MINISTRY OF EDUCATION AND TRAINDING

MINISTRY OF AGRICULTURE AND RURAL DEVELOPMENT

VIET NAM ACADEMY FOR WATER RESOURCES

VU NGOC BINH

STUDY OF THE EFFECT OF CONSTRUCTION CHARACTERISTICS OF SOFT CLAY SOILS IN THE MEKONG RIVER DELTA ON THE QUALITY OF GROUND IMPROVEMENT BY CEMENT COMBINED WITH ADDITIVES IN BUILDING CONSTRUCTION

SPECIALIZATION: GEOTECHNICAL ENGINEERING
CODE: 62 58 02 11

SUMMARY OF DOCTORAL THESIS

HA NOI, 2018

This work has been completed at:

VIETNAM ACADEMY FOR WATER RESOURCES

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The thesis is defended against State level thesis assessment council in Vietnam Academy for Water Resources No. 171 Tay Son Street, Dong Da Dist., Hanoi. At……..hour, on……., 2018

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PREFACE

1. The urgency of the topic

The Mekong river Delta (MRD) has low-lying topography, almost all surface of the MRD is covered by young sedimentary of Holocene age, with a large thickness (about 20m), different components and origins, most of them are soft soils [8], [15]. The issue of constructing works in the area in order to develop the economic infrastructure, prevent floods and landslides ... has been concerned by the Party, State and localities. However, the construction of these works are facing many difficulties due to complex of geological structure, distribution of many types of soft soils located on the surface, with the large thickness. Moreover, in MRD, the search for material mines for embankment and other material when construction is very difficult, most of them have to use local materials, therefore when constructing works needs soft soil improvement. One of the methods that have been applied is to improve soft soils by cement. This method has been applied in a number of projects in the region and has brought about economic efficiency, reduced cost compared with other methods, used local materials, replaced reinforced concrete piles, ... Thus, the potential use of cement treatment in MRD is huge. However, in the projects, experimental results are produced only, not yet available or have not yet been fully researched and the system of factors influencing on the construction characteristics of the soil to the quality of the soft after reinforcement especially the characteristics of the components like: grains, minerals, chemicals, organic, pH of the environment, salt, alum in the soil, adoption and exchange of the cation, ... Therefore, the efficiency of the treatment method is not high. While, according to Vietnam geographic Atlat, in MRD, the group of acidity and saline soils occupy more than 60% of the area, and have often organic in the soil. Therefore, the topic: *"Study of the effect of construction characteristics of soft clay soils in the Mekong river Delta on the quality of ground improvement by cement combined with additives in building construction"* is highly urgent, practical, and modern.

2. Purpose of the thesis

- Clarify the effect of construction characteristics, especially the characteristics of soil composition on soil quality reinforced with cement;

- Study and propose measures to improve the efficiency of cement reinforcement methods in combination with additives to improve soil with high organic content (peat) and saline soils (salty to very salty) in MRD.

3. Subjects and scope of research

- Research subjects: soft clay soils are common in the Mekong river delta, distributed in the depth of less than 20m, with expectation of the full thickness of soft soil layer in order to improve them with cement for the construction of medium-sized structures such as dykes, embankments, small culverts, infrastructure works, industrial buildings and residential low floors.

- Scope of study: Construction properties such as composition (grains, minerals, chemicals, saline, alum, organic, pH, cation exchange) of soil affecting on reinforced quality with cement and cement with additives.

4. Missions of thesis

- Clarification of distribution characteristics, physical - mechanical characteristics and compositional characteristics of soft clay soils in MRD;

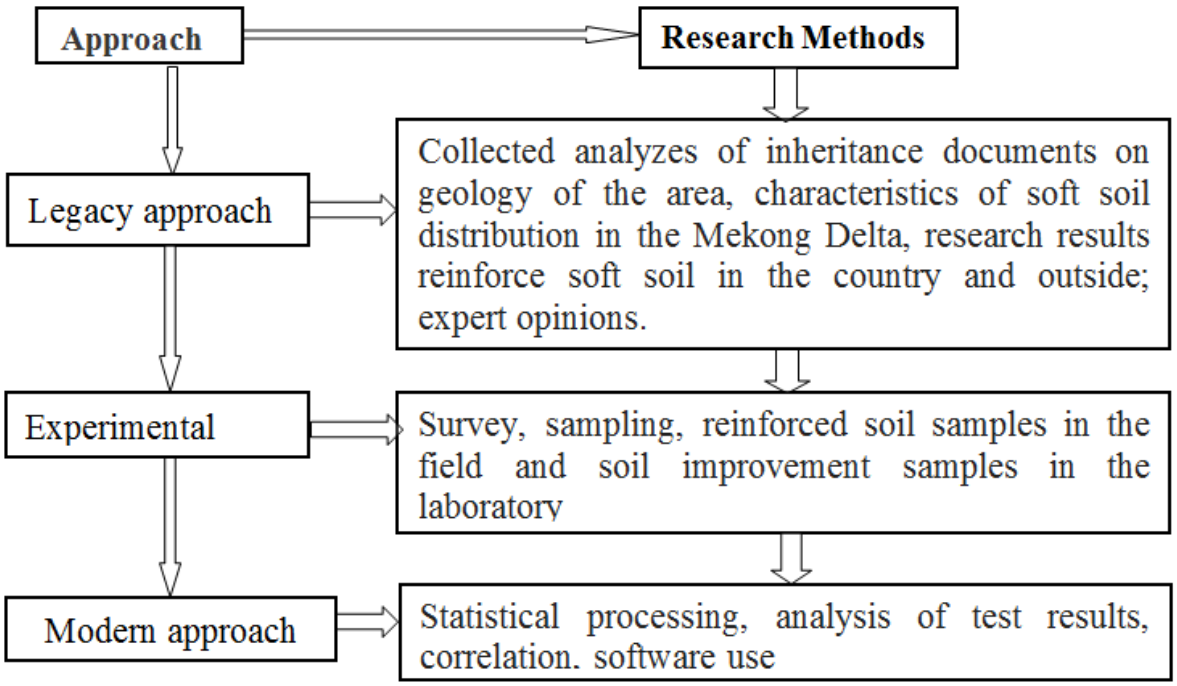
- Evaluation of salt, alum, organic content, cation exchange, compositional characteristics and their effect on reinfoced soil quality.

- Proposed solutions to improve the effectiveness of reinforcement methods.

5. Research contents

1. Overview of soft soil reinforcement by cement and cement with additives, that clarify the effect of construction characteristics on the reinforced soil quality;
2. Study of the distribution characteristics, composition of the soft clay soils distributed in MRD;
3. Study of the improvement of soft clay soils in MRD to evaluate and analyze the effect of soil component characteristics on reinfoced soil quality;
4. Study of measures to improve the effectiveness of soil reinforcement by cement and additives for saline soils salty to very salty and peat.

6. Approach and study methodology



7. Protect argument

Argument 1:

Based on the influence of construction characteristics on reinforced soil quality by cement. The soft clay soils in MRD are classified into three groups:

- Group 1: Advantage;
- Group 2: Less advantage;
- Group 3: Disadvantage.

Argument 2:

Whith soil group 3 and sub-group 2b, the proposed additive has the effect on increasing the strength, stability in curing time. The research results show that with 2% of gypsum, rovo of from 1.0% to 1.5%, lime of 4% and liquid sodium silicate of 0.5% is best. If the content of salt in the soil is high, then it is recommended to use cement that contains calcium oxide or add 2-4% lime to increase soil strength.

8. The new points of the thesis

- The results of the thesis have evaluated and analysis systematically to clarify the effect of soil construction characteristics on the reinforced soil quality and to classify the soft clay soils in MRD into three soils groups according to the level of advantage conditions for cement soil improvement, they are advantage, less advantage and disadvantage.

- Suggested solutions to improve the efficiency of soil improvement of clay mud infected by salt at from salty to very salty level (sub - group 2b) and peat soil (group 3) by cement combined with additives to increase strength of them.

9. Scientific and practical significance

1. Results of the thesis have contributed to the soil research methodology for construction in the area; Initially, they clarify the general rule on the change of construction characteristics of some common soft clay soils in MRD; They also are added to the research achievements in the laboratory and field in the improvement of soft clay soils by cement and cement with additives in MRD.

2. The research results are the scientific basis for use them as a reference, orientation for surveying, designing, treating soft soil by cement and ground treatment measures when encountering especial soft soil for the construction of small and medium works in MRD. The thesis can also be used to the design of soil improvement in the similar soft soil conditions areas.

10. Database of the thesis

The thesis is completed on the basis of the study of the author for many years, author taked samples and studied the characteristics of the soft clay soils in the provinces: An Giang, Hau Giang, Kien Giang, Tien Giang, Bac Lieu and Ca Mau;

author also prepared and compressed unconfined laboratory samples and field samples to determine the compressive strength, deformation modulus, tensile strength (total number of

over 3600 samples, of which 510 samples were obtained from the reinforced pile in Kien Giang and Hau Giang provinces). In addition, the thesis has used the main content of soil belonging to research project of Ministry and a elementary level research project done by author.

11. Structure of the thesis

The thesis includes the introductory and conclusion part and 4 chapters illustrated with 40 table, 73 drawings and graphs, annexes of experimental results, 12 published research papers and 76 references.

CHAPTER 1: OVERVIEW OF RESEARCHS ON IMPROVING SOFT SOIL BY CEMENT, EFFECT OF SOIL CONSTRUCTION CHARACTERISTICS ON REINFORCEMENT QUALITY

1.1. OVERVIEW OF RESEARCH ON IMPROVING SOFT SOIL BY CEMENT

1.1.1. Soft soils

Soft soils have small load bearing capacity (about 50-100kPa), large compressive properties, almost water saturation, large void ratio (e> 1), small young's modulus (E <5000 kPa) [9], [37]. These soils include clay, sandy clay with soft state to very soft, clay mud, sandy clay mud mixed with organic or not and peat. The soils have a moisture content equal to or greater than the moisture content of the liquid limit and large void ratio (clay e> 1.5, sandy clay e> 1.0), undrained water cohesion less than 15kPa, $\varphi_u = 0$, consistency B> 0.5 [9].

1.1.2. Soft ground

Soft ground is in the influence range of works, it has distribution of soil layers with soft construction characteristics that need to be reinforced when building works.

Methods are applied to improve soft ground for works, in wich the improvement method by cement mixed inplace soft soil is one of the method increasing the bearing capacity, reducing hydraulic permeability, deformation, ...suitable to the demand for ground of works.

1.1.3. Inorganic binders and their role in soil improvement

Inorganic binders (lime and cement) are fine-grained substances, when they are mixed with water or other solvents, then this mixture will form a flexible mixture, and happen the hardening process and become hard state and developed strength [12].

During the process of hydrolysis, inorganic binders are able to bind the bulk material into a solid block. Inorganic binders mixed with soil will happen complicated chemical and physical processes. The result changes the nature and physical and mechanic properties of the soil [32], [33]. Thanks to the reactions that occur in the soil, new architectural links are formed. The linkages are relatively stable at the same time with the increases of soil density and the reinforced soil strength. These linkages make the permeability of soil decreases, also does not swell, shrink and disintegrate.

1.1.4. Studies of soil improvement by cement and cement with additives

1.1.4.1. Overview on research and application in the world

In the world, in Sweden and Finland, soil improvement research has been done on cement, cement and lime in the 1960s and 1970s; in the United States, in 1954, Prepakt Co developed in-place mixture method and used single drilling pile and continued studyding in the 1960s (Jasperse and Ryan, 1992) [10].

In Asia, since the 1960s, Japan researched and developed the soil improvement technology by mixing lime and cement. In 1974, Dry Lime Mixing technology (DLM) was applied throughout Japan and Southeast Asia. Wet mixing technology using cement (CDM) was born in 1975. Dry Mixing Technology (DJM) began in 1976 and was tested in 1980 by the Japanese Public Works Research Institute and Construction Machinery Research insitute. Since then, there has been a lot of research into equipment and technology. Among them are Jerashi and etc (1985), Suzuki and etc (1988), Kitazume (1996). So far, millions of cubic meters of cement have been used for soil improvement.

1.1.4.2. Research and application in Vietnam

In Vietnam, soft soil improvement with cement and lime has been studied since 1967 by the Hanoi University of Technology, Institute of transport Engineering (1970). Institute of Civil Engineering (1980) conducted a more detailed study of the subject *"Reinforcement of soft soil by method of soil – lime pile, soil - cement pile and vertical drained equipment.* The subject was accepted in 1985 [35].

Ho Chat (1985) [35] studied *"the possibility of reinforcing the soil with inorganic binder in Vietnam condition"* and analysed the applicability of the method for different soil types basing on particle sizes and some effects when applied such as soil type, binder ratio, curing time and stabilization of reinforcing soil; Ta Duc Thinh (2002) provided a theoretical basis for the soft ground reinforcement method by using cement-lime piles [21], the author proposed the use of cement amount from 7.5 % to 10 % and lime a mount from 7 % to 9 %; Do Minh Toan (2011) studied the improvement of soil by cement in Tra Vinh, Can Tho, Dong Thap and Tien Giang with content of from 3 % to 12 % of dry soil mass and lime from 6 % to 12 %. The results showed that the soil treated with cement had higher compressive strength than that when compared with soil reinforced with lime, the compressive strength of sandy clay was higher than that of clay. When the lime content is greater than 9 %, the sample compressive strength decreases [31].

1.1.4.3. Studies of using inorganic binders with additives

1.1.4.3.1. Additive concept in construction

Construction additives are produced to increase the effectiveness of binders, improve the technique of the binder [12], including the types: Active mineral additives, full fill additives (inert additives), surface active additives,…In soil improvement with inorganic binder, the use purpose additives is to increase the efficiency of reinfocement methods, increase the strength and stability and reduce permeability.

1.1.4.3.2. Studies of soil improvement by cement with additives in foreign countries

Hossein Moayedi, Bujang B K Huat in Malaysia and Sina Kazemian in Iran [64] used liquid sodium silicate (Na_2SiO_3) concentration of 3mol/l in organic soil stabilization; Huie Chen and Qing Wang (China) [65], have studied the improvement of organic soil using sodium sulfate (Na_2SO_4), sodium chloride (NaCl) and triethanolamine additives at the ratio of 2 %; 0.5 % and 0.05% of cement; the Calcium Sulphate ($CaSO_4$) ratio of 2.55% of cement; Aluminum sulfate $Al_2(SO_4)_3$ ratio of 2.55% of cement; Roslan Hashim. Md, Shahidul Islam (Malaysia) studied the compressive and shear strength of the peat with the content of over 85% of organic content in Klang Peninsular [73], the soil was improved by cement content of 300kg/m^3, bentonite (X/B = 85/15), sand 25% of the soil and $CaCl_2.2H_2O$ of 4% of cement.

1.1.4.3.3. Studies to improve soil by cement with additives in Vietnam

Nguyen Thi Tham, Do Minh Toan (2008) [24], studied the soil improvement by mixing cement with rice husk ash additive in clay *am*Q_2^{2-3} in Can Tho and found that, Đ+ 7% XM + 5% T + 2% V mixture reveals best performance in both compressive strength and young's modulus; Trinh Thi Hue (2009) [14] studied the improvement of clay mud and sandy clay mud origined (*am*Q_2) in Tra Vinh by mixing cement at the ratio of 3 %, 6 %, 9 %, 12% and lime at the ratio of 6%, 9 %, 12%. The results showed that the compressive strength of the cement mixing soil increased proportionally with the content of cement and the compressive strength of the sandy clay mud is higher than that of mud clay. The sample strength at 9% the lime mixing sample gives the optimal value.

1.2. RESEARCH INTO EFFECT OF THE SOIL CONSTRUCTION CHARACTERISTICS ON QUALITY OF REINFORCED SOIL

1.2.1. Studies of the effect of component characteristics on the quality of reinforced soil in the world

In the world, there have been studies of the effect of component characteristics on soil quality of reinforced soil: V.M. Bezruk and Elenovitr (1969) studied the effect of particle sizes and divided soil into 4 soil groups basing on the advantages of reinforcing by cement [2], such as: the most advantageous, advantageous, less advantageous and disadvantageous. Samovilov. T.G, Bezruk. V.M. have investigated the effect of salt content and the results have shown that [2], chloride salts content (NaCl, $CaCl_2$, $MgCl_2$) of less than 5 % have a good effect; 5 ÷ 10% will reduce the strength of soil – cement; the carbonate content ($Na2CO_3$) of from 0.5 % to 1% does not adversely affect on the soil strength reinforced by cement; Sodium sulfate content (Na_2SO_4) of less than 1% will increases the hydration process, when the content of from 1 % to 3% can still use cement to strengthen and the strength of the cement is still guaranteed. When Na_2SO_4 content more than 3 %, this reinforcement method is not effective. Samôilov. V.G (1950), Bezruk. V. M and Liubimôva. T. IU (1956-1959) studied the effect of minerals on reinforced soil and divided this effect into 4 groups [2]: the most advantageous, advantageous, less advantageous and disadvantageous. Mohd Yunus. N. Z, Wanatowski. D and Stace L. R (2009) studied the effect of humic acid on soil quality, the results showed that the lime content used for reinforcing soil of 5 % reveal the best compressive strength. However, when the compressive strength of the soil without humic acid increased, and in case with the humic acid, then sample

strength decreased in curing time. The study results of the effect of pH showed that pH less than 7 always had a negative effect on the cohesion and hardening process of the reinforced soil [2]; pH more than 7 will increase the process of forming more stable architectural links, creating cohesion and structure in soil - cement. Bezruk. V. M (1971) showed that pH <12.1 had negative effect on soil-cement hardening process, low pH will inhibits cement hydration process and puzzolanic reactions, pH equal to 12÷13 facilitates the hardening process [21].

1.2.2. Studies of the effect of component characteristics on rienforced soil quality in Vietnam

Do Minh Toan (1993) studied the effect of organic matter and soluble salts in soil on the effectiveness of reinforcement methods [25], [27] for clay *mb*Q_2^3 distributed in the north sea coast by the cement shallow and deep mixing method in the laboratory [32]; Pham Minh Tuan (2001) [35] studied the effect of organic content on clay soft soil with organic of Thai Binh and Hai Hung formation in Hanoi; Nguyen Thi Thu Quynh (2010) [22] studied the improvement of clay soils in Ca Mau province by cement of the content of 5 %, 7 %, 10 %, 13 %, 16 %, also the salt content equal to 0.6%; 1,0 %; 1.5 % and 2%, the result found that when the salt content increases, the strength of the reinforced soil sample decreases. When the alum content of the soil increases (pH is small), the strength of the reinforced soil sample decreases. Nguyen Thi Nu, Do Minh Toan (2010) [18] studied the effect of salt content on the reinforcement ability of clay mud soil in Tien Giang and Soc Trang provinces, the results showed that when the salt content increased the unconfined strength (q_u) decreased, when salt content equal to from 0.2 % to 0.8 %, q_u reduces not very much, when the salt content increased by 1 %, q_u dropped sharply.

1.3. CONCLUSION OF CHAPTER 1

Clayey soft soils with large thicknesses, various origins and compositions are relatively common in the Mekong river delta.There were a few projects using the soft soil improvement by cement, which brought economic efficiency in comparion with other solutions such as cost reduction, quick construction. However, the results of soil improvement research have remained some limitations such as not analyzing and evaluating comprehensively the affecting factors on the quality of reinforced soil, especially the characteristics of soil composition such as grain sizes, mineral, chemical, organic content, pH, ability to exchange cations of soil, ... Therefore, the effectiveness of the reinforcement method is not good, many projects had to change the cement content, the other cement and increased the pile content, which result in slow progress, also needed to have to solve the problem,… Thus, the doctoral thesis oriented to study the effect of component characteristics on reinforced soil quality by cement and proposed measures to increase the effectiveness of the method, which is necessary for science and practice and interests people’s attention.

CHAPER 2: STUDY ON COMPONENT CHARACTERISTICS OF SOFT CLAYEY SOILS IN THE MEKONG RIVER DELTA

2.1. FORMATION PROCESS OF CLAYEY SEDIMENTS IN THE MEKONG RIVER DELTA

The Quaternary sediments of the Mekong River Delta are formed through the following periods: The period of upper Pleistocene (Q_1) sedimentary formation is about 1.6 million years; The period of Middle and Lower Pleistocene (Q_1^{1-2}) is about 700 thousand years; The period of late Pleistocene, late part (Q_1^2) is about 125 thousand years; The period of upper-middle Holocene (Q_2^{1-2}) is about 10,000 to 4,500 years; and the period of middle-lower Holocene (Q_2^{2-3}) is about 4,500 years.

2.2. DISTRIBUTION CHARACTERISTICS OF CLAYEY SOILS IN THE MEKONG RIVER DELTA

The results from colected data, documents, investigation reports and boreholes of projects in studied region show that: the soft clayey soils in the studied area are distributed mostly near or at surface with thickness of over 10m to over 20m. The top layer is clay, sandy clay or filled soil with thickness of 0.5m to 1.5m; at some places in An Giang, the thickness of the top layer is from 2.5m to 3.0m. The thickness of the embankment is usually from 1.0m to 1.5 m. It is possible to generalize the stratigraphic distribution of soft clayey soils in the MRD (Figure 2.3).

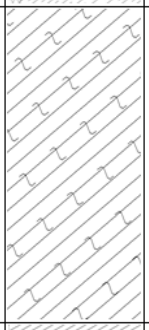
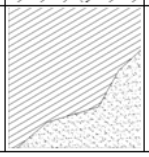
No	Strata	Description
1		Embankment: The soil is firm to stiff with a thickness of 0.7 to 1.5m; the fill soil in place, thickness from 1.0 to 1.5m.
2		Soft soil: The thickness is from over 10m to over 20m, some places up to 30m. Its composition is clay, sandy clay state very soft, clay mud, sandy clay mud,... Soil has many different origins: aluvial- marine (amQ_2^{1-2}; $amQ_2^{2-3}{}_1$; $amQ_2^{2-3}{}_2$; $amQ_2^3{}_1$); aluvial – bog ($abQ_2^3{}_1$; $abQ_2^3{}_2$; $abQ_2^{2-3}{}_2$); marine – bog ($mbQ_2^{2-3}{}_2$; $mbQ_2^3{}_2$), alivial ($aQ_2^3{}_2$), marine ($mQ_2^{2-3}{}_1$; $mQ_2^{2-3}{}_2$; $mQ_2^3{}_2$), ..., In soils usually mix organic, alum, salinity.
3		Clay state stiff to very stiff , sitly sand, sand medium dense to dense in the Hau Giang (mQ_2^2hg), Moc Hoa (amQ_1^3mh) or Long My (mQ_1^3lm) formation.

Figure 2.3: Generalization of stratigraphy of soft soil distribution in the Mekong River Delta

2.3. RESULTS OF RESEARCH ON COMPOSITIONAL CHARACTERISTICS OF SOILS

2.3.1. Location of the studied soil samples

The sampling locations and experimental work are shown in Figure 2.16

2.3.2. Research results of the compositional characteristics and engineering characteristics of the soil

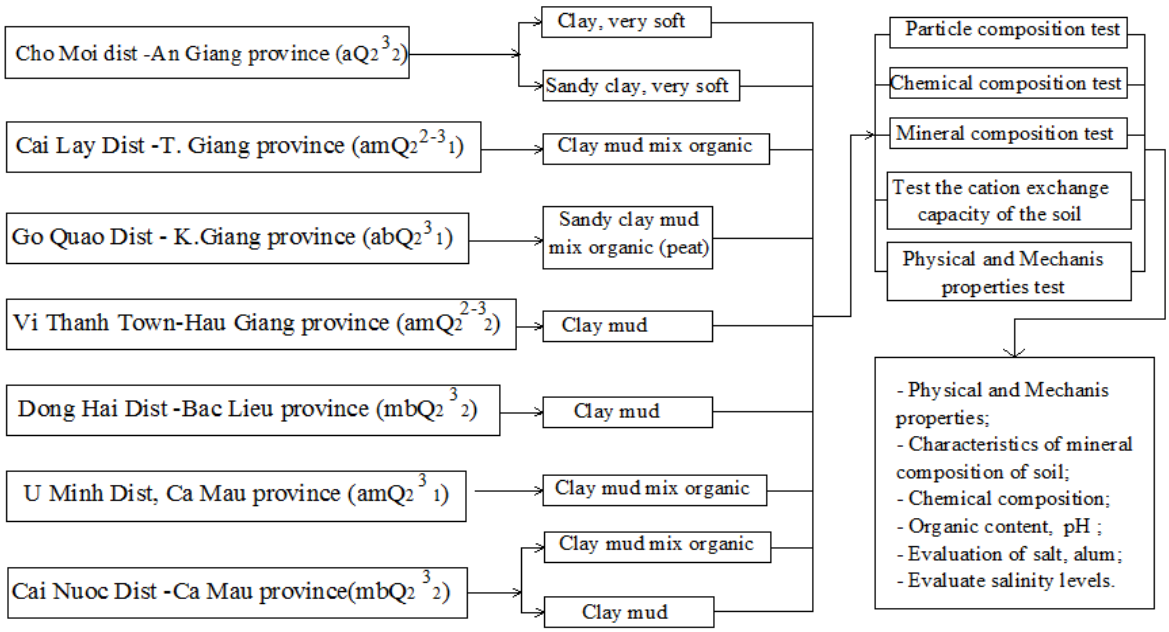


Figure 2.16: Experimental plot of soil composition

The results of this research are as follows: Grading, minerals, chemistry, cation exchange, salt, organic, pH of the medium and the mechanical properties of some common types of soil of different origins, such as soft sandy clay ($aQ_2^3{}_2$) in An Giang, very soft clay ($amQ_2^{2-3}{}_1$) in Tien Giang, peatized soil ($abQ_2^3{}_1$) in Kien Giang, very soft clay ($amQ_2^{2-3}{}_2$) in Hau Giang, very soft clay ($mbQ_2^3{}_2$) in Bac Lieu, Ca Mau and very soft clay ($amQ_2^3{}_1$) in U Minh, Ca Mau, have quantified the above characteristics for each type of soil. Therefore, the Ph.D candidate has evaluated the level of salinity, alum, infection salt, salt level and other soil characteristics

2.4. CONCLUSION OF CHAPPER 2

From the research results, the analysis and assessment of soft soils clay in the Mekong Delta, the author divided studied soils into three groups according to the degree of favorable for soil improvement by cement as follows:

Group 1: Sandy clay is distributed in An Giang, sand content is 61%, silt is 22.5%; clay 16,4%; quartz minerals 47 ÷ 49%, very little montmorilonite, silica oxide (SiO_2 = 68.44%), pH = 5.8, organic content 1.98%, low salt sulfate soil;

Group 2:

- Sub – group 2a: Soft to very soft clay in An Giang and very soft clay in Tien Giang have clay minerals (montmorilonite, ilit and kaolinite) 35 ÷ 43%, quartz from 36 ÷ 40%, silica oxide 57.18 ÷ 59.54%; MKN (9,04 ÷ 11,37%); pH = 5.6-5.7; organic content (2.1 ÷ 2.33%); non-salty soil, sulphate-chloride salts;

- Sub - group 2b: Very soft clay in Hau Giang, Bac Lieu and Ca Mau: clay minerals group 36 ÷ 51%, quartz from 29 ÷ 41%, silica oxide 56.37 ÷ 59.93%, MKN (8.0 ÷ 13.6%), pH = 3.1 ÷ 7.0, organic content (2.67 ÷ 13.39%), saline soil is salty, salty to medium salty, salty to very salty.

Group 3: Peat in Kien Giang, Quartz 23 ÷ 25%, low silica oxide (27.87%), goethite 14-16%, sulfite SO_3 (10.8%), contains pyrite (5 ÷ 7%), pyrophylite 4% and gypsum 15%, pH = 2.1, HLHC 26.56%, MKN 50.05%, Sulphate soils are low, not salty.

CHAPTER 3
RESEARCH ON EFFECTS OF SOFT CLAY'S COMPONENTS IN THE MEKONG DELTA TO STABILIZE SOILS

3.1. RESEARCH METHODOLOGY

To clarify the effects of component's characteristics of soft clay on the quality of soil that is stabilized by cement is a complicated issue. There are two main effect factors, the first is characteristics of natural soil such as: soil type, grain size, physicochemical properties, mineral composition, organic content, pH of soil environment; the second is testing method such as: mixing methods, mixing times, curing conditions, curing times, water/cement ratios, propagating sample methods, testing equipment.

Therefore, to clarify one factor, the other factors must be fixed. There are two approaches:

- Laboratory experiments are carried out for one type of cement and soil samples with variable influencing factors. The advantage of this approach is that it can be implemented theoretically but is less practical.

- Laboratory experiments are carried out for a vast number of cement stabilized soil samples at various curing periods. Soils are collected from different locations and have different origins and components. Many types of cement are used for stabilizing the natural soils. Results of experiment are then analyzed for clarifying the influencing factors. The advantages of this method is that it is consistent with the actual situation and can be applied in construction. However, a relatively large number of samples should be tested for obtaining the reliable results.

Based on above analyses, the second approach was adopted for this study.

3.2. SCIENTIFIC BASIS OF THE METHOD

Mixing soil with cement can create a new sustainable material. Cement acts as a binder and the soil particles are aggregates. The soil contains material components, chemical compositions, dispersed soil particles etc., which will combine with the compositions of cement to create complex chemical reactions. The reaction process includes two periods, which are fixation and solidity period. During the fixation period, the cement mortar gradually loses its plasticity and becomes dense but still has no strength. In the solidity period, hydration processes of the mineral components of clinkers and lime occur. Forming strength of cement treated soils is a complex process, which is effected by many factors and it includes two processes: alkaline and secondary process.

3.3. RESULTS OF RESEARCH ON IMPROVING THE WEAK CLAY OF THE MELKONG DELTA BY CEMENT

3.3.1. The experiment procedure

In this section, the PhD candidate presents the method, standard and implement of experiment as well as the curing condition, sample size, etc.

3.3.2. The chemical characteristics of cement

Results of the chemical components of cements used in the thesis: Tay Do PCB30 (T30), Tay Do PCB40 (T40), Kien Luong PCB40 K40), Ha Tien PCB40 (HT40) and Nghi Son PCB40 (NS40) cement.

3.3.3. Results of research on improving soil by cement

In order to study the capability on improving weak clay by cement in the Mekong Delta, the PhD student has processed and tested the prepared soil samples in Chapter 2 with Tay Do PCB30 (T30); Tay Do PCB40 (T40) and Kien Luong PCB40 (K40). In addition, to evaluate the effects of the components on the quality of soil's improvement, the effect of water/cement ratio, the relation of samples in the laboratory and the field, the PhD candidate tested Nghi Son Cement PCB40 (N40) and Ha Tien PCB40 (HT40). Samples were prepared by wet-mixing method, the cement contents were 250, 300, 350 and 400 kg/m^3, W/C = 1 and maintained under saturated conditions. The samples were tested at the ages of 7, 14, 28, 56, 91 and 180 days old by unconfined compressive strength test. The experimental process can be illustrated as in *Figure 3.6*.

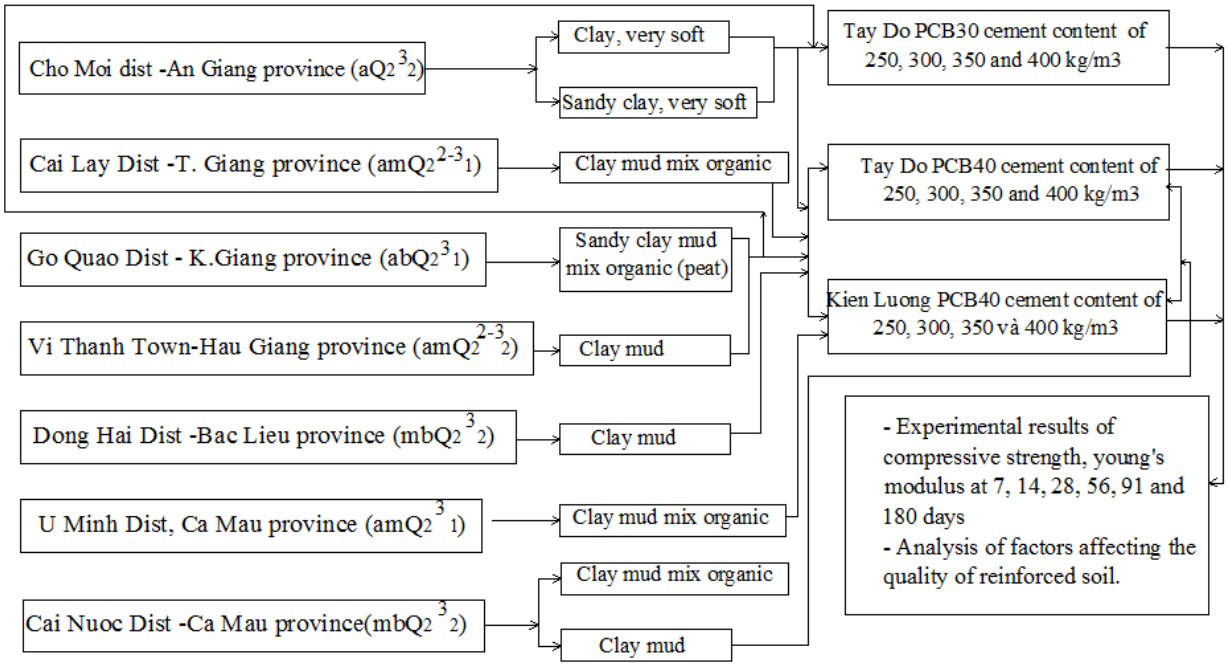


Figure 3.6: Experimental plot of soil reinforced

- *For clay*: sandy clay ($aQ_2^{3}{}_2$) in An Giang (*Figure 3.7*), clay mud ($amQ_2^{2-3}{}_1$) in Tien Giang, muddy clay ($amQ_2^{2-3}{}_2$) in Hau Giang, clay mud ($mbQ_2^{3}{}_2$) in Bac Lieu, Cai Nuoc, Ca Mau, the strength of stabilized cement soil increases with an increase of the curing time.

- For peat soil ($abQ_2^3{}_1$) in Kien Giang (*Figure 3.14*), the compressive strength of the sample increases with an increase of curing time during the period of 7 days to 28 days; however, it deceases significantly after 28 days.

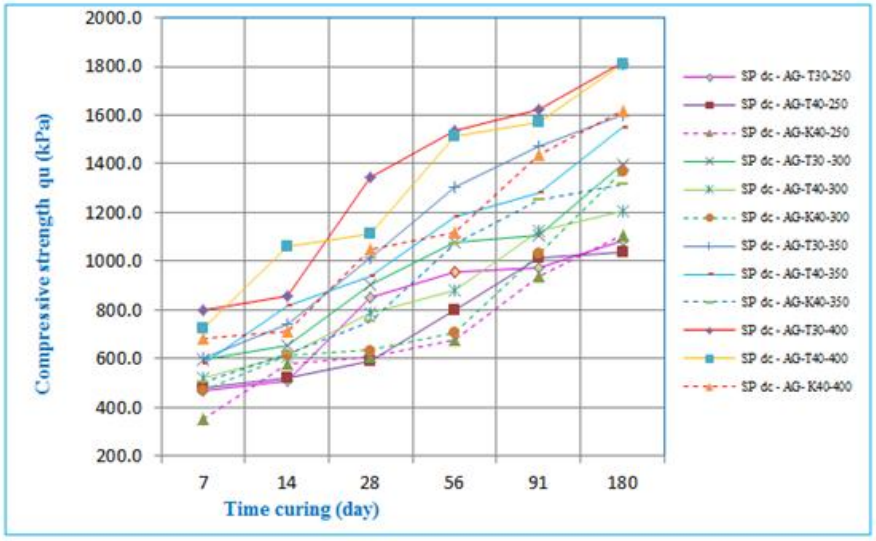


Figure 3.7: Relationship between unconfined compressive strength and curing time of sandy clay $aQ_2^3{}_2$ in An Giang improved by cement

- For sandy clay and clay in An Giang: strength of stabilized soil by cement T30 is higher than that of cements T40 and K40;
- For clay mud in Tien Giang, peat soil in Hau Giang: strength of stabilized soil by cement T40 is better than that of K40
- For clay mud in Hau Giang, Bac Lieu and Ca Mau: strength of stabilized soil by cement K40 is better than that of T40 and T30.

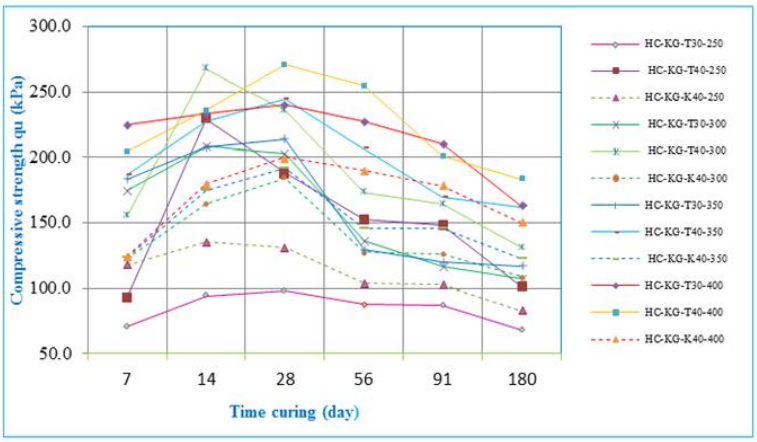


Figure 3.14: Relationship between unconfined compressive strength (q_u) and curing time of peat soil - $abQ_2^3{}_1$ in Kien Giang improved by cement

Thus, for clay in the MRD, in order to strengthen the salty soil, it is better to use the cement which have a higher proportion of CaO (K40) than the cement with less CaO (T40) and vice versa; with less salty or without salt, T30 and T40 cements are more effective than K40

3.3.4. Relationship of compressive strength and curing age

Based on the experimental results of studied soils in the Mekong Delta which were treated by different types of cements: T30, T40 and K40, and with various contents of cement and curing

time; the PhD cadidate summarizes and proposes the relationship between compressive strength and curing age as follow:

Group 1: *Sandy clay at very soft state*

$q_u^7 = (0{,}55 \sim 0{,}81)\, q_u^{28}$ (3.14)

$q_u^{14} = (0{,}60 \sim 0{,}97) q_u^{28}$ (3.15)

$q_u^{56} = (1{,}07 \sim 1{,}42) q_u^{28}$ (3.16)

$q_u^{91} = (1{,}14 \sim 1{,}70) q_u^{28}$ (3.17)

$q_u^{180} = (1{,}27 \sim 2{,}16) q_u^{28}$ (3.18)

$q_u^{91} = (1{,}48 \sim 2{,}06) q_u^{14}$ (3.19)

$q_u^{180} = (1{,}61 \sim 2{,}49) q_u^{14}$ (3.20)

Group 2: *Sub- group 2a: clay mud and soft clay*

$q_u^7 = (0{,}40 \sim 0{,}89)\, q_u^{28}$ (3.21)

$q_u^{14} = (0{,}46 \sim 0{,}90) q_u^{28}$ (3.22)

$q_u^{56} = (1{,}02 \sim 1{,}86) q_u^{28}$ (3.23)

$q_u^{91} = (1{,}12 \sim 1{,}96) q_u^{28}$ (3.24)

$q_u^{180} = (1{,}17 \sim 2{,}80) q_u^{28}$ (3.25)

$q_u^{91} = (1{,}34 \sim 3{,}24) q_u^{14}$ (3.26)

$q_u^{180} = (1{,}41 \sim 4{,}80) q_u^{14}$ (3.27)

Group 3*: Peat soil*

$q_u^7 = (0{,}41 \sim 0{,}96)\, q_u^{28}$ (3.35)

$q_u^{14} = (0{,}87 \sim 1{,}22) q_u^{28}$ (3.36)

$q_u^{56} = (0{,}61 \sim 0{,}96) q_u^{28}$ (3.37)

$q_u^{91} = (0{,}56 \sim 0{,}89) q_u^{28}$ (3.38)

$q_u^{180} = (0{,}53 \sim 0{,}75) q_u^{28}$ (3.39)

$q_u^{91} = (0{,}56 \sim 0{,}99) q_u^{14}$ (3.40)

$q_u^{180} = (0{,}44 \sim 0{,}84) q_u^{14}$ (3.41)

Sub-group2b*: clay mud*

$q_u^7 = (0{,}42 \sim 0{,}77)\, q_u^{28}$ (3.28)

$q_u^{14} = (0{,}51 \sim 0{,}95) q_u^{28}$ (3.29)

$q_u^{56} = (1{,}02 \sim 1{,}73) q_u^{28}$ (3.30)

$q_u^{91} = (1{,}04 \sim 2{,}55) q_u^{28}$ (3.31)

$q_u^{180} = (1{,}13 \sim 2{,}71) q_u^{28}$ (3.32)

$q_u^{91} = (1{,}42 \sim 3{,}20) q_u^{14}$ (3.33)

$q_u^{180} = (1{,}74 \sim 3{,}92) q_u^{14}$ (3.34)

3.3.5. Relationship between compressive strength and Young's modulus

Young's Modulus was determined by the compressive strength tests based on the results of 1182 different samples of weak clay mixed with three types of cement: T30, T40 and K40. The contents of cement are 250, 300, 350 and 400 kg/m^3. The samples were tested at the ages of 7, 14, 28, 56, 91 and 180 days old. The relationships between the compressive strength (q_u) and the Young's modulus (E50) obtained from the tests can be expressed as follow:

$50 q_u^7 < E_{50}^7 < 123\, q_u^7$ (3.44)

$50 q_u^{14} < E_{50}^{14} < 184\, q_u^{14}$ (3.45)

$60 q_u^{28} < E_{50}^{28} < 184\, q_u^{28}$ (3.46)

$90 q_u^{56} < E_{50}^{56} < 184\, q_u^{56}$ (3.47)

$90 q_u^{91} < E_{50}^{91} < 184\, q_u^{91}$ (3.48)

$90 q_u^{180} < E_{50}^{180} < 184\, q_u^{180}$ (3.49)

It was found that the relationship between compressive strength and Young's modulus has an increase from 50 (7 and 14 days old), 60 (at 28 days) and 90 (at 56 to 180 days) for lower bound; while for the upper bound, it varies from 120 (at 7 days) to 184 (for other ages).

3.4. ANALYZE EFFECTS OF WEAK CLAY'S CHARACTERISTICS IN THE MEKONG DELTA ON THE QUAILITY OF REINFORCED SOIL

3.4.1. Effects of particle size and soil type

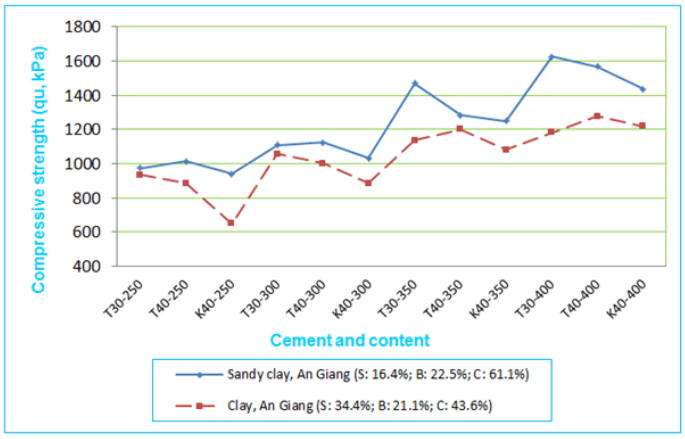


Figure 3.16: The diagram shows the relationship between compressive strength of sandy clay and clay in An Giang at 91 days of age with different cement

Based on the results of comparison of the effects of particle size on various types of soil, which are clay in An Giang (clay, clay mud, *Figure 3.16*); clay mud and sandy clay mud in Can Tho; and clay mud in Ca Mau, when coarse grains (sand) are added into the stabilized soil, it can be found that: When the amount of sand particles and silt in the soil is higher, the strength of the sample increases more than that of the soil with high content of clay particles; and the compressive strength of the reinforced soil increases if the sand content in the soil increases, particularly at the ages of 7 days and 91 days.

The results of the research on the improvement of sandy clay mud and clay mud in Can Tho and clay mud in Ca Mau by cement, show that the strength of reinforced soil decreases with an increase of the organic content. Additionally, for the soil with low organic content, the strength of the reinforced soil develops over time curing, and the strength of the peat soil in Kien Giang province (organic = 26.56%) increases then decreases. The reason of strength decrease is due to the high organic content (high humic acid content) in the soil would causes the pH becomes less. The more organic content of the soil, the more decomposition occurs after mixing with cement to reduce the pH environment, so that the reinforced soil strength is reduced. According to research results of Mohd Yunus. N. Z; Wanatowski. D and Stace. L. R (2011) [69], (2012) [70], when adding 0.5% humic acid to the soil, the samples' undrained shear strength decrease over time; and in contrast, without adding humic acid, the samples' strength improve over the curing period.

To determine the effects of organic content and pH on the quality of reinforcement, the PhD candidate used two types of soil: clay mud ($amQ_2^{2\text{-}3}{}_1$) in Hau Giang and peat soil ($abQ_2^{3}{}_1$) in Kien Giang to mix with different ratio and then reformed with cement. The organic content and pH of the mixed soil is then measured. The results show that: when the organic content is more than 20%, the strength of the reinforced soil first increases (up to 28 days) and then decreases; for the soil that contains less than 18% of organic content, the strength of soil increases over the curing period. Similar to pH, the higher pH, the better soil strength (peat soil).

3.4.2. Effects of salt content

Comparison of compressive strength of clay mud samples taken in Tien Giang, Ca Mau, Hau Giang and Bac Lieu which contain dissolve salt (mg/100g) with amount of 553.1; 2194.4; 2298 and 3624, respectively, at 91 days with two types of cement: T40 and K40. It can be seen that with T40 cement the results are not clear but with K40 cement when the dissolved salt content is high, the compressive strength is also high and even higher than T40 strength. This might be explained that the soil in Hau Giang, Bac Lieu and Ca Mau is contaminated with chloride. In addition, K40 has a higher content of lime than T40 (60.42% and 54.74% respectively). When cement contains a high amount of calcium oxide, it will produce a large amount of Ca^{+2} which facilitates the process of soil improvement [21].

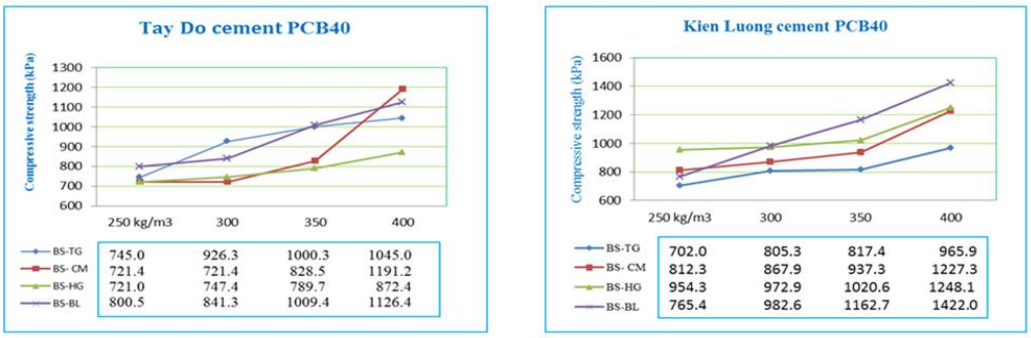


Figure 3.24: Effects of salt content on reinforced soil strength

3.4.3. Effects of chemical content

The results of study on chemical composition to quality of the soil showed that the amount of silica oxide (SiO_2) and sulfite (SO_3) plays major roles on the strength of the reinforced soil. For sandy clay ($aQ_2^3{}_2$) in An Giang which contains silica oxide (SiO_2 = 68.44%) provided the best compressive strength. The peat soil in Kien Giang ($abQ_2^3{}_1$) having SiO_2 content of 27.87% provided the lowest strength. In contrast, the peat soil in Kien Giang has the highest sulfate content (SO_3 = 10.8%), while in other places, it is only 0.95% (sandy clay in An Giang) to 1.91% (muddy clay in Tien Giang). Thus, silicon oxide (SiO_2) has a positive effect and sulfide (SO_3) has a negative effect.

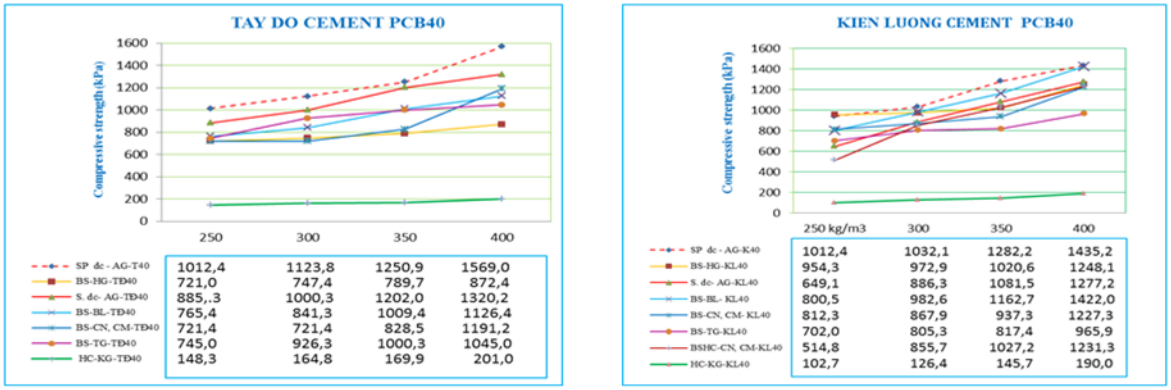


Figure 3.25: Effects of chemical composition on reinforced soil strength

3.4.4. Effects of mineral content

The results of analysis of soil samples reinforced by K40 at 91 days based on the mineral content shows that: the soil contains high clay minerals (clay and clay mud, illite and montmorillonite from 21% to 29 %) has a lower strength than sandy clay (14%).

It occurs in reversed way to soil that contains quartz (sandy clay with large amount of quartz, 47%-49%), clay, clay mud (40%). Peat soil, clay mineral group (25%) , quartz (23-25%), pyrite (5-7%), pyrophylite (4%), geotile (14-16%) and gypsum (15%) has a very low strength because in the soil contains large amount of organic content. Thus, the soil which contains clay minerals, (especially montmorillonite) will be more disadvantageous than the soil which contains quartz mineral. If the soil contains minerals such as pyrite, pyrophosphite, geotile and gypsum; it will be extremely disadvantageous.

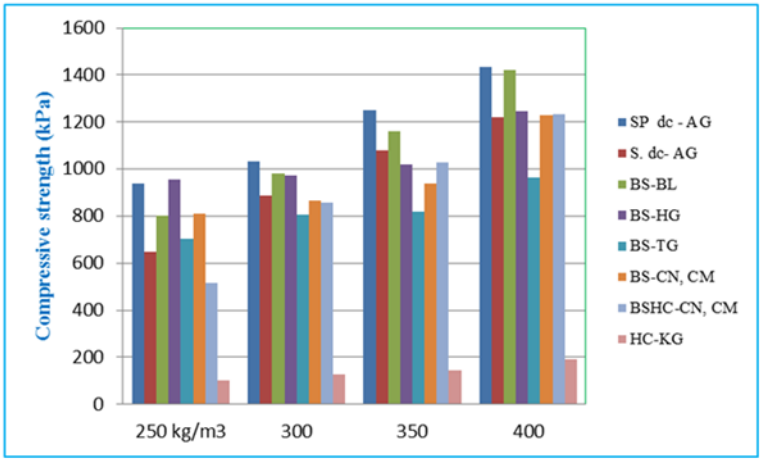


Figure 3.26: Effects of mineral composition on reinforced soil strength

3.4.5. Influence of component characteristics according to the weighting and multivariate method

The results of the weighting, multivariate analysis for the samples showed that:

- For group 1: sandy clay (aQ_2^3) and Sub – group 2a: clay (aQ_2^3) and muddy clay ($amQ_2^{2-3}{}_1$); the components of cement (i.e. SiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, Na_2O and SO_3) have positive influence on the quality of reinforced soil and CaO has a negative impact.
- For sub-group 2b: muddy clay ($amQ_2^{2-3}{}_2$) in Hau Giang, ($mbQ_2^3{}_2$) in Bac Lieu and ($mbQ_2^3{}_2$) in Ca Mau; the components of cement (SiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, Na_2O and SO_3) have a negative effect on reinforced soil and CaO has a positive effect.

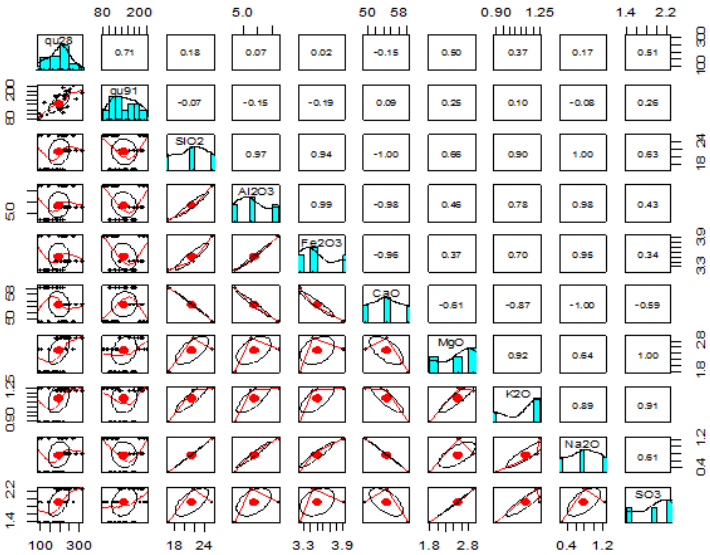


Figure 3.33: Results of weight, multivariate analysis of peat soil ($abQ_2^3{}_1$) in Kien Giang

- Group 3: for Peat soil ($abQ_2^3{}_2$) in Kien Giang, the components SiO_2, Al_2O_3, Fe_2O_3 Na_2O at 28 days old have positive effect but at 91 days, it turns to negative effect; CaO has a change from negative to positive condition; MgO, K_2O and SO_3 are positive but tend to decrease. This might also explain the decrease of sample strength after 28 days of curing (*Figure 3.33*).

The effect of chemical composition of the soil showed that:

- The oxides SiO_2, Al_2O_3, K_2O have positive influence; Fe_2O_3, CaO and SO_3 has negative effect; MgO and Na2O has positive effects with T40 and K40, but negative to T30.
- The minerals illite, kaolinite, quartz and feldspar have a positive influence; Montmorillonite, Gotile have negative influence. The negative cations include Ca^{+2}, Mg^{+2}, Al^{+3}, $SO4^{-2}$, Mn, total N and organic content, in which the organic content (*Figure 3.36.b*) and $Al3^{+}$ have the strongest influence.
- The pH, K^+ and CEC have a positive effect; total dissolve salt, Na^+ and Cl^- had a positive effect on T40 and K40 but negative to T30; Fe^{+2} is positive with T40 and T30, negative with K40.

Figure. 3.36.b: Results of cation and organic content analysis using weighted, multivariate methods

Thus, the effect of soil exchange cations on the quality of reinforced soil is rather complicated. However, in terms of positive factors such as pH, TSMT, Cl^-, Na^+, K^+, CEC; K40 has higher effect than the T40 and T30.

3.5. OTHER FACTORS AFFECTED ON THE QUALITY OF SOIL REINFORCED BY CEMENT IN THE MEKONG RIVER DELTA

3.5.1. The effect of cement content

The results of the study of soil improving by different types of cement on weak clay in the Mekong Delta which have different origins show that: when the cement content increases, the compressive strength of the sample also increases; this phenomena is appropriate. When the cement content increases from 250 to 400kg/m^3, the compressive strength of the soil samples increase. Thus, cement content has a great influence on the strength of soil.

3.5.2. The effect of cement types

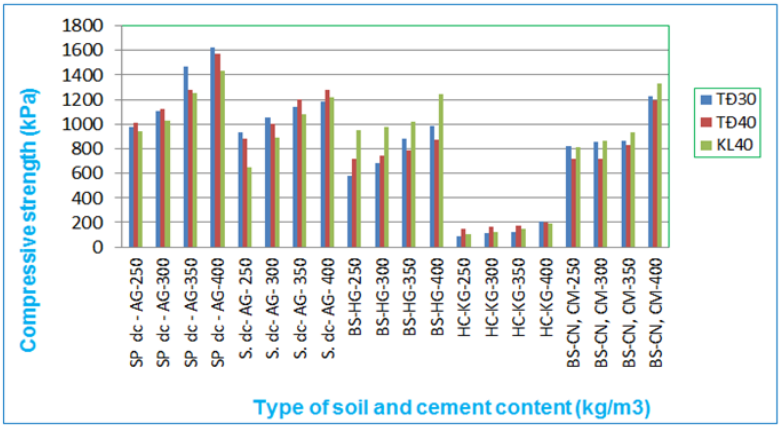


Figure 3.38: Effect of cement types on 91 days

Research results of soil improvement in weak clay in the Mekong Delta with 3 types of cements: T30, T40 and K40 were compared at 91 days shows that: for clay, and sandy clay ($aQ_2^{3}{}_2$) in An Giang, T30 provides the highest strength; for clay mud ($amQ_2^{2\text{-}3}{}_2$, Hau Giang), ($mbQ_2^{3}{}_2$ - Ca Mau) K40 provides most effective solution; for peat soil ($abQ_2^{3}{}_1$) in Kien Giang and clay mud ($amQ_2^{2\text{-}3}{}_1$) in Tien Giang, T40 tends to be better (*Figure 3.38*). Thus, type of cement also affects the quality of reinforced soil. It might be explained by the different oxides of cement's chemical component, especially CaO and SiO_2.

3.5.3. Effect of mixing conditions (Water/Cement ratio)

With weak clay in the Mekong Delta, the PhD cadidate has studied three types of soil with different origins: clay mud ($amQ_2^{2\text{-}3}{}_2$) in Hau Giang, peat soil ($abQ_2^{3}{}_1$) in Kien Giang and clay mud with organic content ($amQ_2^{3}{}_1$) in Ca Mau. The cement in Hau Giang and Kien Giang is 350kg/m^3 (Nghi Son cement, PCB40), in Ca Mau with Ha Tien cement PCB40 (HT40) with a content of 250 kg/m^3 (Figure 3.41). The mixing ratio was applied with two scenarios: W/C = 0.0, 0.5 and 1. Research results show the following relationships:

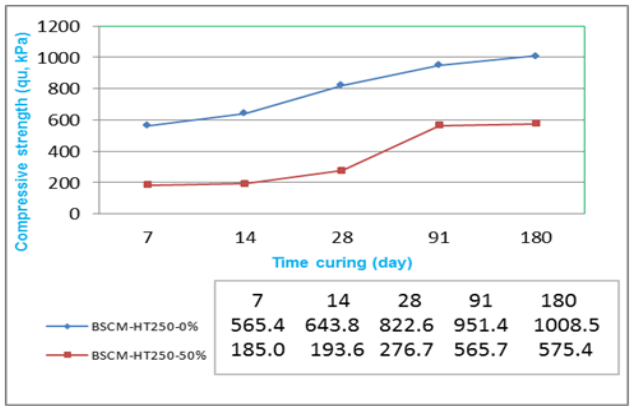


Figure 3.41: Effect of mixing water
(Ca Mau clay mud, cement HT40, content 250 kg/m³)

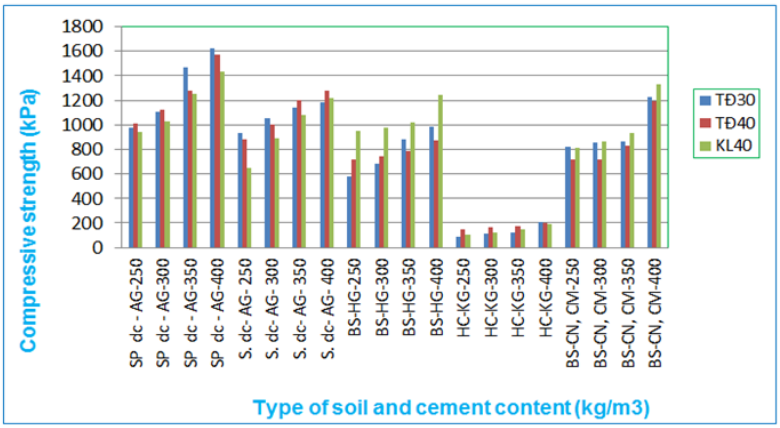


Figure 3.38: Effect of cement types on 91 days

+ Clay mud:

$q_u^{50} = (0{,}30 \sim 0{,}59)q_u^0$ (3.49)

+ Peat soil:

$q_u^{50} = (0{,}50 \sim 0{,}78)q_u^0$ (3.50)

$q_u^{100} = (0{,}25 \sim 0{,}43)q_u^{50}$ (3.51)

$q_u^{100} = (0{,}16 \sim 0{,}32)q_u^0$ (3.52)

3.5.4. Relationship between the strength of the sample in the laboratory and at the field

The relationship between the compressive strength of the sample prepared in the laboratory and drilled from the soil cement column at filed were studied with two types of clay: ($amQ_2^{2\text{-}3}{}_2$) in Hau Giang - Subgroup 2b (*Figure 3.43*) and peat soil ($abQ_2^3{}_1$) in Kien Giang - Group 3. Samples were prepared from the original soil samples, the ratio W/C = 1; the field samples are taken from the core of the soil cement columns by the core drilling method; colums are constructed by Jet-grouting method. The T30 cement was studied at the levels of 300, 325, 350, 375, 400 and 425 kg/m^3, samples were tested at 28 and 91 days; the N40 cement, tested and compared with the cement content of 375, 400 and 425 kg /m^3, the sample was tested at 14 and 91 days. Experimental results show the following relationships:

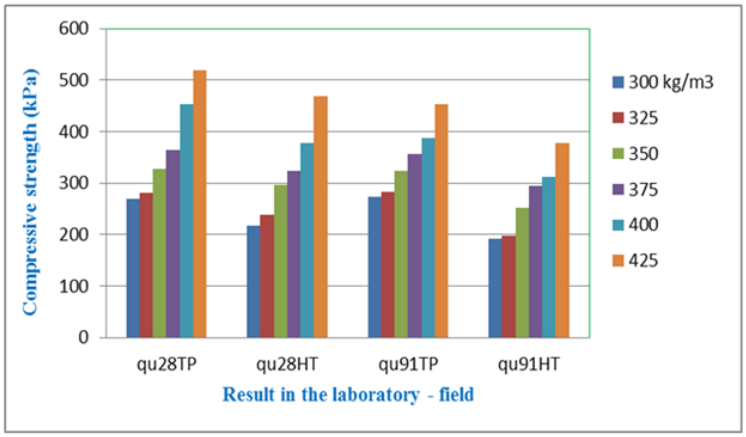


Figure 3.43: Diagram showing the results of tests (q_u) of samples in laboratory and field (Peat soil in Kien Giang, T30 cement)

Sub- group 2b: Clay mud

$q_u^{14ht} = (0{,}85 \sim 0{,}87)q_u^{14tp}$ (3.53)

$q_u^{28ht} = (0{,}77 \sim 0{,}97)q_u^{28tp}$ (3.54)

$q_u^{91ht} = (0{,}47 \sim 0{,}92)q_u^{91tp}$ (3.55)

$q_u^{180ht} = (0{,}81 \sim 0{,}88)\ q_u^{180tp}$ (3.56)

Group 3: Peat soil

$q_u^{28ht} = (0{,}81 \sim 0{,}91)q_u^{28tp}$ (3.57)

$q_u^{91ht} = (0{,}70 \sim 0{,}83)q_u^{91tp}$ (3.58)

3.6. CONCLUSION OF CHAPTER 3

1. The organic content and environment's pH have a great effect on strength of the stabilized soil. When the organic content increases, the soil strength decreases. When organic content is larger than 20%, the strength of the reinforced soil first increases and then decreases over curing time. This is because the low pH invironment will prevent the hydration reaction process of the cement.

2. If the soils contain many clay minerals, especially montmorillonite and gotile, the strength of stabilized soil (q_u) is lower than that of the soil which contains quartz (SiO_2). When the soil has pyrite, pyrophyllite and gypsum minerals, it will has negatively affect the reinforcement process (peat soil). Similarly, the chemical composition of soils contains more silicon oxide (SiO_2) will be than more advantageous than one contains sulfite (SO_3) soils.

3. For the salt content in the soil is high, the salinity is serious or extremely serious (Sub group 2b), it is necessary to increase the amount of cement, or use a higher amount of CaO in cement (K40); with group 1, the cement containing less CaO (T30) is more appropriate.

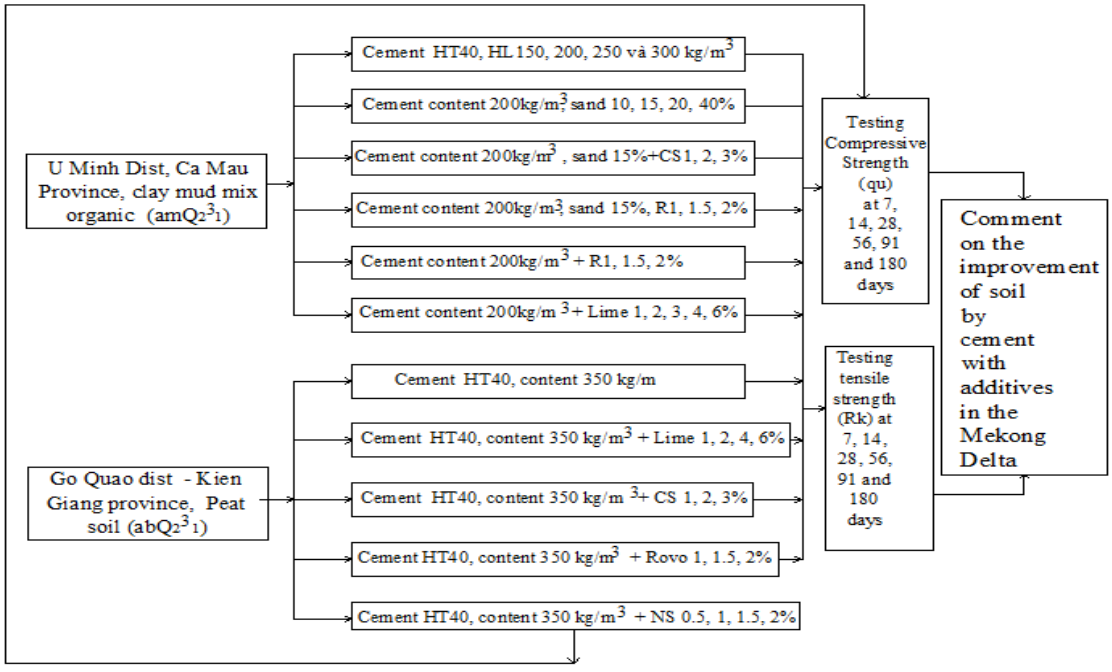
4. The results of weighting, multivariate analysis are quite consistent with the above analysis.

CHAPPER 4

RESEARCH ON IMPROVING EFECIENCY OF THE METHODS TO REINFORCED SOIL BY CEMENT AND ADDTIVES

4.1. MOTIVATION

According to the results analyzed in chapter 2 and chapter 3: There are two types of weak clay with have special characteristics, which are commonly distributed in the MRD, need to be studied in order to improve efficiency when they are reinforced by cement. The first type is Sub-group 2b – clay mud ($amQ_2^3{}_1$) which distributes in coastal areas such as Ca Mau, Bac Lieu; salinity level is serious or extremely serious. The second type is Group 3: peat soil ($abQ_2^3{}_1$) in Kien Giang, low pH. In order to improve the efficiency of the method, the PhD student used additives, i,e gypsum 1%, 2%, 3%; rovo 1.0%, 1.5%, 2.0% and lime 1%, 2%, 3%, 4%, 6%. Particularly, for the peat soil, the PhD candidate had done extra experiments by applying liquid glass. The work flow diagram is shown in *Figure 4.4*



Figire 44: Diagram of soil improvement experiment with cement and additives

4.2. RESULTS OF RESEARCH ON IMPROVEMENT OF WEAK CLAY IN THE MEKONG DELTA BY CEMENT AND ADDITIVES

4.2.1. Study on the improvement of clay mud in Ca Mau by cement and additives

Studied soil is clay mud with high silt content and clay particle (98.8%) so that PhD has researched soil improvement by adding small sand particles (a common type is used for leveling in the MRD) into the soil with proportion of 10%,15%, 20% and 40% in comparison with the dried volume. The amount of additives is calculated according to percentages of the cement.

The selected additives are: Gypsum ($CaSO_4$) with the ratio of 1%, 2% and 3%, symbolized as CS1, CS2 and CS3 [45]; Rovo 1%, 1.5% and 2%, symbolized as R1, R1,5 and R2 [73]; Lime 1 %, 2%, 3%, 4% and 6%, symbolized as V1, V2, V3, V4 and V6. The reinforced soil was studied with compressive strength and tensile strength; the applied cement was Ha Tien (HT40) with the content of 200kg/ m^3, implemented by dry mixing, maintenance under saturation conditions at 7, 14, 28, 91 and 180 days. The results that determine the compressive strength are presented in Figure. 4.5.

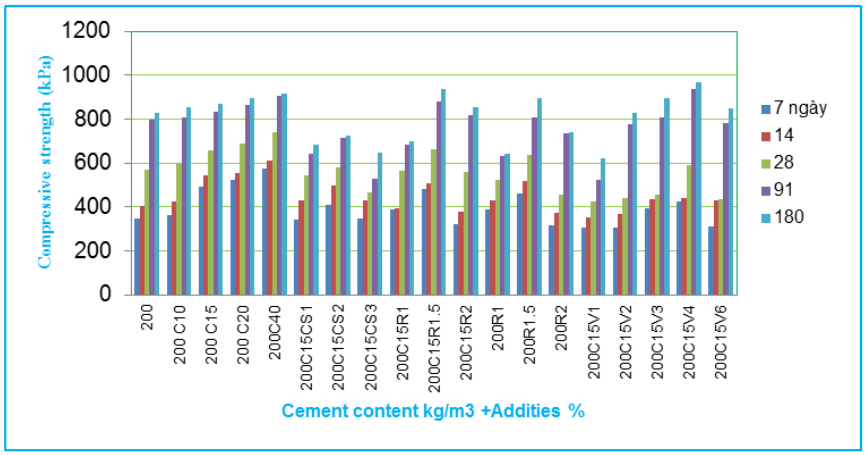


Figure 4.5: Graph showing the results of testing on the compressive strength (q_u) of clay mud soils ($amQ_2^3{}_1$) in Ca Mau with cement content of 200 kg/m^3 and different additives

4.2.2. Study on improvement of peat soil ($abQ_2^3{}_1$) in Kien Giang by cement and additives

Similar to Ca Mau soil, the PhD cadidate studied improvement of peat soil in Kien Giang with Ha Tien cement (PCB40) content of 350 kg/m^3 with similar proportion of additives (lime, rovo and gypsum).

Simultaneously, we have done experiment with liquid sodium silicate with the content of 0.5%, 1.0 %, 1.5%

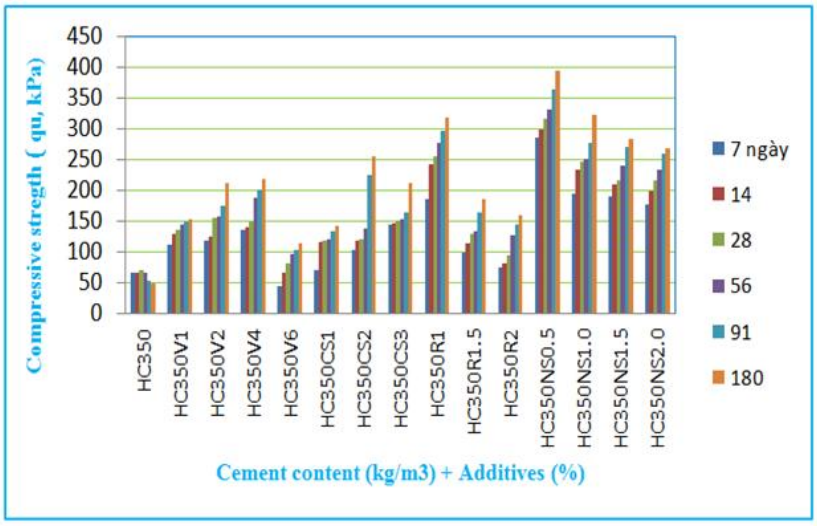


Figure 4.7: Diagram showing the results of determination of peat soil ($abQ_2^3{}_1$) improved with cement content 350 kg/m^3 and additives

and 2%, symbolized as NS0.5, NS1, NS1.5 and NS2. The results of the study of the unconfined compressive strength are presented in Figure 4.7.

4.3. CONCLUSION CHAPTER 4

4.3.1. For soil in the Sub-group 2b

The compressive strength of the reinforced soil with 4% lime provides the highest value in comparison to the proportion of 1%, 2%, 3% and 6%. It is also greater than the non-lime sample with 40% sand (compared with dry weight volume (200C40) at 180 days old). This is also appropriate with the tensile strength.

Soil which was reinforced by cement content of 200kg/m^3 and 15% sand without gypsum additive ($CaSO_4$) provided a higher compressive strength than soil with additives. However, with the tensile strength samples with 2% additive has a higher value than samples without additives. This suggests that gypsum additives play an important role in the formation of plasticity of reinforced soils. Soil that was reinforced by 1.5% Rovo additive provided the highest compressive strength in comparison with 1% and 2% of Rovo and higher than soil without additive. The optimal tensile strength are also provided at 1.5%; this strength is higher than one of sandy or non-sandy samples with proportion of 16% to 30%, respectively.

4.3.2. For soil in the Group 3

When applying additives, the all of soil samples were more stable over curing time; the optimal amount of additives was l4% lime, 2% gypsum, 1% Rovo and 0.5% Na_2SiO_3, where the compressive strength of the sample with 0.5% Na_2SiO_3 had the highest value; tensile strength of sample with 2% gypsum was the highest value, followed by 1% Rovo and 4% lime; compressive strength of the sample was low, only 300 kPa approximately. However, the efficiency in comparison with the soil without additives is quite large, 4.5 to 8.0 times.

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

1.1. In the study scopes, the clay soft soil is mostly distributed in the Mekong river delta, within the thickness of over from 10 m to 20m and over 30m in some places. These are the young sediments of the Holocene, with many different origins, most commonly $amQ_2^{2\text{-}3}{}_1$, $amQ_2^{2\text{-}3}{}_2$, $abQ_2^{3}{}_1$, $abQ_2^{3}{}_2$, $amQ_2^{3}{}_1$, $mbQ_2^{3}{}_2$, $aQ_2^{3}{}_2$, $mQ_2^{3}{}_2$, $bQ_2^{3}{}_2$.... These sediments are usually located on good clay soils such as clay, sandy clay, sand and clayed sand belonging to upper Pleistocene sediments of the Moc Hoa formation ($amQ_1^{3}mh$) or Long Mỹ formation ($mQ_1^{3}lm$).

1.2. The composition of soft clay soil in the Mekong river delta are mainly clay, sandy clay with the soft to very soft state, clay mud, sandy clay mud,... These are special soil types consisting of alum, salt and organic matter of varying degrees. According to the advantage level for soil improvement by cement, PhD candidate divided these soils into 3 groups:

Group 1: Advantages, soft soil with the low or without montmorilonite mineral, low organic content (1.98 %), low level sulfate salts, pH=5.8. These soils was sandy clay with aluvial origin sidement ($aQ_2^3{}_2$).

Group 2: few advantageous

- *Sub-group 2a*: Non-salty soil, sulphate-chloride salts soil, these soft soils had clay minerals (montmorilonite, ilit and kaolinite) content of from 35 % to 43 %, organic content (2,1÷2,33) percent, pH = 5,6-5,7. This sub – group consists soft to very soft clay with aluvial origin ($aQ_2^3{}_2$) and clay mud with aluvial –marine sidement ($amQ_2^{2\text{-}3}{}_2$).

- *Sub – group 2b*: Chlorinated saline soils are salty and have medium salinity, they distributed in the area near the sea, these soils contain clay minerals 36÷51 percent, pH = 3.1÷7,0; organic content (2,67÷13,39) percent. Sub – group soils are clay mud with aluvial – marine sidement ($amQ_2^{2\text{-}3}{}_2$) and marine – bog sidement ($mbQ_2^3{}_2$).

Group 3: Disadvantages, soft soils of this group are peat, sulphate saline soil of low degree without saline, these soils contain components such as gotite (14 ÷ 16 percent), sulfur SO3 (10.8 percent), pyrite (5 ÷ 7 percent), pyrophyllite (4 percent) and gypsum (15 percent), pH = 2.1, organic 26.56 percent. These soil origin from aluvial – bog sidement ($abQ_2^3{}_1$).

1.3. The study results on the effect of component characteristics on the quality of soil improvement by cement allow to have conclusions:

- Organic content: consistent with the research results of the other authors in the world. The general rule is that the presence of organic matter has adversely affects on soil improvement. Research results show that when organic content is over 20%, the soil sample strength increases at the beginning, after that it decreases after 28 days of curing time. Similarly, low pH has a negative effect, the pH of the sandy clay, clay and clay mud (pH = 5.7-7.0) give the strength higher than that of the peat (pH = 2.1).

- When the soils contain the group of many sand grains and the group of few clay particles, improved soil quality is good. The soil studied in the area consisting of sandy clay (group of sand grains content of 61.1%, clay particle content of 16.4%) has better strength than that of clay, clay mud (sand grain group with the content of 31.1 to 43.6 %; clay particles from 34.3 to 42.60 %).

- If the clay minerals content of montmorilonit (M) and illit (I) increase, then the strength of the reinforced soil sample decreases. The results showed that the group soil 1 had got MI group of only 14%, whereas Group 2 soil had MI group of from 22% to 27%, the reinforced soil sample strength of group 2 was smaller than that of group 1. Group soil 3 which contains pyrite, pyrophosphite and gypsum will be detrimental to soil ỉmpovement, as for the soil is rich in silica (group 1), it is more profitable than the soil with a lot of SO_3 (group 3).

- Ca^{+2}, Na^{+} cations are beneficial for the hydrolysis of cement, the soil sub-group 2b that uses cement with high CaO (K40) is better than cement with low CaO (T40); the soil group 1 and the sub-group 2a that use cement with low CaO content will be more beneficial than cement with high CaO content.

1.4. Results of the analysis by weighting, multivariate analysis method showed that:

- Group 1 and sub-group 2a: SiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, Na_2O and SO_3 in cement have a positive effect and CaO has a negative effect;

- Sub-group 2b: CaO content in cement is positive, SiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, Na_2O and SO_3 are negative;

- Group 3: SiO_2, Al_2O_3, Fe_2O_3, Na_2O content in cement at 28 days of age have a positive effect, however for 91 days of age have negative effects, CaO changes from negative to positive; MgO, K_2O and SO_3 are positive but tend to decrease.

1.5. Research results of soil improvement with cement combined with additives showed that:

- Sub-group 2b soil: Research with lime of 4%, gypsum of 2%, Rovo of 1.5% give the best strength. The rate of tensile strength increases more than the compressive strength.

- Group 3 soil: The optimum additives are lime of 4%, $CaSO_4$ of 2% and Rovo of 1% and Na_2SiO_3 of 0.5%, where the compressive strength of the reinforced soil sample with Na_2SiO_3 of 0.5% gives the highest value.

Additives play an important role in soil reinforcement, especially peat. Additives have substantially overcome the deterioration in the curing time and have increased the strength of from 4.5 to 8.0 times for the soil organic (Peat).

2. Limitations of the thesis

- The thesis has not been able to study the triaxial compression tests on trigonometric machines as well as the non-experimental architecture, lithological analysis of reinforced soil on the microelectronic microscope;

- The thesis has not defined the boundary, divided the categories of soils as classified.

3. Recomendations

3.1. It is necessary to continue studying to determine the compressive strength of the reinforced soil sample over 180 days of age and the architectural characteristics of them as well as the studying under various conditions of equipment and curing time (shear, compression on the triaxial).

3.2. Continuing researching into factors affecting on reinforced soil quality in more detail as well as studying of using different additives

3.3. Researching method, experimental conditions in accordance with the technology of construction in field.

LIST OF SCIENTIFIC WORKS RELATED TO THE THESIS

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5. Nguyen Quoc Dung, Vu Ngoc Binh, Phung Vinh An, Phan Viet Dung (2014), "Study of soil improvement in Ca Mau by cement and additives" *Proceedings of the 55th anniversary of the establishment of the Vietnam Academy for Water Resources (2009-2014), Volume II, p. 585-594*
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10. Vu Ngoc Binh (2017), "Effect of component characteristics on the quality of soft clay soil in the Mekong river delta reinforced by cement" *Journal of Water Resources Science and Technology (ISSN 1859-4255) No 38 (5-2017),* p.64-71.
11. Do Minh Toan, Vu Ngoc Binh, Do Minh Ngoc (2017), "Construction characteristics of soft clay soil in the Dong Thap, reinforcement ability of them by cement (x), cement in combination with additives (x + pg) for road construction" *Reported at the 51st Technical-Science Club of Technical Universities in Dong Thap, September 2017, p. 430-439*
12. Vu Ngoc Binh, Pham Hong Cuong (2017), " Effect of mixing water ratio on the quality of soft clay soil in the Mekong river Delta improved by cement" *Vietnam Geotechnical Journal, ISSN-0868-279X, No 3-2017, p.* 17-21.