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STABILIZED SOIL IN BRICKMAKING



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This article from the Central Building Research Institute, at Roorkee, India, reviews experiences from several countries in the use of stabilized soil for building, pointing out that results from this technique in road works could be extended to the production of bricks and blocks made from stabilized soil. However, there are many different kinds of soil, each requiring careful examination before deciding on the appropriate method of stabilization.

Cet article du Central Building Research Institute de Roorkee (Inde) étudie les expériences de plusieurs pays dans l'utilisation de sols stabilisés dans le bâtiment. Il souligne que les résultats de cette technique dans les travaux routiers pourraient être étendus à la fabrication de briques et de blocs. Il existe cependant de nombreux types de sol, chacun d'eux nécessitant un examen approfondi avant de décider du mode de stabilisation à employer.

There has been a steep rise in the cost of modern construction materials in recent times, and it has led to rethinking the use of indigenous and local materials to provide low-cost housing. Soil has been used in building houses for ages. It is abundant and possesses all the attributes of a good building material, except that it shows excessive drying shrinkage and complete loss of strength when wet and gets eroded by driving rain.

The traditional way of building mud walls is to place layers of soil on top of each other, allowing one layer to dry out before the next one is placed. This not only delays the construction but the walls always crack. It is not surprising, therefore, that serious effort has been made to work with stabilized-soil bricks and blocks (refs 1-7).

SOIL PROPERTIES

Stabilization through heat is one of the major achievements in this direction. Addition of materials such as cement, lime and asphalt has also yielded good results. The experience in the African countries on soil stabilization with these additives has been quite encouraging, not only on the grounds of performance but also from economic aspects.

The use of chemical admixtures of various types is the oldest and most widely used technique. The general objective of mixing these admixtures with soil is to improve strength, durability and volume stability. Volume stability of soil mass can be improved by replacing high hydrating cations like Na^+ with low hydrating cations such as Ca^{++} , Mg^{++} , Al^{+++} or Fe^{+++} and binding with waterproofing chemicals.

Stabilization depends on the character of the soil, its mechanical and mineralogical composition and the nature of extraneous constituents present in it (ref. 8). Adsorbed and exchangeable ions also affect the properties of the stabilized soil mass. Alluvial and clayey soils exhibit good dry strength and need stabilization against water only. Sandy, coarse and lateritic soils

need stabilization for improvement in dry strength as well as resistance against water erosion.

Thus, to evolve more effective methods there is a need to review the existing knowledge on the subject. Studies on soil stabilization for the purpose of road and pavement construction have been extensively carried out the world over (refs 8-11), and these findings could be extended for the production of stabilized-soil bricks and blocks.

Many methods for soil stabilization have been proposed. A satisfactory agent must provide the required qualities to the brick and in addition must be:

- Compatible with the soil material.
- Durable and able to retain its character.
- Easily handled and processed.
- Low cost.

The action of organic and inorganic stabilizers is generally quite different. Organic stabilizers are characterized by a rapid gain in strength and water resistance due to their hydrophobic nature as compared to inorganic stabilizers. The principles involved in soil stabilization and the influence of a few important stabilizing agents on soils are discussed below.

COMPACTION TECHNIQUES

Soil mass consists of clay minerals and organic matters besides air and water. Air is present in the voids and can be expelled when the soil is kept in contact with water. Since the increase in water content lowers the strength properties, any attempt to check the permeation of water as a result of void reduction will produce a strong and water-resistant body (ref. 12).

Densification or void reduction can be attained in a number of ways, e.g. by reorientation of clay particles, mechanical compaction, change in chemical composition of pore water, etc. Compaction characteristics of soil mass are best analyzed in terms of clay-water interaction as well as by mechanical particle-to-particle interaction within the soil. However, the studies undertaken by soil engineers on compaction behaviour of soils do not cover some of the basic aspects of soil mineralogy, chemical composition of pore water, nature of adsorbed or adsorbed ions etc. (ref. 13). It is therefore desirable that efforts to stabilize the soil mass by void reduction or compaction should be investigated further in the light of the above parameters.

USING BITUMINOUS PRODUCTS

The effect of water on lowering the shear strength of soil mass can be reduced if a waterproofing material is introduced in the soil particles and water interface. This is best done by providing a coating of waterproofing agent such as asphalt/bitumen over the particles (ref. 11). The coating provides additional cohesive strength and reduces water penetration into the mass.

However, thin bitumen coatings are advised, since a thick coating of bitumen produces a lubricating action, and the treated soil mass becomes liable to shear when kept under the influence of compressive forces (ref. 8). Mechanical mixing of the soil and bituminous products is most desirable. In mechanical mixing the individual soil particles are coated with the bitumen. It is most important, therefore, to have the soil in a dry condition at the time of mixing; the presence of a water film on the soil particle interface inhibits the adhesion of the bitumen coating. The bitumen must also be in liquid form, effected by heating at temperatures between 35°C and 190°C depending on the grade of bitumen used. The soil is preferably kept warm in order to avoid premature hardening of the bitumen (refs 11-15).

The use of hot bitumen has some obvious disadvantages, and therefore cut-back and emulsified bitumens are more frequently used. With an emulsified bitumen, water is actually introduced with the bitumen; hence the soil need not be air-dry initially. Mixing of bitumen emulsion may be made easier by adding the emulsion to the mixing water than by adding water to the soil and then mixing. However, air drying is required when soil is stabilized either by cut-back or emulsified bitumen.

The requirement of mixing equipment is one of the major limitations of bitumen in soil stabilization (ref. 14). Further, the entire process not only involves drying and mixing but also shaping, compaction and finishing, all of which must be completed before the mixture cools and sets to a rigid mass.

Bitumen treatment for soil stabilization has been found quite satisfactory for sandy or sandy loams. In such soils, the inherent cohesion between the particles is poor. The bitumen coating over the particles adds to the cohesive strength in addition to the development of waterproofing properties. Also, mixing bitumen emulsion with sandy or loamy soils is easier and more uniform than with fat clays. However, plastic clays having a liquid limit over 50 have still been successfully stabilized with bitumen.

Soils rich in salt and organic matter reduce the effectiveness of a bitumen treatment as a result of the coating of salt and organic matter over the soil particles. This inhibits adequate adhesion of the bitumen film (ref. 16). The adhesion between the coating and the soil particle is also reduced by efflorescent action of the salt.

However, this deterioration in strength and durability of the stabilized soil bricks or blocks primarily depends on the nature and amount of salt present. Chester (ref. 16) has reported that even 6 per cent sodium chloride can be tolerated in certain soils for bitumen stabilization; beyond this level the treated soil mass may crumble in course of time through efflorescent action.

Efforts have been made to enhance the adhesion of bitumen coatings by incorporating certain chemical additives such as polyacrylamide, cetyl trimethyl ammonium chloride, soap emulsifier etc. These additives fall under the category of colloidal electrolytes or surface active agents. It has been reported that soils stabilized with cut-back bitumen gain considerable strength and water resistance even with less than 1 percent addition of such additives (refs 14, 15).

STABILIZING WITH PORTLAND CEMENT

A variety of soils can be effectively stabilized by cement (refs 1-3, 8, 17-19). The addition of cement in the range of 4-10 percent greatly improve the water resistance and strength properties of the soil mass. However, for a satisfactory hardness and durability 8-12 percent cement (by volume) addition has been found necessary.

The key to successful stabilization with cement lies in thorough mixing. In fact most difficulties in producing soil cement bricks or blocks arise from improper mixing. Pulverization, mixing and compaction all have marked effects on the quality of soil cement bricks/blocks produced. Therefore due allowance for these effects must be given during production.

It is reported that the cement requirement is substantially reduced if the soil-cement mixture is compacted under pressure. A pressure of 1.5 to 2 N/mm² has been found to effect a reduction of 40 to 50 percent cement for the same strength of brick. Further, moist curing produces bricks and blocks of higher strength compared with water curing.

The mechanism of strength development with Portland cement has been discussed by a number of researchers. It has been found that the addition of cement in soils rich in the group of expanding clay minerals results in a nucleated structure at lower proportions (less than 3 percent). This nucleation tends to change to a skeletal structure at higher cement additions. The

cementitious components of cement, such as dicalcium/tricalcium silicate, in the presence of the soil water system form gels of mono/di calcium silicate hydrate and free lime (ref. 18). The formation of insoluble calcium silicate gel and its interlocking effects within the soil matrix explains the development of adequate strength (refs 17, 18).

SUITABLE CLAYS

Sandy/loamy or lateritic clays are more suitable than 'fat' clays for stabilization by cement. Fat clays appear to retain some susceptibility to water softening and tendency to swell with an increase in moisture content. It has been found that soils containing up to 50 percent fraction passing 75 micron sieve and liquid limit less than 50 can be satisfactorily stabilized with cement to yield building bricks and blocks of adequate durability and strength. The presence of organic matter above 2 percent and soluble sulphates (above 0.2 percent) adversely affects the strength development and durability of a cement-stabilized soil mass. It is therefore essential that soil systems are properly evaluated for various mineral and non-mineral components before they are used for making stabilized bricks or blocks.

The method of making soil cement bricks or blocks involves dry mixing of soil and cement, addition of the optimum quantity of water and compaction of the bricks/blocks in a suitable press such as Land-crete, Cinvaram or BREPAK machines (refs 19-21). It has been reported that a compaction pressure up to 10 MN/m² or more can be obtained in such presses.

Added advantages of improved strength and durability of cement clay pozzolana have recently been reported. Nagaraja (ref. 22) has stated that a lean mix of cement:clay:pozzolana (1:32:1) can yield bricks of adequate strength if the mass is compacted at a nominal pressure of 12.5 to 37 kg/cm² and the pressed bricks are moist-cured for a period of 2 to 4 weeks. Further, 5-10 percent addition of a mixture of lime and fly ash (1:2) can also be used for the stabilization of shales by compaction (refs 28-30).



Moulding stabilized soil bricks in a Landcrete machine

STABILIZATION WITH LIME

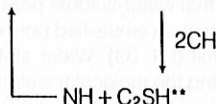
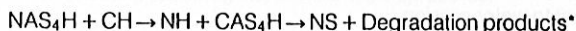
The stabilization of soil mass by hydrated lime has been extensively investigated (refs 8, 12, 22-32).

The purity of lime has been considered as one of the major requirements for successful soil stabilization. The addition of lime (5-15 percent) to clayey soils brings about a significant reduction in plasticity and shrinkage. Therefore lime addition has given better results with heavy and fat clays than with sandy or lean clays.

Numerous hypotheses have been proposed to explain the role of lime in soil stabilization. These include:

- The formation of calcium carbonate.
- The crystallization of calcium hydroxide.
- The formation of a calcium aluminium silicate complex from added lime and the free silica and alumina of the soil system.
- The formation of the calcium alumina silica complex from lime and silica provided by the breakdown of clay mineral as a result of high pH.
- Flocculation as a result of decreased potential.
- Flocculation caused by proton transfer and subsequent binding by Ca⁺⁺ ion.

It has been reported that the reactions in lime soil mixtures are similar to those taking place in cement soil systems but at a slower rate. The lime stabilization proceeds as a result of the attack on clay mineral lattice to form lower calcium silicates, mostly mono and di calcium silicates, which on hydration gain strength and bind the soil particles. These reactions have been represented as follows:



where S = SiO₂, H = H₂O, A = Al₂O₃, C = CaO, N = Na₂O

*As silica is progressively removed, calcium aluminate and alumina are formed residually.

**or mono calcium silicate hydrate.

Lime stabilization of soils rich in organic matter and sandy granular material is not very effective, while clayed soils rich in the group of expanding clay minerals develop adequate strength and resistance to water erosion. As discussed earlier, the gain in strength in lime-stabilized bricks is slow; however, the surface erosion is considerably reduced, possibly due to carbonation of lime, particularly at the surface of the brick body. Kaolinitic clays rich in alumina content show a slow rate of strength development by lime. The improvement in strength and durability of a lime-stabilized soil mass also depends on the temperature during curing. A warmer climate favours rapid strength development.

It has been observed that strength and resistance to water of lime-stabilized bricks can be improved by incorporating pozzolanic materials (refs 5 and 22). Also a mix of waste gypsum and lime gives better strength than lime alone. The increase in strength in gypsum-lime-stabilization is due to the formation of atringite (3CaO . Al₂O₃ . 2CaSO₄ . 32H₂O) in the system (ref. 25).

USE OF CHEMICAL ADDITIVES

The physico-chemical alteration in the properties of a soil mass can be affected by certain organic and inorganic chemicals. They significantly modify the soil-water interactions and/or orientation of soil particles in the soil matrix. These alterations in the fabric of the

soil are of great technological importance. The changes are often associated with improvements in the strength and water resistance properties – the main prerequisites of soil stabilization.

The chemicals which bring about such changes can be broadly grouped as: inorganic and organic.

Inorganic agents

The stabilization of soil mass can be affected by certain acidic, alkaline and neutral inorganic chemicals such as H_3PO_4 , $HFNaOH$, $Ca(OH)_2$, Na_2CO_3 , $CaCl_2$, Na_2SiO_3 , $NaCl$ etc. Acidic and basic chemicals essentially attack the lattice structure of clay mineral particles and precipitate insoluble components which render the soil mass resistant to water erosion, in addition to improvement in the strength properties. The neutral inorganic salts modify the soil structure so as to make it more dense and compact.

As a result of increased compaction by chloride salts, the shrinkage and cracking tendencies are reduced, thereby making the soil mass more resistant to rain water penetration. In addition these salts are known to reduce the plasticity of soil mass due to balancing of the clay lattice charge and change in the soil fabric. However, the treatment by salts for soil stabilization has been found more effective in hot and relatively humid regions.

Organic agents

Various organic chemicals, particularly organic cations, resins or polymers, are known greatly to modify the clay-water interaction (refs 13, 28–32). Apart from mechanical forces, the clay and its adsorbed components, notably absorbed organic chemicals, exert great influence upon particle arrangement or soil fabric. A hydrophobic effect on the clay mineral lattice usually results due to fixation of organic cations such as those of di-alkyl di-methyl ammonium or cetyl trimethyl ammonium. This makes the soil mass resistant to water erosion.

It has also been reported that water-soluble polymers increase the mechanical strength more than emulsified polymers, at least if they become insoluble in soil (ref. 33). Water stability of soil is further improved by increasing the molecular weight of polymers. However, for polymer emulsions, molecular weight seems to be of little importance. The increase in the stability of the soil in water is due more to water-soluble polymers than to emulsions (refs 34, 35). Urea-formaldehyde condensation products have also recently been used for altering soil properties (ref. 36).

Polymers of cationic type carry a positive charge which forms strong electrostatic bonds with negatively charged clay mineral particles and fine silica sand (refs 31, 32). The resultant flocculated clay mass develops increased resistance to water and shear forces. Typical polymers of this type which have been tried are polyacrylamide and products with trade names such as Armeen, Arquad etc., having two long carbon-chain alkyl groups.

Non-ionic polymeric additives such as polyvinyl alcohol, carboxy methyl cellulose and cellulose derivatives are also found effective due to the presence of an active hydroxy bond formation between the surface oxygen atom of the clay mineral and the polymer itself. This becomes effective through coagulation of the soil mass. Polysaccharides have also shown their effectiveness for soil stabilization on a similar analogy. Anionic polymers such as sulphonates are also typical of this mode of soil stabilization, as the charge on the clay mineral lattice polymer is similar. These polymers help to lower the shear strength of the soil mass, enhance compaction and reduce voids.

Many investigations on various organic cations for soil stabilization have also been undertaken. These additives have a marked lowering effect on plasticity besides modifying the wetting characteristics of clay particles. It has been reported that the degree of water resistance is influenced by the amount and type of clay mineral present, the amount of cation adsorbed by clay

mineral, the amount of moisture present and the conditions of ageing or curing of the treated clay mass (refs 35, 36).

Lignin, a major by-product of the paper industry, has also been extensively used for soil stabilization (refs 35–37). It has a large and complex molecular structure with a number of active hydroxy and carboxy groups capable of forming strong chemical bonds with silica. Chrome lignin, obtained by treating lignin-containing material with potassium or sodium dichromate, has been found more effective. The strong Cr^{+++} ion acts as a bridge between the lignin molecule and the clay particle. This method of chrome lignin stabilization is simple; the treatment of the soil mass can be made by brushing or spraying in open-textured soils (ref. 18).

BRICK/BLOCK DURABILITY

The resistance to weathering and/or erosion is one of the prime requirements of all construction materials. In stabilized-soil bricks or blocks, the poor durability is often associated with improper selection of stabilizer, an inadequate quantity of stabilizer used, the presence of extraneous matter in the soil and soluble salts which inhibit the stabilizing action of cement, lime etc.

No satisfactory test is available to assess the durability of stabilized brick/blocks in quantitative terms. However, wetting and drying tests have been suggested to evaluate the durability of cement-stabilized bricks which give an idea of the weather-resistance properties (refs 37–38). The durability of stabilized bricks can be improved by bituminous or latex sprays which provide surface binding of particles as well as providing a waterproof coat over the surface. Such treatments are, of course, temporary in nature; permanent treatments are based on either sealing the entire surface with a waterproof paint containing hydrophobic cement/lime, or the use of water glass. The addition of a small proportion of low-cost vegetable fibre (such as coir, or jute) or a synthetic fibre, such as nylon or polypropylene, has yielded promising results in the improvement in durability of the stabilized soil mass.

CONCLUSIONS

From this review of the subject it may be concluded that:

1. Soil stabilized bricks as construction materials have wide application in house building in under-developed and developing countries.
2. Soil stabilized bricks/blocks also have wide scope in rural areas, as they can be produced on a small scale on a self-help basis at the site of building activity.
3. There is a great need for developing a simple, effective and cheap technique of producing soil stabilized bricks/blocks with adequate durability and strength utilizing locally available materials and resources.
4. Efforts to stabilize the soil mass by void reduction, or compaction in conjunction with pozzolanic material with lime and cement, require further investigation.
5. The poor durability of a stabilized soil mass is usually due to improper or inadequate use of the stabilizing agents; these need critical examination with respect to the soil being treated.

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