International Journal of Transportation Engineering and Technology
2017; 3(2): 19-24
http://www.sciencepublishinggroup.com j/ijtet
doi: 10.11648/j.ijtet.20170302.12

Review Article

A Review on Different Types Soil Stabilization Techniques

Habiba Afrin

Civil Engineering Department, Rajshahi University of Engineering and Technology, Rajshahi, Bangladesh

Email address:

afrinmeno@gmail.com

To cite this article:

Habiba Afrin. A Review on Different Types Soil Stabilization Techniques. *International Journal of Transportation Engineering and Technology*. Vol. 3, No. 2, 2017, pp. 19-24. doi: 10.11648/j.ijtet.20170302.12

Received: June 9, 2017; **Accepted**: July 13, 2017; **Published**: July 27, 2017

Abstract: Soil stabilization is the process of improving the shear strength parameters of soil and thus increasing the bearing capacity of soil. It is required when the soil available for construction is not suitable to carry structural load. Soils exhibit generally undesirable engineering properties. Soil Stabilization is the alteration of soils to enhance their physical properties. Stabilization can increase the shear strength of a soil and/or control the shrink-swell properties of a soil, thus improving the load bearing capacity of a sub-grade to support pavements and foundations. Soil stabilization is used to reduce permeability and compressibility of the soil mass in earth structures and to increase its shear strength. The main objective of this paper is to review the physical and chemical properties of soil in different types of stabilization methods. Stabilization and its effect on soil indicate the reaction mechanism with additives, effect on its strength, improve and maintain soil moisture content and suggestion for construction systems. Soil stabilization can be accomplished by several methods. All these methods fall into two broad categories namely mechanical stabilization and chemical stabilization. Mechanical Stabilization is the process of improving the properties of the soil by changing its gradation and chemical stabilization of expansive soil comprises of changing the physico-synthetic around and within clay particles where by the earth obliges less water to fulfill the static imbalance and making it troublesome for water that moves into and out of the framework so as to fulfill particular designing road ventures.

Keywords: Soil Stabilization, Mechanical Stabilization, Chemical Stabilization, Strength, Stability

1. Introduction

Soil stabilization may be defined as the alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of a soil. Stabilization, in a broad sense, incorporates the various methods employed for modifying the properties of a soil to improve its engineering performance. Soil stabilization refers to the procedure in which a special soil, cementing material, or other chemical materials are added to a natural soil to improve one or more of its properties. One may achieve stabilization by mechanically mixing the natural soil and stabilizing material together so as to achieve a homogeneous mixture or by adding stabilizing material to an undisturbed soil deposit and obtaining interaction by letting it permeate through soil voids [1]. Soil stabilizing additives are used to improve the properties of less-desirable rood soils. When used these stabilizing agents can improve and maintain soil moisture content, increase soil particle cohesion and serve as cementing and water proofing agents [2]. A difficult problem in civil engineering works exists when the sub-grade is found to be clay soil. Soils having high clay content have the tendency to swell when their moisture content is allowed to increase [3]. Many research have been done on the subject of soil stabilization using various additives, the most common methods of soil stabilization of clay soils in pavement work are cement and lime stabilization. The high strengths obtained from cement and lime stabilization may not always be required, however, and there is justification for seeking cheaper additives which may be used to alter the soil properties. Lime or calcium carbonate is oldest traditional chemical stabilizer used for soil stabilization. The study provides details of different types of soil stabilizing methods.

2. Soil

Soil is a mixture of minerals, organic matter, gases, liquids, and countless organisms that together support life on Earth. Soil continually undergoes development by way of numerous physical, chemical and biological processes, which include weathering with associated erosion. Most of stabilization has to be undertaken in soft soils (silty, clayey peat or organic soils) in order to achieve desirable engineering properties. According to Sherwood fine-grained granular materials are the easiest to stabilize due to their large surface area in relation to their particle diameter. A clay soil compared to others has a large surface area due to flat and elongated particle shapes [4]. On the other hand, silty materials can be sensitive to small change in moisture and, therefore, may prove difficult during stabilization [5]. Peat soils and organic soils are rich in water content of up to about 2000%, high porosity and high organic content. The consistency of peat soil can vary from muddy to fibrous, and in most cases, the deposit is shallow, but in worst cases, it can extend to several meters below the surface [6, 8]. Organic soils have high exchange capacity; it can hinder the hydration process by retaining the calcium ions liberated during the hydration of calcium silicate and calcium aluminate in the cement to satisfy the exchange capacity. In such soils, successful stabilization has to depend on the proper selection of binder and amount of binder added [9].

3. Soil Stabilization

Soil stabilization is a method of improving soil properties by blending and mixing other materials. Soil stabilization is the process of improving the shear strength parameters of soil and thus increasing the bearing capacity of soil. It is required when the soil available for construction is not suitable to carry structural load. Soil stabilization is used to reduce permeability and compressibility of the soil mass in earth structures and to increase its shear strength. Thus to reduce the settlement of structures [10, 11]. Soil stabilization involves the use of stabilizing agents (binder materials) in weak soils to improve its geotechnical properties such as compressibility, strength, permeability and durability.

4. Soil Stabilization Methods

In road construction projects, soil or gravelly material is used as the road main body in pavement layers. To have required strength against tensile stresses and strains spectrum, the soil used for constructing pavement should have special specification. Through soil stabilization, unbound materials can be stabilized with cementitious materials (cement, lime, fly ash, bitumen or combination of these). The stabilized soil materials have a higher strength, lower permeability and lower compressibility than the native soil [12]. The method can be achieved in two ways, namely;

1) In situ stabilization and
2) Ex - situ stabilization.

Note that, stabilization not necessary a magic wand by which every soil properties can be improved for better. The decision to technological usage depends on which soil properties have to be modified. The chief properties of soil which are of interest to engineers are volume stability, strength, compressibility, permeability and durability [5, 8].

Some stabilization techniques are listed below-

a Mechanical Stabilization
b Stabilization by using different types admixers
  (1) Lime Stabilization
  (2) Cement Stabilization
  (3) Chemical Stabilization
  (4) Fly ash Stabilization
  (5) Rice Husk ash Stabilization
  (6) Bituminous Stabilization
  (7) Thermal Stabilization
  (8) Electrical Stabilization
  (9) Stabilization by Geo-textile and Fabrics
  (10) Recycled and Waste Products etc.

a Mechanical Stabilization

Mechanical Stabilization is the process of improving the properties of the soil by changing its gradation. This process includes soil compaction and densification by application of mechanical energy using various sorts of rollers, rammers, vibration techniques and sometime blasting. The stability of the soil in this method relies on the inherent properties of the soil material. Two or more types of natural soils are mixed to obtain a composite material which is superior to any of its components. Mechanical stabilization is accomplished by mixing or blending soils of two or more gradations to obtain a material meeting the required specification.

b Stabilization by using different types admixers

(1) Lime Stabilization

Lime provides an economical way of soil stabilization. The method of soil improvement in which lime is added to the soil to improve its properties is known as lime stabilization. The types of lime used to the soil are hydrated high calcium lime, monohydrated dolomite lime, calcite quick lime, dolomite lime. The quantity of lime is used in most soil stabilizer is in the range of 5% to 10%. Lime modification describes an increase in strength brought by cation exchange capacity rather than cementing effect brought by pozzolanic reaction [5]. In soil modification, as clay particles flocculates, transforms natural plate like clays particles into needle like interlocking metalline structures. Clay soils turn drier and less susceptible to water content changes [12]. Lime stabilization may refer to pozzolanic reaction in which pozzolana materials reacts with lime in presence of water to produce cementitious compounds [5, 13]. The effect can be brought by either quicklime, CaO or hydrated lime, $Ca(OH)_2$. Slurry lime also can be used in dry soils conditions where water may be required to achieve effective compaction [14]. Quicklime is the most commonly used lime; the followings are the advantages of quicklime over hydrated lime [13] higher available free lime content per unit mass - denser than hydrated lime (less storage space is required) and less dust - generates heat which accelerate strength gain and large reduction in moisture content according to the reaction equation below $CaO + H_2O \rightarrow Ca(OH)_2$ + Heat (65kJ / mol)

Quicklime when mixed with wet soils, immediately takes up to 32% of its own weight of water from the surrounding soil to form hydrated lime; the generated heat accompanied by this reaction will further cause loss of water due to evaporation which in turn results into increased plastic limit of soil i.e. drying out and absorption [5, 8]. The effect can be explained from Figure 1 for 6 soils at a moisture content of 35% and plastic limit 25%. Addition of 2% lime will change the plastic limit to 40% so that the moisture content of the soil will be 5% below plastic limit instead of 10% above plastic limit [5]. Sherwood investigated the decrease in plasticity as brought about in first instance by cation exchange in which cations of sodium and hydrogen are replaced by calcium ions for which the clay mineral has a greater water affinity. Even in soils (e.g. calcareous soils) where, clay may be saturated with calcium ions, addition of lime will increase pH and hence increase the exchange capacity. Like cement, lime when reacts with wet clay minerals result into increased pH which favors solubility of siliceous and aluminous compounds. These compounds react with calcium to form calcium silica and calcium alumina hydrates, a cementitious product similar to those of cement paste. Natural pozzolanas materials containing silica and alumina (e.g. clay minerals, pulverized fly ash, PFA, blast furnace slag) have great potential to react with lime. Lime stabilizations technology is mostly widely used in geotechnical and environmental applications. Some of applications include encapsulation of contaminants, rendering of backfill (e.g. wet cohesive soil), highway capping, slope stabilization and foundation improvement such as in use of lime pile or lime-stabilized soil columns. However, presence of sulphur and organic materials may inhibit the lime stabilization process. Sulphate (e.g. gypsum) will react with lime and swell, which may have effect on soil strength.

(2) Cement Stabilization

Soil cement stabilization is soil particles bonding caused by hydration of the cement particles which grow into crystals that can interlock with one another giving a high compressive strength. In order to achieve a successful bond the cement particles need to coat most of the material particles. To provide good contact between soil particles and cement, and thus efficient soil cement stabilization, mixing the cement and soil with certain particle size distribution is necessary. Soil-cement is a highly compacted mixture of soil/aggregate, cement, and water. Soil-cement is sometimes called cement-stabilized base, or cement-treated aggregate base. Soil-cement becomes a hard and durable material as the cement hydrates and develops strength. Cement stabilization is done when the compaction process is continuing. As the cement fills the void between the soil particles, the void ratio of soil is reduced. After this when water is added to the soil, cement reacts with water and goes hard. So, unit weight of soil is increased. Because of hardening of cement shear strength and bearing capacity is also increased. Cement helps decrease the liquid limit and increase the plasticity index and workability of clayey soils. Cement reaction is not dependent on soil minerals, and the key role is its reaction with water that may be available in any soil [15]. This can be the reason why cement is used to stabilize a wide range of soils. Numerous types of cement are available in the market; these are ordinary Portland cement, blast furnace cement, sulfate resistant cement and high alumina cement. Usually the choice of cement depends on type of soil to be treated and desired final strength. Hydration process is a process under which cement reaction takes place. The process starts when cement is mixed with water and other components for a desired application resulting into hardening phenomena. The hardening (setting) of cement will enclose soil as glue, but it will not change the structure of soil [15]. The hydration reaction is slow proceeding from the surface of the cement grains and the center of the grains may remain unhydrated [5]. Cement hydration is a complex process with a complex series of unknown chemical reactions [16]. However, this process can be affected by

(a) presence of foreign matters or impurities
(b) water-cement ratio
(c) curing temperature
(d) presence of additives
(e) Specific surface of the mixture.

Depending on factor(s) involved, the ultimate effect on setting and gain in strength of cement stabilized soil may vary. Therefore, this should be taken into account during mix design in order to achieve the desired strength. Calcium silicates, *C3S* and *C2S* are the two main cementitious properties of ordinary Portland cement responsible for strength development [8, 17]. Calcium hydroxide is another hydration product of Portland cement that further reacts with pozzolanic five materials available in stabilized soil to produce further cementitious material [5]. Normally the amount of cement used is small but sufficient to improve the engineering properties of the soil and further improved cation exchange of clay. Cement stabilized soils have the following improved properties:

(a) decreased cohesiveness (Plasticity)
(b) decreased volume expansion or compressibility
(c) Increased strength.

(3) Chemical Stabilization

Chemical stabilization of soil comprises of changing the physico-synthetic around and within clay particles where by the earth obliges less water to fulfill the static imbalance. Calcium chloride being hygroscopic and deliquescent is used as a water retentive additive in mechanically stabilized soil bases and surfacing. The vapor pressure gets lowered, surface tension increases and rate of evaporation decreases. The freezing point of pure water gets lowered and it results in prevention or reduction of frost heave. The depressing the electric double layer, the salt reduces the water pick up and thus the loss of strength of fine grained soils. Calcium chloride acts as a soil flocculent and facilitates compaction. Frequent application of calcium chloride may be necessary to make up for the loss of chemical by leaching action. For the salt to be effective, the relative humidity of the atmosphere should be above 30%. Sodium chloride is the other chemical that can be used for this purpose with a stabilizing action similar to that of calcium chloride. Sodium silicate is yet another chemical used for this purpose in combination with other chemicals such as calcium chloride, polymers, chrome lignin, alkyl chlorosilanes, siliconites, amines and quaternary ammonium salts, sodium hexametaphosphate, phosphoric acid combined with a wetting agent [14].

(4) Fly ash Stabilization

Fly ash stabilization is gaining more importance recent times since it has wide spread availability. This method is inexpensive and takes less time than any other methods. It has a long history of use as an engineering material and has been successfully employed in geotechnical applications. Fly ash is a byproduct of coal fired electric power generation facilities; it has little cementations properties compared to lime and cement. Most of the fly ashes belong to secondary binders; these binders cannot produce the desired effect on their own. However, in the presence of a small amount of activator, it can react chemically to form cementations compound that contributes to improved strength of soft soil. However, soil fly ash stabilization has the following limitations [17]:

(a) Soil to be stabilized shall have less moisture content; therefore, dewatering may be required.
(b) Soil-fly ash mixture cured below zero and then soaked in water are highly susceptible to slaking and strength loss
(c) Sulfur contents can form expansive minerals in soil-fly ash mixture, which reduces the long term strength and durability.

(5) Rice Husk ash Stabilization

Disposal of solid waste on the land fill can be minimized if the waste is having desirable properties such that they can be utilized for various geotechnical application viz. land reclamation, construction of embankment etc. There are several methods used for improving geotechnical properties of problematic soils that includes densification (such as shallow compaction, dynamic deep compaction, pre-loading), drainage, inclusions (such as geosynthetics and stone columns), and stabilizations. Chemical stabilization of the problematic soils is especially significant in concerning with the treatment of soft fine-grained, expansive soils, and collapsible loess deposits. Soil stabilization is the process which is used to improve the engineering properties of the soil and thus making it more stable. Soil stabilization is required when the soil available for construction is not suitable for the intended purpose. It includes compaction, preconsolidation, drainage and many other such processes. Rice husk ash (RHA) is a pozzolanic material that could be potentially used in soil stabilization, though it is moderately produced and readily available. When rice husk is burnt under controlled temperature, ash is produced and about 17%-25% of rice husk's weight remains ash. Rice husk ash and rice straw and bagasse are rich in silica and make an excellent pozzolana. Pozzolanas are siliceous and aluminous materials, which in itself possess little or no cementations value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementations properties. The Rice Husk Ash would appear to be an inert material with the silica in the crystalline form suggested by the structure of the particles, it is very unlikely that it would react with lime to form calcium silicates. It is also unlikely that it would be as reactive as fly ash, which is more finely divided. So Rice Husk Ash would give great results when it used as a stabilizing material. The ash would appear to be a very suitable light weight fill and should not present great.

(6) Bituminous Stabilization

Bituminous soil stabilization refers to a process by which a controlled amount of bituminous material is thoroughly mixed with an existing soil or aggregate material to form a stable base or wearing surface. Bitumen increases the cohesion and load-bearing capacity of the soil and renders it resistant to the action of water. Bitumen stabilization accomplished by using asphalt cement, asphalt cutback or asphalt emulsions. The type of bitumen to be used depends on the type of soil to be stabilized, method of construction and weather conditions. In frost areas, the use of tar as binder must be avoided because of its high temperature maximum susceptibility.

Asphalts and tars are bituminous materials which are used for stabilization of soil, generally for pavement construction. Bituminous materials when added to a soil, it imparts both cohesion and reduced water absorption.

(7) Thermal Stabilization

Thermal change causes a marked improvement in the properties of the soil. Thermal stabilization is done either by heating the soil or by cooling it.

Heating: As the soil is heated, its water content decreases. Electric repulsion between clay particles is decreased and the strength of the soil is increased.

Freezing: cooling causes a small loss of strength of clayey soils due to an increase in interparticles repulsion. However, if the temperature is reduced to the freezing point, the pore water freezes and the soil is stabilized.

(8) Electrical Stabilization

Electrical stabilization of clayey soils is done by a process known as electro-osmosis. As a direct current (DC) is passed through a clayey soil, pore water migrates to the negative electrode (cathode). It occurs because of attraction of positive ions (cations) that are present in water towards cathode. The strength of the soil is considerably increased due to removal of water. Electro-osmosis is an expensive method, and is mainly used for drainage of cohesive soils. Incidentally, the properties of the soil are also improved.

(9) Stabilization by Geo-textile and Fabrics

Geotextiles are porous fabrics made of synthetic materials such as polyethylene, polyester, nylons and polyvinyl chloride. Woven, non-woven and grid form varieties of geotextiles are available. Geotextiles have a high strength. When properly embedded in soil, it contributes to its stability. It is used in the construction of unpaved roads over soft soils. Reinforcing the soil for stabilization by metallic strips into it and providing an anchor or tie back to restrain a facing skin element [15]. Past research has shown that the strength and load-bearing capacity of subgrades and base course materials can be improved through the inclusion of nonbiodegradable reinforcing materials, such as fibers, geotextiles, geogrids, and geocomposites. Use of these materials can improve the performance and durability of future highways and may reduce the cost of construction. At present, most of the research on these materials is based on tests conducted in the laboratory that are only partially complete. Further laboratory tests and evaluations will be necessary to develop design specifications based on material properties, and these specifications will need to be verified using large-scale field tests.

(10) Recycled and Waste Products

Improved chemical and mechanical stabilization techniques are needed for such waste materials as crushed old asphalt pavement, copper and zinc slag, paper mill sludge, and rubber tire chips. The need to recycle many potentially hazardous materials, it will be necessary to develop a realistic, economical and effective means of assessing the risk of pollution posed by these materials through leachates and emissions. In some cases, risk evaluation is hampered by restrictive environmental constraints, and this issue needs to be addressed as well.

5. Factors Affecting the Strength of Stabilized Soil

Presence of organic matters, sulphates, sulphides and carbon dioxide in the stabilized soils may contribute to undesirable strength of stabilized materials [5]

5.1. Organic Matter

In many cases, the top layers of most soil constitute large amount of organic matters. However, in well drained soils organic matter may extend to a depth of 1.5 m [5]. Soil organic matters react with hydration product e.g. calcium hydroxide ($Ca(OH)_2$) resulting into low pH value. The resulting low pH value may retard the 10 hydration process and affect the hardening of stabilized soils making it difficult or impossible to compact.

5.2. Sulphates

The use of calcium-based stabilizer in sulphate-rich soils causes the stabilized sulphate rich soil in the presence of excess moisture to react and form calcium sulphoaluminate (ettringite) and or thamausite, the product which occupy a greater volume than the combined volume of reactants. However, excess water to one initially present during the time of mixing may be required to dissolve sulphate in order to allow the reaction to proceed [5, 16].

5.3. Sulphides

In many of waste materials and industrial by-product, sulphides in form of iron pyrites (FeS_2) may be present. Oxidation of FeS_2 will produce sulphuric acid, which in the presence of calcium carbonate, may react to form gypsum (hydrated calcium sulphate) according to the reactions (1) and (2) below

(1) $2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + 2H_2SO_4$

(2) $CaCO_3 + H_2SO_4 + H_2O = CaSO_4.2\,H_2O + CO_2$

The hydrated sulphate so formed, and in the presence of excess water may attack the stabilized material in a similar way as sulphate. Even so, gypsum can also be found in natural soil [5, 8].

5.4. Compaction

In practice, the effect of addition of binder to the density of soil is of significant importance. Stabilized mixture has lower maximum dry density than that of unstabilized soil for a given degree of compaction. The optimum moisture content increases with increasing binders [5]. In cement stabilized soils, hydration process takes place immediately after cement comes into contact with water. This process involves hardening of soil mix which means that it is necessary to compact the soil mix as soon as possible. Any delay in compaction may result in hardening of stabilized soil mass and therefore extra compaction effort may be required to bring the same effect. That may lead to serious bond breakage and hence loss of strength. In contrary to cement, delay in compaction for lime-stabilized soils may have some advantages. Lime stabilized soil require mellowing period to allow lime to diffuse through the soil thus producing maximum effects on plasticity. After this period, lime stabilized soil may be remixed and given its final compaction resulting into remarkable strength than otherwise [5].

5.5. Moisture Content

In stabilized soils, enough moisture content is essential not only for hydration process to proceed but also for efficient compaction. Fully hydrated cement takes up about 20% of its own weight of water from the surrounding[5]; on other hand, Quicklime (CaO) takes up about 32% of its own weight of water from the surrounding[5,9]. Insufficient moisture content will cause binders to 12 compete with soils in order to gain these amounts of moisture. For soils with great soilwater affinity (such as clay, peat and organic soils), the hydration process may be retarded due to insufficient moisture content, which will ultimately affect the final strength [16].

5.6. Temperature

Pozzolanic reaction is sensitive to changes in temperature. In the field, temperature varies continuously throughout the day. Pozzolanic reactions between binders and soil particles will slow down at low temperature and result into lower strength of the stabilized mass. In cold regions, it may be advisable to stabilize the soil during the warm season [5].

5.7. Freeze-Thaw and Dry-Wet Effect

Stabilized soils cannot withstand freeze-thaw cycles. Therefore, in the field, it may be necessary to protect the stabilized soils against frost damage. Shrinkage forces in stabilized soil will depend on the chemical reactions of the binder. Cement stabilized soil are susceptible to frequent dry-wet cycles due to diurnal changes in temperature which may give rise to stresses within a stabilized soil and, therefore, should be protected from such effects [5, 9].

6. Conclusions

As technology advances and economic conditions change, many more chemical agents will be introduced into subgrades to improve their compactability, durability, and strength. At the same time, more performance-based testing will be necessary to prove the effectiveness of these stabilization agents. In addition, there are chemicals being used today in the petrochemical industry whose use in soils is as yet unexplored. Another area for research is such processes as injection and spray-on techniques for more economical treatment. Global climate change may affect the durability and application of stabilizers. It may be desirable to consider these potential changes in the development of future soil stabilization techniques [17].

References

[1] Perloff. W. H. (1976), "Soil Mechanics, Principals and Application", New York: John Wily, & Sons.

[2] Janathan Q. Addo, Sanders, T. G. & Chenard, M. (2004), Road dust suppression: "Effect on unpaved Road Stabilization".

[3] Chen, F. H. (1981), "Foundation on Expansive soil", Amsterdam: Elsevier Scientific Publishing Company.

[4] DAMAGE TO FOUNDATIONS FROM EXPANSIVE SOILS, J. David Rogers, Robert Olshansky, and Robert B. Rogers.

[5] Sherwood, P. (1993). Soil stabilization with cement and lime. State of the Art Review. London: Transport Research Laboratory, HMSO.

[6] Pousette, K., Mácsik, J. and Jacobsson, A. (1999). Peat Soil Samples Stabilized in Laboratory-Experiences from Manufacturing and Testing. Proceeding of Dry Mix Methods for Deep Stabilization (pp. 85-92). Stockholm: Balkema, Rotterdam.

[7] Cortellazzo, G. and Cola, S. (1999). Geotechnical Characteristics of Two Italian Peats Stabilized with Binders. Proceeding of Dry Mix Methods for Deep Soil Stabilization (pp. 93-100). Stockholm: Balkerma.

[8] Al-Tabbaa, A. and Evans, W. C. (2005). Stabilization-Solidification Treatment and Remediation: Part I: Binders and Technologies-Basic Principal. Proceedings of the International Conference on Stabilization/Solidification Treatment and Remediation (pp. 367-385). Cambridge, UK: Balkerma.

[9] Hebib, S. and Farrell, E. R. (1999). Some Experi ences of Stabilizing Irish Organic Soils. Proceeding of Dry Mix Methods for Deep Soil Stabilization (pp. 81-84). Stockholm: Balkema.

[10] FM5-410, (2012). Soil Stabilization for Road and Airfield. www.itc.nl/~rossiter/Docs/FM5-410.

[11] Lambe, T. W. (1958). The structure of compacted clay. *Journal of Soil Mechanics and Foundation*. 84, 55-70.

[12] Keller Inc., (2011). *Improvement of Weak Soils by the Deep Soil Mixing Method.* Keller Bronchure, 32-01E:http://keller-foundations.co.uk/technique/deep-dry-soilmixing.

[13] White, D. (2005). *Fly Ash Soil Stabilization for Non-Uniform Subgrade Soils.* IHRB Project TR-461, FHWA Project 4.

[14] Rogers, C. D. F. and Glendinning, S. (1993). Modification of clay soils using lime. In C. a. Rogers (Ed.), *Proceeding of the Seminar held at Loughborough University on Lime Stabilization* (pp. 99-114). London: Thomas Telford.

[15] EuroSoilStab. (2002). *Development of Design and Construction Methods to Stabilize Soft Organic Soils: Design Guide for soft soil stabilization.* CT97-0351, European Commission, Industrial and Materials Technologies Programme (Rite-EuRam III) Bryssel.

[16] Hicks, R. (2002). *Alaska Soil Stabilization Design Guide.*

[17] MacLaren, D. C and White, M. A. (2003). Cement: Its Chemistry and Properties. *Journal of Chemical Education, Vol. 8* (No. 6), 623.

Biography

Habiba Afrin received her B. Sc. in Engineering from Department of Civil Engineering, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh. She conducted her undergraduate thesis in the field of Soil Stabilization. Her research interest is in soil stabilization technology, environment management and Soil engineering.