

**Review Article****Environmental Friendly Soil Stabilization Materials Available in Iran****Z. Sabzi\****School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran**Received: 26 November 2017 - Accepted: 20 January 2018***Abstract**

Soft soil is one of the major challenges in engineering projects. Improving soil's engineering properties is called soil stabilization. This paper focuses on soil stabilization materials and methods thereby soils and related materials and structures are made stronger and more durable. Soil stabilization involves the using of stabilizing agents, binder materials, in soft soils to improve its geotechnical properties such as bearing capacity, compressibility, shear strength, permeability and durability. Using of stabilized soils in place with natural aggregates and structure of soil has great environmental and economic advantages. Investigation for selection the best soil stabilizers to overcome geotechnical problems occur by the weak soils is one of the main concerns to attain the required soil engineering parameters by considering the cost, efficiency and the effect to the environment. This paper reviews the application of different materials and additives used in soil improvement in geotechnical projects in Iran and present their effects on soil engineering parameters.

*Keywords:* Soil Stabilization, Environmental Friendly, Stabilizer Materials

**1. Introduction**

Site feasibility study is an important phase in geotechnical projects. Site investigations usually are done before the designing in order to understand the characteristics of substructure elements. Some geotechnical design criteria have to be considered during site selection; For example, Type of foundation and bearing capacity of soil. Soil stabilization is a technique used to change different soil properties and to enhance its performance for engineering purpose [1].

In the recent years, in Iran, with the scarcity of building sites in urban area and with considerable renewal and the accompanying backfill, the underground condition can have significant variations and undesirable sites due to weak soil dramatically increased. To stabilize soft subgrades, the most common approach was removing the soft soil and then replacing by stronger materials such as crushed rock. Expenditures of this process was quite high, thus it leads to various researches to find another method in order to encounter this problem [2]. The underlying reason for conducting a review on stabilized soil as a building material in Iran is the basic need for a low-cost building material which is available [3].

In most geotechnical projects, it is not possible to obtain a construction site that will meet the design requirements without ground modification. Soils that are weak to bear the expected load can be stabilized by the addition of materials which Improve

mechanical strength, decrease water absorption and increase the cohesion of the soil matrix by forming a cement-like compound to hold the matrix together [4]. This review paper focuses on soil stabilization materials and methods available and applicable in Iran.

Soil Stabilization methods help to preserve soils, site development projects, airports, water transportation routes, roads and much more where sub-soils are not suitable for construction. This process is accomplished using a wide variety of additives. Selection of stabilizer for a site depends on the type of construction, type of soil and the availability of materials [5]. All of the soil stabilization methods divided into two categories, mechanical stabilization and chemical stabilization. In mechanical methods, stabilization can be achieved through physical process by vibration or compaction either by incorporating other mechanical tools such as nailing or strands [4]. This method is the process of improving the properties of the soil by changing its gradation. This process includes soil densification by application of mechanical energy using various types of rollers, vibration techniques and sometimes blasting. The stability of the soil in this method relies on the inherent properties of the 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 [6].

Mechanical stabilization is not the main focus of this paper and will not be further discussed. Chemical stabilization methods are the fundamental of this

\*Corresponding author

Email address: sabzi@ut.ac.ir

paper. In these methods cohesion less aggregates and soft cohesive soils can be stabilized with cohesive materials. The stabilized soil materials have a higher strength, lower permeability and lower compressibility than the non-stabilized soil.

## 2. Soil Improvement due to Stabilization

By the soil stabilization, increase in durability, increase in strength, lower permeability, reduction of plasticity index and reduction in swelling potential is achieved. Stabilization improves the properties of construction materials and gives the following attributes [7]:

- a. better soil compaction and gradation is attained;
- b. After saturation with water substantial proportion of their strength is retained;
- c. Permeability is extensively decreased and factor of safety against boiling of water is substantially increased.
- d. Resistance to erosion is occurred;
- e. Settlements and deflections are decreased;
- f. Modulus of elasticity of stabilized soil is increased;
- g. Stiffness and strength of a soil are increased,
- h. Reduction in the costs and the thicknesses of the road subgrade and pavement is happened.

In addition, there are several environmental advantages.

## 3. Some Problems due to Soil Stabilization

Beside the advantages of soil stabilization, some problems may be occurred due to the stabilization of soil [7]:

- a. cracks in soil layers due to thermal changes and shrinkages,
- b. reflected cracks to the surface of pavement and water seepage to the road body,
- c. Non-uniform settlements under the structures or along the road,
- d. Incompatibility with environment in some cases, when the additives mismatch by the site.
- e. If CO<sub>2</sub> has access to the material, the stabilization reaction is reversible and the strength of layer can decrease.
- f. The construction operation requires more skill than un-stabilized materials.

## 4. Soil Stabilization Process

Proper design and testing is an important component of any stabilization project. Laboratory and in-situ tests can establish proper design criteria in determining the proper additive and admixture rate to be used to achieve the desired engineering properties [7].

Soil Stabilization is performed so that proper additives are spread on the weak materials. Additives are mixed with the soil until the desired properties are

achieved as shown in Fig.1. Then the building foundation or road sub-base materials are placed. This process can change depending on the soils and additives required [7]. Moreover it should be noted that presence of organic matters, sulphates, sulphides and carbon dioxide in the stabilized materials may contribute to undesirable soil properties.

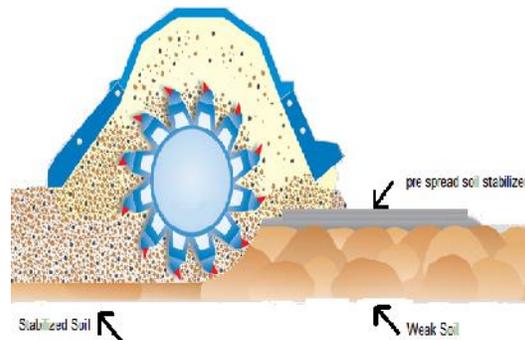


Fig. 1. Schematic Soil Stabilization Process [7].

## 5. Stabilization Materials

### 5.1. Cement

Cement is the oldest soil stabilizer. It may be considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required [4]. Cement reaction is not dependent on soil structures and minerals, and the key role is its hydration process that may be available in any soil [8]. This can be the reason why cement is used to stabilize all of the soils. Also, it is widely available in Iran hence becomes the best material for stabilization of soil.

The Hydration process starts when cement is mixed with water and other components for a desired application resulting into hardening phenomena. The hardening of cement will strengthen the soil, but it will not change the structure of soil [8]. Soil-cement is a highly compacted mixture of soil/aggregate, cement, and water. 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 [7].

Cement hydration is a complex process with a complex series of unknown chemical reactions [9].

However, this process can be affected by [9]:

- a. presence of foreign matters or impurities
- b. water-cement ratio
- c. curing temperature

- d. presence of additives
- e. Specific surface of the mixture.

Therefore, this should be taken into account during mix design in order to achieve the desired strength [8]. The proportion of cement required in soil decides based on the type of soil. Portland cement widely used as a soil stabilizer, because of its easy handling and quality control properties [10]. Calcium silicates, C3S and C2S are the two main cementitious properties of ordinary Portland cement responsible for strength development [11].

In general, it can be said that soil cement provided strength and durability which is outstanding value as a base and sub-base material and cement base pavement has an advantage of great strength and durability. Also, it is best stabilization material for low-cost structure [12].

However, the production of cement involves the consumption of large quantities of raw materials, energy, and heat and also the cement industry is one of the producers of CO<sub>2</sub>, but it should be noted that using cement as soil stabilizer has minor environmental impact.

### 5.2. Lime

Lime is available almost everywhere in Iran and the price is low [3]. Lime is used as an excellent soil stabilizing materials for highly active soils which undergo through frequent expansion and shrinkage. Lime acts immediately and improves various property of soil such as carrying capacity of soil, resistance to shrinkage during moist conditions, reduction in plasticity index, and increase in CBR value and subsequent increase in the compression resistance with the increase in time. The reaction is very quick and stabilization of soil starts within few hours [13].

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% [6]. When lime is added to soil, it immediately releases heat (as shown in Eq.1) and then soil is dried because of the heat generated. After initial mixing, the calcium ions from hydrated lime come to the surface of the clay particles and displace water and other ions. The soil becomes friable and granular, making it easier to work and compact. Slurry lime also can be used in dry soils conditions where water may be required to achieve effective compaction [14]. 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 [15]. At this stage the Plasticity Index of the soil decreases dramatically, as does its tendency to swell and shrink. When adequate quantities of lime and water are added, the pH of the soil quickly increases to above 10.5, which enables

the clay particles to break down. Silica and alumina are released and react with calcium from the lime to form calcium-silicate-hydrates and calcium-aluminate-hydrates. The effect can be brought by either quicklime, CaO or hydrated lime, Ca(OH)<sub>2</sub>. They are cohesive products similar to those formed in Portland cement. They form the structure that contributes to the strength soil layers and the soil is transformed from a sandy, granular material to a hard, relatively impermeable layer with significant load bearing capacity. This soil matrix is permanent, durable, and significantly impermeable, producing a structural layer that is strong and flexible [12].



Lime stabilizations technology is widely used in geotechnical and environmental applications. Some of applications include wrapping of contaminants, execution of backfill, highway capping, slope stabilization and foundation improvement such as in use of lime pile or lime-stabilized soil columns [16]. However, presence of Sulphur and organic materials may inhibit the lime stabilization process. Sulphate in gypsum will react with lime and swell, which may have effect on soil strength and increase the swelling potential of soil [6].

### 5.3. Bitumen

Bituminous soil stabilization refers to a controlled amount of bituminous material is thoroughly mixed with an existing soil or aggregate material to form a stable base or wearing surface. As bitumen is an oil product it cannot be mixed with water. Hence an emulsifier is added with water before bitumen. Addition of emulsifier with water before adding bitumen into particles keeps it dispersed in suspension [17].

Many studies had been done on effect of bitumen on soils. Michael had studied about evaluation of Asphalt emulsion stabilization of contaminated soils [18]. In that study, it was discussed about the environmental fixation of soils contaminated by organic contaminants by using bitumen. Chritz [19] investigated the performance evaluation of mixed in place bituminous stabilized shoulder gravel. It was showed an economical maintenance of gravel shoulders; a very common problem is facing by highway agencies. Putri et al. [20] carried out a work to establish the correlation between CBR value of bituminous stabilized soils and undrained shear strength value from Vane Shear Test. It was shown that undrained shear strength value and CBR value increased with increasing plasticity index. Finally, it was achieved that shear strength and CBR value is inversely proportional to the water content of that material.

Currently, the popularity of soil cement stabilization had been challenged by a new innovative soil

improvement technique, known as foamed bitumen stabilization. Very few of work have been done on it and application of this type of stabilization is currently applied in flexible pavement subgrade stabilization. Huan et al. [21] worked on foamed bitumen stabilization for Western Australian pavements. Foamed bitumen is a mixture of bitumen, air and water. It has been found that rehabilitation using foamed bitumen had proved to be successful because of its ease and speed of construction, its compatibility with a wide range of aggregate types and its relative immunity to the effects of weather. Marandi and Safapour [22] worked on soil stabilization using cement & bitumen. The main objective of this research was to analyze the use of bitumen emulsion in base course stabilization. So that it was examined as replacement with conventional pavement in regions with low quality materials. Stabilization of soils and aggregates with bitumen shows it differs greatly from cement stabilization. Baghini et al [23] worked on Bitumen-cement Stabilized Layer in pavement construction using Indirect Tensile Strength (ITS) Method. In their study, the goal was to mix and blend Portland cement and bitumen emulsion with soil for upgrading the quality, strength and durability of the weak soil. From all of these studies, it is clear that there is a considerable improvement in California Bearing Ratio (CBR) of subgrade due to use of bitumen emulsion. Bitumen increases the cohesion and load-bearing capacity of the soil and increase its resistance to the action of water. Asphalt stabilization can enhance durability qualities by making the soil impervious to the unfavorable impacts of water. Bitumen stabilization accomplished by using asphalt cement, asphalt cutback or asphalt emulsions [6]. 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 cannot be used because of its high temperature maximum susceptibility.

#### 5.4. Nanoclay

Nowadays the stabilization process by Nano materials is becoming widespread. The Nano technologies idea was suggested by Richard Feynman in 1959. The chemical reaction of Nano materials occur in Nano scale, many of natural soil and rock minerals are nanomaterial's [24]. Nanomaterials are effective technique to improve some behavioral parameters of soil such as strength, permeability, self-repairing etc. Abisha et al [24] had used nanoclay as additive to overcome the weakness of soil. The weak soil obtained from manavilai is a clay soil. Various amount of nanoclay were added to study the improvements. When more than 3% of nanoclay is added the CBR value increases and shear strength value decreases. In their project the optimum

mixture design for stabilization of clay soil was selected as 3% of nanoclay.

The effectiveness of using nanoclay in soft soil stabilization was also investigated by Khalid et al. [25] by mean of many laboratories testing to evaluate the compressive strength; effective shear strength and Atterberg limit test parameters. The results of studies showed that the mixing of 3 % nanoclay with soft soil was improved the soil strength and effectiveness of the shear strength [25].

The additive nano composite reduce the swelling property of soil and improves the geotechnical properties of soft clay. The nano composite which can be selected is the nano particles of layered mineral silicate, depending on the chemical composition and nano particle morphology. In general, many studies showed that stabilized soils by nano clay revealed hardening behavior and improved strength compared with other nanomaterial additives. Using Nano materials in soil stabilization causes less permeability that is very important in dam constructions [24].

#### 5.5. Pozzolanas

Pozzolanas are siliceous and aluminous materials, which itself have little or no cementitious value, but in the presence of water and lime, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties and have been used as a cementitious material in construction. Clay minerals such as kaolinite, montmorillonite, mica and illite are pozzolanic in nature. Artificial pozzolanas such as ashes and sarooj are products obtained by heat treatment of natural materials containing pozzolan as such as clays, shales and certain silicious rocks. Soils when burnt, silica taken from soils as nutrients remains behind in the ashes contributing to pozzolanic element [4].

Hossain and mol [26] present the results of a comprehensive investigation of the characteristics of stabilized local clayey soil incorporating natural pozzolans and their combinations. They present the experimental program, the results of various tests conducted on stabilized soils and correlation between properties. Stabilizers with pozzolanic properties can bind soil particles together and reduce water absorption by clay particles. Stabilized soils by pozzolans exhibit enhanced mechanical properties such as compressive and tensile strength, modulus of elasticity and CBR as well as durability in terms of water resistance, water permeability and shrinkage. Sarooj as a traditional construction material in Iran is an artificial pozzolan produced by burning clay which can be used as stabilizer but resulted in an increase in swell pressure. The cementing properties result from the reaction between burnt clay and lime  $\text{Ca(OH)}_2$  in the presence of water to form calcium silicate hydrate and calcium aluminate or calcium aluminum silicate [27].

Amer et al [27] carried out a study on expansive soil which was stabilized using lime, cement, combinations of lime and cement, Sarooj and heat treatment. Initially, the chemical and physical properties of the untreated soil were determined. Then the soil was mixed with lime, cement and Sarooj. They were found that with the addition of 6% lime, both the swell percent and swell pressure reduced to zero. Heat treatment reduced swelling potential to zero. The use of lime showed superior results when compared with the other stabilizers.

### 5.6. Fly Ash

Excessive heave associated with swelling of expansive soils can cause considerable distress to lightweight structures and can cause different damage levels in civil engineering structures. Several methods have been suggested to control this problem. The most commonly used method is addition of stabilizing agents, such as fly ashes to the expansive soil. Fly ash is a byproduct of coal fired electric power generation system that has little cementitious properties compared to lime and cement but it reacts chemically and form cementitious compound in presence of moisture. 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 cohesive compound that contributes to improved strength of soft soil. Fly ashes are readily available in Iran, cheaper and environmental friendly. Studies showed that the reduction of swell potential achieved in fly ashes treated soil relates to mechanical bonding rather than ionic exchange with clay minerals [6].

Cementitious compound formed improves the strength and compressibility of soil. The amount of fly ash influenced the increase in CBR values, soil type and water content in the mixture. But it clearly indicates that the higher content of fly ash the higher CBR values of the soil [2].

Senol et al. [28] presented the results of research involving different types of self-cementing fly ashes for the stabilization of four different types of soft subgrades from various road sites in Wisconsin, USA. The strength approaches were applied to estimate the optimum mixture design and to determine the thickness of the stabilized layer. The performance of fly ash stabilized sub-base depends both on the specific source of fly ash and the engineering properties of soils. It was suggested that the performance analysis of fly ash should be based upon the laboratory tests such as index properties, compaction, unconfined compressive strength and CBR tests of a specific site.

However, soil fly ash stabilization has some limitations [29]. Soil to be stabilized should have less moisture content; therefore, in some cases dewatering may be required. Soil-fly ash mixture which cured

below zero temperature and then soaked in water is highly sensitive to slaking and strength loss. Sulfur contents can form expansive minerals in soil-fly ash mixture, which reduces the long term strength and durability [29].

### 5.7. Expanded Polystyrene Geofabric

As mentioned previously, soil stabilization is extensively used to reduce swelling pressure of expansive soils. Expanded polystyrenes are of the new materials which can be used as soil stabilizer. Expanded polystyrene (EPS) is a rigid cellular foam that has been used in a range of geotechnical projects including rapid embankment construction on compressible soils, slope stabilization, reduction of static and dynamic lateral pressure on walls and bridge abutments and as a sub-base fill material [30]. Moreover, using expanded polystyrene can effectively decrease the swelling pressure.

Ikizler et al [31] carried out a research on this material revealed the potential reduction in swelling pressure using sand and EPS geofabric above bentonite soil specimen. It was observed that geofabric of thickness higher than 10% of the total thickness, proved more effective in reducing swelling pressure compared to that achieved using a sand layer.

Shelke and Murty [30] used EPS geofabric to reduce the swelling pressure of expansive soil. Heave and swelling pressures are reduced considerably with use of compressible geo-inclusion also they are decreased with increase in the thickness of EPS geofabric. Studies showed that stabilizing expansive soils with polypropylene fiber reduced heave. Swelling decreased with increasing fiber content. Swelling pressure also decreased by using EPS geofabric as stabilizer. The reduction in swelling pressures due to EPS geofabric is significant for soils with higher swell potential than for soils with lower swell potential [32].

### 5.8. Agricultural Waste Materials

Disposal of solid waste can be minimized if the waste is having desirable properties such that they can be utilized for various geotechnical applications [6]. Soil stabilization with agricultural waste materials, such as rice husk ash (RHA) is one of the eco-friendliest and inexpensive methods [33]. Rice is produced in Iran, and husk is considered to be an agricultural waste resulting from the grinding of rice. The annual global production of rice husk has been estimated to amount to 108 tons in the world. Rice husk ash is the residue from the combustion of rice husks. Then it is economic, and eco-friendly compared to chemical additives. 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. In waste

materials and industrial byproduct, sulphides in form of iron pyrites ( $\text{FeS}_2$ ) may be present. Oxidation of  $\text{FeS}_2$  will produce sulphuric acid, which in the presence of calcium carbonate, may react to form gypsum (hydrated calcium sulphate) according to the Eq.2 and 3 [6] :



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 [4, 11]. Many studies have been conducted to study the effects of RHA on the geotechnical properties of soils. Rahgozar et al. [33] had been studied on the RHA and the aim of their study is to experimentally investigate the effects of adding RHA and ordinary Portland cement on the geotechnical properties of the clayey sand sampled from the city of Isfahan. The results showed that by increasing the content of RHA, the optimum moisture of the specimens increased, while the dry density of soil decreased. The 28-day-cured specimen with RHA and cement showed the highest values of unconfined compressive strength (UCS) and California bearing ratio (CBR) at 25.44 and 18.2 times more than those of the values for untreated soil, respectively. The scanning electron micrograph test of the stabilized soil was characterized as a well-structured soil matrix with very small pores, which can be attributed to the pozzolanic reactions of the cement and RHA [33]. Moreover Alhassan [34] investigated the effect of RHA on soil samples. Soil sample collected from Minna, classified as an A-7-6 lateritic soil on AASHTO classification was stabilized with 2-12% RHA. Using British standard light (BSL) compaction energy level, performance of the soil-RHA was investigated with respect to compaction characteristics, California bearing ratio (CBR) and unconfined compressive strength (UCS) tests. Their results also indicate a general decrease in the maximum dry density and increase in optimum moisture content with increase in RHA content. There was also slight improvement in the CBR and UCS with increase in the RHA content [34]. So it can be said that the effectiveness, environmental compatibility, and the low cost of RHA is the important attractions as a soil stabilizer and RHA would appear to be a very suitable light weight filler.

## 6. Conclusions

Improving soil's engineering properties is called soil stabilization. Soil stabilization techniques are necessary to ensure the good stability of soil to sustain the load of the superstructures. Especially

soils containing high levels of silt or clay have very varying geotechnical characteristics. They swell and become plastic in the presence of water, shrink when dry, and expand when exposed to frost and have least compressive and shear resistance. These soils extremely need to stabilize. In this review paper the effectiveness of some materials in improving the engineering properties of soft soils explained. The stabilized soils could help promote sustainable development which is one of the basic needs of our country, Iran. But it seems that many other investigations also need to be done so that new materials that would be useful as soil stabilizer could be found. Moreover for a successful stabilization, some laboratory tests followed by in-situ tests may be required to determine the soil parameters.

## References

- [1] H.F. Winterkorn, Soil Stabilization, "Foundation Engineering Handbook". Chapter 8, Winterkorn and Fang, eds., Van Nostrand Reinhold, New York, (1975), 312.
- [2] S.Z. Sharifah Zaliha, H. Kamarudin, A.M. Mustafa Al Bakri, M. Binhussain, M.S. Siti Salwa, Aust. J. Basic & Appl. Sci., 7(5)(2013), 258.
- [3] Experiments on Soil Stabilization In Iran, Housing and Home Finance Agency, International Housing Service, Ekistics, 7(42)(APRIL 1959), 330.
- [4] P. Sherwood, Soil stabilization with Cement and Lime. State of the Art Review. London: Transport Research Laboratory, HMSO (1993).
- [5] K.N.Derucher, G.P.Korfitatis, A.S.Ezeldin, Engineers. Prentice-Hall.
- [6] H. Afrin. A Review on Different Types Soil Stabilization Techniques. Inter. J. Trans. Eng. Technol., 3(2)(2017), 19.
- [7] S.Dhakar, S.K. Jain, Inter. J. Sci. Res. (IJSR) 5(6), (2016) 545.
- [8] Euro Soil Stab, 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, (2002).
- [9] R.Hicks, Alaska Soil Stabilization Design Guide, (2002).
- [10] S.Y.Saitoh, Suzuki, K.Shirai, Proc. of the 11th ISCMFE, San Francisco, 3(1985), 1745.
- [11] Al-Tabbaa, A. and Evans, W. C. Stabilization-Solidification Treatment and Remediation: Part I: Binders and Technologies-Basic Principal. Proceedings of the International Conference on Stabilization/Solidification Treatment and Remediation(2005), 367.Cambridge, UK: Balkema.
- [12] A. Pandey, A.Rabbani, Inter. J. Civil Eng. Technol., 8(6)(2017), 316

- [13] A.S. Negi, M. Faizan, D.P. Siddharth, R. Singh, *Inter. J. Innovat. Res. Sci. Eng. Technol.*, 2(2)(2013), 448.
- [14] C.D.F. Rogers, and S. Glendinning, *Modification of Clay Soils using Lime*. In C.A. Rogers (Ed.), *Proceeding of the Seminar Held at Loughborough University on Lime Stabilization (1993)*, 99. London: Thomas Telford.
- [15] Inc.Keller , *Improvement of Weak Soils by the Deep Soil Mixing Method*. Keller Brochure, (2011).
- [16] O.G. Ingles, and J.B. Metcalf, *Soil Stabilization: Principles and Practice*. Butterworths, Sydney,(1972).
- [17] R. Deby, Y. Linsha, Preethy, V. Dharanya, Vinodhini and C. Pavithra, *Inter. J. of Civil Eng. Technol.* , 7(6)(2016), 156.
- [18] F. Michael, P.E. Conway, *J. Soil Conta.* , 2(2)(1993), 157.
- [19] A.P. Chritz “Performance Evaluation of Mixed-in-Place Bituminous Stabilized Shoulder Gravel” Michigan Department of State Highways., (2006).
- [20] E. Eka, N. Putri, S.V. Kameswara Rao, M.A. Mannan, *Evaluation of Modulus of Elasticity and Modulus of Subgrade Reaction of Soils Using CBR Test*, *J. Civil Eng. Res.* , 2(1)(2012), 34.
- [21] Y. Huan, K. Siripun, P. Jitsangiam and H. Nikraz , *Sci. Res. Essays Vol. 5(23)*, (2010) 3687.
- [22] S.M.Marandi, P.Safapour , *American J. Appl. Sci.*, 6(1)(2009).
- [23] M. Shojaei, A. Baghini, B. Ismail, M. Kheradmand, H. Hafezi and R.A. Almansob, *Res. J. Appl. Sci. Eng. Technol.*, 5(24)(2013), 5652.
- [24] M.R. Abisha, S. Anushia, J. Jenitha singh, S.Dynisha, S.A.Lavanya , *IJARIE*, Vol-3 Issue-5(2017), 1476.
- [25] N. Khalid *Effect of Nanoclay in Soft Soil Stabilization*. InCIEC, Springer, Singapore. (2014).
- [26] K.M.A. Hossain , *L. Mol, Const. Build. Mater.* 25(2011), 3495.
- [27] Amer Ali Al-Rawas, A.W. Hago , Hilal Al-Sarmi, *Build. Envir.* ,40(2005), 681.
- [28] A. Senol, T.B. Edil, M.S. Bin-Shafique, H.A. Acosta, C.H. Benson ,*Soft Subgrades’ Stabilization by using Various Fly Ashes, Resources, Conservation and Recycling Volume 46, Issue 4, April(2006)*, 365.
- [29] D. White, *Fly Ash Soil Stabilizationfor Non-Uniform Subgrade Soils*. IHRB Project TR-461, FHWA Project 4 (2005).
- [30] A. Shelke, D. Murty, *Reduction of Swelling Pressure of Expansive Soils using EPS Geofoam*. In: *Proceedings of Indian Geotechnical Conference*, (2010), 495.
- [31] S.B. Ikizler, M. AYTEKIN, M. VEKLI, *Reduction of Swelling Pressure of Expansive Soil Stabilized using EPS Geofoam and Sand*, *Geosynthetics Inter.* 16(3)(2009), 216.
- [32] A. Shelke, D. Murty, “Swelling Pressure of Expansive Soil Stabilized Using Eps Geofoam” *Proceedings of Indian Geotechnical Conference December 15-17,2011, Kochi (No 2011 H-128)*.
- [33] M.A. Rahgozar, M. Saberian, Jie Li , *Trans. Geotech.*, 14(2018), 52.
- [34] M. Alhassan, *AU J.T.*, 11(4)(2008), 246.

