

Screenings

from the Soil Research Lab

IOWA ENGINEERING EXPERIMENT STATION
IOWA STATE UNIVERSITY of Science and Technology
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SOIL STABILIZATION VIA QAS (QUATERNARY AMMONIUM SALTS)

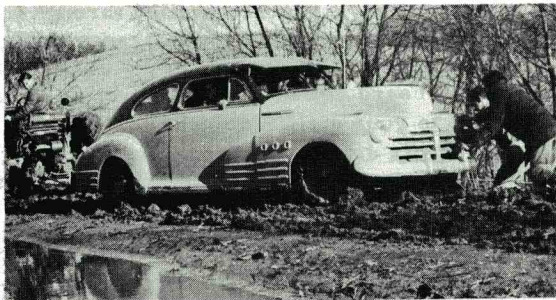
Historical

In 1946 one of our graduate students, now a full professor no less, looked raptly on a jar of sour hogfat and said, "Gadfrey; I believe this will make me a road!"

Like lightning, research took over and scooted like a sleepy turtle until now, only 11 years later, we think we've found something! We are so excited we must pause and catch our breath. Research moves so fast nowadays. If you're wondering where the 11 years went, some were spent doing other things; others were spent testing a myriad of chemicals not only to find the best one but to find out how to use it. Currently the best chemical is a treated byproduct of the meat packing industry. It is a dihydrogenated tallow dimethylammonium chloride (ooo!); it disperses in water to form a milky suspension, and that's how we mix it with soil.

The facts

Well now, we say to you, we know what it is but what do it do? We're lucky we're not ad men and we don't have to sell anything; we can afford just being honest. The fact is that QAS water-proofs soil and retards the formation of mud. It reduces the dry strength and increases the wet strength, and wet strength is what counts. Only a small amount of the QAS is used, about one-tenth to one-half percent of the dry weight of the soil, and the actual amount depends on the kind and amount of clay mineral. More on this later, but now let's look at the treatment.



Soil Research Laboratory personnel learn first-hand about mud. Their car is stuck so badly it has disappeared (from the photo, anyway).

As you may know, engineers don't just plow soil: they dig it and proportion it and mix it and spread it and add water if they need to and end up compacting it until it is hard and can carry a load. The same deal with QAS, only we add the chemical to water before we sprinkle the soil. Then we compact and, if we're smart, we allow it to dry out. The drying out does something, and once the soil is dry it does not easily wet up again. It is, we hope, stabilized.

How now, brown soil?

The object of our studies, if you haven't seen our Vol. 1 No. 1, is to find a way to treat soils for use in roads. Will QAS work in roads? We hope to kiss a cow it will! We think. If we're going to use it in a road we need some design dope. In checking around the lab we found we have some, but we won't mention any names. A useful measure of soil strength is the CBR, or California Bearing Ratio, names after a State 'way out on the West Coast. (We don't want you to think we Midwesterners are provincial--we know what's where.) The CBR of our untreated Iowa silty soils after soaking in water runs about 2.0 or 3.0, which is very low. In fact, it isn't even a very strong mud. The CBR of treated soils after soaking in water runs from 10 to 30, depending on the clay content. The best soils have the least clay and, incidentally, require the least QAS. What a happy circumstance!

A CBR of 30 indicates that our soil has adequate strength for use as a road base or subbase, but it should be covered up with about 6 inches of something stronger to spread the load. That is, according to the CBR design theory, we put a layer of strong material or surfacing on top; this spreads out the wheel loads before they reach the weaker materials underneath.

Treated soil specimens stand up in water. Believe us, this is an improvement. Otherwise we wouldn't have anything to talk about.



Wet-dry, shiver and shake

Another wild scheme for evaluating stability of a soil is to see how molded specimens stand up under repeated cycles of wetting and drying or

(Continued on next page)

Return to Table of Contents

freezing and thawing. This is supposed to simulate field conditions in a road. Frankly you could not prove it by us; off the record we would bet you could store samples in any low rent apartment house and get the same effect. But anyway, we wet and dry or freeze and thaw our molded soil specimens with scientific precision. And we measure the strength losses along the way. For comparison we will also run a batch of untreated specimens. These are very easy, because they fall apart and are discarded during the first cycle.

Actually the wet-dry test is a good indication of degree of waterproofing, and the treated soils, we are happy to say, stand up fairly well. Freezing and thawing are done with the specimens placed on pads of wet felt--this gives water an opportunity to enter the soil and exert its muscles. Water expands on freezing, you know, and to the strength of a saturated soil this spells the End. Our QAS treated soils resist saturation and so resist damage from freeze-thaw. Some strength loss is evident after 5 or 6 cycles, but if we bury our treated soil deep enough it will last that many cycles through the ordinary winter.

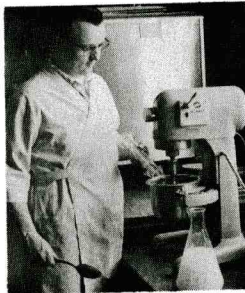
Dollars make extra sense

Forgive us for being so mercenary, but we work for a college and we can't escape having our attention directed to the almighty dollar. If we don't our stomachs growl. The current price of QAS is about 36 cents per pound, so we don't go throwing it around. It is indeed fortunate we don't have to use very much. The cost for chemical for a road works out to be about 20 cents to 40 cents per sq. yd. of 6 inch compacted thickness. We know; you're shocked, because you pay taxes. Still, compare the cost with about 70 cents per sq. yd. for soil-cement or 45 cents to 90 cents per sq. yd. for crushed stone, and you see we stand to save some money. If this works out we can vote for lower taxes! Don't count on it; that's an adolescent promise. (When we get older, we'll be wiser.)

Where do we go from there? Dept.

Now we have the chemical, we know it works in the lab, but we don't know how it will act in a road. This does not mean we are hot guns for a million-dollar road project; no, right now we're all out for a test road. The Iowa Highway Commission believes this is a wise move, and during the coming summer a 1000 foot section of Iowa primary highway 117 will be built on a subbase of QAS treated soil. The 6 inch layer of QAS-soil will be placed underneath 3 inches of asphaltic concrete surfacing and 7 inches of soil-cement. To outward appearances the road will be a "blacktop." The purpose of the experiment is to see if the waterproofing is permanent or if it is just a passing phase. If it's a passing phase we quit; 11 years shot, horrible

thought! (But we can always go on with something else.)



Research gets a hearty start as a batch of soil is mixed with QAS. The QAS is first dispersed in water, making a milky suspension shown in the bottle.

THE FERGUSON CONCEPT OF CLAY MINERALS

Several times lately we've been asked what happened to our soil-engineer groundhog, and would he come out again some time in the future?

Actually, of course, Ferguson took off on such a scientific bent studying books and articles about soils that we didn't expect to see him much before next February 2, when every groundhog has his day. However, Ferguson recently laid aside his library and said, "Wife Henrietta, where is my clover juice? I feel a bit of a thirst."

"A thirst for more knowledge, no doubt."

"No, a thirst for clover juice," Ferguson replied with the air of a wounded spaniel. "I've drunk so much of that other stuff I feel like a condensed belch."

Henrietta was not amused. "Well, don't crank it off in here; those rabbits upstairs will think they have heard the Final Call."

"Is it my fault our home is shaped like a trumpet?" Ferguson rumbled. "You're the architect; I am but an engineer. Furthermore I can't always be watching out for trespassers. That's the trouble with being an engineer; you've got to live with just everybody!"

For the next six minutes Ferguson moped. Life is tough for engineers.

Clay mineral Henrietta

"Henrietta," Ferguson smiled through the watery haze of clover juice, "I daresay you're getting a little stout. It can't be autumn already! I swear, I heard you drag on both walls. What's happened to your girlish slouch?"

Henrietta did not answer. She was being coy.

"Hmmm. I see; scientific problem. Let me give a little calculation to it. Two times two is four, integrated. I know, you're a montmorillonite, and you've expanded!"

Henrietta thought science could be very frightening.

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"That's it, all right. Montmorillonite. Very common in soils. Just be careful when you dry out you don't shrink and fall apart."

Henrietta became confused. These were things her mother had not taught her.

"In fact I strongly suspect a cation exchange," Ferguson continued. "Quite possibly some new cations in the old clay mineral structure. I wouldn't get too near the water; you might explode. Nothing quite like a montmorillonite for taking in excess water."

Henrietta heard this and was moved first to tears and then to a back tunnel where she went on a diet avoiding the use of water. She greatly admired her hubby for being so smart, albeit in a rut.

One day as Ferguson had predicted, the swelling disappeared. Ferguson was charmed to see so many little cations and he named them Calcium, Sodium, Hydrogen, Magnesium, and Argon. Argon is not an exchangeable cation but it's a good name for a junior groundhog and after all that's what counts. His home now resonant with the pitter-patter of little tunnel builders, Ferguson set forth on a series of great engineering feats for the summer.

While we're here we may as well mention that Ferguson's prize-winning paper, "Relation of cation exchange capacity and volume change to identity and amount of exchangeable cations" will soon be published in the North Central Idaho Tunnel Builder, Harry Marmot, editor. We suspect that some of the ideas are wrong, but the language is so technical nobody knows the difference. It is for this article that Ferguson won the coveted Beaver K. Smedley Award for Excellence in Technical Reportage for the Year 1957. Also he has been nominated a Fellow to the American Society for Recalcitrant Prairie Dogs, T. Fred Wolfgang, chairman-in-chief, in charge. We extend our heartiest congratulations.

Review: What's a clay mineral?

It seems Ferguson is a little mixed up, but he does have his primary facts right. For example, soils are indeed made up of minerals. A pile of ordinary sand is mostly quartz, but it may also contain feldspar, mica, hornblende, and many other minerals as well as occasional small boys practicing to be engineers. Mineral grains can usually be identified under a polarizing microscope because they are crystalline materials. That is, they have an orderly internal arrangement of atoms, like bricks in a wall. They make light do crazy things. For color, flash, and spectacle it's hard to beat a bunch of clean soil grains viewed through a polarizing microscope.

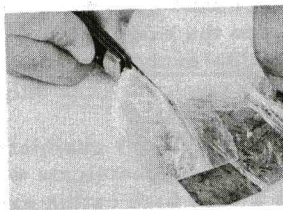
Unfortunately when we look at clay under a microscope we don't see much. Clay particles

are still crystalline materials, but they are too fine to be resolved. An electron microscope will do the job. For identification purposes, however, other tricks are more useful. These include X-ray diffraction, differential thermal analysis, and chemical analysis, and don't ask us to explain them because we haven't got time right now. The important thing is that in the clay particle size range a new set of minerals takes over. These, for want of a better name, are called clay minerals. Now, isn't that something?

Review: Illite for Illinois

The earliest recognized clay mineral is kaolinite, which is the common clay used for making porcelain dishes, also for sizing paper, etc. Clay minerals are a little bit like stinky cheese; they are named after the places they were first discovered. The name kaolinite comes from Kaoling, a mountain in northern China where the whole dish deal started. In fact, fine porcelain is still called china porcelain, china-ware or just plain china, and kaolinite is called china clay. Kaolinite is also a common constituent of soil clays--unfortunately it is seldom pure enough for making pretty dishes.

The two other major groups of clay minerals are montmorillonite, named from Montmorillon, France, and illite, named from the Lollipop State. Both groups of minerals are common in soils. In Iowa we suffer plenty from montmorillonite, probably because our hearts are pure and we need something to brag about. Montmorillonite makes for incredibly muddy roads. And if you'll look back a few years you'll find that Iowans led in the campaign to "get out of the mud." Iowans had to lead; they had the most mud to get out of. But still they don't complain; Iowa soil is fine for growing corn.



Mica splits off into thin flakes; mineralogists say it has basal cleavage. Theoretically flakes could be obtained having a thickness of only 10 Angstroms, or one millionth of a millimeter.

Review: Mica and pages in a book

Montmorillonite, illite and kaolinite have one thing in common; a layer crystal structure. You all know the flaky nature of mica, which tends to break off in sheets, like pages in a book. X-ray diffraction shows that clay mineral crystals are much the same; they are flaky or platy in nature. In fact, illite is sometimes called "mica clay mineral" because of the similarity, and the only real difference between illite and mica is that illite crystals are weaker and never grow very large.

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spheres. The average corner roundness is also high, 0.6 and 0.55, indicating that the radius of the average grain corner is over one-half the radius of the particle. Such high values for sphericity and roundness can only give poor interlocking and development of internal friction, therefore a low C.B.R.

(2) The silt, believed to be a wind deposit, contains about 20 percent clay. Weathering apparently has not progressed very far, as most of the clay-size material was found to be unweathered organic matter -- very finely divided peat. This would contribute little to strength. The very small amount of clay mineral present is probably illite, named after a type locality where it was first described in Illinois. Illite is not a very sticky clay mineral and gives relatively low cohesion. The stickiness of a soil is measured by the plasticity index, which in this case is relatively low at 12.1. All of these factors add up to low strength due to cohesion.

Conclusion:

Stability of the Barrow beach sand is greatly increased by mixing and compacting with the right amounts of silt and gravel. However, the stability is still not high, and we would prefer something to do the job better.

Where-do-we-go-from-there? Dept.

The results are in and analyzed; where do we go from there? The answer is we went back to Alaska. Dr. Keith M. Hussey, Dept. of Geology, and John O'Sullivan, Engineering Experiment Station, went this time, followed by a sick squirrel named Handy. Objectives were a more comprehensive materials survey and gathering of more samples. For example, an answer to the roundness problem might be to use artificially crushed gravel, so it was decided to look for coarse gravel. An answer to the clay cohesion problem would be to find more and better clay, or a different binder material altogether. In the summer



"Egad! Me nostrils seem to catch a faint monstrous whiff of whale!" A fellow scientist at the Arctic Research Laboratory checks up on a local Eskimo industry -- that of chasing whales. Here Eskimos are removing the layer of blubber. Whales are pursued from skin boats, harpooned, and shot with 30-06's. After the whale is dead they eat him (a little at a time).

of 1955 both of these objectives were realized, and samples are now in the laboratory being tested and evaluated. That is part of another story.

References:

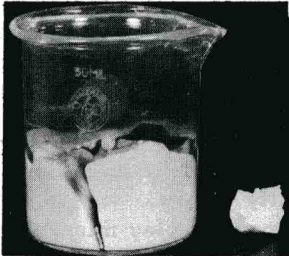
Further reading can be obtained in a mimeographed Progress Report, "Mechanical Stabilization of a Gravelly Sand from the Beach at Point Barrow, Alaska," by I. J. Ward, R. L. Handy, D. T. Davidson and C. J. Roy, a few copies of which are yet available. A condensed more carefully planned version appears in Bulletin 129, "Chemical and Mechanical Stabilization," of the Highway Research Board, 2101 Constitution Avenue, Washington, D. C.

Acknowledgement

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RLH

But montmorillonite is the true tiger's tummy-ache. Montmorillonite has a sheet or layer structure but it also has a great craving for water. Add water and the layers separate and inhale water like air into an accordion. Montmorillonite has such a thirst it can swell and raise a building, pull a pile, push over a retaining wall, or do all sorts of similar naughty tricks. And it's up to engineers to control it. Which is not easy, because montmorillonite has less decision than a pretty girl. Fortunately we know how to sway pretty girls; we give them pretty baubles, but we must admit that sometimes we don't know what we're doing. It's exactly the same deal with montmorillonite, even including the ignorance, which as in love adds spice at the expense of security. Our enticements are usually cations, as found in any old bag of salt. Cations are rather cheap baubles, if you ask us. (If we had any sense we would stick with soils--forget all about the girls.)



Montmorillonite clay mineral readily separates into flakes when we add water. Here the clay has taken in water to become many times its original volume, shown on the right. Subsequent drying has caused some shrinkage and cracking. The same occurs to a lesser degree in many Iowa soils.

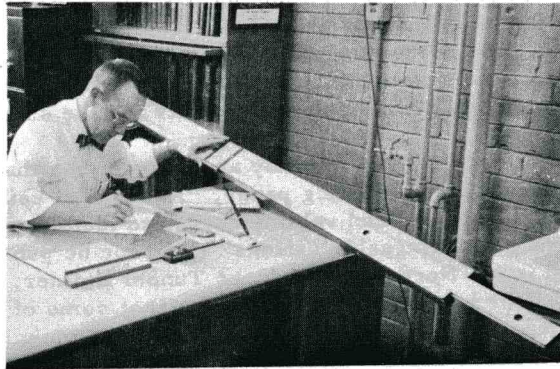
Review: Taking clay with a grain of salt

Cations, as if you didn't know, are positively charged particles, usually atoms. And clay minerals, if you've forgotten, have a negative surface charge because of their internal crystal makeup. Positive ions and negative surfaces--need we say more? Naturally, the ions cling, ding! And with varying degrees of tenacity, depending on the kind of ion. Most ions are rather loosely held; they are, therefore, exchangeable--that is, we can push one kind of ions off if we put another kind on. When we do that we find there's a limit to the exchange for any given soil. That is the cation exchange capacity, and all it means is that so much clay can only hold so many ions. Logical, isn't it?

Of course, in playing around with our chemistry book and splashing our hands in a few chemicals we find that montmorillonite has a very high cation exchange capacity compared with other clay minerals. This cannot slip by undiscovered; we'll have to give it a small ration of attention. Montmorillonite seemingly has more electricity than a wool carpet in the wintertime, but unfortunately we can't drag our feet and go around sparking our neighbors. Montmorillonite is all charged up, all right, but it is pretty well balanced out with cations. The reason it has such a high exchange capacity is that it expands, and cations can slip in between the layers. In other clay minerals the cations have to

hang on around the grain edges--there's only room for a few on the crowded ledge. Montmorillonite takes in cations as pages of a book take print, and lets a few hang on the outside too for good measure.

You can see that an exchangeable cation inside of a clay mineral grain is in a pretty tricky spot for espionage. If it's a strong cation it can hold the clay mineral together and even keep it from expanding when we add water. If it's a weakly constituted cation it can let loose and allow the clay to blossom forth like a moo. And that is the story of the engineer and his pretty baubles; he can change clay expansion by shifting around a few cations. He can add calcium and reduce expansion, he can add sodium and increase expansion, or he can add any number of complex organic ions and stop expansion altogether. He can, in a word, be pretty cute. And of course, like any good groundhog, he likes to see where he's going and feel something solid where he's been. That's soil engineering for you.



Check the long slide rule! Its length has nothing to do with the length of the test road; some one is pulling a funny.

A FINAL WORD ON QAS

Our soil stabilizer for today is nothing more than a big cation and a small anion temporarily hooked together. When we disperse in water we make the cations available to cling to soil. Of course QAS does not supply just ordinary cations; it gives large, greasy things that pretty well glob up our clay mineral. That, friend, is the advantage; the cation sticks to the clay mineral, and the long, greasy tail sticks out and says scat to water. Our clay not only stops expanding, it is waterproofed. How lucky can you get?

On the other hand, we have found we can add too much QAS and cause a decrease in strength. No matter how hard we try, the optimum amount continues to be just a little bit. Not that we're dissat-

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isfied, this is economy--why argue? Still the optimum amount calculates out to be about 5 percent of the cation exchange capacity of the soil. That is enough to make our compacted soil specimen essentially waterproof. Yet if we repulverize the soil and mix it with water, it does wet up. If we run an X-ray analysis we find that only a small fraction of the montmorillonite is actually stabilized.

What does it mean? Why, simple! In order to stabilize a soil mass we add only enough QAS to make the soil pores repellent to the entry of water! Montmorillonite cannot expand if it does not get water. So we keep it dry.

Water equals glue

This still leaves unanswered our loss in strength from too much QAS. In order to understand this we must explain that water, if it's present in very thin layers, makes a very good glue. Now don't run for your empty glue-pot; it's only temporary. The thinner the layers of water the better oriented are the water molecules and the better the glue. When a soil dries out it becomes hard; it becomes hard because the water layers are thinned down to beautiful, though temporary, glue. The soil grains are thus held together until the next rain adds excess water, thickens the water layers, and ruins the bonding.

In QAS treated soil the same deal occurs, only we keep out the rain and so retain some of the glue action of our thin layers of water. But you will remember that QAS repels water; if we add too much QAS we will completely coat our soil and kill the bonding action of water. Therefore add only enough --not too much or you will defeat the purpose, which is strength.

How dry we am

Way back somewhere we mentioned that the QAS treatment of soil is most effective if the soil is allowed to dry out. Now we hope it is obvious; when we dry down we thin out the water layers and increase the

strength of our glue. Actually things may be a bit more complicated; we've found from X-ray that drying is easier in treated soil, and much of the montmorillonite collapses irreversibly, with all of the water going out. When we get this explained we'll really know something.

Where do we go from there?

So much for QAS as it stands, we hope. As you can see, it is a waterproofer but it has no cementing action. Therefore some of the guys who think up things thought it would be nice if we could get a little cementation too. One of our fellows now thinks he may be able to polymerize QAS after it sticks to soil. Oh, we swoon with impatience! If we could but do this, we would first drive the nails and then weld their heads together! We can easily visualize a new kind of concrete. But let's not get too excited until we know if it works. Someday our man will have his degree and perhaps his patent, and then we can talk about it.

Aids, cohorts and sponsors

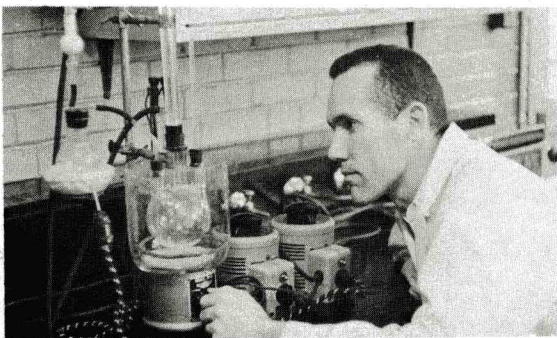
Work on QAS and related chemicals was done by graduate students J.M. Hoover, whose picture we show on p. 2, F.B. Kardoush, who came here from Jordan and went back to Saudi Arabia, and R.L. Nicholls, whose face charms the photo to the left. Also in the swim are a Dr. RLH, shown on p. 1 by an ear, and Dr. D.T. Davidson. We could not have done the job without money, and Projects 283-S and 340-S of the Iowa Engineering Experiment Station, under contract with the Iowa Highway Commission, are supported by funds from the Iowa State Highway Commission and the U.S. Bureau of Public Roads. We couldn't have done the job without chemicals, and these were supplied through the courtesies of the Chemical Division of Armour and Company, the Hercules Powder Company, and the Monsanto Chemical Company.

For you groundhogs who like to dig library style, we recommend Bulletin 129 of the Highway Research Board, 2101 Constitution Avenue, Washington, D.C. Other papers on the subject have been presented to the Highway Research Board and to the Iowa Academy of Science but are not yet in print; a few mimeographed copies are available.

Final word: Much ado, or how he doth Krilium

What's Krilium? If you don't know don't worry; if you do know, don't confuse it with QAS. Krilium is the trade name for a trace chemical "soil conditioner" for plant growth. It differs from QAS in that it is anionic and not as miraculous as some publicity departments first supposed. Furthermore it costs several dollars a pound. Nobody mentions Krilium any more; the advance notices played so many front pages the memory is embarrassing. So we won't mention it either.

RLH



Polymerization of QAS. Our researcher knows it fastens to soil and he wants to tie everything together. If he succeeds we'll all drink aspen juice and celebrate.