The Comparison between the Strength of Stabilized Cement Clay Columns and Remolded Cement Clay Samples

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Abstract: The addition of a stabilizer i.e. cement or lime changes the clay particles in the clayey soils. Instead of the plate-like or flaky shape of particles, the formation of CSH or CAH cluster which has spider or hairy cluster shapes (under scanning electron microscope) has created bonding which increased the shear strength of the stabilized soils significantly. According to BS 1924, in preparing the soil samples for unconfined compression, the stabilized soils need to be compacted to a certain degree of compaction utilizing dynamic compaction. The author suggested that this dynamic compaction, without any measurement regarding what was the energy amount being imposed on the stabilized soil samples, might damage the CSH clusters or CSH matrix gel thus resulting in non-reliable results on the strength of the laboratory-prepared specimens. This result also does not resemble the strength developed in cement columns or lime columns in the field. The study is divided into three major stages. The first was the preparation of samples for UCT based on BS 1924, which were compacted using static packing pressure (SPp). Secondly is the development of a small-scale physical model to study the undrained shear strength of the stabilized kaolinite. Thirdly, the preparation of UCT samples compacted to a pre-determined packing pressure (PPp). Pre-determined packing pressure is 50% of the (SPp). It was found that reducing 50% of the (SPp) has reduced the strength of samples significantly. The strength of the samples compacted to 100% SPp is approximately ten times higher than that of the uncompacted cement column strength after 56 days of curing. The ionic conductivity trend shows that as the strength increases, the conductivity value decreases. This finding has led to the conclusion that electric or ionic conductivity tests can be applied as supporting tests in predicting the strength development in cement-stabilized kaolinite.

Keywords: Packing Pressure; Ionic Conductivity; Static Packing Pressure; Cement Clay.

1. Introduction

1.1 Background

Geotechnical engineers face challenges in building structures on compressible soil, such as clay. Pile foundations are costly. Instead, stabilizing the soil itself can be more cost-effective. Swedish and Japanese researchers have been pioneers in deep stabilization or dry mix procedures for almost 30 years. However, replicating exact site conditions in the laboratory is not possible for deep soil stabilization due to distinct sample preparation techniques. The engineering efficacy of chemically stabilized clay remains limited.

1.2 Objectives

The main objective of this paper is to explore the relationship between cement dosages and UCT strength development in cement-stabilized clay columns and propose an electrical method to support this relationship.

2. Review of Literature

Before using the dry mix method for soil development, it's essential to investigate the soil's natural location to determine the appropriate binders. Different soil types require different binders, resulting in stronger stabilized soils. However, soil composition in specific locations is inconsistent. Jacobson's study (2002), on lime-cement columns emphasizes the need to examine the correlation between laboratory samples and cement or lime columns' potency.

Furthermore, he pointed out that there is a noticeable discrepancy in the laboratory methods being assessed, namely on the required level of compression and the method used for insertion. At first, the soil/binder combination is placed into a mold with appropriate dimensions in layers that are approximately 1 inch thick. Each lift is compacted through hand compression using a rodding tool (URS 2001), by striking it against a firm surface (Haley & Aldrich 2001), or by utilizing a compaction tool with a diameter of 45 mm (Carlsten and Ekstrom, 1995). These approaches can produce markedly distinct results, indicating that compaction is an essential aspect of specimen preparation and consistency is necessary (Den Haan 2000). A pressure of 100 kPa is typically required to be applied to a compaction instrument with a diameter of 45 mm. The references provided are Carlsten et al. (ASTM 1995) and den Haan (2000). Alternative packing methods do not have a specific pressure requirement and are only compressed to a sufficient degree (URS 2001, Haley & Aldrich 2001). While there is a lack of studies investigating the specific effects of these various treatments on strength, it is logical to infer that as compaction intensifies, strength also increases.

2.1 Preparation of samples according to BS 1924 Part 2: 1990

The research discusses the preparation of cylindrical specimens for unconfined compression tests, following BS 1924 Part 2:1990 specifications. The weight of materials is determined based on the relationship between optimum moisture content and maximum dry density. The author proposes using packing pressure to compress samples to a predetermined density, quantifying the necessary packing pressure magnitudes using various cement dose configurations. The research suggests that chemical investigations into stabilized materials, specifically soil cement, are needed, rather than focusing solely on their mechanical properties.

Figure 1. Stiff mechanism resistance within its mass in stabilized soil (Hafez, 2007)

The study proposes that the significance of packing pressure may vary when packing natural clay in the UCS test mold, but it is crucial when dealing with stabilized lime or cement clay. This is because the stabilization of clay soils occurs through two separate chemical processes induced by the stabilizing agents. The immediate impacts include cation exchange and flocculation, whereas the time-dependent effects consist of pozzolanic reactions and hydration. The outcome of these chemical reactions produces various types of active chemical bonding, resulting in the formation of an internal network of clusters composed of CSH or CAH matrix. This network contributes to the overall stiffness and resistance of the specimen. The clusters are depicted as black clusters in Figure 1.

3.0 Methodology

This study is based on laboratory investigations. The study can be divided into three major stages. First is the testing of the compacted samples while second is the testing of small-scale physical models of soil cement column. In the final stage, compacted samples were made again. At this stage, half of the pressures applied during the preparation of the samples in the first stage were imposed on the samples to compact them without taking into account what were the final heights of the samples. The testing is designed so that the strength and conductivity of the prepared samples can be measured. The materials used are kaolin, Portland Cement, and water.

Table 1. The chemical constituent of the stabilizer

CHEMICAL CONSTITUENT	LIME	CEMENT
Silica SiO2	12.25%	20.63 %
Alumina Al2O3	7.78	5.87
Iron Oxide Fe2O3	3.82	2.52
Calcium Oxide CaO	69.67	63.55
Magnesium Oxide MgO	0.88	2.79
Sodium Oxide (Na2O)	0.12	0.85
Titanium Dioxide TiO2	0.76	0.63
Sulphur Trioxide SO3	2.77	1.62
LOI	1.95	1.54

During the initial phase, samples were made with a diameter of 50mm and a height of 100mm.

The weight of stabilized materials was estimated using the correlation between optimum moisture content (OMC) and maximum dry density (MDD) as specified in BS 1924: 1990. The samples were further compressed using static packing pressure until they attained dimensions of 50mm in diameter and 100mm in height. In the second phase, prototypes of cement clay columns at a small scale have been created. The samples were subjected to a state of saturation. During the last stage, the samples that were initially prepared were remade. In this instance, the static packing pressures were decreased by 50% regardless of the height of the sample. The initial static packing pressure during the first stage is referred to as the standard packing pressure (SPp). The packing pressure applied at the final stage of sample preparation is referred to as the pre-determined packing pressure (PPp).

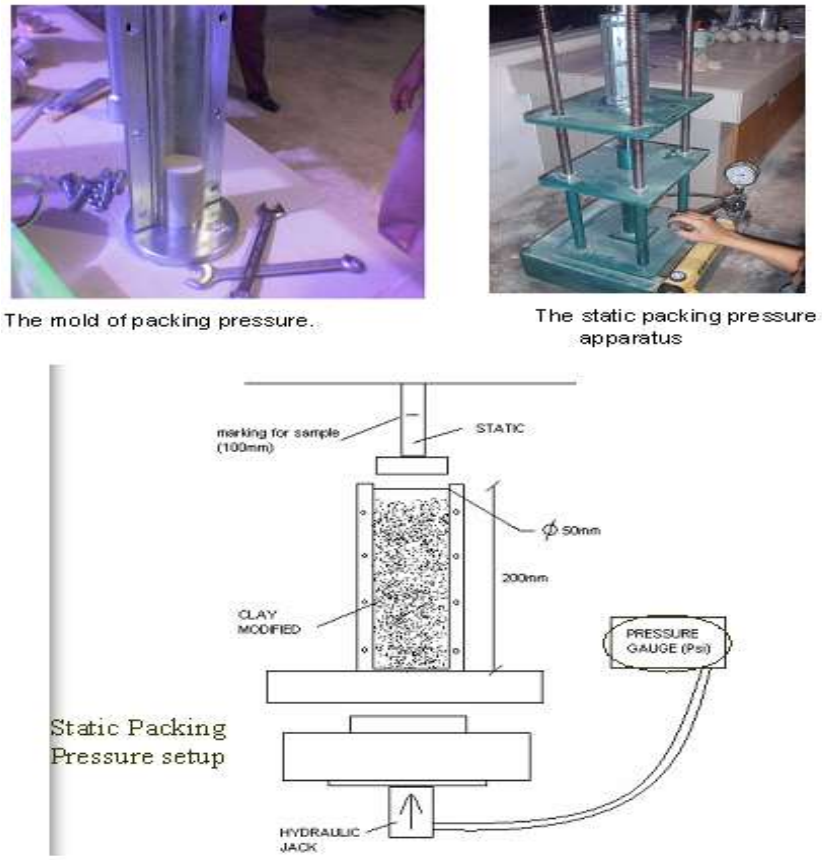

Figure 2. The static packing pressure apparatus

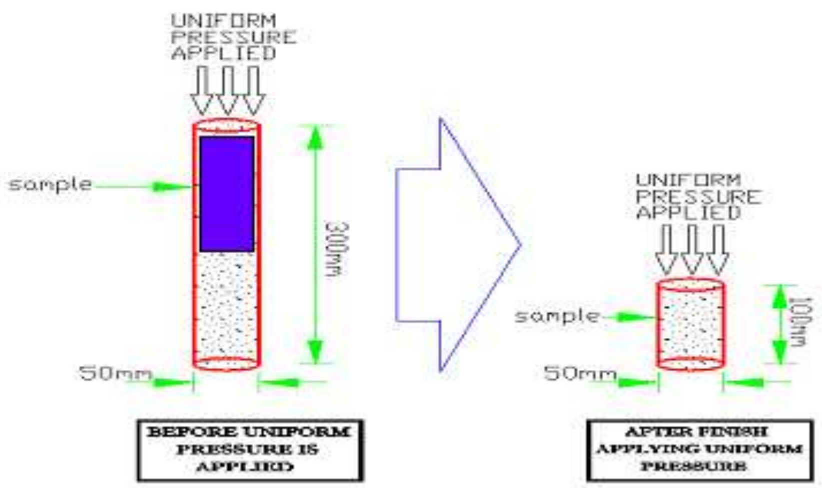

Figure 3. Applying standard packing pressure to produce 50x100 mm

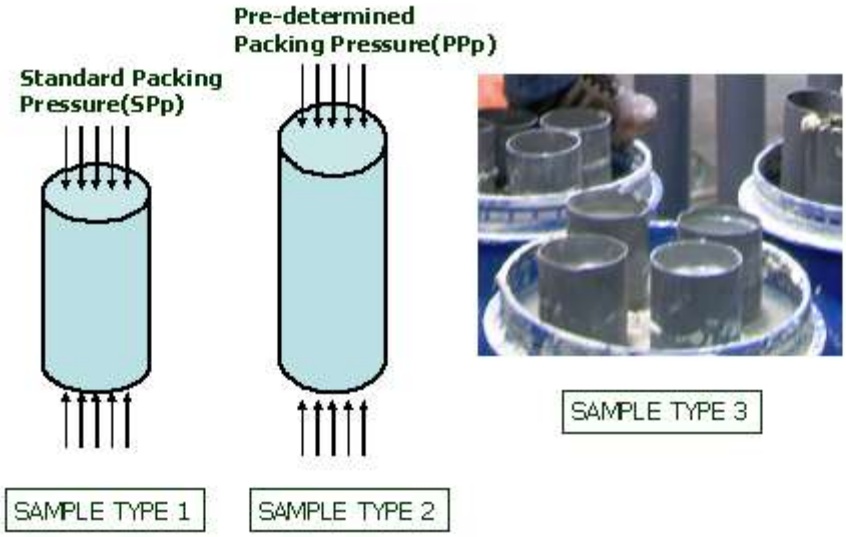

Figure 4. Preparation of two different remolded samples and one small-scale model sample

4. Results and Analysis

Samples compacted to SPp which were prepared with different configurations of cement namely 6%, 12%, 18%, and 24% are found to require different amounts of static packing pressure. The higher the cement dosage, the higher would be the required packing pressure. This phenomenon is illustrated in Figure 5 below.

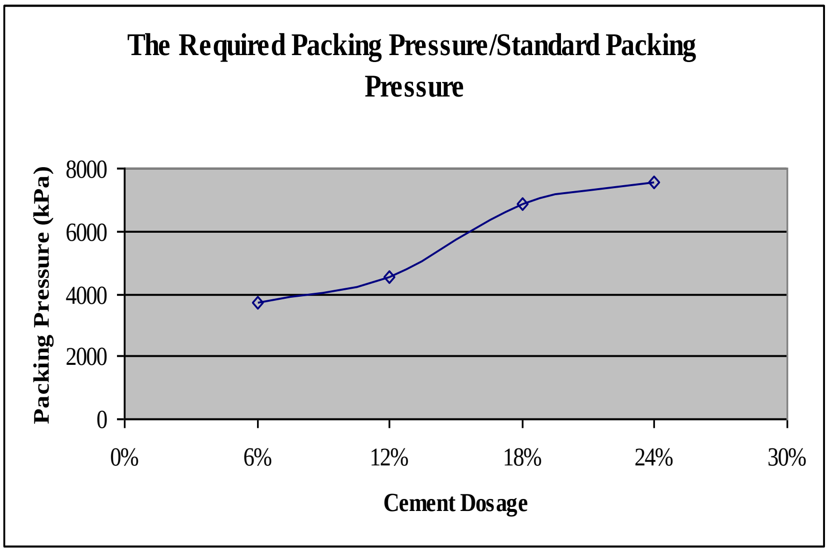

Figure 5. Standard Packing Pressure for Different Dosage of Cement

Samples compacted to SPp were tested for unconfined compression tests for a curing period of 7, 28, and 56 days while samples of the cement column model were tested for UCT for a curing period of 28, 56, 90, and 120 days. Samples compacted to PPp were tested for UCT for a curing period of 7, 28, and 56 days. Since all the samples have UCT results for 28 days and 56 days of curing, the author decided to compare the strength of all the samples for a curing period of 28 days and 56 days. The comparisons are made for 6%, 12%, 18%, and 24% cement dosages. Figure 6 shows the comparison for all dosages of cement at 28 days of curing while Figure 7 illustrates a comparison for 56 days of curing.

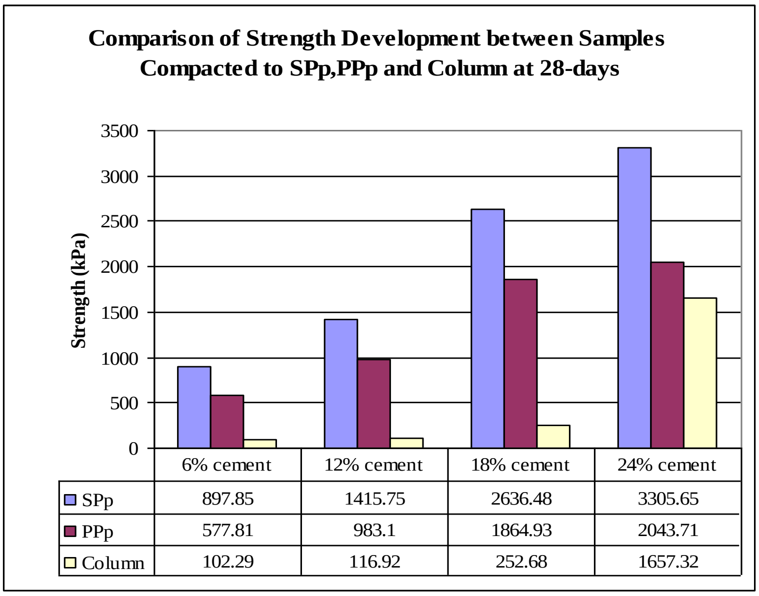

Figure 6. Comparison of Strength between Samples Compacted to SPp and PPp at 28 days

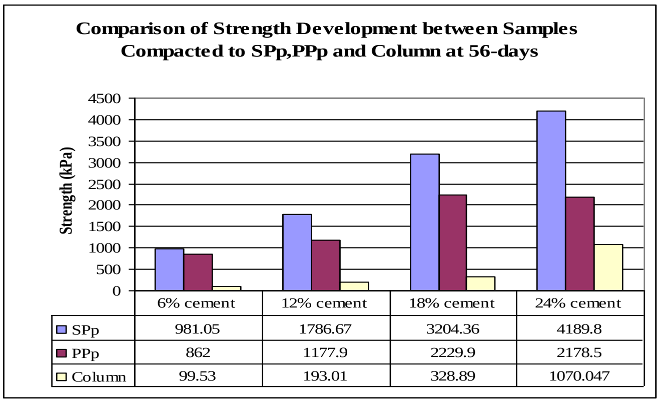

Figure 7. Comparison of Strength between Samples Compacted to SPp and PPp, at 56 days

Electric conductivity tests were also conducted on the samples to investigate the ion migration in the stabilized specimens as time went by. The trends of conductivity value were compared with the strength development for the samples of 6%, 12%, 18%, and 24% cement. Figure 4.4 to Figure 8 shows the trend.

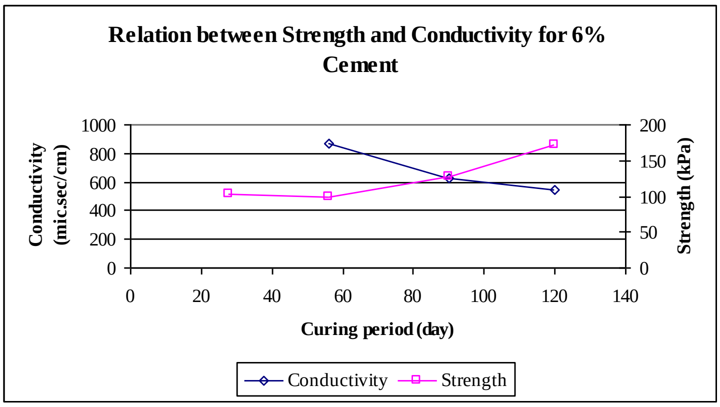

Figure 8. Relationship between Strength Development and Ionic Conductivity for 6% Samples

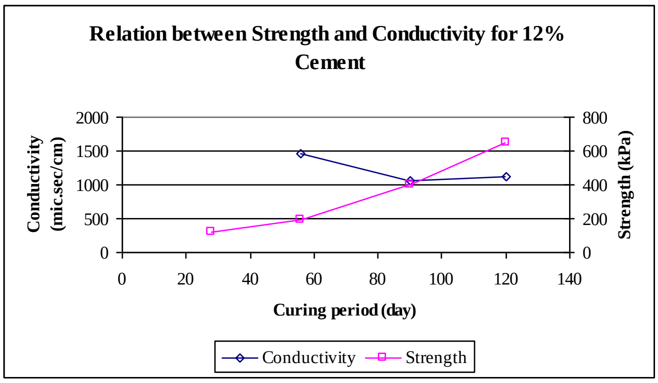

Figure 9. Relationship between Strength Development and Ionic Conductivity for 12% Samples

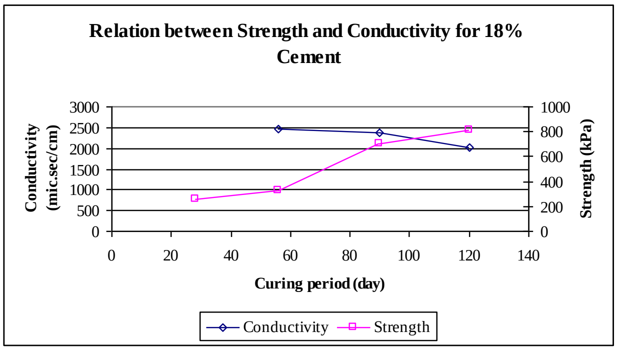

Figure 10. Relationship between Strength Development and Ionic Conductivity for 18% Samples

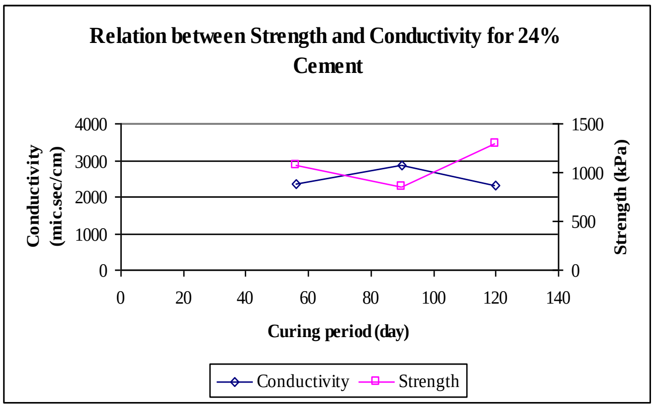

Figure 11. Relationship between Strength Development and Ionic Conductivity for 24% Samples

5. Discussion and Findings

5.1 Static packing pressure

Compaction is crucial for determining the shear strength of stabilized materials in remolded samples. However, there is uncertainty about the extent to which compaction can significantly enhance soil strength. Stabilized kaolinite has been subject to doubts about the mechanical effort involved in preparing samples for unconfined compression testing. Stabilization involves chemical processes, with long-term shear strength enhancement controlled by pozzolanic interactions between lime or cement and clay. The study suggests that relying solely on preparation for unconfined compression testing following BS 1924 is inadequate for accurately forecasting cement-stabilized soil strength. Further research is recommended to examine the impact of static packing pressure on the strength development of different additive dosages in stabilized soils.

5.2 Strength Development

Upon contact with water in the soil, cement undergoes fast hydration, resulting in a rapid increase in strength. Johansson and Janz (2002) reported that around 50% of the cement undergoes reaction after 3 days, around 60% within 7 days, and approximately 90% within 3 months. The author's conclusion from the statement is that the majority of the increase in strength in cement stabilization takes place during the initial phase of the stabilization process. The study revealed that stabilized samples exhibit accelerated strength growth. The rate of strength gain during the initial stage of the curing process has significantly accelerated. The long-term strength development was determined to be insignificantly significant.

Upon evaluating the strength development of three types of samples - those compacted to SPp, compacted to PPp, and the cement column model - it was revealed that compaction and Ionic Conductivity play important roles in the initial strength development.

Flocculation-agglomeration alters the texture of clay soil particles, transforming them from a flexible, fine-grained state to a more granular composition. This phenomenon has been attributed to an increase in the electrolyte content of the pore water and the adsorption of Ca2+ ions during the exchange process (Herzog and Mitchell, 1963). Calcium can also undergo a reaction with alumina, resulting in the formation of calcium aluminate hydrate (CAH), which exhibits cementitious properties. The subsequent responses are as follows:

$$Ca(OH)_2 + SiO_2 \text{ ------ } CSH \qquad [eq1]$$
$$Ca(OH)_2 + Al2O_3 \text{ ------ } CAH \qquad [eq2]$$

The formation of cementing materials (CSH and CAH) may require solubilization of silica and alumina from soil components. An electrical conductivity test is used to examine the electrochemical characteristics of altered clay and predict the interaction between additive and clay. Strong electrolytes undergo complete ionization in modified clay sample solutions, while weak electrolytes undergo partial ionization. The ionic conductivity test or electric conductivity test can be a useful supplementary method for assessing strength development in cement-stabilized soil, demonstrating the importance of understanding the physics and chemistry of soft clay treatment.

6. Conclusions

a) The study reveals that increasing additive amounts necessitates a higher packing pressure for samples, suggesting that using the packing pressure concept as a supplementary testing method could enhance the British Standard.
b) The author found that strength enhancement in cement-stabilized soil depends on additive quantity, packing pressure, and clay mineral concentration. Despite aiming to eliminate packing pressure, a 50% predetermined packing pressure was used. Decreased packing pressure reduced samples' strength, indicating both standard and predetermined pressures impact initial strength development.
c) Samples with 6% and 18% cement percentages compacted to SPp showed a tenfold increase in strength compared to the cement column model.
d) The author found that reducing packing pressure by 50% significantly improved the strength of samples compacted to PPp and the cement column model after 56 days of curing.
e) The study shows that long-term pozzolanic reactions within stabilized kaolinite increase undrained shear strength, resulting in lower conductivity.

6.2 Recommendations

The study found that static packing pressure significantly impacts the strength development of laboratory-prepared specimens, with an increase in cement quantity causing a corresponding increase in necessary packing pressure. Further research is needed to explore the impact of static packing pressure on remolded samples. The study also revealed a relation between conductivity value and strength growth, suggesting that predicting field strength using undrained shear strength of saturated stabilized soil samples after 90 days is more reliable.

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