Final Report

TO

IOWA STATE HIGHWAY COMMISSION

X-RAY DIFFRACTION STUDIES OF SOILS AND SOIL STABILIZERS

Iowa Highway Research Board Project HR-106
Iowa Engineering Experiment Station Project 531-S
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TABLE OF CONTENTS

INTRODUCTION - OBJECTIVES

The two goals of this project stated in the Proposal were: (1) study lime diffusion in clayey soils, and (2) find the role of MgO in soil-dolomitic lime stabilization.

Because of the practical significance of these goals we temporarily overstaffed this project, giving somewhat a "crash" program. As a result, proposed work was finished up early (as were the funds), and more important, some of the findings were early enough and of sufficient merit to put into field trials in the Fall of 1964.

The work now being completed and the funds all being expended, this Final Report is therefore submitted before the anticipated project termination date.

MECHANISM OF DOLOMITIC LIME STABILIZATION

A. Previous work.

Identity of $Ca(OH)_2$-clay reaction products were achieved and reported under a previous IHRB project (HR-48). Products of the $Ca(OH)_2$-clay reaction include many of the same compounds that result from hydration of portland cement.

B. Results from present studies.

Exhaustive X-ray studies of the MgO-$Ca(OH)_2$-clay-water system failed to reveal any differences in identity or rate of formation of the reaction products from those of the $Ca(OH)_2$-clay system except at high curing temperatures. It was therefore concluded on the basis of X-ray and compressive strength tests that hydration of MgO in monohydrate dolomitic lime [$MgO + Ca(OH)_2$] is a cementitious reaction, increasing early strengths over those obtainable with $Ca(OH)_2$-soil alone. Details of the study are in a Progress Report, "Role of MgO in Soil Lime Stabilization" by J. W. H. Wang and R. L. Handy, submitted under separate cover.

C. Towards a dolomitic lime specification.

1. Properties to be tested. The conclusions from this study suggest that monohydrate dolomitic lime should be looked on as a special kind of hydraulic lime, really part lime and part MgO cement.

For the most benefit from the MgO hydration:

(a) The lime must not be overburned such that the MgO won't hydrate.

(b) Spreading, mixing, and compaction should follow in fairly close order so the hydration will not be premature, although this is not nearly so critical as with soil-cement.

(c) The lime must not be the dihydrate, $Ca(OH)_2 + Mg(OH)_2$.

A dolomitic lime specification could be written either on the basis of X-ray analysis or strength tests—chemical data are not enough since they do not indicate (a) and (c) above. X-ray tests would tell more what's wrong with a particular lime and how to correct it, but strength tests are much more readily run. Perhaps best would be a strength test, with use of the X-ray facility freely offered in case of problems.

2. Outline of strength test:

(1) Mix lime with a set amount of at least water sufficient to hydrate the MgO. (Appendix A).

(2) Use static compaction to mold samples to a specified density.

(3) Wrap and moist cure 1 or 2 or more days.

(4) Measure unconfined compressive strength.

We may note that this test is designed to measure strength from hydration of MgO, and gives no indication of pozzolanic reaction. If the lime is either overburned or overhydrated, MgO in the samples won't hydrate and strength will be low. Similarly if the magnesium content of the lime is down, low strength should result.

Details of standardizing could be worked out and specifications could be drawn only after testing a number of commercial limes.

D. Choice of dolomitic vs. calcitic lime.

Iowa is presently the only state specifying dolomitic lime, the National Lime Association maintaining that lime is all good, and after all the high-calcium variety is plenty all right for Texas.

1. For cementation. X-ray studies confirm that there is as much difference in lime reactions as between Iowa and Texas, and monohydrate dolomitic lime is still to be preferred in cooler climates or late in the construction season. The data show that in a cool temperature, pozzolanic reactions are very slow but MgO hydration proceeds to give quick early strength.

2. For modification of clay. An exception is low percent lime treatments, intended only to alter soil plasticity, in which case high-calcium lime is preferred. This is discussed in more detail in a Progress Report entitled, "Comparison of various commercial hydrated lime for reducing soil plasticity", by J. W. H. Wang and R. L. Handy.

LIME MIGRATION IN CLAY

Soil pulverization specifications for soil-lime stabilization of clays are often difficult or impossible to meet, ahd have discouraged contractors from bidding jobs. However, observations of unmixed lumps in core samples of old soil-lime or soil-cement (approximately 25% of portland cement after hydration is lime) indicated the lumps were stabilized, i.e., they had strength and would not disintegrate in water. The goal of this study was to study this apparent phenomenon: the reactions occurring, and the rate at which they proceed, the eventual aim being a possible revision of specifications. X-ray, chemical, and physical tests were relied on in the analysis.

A. Laboratory results.

Results of this study are reported under separate cover in "Soil Pulverization and Lime Migration in Soil-Lime Stabilization", by L. K. Davidson, T. Demirel, and R. L. Handy. Conclusions are as follows:

1. Although soil lumps lower the strength of a compacted soil-hydrated calcitic lime-water mixture, the effect diminishes with time as the lumps are stabilized as a result of lime movement in the system. The degree of lump stabilization depends on time and the size of the lumps.

2. The rate of hydrated calcitic lime penetration by diffusion into the particular soil-water system investigated is given by the expression $l = 0.08\ t^{1/2}$, where l is the lime penetration distance in inches and t is the time in days. The expression relating lime penetration and time will hold so long as solid lime is available to the soil-water system. Although an adjustment may be needed in the constant, this expression should be applicable to any similar soil-water-lime systems.

3. Water movement may assist the movement of lime within a soil-water system, but is essential only because it provides a medium for lime diffusion.

4. Lime diffusion can occur in sufficient amounts to cause both flocculation and pozzolanic reactions in the soil-water system. The amount of reaction depends upon time and the availability of lime. A minimum pH of approximately 10.5 is necessary for pozzolanic reaction.

5. Calcium-aluminate-hydrates crystallize in a room-temperature cured montmorillonitic soil-lime-water system after less than 20 days curing. Calcium-silicate-hydrates probably are formed at the same time as the calcium aluminate hydrates, but poor crystallinity prevents absolute detection by X-ray diffraction after such a short curing time.

6. Providing no carbonate is present, pozzolanic reactions may be detected from a change in the calcium ion content of the hydrochloric acid leachate from soil-lime-water previously leached free of dissociable calcium ions with a potassium chloride solution.

B. Revision of pulverization specifications.

Conclusion 2 above points to a revision of specifications, although the equation is specific only for the one soil investigated, an A-7-6(12) loessial B-horizon (Sharpsburg Series). Conclusion 7 of this report states:

Some soils which pose a pulverized problem may be more effectively and economically stabilized with lime if pulverization requirements are relaxed. Rather than to specify a minimum percent passing any given sieve, a specification might dictate a maximum lump size, which could relate to time allowable for complete stabilization.

C. Field trials.

An unusual opportunity for a field test presented itself in the Fall of 1964, through consulting activities of Prof. Robert Nady of ISU. On our recommendation Prof. Nady ran some check tests using the C.B.R., and suggested lime base course stabilization for an airfield to be constructed at Mt. Pleasant, Iowa, on plastic loess. The pulverization specification stated only that the maximum lump size should be 1 1/2 inches, the compacted density requirements remaining the same as indicated by compaction tests of the pulverized soil.

According to the equation (Conclusion 2 above) the time for lime migration through a 1 1/2 inch lump would be:

$$l = 0.081 \sqrt{t} = 0.75''$$

$$\sqrt{t} = 9.25$$

$$t = 85 \text{ days}$$

The FAA approved of the project, construction was started and completed in record time, and the airfield is in service. Field tests are planned.

Particularly reassuring is that the migrating lime not only alters plasticity, it reacts with the clay to give crystalline pozzolanic reaction products similar to compounds resulting from hydration of portland cement.

An unofficial test of lime migration was to stabilize a landslide in Des Moines. Lime was "seeded" into the shear zone in Fall '63 when the factor of safety was visibly 1.0; test drilling one year later revealed the factor of safety was 1.8. The treated houses have stopped sliding, whereas others have continued. Care must be exercised in use of the process because of the dependence on proper soil clay minerals for the reaction to proceed.

Lime migration in clays was also discovered by the Oklahoma highway maintenance department, and used to stabilize some shakey embankments. However, a similar trial by the Santa Fe Railroad was a failure, because of insufficient attention (or knowledge) of soil factors involved.

OTHER STUDIES

Other studies completed under this project and not stated in the Proposal include a detailed clay mineralogy of a gumbotil to find out what kind of montmorillonite, and a study of effects of low-temperature heat treatment on clays, with a view towards possible highway uses. Results are summarized in two Progress Reports, numbers 4 and 5 in Appendix B.

A. Clay mineralogy of a gumbotil.

The gumbotil clay is mainly calcium-saturated dioctahedral (i.e., aluminum) montmorillonite, plus kaolinite and mica.

B. Low-temperature heat-treatment of clay.

The heat-treatment study indicated that heating to 200°C dehydrated the montmorillonite and immobilized exchangeable Ca^{++} ions, reducing the liquid limit and the P.I. Unfortunately prolonged soaking in water resulted in partial recovery, so practical usage appears nil.

APPENDIX A

CALCULATION OF WATER TO HYDRATE MgO

Reaction:	H_2O	+ MgO	+ $Ca(OH)_2$	=	$Mg(OH)_2$	+ $Ca(OH)_2$
Molecular wts:	18.0 +	40.3 +	76	=	58.3	+ 76

water = 18.0 lime = 116.3

water/lime ratio = 0.154, or 15.4 gm water to 100 gm lime.

APPENDIX B

LIST OF SUBMITTED PROGRESS REPORTS

1. Wang, J. W. H. and Handy, R. L. Role of MgO in soil lime stabilization. 64-8.*
2. Wang, J. W. H. and Handy, R. L. Comparison of various commercial hydrated lime for reducing soil plasticity. 64-4.*
3. Davidson, L. K., Demirel, T., and Handy, R. L. Soil pulverization and lime mibration in soil-lime stabilization. 64-11.*
4. Kelley, W. A. and Ho, Clara. Clay mineralogy of a gumbotil. 64-7.*
5. Ho, Clara, and Handy, R. L. Modification of ca-montmorillonite by low temperature heat treatment. 64-6.*

APPENDIX C

SUGGESTIONS FOR FUTURE RESEARCH

A. Lime migration - lab studies.

The field projects were initiated mainly on faith and a small amount of data. Fortunately the dice rolled a seven, but in order to extend the results and minimize possibilities for error, the following must be examined:

*Soil Research Lab. Contribution Nos.

1. Relation of migration rate to clay content and clay mineral.
2. " " " " " " " to moisture content.
3. " " " " " " " to density.
4. Comparable migration rates of lime liberated from hydrating portland cement.

These problems can best be studied in the lab by means of X-ray, chemical, and surface free energy studies.

B. Lime migration - field studies.

As already mentioned, one field test utilizing the new outlook on soil pulverization is already under way. We therefore strongly urge that this and future projects be followed up by periodic coring and testing to measure lime migration and property changes in unmixed soil lumps and in the matrix.

Another vital area is soil-cement: cement liberates about 25% of its weight as free lime when it hydrates. Presumably this lime is available for migration into the clay, and if so, pulverization requirements for soil-cement might also be reduced. It is therefore urged that cores be taken from various existing soil-cement roads, and efforts be made to detect unmixed lumps and measure their extent of pozzolanic reaction by X-ray diffraction, X-ray fluorescence, and chemical tests for silica and alumina removable by mild acid leaching.

C. Dolomitic lime test and specification.

Every recent lime stabilization job in Iowa has re-introduced the problem of what and how to specify the lime. It is therefore urged that a laboratory test be devised and tried with various commercial limes, relative merits of which are already known, so a specification may be suggested. It appears that this could be done with a relatively small amount of laboratory testing which could be included in another project.