THE STUDY OF FLY ASH STABILIZATION ON LATERITIC SOIL IN TAIWAN

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The Study of Fly Ash Stabilization on Lateritic Soil in Taiwan

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SYNOPSIS: A laboratory experimental investigation was carried out to study the effects of the addition of fly ash on the physical and chemical properties of lateritic soils in Taiwan. This paper describes the design of the experiment, where type F fly ash and lime were applied to two kinds of soils. Harvard miniature compaction tests, unconfined compression tests, swell tests, pH tests and atterberg limits tests were performed on the fly ash treated soil samples. Test results showed that the physical and chemical properties of treated soils had been significantly affected by fly ash-lime stabilization, including plastic indices, swelling potential and strength characteristics. Exception may occurs on the low quantity of fly ash used with soils. Using pH method to define the "Fly Ash Modification Optimum" (FAMO), as the unit for amount of fly ash addes in soil, is the effective method to approach the purpose of soil stabilization.

1 INTRODUCTION

Lateritic deposit is widely distributed in the rolling hills and coastal or river terraces of western Taiwan. They are exposed in the Linkou terrace, the northernmost of a series of high coastal terraces between Taipei and Hsinchu. The coastal terraces are all covered with the same gravel beds. In the Linkou terrace, the terrace deposit is known as the Linkou Formation which is comprised of gravel and a lateritic mantle with high shrinkage and swelling properties [1]. Cracks usually appear in the lateritic mantle near the ground surface. Seepage which flows into the cracks causes the problems of soil erosion and strength decrease. In order to improve the swelling and shrinkage properties, a fly ash stabilization method was investigated during this study.

Fly ash has been used successfully in improving engineering properties of cohesive soils by mixing fly ash with soil. Since fly ash is a product which can be obtained freely from electric power plants in Taiwan, the development of fly ash stabilization may be of economic benefit in the construction of roads and other civil engineering structures.

2 RESEARCH PROGRAM

The specific purpose of this study was to explore the feasibility of using fly ash to improve the engineering properties of Linkou lateritic soil in Taiwan.

The soil samples used in this research were natural soils obtained from flat and sloped areas which had been subjected to erosion by ground runoff water. The fly ash which was used as stabilizer was classified as type F fly ash, and obtained from the Linkou electric power plant.

A total number of 556 samples mixed with modified fly ash (hydrated lime added, FA') was prepared. The compacted samples for strength tests were cured with a constant temperature (21°C) until the time of testing. The plasticity and engineering properties of stabilized soil were evaluated in this study. The applicability of method for determining the percentage of FA' which used in soil was also analyzed.

3 MATERIALS

Linkou lateritic soil is from the Linkou Formation which is a transitional coastal sediment of the Quaternary and Pleistocene periods, usually redish-brown in color. The location of the Linkou terrace is shown in Fig. 1 [2]. Some chemical properties of Linkou lateritic soil collected from previously published data [3] are shown in Table 1. Two types of soil samples were used in this study, one taken from a depth of 1m to 2m below existing flat ground surface (soil I) and the other from the eroded area (soil II).

Fly ash used in this study was taken from the Linkou electric power plant. The composition and properties of this fly ash are shown in Table 2 [4]. For enchancing self-hardening potential of this type F fly ash, quick lime and hydrated lime used as modifier agents.

The contents of CaO in the quick lime and $Ca(OH)_2$ in the hydrated lime were both greater than 95%. In order to prevent carbonation of the limes, they were kept in sealed bottles until used.

The amount of lime used in this study were 1:12 and 1:8, as the ratio of lime to fly ash by air-dried weight. The ratio of 1:12 was concerned as the lower boundary (10% of lime in fly ash) for the self-hardening pointview. And the ratio of 1:8 was the arbitrary value for comparison purpose. The combined materials may be defined as "modified fly ash" (FA'). Since four FA's may be confused for expression, the clarified name and defination are listed in Table 3.

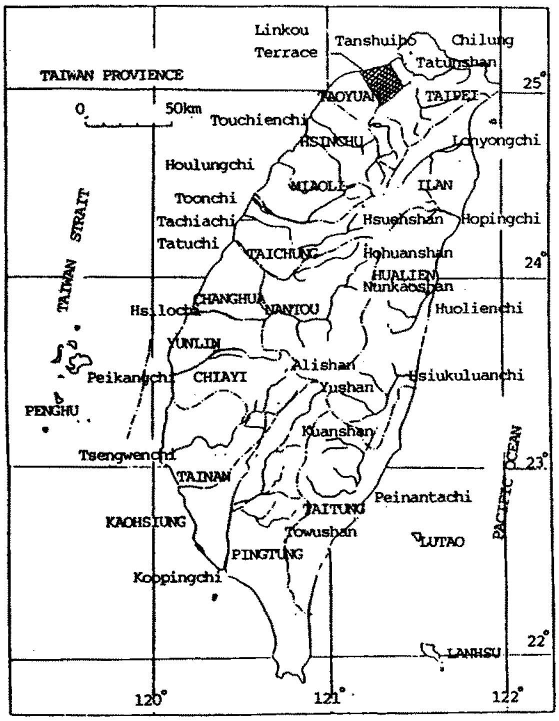

Fig. 1 - The Location of Linkou Terrace

Table 1 Chemical Properties of lateritic Soil [3]

Total Chemical analysis (% by weight)							
SiO_3	Al_2O_3	Fe_2O_3	H_2O	K_2O	MgO	Na_2O	CaO
50-70	12-20	2.5-9.4	4-12	1.2-3.3	0.4-1.4	0.3-1.2	0.2-0.7

Table 2 Composition of Fly Ash from linkou Electric Power Plant [4]

Total Chemical Analysis (% by weight)							
SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	TiO_2	SO_3	Others
51	11	27	4	1	3	1	2

Table 3 The Clarified Name and Definition of Modified Fly Ash

Lime Type	Lime: Fly Ash 1:12	Lime: Fly Ash 1:8
Hydrated (FA'_H)	FA'_{H1}	FA'_{H2}
Quick (FA'_Q)	FA'_{Q1}	FA'_{Q2}

4 TESTING

The specific gravity, grain size distribution and atterberg limits for the natural soils were determined according to the methods specified by the ASTM. Texas Linear Shrinkage Tests were performed according to the procedures suggested by the Texas Highway Department [5]. pH testing was used for determining the amount of FA' used in soil. The detailed procedure was based on the method suggested by Eads and Grim [6]. For treated soils, only atterberg limits and shrinkage limit were determined for the purpose of comparison.

A testing program for harvard miniature compaction test was used to determine maximum dry density($\gamma d,max$)and optimum moisture content (OMC), for specimen preparation. A mold of 3.38cm inside diameter and 7.06cm in height was employed. The soil was put into the mold by three layers. Each layer was compacted with twenty-five evenly distributed blows of the hammer. The detailed procedure followed the method which recommended by ASTM.

For swelling tests (free swelling and swelling pressure), the static compacted soil specimens of 7.11cm. in diameter and 15.24cm in height were sealed with PVC film and wax, in order to preserve their moisture content during the 7-days curing period. After 7 days of curing, the specimens were stored in the laboratory under air-dried condition until the moisture content of the specimens was reduced to about the OMC-6%, and then were sealed in plastic bags for one day of curing time. All of the cured specimens were tested for their free swelling and swelling pressure response according to the methods recommended by the U.S. Army Corps of Engineers [7].

Harvard miniature compacted specimens were used to evaluate the unconfined compression strength of treated soil. The compression rate applied in this study was 1.7 mm/min. The soil specimens which sealed with PVC film and wax. were stored in a humid room which was maintained at a temperature of approximately 21°C and an absolute humidity of 90%. 0, 7, and 28 days of curing periods were used in this progrom.

5 RESULTS ANALYSES AND DISCUSSION

Through grain size analysis, it was shown that the eroded soil (Soil II) slightly coarser than Soil I. And the specific gravities are 2.73 and 2.74, for Soil I and Soil II respectively. Other results are presented and analyzed below.

5.1 The variation of pH values, plasticity and shrinkage

Because the results for Soil I and Soil II are fairly similar to each other, only plotted the results from Soil I in Figure 2 and Figure 3. The determined values of FAMO are listed in Table 4.

The typical testing method which was used in the FAMO determination procedure basically followed the "LMO" (Lime modification optimum) determination method. During that procedure, the pH of soil-lime-water mixtures remains

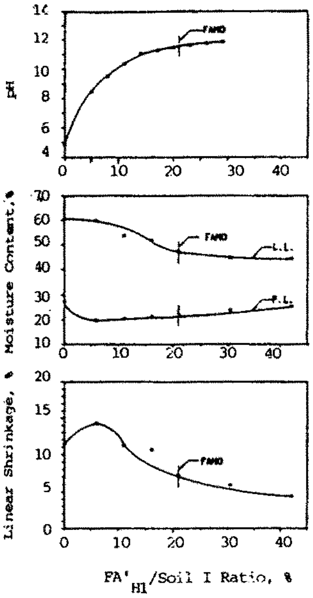

Figure 2. The Determination of FAMO for FA'$_{H1}$ Treated Soil I with the Variation of Plasticity and Shrinkage

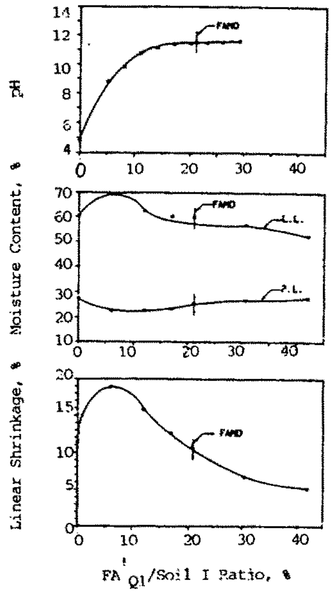

Figure 3. The Determination of FAMO for FA'$_{Q1}$ Treated Soil I with the Variation of Plasticity and Shrinkage

Table 4 The Determined FAMO Value

FA'S	Soil I	Soil II
FA'$_{H1}$	21%	22%
FA'$_{H2}$	20%	18%
FA'$_{Q1}$	21%	21%
FA'$_{Q2}$	20%	20%

constantly beyond the LMO point and the soil is constantly fixed with calcium. Through the FAMO study, some additional conditions had to be reviewed. From the results, it was apparent that the pH value would not remain constant. The values increased slightly with increases of fly ash content. Thus, for economical purposes, the FAMO may be determined at the point which represents the highest degree of calcium fixation. As indicated in Figure 2 and Figure 3, beyond the FAMO, the slope of these curves remains approximately constant and flat. The applicability of this method may be analyzed. For treated soils, both plasticity and shrinkage have abrupt changes at the FAMO. Beyond this point, change in both properties becomes gradual. This finding indicates that the determination of FAMO by the previously described method is applicable and reliable. The changes in plasticity and shrinkage of both treated soils were insignificant. The modified soils may be defined as CL or CL-CH, based only on plasticity index values. For modification purposes, these results are unsatisfactory. Thus, direct evaluation by swelling potential changes was indeed and performed.

5.2 Effect of modified fly ash on plasticity and swelling potential

For evaluation purposes, plots of the PI, percent swell and swelling pressure, together with the various FA' contents, are shown in Figure 4. It is observed that at low FA' content (0.25 times the FAMO), plasticity tends to increase, and then reduces as more FA' was added. This may have been caused that calcium broke colloidal - state of free iron oxide which coating on clay particles, and then the plasticity of the original clay mineral was represented. Also, swelling potential shows the same tendency. Because the cluster structure exists in eroded soils which have been subjected to dry-wet cyclic action, thus, the lower swelling potential resulted. And the higher swelling potential exhibited in the natural soil with the domain structure. For plasticity, the same tendency can be observed.

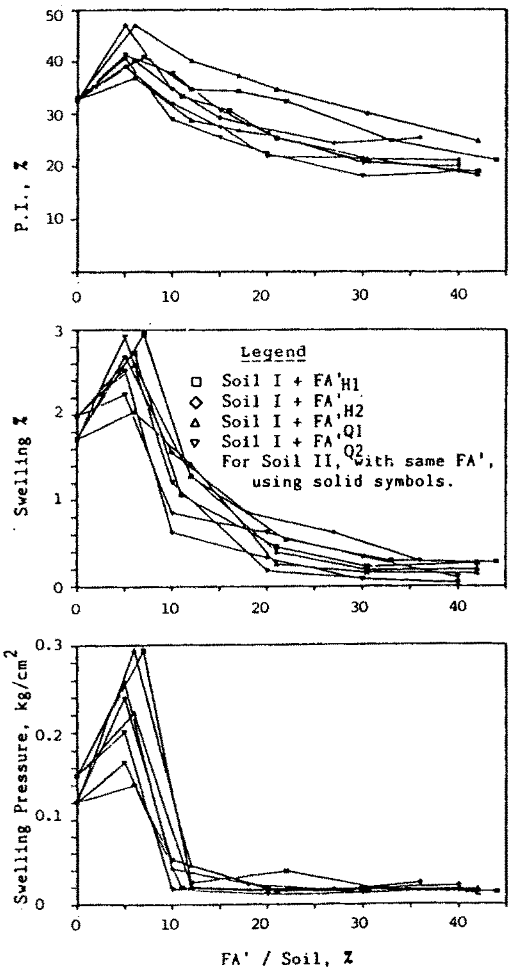

Figure 4. The Relationships among PI, Percent Swell and Swelling Pressure

In Figure 4, it is indicated that both percent swell and swelling pressure were reduced as a result of FA' action, and exhibited the negligible swelling potential as the FAMO was reached. These results directly describe the actual swelling properties of the compacted mixtures. Different findings were obtained from plasticity changes as described previously. Therefore, using plasticity to define the swelling potential for modified clay soils would be improper. Factors which affect the correlation between plasticity and swelling potential are described below.

(1) Compaction effort applied. As pointed out previously, the pH leveling condition cannot be reached regardless of how much fly ash is added, and the plasticity may not drop beyond the FAMO. Once the FAMO is obtained, the potential for clay particles to take calcium from extra fly ash is lower than that of the fly ash using calcium to form the cementing agent. It is apparent that this agent can hold clay particles together and eliminate the development of double water layers while compaction effort is applied.

(2) Curing applied. Samples prepared for the atterberg limits test were not cured. This may result the incomplete actions on cation exchange process and formation of cementing agents; these are all influence the plasticity. For swelling specimens, compaction energy was applied, as well as curing for 7 days which allowed the cementing agent to form and more complete reaction on cation exchange.

5.3 Effects of compaction behavior of FA' treated soils

In order to describe the effects of FA' on the compaction behavior of lateritic soil, curves for OMC and $\gamma_{d,max}$. versus percent of FA' are shown in Figures 5 and 6. For low percent of FA', comparison made with untreated soil, OMC decreases and $\gamma_{d,max}$. increases, and the vice versa as FA' reached to FAMO. However, Behind the FAMO, the compaction results showed that OMC values dropped with increases of FA'. On the other hand, the $\gamma_{d,max}$. tended to remain stable with increases of FA'. In this analysis, the FAMO plays an very important role as the turning point to separate the different compaction behaviors in both OMC and $\gamma_{d,max}$. It can be demonstrated in two ways:

(1) <FAMO. The cation exchange reaction has developed, and a high degree of calcium fixation has been reached at the FAMO. Thus, the plastic limit increases and makes the OMC raise. Also, a part of the soil has been replaced by fly ash with a lower specific gravity which makes $\gamma_{d,max}$. drop.

(2) >FAMO. The modified soil particle have formed a cluster structure at the FAMO. Thus, the extra fly ash has started to fill the voids. This made greater $\gamma_{d,max}$. and lower OMC than that at the FAMO.

The analyzed results from (1) and (2), may only exit with the ratios of lime to fly ash which used in this research. For other ratios, the variation of OMC and $\gamma_{d,max}$. may be represented in different way.

The findings again indicate that the suggested FAMO determination method is applicable and reasonable.

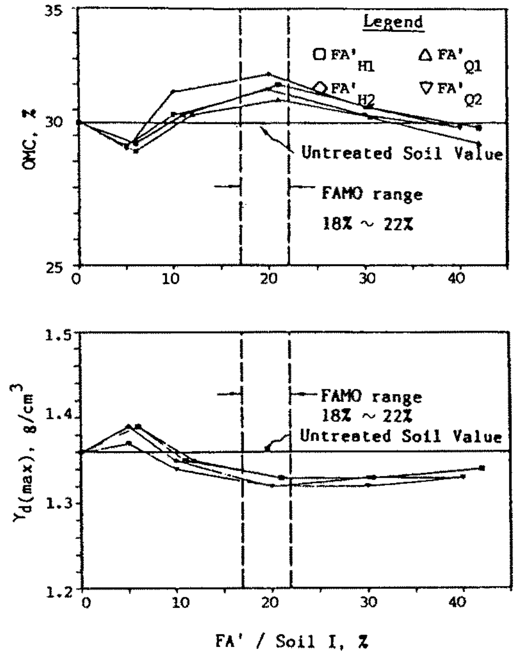

Figure 5. The Compaction Effects for Treated Soil I

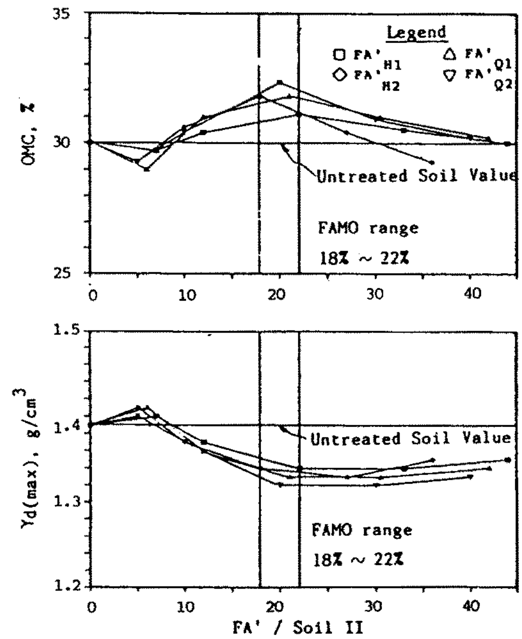

Figure 6. The Compaction Effects for Treated Soil II

5.4 Effect of modified fly ash on strength improvement

For evaluation and comparison purposes, the normalized unconfined compression strength of FA' treated soils to untreated soils for various curing periods were combined and plotted in Figure 7 and Figure 8. Using these results, several analyses can be drawn.

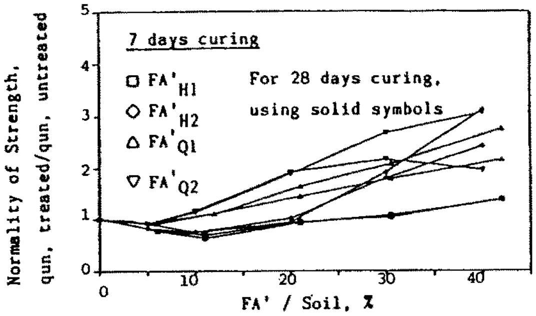

Figure 7. Soil I Strength Development with Various Ash Content for Cured 7 and 28 Days

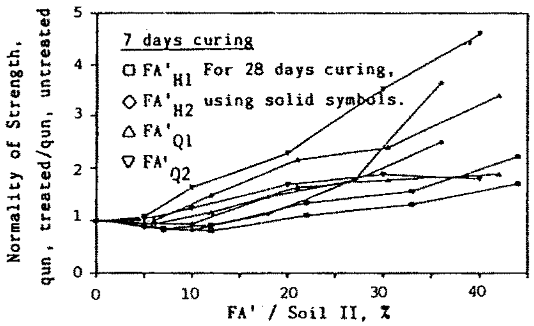

Figure 8. Soil II Strength Development with Various Ash Content for cured 7 and 28 Days

For soils cured 7 days stabilized by four FA's with percents less than the FAMO, there was no significant improvement in strength. For percent at the FAMO, only FA'$_{Q1}$ and FA'$_{Q2}$ had significant influences on strength. The significant improvement in strength was found in all samples with FA' percents of 1.5 times the FAMO and 2.0 times the FAMO. These results show that, as more FA' was used, the strength improved. The only exception was found for FA'$_Q$ in both soils, where 1.5 times the FAMO produced a higher strength than 2.0 times the FAMO. This might be caused by testing errors and no futher discussion in this paper. For 28-days curing, the results are similar to those for 7-days of curing. No significant change in strength occurred as the percent of FA' increased to the FAMO. However, for 1.5 times the FAMO, FA'$_H$ and FA'$_Q$ caused increases of strength (compared to untreated soil) which ranged from 50% to 200% and from 100% to 300%, respectively. As 2.0 times the FAMO was used, FA'$_H$ caused increases in strength from 200% to 250%, and FA'$_Q$ caused from 250% to 400% increases in strength.

Reviews of these results, it is indicated that beyond the FAMO, the types of lime and ratio of lime to fly ash are the factors which affect strength improvement. This is believed that the potential of strangth changes is caused by the extra FA' used to form cementing agent and to strengthen the compacted soil. The findings also indicate that the FAMO determination method and the defined reaction mechanisms are satisfied.

5.5 Properties variation between two types of soils

From the evaluation and analyses throughout this section, some differences between the two soil samples are obtained:

(1) Soil I has a higher PI and swelling potential than Soil II. This is believed to be due to the fact that soil II has been subjected to wet-dry cycles to reduce its swelling potential.

(2) FA' provides a higher tendency to reduce swelling potential and to improve strength for Soil.

(3) For Soil I, a higher amount of FA' is required to modify its plasticity and swelling potential and to provide strength improvement.

6 CONCLUSION AND RECOMMENDATION

The objective of the investigation reported herein was to evaluate the uses of low calcium content fly ash to stabilize two types of lateritic soils in Taiwan. The objective was realized by preparing numerous samples which were tested throughout the designed testing program. Analysis and discussion of the results may be summarized in the following conclusions:

(1) Although the plasticity of the two types of soil were not satisfactorily modified by the FA', the reductions in swelling potential were significant.

(2) For strength improvement purposes, in the ranges of 1.5 times the FAMO to 2.0 times the FAMO significantly influenced lateritic soils in Taiwan.

(3) Using determined FAMO values to control the sample preparations was found to be satisfactory.

(4) Compaction behavior of stabilized soils met the assumptions for the determination of FAMO quite well.

(5) Using the determined FAMO as a unit to select ash percentages for strength improvement was found satisfactory.

The recommendations offered as a result of the findings of this study are as follows:

(1) Other ratios of lime to fly ash for the purpose of soil stabilization should be evaluated in future studies.

(2) The effects and benefits derived should both be investigated from an economic point of view.

(3) The methods used to determine the FAMO are valid for future research use.

Recent research sponsored by the Taiwan Power Company and the Taiwan Highway Bureau includes more details of studies as pointed out above. And the results will be presented in the future.

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