Screenings
from the Soil Research Lab

IOWA ENGINEERING EXPERIMENT STATION
IOWA STATE UNIVERSITY of Science and Technology
AMES, IOWA

Sept. - Oct., 1957
Vol. 1, No. 5

SUBJECT: LIME

Roman in the Gloamin'

One day a noble Roman named Nero was flitting over the highway in his gay new 57 A.D. sweptwing chariot, little realizing that under his very wheels ran roads stabilized with LIME. "Bless this added horsepower," he smiled, plucking out a happy chord on his mandolin.

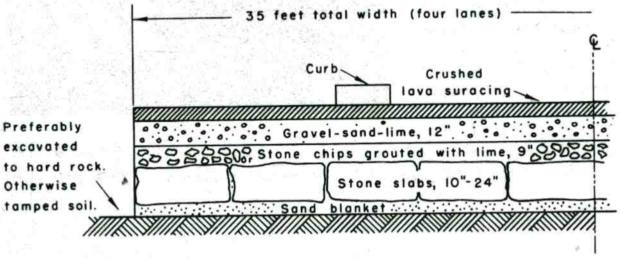
Suddenly whilst rounding the corner of Appian at IVth Street, our hero's chariot hit a bump. "Ye Gods! E pluribus unum (one among many)," said Nero, to phrase a coin. Where is my road engineer? I must ask him to join my club!"

The road engineer, always the sucker for honoraries, accepted, and the following Saturday he was taken into a Roman Christian organization known as the Lions.

Nowadays our initiations into engineering societies are less strenuous. However, the annual dues are enough to make anybody feel like he's being fed to the lions. Romans paved the way.

All Roads Lead To Rome

The roads of Rome were built for permanence. Well, actually they were built to make war, which from the Roman point of view meant practically the same thing. Probably the most famous road in history is the Appian Way, which ran from Rome all the way down to the boot's heel. Construction began in 312 B.C. and started an era when "All roads led to Rome," or at least all the good ones did.



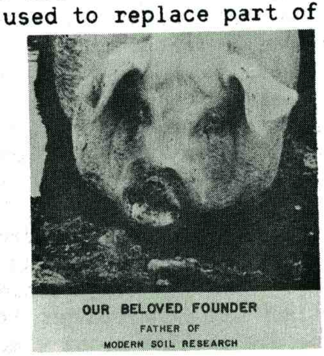
Typical section in the Appian Way
Total thickness, 3-5 feet.

The Appian Way was built in four main layers two of which contained lime. The total road thickness was 3 to 5 feet, and this before the invention of the overloaded semi-trailer. On the other hand Roman roads had to withstand the pounding from iron-tired wheels. Therefore the Roman load limit for wagons was set at 700 kilograms (1540 lb.), or half the weight of a modern automobile. (Check that, you truckers!)

Although Romans knew the value of compaction they lacked equipment, so the lime was usually used in mortar. The common mortar was two parts locally derived sand and one part lime. Nine parts gravel were added to make a lime-concrete or the mortar was used to fill in the voids around stone chips or slabs in the road.

About 150 B.C. modern technology took the place of old cut-and-try methods and the Romans discovered a cheap partial substitute for lime.

A volcanic ash from near Pozzouli (a town near Naples) could be used to replace part of the lime and give stronger mortars. Later other deposits of ash were discovered and used; they also were given the name "puzzoulana" after the Roman town. Now we usually reduce this to "pozzolan." The common mortar became one part lime, three parts ash and about three parts sandy material, the proportions varying depending on the quality of the sand. The average life of travelled roads was up to 100 years, and examples of the Roman pozzolanic concrete can be found intact today.



No Roman; just a pig.

REVIEW: WHAT IS LIME?

The word "lime" is such a convenient handle

Return to Table of Contents

that it has been applied to everything from boiler scale to powdered limestone for agriculture.

Quicklime

Strictly defined, lime is the product obtained by burning limestone. Limestone is a calcium carbonate, $CaCO_3$. At red heat the carbonate breaks down and releases carbon dioxide, CO_2--the same gas as in soda pop. Note that $CaCO_3$ minus CO_2 = CaO, calcium oxide or lime. CaO is also called quicklime, probably because some incautious soul found out it burns but quick.

Quicklime is highly caustic partly because it reacts chemically with water and gives off heat: $CaO + H_2O = Ca(OH)_2$ + heat. Calcium hydroxide, $Ca(OH)_2$, is the hydrated lime commonly used in plaster. It is also called slaked lime.

Dolomitic Lime

Dolomite (doll-ō-mīte) is a carbonate rock very similar in appearance to limestone. It is often used to make lime. Dolomite is a calcium-magnesium carbonate, $CaMg(CO_3)_2$, and the resulting quicklime contains both calcium oxide and magnesium oxide, CaO + MgO.

When water is added to dolomitic lime, CaO converts, as per habit, but the MgO balks and doesn't. The result is a mixture of $Ca(OH)_2$ + MgO. The mixture is usually called monohydrate dolomitic lime, which is poor chemistry, but they didn't ask us. Under steam and pressure the MgO can be converted, and the resulting fully hydrated mixture, $Ca(OH)_2 + Mg(OH)_2$, is so-called dihydrate dolomitic lime. Dolomitic lime is preferred for making smooth, workable plaster, but dihydration is necessary to avoid cracking in the wall. (MgO slowly hydrates over the years, expands and may cause cracking.)

Finally, what is lime? Lime is quicklime, which is either CaO or a mixture of CaO and MgO. Unfortunately people talking about hydrated lime usually forget to say "hydrated," and people talking about limestone, whether in kidney stones or in boiler scale, often leave off the suffix "stone." Other people think of lime as a small green fruit. Thus lime is different things to different people. Probably the safest path is to already know what they're talking about.

LIME AND SOIL

Lime added to soil reacts in several ways. These will be discussed one by one.

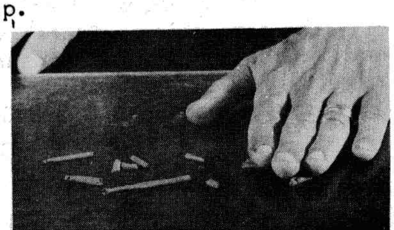
REVIEW: PLASTICITY, OR GENERAL CHEWINESS

One day a German Herr Professor named Atterberg strolled into the kitchen where his wife was rolling out a fresh batch of mud pies. He noticed something: namely, too much water makes mud runny. Ordinary people would have let this slip by, but a college professor had to make something of it. "Der wasser causen der mudden geschlopt!" or, add water above a certain amount and soil becomes liquid. This moisture content is known as the Liquid Limit. Surprising, is it not?

Then Herr Atterberg discovered that through a certain range in moisture contents mud is plastic, or can be molded. Dried below this range it falls apart when worked by hand. "Der dry mudden maken der piecrust geflake!" he rumbled, and they call that the Plastic Limit. The difference between the Liquid and Plastic Limits is the Plasticity Index or P.I. and represents the moisture content range through which a soil is plastic and makes good mud pies. We know this is brutally complicated and we apologize for being so technical.

Sand vs. Clay

Extremes of plasticity are represented by sand and by clay. Sand is non-plastic: The P.I., if it can be measured, is zero. This means that enough water for workability causes sand to be on the verge of becoming liquid. This is because sand has little or no storage capacity for water; add water above the plastic limit so the mass doesn't crumble when it's rolled out into threads and you've added water to exceed the liquid limit--the grains are lubricated so they slip.



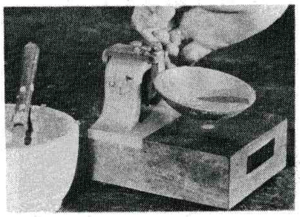
A Plastic Limit test consists of rolling and re-rolling a moistened soil until it dries out enough that it crumbles. The moisture content is then at the Plastic Limit.

Clay, on the other hand, is a veritable reservoir for water. Some clays (the mont-

Return to Table of Contents

Sept. - Oct., 1957
Vol. 1, No. 5

morillonites) expand and absorb excess water; others merely hold water at the grain surfaces. This sometimes leads to the erroneous idea that clay mineral surfaces are necessarily unique in their attraction for water. They are not.



Turn the crank and out comes a Liquid Limit, almost. Moist soil spread in the dish is grooved; then the dish is bounced until the groove closes. If it closes at 25 blows the moisture content is at the Liquid Limit. Use of several trials allows the L.L. to be read from a graph.

Other minerals also hold water but larger grains have less available surface for wetting.

A 1 mm cubic grain of sand has a surface area of 6 sq mm. Divided into 0.001 mm cubes of clay, the surface area increases to 6,000 sq mm. Add to this the factor that clay grains are usually plates, not cubes, and you really have something.

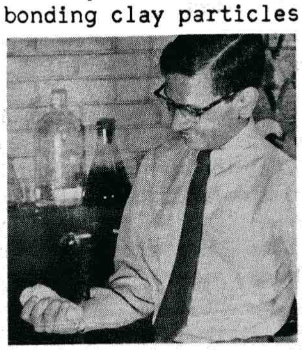
Less Slime with Lime

In a highly charged atmosphere such as clay-water, a relatively minor change in chemistry can really beef up the P.I. (Note to translators: "beef up" a colloquialism; substitute "transmogrify.")

One of the virtues of lime is that it changes the P.I. cheaply. As you know, granular soils--sand and gravel and such--make the best roads, the reason being that these soils don't easily become plastic.

Clay roads on the other hand are rather insecure. All of the compactive effort we can use is mere twiddle compared to the electrical attraction of clay for water. Therefore clay roads, even though compacted, may slowly wet up and become soft in rain. The clay becomes plastic. Eventually if clay absorbs enough water the water "chains" bonding clay particles become so extended they lose some of their orientation and are weakened. Remember that next time you get stuck. All you have to do is wait for the road to dry out.

A dry, powdery soil can be made plastic by placing it in a rubber balloon and merely sucking out the air. Air pressure on the outside of the balloon causes intergranular friction, much the same as electrical attractions cause an analogous "friction" in wet soil.



Ah, but add some lime! Magic! Suddenly the road dries up and hardens into a concrete highway, center stripe and all! Well, perhaps we exaggerate. But lime mixed with clayey soils does reduce the P.I., and it can cause a wet plastic clay to appear to "dry up." Actually the water is still there, but lime causes clay particles to flocculate--to stick together and behave like silt. (Silt is the size between sand and clay.) For the enchantment of the engineers we include a Table:

Soil	LL,%	PL,%	PI
(a) Plastic loess	53	26	27
" + 6% lime	46	30	16
(b) Friable loess	33	21	12
" + 6% lime	34	24	10

Note that lime increases the plastic limit and reduces the liquid limit, both factors acting to reduce the P.I.

CEMENTATION

Cementation by lime occurs in two ways. If carbon dioxide from the air can gain entry, lime readily converts back to calcium carbonate. Tiny crystallites of $CaCO_3$ grow and interlock and make the lime mortar hard. Very simple.

Pozzolanic Cementation

Actually carbonation, as the above reaction is called, is rather wasteful of lime. Calcium carbonate is not the best cement; it is rather weak and a considerable quantity may be required for satisfactory strength. An alternate reaction was found when the Romans substituted volcanic ash for part of their lime. They used less lime and got as good or better strengths.

Pozzolanic reactions appear simple or complex, depending on your outlook. Actually nobody knows much about them, or if they do know they don't tell. Reactions which involve only the surfaces of tiny grains are difficult to see and difficult to measure

Return to Table of Contents

It is believed the hydroxyl or (OH) part of the lime reacts with pozzolans such as volcanic ash to produce a gel, perhaps like that from hydrating portland cement. Carbon dioxide is not necessary--in fact, its action is deleterious as it "kills" the lime and prevents its reacting with pozzolans.

Are Soils Pozzolans?

The best pozzolans have no crystal structure--that is, they are glasses. Volcanic ash is a powdered glass. Artificial pozzolans can be made by heating a natural crystalline material such as clay until it loses its crystal structure, and then cooling it rapidly so it stays a glass. Alkali activity of portland cements is sometimes measured in mortars made with Pyrex glass. Today the most widely used pozzolan is fly ash, the ash from the burning of powdered coal. Fly ash is collected from smoke.

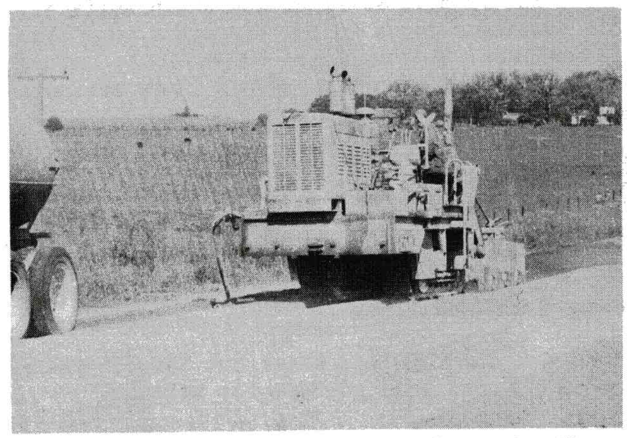
One of the reasons glass is reactive is because the disorganized arrangement of ions leads to distorted chemical bonds and "weak places" on the grain surfaces. Unfortunately for pozzolanic reactivity, soil minerals are not glasses. They have crystalline structures, which means they are regular arrangements of ions and have better balanced chemical bonding. Pozzolanic reactions with minerals are therefore slow if they occur at all.

As a matter of fact, soil-lime mixtures do get hard, even when they are sealed to prevent entry of CO_2. Probably some of the minerals in soil are slightly pozzolanic. Our own meager knowledge of crystal chemistry suggests that a major reactant may be silt and clay-size quartz, but this is 80 percent conjecture and 20 percent unrehearsed data. We don't yet know for sure.

LIME ROADS

Modern experimentation with lime in roads began in the 1920's when one of the first field tests was initiated in that garden spot of the nation and Home of the Happy People, Iowa. Unfortunately the road failed. Lime was added to reduce soil plasticity, and little thought was given to the possibility of it doing anything else. Actually had a wearing surface been applied the road might have stood up. Eventually it rutted and reverted to its original status, that of mud.

Nowadays lime stabilization is used for the base course of roads. A wearing surface, usually a couple inches of blacktop, is applied on top. Most of the recent work with lime has been in the South in the great states of Texas, Texas, Texas, and Texas. (That takes in a lot of territory!) The cumulative length of lime-stabilized roads in Texas can now be measured in hundreds of miles.



Blimey but it is limey! Modern soil-lime construction begins by spreading of the lime. A special mixer then follows, ripping and pulverizing the underlying soil, adding water, and mixing in the lime.

Freeze-Thaw and the Need for More Strength

The northern Yanks have not been too receptive to use of lime in roads because lime-stabilized soil specimens often fall apart after a few laboratory cycles of freezing and thawing. This would not be a very happy condition in a road. Therefore, research. A high compressive strength correlates fairly well with a good resistance to freeze-thaw.

EUREKA! ETC., ETC.

One day a shimmering thread of sunshine flicked forth through the lab, as often happens when one can't afford electric lights, and somebody suggested trying dolomitic lime. Early data showed we were on the track of something.

A more elaborate program was laid out in which a variety of lime compositions was represented by synthetically prepared mixtures of chemicals. A comparison was then made between these and commercial limes.

Calcitic vs. Dolomitic Limes

Prepare yourself for a shock, Farnsworth, we've got news for you. (Farnsworth is the pet cat.) Strengths are increased 220 to 450 percent by use of a dolomitic lime! To hold the interest of the scientists we submerge our data in a Table. Calcitic lime strengths on the left, dolomitic on the right:

Return to Table of Contents

Sept. - Oct., 1957
Vol. 1, No. 5

Soil	28-day comp. strength after soaking — Kind of lime: Calcitic hydrated[a]	Dolomitic monohydrate[b]
Glacial till	220 psi	560 psi
Friable loess	120 psi	506 psi
Plastic loess	95 psi	356 psi

[a] 8% $Ca(OH)_2$
[b] 8% $Ca(OH)_2$ + MgO; artificial prepared mixture.

Since the strength requirement for lime-stabilized soil to resist freeze-thaw is of the order of 300 psi, it looks like we have arrived.

Mono- vs. Dihydrate

The happy results above are with synthetic monohydrate dolomitic lime, a mixture of $Ca(OH)_2$ and MgO. Commercial dolomitic limes are sometimes autoclaved, or heated under pressure, to convert the MgO to $Mg(OH)_2$. Strengths with this artificial blend to simulate dihydrate lime fit into the above table as follows: 210, 220, and 95 psi for the three soils, respectively. In other words MgO may be beneficial, but $Mg(OH)_2$ generally is not.

Not for Real

Alas! Poor Yorick, neither are strengths as high when one uses the commercial hydrated lime! In fact, see the Table below. Most of the commercial limes give strengths close to those obtained with pure chemicals; only friend monohydrate does not. Strengths with the monohydrate are still highest of the different types of commercial limes but they are not as high as could be expected.

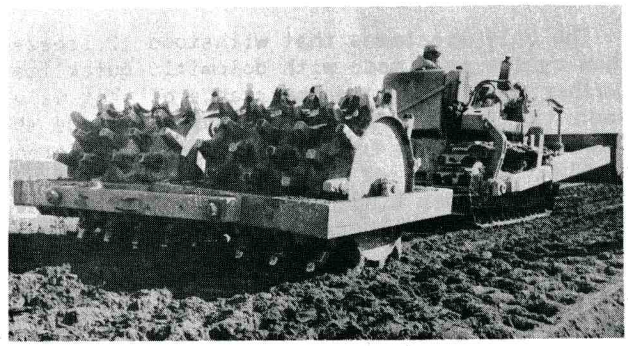
	28-day comp. strength after soaking — Kind of lime: Synthetic*	Commercial*
Friable loess	506 psi	274 psi
Plastic loess	356 psi	122 psi

*8-9 % $Ca(OH)_2$ + MgO

Quicklime

Fortunately for peace of mind the sensational strengths again show up with quicklime. Dolomitic quicklime strengths are 588 and 312 psi for the friable and plastic loess, respectively. As would be expected, calcitic lime strengths are not nearly so high.

Whereas quicklime gives off heat when it hydrates most of the heat is lost when the lime and soil are still in the mixing bowl. CaO goes to $Ca(OH)$; MgO remains MgO.



Compaction is often with a sheepsfoot roller. It is rolled back and forth until it "walks out," indicating that the soil has reached a satisfactory density. The soil surface then looks like a tired waffle. After final rolling with a smooth roller and shaping with a blade, the soil-lime is covered with a bituminous surfacing.

Sherlock

What happened with commercial lime?--Well, Watson,in commercial hydration of dolomitic lime the MgO may be partly hydrated to $Mg(OH)_2$, perhaps at the grain surfaces. This would reduce the activity.

---I daresay, Holmes, you are a clipper. But what about the, ah, the quick...

---Quicklime? Very simple, my dear doctor; quicklime hydration after it is mixed with soil is very cool, man, cool. No MgO is converted so the commercial lime is very close to the synthetic mixture prepared from chemicals. The evidence is not conclusive, but you must agree this answer appears logical, right! Care for a bit of snuff?

WHERE DO WE GO FROM THERE? DEPT.

Alternative one is build a test road. An 800 foot section of subbase stabilized with monohydrate dolomitic lime is now completed in Highway 117 north of Colfax, Iowa. If it stands up we'll let you know or build another.

Alternative two is to study the use of trace chemicals to boost strengths with lime. Perhaps then the kind and brand of lime will not be so critical. Research is under way now.

Return to Table of Contents

APPENDIX: FREEZE-THAW AND C.B.R.

Does lime-stabilized soil now resist freeze-thaw? To answer this, 2 by 2 inch cylinders were alternately frozen at -10 F and thawed sitting on wet felt. Ooo! We hate to think about it. The ratio of the strength after 12 cycles to the strength after moist-curing the same time gives an index to durability.

The only specimens that withstood 12 freeze-thaw cycles were made with dolomitic quicklime, further emphasizing the importance of what we've been talking about. At 80 days total age the durability ratio was from 0.8 to 0.4 for different soils, a value of 1.0 indicating no loss in strength. Other kinds of commercial limes gave a durability ratio averaging 0.00, which is very low.

C.B.R.

California Bearing Ratios are sometimes used for pavement design. They show that lime-stabilized soils have strengths which are quite adequate for use in a base course. Values in the table are obtained after 4 days soaking in water. A C.B.R. of 100 indicates the strength of a rolled stone base.

Soil	Lime (commercial)	C.B.R., % Moist cure, days 0	7	28
Friable loess	9% dol. dihyd.	23	104	132
	9% dol. quick	29	205	215
Plastic loess	9% dol. dihyd.	39	52	66
	9% dol. quick	99	84	115

REFERENCES SIGHTED

The beauties of lime stabilization are more fully described in Lime Stabilization of Roads, Bulletin 323 of the National Lime Association, Washington 5, D. C. Discussions of the relative merits of calcitic vs. dolomitic limes may be found in "Evaluation of Lime for Stabilization of Loess," by J. G. Laguros, D. T. Davidson, R. L. Handy and T. Y. Chu, published in the A.S.T.M. Proceedings Vol. 56, 1956. Further dope is in "The Calcium:Magnesium Ratio in Soil-Lime Stabilization," a sparkling technical paper by L. W. Lu, D. T. Davidson, R. L. Handy, and J. G. Laguros, presented at the Highway Research Board in 1957, and not yet published.

EDITORIAL PAGE:
R.S.V.P.

As most of you know, we stepped off a milestone for our circulation department by including reply cards with the last issue. Also in a gross display of bravado we left a place on the cards for your comments. Now most of the results are in, the Circulation Department (our secretary) wears a harried look, and the Editorial Staff, as soon as he gets over his surprise, may ask for a raise.

Modesty forbids that we repeat the nice things that were said. (Disgression tells us to keep everything else quiet.) The Approvement Ratio (if we may be so technical) is about 50 to 1 or 100 to 1, depending on how one evaluates the critique. It's enough to make us smile and say thank you from the heart, which is something you won't see very often in a technical publication, but something sincerely meant.

We may be new to some of you, in which case your name was given us by a mutual friend. If you would like copies of the earlier issues they are available on request. Address correspondence to: Screenings Editor; Iowa Eng. Exp. Sta.; Iowa State College; Ames, Iowa.

Identification

The gentleman with the handful of mud on p. 3 is Mr. R. K. Katti, a graduate student from India whose American nickname is "Dynamite" because he gets things done. Mr. Katti is now completing work for his Ph. D. degree. Other foreign countries currently represented in this lab are Chile, Ireland, Spain, Turkey, Illinois, Kentucky and Minnesota, to mention a few. Other graduate students are members of the U.S. Army Corps of Engineers or come from other far-off places such as Iowa.

If we're late on your doorstep with this issue it's because of the flu--the weather got cold and the ducks flu. You know; quack quack, blam blam! yummy.

IN THE NEXT ISSUE: A new use for smoke:
Lime-fly ash stabilization

RLH

Return to Table of Contents