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Effects of Alkaline Activated Egg Shell Powder in Soil Stabilization

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Abstract
The effectiveness in soil stabilization by adding alkali activated egg shell powder (ESP) to cohesive soil has been studied taking into consideration Atterberg's limits, compaction characteristics and unconfined compressive strength (UCS) behavior. Laboratory test have been conducted at various proportions of activator egg shell powder (5%, 10%, 15%, 20%, 25% & 30% of total solid mass). The combination of sodium hydroxide and sodium silicate serve as the alkaline activator solution. The activator to alkali ratio used was 0.45. The mass ratio of Na_2SiO_3: NaOH was fixed at 2 and a constant 10 Molar concentration of NaOH was adopted. The effects at different curing periods of 1, 7 and 28 days were analyzed. The increase in maximum dry density and unconfined compressive strength imply the improvement of soil geotechnical properties. This marked the feasibility of using alkaline activated egg shell powder in stabilization of soil.

Keywords
Soil Stabilization, Unconfined Compressive Strength (UCS), Egg Shell Powder (ESP), Atterberg's Limit, Compaction

1. Introduction

Soft soils are characterized by high water content, low permeability, high compressibility and low shear strength. Due to these properties, constructing above soft soils with high clay content have been a challenge to the engineers. Because of poor engineering properties, such soft soil undergo problems of differential settlement, excessive post construction settlement, shear failure, bearing capacity failure, etc, and are thus unsuitable for all construction works. Improving the engineering properties of soft soils can be achieved through soil stabilization. Whenever the soil available for construction is unsuitable for meeting construction engineering demands, soil stabilization can be implemented. Soil stabilization involves the addition of stabilizer materials which alter the soil engineering properties to meet the desired requirement. The use of waste materials and industrial by-products for soil stabilization is anticipated to be environment friendly, economic and sustainable. Industrial by-products and wastes such as fly ash, cement kiln dust, stone dust, brick dust, ground granulated blast furnace slag, lime kiln dust, burned sewage sludge, sawdust ash, bagasse ash, egg shell powder (ESP), coconut coir fibers, jute fibers, steel slag, waste paper sludge ash, polymers etc can be used in the stabilization of soft soils. Egg shells are the waste obtained from restaurants, cafeterias, bakeries, fast food centers, poultry farms and households, and are currently facing global disposal problems. In year 2018/2019 the production of eggs in Nepal was reported to be around 1.54 billion eggs [1] which approximates to about 10.78 metric tons of egg shell waste. The production rate is growing each year, and the problem of egg shell disposal has been an issue. Utilization of waste egg shells in soil stabilization abolishes the disposal problems, and is very environment friendly.

Alkali activation involves the reaction between binder material and alkaline solution to form binding gels of different compounds, such as sodium aluminosilcate hydrate (NASH), calcium silicate hydrate (CSH), calcium aluminosilicate hydrate (CASH) or calcium aluminate hydrate (CAH) based on the availability of silica, calcium oxide and alumina content in the binder material [2]. The alkali activation of ESP containing high amount of CaO result in the formation of CSH and/or CASH binder gels [3]. The main purpose of adding the alkali is to increase pH in order to break down the silicate minerals of soil [4] and permit pozzolanic reaction with added ESP.

This study aims to check the feasibility of using alkali activated ESP in improving geotechnical properties of parent cohesive soil. The mix of soil and ESP activator is activated by the mixture of 10 Molar NaOH and Na_2SiO_3 with Na_2SiO_3 to NaOH mass ratio of 2 as alkaline activator solution and alkali/activator ratio of 0.45. Compressive strength is tested for specimens with curing age up to 28 days.

2. Materials and Methodology

2.1 Materials

2.1.1 Soil

Brown colored silty-clayey soil was collected from an excavataion of building construction site located at Bhaisepati, Lalitpur, at the depth of about eight feet. The natural soil had a high water content and was very hard upon drying. The soil was first air dried for a week, then crushed and pulverised. The soil was further oven dried for 24 hours, and finally stored after screening through 425um IS sieve. The specific gravity of soil was found to be 2.51. The soil had a liquid limit of 54%, plastic limit of 27.45%, plasticity index of 26.55%, percentage of clay particles 15.85% and unconfined compressive strength of 114.47 KPa. The soil was classified as clay with high plasticity (CH) according to the Unified Soil Classification Systems (USCS). The particle size distribution curve of the soil is shown in Figure 1.

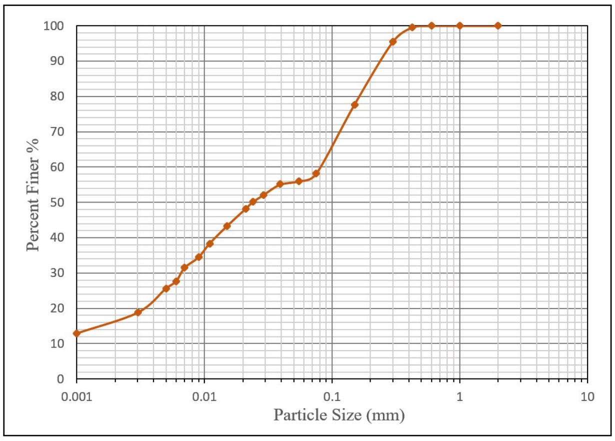

Figure 1: Particle size distribution curve for original soil

2.1.2 Egg Shell Powder

Egg shells were collected from different bakeries in Lalitpur. The egg shells were washed with water for several times and sun dried. The dried egg shells were then pulverized by mechanical means, and passed through 425 μm sieve. The specific gravity of ESP was measured to be 2.48.

2.1.3 Alkaline Activator Solution

Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) was used in combination as the alkaline activator solution. The sodium hydroxide was purchased in the form of pellets with molecular weight of 40 gm/mole and 97% purity, and sodium silicate was procured in solution form with density of 1.5g/cc from Science House Pvt. Ltd, Tripureshwor, Kathmandu. The concentration of NaOH used was fixed at 10 Molar. The Na_2SiO_3 solution was diluted to obtain the density of 1.35 g/cc. The sodium hydroxide and sodium silicate solutions are mixed together keeping the mass ratio of sodium silicate to sodium hydroxide constant at 2.

2.2 Methodology

2.2.1 Experimental setup

The percentage of ESP in total solids (Soil+ESP) used were 5, 10, 15, 20, 25 and 30% with alkali/ESP ratios (AAR) of 0.45. The nomenclature of treated soil specimen is given as:

$$[SOIL - ESP\%]$$

Where, ESP%- percentage of ESP in total solids. Example, for soil treated with 10% ESP with 0.45 AAR, the nomenclature is given by SOIL-10.

2.2.2 Preparation of soil specimen

As per the proposed flowchart in Figure 2, the design of a mix requires the knowledge of type of lab test and the amount of total solids required for the particular anticipated test. Then the amount of ESP and soil can be calculated using ESP%. The AAR is used to calculate the mass of alkali. Using the ratio of Na_2SiO_3:NaOH of 2, the individual masses of Na_2SiO_3 and NaOH can be calculated. Solution of 10Molar NaOH is prepared, and a 1:1 solution, i.e. one part Na_2SiO_3 and one part water, is prepared with a density of 1.35 g/cc. Both the solutions are mixed together and left for 24 hours for the exothermic

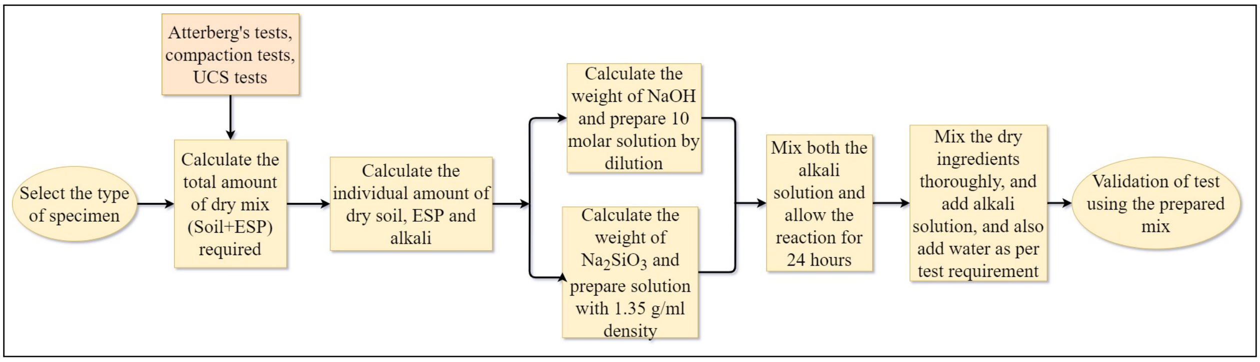

Figure 2: Flowchart showing the steps involved in specimen preparation

reaction to complete. After 24 hrs, the dry ingredients i.e. ESP and dry soil are mixed to form a homogenous blend. Alkaline activator solution is then added to it and mixed well. Water is supplemented finally only if demanded by the experiment.

2.2.3 Execution of tests

The following lab experiments were carried out to determine the change in properties in the raw soil before and after the stabilization process:

1. Particle size distribution [5]
2. Liquid limit, plastic limit for each soil specimen [6].
3. Standard proctor test to determine the MDD and OMC [7]
4. UCS test for 1, 7 and 28 days [8]

3. Experimental Results and Discussion

3.1 Effects on Atterberg's Limits

The liquid limit (LL) as well as plastic limit (PL) of treated soil decreased on the increment of ESP. The liquid limit attained a minimum value of 40.1% at 30% ESP and 0.45 alkali activator ratio, which is 25.74 percent reduction compared to untreated soil. It was observed that the plastic limit of the soil decreased from 27.45% to 21.28% with addition of 30% ESP at 0.45 alkali activator ratio. This is a reduction of 22.47 percent. Moreover, it can be observed from Figure 3 that the plasticity index (PI) of the treated soil is reduced compared to the untreated soil. This reduction in liquid limit, plastic limit and plasticity index is due to the decrease in proportion of clay particles. The formation of calcium silicate hydrate gels binded the clay particles together, thus increasing the overall particle size. The percentage of clay particles in treated soil thus get reduced. The Atterberg's limit values also decreased on increasing alkaline activator content with same ESP content. Increasing the activator content led to increase in pH value, and higher pH value promoted the pozzolanic reaction between soil, ESP and alkaline solution.

3.2 Effects on compaction characteristics

The MDD increased from the value of 14.67 KN/m^3 to maximum of 17.27 KN/m^3 for samples treated with 30% ESP and 0.45 alkaline activator ratio. The relationship between MDD and ESP content is represented by Figure 4. The OMC was observed to decrease with the increase in ESP content. At 30% ESP content and, the OMC decreased from 25.2% to a minimum of 16.8%, which is 49.55% reduction. Figure 4 shows the relationship between OMC and ESP content.
The increase in cation concentration (Ca^{2+}, Na^{+}) around the clay particle causes the overall force between two clay particles to be repulsive [9]. This results in formation of dispersed structure which have less void ratio. As a result, MDD increased with increasing ESP content.

3.3 Effects on compressive strength development

It can be observed from Figure 5 that the compressive strength of treated samples increased with curing period. The 28 day compressive strength increased persistently, and attained maximum values at 30% ESP. Comparing to the untreated soil, 1002.48 percent increment was found in the strength of soil treated with 30% ESP.

As the ESP consists of CaO in an abundant amount, CaO reacts with alkali, water and soil to form calcium

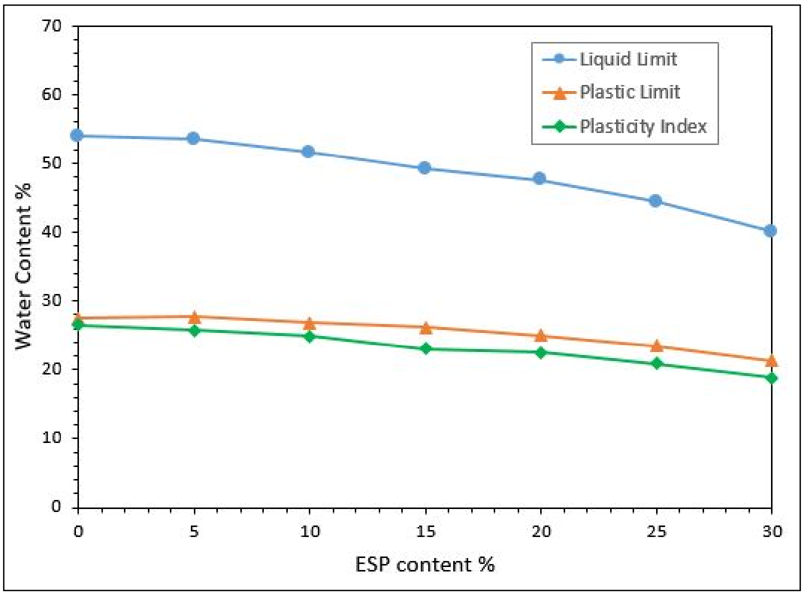

Figure 3: Relationship between plasticity index, ESP content and alkaline activator ratio

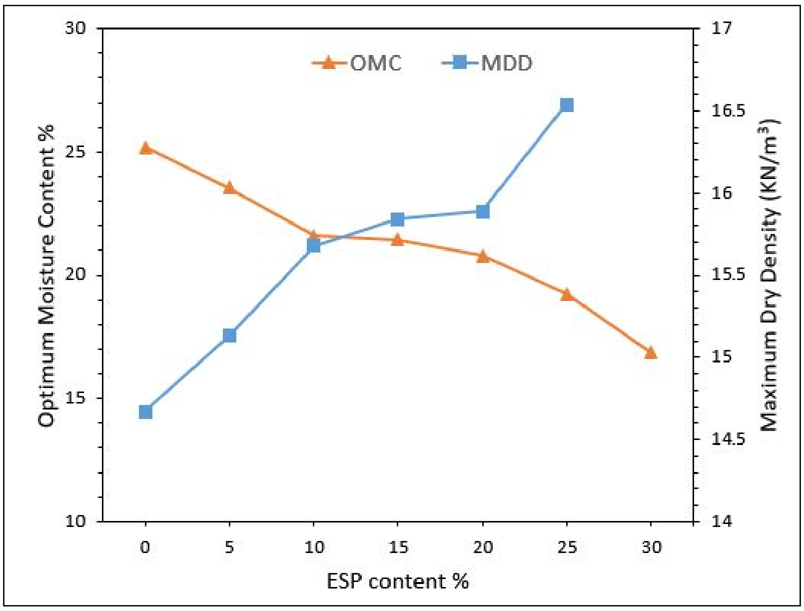

Figure 4: Relationship between OMC, ESP content and alkaline activator ratio

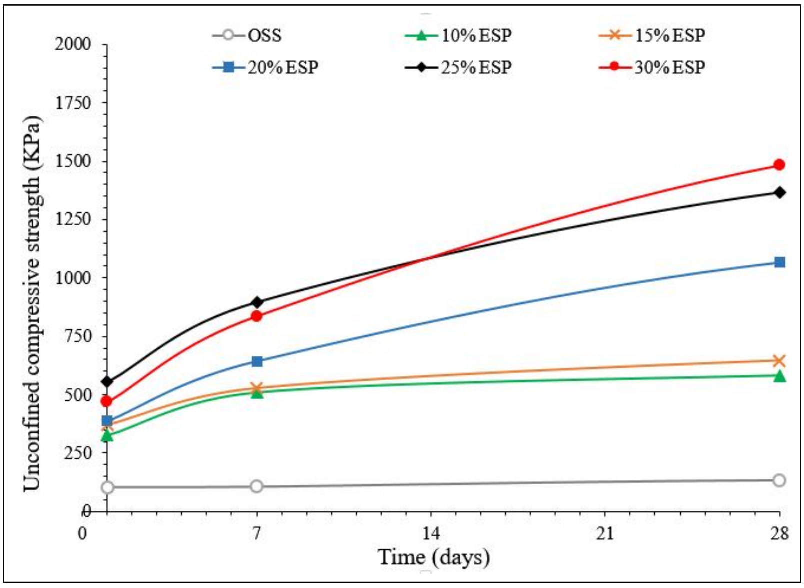

Figure 5: Relationship between UCS, sample type and curing days

silicate hydrate (CSH) through pozzolanic reactions [3]. The formation of CSH is a pozzolanic reaction process comprising the phases of cation exchange, flocculation and hydration. The formation of CSH by mixing alkaline solution with high Ca content binder was also reported by many authors [2, 10]. The formation of stiff CSH resulted in the increase in compressive strength of the treated soil. The addition of alkaline solution increased the pH of the pore fluid, which helped in the breakdown of silicates present in soil as shown in Equation 1 [11].

$$OH^- + Si - OH \rightarrow Si - O^- + H_2O \quad (1)$$

The silicate breakdown aids in formation of CSH as shown in reaction mechanism in Equation 2, 3 and 4 proposed by Garcia-Lodeiro et al., 2015 which is applicable to CaO and SiO_2 rich materials [10]

$$Si - O^- + Na^+ \rightarrow Si - O - Na \quad (2)$$

$$Si - O - Na + OH^- \rightarrow Si - O - Na - OH^- \quad (3)$$

$$Ca^{2+} + Si - O - Na - OH^- \rightarrow Si - O - Ca - OH + Na^+ \quad (4)$$

4. Conclusion

Based on literature reviews, experimental investigations and discussions made, the following conclusions can be drawn:

1. The value of liquid limit and plastic limit decreases with increasing the percentage of ESP. The liquid limit decreases by 26.29% at 30% ESP and plastic limit reduces by 22.47% with the addition of 30% ESP at 0.45 AAR.
2. The maximum dry density of soil increases with increasing ESP content, and attained 15.06% increment at 30% ESP. The value of optimum moisture content of ESP treated soil decreased on increasing ESP content. Minimum OMC of 16.85% is obtained at 30% ESP, which is 49.55% reduction.
3. The compressive strength is found to be increasing with number of curing days. This means that ESP exhibits a time dependent pozzolanic reaction when mixed with alkaline solution and soil. The formation of CSH results in the increase of compressive strength with increase in ESP content. The compressive strength of soil is also found to vary with the alkaline activator ratio.

It can be concluded that the use of alkali activated ESP for chemical stabilization of soil is feasible. This technique of using waste ESP also proves to be environment friendly.

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