ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

A Review of a Stabilization Method for the Nigerian Deltaic Peaty Clay (Chikoko)

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Abstract

The Nigerian deltaic clay (locally known as chikoko) is extremely soft marine clay (peat) requiring expensive deep foundations. It is highly organic. Like every other peat, it deforms and fails under light surcharge loads. An effective method for its improvement is mass stabilization, which is a new method that can increase strength, improve deformation properties and save costs.

This paper reviews the mass stabilization technique as well as various binders that are currently used to strengthen peat.

Keywords: Chikoko, Soft marine clay, Organic, Mass stabilization, Binders.

Introduction

The Nigerian deltaic marine clay present as dark grey, dark brown to black material with characteristic foul odour of decaying fibrous organic matter (peat). Depending on the thickness and uniformity of deposits, large scale settlement, differential settlement and shear strength failures are the fears of founding structures on these soils (Adesunloye 1987). Apart from the Niger Delta, Nigeria, peat is found in all parts of the world, except in deserts and the arctic regions. There are about one billion acres of peat land in the world or about 4.5% of total land areas (Deboucha et al 2008).

Problematic peat exhibits high compressibility, medium to low permeability, low strength and volume instability (Wong et al 2008). Study conducted by Islam and Hashim (2008) revealed that the bearing capacity of peat soil is very low.

Where laboratory and in-situ parameters which are essential for foundation design indicate that the in-situ soil is not capable of carrying the design load, then there are two alternatives to choose, either the limitation imposed by the in-situ soil properties be accepted or the techniques outlined by Kalantari and Haut (2008) be adopted:

(i) Transfer the load to a more stable soil layer without improving the properties of the in-situ soil.
(ii) Improve in-situ soil properties with various techniques of ground improvement.
(iii) Remove the soft soil and replace it, finally or partially, with better quality fill.

Various techniques as well as various binders are currently used to strengthen peat. Hebib and Farrell (2003) combined surface stabilization with stabilized cement columns to support foundation loads. Black et al (2007) used reinforced stone column to transfer loads to the lower firm structure. Rahman et al increased the shear strength of undrained peat by almost 36% using a drainage method. According to Jelisic and Leppanem (2000), an effective method of soil improvement is mass stabilization.

This paper therefore, presents a review of this new and efficient method of soil improvement (mass stabilization), where the whole mass is strengthened

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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to a homogenous block structure, which behaves like dry crust.

Figure 1: Peat Site at Eagle Island, Port Harcourt, Nigeria.

Mass Stabilization Technique.

Mass stabilization of peaty clays started since the 1990's in Finland and ever since the technique has spread very quickly (Lahtinen and Niutanen 2008). Mass stabilization is done by mixing a binder or mixture of binders throughout the volume of the treated soil layer. Binders could be cement, lime, fly ash or furnace slag. Mass stabilization could also be combined with another stabilization method such as column stabilization shown in figure 2 (after mass stabilization manual (2005).

Once mass stabilization is achieved, embankments, buildings etc can be founded on it, in the same way as on natural firm soil (Jelisic and Leppanen 2000). According to the mass stabilization manual (2005), the benefits of the mass stabilization method may include:

(i) Rapid ground improvement that can be adopted to varying soil conditions.
(ii) Economically efficient, saves material and energy.
(iii) No differential settlements.

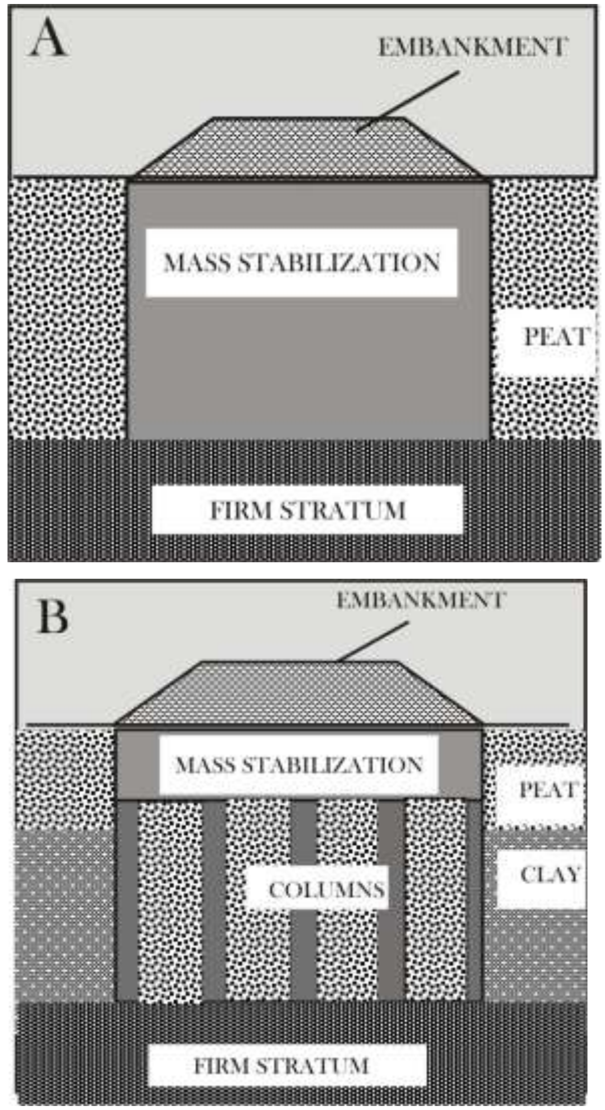

Figure 2: (A) Mass Stabilization and (B) Combined Mass and Column Stabilization (after mass stabilization manual 2005)

(iv) Soil replacement is not needed. So, no problem of transportation, traffic pollution nor disposal sites.

Safety And Quality Of Stabilized Product.

Laboratory tests to establish the most suitable stabilizers, to optimize the quantity of stabilizer and to assess strength deformation properties, must be carried out prior to the mass stabilization, in order to assure safety and quality of the final stabilized product.

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To simulate field conditions in the laboratory, a new laboratory testing procedure is in place (Jelisic and Leppanen 2000). The binder constitutes over half of the total cost in a stabilization project. Savings can only be achieved by careful laboratory tests to select suitable binder and its optimised quantity.

Common Binders.

Common binders used for soil stabilization include:

A. Lime Stabilization.

The benefits of sub-grade lime stabilization was incorporated by Qubain et al (2000), for the first time, into the design of a major interstate highway pavement in Pennsylvania. For clayey sub-grade such as experienced in the project, lime improves the strength of clay by three mechanisms; hydration, flocculation and cementation. While the first and second mechanisms occur immediately after introducing lime, the third mechanism is a long term effect. Qubain et al (2000) investigation showed significant increase in strength by introduction of lime; which when incorporated into design, reduced the pavement thickness and resulted in substantial savings.

White (2005) investigated the effect of curing and degree of compaction on loam stabilized with different additives. He got best results at ambient temperature, while the lime continued reacting on cured specimens. He also noticed that the behaviour of the stabilized specimens were affected by the degree of compaction, which led to brittle failure behaviour at maximum densities.

Ismaiel (2004) studied materials and soils from some part of Germany, which includes petrological, mineralogical studies and scanning electron microscope analysis. He stabilized these materials with lime (10%), cement (10%), and lime/cement (2.5%/7.5%). He determined consistency limits, compaction characteristics, and shear and uniaxial strength; and concluded that the optimum moisture content was inversely proportional to the maximum dry density, while the strength parameters was directly proportional to the stabilizing content.

Ampera & Aydogmust (2005) treated clayey soil with lime (2,4 and 6%) and cement (3, 6 and 9%), and conducted compaction, unconfined compressive strength and direct shear tests on untreated and treated specimens. They concluded that the strength of cement-treated soil was generally greater than that of lime; and that lime stabilization is in general, more tolerant of construction delay than cement stabilization and more suitable for the clayey soils. The direct shear tests and unconfined compressive strength tests gave similar relationships.

B. Fly Ash Stabilization.

Use of fly ash (by-products) for soil stabilization has been studied by a number of workers (Watt and Thorne 1965, Hesham 2006, Khan 1993, Margason & Cross 1996, Rouch et al 2002). Edil et al (2002) studied the use of by-products such as fly ash, bottom ash, boundary slag and boundary sand for soil stabilization. Unconfined compression testing showed that 10% by dry weight of fly ash was sufficient to provide the strength necessary for construction. Laboratory data such as UCS, soil stiffness and dynamic cone penetration index on undisturbed samples were obtained before and after fly ash placement. CBR of 32% was reported for the stabilized sub-grade, which is rated as 'good' for sub-base highway construction. CBR of the untreated sub-grade was 3%, which is rated as "very poor" according to Bowles, 1992.

White (2005) reported:

- Iowa self-cementing fly ashes are effective at stabilizing fine-grained Iowa soils for earthwork and paving operations.
- Fly ash increases compacted dry density and reduces the optimum moisture content.
- Strength gain in soil-fly ash mixtures depends on cure time and temperature, compaction energy, and compaction delay.
- Rapid strength gain of soil-fly ash mixtures occurs during the first 7 to 28 days of curing, and a less pronounced increase continues with time due to long-term pozzolanic reactions.
- Fly ash effectively dries wet soils and provides an initial rapid strength gain, which

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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is useful during construction in wet, unstable ground conditions. Fly ash also decreases swell potential of expansive soils by replacing some of the volume previously held by expansive clay minerals and by cementing the soil particles together.

- ❖ Soil-fly ash mixtures cured below freezing temperatures and then soaked in water are highly susceptible to slaking and strength loss. Compressive strength increases as fly ash content and curing temperature increase.
- ❖ Soil stabilized with fly ash exhibits increased freeze-thaw durability.
- ❖ Soil strength can be increased with the addition of hydrated fly ash and conditioned fly ash, but at higher rates and not as effective as self-cementing fly ash.
- ❖ CaO, $Al2O_3$, SO_3, and Na_2O influence set time characteristics of self-cementing fly ash.

C. Cement Stabilization.

Portland cement is hydraulic cement made by heating a limestone and clay mixture in a kiln and pulverizing the resulting material (Kowalski et al 2007). The same type of pozzolanic reaction are found in cement and lime stabilization. Both contain the calcium required for the pozzolanic reactions to occur. With lime stabilization, silica is provided when the clay particle is broken down. With cement stabilization, the cement already contains the silica and is therefore, independent of the soil properties process; but need only water for hydration process to begin.

D. Rice Husk Stabilization.

Musa Alhassan (2008) studied rice husk stabilization and came to conclusion that there is a general decrease in the maximum dry density and increase in the optimum moisture content with increase in rice husk ash (RHA). There was also slight improvement in the CBR and UCS with increase in the RHA content. He also concluded that there is a little potential 6.8% RHA for strength improvement of A-7-6 lateritic soil.

Brooks (2009) investigated soil stabilization with fly ash and rice husk ash. UCS showed that failure stress and strains increased by 106% and 50% respectively when the fly ash was increased from 0 to 25%. When the RHA content was increased from 0 to 12% UCS increased by 97% while CBR improve by 47%. Therefore an RHA content of 12% and a fly ash content of 25% are recommended for strengthening the subgrade soil.

E. Soil Reinforcement Method.

Using natural or synthesized additives to improve the properties of soils is called soil reinforcement. Several reinforcement methods are available for stabilizing problematic soils; and which can be classified into categories (see fig 2). Some of the methods in fig. 2 may be ineffective and/or expensive (Hejazi et al 2012). Use of scrap tyre rubber (STR) may be a viable and sustainable inexpensive alternative (Carraro et al 2008).

F. Scrap Tyre.

Waste tyres generated everyday in Diobu part of Port Harcourt, Nigeria, can be used as light weight material either in the form of whole tyres, shredded or chips, or in mix with soil. Many studies regarding the use of scrap tyres in geotechnical applications have been done (Ghani et al 2002). The re-use applications for tyres depends on how the tyres are processed. Processing basically includes shredding, removing of metal reinforcement and further shredding until the desired material is achieved (Carreon, 2006).

Bernal et al (1996) reported of the technical, economic and environmental benefits of using tyre shreds and rubber-sand; which includes reduced weight of fill, adequate stability, low settlements, good drainage and use of large quantities of local waste tyres, which would have a positive impact on the environment.

Akbulut et al (2007) studied the modification of clayey soils using scrap tyre rubber and synthetic fibres and concluded that they improve the strength properties and dynamic behaviour of clayey soils.

Optimzation Of Techniacal Performance And Economy.

The binders mentioned above, may be blended in different properties with each other in

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

factory or at site, to optimize technical performance and economy (mass stabilization manual 2005). The most important binder components are cement, lime, blast furnace slag and gypsum. Mostly used binder for stabilization of peat is the fly ash.
The quantity of binder in peat need to exceed a "threshold" (Sing et al 2009). Thus, watery soil such as the "Chikoko mud" (peat) would need more binder of a given type than a more densely compacted soil. This is because sufficient binder neutralizes the humid acids within the soil, thereby increasing the soil pH. Blast furnace slag blended with cement produced stabilized soil with lower early age strength compared with peat stabilized with cement only.

Additon Of Filler Materials In Mass Stabilization.

Fine sand may be added as filler in soil stabilization. It would not react, but would increase the strength of the soil by acting as a "stiffner", and so, it is of greatest relevance in the stabilization of peat and mud, which requires large quantity of stabilizers.

Fillers can be used to replace part of the binders to save costs, with added advantage of filling any voids formed during stabilization. However, the effect if fillers of any type is considerably less than that of the same quantity of binder (Axelsson et al 2002).

Peat has a much higher water/soil ratio than clay. The large amount of water in the soil implies larger voids, requiring more stabilizers (Axelsson et al 2002). So, peat requires greater quantities of stabilizer than clay.

Effects Of Curing Time And Degree Of Compaction.

Different mixes of binders and soil have different curing time. Stabilization reactions for cement stabilization may be finished within a month, while that of lime, furnace slag, gypsum or fly ash stabilization can continue for several months after mixing. Therefore, extended time dependent laboratory test is needed to study both short and long term effects.

As the ratio of voids to solids is relatively high in peat, the bulk density of peat is normally very low. However, it tends to increase on stabilization as the water in the voids is replaced by the stabilizer; and strength in turn, increases, while voids fraction decreases. The effectiveness of stabilization in peat depends on degree of compaction. Peat often gets very sticky during mixing, making it difficult to compact. In laboratory test, storage under load expels any air pockets and hence higher strength is achieved.

The stabilizer has to be homogenously mixed with the soil to enhance complete reaction as stabilization effectiveness increases with the homogeneity of the stabilized material (Axelsson et al 2002).

Conclusion

The study has shown that mass stabilization, a relatively new method of ground improvement, can be used to stabilize the Nigeria deltaic peaty clay. The properties of peat and choice of binder have a significant effect on the results of stabilization. The strength of the product increases with binder amount in the mix. It is also important for the binders to homogenously mix with the soil.

Greater amount of stabilizer is required to stabilize peat than to stabilize clay, because peat contains fewer solid particles. A filler such as fine sand may be added in peat stabilization to increase the number of solid particles, replace part of the large quantities of stabilizers required, to save cost and increase the strength of the peat by acting as a 'stiffner'.

Since some of the water in the soil is replaced by the stabilizer, the density of peat normally tends to increase on stabilization. The effect of curing time differs between different mixes of binder and soil.

In conclusion, mass stabilization is suitable for the stabilization of the Nigerian deltaic clay and most especially for wide area projects where economical reinforcement is required.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

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