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STABILIZATION OF DISPERSIVE SOIL USING HYDRATED LIME

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ABSTRACT

Lime stabilization is one of the most practical methods to improve undesirable characteristics of the so-called *dispersive soils*, which are susceptible for severe erosion when wet. In Thailand, the technique is often recognized as *Lime treatment*. The major advantages are attributed to the physico-chemically stabilizing effects due to soil-lime reactions so that the stabilized materials can be used safely as a construction materials for earth-fill typed infrastructures such as dam, embankment and so on.

This study has focused on the comprehensive tests in order to assert a better understanding on essential factors by which the improved properties such as strength, plasticity and soil permeability are controlled. Durability test under repeated wetting and drying cycles has also been performed in order to evaluate the ability of the stabilized materials to withstand changes on environmental condition. Emphasis has been paid on the effects of soil properties such as initial degree of dispersion, initial grain size, and the effects of compaction techniques on the degree of stabilization and durability characteristic. An overview on the sequential construction on lime treatment for Mun Bon Dam is presented and practical guidance for quality control has been recommended.

Experimental results have revealed that stabilization of dispersive soil can be achieved with high satisfactory level when the soils are mixed properly with their optimal lime contents and with sufficient water for mixing and curing, depending on the initial degree of dispersion. The properties of the lime-stabilized soils are improved significantly by allowing the soil-lime mixture to compact soon after mixing. It is believed that the prompt treatment promotes good contacts between the reacting hydrated lime and soil particles, and thus enhance the early hydration. Based on the regular field test during the construction and timely comprehensive tests on the lime treatment of Mun Bon Dam project, it is concluded that the stabilized materials exhibit good performance as slope protective base courses.

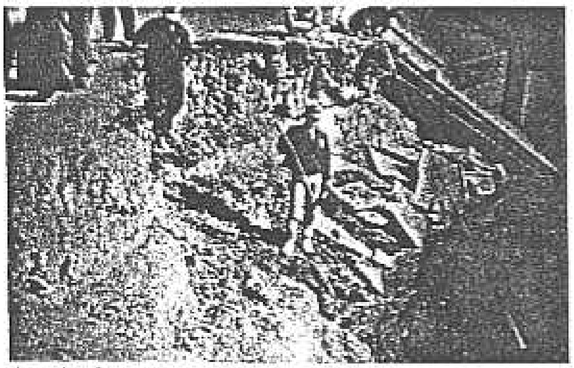
1. INTRODUCTION

Dispersive soils are one of those regional soils that have been found substantially worldwide. 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 suspension even in still water. Visual evidence can therefore be seen easily through the observation on turbidity of seepage water in the ponds or reservoirs nearly. The dispersive soil can also be observed by the erosion features in the forms of gullies, sinkholes, and piping tunnels.

Soil dispersivity can be determined in accordance with several identifications. These methods include the physical index tests such as field crumb test, dispersion test in accordance with ASTM D4221, dilution turbidity ratio test, and pinhole test (Emerson,1969; Ryker, 1976; Sherard et al.,1976) and the chemical index tests such as exchangeable sodium percentage and sodium adsorption ratio (Richards, 1954).

Damages in civil engineering infrastructures such as earth-filled dam, embankment, and irrigation canal can often be attributed dispersive soils whose erosions may lead to failure of structures. *Figure 1* shows some examples of dispersive effects on earth-filled structures. In Thailand, it has been reported in the past decade that several dams were subjected to severe failures due to leakage at the first season, while many irrigation canals failed after operations for several years. Occurrence of dispersive soils and results of destructive phenomena such as this ascertain the need for effective treatment prior to construction.

Treatment of dispersive soils can be either in the physical and/or chemical procedures. Physical treatment can be provided using well-designed filter, good compaction, and provision of sufficient slope protection. Chemical treatment aim at improving their dispersive properties so that the soils become nondispersive eventually. This can be accomplished by mixing the soils with optimal amounts of stabilizing chemicals such as lime, fly ash, and their combination (Supakij et al., 1994) or other cementing material such as cement. For a large-scale earth filled dam, when soils in the nearby area are dominantly dispersive, combination of physical and chemical treatments is used to increase the stability, such as for the case of Mun Bon Dam.


(1-a) Severe collapse of fill material under concrete slab of an irrigation canal

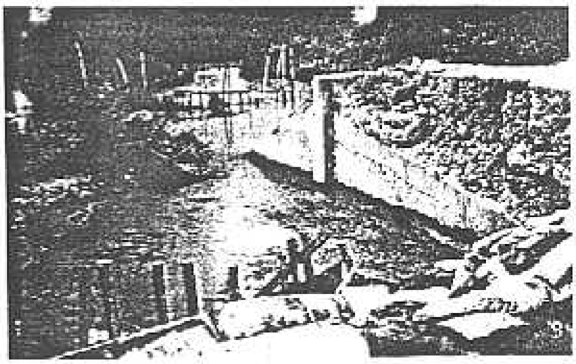

(1-b) Completely failure of tributary canal

Figure 1 Dispersive effects due to erosion on earth-filled embankments.

2. CURRENT RESEARCH AND TEST PROGRAM

Our preliminary study (Supakij et. al, 1994) has shown that addition of 2-3% of hydrated lime improves chemical behaviors of moderately and highly dispersive soils while compaction of the lime-treated soil promotes additional improvement to engineering properties. The double hydrometer test in according to ASTM D4221 is used effectively to identify degree of dispersion of soil. Based on the results from field test sections associated with laboratory testing, it can be concluded that degree of dispersion, plasticity index, relative compaction, and permeability are essential factors which control quality of the stabilized soils for dam slope protection purpose.

In addition, a construction guideline which called for : degree of dispersion (DHT) at ≤ 20 %, Plasticity Index (PI) between 10 - 20 %, Percent Compaction at ≥ 95 % Standard Proctor and Coefficient of permeability at ≤ 1 E-04 cm/sec, has been proposed. It has been used to control quality of the construction of lime-treated layer compacted on the slope for Mun Bon Dam Rehabilitation project (Supakij, 1993, Warakorn and Supakij, 1995)

This paper continues research on the stabilization of disperive soil using lime treatment technique. The main objective is to illustrate the improved properties of the soil via the comprehensive laboratory tests in order to assure field performance of the lime-treated soil layer in the site. A summary on the field practice of lime treatment for Mun Bon Dam Project is also presented. Experimental program as illustrated in *Figure 2* below is conducted to study the following areas;

- Evaluate the effect of initial degree of dispersion and initial grain size of the soil
- Further substantiate the tests on the effects of improvement technique
- Determine the durability in term of the unconfined compressive strength test (UCS) of the stabilized soil after wet-dry cycles.

Soil sampling, General property test, Soil Classification
Identification of degree of dispersion

↓

Trial mix proportions of natural dispersive soil
to obtain the predetermined initial soil dispersions
which are identified as moderately and highly dispersion

↓

Scarification of air-dried soil
to obtain the initial soil grain with different sizes
which cover the range of field applicability

↓

Laboratory tests on Physical and Engineering Properties (before mixing)
which include UCS, Compaction, Atterberg's limits and Permeability tests

↓

Determination on the optimal mix proportions of lime

↓

Laboratory tests on Physical and Engineering Properties (after mixing)
which include UCS, Compaction, Atterberg's limits and Permeability tests

↓

Durability test under repeated wet and dry cycles in conjunction with UCS test

Figure 2 Flow chart of the experimental program

3. RESULTS AND DISCUSSION

3.1 INITIAL DEGREE OF DISPERSION AND INITIAL GRAIN SIZE

According to the preliminary soil sampling in the borrow areas of Mun Bon Dam Project, two types of soils with different initial degree of dispersion were obtained. One group could be identified as nondispersive soil having an average DHT ratio of 27.03 %. The other has an average DHT ratio of 84.15 %, which therefore was classified as a highly dispersive soil. The latter will be selected as a soil representing highly dispersion group for further subsequent tests. In order to obtain another representative soil which has initial degree of dispersion substantially defined as moderate dispersive clay, trial mix proportions were performed by varying the amount of highly dispersive and nondispersive soil.

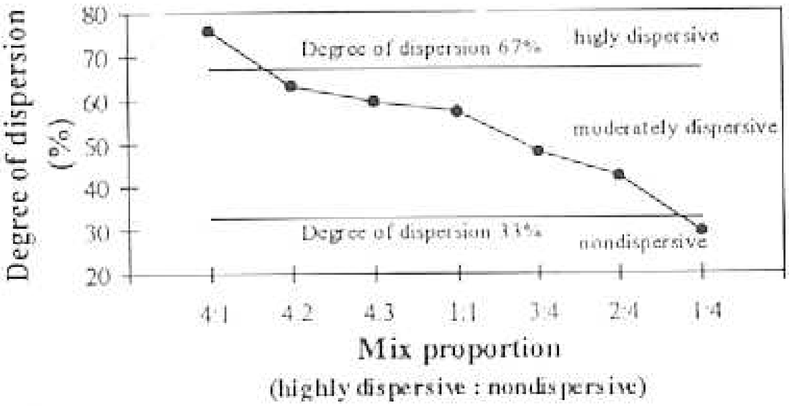


Figure 3 Degree of dispersion of trial mix to determine a mixing ratio for producing moderately dispersive soil group

Figure 3 illustrates the results of the double hydrometer test for the trial mix proportions of the soil. Obviously, the degree of dispersion decreases with an increase quantity of nondispersive soil into the mixtures. The mixing ratio between highly dispersive soil and nondispersive soil of 4:2, which has a corresponding degree of dispersion of 62.84 %, was selected to produce a soil representing for moderately dispersion group since it is close to the natural soil found in borrow area.

Theoretically, inasmuch as relatively small grain size of the soil can be scarified, the chemical reaction of lime-stabilized soil mixture is easily progressed. However, in practical procedure such as for area mixing method, to crush soil lumps into particles smaller than 25 mm is rather time consuming and even more difficult particularly when wet.

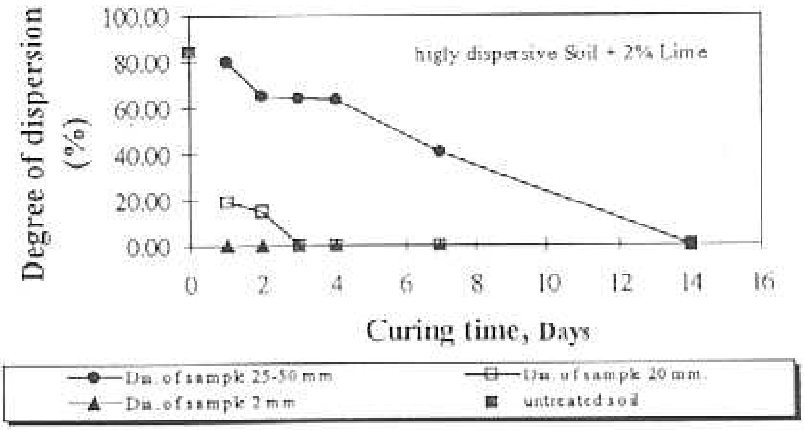


Figure 4 Relation between initial grain sizes and degree of dispersion at various curing time.

Figure 4 shows results which are agreeable to the fact that initial grain size of the soil affects rate of improvement on soil dispersiveness, especially at the early age. Soil having the average grain size larger than 25 mm initially reacts slower than those of smaller in sizes. However, after 12 days or longer, the stabilized soil with initial grain size within a range of 25-50 mm can satisfy the criteria for lime stabilization purpose.

Figures 5 and 6 illustrate the relations between degree of dispersion against time for the lime-stabilized soils with various stabilizing contents. For moderately dispersive soil, lime reaction causes significant reduction in the degree of dispersion. Trend for declination seems to intensify and conforms to the desired value when lime content is increased from 0.5% to 1.0%. However, there has been some questions of the permanency of the hardening effects due to lime reaction at the early curing period, which thus needs further substantiation in future work.

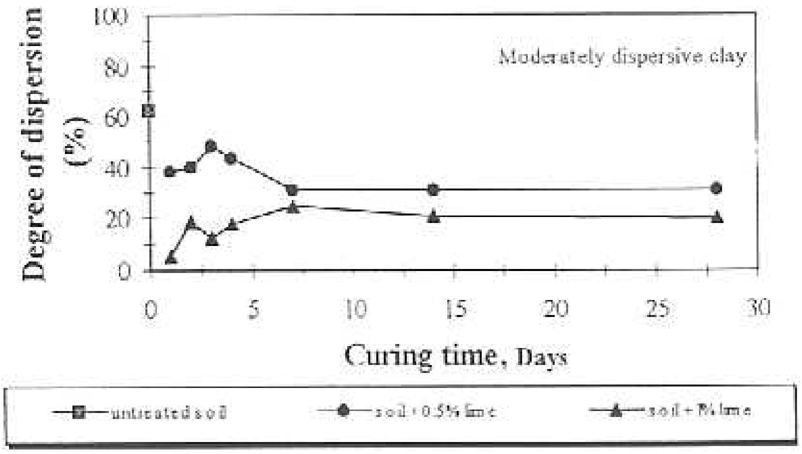


Figure 5 Relation between degree of dispersion of moderately dispersive soil stabilized with lime in corresponding to curing time.

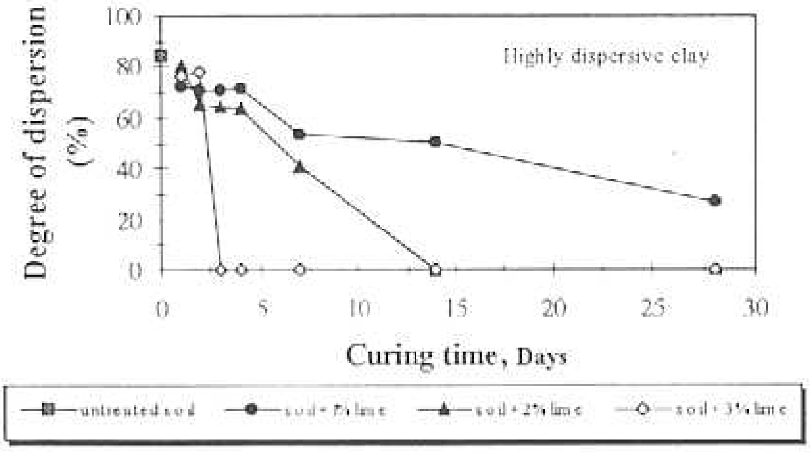


Figure 6 Relation between degree of dispersion of highly dispersive soil stabilized with lime in corresponding to curing time.

It is obviously seen that higher degree of dispersion needs more lime in order to improve the dispersive behavior of the soil. *Figure 6* reveals that the rate of reaction seems to progress more rapidly in the order of low to high lime content. A mix proportion of 1% lime seems to decrease as curing period increases. However, insufficient lime content may lead to incomplete reaction especially when applied to in-situ mixing. Marked reduction in degree of dispersion is more pronounced when 3% lime is added into the soil. Nevertheless, our preliminary tests indicated that vigorous reaction due to excessive addition of lime can impair some engineering properties of the lime-stabilized soil. On the other hand, when relatively high lime content is used, generally, lime-stabilized soils have trends to become less cohesion and more brittle, resulting in relatively higher coefficient of permeability. It is therefore considered that addition of 2% lime by weight is the most suitable proportion for the stabilization of highly dispersive soil since it compromises concerns for technical and economical aspects along with field practicability.

In summary, it is therefore decided to set the initial grain size of approximately 25 - 30 mm. for subsequent mixing in laboratory since it reflects closely to the capacity of mixing equipment obtained in the field practice. Specimens are prepared by mixing the soil with hydrated lime using the predetermined optimal mix proportions by total weight of air-dried soil; i.e., 1% and 2% for moderately and highly dispersive soils, respectively. The prepared cylindrical specimens of ∅5 cm x 10 cm are cured and then used substantially for the following tests.

3.2 PROPERTIES OF THE LIME-STABILIZED SOILS (TIME-COMPACTION EFFECT)

In order to elucidate the effect of delaying time to compaction on the properties of the lime-stabilized soils, the prepared specimens were subjected with two different conditions, i.e., compaction immediately after mixing and compaction after a curing of 4 days as recommended by Royal Irrigation Department (RID) of Thailand (Pattanasophon, 1989). Stabilizing effects are evaluated in terms of unconfined compressive strength, plasticity, and coefficient of permeability as a function of time, the results of which are discussed as follows.

(a) Unconfined Compressive Strength

Compressive strength of the soils mixed with the optimal lime contents show an increase in strength with time. In With independent to degree of dispersion, rapid improvement on the early strength for the mixtures quickly compacted after mixing (MIX-1 and MIX-3 in *Figures 7 and 8*) can be observed. Strengths increase with increasing lime content; i.g., MIX-3 have higher strength than MIX-1 when compared to the same curing time. On the other hand, when lime-stabilized soil mixtures were moist-cured in loosely compacted state and then recompacting after 4 days (MIX-2 and MIX-4), the gains in strength are relatively small. The rates of gain in strength seem to be much less prominent when compared to MIX-1 and MIX-3, respectively. In addition, no distinct change in strength of the mixtures having different lime contents (MIX-2 and MIX-4) can be observed. Test results thus reveal that although the delay time to compaction may enhance the chemical reaction, it significantly affects strength increasing characteristics of the lime-stabilized soil. For an example, the 28-day strength of MIX-1 is approximately 2.5 times of MIX-2 at the same curing period, while, the 28-day strength of MIX-3 is approximately 3 times of MIX-4.

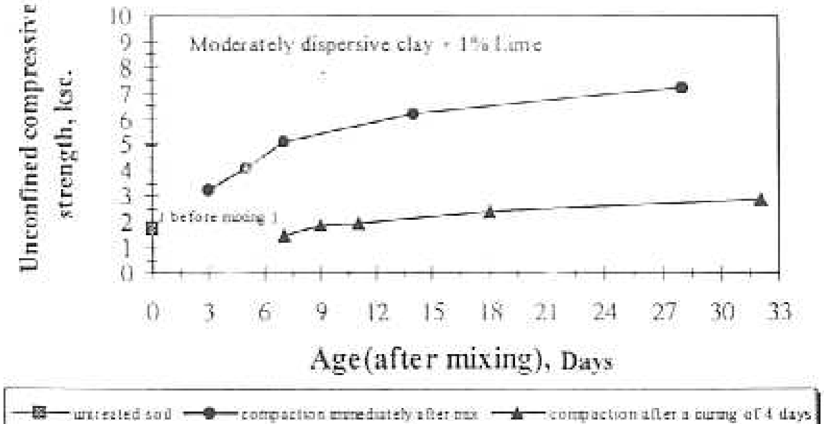


Figure 7 Relation between unconfined compressive strength of moderately dispersive soil stabilized with 1% lime and time-to-compaction at various curing time.

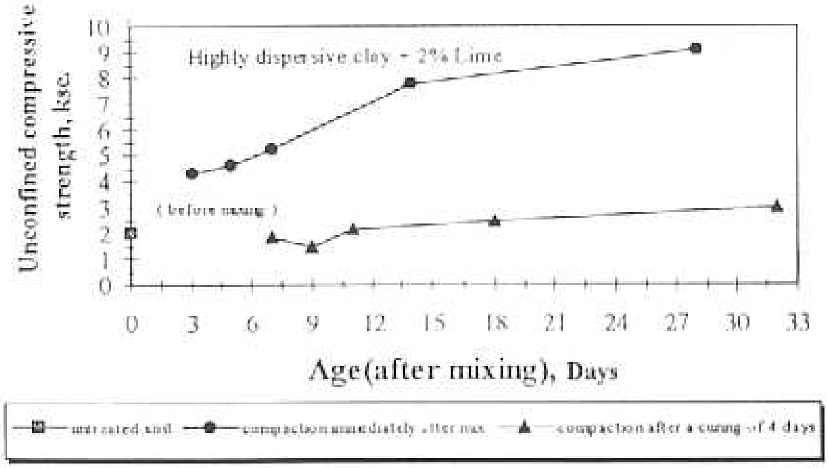


Figure 8 Relation between unconfined compressive strength of highly dispersive soil stabilized with 2% lime and time-to-compaction at various curing time.

(b) Plasticity

The plasticity of the lime stabilized dispersive soils broadly follows the pattern for chemical soil stabilization such as soil-cement mixtures. As obviously seen in *Figures 9 and 10*, for all mixtures, the liquid limits remain unchanged as curing time increases, while, the plastic limits markedly increase, especially at the early age. This results in remarkable decreases of the plasticity index, however, the rates of which decrease as curing time continues.

It is noted that the higher the degree of dispersion the more prominent of increasing plastic limit. Plasticity index are slightly lower when stabilized soils are quickly compacted after mixing. It is believed that an early compaction promotes more rigid structures due to an additional cementation that forms on the contacts of soil particles. However, the rate of increase in solid phases due to the effect of time-to-compaction and subsequent relationships to the development of strength is not clear and thus needs further elucidation.

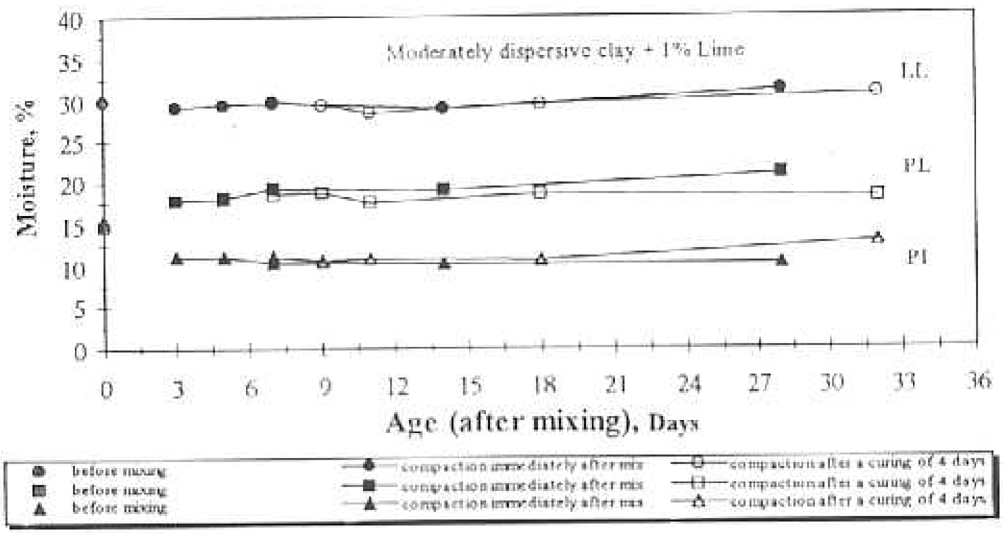


Figure 9 Relation between the plasticity and time-to-compaction for the lime-treated moderately dispersive soil.

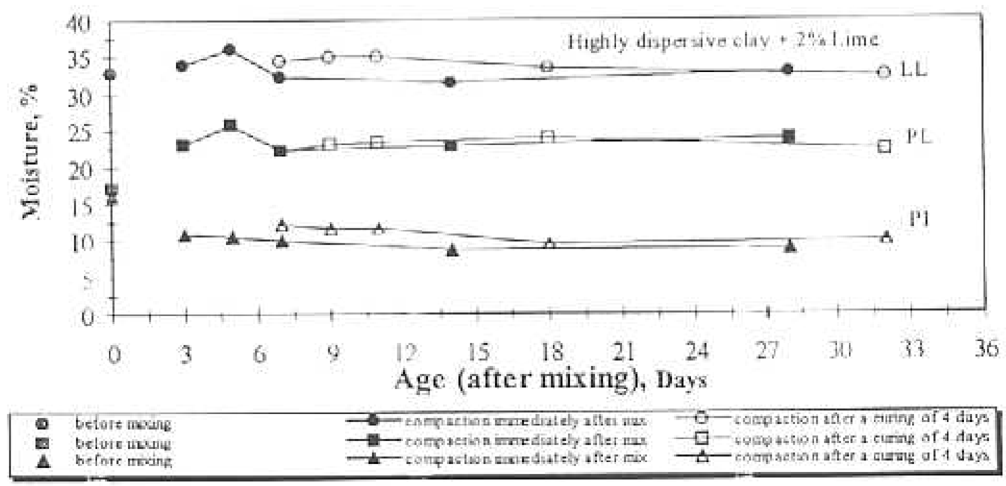


Figure 10 Relation between the plasticity and time-to-compaction for the lime-treated highly dispersive soil.

(c) Coefficient of Permeability

The coefficient of permeability of the lime-stabilized soils are shown as a function of curing time in *Figures 11 and 12*. The results indicate that the coefficients of permeability increase with increasing time to a certain level, approximately after two weeks and have trends to decline at longer curing time. Obviously that is due to the fact that the early hydration will establish cementitious bonds combining fine particles together, whereas reactions at long term constructs denser structures. Typical values of MIX-1 and MIX-3 (compaction immediately after mixing) range from 6.43 E-05 to 1.32 E-05 cm/sec and 4.31 E-05 to 1.05 E-05 cm/sec, respectively, whereas those of MIX-2 and MIX-4 (compaction delay) range from 2.63 E-04 to 5.43 E-05 cm/sec and 8.73 E-05 to 3.99 E-05 cm/sec. Additionally, the results illustrate that the coefficients of the former are situate within the specified guideline, whereas the latter somewhat situate beyond the boundary line. It can thus be stated that improvement on soil permeability can be obtained by allowing the stabilized soil to compact as soon as it can be practically done after a homogeneous mixing.

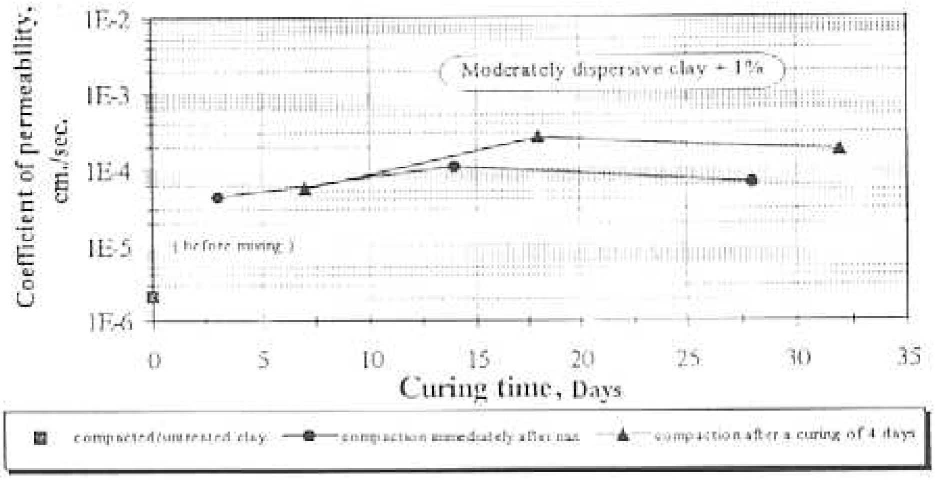


Figure 11 Effect of time-to-compaction on coefficient of permeability of moderately dispersive soil in corresponding to curing time.

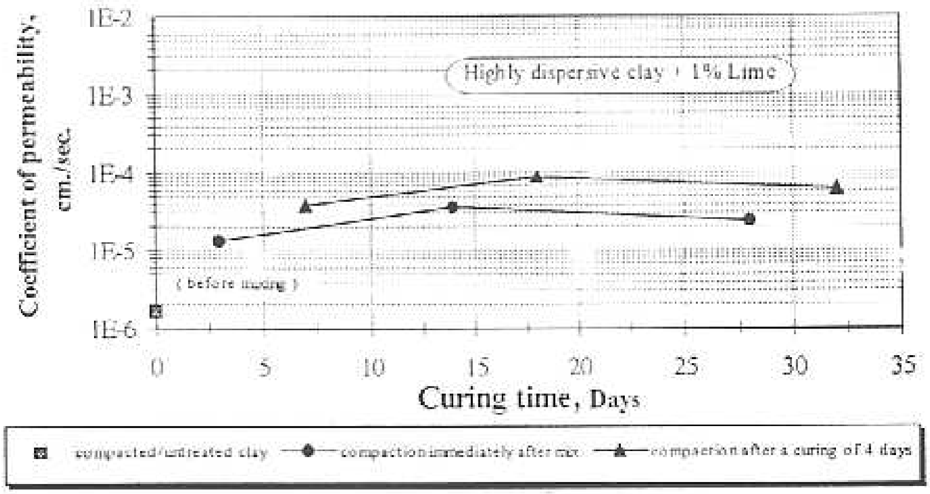


Figure 12 Effect of time-to-compaction on coefficient of permeability of highly dispersive soil in corresponding to curing time.

3.3 DURABILITY TEST UNDER REPEATED WET-DRY CYCLES

In order to evaluate the ability of the lime-treated soil to withstand change of climatic stresses durability test under repeated wetting and drying (ASTM C 672-91A) was conducted reflecting closely to the conditions in the in situ. Actually, no standards have been established for determining acceptance after durability test. In this study, durability characteristics are evaluated in terms of slaking resistance and resultant strength (UCS) after 5 cycles. Lime-treated soils that can withstand without slaking and can maintain strength greater than 1.5 kg/cm^2 are indications of satisfactory durability. Strength and durability may not be directly established into a correlation. However, in general, better strength provides superior durability (Takano and Sakamaki, 1984; Kamon et al., 1990).

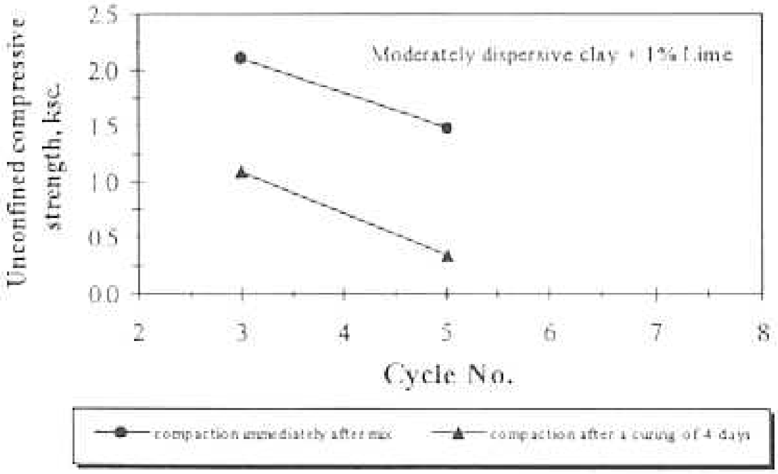


Figure 13 Durability test under repeated wetting/drying cycles. (lime-stabilized moderately dispersive soil)

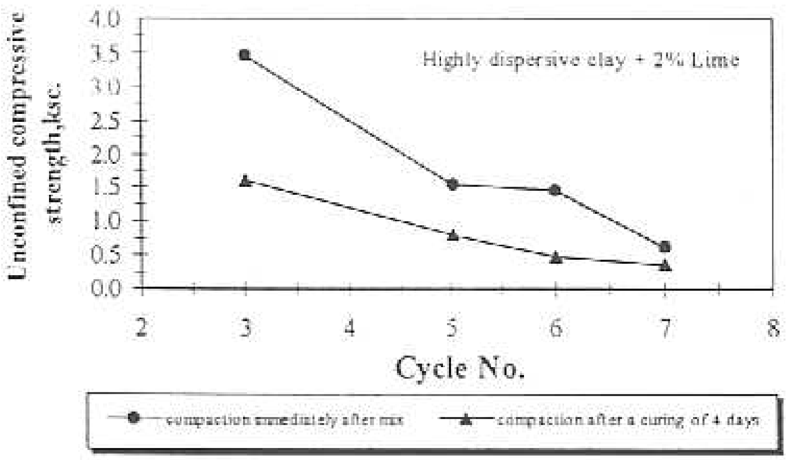


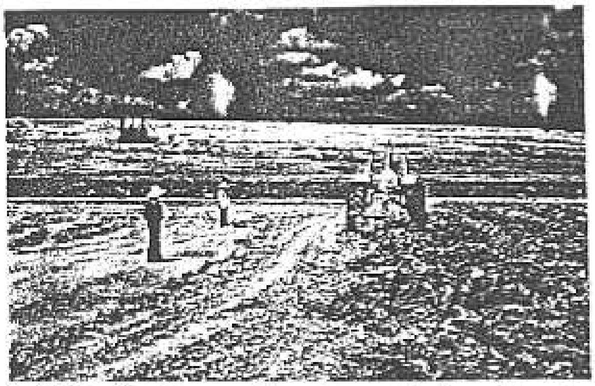
Figure 14 Durability test under repeated wetting/drying cycles. (lime-stabilized highly dispersive soil)

There is a general trend in high resistance to water-softening (slaking resistance) for all mixtures when the specimens were subjected to wetting cycles. Addition of lime with their predetermined optimal amount results in improvement on particles integrity when compared to the compacted samples of untreated soils. *Figures 13 and 14* illustrate changes in strength with respect to the number of drying and wetting cycles and improvement techniques for the moderately and highly dispersive soils. Strength declination can be markedly observed for MIX-2 and MIX-4 which are compacted after 4-days curing when compared with MIX-1 and MIX-3 which are compacted soon after mixing. In addition, MIX-4 has remarkable strength loss (about 85%) in the early cycle though this trend becomes smaller as the cycles continue.

For MIX-1, MIX-2 and MIX-3, strengths significantly decrease after 3 cycles, however, MIX-1 and MIX-3 were able to sustain stresses higher than 1.5 kg/cm^2 at the end of the 5th cycle. It is obvious that MIX-1 and MIX-3 exhibit satisfactory characteristics to withstand environmental stresses. This indicates that the compaction of lime-stabilized soil soon after mixing promotes good contacts between the reacting hydrated lime and soil particles which subsequently enhances both short- and long-term reactions. The results also suggest that the stabilized material that has a high early strength can exhibit a high durability.

4. OVERVIEW ON THE FIELD PRACTICE OF LIME STABILIZATION OF DISPERSIVE SOIL FOR MUN BON DAM PROJECT

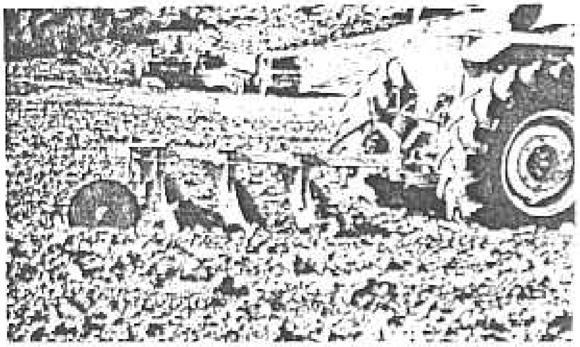
Lime treatment is one of those remedial works used to rehabilitate the Mun Bon Dam, besides the construction of plastic concrete cut-off wall, the installations of dam instruments, the redesign and reconstruction of filters and dam slope, and the enlargement of upstream impervious blanket (Warakorn and Supakij, 1995). Major advantage of lime treatment is to supplement series of protective layer on dam slope. The compacted lime-stabilized layer will increase the overall stability of the dam by the prevention the untreated soil inside from erosion due to the change of climatic stresses. For Mun Bon Dam, the lime treatment for dispersive soil was successfully and timely constructed and jointly provided good functions with other slope protection materials such as sand and gravel beddings, and rock riprap. The sequence of lime treatment construction is illustrated in *Figures 15 (a) - (j)*.

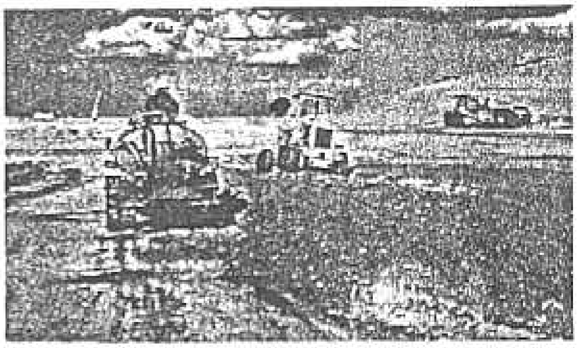


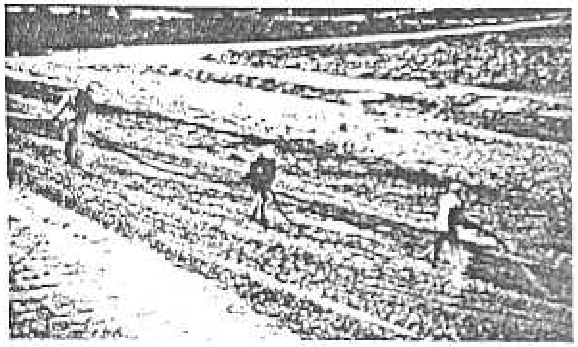
(a) Scarification and Aerating with Farm Tractor

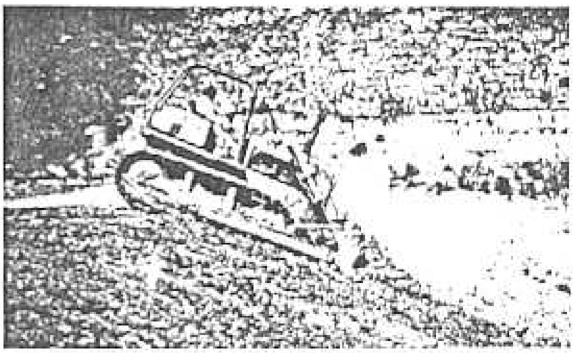
(b) Spreading lime by hand

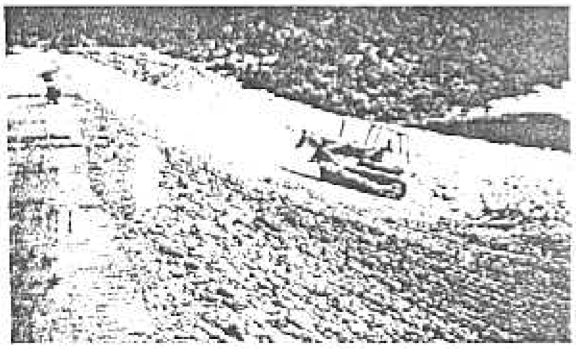
Figure 15 Construction sequence of lime treatment for Mun Bon Dam

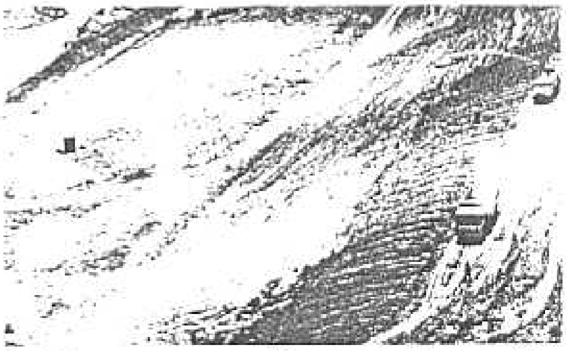

(c) Disc harrow mixing lime with scarified soil

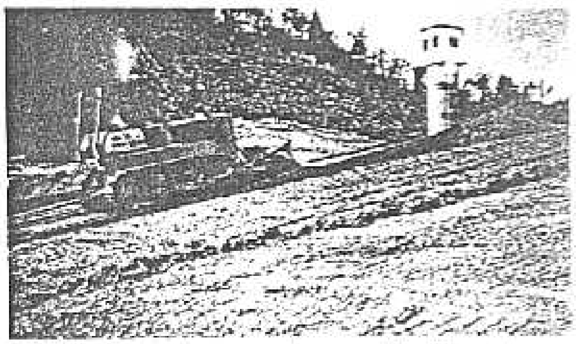

(d) Adding water by spraying and remixing


(e) Spraying water on trimmed slope


(f) Layering lime-treated soil


(g) Compaction of lime-stabilized soil on slope by track-wheel bulldozer


(h) Curing compacted lime-treated layer with water before covered with sand


(i) Placing and compacting sand bedding layer

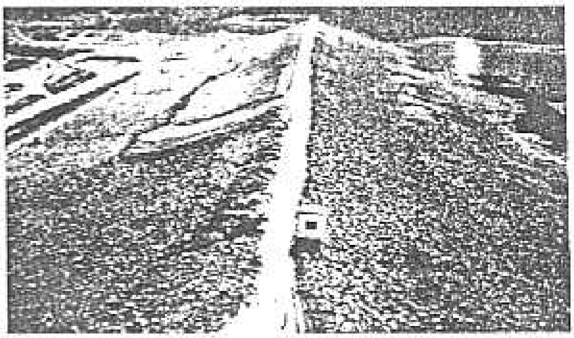

(j) A plan view of the dam with 95% completion

Figure 15 Construction sequence of lime treatment for Mun Bon Dam (continue)

In summary, the whole amount of the compacted layer of lime-stabilized soils used in this project is about 60,500 m^3 . Untreated soils in borrow areas were dominantly sandy and silty clay having a degree of dispersion (DHT) range from 20 - 60%. Based on the results of laboratory trial mix and field test sections, the appropriate lime stabilizing contents for the in-situ area mixing fall within a range of 1.5 - 2.0 %. According to the chemical reactions, the stabilized soils have their improved degree of dispersion with highly satisfactory. From a total number of 86 tests performed by using double hydrometer method (ASTM D 4221), an average value of degree of dispersion of 13.6% for the hole lime-stabilized soil could be achieved. In addition to chemically improved property, most of the lime stabilized soils had their plasticity index falling within a range of 10 - 17 % and had an average value of approximately 14%. Compaction of the lime-treated soil on dam slope was rather a difficult task, however, results from the field density tests illustrated that the soils could be efficiently compacted to achieve an average relative compaction of 98.12% Standard Proctor test with an average final moisture content of 0.7% greater than the optimum moisture content. It can be concluded that the quality control such as this in the field could assure the improved physical and engineering properties comparable to those tests in the laboratory.

5. CONCLUSION

Based on the experimental tests on lime stabilization of the dispersive soil, the main results can be summarized as follows,

1) Stabilization of dispersive soils using hydrated lime can be achieved to a satisfactorily high level when the soils are mixed with their predetermined optimal lime contents. Stabilizing effects significantly improve both physical and chemical properties agreeable to the proposed construction guideline. It has been revealed that the optimal lime content is substantially influenced by the initial degree of dispersion of the soil. In this study, a lime content of 2 % was sufficiently improved the properties of highly dispersive soil, while, for moderately dispersive soil was 1.0 % by total weight. For the process of pre-treatment of soil before the in situ area mixing, it is suggested to scarified the soil into an approximate of 25 - 50 mm in size as it meets all concerns for technical and economical aspects as well as field practicality.

2) Compaction performed soon after mixing promotes good contacts between the reacting hydrated lime and soil properties, which it is believed can enhance the early hydration. It is obvious that the prompt treatment can significantly improve the important properties such as compressive strength, plasticity and coefficient of permeability to a higher level when compared with the delay compaction method.

3) Dispersive soils stabilized by optimal mix proportions exhibited satisfactory durability under wetting and drying cycles. In addition, the results emphasize that immediate compaction can markedly enhance relatively high durability as evaluated in term of slaking resistance and strength loss. The results also asserted that stabilized material that has a high early strength can develop a high durability.

4) Lime stabilization of dispersive soils for Mun Bon Dam Rehabilitation Project was successfully constructed and exhibited good performance as slope protection based on the field test results.

6. ACKNOWLEDGMENTS

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