Improvement in engineering properties of soft-soil using cement and lime additives: A case study of southern Vietnam

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Abstract. This paper presents the experimental results of using two additives to improve natural soft soil properties in southern Vietnam (i.e., cement and cement-lime mixture). The specimens were prepared by compacting method. Firstly, the natural soil was mixed with cement or cement-lime to determine the optimum water contents of various additive contents. Then, optimum water content was used to produce samples to test some engineering properties such as unconfined compressive strength, splitting tensile strength, and Young’s modulus. The specimens were tested by various curing duration of 7, 14, and 28 days. Results indicated that using cement additive is suitable for improvement of soft soil in the local area and cement-soil stabilization can be replaced as the subbase layer of the flexible pavement according to current Vietnamese standard. In addition, a higher cement content has a greater compressive strength as well as tensile strength. Besides, the Young’s modulus has significantly increased with a long-term curing age and more cement content. No evidences of increasing in strength and modulus are found with the cement-lime-soil stabilization. Finally, the best-fit power function is established by the relationships between unconfined compressive strength and splitting tensile strength as well unconfined compressive strength and Young’s Modulus, with the coefficient of determination, $R^2>0.999$.

1. Introduction
The Mekong Delta is the region in Southern Vietnam; it has a total of approximately 39,734 km², of which 12 % is in Vietnam. The surface is low elevation, mainly from 0 to 4m above the mean sea level. Recently, certain studies have revealed that the Mekong delta was mainly covered by Holocene deposits due to the increase and decrease in sea level at the age from 20,000 to 4,000 years before present [1]. Therefore, soft soil is widely and deeply distributed in this region. The soft clay deposit is found from the surface to a depth varying from 10 m at Long An in the north to 50 m at Can Tho and approximately 20 m at Ca Mau in the South [2]. Actually, Mekong delta is also one of the biggest economical centrals in Vietnam. The infrastructure of this area remarkably is developed in recent years such as road, bridge, dam, industrial zone. Generally, any structure laid on soil is generally sustained to settlement, inclined settlement. But for soft soil, the settlement is more significant and greater. Excessive settlement is tipped to cause big problems as it often exceeds the permissible limits [3]. In fact, some constructions were unsafe as building on such soil condition such as settlement, inclined settlement, and disruption. Therefore, it is essential to find out a solution for treating the soft soil condition to ensure a good foundation design against failure as well as differential settlements.
Over the past five decades, many soil improvement techniques have been considered and employed in practice, including mechanical stabilization, stabilization using soft aggregates, bituminous stabilization, lime stabilization, cement stabilization, thermal stabilization, chemical stabilization, and electric stabilization. Various admixtures such as cement, fly ash, lime, blast-furnace slag cement, calcium chloride were used in different areas on the world [4]. Particularly, in among them, cement and/or lime soil stabilizations were known as well-known methods and most widely used. Compared to pure soils, soil stabilization has more advantages such as low compressibility, high compressive strength, and its cost efficiency. Al-Rawas et al. (2005) [5] indicated that lime, cement and an artificial pozzolan can reduce significantly the swelling potential. Kavak and Akyarlı (2007) [6] used lime to increased CBR from 16 and 21 times compared to initial soaked values for green and brown clays. Due to these significant advantages. It is very essential to fully find the mechanical behavior of soil stabilization to satisfy various requirements in the field. So far, the current criterion to evaluate the mechanical behavior of soil stabilization mainly focuses upon such parameters as unconfined compressive strength, internal friction angle, and cohesion, and ignores the important role of curing stress. In general, based on the previous results, some conclusions were drawn such as when cement content increased, liquid limit decreased, shear strength parameters increased with cement content; unconfined compressive strength (UCS) and isotropic compressive strength remarkably increased with the increase in curing time, UCS significantly increases as vertical stress increases.

In Vietnam, although additives have popularly been used in practice, there were no obvious reports on the strength of using these additives in laboratory as well as in the field. The present study is addressed toward employing the different additives for improving the soft soil condition. Soil stabilization was conducted by different additives including Portland cement Blended and/or lime. The unconfined compressive strength (UCS), splitting tensile strength (STS), and Young’s modulus of soil stabilization was tested. The results of study elucidated some engineering properties, some correlations from obtained data are established. The findings derived from this result are expected to contribute deeply the understanding the usage of additive as well as to meet the requirements of further design and construction purposes in the studied area and the Mekong Delta region.

2. Materials used

2.1. Natural soil

The excavated soil was collected from Vung Liem District, Vinh Long Province, located in the Mekong Delta, Southern Vietnam. Once the location has been located, the soil sample was collected from three trial pits that had been excavated to a depth of 0.5 to 1.0 m. Nearly 150 kg of natural soil was taken from these pits for this experimental program. The collected specimen was stored in a plastic bag to remain the natural moisture conditions. The basic properties of soft soil included such items as specific gravity, water content, unit weight, Atterberg limits, grain-size distribution were determined during the testing process and measured by following American Society of Testing Materials (ASTM) Standard D854, D2216, D4318, D421 and D422, respectively. Basic physical properties of samples are presented in Table 1. The grain-size distribution is plotted in Figure 1.

| Basic properties               | Tested value |
|-------------------------------|--------------|
| Specific gravity, Gs          | 2.60         |
| Moisture content, %           | 35.15        |
| Dry unit weight, kN/m³        | 13.04        |
| Liquid limit, LL, %           | 46.12        |
| Plastic limit, PL, %          | 25.45        |
Plasticity index, PI, % 20.67

The consistency limits tests shows that the liquid limit (LL), plastic limit (PL), and plasticity index (PI) are 46.12 %, 25.45 % and 20.67 %, respectively. Based on ASTM D2487 classification system, the sample is classified as low plasticity organic clay (CL). According to the current design specification of Vietnam (22 TCN 211-06), the soil listed in Table 1 is soft soil and must be improved before building highway structures.

![Figure 1. Grain size distribution of soft soil](image)

2.2. Additives used
The additives used for the stabilization of soft soil are commercially available Portland cement blended and hydrated lime. Portland cement Blended is produced by mixing Ordinary Portland Cement (OPC) and mineral admixtures such as fly ash, slag, or silica fumes. PCB is now being used more popular than OPC in Vietnam due to some technical and environmental advantages. For example, the PCB significantly reduces water demand and water-cement ratio. The PCB is finer than OPC, and therefore the permeability of concrete is less and the result is to improve workability and durability. Furthermore, the manufacturing process of PCB save energy and reduce the precious minerals like limestone, clay, and silica due to using the waste products of thermal and steel plants. PCB is the most common stabilizer in treating the soft soil condition. The basic properties of PCB 40 are tabulated in Tables 2.

| Table 2. Basic properties of PCB 40 |
|-------------------------------------|
| Basic properties | Tested value |
| Compressive strength, MPa, 28 days | 45.00 |
| Setting time, min. | |
| Initial | 120 |
| Final | 205 |
| Fineness, cm²/g | 4050 |
| Specific gravity | 3.15 |

Quicklime is used in this study. The basic chemical properties can be found more than 85% of Calcium oxide, and the percentage passing of a 0.075m sieve is more than 90 %.

3. Specimen preparation
The disturbed soil specimens were dried for a duration of 24h and then pulverized using a wooden hammer. The pulverized soil was then completely dried by placing it in a drying oven at the
temperature of 100 ± 5°C. The dry specimen was sieved through a 5.00 mm sieve to obtain a uniform soil mixture. The dry soil specimen was uniformly mixed with the predetermined percent of the additive. The first set was mixed with cement at 8%, 10% and 12% by dry weight and the other set was mixed with cement-lime at 8% cement + 2% lime, 8% cement + 4% lime, 8% cement + 6% lime by dry weight of soil. The soil-cement and soil-cement-lime mixtures were mixed at optimum moisture content to obtain homogeneous mixtures. All specimens were cured at room temperature (27 ± 0°C) and relative humidity 90% for durations varying from 7, 17, 28 days. Thereafter, the specimens were placed in airtight plastic bag to maintain the test environment. For each content of the additive, nine specimens were prepared for each mixture corresponding to the durations varying from 7, 14, 28 days. The obtained data are in mean value of three specimens. The optimum water content is determined by the Standard Proctor compaction test. Table 3 summarizes mix proportions for the experimental program. Figure 2 presents some typical equipments in this study, including compaction, UCS, STS, and Young’s modulus tests.

Table 3. Mix proportions

| Mix code | Cement (%) | Lime (%) | Soil (%) | Water / (Additive +soil) (%) |
|----------|------------|----------|----------|-------------------------------|
| 1        | 0          | 0        | 100      | 11.40                         |
| 2        | 8          | 0        | 92       | 11.10                         |
| 3        | 10         | 0        | 90       | 10.90                         |
| 4        | 12         | 0        | 88       | 10.80                         |
| 5        | 8          | 2        | 90       | 10.90                         |
| 6        | 8          | 4        | 88       | 11.00                         |
| 7        | 8          | 6        | 96       | 11.20                         |

Figure 2. (a) Unconfined compressive test; (b) Splitting tensile test; (c) Young’s modulus test

4. Results and discussion

4.1. Compaction characteristics (UCS)

The variations in optimum moisture content (OMC) and maximum dry density (MDD) for various cement and lime-cement contents are plotted in Figure 3. It is clear that a decrease in MDD for cement-soil stabilization is obtained from 1.886 g/cm³ to 1.839 g/cm³; while for cement-lime-soil
stabilization is to be decreased from 1.869 g/cm³ to 1.861 g/cm³. However, the decrease in MDD of lime-cement treated soil is insignificant. The OMC of cement-soil stabilization increases from 10.7% to 11.1%, while in the case of cement-lime treated soil increases from 10.9% to 11.2%. The decrease in MDD can be attributed to the chemical reactions that play a role in reducing the density of the cement or lime mixtures. Additionally, the addition of stabilizers leads to an increase in the specific surface area of the mixture which thereby increases the OMC. The cation exchange reaction further intensifies the increase in OMC since the reaction utilizes higher amount of water to mobilize the Ca²⁺ ions that are introduced into the mixture by the stabilizers. The similar type of observations have been reported by other researchers [7].

![Graph showing MDD and OMC content](image)

**Figure 3.** Compaction characteristics

### 4.2. Unconfined compressive strength (UCS)

The UCS obtained for all the mixing ratios can be plotted in Figure 4. This figure shows the effect of curing time on the unconfined compressive strength. In general, a cement-soil mixture increases the compressive strength when cement content increases. Adding 12% cement increases UCS from 3.94 MPa to 5.18 MPa, for the specimens have been cured for a duration of 28 days. The specimen improves the strength at long-term curing age. The strength development is thought as the calcium silicate hydrates (C-S-H) are established as the cement content is hydrated. As cement content increases, C-S-H gels form in greater amounts, increasing the compressive strength [8]. As expected, this behavior is also true for three cement contents. However, considering lime-cement treated soil, the
compressive strength increases until 4% lime is added, then it slowly decreased with a further increasing in lime content. According to current Vietnamese Specification [9], 8% cement or more content can be substituted for crushed aggregate using in subbase layer of flexible pavement.

A comparative analysis between the effect of lime and cement suggests that the UCS of cement-soil stabilization is higher than the cement-lime stabilization. The reduction of strength is more prominent in the case of lime-blended soil as compared to soil-cement mixture. An increase in the addition of stabilizers does not favour the pozzolanic reaction. The phenomenon of decrease of UCS on the addition of large quantity of additives is more prominent in the case of lime [7].

4.3. Splitting tensile strength (STS)

The splitting tensile strength, mean value of three specimens, of different stabilized mixtures cured for 7-, 14-, 28-day are summarized in Figure 5. All cylindrical groups have the STS for curing age of 7-, 14-, 28-day in a range of 0.13-0.35 MPa, 0.16-0.51 MPa, and 0.21-0.55 MPa, respectively. In general, a longer age of curing is greater STS because of cemented-hydration. For instance, 28-day STS is 0.55, 0.37, and 0.21 MPa for 1-, 2-, 3-soil stabilization at curing age of 28-day, respectively. Accordingly, the closed relationship between the additive content and splitting strength of soil
stabilization is realized such as the higher content of used additive, as shown in Figure 5, yields greater STS of soil stabilization. Similar to UCS, STS of cement-lime-soil stabilizations generally show the decreasing tendency when the lime content increases from 4% to 6%. This is likely because more lime is expected to reduce the reaction of C-H-S, and the result is to decrease the STS.

4.4. Young’s modulus, $E$

Figure 6 presents the result of Young’s modulus of soil stabilization with different additives at various curing duration of 7-, 14-, 28-day. The data presented in this figure are defined by the ratio of compressive stress and strain. As shown in this figure, the Young’s modulus increases with the increasing in curing age and additive content. In general, when lime is added to the mixture, the Young’s modulus slowly increases until the lime content reaches 4%, then it slowly decreases with the more lime content. In addition, cement-soil stabilization has larger Young’s modulus than other cement-lime stabilizations.

![Figure 6](image)

**Figure 6.** Young’s modulus: (1) 8%C; (2) 10%C; (3) 12%C; (4) 8%C+2%L; (5) 8%C+4%L; 8%C+12%L

4.5. Correlations from obtained data.

![Figure 7](image)

**Figure 7.** Relationships between Unconfined compressive Strength and Splitting Tensile Strength

The closed relationships between UCS and STS were realized, as plotted in Figure 7, higher UCS yields greater STS of soil stabilization. Also, there are best-fit power functions displayed the
relationship between UCS and STS \((R^2 \geq 0.99)\). The results are suitable for three ages of 7-, 14-, 28-day.

![Relationships between Unconfined Compressive Strength and Young’s Modulus](image)

**Figure 8.** Relationships between Unconfined Compressive Strength and Young’s Modulus

In practice, Young’s modulus is usually employed to calculate the foundation engineering as well as bearing capacity of subgrade. There, it is essential to evaluate Young’s modulus to give how much increase in Young’s Modulus the unconfined compressive strength and answer is plotted in Figure 8. According to the obtained results, it concluded that the Young’s modulus increases with the increase in unconfined compressive strength. Also, there are best-fit power functions displayed the relationship between Young’s Modulus and unconfined compressive strength. Similar to Figure 7, Figure 8 presents relationships between Unconfined Compressive Strength and Young’s Modulus for cement-soil stabilization. Also, there are best-fit power functions displayed the relationship between UCS and STS (coefficient of determination, \(R^2 \geq 0.99\)). The results are suitable for three ages of 7-, 14-, 28-day. Based on the formula presented in Figures 7-8, it is easy to predict the STS and Young’s modulus once UCS is obtained in the laboratory.

5. Conclusions

Based on the obtained data, some potentially important aspects of soil stabilization can be drawn as follows:

- The addition of stabilizers leads to an increase in the specific surface area and chemical reactions of the mixture which thus increase the optimum moisture content and reduce the density of the mixture.
- Portland cement blended can be considered as the suitable additive which can be applied to improve the soft soil condition in the study area. Adding lime content does not show the increasing in strength due to reducing the reaction of C-H-S in the mixture.
- The soil stabilization with the cement content of 8 % or more can be replaced for the subbase layer in flexible pavement design according to the current Vietnamese Specification.
- Some equations for predicting splitting tensile strength and Young’s Modulus development based on unconfined compressive strength have been reasonably established. However, the suggested formula was obtained by limited results tested in the laboratory and they should be further considered and corrected in the practical uses.

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