

Reaction Mechanism of Chemical Stabilization in Expansive Soil

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ABSTRACT

Chemical Stabilization in expansive soil have applications for many structures such as foundation, embankment, roadways, and water, sewer lines and play important role. Stabilized soil properties like plasticity, shrinkage and swelling, permeability and strength are depends on the type, shape, dimension and distribution of reaction products and pores. Proper mix design and curing conditions controls the capability of expansive soils and stabilizers to engage in the formation of cementitious compounds. Due to alteration in the mineralogy of the treated soil and new mineral formations with more stable are produced. Traditionally lime, salt and cement were used as a stabilizer but recently many stabilizers which are coming in the market required more attention. Most published reviews focus on defining the test results and performance of pozzolanic material properties and do not treat the subject of the mechanism of the pozzolanic reaction in detail. Hence the main objective of this paper is overview the reaction mechanism of chemical stabilization in expansive soil.

KEYWORDS: Chemical Stabilization; expansive soil; reaction mechanism; pozzolanic reaction; sulphate activation; alkali activation; cation exchange

INTRODUCTION

Expansive soils property depends upon mineral presents and chemical constitutions. These soils undergo large swelling. The clay minerals have a high adsorptive capacity for water which leads to the problem of swelling. Stabilization of expansive soil with various additives is for remedying the problems like reduces the expansibility and contractility of soil. It has been seen that proper dose of stabilizer bind the soil particle together and reduce water absorption by clay particles and improving strength of expansive soil significantly. To achieve better results in stabilization of expansive soil,

selection of suitable chemical stabilizer and proper dosages is important and at the same time practical processes of handling the chemicals and financial aspect should be considered in mind. The focus of the study to understand the chemical process for improvement of the geotechnical properties by short term reaction including cation exchange and flocculation along with long term pozzolanic reaction. Most published reviews focus on defining the activity and performance of pozzolanic material properties and do not treat the subject of the mechanism of the pozzolanic reaction in detail, due to this problem arise when trying to compare and relate the activity controlling properties of different chemical stabilizer. In this respect, pozzolanic properties and activity remain limited to materials of a similar origin. To determine which material properties are important and become essential in the pozzolanic reaction, a detailed knowledge of the pozzolanic reaction mechanism is needed. Research is needed to understand cementitious reactions and their short and long term roles in the stabilization process. In this paper, reviewing previously published work related to effect of different chemical stabilizer on reaction mechanism of expansive soil is summarized.

CHEMICAL STABILIZATION

Chemical stabilization is an effective method to enhance soil properties by combining chemical additives to the soil. Advantages of chemical additives as compared with the conventional additives are soluble capacity in water due to this adequate number of cations for ion exchange reaction. Chemically stabilized soils requires a understanding of two distinct aspects, the thermodynamics and kinetics of chemical reactions as a function of relevant environmental factors (pH, water content, temperature); and the correlation between the chemistry and the mechanics of the system, i.e., the effect of chemical composition on strength. The swelling, electro kinetics, and other engineering properties of clays were significantly affected by additives. It is well known that the swelling properties of expansive soils significantly affected due to cation exchange capacity (CEC), pH, and zeta potential of soil.

Chemical stabilization of expansive clays consists of changing the physico - chemical environment around and inside of clay particles. When the soil at the site contains clay size particles, a free passage of liquids and longer wetting periods is essential. In this situation chemical such as KCl, NaCl, $MgCl_2$, $CaCl_2$, $AlCl_3$ are effective than non-chemical stabilizer. Quantity of chemical additive is significantly lesser as compared with those of cementitious or non-cementitious categories. Calcium hydroxide (lime), Cement as well as cementitious material successfully utilize in stabilizing both granular and fine-grained soils.

Pozzolanic Reaction

The addition of lime or cement to a soil causes two reactions, one being a short-term reaction while the second is a long- term reaction. The immediate effect to the soil is to cause flocculation-agglomeration and carbonation of the clay particles caused by cation exchange. The effect of short-term reaction is to enhance workability and provide an immediate reduction in swell, shrink- age, and plasticity of expansive soil. The Pozzolanic reactions which are require longer time attributed to strength and durability.

Chemical reaction involves pozzolanic reactions within the additives-soil mixture, resulting in strength gain over time. When the pH value of additives-soil mixture reaches above 12, then silica and alumina from the clay become soluble and are free from the clay mineral. Pozzolanic reaction will continue as long as the pH remains high enough to maintain the solubility of the silica and alumina. The reduction of the alkaline environment will give the negative effect of the pozzolan dissolution process and tends to be retarded. Pozzolanic reactions, cation exchange capacity, carbonation and

cementation controlled by particles grain size, shape and particle size distribution of various additives show significant change in the behavior of expansive soils.

Alkali and Sulphate activation

Chemical activators are utilizing to accelerate reactivity by sulfate activation and alkali activation. Some of the researches show that sulphate activation can be done by using several accelerators such as Sodium and Calcium sulphate, Gypsum, whereas Sodium and Calcium hydroxide are use for alkali activation. Sulfate activation can be made by chemicals such as gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ and sodium sulfate, Na_2SO_4 , alkali activation can be done by NaOH and $\text{Ca}(\text{OH})_2$. Chemical additive of higher valence of cations (CaCl_2) performs better than lower valence (Na_2SiO_3). Some of the researchers use shows $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ and NaCl to accelerate pozzolanic reactivity of different mineral admixture use for chemical stabilization. Chemicals other than Sulphate and alkali group are used for early age strength.

REACTION MECHANISM WITH ADDITIVES

Lime

When lime is added into expansive soil, chemical reactions take place. Lime stabilization is adopted for many structures. Plasticity of soil, are influenced by lime, the action of hydroxyl ions modifying the water affinity of the soil particles. Hence, lime stabilization is more effective for montmorillonite soils than kaolin soils. Curing is important aspect for lime-stabilized soils. The first phase of the chemical reaction is cation exchange. The flocculation and agglomeration phase of lime stabilization results in a soil that is more readily mixable, workable, and, ultimately, compactable. Expansive soils when treated with lime in the presence of water undergo rapid cation exchange and flocculation/agglomeration reactions. After the formation of the positively charged calcium cations from either quicklime or hydrated lime, an immediate cation exchange begins to take place between the surfaces of the clay particles and the calcium. The effects of the cation substitution cations from the lime subsequently leads to a reduction in plasticity as the clay particles flocculate and then agglomerate. These processes occur within the initial 24 h rapidly after addition of lime to the clay.

Cement

Cement stabilization consists of mixing pulverized soil, fixed quantity of Portland cement, and water. Portland cement consists of calcium silicates and aluminates, when they combine with water, to form the hydrate cementing compounds, as well as excess calcium hydroxide. This method immediately reduces the plasticity characteristics of the soil which are caused by calcium ions released during the initial hydration reactions. Addition of cement stabilizer increases the aggregation reactions rapidly and decreases the Plasticity Index. Tri calcium silicate first dissolves in water, forming calcium and bi calcium silicate hydrate and the formation of calcium aluminate hydrate. The cementation of the particles at the points of contact is due to the calcium silicate hydrate and calcium aluminate hydrate. This results in high strength in the cement-clay skeleton and clay matrix. The individual units of this matrix contain a core of hydrated cement gel surrounded by a zone of flocculated clay which is glued together by secondary cementation.

Fly Ash

Fly ash is one of the by-products generated when coal is burnt in thermal power plants. F Class fly ash, the calcium content varies from 1 to 12% whereas Class C fly ash as high as 30 to 40%. similarly,

the amount of alkalis and sulfates is generally higher in Class C fly ash, shows Class C fly ash a better in soil stabilization process. When fly ash is mixed with soil for stabilization, the short-term reactions cause flocculation and agglomeration of the clay particles due to the ion exchange at the surfaces of the soil particles to enhance the workability in soils and provide an immediate reduction of swell, shrinkage, and plasticity properties. Long-term reactions which lead to increased strength in the treated soil, from a few weeks to several years. The amount of time is dependent on the rate of chemical breakdown and on the hydration reactions of the silicates and aluminates. These reactions help to improve and bind the soil grains together to form cementitious materials. As lime with fly ash are mix into a soil, then, rapid hydration process occur and a simultaneous cation exchange that flocculates the soil. The cementation by pozzolanic reaction produces new pozzolanic reaction products (such as calcium silicate hydrates and calcium aluminate hydrate).

Silica fume

Silica fume is a by-product obtained during manufacture of silicon and ferrosilicon alloys. Silica fume is 10 to 20 times finer than fly ash. Silica fume is pozzolanic because of its high silica content and its high specific surface area. SF consists of very fine particles of a surface area $20,000 \text{ m}^2/\text{kg}$. Due to this it is a highly effective pozzolanic material. Lime reacts with Silica Fume to form silicate gel proceeds immediately to coat and bind clay lumps in the soil. The micro-crystals can also mechanically interlock. In addition to pozzolanic reactions, carbonation can also lead to long-term strength increases. Carbonation process starts when lime reacts with carbon dioxide from the atmosphere. However, prior to mixing, exposure of lime to air should be avoided for premature carbonation of the lime.

Calcium chloride

Chemical additives exhibit better performance at an accelerated rate that to in considerable lesser quantity than of cementitious or non- cementitious additives. When calcium chloride electrolyte is added to soil, it easily made into the calcium charged supernatant, which helps in ready cation exchange reactions with clay particles. Use of CaCl_2 and Na_2SiO_3 added in the soil then mechanical bonding or cementation is occur as a substitute of an ion- exchange phenomenon and the efficiency of earlier one in is considerably better than later one. This is because of the additive CaCl_2 contains divalent cations as against Na_2SiO_3 , which contains monovalent cations. A Base Exchange phenomenon occurs due to strong calcium ions replacing the weaker sodium ions, causes modification of electrical charge around a clay particle by reducing the space between clay particles consequential formation of flocculated structure.

Bio-enzyme

Bio-enzymes are liquid concentrated chemicals use to improve the properties of expansive soil. The use of bio-enzyme in soil stabilization is not very popular due to lack of awareness between engineers and non-availability of standardized data. By utilizing fermentation processes specific micro-organisms can produce. An enzyme would stay active in a soil until there are no more reactions to catalyze. The enzymes themselves are unchanged by reactions. The adsorbed water or double layer gives clay particles their plasticity. In some cases the clay can swell and the size of double layer increases, but it can be reduced by drying. Therefore, to truly improve the soil properties, it is necessary to permanently reduce the thickness of double layer. There are many bio-enzymes available for soil stabilization such as Renolith, Perma-Zyme, Terra-Zyme, Fujibeton etc.

Renolith

Renolith's usual application is as a mixture with water in specific proportions. Renolith when thoroughly mixed and stabilized with a soil produces an exothermic chemical reaction and forms a polymer. The renolith stabilizer creates a physical bond between the soil particles

Perma-Zyme

Permazyme is a natural organic compound. Their large molecular structures contain active sites that assist molecular bonding and interaction. Permazyme combines with the large organic molecules in the soil to form a reactant, breaking down the clay structure and causing the cover-up effect, which prevents any further absorption of water. The enzyme is regenerated by the reaction and goes on to perform again. Because the ions are very large, little osmotic migration takes place, and intimate mixing is required.

Terra-Zyme

Terra-Zyme is non-toxic liquid, formulated using vegetable extracts. The use of Terra-Zyme enhances weather resistance and also increases load bearing capacity of soils. These features are particularly evident in fine-grained soils such as clay in which the formulation affects the swelling and shrinking behavior.

Terra-Zyme replaces adsorbed water with organic cations, thus neutralizing the negative charge on a clay particle. Terra-Zyme reacts with the adsorbed water layer of clay particle and reduces the thickness around the soil particle due to which void between the soil particles reduces and the soil particle gets closer orientation with lower compactive effort and compacted more tightly together.

Fujibeton

Fujibeton is an inorganic polymer that chemically binds with all compounds. This product is developed in Japan. The blended mix with ordinary Portland cement is called Fujibeton, improves CBR of the sub-grade, Fujibeton constituent, dispersing agent gives a surface activating agent. Fujibeton, due to the high water contents of some of its constituents; it is desirable to expose the surface to the air.

CONCLUSIONS

Considering all the above aspect following conclusions can be drawn.

- (1) Chemical stabilization is dependent on several factors such as soil type, its mineralogy, additive content, and curing period, and is a complex problem that needs careful evaluation.
- (2) Although many years of stabilization with cementitious materials, research is needed at all levels to understand the reaction mechanism of the stabilized element for effective predictions of short and long term performance.
- (3) It is obvious that the chemical stabilization is achieved through the chemical reaction that takes place between the chemical components of the soil and the stabilizers. It is recommended that geotechnical engineers should consider the reactive effects of different chemical stabilizers.
- (4) Results and experience show that lime is a better chemical stabilizer than the others.
- (5) Study shows that quantity of chemical additive required for stabilization is less than cementitious or non cementitious binder.
- (6) To better guide in chemical stabilization, technical specifications of additive and proven procedures should be developing in better way.

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