INFLUENCE OF DELAY COMPACTION ON STRENGTH OF LATERITIC SOIL CEMENT

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ABSTRACT: This study attempted to investigate compaction parameters such as cement and moisture content and time to compaction which influence strength of the soil cement. Experimental programs included determination on the optimum cement and optimum moisture contents (OMC) in order to study effect of delay time on compaction.

Lateritic soil from Saraburi province, A-2-4 (0) based on AASHTO classification, was used in the study. The soil was mixed with cement 4%, 5%, 6% and 7% by weight. Specimens were compacted in ϕ 2″ x 4″ mold using equivalent modified compactive energy with moisture content within a range of OMC ± 2% and with a delay period to compaction of 1, 2 and 3 hours. After being cured for 7 days, unsoaked and soaked specimens were tested using unconfined compression test.

Based on the experimental results, strength of the stabilized lateritic soil is markedly influenced by compaction parameters such as cement content and initial mixing moisture content. Loss in strength could be found when specimens were soaked in the water before tests. Results also revealed that delay in compaction had markedly effect on strength of the lateritic soil cement. It is recommended that compaction should be done within 3 hours after mixing, depending on the initial mixing moisture content and required strength. Compressive strength of the cement-stabilized lateritic soil cement showed promise for use as base and subbase courses for road.

KEYWORDS: SOIL STABILIZATION, COMPACTION, LATERITIC SOIL, CEMENT

1. INTRODUCTION

In road construction, crushed rock is major material used as base or subbase course due to their good engineering properties. When compacted, it has high strength and bearing capacity for vehicles to move on. Due to lack of crushed rock in some area, it is therefore suitable to improve an insitu soil and use as substitution of crushed rock.

Lateritic soil is a product of weathered rock in a temperate area having high humidity. In Thailand, they are widely distributed through the country especially in northeastern region. It posses self hardening properties when air-dried. Properties of lateritic soil depend on its parent rocks, chemical compositions and climate. When compacted, it possesses good characteristics and can be used as subbase and base materials.

In case that a soil has some deficiency in its property and we want to use it, appropriate soil improvement technic is needed. Chemical stabilization is one of the most practical methods to improve undesirable characteristics of soil. Among those stabilizers, cement is the most effective and widely used. Reactions among soil, cement and water in soil mass markedly change its engineering properties such as strength, durability, and volume stability.

Nontananandh and Kamon indicated that soil properties, moisture content, type and amount of stabilizer, and technics of stabilization are factors which influence degree of soil stabilization [1],[2].

Appropriate amount of water is required to obtain maximum dry density and in the same time to obtain desirable strength due to reactions. Differences in mixing periods, mixing speed, and curing conditions including pre-treatment and post-treatment can result in variations in strength.

Significant loss in strength of stabilized soils was found when there was an interruption during the mixing period (Marshall, [3]). According to Sivapullaiah et al. [4], delay in compaction with a period of 7 days, could lead to decrease in dry density, increase in OMC, and decrease in strength. Based on the study on lime stabilization of dispersive soil, Nontananandh and Kawinvong-paiboon [5] also indicated that compaction performed soon after mixing could enhances early hydration and thus contributes to a remarkable strength development, favorable permeability, good durability.

This paper concentrates on the study of certain parameters such as cement content, moisture content and time to compaction which influence strength characteristics of the soil cement. Emphasis is placed on investigation of effect of delay time between mixing and compaction within a period of less than 3 hours.

2. EXPERIMENTAL PROCEDURE

a) Materials

The lateritic soil used in this investigation was sampled from Kangkoi, Saraburi Province. The natural water content is about 7.1%. Upon visual inspection, the soil has a red-brown color, containing natural round-shape clods. Further data on physical properties of the soil are given in Table 1. The soil can be classified as silty sand (SM) or A-2-4(0), according to the unified soil classification system and AASHTO classification system respectively. When compacted with modified compaction energy and at its optimum water content, the soil obtained a strength of 4 kg/cm^2. Properties of the lateritic soil used in this study fall within a range of those found in Thailand as reported by Merrison [6], as shown in Table 1.

Table 1 Properties of lateritic soil in Thailand and that used in this study

SOIL PROPERTIES	MIN. VALUE	IN THIS STUDY	MAX. VALUE
% passing Sieve No. 200	0	26	66
Liquid Limit (%)	18	19	97
Plastic Limit (%)	NP	16	51
Soil classification by AASHTO	A-1-a	A-2-4	A-7-6
Group Index (GI)	0	0	10
Specific gravity, Gs	2.59	2.64	3.20
Maximum dry density (ton/m^3)	1.89	2.04	2.32
Optimum moisture content (%)	7.0	9.4	13.4

On the other hand, the stabilizer used in this study is an Ordinary Portland Cement type I. The cement powder has a specific surface area of 3,223 cm^2/g and a specific gravity of 3.07. Its initial and final setting time are 81 and 127 minutes, respectively.

b) Specimen preparation and Test

Experimental programs were divided into 2 parts, namely, study on the determination of an optimum cement content and mixing water content and the effect of delay time in compaction on strength of a cement-stabilized soil. Experimental programs were illustrated by flow charts as shown in Figure 1 and Figure 2, respectively.

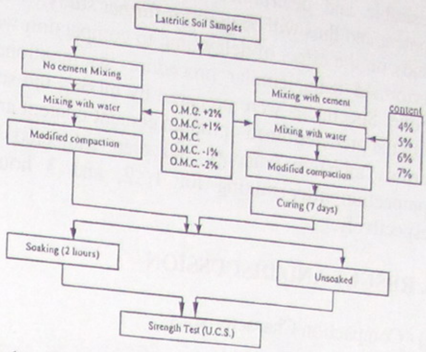

Fig.1 Flow chart of the experimental program 1 (Trial mixes to determine an optimum proportion)

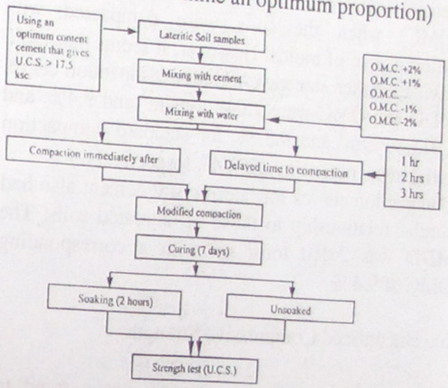

Fig.2 Flow chart of the experimental program 2 (Effect of delay time to compaction)

In order to determine an optimum cement content, specimens were prepared by mixing the soil with cement. Mix proportion were 0% (for untreated soil), 4%, 5%, 6% and 7% by air-dried weight. Consequently, the initial water contents were set to be in the range of the predetermined OMC ± 2%; i.e., at OMC, OMC+1% and OMC+2% for wet side, OMC-1% and OMC-2% for dry side.

Preparation of specimens was performed using a mold of diameter 2 inches and height of 4 inches. Compactive energy applied was equivalent to that of modified Proctor compaction (56,050 lbs-ft/ft^3). After molding, the specimens were sealed tightly in plastic bags to prevent loss of moisture due to surface evaporation. The specimens of soil-cement mix were cured for 7 days before testing to determine their unconfined compressive strengths (UCS). For unsoaked condition, the specimens were subjected to strength test soon after demolding, while, they were submerged in water for 2 hours before testing for soaked condition. The lowest mix proportion that allows the cement-stabilized soil to obtain 7-days strength greater than 17.5 kg/cm^2 is desirable and determined as an optimum cement content and thus will be used for further study.

Study on the effect of delay time to compaction was performed using similar procedures as mentioned above. Specimens were prepared by mixing the soil with the predetermined optimum cement content and various moisture contents and then subjected to compaction after mixing for 1, 2, and 3 hours respectively.

3. RESULT AND DISCUSSION

a) Compaction Characteristics

There is no difference between the maximum dry density (MDD) and the optimum moisture content (OMC) when the soils were compacted with different size of molds. However, it seems that mold having smaller size gave a flatter compaction curve. MDD and OMC were 2.042 tons/m^3 and 9.4%, and 2.015 tons/m^3 and 9.5 %, for standard compaction and compaction using $\phi 2'' \times 4''$, respectively.

Compaction curves for lateritic soil cement also had similar relationship to those of untreated soils. The MDD was 2.010 tons/ m^3 with a corresponding OMC of 9.4 %.

b) Unconfined Compressive Strength

For unsoaked specimens, strength has a trend to decrease as moisture contents increase, while peak strain (ε_f) has an opposite trend. As shown in Figure 3, higher strengths were obtained when initial water content was lower than OMC. For initial water content greater than OMC, stresses have declining trend and their peaks did not appear clearly.

When initial water content is at OMC, the compacted soil gave a moderate strength of approximately 4 kg/cm^2 which was higher than those compacted on wet side. Its peak strain (ε_f) was approximately 4 % which was higher than those compacted on dry side. It is found that all untreated soils were collapsed when placed in the water for 2 hours. Slaking is due to the loss of capillary forces in compacted soil structures.

Figure 4 shows relationship between stresses and strain at peak of lateritic soil cements for all mix proportions. Results indicate that strengths were greater than those of untreated soils. However, it is obvious that, the strains at their corresponding strengths were lower than those of untreated soil. Strains (ε_f) laid within a range of 0.6% - 1.5%.

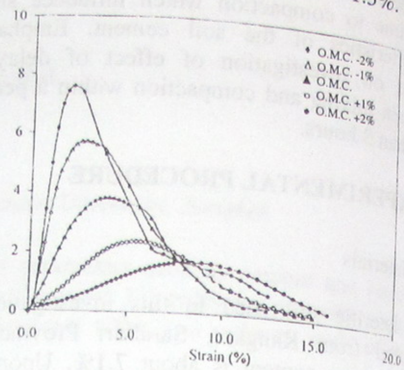

Fig.3 Stress – strain characteristic curves of lateritic soil compacted using various moisture contents

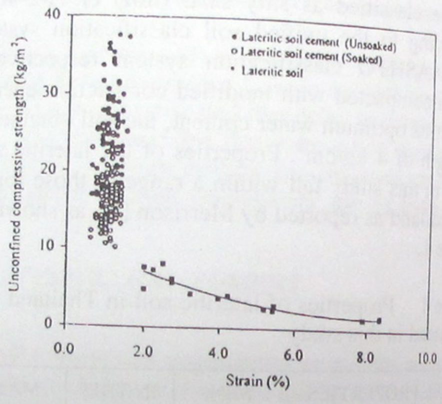

Fig.4 Unconfined compressive strength and peak strength of cement – stabilized soils and compacted natural soils

c) Strength- Cement Content Relationship

Strength increases with an increase of cement content. Figure 5 shows a linear relationship between UCS of unsoaked samples and cement content. For the same cement content, samples having lower water contents had higher strengths than those having higher water content.

For soaked specimens, as illustrated in Figure 6, there is loss in strength due to soaking for mixing beyond OMC. In addition, significant reduction on strength could be found for specimens mixed with water content on dry side. It is obvious that there was little effect due to soaking when mixed at its OMC, resulting in higher strengths than other specimens.

Mixing water content close to OMC (i.e. OMC ± 1%) could result in a relatively higher strength than those of OMC ± 2%. For soaking condition, compaction on wet side seems to have less effect than that on dry side. Most specimens were able to sustain stresses greater than 17.5 kg/cm^2.

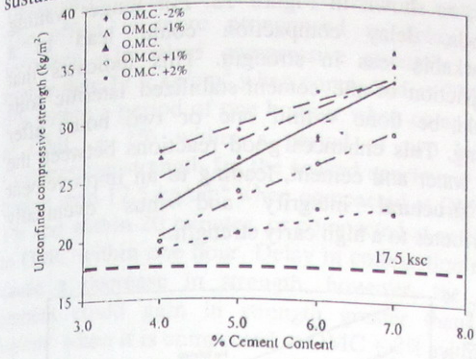

Fig.5 Relationships of unconfined compressive strength of lateritic soil cement and cement content for unsoaked condition

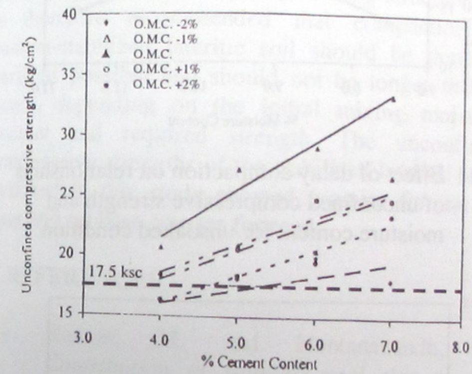

Fig.6 Relationships of unconfined compressive strength of lateritic soil cement and cement content for soaked condition

d) Strength – Moisture Content Relationship

Figure 7 shows relationships between unsoaked strength and moisture content for soil mixing with various cement contents. For cement contents of 4%, 5% and 6%, strength had a trend to decrease as moisture content increased. For a cement content of 7%, strength increased with moisture content increased up to OMC and then markedly decreased as water content was greater than OMC.

As shown in Figure 8. Compaction on dry side results in significant reduction of strength especially when mixing moisture content were less than OMC about 2%.

Figure 7 and 8 also revealed a cement content of 4% and mixing moisture content within a range of OMC ± 1% could result in favorable strengths. The 7-days strengths were higher than 17.5 kg/cm^2 for both unsoaked and soaked conditions. According to the Department of Highway's standard for soil cement, the compacted cement-stabilized soils showed promise for use as subbase and base materials for roads.

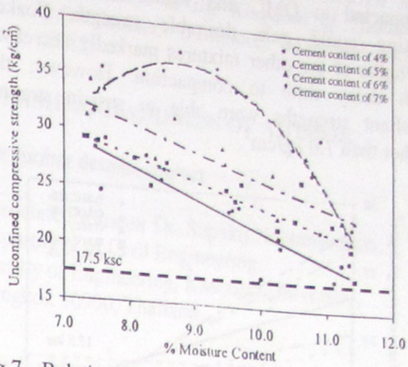

Fig.7 Relationships between strength of lateritic soil cement and mixing moisture content for unsoaked condition

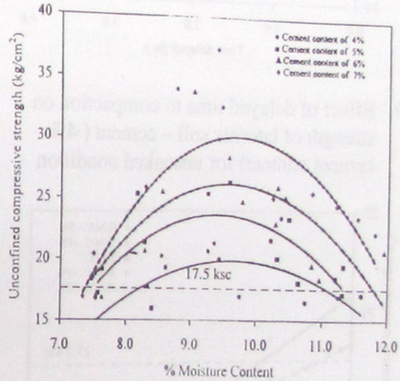

Fig.8 Relationships between strength of lateritic soil cement and mixing moisture content for soaked condition

e) Strength – Delay time to compaction

Figure 9 shows relationship between unsoaked strengths (4% of cement and various moisture contents) and delay time to compaction. For all cases, when compacted within one hour, unsoaked strengths were higher than 17.5 kg/cm^2. However, the strengths had trends to decrease linearly as delay time to compaction increased. Obviously, the unsoaked strengths were lower than the recommended strength for road subbase when compaction was delayed for 3 hours. It was also found that reduction on strength was more pronounced when compacted on dry side of OMC than when compacted at OMC or on wet side of OMC.

When the stabilized soils were soaked before testing, significant loss in strength due to delay time to compaction could be observed, as clearly shown in Figure 10. Only the cement-stabilized soils that compacted at OMC and within one hour after mixing could gain desirable strength. Soaked strengths of the other mixtures markedly decreased with delay time to compaction. However, the resultant strengths were able to sustain stresses higher than 7.0 kg/cm^2.

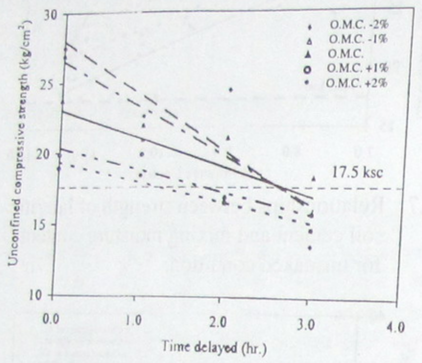

Fig.9 Effect of delayed time to compaction on strength of lateritic soil – cement (4% cement content) for unsoaked condition

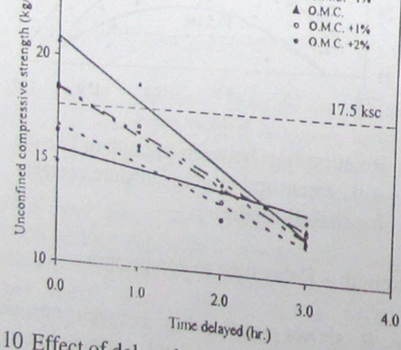

Fig.10 Effect of delayed time to compaction on strength of lateritic soil – cement (4% cement content) for soaked condition

Figure 11 shows effect of delay compaction on unsoaked strengths with various moisture contents. For a waiting period less than two hours, compaction on dry side resulted in relatively higher unsoaked strengths than the others. However, loss on strength could be found when delay time to compaction increased to three hours. Compaction with moisture contents at or close to OMC seems to obtain more favorable strengths. This evidence is true particularly when the cement-stabilized soil had to be submerged before testing and delay time to compaction was not allowed to be more than one hour, as shown in Figure 12. For longer waiting periods, delay compaction could lead to a remarkable loss in strength. This indicates that compaction of the cement-stabilized lateritic soils should be done within one or two hours after mixing. This enhances good reactions between the soil, water and cement, leading to an improvement on structural integrity and thus eventually contributes to a high early strength.

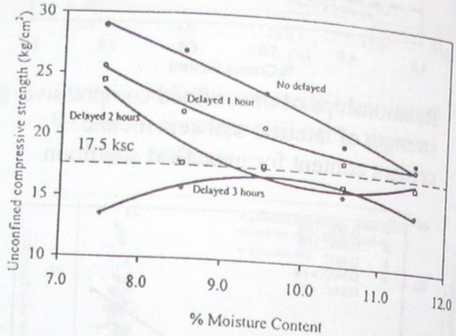

Fig.11 Effect of delay compaction on relationships of unconfined compressive strength and moisture content for unsoaked condition

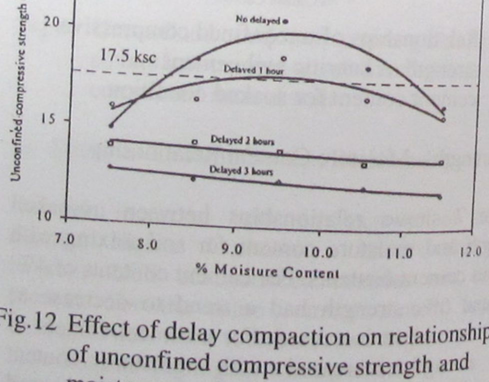

Fig.12 Effect of delay compaction on relationships of unconfined compressive strength and moisture content for soaked condition

4. CONCLUSIONS

Based on the test results, it is concluded that cement content, initial mixing moisture content and time to compaction are important compaction parameters which considerably affect gain in strength of the compacted lateritic soil cement. Basically, strength increases as cement content increases. Lateritic soil cement mixed with water at or close to OMC could gain the most favorable strength with slightly loss in strength when soaked.

Delay in compaction leads to decrease in strength. The effect is more pronounced as delay time increases. Unsoaked compressive strengths were higher than 17.5 kg/cm^2 when compacted at OMC $\pm$ 2% within a period of one hour or when compacted at OMC $\pm$ 1% within a period of two hours. Compressive strength for the soaked specimens was higher than 17.5 kg/cm^2 when compacted at OMC $\pm$ 1% and within 20 minutes, or compacted at or close to OMC within one hour. Delay in compaction may cause a decrease in strength, however, the soil cement could gain in strength greater than 7.0 kg/cm^2 when it is compacted at OMC $\pm$ 2% within 3 hours.

It is believed that loss in strength is due to loss of moisture content, decreasing in dry density and destroying of the developed hardening structures. It is therefore recommended that compaction of cement-stabilized lateritic soil should be done as early as possible and should not be longer than 3 hours, depending on the initial mixing moisture content and required strength. The unconfined compressive strengths of the stabilized lateritic soils obtained in this study showed promise for use as base and subbase courses for road.

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