarters for civil servants. In the 60's, the concern was on the increase of housing ownership, most especially affordable housing for the poor, and this policy continued well into the 70's until the year 2000, when the policy review also highlighted that there were not sufficient low-cost houses in the housing market for the low-income group (Abdul & Lee, 1997). In some other countries, like Ghana, Humphrey Danso (2013) stated that "according to the Ghana News Agency (GNA) publication of March 29, 2011 that Ghana has issues of housing which have been a major problem that the government tried to tackle but over 1.6 million houses are expected, which will solve the need of housing in Ghana and this problem will likely double within ten years, although the government and a combined private sector have managed to deliver 25,000 housing units to the market each year. But from the analysis housing problem must be increased from 25,000 to 160,000 every year to meet the demand for housing in the country".

Based on the problem of insufficient housing and high cost of building materials, a local, less expensive and durable building material will be necessary for building for those living in rural and urban regions who are low-income earners. In addressing this issue, attention has been given to low-cost alternative building materials (Agbede I.O & J, 2008). Such a material is earth soil (laterite), which will eliminate the cost of building material, and its product is still durable. In India, there might be up to 80 million people living in earth buildings (often called mud houses) and even more in Asia and Africa (Norton, 1997). As more countries develop and populations are increasing, many people move from undeveloped to developed (town) areas in search of "greener pastures", and so the demand for houses in the latter region increases more rapidly than the supply, and therefore the attendant increase in price due to lower supply of housing will ensue. The use of earth as a building and construction material became extremely less popular due to the increased use of the present conventional building materials in the urban region and even in rural areas, and this reason made earth construction fade away in the construction industry in most developed and underdeveloped countries. However, it is well known that some of those conventional building materials are expensive and sometimes scarce, but earth soil is everywhere and available in our environment in abundance.

Furthermore, in Sri Lanka, it is suggested that building with compressed stabilised earth block would provide an alternative to the conventional building materials (Jayasinghe & Mallawaarachchi, 2009). Recently, there have been hints that earth as a cheap building material is now being taken more seriously in the United Kingdom, and there is also a technical guide for design and construction with earth building materials that is for earth buildings, for both new buildings and the repair of old houses. Irrespective of the hitch of having no earth building code of practice and standard (Morton, 2008), some countries have codes for the production of blocks and sandcrete, notably including Malaysia, India, Uzbekistan and Nigeria (Nigeria Industrial Standard). It is also applicable to all earth blocks (laterite blocks), CSEB.

Earth blocks (EB) have been the material which will rank as a prehistoric material used for buildings, and their strength, low cost of production, local nature and durability will increase their appeal for higher usage in the present time. One can recall that back then in Ancient Egypt, when earth was used in the traditional and ancient houses, the pyramids built then are still standing tall to the admiration of the modern world.

When traced back to history, when civilisation was not yet there in most countries of the world, people were already making local housing, which is known as the traditional earth building (TEB) or hut, for themselves with the local earth dug out and "processed" within the environment. They never spent money on transportation of materials for building or any additional materials. The use of this local material for buildings will make the general population appreciate nature and will also attract tourists into the country, and at the same time generate revenue, since traditional houses are practically the representation of the heritage of any country or people and reflect the country's traditional norms and values, and more especially culture (Rumana, 2007).

Among all the other alternative and available building materials for the construction of low-cost housing, CSEB is said to be the best and the cheapest. In some rural and urban areas of some of the developing countries, traditional buildings, which are made of laterite soil, still exist to date, though some still crack due to the intense heat of the sun and the rain (weathering). Some of the buildings constructed with earth do not stand the rainy season due to insufficient or low binding potentials, though laterite has been proven to have more binding features, but still requires a stabilising material to improve its binding strength. According to Ghoumari (1989), researchers and builders have been working hard and seriously too on improving the life span of building materials, most especially the material which will really cut down the cost of building for economic purposes. It is the view of this writer that the use of locally made materials should be supported in both developed and developing countries, so that it will be widely known and applied by the people.

Again there is need to improve its strength and make it more durable rugged to stand different high climatic conditions ranging from heavy rain, freezing (winter season) to the hot season because most traditional walls built without any additional stabilizing agent do not endure those higher seasonal conditions and require being maintained regularly when cracked by patching the affected walls (Batcbelder, Caiola, R.E., & Davenport, S.W., 1985). Traditional houses made of mud soil require intensive labour due to constant maintenance when cracked (Harper, 2011). Also, Laterite soil is known to show some negative characteristics of excessive shrinkage, cracks and swelling under different moisture circumstances. These limitations of shrinkage, cracking and swelling characteristics of laterite depend on the rate of water it absorbs and retained which will cause deformations or defects that cannot be predicted because different soils have different moisture contents and plastic limit according to location. The movement is usually in an uneven pattern and to such an extent as to cause damage to a building or structure (Nelson & Miller, 1992).

Earth buildings are not only common in third-world countries, as it may seem, but are also found in developed countries like the United Kingdom and some parts of the Americas (Houben & Huillaud, 1994).

However, the identification of materials that will be used for construction is of great importance to be sure it satisfies every quality of an earth soil for construction. Through the use of natural and locally available materials, the production of CSEB is a sustainable building system that can make good and reasonably priced houses available, empower the people in the community by paid employment, save funds for the local economy instead of spending it exclusively on imported materials, and move forward into a better, natural environment. From the foregoing, we have shown some of the discovered benefits and importance of CSEB it is then our honest advice that it be used for low-cost housing programmes and projects by governments and corporate and individual developers and shift emphasis away from over dependence on imported materials that are expensive and at times scarce in view of the yawning gap between housing needs, availability and affordability.

2.1 The Use of Laterite

The use of laterite for building has been in existence for a long time, and some people in the rural areas still see this material as the only affordable material around them, though the maintenance is high, its availability and low cost have made it the only material for building in some areas. There are up to six regions in the world where Laterite architectural work exists, namely Africa, India, Southeast Asia, Australia, Central and South America, etc., as highlighted in Figure 2.1.

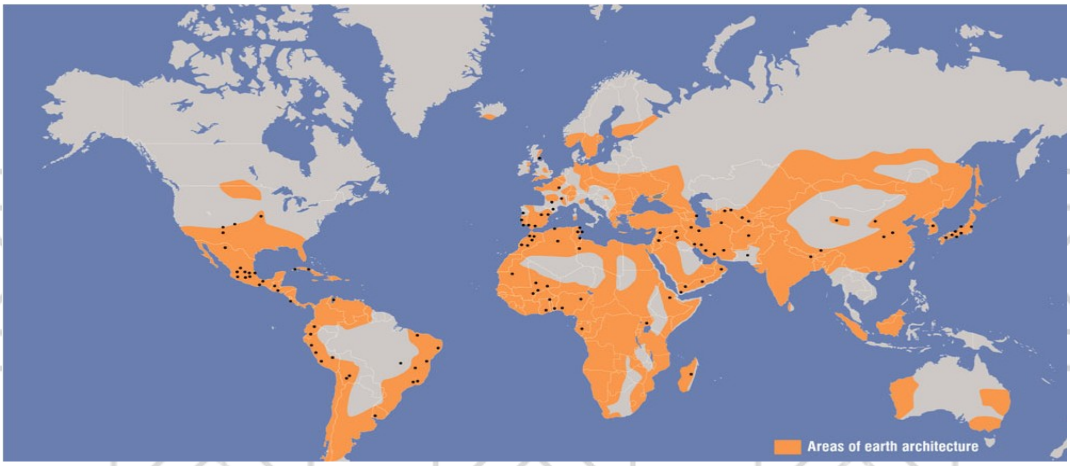

Figure 2.1: Map Showing Region Distribution of Laterite Architecture (CIRIA, 1995)

Given the search for cheap, affordable building materials, Laterite is generally used in construction. It is the most readily available material which can be found anywhere in our environment and is believed by many to be an ancient material that is dependable for building houses. Fitzmaurice (1958) stated that "housing is important in everyone's life and up to 25-50 of the world population in the rural areas still lives in shack houses". Furthermore, several attempts have also been made to develop walling units that will serve as an alternative to the modern and more expensive fire bricks and concrete blocks. The use of laterite (a cheap and durable material) was supported and introduced by the United Nations (United Nations & Fitzmaurice, 1958) in some parts of the world, such as Nigeria. Some people in the remote rural areas still live in huts, mud and thatch houses and such houses, though they served their purpose as traditional housing, but they have been rated as very poor shelter, and their walls crack with time due to weather conditions.
The traditional hut, often found in various rural regions, particularly in Nigeria, has notable advantages and disadvantages concerning maintenance and durability. One significant drawback is the high rate and cost of maintenance associated with these structures. As time progresses, the walls of these huts can develop cracks due to environmental factors. When this occurs, builders typically use a mix of laterite and water to plaster over the damaged areas. However, during periods of heavy rainfall, this plaster can wash away, leading to further deterioration and highlighting the hut's limited durability.

Despite these challenges, traditional huts are regarded as environmentally friendly constructions. The materials utilised in their construction are entirely natural, sourced directly from the surrounding environment. This characteristic not only reduces the environmental footprint but also means that complex construction techniques are unnecessary, making the building process accessible even for those with limited resources and skills.

In some remote rural areas of Nigeria, for example, the abundance of natural resources means that people can construct these huts without significant financial investment. The materials needed, such as laterite, are readily available, allowing for cost-effective building solutions that cater to the community's needs.

In recent times, laterite has gained recognition as a superior building material compared to alternatives. Historical evidence supports its advantages, as the processes of stabilising and compacting laterite enhance its overall quality, strength, and performance. When processed into blocks, laterite can now serve as a more modern building material, thanks to these improvements. This evolution in its use signifies a shift towards more sustainable building practices while maintaining the cultural significance of traditional architecture. The ongoing development and adaptation of laterite blocks showcase their potential in contemporary construction, addressing both durability and environmental considerations.

Figure 2.2: A Traditional Hut in Africa Built with Laterite Soil and Thatch Roof. (Google, June 2012)

2.2 Laterite

Laterite soil is of more special interest regarding building and construction among the other soil types that exist in the tropical and sub-tropical regions. It is a high weathering soil that is made of a high proportion of iron and aluminium oxides and other minerals. Laterite soil is found at tropic and subtropical regions below the surface of wide grassland or regions that have high rainfall Schellmann, 2010). Laterite soil is usually produced by an in-situ (Lateritic) weathering process of a basement rock; this process occurs under tropical climate conditions. Balam (2007) described the characteristics of laterite soil in its physical appearance when exposed to air, and that it can be more resistant to moisture content depending on how dark it appears (see Table 2.1). Thagesen (1996) defined laterite as "the high weathered soil that occurs by the concentration of hydrated oxides of iron and aluminium"

Table 2.1: Characteristics of Laterite and its Difference from Other Soils (Balam, 2007)

Characteristics	Discription
Soft occurrence	Laterite soil appears soft in nature and hardens when it is exposed to air, which makes it possible to cut the laterite into blocks or bricks, and allow it to harden by air, then use it for walling (just as the name coined from a Latin word "later" meaning bricks)
Colour	Laterite have more resistance to moisture content; its heaviness and hardness depend on how dark it appears.
Pozolanic reaction	When laterite is mixed with Lime as a stabilising agent, laterite will be found to have a pozzolanic reaction, which is caused by high clay content, and it will produce a durable building material

In some Asian countries, laterite has been known as a building material for over 1,000 years. But then, if the use of laterite were traced back in some regions where the soil cohesion and concentration of carbonates are high, the soil will be cut out directly in shapes to be used as blocks, stones and bricks. (Makasa, 2004). This process is commonly found in the tropic region, where laterite gives a durable building material. Laterite in some regions are found in a soft soil, which hardens after it is exposed to air due to a chemical reaction of the soil with air (carbonation reaction) and such an occurrence is called "induration" (Makasa, 2004). The soil with such property is found on the west coast of India.

Figure 2.3: Locally Sourced Laterite Soil Cut Out in Block Shape and Taken for Firing.

In India, the process of utilising moist and soft laterite soil involves cutting it into manageable sizes, typically in the form of blocks or bricks. Once shaped, these blocks are laid out to dry under the sun's intense heat, allowing them to undergo a transformation into a hard and durable building material. This method capitalises on the intrinsic properties of laterite soil, which becomes significantly firm and robust after the drying process.

These types of soil possess several distinct characteristics that make them suitable for construction. When dry, laterite soils are notably very hard and impermeable, which means they do not allow water to pass through easily. This quality not only contributes to their strength but also makes them a practical choice for building foundations and walls. Furthermore, the hardening of laterite soils is largely irreversible, providing long-lasting structural integrity once set.

Fookes (1970) provided valuable insights into the composition and nomenclature of laterite soils. He noted that the term "laterite" itself derives from the hardening of the soil particles, which often results in a cemented crust rich in iron (see Table 2.2). The iron-rich layer, referred to as "ferric," offers enhanced durability due to its high iron content. In contrast, another variant known as "alcrete" is identified by its aluminium-rich cemented crust.

Table 2.2: Chemical Composition of Laterite (Far et al, 2013)

Compound	**Value (%)**	**Explanation**
SiO_2	33.55	Silica content, though reduced compared to the parent rock, is due to leaching.
Al_2O_3	22.31	High aluminium oxide, precursor to bauxite formation.

Fe_2O_3	19.40	Iron oxide gives laterite its red colouration and hardness.
MgO	2.07	Minor magnesium oxide, often leached in tropical weathering.
P_2O_5	0.11	Trace phosphate is usually insignificant.
K_2O	16.71	Potassium oxide is relatively high, contributing to soil fertility.
SO_3	1.98	Sulfates are present in small amounts.
CO_2	3.65	Carbonates are retained in minor quantities, despite leaching.

These types of laterite soils, observed primarily in their hardened states, are prevalent in various regions and have been widely used for construction due to their favourable physical and chemical properties.

Some laterite soils appear already hardened, and such soils are cut out in the shape of bricks or blocks to make building blocks after excavation. Buildings like "Castle of Seron de Nagima" and "Yanguas Castle", Rollo tower in Agreda constructed with stone masonry and mortar masonry. "Castle of Raya", "Temple at Angkor Wat" in Cambodia are also examples of the buildings achieved through this process with laterite and stones, and to date they still exist and are places of tourist attraction (see figure 2.4).

Figure 2.4: Temple at Angkor Wat in Cambodia

In the 19th century, this soil attracted the attention of scientists when a surgeon, Francis Buchanan-Hamilton, named the soil “Laterite” in 1807, in southern India. Nazeer (2006) reported that in India, laterite is one of the most valuable building materials, which is quarried in very large quantities and used as blocks and bricks for building. Another typical example of its notable use was in the construction of a primary school in Gando, Burkina Faso in Africa (Real, 2010), a building project that was built with communal effort and supervised by Architect Diebedo Francis Kere and Group of friends’ The walls of the school were built with CSEB which was stabilized with little quantity of cement (see figure 2.5).

Figure 2.5: (a) Primary School Building in Gando, Burkina Faso (Real, 2010)

Figure 2.5: (b) The Arrillhjere Demonstration House in Alice Springs, Australia (Real, 2010)

The walls of the above (figure 2.5: b) building were made of hand-made mud bricks from Laterite soil (red soil) dug from the site and stabilised with bitumen, which acts as water resistance to the walls of the building. The advantage of laterite soil rather than sand (fine Aggregate or river sharp sand) in making blocks is the economic advantage, which is the low cost of production, because a small quantity of stabilising agent is required to make blocks that have adequate strength (Isiwu, 2012). According to Madedor (1992), the Nigerian Building and Road Research Institute (NBRRI) successfully used laterite to make blocks for building bungalows in some rural areas
areas in Nigeria so as to meet the demand for shelter for the low-income group.

2.2.1 The Occurrence of Laterite

The hot and wet climate conditions of tropical and sub-tropical regions are the main origin of Laterite with a three-stage in-situ decomposition and weathering process in laterite soil production (Ganssen, 1965). Glaser, B (2005) classified Laterite as soil that has a reddish to yellowish colour, and its colour also depends on the water region during origin, and the mineralogical composition of the parent rock. Based on different classifications of laterite soil regarding the colour "Red Earth" or "Tropical Red clay", it has also been classified as soil that results from weathering of tropical basement rock, for instance, Granites frequently classified in engineering practices as a different classification of laterite soil.Unfortunately, the term reddish tropical soil still refers to laterite clay and laterite by some engineers. So some of these soils are not what they are assumed to be, but fortunately, for engineering works, it does not matter if the classification is right or wrong; what matters is that the engineering properties of the soil are to be classified and derived from testing that is reliable (Haselsteiner, Hans-George, Osan, & Bjorn, 2005).

2.2.2 Laterite Soil Composition

In view of the characteristics of laterite soil, there are factors that affect soil suitability for the production of blocks, and these factors are soil composition, soil moisture content, and soil plasticity. A proper soil would be composed of clay (15-20%), contain silt approximately 25-40 per cent by volume and approximately 40-70 per cent by volume of sharp sand" (Onaolapo, 2010). The soil plasticity depends primarily on the function of the clay content of the soil, with a plasticity index up to 20-30, which is adequate to apply when producing blocks (Onaolapo, 2010). When a proper soil mix design and the optimum moisture content are established, blocks can now be produced.

Some soils differ from each other depending on the area of collection and the nature of that particular soil, some of which have characteristics that can likely shrink, losing strength when they have high moisture content, and this might affect the performance of the resultant block. Nevertheless, proper compaction of the soil and a stabilising agent like cement or lime can still be used to improve and enhance the performance of the block in practical terms. It should be pointed out here that different laterite soils may appear in such a form that might be unsuitable for block production, for example, soil that was taken from a borrow pit might contain lumps which will require crushing so that a homogenous mix will be obtained (Ajao, Lawal, Onaolapo, & Eniayekan, 2012). The soil will be sieved with 6mm sieves so that the lumps or big stones will be removed. It can also contain a high percentage of clay and would make the blocks crack when curing, thus practically reducing the quality of the block to be achieved without the measures indicated. Such a soil should be mixed properly and with an appropriate amount of fine sand to have an excellent soil mix before block or brick production (Onaolapo, 2010).

2.3 Compressed Earth

The word earth in this report means Laterite soil. Compressed Earth is the process whereby soil is mechanically improved by pressing the earth soil particles together in very close contact, by expelling air from the soil mass. Compressing the soil increases the strength properties of the soil, reducing permeability and settlement, and increasing soil stability. The effects of compressing a soil in the form of a block differ from each other, and they are affected in different ways. One of the effects is the effort used to compress the block - higher effort used to compress the block results in higher energy and greater density (Osinubi, Ijimdiya, & Nmadu, 2008). Another effect is the elapsed time between mixing and compression, which harms the strength of the soil that is being stabilised by lime; that is to say that a sample that was compressed within 1 hour immediately after mixing will have more strength than the sample compressed after 1day of mixing (Osinubi, 1998; Mitchell and Hooper, 1961). Therefore, the delay after mixing soil with the stabilising agent affects the strength and development of the mix.

However, earth compacted with wooden tamps was the first form of compressing an EB in some parts of the country. The machine that was used for CEB was developed around the 18th century in France by Francious Cointeraux, an advocate of “new pise” (rammed block). In the 70’s and 80’s, a manual compressed machine was manufactured, which made the production of compressed earth blocks more energy-saving and economical to produce (Guillaud, Joffroy, & Odul, 1995). Compressing block (CB) is a recent form of earth block manufacturing which came into use all over the world about 30 years ago. It was not used only in third world countries but also in other developed countries, for example USA, Canada, France and Australia (Guillaud, Joffroy, & Odul, 1995). Historically, while the earliest machines were first used in the 18th century to compress earth into building blocks, in 1952 the modern ones came into existence by "Engineer Raul Ramirez of the CINVA in Bogota (capital of Columbia), then after the CINVA Ram press machine was adopted and used all over the world", more especially in the developing countries of Asia, Africa and South America (Rigassi, 1995; Gurllard, 1995; Hearthcote K.A, 2002). The compressed earth block is invariably an important modern building material, especially for building of low cost housing projects for those in the middle- or low-income group (see figure 2.6).

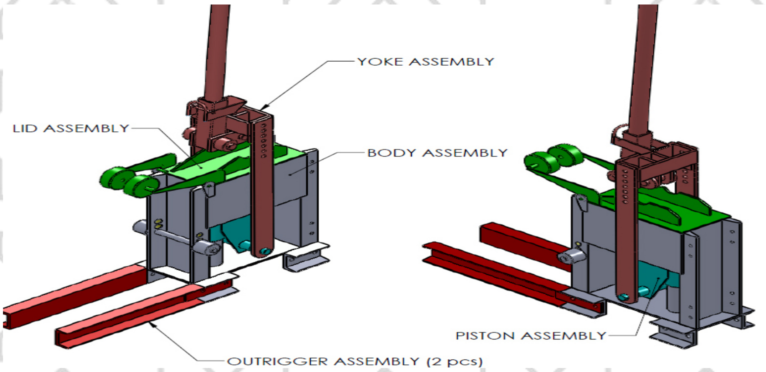

Figure 2.6: The CINVA- Ram Pressed Machines

2.4 Soil Stabilisation

According to some dictionary meaning of stabilisation is the application of a chemical treatment of a mass of soil to increase or uphold its stability and improve its engineering properties is known as soil stabilisation. Soil stabilisation takes place when cement, lime and fly ash are added to the soil in a mix; the pozzolanic reaction between the stabiliser and the soil develops a bond between the molecules in the soil and makes the soil durable for engineering purposes. In effect, soil stabilisation is the process of mixing a binder content with a soil (Laterite) to produce a material whose strength will be greater than that of the original material (Bell, 1993).

Table 2.3: Characteristics of Soil Stabilisation and its Effect on Soil (Bell, 1993).

Effect	Characteristics/ Description
Reduction in plasticity index.	The soil suddenly switches from plastic (sticky) to being crumbly (rigid and grainy). Then, later, it is easier to excavate and compact.

Improving the compaction properties of the soil.	In this process, the maximum dry density drops, while the optimum water content increases, therefore making the soil move into a humidity range that can make compaction easy. This effect is obviously an advantage when used on soil with a high-water content.
Improving the bearing capacity.	In almost every case, two hours after treatment, the California Bearing Ratio of a treated soil is between 4 and 10 times higher than that of the untreated soil.

Soil stabilisation has been defined in various ways. Soil stabilisation is also the treatment to improve the engineering performance of natural earth soil (Garber & Hoel, 2000). Thagesen (1996) stated that soil stabilisation is a process by which soil is improved and made more workable for the production of a good block. Generally, soil stabilisation is a process to create certain desired properties in a soil so as to make it suitable, useful and stable for an engineering purpose. Stabilisation of laterite soil takes place when a stabilising agent is mixed with the soil to change its properties to a more durable and long-lasting strength for making quality blocks. This process has made some soils, which were hitherto labelled unsuitable for some engineering purposes, turn out to be useful and have been applied in many areas of engineering work. McNally (1998) stated that the improved engineering properties of a given soil resulting from stabilisation are described as: an increase in soil strength, workability and durability, and reduced water absorption. Every stabilising agent has its particular soil material, which, when it is applied in that particular soil, will yield the expected properties. Table 2.4 shows some stabilising agents and their suitable soil for stabilisation.

Table 2.4: Different Stabilisers for Different Kinds of Soil. ((Esther, Joseph, & Malarizhi, 2010)

Types of Soil Conditions	Stabilizer
For nearly all types of Soil	Portland Cement
Medium, moderately fine and fine-grained soils	Hydrated Lime
Oarse-grained soil with little if any fine grains	Fly Ash
Cold Climate application	Calcium Chloride
For increasing the resistance of water & Frost	Bitumen

Stabilising soil is very important so that durability and sustainability will be achieved with the local and available earth soil. However, there are three classifications of stabilisation techniques as shown in Table 2.5, namely Mechanical, Physical and Chemical stabilisation (Houben & Huillaud, 1994).

Table 2.5: Stabilisation Techniques (Houben & Huillaud, 1994).

Stabilization Type	Characteristics
Mechanical Stabilization	This involves compressing the soil particles together to change their density, compressibility, Permeability and Porosity (Hicks, 2002)
Physical Stabilization	Changing the texture properties of the soil. It can be done by controlling the mixture of different grain fractions, drying or freezing, or heat treatment.
Chemical Stabilization	Changing the original properties of the soil by adding other chemical stabilising material(s). This happens either by creating a medium, which binds or coats the grains or by a physical-chemical reaction between the grains and the additive materials (Gooding and Thomas, 1995)

Physical stabilization comprises modification of properties of soil by bringing together the missing size fractions, the soil texture in this manner can be altered by calculation and mixing of different sizes of soil together, after which most of the void that existed earlier are closed because of the close-packing of the grains, and this process limits the movement of the grains in the soil (Metcalf and Ingles, 1972). According to Rigassi (1995), as in the case of applying mechanical stabilisation, physical stabilisation does not have a permanent effect on the soil. When the soil is in contact with water the soil grains are easily washed away, so to get a better result, it is then more advisable to use the other two methods.

Mechanical stabilisation is accomplished by a physical process of altering the physical nature of the soil by compacting or vibrating the soil and changing its density and reducing porosity. The process of compaction is what forces the soil particles closer in a way that the air is eliminated from the soil void. Again, this is achieved when there are no gaps graded and not uniform, thus helping the grain with different sizes to close the void that is created by other soil particles. The application of the method of stabilisation alone is not effective because it can be easily changed to its initial state when the soil is in contact with water. The water will cause the soil grain to move within, and in this method, the need for binder is highly imperative to override the reversible effect when in contact with water (Norton J, 1986).

Chemical stabilisation, according to Keller Bronchure, 32-01E (2011), occurs when a stabilising agent (cement, fly ash, lime, bitumen or a combination of these stabilisers) is mixed with a soil, to give the soil higher strength, lower permeability, and lower compressibility than the natural state of the soil or the native soil cannot provide.

When the stabiliser, which is the binder, reacts with and modifies the soil properties by means of cementation or linkage, both of which are the outcome of chemical reaction with the water and binder (Guillaud & Houben, 1994). The cementation creates a strong medium that can limit movement in a soil and fill the voids in the soil with an insoluble by-product of the hydration reaction, while some soil particles are held firmly by the binder and coated (Ingles, 1962). The major binder for such a chemical reaction is the Ordinary Portland Cement (OPC). In most literature on CSEB, it is reported that the effect of chemical stabilisation is permanent, and it will take years to partially reverse. Because of that fact, chemical stabilisation is regarded as the most superior way of improving or stabilising the soil.

The selection of soil for usage depends on the properties of the soil that is to be modified. The main properties of the soil that are required by engineers are strength, stability, volume, compressibility, durability and permeability. EuroSoilStab, (2002) and Sherwood (1993) explained that for a stabilisation to be successful, a laboratory test must be conducted so that the environmental and engineering properties will be determined. According to literature sources, in most cases, some laboratory tests conducted may give a higher result of strength than the one in the material at the site, but it will assist in assessing how effective a stabilising material will be in the field. The result generated from the laboratory will improve the knowledge of the amount and choice of binders. The combination of both the physical, mechanical and chemical stabilisation methods is highly recommended for the production of strong and durable CSEB (Gooding, 1994).

2.4.1 Stabilised Earth

Earth that is stabilized with cement, lime or bitumen before compressing gives the soil the ability to reduce the rate of water absoption and it has a greater change in the characteristics of the earth from unstable state of strength and volume with changing its moisture content to a suitable construction material and, on the other hand, the suitability of CSEB depends on the soil composition. The type of material that will be used for the stabilisation also depends on the composition of the soil. Laterite soil with a higher percentage of sand is best stabilised by cement, while lime works more with clay soil, but slowly with the clay to form a more stable pozzolanic material. Some authorities have stated that 5 per cent to 8 per cent of cement is recommended for the suitable performance of compressed earth wall (Venkatarama & Jagadish, 1987). Most soils might also possess different compositions that might warrant a higher percentage of additional stabilising agent, up to 12 percent before it will appear durable for block production. The CSEB is the more modern way of producing earth blocks. The reason for compressing the earth is to improve the quality and performance of the earth block.

2.4.1.1 Compressed Stabilised Earth Block

Compressed stabilised earth block (CSEB) is a manufactured construction material which is made up of earth (laterite) mixed appropriately with a stabilising agent, be it cement or lime, into a compressed block. It has been revealed that the use of compressed stabilised earth block has been of rising interest in the provision of low-cost houses, and stabilised earth building materials shall be of immense value as society progresses with respect to ecological design imperatives in building.

CSEB can be defined or explained in so many ways. It can be said to be the improvement of the earth's mechanical behaviour and the improvement of the soil durability, workability and compaction characteristics using a stabilising agent. This means that a proper use of mix with a high amount of stabiliser content (lime or cement) produces a very good building material with an outstanding chemical behaviour, while well planned application of mixture with low content of those stabilizers will be used to achive an economical and efficient solution to earth building and construction (Solanski, Zaman, & Hhoury, 2009). However, the environmental condition and the degree to which laterite is being compacted for the production of CSEB will also determine the nature and the strength of the block that will be produced (Gidigasu, 1976).

Building with earth is the cheapest material and is practically more economical due to its local availability and abundance in the environment, and some analyses have been carried out to prove that earth as a building material is cheaper. It was proven by Satprem (2010), who compared the wall made with CSEB and the wall made of fired bricks in India.

Table 2.6: Cost Comparison of Walls Made of CSEB and Walls Made of Fired Clay Bricks (Satprem, 2010)

CSEB wall 24cm thick	Country fired clay Brick wall 22cm thick
3,067 Rs Per M^3	4,243 Rs Per M^3
736 Rs Per M^2	934 Rs Per M^2

From Table 2.6 above, it can be proved that CSEB is more economical than the country-fired brick, and it is also more environmentally friendly than the country-fired brick because no fire is required, but only curing. This reason makes it superior to the fired bricks because pollution during firing is eliminated (Satprem, 2010). In the review of recent research work on CSEB, it was observed to be of great importance because of its features as a commercial building and construction material, since only one material will achieve numerous important benefits, which include structural reliability and durability when it is used for construction and in building. Compressed stabilised earth block (CSEB) technology is said to be superior to other walling materials like concrete blocks and wood construction due to its health benefits, affordability, and energy efficiency.

Laboratory tests have also been conducted on compressed earth blocks, concrete blocks and Adobe for thermal tests by the "Biology Department of Southwest Texas Junior College, Del Rio, Texas". These tests were conducted to know the thermal change on the three block materials (Biology Department of Southwest Texas, 2004) as shown in Table 2.7.

Table 2.7: The Thermal Change on Three Blocks Materials (Biology Department of Southwest Texas, 2004)

Concrete building	111 ºF (44 ºC) 4 degrees Fahrenheit above ambient
Adobe building	95ºF (35 ºC)
CEB building	91 ºF (33 ºC)

The above results show that the internal temperature of the compressed earth block and adobe was lower than that of the concrete block, and this has given the compressed earth block an advantage over the others. Also, it proves that the laterite block is cooler by up to 4 degrees than adobe. Another analysis done on compressed earth block walls by Abd Halid (2013) proved that the use of compressed earth block as a walling material reduced the indoor temperature during the day and even remains in a comfortable condition during the hot day. It is clear from the foregoing that compressed earth block provides a much better indoor thermal performance and improves indoor environmental conditions than other materials (Halid, Siti, & Ismail, 2013), with the test and analysis done based on the result of "thermal simulation" with ECOTECT program.

Recently, researches have been carried out on rammed earth construction in North America for the purpose of generating more shelter for the population with low income in view of the building challenges facing the people of the region and also recognising the benefit of stabilising earth for a more effective and durable building. It also created wider awareness that the stabilised earth or rammed earth has the capability of lasting longer than some building materials (Windstom & Arno, 2013). These prove that the construction process of a stabilised earth wall creates a relatively high compressive strength that is suitable for a broad range of cooling and heating climates and has proved successful in moderate to hot climates, as the thermal mass effectively moderates the daily temperature changes (Windstom & Arno, 2013). The immediate findings also agree with the test that was conducted by the Biology Department of Southwest Texas (2004) on a thermal test that earth block or earth houses are cooler than the walls built with conventional materials and the adobe blocks. Stabilised earth is also generating increased interest in the building of public, residential and institutional buildings all over the world (Windstom & Arno, 2013). Windstom & Arno (2013) said that "Laterite (earth) locally sourced when used for building has a very low embodied energy and will provide shelter for generations if the earth is properly selected and stabilized as can be seen in Table 2.8.

Table 2.8: Embodied Energy and Pollution Between CSEB, Wired Cut Bricks and Country Fired Bricks (Satprem, 2010)

Little embodied energy per m^3 material	Less pollution per m^3 of material
CSEB – 1,257 MJ per m^3	CSEB – 113 kg of CO^2/m^2
Wired cut bricks – 3,294 MJ per m^3	Wired cut bricks – 296 kg of CO^2/m^2
Country fired Brickes – 5,447 MJ per m^3	Country fired Bricks – 410 kg of CO^2/m^2

The compressed stabilised earth block is environmentally friendly because no firing is required, and there will be no air pollution, but only curing is required. But blocks or bricks that have been fired (fired bricks) are not environmentally friendly due to the pollution of air that comes from burning the laterite bricks (Satprem, 2010). Laterite is an outstanding material for walling when compared to fired bricks that are used for building.

2.4.1.2 Stabilising earth soil with cement

Cement is an important material in the field of building and construction and it could be divided into different types namely: Portland cement (ordinary Portland cement) Stag cement, Pozzolonic cement and High Alumina cement Furthermore, each of the cement types differs from one another in respect of their rate of strength, rate of heat evolution, resistance to sulphate attack, and Dry shrinkage. However, in all the different types of cement, the one most widely used in building is the Portland cement (ordinary Portland cement), while the other types of cement are used in cases where concrete materials with special properties are needed.

Figure 2.7: Cement

Ordinary Portland cement is the major binding agent used in every building because of its binding capability when it comes in contact with water, and it has the ability to speed up its features of hardening and setting. Ordinary Portland cement is a hydraulic cement (an inorganic material or mixture of inorganic materials that sets and develops by chemical reaction with water by a formation of hydrates, and is capable of doing so under water). Composed primarily of hydraulic calcium silicates, the effects on the physical properties of cement mortars are strength and soundness, hydration, setting and hardening, fires and chemical composition.

Ordinary Portland cement (OPC) which is the cement that is famously used in the construction industries for building and construction, it plays a very important role in improving the performance of CEB because without its addition, CEB will be nothing different from the other earth blocks like mud blocks, sundried blocks which break apart or crumble when it absorbs and retains water or subjected to impact load (ILO/UNIDO, 1984).

Apers (1983), Stulz and Mukerji (1988), explained that the major function of the OPC is to bind the soil particles together in a strong, dense, dimensionally durable and stable form. They also asserted that there are still some other binders that are commonly used, which include Lime Gypsum, Pozzolans, Resins and Bitumen. The selection and use of OPC in this thesis is as specified in ASTM C 150 -94. In this research, the two reasons I selected OPC are, first, its superior, unique and faster binding capacity, and second its availability in all parts of the world. OPC is unique in comparison with other binders because of its binding ability to gain its maximum strength in about 28 days, unlike most other binders. According to Gooding (1994), “stabilising block varies in OPC quantity and amount, and that can drastically affect its properties and behaviour”.

Unfortunately, the use of OPC, as applied at times, makes the CEB less durable. The misuse and incorrect use of most binders is now becoming the order of the day (Fullerton 1979, Spence& Cook, 1983) and this issue of misuse or incorrect application of OPC to the soil can still be observed when there are low amounts of water to ensure a complete hydration of the cement, and so due to this reason an adequate amount of OPC and water content are to be applied in mixing to get a good and durable CSEB.

2.4.1.3 Stabilising earth soil with lime

Lime has been used for a long time for the treatment of soils in order to improve their workability and load-bearing characteristics. Many research works have revealed that lime reacts with medium fine soil or fine-grained soil to have an increased workability, decreased plasticity and increased strength (Little, 1995). This gained strength is practically based on the chemical reaction due to the involvement of an immediate change in the soil's visual properties caused by cation interchange. The calcium of the lime exchanges with the cation of the soil that was absorbed, which will cause the water layer around the soil particles to reduce in size and the process allows the soil particles to come in close contact with each other, causing agglomeration of the soil particles. Eades and Grim (1960) indicated that only soils that are readily mixable, workable and compactable can achieve the agglomeration phase of lime stabilisation, and also that all fine-grained soils go through the cation exchange and agglomeration reaction with lime when in contact with water

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Figure 2.8: Hydrated Lime

Another chemical reaction in lime stabilisation is the pozzolanic reaction within the lime and soil mixture, which results in gaining strength, according to Eades and Grim (1960). Carbonation is another process that can cause a long-term increase in strength for soil that is stabilised with lime. When lime is mixed with soil, it reacts with carbon dioxide to produce an insoluble calcium carbonate. Arman and Munfakh (1970) added that the process is an advantage since, after the mixing, the sluggish process of carbonation and formation of cementation products may cause a long-time increase in strength. It was reported by Magafu (2010) that stabilising soil with lime has been proven by a permanent increase in the strength of the soil, reducing soil swelling and provides an excellent result in freeze-thaw resistance.

Lime is widely used to stabilise earth blocks for good block production. Quicklime is used to dry wet soil at construction sites, to reduce downtime and providing improved working surface. Lime is commonly used to modify and stabilise the soil for block production or soil beneath for road construction, as its application to soil will increase the stability, load-bearing capacity and permeability. However, lime is among the oldest stabilizing agents and the oldest material that is used to improve the engineering properties of earth soil, and it is also economical to use, even for the sub-base and the base materials (Garber & Hoel, 2000). These researchers also reported that the addition of lime in fine-grained earth has a great beneficial effect on the engineering properties, which includes reduction in swelling of CSEB, plasticity, improving workability, increasing stiffness, increasing strength, enhancing durability and binding the soil particles. In most construction work, it is used to dry and temporarily modify the earth. A good and proper treatment of soil supported with testing, proper construction techniques and design produces a permanent structural stability of earth. According to Garber and Hoel (2000)

“The percentage or quantity of lime used to stabilise a soil depends mainly on the type of soil that is to be stabilized and the determination of the quantity of lime is based on the analysis of the effect that different lime percentages have on the reduction of plasticity and increase in its strength on that particular soil”.

This means that proper analysis should be made on the earth soil to know the properties of that particular soil to know the right quantity of stabiliser and the proper stabiliser that will be suitable for the soil. Ankit, Faizan, Devashish, and Rehanjot (2013) concluded in research on soil stabilisation using lime that

“Lime is used as an excellent stabilising material for highly active soil which undergoes frequent expansion and shrinkage, and the properties of the soil determine the rate of reaction with lime, and the high strength of the stabiliser will make the soil gain”

This is to prove that lime reacts or works more with a soil that is more clayey and has binding properties. According to Osinibu (1995), "lime is understood to work effectively to stabilise a clayey soil that has more fine content in surplus up to 25% because it makes the soil more workable and less plastic". Also, Garber and Hoel (2000) reported that although oxide and hydroxide of calcium and magnesium are known as lime, the main material that is commonly used for stabilisation with lime are calcium hydroxide (Ca (OH) 2) and dolomite (Ca (OH) 2 + MgO). However, lime has a very important role to play in the stabilisation of earth block, and it can effectively stabilise a fine-grained earth soil with 3% - 10% of lime, based on the soil dry weight It is also more effective to treat plastic clay that is capable of retaining a large amount of water. Mixing lime with a fine-grain soil and the addition of water gives several reactions that are cation exchange and agglomeration or flocculation that takes place immediately with immediate improvement in the earth soil plasticity, workability and increase in strength over time; which takes place during and after curing of CSEB. The long-time reaction is a result of the pozzolanic strength gained due to its presence in the CSEB (Quintus, Mallela, & Smith, 2004). It means that lime gradually gains its strength; the more it stays, the more strength it gains.

2.5 Compressive Strength of CSEB

Compressed Stabilised Earth Blocks (CSEB) are widely studied for their mechanical performance, especially compressive strength, since that property determines their suitability as a load-bearing construction material (see figure 2.14 for setup of compressive strength).

Figure 2.14: Stabilised earth block Specimen in a Compressing Machine

Many related works have reviewed the strength of CSEB, and the results have been very motivating, not only on the economic benefits of using CSEB for low-cost housing but also on its strength as a walling material. Chee-ming and Liang-pin (2010) developed a Strength Prediction Model from Green

Compressed Stabilised Earth Block, which achieved a maximum strength of 1.2, 1.9 and 2.4N/mm² for cement content of 5%, 8% and 10%, respectively. The result of the compressive strength did not meet the Malaysian Standard (MS 76: 1972), and further advised that an additional 13% of cement should be added to each soil so as to achieve the standard strength required by the Malaysian Standard. Agbede and Manasseh (2008) reported that bricks made of laterite, admixture with 45% sand and 6% cement, gained a compressive strength of 2.12N/mm² with an increase in cement content after 28days of curing, as shown in Table 2.9. Six percent (6%) cement content is economical for the production of laterite bricks for low-cost housing, and such strength of bricks could be used best for one storey building (Adam, 2001)

Table 2.9: Result of Compressive Strength (Agbede and Manasseh, 2008)

Cement Content (%)	**0**	**3**	**6**	**9**
0%Sand Content				
Weight of Bricks(kg)	11.40	12.42	12.67	12.82
Density of Bricks(kg/m^3)	1534.3	1671.6	1705.2	1725.4
Load at Failure (kN)	12.4	35.0	63.0	82.0
Compressive Strength (N/mm²)	0.25	0.70	1.27	1.66
45%Sand Content				
Weight of Bricks(kg)	11.33	13.48	13.59	13.74
Density of Bricks(kg/m^3)	1524.9	1814.3	1829.1	1849.3
Load at Failure (kN)	10	41.0	105.0	164.0
Compressive Strength (N/mm²)	0.20	0.83	2.12	3.31

Portelinha, Lima, Fonts, and Carvalho (2012) reported that cement stabilisation had a higher strength than lime after 7 and 28 days of curing and that cement is more efficient than lime due to its speed of gaining strength in a short period of time. However, it is also clear that compressive strength of CSEB increases as the percentage of stabiliser increases for both lime and cement, but cement stabilized block have a better quality and are cheaper than the block stabilized with lime.

Aguwa (2009) reported on a study of “compressive strength of laterite cement mix” that laterite cement mix improved with an increase in cement percentage content up to 20% and 10% cement content and met the strength of load bearing and non-load bearing wall with a compressive strength of 2.5N/mm² and 1.8N/mm² according to Nigerian Industrial Standard NIS: 87:2004. The results also show that laterite cement mix is an economical building material due to less cement content, and also that the cost of the block depends so much on the cement content.

2.6 Water Absorption of CSEB

Water absorption of CSEB is the ratio of the mass of water that was absorbed to that of the mass dried in CSEB. Every mass of absorbed water is different in mass between saturated surface-dry (SSD) in CSEB after being placed in water for 24 hours. This process is always expressed in percentage (Ahmade, 2008). However, the absorption of water is greatly influenced by the porosity and surface texture of that particular material. Akeem, Olugbenro, & Kehinde (2012) opined that the water absorption of interlocking blocks decreases with an increase in the percentage of cement stabiliser. The result proved that the cement binds the laterite particles together and reduces the size of pores where water will flow into the block. The block without a stabiliser (control sample) disintegrated in the water. According to the result of the laterite interlocking blocks in a work by Akeem, Olugbenro, & Kehinde (2012) which satisfied the water absorption recommendation of 12% by the Nigeria Industrial Standard (N.I.S: 2004) with a percentage of water absorption of 7.62%, 6.07% and 5.23% for blocks with 5%, 10%, 15% percent of stabilizer respectively as shown in Table 2.10.

Table 2.10: Water Absorption of Cement Stabilised Interlocking Blocks (Akeem, Olugbenro, & Kehinde, 2012)

Cement Stabilisation (%)	Dry Mass (kg)	Wet Mass (kg)	Water Absorbed (%)	Average of Water Absorbed (%)
0	- -	- -	- -	- -
5	14.440 14.530	15.530 15.648	7.55 7.69	7.62
10	14.092 13.871	14.987 14.675	6.35 5.79	6.07
15	14.120 14.333	14.842 15.098	5.11 5.34	5.23

2.7 Effect of External Water on CSEB

Water causes earth blocks to deteriorate. Most traditional walls suffer from such a problem, and there have been so many ways in which water has an effect on earth block or walls made of laterite. Notable kinds of water with this effect are rainwater and rising dampness from the ground.

However, McHenry (1984) and Fransworth (1999) stated that water also hurts blocks, for it erodes the base of the walls of earth buildings, causing them to crumble and fall apart easily. Since water hurts earth buildings through erosion, it is advisable to use an alternative material to prevent it from getting very moist from rain, soil humidity and groundwater or water from the internals, like water from a leaking tap, pipes or used water.

Observations have been made by UN (1964), Agarwal (1981), Spence (1985), and ILO (1984) on the deterioration of earth blocks, and it can occur in different forms, such as solvent, abrasive and swelling of earth blocks. Solvent is the ability which makes the surface of the block to get wet easily and the capability of that block to absorb and hold water for a long time. This will leave the block to be weak and cause it to fall apart. Solvent is a common failure that occurs in blocks (Sjostrom, 1996). Although Herzog and Mitchell (1963), Houben and Guillaud (1994), pointed out that in stabilized block, when the soils are not properly selected and not properly stabilized the cement or any stabilizing agent will not affect all the content of the blocks leaving the block less durable and easily attacked by water. Moreover, most of the traditional walls which are not properly stabilized or not stabilized at all have the capacity of absorbing water just like the sun-dried bricks which are not stabilized will absorb water and retain it, and as the brick allows the water, then the brick wall will be expected to soften. When this process of water intake keeps repeating itself over years, it may lead to a total softening of the bricks or walls, and this effect may also cause the soil to fall apart from the walls and likely increase during raining season.

Abrasion of the block or walls of a building may sometimes be caused by rainwater (Atkinson 1970, Eaton 1981, Fullerton 1979). Ola and Mbata (1990) also stated that “abrasion, which is caused by rain water, has been identified by many as one of the common deterioration agents”. The only place that really suffers surface erosion is mostly the areas that are liable to frequent rainfall, such as the Tropical areas. Ellison (1944) and Goldsmith et al (1998) discussed the process and the rate at which rainfall removes the loose particles (parts of the block which are not properly bonded with a stabiliser or particle of an unsterilized earth block), and the rate of the eroding process on the bonding state of the block and features of the rainfall. When rain drops on the block, they will definitely impact with a force on it, and with water splashing on the surface of the block, the impact will cause the block particles that are not properly bonded with a stabiliser to fall apart and leave the block surface to get wet.

Figure 2.9: Wall of a Traditional Building that Cracked after Frequent Years of Rainfall

Gunn and Kinzer (1949), Hudson (1963) defined the rate of the rain drop on the blocks as "the drop size, wind speed, fall and impact velocity energy which can impact on the surface of the block and cause the soil particles that are not stabilized to fall apart (removing the particles on the block that are not stabilized)". Most of these limitations of earth soil as a building material are clear even to the unprofessional and professional, like loss of strength, a high increase in permeability, and mass loss from the block surface. Proper measures are to be taken to improve the strength of the earth blocks and to prevent the earth blocks from absorbing and retaining too much water. Such measures are the proper stabilisation of the earth block, which will be practically demonstrated in this report.

3. Conclusion and Recommendation

Laterite is a versatile and culturally significant construction material found in tropical and subtropical regions. Its historical use in monumental architecture and vernacular housing highlights its durability and adaptability. Today, laterite is utilised in modern applications like compressed stabilised earth blocks (CSEB), road bases, and decorative facades, demonstrating its relevance in sustainable construction.
With a high oxide content, moderate strength, and natural plasticity, laterite is an ideal option for low-cost housing solutions, particularly important in developing countries where affordability is crucial. Locally sourced, it supports regional economies while minimising environmental impact.
However, challenges exist, including variability in composition, weathering susceptibility, and shrinkage under moisture. To enhance its performance, stabilisation with agents like lime, cement, or bitumen is often necessary.
Overall, laterite bridges traditional practices and modern engineering, providing a pathway toward eco-friendly, low-carbon housing solutions

that align with global sustainability goals.

Recommendations

- *Government and Policy Support:* National housing programmes should integrate laterite-based construction, particularly CSEB, into affordable housing schemes to reduce reliance on costly imported materials.
- *Standardisation and Codes:* Establish clear building codes and standards for laterite block production to ensure quality, durability, and safety across regions.
- *Research and Innovation:* Continued research into stabilisation techniques and soil mix optimisation is essential to overcome limitations such as cracking, shrinkage, and moisture sensitivity.
- *Community Empowerment:* Encourage local production of laterite blocks to create employment opportunities, strengthen rural economies, and reduce transportation costs.
- *Sustainability Integration:* Promote laterite as a low-carbon alternative in construction, leveraging its thermal efficiency and natural abundance to meet eco-friendly housing targets.
- *Education and Training:* Provide technical training for builders and communities on modern laterite construction methods, ensuring proper compaction, stabilisation, and maintenance practices.

By adopting these measures, laterite can evolve from a traditional material into a cornerstone of sustainable construction, addressing housing shortages while preserving cultural heritage and environmental balance.

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