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Chemical treatment of dispersive soils for earth-filled dam in Thailand

Supakij Nontananandh, *Lecturer*
Warakorn Mairaing, *Assistant Professor*
Department of Civil Engineering
Kasetsart University
Bangkok, Thailand

Takeshi Katsumi, *Research Associate*
Masashi Kamon, *Professor*
Disaster Prevention Research Institute
Kyoto University
Uji, Kyoto, Japan

ABSTRACT

The occurrence of dispersive soils and their subsequent failure to dam in Thailand ascertain the need for effective treatment prior to construction. In this study, hydrated lime is used as a hardening material to improve dispersive characteristics of the soil. Utilization of lignite-coal fly ash as a partially replacing material for lime is also examined, based on an environmental geotechnological viewpoint. Specifications based on the field-related performance have been proposed as guidelines for quality control.

The present study investigates degree of dispersion according to double hydrometer method (DHT) and by using centrifugal particle size analyzer (CPA) in order to classify a dispersive soil and to compare with the DHT standard testing method. Results revealed that CPA can be used to determine the dispersivity of the soils with high reliability.

Based on the experimental results, lime, fly ash, and their combinations, in certain proportion, show promise for use in stabilizing a dispersive soil. For the same stabilizing level, fly ash-blended lime results in a significant decrease of percentage of dispersion. The contribution of fly ash to improve dispersive characteristics is examined using X-ray diffraction (XRD) analysis and scanning electron microscope (SEM) observation. Calcium silicate hydrate (CSH), hydrated gehlenite (CASH) and ettringite are reaction products contributing to the flocculation and cementation of fine-grain soils. It is found that suitable time lag for compaction is underlying factor which effects properties of the treated soil. Engineering properties such as compressive strength and permeability are markedly improved when the soils are compacted soon after mixing. It is concluded that the chemically modified soil can be used as material for dam construction.

Chemical Treatment of Dispersive Soils for Earth-filled Dam in Thailand

by

Supakij Nontananandh[1)]Masashi Kamon[2)]

Warakorn Mairaing[3)] Takeshi Katsumi[4)]

1. Introduction

The occurrence of dispersive soils and their subsequent failures to dam in Thailand ascertain the need for effective treatment prior to construction. The treatments of dispersive soils can be either in the physical and / or chemical procedures. Chemical treatment focuses on modifying the dispersive behavior of soils by mixing them with stabilizing chemicals such as lime, gypsum, fly ash, and their combinations. Physical treatment to the prevention of leakage and cracks can be provided using a well-designed filter, good compaction, proper slope protection and foundation improvement.

Improvement of dispersive soils as a filling material for dam has been recommended based on an environmental geotechnological viewpoint;i.e., Geotechnical engineering for the prevention of environmental risks due to human activities (Kamon, et al., 1991). Concepts for a successful treatment have been proposed as guidelines for quality control.

In the beginning stage, study has been focused on the determination of optimal mixes and their subsequent effects on properties of the treated soils. In situ trial test sections have been also carried out before actual construction, in order to determine the actual mixing efficiency and the modified properties of the soils. Hydrated lime ($Ca(OH)_2$) is used as a stabilizing material to improve dispersive characteristics of the soil. Utilization of lignite-coal fly ash as a partially replacing material for lime is also examined in order to explore prospective for resource recovery of this material.

The present study investigates degree of dispersion according to double hydrometer method (DHT, ASTM D422). This classical test is then compared to the test using a centrifugal particle size analyzer (CPA) to determine the gradation of soil particles. According to ASTM D4221, the double hydrometer test for the determination on dispersive characteristics of soils, degree of dispersion (DDS) can be expressed as;

$$DDS = \frac{\%\ \text{particles finer than } 5\mu m (\text{ASTM D4221})}{\%\ \text{particles finer than } 5\mu m (\text{ASTM D422})}$$

Identification of dispersive soils based on inherent degree of dispersion can be determined as follows,

- For dispersion of 0-33%, the soils are non-dispersive
- For dispersion of 34-66%, the soils are moderately dispersive, and
- For dispersion of 67-100%, the soils are highly dispersive.

Experimentally, the approach used in this study also consisted of X-ray diffraction analysis (XRD) and scanning electron microscope (SEM) observation to investigate stabilizing effects of the chemically treated soil mixes; i.e. contribution of lime and fly ash on the particle flocculation and cementation.

2. Dispersive Soils and Relevant Problems in Construction

Dispersive soils are one of those regional soils that have been found substantially world wide. In Thailand, they are widely distributed in northeastern and eastern regions. Some are found in northern and central regions. The so-called dispersive soils can easily erode due to chemical deflocculation of the clay particles in the presence of water from the sources outside. According to Sherard et al. (1972), dispersive action occurs when repulsive forces between clay particles exceed attractive forces, causing these fine particles remain in colloidal state even in still water. Visual evidence can therefore be seen easily through the observation on turbidity of eroding water in the

1), 3) Lecturer and Assistant Professor., Department of Civil Engineering Kasetsart University., Bangkok 10903, Thailand

2), 4) Professor and Research Associate, Disaster Prevention Research Institute, Kyoto University,Gokasho, Uji, Kyoto-611, Japan.

ponds or reservoirs nearby. The dispersive soil can also be observed by the erosional features in the forms of gullies, sinkholes, and piping tunnels.

Dispersive characteristics are inherently underlined by many factors such as sodium and bicarbonate ions concentration, type of clay minerals and subsequent specific surface areas, and the total salt concentration of eroding water (Holmgren and Flanagen, 1976; Cole et al., 1977; Udomchoke, 1991). Enhancement on chemical pipings are related to subsequent formation of expansive double layers of clay particles which results in an increase of repulsive forces, causing dispersion. Therefore, successful treatment for dispersive soils can be achieved by the addition of active chemical agent in order to suppress the diffused double water layer, or turbidity in the basin water.(Mc Donald et.al., 1985)

Soil dispersivity can be determined in accordance with several identifications. These methods include physical index tests such as field crumb test, dispersion test, dilution turbidity ratio test, and pin hole test (Emerson, 1969, Ryker, 1976; Sherared et.al., 1976) and the chemical index tests such as exchangable sodium percentage (ESP) and sodium adsorption ratio (SAR) (Richards, 1954). The double hydrometer test(ASTM D4221) is selected in this study because the test procedure is reliable and similar to the method for particle-size analysis of soils (ASTM D422), which is easy to understand by engineers.

Destructive phenomena in civil engineering structures such as earth-filled dam, embankment and dike, irrigation canal can often be seen due to piping of soils. Dispersive soils are among those of problematic soils which are susceptible to unusual erosion and may lead to failure of structures.

For earth-filled dams constructed with dispersive soil, failures could be existed both at short- and long time; i.e., soon after the completion of construction and the first reservoir filling and the repeated wetting and drying encountered over time. In Thailand, it has been reported in the past decades that several dams constructed in the northeastern region were subjected to catastropic failure due to leakage at the beginning stage of reservior operation. Also, minor damages could be found in several other dams. Photo 1 shows an example of surface erosions which are formed in the patterns of gullies, sinkholes and piping tunnels, occuring along the dam slope. The results of destructive phenomena such as this have led to studies to improve the dispersive characteristics of the soil.

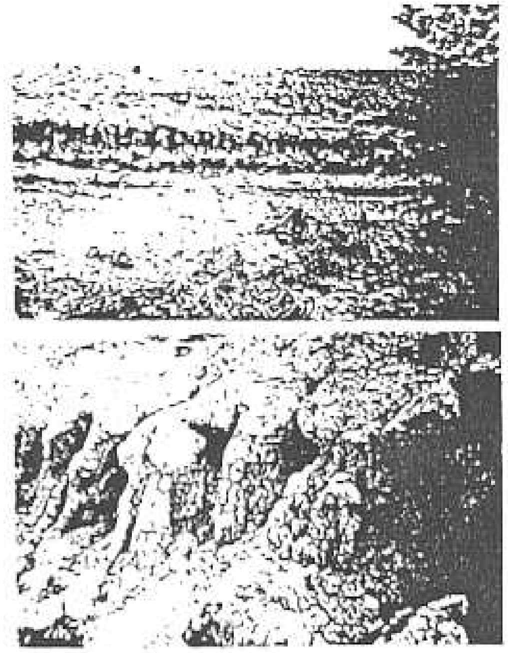


Photo. 1 Erosion on dam slope due to the dispersive effects of soils.

3. Concepts of Lime Treatment and Design Requirement

The main concept of lime treatment for dispersive soils is to improve their dispersive characteristics so that the soils become non-dispersive eventually. It is essential that the chemically modified soils are able to achieve serviceability and will retain their good stability on dam slope throughout their service life. Therefore, adequate consideration of the comprehensive specifications concerning chemical as well as engineering properties is a very important step in the overall construction process.

Typical section of earth-filled dam is shown in Fig. 1. In order to increase safety of the dam, the protection layers on dam slope must be provided in good functions. Slope protection includes material such as native soil, sand and gravel bedding, and rock riprap. When dispersive soils are unavoidably used to fill up the dam, stabilization of the outter layer must be made for the elimination of dispersive defects before other slope-protection materials are laid down. Recommendation for specification of lime treatment is summarized in Table 1, accompanying with the following concepts.

Degree of dispersion lower than 20% indicates a satisfactory non-dispersion with high reliability since under normal condition, the hardened soil has higher density and less surface-water infiltration.

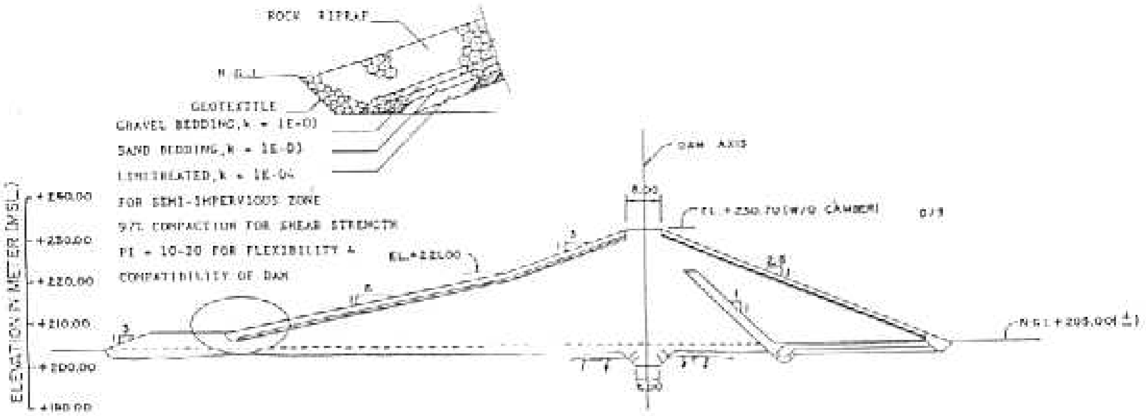


Fig 1. Typical section of dam (Mun Bon Project, Korat, Thailand)

Requirements for plasticity index and permeability of the soils are made in order to provide a flexible workability and good interfaces; i.e. increase materials' compatibility between untreated and treated soils. This associated with compaction control in the field will significantly increase the whole stability of the dam.

4. Laboratory Study and Field Test for Lime Treatment of Dispersive Soils.

Experimental studies are performed in accordance with the standard tests in Table 2. The properties of materials used in this study are given in Table 3(a) and (b). In the beginning stage, experiments were mainly concerned on the determination of optimal mixes for the convertion of the soils to be non dispersive material. Following the recommendation of RID (1989), it was decided to compacted the soils which are treated with certain types of additives after mixing for 4 days.

Table 1. Specifications for lime-treated soil in this study.

Chemical property	Physical and Engineering properties		
Degree of dispersion by DHT, %	Plasticity Index,%	% Compaction	Coefficient of Permeability, cm/sec
≤ 20	10 -20	≥ 97	≤ 1E-04

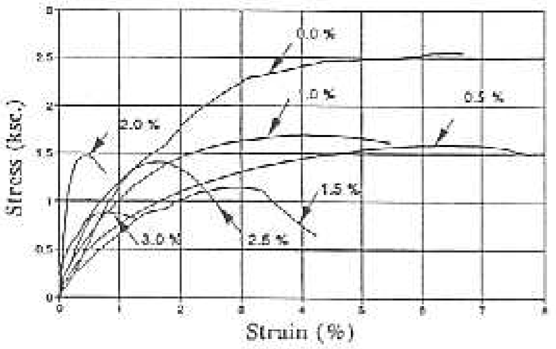


Fig. 2 Unconfined compressive strength of lime-treated Soil (Compacted after 4 days)

Table 2 Laboratory and Field Test Standard

Test	Standard
Sieve and Hydrometer Analysis	ASTM D 422
Consistency Test	ASTM D 423 - 424
Standard Proctor Test	ASTM D 689
Unconfined Compression Test	ASTM D 2166
Direct Shear Test	ASTM D 3080
Degree of Dispersion	ASTM D 4221
Permeability Test	ASTM D 2434
Field density Test	ASTM D 1556

Table 3 (a) Properties of soils.

Soil Property Test	Borrow 1	Borrow 2
(a) Grain Size Analysis		
Fine Gravel [9.52 - 4.76 mm (%)]	0.00	3.00
Sand [4.76 - 0.074 mm (%)]	40.00	50.00
Silt and Clay [less than 0.074 mm (%)]	60.00	47.00
(b) Consistency Test		
Liquid limit [w_{LL} (%)]	33.30	31.00
Plastic limit [w_{PL} (%)]	13.80	15.30
Plasticity Index (PI)	19.50	15.70
(C) Standard Compaction		
Maximum dry density (t/m^3)	1.91	1.86
Optimum moisture content (%)	13.50	14.20
(d) Dispersive Characteristic		
Dispersive Identification	Highly	Medium to none

Table 3 (b) Chemical compositions of Fly ash

Type	Composition (%)						Ignition
	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	SO_3	loss,%
LigniteFly ash	29.8	18.2	22.2	14.4	4.0	8.9	0.2

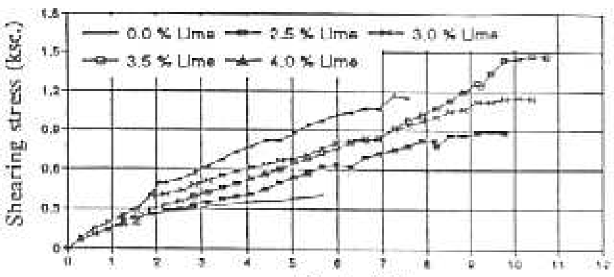


Fig. 3 Shear strength of lime-treated soils

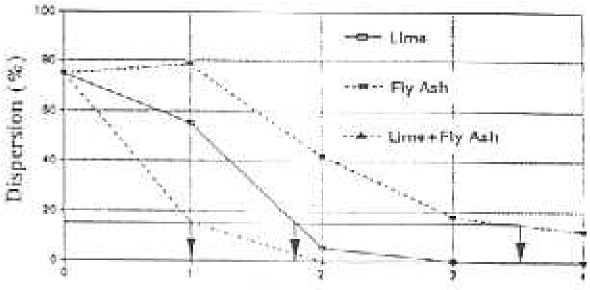


Fig. 4 Degree of dispersion of soil before and after mixing with various type of stabilizer and mix proportions (at 4 days)

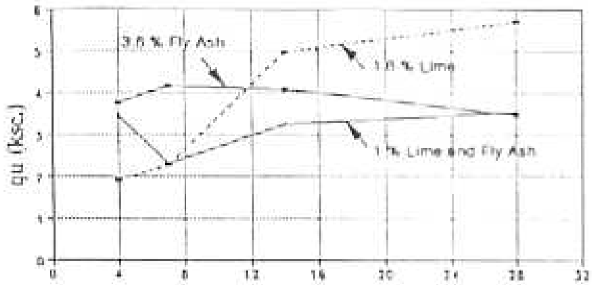


Fig. 5 Compressive strength of mixed soils at the predetermined mixing ratio. (compacted after 4 days curing)

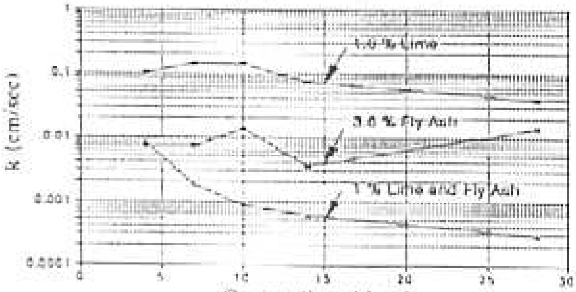


Fig. 6 Coefficient of permeability at the predetermined mixing ratio. (compacted after 4 days curing)

Results on the unconfined compressive strength and shear strength of the lime-treated soils (Figs. 2 and 3) revealed that the soils (Borrow 1) became less cohesion and more brittle as lime contents increase. In order to maintain the plastic behaviors, the appropriate lime contents should be less than 2%. For all samples, the unconfined compressive strengths were lower than the compacted natural soil.

Based on reduction of dispersion, the optimal contents for each additive to modify the soils are 1.8% by wt. for lime, 3.6% for fly ash, and 1% for lime containing fly ash with a weight ratio of 50:50 (Fig. 4.). Compressive strengths of the soils at the predetermined mixing ratio show an increase of strength with time. Improvement on the early strength due to the addition of fly ash can be observed. The benefit of lime in terms of strength is markedly obvious at a prolonged curing time, as illustrated in Fig. 5. Coefficients of permeability of all mixes, as shown in Fig. 6, indicate that lime additive and a combination of lime and fly ash have potential to decrease the permeability of the soil. However,the coefficient of permeability of lime-treated soils which were compacted after 4 days curing was relatively higher than that recommended in the specification. Too high permeability may lead to erosion of the unstabilized soil below. The results light up the idea that compaction should be done soon after mixing rather than to wait (for the confirmation on a decrease of dispersion ratio) and then compacted after a specified period of 4 days.

In order to elucidate the effects of prolonged compaction time on the engineering properties, the preliminary tests were performed and results are summarized in Table 4. Higher strength could be attained for the soils that were compacted just after

Table 4 Compressive strength of untreated soil and soils mixed with lime at a curing period of 4 days.

Materials	Compressive strength[2] ksc.	% peak strain[2]	Remarks
untreated soil	2.43	5.3	
soil mixed with lime (1.8%)	2.67	1.0	compaction immediately after mix
soil mixed with lime (1.8%)	1.90	[illegible]	compaction after a curing period of 4 days

Note 1) Compaction was performed using [illegible] Miniature Test.
2) Compressive strength and [illegible] are the average values of 3 samples

Table 5 Percent passing 5 μm of dispersive soil and soils mixed with certain types of stabilizer.

Soil	Percent passing 5 μm, in according to	
	Hydrometer	CPA
soil (ASTM D 422)	22.10	23.94
soil (ASTM D 4221)	29.80	30.80
soil + 1% lime	16.50	20.61
soil + 2% lime	7.80	11.26
soil + 3% lime	0.00	2.15
soil + 4% lime	0.00	1.26
soil + 1% FA	23.50	26.01
soil + 2% FA	12.50	22.75
soil + 3% FA	5.50	6.14
soil + 4% FA	4.20	3.85
soil + 1% L-FA	4.40	14.24
soil + 2% L-FA	0.00	1.27
soil + 3% L-FA	0.00	2.06
soil + 4% L-FA	0.00	1.54

Note: L-FA for lime containing fly ash (50:50) and FA stands for fly ash.

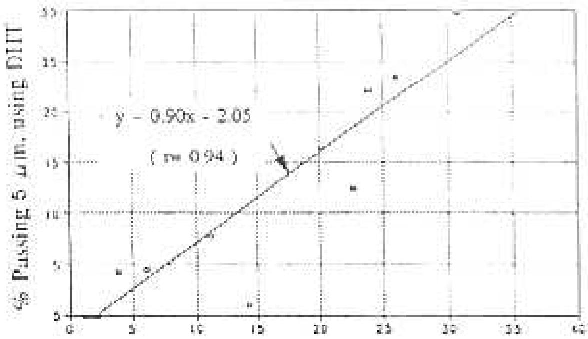


Fig. 7 Correlation between DHT and CPA

mixing. The peak strain, however, was rather small compared to the untreated soil. It is therefore recommended that lower lime contents and / or soil having less dispersive property should be used.

As a result of reaction, additives added into the soil affect the engineering and physico-chemical properties of the soil. The hardening effect will establish cementitious bonds connecting soil flocs together, resulting in an increase of resistance to an externally applied load and an increase of particle size. Table. 5 shows the percentage of particles size

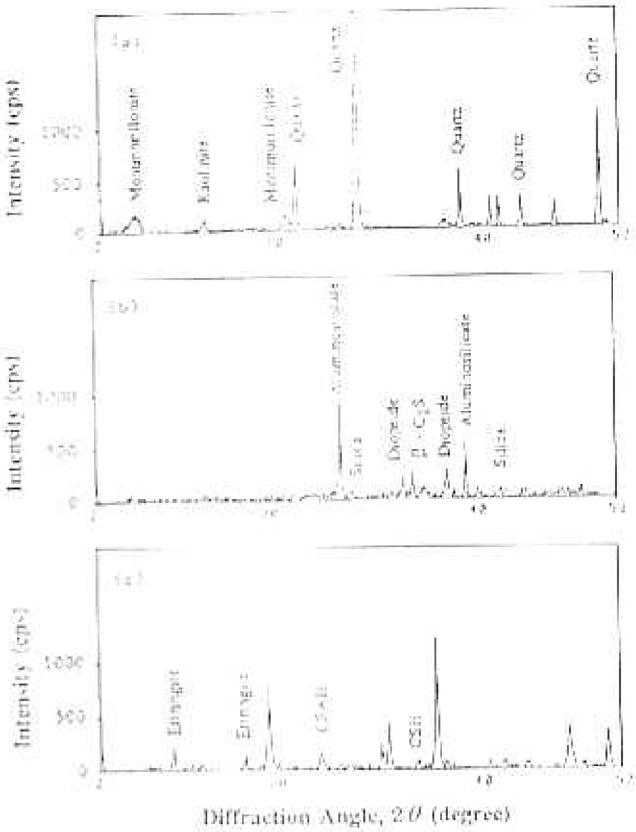


Fig. 8 X-ray diffraction patterns of

(a) Dispersive clay

(b) Fly ash

(c) Lime+Fly ash (50:50)

(w/c ratio = 35%) 28 days curing period

smaller than 5 μm which contains in the soils. It is evident that the treated soils have a smaller percentage of 5 μm soil fraction than the untreated soil.

Investigation on the particle sizes, i.e. the degree of dispersion, using the application of double hydrometer test (DHT), is simple. Similar results to DHT could be obtained when the centrifugal particle size analyzer (CPA) was used. Correlation between DHT and CPA is consistent to a linear regression line, the equation of which is expressed in Fig. 7. The result thus confirms the use of CPA as equally reliable as DHT. The benefits of using CPA is prominent as it takes a shorter time and requires a smaller amount of soil when compared to the classical test.

The typical X-ray diffraction pattern (XRD) of the dispersive soil, as shown in Fig. 8(a), indicates that the soil is composed of large amounts of silica (in the form of quartz) and montmorillonite as major minerals, and small amounts of kaolinite and amorphous materials. Fig. 8(b) and (c) illustrate the XRD patterns of the untreated lignite-coal fly ash and hydrated fly ash blended lime mixture, respectively. Obviously, the peaks corresponding to quartz (SiO_2) and alumino silicate are well reflected. The XRD pattern of fly ash also exhibits peaks of silica (SiO_2), diopside ($MgO.CaO.2SiO_2$) and $\beta - C_2S$ compounds. When lime is added into fly ash and in the presence of water, the changes in mineral compositions could be observed. As shown on Fig. 8(c), the lime fly ash mixtures cured for 28 days show significant attenuation of alumino silicate compound, diopside and $\beta - C_2S$ peaks and increase in ettringite, calcium silicate hydrate (CSH) and hydrate gehlenite (CASH) peaks, which, it is believed, contribute to particle imparting mechanisms.

Observation by scanning electron microscope (SEM) supports the results by XRD. Photo 2(c) and (d) show markedly changes in the mineralogical phases of fly ash in the presence of lime and water. It can be noted that the surface of the spherical fly ash particles are abundantly covered by reaction products, agglomerating fine grains into clusters. The mechanisms explain the contribution of fly ash to the particle cementation; i.e., resulting in an increase of compressive strength and less permeability as curing periods increase.

The electron micrographs [Photo 3 (a)-(c)] reveal that fly ash particles in lime-stabilized dispersive soil act as spherical cores where upon reaction products are formed extensively. The modified interactions of microstructures, however, are seemingly less prominent for the lime-soil treatment and fly ash-soil treatment, respectively.

Although lignite-coal fly ash shows potential for use as a replacement material for lime. The effects of fly ash on lime-treated soils need further elucidation. Thus, for practical and economical reasons, it was decided to use only lime to modify the dispersive soil in a large-scale test section.

The properties of the soil used in field test section is given in Table 3(a); designated as "Borrow2". The soil is moderately dispersive. Preliminary test on trial mixes indicated that the practical lime admixtures ranged from 0.5-1.5% by weight of soil. It was decided to use 1% of lime mixing with the soil in the field. Photo 4 shows test sections for lime treatment. Two test sections of 20 m. in width × 60 m. in length and 30 cm. in thickness were prepared. In order to elucidate the compaction-time lag effects, one test section was subjects to the compaction by sheep foot roller just after mixing. The other was compacted after being mixed and cured for 4 days. Sample were randomly taken and laboratory tests were performed.

Results obtained recently, as shown in Figs. 9 and 10, confirm that the dispersive soils from both test sections could be modified to produce non-dispersive materials having chemical properties consistent to the specifications recommended in Table. 1. However, engineering property such as permeability was markedly improved for the soils that were compacted soon after mixing. The resultant properties of the soils in this case show promise for use as material for dam construction.

5. Conclusions

Based on the test results, it is concluded that lime, fly ash, and their combinations, in certain proportion can be used as a stabilizer for a dispersive soil. Stabilized soils appear satisfactory as material for dam construction. In conclusion, degree of dispersion of the soil, type of stabilizer, stabilizer content, mixing efficiency, method of compaction and time for curing are underlying factors that control the degree of stabilization.

The quality of this modified soil can be controlled by precedently determining the dispersive characteristics and their appropriate mixes, using the recommended specifications as quideline. It is necessary that a large-scale test section should be carried out, prior to actual constructions.

Improvement on dispersivity and engineering properties of soils related to chemical treatment is attributed to early hydration and pozzolanic reaction. Calcium silicate hydrate (CSH), hydrated gehlenite (CASH) and ettringite are major reaction products which contribute to the particle imparting effects and strength developing mechanism. The reactions are prominent when some pozzolana such as lignite-coal fly ash is added into lime.

Research on chemical treatment of dispersive soil has been carrying on to search for practicality and / or economics as well as data for long-term durability.

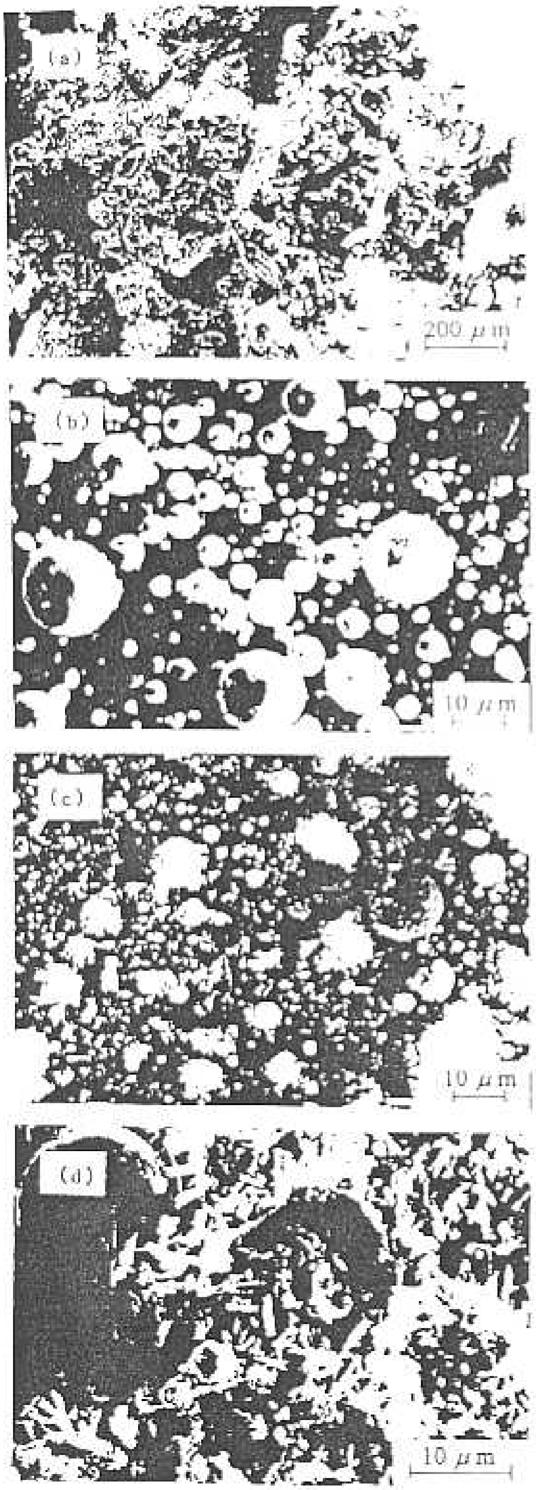


Photo 2 Scanning electron micrographs

(a) Untreated soil

(b) Fly ash

(c) Unhydrated lime and fly ash (50:50)

(d) Hydrated lime and fly ash (50:50)

(w/c = 35 %., 28 days curing)

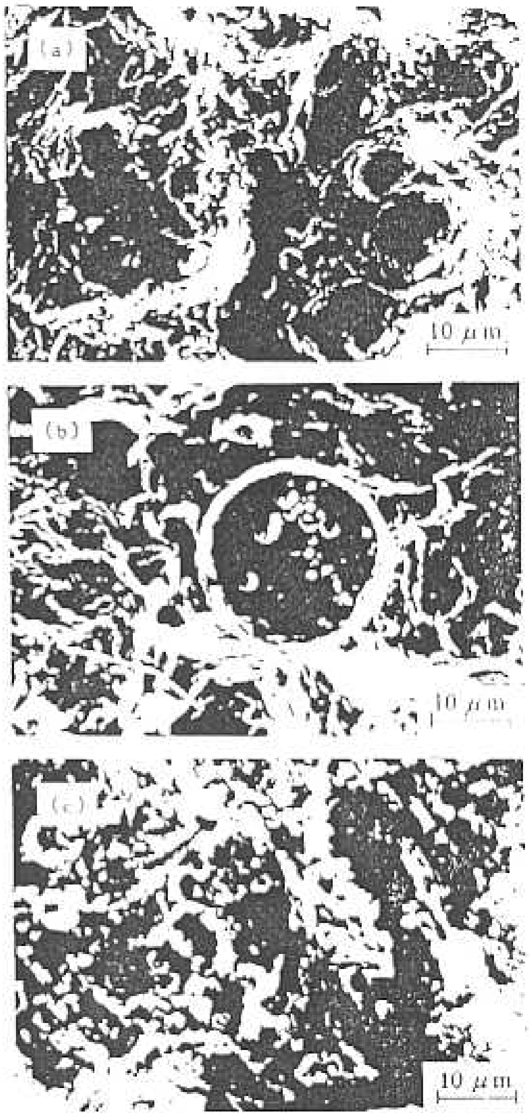


Photo 3 Scanning electron micrographs

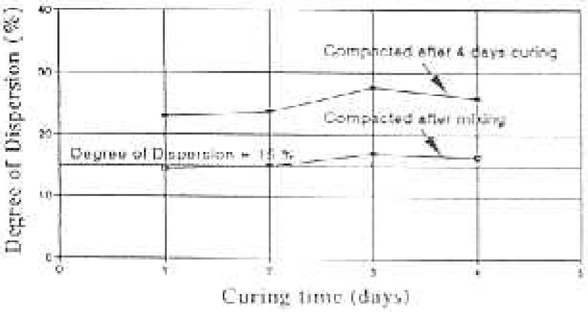
of soils treated with

(a) Lime and Fly ash 2 %

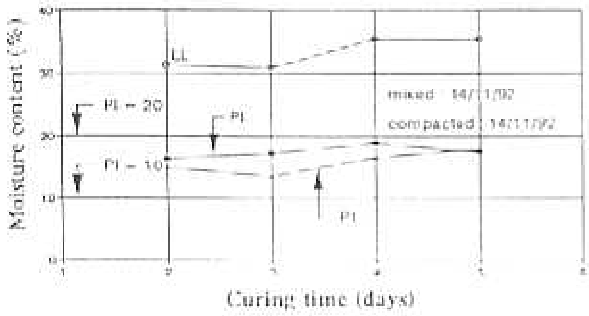
(b) Fly ash 3 %

(c) Lime 2 %

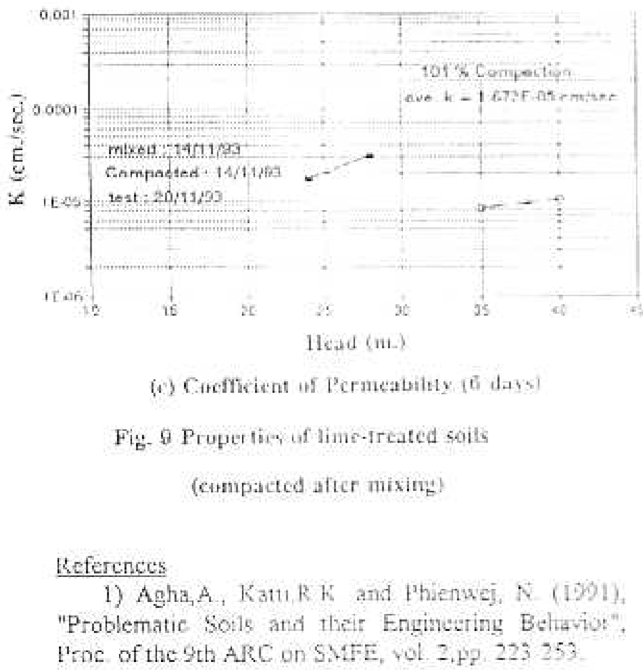
(compacted after mixing)



(a) Degree of dispersion by DHT



(b) Consistence of lime-treated soils



(c) Coefficient of Permeability (6 days)

Fig. 9 Properties of lime-treated soils

(compacted after mixing)

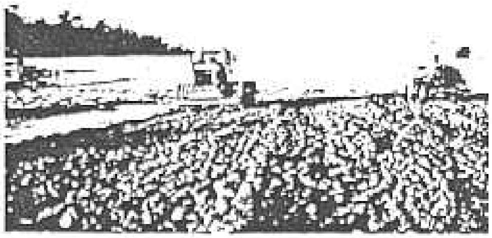
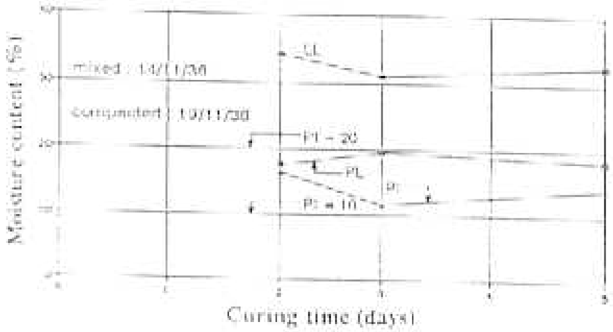
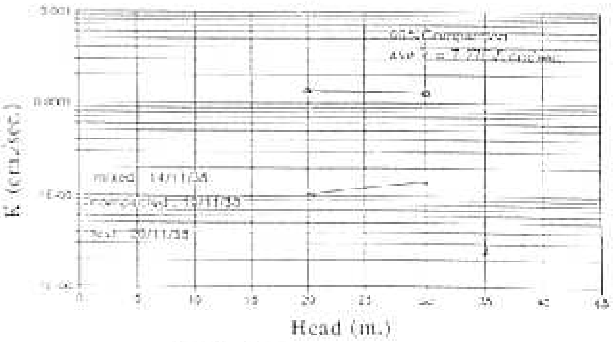


Photo 4 Test section of lime treatment;

mixing and compaction process



(a) Consistency of lime-treated soils



(b) Coefficient of Permeability (6 days)

Fig.10 Properties of lime-treated soils

(compacted after 4 days)

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