To the Editor:

I have recently had the pleasure of reading several issues of your excellent publication, and I was most favorably impressed by its contents. I would therefore greatly appreciate it if you would place my name on your mailing list.

Karl Terzaghi, Winchester, Mass.

To the Editor:

Considering that this topic (electro-osmosis) does not lend itself well for such a write-up, you have certainly succeeded remarkably well. In fact, I would like to buy 100 copies*

L. Casagrande, Harvard University

* Photo courtesy of Iowa State University Library/Special Collections Department
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**SCREENINGS FROM THE SOIL RESEARCH LAB**  
Engineering Research Institute, Iowa State University  
Published 1957-67, Nobody knows why.

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HISTORICAL SURVEY OF THE FIELD OF ENGINEERING, AND THE REASON FOR THIS PUBLICATION

It was late spring of '27 when the groundhog stuck his head out of the ground and sniffed the air and said, "Forsyth! It is Spring, and I have much Soil Engineering work to do. I believe I shall have at it!" So saying, he turned around and went back down his hole and began his engineering works for the summer.

Our reason for mentioning this is that although groundhogs are a grand bunch they haven't always used a lot of science in their work. They still scoop out dirt and push it around. Technological improvement has been limited.

Then one day Ferguson (the groundhog) was sitting hunched over his third glass of tunnel drippings when a thought came to him. "Egad, Henrietta!" (Henrietta is also a groundhog. You don't expect groundhogs to live alone, do you?) "Egad, Henrietta, I am the acknowledged expert at pushing dirt around, yet I do not know that whereof I have been pushing! I am ignorant! I must become educated!" He then trundled off and read a book.

This was many years ago, and it is the first recorded instance of a soil engineer ever actually worrying about soil. We like to repeat it because it is such a landmark in our history. Soil engineering has, of course, gone on from there, particularly in recent years. Nowadays all soil engineers worry about soil. In fact in recent years there has been a tremendous multiplication of specialists called Research Groundhogs. That is our topic for today.

Research Groundhogs are distinctive in that their greatest delight is seeing what new can be dug up. We have quite a few of these characters laughing and cavorting and scooping the dirt around at Iowa State College. They are a conglomeration of civil engineers, geologists, chemical engineers and chemists, most of them working on soil stabilization.

With such a wide variety of approaches to different problems our Research Groundhogs have naturally unearthed some interesting things. They have, in fact, published scientific papers and reports in a flood to rival the Gargantuan deluge. The only difficulty is that as scientists they must write their reports giving all relevent information, which usually includes charts and graphs and masses of data. This does not make for a very high readability.

(Continued on next page)
HISTORICAL SURVEY (Continued)

Also we might point out that groundhogs don't often speak English; they insist on communicating by grunts and whistles. This is apparent as you read a few technical papers. Fortunately translation is not too difficult. Another problem is that after burrowing in the ground for many months a Research Groundhog may know very well that he has gotten somewhere, but due to the difficulties inherent in subterranean surveying, he may not know exactly where he has gotten. He is naturally impressed by the long and tortuous route. So in writing up his work as a thesis it is good scientific policy to miss the point or bury it way back at the end somewhere. That is the history of the experiment; that is how the mind works. Translation becomes a bit more difficult.

Therefore, the birth of a new journal! We will be go-between; translator; we will try to show the meaning of the grunts and whistles, to give intelligence to the unintelligible. This paper will enjoy a much wider distribution than our technical papers and will reach many non-technical persons. Our aim is to increase interest and inform; for the interested reader we will suggest appropriate reprints which describe more fully the work mentioned here.

Our main goal will be to disseminate findings from soil stabilization research. Furthermore you can expect us to be a little hoggish; we will like to point out what we have done. We're still groundhogs, you know; a groundhog can't see very far into the next burrow. That's not our problem; it's the other groundhog's. On the other hand don't worry; we will try to maintain a high general awareness and will not omit passing on pertinent information from other sources, giving credits of course, especially if they are friends.

RLH

ROAD RESEARCH PASSES THE HAT FOR A NEW CONSTRUCTION ERA

Since time immemorial man has preferred to follow the beaten path, so much so that he likes to have other people to run ahead and beat it down for him. From native boys sent ahead to hack out a jungle trail we have progressed to the modern Highway Engineer, whose job is somewhat more complicated even though on a roughly parallel pay scale. Today's manufacture of beaten paths requires much more than just a machete. It takes a bulldog, or, excuse me, a bulldozer, and a lot of other things as well. One of these things is materials. That is our subject for today.

The dominant materials in most roads are sand and gravel or crushed rock. This is true whether the road is made with asphalt, portland cement, or grandma's toothpaste. Even ordinary gravel roads contain gravel or rock, although some people estimate them at 100 percent dust. But it's a fact; gravel roads usually have gravel. This is turned into dust or flung from the road by a process of scramble and bounce. Then we have to put on more gravel or crushed rock.

This road maintenance plus bountiful new road construction leaves us with an urgency for more gravel and rock. In Iowa this is not so easy because of the gosh-blasted cold weather -- not the cold weather now, but the cold weather a few thousand years ago when Iowa was smushed out under a series of mighty glaciers. As you know, a glacier dries things up when it melts, and the glaciers really dirtied up Iowa. They left a lot of soil and covered up our nice rock. We engineers naturally look on this with some tinge of regret, but we'll be big about it and admit it's great for the corn. Still, we'd like more rock.

The apprehension over dwindling available rock resources had to lead somewhere, if only to ulcers and poor roads. A more productive attitude was to look towards research. The Iowa Highway Research Board boldly tackled the problem by sponsoring a wide variety of investigations by the Iowa Engineering Experiment Station and the Iowa Geological Survey. Suddenly the search was on! Since then, similar investigations have been started in other states and on a national level.

Soil Stabilization

The largest single effort in terms of personnel and money spent has been an intensive study of Iowa soils and methods of soil stabilization. Soil stabilization is simply that -- increasing the stability of soils under all weather conditions so they may be used as the structural members in roads. An ideal might be to sprinkle some magic substance over a muddy road and have it instantly dry up to have a strength equivalent to, say, soft steel. We are not quite so naive as to expect this, and we will settle for something less. We will settle for anything that will make soil strong enough to support light traffic on secondary roads. Furthermore it must be cheap. Not only will we save gravel; we will settle a lot of nasty old dust.

Soil stabilization research got a big boost in September, 1950, when a project was set up at the Iowa Engineering Experiment Station, Iowa State College, with funds from the Iowa Highway Commission. The title of the project is, "The Loess and Glacial Till Materials of Iowa; An Investigation of Their Physical and Chemical Properties and Techniques for Processing Them to Increase Their All-Weather Stability for Road Construction," a meaningful mouthful when you stop to read it.

(Continued on next page)
ROAD RESEARCH (Continued)

The project is under the supervision of the New Hampshire dynamo, Dr. Donald T. Davidson, who says, "We can stabilize anything soft, including a lady's smile. All we need is the right treatment or admixture."

You tell them, Doc; the only question is how do we find the right treatment or admixture? Men have looked for the one answer for years; our fervent hope is that soils will be easier to engineer for permanence than a feminine smile. Otherwise we give up.

The Scientific Approach

As for soil stabilization, our plan is to put some science in the research. You can tell we've been watching cigarette ads. There are two ways to launch into research; trial-and-error, and the scientific approach. Trial-and-error is easiest but also a little blind; each trial gives you a yes or no, and your chances for a yes are little better after 10,000 no's than they were after the first. Science allows you to figure out how and why, so your trials and errors mean something. Then you can use your wits and go ahead with better and fancier trials and perhaps fewer errors.

Since this is to be a scientific approach, first we must know soil. A knowledge of soil is basic and essential to the whole operation; how are you going to figure out what happens if you don't know what you're working with? Unfortunately soil is not just soil; it varies literally all over the place. So soil stabilization rightly starts in the outdoors with a field study of soils. A part of this study is the intelligent collection of samples. Actually this is a critical phase of the investigation; there is nothing so worthless or insulting as a poor sample. You can spend six years running laboratory tests on a bad sample and think you've gotten somewhere when actually you've done is learn how. The sample must represent something or results cannot be properly evaluated or applied to soil in the field.

Field sampling completed, we can go into the lab; objective, to know the soil. One can start by identifying the minerals. If your impression of minerals comes from animal-vegetable-mineral idea, forget it; this is something different. Minerals in soils are crystalline chemical compounds with definite atomic arrangements -- such things as mica and quartz. The kinds of minerals present have a terrific influence on a soil's engineering properties. Also the mineralogical composition will determine reactions with chemical stabilizing treatments.

Laboratory study begins with an investigation of fundamental properties of soils. Dr. J.B. Sheeler titrates a soil to determine its alkalinity.

In the laboratory the soil samples are sieved, separated, studied under a polarizing microscope, ground, boiled, baked, treated burned, treated with chemicals, melted, X-rayed, photographed, stained or whatever else may help. Directly or indirectly one tries to find out all that present techniques allow. We measure percentages, particle sizes, surface areas, and what all.

This much is pure science, with practical applications practically invisible. Now we can come up with a little engineering use. One can measure engineering properties such as plasticity, bearing capacity, shrinkage, etc., the plan being to compare these data with the wealth of background information on each soil. For example, plasticity should be related to composition, and as it turns out it is. Similarly, composition is related to field relationships. You can see the ready possibilities for shortcuts in future studies of these soils. This is science, learning about the orderly arrangement of things.

We still haven't discussed trial-and-error. Soil stabilization is so new there is little else a beginner can do. But after a few trials he is no longer a beginner; he can look at his results and look at the soil and say this or that will or won't work and why. This is trial-and-error with an open eye. If the eye gets sleepy and tends to close sometimes we say that's OK, take a break and go fishing. But come back with an open eye. The laboratory research pattern boils down to this: (1) Select a problem and if possible predict the answers, (2) design the research to satisfactorily test the predictions, (3) do the work, (4) analyze the results, paying as little heed as possible to all those loose predictions, (5) to every result apply the ubiquitous question "why." Possibilities for "Why" often show the way and give the predictions for new and better research and carry us closer to the final answer.

RLH
MECHANICAL STABILIZATION OF AN ARCTIC BEACH

Problem:
To stabilize a beach in the neighborhood of Pt. Barrow, Alaska, for wheeled vehicular traffic.

Historical:
In 1910 Admiral Peary, back from the North Pole, said "Great Scott!" Scott being a polar explorer too. "Great Scott! We don't know how to stabilize an Arctic beach! We must act immediately; MacArthur may want to wade ashore!"

The beach near Pt. Barrow. Land to the right, sea to the left. Since most activities are directed from the beach, it would be a good place for a road.

So a directive was issued and marked "Expedite!" and sent to Washington, D.C. Unfortunately Washington was indisposed at the time and the directive slipped by Martha and ended up in the files. It was pulled out and remarked "Expedite!" in 1926, 1929, and 1937, then went back in the files.

Then in 1954 a couple of Iowa State College engineers were discussing a world problem when one of them said "Gad, this coffee's terrible! Let's go to Alaska!" The other took a gulp and cried, "Check; when do we go?" They wired the Office of Naval Research, asked about the Arctic Beach, and in the summer of 1954 left for Alaska. The Iowa State College research team consisted of three men, Dr. D.T. Davidson, Dept. of Civil Engineering; Dr. C. J. Roy, head of the Dept. of Geology, and an obscure employee named Handy.

Perspective:
Northern Alaska is a broad, flat area of Arctic coastal plain isolated from the atmosphere's central heating plant by high mountains to the south. Even though the annual precipitation is very low, of the order of 10 inches, the extremely poor drainage causes very wet conditions in the summer. Drainage is inhibited by permafrost, or permanently frozen ground, below a depth of about 1 to 3 feet. The plain is dotted with lakes, and the "dry land" in between is tundra -- mainly grass, peat, and water. Because of this, large scale summer land travel is practically impossible except over natural routes such as beaches.

The Arctic Coastal Plain. Lakes, permafrost, and not many trees. Land travel is practicable only during cold weather. The Lakes shown have gone through several stages of development. Often they are square or rectangular in shape and are parallel to each other.

The beach at Point Barrow is made up of highly rounded coarse sand, and for walking or truck travel the beach is literally unbearable. The sand has very low bearing capacity, and one finds that each step is up out of a hole. A short walk convinces one of the utility of soil stabilization, and a short ride in a jeep convinces one even more. A jeep grinds forward in four-wheel low.

Approach:
Because of the remoteness of the Arctic areas the most desirable method for stabilization would be to use locally available materials. An abbreviated materials survey was conducted by the field party, and samples were shipped back to Iowa State College.

Method:
As always, the most appealing method for doing the laboratory work was to turn it over to someone else. A research study such as this (Continued on next page)
Ice-wedge polygons on the Arctic Plain -- severe cold causes the ground to crack; surface water running into the cracks freezes to ice which does not allow the cracks to close. Successive cycles cause squeezing up of the enclosed ground and thickening of the ice wedges. Areas lower in the middle with water in them are known as low-centered polygons. Shadow of the small seaplane for scale.

constitutes a satisfactory problem for a graduate student, and each graduate student must write a thesis in order to get a degree. Captain Ira J. Ward, Corps of Engineers, U. S. Army, accepted the problem and integrated it with his program for a Master of Science degree in Civil Engineering.

Samples turned over to Capt. Ward included the following:

1. Composite sample of gravelly beach sand representing the material to be stabilized.

2. Silt from an old beach ridge located inland on the tundra.

3. Coarse gravel carried onto the beach by ice the previous winter.

These were studied and analyzed by Iowa Engineering Experiment Station personnel to measure such things as particle size, roundness, mineralogic composition and physical properties, and the data were kept in reserve for later engineering interpretations. Meanwhile various mixtures of the three materials were prepared and evaluated for stability by means of the California Bearing Ratio (C.B.R.). The C.B.R. measures stability under load, and results are expressed relative to the stability of rolled (i.e., compacted) stone.

Results:

The best mixes proved to have close to "ideal" particle size gradings given by Talbot curves. This theoretical grading scheme considers the mix an aggregate of interlocking coarse particles. The voids are then filled by the next size finer, and the then remaining voids are filled with the next size finer, and so on down to clay size material. In this way grain contact area and supposedly friction are at a maximum, although now there is disagreement on this. The same theory is used in the design of various concrete mixes. In concrete the ultimate binder is portland cement or asphalt, whereas in mechanical stabilization it is clay. Clay has peculiar sticky or cohesive properties which, while not permanently water stable, can give a strength which is very satisfactory. A bituminous surfacing can be added to the road if dryness must be preserved.

The best mix gave a C.B.R. of 31 percent, or about a tenfold increase over the C.B.R. of the natural beach material, which as they say about Marilyn, ain’t bad. The best mix consists of 60 percent beach sand by weight, 30 percent tundra silt, and 10 percent ice-rafted gravel. Omission of the ice-rafted gravel reduced the C.B.R. about 4 percent. In all cases the C.B.R.’s were higher after soaking in water. Data indicate that alternate wetting and drying would increase the C.B.R.

A current answer to the road problem in the Arctic is the Weasel, a tough suffering track vehicle originally designed for the invasion of Normandy. On this occasion a Weasel successfully carried its passengers 14 trouble-free miles before it broke a track. Drs. Roy and Davidson have a look. Everybody but the Weasel walked back. (It had to be carried.) The location is south of Pt. Barrow only a few hundred yards from where Will Rogers and Wiley Post had more serious problems in 1935.

Evaluation:

A C.B.R. of 30 would be satisfactory for a light traffic road or for a heavy traffic road only if a base course of stronger material were laid on top of it. Stability of the beach sand mix is not as high as expected.

Discussion:

The mix has an ideal gradation, and departures from the ideal were found to give a weaker mix. The intriguing thing is that even with the best gradation possible the mix insists on having rather low stability. Further study gave two possible explanations for this; both have to do with unique properties of the materials:

1) The sand and gravel consist of highly rounded chert particles, chert being a very hard, siliceous rock often called "flint." The average sphericity was 0.7 and 0.8 for the two materials, a value of 1.0 indicating a collection of perfect spheres.

(Continued on next page)
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 (ool); 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 waterproofs 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.

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)
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.)

**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 trumpetaet?" 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.

(Continued on next page)
"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 hobby 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 were 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 Reporterage 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.

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.

(Continued on next page)
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 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:**


**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-

(Continued on next page)
satisfied, 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 repulsorize 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 repellant 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 are

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 waterpoboer 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 courtesses 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
A GEOLOGICAL ISSUE --
PART ONE

Scientists are human, bless their hearts, and soil engineers frequently work with a brand of scientist called geologists.

Geologist "Ifbut" Smedly regards his engineer buddies as the pleasant fellows whose main conversational talent is to ask geologists impossible questions and expect quick, clear answers. Geologist Smedley always tries to answer with scientific accuracy, which means the plentiful use of if's and but's. Which is how Smedley got his nickname, "Ifbut."

Engineer Ferocious K. Dammaker is dissatisfied with routine scientific answers. When he asks three geologists the same question he is disturbed to get three different answers. He may deliver an opinion in special technical language called swearing. He also has a bone to pick with the geologist who goes around muttering about "pre-Cambrian porphyritic anticlines" or some other such nonsense. He thinks they should talk English.

The Point of View

The difference in viewpoint probably stems from a basic difference in training and in thought because, basically, scientists like to learn things, and engineers like to do things. A scientist may spend days, weeks, or years investigating and deliberating a problem that has no more apparent practical worth than a wood tick. The engineer says, "The hell with it; let's build our road." The geologist retorts, "All right, but it may be a hell of a road." Sometimes he's right—it isn't much of a road. This increases his stature but not his popularity.

With all this emphasis on knowledge it's understandable that a geologist almost comes apart if he doesn't understand things. A fact requires a reason, even if he has to guess. He then back-checks his guess to see if it explains things. If it does, he has a theory. If it doesn't, he guesses again. Often two or more guesses satisfactorily explain things, and one theory will appear better to one man than another theory which appeals to another. This leads to....

An experimental stair-step loess road cut near Magnolia in western Iowa. The ability to stand in vertical cuts is believed by some to be due to high permeability of the loess. The exposed loess never becomes water-logged enough to lose its cohesion.

Argumentism

Geologists, the most cantankerous, restless individuals imaginable, are forced to rely on the earth's clues; and these are sometimes dim. Much is left to the imagination, and geologists prefer to imagine independently. A theory must be tested, and you can't try science in a court of law.

The Dread Peril

Sometimes in the course of the arguments you see signs of Deductive Astigmatism. Sufferers of Deductive Astigmatism can't see straight. A man with a severe case of the D.A.'s becomes totally blind to all forms of contradictory evidence. The deductions have taken over his soul. Fortunately such severe cases of Deductive Astigmatism are rather rare. Mild attacks are common.

Special eyeglasses are sometimes worn in an attempt to correct Deductive Astigmatism. Otherwise eyeball distortion dims the vision when the victim is confronted with all forms of contradictory evidence.
Unfortunately when a man has it he doesn't know he has it, and he automatically thinks the other guy has it, so in reality nobody knows who is afflicted. That's what makes science so interesting. You find the deductive astigmatism transmitted through such impersonal media as books, articles and college lectures, so nobody is safe. In fact, we suspect everybody suffers it once in a while.

On the Wierd Prevalence of Flapdoodle

Our final bit of bone rattling concerns use of technical language. One side accuses the other of using big words to sound high-falutin, and the defendants claim that big words are needed to convey the dope with accuracy.

We believe that anybody who uses technical language for the sake of the language should be shot or at least whistled up a bit. It's not hard to make something difficult, and perhaps it does give a certain satisfaction. If people can't understand a man they are likely to think he is a genius.

The topography in the areas of thick loess is steep and bisected by streams. It is quite hilly country. some little bit. The question is how it got there.

Pronunciation

Loess is a German word, Lōss, pronounced "loess" with the "oer" deep down in the throat like a gargle. When most people say it, it sounds like a shallow "lurs," or else they give up altogether and say "low-ess" or even "luss." Of these, Webster approves the first two; many professional men are naturally inclined to prefer the last. In Iowa we usually say "luss" to rhyme with "lust." But we bow to regional preference.

Definition

The loess battle is a very serious one because the debaters aren't even agreed as to what they're talking about. Many would prefer to tie the definition of loess in with origin, but others say this is not conducive to scientific objectivity. In fact, some people have gone to the term loessoid to avoid the question of origin. Loess is so variable in different regions that a definition broad enough to cover all loess deposits, if they are deposits, and narrow enough to exclude everything else is almost impossible.

Therefore, loess is characteristically a tan, unstratified silt with a variable percentage of clay, and very little sand. The mineral composition can be almost anything but seems to remain fairly consistent over any one area. The thickness of loess varies from zero to over 150 feet, although with zero thickness it is most logically called something else. This zero is mentioned only to establish the lower limit.

Appreciation

The areas of deep loess in the United States have been eroded into topographic magnificence with a grandeur, artistry, and spectacle that easily inspire awe. Not only do we have the superbly sculptured landforms with sharply de-
The Delta River in central Alaska is a fine example of a braided stream fed by melting glaciers.

defined drainage patterns, we see the high, almost vertical cliffs cut and standing in this friable, compacted "dirt," and the innumerable cat-steps tracing the approximate contour lines around the hills.

And then some look at our beautiful hills and say, "Students, loess is a wind deposit. Notice the dune shaped hills." This is still in some books, but most of those who should know say that the topography is erosional, which means the hills were carved by running water. Frankly we don't see how they could look dune shaped, except possibly to verify that they are a wind deposit.

Earthworms and the Outer Cosmos

By the year 1900 the guesses on origin of loess already included being washed in by the ocean, carried about by water from melting glaciers, blown in by wind, or descended from a cosmic dust cloud such as encircles Saturn. One scholar proposed that loess emerged from mud volcanoes and was then distributed by a great post-glacial flood. A favorite is the suggestion that loess deposits represent gigantic accumulations of earthworm castings, the earthworms gobbling up glacial till at the front end and leaving a trail of loess behind them.

The Wind Blew and the Silt flew

The aeolian theory is one of the oldest and is still the most popular. In the 1880's a Baron F. von Richthofen studying some of the widespread deposits of loess in China concluded that wind was responsible—that Chinese loess was an accumulation from countless dust storms flowing from the deserts of interior China. In 1897 T. C. Chamberlin applied the aeolian hypothesis of loess to the central U. S. He reasoned that this loess did not blow off the deserts but from nearby glacial outwash areas.

His evidence was that the mineral composition of loess approximates that of the regional glacial deposits.

Taking in the Outwash

To understand the theory of a glacial source for dust storms one needs to know something about glaciers. A glacier is either a creeping river or a creeping flood of ice, depending on whether it is confined in a valley or not. As it creeps it incorporates gravel and other debris in the basal ice. At the margin of the glacier where the final ice melts, the melt water forms a river with a very heavy load of sediment. Because of this the river develops a braided channel with extensive sand and gravel bars. The channel continually shifts about, divides and recombines as if not sure where it's going. The river bars swept by wind form a ready source for sand and silt.

Salt and Pepper

Particles picked up by wind and carried in air ordinarily tend to settle out. The larger the particles the more rapidly they settle. Sand particles carried in air are large enough that they skip along over the ground, a mechanism called saltation and responsible for the peppering one gets in a sand storm. Saltation is a major factor in the building and migration of sand dunes, and the need for sand to bounce on something means that sand dunes gradually grow outward from the source area.
Facies Change

A favorite with aeolian theorists is that loess changes gradually with distance downwind from the source. Some say distance can not be the major controlling factor, because the rate of change is variable at different places. As a general rule loess does thin out and is finer as one travels away from a logical source. A theory is that the coarse silt settles out faster and is concentrated in deposits near the source. Farther away the amount of coarse silt in the air is depleted, and finer materials become the major constituents in the deposit.

For the budding geologists such a change is called a sedimentary facies change. (This is Latin, but there's no other word for it.) The complete facies change would be from sand dunes adjacent to the source area to loess that is first a silt, then farther away a silt loam, a silty clay loam and a silty clay, as the clay content increases and the silt content decreases. If the depletion theory is correct, the rate of change is not so dependent on distance as it is on other things such as source area, wind velocity, height of blowing, etc.

Fossils, Root Tubes and Paleosol

Minor features of many loess deposits include fossil snail shells, often given in evidence that loess is a wind deposit because the snails are land snails. That is, they lived in air, not in water. Other dead things in loess include occasional mice, gophers, and broken-headed geologists who chose the wrong time to argue. Fossil animal holes, denoted by educated as paleocrotovina, (jargon) occur occasionally. Tiny vertical holes believed to be root channels infiltrate the loess, improve its vertical drainage, and act as tiny cylindrical structural surfaces for the deposit of carbonates and iron oxides. The resulting tubes are called "piperests." Much of the recent work on loess has been to identify and correlate fossil soil profiles. Soil at the surface of the ground becomes discolored, forming a dark topsoil. Somewhat deeper in the ground it becomes clayey, forming a subsoil. Similar layers occur buried within the loess, where they are interpreted as representing weathering which took place when loess deposition temporarily halted. Material then exposed at the surface of the ground had time to weather. Later on deposition was renewed so that the soil profile was covered up. These pauses in deposition are believed related to different glacial advances. And a buried soil is called a paleosol, meaning ancient soil.

Is loess a Soil?

Finally we can jump in on another argument, this time between engineers, geologists, and agricultural soil scientists. Let's assume for the moment that loess is a wind deposit. Is loess a soil? The engineer says "yes," because he can dig it. Some soil scientists say "yes," because it will grow things, but others emphatically say "no!" loess is the parent material for the true weathered soil profile, or solum, which forms near the ground surface. Geologists, if they believe in wind, say loess is properly called a sediment. Who's right? They're all correct, considering the uses to which they want to put it. Here is the difference between scientists and engineers: the scientist wants to know about something, but the engineer's main concern is how he can use it. Loess behaves like a soil, therefore it is a soil. For scientific value this definition is about like saying kerosene is water because you can drink.
it. If the processes of formation are different, the materials are different. Clay formed by weathering is not the same as clay laid down by a river. The latter is a sediment; the first is a soil.

LOESSIFICATION, Y'ALL

In loess as in life it's hard to buck the wind, but some people do so. Most recently Dr. R. J. Russell of Louisiana State University, after working extensively with river deposits of the Mississippi, reasoned that from its position on the hills loess could be slumped terrace deposit. Loess in the south-central United States is close to the river on terraces, although there is again some disagreement on nomenclature. Hence the theory of "loessification."

According to Russell, loess has the same particle sizes and minerals as floodwater deposits of the Mississippi called backswamp deposits. Older backswamp deposits exist higher up on river terraces that represent former floodplains. Weathering leaches the carbonates and removes much of the clay, the carbonates later being replaced when the loess sits at a lower level. Snails and gravel are incorporated into the loess as it churns and mixes during its creep downslope. A strong point in the argument is that it explains how gravel could be mixed in the basal portion of the loess. Gravel in basal loess is a little hard to explain if you blow everything in on the wind.

Retorts and Reverberations

Gravel? replied the aeolianists--carried in by animals; and as for loessification, where did the clay go? How did all that clay get washed out? And what about the increase in loess fineness away from the river? Loessificationists replied, of course loess changes away from the river floodplain--what do you expect when it grades into the unaltered clay-rich backswamp deposits? As for those minor discolored zones, they are not "paleosols" they are clay zones, although most of the clay was left behind when the loess moved downslope. Furthermore the loess is always thicker on the flanks than on the crests of hills--how do you explain that by wind?

On the other hand the evidence is not all in agreement. Recent work by Iowa geologist Dr. R. V. Ruhe shows that in Iowa the loess is commonly thicker on crests of divides, and gravelly basal portions are not loess but are a result of slope erosion and sedimentation prior to major loess deposition. Ruhe believes in wind.

Perhaps a major source of trouble lies in extending results of studies in one area to other areas. Yet wind-blown loess of the northern U. S. can be traced hill by hill into the south, and the loessified loess of the south can be traced hill by hill up north. If everyone is correct, somewhere there is a sudden shift in the mode of origin, probably at some arbitrary boundary like a state line. Geologists have a little trouble accepting this.

The Far North und der Nederland

In the U. S. we're either all wet or full of wind, but people in Alaska are full of frost action. A theory advanced by Stephen Taber, an authority on permafrost, is that the common upland loess in Alaska is nothing more than local bedrock which has been disintegrated by frost action. Most Alaskan geologists and soils men say the major evidence still points upwind, and the silts are wind-deposited loess. However, downslope movements associated with frost action account for much thickening of the deposits in the valleys. Some of these translocated valley silts are highly organic, have a rather undelicate odor and are called "muck."

A major argument in favor of Taber's theory is that the mineral composition of the silt corresponds to that of the supposed parent rock. A major argument against the theory is that the mineral compositions do not always correspond to those of bedrock. And so the story goes.

A Netherlands geologist named van Rummelen has been talking against the wind for some thirty years, his conversation somewhat resembling the words of Taber and Russell. Van Rummelen's loess, which he prefers to call "loessoid" to keep it out of the wind, is derived from weathering of Cretaceous age bedrock followed by soil creep and mixing. Most Dutch geo-
logists and soils men still stick with the wind, but they will go along with the idea of slight soil creep incorporating gravel or boulders in the basal loess.

Majority Accuracy

If scientific questions could be reliably decided by a vote—which they can't or the world would still be flat—loess would unquestionably be wind blown, other theories notwithstanding. But a new theory is at least partly a success if it causes critical re-examination of the old ones. So let's not stop the argument.

ACKNOWLEDGEMENTS

Again we thank the Iowa State Highway Commission and the U. S. Bureau of Public Roads for picking up the tab.

Since loess is the most abundant surficial material in Iowa our soil engineering investigations naturally started with this material. The work on engineering properties of loess has been skipped over in this issue so that we might present the more fundamental question of origin. Engineering data will be presented in future issues. A separate engineering and geological investigation of Alaskan silts and glacial materials was undertaken by Engineering Experiment Station personnel under the sponsorship of the Office of Naval Research.

We also gratefully acknowledge the abundant correspondence which came in reply to questionnaires sent to various soils bureaus and geological surveys in other states and countries. The answers have proved very helpful and warrant a much more thorough presentation.

REPLY CARDS

With this, our fourth issue, we finally have the nerve to test our popularity. Actually we're encouraged by your letters, for which we extend a very deep and sincere thanks. Please return the enclosed card if you want to remain on our mailing list; otherwise we're afraid we may lose a customer. You'll notice we don't even buy the stamp; we're a very low budget operation, and we can't afford that plus salaries. Please note that this card is only for SCREENINGS, since our list does not coincide with other Iowa State College mailing lists. Mail the card only if you want SCREENINGS.

Finally a long overdue apology to our foreign readers because we are so slangy and sometimes unintelligible; we find that a little nonsense helps our days along. We hope we don't completely ruin yours.

IN THE NEXT ISSUE: Stabilization of soils with lime.
Screenings from the Soil Research Lab

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

SUBJECT: LIME

Roman in the Gloumin'

One day a noble Roman named Nero was flitting over the highway in his gay new 57 A.D. swept-wing 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 honorariums, 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.

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 Pozzoull (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 "puzzolana" 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 puzzolanic concrete can be found intact today.

REVIEW: WHAT IS LIME?

The word "lime" is such a convenient handle
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, CaCO₃. At red heat the carbonate breaks down and releases carbon dioxide, CO₂—the same gas as in soda pop. Note that CaCO₃ minus CO₂ = CaO, calcium oxide or lime. CaO is also called quicklime, probably because some incautious soul found it burns but quick.

Quicklime is highly caustic partly because it reacts chemically with water and gives off heat: CaO + H₂O = 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-o-mite) is a carbonate rock very similar in appearance to limestone. It is often used to make lime. Dolomite is a calcium-magnesium carbonate, CaMg(CO₃)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 basks 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 dihydation 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 CHEWININESS**

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 mudder 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 mudder 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-
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.

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.

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 floculate—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:

<table>
<thead>
<tr>
<th>Soil</th>
<th>LL, %</th>
<th>PL, %</th>
<th>PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Plastic loess</td>
<td>53</td>
<td>26</td>
<td>27</td>
</tr>
<tr>
<td>&quot; + 6% lime</td>
<td>46</td>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td>(b) Friable loess</td>
<td>33</td>
<td>21</td>
<td>12</td>
</tr>
<tr>
<td>&quot; + 6% lime</td>
<td>34</td>
<td>24</td>
<td>10</td>
</tr>
</tbody>
</table>

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.
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 CO₂. 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 unhearsened 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 the lime. A special mixer then follows, sifting 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.
### Soil Compaction Strengths After Soaking

<table>
<thead>
<tr>
<th>Soil</th>
<th>28-day comp. strength after soaking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kind of lime</td>
</tr>
<tr>
<td></td>
<td>Calcitic hydrateda</td>
</tr>
<tr>
<td></td>
<td>Dolomitic monohydrateb</td>
</tr>
<tr>
<td>Glacial till</td>
<td>220 psi</td>
</tr>
<tr>
<td>Friable loess</td>
<td>120 psi</td>
</tr>
<tr>
<td>Plastic loess</td>
<td>95 psi</td>
</tr>
</tbody>
</table>

*a 9% 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.

<table>
<thead>
<tr>
<th>Soil</th>
<th>28-day comp. strength after soaking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kind of lime</td>
</tr>
<tr>
<td></td>
<td>Synthetica</td>
</tr>
<tr>
<td></td>
<td>Commercialb</td>
</tr>
<tr>
<td>Friable loess</td>
<td>506 psi</td>
</tr>
<tr>
<td>Plastic loess</td>
<td>356 psi</td>
</tr>
</tbody>
</table>

*a 9-9 % 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)₂; MgO remains MgO.

**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 17 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.
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.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Lime (commercial)</th>
<th>Lime</th>
<th>Moist cure days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% dol. dihyd.</td>
<td>23</td>
<td>104 132</td>
</tr>
<tr>
<td>Friable</td>
<td>% dol. quick</td>
<td>29</td>
<td>205 215</td>
</tr>
<tr>
<td>loess</td>
<td>Plastic</td>
<td>39</td>
<td>52 66</td>
</tr>
<tr>
<td></td>
<td>9% dol. dihyd.</td>
<td>99</td>
<td>84 115</td>
</tr>
<tr>
<td>Plastic</td>
<td>9% dol. quick</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

REFERENCES SIGHTED


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 Approval 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! yummy.

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

RLH
THE STORY OF FLY ASH, OR, SMOKE GOT IN THEIR EYES

Not many years ago a melancholy shroud cloaked our cities, transforming them into stark gray pillars of brick and stone jutting upward like dirty coral into an air clouded and choked with grime.

There was too much smoke about.

The increase in dinginess was so gradual that city dwellers did not at first give much heed. A few moved to the country; others had sick lungs. A few laid aside their cigarettes in disgust when they found they couldn't see the smoke any more.

Then the air got even grayer, and many people went back to cigarettes because they enjoyed the clear spaces the smoke made in the otherwise dark city air. Filter cigarettes became the rage; they were so much less conspicuous than wearing a gas mask.

As generations progressed and children grew up, the parents came to realize that something was amiss. A child reading his books might look up puzzled and ask, "Daddy, what's the sun?" Then Daddy had to hire an airplane and take the family up for a quick reminder.

Housewives gently (?) complained about the way their wet laundry acted as a filter, and the man in the gray flannel suit either wore a fresh, bright tie or became permanently invisible.

In fact it was during this era that city people, normally a loquacious group, learned their precious trait of never speaking to one another, simply because the neighbors had faded away into the gloom. The noble tradition has carried through to the present day, when outsiders mistake it for unfriendliness.

---

Saving the Day.

In this grave oppression it was the Engineer in his track suit who boldly stepped up and literally saved the day.

Electric power station going full whirl, but no visible smoke! The fly ash is being removed by static electricity. Ash particles are first charged up and then caught on oppositely charged plates, leaving the smoke sweet as dew-kissed sunshine leaping on a sea of whispers.

Fly Ash

Smoke collectors, more properly called "precipitators," remove solids from smoke, leaving gases which ordinarily keep going up. The collected solids constitute a very fine dust called fly ash to rhyme with fly specks, which by nature it resembles.

Approximately 25,000 tons of fly ash are now collected in this country every day. Most precipitators operate either mechanically by utilizing centrifugal force, or electrically by attraction of electrically charged smoke particles.

Powdered Coal

One reason such a tremendous bulk of fly ash is being produced and collected is the changeover to use of pulverized coal. Electrical power plants operate more efficiently if coal is first powdered and then blown into the furnace. Money is saved and more power is produced. However, 90% of the ash is then fly ash instead of famous old-fashioned cinders.

---

A most frequent use of fly ash is to haul it out to the dump. This ash has been moistened to prevent blowing. Detroit Edison Co., Detroit, Michigan.
DISPOSAL

Now that the fly ash is being collected there remains but one chore: What to do with it? For some reason people do not put a very high value on something which is worthless, unless of course it is pushed by clever advertising. Fly ash is a waste product which ordinarily must be hauled away, dumped, and buried. Otherwise it will blow around.

What is it?

If you visualize fly ash as soot, you're wrong. Fly ash usually contains only a minor amount of carbon. In appearance fly ash is a gray dust, somewhat like portland cement powder. Chemically it is quite a bit different.

Fly ash for the most part represents melted foreign materials from the original coal. The minerals have been melted and blown into a spray of tiny droplets, where they are cooled rapidly to form spheres of glass. Some of the spheres are hollow, like soap bubbles. Other particles are opaque and consist of magnetic iron oxides. But for the most part fly ash is a glass composed of silica (SiO$_2$) and alumina (Al$_2$O$_3$) with variable amounts of iron. Other elements present are carbon, calcium, magnesium, sulfur, sodium, potassium, not to mention many rare and exotic forms such as titanium, phosphorus, and germanium. The composition varies quite a bit from grain to grain, probably because the original mineral particles melted separately and never recombined.

A Pozzolan!

Remember Pozzouli, a small town in Italy where Romans discovered the use of volcanic ash in mortars? Volcanic ash is glass, and it reacts with lime to give something hard. It is a pozzolan.*

Now, with the use of modern technology and scientific knowledge plus a little fly ash, we are successfully doing what the Romans did over 2000 years ago, bless their pagan little hearts. We are using fly ash as a cheap pozzolan to increase the strength of our concrete, especially in big structures where economy is most worthwhile. The fly ash reacts with lime liberated from the hydrating portland cement. The reaction is relatively slow compared to that of hydrating cement, so there is little gain in early strength. Advantages show up later.

Whither Now the Fly Ash?

To bring our story to a happy ending we will maintain a fast report on the current uses of smoke dust.

Firstly, fly ash is used as a land fill. Ash has always been used as a land fill, and this is not a very new use. Land fill doesn't even have to be a pozzolan.

Secondly, fly ash is sometimes used as a fine filler in asphaltic concrete mixes. Because of the small amount consumed we don't wax much excitement here.

Third, and now we're getting important, fly ash is used in concrete. Since the fly ash adds a pozzolanic cementing reaction, in many cases the cement content can be safely reduced. This saves money and pleases everybody but the cement companies, who happen to be in business too. Fly ash is also used in concrete pipe and block.

Fourth, fly ash is used in grouting, especially in the placement of mortar by means of pumps. Such grouting can be used to fill cracks and voids which could not otherwise be easily filled, for example beneath foundations. Fly ash offers a peculiar advantage in grouting because the spherical particles improve flow and pumpability.

*Described in *Screenings* Vol. 1, No. 5
Probably the largest amount of fly ash used today is in a special kind of grouting inside of oil wells. Portland cement-fly ash mortar is pumped down wells to fill the space between the casing and the outside of the drill hole. The mortar sets up, seals the casing in the hole, and prevents unwanted water from entering and diluting the oil. Only specific layers of oil-bearing rock are allowed to produce. In oil wells because of heat involved (wells are often hot) the slowness of the pozzolanic reaction is often an advantage, as a flash set before pumping is completed can be disastrous from the viewpoint of the local stockholders. They may have to start drilling all over again.

SOIL-LIME-FLY ASH

Moistened mixtures of soil, lime, and fly ash can be compacted into a slowly hardening subbase or base course for a road, airfield, parking lot, or similar use. The lime and fly ash react pozzolanicly. Immediately after compaction the road should be covered with a bituminous surface to prevent traffic abrasion and drying out.

Variables Affecting Mix Design

Research is often a study of variables, ideally to isolate each one and allow it to find its place in a formula or on a graph.

For example, a boy chasing a girl will do well to investigate such variables as climate, emotional sensibility and softness of the moon. Otherwise she may laugh at him and say, "Oh, go take a pill." He must learn to compensate for inevitable variables.

First things first: Sample size, molding procedures, etc.

Since we expect to mold about 14 billion samples (more or less), we had better keep the sample size small and convenient. A 2 inch diameter by 2 inch high size was decided on and the molding technique calibrated to give a standard compaction known as Proctor density.

Soil-lime-fly ash must cure to develop strength. The method of curing most nearly duplicating that in a road is to wrap the molded samples and put them in a moist-cure room. Wrapping is necessary to prevent a chemical change in the lime from the entry of CO₂. Temperature is commonly maintained at 70° F. Accelerated curing at higher temperatures has sometimes been found to give erroneous results.

Finally, testing. The most severe preparation for testing is to soak a soil in water. Therefore we usually soak our soil cylinders in water.

Then we know the strength, if any, is purely due to the use of admixtures. (Dry soils have some strength by themselves.) Supplementary tests are sometimes used where specimens are alternately soaked and dried or frozen and thawed to find test durability.

Optimum moisture and eureka! Now a short cut, but since nine out of ten people are confused by triangular charts we will not dwell on uncertainties. We will merely mention that the compacted (standard Proctor) density and optimum moisture content vary depending on percent lime and percent fly ash. Therefore every mix would presumably require a separate moisture-density test. This surmise ignores the fact that we are lazy.

It was found that if, for example, the addition of 20 percent fly ash increases the moisture requirement 6 percent, addition of half as much fly ash will increase it only half as much. The same is true with lime. And the same linear relations hold for the density; lime and fly ash both decrease density in an amount proportional to percent added.

Therefore three tests can be run at compositions indicated at the corners of the triangular chart. The chart is scaled off, and data for all intermediate compositions is read directly from the charts, with a fabulous saving in time, effort and exercise.
Lime and Other Remote Considerations

A previous issue of Screenings discussed soil stabilization with lime alone. Here there were three major variables: soil, lime content, and kind of lime. All three influenced strength. Added to these were other routine considerations such as density, moisture content and method of curing.

The addition of fly ash spells out even more variables, each requiring a separate investigation for each combination of the preceding ones. (Things are so variable they are getting a little confused.) A study with independent variables thus proceeds in geometric progression—that is, addition of one variable doubles the work; addition of two quadruples it.

VARIABLES ONE BY ONE BY ONE

Percent Soil, Lime, and Fly ash

This may look like three variables in a lump, but it is not because all three have to add up to equal 100. That is, fix two and the other one is set automatically, like sales tax.

A study with these two variables—percent lime and percent fly ash—is shown below. Compressive strength is plotted on the y-axis. (Here's looking at you.) It is therefore shown by contours.

Construction of such a graph is not an idle hobby, for it means that soil-lime-fly ash specimens are molded at each percent lime and each percent fly ash within the area of the graph. Furthermore all tests are run in triplicate. It's enough to make one tired.

A beautifully symmetrical sand-lime fly ash graph. Contours represent 28-day strengths after soaking one day in water. Dune sand from eastern Iowa, Detroit fly ash, monohydrate dolomitic lime. The Optimum lime-fly ash ratio is about 1 to 5 except in the area at the lower left.

Kind of Soil

The graph presented above applies only with one kind of soil, one kind of lime and one kind of fly ash. Similar graphs can be prepared for other mixtures.

So far it has been found that lime-fly ash stabilization works best with silts, sands, and coarser soils. Clays sometimes require more lime, but not always.

Kind of Lime

The kind of lime, previously discussed for lime stabilization, also has an effect on lime-fly ash. Dolomitic monohydrate lime was usually found to be the most satisfactory. Calcitic lime is almost as good in certain mix combinations, not so good in others. The graph below is for sand-lime-fly ash as above, but with calcitic lime. Note the very much lower strengths.

Kind of Fly Ash

Fly ashes differ depending mainly on method of collection and efficiency of combustion. The poorer the efficiency the more unburned carbon remains in the fly ash. And, as it turns out, the poorer the fly ash for use as a pozzolan. Several tests have been found to give a fairly reliable indication of the quality of fly ash. Two are the percent loss on ignition, and the percent retained on the No. 325 sieve. Both tests actually take a sidelong look at the carbon. The carbon in fly ash occurs as large, porous chunks of coke; they absorb water and do little good.

<table>
<thead>
<tr>
<th>Fly ash %</th>
<th>Loss on ignition</th>
<th>Compacted density</th>
<th>45-day compressive strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix: 8% calcitic lime, 92% fly ash, 0% soil. Moisture added for optimum compaction.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Louisville</td>
<td>3.2%</td>
<td>83.2 pcf</td>
<td>2220 psi</td>
</tr>
<tr>
<td>Kentucky</td>
<td>10.2</td>
<td>69.4</td>
<td>969</td>
</tr>
<tr>
<td>Minneapolis</td>
<td>15.6</td>
<td>62.2</td>
<td>905</td>
</tr>
<tr>
<td>Venice, Illinois</td>
<td>27.7</td>
<td>52.8</td>
<td>178</td>
</tr>
<tr>
<td>Kansas City, Missouri</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Durability and Effect of Density

Durability is like woman's love--turbulent and mysterious, but sometimes answering to pampering. And testing inevitably contributes towards destruction. Durability of soil-lime-fly ash is tested by wetting and drying or freezing and thawing. Specimens usually gain strength through wetting and drying, so this is nothing to worry about.

Freezing and thawing offers more problems. The molded soil specimens are allowed to absorb water, after which they are frozen. The water expands, tending to push things apart. The resistance depends to a large degree on the kind of soil, which influences cementation and permeability.

In an effort to increase strength and durability, soils may be compacted utilizing heavier rollers giving a greater compactive effort. Tests of strength showed that on the average, 

\[ S = S_0 + 43.5P, \]

where \( S \) is the strength after 28 days, \( S_0 \) is the strength when compacted to standard Proctor density, and \( P \) is the percent increase in density over standard Proctor. Compaction was most beneficial to clay, least beneficial to sand.

Increased density also increases the resistance to freeze-thaw, partly because of increased strength from better cementation, but also because tighter voids reduce the take-up of water.

<table>
<thead>
<tr>
<th>Density</th>
<th>Immersed strength after 14 days</th>
<th>Strength after 12 cycles of freeze-thaw</th>
</tr>
</thead>
<tbody>
<tr>
<td>103.0 pcf</td>
<td>528 psi</td>
<td>754 psi</td>
</tr>
<tr>
<td>106.4 pcf (Mod. Proctor)</td>
<td>503 psi</td>
<td>774 psi</td>
</tr>
<tr>
<td>103.0 pcf</td>
<td>506 psi</td>
<td>795 psi</td>
</tr>
</tbody>
</table>

Test Roads

Extensive test work has been conducted by the Detroit Edison Company, Detroit Michigan. Construction includes primary and secondary roads as well as parking lots. Soil types include fine sand, lake clay, material in an old gravel road, and various mixtures of these materials. Variables tested in the field include: kind of soil, kind of lime, percents lime and fly ash, kind of mixer, thickness of base, and kind of surfacing. Truly a noteworthy test! (P.S. We did the design.) Results are not yet completed.
The Iowa Highway Commission test sections in Highway 117 north out of Colfax contain 4000 feet of soil-lime-fly ash, much of it containing a secret accelerator believed useful because of the late-season construction. The soil is 75 percent fine sand 25 percent loess. The mix is 27 percent fly ash from Cedar Rapids and from Chicago, and 3 percent monohydrate dolomitic lime.

Commercial Prospects

Some of the work on lime-fly ash is motivated by profit, as contrasted with our own which is of a more heroic nature. Commercial use of lime-fly ash has begun in areas close to sources of fly ash, mainly Philadelphia, St. Louis and Chicago. Utilization is still mainly in the driveway-parking lot stage, although with future improvements through research the use will surely extend more to airports and highways. It has been found that soil-lime-fly ash offers a peculiar resistance to heat, making it suitable for use as jet aircraft landing aprons, where other materials quickly go to pieces. We are obliged not to comment on patents existing on soil-lime-fly ash; we still live in awe of the early Romans.

References Sighted

We know that reading of scientific papers is an unnatural task, just as writing them is, but here are a few jokeless wonders anyway. Best to classify them according to subject:

- Short-cut design: Not in print. Mimeo on request.

Acknowledgements

Many thanks to the Iowa Highway Research Board and the Iowa State Highway Commission whose controlled benevolence makes this work possible. Also to the Walter N. Handy Co. of Evanston, Illinois, distributor of fly ash and sponsor of some of our early work. Special gratitude goes to the many lime companies and power companies for the tons of free lime and fly ash consumed in the lab.

And we thank the U.S. Army Corps of Engineers for wanting their top young officers to have M.S. degrees; we think it's a good idea too. Officers who have completed portions of the lime-fly ash research are Lts. R. L. Crosby, N. G. Delbridge Jr., C. E. Sell Jr., R. Segal, and Capt. R. H. Viskochil. Other work has been done by Z. Chieh Moh, formerly of Formosa now of M.I.T., and Wes Goecker, now with the U.S.C.E. in Sacramento.

EDITORIAL PAGE:

Christmas Giving

In answer to the inquiries concerning subscription rates and the offers to pay (1), please accept Screenings as a wee little Christmas gift from us to you with no strings attached, other than that you must want it. If gratitude causes your heart to wax irrevocably mellow, just send your Christmas donations and old clothes along to Ye Olde Editor and he will see they are proportioned amongst the professors and other needy persons on the staff.

Meantime if your name is new on our gift list and you want back issues we'll send what we have, but mostly we're out. If requests keep coming we may test their sincerity by printing up a few more copies and charging to defray the cost.

Requests for several copies of a specific issue will also be gladly honored, provided you're willing to come through with about 10 cents per copy. We hate to be so mercenary, but our kind-hearted secretary sometimes objects when we pay all the costs out of her salary. (She has not yet learned to starve like the rest of us.) And if it hasn't been said before, Merry Christmas and a Happy New Year too.

IN THE NEXT ISSUE: A quick trip to Mexico City to see some world-famous foundation problems.

RLH
EXCURSION A LA CIUDAD DE MEXICO

Approximately four hundred and thirty-seven years ago the Spanish invaded Mexico City, shooting Indians, taking hostages and stealing gold. They are also reputed to have had a wicked way with the women.

Four hundred and thirty-seven years later your Roving Editor strode into Mexico City and created much less of a fuss, except when he ate the red pepper and thought it was an olive. (They almost had to shoot him down after that one.)

The reason for our pleasant excursion to Never Never Land (never punctual, that is) is to see if what they say about Mexico City is true—that buildings are sinking into the ground so fast today's ground floor will be tomorrow's basement. Mexico City is the home of exquisite world-famous, and altogether fabulous settlement problems.

GEOGRAFIA

Mexico City is located in a large, flat valley surrounded by mountains including the lyric Popocatépetl and the harder-to-pronounce Ixtaccíhuatl, pronounced Ixtacíhuatl. (Es-tah-see-wah-tl). The latter is supposed to look like a dead dog or sleeping woman or something of the kind. According to Aztec legend she is condemned to death and good old Popo is standing guard. Popo occasionally cuts loose with great streaming tears of lava, presumably out of grief but more than likely because he's been standing there so long.

The Valley of Mexico is now flat because long ago it was dammed up by volcanic debris, making a lake. Then the lake basin filled up with gravel, sand, silt and clay, mostly of volcanic origin. Small isolated lakes such as Lake Texcoco still remain.

Mexico City's underlying difficulty is a rather soupy clay which contains montmorillonite. Montmorillonite you will recall, is the clay mineral that expands like a pregnant groundhog (Screenings Vol. 1, No. 3). The Mexico City lake clay contains from 200 to 400 percent water figured on the basis of the weight of the dry clay. This means that 100 pounds of clay commonly contains up to 80 pounds of water, the water being held chemically to make a gel.

Obviously it's not very easy to build a city on a bowl of jelly without getting some sinking here and there. The weight of a building squeezes some water out of the clay, causing settlement of the building and consolidation of the clay. Fortunately the rate of consolidation slows down as water is squeezed out, because the soil gets harder.

Slow leak not so slow

An effective brake holding back consolidation of clay is low permeability—a long time may be required for the water to leak out. Unfortunately the clay under Mexico City is shot through with lenses of sand, greatly increasing horizontal permeability and replacing the slow leak with a fast one. Therefore consolidation takes place rapidly.

The Valley of Mexico is a vast lake plain surrounded by volcanic mountains and dotted with extinct cones. The Aztecs went one better; they built theirs square.
LA TRAZA

La Traza is an old Spanish section of town, where many generations of gay fiestas and clicking heels and tangos and boleros and hat dances and such have partly consolidated the soil—anyway the soil is harder and the moisture content is down around 300 percent. (Some unromantic souls have suggested the consolidation was due to the weight of the buildings.) Whether one builds or dances in La Traza he does so on firmer ground. Eventually all of Mexico City may reach this condition. Consolidation can't continue indefinitely because the water does squeeze out.

Part of La Traza rests on the older Aztec city of Tenochtitlan, where consolidation was presumably aided by vigorous renditions of the Rain Dance or some other ancient mode of prayer.

PALACIO DE BELLAS ARTES (Palace of Fine Arts)

Directly across the street from La Traza is a beautiful white marble building with tilted porches and sunken parking lots. This is the Palace of Fine Arts, home of art exhibitions, ballet, and similar cultural extravaganzas. Unfortunately it was built on the wrong side of the street, and it settled.

A historic Spanish aqueduct constructed of blocks of welded tuff, or volcanic ash which flowed and consolidated while still hot. Soils here and other places outside the lake area are usually solid.

Since the foundation for the Palacio is a 3 foot thick slab of steel-reinforced concrete, the building has settled as a unit and is not far out of trim. Settlement was rapid. In fact, the slab settled 2 feet before the building was built.

Settlement of the Palacio now totals about 10 feet relative to the surrounding area. Differential settlement has practically stopped. Now, for a reason explained next, adjacent streets and parking areas are going down faster than the Palacio and the Palacio appears to be coming back up! It's a wilder and wonderful world.

WELLS

A city with 2½ million residents needs water even more than it needs a solid basement, especially if everybody would happen to get thirsty all at once. Which they would if there were no water. The water comes from wells extending down through the clay into more permeable sands and gravels underneath.

Tarango

Wells pumping from the Tarango formation, as the underlying gravels are called, create quite an interesting reaction analogous to that from pulling the plug in the bathtub and humbly sitting by and watching the water drain out. Whether one realizes it or not, as the water level goes down his bouyancy becomes less and he sits harder against the bottom of the tub. In Mexico City water is pumped from the Tarango reducing pressures so that the overlying clays sit harder on the sands. This causes consolidation of the clays and gradual lowering of the whole city, at a rate measurable in inches per year.

The Palace of Fine Arts sits rather low but not quite so low as in this photograph. Photo was taken from the top of the Latino Americana Building.
The clay itself, apart from being mostly water, is about 40 percent finer than 2 microns. Of this about half is the mineral montmorillonite. Other major solid constituents in the clay are volcanic ash blown in from neighboring volcanoes, and tiny shells of animals and plants (ostracods and diatoms) who gave their all in a final vain-glorying strive for immortality.

Pressures and Consolidation

Ordinarily one doesn't have to worry about water pressures unless he drives a fire truck. But not so here. Mexico City's wells are 150 to 1500 feet deep and have lowered water pressures enough to sometimes double the acting weight of the clay. The most effected zones are the lower clay in the Tacubaya and the upper clay in the Tarango, these clays being just above where the wells are.

An accurate check on settlements was made in the City's Central Park, where there are no heavy buildings, and settlement is believed caused only by wells. In 1951 the ground surface was settling 13.4 inches per year, whereas the upper sand in the Tarango went down 8.7 inches. The latter figure represents consolidation within the Tacubaya. Both of these figures are important to the man designing the buildings.

Total settlements in Mexico City are difficult to measure because of the undependable nature of benchmarks. However, there is some rather good evidence for gross movements down. For example, Spanish canals originally designed to drain away from the city would now run backwards. The clues show that the city has gone down a total of about 17 feet since 1910. Needless to say, this is bad for sewers and other public works. Presently all well drilling has stopped, although many wells are still pumping, and arrangements are being made to bring in water from outside.

The Basilica of Guadalupe and the neighboring priests' home tilt in opposite directions. A buried rock ridge extends beneath them from the volcanic neck in back. The clay is thinner over the buried ridge, giving less total consolidation. The left corner of the Basilica is about 6 feet lower than the right.
Drying

A relatively minor problem associated with montmorillonitic clay and present even in our home territory of Iowa is caused by drying out. Montmorillonite shrinks incredibly on drying. As a result long cracks open in the ground, causing great consternation among the lizards, snakes, roadrunners, and drivers of small automobiles. Roads take on an up-and-down aspect, and sometimes building foundations crack or settle. All of this happens when something or somebody removes the water. A good well can be the equivalent of two or three dry years, showing the efficiency of our modern methods. A better plan is to leave the clay wet.

FOUNDATIONS

In the U. S., if one can believe the ads, our biggest strides in foundation engineering have been in the ladies' garment industry. It's rather pleasant to visit a place where foundation engineering takes on the more serious meaning and women are left to shift for themselves. (Nothing escapes the wary eye of the Editor.)

Pile

Many of Mexico City's newer buildings are built on piling, or long shafts of wood or concrete sticking down into the clay. The piles develop little friction with the clay, so are extended down through the clay to rest on the upper sand ("A") in the Tarango. The depth is about 110 feet but varies depending on the section of the city.

Buildings on piles sometimes give trouble when adjacent areas keep going down. The building then appears to be emerging, causing tilting sidewalks and general dizziness if one is unused to it. Sometimes adjustable jacking arrangements are installed to keep things on an even keel. Otherwise the owners periodically build new sidewalks and add steps to the outside stairs.

Critical Pressures and Floaters

The alternative to pile foundations is to rest the building on clay. So long as pressures are kept below a critical value, about 7 to 16 pounds per square foot depending on the clay, consolidation will be comparatively small. When pressures exceed the critical value, either from overloading, changes in buoyancy, or some other cause such as earthquakes, devastating settlements can be expected.

The high initial strength is from an electrical network of attractions which builds up in clay mud. When pressures are great enough to disturb the clay the network collapses and the clay becomes soft. You would think they would find a simpler word for this than thixotropy, which isn't even in the dictionary. We suggest thixotropic para-pseudometacongealit. It has a rather nice scientific ring.

One method to keep bearing pressures low is to sit a building on a deep hollow concrete box which acts like a pontoon, partially floating the building. Many of the newer buildings in Mexico City are built with this principle, and the ingenuity of some of the constructions is pure delight.

For example, construction of the box foundation necessarily begins with deep excavation and removal of clay. Not only is continuous pumping necessary to remove water from the hole, but once the excavation is started the unloaded clay in the bottom starts heaving up. Excavation thus becomes endless, and one may begin receiving discouraging legal forms from adjacent property owners.

An answer is to excavate "cells" which extend to full depth and are preserved in concrete. The concrete floor in the bottom of the cell extends halfway under the walls to join to the floor slabs of the next cell. Each completed cell is then filled with ballast to keep a heavy weight on the clay. Other cells are constructed in the same manner, until the foundation is completed. Then the ballast material is used in construction of the rest of the building.
Completed cellular foundations allow tricky provision to control settlement and tilting. In the new Condominio Insurgentes office building, elevations are checked every few weeks, and cells on the high side are filled with water to increase weight on that side. Eventually consolidation slows down so the vigil can be relaxed.

Another trick to control tilting of floating foundations is to allow air pressure to bear down the high side. Relief pipes extend below the foundation so that water can be pulled out from under the floor, causing air pressure to press down. Actually, air pressure or "suction" may play a very important role in keeping many asymmetrically loaded buildings from gradually tipping more and more. And this at an elevation of 7400 feet, where air is rare and people breathe sunshine and exhale smoke. The air pressure is about 11 psi, or 1580 pounds per square foot.

The new multi-building Medical Center now under construction offers another superb glimpse at gala foundation engineering. Here the buildings are floating, but provision is made to add piles if needed.

Constructing a pile underneath an existing building can be a rather mean job, and here's how they do it: First of all they leave holes in the floor and allow enough room under the building for drilling and jacking. A hole is drilled to the Tarango, and a cast concrete point is suspended on a cable in the hole. A cardboard cylinder is placed on top of the point and around the cable, and is poured full of concrete. The unit is then lowered the length of the cylinder and another cylinder is added and filled with concrete. This sort of thing goes on until the completed pile finally touches bottom. Hydraulic jacks and steel spacers are used to give the pile its share of the load.

EARTHQUAKE!

On July 28, 1957 the earth's stomach rumbled with such gleeful enthusiasm that the reverberations were heard for miles. In Mexico City the rumbles caused some buildings to fall down. It was the most severe earthquake since records started in 1900. The epicenter, probably a new volcano, was on the Pacific Coast about 150 miles from Mexico City.

Earthquake Waves in Clay

It was learned in the great San Francisco quake of 1906 that structures on soft ground sustain five to ten times the damage of those located on hard rock. Mexico City can therefore expect the worst. Waves entering the clay under Mexico City apparently reflect and refract, nullify and reinforce, due to the uneven consolidation of the clay. Therefore in some areas the waves tended to cancel each other out, whereas in others they reinforced one another and became stronger. The intensity at any one location was largely a matter of luck. An extreme case is one building which had already been condemned but came through the quake without further damage.

Intensity

Earthquakes are complex vibrations acting both horizontally and vertically, the horizontal shake usually being the strongest. The intensity of the July 28 quake is estimated at 7 on the Mercalli scale of 12, which means the maximum horizontal acceleration was equal to about 1/20 to 1/10 that of gravity.

The effect of a quake on buildings is to put the base in shear when the ground moves and the building tries to catch up. Some buildings can't take the shear; columns bend and the floors fall in. Typical structural damages include shattered walls and windows, cracked partitions, fallen
plaster, sheared columns, and occasional broken heads, on people that is. Fortunately the July 28 quake came in the wee hours of the morning. The death toll was in the sixties.

Related to shear is the fact that buildings develop movement and tend to sway or rock. Swaying causes high foundation stresses first under one side, then under the other. If pressures exceed the critical value for the clay, the building will settle, probably out of plumb. Some buildings settled 4 to 6 inches, and telltale V-shaped cracks now exist between many adjoining structures. Long buildings often settled at the ends more than in the middle, another indication of tipping stresses. In the new Conrad Hilton Hotel windows were broken and the elevator shafts were sprung, jamming the elevators.

Other type of damage was caused by hammering together of adjacent buildings, particularly when the floor on one lined up with the columns on the other. (One can just see the crash!)

Resonance

Unfortunately buildings have natural vibration frequencies—there's no way to get around it. Like a pendulum, tall buildings tend to vibrate slower than short ones, and rigid buildings vibrate faster than flexible ones. Earthquake waves also have natural frequencies, the periods in the July 28 quake being 0.9 and 1.8 seconds. These probably coincided with the natural vibration period of some buildings, resulting in resonance and "whipping", or greatly increased movement. Such a condition spells doom.

Latino Americana

Mexico City has one skyscraper, the 43 story Latin American Tower, and this escaped the quake without major damage. It was designed against earthquakes, and its natural period, about 1.5 seconds, did not coincide with that of the ground. This building is in La Traza. It is half supported by a floating foundation, half by piles. During construction the water from the excavation was pumped back in the ground to prevent settlement of neighboring buildings.

MUCHAS GRACIAS

Many devoted thank you's go to the Mexican Society of Soil Mechanics (Sociedad Mexicana de Mecánica de Suelos) for the excellent soil mechanics tour of Mexico City Dec. 11, 1957, in connection with a joint meeting of the Society with Committee D-18 of the A.S.T.M. (American Society for Testing Materials). Also many thanks to the local engineers who gave willingly of their time to take us strangers on tour of new building projects. The strangers from Iowa were Drs. D. T. Davidson and R.L.H., and exceptionally fine translators Mr. and Mrs. Bill Noguera, temporarily in Iowa from Chile.

Geological information was gathered from the tour and from "Outline on the Stratigraphical and Mechanical Characteristics of the Unconsolidated Sedimentary Deposits in the Basin of the Valley of Mexico," by Dr. Leonardo Zeevaert, a consulting engineer and Professor of Soil Mechanics at the University of Mexico. The paper was presented at the Fourth International Congress on the Quaternary in Rome, 1953. Additional information is in "El hundimiento del suelo en la ciudad de Méjico y su repercusión en los sistemas de cimentación," by Federico Macau Vilar, appearing in a Spanish publication, "Revista de Obras Públicas," Vol. 105 No. 2909, September, 1957. Earthquake damage is discussed in "Engineering News Record" August 15, 1957.

IN THE NEXT ISSUE: Loads on underground conduits (why pipes squash).

RLH
IN DEFENSE OF CENTENNIALS

Spring is spilling out a merry cascade, and the Centennial fever is upon us. We say hallelujah! and hats off to Iowa State College, now in her one-hundredth year. A very happy time, and a merry time for visitors. May we suggest you see Veilshea, the nationally known student-run fair, May 15-17. Education with plenty of action and color, and one century of change.

Ah, but perhaps the intellect rebels; you specialize in the frailties of human endeavor and see anniversaries as an excuse for nonsense. True, true. But nonsense must have its charm, or would we consent to be civilized? What is life, but a long happy string of nonsense, welded together by Bromo Seltzer? A proper celebration requires remoteness of responsibility—we say Happy Birthday to the son but never to the father. Therefore Happy Birthday to Iowa State College, may she live long and happy and continue to pay our salary. And no nonsense.

GOLDEN ANNIVERSARY

Whoa there, calendar; our day overfloweth with celebrated events. Just four years ago the Iowa Engineering Experiment Station, one of the first two in this country, turned 50, and now we're nearing the fiftieth anniversary of the start of some celebrated research in soil mechanics.

PIPE DREAMS

In 1909 Professor Anson Marston, then director of the Engineering Experiment Station, undertook to learn the truth about the earth loads on buried pipe.

Use of pipes and conduits is old as civilization, but prior to 1909 the design was based on experience plus frisky amounts of guesswork. Then the uses of pipe changed so fast that guesswork, no matter how frisky, could no longer keep up. Everywhere pipe cracked or broke—particularly the large drainage pipe coming into use at that time. Nothing is quite so useless as a caved-in drainage tile, unless it's to have the replacement tile cave in as well. Many failures involved cracked tile which filled with soil. Research became vital.

A rare photo—from the left are Anson Marston, Dean Emeritus of Engineering and author of the Marston Theory, W. J. Schlick, known for his studies of cast iron pipes and T. R. Egg, then Dean of Engineering. Photo taken about 1940. All three have since passed on.

Theoretical Approach

Theory has all the beauty and refreshing symmetry of a pretty girl emerging from her bath. A theory perceives a basic truth and avoids witless tangles with impertinent adornments. If one has a car with a rattle he can either develop a theory for locating the rattle, or he can take the car apart, piece by piece, eventually uncovering the rattle. Both methods work, but one is decidedly slower.

The drain tile problem is an excellent, almost classic, example of a theoretical approach. The original theory was proposed and proved, then this led to new theories and applications which are vastly more complex. They would have been impossible without the good groundwork.
MARSTON'S THEORY

In Ditches

Calculation of the load on pipe in a ditch now looks so simple one wonders why all the fuss. Briefly, the load equals the weight of the backfill minus the frictional support the fill gains from the ditch walls.

What about other factors, such as the shape of the pipe? Relatively unimportant. Skipping the mathematical gymnastics the equation is

\[ W_C = C_d w B_d^2 \]

where \( W_C \) is the load in pounds per linear foot of pipe, \( C_d \) is a coefficient, \( w \) is the unit weight of backfill in pounds per cubic foot, and \( B_d \) is the breadth of the ditch at or a little below the top of the pipe. \( C_d \) depends on fill dimensions, the coefficient of friction of the soil, and the ratio between lateral and vertical earth pressures from the backfill. For convenience \( C_d \) is usually read from a graph. To impress the natives we can give its equation:

\[ C_d = \frac{1 - e^{-2Ku' \frac{H}{B_d}}}{2Ku'} \]

where

\[ K = \tan^2(45^\circ - \frac{\delta}{2}) \]

Fortunately it's not necessary to read these equations to know what's going on. We merely present them to show that even the simple case is not entirely easy.

Verification

The proof of a theory is in the testing, and needless to say this theory has been pretty well verified or we wouldn't be talking about it.

That could have been the end of the research, but it wasn't. One thing leads to another, and the success with drain tile led to tests on...

CULVERTS

Culvert pipe under highways and railways are not laid in ditches; they are laid on the surface of the ground and then covered by the embankment. They are called "projecting conduits" since they project up into the soil. How does one calculate the loads on a culvert pipe? It takes more theory:

Load experiments were started in 1915 and again in 1919, with some time out for the Great War. The mathematics proved much more tricky than for ditch conduit, and it was not until 1922--seven years after the research began—that Marston announced the solution.

The key was in the conception and mathematical proof of a "plane of equal settlement" at some level in the embankment. A glance at the sketch shows the analogy to the ditch condition. However, frictional forces...
Laying some big ones, 108" (9 feet) in diameter. Cedar Rapids, Iowa, 1949.

push down on soil over the pipe rather than pushing up to help support the soil. The outer "exterior prism" settles more and drags down on the "interior prism," increasing the load on the pipe. Obviously not a very good deal. The equation may be written the same:

$$W_c = C_c W'_{c}^2$$

The additional factors of height of the plane of equal settlement and reversal of the friction forces are taken into account through $C_c$. If the embankment is shallow, the plane of equal settlement may be imaginary, existing above the embankment surface.

**Negative Projecting Conduits**

The solution for projecting conduits showed the advantage of using a ditch—the load is reduced on the pipe. The next step was to invent the "negative projection" condition, where pipe under an embankment are first laid in a ditch. Soil settles more over the ditch, drag forces are reversed, and the interior prism becomes partially supported. Bravot for a good idea; and experiments show it works. The same load equation is used, but $C$ depends on additional factors including the depth of the ditch.

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**Embankment**

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**Natural ground surface**

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**Time**

Loads on pipe are partly caused by invisible friction forces in the soil—but are these forces permanent? To answer this, test culverts loaded in 1927 were periodically checked for about 20 years. Result? Indeed the loading is permanent, reaching a maximum during the spring of each year.

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**STRENGTH TESTS**

'Way back among the whispers of the past somebody invented the testing machine, and engineers have been breaking things ever since. Ladies, if your small boy likes to see things go smash consider it a good sign; he may grow up to be an engineer.

Three-edge bearing test of a large concrete pipe. Date, 1929.

As any small boy will tell you, testing is not without its purpose. He tests in order to see if and how things break. For example, what good does it do to calculate the loads on a pipe if one doesn't know the strength of the pipe? A woman buying a girdle has to know at least two specifications with regard to size—hers, and its; then she subtracts a little. An engineer would call this a factor of safety, with due regard that it is in the wrong direction.

![Three-Edge Bearing Test](image)

(a) THREE-EDGE BEARING
(b) SAND BEARING
(c) TWO-EDGE BEARING
(d) MINNESOTA BEARING

Laboratory testing of circular pipe. Strengths of other shapes such as box culverts may be calculated from engineering mechanics.

Typical test bearing setups for the pipe and tile tests are shown above. For convenience the three-edge bearing test is most often used. Values obtained in other tests are divided by a load factor to obtain the equivalent three-edge bearing value. Note that the distributed loading conditions give better strength.

![Embankment and scale houses](image)
BEDDING AND LOAD FACTORS

A soft bed improves sleep and prevents a broken back, provided there is not undue sag in the region of greatest loading.

Calculation has given the loads on pipe after installation, and a testing machine gives pipe strengths—the next step is to try to link the two. The main difference between testing machine strengths and those effective in the field lay in the bedding under the pipe, or care with which the bed was prepared to spread the load.

(a) NOT PERMISSIBLE  (b) ORDINARY  (c) FIRST CLASS  (d) CONCRETE CRADLE

Load factors = 1.5  1.9  2.25 to 3.4

Pipe bedding in ditches was classified by Professor W. J. Schlick of the Iowa Engineering Experiment Station as Impermissible, Ordinary, First Class, and Concrete Cradle. Extensive testing gave load factors as shown; the better the bedding, the greater the permissible load.

Bedding of Projecting Conduits

Load factors of culvert pipe in embankments are quite a bit more tricky than for pipe in ditches because the compacted embankment material lends lateral support to the pipe. Again development of a theory provided a much needed shortcut. In 1933 Professor M. G. Spangler of the Iowa Engineering Experiment Station published his mathematical analysis and supporting data, and another mystery expired.

Load factors on projecting conduits are calculated from

\[ L_f = \frac{1.431}{N - xq} \]

where \( N \) depends on bedding, \( x \) depends on the amount of projection, and \( q \) is the ratio of lateral pressure to vertical load. Calculation is improved by use of tables and graphs. For the first-class bedding the \( L_f \) is commonly 2.0 to 2.3, meaning the pipe in effect becomes over twice as strong.

END OF THE ROAD? NEW ROUTES TO FOLLOW

Thus ends the story of loads on rigid pipe, may a cracked tile or culvert be as rare as hogs elbows. But is it ended? Actually research then took three different directions and continued up until about 1949. For example...

Flexible Pipes

Many culverts are constructed with corrugated sheet metal pipe having comparatively little inherent rigidity. Pressure on the top causes sides to bulge, but collapse is opposed by resulting earth pressure on the side walls.

Spangler's work extending from 1927 to 1941 showed that circular flexible pipe under load behave in accordance with mathematical theory for elastic rings, a bold trick if you can do it. Briefly, the vertical load is distributed uniformly over the breadth of the pipe, and the support from below is exerted evenly over the width of the bedding. The side pressures caused by deformation then have a parabolic distribution.

Most interesting is the question how do flexible pipe fail? They can't crack, so the top folds in. The amount of deflection, not the amount of stress, becomes critical. Deflection
is usually limited to 5 percent of the initial pipe diameter. Spangler's formula is

$$\Delta x = \frac{D_e}{E} \frac{KW_r T^3}{1 + 0.061(\epsilon)r}$$

where $\Delta x$ is the horizontal deflection in inches (about equal to vertical deflection), $D_e$ is a deflection lag factor (normally 1.25 to 1.50), and other factors take into account the effects of bedding, vertical load, and pipe radius and stiffness.

One of the most important factors is "$\epsilon$," which is the "modulus of passive resistance," and represents the rapidity with which lateral earth pressures build up as the pipe squashes out. Anything that increases $\epsilon$ improves strength. Therefore fill material alongside the pipe should be good stuff well compacted.

Stainless steel "friction ribbons" measure soil pressures against the outside of corrugated flexible pipe.

Pipe with Internal Pressure

Simultaneously with the flexible conduit research W. J. Schlick in 1926-1940 checked up on the added effects of earth load and internal pressures on cast-iron pipe such as used for water, gas or oil.

The first step was to recognize that field practice required a different evaluation of bedding conditions. Condition F means a shaped-bottom trench with the backfill firmly tamped in and around the pipe. Condition C has the pipe set on blocks with no tamping of the backfill. Obviously it makes a difference.

Schlick found that the relationship between internal pressure and three-edge bearing strength at the time of failure is

$$t = T \left[1 - \left(\frac{5}{5}\right)^{\frac{5}{5}}\right]$$

where $T$ is the bursting strength of the pipe, $S$ is the three-edged bearing strength without internal pressure, and $s$ is the three-edged bearing strength when the pipe has internal pressure. As pressure $t$ increases, strength $s$ decreases.

Wheel Loads

So much for soil loads; properly designed, a pipe will now be adequate unless you want to drive over it. Undoubtedly loads on pipes are increased by the weight of cars, trucks, trains, planes, and small burrowing animals. But how much is the load, and how would you design for it? More research, please.

Nowadays when you say "Boussinesq" to a soil engineer he hears music of a most enchanting and elegant variety. He is likely to swoon. But thirty years ago he wouldn't have known what you were talking about.

One of the first men to suggest application of the Boussinesq equations to soils was Prof. John H. "Pop" Griffith of the Iowa Engineering Experiment Station. Griffith was a deep, bold and undisciplined thinker. Many of his theories even after 20 years are not completely understood; others are understood too well. It's not surprising that at least one carries real dynamite. Persons fascinated by the unusual should check Iowa Engineering Experiment Station Bulletin 117, 1934.

Extensive experiments in the 1920's showed that Griffith's suggestion carried weight, literally, and wheel loads are transmitted substantially in accord with the Boussinesq solution. Results were published in 1925. The upshot is that the effect of traffic loads rapidly decreases as the height of the fill increases. In other words the pipe is protected by the fill.
ESSAY ON THE "IMPERFECT DITCH"

"Imperfect ditch" doesn't exactly mean a poor ditch, as the name might imply; it is a method first suggested by Marston in 1919 to reduce the loads on culverts under high fills. The theory of loads was worked out by Spangler and experimentally proved by Schlick prior to 1952.

In the Imperfect Ditch Method part of the fill is placed and compacted, then a ditch is dug in the compacted fill above the pipe. The ditch is then backfilled with loose material.

The Imperfect Ditch operates by increasing settlement of the "interior prism" of soil above the pipe so that drag helps to hold the soil up. The method is somewhat analogous to the use of negative projection conduits, described on p. 3.

An interesting application of the Imperfect Ditch Method was in 1955 in Atlanta, Georgia. A reinforced concrete pipe sewer built in 1937 was in bad odor with the Southern Railway because they wanted to increase the height of the fill from a former maximum of 35 feet to a new level of 95.5 feet. Calculations showed the sewer couldn't take it unless somebody got tricky with the fill.

First a ditch was dug from material already on top of the sewer. The backfill was loose soil, and to make sure it remained loose it included three layers of leaves. The leaves may rot out, but who cares? The interior prism is supported by shear forces, which tests prove can last for many years. The method worked, and the city of Atlanta saved about $130,000 from the price of a new sewer.

THE LAST WORD, OR IS IT THE LAST?

Where basic research has been sound and true, applications can go on and on.

Most recently the Marston and Boussinesq Theories have been applied to the problem of high pressure gas and oil pipeline crossings under railways and highways, something unheard of 40 years ago. All the more credit to the basic research. What's next? Who knows?

ACKNOWLEDGEMENTS, REFERENCES SIGHTED

These 40 odd years of research (pardon us for being odd) were sponsored by the Iowa Engineering Experiment Station, the Bureau of Public Roads, and the National Bureau of Standards. Results have taken well over a dozen bulletins and many technical papers. Obviously in this review many things have been skipped over, or just plain skipped. A more detailed summary of the Iowa work is, "Underground Conduits--an Appraisal of Modern Research," by M. G. Spangler, ASCE Transactions, 113: 315-374, 1948.


IN THE NEXT ISSUE: Soil-cement for low-cost roads.

RLH
SAGA OF SOIL-CEMENT

Days of the Deal

Back in the good old days when they still spelled Depression with a D and lined up for bread instead of unemployment benefits, the whole world recognized the salesman of portland cement because he had the stuff running out of his ears. And this before the government had learned about subsidizing to increase overproduction.

One fateful day cement peddler Archimedes Beowulf in a sudden burst of zeal sprinkled cement on his breakfast food. Breakfast was crunchier than usual that morning. Beowulf also used portland cement to fertilize the tulips, and his wife complained he was turning the back yard into a rock garden. He patiently observed, "Quite so, nothing can grow, but at least there are no weeds."

One thing led to another, and great inventions from little inspirations come, otherwise who ever could have invented Kleenex? Our hero resolved to make the whole world his rock garden. Unfortunately his wife still preferred tulips. "All right, I shall build roads," he countered. And he did. The End. This is a true story except for slight deviations to protect the distorted outlook. Necessity is the Mother of Invention; the only question is who the hell ever thought of necessity.

Scientific Version

A first try is like kindergarten art; the impulse is there, but in the end a horse may look like mother, or vice versa. Actually soil-cement was first tried in the 1920's by state highway departments in Iowa, South Dakota, Ohio, California, and another state that slips the mind--oh, yes, Texas. The necessary dose of exactitude didn't come until 1929 when R. R. Proctor devised the test that would revolutionize soil compaction and spell doom to guesswork. Now one runs soil into a mold, weighs it and predicts field density and finds the optimum moisture content.

In 1932-34 the South Carolina Highway Department built several test sections of road and further showed that soil-cement was feasible. The Portland Cement Association gasped with pleasure and inaugurated what is now considered the classic research program in soil stabilization. The major conclusion was that durability was the most important criteria in design, and tests were devised to show how much cement was needed to stabilize any given soil.

Gorgeous soil-cement highway in California. On the surface it looks like black-top. On the surface it is black-top. (Got to protect that soil-cement.)

The Johnsonville Pavement

The first scientifically controlled field test of soil-cement was in 1935, when a ½ mile section of State Route 41 near Johnsonville, South Carolina, was stabilized. Mixing was done the only way anybody knew how, with farm equipment and blade graders. Yes, and the road stood up. In fact, it's still standing up, a rather sensational record for an experimental project with a new material.
By 1937 thirteen states had put in experimental soil-cement roads and the boom was on. Research results were disseminated through papers presented to the Highway Research Board, and in 1940 the Portland Cement Association began publication of the Soil-Cement News. In the meantime soil-cement was going international; jobs were built in France, England, the Netherlands, South Africa, Brazil, Argentina, Canada, China, Australia, Germany and Japan.

The original Johnsonville, S.C. soil-cement pavement constructed in 1935. Cores taken a month after construction tested at 480 psi, whereas cores cut 20 years later broke at 922 psi. Such long-term strength gains are characteristic of soil-cement.

Coming in on a Wing and a Soil-Cement Landing Strip

About 1940 soil-cement went to war and turned in a creditable job. For both sides. The main use was for airfields, which had to be built quickly and with a minimum of imported materials. Germany put in 120 million sq yd, equivalent to about 10,000 miles of 20 foot roadway. The U. S. put in about 25 million sq yd. New special machines replaced the farm implements formerly used for mixing, and the rate of production soared until a well organized team could construct 5,000-10,000 sq yd or upwards of a mile of road a day.

Peace Effort

After the war soil-cement marched home, joined a veterans' organization and quickly outgrew its uniform. In five years the total U.S. yardage doubled, and in five more years it doubled again! And it's still doubling. By June, 1958, 230 million sq yd of soil-cement had been awarded or constructed in the U. S. This is equivalent to about 20,000 miles of 20-ft pavement, or once around the earth not quite. Only a slight extrapolation is necessary to show that in 75 years the entire country will be soil-cement and you will be able to drive anywhere except Lake Michigan without getting stuck. Another 25 years and the entire earth so it will look like an oblate billiard ball. If you don't believe this you have an insecure grasp of higher mathematics.

A major emotional snag for soil-cement roads is that their beauty must be forever obscured by a black, noxious film called asphalt. Soil-cement base courses need a bituminous wearing surface. Despite parental objections the marriage has come off rather well, except that on the surface the offspring looks too much like asphalt and too little like soil-cement. Maybe both sides want the credit and neither wants the blame.

HEY MAN, WHAT IS IT?

If you're not in the know you may not dig this crazy stuff. Therefore we shall explain. Soil-cement is a mixture of soil plus cement, but instead of pouring it like concrete it is moistened and compacted like--well, like soil-cement. Then in a few days it gets hard. Strength is adequate but not so high as in concrete. The price is not so high either.

Concrete people will be happy to know that soil-cement is currently recommended only for light traffic roads, runways or parking lots or for impervious ditch, canal, or reservoir linings. In roads, runways or lots it constitutes a base course which otherwise would be constructed of granular material such as crushed stone. California now specifies soil-cement as a subbase under all main route concrete highways.

HOUR OF DECISION;
HOW MUCH WILL IT COST?

One fact is brutally clear: a pocketbook opens rather easily to buy a bit of fluff and feathers, but necessities must be haggled over and purchased with a scowl. How sad that autos, TV sets, college degrees, and other once-glamorous commodities have now crossed over into the catalogue of humble necessities. Cuts down on their retail value. In fact, it's questionable whether college profs should want to be thought of as being really necessary; it might lob them into the same lifeboat with public school teachers. Better to maintain an air of prestige, glamour, and overall worthlessness, like a football coach. Might as well trade on the foibles of the public rather than stand by for the crucifixion.
Roads, unfortunately, have long been thought of as necessary, and there is seldom a semblance of glamour or romance except in an Alaska Highway or some spectacular pretzeline tunnelliferous interchange that's fun to drive over. In other words, roads should cost as little per year as possible. This opens the door for soil-cement, which is often cheaper than other modes of construction and is now known to last at least as long as 20 years, and probably longer. The next question is how much cement do we have to put in the road? It depends on the soil. Got to have tests.

Tests, Part II. Prime Ribs and Short Cuts

Laziness on the part of an engineer is a matter of sincere self denial, since everybody knows that hard work makes the body strong and benefits the liver. Soil-cement durability tests cause undue bodily exercise when one's natural inclination is to sit around and loaf. An easier way is needed.

Compressive strength is now the standby in jolly old England, where the American durability tests are regarded as a bit on the harsh side. A seven-day strength of 250 psi is the magic number for acceptance, with a minimum of 400 to 500 psi recommended for more severe climates or uses.

In the United States, unconfined compressive strength has been regarded with caution because of our more rigorous climate, and it wasn't until 1953 that J. A. Leadabrand and L. T. Norling of the P.C.A. came up with some helpful answers. From tests on 2,229 sandy soils they devised a short-cut procedure which relates cement requirements to grain size, compacted density, and compressive strength. Since soil-cement often utilizes sandy or gravelly soils this makes for a monumental saving in time and effort. Results are published in Highway Research Board Bulletin 69. No shortcut test has yet been developed for silty and clayey soils, but more research should give an answer.

BIG SHORTCUT: THE SOIL SERIOUS

Ordinarily we avoid discussions of religion, but it seems pertinent to mention the First Church of Soil Science and followers of the prophet Glinka and his various apostles and archangels, the most famous being Marbut.

Somewhere in this shadowy realm lurks the Soil Surveyor, his head bowed and eyes focussed downward to get a better look at Heaven. Symbols of his order are the auger and spade, plus that holy look. The soil surveyor maps soils, ostensibly to show how well they grow wheat or corn but actually because his eager mind is fascinated by the pretty colors and layers. The result of his efforts is the Agricultural Soil Map, also in colors. Fortunately for engineers the soil map is drawn on scientific principles, not on how much wheat or corn. We therefore find it useful. The latest scheme is to try to relate cement requirement to the basic soil map unit, the soil series.

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Construction begins with doling out of cement.

Mixing is done with special machines. This machine adds water, mixes, and leaves the soil in a windrow.

Compaction begins. Sheepfoot roller feet penetrate loose soil and compact the base from the bottom up. Usual compacted base thickness is 6 or 8".

A rubber-tired roller compacts the surface layer.

The compacted road-base is accurately trimmed to grade and occasionally sprinkled to prevent drying.

Asphaltic prime coat and wearing surface finish up the paving. Soil-cement offers a cheap conversion for existing gravel roads, which usually require a low percent cement.
The Soil Profile

Anyone who has ever dug a ditch or played around a post hole knows that the color and texture of soil differ as one digs down. These differences show up as layers called horizons. In keeping with the educational level of the ditch digger the horizons are designated by A, B, and C.

The A horizon is the brown or black, organic, loamy material the layman calls topsoil. (In forested regions the A horizon sometimes includes a light, ash-like layer or A2.) Underneath the A is the B horizon, often clayey because of accumulation of weathered materials derived from the overlying A. In lay terminology the B horizon is the subsoil. The C horizon is the unconsolidated parent material, which was the start of it all. It is either unweathered sediment such as glacial till, or weathered and disintegrated bedrock. The A and B horizons together constitute the solum, a precious bit of Latin meaning soil.

Zones, Intrazones, and Azones

The variables affecting the soil profile are five toes that support the foot: climate, organisms, topography, parent material and time. Theoretically a change in any one factor will give a different kind of soil.

A scientist's instinct is to classify, whether his subject is personality quirks of the dung beetle or how to bet on a horse. Classification of soils follows a biological scheme, decreasing from order through group, family, and series. The three orders are first of all zonal soils, whose character mainly reflects climatic zone. Zonal soils include such great soil groups as Podzols, Chernozems, Chestnuts, Brunizems, Latosols, and dirt, which has got to be included somewhere. Intrazonal soils are affected more by local saline or boggy conditions and include such classics as Wiesenboden, Planosol, Brown Forest, etc. Azonal soils reflect mainly parent material and are more a problem in geology. Each great soil group includes a large number of series to reflect the lesser variables which still like to vary: For example, all Podzols are similar but not identical; differences which depend on parent material, topography, etc., are reflected in soil family and series.

GREAT PAINS STATES

The reason for mentioning all this is that cement requirement does relate to soil series and to a lesser extent to great soil group. Proof came in studies of 43 series in various Great Plains states and Washington and Idaho. Cement requirement not only relates closely to horizon and series, but it is consistent! Now we say poof! to lab testing; just give us the soil series, available from soil survey reports of the U. S. Department of Agriculture. Cement requirement—soil series correlations are described by Leadabrand, Norling and Hurless in Highway Research Board Bulletin 148, 1957.
Sadness in the Silt Loams

Correlations, like politicians, sometimes have their off-years. Sampling locations in Iowa were intentionally chosen to give variations within each soil series, not an average or modal series profile. This sharpens the stark. Result? Coarse-textured loess in the high western Iowa bluffs mapped in the Hamburg series has an almost uniform cement requirement of 12%. Unfortunately right next door the Ida and Monona series also on loess require up to 20% cement. Farther east, where the loess has more clay and more soil profile, the Marshall series requires 18% for the A horizon and 16% for the B and C. In eastern Iowa the correlations are much worse, partly because of the variability of the series. Fayette in one area requires 10% cement, in another 23%. Actually this is not so much correlation trouble as an extraordinary unnatural appetite for cement.

Reasons

Back to the lab, Sir Galahad. The answer was abnormal freeze-thaw destruction by scaling. Why? One looks at the specimens. One sees ice. Obvious.

During freezing, the water in soils moves towards the cold zone by a process called thermal osmosis. Put soil-cement specimens in the deep freeze, water tends to move out from the middle and saturate the surface layer. Here it freezes, expands, and causes the surface layer to spall off. Next cycle, new surface, new spall. Repeat, repeat, repeat. Finally no specimen left. How now?

This beautiful bit of theory does not hold for coarse loess because the pores are too large for easy ice plugging and building up of pressure. Conversely in high-clay loess the water movement and spalling are reduced by lower permeability. It is only the middle area that is critical.

Continue?

Unshaken by grimness, our hearty researchers blink off a tear or two and continue the march. One possibility to reduce freeze-thaw loss from spalling is to add a little sand. This should be looked into. Meanwhile the series correlation work continues with other Iowa soils, and results are practically guaranteed to be at least as good as for the loess. Possibilities for reduction in cement requirement are also under study. For example, can we cut requirement by adding a little lime or fly ash? And then there are trace chemicals like acetyl-salicylic acid, which has great promise as a pain reliever. Research goes on.

REFERENCES SIGHTED


ACKNOWLEDGEMENTS

Research on soil series cement requirements is a joint program of the Iowa Engineering Experiment Station and the P.C.A. Iowa soil stabilization research is carried on under projects sponsored by the Iowa Highway Research Board with funds from the Iowa State Highway Commission.

Finally, a joyous hug to Geotimes and Robert Bates for a kind and clever write-up on Screenings. We're really not that good, you know....

RLH

IN THE NEXT ISSUE: X rays, for the analysis of soils?

High bluffs in western Iowa. About the top half of the hills is loess, mostly Hamburg series which is azonal--no soil profile because of dryness and rapid natural erosion. This loess can be stabilized with 12% cement.
ABC's of yz X RAYS

'Way back in 19 ought '95, when you and I were young, Macbeth, a German Herr Prof. Wilhelm Röntgen (we called him Bill) was shooting high voltages through a vacuum tube when invisible rays seemed to zip through the shield and make some nearby chemicals brightly fluorescent.

"Ach! Was ist maken dem Chemicalen go geglitter?" exclaimed Bill, swearing off liquor and reaching for his hat.

There were no comic books in those days, so scientists weren't hell up on what they were supposed to find out. Fortunately from his previous training Bill could pretty well work along on his own.

After thorough investigation the invisible rays were still unexplained. They were therefore called X rays, X signifying unknown, like Uncle Chester's signature. Nowadays they are sometimes called Röntgen rays except by Uncle Chester, who puts down X for everything, X, XX, XX X XXX X X.

As a rule in school the plowheads drool, infants stool, and eggheads graduate but don't win elections.

Where, why, and how?

The next decade was one of wild hypothesis and speculation on the nature of X rays, further illustrating suitability of the term X. In 1912 Herr Dr. Prof. Max von Laue stumbled onto a fantastic double-barreled discovery that still makes a physicist's eyes glisten and puts a lump in his throat.

In one gala experiment Von Laue and associates demonstrated the nature of X rays and also incidentally the internal structure of matter. It's hard to grasp how they learned so much doing so little. Nowadays physicists walk on tile floors down guarded corridors, and the price has gone up.

Dr. R. L. Handy, professor-in-charge of the X-ray project. He also writes Screenings, or could you tell?

A modern X-ray diffractometer. The X-ray generator and tube are housed on the left. Rays are caught by a Geiger or scintillation counter which sends signals to the electronic recording unit, on the right, so it can draw those jiggly lines.

Von Laue took his clue from the diffraction grating, long known for its effect on visible light. A diffraction grating is nothing more than closely scribed lines on a glass plate. White light shining through the grating shows colored spectra, because individual slits are close enough that the light waves emerging will reinforce or annul at certain angles.

A grate day comin'

Perhaps a diffraction grating could demonstrate a wave-like character for X rays, but the suspicion was that their wavelength was extremely short, and how could one write a grating fine enough?

One day Von Laue heard of an unproved notion on what makes crystals pretty. Their flat faces could indicate an orderly internal arrangement of atoms. Ah, he thought, if a crystal is really composed of closely spaced atoms it could be a natural grating! Well worth a try.
Friends of Von Laue shot an X-ray beam through a crystal of zinc sulphide and caught the invisible diffracted glitter on a photographic plate. Breathlessly they scurried to the darkroom to see what developed. Eureka! Spots! The experiment was a success. It proved the wavelike character of X rays, and the orderly internal arrangement of atoms in a crystal. Von Laue, like Röntgen, got the Nobel prize. Progress stems from uncommon sense.

Something to Bragg about

While Von Laue’s discoveries were momentous, the practical use of X rays for analysis of crystals was a little hard to grasp. The mathematics proved hairier than a Grecian male stomach.

Then two British scientists, Sir William Henry Bragg and his son William Lawrence made a beautifully imaginative simplification. They visualized crystals as stacked layers of atoms which in effect reflect X rays something like a stack of mirrors.

Angle tangle

The only catch is that the incident angle must be right for “reflection” to occur. Why? Because X rays behave like light waves, and must be in phase in order to get anywhere. Out of phase they annul quicker than a high school marriage.

For adjacent reflected waves to remain happily married, the spaces between atomic layers must account for an X-ray path difference of a whole number of wavelengths, abbreviated nλ. If we let nλ equal path difference and exerrire reasonable care in trigonometry, the result is the Bragg Law, easily the most important equation in X-ray diffraction.

A peek through an open window of an X-ray tube. Hoses are for water cooling of the target.

Equation

The Bragg Law reads

\[ n\lambda = 2d \sin \theta \]

Where n is a whole number, \( \lambda \) is the X-ray wavelength, \( d \) is the distance between layers of atoms, \( \theta \) is half the diffraction angle, \( = \) is \( \approx \), and 2 is 2. If you want to play the hep physicist, derive the Bragg Law from the sketch. If it’s any consolation this also won the Nobel prize for both Drs. Bragg.

Laying down the law

Significance of the Bragg equation? Let us take a crystal and reflect. The diamond seems very popular for one reason or another. Diamond gives a strong diffracted X-ray beam at an angle 2θ of 43.9° from the incident beam. What’s the interplanar spacing?

Ans. The X-ray tube we’re using gives a wavelength of 1.54Å, and for a strong reflection n usually equals 1. Plugging in and turning the crank, we have

\[ n\lambda = 2d \sin \theta \]

\[ 1(1.54) = 2d \sin (43.9° / 2) \]

\[ d = 2.06Å \]

From this, if we are that turn of mind, we can figure out the size of the atoms in a diamond. Or if we X ray an unknown and have a strong reflection at \( d = 2.06Å \) we can suspect the presence of diamond and run right out and sell stock. Much money can be made this way if one is not adverse to travel.

Path difference = BC + CD

About that

A WITH THE ° OVER IT...

Atomic dimensions are so tiny we need a tiny unit of measure—something less than an inch, if you please. The choice is the Ångström, named after a Swedish physicist and abbreviated Å. One Å = (10)-8 cm, or one hundred millionth of a centimeter, or one thousandth of a micron. This is rather small. The diameter of an oxygen ion, the building block for most minerals, is 2.7Å.
X RAYS FOR THE INSIDE STORY

But why all the fuss, Farnsworth? Everybody knows that real crystals are as rare as sin in Congress. But now with a little inside information we know a lot more about crystals, and we aren't at all sure about Congress.

For one thing we know that internal crystalline structure is much more common than previously supposed, and frequently doesn't show on the outside. In fact, the vast majority of solid materials have crystalline structure. Metals, woods, rocks, clays, plastics, etc., are mostly crystalline. Even our secretary is included, from her hair, muscles and bones right down to her toenails. This is pure speculation, of course.

In a soil lab, X ray diffraction is the only sure way to identify many minerals, particularly clays too fine to see adequately under a microscope. For chemical reasons these are the most important grains to know. Without X ray we stumble and stab in the dark.

TAKE A POWDER

Many techniques have been worked out for measuring X-ray diffraction angles. Often single crystals are oriented in the X-ray beam, and diffractions are recorded on photographic film.

Unfortunately this won't work very well for fine-grained materials such as soils; how in holy hosiery are you going to orient individual crystals when they're too small to see?

The solution is rather simple, because only crystals nearly perfectly oriented will reflect X rays. Therefore one X rays a powder--if orientation is random, a few of the crystals will surely reflect. To increase the number of orientations and assure getting all reflections, samples are ground very fine and are often rotated or spun while in the X-ray beam. Even so, fewer than a third of the crystals in the powder will diffract. On the other hand if you're facing a machine gun it's not the bullets that miss that count.

For diffraction, a crystal must be oriented; \( \theta \) must = \( \theta \)

Cameras but no lenses

An X-ray diffraction "camera" looks about as much like a conventional camera as a crippled yo-yo. It won't click and it won't focus; all it does is steady the subject and hold the film.
Diffracted rays from any one d spacing will be at a constant 2θ angle with the incoming beam of X rays, so their locus is a cone. This causes arcs, or halos, on the film. Diffraction angles are easily measured from the film and converted to d spacings by the Bragg equation.

Take an order

An X-ray diffraction film has many lines, partly because n in the Bragg equation is not always equal to one. It can equal 2, 3, or even more if we could count. Each value of n gives a different diffraction angle and a new line. But the angles are entirely predictable. When n = 1 we say we have a first-order reflection; n = 2 gives a second-order reflection, and so on.

For example, diamonds are a girl's best friend and have a major spacing of 2.06 Å. Girls, at what angle will the second-order reflection occur?

As if you didn't know,

\[ 2(1.54) = 2(2.06) \sin \theta \]
\[ \theta = 48.4^\circ, \text{ or } 2\theta = 96.8^\circ \]

Note the 2θ angle is much higher. In fact, it is the same as for a d spacing of 1.03 Å. Actually diamond is a bad example; it's so perfect the second order annulus. We should have used something cheap, like zircon.

KEEPING COUNT

Film detection of X rays is a little slow and messy and doesn't look very scientific. Better to have some blinking lights.

In 1928 Geiger and Müller invented a counter tube that measures X-ray intensity directly, and in 1935 the tube was adapted for X-ray diffraction. Only as recently as 1945 was the instrument perfected, partly due to some tricky redesign by an American named Friedman.

Soon afterwards the first commercial diffractometer came out, built by the then North American Philips Co. (Norelco). At present two very warm competitors for the U.S. diffractometer trade are Philips Electronics, Inc. (new name) and General Electric (Progress is our most important product). Both make exceptionally fine instruments, and we don't mean electric shavers or vacuum cleaners, although they're okay too.
Robot

A diffractometer is nothing more than a glorified powder camera with a Geiger counter scanning the arc formerly occupied by the film. Counts are fed to a ratemeter, and the counting rate is continuously recorded on a strip chart. While the machine scans through different 2θ angles the chart runs and a pen draws peaks. As with the diffraction halos on the film, each peak represents a particular d spacing. The 2θ angles can be read right off the chart and converted to d's through the Bragg equation.

Plane talk, please

Why so many peaks? Higher order reflections contribute, but in addition there are a lot of ways to slice a crystal and still have a plane full of atoms. Just look at crystal faces—they go in all directions, practically. A glance at the sketch shows why. Different directions give different interplanar spacings, which in turn gives different diffraction angles.

Obviously we need nomenclature. Fortunately a system of Miller Indices was worked out years ago by mineralogists to describe faces on a crystal. We now know the faces are parallel to interior atomic planes. Once a crystal structure has been worked out, a Miller index number can be salvaged for every d spacing. The numerals in the index indicate the way the plane cuts three crystallographic axes. A (100) cuts the a axis and is parallel to the b and c, whereas a (110) cuts both the a and b and is parallel to the c.

Routines and Shortcuts

Enough of theory! There is left but one major question: how do you use it? With every crystalline material giving different lines and d spacings it isn’t long before we’re submerged in data sufficiently deep to drown. Two unknowns can double the number of diffractions, and you don’t know which peaks belong to what. Four unknowns can spell only confusion.

Fortunately, A.S.T.M. to the rescue! The American Society for Testing Materials has published some 7000 Diffraction Data Cards compiled by many workers and gleaned from the stacks of science under cover. Cards are catalogued by the three strongest lines for each material. For convenience in sorting, the lines can be punch-coded around the edge of the card or run out through I.B.M.

Special topic: clay minerals

Clay minerals are the feminine fraction of soils—vital, soft and intriguing, but ultimately hard to reason with. X-ray has opened the door to understanding, but clay identification requires special knowledge and techniques.

Most clay minerals have a sheet structure and can be grouped according to thickness of the sheets. The thickness depends on the number of structural units such as the silica and alumina layers, and is easily measured by X-ray.

Most interesting of the clay minerals is montmorillonite, which drinks water between the plates, expands, and turns soil into a very sticky
mud. You know, gumbo (local term). X rays show montmorillonite to be the most abundant clay mineral in Iowa soils, although kaolinite, illite and vermiculite are also common. Montmorillonite expansion is limited by many chemicals and soil stabilizers. In fact, identification of montmorillonite is aided by treatment with glycerine or ethylene glycol, which causes a uniform expansion and gives a nice X-ray peak.

FINALLY, CHEMICAL ANALYSIS!

Look out, Hornblower, there's alligators afoot. We don't want to sound like instrument salesmen, but the fact is that X-ray diffraction units are easily converted for spectro-chemical analysis. This means a chemical analysis in a matter of minutes where formerly it took days. And all this without destroying the sample, whether it's harsh as hair on a goat or delicate as a buzzard's sigh.

How now? Examine Bragg's Law. Previously we knew X-ray wavelength, or λ, and solved for d. Now we'll use a known d and solve for λ, a very usable idea since λ is characteristic of the elements giving off the X rays.

The technique is to brighten the sample with hard X rays, usually from tungsten, so that elements in the sample give off a secondary emission or fluorescence. These rays are analyzed by diffraction from a crystal with a known d spacing. The right combination of wavelengths is sufficient to identify an element.

Drawbacks? Elements with low atomic numbers give off such soft X rays they are absorbed by the air. An enclosed helium atmosphere helps. Even so, sodium, oxygen, carbon, and other low-number elements can't be measured. Quantitative analysis requires calibration curves.

ACKNOWLEDGEMENTS

Iowa Highway Research Board Project HR-48, X-Ray Diffraction Analysis of Highway Materials, was set up to investigate the composition and changes in soils and other highway materials to better understand their behavior and lead to more intelligent use. Funds are supplied by the Iowa State Highway Commission.

BACK ISSUES!

Now available? Genuine, unexpurgated, uncorrected reprints from Vol. 1, No. 5 on! Going rate 10¢ per copy, but any loose change in the cup will help. Subjects: soil-lime, soil-lime-fly ash, Mexico City clays, loads on pipe, and progress of soil-cement.
An Unhurried Look at the Pleistocene:

OPERATION DEEPEST FREEZE

One day Great Uncle Aurignacian, 300 generations removed, was sitting in his cave swapping shaggy mammoth stories with the boys when the talk turned to that universal topic, weather.

"Bastardly cold lately," exclaimed one of the older cavemen, who often recounted stories of seeing and stepping on a vast hill of ice that reached to the moon. He singled out a young idealist and said, "John Foster, why don't you wander north, build a fire, and melt all that ice?"

Unfortunately when John Foster got to the glacier his wood was wet, and the ice age was thus prolonged several thousand years. Science is a long history of failures.

Of Time and Temperature

Pleistocene means the ice age, or a time when glaciers repeatedly slathered ice over as much as 30 percent of the earth's land surface. The actual time involved in the Pleistocene is the merest witt of Father Time, probably less than a ten-thousandth of his entire configuration since the earth began. Even during this geologically short period of time, variously guesstimated at 300,000 to a million years, most of our modern landscape was formed. The time is so short that a hard-rock geologist thinks Pleistocene is a dirty word. He's just disappointed because there is no oil.

Melting glacial ice (upper right) leaves plentiful heaps of pulverized rock debris, or glacial drift. Unstratified drift shown in the photo is called glacial till. Original color usually gray, but very slight weathering changes the color to tan or brown.

Glaciation gave the earth a new face, in some places severely smoothed and sculptured, in other places coated with pulverized, mixed rock debris commonly called glacial till. Till is a very important soil material. Side effects of glaciation are even more spectacular because once known they are obvious, but ordinarily they go unsuspected. These will be discussed a bit later.

During the Pleistocene, modern man evolved and eventually succeeded in getting the under hand. Apparently his arrival so kindled the fires of hell that practically all the ice melted. Remnants of continental glaciation are in Greenland and Antarctica.

Recent?

The time since the last retreat of the glaciers is formally or informally called the Recent. Because the disappearance was not very sudden and the departure time varies from place to place, the term Recent is losing out. It's probably more accurate to assume we still live in the Pleistocene.

The Pleistocene and Recent epochs together make up the Quaternary period. The Quaternary and its predecessor, the Tertiary, together make up a large time unit, the Cenozoic era, or time of the mammals. Now you know where you are. The previous major time span, or Mesozoic era, belonged to the dinosaurs. In view of this it's interesting to contemplate what will come next.
Glaciation in Stages

Careful study of glacial deposits shows that the ice made more advances than a college boy on a first date. Between advances the terrain was allowed to warm up and weather a while. The soil profile resulting from each of these weathering intervals is aptly termed a paleosol, literally meaning ancient soil. Paleosols are often buried and preserved under later glacial deposits and thus serve to separate the older from the younger. A good roadcut in the right place may show one or more paleosols.

At this point we must modestly admit that Iowa is world-famous for its paleosols. In fact, much of the fundamental work on the Pleistocene was done in Iowa and adjacent states such as Illinois. The succession of glacial and interglacial stages were first recognized and named here, and is taken as a reference point for other areas.

Glacial stages are named for states where the deposits are fairly well exposed. The Nebraskan and Kansan ice sheets pushed across Iowa into Nebraska and Kansas, and incidentally far enough south into Missouri for people to say you-all and whistle Dixie. Actually the Nebraskan is so covered up and eroded that nobody knows exactly where it goes.

Farther east a later glaciation, the Illinoian, covered most of Illinois, Indiana and Ohio, and even took a nip at Kentucky.

Between Glacial Stages

The time between two successive glaciations is called an interglacial stage, and is a period of warmth and weathering. Interglacial stages are named after important places like Afton and Yarmouth, Iowa, and Sangamon County, Illinois.

SUBDIVISION OF THE PLEISTOCENE

Note that a geological column is read from the bottom up: oldest formations are put at the bottom to correspond to the sequence seen in exposed sections.

<table>
<thead>
<tr>
<th>Stages in North America</th>
<th>European Equivalents</th>
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<tbody>
<tr>
<td>Glacial</td>
<td>Interglacial</td>
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<tr>
<td>Wisconsin</td>
<td>Würm</td>
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<tr>
<td>Illinoian</td>
<td>Riss</td>
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<tr>
<td>Kansan</td>
<td>Mindel</td>
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<tr>
<td>Nebraskan</td>
<td>Günz</td>
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<td>?</td>
<td>Donau</td>
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Like modern surface soils, the character of a paleosol depends on such things as climate, slope, and time for weathering. And some paleosols really have a lot of character. For example, our most famous paleosol is a highly weathered, gray, blocky clay called gumbotil. The best way to remember about gumbotil is to try to drive over it after a rain. It contains over 50% clay, nearly all of it our sticky friend montmorillonite. Need we say more? We will.

In better drained, eroded areas the gumbotil passes into a thinner, red-brown clayey soil designated by the old-time geologists as ferroto. Recent detailed work by R. V. Ruhe relates properties of a paleosol to age of the surface on which it has developed. That is, erosion can cut a fresh surface in very old stuff, with the result that there is less time for the eroded surface to develop a paleosol. For example, a Kansan till surface weathering throughout the Yarmouth, Illinoian and Sangamon will have a very good gumbotil. But if erosion were active in, say, the late Sangamon, the late Sangamon erosion surface will be weathered much less.

Light-colored Wisconsin loess over darker colored Kansan till. To the left of the man is a thin paleosol, or darker, weathered zone in the surface of the Kansan till. On a flat, uneroded area this will become gumbotil.
THE WISCONSIN GLACIAL STAGE

 Fortunately for man and beast, whether she be wife or mother-in-law, the glaciers came back, smoothed over the rough spots and spread a nice new layer of till. This Wisconsin age till has magnificent corn-growing qualities far excelling the sticky sterility or blocky hardness of a paleosol.

 But what of areas not covered by Wisconsin till? Never fear, for God also gave us loess, a widespread silt layer excellent for corn, beans and alfalfa. In fact, where would we be without it? Probably raising tobacco and closing schools like some solid citizens farther south. Pride can be a very stubborn refuge if you don't have anything else.

Draft from the Drift

 Glacial till is a wild mixture of clay, silt, sand, gravel and boulders deposited directly from melting ice. Some is believed deposited under the ice sheet where melting is caused by pressure; some is deposited at the ice sheet margins.

 Ah, but when ice melts it makes water! Subglacial melt water happens to be very muddy. Washed material left by this water is called stratified drift. It comes in two varieties: outwash, which is washed out from the glacier and occupies river valleys, and ice-contact features, which are as the name implies. Ice-contact features usually exist as hills or ridges, meaning the water that left them must have been confined by ice.

 According to popular theory, (Screenings, Vol. 1, No. 4), the silt that makes up loess blew from glacial outwash rivers like the Missouri. Most loess is believed deposited during Wisconsin time, since it buries all the old till plain paleosols but is thin or absent on areas of Wisconsin till.

 In some places an older, probably Illinoian, loess has been identified; this underlies the Wisconsin loess and is separated from it by a paleosol. It is called the Loveland loess after another important place, Loveland, Iowa.

EUROPE AND OTHER PLACES

 Glaciers in different parts of the world kept the same time schedule, so that when America was plastered Europe and Asia were too. Studies in the Alps show four major glaciations which may correlate to the four stages in this country. Later studies show there may be a fifth, earlier stage of limited extent.

 Alpine glacial stages are called the Donau, Günz, Mindel, Riss, and Würm. Interglacial stages are denoted G/M for Günz-Mindel, M/R for Mindel-Riss, etc., a system which blesses the memory. The Würm shows several similarities to our own Wisconsin, including the deposition of loess. Two divisions of the Würm are recognized, and detailed studies of the loess have shown evidence for at least four substages.

Substaging the Wisconsin

 In history, religion and politics the most recent events are known in the most detail. The Wisconsin glacial stage is therefore divided into a set of substages, on the basis of evidences that the ice front did not retreat evenly, but retreated part way and then re-advanced. At latest count there were six sub-stages, some solidly established, some in doubt. The Wisconsin loess reflects some of these breaks with weakly developed paleosols, indicating pauses in deposition.

<table>
<thead>
<tr>
<th>Substages of the Wisconsin</th>
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<tbody>
<tr>
<td>Glacial</td>
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<td>Interglacial</td>
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<td>Valders</td>
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<td>Two Creeks?</td>
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<td>Mankato</td>
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<td>Cary</td>
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<td>Brady</td>
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<td>Tazewell</td>
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<td>Iowan</td>
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<td>Farndale?</td>
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</tbody>
</table>
Man in the New World

Man came to the American Eden rather late, and through a natural process of doing what he wanted to do he became an Indian. The Eskimos did similarly, although they came later. The probable route was via the Bering Strait.

Entry of man apparently caused widespread extinction of edible land mammals, including camels, horses, giant bison, giant beaver, mammoths and mastodon. Most of these animals lived in the Americas until the retreat of the last glaciation, 10,000 to 5,000 years ago. Man was here at least 10,000 years ago.

Dating

Fortunately for figuring out the Pleistocene, a radioactivity method may be used to date plant or animal remains. Unfortunately the method only reaches back 30,000 years, or to about the beginning of the Wisconsin.

Cosmic rays bombarding nitrogen atoms in the air cause a slight conversion to radioactive carbon, C¹⁴, which has a half-life of 5,570 years. Living plants and animals contain a certain percentage of this carbon. When an organism dies, it no longer replenishes its carbon, and radioactivity slowly peter out.

Results of the method are widespread verifications and complications. The Farmdale, or earliest substage of the Wisconsin, is dated at about 24,500 years ago. Several samples of wood from the Iowan, supposedly later, have come out radioactively dead, or older than 30,000 years, and the dates have given some people to doubt radiocarbon dating. Tazewell loess was probably deposited 17,000 to 15,000 years ago. The Cary glacial maximum, which in Iowa reached to the city of Des Moines, was 14,000 years ago, and the Mankato started its advance about 11,400 years ago. Final retreat of the Valders ice and drainage of Lake Agassiz was perhaps 5,000 years ago, and the shores of Lake Agassiz were hunted by early man.

Early man is easily recognized from his close-set eyes, heavy brow ridges, and receding chin and forehead. This living specimen of Homo erectus altipennis (Milkweed) was discovered during a recent outing of the Greater Louisiana Lowland Bird-Watchers' Society. Apparently it had roamed around unnoticed for years.
AND WHY DO WE HAVE GLACIERS?

Glaciations have been blamed on everything from sunspots to dust storms to the attitude of the American female. However, now it's believed that cold temperatures are not so vital as having everything just right for the accumulation of snow. For example, in Alaska the major glaciers all prefer the warm, clammy climate of the South, rather than the cold, dry crispiness of the North. Heavy snowfall south of the mountains is related to evaporation from the nearby warm and salty Japan Current.

The Ewing-Donn Theory to explain glaciers was developed from studies of mud cores from the Caribbean. Micro-fossils plus a radiocarbon date showed that there was a sudden ocean warming 11,000 years ago, with virtually no other change in temperature for the last 90,000 years.

Briefly, the theory is this: An Arctic Ocean freely connected with the Atlantic should remain open with no permanent accumulation of pack ice as we know it today. A warm and open Arctic Ocean could supply plenty of evaporated water for glaciers.

But as glaciers accumulated, sea level went down so that a submarine ridge known to connect Norway with Greenland served as a water barrier. Isolated from the Atlantic, the Arctic Ocean would again freeze over, and incidentally following isolation the Atlantic should suddenly warm up. No open ocean, no evaporation, no snow, no glaciers. The beauty of the mechanism is that it is cyclic, and could explain the repeated glaciation during the Pleistocene.

What next? Sea level is now up and rising; the Arctic pack ice has thinned 40 percent in the past 15 years. In other words, if you plan to live for a while be careful not to get run over by any glaciers. If the theory and measurements are right it could all get started in the next hundred years.
GLACIAL DEPOSITS IN IOWA

Glacial till

Studies of Kansan and Illinoian tills in Iowa show that an average unweathered sample is about one-third clay, one-third silt, and one-third combined sand and gravel, the gravel fraction usually amounting to less than 4 percent of the total. A statistical sampling scheme shows that the till is not highly variable from place to place. The major clay mineral is montmorillonite. Engineering-wise, the till nearly always classifies as A-7-6.

Gumbotil

Statistical sampling of gumbotil shows that it contains from 55 to 75 percent clay, or enough to give an engineer bad eyesight. Montmorillonite is the major clay mineral. Engineering classification, an extreme A-7-6.

Loess

Loess in Iowa varies from about 10 to 45 percent clay, depending on the locale. The remainder of the loess is nearly all silt, although some loess contains a trace of sand. Fineness, sand and clay content are believed related to the distance from a source. The major clay mineral is montmorillonite. Coarse loess classifies as A-4, fine loess as A-6 or A-7-6.

An interesting feature of thick, low-clay-content loess deposits is that they absolutely refuse to hold a water table. Percolating water usually seeps down until it encounters a stumbling block such as Loveland loess or gumbotil. Whereas unsaturated loess has sufficient cohesion to stand in vertical faces, saturated loess is but a weak mud. Therefore when roadcuts are cut all the way through the loess, slides may reasonably be expected.

Summary

The soils of Iowa so far studied for engineering uses are rather rich in montmorillonitic clay. Areas not yet investigated are in north-central Iowa, the Iowan and Cary-Mankato drift areas. A major purpose of the field studies is to give an idea of what we are working with and allow an accurate selection of representative samples. The guiding premise is that sampling is the most critical step in setting up a laboratory study—nothing is so worthless as a bad sample. Thus the few samples selected for soil stabilization and mineral content studies are very carefully chosen from hundreds already analyzed for plasticity and particle size.

ACKNOWLEDGEMENTS AND REFERENCES SIGHTED


Iowa Engineering Experiment Station studies of Pleistocene are paid for by the Iowa State Highway Commission through Projects HR-1 and HR-48 sponsored by the Iowa Highway Research Board.

IN THE NEXT ISSUE: CHLORIDES for dust-free roads.

RLH
CHLORIDE ROADS

Lo, The Dusty Road!

Man's first notable landmark scribed into the face of the globe was the dusty wagon track, which later developed and flourished into the common dusty road. This is one of our most persistent and bothersome contrivances, being almost in a class with relatives, which just happened along.

But dust thou art, to dust returnest, so if we want to get new blood and resurrect some of the old we had best keep things stirred up. Therefore drive the dusty road, and be sure to inhale. The next sneeze you breathe may be Napoleon; the next clod you kick may be King Arthur. And it's nice to get an occasional snootful of Beethoven, Aristotle, Moby Dick, or Robin Hood. We have such a wealth of available ancestry in our dusty roads. Particularly when roads run by a cemetery.

Now with Seasoning

Unfortunately for those who like to keep in touch, the billowing ancestral baths are coming to an end. More roads are being surfaced, and more of the remaining roads are being treated with chlorides to help bind particles and hold down dust.

Visiting Cossack delves in. This calcium chloride treated road is now 7 years old. Maintenance is by light blading and a yearly surface application of more chloride. Dallas County, Iowa.

Now in use are two chemical kissing cousins, sodium chloride and calcium chloride. The former, common table salt, once had such scarcity and high value that certain crafty primitives would gladly trade their wives to get it. No such useful arrangement exists today. (Actually, even then salt was very cheap, and the wives found out.)

Lo, the Undusty Road!

An ample application of chlorides will convert the meanest gravel or rock byway into a delightful, hard-surfaced thoroughfare with plenty of fortitude for light traffic and at a cost to salve the wounded taxpayer.

Maintenance is required or the road will go to pot, but maintenance costs are usually much less than for the original gravel or rock road. Maintenance is by occasional light blading or patching, plus a light surface application of chlorides every year or two. An alternative is to preserve the road under thin blacktop.

STRENGTH FROM WITHIN

Chlorides are not good cements; all they do is hold water and tighten the road by a variety of mechanisms discussed later. The road must have some interlocking, granular stability by itself. Chlorides on a clay road would do little good.
Not only must the road contain some coarse particles to interlock and give strength, it should be dense enough to deflect rain if the salts are to stay put.

The way to a dense mix is through grading. This means gravel or crushed rock for strength, plus small amounts of sand, silt, and clay to fill in the voids. Unfortunately such roads slowly disappear in a cloud of dust.

Putting the damper on

Now for the chlorides. One specification is 1/2 lb of sodium or calcium chloride per sq yd per inch of road thickness; for a 4-inch road 21 ft roadway, this comes to 12 1/3 ton per mile. Actual practice varies.

Chlorides are added either dry or in solution, either to material on the road or at a batch plant for later hauling to the road. If added on the road, a special road mixer is used, or the mix can be tumbled back and forth with blade graders. Mixed materials are spread and compacted.

During compaction the technique is to splatter on enough water to hold the moisture content high enough to gain density. This also helps to draw some fine materials up into the surface, giving a better seal against rain.

The Dry Cure

Once the road is completed it is allowed to dry out or "cure," implying a previous illness. If salt is used, crystals now form in the surface zone and help knit the road. If calcium chloride is used, no crystals form, but the whole road shrinks and becomes harder. Curing of salt-stabilized roads usually takes about two days; curing of calcium chloride roads takes 2 to 10 days, depending on the weather. Light traffic in this period does no harm.

MECHANISMO

We know you're just dying to know what it is that chlorides do in roads, besides making them taste sour and salty. For one thing the chlorides keep grass from growing, not too much of a problem, actually, except when traffic is light. In Iowa, of course, our problem is corn; the soil is so rich that overnight the corn will----never mind, you wouldn't believe us, though our eyes are weak and our breath is strong, and our hearts as pure as driven golf balls.

Added Slick-Slipperiness

The first benefit from chlorides is to aid in compaction. Calcium chloride solutions are effective lubricants, and sodium chloride lubricates by dispersing the clay binder. Anyway, compacted density is usually up to 75% with the same compactive effort, or the same density may be obtained with fewer roller passes. In some rather spectacular examples the number of roller passes is reduced as much as two-thirds.

Extra Slop-Slopperness

Anybody who has tried to salt his french fries in wet weather knows about hygroscopicity. Plainly, salt absorbs water.

Not only do chlorides absorb water in wet weather, they retard evaporation when the day is dry. These phenomena are related to an obscure vitality called vapor pressure. Salts lower the vapor pressure of water, which at 77° F comes to 23.8 mm of mercury. For example, calcium chloride can lower the vapor pressure to 7 mm, reducing evaporation from a free surface more than three times.

Vapor pressure of water in air is proportional to relative humidity, or general dampness. Thus if the humidity is low enough, vapor pressure

Vapor pressure of calcium chloride solutions. Temperature, 77°F.

Examples: Relative humidity 75%, will calcium chloride take up water and dissolve? Yes, yes! The equilibrium solution is at B, 31%. Note that humidity must fall below 25%, a very dry day, before calcium chloride crystallizes out.
can drop below that of the salt solution. The solution dries out. If humidity is high, vapor pressure is higher than that of the salt solution, and it absorbs more water.

Nervous Tensions

Here our two salts really part company regarding behavior in roads. The reason is related to moisture retention—one usually stays dry, the other stays wet.

Calcium chloride increases tensions more than a frown in the U.N. This is not a political tension or a mental tension, but is more like the one that holds in Marilyn. It is called a surface tension and can land a snappy comeback. Surface tension of water is caused by unbalanced molecular attractions in the surface zone. Throw in some chlorides, we increase the attractions and the surface tension.

The result is that when a treated road first dries out, calcium chloride solutions occupying the tiny crevices exert more tension along water-air interfaces. The sum of these tiny tensions literally pulls the road together, increasing density as much as 15%. This will increase strength and stability (C.B.R.) several hundred percent. The slow rate of drying allowed by calcium chloride is an advantage, for shrinkage becomes uniform. Resulting cracks appear to do little harm.

Chemical Sunshine

A sweet face is said to melt more ice than a salty one, but chlorides are effective nevertheless. In the face of a strong dose of chlorides ice loses all its ordinary composure, reserve, and fortitude. Its knees are weak; it turns to water. This trick is widely used to put the smile on icy streets in winter.

In a chloride-stabilized road, water simply doesn't finish freezing until the temperature sinks to subzero. In the case of calcium chloride, the temperature must hit 80 below (Fahrenheit). This is important because otherwise water in the voids freezes, expands, and pushes apart the aggregate. Field tests show that winter strength loss of chloride-treated roads is far less than strength loss in similar untreated roads. Other tests show that moisture migration and frost heave may also be reduced.
EVIL DEEVIL: CORROSION

Nobody wants to drive on a stabilized road if it will make his car a rusty hulk. Up until now this has been almost a subservient subject, like is money wasted on the military? Obviously there are two sides to the question.

First and foremost, much less splashing occurs from a chloride-stabilized road than from city streets treated with chlorides for ice removal. City life is much more corrosive to autos, lungs and eyeballs. Best to live in the country.

Calcium or magnesium chloride in water make it acidic. Acidity is indicated by pH—high acidity, low pH. Water has a pH of 7, concentrated calcium chloride solutions have a pH in the range 4.5 to 5, and magnesium chloride solutions have a pH of about 3.9.

The corrosion rate of mild steel is not much influenced by acidity until pH becomes critically low, less than 3.5 to 4.5. Below this pH steel quickly dissolves in a fast array of hydrogen bubbles—z-z-z-z-z. Apparently the critical acidity is reached by magnesiumchloride, which is very corrosive. You sea coast dwellers will be happy to know that the corrosive vigor of sea water is mainly a result of magnesium chloride and should not be blamed on salt.

Sodium chloride in water makes hydrochloric acid which is balanced by an equal amount of a strong alkali, sodium hydroxide. Dilute solutions increase the corrosion rate about one-third by increasing electrolytic action. Strong solutions actually inhibit corrosion by limiting the amount of dissolved oxygen.

A final factor is that of maintaining moist conditions—highly desirable in a road, but not so pleasant on the underside of a car. Moisture is essential for corrosion. On this subject all we can do is excuse ourselves and say the factor has not been well evaluated. By interesting coincidence many cars are undercoated.

MAINTENANCE

A chloride road not maintained becomes a chloride road not at all the chlorides leach out. One alternative is a bituminous surfacing, which may solve the problem for several years. But because a chloride road is first of all a cheap road, many are left unsurfaced.

The first step towards maintenance is to select a short length of two-by-four and lightly bend it over the head of the operator of the blade grader. This action conveys a certain sense of responsibility, and also helps him to overcome intrinsic bullheadedness. Actually a good blade operator is a highly skilled artist, and he can make or ruin a stabilized soil road.

2 x 4

If a blade is used at all, it must be with a very light touch so as not to rip up that valuable, compact surface. The blade is used only to carry forward loose material to fill in the holes. Don't throw away the two-by-four.

As originally constructed, the road is built like a roof, with an "A-type" crown with flat, sloping sides. The blade should not allow this to slip away into the usual rounded crown, which drains poorly in the middle. Remember the two-by-four.

Potholes spell slow doom, because they trap rain water which can then seep through the road long after the rain is over. One of the best ways to fix potholes is to dig them out like a cavity in a tooth, then fill and tamp with pre-mixed, chloride-stabilized material.

Rain or shine, chlorides are on the move in a road. Rain causes leaching, shine brings salts back up by evaporation of water. Added to this is a permanent tendency for ion diffusion downward (short arrows).
FACTS AND FINANCES

A final diversion is the cost of chlorides, closely dependent on source or manufacture.

Close to a source, the cheapest chlorides are natural brines from salt lakes or wells. These are so cheap they are often given away, and the only cost is to haul and spray onto the road.

Unfortunately, natural brines often contain magnesium chloride, which is very corrosive. Then it’s a matter of what do you want--dust or rust. Many natural brines are perfectly satisfactory.

Chemical industry waste brines are also used, particularly calcium chloride brine from the Solvay process for making soda ash.

Very far from a source of one of these brines, transportation costs rise, and nobody likes to pay for hauling water. A commercial crystallized product becomes cheaper overall.

Rock salt

The major source of sodium chloride is rock salt, currently available in salt mines (p.2). Salt is also produced by evaporation of brine either with heat from the sun or with steam heat evaporators. Much of this salt is first “mined” from wells, by drilling into a deep rock salt formation, pumping down water, and pumping up brine.

Calcium chloride

About half of the calcium chloride in the U. S. comes from refining natural brines; the other half comes from the soda ash industry. Brine is concentrated by evaporation and treated with lime to get out the magnesium chloride. Further evaporation settles sodium chloride as crystals. The remaining product is called 75% calcium chloride, chemically CaCl₂ + 2H₂O. This may be flaked or pelletted. Ordinary commercial flakes run 77 to 80% CaCl₂.

Prices

Nobody can accuse salt of being expensive; the current price for rock salt runs about $10 per ton, plus transportation. Calcium chloride costs several times more, but is still a cheap chemical.

USE IN IOWA

Naturally, we Iowans like to regard ourselves as leaders in everything, our only problem being to prove it and keep leading. In this connection we now present a surreptitious preview of an in-state survey made by Dr. John B. Sheeler for the Iowa State Highway Commission.

Interviews were with county engineers known to be heavy chloride users. The tally shows 14 counties with a total of 524 miles of sodium chloride roads and 11 counties with 737 miles of calcium chloride roads. Many counties use both.

Quantities

Amount of salt used varies from 5 to 20 tons per mile, to give 2 to 4 inches of compacted road material 22 to 28 feet wide. Some counties report 8 to 12 pounds of salt per ton of soil. Salt is mixed with glacial till as the binder material.

Calcium chloride is usually applied to give 8 pounds per ton of mix, although one county uses 10 pounds per ton. For “soil” most use 3/4 inch crushed rock; a few use pit run gravel plus 12 to 25 percent glacial till for binder.

Screws

Many county engineers report trouble with their blade men; apparently they have not been teaching with the 2 x 4. Properly dented, a good blade man knows enough to keep his scrape shallow. The amount of blading is but a fraction of that necessary for untreated roads.
Either kind of chloride road may be maintained with an occasional surface shot of calcium chloride. Half the counties using salt report they apply 5 tons of calcium chloride per mile every year. On calcium roads the application varies from 5 to 20 tons per mile per year. The alternative for either is black-top.

Both kinds of stabilized roads are reported as showing a decided tendency to pit. Large pits or potholes are best repaired by hand-patching with mixtures of clay, gravel, and calcium chloride. Filling of potholes with loose, bladed material is only a temporary expedient.

**Qualities**

Aggregate retention on chloride-stabilized roads is reported as excellent, and is often the decisive factor in economy. One county reports annual savings of 250 tons of gravel per mile.

Chlorides rate well for dust prevention, most roads being described as slightly dusty but not completely dust-free. The traffic count varies anywhere up to 450 or 500 cars per day. Under less traffic the roads last longer. Because of the dustlessness and smoother riding qualities, chloride roads are reported as attracting traffic and easing the load on adjacent gravel roads. Winter damage is generally considered much less severe.

**Some county engineer comments:**

**Salt**

Black Hawk County—Most everyone is well satisfied, and gravel is conserved.

Butler—Average road life 5 years. A new road is built when the old one wears out.

Fayette—Good for 125 cars per day.

Franklin—Roads develop hard crust, stay hard in spring. Hold up until traffic exceeds 150 cars per day.

Hancock—Roads serve 2 to 4 years, then blacktopped.

Linn—Plant mix preferred.

Mitchell—75% salt, 25% calcium chloride holds road for blacktopping.

**Calcium chloride**

Benton County—Saves money in long run.

Chickasaw—Used with limestone or in soil-aggregate. Two roads going on 8 years.

Dallas—Large savings in aggregate and maintenance.

Linn—Plant mix with limestone.

Kossuth—Blacktop third year.

Pottawattamie—Plant mix with limestone.

Winnebago—Gravel savings invaluable.

Dust is evil. It brings on discomfort, sneezes, carburetor drag, dirty ears, and blind-man's bluff around the curves. Road on the right has been treated with calcium chloride.

**ACKNOWLEDGEMENTS AND REFERENCES SIGHTED**

Beaucoup literature on use of calcium chloride in roads is available from the Calcium Chloride Institute, 909 Ring Bldg., 18th and M Streets NW, Washington 6, D. C. For information on use of salt, contact the Salt Producers Association, 33 N LaSalle St., Chicago 2, Ill., or one of the major salt companies.

You will be pleased to know the latest word in highway engineering includes some late thrilling words on chlorides; we mean Prof. K. B. Woods' Highway Engineering Handbook, due out next summer. By coincidence the chloride stabilization section was written by Dr. D. T. Davidson and local penpal, RLH.

**Photo credits**

Whole-hearted thank-yous go to the International Salt Co., Scranton, Pa., for the mine shot on p. 2; to the Ohio State Highway Department for the road photos on p. 3 (r) and 5; and to the Diamond Crystal Salt Co., St. Clair, Michigan, for the well photo on p. 5. If hard pressed we might admit to a tiny bit of retouching on p. 3(r). Graphs are reproduced by permission of the McGraw-Hill Book Co. from Highway Engineering Handbook, copyright 1959.

**The tab**

Use of chlorides in roads is being studied under Iowa Highway Research Board Project HR-33 of the Iowa State Highway Commission and Project HR-1 with the Iowa Engineering Experiment Station. Research funds come from the Iowa State Highway Commission.

**IN THE NEXT ISSUE:** Soils in our 49th state.

Our last word for this year is to say hello to the next—Merry Christmas to all, and to all a good night.
TALES OF ALASKAN GREATHOOD...

Plus Some Stray Lowdown on Soils

Alaska, the Great Land, home of sourdoughs and sockeye salmon, northern lights and southern comfort, soon will be wearing its union suit on the outside, looking taxworn and tired like the rest of us. Suddenly the United States will become 20% larger in area, almost 100% wider and 100% longer.

The new state is about 200 miles north of the rest of the congregation, but mostly it is west-straight north of Hawaii, as a matter of fact. Central Alaska is two time zones removed from our Pacific Coast states, four away from Iowa, and five away from the centrally located capital in D. C. Actually four time zones are used in Alaska—from east to west they are Pacific Time, Yukon, Alaska Standard and Bering. The U. S. will have seven standard time zones in all. And you say you're confused by daylight saving?

Physically, Alaska is about one-third above the clouds and one-third under water, and with a climate varying from the cool wet of Philadelphia to the cold dry of Montana to the prolonged cold and dryness of the Arctic. In general, the colder areas are the drier areas; the glaciers are all in the wet and snowy south, where they form in the well refrigerated mountains and shiver their way down to where it's warm.
Creek for mountain and Spanish for gold, which figures if you read history. When the warm and wet Pacific Ocean air whisks into the mountains it catches its death of cold. Result, sniffles, or, more accurately, snow. Annual precipitation on the southern coast runs around 100 inches, with snow accumulation of the order of 10 to 25 feet, depending on winter temperatures. Yet in many coastal areas the mean winter month temperature is scarcely below freezing.

Higher in the mountains, where it is colder, vast amounts of snow accumulate and never melt. Result, glaciers—the largest and most spectacular in North America. They slide down to the lowlands and melt, or slowly plow down to the sea and make white puffs on blue water.

Face and Physiography

Whereas most of our states have to be satisfied with a frowsy mountain or two, Alaska has two major mountain ranges! A Pacific Mountain system bolts northward from Oregon and Washington through British Columbia into the Alaskan panhandle, and bends across southern Alaska and down into Kodiak and the Aleutians. It is called the Alaska Range, and includes modest Mt. McKinley, 20,300 ft., and a few hundred littler ones.

In northern Alaska an extension of the Rocky Mountain system (the fact is they’re all rocky) cuts east-west across the northern third of the state. This is the Brooks Range. Between the two mountain ranges is a central plateau region, flat by contrast but otherwise not very flat. In walking over this terrain much exercise will be instinctively spent stooping over and picking blueberries. They are delicious.

North of the Brooks Range is the true Arctic, a region of happy Eskimos, gentle slopes, angry dogs, and no trees. We might suggest a reasonable correlation between the two latter.

Warm Bottom and Cold Heart

North though it is, southern Alaska and the southeastern panhandle receive a lot of canned Pacific heat via the Japan Current. The mountains exhibit human weakness and retaliate this kindness by filling the ocean with ice cubes. Then we send the water back to Japan.

Actually the southern Alaskan mountains form what is called an orographic barrier, or being
A Firm Understanding

Friendships notwithstanding, a mean annual temperature below freezing usually means that freezing will exceed thawing, and things slowly freeze up. Such a perennial frigidity is called permafrost. In soils there is more to permafrost than meets the eye, since the perennially frozen part is well below the ground surface. Above the permafrost, terra is not so firma; this is the so-called active layer, which freezes and thaws every year.

Permafrost usually has ice in its veins, in which case frigidity lends rigidity—in other words, the frozen soil is hard. Unfortunately when it thaws the reverse is true; ice turns to water, soil turns to mud, and life is full of problems.

You would never guess it to look at the ground surface, but most of Alaska and about one-fifth of the world is in permafrost. In the Arctic around Barrow, the permafrost extends over 1000 feet deep, and the thickness of the upper, active layer is only one to three feet. In central Alaska the permafrost commonly extends a few hundred feet and is locally absent, depending mainly on the vegetative cover. In southern

A famous condition known as "drunken forest." Trees get tipsy when the lake thaws the permafrost and enlarges.

Alaska permafrost is present only where the ground is well protected, and may have formed in an older, colder climate.

How to Thaw Permafrost

Permafrost is a master of romantic suspense, and a partial thaw can either warm the heart or be a terrible letdown. Permafrost is perched in such a delicate equilibrium with climate and local environment that the slightest twitch of improper nudge can really tip things up. A heated house will thaw its own little notch in the permafrost and often sink down into it.

Clearing of timber for farm land or roads is the most important cause for permafrost thawing. Apparently removal of trees allows greater heat absorption in summer without greatly affecting heat loss in the winter. Curiously, lakes also cause thawing and may thus be self perpetuating, like Congress. Whether or not thawed ground subsides depends on the amount of ice incorporated in the permafrost. This is related to type of soil.

SOILS IN ALASKA

In the soils department Alaska unquestionably ranks as America's Number One Rock Garden. Soil materials exist mainly in the valleys, which is where everybody lives unless he's a mountain goat. Soils fit into several categories, depending on whether they originated by action of wind, water, ice, or humbug. Soil formation by routine chemical weathering of rocks is practically non-existing in most of Alaska; weather too cold. One result is a state-wide scarcity of clay except in older sedimentary rocks.

Deltas and Coastal Plain

First let's fly to the land of the Eskimo. Much of the area north of the Brooks Range is coastal plain—flat, wet, treeless and clayey, just like southeast Texas only colder. Also the "clay" is mostly silt. A similar area is the large Yukon River delta which forms the chin on Alaska's face, between Nome and the Aleutians. Such flat areas of sediment are studded with lakes, permafrost, lemmings, and Arctic owls.
Ice on the Move

Farther inland, most soil is a direct or indirect result of glacial action. Compared to the large continental glaciers that inhabited Iowa and the Midwest, Alaska glaciers are little fellows. They spend their time skimming down the mountains and through the valleys. When these valley glaciers reach the lowlands they may spread out into a large, flat, piedmont glacier or ice field, but these are not common.

As everybody knows or supposes, glacial ice grinds rocks into soils which are then carried along and deposited when the ice melts. In Alaska such glacial till mainly occurs as hilly, hummocky moraines downstream from what's left of the glaciers. Deep lake-filled depressions, or kettles, occur where blocks of included ice have melted. All in all, glacial till is a relatively minor soil type in Alaska.

Gravel

Far more important economically are deposits from water. In Alaska most river water anywhere near the Alaska Range is entirely fish-free and resembles thin mud soup because it comes from melting glaciers. As the water moves downstream from the ice front it swishes back and forth, removes a lot of glacial till and replaces it with water-deposited gravel, cobbles, and boulders. These are fast rivers, and finer materials are carried on out to sea to build deltas and coastal plain.

Readjustment of stream systems to a lower level, as often happens, leaves widespread gravel terraces that are beautiful places on which to build things. Your building may thaw the permafrost, but who cares, since the gravel most likely won't settle. Also there's plenty of gravel available for building material. And to make a road all you have to do is push off the trees. Indeed a beautiful arrangement, unless you plan on farming.

Silt

Fortunately for the farmer but sad news for the engineer, much of the terrace gravel is covered by a layer of silt. The silt also extends onto the uplands, a reasonable reason to assume it is wind-blown. It is sufficiently important to warrant special action by engineers. We'll have to tell you about it.

The Dusty Crew

During the summers of 1954-55 seven men from Iowa State College sniffed and savored silts in Alaska and brought back tales of wonder and woe. For example, thickness, clay content and sand content are closely related to the braided river systems. Thickest deposits with coarsest silt are usually close to a river.

<table>
<thead>
<tr>
<th></th>
<th>Fairbanks (3 samples)</th>
<th>Big Delta (3 samples)</th>
<th>Matanuska (5 samples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>42</td>
<td>32</td>
<td>30%</td>
</tr>
<tr>
<td>Feldspars</td>
<td>27</td>
<td>23</td>
<td>4</td>
</tr>
<tr>
<td>Micas</td>
<td>13</td>
<td>31</td>
<td>3</td>
</tr>
<tr>
<td>Rock fragments</td>
<td>7</td>
<td>3</td>
<td>45%</td>
</tr>
<tr>
<td>Amphiboles, pyroxenes</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Clay minerals Montmorillonite Ill., KaoL., Chlorite Chlorite</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

*Mainly metamorphics

Contours show the variable sand content of Matanuska Valley loess. Thickness and clay content contours show the same trends. From west to east thickness varies from one to several tens of feet, and clay content drops from 20 to less than 6 percent. Table below shows average mineral composition of some Alaska loesses.
This buried ice mass was exposed in the search for cold cash, in this case gold. It is embedded in a thick deposit of silt. Curious concave structure comes from giant nozzles used to wash away the silt.

Winds from the glaciers now whip up noticeable dust storms which leave noticable dust deposits of silt. However, local distribution pattern of dust is not always identical with that of the older silt.

The Alaskan loess nearly always falls in the B.P.R. category A-4(8)—no active clay mineral. As any soil engineer can tell you, A-4(8) friable silty soils are the absolute worst for frost action. These soils combine high permeability with good capillary action, both of which bring water into the freezing zone. Icy fingers push the silt grains apart and make a frost "heave." Even more important, in permafrost areas large masses of clear, subterranean ice form by mysterious means, perhaps from thermal contraction cracking, and filling of cracks with surface water. (Photos above.)

Such icy phenomena occur mainly where silt is thick. They are particularly prominent around Fairbanks, where silt is thicker in valleys and on lower slopes due to wash and downhill sliding.

Actually even here there is little trouble with permafrost until the ice melts. Then, look out. In two or three years cleared fields can thaw and become so hummocky they are more like an obstacle course than a cabbage patch. Many must be abandoned. One farmer was nonchalantly driving his tractor over a new field when the ground failed and he had to climb out. A golf course near Fairbanks has some of the most spectacular traps imaginable—15 foot holes with vertical walls and no places to grab. Approximately one-fourth of the land near Fairbanks is underlain by permafrost containing large masses of ground ice. So it pays to reconnoiter before buying, building, or clearing off trees.

Fine ice lenses in soil make a "frost heave." Unfortunately such action is not limited to Alaska, but pushes up underneath roads whenever conditions are right. When the ice melts and the road gets pot, it is referred to as "spring break-up" because of what it does to a car.

GREAT SOIL GROUPS

Drop the Landing Gear

In low, soggy permafrost areas, Alaska silts show a remarkable proficiency for getting things stuck. Permafrost is often the major reason for the wetness, since the underdrainage is sealed.

In this connection we might lean on the agronomist's scheme for describing the upper soil layers or soil profile by means of great soil group. One of the most common great soil groups in Alaska is aptly called the Half Bog. A Half Bog soil consists of a thin layer of peat over a layer of water-mineral soup. It is often sprinkled on top with trees.

The treachery of the Half Bog is that the peat layer is strong enough to support one pass of one vehicle, but once wheels cut through the peat the next stop on the way down is permafrost. This means you can usually drive into a place but you may not be able to drive out. Life is like that. "Looks like All Bog to me."

Muskeg and Tundra

Another great soil group with a liquid sound is Bog, locally called muskeg. In Bog soils the peat layer is thicker, trees usually don't grow, and water often stands in ponds. Nobody tries to go very far on Bog soil. One interesting condition is "quaking bog" which vibrates when you stamp your feet. Soil beneath the peat is so wet it behaves as jelly.
Tundra, with an oblong thaw lake in the background. Streams often develop queer meander patterns because they melt into and run along the top of vertical ice wedges. The ultimate is when Eskimo boatmen can portage across meanders and drift downstream to go upstream.

A third major group is Tundra, the soil of the Eskimo. Whereas profile development in the Bog and Half Bog great soil groups is mainly halted by excess water, in Tundra it is halted by cold. Tundra is thus a xerol soil because it is the normal product of the cold arctic or subarctic climatic zone. Actually, Tundra is very similar to Half Bog. One difference is no trees.

Most Tundra is in permafrost, and the associated ice masses often shape and squeeze the terrain into some thoroughly spectacular patterns. The soil itself consists of a foot or so of tough vertically fibrous peat overlain by grass and wildflowers and underlain by wet, chunky soil. The main productivity is caribou, reindeer, ducks and Eskimos. Domesticated reindeer from Siberia offer the Eskimo a chance to settle down and turn rancher, but he is reluctant so long as there is good hunting. As for trafficability, Tundra is practically impassable except in winter. Even walking is very slow unless you’re a duck.

No ice wedges visible, but their message can be seen...

A "beaded stream" results when the stream crossing buried ice wedges melts out deep holes. Holes are 5 to 20 feet across, about as deep as they are wide.

Whither the Farmer?

Where trees have grown and drainage is good, the most common great soil group is a new one called Subarctic Brown Forest. There is very little weathering or increase in clay content, the "soil profile" being a layer somewhat darker in color and loaded with fine roots and fluffiness. The loose structure and good drainage make this Alaska's number one agricultural soil, though it does require fertilizer. Initial clearing of trees with bulldozers can be a little harsh on the topsoil unless clearing is done while the ground is frozen; otherwise the bulldozers clear away soil and all.

Because of the long hours of summer daylight our biggest state also has some of the biggest vegetables. Potatoes, cabbages, turnips, rutabagas, carrots, and dairy cattle do well in Alaska, although cattle feeding has its problems during the long winter. Typical Alaska barns exhibit a very superior storage capacity.

The most prominent agricultural area is the Matanuska Valley, 500 miles north of Anchorage. A big boost came in 1934 when some 200 farm families were moved here from dust bowl areas in Oklahoma. The number two area for agriculture is around Fairbanks, and there aren't many more numbers. In 1950 Alaska produced about 15 percent of its own needs, but still had enough potential farm land to come out about even.

The Alaskan who does make a go of it can gain satisfaction from living in the true homesteader tradition, finding his way in the face of genuine hardship, even if the hardship is merely a wife who balks at cooling her crupper in the outdoor plumbing. Still, it may be five years or more before he can make the land begin to pay out, and one can experience a lot of privation in five years. Many of the early homesteaders were bachelors who didn't make out so well gold mining, so they were already used to going without.

Podzol—the Ashy Soil

Whereas the Subarctic Brown Forest soil group is typically of Alaska loess and is

Representative scenery includes a bit of loose loess. Bulk density runs as low as 60 lb per cu ft.
literally fine for farming, the loess doesn't occur everywhere. Where loess is thin and the underlying material is sandy, weathering is either prolonged or more intense because of less mineral surface area, and the result is a leached ash-gray layer directly underneath the forest mat.

Podzols offer a good contrast to the loess soils, which by comparison are as fertile as a rabbit's living room. Podzols are gardened near Anchorage and other towns mainly as a matter of convenience, but with so much land available a large-scale effort on a Podzol can be regarded as a mistake.

SUMMARY

Alaska soils accumulate in and around the mountains like lint in a navel. Common soil materials are glacial till, alluvium, and loess. Deltaic and marine soils are widespread in less settled areas. Ice accumulates in fine grained soils in permafrost and can raise some difficult problems if the warmth of humanity makes the permafrost melt.

The slight weathering of the loess is described by the Subarctic Brown Forest great soil group. On sandy soils, sour old Podzols may develop.

In wet areas the typical soils are Bog (muskeg) and Half Bog, depending on the thickness of the peat. In the treeless Arctic the great soil group is Tundra, also mostly peat. None of the latter are any great shakes for agriculture, although they can surely shake the engineers.

ACKNOWLEDGEMENTS AND REFERENCES SIGHTED


Iowa Engineering Experiment Station investigations in the Far North were sponsored by the Geography Branch, Office of Naval Research, under Contract Nonr 530(04), now expired, rest in peace.

IN THE NEXT ISSUE: Fine sands in eastern Iowa.

RLH
A WORD ABOUT SAND

In a word, sand is sand, and we aren't going to pretend you don't know what sand is.

Still, to be truly objective we must include a definition:
Size-wise, sand is a cheerful adolescent between silt and gravel—too big to carry very far and be called silt, too small, fine-featured and unsettled to be called gravel.

From another point of view, sand is a coquettish sprinkle of beauty marks on suntanned thighs, or outrageous specks of whimsy cornered in sleepy eyes. Sand is trickling lifeblood to the hourglass, intestinal dignity to the earthworm, ephemeral castles to the child.

Sand is a public mirage of the Sahara or the American West; there's sand on the palms of Texas, held out in a prayer for rain, and there is sand all over the back porch of Nebraska, stretched out likewise. There's sand in the seat of Kansas, sand in the heart of Florida, sand in the hair of Minnesota and Wisconsin, sand on the lanes of Illinois and Iowa. There's even sand in Hell, where they French-fry it in lizard fat and feed it to Congressmen for popcorn. On the Second Day God created land, and before the week was out there were wind and snakes and rivers and, undoubtedly, sand.

Grandpa

If this is nonsense to the academician, as to some others, we had better bristle some alternate views. The ultimate grandparent for most sand is coarse-grained crystalline rock such as granite. Granitic rocks are widespread, and when they weather they do a stately transformation into individual grains of sand.

Granitic rocks average about a quarter quartz, the remainder being pink or white minerals called feldspars. But the feldspars are weathered rather readily to clay, whereas quartz is as persistent as hunger pangs in an insurance man. This creates a preponderance of quartz, much like it creates a preponderance of insurance men, and in natural sands quartz is our most important product. The remainder is feldspar, micas, dark minerals, gold and uranium. (So we dream a little.)

Sand? Naturally! This stable dune area is in North Dakota. Unstable or active dunes have that fresh, bare, windblown look (above).
Blowout. Even a stable dune area shows signs of life if vegetation is removed by farming, overgrazing, roadcuts, etc. This blowout is in Benton County, Iowa.

Rounded outlines are typical of quartz grains derived from granitic rock, although the sand may experience much subsequent rounding due to its rugged social life. Through a process of grinding against neighbors, individuality soon gets its corners rubbed off.

Stop and Go

The reason that sand is such a geological gypsy is its grain size: it is easily eroded by wind or water, readily transported, but given the least opportunity it will settle down and stay a while.

During such relocations sand is separated or sorted from associated clay, silt, and gravel. Like many a minority group it forms small Bohemian settlements where most of the population is alike in origin and habits. If the sand stays long enough and becomes stable, it adopts some native dress and develops a soil profile, which ordinarily means loss of racial purity from infiltrations of silt and clay.

Since sand can be sorted by either water or wind, we have two kinds of deposits. Wind-deposited sands are called eolian after the Greek god Eolus, who occasionally whistled up a storm. Water-deposited sands include beach sands, marginal to lakes and oceans; also stream deposits or alluvium, from the great Sioux Chief Allu, who stood on the banks of the Mississippi, drank the river dry and created the Missouri, single-handedly making green Iowa. (Actually alluvium is from Latin, to wash.)

As a general rule eolian sands are finer than alluvial sands, for birds are small and shifter than whales. Water can move coarser particles than wind, although the difference is reduced because wind usually moves faster.

Peppy peppering

When sand moves it doesn’t glide, it bounces. This primeval jitterbug is called saltation and accounts for quite a peppering near the ground. Thus in sandstorms the moving sand is concentrated low, chewing off fenceposts and the like. Most likely that’s what makes rattlesnakes so mean; shotgun effect.

Saltation or bouncing accounts for the ripples commonly seen in sand deposits, and on a much larger scale contributes to the formation of billowy, sometimes beautifully symmetrical deposits called dunes. Sand grains confidently bounce up the front face of a dune and suddenly find there is no more dune to bounce on. After a short glide a la Wright Brothers they fall and skitter down the back side of the dune, called the slip face because the sand is loose and slips.

Sand dunes are sometimes troublesome neighbors because they migrate, encroach, and literally take over. The best way to avoid the inevitable is not to be there when they do. Other ways are to cut off the supply of sand or stop the wind from blowing; whichever is easier.

Back side of an active dune. Loose sand in the slip face is said to lie at the angle of repose (illustrated). Dune is slowly migrating to the right, drawing innocent by-standers and wayfarers. Eventually, if you wait long enough, they may come out the other side.

HOMESPUN TALES

Naturally we’re going to have to talk about Iowa to impress people with our nationalism so we can hit the United States for a loan. (Obviously this is not the idle provincialism of a New Yorker.)
Iowa has the spice of variety in her sands, what with her moody wind and weather.

River sands, or fluvial sands, occur on the flat floodplains adjacent to rivers, and in raised floodplain remnants appropriately called terraces. Very common. If you walk around a sand pit the chances are you’ll be on a terrace.

But sometimes there is water-laid sand in a most unlikely spot for a terrace, because there is no river. Then the chances are it’s a glacio-fluvial deposit left from melting glaciers, which were notoriously untidy. Many glacio-fluvial deposits are also terraces. Then they actually represent former river levels when valleys were filled high with debris from glacial melting.

The average Ewan would not believe there are dunes here except for runty corn, which is so unusual. Our sand dunes are all stable and no longer busy building or on the go. This is because sources of sand were mainly sand bars associated with glacial meltwaters; once glacial prohibition closed all the bars, the dunes quickly declined and vegetated.

Although sand is not exactly a priceless commodity unless you buy war surplus, sand has value, for example in areas of sales or promotion where grit and a toe in the door are major professional assets. Engineers prefer to use some of their sand in roads, where it at least outperforms silt or clay.

Detailed engineering studies of Iowa sands have not been done since the days of the Sioux, who discovered the sand was no good for either clay pots or arrowheads, and therefore let it lay. A more modern evaluation is to find out where it is, what it is, why it is where it is and why it is what it is. This allows us to map and predict and make intelligent use.

**Eyes of the eagle**

The first problem in mapping sand is to find the sand. With the aid of aerial photographs this becomes easy; sand areas are better drained and appear lighter, and the man truly gifted in photo interpretation can almost smell the sand burrs and feel prickles. Iowa sand dunes often look like longitudinal drifts aligned by a northwest wind. Terrace and glacio-fluvial deposits are detected by position and appearance.

Rule One when using aerial photographs is to cheat in every way possible. That is, use other clues for help. Two major sources of information are U.S.D.A. soil surveys and local geological survey literature. Soil Survey reports are mainly about surficial soils and have little or no engineering dope, but they are excellent first-hand information.

Many blue-eyed soil engineers have only recently learned the value of Soil Survey reports and tend to regard them as gospel. This is all right if you remember that gospel is forever tentative and subject to change.

For example, most of the sandy counties of eastern Iowa were surveyed 30 to 40 years ago, and while the maps are still very useful, nearly all the series names have since been revised or renamed. The Knox series (sollan sand) of one county has been mapped as Lindley series (glacial drift) in the next. To avoid renewal of confusion both might be mapped as Chelsea today?
A PEDOLOGICAL POSTNOTE:
MYSTERY OF THE SAND BANDS

Now is the time for all good men to go afield with rod and gun and auger and blade and see what can be dug up.

It so happens if you really dig those sand deposits you often find horizontal brown-eyed bands lacing through the sand like frosting in a multi-layered cake. The bands commonly extend 2 to 10 or 12 feet deep, so they can't be ignored by even the most myopic of engineers. Furthermore, the bands are interesting.

The origin of these clay and iron oxide rich bands is undecided, but the best guess is they are part of the soil profile. In ordinary midwestern soil, clay migrates downward from the "A horizon" to make a clay-rich "B horizon."

The bands may be analogous to B horizons, but why are they thin and repeated? One suggestion is that the bands represent former levels of saturation or water table. If so, the water table must have had some strange notions of level or lay of the land. Another idea is that the iron reacted with clay to plug the pores and start a band. The location of bands might then be related to original zones of fineness.

A third school of thought is the bands represent a cyclic precipitation, or so-called diffusion banding or Liesegang phenomenon. Reacting solutions of chemicals do this if oversaturation is required for the reaction to start. The reaction starts, uses up all the chemicals in the vicinity, and makes a band; then it won't start again until the same point of oversaturation is again reached farther down or farther out.

Yet another wild-eyed possibility is that the bands were there in the first place. A most unhappy thought, because it ruins speculation.
On secondary thought

If the bands are truly secondary, they could be reproducible in the lab. Vertically held glass cylinders were filled with sand and leached downward with water or acid. Studies by the Agronomy Department used oxalic acid; other studies by us used distilled water or distilled water made acidic by bubbling with carbon dioxide, CO₂.

In all tests, bands were formed after one week. The CO₂-charged water gave the best overall development and visibly leached the upper few inches of sand. The question still remains: are the bands true rhythmic precipitations or do the clay and iron stop wherever the sand is finer? Laboratory experiments favor the latter. Field samples of band and interband sands have shown no consistent relationship between band site and native fineness.

STUDIES

From the view of the pocket gopher, who happens to be a rank engineer of the first water, sands are no good unless you use them.

Sampling

The most critical step for any soil laboratory is sampling, which is not done in the lab but in the field. A bad or non-representative sample is worse than worthless; it can ruin the mental health of the researcher, destroy his confidence in the orderly nature of the universe, or, if he has wasted over a year, reduce him to the homicidal righteousness of a Wyatt Earp.

Size

Sand, since it lacks intellect or initiative, is characterized mainly by its size. The quick way to measure size is with a stack of different mesh sieves, the coarser ones at the top, so each grain falls through as many sieves as its size will allow. Vigorous shaking helps keep things on an uneven keel and contributes valuable noises to keep up the researcher's general awareness. The amount of sand retained on each sieve is weighed, converted to percent, and plotted in a so-called cumulative curve.

The median diameter is the 50 percent size from a cumulative curve, and is a good way to express average size of a sand or soil. It turns out that eastern Iowa eolian sands associated with loess have a rather small median diameter. Those associated with glacial drift have not been blown around so much and are coarser.

This is also reflected in another measure called sorting. Well-sorted sands have been picked up and deposited so much the grains are
SOIL STABILIZATION

Data hot off the lab sheets indicate that the sand surveys are not for naught, for the sands are among the most readily stabilized of all Iowa soils.

Tests on three different samples of eolian sand show that it can be converted to highway base course material with the addition of 8.5 to 9.0 percent portland cement. A sample of eolian sand rich in clay bands also requires 9.0 percent cement. A sample of fluvial sand requires only 7.5 percent cement, probably because it is coarser, which gives an interesting contrast. Since samples were selected to represent the extreme range of sands, it's probably safe to say nearly all eastern Iowa sands could be stabilized with 9 percent cement. Check tests may be made by new short-cut methods especially devised for sandy soils by the Portland Cement Association.

ACKNOWLEDGEMENTS AND REFERENCES SIGHTED

Our cover glamorous pin-up is that famous international beauty and irresistible charmer, Miss Ann D., rumored to be close friend and fiancée of Ye Olde RLH. The cover picture middle right, shows White Sands, New Mexico, courtesy U. S. Department of Interior.

Further enlightenment is available from "Fine Sands in east-central Iowa," by A. E. (Wicked) Wickstrom, Karl Riggs and D. T. Davidson, Iowa Academy of Science Proceedings 62: 299–317, 1955. For more dope on more counties, plus a literature review and laboratory band experiments, see the thesis "Fine sands in eastern Iowa," by A. E. Wickstrom, Iowa State College Library, 1957. This was also put out in a limited edition as a progress report; contact Ye Olde Editor.

Work on eastern Iowa sands was completed under Iowa Highway Research Board Project HR1 with funds from the Iowa State Highway Commission.

RLH
ALL UP IN THE AIR (looking down)

The straight dope on aerial photography

Eureka and Banzai! Avast and Ahoy, all you bicipitous beard-tuggers, here comes another centennial—one we'll bet you've missed.

Slightly over 100 years ago, 101 as a matter of fact, was invented the greatest boon to surveying since the hatching of the first civil engineer in your early Paleolithic.

We refer to the inception of the most widely used tool for modern mapping, the aerial photograph. True, aerial photography took a while to catch on, but it's not the end of a pregnancy that gets the credit. Necessity may be the mother of invention, but invention also needs a father. The fatherly basic research is mostly for fun. Necessity then comes along and dictates the drudgery of perfection.

In 1858 a daring Paris photographer-aeronaut named A. Nadar went aloft in a balloon, ostensibly to take pictures of the ground but actually to record the merits of some jeunes filles sunbathing on the roof of the nearby Hôtel George V.

As usual, science lagged behind art, and the wet collodion photographic process required fast work to get an image. With astute dedication to purpose (j'aime those jeunes filles), by 1863 Nadar had built himself the biggest gas balloon in existence, complete with two-story basket chemical laboratory. Unfortunately this time the basket was too large, and his wife went along. The paths of research are ever precarious, especially when efforts become unwieldy.

More fatherhood

Meanwhile in 1851 another Frenchman, Col. Aimé Laussedat, was busy siring photogrammetry, or use of photographs for mapping.

Actually Laussedat's photographs were taken from the ground. After the normal gestation period of 50 years, necessity again became a mother, and a Canadian named Deville resurrected photogrammetry and invented a stereo plotter.

Oblique air photo of Koyukuk River, central Alaska. Oblique photos may be corrected to vertical for mapping, but are used mostly for reconnaissance because of fogginess near the horizon. Loopy scarred areas are sand bars.

By the start of the Great War the use of the so-called phototheodolite (camera) and stereo plotter was a wild success. Photos taken on the ground from both ends of a measured base line were viewed in a plotter, and from the difference in angle of view each visible landmark could be pinpointed directly on a map. This eliminated a lot of field note-taking and eyeballing through a transit.

Unfortunately with photos made from the ground a lot of landmarks remained behind hills. Conditions were ripe for somebody to come up with something else.

Enter the airplane

In 1909 a daring young man took some pictures from his homemade flying machine, perhaps to bring home some of the thrill of flying. His name was Wilbur Wright; you may have heard of him before.

Within a very few years hostilities commenced, and armies took to the air. Fliers threw bricks at one another and also took a few pictures. The pictures proved far more damaging than the bricks, and not only proved the merit of aerial photography, but did much to make the airplane. Vertical shots gave up-to-date maps where you could almost see the spike on Heine’s hat. Techniques were developed to make interval sequence shots to give continuous photo coverage along a flight line, and parallel flight lines could be laid out to give complete coverage of an area.

Exit the phototheodolite

Air photos spelled doom for the phototheodolite almost before it got started, and the special cameras and accompanying stereo plotters were fair game for museums. Air photos gave much better coverage more cheaply and more quickly.

What of the transit?

Now the majority of mapping is done from vertical aerial photographs, and the use is rapidly increasing. Decline of the older surveying methods is reflected in engineering college curricula across the country, partly to make room for more science and math, you lucky future students.

Older methods of surveying are far from dead and can never die so long as highways go where the stakes are. You can't drive a stake with an air photo. Furthermore ground surveys are necessary to establish control points, as it is otherwise impossible to accurately determine the scale of a photograph. For one thing scale depends on flight altitude, and airplanes don't run on a track. Terrestrial surveying is still the thing for high accuracy or for small areas not already flown or for areas observed by such things as trees or girls dormitories; in the latter instances air photos are practically worthless.
BIG SWITCH TO STEREO

To hark back a little, you may recall the thrill of seeing and almost feeling mountains, parks or monuments, by slipping a picture card in the old parlor stereoscope. Perfected by Oliver Wendell Holmes, who was famous for other reasons, it practically revolutionized the entertainment industry in the 1890's. Then about 1915 came movies; goodbye stereo. Stereo movies returned in the '30's and '50's, but apparently people didn't like their curves through goggles.

3D from the air

The usefulness of air photos and much of their enchantment comes from their adaptability to stereo vision. One can look at a pair of photos and get tremendous depth. Houses appear as castles, valleys become deep, sinuous canyons, and trees look like marshmallowy blobs suspended in the air on toothpicks. It's enough to make one airsick, or at least a little woozy.

Actually the stereo effect is like something you'll never see from the air because depths are greatly exaggerated. Our eyes see depth because they view an object from slightly different angles (Euclid, 300 B.C.).

Normal eyes are two to three inches apart depending on the fatness of the head. Air photo pairs are often taken miles apart. Therefore the angle difference to an object, or parallax, is greatly increased, and heights of hills are exaggerated thousands of times. It's much like looking at a model.

Maps

One way to make a map from air photos is to trace, like in kindergarten.

Unfortunately if no correction is made for parallax or elevation differences of the airplane the photos won't match, and straight roads will show crooked (or crooked roads will show straight).

Maps can be corrected for photo scale differences or tilt by mounting the photos in a vertical sketchmaster. Mirror system allows you to see photo and map table at the same time. Where! Miss Jones.

A number of correction schemes have been devised. One method assumes that angular positions of objects from the center of the photo are correct, but distances may be off. Radial slots are punched through landmarks in common to overlapping photos; then when two photos are overlapped, pegs are inserted common to both slots, and distances are fixed by the two or more angles. Minor adjustments are made to tie in with ground control.

Contouring

Our final bit on photogrammetry is to tell about preparation of contour maps from photos.

If you lay the two photos of a stereo pair side by side and get out your ruler, you'll find that corresponding points on the two photographs are not at the same distance apart. Due to angular parallax, a hilltop will measure closer between photos than will two corresponding points in a valley.

From this difference in distance, or parallax, p, one can get the height of the hill:

\[ H = \frac{p \times \text{altitude of plane}}{p + \text{photo base line}} \]

The photo base line is the center-to-center measurement corresponding to the distance the plane travelled.

Example: \( p = 0.10" \), \( A = 10,000' \), \( b = 4.0" \).

\[ H = \frac{0.1 \times (10,000)}{4.1} = 234'. \]

For better accuracy a simple measuring device, variously called stereometer, parallax bar, stereocomparator, or peek-a-boo, puts the photos

Sand and gravel, we'll bet. Looks like a braided river without the river. Glacial outwash, Indiana.

Replica of the very first vertical air photo, two feet above the ground.
under a stereoscope so both are seen at once. Distances are measured by means of two dots, one placed on top of each photo. The interdot distance is adjusted so the dots are at corresponding points on the two photographs; they then appear to merge, and the distance may be recorded. The adjustment usually employs a micrometer for fine accuracy. When the two dots are not at corresponding points they appear as two, or the eyes may compensate so they appear as one but it is either floating in space or buried in the ground. Hence the term "floating dot;" another optical disillusion.

If the stereometer is moved over the photos so the floating dot is always exactly on the ground, the dot is following a line of equal elevation, or, in the parlance of the professional, a contour line (science). Usually a mechanical hookup is made to simultaneously draw a contour map.

More elaborate methods use projectors which project alternate photos in red and blue. Viewing with a red lens - blue lens pair of glasses gives the stereo image. A floating dot or cross is added optically on a surface of small movable stand, and made to fall on the intersection of rays from the projectors by varying the height of the stand. If the height is adjusted for a certain elevation, the stand can be shifted around so the dot stays on the ground and thus follows a contour. Add a drawing attachment and you get a map. If the dot is too high it "floats" stereoscopically, or if the eyes focus on the ground it will appear as two.

Accuracy? Ordinarily error is less than one half a contour interval, and the minimum contour interval is about 1/500 of the flight altitude. For a 10,000 foot flight, 20 feet.

C. L. Hutt of the Iowa State Highway Commission draws contours with a Keith plotter. A similar apparatus called a Multiplex, projects a series of photos to allow fitting or "bridging" of photos between ground control.

Shale lends itself well to erosion with a dendritic stream pattern. In the upper right portion of the photo shale has been stripped from a more resistant bed, probably sandstone.

AIRPHOTO MAPPING OF SOILS

Entirely apart from aerial surveying, air photos have a happy heart for showing rocks, soils, vegetation, houses, gun emplacements, etc. Between wars geologists make much use of photos to study rock structures and locate likely spots for oil.

Use of photos to map soils was pioneered by the U.S.D.A. Soil Survey, which soon found that photos are a reliable accessory, but they surely don't tell all. Air photos are now used as base maps for nearly all agricultural soil mapping. Soil boundaries often follow color or erosion breaks on the photos.

More recently soil engineers have picked up air photos as their Magic Tool. Under experienced eyeballs, air photos can be extremely valuable to locate everything from gravel deposits to landslides. Usually the soil type in any given area can be guessed at if not positively identified. However, to remove the guesser from the possible category of ignoramus he had better have all clues possible, in the form of geological reports, soil survey reports, and, preferably, field experience in the area being mapped. Also nice is the opportunity to field check the maps before somebody else does. Profitable mistakes improve the art. Other mistakes could destroy it.

Interpretation

Soil areas are best categorized by parent material, or, to be strictly geological, rock type.

For example, igneous rocks are those hard, crystalline head splitters that were once probably melted. They usually come in two varieties, granite, light-colored and coarse grained, and basalt, dark-colored and fine grained. Granite areas are shown on air photos by extensive frac-
ture patterns. Fractures in turn influence drainage, and make streams run straight and turn square corners.

The most familiar basalt is lava, which spews forth from volcanoes. Just as spectacular from a soils standpoint are basalt lava plains, built up by quiet eruptions from fissures. Both types of flows give a typical bubbly, crenulated or taffy-like appearance on photos.

**Sedimentary rocks**

Common sedimentary rocks are limestone, sandstone, and shale, often interlayered. If they lie flat the drainage pattern is dendritic; it branches upstream like twigs on a tree. Often the softer shale is stripped off by erosion, exposing harder ledges as cap rocks. Result, flat-topped mesas or buttes with resistant rocks on top.

A giveaway on limestone areas is the occurrence of collapsed caverns, or sinks. Note how fine drainage lines lead to the sinks, some of which contain water.

Sedimentary rocks are not necessarily sedentary rocks, for they are often tilted or folded into patterns reminiscent of network trouble on TV. Inclined, resistant layers stand up as ridges which bend drainage lines into a parallel, trellis pattern. If the rock sequence is known, mapping is simple, because the harder rock layers resist erosion and stand up as sloping ridges, or hogbacks. Between is often shale.

**SEDIMENTS**

Whereas rocks are political stalwarts, sediments are the vast unconsolidated masses, identified by group, easily manipulated, and inherently unstable and dangerous to the unwary. Certainly the most important civil engineering "soils" are the recently deposited, unconsolidated sediments. Some are similar in origin to sedimentary rocks but most are not; most are land deposits by wind, water, or ice.

**Wind**

Wind deposits are sand or silt, although some people take exception to the silt. Sand dunes are easily recognized by curvaceous form, mobility, and excitement; or in stable, vegetated areas the shape gets old and sloppy, and may show wind eroded pock-marks or blowouts.

Silt is easily eroded by water. Where thick it gives land a distinctive badlands appearance. Stream cuts are often near vertical, but this is not a universal criterion. The best way to map silt, or loess, is to already know it's there, then look for signs.

**Ice**

Glacial deposits cover much of Europe and North America. Moraines are usually poorly drained and present a mottled appearance on photos. Special forms, such as drumlins (elongated hills), eskers (sinuous gravel ridges), kames (conical gravel hills), etc., are easily recognized.

**Ice water**

Water from melting glaciers swelled major streams and made gravelly floodplains which now stand as terraces. Very important to engineers. However, many terraces are low and more easily spotted from the ground than from the air photos, once you know where and how to look.

Other ice water was dammed up, making large lake basins which quickly filled with sediment. Very big, very flat, but with beaches.

**River water**

River deposits are exceedingly susceptible to mapping from air photos because of the beautifully drawn slashes and patterns. Rivers fall into two categories, braided and meandering. Braided streams are heavily loaded, have high gradients and fast water, and mostly leave sand and gravel. Meandering streams are
slower and more orderly about their deposition; sand goes inside the meander loops; silt and clay fill abandoned oxbows or sludge up the floodplain during flood.

Local alluvium and fans

In tiny streams much of the sediment has merely moved down from the hills. It is still hill folk, little changed by its translocation. Call it local alluvium.

Other sediment is carried along for a while, then dumped most ungraciously when the river gets tired, usually because it runs out on a plain. The result is an alluvial fan. Very important, and often a site for roads. Desert basins are practically filled with alluvial fans. While fans are identifiable on photos, their subtle changes in slope are often more easily seen from the ground.

Deltas, beaches, and coastal plain

When rivers hit quiet water they really relax and drop everything. Result, a delta.

Reworking of delta material by waves gives sandy offshore bars and beaches, and helps wash finer material farther out.

Bordering the oceans are broad, flat, recently emerged sea bottoms called coastal plains. Materials are mostly fine, which is why there's a lot of clay in east Texas. Usually very flat and featureless on air photos. Older, inland sections of coastal plain are actually sedimentary rocks and give similar outcrop patterns, except the "hogbacks" are low, and called cuestas.

MODIFICATIONS

Life is sweet but life is wearing, and the most important change in soil parent materials is weathering and formation of a soil profile. Here local knowledge is essential before you even whisper air photo.

In general, weathering depends on climate, and profiles are classed into great soil groups. Local areas where climate doesn't control are more obvious; wet spots or alkali spots are readily seen on air photos by dark or light color, respectively, and occurrence in depressions. Very poorly drained depressions may have peat bogs, revealed by a unique ringed appearance.

Another type of modification so evident it tugs the heart is the effect of permafrost, which makes flat ground look like bad paint, all cracked and ready to peel. Cracks are occupied by ice wedges. In permafrost border areas the ice wedges are deep and don't show, either on the ground or on photos.

OVERALL DOWNLOOK

In industry and in highway engineering automation is the latest word, and one man with photos and a plotter can automate quite a few survey parties into other jobs. Often three or four alternate highway routes are surveyed.
from the air without anybody outside of the office even knowing about it, thus eliminating much of the lobbying and political windjamming connected with selection of a final route. The saving in noise alone makes photos worth considering.

Actually aerial surveying is not true automation. However, if you throw in the services of an electronic computer, which compiles elevation data and computes earth quantities quicker than a fast-acting headache remedy for humans who used to do the same thing, you've got a real engineering organization. Add another machine which takes elevation data and automatically draws cross sections and even tells itself how many to draw, and most of your engineers can stand around the Coke machine, in theory at least.

Unfortunately a machine has not yet been invented to interpret air photos, identify soils, and locate highway routes to avoid trouble spots. This is a wide open field waiting for experts with plenty of new how. Eventually photo interpretation information along with elevation and grade data may be funneled directly to a computer which would calculate not only total earth quantities, but different kinds of earthwork—rock, topsoil, clay, etc.

Footnotes

Many of the air photo glimpses of soils offered here are discussed in more detail in other Screenings.

1 Wind-blown silt and loess, Vol. 1 No. 4
2 Sand, Vol. 3 No. 2
3 Glacial deposits, Vol. 2 No. 5
4 Alluvial deposits: Next year?
5 Alaskan great soil groups and permafrost, Vol. 3 No. 1

ACKNOWLEDGEMENTS AND REFERENCES SIGHTED


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Turn the page for instructions for vivid stereo. Stereo pair below shows blowouts in stable sand dunes, western Nebraska.

RLH
Needed: One pocket mirror. Hold the mirror edgewise vertically between your eyes so one eye looks directly at a photo while the other one sees the companion picture in the mirror. Are you seeing double? Good! What a cheap drunk. Once you see double, the images are moved to superposition by tilting the mirror sideways. Suddenly, stereo! Wow? One-eyed persons out of luck.

Flat-lying sandstone cap rock over softer shale. Dendritic drainage pattern. Colorado, U.S.A.


Tilted sedimentary rocks forming hogbacks. Upward area to the left is called an anticline; the center has been eroded out. Very typical, W. Algeria.
SURFACES, SUDS, AND ASPHALT

Pardon us for going soft, but suddenly the subject is asphalt, notable for its hardy tenacity, water repellancy and black-hearted stamina. It varies in consistency from a casual collegiate Goo willing to adapt itself to any smart situation, to a sophisticated shining Gunk, stiff, strong, righteous and unyielding. Fortunately the goo-to-gunk transition is readily controllable. Both have their uses.

Asphalt is a petroleum product and not to be confused with tar, with which everybody confuses it. Tar is produced from coal, gas, wood, peat, or bones; asphalt is the left-over from crude oil after the naphtha, gasoline, kerosene, fuel oil, etc., have been cooked out. Both tar and asphalt come under the general class bitumens. Useful tar products include creosote, phenols, naphthalene, coal oil, roofing pitch, and inedible shotgun targets.

But our subject is asphalt.

Within Mummies' Tummies

Perhaps the most inspiring use of asphalt was as a preservative in cut-rate Egyptian mummies, where it assured immortality of the soul but not of Egypt. Nowadays we rely on clean living, psychoanalysis and Democrats.

About two-thirds of our asphalt goes into roads, and most of the rest goes for dry roofs. We can say with a fair degree of confidence that virtually none goes into mummies, except perhaps as a prank. (Are you absolutely sure you know everything that goes on in the Masons?) A somewhat similar use of tar, on the outside and in conjunction with feathers, has also declined in recent years, although the number of logical nominees is reported on the increase.

Black hearts and sticky feet

Already several thousand years B.C., asphalt was used in highways and water reservoirs in Mesopotamia and similar garden spots. Builders used naturally occurring asphalt, produced when crude oil leaking out on the surface of the ground slowly loses its volatiles to the air. This leaves pools of asphalt and outcrops of asphalt-impregnated rock.

Still, the first use of asphalt as a roadway was much earlier—prehistoric, as a matter of fact. During the Pleistocene, most notably at Rancho La Brea, near Los Angeles, quite a variety of beasts sauntered over the natural asphalt pools and failed to extract themselves before suppertime. Hence the term asphalt jungle, or in the words of Uncle Remus, some tar baby. Brer Elephant and Brer Camel, among others, got caught by the hundreds. Brer Saber-toothed Tiger and Brer Dire Wolf and other union leaders felt a vibrant twinge of social conscience and jumped in to tidy up. They of course got caught, a sort of primitif income tax. Thus was born the fearsome howl of the first Beatniks. Howls have been emerging on and off ever since, heard or not.

That old black magic called roads

The mistake of Brer Camel and other beatniks was in assuming that asphalt, which is merely an essence of life, is strong enough to support the humdrum of everyday traffic. Asphalt is properly
But another campus drive cheaply built with foamed asphalt. "Before" photos are on pp. 3 and 5 (under the machine).

Engineering Experiment Station buildings are on the right. Only the stickum for the solid particles that give life its substance, binding them together into a waterproof, cohesive mass. Asphalt is but a cement for mineral aggregates. In fact, asphalt refined and controlled for use in roads is termed asphalt cement, abbreviated A.C. Asphalt cements vary from soft to hard, the hardness being in part controlled by addition of a viscous flux oil. Hardness is measured by penetration with a standard needle; a large penetration indicates a soft asphalt cement.

ASPHALT + AGGREGATE

Problem for the asphalt engineer is not the asphalt but the aggregate. Aggregate may be graded, with a wide range of particle size to give maximum packing and intergrain contact, or it may be ungraded and stuck together with an asphaltic mortar. Pardon us if we skip the details.

The best asphalt roads are built by mixing aggregate directly with asphalt cement. Because the A.C. is more than a little viscous at ordinary temperatures, mixing is accomplished by heating both A.C. and aggregate to the neighborhood of 300°F prior to mixing. The hot asphaltic concrete mix is quickly hauled to the job, dumped, spread, rolled, painted with white and yellow lines, and decorated along the side with billboards and speed traps. One of the advantages of civilization is System; everything is worked out in advance.

Cutbacks and emulsions

Heat is expensive, or at least heat in the neighborhood of 300°F is expensive, and another way to apply asphalt is to cut it back with a solvent. Cutbacks come in a variety of grades, depending on the kind and amount of solvent. Naptha, kerosene, and fuel oil are usual solvents, and give rapid curing, medium curing, and slow curing cutbacks, respectively. Temperature of application varies from about 50° to 275°F, depending on amount of solvent, i.e., how close the cutback is to being pure asphalt cement. For plant mixing, the aggregate is also heated. Cutbacks are extensively used for spray treatments of new or old roads.

Disadvantages of cutbacks are the curing time required for volatiles to evaporate, and cost of the volatiles, which add nothing to the final road.

A third type of asphalt for roads is emulsified asphalt, a creamy black suspension, usually colloidal asphalt droplets in water. Emulsified asphalt may be applied cold and even to cold, wet aggregate. If it is properly constituted, the emulsion then breaks, water comes out and leaves the asphalt stuck on the aggregate. Problems in use are engineer fear, correct timing of the break, and what to do with the excess water. Emulsions are the ticket for small jobs or for patchwork where heating is impractical.

FOAMY!

So much for ordinary, run of the plant methods; now we must mention the greatest engineering lift since discovery of foam rubber life preservers worn by today's women. We refer to controlled foaming of asphalt, a new and slightly sensational mixing aid that allows low temperature mixing of asphalt cement without solvents or emulsifying.

Actually foams form a good part of today's living, as already implied. Foams put the puff
in whipped cream, the bulk in a candy bar, the glue in meringue, the bounce in a mattress, the head on a bubble bath or a beer, the wetting power in lather, the mouth watering symptoms in advanced hydrophobia. Combining these factors of bulk, tenacity, elasticity, beauty, aroma, penetration, and fear of water, asphalt foams have nevertheless been regarded as very bad.

Unexpected foaming converts a hard and healthy asphalt cement into an overflowing, vicious mass with all the perverted sensitivities of fresh bubble gum. It oozes, it flows, it penetrates, it stretches, and it sticks to everything. Special antifoaming agents have been developed to keep the asphalt kettles from foaming over and violating shoes, temps, language, and equipment.

From such vexatious clues, evener tempers prevailed. One day Professor Ladis H. Csanyi (Sahn'ee) of Iowa State began to wonder. Under Csanyi's direction, special foam generating equipment and nozzles were developed in the Bituminous Research Laboratory of the Iowa Engineering Experiment Station. Foamed asphalt was shot directly into mixers, and extensive laboratory and field tests disclosed a number of unsuspected advantages. Such as:

1. More even and uniform distribution of asphalt is obtained throughout the aggregate.
2. For high-type mixes, aggregate temperatures may be lowered to about 240°F.
3. For lower-type mixes, cold, damp, or wet aggregates can be successfully coated.
4. Hot mixes can be converted to cold stock pile mixes by chilling with water as the mix leaves the mixer.
5. Hot mixes may be laid on wet surfaces or even under water.
6. Wet, slurry-type seal coat mixes can be produced with asphalt cements as the binder.
7. Ungraded local aggregates may be used in mixes.
8. Clayey, silty, or sandy soils can be stabilized in a moist condition with the foamed asphalt cement.

SHADES OF SURFACE CHEMISTRY

These lucrative benefits will sound more believable if we beat the drum and make abori-

original noises—in other words, make with the theory.

Physical properties of foamed asphalt are quite different from those of the parent liquid. Most obvious is that the asphalt bulks up like a plump one removing her girdle; this in itself should promote wider distribution of small percentages. A somewhat closer analogy is a foam fire extinguisher, which spreads farther and is more effective than a pall of water.

Furthermore, foamed asphalt cement is temporarily softer than the non-foamed material at the same temperature. An A.C. with a penetration of 85 to 100 will have a penetration over 300 for some time after foaming because it's so full of vapor. And soft asphalts traditionally mix better. When the foam breaks, the asphalt regains its original strength and hardness.

Bubble bath

Perhaps most important of all is increased surface area from the bubbles. This brings in surface tension, or the reason for no corners on a soap bubble. Surface tension in the soap film causes it to assume a minimum area, whether in a bubble or on a small boy's hands and face. Mothers, that's why wrists, neck and ears are practically never bathed of their own accord.
Manipulation of surface tension is one of the most important arts of the modern chemist and has revolutionized such chores as washing, painting, oiling, greasing, gluing, and kissing without smearing. Obviously we owe an incredible debt to the surface chemist, although the debt is being amortized by thousands of idiotic detergent ads. In fact, one could almost wish for a little less self-acclaim.

And what causes surface tension? As any newspaper can tell you, tensions occur at borders patrolled by foreigners. Atoms or molecules within a mass are attracted equally in all directions, so much so they don’t know which way to turn, but at a surface the attraction is mainly towards closely similar neighbors and folks back home. Though surface lacks some attractions, a close brotherhood exists between surface molecules; this clannishness creates surface tension. At a water-air interface the resulting "film" is strong enough to walk on, if you happen to be a lightweight water insect with greasy feet. Otherwise you’d better not try it.

The same clannishness exists between molecules within the mass, and will come into play as soon as you try to zip them apart and create more surface. Thus surface tension is practically synonymous with surface energy, but not quite.

Surface tension of liquids can be measured a number of ways, such as height of capillary rise in a tube or maximum size of a pendant drop before one needs a handkerchief. For illustrative purposes, consider the wire frame special deluxe soap film surface tension measurer shown at the right.

Obviously a pull, \( f \), is required to keep the frame open due to surface tension of the soap film. Neglecting friction, the surface tension equals the force divided by the length of the wire and furthermore divided by two, because two soapy surfaces are at work, one on each side of the film.

All right, you physicists, if we pull the wires apart we do work which goes to make more surface. If we let up a bit, the soap film will do work and move the wire. To be strictly formal about this, if the wire is moved one centimeter by \( f \) dynes of force we have done \( f \) dyne-centimeters of work. There’s certain poetic charm in calling a dyne-centimeter of work an erg.

By assuming a length \( \frac{1}{2} \) (try one-half centimeter), it’s not too hard to demonstrate that surface tension in dynes per centimeter is numerically equal to surface energy in ergs per square centimeter. Well, now!

**Practicalities and reversibilities**

It is not necessary to believe all this in order to be anything but educated, so put away the puzzled look and let us philosophize.

For example, heat is required to boil water. (Some statements just have to be stupid.) But one way to look at it is that heat energy is used to break away water molecules and make new surface. A considerable amount of heat is required—about 540 calories per gram. By comparison it takes only 80 calories per gram to melt ice, and 100 calories per gram to heat ice water to boiling. Surface is expensive.

Fortunately, the expense is not for naught, because surface energy reactions are reversible. When steam condenses it gives back the 540 calories per gram and can cause a severe burn, ouch! or energize radiators on the fourth floor after the first three floors are unspeakably hot. Similarly you never see a soap bubble die slowly. It expires with a vigorous snap, due to release of its surface energy.

**THE FOAM GENIE**

A few more drum beats should assure you that we aren’t fooling. Actually artificial foaming of asphalt is put another brilliant and masterly scheme for storing up heat. The foam contains literally acres of new surface surrounding the jillion quadseptillion bubbles of asphalt. This asphalt-vapor interface is really canned energy, waiting for Aladdin to come along with a can opener. The beauty of the arrangement is that the surface energy is released precisely when and where it does the most good—during mixing. The foam disintegrates, and the energy goes to help coat aggregate.

Therefore even cold, wet aggregates can be coated with asphalt cement. Furthermore the release of surface energy aids penetration, for
dusts and soil particles can be individually coated, whereas mixing with liquid A.C. merely gives weak, coated balls.

Kinds of foam

By varying the pressures and adjustment of nozzles, two types of foam may be produced. "Discrete foam" contains the most surface area and consists of individual bubbles, a la Lawrence Weik. For discrete foam the steam pressure is 60 to 90 psi, and the asphalt is pumped at 50 to 80 psi. The pressures chosen govern the size and style of bubbles.

In "concentrated foam" the bubbles are joined together more like bubble bath. Steam and asphalt binder pressures may be as low as 35 psi and 20 psi (gauge pressure), respectively.

Saturated steam at these pressures contains not only the heat of vaporization, 540 calories per gram, but it is at a temperature well above 100°C. At steam pressures for discrete foam, the temperature is in the neighborhood 310° to 330°F; for concentrated foam it may be down to 280°F. Steam is used to clear the nozzles before and after foaming, so all remains neat and clean for an asphalt plant. Because of the low asphalt pressures, all that is needed to convert existing equipment is steam and nozzles.

Example 1: Asphalctic concrete

Asphalctic concrete concocted to meet Iowa Type A Specifications was sampled from an actual construction job, tested, and used as a basis for comparison. Stockpile aggregate from the same job was then heated to different temperatures and mixed with foamed asphalt.

(a) When aggregate is dried and heated according to specifications (300°F), foamed asphalt mixes perform quite as ably as those with unfoamed asphalt.

(b) Aggregate temperatures as low as 180°F still give excellent mixes, and more important, aggregate temperature is less critical. This means increased drier capacity and plant production.

(c) With aggregate at about 160°F, coating becomes incomplete. However, the Marshall stability of a 180°F mix is still 610 lb, compared to 1280 lb for the reference. With aggregate heated to 200°F the Marshall value is 700 lb. The minimum criterion is usually 300 lb.

(d) Cold, wet aggregates with 3 to 8 percent moisture were successfully coated. There is a slim suggestion here that water may help mixing.

Example 2: Upgraded aggregate mixes

Mixtures of natural fine sands heated to 350°F, plus loess or limestone dust plus discrete foam, give Hubbard-Field Stability values in the neighborhood of 1500 to 2500, with some mixes going over 5000. Comparable mixes with high-pressure atomized asphalt gave values in every case lower, and averaging 500 lower. We sincerely believe such mixes could not be prepared with ordinary liquid A.C. Other engineers believe this, too.

Prof. Csanyi (left) says keep this road on the road. Asphalt kettle on the right, hooded pulverizer-mixer at rear. Prof. Bob Nady is at the helm.

Similar mixtures were prepared with concentrated foam, and results were about the same. Advantages of concentrated foam are lower foaming pressures, and the fact that aggregates needed to be heated to only 240°F.

Test road

In June, 1957, a section of a test road was constructed in Ringgold County in southern Iowa. The mix consisted of pulverized agricultural limestone heated to 300°F, plus 5% A.C. concentrated foam. Mixing was done in a Cedar Rapids Continuous Mix plant with the output about 140 tons per hour.

We are pleased to report the road has stood up under pounding of loaded quarry rock trucks plus 250 paltry cars per day. We might remark that subgrade soils in Ringgold County are not the best for roads, being plastic loess over Kansan till and gumbotill.

Cold test

Another test area was built with 75% fine sand and 25% loess, plus 6% A.C. concentrated foam, only this time the aggregates were not heated at all, and water was added to aid mixing.

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Foamed 150-to-200 penetration A.C. was shot right into the moist (8% water) soil mixture. Hubbard-Field Stability ran about 3000 at 77°F dry, 1600 to 2200 at 140°F dry, and 600 at 140°F wet. A seal coat was added to prevent scuffing.

The pavement was laid in September, 1956 and have been carrying about 250 cars a day ever since. At last look it was still there. You are welcome to drive over it and sigh.

Example 3: Soil stabilization

This last little experiment is actually soil stabilization, since soils were not heated or treated prior to mixing. Another kind of soil stabilization is with a road mixer, which chews up the existing soil, adds stabilizer, and lays it all back down in one operation. Previously soil stabilization had been tried with cutbacks and emulsions, but not with asphalt cement.

One of our lovely campus thoroughfares was selected for this experiment, the natural in-place soil being 1½ to 2 inches of cinders on top of clay, which is actually not so lovely unless we do something about it. Six percent concentrated foam A.C. was added with a Seaman Pulvi-Mixer in several passes which were interrupted by rain, blast that weather man! A seal coat was applied to prevent scuffing.

Two test lanes were constructed and opened immediately to about 400 cars per day. That was in 1957. So far no distress, no weakening.

Now to the country! In 1957 about ½ mile of a county gravel road was given the treatment, 5½ percent foamed asphalt cement. Soils ranged from A-4 (3) to A-7-G (15), or loam to heavy clay. All went well until a gruesome Spring dumped 15 inches of water in one month, and in some places the subgrade soils gave the asphalt a bit of a letdown. Repairs and resealing have kept the public faith.

Parking a lot

The latest use of foamed A.C. is a 5-acre parking lot at a new shopping center in Sioux City, NW Iowa. Advantages of the foam are evident when you see what was used for aggregate—a mixture of 65% silty loess soil plus 35% blow sand.

Foam was applied to unheated soil containing 12% moisture. Soil was picked up, coated, mixed and spread in a single pass by a P & H Soil Stabilizer moving along at 27 feet per minute. This is not bad when you consider that soil is taken in at one end and road comes out the other. The asphalt-treated soil was compacted, covered with a chip coat surfacing, and laid open to the onslaught of time, weather, and the woman driver. Currently foamed asphalt soil stabilization is being tried for Sioux City streets.

ACKNOWLEDGEMENTS AND REFERENCES SIGHTED


Patents on use of foamed asphalt are licensed by the Iowa State University Research Foundation on a non-exclusive basis.

Research on foamed asphalt was sponsored under the Iowa Highway Research Board Project HR-20 with funds from the Iowa State Highway Commission.

NOTE THE NEW NAME

Hello from Iowa State University; after 101 years Iowa State College is no more. The term "college" harks back to our land-grant status but does not quite describe the size or reach of our endeavors. Foreign students are particularly name conscious.

Now the obvious confusion. Iowa State University, or simply Iowa State or ISU, is located in Ames, 30 miles north of Des Moines, and features engineering, science, agriculture, vet medicine, home economics, and visits from Soviet Premier Khrushchev. The State University of Iowa, or Iowa U. or UI, is located at Iowa City and features medicine, law, science, arts, hydraulic engineering, and trips to the Rose Bowl. We at Iowa State would like to go, too, but we can't find anybody to blow up our football.
SOIL: FOR BETTER HOMES AND GARDENS

Plus Thunderation! Or, Who Rules the Roost

Gather ’round, do-it-yourselfers, and hear of the housing that very little jack built.1,2

Prehistorically the cheapest housing was the cave, which is not unrelated to soil, being limestone weathered to its ultimate emptiness. The first grouchy landlord was probably the cave bear, who preferred caves because his growls echoed and reverberated in vibrant, stereophonic hi-fi. Even a belch could create terror.

Man was quick to perceive the acoustical advantages of the indoors, and after a few threats of peaceful coexistence he moved in and the bears moved out or had their heads bashed. Soon every cave in the valley had a man inside it, growling and singing and stoutly issuing commands, all for sport.

Unfortunately when wives heard the ruckus they also moved in. While true that a cave was a nice auditorium, it was an even nicer place to live.

A "cob" house built some 50 years ago in Wervic Olde Devonshire, SW England. For more about cob see par. 2 under "Stud and mud," next page. "Cob" contains no cobs.

This was woman's mistake, because men's voices, being lower than women's, are much better adapted to reverberating in caves. Masculine voices thundered authority, and women became submissive by the first echo. Thus from the hollow resonance of caverns was born our male dominated society. It was when man left the caves that his troubles began; without an echo he's been losing his voice in matters ever since. It's no accident that men sing in the bathtub, or that singers use electronic echoes. Gives them that virile, cave-man sound. Ugh.

Castles of Sand, Plus Clay

Now everyone is suitably impressed that housing dictates society, we continue.

After caves came mud. Our evidence is that small boys smear mud, and things small boys do are fun for big boys, too; else why would we have baseball?

Early mud houses were built after the manner of the beaver, with sticks and twigs and generous

1In this issue we kick around another literary toy, the footnote. It is extensively used in scientific writing where it is necessarily set apart from other kinds of notes which are supposed to originate more from the head.

2This particular footnote has to do with the use of the word "jack." Foreign readers may not know that "Jack" is slang for money. As here used it also alludes to a nursery rhyme, "Jack and Jill went up the hill to buy some things on credit; Jack fell down, and broke his crown," etc., etc.
amounts of mud plaster. In view of this, man could reasonably have been expected to evolve a large flat wall. Instead he broadened his palm. The broadened, upturned palm remained to become a dominant symbol of our urbane culture for example around the check-out desk in a large hotel. Future men will probably have hands the size of dinner plates, and fingers that mesh over and look like a vault.

**Stud and Mud**

Mud housing is used today in Africa and Asia, although it's something you would ordinarily prefer more for your in-laws than for members of your own family. The twig-and-mud construction is called wattle-and-daub, wattle being the twig work and daub being as the name implies. A more formal approach still used in Europe is to erect timber framing, lace in twigs, and daub mud on both sides with the subjective thoroughness of an actress applying skin cream. The result has surprising longevity, but on close examination usually looks a little humdrum and certainly like nothing you would want to marry. Wattle-and-daub exists mostly in farm buildings, conveniently built during slack seasons.

Another style of building is to leave out the twigs and build walls from mixed straw and mud, called "cob." The cob was mixed on the job, usually by horse foot, then slapped on the wall in a continuous layer about a foot high, packed into place and trimmed even on the two sides. By the time a building wall was thus circumnavigated the cob was usually dry enough to support another lift.

Cob construction was very common in France and drier parts of England up until the present century, and many cob houses a century or so old are holding up well today. They usually wear a protective camouflage of plaster, and look quite respectable and presentable. Increased cost of labor is what cooled the cob, and cob building is almost a lost art.

**IN MY ADOBE HOUSIENDA**

Adobe, or mud brick, is such a lovable way to build, that enthusiasm is a popular hobby, like love or stamp collecting. Adobe differs from cob or wattle-and-daub in that whereas walls of the latter are built from soft mud, walls of adobe are built with dried adobe bricks laid up with mortar.

Adobe is especially common in the southwest United States and in Mexico, but is found the world over. It is a very ancient invention. The name is Spanish, but probably came from the Moorish word *attöba*, which probably came from the Egyptian *hōbe* and the hieroglyph *th*. It is rather characteristic of the British to ignore all this and call the same thing "clay lump." Unromantic British.

Traditional adobe is mixed much the same as cob, the fresh mix being a creamy sand-clay mud containing short cuts of straw. The mud is poured and worked into large molds laying on the ground, the top is struck off, the mold is lifted, and the brick allowed to dry. Usually by the third day bricks have gained enough strength to be tipped up on end to save space and promote more even drying.

The function of the straw is to give the bricks wet strength so the forms can be lifted with little damage, and also to provide capillary channels for more even drying. The bricks invariably shrink, and if they dry and shrink uniformly there is less cracking. There is a rather well documented historical instance of the need for straw in adobe brick manufacture (Exodus V, 7). About three short cracks per adobe brick is considered allowable. Too many shrinkage cracks mean too much clay in the soil, but too little clay gives weak brick. Specifications are usually trial-and-error; to see if a soil is satisfactory you mold a few bricks and test them.
The dry brick should have an unconfined compressive strength of over 300 pounds per square inch.

Incidentally, there’s a bit of the old erroneous in calling adobe “sun-baked” even though it’s usually dried in the sunny outdoors. Adobe could dry just as well in the shade, if there were any shade. In fact, shading is sometimes attempted the first few days to reduce cracking. The reason adobe lasts is not that it’s “baked,” which it is not, but that it is forever kept reasonably dry or it contains a chemical stabilizer.

Instead of straw some writers suggest use of an equine byproduct commonly shovelled out from stables. It is called horse manure. There might be some advantages to using it in a guest house, or to give an authentic flavor to modern ranch-type dwellings, but from a purely personal prejudice, we would veto.

Adobe is now mainly used for one story construction because a second floor requires such thick bearing walls. Some of the adobe houses in California now over 100 years old have three-foot-thick first floor walls. Now the usual wall thickness is 12 to 18 inches, and about 8 inches for interior non-bearing walls. A convenient brick size is 4 x 12 x 18 inches, which when dry will weigh 50 to 60 pounds. Bricks are laid up with cement, lime, or mud mortar.

Adobe lasts well in climates of moderate rainfall, but like cob or other untreated soil walls it must be protected by a high and dry foundation plus wide overhanging eves. The outside is protected by plaster or smoothed with mud plaster and given an annual whitewash. The abundance of white plaster gives south European towns a bright, clean look when seen from afar. Unfortunately the plaster does not stick well and is in constant need of repair, so the trim look dissolves on closer view.
Post adobe + pipe dreams

In this country adobe is no longer cheap unless one lays the walls himself or lets the little wife do it. A recent neat trick invented by a California architect is to support the roof on four-inch or eight-inch timber uprights, and use adobe to fill in the walls. Advantages are reduction in wall thickness and hence number of bricks, and after the frame is erected the walls can be laid by somebody without much skill or talent, which means, of course, the little woman.

An even neater trick is to support the roof on four-inch pipe and use special brick which fit around them. The wall appears to be solid brick, and there are no wood uprights to paint, and windows can run to the corners. Plumbing and electrical connections are run through the pipes.

Advantages are immediate strength gain upon compaction, and higher density and greater final strength than are obtainable from merely drying a mud and watching it shrink.

Tamping

A disadvantage of rammed earth is the hard work of ramming and the natural tendency for workers to tire with the result that the walls may get tired, too. One needs a good foreman.

Pisé walls are traditionally built on an initial course of stone, concrete, or brick, by erecting wood "shuttering" two or three feet high on both sides of the wall, spreading moistened soil in a four-inch layer inside the forms, and ramming until the tamper "rings," indicating thorough compactness. More layers are then spread and compacted.

Once the shutters are full, the tie bolts holding the shuttering are carefully removed and the bolt holes filled with soil, and the shutters are shifted to another location to continue the lift or begin another one. The rammed earth has enough strength that construction proceeds without delay. The soil gains more strength as it dries out.

Traditionally the ramming tool weighs about 15 to 18 pounds and has a semi-pointed heart-shaped head, but tests at South Dakota State College in 1945 showed a flat-faced rammer to be superior. The answer to the laboror's prayer is pneumatic, air-driven rammers, to save both time and back muscles. The main requirement is a compressor big and windy enough that ramming does not become weak-kneed.

Proper water for ramming

Because the rammed earth method of compaction is similar to ways and means in highway engineering, much know-how has been borrowed. For example, we know that for any given compactive effort an optimum moisture content will give maximum strength and density. This can be predicted by laboratory test and aimed for in batch mixing by "feel." Usually the O.M.C. will make a soil damp enough to just hold a cast when molded by hand.

Soil-cement

Anybody who goes to the trouble of ramming soil into a wall will probably look favorably upon addition of a bit of something to assure

Rammed from earth, oo la la!
preservation. The most widely used chemical soil stabilizer in highway work is portland cement, and standard tests have been devised to determine needed percentages for a given soil (Screenings Vol. 2 No. 3). The mixed and hardened soil, or soil-cement, is strong, permanent and durable for houses. Most readily stabilized are granular soils having a dash of clay; they usually require about 4 to 8 percent cement.

Soil-cement blocks

Monolithic rammed wall construction is not the most versatile for houses with many corners, nooks and notches, although it is just the thing for simple, cheap little units that often look the price. More versatile and more costly, since it involves additional handling, are machine-produced rammed earth block. The block are usually soil-cement, although other soil stabilizers such as lime or lime-pozzolan should also work.

HOW GOOD THE WALL?

Two questions regarding soil housing are to be answered: how good is it, and how much does it cost? In the early 1940’s the U.S. National Bureau of Standards concerned itself with merits of test walls were constructed of soil-cement and plank rammed earth 14” thick, and of plain adobe block, asphalt-stabilized adobe block and soil-cement block, all with 12” wall thickness.5

Monolithic soil-cement came off very well, with no water through the wall, even without the recommended covering with white portland cement slurry. All of the stabilized soils satisfactorily resisted erosion. Block walls leaked at the mortar joints, giving some indication of the driving nature of the "rain." Bitubode or Caladothe is now laid up with asphalt-treated cement mortar.

Strength

Supporting strength of the soil walls ranged from a low of 5.6 T per ft for Bitubode to a high of 117 T per ft for monolithic soil-cement. For comparison, frame walls will take about 5 T per ft, brick walls will take about 30.

Loads pushing laterally against the walls indicated the weakest walls withstand a 145 mph wind and are the equal of brick or concrete block masonry. Similarly, under impact loading from swinging sand bag the soil walls fared better than brick or concrete block, but not so well as frame construction. In earthquake areas steel reinforcement is often used in earth block construction.

Racking loads applied longitudinally along the tops of the walls show the weakest earth walls to be about on a par with frame construction, with monolithic soil-cement having a strength much higher, about equalling brick construction.

It was concluded that earth walls are structurally adequate for one or two story buildings. Soil-cement strengths are especially high.

Temperature

A big advantage of earth walls is a reputed high insulation value, but as usual you can’t depend on a reputation to accurately describe anything. Measurements on 12-inch walls gave heat transfer coefficients of 0.646 for soil-cement and 0.54 for rammed earth, adobe, and Bitubode. The 0.54 is about equal to that of an 8-inch concrete block wall with cores not filled. Twelve-inch brick or cinder block walls get heat transfer down in the neighborhood of 0.35. The earth construction still has a higher heat capacity which even out temperature changes of day and night.

6B.T.U., per hour per square foot per degree Fahrenheit.
<table>
<thead>
<tr>
<th>Type of wall</th>
<th>Compressive strength ton/foot</th>
<th>Transverse strength lb/sq. ft</th>
<th>Racking strength ton/foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>14” soil-cement</td>
<td>53</td>
<td>104</td>
<td>3.1</td>
</tr>
<tr>
<td>14” rammed earth</td>
<td>7.0</td>
<td>59</td>
<td>0.9</td>
</tr>
<tr>
<td>12” soil-cem. block</td>
<td>58</td>
<td>112</td>
<td>2.8</td>
</tr>
<tr>
<td>12” adobe block</td>
<td>7.0</td>
<td>59</td>
<td>1.3</td>
</tr>
<tr>
<td>12” Bitudobe block</td>
<td>6.6</td>
<td>80</td>
<td>1.5</td>
</tr>
<tr>
<td>8” brick</td>
<td>30</td>
<td>50</td>
<td>3.2</td>
</tr>
<tr>
<td>8” concrete block</td>
<td>15</td>
<td>40</td>
<td>1.7</td>
</tr>
<tr>
<td>6” wood frame</td>
<td>6</td>
<td>270</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Although dirt may be cheap, labor costs money, and before soil becomes a house it must be pulverized, mixed, and either rammed in place or laid up as bricks. Stabilized adobe is popular in our Southwest not so much because of the saving in dollars, although the cost is comparable with other types of masonry construction, but because adobe is very nice to live in and pleasant to look at and requires little upkeep.

Monolithic rammed earth construction probably could be made quite cheaply because of the reduced handling, particularly if a machine could be devised to exploit its peculiar construction advantages. The mix could be transported to the wall by truck and bucket or belt, rammed in place, and the forms shifted immediately to continue construction along or up the wall. Window and door openings might be sawed out afterwards. With conventional concrete the walls must be completely formed and braced, and the forms left in place until the concrete hardens. Rammed earth has not had the benefit of widespread use, with accompanying trial and experiment.

In labor surplus areas such as India, Africa, or around steel mills, the earth house fever may be said to be spreading slowly. Often where labor is cheap the conventional fired brick are cheap, too, and are competitive. An educated estimate is that stabilized soil will cost 10 to 15 percent less than equivalent brickwork, depending on local conditions.

A final factor is psychological, with prejudice typically an inverse function of education, and strongly seasoned by personal history. Whereas California corporation presidents are enthusiastic over their adobe homes and don’t hesitate to recite the advantages, Gold Coast natives regard any soil housing as substandard and but another device to exploit and advertise inferior social standing. On the other hand the Gold Coaster’s ancestral mud hut was substandard. When the soil house is made better than any other he may accept it as just as good.

ACKNOWLEDGMENTS AND REFERENCES

Most of our photographs are through courtesy of American Bitumuls and Asphalt Co., 320 Market St., San Francisco. The Company will supply a list of adobe brick manufacturers on request but is not itself in the business of testing soils. Adobe do-it-yourselfers should see "Build Your Own Adobe" by Paul and Doris Aller, Stanford University Press, 1946. A more recent summary of adobe, post-adobe, and steel-frame-adobe, plus references, appears in California Division of Mines Mineral Information Service Vol. 12 No. 7, July, 1959, "Adobe Brick." Address Division of Mines, Ferry Building, San Francisco.


What did we tell you about wives helping?

RLH
PARTICLE SIZES AND GRADATION

Nothing is so fundamental to a soils man as particle size, unless it be God, women, or the day the paycheck arrives. Particle size grasps at the fundine until a man wants to preach, cry, kick, roll, and pray thanks for Mechanical Analysis, which is what one does to measure particle size. One good mechanical analysis will tell more than 17 expert opinions, primarily because any expert opinion in excess of one means argument.¹

It was with the advent of the slingshot that particle size took on something like scientific precision. The slingshot was much used for warfare, love, and the like. For example, a smooth stone carefully slung could effect a romance as well as four fingers of gin, hence the popular expression "to get stoned."²

Unfortunately women soon got romantic monetary notions about the kinds of stones thrown and ultimately attentions were misdirected to exemplify facts of carats, cut, and blue-white brilliance. These more ridiculous aspects of romantic stone-throwing have survived to today, sans slingshot. I'll thank you dear to return my ring.

Shifting, sifting soils

To return to the grosser aspects of our subject, the happiest way to measure soil particles quickly is to pass the soil through a sieve. Particles smaller than the holes pass through and particles larger than the holes do not, which is something we could use on our bank account but with no holes at all.

¹Third General Law of Humanitarianism, from the Guidebook for Martian Visitors (forthcoming): "In Earthman the ear is located unsuitably close to the mouth, so that each creature hears its own voice louder than any other. One voice thus usually circumscribes the extreme boundaries of agreement. One plus one equals war--without they whisper in each other's ears, and that only delays the conflict."

²Soused, looped, blasted, plowed, pickled, soaked, knee-walking, tight, embalmed, drunk.

Just as one measurement does not make a beauty contest, one sieve does not supply much information on a soil. Usually a stack, or nest, of sieves is used, successive sieves being finer downward through the stack. Soil is put in the top and the stack is given a prolonged shake on a mechanical shaker. Then the sieves are separated and the contents of each emptied and weighed.

Sieve analysis data can be plotted directly as a bar graph called a histogram. The narrower the bars the more accurate the graph becomes, but the more sieves required, and there is a practical limit. Therefore histograms are sometimes "smoothed" by eye to give a "frequency curve" (below), which is a more true representation of actual sizes present in a soil.

Cumulative curves

Our final bit of introductory programming concerns the cumulative curve, which has a rather corpulent sound suggestive of middle age. A cumulative curve is a kind of fingerprint of a soil or sediment, and an experienced soils man can look at such a curve and tell you what the soil is and what it is good for, and perhaps where it was and how it got there.
Because of the grace, clarity and usefulness of cumulative curves, many professions use them, not only for soils but for anything with varying particle size. To prevent one profession or group from gaining too much from work of another, each has its own way of plotting the data.

Geologists, for example, plot curves upside down and backwards, which may account for some of their peculiarities. Soil physicists plot theirs upside down. Other cumulative curves can be properly read only with aid of a mirror, and this within the civil engineering profession! There is a great need for translation, or as an alternative we will be glad to arbitrate and let others do it our way.

Please pass the logarithms

For reasons both aesthetic and practical, particle sizes are almost universally plotted on a geometric or logarithmic scale. Note in the graphs the sizes do not read right to left 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.063 mm, and 0.037. To keep things bllte and inconsistent, sizes in the U.S. Series above 6.35 mm (1/4 inch) are designated in inches. However, they may be selected to continue a ratio of the fourth root of two.

Earthworms, indeed! (Science, 130: 3383: 1162)

Third General Law again.

Tom McGee of the Iowa State U. Dept. of Ceramic Engineering revs up a long-arm centrifuge. Very small particles settle by gravity so slowly that centrifugal acceleration is substituted for g in the Stokes' equation. This particular apparatus is adapted to hydrometer analysis.

Dept. of clouded waters

Sieve analysis is fine as far as it goes, or to spin a pun, it is coarse as far as it goes, but for soils it does not go fine enough. The finest sieves commonly available are 325 mesh, which means 325 wires woven to the inch to give openings about 0.054 mm across. Such a sieve is fine enough to hold water unless agitated. Yet a goodly portion of soil, namely silt and clay, goes through.

To measure amounts and sizes of silt and clay one uses an ingenious means reminiscent of poorly stirred bean soup. Just as the beans tend to settle out and arrive in the bowl of the lucky last person, usually the cook, so do soil grains settle from muddy water, the largest grains first.

Stokes' Law

To further illustrate, a man leaping from an airplane will reach a terminal velocity of only a few hundred miles per hour due to drag from the air. Similarly particles settling in a fluid reach a velocity which is constant and calculable. For this we thank the brilliant English mathematician G. G. Stokes, who in 1851 said:

"F = GVTVV."

It can be very terminal.
The equation gives viscous drag on a sphere moving in a fluid. If the sphere is a soil grain settling from water, force down must equal force up, or pull of gravity must equal viscous drag.

\[ F = \frac{4}{3} \pi r^3 g (G - G_1) = 6\eta rv. \]

Solving for \( v \), we get

\[ v = \frac{2}{9} \frac{(G - G_1)}{\eta} r^2. \]

where: \( v = \text{cm/sec} \)
\( G = \text{specific gravity of the particle} \)
\( G_1 = \text{specific gravity of the liquid} \)
\( r = \text{radius of the particle, cm} \)
\( n = \text{viscosity of the liquid, poise} \)
\( g = \text{acceleration due to gravity, cm/sec}^2 \)

Translation

Perhaps you are one of the poetic beat for whom mathematics holds no charm. Then be assured that eventually you, too, will know what we're talking about—just as soon as we find out.

The gist of Stokes' Law is that particles half the size of a reference particle settle one-fourth as fast. Furthermore you don't even need the reference grain because settlement distances can be calculated with handbook numbers and by looking at the clock on the wall. The Law holds well for spherical particles finer than 0.1 mm. Admittedly very few soil grains are spherical, so we rationalize by speaking of "sedimentation radius" or some such.

Application

A column of water thus performs like a stack of sieves, except that soil is not put in the top but is stirred throughout. Then to measure, say, the percent of the soil finer than 0.005 mm (5 microns) one measures the amount of soil remaining in suspension at the calculated time and depth of settlement of 5 micron material. That is, at this time and depth only particles 5 microns and smaller can remain higher in the suspension. Ideally one should remove a layer, as indicated in the before-and-after sketches on the preceding page.

Gimmicks

The most direct method for measuring the amount of soil remaining in suspension at a specific depth and time is to extract some of the suspension with a pipette, dry the extract, and weigh it.

Let us assume the starting concentration of the suspension was 10 gm of soil per liter, and the pipette sample contains only 3 gm of soil per liter. Then 30% of the sample is finer than the size being measured. Pipette analysis is one of the most accurate methods and holds mighty sway in the U.S.D.A.

A similar method with a tricky idea for extraction is the Atterberg cylinder, suggested in 1914 and still widely used in Europe. Samples of suspensions are periodically drawn out the side. Calculations are the same.

A third method which requires more calculation but less work is to measure suspension concentrations with a hydrometer such as used to test anti-freeze, urine, or wine. The hydrometer can be read directly in grams of soil per liter of suspension, which saves the trouble of sampling, drying and weighing. On the other hand the depth the hydrometer sinks depends on the amount of soil remaining in suspension, so the exact size being measured must be calculated for each reading. Calculation is speeded with tables and graphs. The hydrometer method is standard in engineering laboratories.

Any sedimentation analysis requires careful control of the temperature to prevent thermal overturning of the suspension, and give some control on the viscosity, \( n \).
DISPERSION

Crowds, particularly resentful crowds, can be very un-nice people, and dispersion of the crowd becomes necessary or grandma may throw a rock through somebody's window or find herself super-intending a lynching.

Soil particles must also be dispersed, for they are hopelessly gregarious and like to gang up. Dispersion is both mechanical and chemical, like night sticks and tear gas.

Agitation

Machines for stirring include first the end-over-end shaker, in which bottles containing soil and water are tumbled end-over-end for a number of hours. This is one of the oldest and gentlest methods, still widely used in agronomy, geology, ceramic engineering, and cocktail parties. It is also the slowest.

George Buoyoucous, the American soil scientist who suggested the hydrometer to measure particle size, also suggested use of a high speed malted milk mixer to reduce stirring time to a few minutes. Soil engineers have adopted the high speed stirrer, primarily because they are fond of malted milks, but also because of the saving in time. Recurrent objections are that grain separation is sometimes incomplete, and prolonged stirring to attain proper separation causes breaking and wearing of primary soil grains. Tests at Iowa State showed these difficulties can be avoided with use of a rubber stirring paddle instead of the conventional metal tip.

From agitation we go to vibration, and in Europe 50 cycle magnetic vibratory stirrers are used. The comparable machine gun for this technique is the ultrasonic vibrator, which separates soil grains with inaudible high-pitched sound waves that make a dog howl. This apparatus is electronic, expensive, and not standardized, but gives superior cleaning of grains for such purposes as microscopic analysis.

Wind

A third class of stirring devices uses compressed air, and here we most graciously acknowledge invention of a new, inexpensive air-jet device unconditionally guaranteed far superior to anything else you have ever seen anytime anywhere, with less tars and nicotine and absolutely no ties with cancer, senility or athlete's foot.

The Soil Dispersion Tube blows and swirls air like underwater gaseous trepidations in a bathtub, lifting and erupting the soil-water suspension with great fervor but keeping it in the jar. The principal advantage is that stirring is done directly in the sedimentation jar, saving time and transfer. Other advantages are good dispersion without degradation, and reasonably low cost.

Chemicals

For good dispersion or sweet laundry one had best add a little water softener, because otherwise excess calcium in the soil may cause sudden settlement. In soil dispersions, clay

---

The hard sell.

---

Cumulative curves for one soil, a California clay, dispersed four different ways. The air-jet dispersed the clay best (top curve). Similar tests on washed sands proved that the air-jet causes least degradation or wearing down of primary grains.
particles carry an electrical charge causing them to join together in feathery wisps or floc-
culi resembling bits of wool and reminding one
to dust under the bed. The flocculated clay
settles out and leaves the suspension clear
and potable, and worthless for measurement of
particle size.

To prevent flocculation one must change the
effective electrical charge, or zeta potential,
of the clay. Zeta potential is measured by
noting the migration rate of clay particles in
an electrical field; it is ordinarily negative.
If it is negative enough, clay particles repel
one another and remain dispersed. If it is
not negative enough, odds are that a few loose-
living individuals will become positive, and
positives and negatives will attract and settle
don

When a clay particle
moves in suspension it
carries with it a diffuse
layer of hydrated ions
which can do much to the
zeta potential. Small,
nicely charged cations
such as calcium\textsuperscript{2+} love
to crowd in, make things
less negative and cause
flocculation. In contrast, sodium ions are mono-
valent and carry a big, bulky water hull; they
crowd in poorly and leave the clay pessimisti-
cally negative and repulsive to strangers.

Dispersing agents

Sodium salts are good clay dispersing agents,
but as with children, steaks, and candy bars,
some are better than others. This is because
clay, with characteristic weak character, has
a preference for calcium or other polyvalent
ions and tends to ignore sodium. Therefore
we play rich father and force the desired alli-
ance by tempting away calcium and tying it up
in an insoluble reaction product.

Presently the dispersing agent gaining wide
adoption is sodium metaphosphate, for which this
laboratory must modestly accept some measure of
credit. Previously sodium hydroxide, sodium
oxide, and sodium silicate were most popular.
The dispersion results from a cation exchange,
which reaction may be written

\[
\text{Ca[Clay]} + 2\text{NaPO}_4 \rightarrow \text{Na}_2[\text{Clay}] + \text{Ca(PO}_4)_2
\]

Flocculated \hspace{1cm} Dispersed \hspace{1cm} Precipitate.

MAKING THE GRADES

Gravel, sand, silt, and clay are size grades
in soils, and a single soil will contain varying percentages of each, the only requirement
being that they add up to 100. Sometimes coarser
grades—pebbles, cobbles, and boulders are de-
dined, but for now let's delve into the first
four.

Gravel (at left, \(\times 1/10\)) is usually
well rounded due to vigorous banging in
transport. Sand (not shown) is less
well rounded and is mainly discrete min-
eral grains such as quartz and feldspar.
Silt (right, \(\times 100\)) is microscopic and
more angular. For
clay, turn the page.

One of the early grading schemes still widely
used was devised by Udden at Augustana College
in 1898, and later modified by Wentworth. Udden
suggested a geometric interval based on a root
of 2, which later became the basis for the Tyler
Slieve Series. The gravel-sand break is at 2 mm,
the sand-silt at 1/16 mm, and silt-clay at 1/256
mm. These breaks are currently favored by geol-
ogists.

Pedological ideas were forthrightly expressed
by Atterberg in 1905, who also used a logarithmic
interval but preferred to avoid fractions. Atter-
berg drew the boundaries at 2 mm, 0.02 mm, and
0.002 mm. Atterberg was first to suggest that
size grades represent natural boundaries; sand
differs from gravel by holding some capillary
water, silt is microscopic, and suspended clay
vibrates due to molecular bombardment.
Clay contains a distinctive group of minerals which resemble mica, but hold water like a sponge and carry a negative electrical charge. Individual grains are so small their shapes can be seen only by electron microscopy. These grains are of the mineral kaolinite (china clay), × 46,750.

The U.S. Bureau of Soils modified the Atterberg system to make use of U.S. Standard Sieves, and the sand-silt boundary was moved to 0.05 mm to coincide with the No. 270 sieve. The silt-clay boundary was moved to 0.005 mm to better fit an eyepiece calibration in one of their microscopes.

Finally soil engineers got into the swim by adopting the U.S. Bureau of Soils system, but changing the sand-silt boundary to the No. 200 sieve (0.074 mm) because the No. 270 was too delicate for engineers to handle safely.

Next the U.S. Department of Agriculture moved back to the old Atterberg definition of clay, 2 microns rather than 5 microns, because 2 more accurately described the break in characteristic mineralogy.

Therefore currently there is some small disagreement on proper definitions of sand, silt, and clay. In the U.S., soil engineers break their bread at 200, 64, and 5 microns; soil scientists at 200, 50, and 2 microns; and geologists at 200, 62.5, and 3.91. To summarize, see footnote 1.

TEXTURE

Now that the soil has been adequately taken apart and graded, it can be mentally re-assembled and denoted by texture. Texture originally meant feel, but now it means particle size because feel is unscientific. Kiss me baby; I'm a gravel.

ACKNOWLEDGMENTS AND REFERENCES

Studies of dispersing agents were started under Project HR-1 of the Iowa Highway Research Board and continued to completion under Project 300 of the Iowa Engineering Experiment Station, along with development of the air-jet apparatus. Results of these studies are reported in a series of reprints in our Engineering Report 21 by D. T. Davidson, T. Y. Chu, et al., 1954-1955.

The air-jet dispersion apparatus is manufactured and sold by Testlab Corporation, 3398 North Milwaukee Ave., Chicago 41, under a patent owned and licensed by the Iowa State University Research Foundation.

The electron photomicrograph, above, is by the Zentrallabor f. angew. Übermikroskopie, University of Bonn. Peerless sieving technique, p. 1, is dramatized by Arthur Dahl, Research Associate and graduate student in soil engineering and geology.


Ye Olde Editor and the rest of the happy flock extend their best wishes for a Merry Christmas and a Happy and Spirited New Year, as well as Happy Birthday, Joyous Thanksgiving, Amicable Valentine, and Pleasant and Virtuous Lent.

RLH
ELECTRICAL DRAINAGE OF SOILS

A Shocking Exposé: Watt's Watt Witt Watts

Un-man the pumps, lads, and dry away those tears, fears, ears and backsides. Step into the fo'c'sle and we'll narrate the greatest discovery since Grandpa's Electric Belt took the gastritis out of his dyspepsia and simultaneously sweetened his corns.

But we suffer the chore, for electrical gadgetry is so commonplace. So many things are electric, from clocks to can openers, frying pans to chairs. Suddenly the world has become a Leyden jar, lit up and running, ever in danger that a little mismanagement may set off a precipitous discharge. But we mustn't lose heart, mates; a Leyden jar does not hold its charge forever; demilitarization is largely a matter of forgetfulness.

The natural histories of water and electricity are intertwined like two dogs sniffing navels. For example, there was the incident of Dr. Franklin lifting his kite in a rainstorm and almost catching his death of sparks. An indirect but more useful connection is through the Cardinal Rule of Hydrology*; water over the dam is not merely water over the dam; it generates hydroelectric power.

Electrical stabilization of a silt soil to allow excavation for bridge piers. Oval area is the complete dation for one pier. Above this the bank is laced with rows of anodes (+) and cathode weld points (-), all delivering a large charge. Electricity forces water out of too-wet soil. For a "before" picture illustrating need, turn the page. Completed bridge is shown below.

Electro-osmosis

The reverse of water over the dam is electricity which turns the pump that pumps the water, much to the distress of windmill salesmen. But our subject is nothing so prosaic, dull or efficient as pumps. Instead we will use only electrons, wires, and pipes—no pumps, limbs, or hidden devices; no sorcery, trickery, or calling on the occult; and only incidental use of prayer.

Purely electrical movement of water is not a mere laboratory curiosity; now it is a field curiosity as well. Electrical drainage will de-water and stabilize problem soils that refuse to be de-watered by ordinary means. That is, ordinary pumps can push water endless distances once they've got a hold of it, but a pump drawing from a well point can only muster so much suck. Fine silty and clayey soils are so tenacious the water won't run out by itself; it must be driven out or chased out with electrons. The action is termed electro-osmosis. Osmosis means diffusion of a fluid through a membrane; here soil is the membrane, and electricity is the driving force.

* Water runneth downhill.
HYSTERICAL BACKGROUND

a. Discovery

In 1807 Ferdinand Reuss was putting around in his garden in Moscow when it occurred to him to try a little electrolytic decomposition of water into the component \(H\) and \(O\). This was all the rage just then, having been discovered only a few years earlier. To be different, Reuss put two rods into the moist earth of his garden rather than into the usual glass of water.

It's beginning to look as if electro-osmosis might have been discovered by accident, but all Reuss saw were bubbles of gas—no water movement to or from the electrodes. Fortunately he became intrigued as to how the electricity could move through the ground so readily. He went to the lab.

Reuss reasoned that something in the water must have carried the "galvanic fluid," as they called electricity in those days. Therefore the water must move? To find out, Reuss put some powdered quartz in the bottom of a U-tube, filled it with water, and stuck an electrode in each side. The current was turned on, and the water level rose on the negative side. When the battery was disconnected, water levels again became level. Reuss could now retire to a life of mountain climbing and political comment. His name was made.

b. Elaboration

After a land is discovered, exploration continues until the area is fully mapped and in hand, i.e., taken from the Indians. In 1852 a German named Gustav Wiedemann slew a few when he discovered that the volume of water moved is proportional to electric current (amperes), and that water pressure built up by electro-osmosis is proportional to applied voltage. Followers were so elated they called these Wiedemann's first and second laws.

Wiedemann also found that certain salts or acids in the water could stop the flow, but this is sort of a negative result and not good material for a law.

Ingenious experiments were conducted a few years later by Georg Quincke. Although Georg was too late to discover any more empirical laws, he was very thoughtful about explaining things.

Quincke demonstrated that most materials have a negative surface charge which varies depending on the material, and nearby water is in effect charged positively. When an external voltage is applied, water moves to the negative pole. From this, Quincke reasoned that the converse also should be true; if water is mechanically pushed through capillaries it should make a voltage. This he called streaming potential.

c. Formulation

In 1879 von Helmholtz worked from Quincke's model and published a famous bit of arithmetic which describes electro-osmotic flow through a rigid, straight capillary tube. This is known as the Helmholtz equation or sometimes the Helmholtz-Smoluchowski equation after Smoluchowski re-derived it showing that the capillaries can be crooked:

\[
q_e = \frac{4\pi \varepsilon \sigma}{\eta L}
\]  

(1)
or, milliliters of water, equals voltage $E$, times dielectric constant $\varepsilon$, times capillary radius squared, times zeta potential $\zeta$, all divided by four times viscosity $\eta$, times length of the capillary $L$ between electrodes. Ah, life has that old zip again!

The Double Layer

\[ \eta \text{ Quincke-Helmholtz} \quad \text{la Gouy-Freundlich} \]

Helmholtz assumed an ideal (+) and (-) double layer arrangement at the surfaces of capillaries, the +’s being like platoons of mercenaries ready to march anywhere on command. In 1910 Gouy suggested that they might be more like grasshoppers. Meanwhile Freundlich and Smoluchowski pointed out that zeta potential, or marching strength, is not all it should be; that perhaps the army has some lazy ones or deserters. Now the double layer is believed to be diffuse, with some (+) charges immobilized by attraction to the opposite sex, that old feminine negative.

Carrier pigeons

One final bit of theory—what are those positive charges, i.e., what moves? In a word what moves is ions. "Ion," from Greek, appropriately means "going." Ions are charged atoms such as hydrogen, sodium, calcium, etc. Positive ions are called cations (cat-ions) because they go to the cathode, which is negative. Conversely, anions go to the anode.

When cations go, they apparently drag along clusters of water molecules, explainable because water molecules have (+) and (-) ends on them and are attracted like chickens to corn.

\[ \text{Water molecule} \quad \text{Cation + water molecules} \]

Since capillary walls are coated with hydrated ions on the move, free water in the capillary is also dragged along, greatly increasing the effectiveness of electro-osmosis.

BACK DOWN TO EARTH

Electro-osmosis finally made the full circle by 1930, when Leo Casagrande of Berlin (now of Cambridge, Massachusetts) studied electrical treatment of soils. He found that treatment, particularly utilizing aluminum anodes, caused permanent hardening and drying of soft, mucky soils.

Beginning in 1939, Casagrande engineered a series of practical applications of electro-osmosis to firm up the heart and foundations of mighty Germany, or at least take some of the water out. The first application was at Salzgitter in northern Germany, at a railway cut which slid in as fast as the earth was removed.

Twenty well points spaced at 30 foot intervals, each sunk $22\frac{1}{2}$ feet into the embankment, drew practically no water by ordinary pumping. The well points were then made negative, half-inch pipes being driven between the well points and made positive to complete the circuit. A 180 volt potential was applied. Immediately the wells began flowing at the rate of 90 cubic feet per hour, or about $22\frac{1}{2}$ gallons per well per hour. By the next day the area was stabilized, and excavation was continued with no further difficulty. The total energy consumption was one kilowatt-hour per cubic yard of earth removed.

Leo Casagrande

Other applications in the 1940’s were in excavations for bridges, tunnels, and trenches. These trials not only showed that electro-osmotic drainage of soils will work; in some situations it is highly practicable and the thing to do.
U-boat Pen

A dramatic application laden with nostalgia is stabilization of a U-boat pen at Drontjem, Norway. The walls of a proposed 46-foot excavation were protected by two rows of steel sheet piling, but as excavation proceeded, the sheet pile moved and the bottom of the excavation heaved up. Electrodes were driven at 15 foot spacing, alternately (+) and (−), to a depth of 60 feet. Forty volts was found to be sufficient push for the electricity, and within two days excavation was resumed with no further difficulty. Total power consumption, 0.4 kWh per cubic yard of earth removed.

Electrodes or Pumps?

Electro-osmosis finds its particular vocational niche with fine-grained soils where ordinary wells or vacuum wells won't work or are too slow; see below. Small capillaries contain more charges than a TV shop in a poor neighborhood, and as any mother knows, small charges can be hurried along electrically when gravity alone won't do the job. Often the driving forces are combined; electricity attracts and then pumping takes over.

Proof and permeability

Returning to the Helmholtz equation for water flow in a single capillary equation (p. 2), by assuming a few things constant and substituting capillary cross-sectional area for the radius squared \( a = \pi r^2 \), we get

\[
q_e = c_1 i_e a,
\]

where \( i_e \) is the voltage gradient, E/L, and \( c_1 = \Delta E/4\pi n \). For a bundle of capillaries such as in soil, the equation may be re-written

\[
Q_e = k_e i_e A,
\]

where \( A \) is the total pore area transverse to the direction of flow.

Here \( k_e \) is defined as the electro-osmotic coefficient of permeability, cm/second per volt/cm. If voltage gradient, \( i_e \), is volts per cm and \( A \) is in cm², \( Q_e \) gives the water discharge in cm³ per second.

The Good Lord smiles at him who fools with electricity; when zeta potential goes up, capillary size usually goes down, and electro-osmotic permeability does not vary much from soil to soil. A good average value is \( 0.5 \times 10^{-4} \) cm/sec for 1 volt/cm. Extremes are 0.2 to 0.7.

In practice, permeability and flow rate often change as drainage continues, partly because of the change in availability of water molecules. Casagrande points out that flow practically ceases after a soil reaches the plastic limit. Actually, forever and amen, that's dry enough.

Another very important factor affecting flow rate is identity of the carrier ions. Some ions transport water better than others, just as some dogs have more fleas. Work by Dr.

Excavation at the Joppe, Illinois, power plant. The cut was protected by sheet pile but as digging continued the clay bank on the right started to move in, letting the building down (upper right) and painfully shearing off its piles. Electrical drainage increased shearing strength five times and effected a cure. Anodes and cathodes may be seen poking up under the tarps.
Ralph Rollins in this laboratory showed aluminum to be very flea bitten, and transporting ability of this and other ions in a kaolin clay was in the order Al > Na > Ca > Fe > H. Electro-osmotic flow often slows down after metallic ions complete their journey and are depleted, leaving only water-derived hydrogen as the substitute stevedore. In calcareous soils, calcium moving to the cathode is deposited as hydrated lime, Ca(OH)$_2$, retarding flow.

Finally there is the effect of consolidation, mentioned later. When a clay consolidates the pores become smaller, and electro-osmotic permeability reasonably should fall off. Theoretically $k_e$ is related to what engineers call the void ratio, being proportional to $e/(1 + e)$.

The way of Poiseuille (Pwa-zaiy)

An interesting contrast to electro-osmosis is Poiseuille's equation for hydraulic flow in a capillary:

$$Q_h = k_h \cdot h \cdot A.$$  \hfill (4)

Note the analogy with equation (3). However, whereas $k_e$ varies perhaps two or threefold, the hydraulic coefficient of permeability, $k_h$, varies in the extreme. Usually it is in the neighborhood of $10^{-2}$ to $10^{-11}$ cm per second, depending on whether the soil is a sand, silt, or clay, and that is a rather large neighborhood. In other words, ordinary wells won't drain an impermeable clay, which is what we've said before.

Example: If $k_h$ of a clay is $10^{-7}$ cm/sec, what hydraulic gradient would effect the same drainage as a potential gradient of 0.10 volt/cm?

\begin{align*}
Q_e & = 0.5(10)^{-4} \frac{\text{cm}}{\text{sec}} \cdot \frac{\text{volt}}{\text{cm}} \times 0.10 \text{ volt/cm} \times A \text{ cm}^2 \\
& = 0.5(10)^{-5} A \text{ cm}^2/\text{sec}.
\end{align*}

If $Q_h = Q_e$, $0.5(10)^{-5} A = 10^{-7} h A$

$$i_h = 50 \text{ cm/cm or 50 ft/ft}.$$ 

Since the maximum suction is limited by atmospheric pressure to about 27 feet of water, wells for equivalent drainage would have to be spaced about half a foot apart. We'll use electricity.

PRACTICAL PRACTICE

This may seem a horrendous bit of mathematics except to engineers, who read an equation like $Ma$ reads the recipes on the backs of frozen pies. But we fear the public eyeballs may be a bit glassy--perhaps it will relieve the vitriication to spin a joke or two:

When rockets fall
And singe us all
And the world is filled with groaning,
Please don't revile;
Project thy smile,
"Good moaning, friends; good moaning."

Power plant excavation at Bay City, Michigan. The upper 20 feet of strata are sandy, and were de-watered with conventional and vacuum well points spaced 20 feet apart around the perimeter. Then deeper excavation into silt caused shifting of the sheet pile in the foreground.

The well points were converted to cathodes by driving pipes between them and hooking up the generators after 3 or 4 days de-watering was sufficient that excavation could be continued. Note the river perched almost at ground level in the background.
Generators

Electro-osmosis requires current to be strictly one way, or the water won't know which way to turn. D.C. generators putting out from 30 to 180 volts have been used—in fact, ordinary welding units can turn the trick. Voltage divided by distance between electrodes is $V_e$ of equation (3) and thus is proportional to rate of water flow. However, $V_e$ should not exceed about a volt per inch or appreciable wattage will be lost for useless heat. Also, higher voltage means more current.

Current

So far the equations have kept judiciously mum on electrical current requirements. For this we pull in the first three years of undergraduate electrical engineering: $I = E/R$ (Ohm's Law). Or to put it another way, $I = E_0$, where $I$ is current in amperes, $E$ is in volts, and $E_0$ is mhos*. Conductivity of soils in mho/cm may be measured as the number of amps through a square centimeter when the voltage gradient, $E_0$, is 1 volt/cm. Conductivities in saturated soils vary from about $75 \times 10^{-4}$ for sodium montmorillonite to 10 to $20 \times 10^{-4}$ for friable silt.

Amperage requirements are loosely predictable from conductivity, voltage, and electrode geometry. Solving equations for the latter may be a little weird, so a model may be used. Pins stuck through cardboard represent the electrodes; a tray of salt water represents the soil.

Aluminum anodes

As previously indicated, some of the earliest work on electro-osmosis in soils utilized aluminum anodes, in recognition that carrier ions move along and can be replaced. Therefore one might as well add something dynamic like aluminum.

Aluminum ions do well at holding clay together, and aluminum hydroxide cements the soil. Experiments by Prof. M. G. Spangler and others showed the method could be used to greatly increase bearing values of aluminum pile. However, it has not been extensively employed in practice. Too sedentary; much easier for an engineer to keep driving until he can "feel" the pile take hold.

Consolidations and sheer strength

There is still some hocus-pocus concerning strength gains of soils during electro-osmosis. Unusually high and rapid consolidations and strength gains are observed, particularly if the soil is already under load.

One explanation is that pore water is under tension when the electrons are chasing, and the tension helps collapse the walls of the capillary. Under ordinary conditions, electro-osmosis is equivalent to increasing the consolidating load 0.01 to 1.0 tons per square foot.

ACKNOWLEDGMENTS AND REFERENCES


Research on electro-osmosis at Iowa State University is sponsored by the Iowa Highway Research Board with funds from the Iowa State Highway Commission.

On-the-job photographs in this issue are courtesy of the Wellpoint Dewatering Corporation, 681 East 141 Street, New York 54, N. Y.

WE ARE SAD

TO REPO: A major error in the last issue. The soil textural triangles, p. 6, were reversed: "New" is really old, and "Old" is new. There is no excuse for this, and you will be pleased to know the Editor promptly shot himself close between the toes. Please make the change if you save "Screenings."

RLH
A CONDENSED HISTORY OF ROADFARE

From Pristine Bog to 104 per Gallon

Highway engineering is a primordial art, probably starting with the ant. Larger animals literally let the roads grow under their feet, their relentless pitter-patter compacting the soil to form trails.

Pedestrian-pounded roadways can be rather indelible, as anybody knows who tries to grow grass in a neighborhood full of paper boys. Stone Age "Ridgeways" are still traceable in England. Other prehistoric trails are better kept up, to the extent that they now wear highway markers. Many roads and railroads in the central U.S. follow stagecoach routes, which in turn followed buffalo trails.

The first roads of man were probably game trails until man objected to the way other predators played the game. He then took off for the highlands, and the Ridgeways were truly ridge ways. Trails in Africa often run high and avoid lurking appetites in the valleys.

Next, man gradually turned from hunting to agriculture as women got the upper hand and wanted somebody to stay home and wash dishes. Because valleys were better for growing and closer to the water, homes and roads relocated downward. "Hillside Ways" therefore superseded the Ridgeways in the late Stone and early Bronze Ages. Lower routes could not avoid wetter and softer soils, and already people were looking around for somebody to take charge and call himself a highway engineer.

All aboard

Literally the first major step toward road improvement was to find a tree in the right place, push it down, and walk on it.

According to the widely quoted anthropologist, Et Al, the log road was invented because some aboriginal chief's sister-in-law objected when her feet got muddy. The men were not happy to halt their native interpretive dancing and lay the logs, and they stood aside and braced themselves for an upbraiding laugh should sister-in-law happen to slip and fall in.

The ensuing catastrophe caused future log roads to be built with logs laid in pairs for better stability. Sometimes they were laid on boughs to retard sinking.

Some time later, Stone Age man realized he had clear title on the government timber concession, and there was no stopping him. Log pairs or trios were spread apart to act as longitudinal girders which supported a continuous blanket of other logs laid cross-wise and even pegged in place. Such prehistoric roads have been dug up in Holland.

The log method is still the best for roads crossing a marsh or swamp. American "corduroy" is a simplification from the Stone Age acme, in that longitudinal members are not used.

*Ants wisely pooled their not too copious brains to form committees. Unfortunately, it is practically impossible to dissolve a committee. That's why there are so many ants, always hurrying.

*They also stepped on the committees.

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Merrily we roll the wheel

Throughout history, highway engineers have been forced to roll with the punch of each new innovation in travel. For example, about 3500 B.C. the Babylonian Research Council got hot rockets to invent the wheel before somebody else got it, without so much as a wisp of worry about what this would do to local dirt roads. As a result roads were rutted, and hard pavement was needed.

Unfortunately paved highways are not built with need but with cold cash, which usually means a strong central government to collect the loot through war or taxes. Egypt was strong enough and had the cash and slaves, but the Pharaohs' religious integrity dictated that all major engineering effort be expended on monuments to themselves. Roads were used mainly for sliding stone blocks into conspicuous piles hither and yon.

Meanwhile Babylonians were building sun-dried mud brick streets laid up with soil-asphalt or gypsum mortar, but the bricks were soft and intended only for foot traffic. A few were stone-paved, with ruts intentionally made for wheels. Invasion by Persians about 540 B.C. did something to initiative, and nothing new developed. The Persians, a rowdy lot always in a hurry, took a dim view of road improvement. The Persian view was that you could pull through anywhere if you didn't spare the horses.

India and China

Away from the western main stream, India and China made some notable roadbuilding achievements which were lost or superseded before they could become known and woven into the general evolutionary fabric. An Indian road dated at 800 B.C. appears to be soil burnt in situ, a technique still untried in modern times. China's trade routes to the west were paved with stone slabs, and traversed elegant cantilever, arch, and suspension bridges. However, by the time of communication with Rome, Rome had superior pavement designs of its own.

THE MASSIVE SCHOOL (2000 B.C. - 1775 A.D.)

The thick, massive school of road engineering, best exemplified by the superb highway system of the Romans, lasted about as long and served as well as any incorrect idea should. It probably had its roots in the Minoan stone-paved streets of ancient Crete. Greeks picked up some pointers from Minoans but were all wrapped up in local politics and philosophy, and lacked a strong central authority to build many roads.

Rome was the first mighty empire and built the first mighty roads, unexcelled until the present century. Colonization of Italy began about 500 B.C., and the first of 23 great highways radiating from Rome was started in 312 B.C. This, the Appian Way, took almost 70 years to complete, which is understandable when you see how they built it. By the second century A.D. the highway system in Italy and European and African provinces totaled 50,000 miles, or 20 percent more than in the new Interstate system under destruction in the U.S.

Pompeii street paved with slabs of lava. Street was preserved under hot ashes from Vesuvius in A.D. 79; note how tops of buildings are weathered and long gone.

Main Roman highways were four lanes, 3½ to 4½ feet thick, and are best described as "walls laid flat." First the soil subgrade was prepared by compaction by nine or more slaves jumping up and down. Some road builders then recommended a thin layer of crushed beetles, although this was not universal practice and the exact function is somewhat in doubt. Probably the beetles were a nuisance anyway. Stone slabs were laid either on the soil or on a blanket of sand and grouted with lime mortar.

On top of the stone slabs was a layer of cobbles or broken stone grouted with lime mortar, then a layer of gravel concrete. The topmost layer could be stone slabs for durability under iron-tired traffic, or concrete or gravel grouted with mortar. Sometimes loose sand or gravel was spread on top to reduce wear.

They also used rollers and wooden rams, but these are hardly as picturesque.
The Roman roads were about three or four times as thick as modern highways and would have been vastly more expensive except for cheap labor of the foreign draymen. The load limit for wagons was set at about half the weight of a modern automobile, and an average road lasted maybe 30 to 40 years, high class ones 80 to 100.

Roman concrete dates from about 150 B.C., when some pioneer chemist discovered that a volcanic ash from near Pozzuoli could replace part of the lime in mortar and give more strength. Later other ash deposits were also exploited and given the name Pizzouline. A common mortar was one part lime, three parts ash, and about three parts sand, the proportions varying depending on the quality of the sand.

When Romans invaded the soggy North they had to either adopt local practice and use log roads or watch their massive ledges of stone and concrete sink slowly out of sight. Some roads were set on vertical logs, or pile, another very cogent idea. Roman log roads gave fanciful attention to detail: longitudinal girders being of split fir or oak, and cross members being hand-hewn overlapping planks.

The Americas

Incan roads in Equador, Peru, and Chile ran some 10,000 miles across the most difficult mountainous terrain, an engineering feat rivaling the road system of the Roman Empire. The Incas are unexcelled in history as stone cutters, and put together flagstone roads with tunnels, rock fills, and suspension bridges. Research lagged in another field, however, and the Incas did not have the wheel. This may be one reason their roads lasted so long.

In 1532 Pizarro and his bandits swung a bold sword in Peru but took little notice of roads or architecture, having sustained a peculiar blindness caused by close proximity to somebody else's gold. In Mexico, Aztec and Mayan civilizations also had built stone roads of considerable merit, but in the glitter of gold these too were forgotten.

The Middle Ages

Curiously enough, at the time the Spanish came to America, roads in Europe had reached an all-time miserable low. When the Roman Empire deteriorated so did the roads, and many of the stones were dug up to be put in houses, castles, or catapults. Twelfth century kings took a dim view of improving roads because nobody traveled much except to invade and plunder, and why make it easy? Overland travel was restricted to walking or horseback, and the secrets of Roman cement had been thoroughly forgotten.

The Crusades gave a new outlet for boyish enthusiasms, and with the delinquents off for Palestine interest was renewed in roadbuilding. Streets were paved with cobblestones, until in 1550-1750 statute labor laws required every man to put in some time on the road gang. By 1600 wheels came back but had a rough time, roads at best being an inferior copy of those of the Romans.
Blind Jack's turnpikes

By the late 1700's coach travel was going by leaps and bounds, which was a little rough on the passengers and ushered in the era of the turnpikes. In 1765 John Metcalf, popularly known as Blind Jack, left his dry goods business to become England's first turnpike road contractor.

Metcalf was blind but shrewd and no idealist, and he pecked and probed along a proposed route like a fawn exploring the universe. He instinctively tried improving drainage, raising the road grade by digging side ditches and heaping the soil up between, then shaping the road and giving it crown so the rain would run off. Then he spread the gravel.

Metcalf's gravel-surfaced turnpikes formed a startling contrast in a world used to mudholes and ruts. His design is still copied for much modern secondary road construction in the U.S. and elsewhere. But Blind Jack was a man of action, and had no patience for describing his methods to others who might compete. Therefore other designs took over.

Tresaguet-Telford departures

At the same time as the intuitive designs of Metcalf, a French engineer named Pierre Tresaguet was wondering if the Romans were entirely right.

Tresaguet shaped his roads with a 20° crown to improve drainage, so much so that one wonders that the carriages didn't slide off. Then Tresaguet noticed that stone slabs laid flat after the manner of the Romans might readily tilt or shift under pushing from wheeled traffic. He therefore tried laying stones on edge with the thick edge down, crevices between the stones being filled with crushed stone hammered tight.

Tresaguet's brilliance reduced Roman thickness by one-half and made a better road. In 1775 Louis XVI named him Inspector General of Roads and Bridges, which was no small plum to a struggling engineer. This allowed him to see to it that his roads were maintained and not thoughtlessly allowed to go to pot.

In the early 1800's Britain's first professional road engineer independently came upon the same design principles. Thomas Telford was authorized by an Act of Parliament to build roads to encourage commerce with hungry Scotland. Telford's Scottish integrity allowed him to view with alarm the incredible waste of the Roman design, and he ended up using a 7 inch layer of stone slabs laid on edge and chinked, covered by 7 inches of crushed stone and an inch of gravel.

Telford's most famous effort is the 194-mile Holyhead road to North Ireland. Started in 1815 and completed in 1830, it was at that time acknowledged to be the finest road in the world. The telford type of construction is still widely used in areas of plentiful rock and cheap labor, but already by 1830 Telford's design was up for grabs.
The Renegade

The ultimate heresy to Roman road doctrine came from another Scot, John Loudon Macadam. Even his name reflects a certain familial impudence; actually descended from the outlawed clan MacGregor, the family name was changed to Macadam because nobody could deny they were descendants of Adam.

The fine Telford roads in Scotland and Ireland gave a dismaying contrast to the sorrowfully inadequate English roads of the early 1800's. The House of Commons reacted to the problem with characteristic political insight by sharply limiting traffic. Finally public clamor was so terrifying that elected officials invited suggestions.

One respondent was Macadam, whose letter caused a sensation and overnight made him the popular expert on roads.

Macadam scoffed at limiting traffic, insisting that roads be designed to fit the traffic, not the traffic to fit the roads. (He could still raise some heat with that one.) He discarded the idea of large foundation stones, insisting that large stones merely formed an anvil upon which smaller surface stones were crushed and destroyed. Macadam's stones all passed a 1-inch ring, selected on the basis of contact area of the iron tire. Furthermore large stones settling unevenly would pocket water within the road.

Macadam's design was deceptively simple; roads were usually 6 to 12 inches of crushed limestone placed on the drained, shaped, and compacted soil subgrade. Pounding from traffic created a dust which infiltrated and with the aid of water cemented the road tight and solid. Macadam held that the stone surface had only two major functions, neither of which was strength; Stone inhibited wear, and after cementation it served as a "roof" to keep subgrade soil dry and firm.

Professional trespasses easily provoke professional jealousies, whether from trade unions, acrobats, or department heads, and the controversy over Macadam vs. Telford styles of road building was the hottest item since the medieval curse for witchcraft. The fact that Macadam was a popular hero didn't help, and his zeal for reform led him to state his case, which didn't help either. For example, he claimed his roads were best on a weak, boggy, "elastic" soil, since this formed the poorest anvils for destructive breakage. This view led to much critical buffoonery.

Eventually criticisms faltered in the face of success, and macadam roads became widely adopted and remain so. Unquestionably Macadam's unlettered audacity literally paved the way for the Industrial Revolution.

The turnpikes: boom and bust

By 1830, highway systems had reached their highest development since the time of the Romans. This was also the year a stage coach was outrun by an American train called the Tom Thumb, a grim foreboding of more thumbs to come. The train came in as rapidly as it is fading out now, and within 20 years the stage coach was completely extinct except in frontier areas. Turnpike trusts had also collapsed and were gone, and maintenance of existing roads fell on local governments.
From 1850 to 1900 were very dark ages for the road. Only feeder lines to the railroads were maintained, and overland travel in bad weather was impossible except by foot, horseback or rail.

THE TWENTIETH CENTURY

The present century swirled in with a cloud of dust and a cacophonous beep and clatter, the sign, song and signal of a monstrous little beast called the automobile. Soon macadam and gravel road building revived, but rubber tires and fantastic speeds made goggle and dust a matter of good sense. Roads also "ravelled" or were washedboard as fines were blown out.

Merrily the world began rolling along and the dust clouds began rolling bigger until Sunday driving in the country was too literally in the country, and people objected to driving by braille. Women also fidgeted, believing the dust to be inedible, and in 1908 an international conference met to try and solve the dust problem.

Soon all manner of tar, asphalt, salt, or sea water were being spread to lay the dust. Asphalt treatments in particular showed promise of giving a higher type of pavement, and a common construction became the "asphalt penetration macadam," made by spraying hot asphalt on fresh crushed stone macadam. The decade 1904-1914 saw construction of over 10,000 miles of bituminous highways in the U.S. It was the undisputed era of the blacktop.

Trucks and highways

Unfortunately the delicate flavor of victory lingered only long enough to be mangled under the onrushing truck. Trucks proved too much for the macadam, and stronger roads were needed. By 1924 the U.S. highway system included 10,000 miles of hot plant mix, bituminous concrete and the finer textured sheet asphalt, 31,000 miles of portland cement concrete, and 4,300 miles of brick. (We predict a slow future for brick.)

Currently portland cement concrete highway slabs are usually 6 to 10 inches thick, with or without internal reinforcement of steel, and resting on a thin granular sand, gravel, or crushed stone subbase to prevent soil from pumping. Bituminous concrete thickness is usually less but more variable, the difference being made up by the underlying material. The New Jersey Turnpike, for example, is 41/2 inches of asphaltic concrete over 7 inches of macadam over 61/2 inches of gravel. Competition between the two major classes of construction is fierce.

Secondary roads are still gravel or macadam or telford (in Europe), but garden spots such as Iowa are running out of rock. Therefore a late research aim is to stabilize or harden soil for a substitute, a search fairly well assured of success. Satisfactory stabilized soil roads have been built with portland cement, lime, lime-pozzolan, asphalt, clay, or lignins. Further improvements are in the works.

ACKNOWLEDGMENTS AND REFERENCES

Foreign photos are from color photographs by Dr. E. A. Rosauer; paintings on p. 5 and 6 are reproduced courtesy of the U.S. Bureau of Public Roads.

For more information with less deformation see The Story of the Road by J. W. Gregory, MacMillan 1931; Public Roads of the Past and Historic American Highways by the Old Roadbuilder (Albert C. Rose), American Association of State Highway Officials, 1952 and 1953.

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TO MARIAN THE LIBRARIAN:

With this issue Screenings degenerates to a quarterly to give Ye Olde Editor time for other pursuits such as golf. Thus the next lively issue should be bouncing along three months from now. Meanwhile to the hammock, to contemplate.
CRUISING DOWN THE RIVERS

Overture: Water Music

All the world's a stage, which would be agreeable enough except for so much recurrent bad acting. Let us away from the discord and melodrama, to enjoy the prodigious scenery and set design. Design credits go to wind, water and ice, plus a few periodic pyrotechnics and minor ups-and-downs. Of these, water is the most vigorous sculptor, carving massive monuments and daubing widespread abstractions with the debris. Our subject today, rivers.

Biography of a stage hand

Rivers are confederated raindrops with only one goal: downhill. With such singleness of purpose their enthusiasm easily runs all over itself. Gay, impassioned youth cuts a hctic channel, and gullies form, enlarge and deepen into V-shaped valleys.

Downward cutting of young streams often involves upstream migrations of a series of waterfalls, or nickpoints. In addition to cutting downward, the streams cut headward so that gullies not only grow deeper, they grow longer. Gradually, fields and farms -- goodbye.

Eventually downward cutting by a given section of stream must stop or the water will run backwards and we will all be eaten by sharks. Downcutting is controlled by a base level, the ultimate base level being sea level. A stream can't cut its valley much below sea level unless it runs uphill.

Youthful valleys often get their start and are cut downward in a series of retreating nickpoints (arrows). Here nickpoints are chopping at easily eroded loess or silt soil, western Iowa.

To many Americans Niagara reenacts the incandescent thrill of falling in love, the romantic version of being sold down the river. Don't dash your head on the rocks.

In addition each river forms the base levels for its tributaries, and local base levels can be hard ledges of rock. A stream bed trimmed to a downstream base level approaches a condition known as graded, where on the overall it neither cuts nor fills, it just carries.

Mastery by a base level changes a river's personality and vigors; it can no longer cut downward so it cuts sideways, gradually expanding its valley at the waistline and changing the shape from a V to a . This stage is aptly termed maturity, the middle-aged spread. The flat portion of a mature valley is the floodplain.

The Missouri: Today here, here yesterday. The river cut off a meander and departed to the right background. Very common. For details and reasons, turn the page.
An overwhelming complication is that during the relatively recent continental cold spells much water was engaged in being glaciers. Therefore sea level was undecided, and the base level for all major rivers went up and down like a yo-yo. Every time it came up, river valleys filled with whatever was available, and the rivers got some floodplains. Whenever sea level went down, rivers were "rejuvenated"; they cut downward and left the old floodplains as terraces. Currently sea level is high and valleys are full, but there are a few terraces stuck along the edges.

BRAIDED RIVERS

Graded streams burdened with a manly load of sediment appear energetic enough, but they are easily triggered into relaxing and dropping their socks. The result is that the stream bed, like any other bed under the circumstances, becomes a bit of a clutter. Channels are continually plugging, dividing and recombining until the pattern reminds one of braiding taught by a three-year-old.

MEANDERING RIVERS

The other breed of mature streams is in the leisure class and still has enough energy for play. These streams are the glamour folk of the stage, sweeping about, winding and weaving a delicious musical fantasy complete with rhythm, symmetry, pattern, harmony, and dancing girls.

By meandering, a stream dissipates some of its mechanical energy as heat because of increased frictional drag and eddying. Furthermore meanders increase the channel length, decreasing the feet-per-mile gradient and hence stream velocity. Artificially straightened stream channels eventually meander again. Even the Gulf Stream meanders.

Once the fact of meanders is established in a stream, the loop curvature tends to adjust so energy loss is at a minimum. It is much like golfing for exercise, then riding all day on a golf cart. To minimize energy loss, average meander loop radii adjust to about two to three times the channel width, whether measured in inches or in miles.

Water flowing through a meander exerts some push against the outer bank, deepening the channel and making a catfish haven. (That's hill talk for heaven.) The water also tends to cut away the bank and deposit material on the opposite shore, with the net effect that the meander slowly migrates downstream. Most meander migration occurs during the late stages of high water, when the saturated and relaxed river bank is losing the support from buoyancy, and just sighs and slips in.
Point Bars

Lab experiments show that erosion from a river bank lends to sand deposition along the next convex bank downstream on the same side of the river. As meanders migrate they leave sandy point bars, hummocky deposits filling the areas within the meander loops. On airphotos the regular scarred pattern resembles finger prints. Sometimes the pattern is finger prints if your photos are not the best.

A miscellaneous feature of some point bars is chutes—narrow shortcut channels across the toe of a meander. Chutes on the Mississippi were once used by scumpering steamboats during high water, at some little risk of scraping the sides or running aground several miles from the river. Permanent chutes develop their own miniature meander pattern, and if a chute is so seditious as to capture the entire river it is called a chute cutoff.

Neck cutoffs once created so many political embarrassments by overnight reversing taxation, oil rights, citizenship, slavery, etc., that most such boundaries have been fixed by agreement to be the river channel as of a certain date. This is not entirely satisfactory, because the river keeps changing, and laws, roads, and civil allegiance are hard to maintain when small chunks of states or nations are isolated on the wrong side of major rivers.

Once a meander is cut off and left behind as an oxbow lake, its life is one of seclusion with gradual filling by clay, turtles and bullheads. Floods periodically bring more clay and remove the bullheads, making a deposit called a clay plug.

Clay plugs make up hard banks difficult for meanders to erode; an impinging meander distorts and wraps around but can't get by, so it is cut off, renewing the cycle. Clay plugs therefore beget more clay plugs, an asexual reproduction. On wide floodplains clay plugs also fence the area of active meandering, making it a meander belt.

OVERBANK DEPOSITS

During flood all manner of items may come tumbling out over the river banks, including water snakes, muskrats, chickens, bath tubs, privies, and wet neighbors. In fact, on the river one hardly expects to enjoy the same outdoor plumbing two floods in a row unless he has the affectionate foresight to provide it with an anchor. Houses can be put on stilts, but there's no easy answer for privies.

Other materials over the banks include sand, silt, and clay, plentifully diluted with water. With the lowered water velocity, transported sediment begins to settle, coarser materials near the river and finer materials farther out. One result is natural levees, which occur as long, low ridges along the river, as the name implies. Turn the page.
Creasses

A surficial floodplain deposit with a garrish appearance on aerial photographs comes from crevassing of levees during floods to give braided flood distributory channels. The braided appearance and light color foretell thin sands and silts, but they are usually over clay.

Backswamps

Farther out on the floodplain, beyond the natural levees, fine silt and clay settle, gradually accumulating many feet of thickness and obscuring older point bars, clay plugs, fences and sleepy hogs. These deposits are the backswamp clays or slack water deposits. Thin clay layers of similar origin also cover all but the latest point bar sands, particularly in the low places or swales.

Natural levee with crevasse, located along a now abandon-
ed braided channel a mile northeast of Blair, Nebraska. Natu-ural levees never die; they just fade away into backswamp clay (right).

Sometimes the combination of natural levees and clay plugs effectively fences off tributaries from the main river. The victims meander miles before they are let in, often as not where the main stream carelessly crowds them against a valley wall. Such bullied tributaries are called yazoo, after the Yazoo River, in the state of Mississippi. As it turns out the Yazoo River is not a very typical yazoo, but the name is such pure poetry it probably will be retained.
MISSOURI RIVER DEPOSITS (Contd.)

Of our two big border rivers the Missouri, "Big Muddy," left the lustiest smear, the floodplain being up to 15 miles wide. The floodplain is fertile and is therefore mostly in Iowa; Nebraska got steep banks and sand bars. In other words, the river keeps working against the right hand side. The reason may be partly because of earth's rotation; streams, winds, and bullets are slightly deflected to the right in the northern hemisphere, which can be rather tough on conservatives.

In her caper along Iowa, the Missouri cuts a triple-threat figure, being widest at the top and narrowest down around the knees. From Sioux City to Crescent, the wide floodplain consists of an active channel belt 1 to 3 miles wide; a recognizable meander belt, including the channel belt, 5 to 13 miles wide, and a relatively featureless area of flood basin deposits, backswamp and fans, for the remaining 1 to 12 miles. Adjacent hills whose toes were cut off by the river (photo top p. 2) are composed of glacial drift capped with thick loess.

South of Crescent, the Missouri wears a girdle; bedrock confines the floodplain to 4 to 5 miles wide. As might be expected from such a pinch at the vitals, the floodplain is mostly active channel and meander belt, with very little of the featureless flood basin deposits.

The next major change in environment is the entry of a wild neighbor from the west, the Platte River. The Platte is a heavily loaded, braided stream, and suddenly the sediment load in the Missouri is doubled without very much increase in the amount of water. Therefore downstream from this point the meanders are much straighter, giving a steeper gradient, and the channel is wider and shallower and begins to look a bit braided. Floodplain point bar and clay plug deposits are thinner because of the shallower stream, and some of the bars have been blown around a bit by wind.

Engineering

Engineering soil maps of floodplains may be readily made from air photos because meander features and braids show so clearly. Maps for the Missouri River floodplain have recently been prepared, and engineering properties of soils on the spot checked from field samples.

Point bars. Point bar samples classify as sand or sandy loam, A-3 soils. That means good. On top of the sand is a variable thickness of clay + silt which generally classifies as A-7 and is analogous to backswamp deposits. Not so good. Thickness of the top material ranges from 0 to less than 20 feet, the thicker deposits causing veiling of the original hummocky point bar topography as seen on air photos.

* This is the Coriolis effect (mathematics): Velocity is a vector quantity which includes both speed and direction. Therefore when you whirl around a corner on a motorcycle you change velocity, for example from east to south. Accept this and the rest is easy; a change in velocity must mean an acceleration, and from Newton's law this means a force directed radially to oppose the so-called "centrifugal force." The earth's rotation changes all velocity vectors on the earth's surface, meaning acceleration and a force directed radially perpendicular to the earth's axis. In the northern hemisphere the horizontal component of this force comes from the right or rivers, winds, and bullets will drift to the right. Didn't think we could do it, did you? Uninfluenced by other factors such as downhill, a river flowing 2 mph at a latitude of 60° would travel a circle with radius 8 miles.
Clay plugs. Abandoned oxbow channel fills are usually clay classifying as A-7, 20 or more feet thick, and to be avoided.

Natural levees and backswamp. Natural levees are most prominent in the upper and middle segments of the floodplain. Samples usually classify as clay, but may be A-4, A-6, or A-7. Material is coarsest at the crest, and becomes finer away from the channel, grading into backswamp clay, A-7. The backswamp is not good for engineering structures, but is usually unavoidable.

Fans. Fans from the tributary valleys are locally important, and usually classify as silty clay loam, A-6 or A-7. They occur along the floodplain margins plastered on top of the primary floodplain deposits.

Substratum

Borings reveal that underneath all of the surficial materials described above is sand and gravel hiding a canyon 70 to 150 feet deep. This sandy substratum is easily reached by pile for the support of large engineering structures, and under point bars grades imperceptibly upward into the point bar sands which are relatively shallow.

Origin of the substratum sands and gravels is a tricky question currently being investigated with deep boring equipment. A likely possibility is valley filling during the last glacial melting; sea level came up some 300 to 400 feet, and raised the river base levels. Sand and gravel for valley fill were plentiful from the melting glaciers. On the other hand, glacial geologists have found that terraces merge into the upland at or near ice sheet margins, suggesting a similar deposition of coarse material occurred during ice maximum, when sea level was lowest. Problems, problems...

ACKNOWLEDGEMENTS AND REFERENCES


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A few scattered remarks on earth dams

Nobody knows who invented the dam because most likely the inventor was not a man, but a beaver. Engineering is a very old profession if not the very oldest, traditions to the contrary.

History’s eagerest beaver lived in a time when the earth was flat, and he decided to dam up the edges to make the world one vast beaver pond, like Communism. The project was moving along well when somebody said, “Noah, why don’t you stop all this dam foolishness before somebody gets drowned?” “None of your business,” replied the beaver.

Rather than submit to life in a beaver pond, a group of reactionaries started a movement to stamp out the beavers, but the beaver proved too agile and sustained only a flattened tail. Eventually, of course, dam project was doomed because despite the propaganda, the earth was not very flat, and after the water was up for a few months it began to run off. Meanwhile the beaver had grown reflective and was rather frightened by it all, so he retired to a sedate life of nibbling alders.

As a matter of further record, the world’s largest dam builder was the Giant Beaver, seven feet of fur coat plus tail and gnawing appetite. The Giant Beaver lived and died in the Pleistocene, along with many other gigantic experimental models such as the La Salle, Packard, big Buick and DeSoto.

The only other time the beaver caught up with fame was as an accessory for the beaver hat. Or rather, fame caught up with the beaver; the public fancied his exterior to be beautiful— which as any actress knows is how fame operates, often with devastating results for the famous. Only in recent years has the American beaver recovered. Others are not so fortunate.

Eager beaver business

Given the chance, small boys of America invariably follow in the wide path of the beaver, cutting trees and building experimental dams and watching water back up and spill over. Given the chance, large boys do likewise, which should help wives understand how much fun it is to be an engineer.

*Proofreaders remind us of an unscrupulous pun which from our purity of heart we almost failed to recognize. We promise to shake it up and stand corrected.
KINDS OF DAMS

Although beavers have the most experience and would probably dominate in unions where experience counts, man tempers his skill with originality and has stolen all the dam building laurels. Man dams are constructed from a variety of materials:

Leakiest dams are timber or timber cribs filled with rocks. Simplest dams, and those that usually catch the eyes of municipal authorities, are solid blocks of concrete cast in place in the river, called "gravity dams" because tipping and sliding are opposed by gravity and by friction caused by weight of the dam.

Rather more elegant are "hollow gravity" dams, which resemble a concrete wall with the top leaning downstream and propped up by vertical buttresses. Thus the dam is held against tipping by weight of the water. Hollow gravity dams save some concrete but require more elaborate forming.

Perhaps most spectacular are concrete arch dams such as Hoover Dam, where a concrete wall is arched upstream against the water and transmits the force as thrust against canyon walls. Arch dams are limited to deep, narrow, rocky canyons.

The earth dam situation

If concrete arch dams are the high and mighty glamour girls of the dam work, earth dams are more the shape of older girls where uplift fails, very broad at the bottom and tapering upward, perhaps with an occasional shelf, or berm, wide enough for a herd of elephants. The understanding male will recognize that earth dams constitute the largest man-made structures in the world, rather super colossal. Ft. Peck Dam in Montana, for example, has volume enough for 32 Great Pyramids plus a Sphinx or two, with enough mud left over for 27 general elections.

In smaller economy packages, earth dams outnumber all other types, particularly for construction of small reservoirs and farm ponds. In fact, conflicting sponsorship of government agencies has enhanced debate, to wit, which give better flood control, a few large dams on major rivers, or many small dams near river sources? The argument also demonstrates the fairness of statistics, which can be used effectively to support both sides. Actually the two arguments mesh rather well, like marriage.

For dam construction, soil is cheaper than concrete but more is required. Earth dams are preferred where soil is readily available and the required dam height is not excessive, earth volumes increasing geometrically with increased height. On the other hand earth dams are less sensitive to settlement than are masonry dams, and may be built on weaker foundations, and the long base length reduces under-dam seepage. Finally earth dams are the darlings of the park services because their appearance is less in conflict with natural surroundings.

In recent years the U.S. Bureau of Reclamation, among others, has been laughing at the prejudice that earth dams can't be very high.

Trinity Dam (above), recently completed in California, is 537 feet high, highest earth embankment in the world. Soil was transported to the job aboard a two-mile-long conveyor belt. The proposed Oroville Dam in California will be 730 feet high, or 4 feet higher than Hoover Dam, the U.S. highest.

A monumental series of earth dams on the upper Missouri, including several of the world's largest. Only Big Bend remains to be completed.
DESIGN OF EARTH DAMS

Strength considerations easily tingle the emotions of visitors to large dams, particularly visitors from the downstream side. Design of an earth dam embankment is relatively simple but requires a few minor precautions, such as extermination of muskrats.

Wave erosion of the upstream face is prevented on small dams by vegetation, on medium and large dams by a covering of boulder-size crushed rock called riprap. Protection against overturning and sudden, disastrous erosion is obtained with a concrete outlet works and paved emergency spillway.

Limestone riprap for protection of the upstream face of Coralville Dam, Iowa River, Iowa.

On smaller dams the outlet may be simply a pipe or "drop inlet," and the emergency spillway may be a heavily sodded channel several feet lower than the crest of the dam.

Water rushing through the outlets of high dams gains velocity such that it becomes wild and erosive, tending to slice a gorge downstream. The usual procedure is to dissipate excess energy and bedevilment in a stilling basin which includes a splashy "hydraulic jump," one of the few places where water freely runs uphill. That is, water rushing down through the outlet greeted at the bottom by a sudden change in channel slope tends to pile up deeper, with great turbulence and loss of energy. Also some of the violent kinetic energy of motion is converted into relatively stagnant potential energy of elevation.

Leaky lakes

Nothing rankles like a leaky dam or reservoir, the folly is so conspicuous. Other engineering mistakes may fall down or explode and kill a few people, but are quickly repaired or removed and forgotten. A dry dam remains and pains; children laugh and grownups cry.

Assuming the reservoir is tight, which should be checked before damming is even attempted, seepage has two possible routes--under the dam and through the dam. For example, sand or gravel make a very leaky dam. The remedy is to include a core of impervious material such as clay, even though such soil may have to be hauled for miles. If a clay core is altogether too expensive, steel or concrete may be used.

A more sneaky route for leaks is under the dam, a frequent problem because river sediments often contain permeable layers. A common preventative is to excavate a cutoff trench before the dam is built, and backfill with clayey material similar to that which will make up the core. Another approach is to drive an impenetrable steel curtain of sheet pile. Or if the permeable layer is too thick, the bottom of the reservoir may be coated with clay for a distance upstream, to increase distance the seepage water must travel and thus decrease the rate of flow.
A deeper route for under-dam leaks is through the underlying bedrock, limestone in particular being a likely place for caverns and tunnels. The remedy is some colossal dental work--drilling followed by pressure grouting, or pumping of a cement slurry down the drill holes. A little preliminary exploratory drilling is in order so the contractor will not be trying to fill a cavity the size of Carlsbad. Some areas such as limey parts of Kentucky would need a bigger dam underground.

Flow net

Once a dam cross-section is tentatively selected, seepage rate can be predicted by sketching a "flow net". The slightly tilting stream lines indicate probable paths of water molecules; the cross lines show the gradual loss of energy, or head. Rules for sketching a flow net are that all blocks are essentially squares.

Excavation of a cut-off trench which will be filled with impervious core material. Adjacent rows of well points are keeping the trench dry. Coralville Dam, Iowa. Purpose: flood control and duck hunting but mainly flood control.

Flow rate is found from the equation:

\[ Q = k \cdot h \cdot l \cdot \frac{F}{N} \]

Where \( F \) is the number of flow paths, or spaces between pairs of stream lines, \( N \) is the number of spaces between the cross lines (equipotential lines), \( h \) is the total head loss, \( k \) is the coefficient of permeability, and \( l \) is the length of the dam. This is not particularly interesting, but we want to emphasize the quantitative aspect and keep with the trend. For example, what was formerly a shapely figure is now 36-24-36, or is it 34-34-36, or 34-36-49? Unquestionably there's a trend.

Stability of slopes

Perhaps the most important part of earth dam engineering is the question of stability, especially where much downstream populace and real estate can be imperiled. Embankment failures are landslides--that is, shear takes place on an internal surface, everything above the shear surface slipping and sliding downhill and engulfing as it goes. Sliding tendencies are related to shearing strength of the soil and to embankment geometry; slides are inhibited if the embankment has a broad bottom and low slope angle.

Cross-section of Garrison rolled-earth dam on the Missouri. Note the triple-barreled attempt to reduce under-dam leaker: cut-off trench, steel sheet pile, and impervious upstream blanket.
For example, sands with a relatively high shear strength can safely stand in a rather steep heap, sloping as much as 34° (1½ to 1), whereas clays require a low slope angle, 18° (3 to 1) or less. Because low slope angle means more soil in the embankment, economy dictates some careful evaluations and studies of all available soils, particularly for large dams. Shear strength of soils can be increased by compaction, which gives an additional advantage of stamping out some of the permeability.

Earth dams also may suffer the nagging backache from too much seeping water. Seepage water emerging at the toe tends to push out the soil and create a marshy hill of mud. Preventatives are to incorporate tile or a sand or gravel drain. (See flow net sketches on the preceding page.)

Another circumstance to be avoided is sudden drawdown, or quick lowering of the water level in the reservoir, leaving seepage water perched high within the dam. Ordinarily, weight of the water in the saturated soil is borne by buoyancy, but with sudden drawdown buoyancy suddenly disappears. This is a critical time for slides—in fact, most river bank failures occur immediately after, not during, high water. The only preventatives for earth dams are to avoid sudden drawdown, which would flood the lower valley anyway, or to use a coarse, free-draining soil.

Rock fill dams

Related to earth dams but often discussed separately are rock fill dams, where rocks are used instead of soil. Safe slopes can be much steeper, and leaks are prevented by concrete, wood, steel or masonry facing, or use of an impervious earth core.

CONSTRUCTION

Earth dams are usually built in much the same manner as highway embankments: A layer of soil a foot or so thick is spread and compacted with rollers, then another layer is spread and compacted, etc.

A spectacular impetus to earth dam and all earth embankment construction came in the late '30's and '40's, when gasoline and diesel equipment took the place of mules and the W.P.A., and evolved into the gigantic earth hauling trucks, scrapers, and tractor-trailer units used today. Largest trucks now carry 50 tons, as much as a small freight car, and must be dismantled for transportation to other jobs. Hauling operations for the large dams are conducted at top speed, and haul roads are kept near perfection as endless successions of roaring, big-tired machines go around the route, in a fabulous display of power, speed, and timing.

Hauling and sheepsfoot rolling for a section of Garrison Dam, North Dakota. Water sprinkler and disc harrows at right maintain proper moisture content for compaction.

Often the time of troubles in earth dam construction is during building, when soil has not regained full cohesive strength, and engineers don't know what to expect from the unexpected. In 1938 a very troublesome 10 minutes occurred at Ft. Peck, when about 5 million cubic yards of earth came tumbling down due to undetected bentonite clay seams. About 180 men were in the slide area; eight were killed.

In other instances earth dams have been built too fast, the gradually increasing weight consolidating foundation soils faster than pore water can escape. Excess pore water pressure separates soil grains, giving sudden lubrication and dangerous possibilities for shear. Pore water pressures are closely checked during construction.
A neat alternative quick trick for earth moving used in only a few of the largest dams, including Ft. Peck in Montana and Kingsley in Nebraska, is hydraulic fill: soil at the borrow pit is mixed or jetted into mud by use of giant nozzles, and the mud is sluiced to the job in pipe lines. There it is deposited from two parallel lines and retained by temporary alluvial deposits making up the shores and eventually the shell of the dam, while fine materials are carried into the lake and settle from suspension to form the less permeable core. As the dam increases in height, underlyings materials consolidate and gain strength due to weight of the dam.

Closing drama

Large dams require years of methodical, round-the-clock construction involving many separate contracts and subcontracts, and played by a cast of thousands. At long last comes a unique drama, one of the few in engineering which so satisfactorily signifies triumph—the moments of final closure. The river has by this time become a violent torrent because of the sharply restricted channel, and hauling and dumping of earth must exceed rate of erosion if the river is to be tamed and plugged. Preparations are elaborate and excitement hangs, for these are telling moments.

The most recent closure of a large earth dam was in 1958 in Oahe Dam, near Pierre, South Dakota. The town was vibrant and booming with dignitaries and interested persons streaming in to socialize and watch a conquering of the mighty Missouri. Weather reports were noted with a nervous eye, the river flow was reduced from other dams, and all available earth moving equipment was made ready for the final push. By midafternoon the channel had been restricted until the water lashed with furious turbulence at the steadily growing and impinging banks. By evening the water was indeed riled as the channel was entering its final fight for life, and at 3:00 a.m. the end was near; the flow was greatly impeded and water was beginning to pile up. At 3:35 a.m. under the lights two bulldozers shoved the final plug, enabling one to walk across the Missouri on land.

Next to the last truckload for final closure, Oahe: the water is beginning to pile up. Truck holds approximately 50 cubic yards; note the comparative narrowness of the standard-width cab.

ACKNOWLEDGEMENTS

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FROST ACTION IN SOILS

The first known instance of frost action was a bad day for the family of man, brought about when Adam overlooked a wedding anniversary and came home in the early a.m. smelling of cigar smoke and hard cider. Directly thereafter was held the first World Championship Fight in the Garden. Adam lost, we don't need to be reminded.

Another type of frost action is called the frost heave, which occurs as an aftermath of too many ice cubes in the highball glass, waging war on the antifreeze. Prior to the heave, rather ordinary conversationalists are transformed into great wits who seem dull only to others; then they heave unto themselves, and they feel better.

In most frost action the troublemaker is ice, whether in the eyes of our true love, or in the icicles which form from her nose as she shovels out after a snow so we can drive to work. Ice is bothersome on roads or windshields, where it reduces highway speeds to the point where they are no longer lethal, and cuts visibility to a couple feet or so inside the car.

If we overlook occasional connubial glaciations, the most perplexing ice to the road engineer is not on top of the road but hidden away underneath. During the cold weather, ice forming in soil can easily boost a pavement as much as several inches, and later thaw and relax to a mucky hole. Thus winter brings trouble, and spring brings it to the surface.

CONDITIONS

Three factors cooperate to cause frosty upheavals: the first requirement is some non-Freudian frigidity, in other words cold weather; the second is water, a customary raw material for ice; and the third is a frost-susceptible soil. If one of the conditions is not met, there is no frost action. For example, a ready way to avoid frost action is to have a warm winter. Write your Congressmen, or move to the Congo. Other ways to avoid frost action are reduce the availability of water, or change or exchange the soil.

Frost action is so common it probably occurs in your front yard, but it is seldom noticed unless some engineering structure does a shuffle. Smallest of buildings may rise and fall so uniformly the change is not noticed, except to stretch the outdoor plumbing. Under larger buildings the heave is seldom uniform, explaining why the floor in an unheated garage may mysteriously warp up at the edges and crack.

The most common prevention for such difficulties is to rest building foundations deeper than the frost can reach, ordinarily a matter of a few feet. In two general areas of construction this recipe is not feasible; these are the Arctic, where the frost goes too deep, and in building of roads, where the cost is too much. These are two admirable justifications for further small talk on frost action. Today we exclude permafrost; it will keep for later.
moves to the freezing zone. Two years later a young University of South Carolina geology professor named Stephen Taber began assembling such facts in a new theory of frost heave.

THEORY, Part I

Taber knew that chemical crystals growing from a saturated solution exert enough pressure to lift weights, and he reasoned that the growing ice crystals should be able to lift weights likewise. He tried it. He placed metal weights on wet sands and clays and subjected the soils to freezing. True to prediction, weights resting on clay were raised. Those resting on sand were not; obviously more work was needed.

For the next 10 years Taber worked much and published little, virtues essentially the reverse of the practice today. In 1929 and 1930 he opened the vault and published three summary articles to try and explain frost action. He disproved that the 9 percent volume change of water on freezing is a major factor by substituting nitrobenzene, which shrinks on freezing and still causes frost heave. As he had first suggested in 1916, the major cause of frost heave therefore appeared to be gradual movement of water to the zone of ice formation.

Part II

Before launching on, we flash back to the lab where a young Michigan State research associate in soil physics named George Bouyoucos was busy investigating freezing points of water in soils.

Bouyoucos found that not all soil water freezes at 32°F; in fact in clays the freezing point may be many degrees lower. Furthermore the drier the soil, the colder it must be before water freezes.

Apparently water loosely held in large soil pores freezes more readily than water in small pores, absorbed and held under pressure on the surfaces of mineral grains. An analogous condition occurs under glaciers or underneath ice skates; pressure lowers the freezing point and melts ice. Resulting instant water probably helps both to slide.
In the case of frost action, water held under pressure on grain surfaces remains liquid and readily seeps along to join the ice lenses. Freezing point depression is greatest in clays, which have tremendous grain surface, and least in sands and coarser materials. Perhaps this is a reason why sand doesn't frost heave (see Part I); where soil grains are large and freezing is rapid, grains are caught by the ice and entombed. But where soil grains are small, their comparatively thick coating of liquid water exerts hydraulic pressure and keeps them pushed away from the growing ice mass.

Part III

And where does the ice form? It depends how long it takes mein Frau to shovel the walks. Sometimes her very heart seems affected.

In soils, ice forms at the place where the water freezes, which seems logical. Because freezing occurs along an advancing front, ice tends to form in a horizontal layer (vertical behind a retaining wall). Furthermore water migrating to ice zone and freezing gives off heat which impedes advance of the freezing front.

This action could presumably go on and on and build a subsurface ice layer thicker than a glacier's toenail, but it doesn't. As water in a zone is used up, remaining water is more tightly held and less mobile, and rate of growth of the ice lenses is slower. Meanwhile cold temperatures are penetrating deeper, until they intercept relatively free water and start another ice lenses. The action then repeats.

Part IV

Finally, how does the water move and why does the ice push? An early suspicion was that water moves by capillarity caused by surface tension, but this would require air-water sur-

faces in the soil, and water appears to move to the freezing zone even though soil contains no air. Therefore molecular cohesion or "suction force" in the water has become the favored explanation.

As for where the ice gets its push, it relates to supercooling. No freezing point depression and there is no excess energy; it all goes to make ice. But a single cc of water freezing at -1 C (31.2 F) can theoretically lift a 12.5 kg (56.8 lb) weight one cm. Alternately it would lift 125 kg a distance of 0.1 cm, or 125,000 kg (28.4 T) a distance of 1 micron. Obviously surcharge should inhibit frost heave, and a pavement will heave higher than a bridge pier under the same conditions.

CONDITION COOL

The not-so-hot climate which gives frost action dips farther south than most Chambers of Commerce care to admit, but that's not our crop of oranges. Evaluation of sales records of long underwear substantiate that winters are milder now than in the good old days out on the farm. This is also reflected in other scientific indexes such as decline in sale of hot water bottles and increased popularity of shortie nighties, although there may be other factors.

One of the more reliable functions of clairvoyants in the Weather Bureau is to take temperature. Because rate of ground freezing depends on the amount the temperature goes and stays below 32 F, average daily temperature subtracted from 32 gives a pertinent measure called "degree-days below freezing." Or the average comes above 32 the difference is "degree-days above freezing." Mathematics is almost routine when you know how.
From field correlations by the Corps of Engineers a rough idea of depth of freezing under pavement can be obtained from the preceding graph by

$$X \text{ (in.)} = 1.4 \sqrt{F}$$

Examples: \(F = 3000, X = 77''; F = 1500, X = 54''; F = 750, X = 38''; F = 100, X = 14''.

The above formula is but rough, and may be off by a factor of one-half because depth of freezing depends on other things besides the freezing index. The modified Berggren formula for depth of freezing is

$$X = \lambda \frac{48}{kF} L,$$

which brings in thermal conductivity \(k\), latent heat \(L\), and a correction \(\lambda\), in addition to surface freezing index \(F\).

The formula points out some perplexities: Compact soils freeze deeper than loose soils because of change in \(k\). Dry soils freeze deeper than wet soils because water contributes the latent heat \(L\); the highway engineer therefore builds a long ice box.

Finally the correction factor \(\lambda\) depends on how warm the soil is to start with—in other words how much volumetric heat is contained due to a mean annual temperature above freezing. For saturated soils and in northern climates \(\lambda\) is close to 1.0, whereas in dry soils or farther south \(\lambda\) may be as low as 0.5.

Freezing index in the formula ideally represents temperatures at the ground surface, which probably differ from air temperature data supplied by the Weather Bureau. The exact relationship is a very tricky problem in heat transfer, and involves such things as color and texture of the surface, angle of the sun, and which way the wind blows on Thursday. All this has not been worked out yet. For pavements \(F\) is sometimes multiplied by 0.6.

**Ice Breaking**

Comes the hot heart of spring, frozen ground thaws, and the ice contained therein melts. Thawing is mostly from the top, and rate may be predicted from the Berggren equation, except that \(k\) is lower because it represents heat penetration through thawed soil rather than through frozen soil, and \(F\) is a thawing index (degree-days above freezing).

All soils exposed to cold weather freeze, but many don't misbehave and invite in ice lenses. It's a matter of character and upbringing. Soils with ice lenses thaw and mingle to form mud, especially because thawing from the top keeps the water perched in its icy bucket. Only when thawing is complete can normal downward drainage resume. Meanwhile the road is soft as baby's smile or something else. Graph below shows strength of a gravel base course on a frost-susceptible soil, Maine.

No winter is complete without an occasional thaw to make us wish for spring. Freeze-thaw cycles are devastating to strength of saturated
soil whether the soil heaves or not, because of that old 9 percent volume change of water on freezing. Ice lensing helps the soil to be saturated, but is not required, although alternate freeze-thaw also increases frost heave by permitting periodic additions of more water.

The graph below shows a year's total freeze-thaw cycles in the pavement of the preceding page. Obviously the top part of a pavement takes more abuse than the bottom.

Freezing control

One way to stop frost heave is to stop freezing. To do this Swedish roads have been built on blocks of moss, straw, or moor (peat), and the Corps of Engineers suggests slag or cinders. Frost penetration into moss is about half as fast as in wet sand; frost penetration in slag or cinders is about two-thirds as fast.

CONDITION WET

Forgive us for detailing the obvious, but the second requirement for frost action is water for ice. Cool some dry soil below freezing and it doesn’t harden, heave, or even hiccup; it just gets cold.

Soil water fits in one of three political camps: Free water is found below the water table and is what the well drillers are after. Capillary water occurs above the water table, held up by capillarity, or forces of surface tension. Hygroscopic water occurs even in air-dry soil, where it is chemically adsorbed in thin films around soil grains, and has the lowered freezing point needed for migration to the ice lenses.

If hygroscopic water borrowed for ice lenses is replenished from the outside, the system is "open," and heave goes on and on, or rather up and up. If water is not replenished the system is "closed."

Open systems are the rule, as proved by success of water witches, the secret being that water is underneath about anywhere you care to drill a well. Some heavy clays are so impermeable that the system is practically closed; ice lenses form, but at expense of water in adjacent soil. Therefore a clay soil may shrink rather than heave! Graduate students will please leave the room, go home and think this over and write a term paper on it, due tomorrow. The rest of you may cogitate for the remainder of this paragraph.

Apparently ice lenses forming in a closed system remove sufficient moisture from clay soil immediately below that it desiccates and shrinks. Comes spring the soil moistens and springs back up. Freezing shrinkage accounts for apparent winter heave of many bridges and culverts; actually soil and pavement on either side temporarily have gone down.

Swingin' in the Rain

A fourth class of water and the only kind conveniently attributed to leaky angels is rain, which in showers brings May flowers. Coming down to earth, rain hastens thawing of frozen soils and readily makes mud, ice lenses or no. Therefore a road needs a tight roof such as pavement. Pavement halts rain action but not frost action.

Moisture Control

Even before the word was out that frost heave is dictated by availability of water, patents had appeared, which shows how far some inventors run ahead. A patent in 1888 prescribed lateral drains and a waterproof membrane, and in 1929 Taber suggested use of a membrane of coarse sand to cut off movement of adsorbed water toward the ice zone.

A less absolute approach which is more often needed is to either raise the ground or lower the water table. Highway engineers generally prefer to raise the ground, building roads on a fill. As part of his extensive studies of frost action the Swedish authority Beskow found that doubling the distance to the water table would cut frost heave about one-half.

A method not directed at controlling frost heave, but effective for reducing spring slippiness or "frost boils," is to build the road on
sand- or gravel-filled trenches which act as drains. The proper name is "French drains," probably because of all that salt air in Paris.

CONDITION SUSCEPTIBLE

Because the first two conditions for frost action, climate and moisture, are rather difficult to control, highway engineers are forced to take elegant precautions with the third, which is soil.

Whereas some soils frost heave inches or feet, other soils under the same conditions show complete disdain and don't heave at all. Coarse sands and gravels are generally safe and stable; hence their popularity in roads. Their hygroscopic water is insufficient for even a token uprising.

Silts are the real agitators and fomenters of revolution. Silts have larger surface area which holds mobile hygroscopic water, and they have high permeability, which means an open system with plenty of water available for ice lenses. In clays frost action is slowed because of low permeability, although the potential for unrest is still there.

Soil Control

Obviously one way to avoid frost action is avoid use of silty or clayey soils in the freezing zone. A much-used empirical criterion established by A. Casagrande is that any soil containing more than 3 percent finer than 0.02 mm (20 microns) is suspect. Where such soils occur, the engineer can cover them so they don't freeze, usually a matter of 3 feet or more. Then no more worry, except who is going to pay for it.

The above method works well for airfields where pavements must be thick anyway, but costs too much for highways. The alternate plan is let traffic tolerate heave and hope that it is uniform, and make the pavement sturdy enough to still carry the loads when the soil is weakest.

Admixtures

Several soil stabilizing agents prevent frost heave, either by cementation, as in soil-cement, or by decreasing water freezing temperature, as with salt, or by reducing soil wettability and permeability, as with asphalt.

In general the amount of portland cement or asphalt required to produce frost resistance is in the realm of the amounts needed to make a stabilized base course, and few states care to install a base course 3 to 5 feet thick. Heave in silts may be prevented by about 2 percent calcium chloride, but the latter is ordinarily applied only in the upper 6 to 12 inches of road.

A very nifty scheme used by the Iowa State Highway Commission is to drill 6-foot-deep holes at 5-foot intervals and back-fill with gravel and calcium chloride. The holes do not prevent frost heave, but act as vertical drains for excess perched moisture during the spring thaw.

Similar and different from chlorides is non-alcoholic waste sulphite liquor from northern paper mills. The brew depresses the freezing point only a few degrees, not 10 or 20 as in the case of chlorides; nevertheless the rate of ice crystallization of supercooled solutions is greatly retarded, and frost heave is reduced. Probably molecules plug growth sites on the ice crystals. Like chlorides, sulphite liquor slowly leaches down.

Other chemical additives such as quaternary ammonium chlorides (sour hog fat) are effective in trace amounts but most likely would need to be incorporated into the road as it is built.

REFERENCES AND ACKNOWLEDGMENTS

Since about 1948 the Highway Research Board has been the major clearing house, sounding board, and tuning fork for soil frost action research. Recent readings: HRB Special Reports 1 (A. W. Johnson literature review 1/65-1/61), 2 (symposium), and 40 (soil water); and annual bulletins 71, 96, 100, 111, 135, 168, 207, and 218. See also Jumikis, "The Frost Penetration Problem in Highway Engineering," Rutgers Univ. Press, 1955.

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RLH
CARE AND SHOOTING OF GROUTS

Early man, the hunter, seldom dug a hole in the ground except to cool a watermelon or bury a ripe neighbor. Furthermore the Great Spirit usually tabooed hard work on Sundays and other days, except by the women.

Now in the cadence of decades, the Twentieth Century is turning a deep revolution in architecture. When man took to the air he soon became so afraid of himself he is a new burrowing animal, brave and wise like a rabbit. Fortunately he still has his wits—save the governments first; women and children come after.

Shelters, mines, tunnels, basements, wine cellars, trenches, subway excavations, etc., often introduce seepage water, mold and un-tidiness, plus occasional trench-foot, mouth, and fever. Tunnels are usually pressurized to help keep water out during construction, and cemented to keep it out later. Otherwise, man the pumps, sink, swim, or pump grout.

Don't Be Gruel

Grout, not to be confused with gout, which is unrelated, is thin, soupy mortar. In Anglo-American usage, "grout" is the word for plaster laid to fill cracks and other small spaces. "Gruel" came to mean grain soup or gruel. Modern grouts are oatmeal, popular because it "sticks to the ribs," and the new liquid diets, popular because they do not. Similar mixtures once favored by librarians have largely been replaced by rubber cement.

Perhaps from the flavor of it, the word "grout" or "grout" came to mean dregs. "Groudy" means grouchy, probably from drinking too much grout.

Maybe from the thickness of it, "grout" also came to be applied to any soupy or pasty mortar which could be used to fill voids, whether in stomachs or between bricks or stones. It is in this latter sense that "grout" has stuck with us until now. For example, stone pavements or walls were once grouted with mud to add strength and waterproofing.

Pressure

For centuries the art of grouting bricks and stones was as routine as the art of lying and not nearly so common; then modern innovations elevated both into respective realms of engineering and practical politics.

The transition came about through diligent application of a legislative principle called pressure. Anybody knows that in a fluid medium like grout or politics a little pressure carries a long way. Pressure forces grout into fine rock fissures or soil pores, increasing strength and watertightness.

APPLICATIONS

Presently the major use of grout is to improve natural rocks and soils, where it functions as a combination rubber pants and foundation garment. Either it reduces threat of flooding, firms up a sloppy undercarriage, or does both.

1 There is no footnote 1.
2 See footnote 1. This way we keep the footnotes straight—very necessary when you write things backwards.
For example, tunneling into a fast flowing water zone such as gravel could cause an unreasonable number of drownings among the crew. Before this happens, pipes can be set out from the tunnel to pump the gravel full of grout, which sets tighter than an old maid's jaw at a romantic movie.

Grouting of a leaky sand in a mine tunnel near Grand Rapids, Minn., note water seeping in at right. Pipes and valves are arranged for a two-shot (Joosten) grouting process, discussed later. Below, same tunnel after grouting, sand tests at 480 psi.

Alternately the tunnel, subway, mine shaft, privy or fallout shelter might encounter loose rock or quicksand, making further digging impossible. One remedy is hardening by grouting. A bad dose of tunnel quicksand is practically impossible to handle any other way.

Still Water Runs Deep

Unfortunately still water which runs deep under dams does not stay in the reservoir. This is one way to combat water skiing.

Most dams rest on permeable strata which require sealing if the dam is to hold water. Leaks may be through buried gravel—very common in river valleys—or through cracks or caverns in the bedrock. A cutoff wall of concrete, clay, or sheet pile may do the job, but deep troubles are best handled by grouting.

"Curtain grouting" is achieved by drilling one or more lines of closely spaced holes where you want the curtain, for example under the axis of a dam. When the holes are pumped they form a more or less solid vertical wall.

Consolidation Grouting

Another arrangement which puts in a grout layer horizontally is "Blanket grouting" done with a network of shallow holes. Blanket grouting is particularly useful to increase bearing capacity, for example under a building. It then becomes "consolidation grouting."

Penetration tests of Polarsis missile site, before and after grouting.

Speaking of under a building, some basements occasionally turn into swimming pools, indicating the time is right to tile, grout, or hire a slick realtor. Excavations for buildings sometimes strike more water than the pumps can handle, or if they can handle it the neighbor's wells go dry. Because most workmen object to working in 12 feet of water without overshoes, a needed remedy may be grouting. The bordering areas can be curtain-grouted or the bottom blanket-grouted or both.

Frequently in city excavations the problem is not water so much as to avoid unwanted calls from the neighbors, who may drop in unexpectedly any time the soil next to the excavation happens to give away. Answers are shoring and perhaps grouting.

Oil's Well that Ends Well

As soon as man dropped his harpoon and took to close order drill, the crude began to erupt, "crude" meaning oil? It was soon discovered that a well drilled through both oil bearing and water bearing strata would show a deceitful tendency to produce water. Initial grouting tried about 1903 involved drilling through the water zone, dumping cement grout in the bottom of the well with a special trap-door bailer, and lowering well casing into the cement. After a month's wait for the cement to harden, drilling would be resumed into the oil zone.
About 1910 a Californian named A. A. Perkins played it cool and clever by pumping cement directly through the well casing. Drilling mud already in the well was pushed ahead and kept separate by a travelling plug which ruptured when it hit bottom in order to let the cement through. Another plug introduced at the top of the cement column cleaned out the casing and pushed the cement down, out and up where it was supposed to be, between the casing and the rock.

Perkins patented his method and started the first oil well cementing company. But it was an age of conservatism, and most operators preferred to do the job themselves.

By the 1920's a former Perkins truck driver and well cementer named Erle Halliburton, operating with war surplus trucks and a string of anxious creditors, introduced innovations and portability. Not the least of his improvements was a continuous water-jet mixer that did away with the old mortar box and hoes. Jet mixers now in use can consume from 15 to 50 sacks of cement per minute. Halliburton also invented a measuring device: a weight suspended on a wire rides the top plug down, showing progress of cementing. Special high pressure pumps were used, and business caught on. The ex-truck driver eventually bought out his former boss.

Once an oil well is cemented bottom to top, troublesome water flows no more, but neither does oil. Drilling can open up the bottom, but other potential oil zones farther up the well remain entombed. The Roaring Twenties introduced the wider civilian use of guns, and in 1932 an Iowa State graduate named Walter Wells together with William Lane found a better use than bank robbing. Soon cemented oil well casings were being shot from within. Electrically detonated .45 caliber cartridges shoot radially from a "gun perforator" lowered the proper distance in the well, and holes penetrate casing, cement, and rock to allow hopeful entry of oil.

A special procedure in oil well cementing is called the "squeeze job," which despite the romantic implications is akin to pressure grouting. It a previously cemented and perforated well is flowing all wrong, a special packer may be inserted for local grouting under high pressure, thereby stopping the water flow and increasing well production.

PREPAKT CONCRETE

Another most intriguing use of grout is to make a kind of instant concrete. In the Prepaqt or Colcrete processes, forms are filled with coarse aggregate, then the aggregate is grouted with sand-cement-water to build concrete. A principle advantage is better interlocking of aggregate, minimizing shrinkage, and increasing strengths to as high as 13,000 psi (one year) or allowing use of less cement—as low as two bags to the cubic yard though three to five is normal.

The grouted concrete process is nicely adapted to fitting concrete in tight places like tunnels, piles, or around closely knit steel. Not that ordinary concrete can’t be pumped; it can be and is, but not so far. Underwater installations are also a favorite for the grouted concrete method—they require no de-watering and nobody climbing down into a caisson, and are built quicker in fewer lifts because some 60 percent less material goes through the concrete mixers. Mighty Mackinac bridge sits on Prepaqt piers, as does an occasional Texas Tower.

Grouted concrete does nicely at repairing old crumbly structures because the grout penetrates the old concrete, insuring a good bond.
GROUTS

Your doctor would be amazed at the number, variety, and combinations of internal medicines that are pumped down holes in the ground. Everything from sand to cement, clay, acid, water, plastic, asphalt, oat hulls, cellophane, temperament, and chewing tobacco.

Many of the chemical grouts carry trade names loosely connotative of the ingredients, if you already know what they are. Actually the exact recipes are trade secrets, secrecy being the best patent. There also is a little of that chemical or drug industry aura of mysterious nonsense to increase customer loyalty, i.e., augment the snow job.

Cement Grouts

By far the most common grout material is also one of the oldest, called neat cement, neat meaning pure as our tender hearts, and cement meaning portland cement plus water. Neat cement pumps well well and sets up admirably.

Cement shrinks a bit on setting, a peculiarly unfortunate circumstance in grouting. Shrinkage is sometimes prevented by addition of a sprinkle of metal dust such as aluminum, calcium, magnesium, or zinc. The metals react with alkali from the cement to produce bubbles of hydrogen gas which not only counteract shrinkage but build up a pressure, aiding gROUT penetration. Other bubblers which may be used are peroxide, calcium hydride, etc. Very important is not to use too much, or the grout may float off to the moon.

Cement + Filler

Cement is costly enough that where holes are deep or voids are large it is not improper to think of adding a little extender. Sand does nicely in soils with large pore openings, and does not decrease strength of the grout. Usually a little bentonite (montmorillonite clay) also is added to help keep the sand dispersed.

In cavernous problem areas such as limestone (as under most of the dams for TVA) a "prescription" grout may be concocted to try and reduce pumping losses; in goes the sawdust, rock flour, or whatever else looks cheap, bulky, and inanimate.

In many soils and rocks to be grouted, sand grains would cause clogging, and clay may be used as the extender. Whereas a cubic yard of neat cement grout might use 10 sacks of cement, a cubic yard of clay-cement grout may contain one sack (100 lb) of clay and only three of cement, because of the expansion and colloidal behavior of the clay. Lower strength after setting often rules out clay-cement for consolidation grouting, but it is still adequate for sealing leaks. Incidentally, in mixing, the bentonite is added first. That way it disperses better and goes farther.

Cement + Pozzolan

As you may gather, nowadays very little cement and water go into grout holes unaccompanied. Currently the favorite companion is a pozzolan. Pozzolans are fine grained and do not subtract appreciably from long-term strength because they react with lime released by the cement on hydration, building more cementing compound. Fine pozzolans aid dispersion and reduce bleeding. In most areas the cheapest pozzolan is fly ash, a waste product from power plants burning powdered coal. Fly ash has a property admirably suited to pumping—grains are spherical, nearly non-abrasive, they go through friction. Most grout now contains up to 50 percent fly ash. Pozzolan also slows the set and allows a longer pumping time, needed in grouting hot rocks in deep tunnels or oil wells.

It is also the best protection against a patent, if through some legal mishap the patent happens to belong to somebody else.
In very hot rocks or where fast hardening is not required, admixing lime can allow a further saving of cement, replacement going as high as 80 or 100 percent.

**Grouting into Sand**

Grout, like women and automobiles, can push its way into very tight spaces, but much energy is expended with little corresponding gain in beauty or convenience. Better is to use a finer grout.

Voids in sands are about borderline for ordinary cement grouting, although a finer grind such as high early strength (Type III) cement will still go. Alternately blast-furnace slag can be wet-ground to extreme fineness and used with NaOH (lye) or to replace up to 70 percent of the cement. If the only object of grouting is to stop leaks, clay alone may still be used.

A common criterion to check whether a grout will go is to divide the D15 size of the soil (size which has 15 percent finer) by D95 of the grout. For good grouting the ratio should be at least 15 or 20.

**CHEMICAL GROUTING**

The above grouts are all suspensions of solid particles, leading to clogging problems. More expensive but far more penetrating in fine pores are the chemical grouts, most of which are true solutions. They do cost more.

One of the oldest and best known chemical grouts, dating from the 1920's, is sodium silicate, or water glass. As the name implies, sodium silicate is soluble in water, but it will react with any number of other chemicals to make silica gel. Therefore grouting with sodium silicate is often a two-shot process—first the silicate, then the other chemical, usually a solution of calcium chloride. This goes by the name the Joosten process, which sounds like getting the juice in. The name comes from the inventor, a Dutch Mining Engineer named Dr. Hugo Joosten. The Joosten process chemicals do well in soils as fine as fine sands, but silts and in particular clays usually remain inhospitable to grouting. In some cases Joosten chemicals have even been used to further plug a soil already cement grouted.

Where pore size allows it, chemical grouts can be effectively diluted with clay to still give better penetration than cement or cement-clay. Compressive strength goes down, but may not be needed, particularly if the main goal is to seal off water.

**Single Shots**

An objection to the Joosten method is that it requires two shots of chemicals, meaning duplicate pumps and no control on mixing, which takes place after injection. Many one-shot chemical grouts have been discovered; unfortunately the added conveniences is usually paid for by lower strength. The two-shot process gives compressive strengths in sands of about 400 to 600 psi, while one-shot strengths run about 50 to 200 psi.

A one-shot timed-set sodium silicate grout may be concocted using any number of second chemicals or combinations such as sodium bicarbonate, hydrochloric acid, sodium aluminate, copper sulfate, or grandma's lye soap. Setting time is controlled by dilution, temperature, and amount of the second chemical(s).

A one-shot grout used at Heart Butte Dam, N. D., employed lignin (where did we see that before?) and sodium dichromate, which polymerize to chrome-lignin. Acid and ferric chloride controlled time of set.

Calcium acrylate polymerizes in the lab to a rubbery mass, but proved unduly sensitive to trace comicals in the soil. More successful have been trials with acrylamide methylene bis acrylamide (AM-9), a current hot prospect. Variations used in oil wells include gypsum cement (plaster-of-Paris), phenol-formaldehyde, gypsum-resin cement, and a host of other mixtures which make resins.
PRESSURES AND TECHNIQUES

Grouting pressure is a highly versatile variable, and is adjusted to either intrude grout into existing pore spaces, or ram it in where ordinarily it would not go.

In the early 1930's an Iowa State Highway Commission man named John Poultier invented a high pressure specialty called "mud jacking" to lift tired pavements. Mud jacking now saves many a mile where good pavement rests on sagging subgrade, and gives benevolent taxpayers that bad ride. Holes are drilled through the pavement, grout pipes are installed, and cement soil grout is pumped under to raise the pavement as much as needed. To prevent cracking of large slabs, the several holes either may be pumped at one time, or pumped a little here, a little there. Mud jacking also is used by railroads, in which case the grout is not shot in right under the slab because there isn't any; the grout is intruded perhaps 10 feet down into the embankment.

Similarly, grouting can be used to jack many settled or tilted structures, such as foundations, retaining walls, or leaning towers.

The oil industry makes unique use of super-pressure techniques to increase flow of oil by fracturing the oil-bearing rock. Water is pushed in to do the fracturing; then near-spherical grains of Ottawa sand prop the cracks open and make artificial sand lenses for the oil to creep through. Alternately acid may be used to add zest to the fracturing. Pressure fracturing has rejuvenated many otherwise dry holes for the oil industry.

No Lift Needed

Much more common is to keep grouting pressures under control so as not to cause lifting. Higher pressures are allowable in deeper holes because of the greater weight of overburden. Allowable pressure varies from about one to four psi per foot of depth, depending on competence of the rock.

The next question is how to apply higher pressures at greater depth, all in the same hole.

Two procedures are used: packer grouting, where a packer is inserted to seal off portions of the grout hole, or stage grouting, where each hole is drilled shallow and grouted with low pressure, then re-drilled deeper before the grout fully hardens and re-grouted with higher pressure. The procedure is then repeated. Grouting under heavy structures such as dams is usually done after the structure is built, to gain the advantage of higher confining pressures.

Refusal

An important part of grouting, like eating, talking or making love, is to know when to stop. The end point is called "refusal" when even under pressure the formation won't take any more. Sometimes curtain grout holes are drilled on "split spacing," where initial grout holes are widely spaced and tested with water pressure, then secondary grout holes are drilled in between and tested to check the effectiveness of grouting. Tertiary grout holes between the others are drilled only where needed.

REFERENCES AND ACKNOWLEDGEMENTS

For generous help, literature, and photos we owe thanks to the Chemical Soil Solidification Co., 7650 S. Laflin St., Chicago (p. 2L, 5L); The Halliburton Oil Well Cementing Co., Duncan, Oklahoma (p. 3L, 5R, 6R); and Intrusion-Prepakt, Inc., Union Commerce Bldg., Cleveland 14, Ohio (p. 1, 2R, 3R, 4).

Vast symposia on foundation grouting have been published over the past four years in A.S.C.E. Proceedings 83:SM2, 83:SM4, 84:SM1, and 87:SM2. Oil well uses are described in Oil-Well Cementing Practices in the United States; American Petroleum Institute, 297 pp., 1959.

Iowa State University studies in soil stabilization are sponsored by the Iowa Highway Research Board with funds from the Iowa State Highway Commission.
The Seventh Approximation
A New Pedological Scheme of Soil Classification

By RICHARD L. HANDY

Classification is the first handmaiden of science. Perhaps more precisely it should be called the wet nurse of science, later becoming its consort, in some sciences being elevated to queen supreme. Without classification, knowledge would be factual chaos, difficult to retain and impossible to understand, like women, horse racing, and social studies.

Actually, classification on the basis of need is one of our lower instincts, predating science by about the same amount that eyesight predates ophthalmology. For example, even the lowly worm will turn when he learns his two most pertinent categories of everything—can I eat it or will it eat me? In the case of parasitic worms the answers to both questions are yes, and the classification breaks down. Another instinctive classification is by sex, but the worm cannot make head nor tail of that either, being a bilateral opposed.

Scientific classification relies not so much on use or general appearance as on objective observations and attention to detail.

At this point we interrupt with a brief comment on the purported subject of this article, which is soils. The various engineering classifications of soils are rather closely allied with use. Or we can look more kindly and mumble that engineering soil classifications are based on properties which have engineering pertinence. As already implied, a use classification may be totally inept if the use should change. For example, a soil classification that works like a marvel for concocting a granular road base may be of only passing interest when strength comes from a chemical additive such as lime or portland cement.

A hidden goal in classification is to provide something to revise, and soil scientists in the U. S. Department of Agriculture have been revising. Re- vision of the soil classification has been uniquely implemented with a number of "Approximations" submitted to soil scientists the world over for comments and revisions. The new pedological soil classification is currently in the Seventh Approximation, and in another three years or so should be fairly complete.

Most soil engineers will feel sorely wounded by all this, for it is only rather recently that we have become familiar with what the soil scientists were up to 20 years ago. At the present rate of acceptance the present revision may take a couple of centuries to assimilate. Let us first review.

"The Entisols are those soils, exclusive of Vertisols, that have a plaggen horizon or that have no diagnostic horizon other than an ochric or anthropic epipedon, an albic horizon, an argic horizon, or, if the N value exceeds 0.5 in all horizons between 20 and 50 cm, a histic epipedon..."

The Seventh Approximation, Chapter 8, "Entisols."

The Russian School
Any history of science always refers to this school or that school, further illustrating our exaggerated regard for degrees in education. In the 1870's a Russian scientist named V. V. Dokuchaiev created some rather enduring fallout; Dokuchaiev noted that the character of any soil appeared to be the result of five factors of soil formation: climate, organisms (especially vegetation), parent rock, relief, and time. Vary one factor such as climate, vegetation, or parent rock, and you find a different soil.

The heart of Dokuchaiev's soil classification is the "normal" or "zonal" soil, which primarily reflects climate and vegetation, that is, geographic zone. A comrade named Sibertsev then suggested the concepts of "intrazonal" and "azonal" soils. Intrazonal soils primarily reflect some local factor such as excess water or carbonates (which relate to relief and parent material). A particular intrazonal soil may occur in several geographic zones. Similarly, an azonal soil crosses zonal boundaries, and is essentially unweathered parent material.

The Russian classification based on genetic factors has been periodically modified, kicked out, hauled back, and barely tolerated by numerous later workers. The Americans G. N. Coffey and later C. F. Marbut maintained that...
zonal soils to climate are illustrated in Fig. 1. Although each great soil group is defined on the basis of properties, the 1938-1940 classification is essentially genetic, and genesis invariably brings arguments. Some perfectly respectable soils have been left out because nobody knows which is the dominant factor. Furthermore, the Russo-American classification leaves no room for soil intergrades, which balks us liberals who look for answers in compromise. Nor is there provision for changes in soils due to cultivation or social climate, which provokes the Soviets who want it known that everything becomes better under Communism. Therefore, a new classification was needed—one based on soil properties (which relate to soil genesis) and not so closely oriented to prejudices regarding virginity. Any reasonable man knows one must love out of place, as on shoes, carpets, little boys, or pages of a two-bit novel. To a soil scientist or engineer dirt is a dirty word. It is not used.

A horizon.—Topsoil is more formally designated the A horizon. The A horizon may be either a dark-colored A<sub>d</sub> dark because of organic matter, or it may be a light-colored A<sub>g</sub>, light because of loss of clay, iron, and aluminum. The A<sub>d</sub> is characteristic of podzols and podzolic soils, podzol coming from folk Russian meaning ashy soil. An A<sub>g</sub> is a transitional horizon to the underlying subsoil. The A horizon may be a foot or so thick, more or less, somewhat and depending.

B horizon.—Subsoil is better termed the B horizon, and is even more variable than the A. It may be an accumulation zone of clay, iron, aluminum, humus, or a combination of these, or it may be a residual concentration of such materials. horizon due to plowing. A subscript to means cemented, so a C<sub>ca</sub> is a C horizon carbonate cemented into a hardpan, or duripan. The subscript x, as a B<sub>x</sub> or C<sub>x</sub>, indicates a "fragipan," or literally brittle pan, in other words a hard layer of high density. The x signifies what is known about its origin.

Progressive Education

Every soils man—engineer, scientist, shovel superintendent, or whatever, must dig these ABC's. Unfortunately the letters are not very completely descriptive; for example, they say nothing of the variability of different B horizons.

Fig. 2.—Gray Wooded soil (Typic Pale) on a Manitoba lake clay. The A horizon is white (A<sub>d</sub>) and overlies a clayey, somewhat blocky B. Below 24 in. is the C horizon.

Therefore, a few supplemental terms have been defined in the Approximations. The terms are for diagnostic horizons pertinent to the new classification, and the names smack strongly of the new soil classes. Actually when one understands what these are about, the rest, like sin, is almost easy.

Pedon.—First we come head-on with the pedon, which rhymes. The pedon is considered to be the smallest volume which satisfactorily represents a soil, and is analogous to the unit cell in crystallography. The pedon is thus a hexagonal prism ordinarily 1 to 10 sq m in area and with a rather vague lower limit.

Epipedon.—The epipedon (overpedon) is loosely the A horizon plus any of the B darkened by organic matter. In the new classification six kinds of epipedon are recognized, from Molly to Manure. Only 1, 3, 4, and 5 (asterisk) are common in the U. S.:

*1. Mollie (= soft) epipedon, a thick, dark, organic A horizon, Ca++ saturated, feels nice and loamy. Where the tall corn grows.

Fig. 1.—Idealized relationship of zonal great soil groups to climate.

<table>
<thead>
<tr>
<th>Order</th>
<th>Meaning</th>
<th>Approximate Equivalents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1... Entisols</td>
<td>Recent soil</td>
<td>Azonal soils, and some Low Humic Gley soils</td>
</tr>
<tr>
<td>2... Vertisols</td>
<td>Inversion soil</td>
<td>Grumusols</td>
</tr>
<tr>
<td>3... Inceptisols</td>
<td>Inception soil</td>
<td>Ando, Sol Brun Acide, some Brown Forest, Low Humic Gley, and Humic Gley soils</td>
</tr>
<tr>
<td>4... Aridisols</td>
<td>Arid soil</td>
<td>Desert, Reddish Desert, Sierozem, Solonchak, some Brown and Reddish Brown soils, and associated Solonetz</td>
</tr>
<tr>
<td>5... Molisols</td>
<td>Mollic Epipedon</td>
<td>Chestau, Chernozem, Brunizem (Prairie), Rendzina, some Brown, Brown Forest, and associated Solonetz and Humic Gley soils</td>
</tr>
<tr>
<td>6... Spodosols</td>
<td>Podzol (ashy)</td>
<td>Podzols, Brown Podzolic soils, and Ground-Water Podzols</td>
</tr>
<tr>
<td>7... Alisols</td>
<td>Pedalfer (Al-Fe) soil</td>
<td>Gray-Brown Podzolic, Gray Wooded soils, Non-calcic Brown soils, Degraded Chernozem, and associated Planosols and some Half-Bog soils</td>
</tr>
<tr>
<td>8... Ultisols</td>
<td>Ultimate soil</td>
<td>Red-Yellow Podzolic soils, Reddish-Brown Laterite soils of the U. S., and associated Planosols and Half-Bog soils</td>
</tr>
<tr>
<td>9... Oxisols</td>
<td>Oxide soil</td>
<td>Laterite soils, Latozols</td>
</tr>
<tr>
<td>10... Histisols</td>
<td>Tissue soil</td>
<td>Bog soils</td>
</tr>
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</table>

Disperses the clay, making for sticky problems. Southwest U. S.

4. Spodic (= ash) horizon, a B-horizon enriched with humus or sesquioxide such as Fe₂O₃ or both. No clay enrichment, no structure, no clay skins. May be cemented into a hard layer called an ortstein. Podzols.

5. Cambic (= changed) horizon, a mildly weathered horizon between the A and the C with original rock structure gone. Little or no structure, no clay skins. Does not form in sands.

6. Oxie (= oxide) horizon, a concentration of sesquioxide and kaolin clays due to removal of silica by strong weathering. Grows pineapple.

Orders

One of the first inspirational things man did when he invented language was to execute some orders, or was it order some executions? Anyway, we have a new language and a whole world to talk about, so let us sound off: Entisol, Vertisol, Inceptisol, Parasol! The first three are new names for soil orders. The last keeps the old sun.

Names of the soil orders are supposed to suggest vaguely the kind of soil. For

Subsurface New Words

1. Argillic (= clayey) horizon is a B-horizon significantly enriched with clay from above. The soil may break into blocks or “peds” that must show “clay skins,” which are thin coatings of oriented clay formed around soil pores, grains, or peds, giving a shiny appearance. Clay skins are most readily seen and verified under a microscope. Clay skinning has recently become a favorite outdoor and indoor sport among U. S. soil scientists.

2. Aegric horizon. Same as argillic but modified from long cultivation.

3. Natric (= sodium) horizon, same as argillic but with columnar or prismatic structure and over 15 per cent exchangeable sodium. Sodium

*This joke has peculiar academic franchise. M.S. = more of same; Ph.D. = piled higher and deeper.

Fig. 3.—Clay skin (white banded area) enclosing a soil pore (black) as seen under a polarized light microscope.

Fig. 4.—Chernozem ABC, North Dakota. The A is black, rootty, a mollic epipedon. The B is dark but weak, a cambic horizon. The white is a C₁₀₂. New classification is Haplaltoll.
example, Entisols are the exceptionally unweathered recent soils, formerly called Azonals. Vertisols include Black Cotton Soils or Grumusols, characterized by inversion, or vertical mixing due to sloughing into desiccation cracks. Our ultrarich prairie soils come under Mollisols, meaning they have a mollic epipedon (organic, calcium-saturated A-horizon). Alfisol looks like it might be

(Aqu/ent = aqueous recent) is the hydromorphic suborder of Entisols. Similarly, there are Aquert (hydromorphic Vertisol), Aquert (Inceptisol), Aquoll (Mollisol), Aquud (Spodosol), Aqualf ( Alfisol), and Aquult (Ultisol). A major overhaul from the old classification is that hydromorphic soils fall under six suborders. Other suborders of Entisols are Psamment (sandy), Ustent

beginning to have a rather foreign sound suggesting high Eksimo. Actually the resulting great group name is as easy as 1–2–3, only it’s 3–2–1. For example, in Arctic cold the Aquent becomes a Cryaquent, Cry means cold. Or an Aquoll (hydromorphic Mollisol) with an argillie or clayey horizon is an Argaquoll.

Subgroups

Stop us if you’ve heard this before, but Albollie Argaquoll! What we mean is the soil is not just an ordinary Argaquoll (see above), in which case it would be an Orthic Argaquoll; it is Albollie, Albollie denoting the subgroup and indicating an intergrade character with an Alboll—whatever that is. If we take it apart we see Alb, meaning white horizon, and ol, meaning Mollisol. Starting at the back, an Albollie Argaquoll should have a dark A horizon (ol), wet conditions (aqu), an argillic or clayey B horizon (arg), and least of all a weak albic or A1 horizon probably just above the B.

Finale

Beneath the subgroups remain as always the families and the basic mapping unit, the soil series. These still are named after a locality such as Ames, Boone, or Dubuque.

And that, friends, is the new pedological classification system in a nutshell and ready for roasting.

![Image](https://via.placeholder.com/150)

**Fig. 5.—Inversion in the Vertisols tips fence posts and eucalyptus trees, South Australia**

_Courtesy Guy D. Smith, USDA._

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<table>
<thead>
<tr>
<th>TABLE II.—GLOSSARY OF FORMATIVE ELEMENTS FOR ORDERS, SUBORDERS, GREAT GROUPS, AND SUBGROUPS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>aer…….most weathered</td>
</tr>
<tr>
<td>agr…….argic horizon</td>
</tr>
<tr>
<td>alb…….albic horizon</td>
</tr>
<tr>
<td>alf…….Pedalfer (Al-Fe)</td>
</tr>
<tr>
<td>alt…….high (cool)</td>
</tr>
<tr>
<td>and…….Ando (volcanic ash)</td>
</tr>
<tr>
<td>anthr…….man-modified</td>
</tr>
<tr>
<td>agu…….water-modified</td>
</tr>
<tr>
<td>arg…….argillie horizon</td>
</tr>
<tr>
<td>brum…….brum soil</td>
</tr>
<tr>
<td>cale…….calcic horizon</td>
</tr>
<tr>
<td>camb…….cambellic horizon</td>
</tr>
<tr>
<td>crust…….crusting</td>
</tr>
<tr>
<td>cry…….cold</td>
</tr>
<tr>
<td>cryp…….deep horizon</td>
</tr>
<tr>
<td>cumulic……accumulating</td>
</tr>
<tr>
<td>dur…….duripan</td>
</tr>
<tr>
<td>dystr…….low-base sat.</td>
</tr>
<tr>
<td>eutr…….high-base sat.</td>
</tr>
<tr>
<td>ent…….recent</td>
</tr>
</tbody>
</table>

(hot climate), and Udent (humid climate).

Great Groups

There are so many great groups we'll not be able to call them all, but there are the New York Yankees, Elks, Young Republicans, ASTM, Laurel and Hardy, and the Mills Brothers, to name a few. Great groups of soils further divide the suborders, and are indicated by a third syllable tagged on the front. You may notice that names are

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**Acknowledgments:**

The author extends his thanks to Dr. Guy D. Smith, Director, Soil Survey Investigations, USDA, and Dr. Frank F. Rieken, professor of agronomy, Iowa State University of Science and Technology, for their help and indulgence. Soil engineering research at Iowa State is being carried on under several projects of the Iowa Highway Research Board under sponsorship of the Iowa State Highway Commission.
SOIL CLASSIFICATION, II.

'Twas brillig...

Engineers are eminently practical men, and whether they're evaluating something for the job or furnishings for the home, such as a wife, the questions remain basically the same: Will it work, how soon will it wear out, and how much does it cost? Some engineers get on space-age jobs where these particular answers don't seem to make much difference, but practicality also can take other directions.

For example, in this outer space mischief you don't find one engineer sending himself up. There's always somebody better qualified, like officers, mice, and chimpanzees. Engineers are no astronauts, and they let the chimps be the chumps who ride the long shots for fleeting fame and speaking engagements. The thinking rocketeer maintains a proper perspective by keeping his feet on the ground, or on the desk if necessary, and letting the chimps fall where they may.

Speaking of on the ground, engineering classifications for soils are sweet and simple as a good night kiss on a lighted porch. That is to say they are usually adequate for the immediate purpose, such as to say good night, but they may leave something to be desired.

And so we present Part II of a II-part parlay on soil classification. The first, presented in the last issue, gave recent thinking of soil scientists, or agronomists. Now we are going to devastate soil engineers.

Three moisture conditions of soil:

<table>
<thead>
<tr>
<th>Solid</th>
<th>Plastic</th>
<th>Liquid</th>
</tr>
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</table>

Plastic limit | Liquid limit

The plastic limit (left) is the moisture content needed to make a soil plastic. Below the P.L. the soil crumbles when shaped by hand -- unquestionably the simplest and therefore one of the most criticized of all soil lab tests.

On the right, former Robert College soil mechanic Joakim (Jim) Laguros, now at Iowa State, tests for the liquid limit, or moisture content needed to make a soil liquid when tapped on $65$ standard machine. That's more like it.

In the 1920's the father of soil mechanics, Dr. Karl (or Charles) Terzaghi, came to this country after 10 years at Robert College in Turkey. Soon he met mother Chester Hogentogler, Senior Highway Engineer with the U.S. Bureau of Public Roads, and they became parents to the first and most widely used system of engineering soil classification. It was probably the greatest single advance in highway engineering since free air.

With almost startling insight and perception, Hogentogler and Terzaghi grouped soils according to performance as pavement subgrades, and roughly characterized the soil groups by pertinent engineering tests. A group soils gave uniform support to pavements, whereas B group soils did not. The latter were not very carefully defined and have since gotten lost.

A soils were classified as A-1 through A-8. An A-1 soil is as the tag implies, A-1 for highways, whereas A-8 is at the other extreme, like peat bogs. In-betweenes are in between.

This epic classification was published in 1929. Requirements for an A-number-one highway soil had been described a couple years earlier by C. M. Strahan in Georgia, who pointed out that the best is not a gravel or a sand or a silt or a clay, but a graded mixture of all...
sizes. And so it is with the A-1's in the engineering classification.

A-2 soils are almost like A-1's but they soften in the rain. Too much clay and fines.

A-3 soils are rutty, cohesionless sands, soft when dry. Too little clay.

Sizes in mix:

<table>
<thead>
<tr>
<th>Gravel</th>
<th>A-8, peat and muck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silt</td>
<td>Best .... Poor</td>
</tr>
<tr>
<td>Clay</td>
<td></td>
</tr>
</tbody>
</table>

A-4 soils are very fine sands without much granular interlocking as in A-1, 2, and 3, and without much clay. Not strong, and very susceptible to frost action.

A-5 soils are like A-4 but difficult to compact because of the content of mica or diatoms (Fuller's earth).

A-6 soils are clayey, swelling soils which need a tight roof or they become mud.

A-7 soils are like A-6 but more so. In addition they are spongy and difficult to compact. Much expansive clay mineral.

A-8 soils are utterly ugh. Peat and muck.

Organization Men

In the 1920's as highway engineering blossomed and engineers first became literate, they organized, the better to write things down and talk things over.

As a general rule when a group becomes larger than about 20 the time is right to either disband or break into committees so everybody has a chance. When the committees grow to about 20 or more you will begin to see subcommittees, and when these grow, sub-subcommittees, and sections and subsections, and so on, to the tune of Hi-Ho. Work is then pursued by a few while business is conducted by all the rest.

By the 1940's the Public Roads soil classification system had had extensive trial and was ready for revision. The Highway Research Board Committee.

Department of Soils Investigations Committee on Classification of Materials for Subgrades and Granular Type Roads Subcommittee Representing Highway Engineers did the job in fast time for a committee. They proved that the committee route is best for widespread acceptance, albeit quite a strain on individuality. D. J. Steele was subcommittee group leader.

The A soil groups remained much the same but were more precisely defined on the basis of sieve analysis and plasticity. By use of a key somebody who knows nothing about soils can now classify and talk knowingly.

<table>
<thead>
<tr>
<th>% sand + gravel (ret. on 200 sieve)</th>
<th>% fine sand, silt, clay (pass 40 sieve)</th>
<th>% coarse sand + gravel (ret. on 40 sieve)</th>
<th>% gravel (ret. on 10 sieve)</th>
<th>Plasticity Index Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;85</td>
<td>&lt;70</td>
<td>&gt;30</td>
<td>6 max</td>
<td>A-1-b</td>
</tr>
<tr>
<td>&gt;75</td>
<td>&lt;50</td>
<td>6 max</td>
<td>A-1-a</td>
<td></td>
</tr>
<tr>
<td>&gt;50</td>
<td>&gt;35</td>
<td></td>
<td>NP</td>
<td>A-3</td>
</tr>
<tr>
<td>&gt;65</td>
<td></td>
<td></td>
<td>A-2</td>
<td></td>
</tr>
<tr>
<td>&lt;65</td>
<td></td>
<td></td>
<td>A-4, A-5</td>
<td></td>
</tr>
</tbody>
</table>

*See graph of PI and LL (left column, next page).

The A-1, A-2, and A-7 groups have been subdivided, the subgroup number in most cases suggesting the near intergrade. For example, an A-2-4 is an A-2 with silt, like an A-4, an A-2-6 is an A-2 with clay, like an A-6. The only exception is in A-1; A-1-a contains gravel or stone, whereas A-1-b contains mainly coarse sand.

In the revised system soils also were given a "group index" based on plasticity properties and percent fines, and written in parentheses. The higher the group index the lousier the subgrade. Example: A-7-6(20) is not so good as A-7-6(18), although the difference would be

---

1Because of growing complexity many groups now use abbreviations. For clarity this should be HRDSTCOSGSRHBE.
scarcely distinguishable. When you can split differences to the vanishing point the classification may be considered real fine. Group Index is obtained from liquid and plastic limits and percent fines by means of an horrendous empirical formula, or from two charts, shown at right.

The modified Public Roads classification was subsequently adopted by the American Association of State Highway Officials and dubbed the AASHO (ash-o) system.

**Brief problem:** My back yard is strewn with boulders from 6 inches to 34 feet in diameter which catch in the lawn mower. Is there any way to correct this? I live at the foot of a cliff. -- Californian.

**Ans.1** According to the AASHO soil classification your back yard is A-1-a soil and you should have no problem; go ahead and build the road. As for the boulder, paint on a door and call it your fallout shelter.

**Another problem:** My husband tracks mud into the house. Upon drying, smashing and sieving I find that 45 percent passes the No. 200 sieve; the liquid limit is 60 percent water, below which the plastic range is down to 20 percent water. What do you recommend? -- Farm Wife.

---

**AASHO Classification of Fine-Grained Soils**

<table>
<thead>
<tr>
<th>Plasticity Index</th>
<th>Liquid Limit, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

- A-4, A-2-4
- A-6, A-2-6
- PI - LL = 30
- A-7-5
- A-2-7
- A-7-6

**Another ans.1** The way the population is growing one must never forget the group index! In the example above the group index is 3 from Chart 1 plus 6 from Chart 2, or 9. The full classification is A-7-6(9). You now may intelligently compare notes with your neighbors.

**Future Trends**

According to Will Rogers a hidden goal of classification is to provide something to revise, and the AASHO classification is again up for grabs. Current thinking based on highway engineering experience in Nebraska, Oklahoma, and Ohio is that group index charts should be extended or revised. Several charts have been offered, and an AASHO committee headed by Preston Smith of the Bureau of Public Roads is up to arbitrate.
UNIFIED CLASSIFICATION

In the early 1940's came a sudden need for many far-flung airfields, the better to deliver the mail. In the fury and scurry to get things going a visual soil classification appeared the thing, and in those Ivyed halls of Harvard a committee of one headed by Dr. Arthur Casagrande found itself in unanimous agreement on a new system.

A committee of one is best for getting the job done with a minimum of static but it is not so good for getting the point across. Casagrande used a professor's prerogative of teaching the new system to classes, primarily U. S. Army Corps of Engineers students.

The AC or Airfield Classification system was used by the Corps in the War, and after modification was adopted for peacetime by both the Corps and the U. S. Bureau of Reclamation in 1952. This singular point of agreement was so noteworthy the system is now called the Unified.

The first step in the Unified Classification is to decide if the soil is predominantly gravel, sand, silt, or clay. Usually this is not a difficult decision unless you are blind and can't feel. The soil is then tagged with the appropriate very difficult symbol:

G . . . . gravel
S . . . . sand
M . . . . silt
C . . . . clay

The symbol M for silt is the only one which doesn't seem logical, but S already has been used. M comes from Swedish mudder, signifying non-plastic silt or rock flour.

In addition two other symbols must be committed to memory:

Q . . . . organic
Pt . . . . peat

A soil is called Q if it stinks; otherwise Q soils test out like those in the M group. Peat is peat.

Gravels and Sands. If the soil is either a gravel or a sand, the next step is to determine if it contains appreciable fines. If it does, and the fine fraction is clayey or plastic and gives dry strength, the soil is a GC or SC (gravel-clay or sand-clay). It should be good to excellent as a foundation soil, moderately susceptible to frost action, and poor draining. Approximate AASHO equivalents are GC = A-1-a and SC = A-1-b, although GC and SC tolerate more plasticity.

If the fines are not plastic, the soil is GM or SM, which in general is not quite so good. Approximate AASHO equivalents, A-1 and A-2.

If on the other hand the sand or gravel contains but a mere pittance of fines, the engineer must make another kind of decision: Is the soil well graded? Ordinarily one hands out grades on the basis of tests, and this is still recommended, although those tested perennially take a
dim view. A well graded soil is like a well rounded personality (not a well rounded person) and is a conglomeration of all sizes or grades. A poorly graded soil is "skip graded"; it skips grades like a village genius. For example, the skip-graded child may have no sand, which eventually gives a problem product. For this description we need two more mysterious symbols:

W . . . . well graded
P . . . . poorly graded

GW soils are tops for subgrades, or road bases; GP and SW are about on a par, OK for subgrades but questionable for bases, and SP is another step down.

Silts and Clays. If a soil is over half finer than a 200 sieve, the classifying content is the liquid limit, or the moisture content at which the soil becomes liquid as defined by standard test. The dividing point is arbitrarily taken as 50, and we introduce two more secret symbols:

H . . . . high liquid limit
L . . . . low liquid limit

In general high liquid limit soils show high shrinkage and low liquid limit soils show low to medium shrinkage on drying.

The final question is whether it's a silt or clay. Dried just to the point where it crumbles (the plastic limit) a silt (ML or MH) crumbles easily whereas a clay (CL or CH) is tough and gummy. Completely air dried, the silt is weak and friable whereas clay forms a hard clod near ideal to bear a neighbor.

A third alternative plain as the nose on your face is highly organic silts and clays, designated OL and OH, depending on their liquid limit.

Problem: My boy friend has been dating me for 27 years but is afraid to ask me to marry him. Instead he goes swimming every day. Please tell me if there's anything I can put in his trunks to make him see things my way. -- Breathless Spinster.

Dear Spinster: Your boy friend obviously has feet of clay with a high liquid limit, or CH. This means that he will firm up if you can keep him out of the water. Another possibility is that the feet are OH, which are as the name implies, and little could be done, Q soils being the worst. Romance is dead when one of the party's feet smell ripe. Or perhaps he has a heart of stone, GW or GP. We suggest some classifying tests. Like does he favor pets and children, weep at movies, etc.

CAA CLASSIFICATION

The early 1940's were monumental for engineering soil classifications. In 1944 the youthful and zoot Civil Aeronautics Administration got into the act with the goal that a classification should be more directly applicable to runway design. The CAA system therefore included a popular strength test, the California Bearing Ratio. The ten soil groups were labelled E-1 through E-10.

The number of groups was later increased to 13 and CBR was dropped, and test criteria are therefore the same as for AASHO and Unified gradation, liquid limit, and plasticity index. However, the CAA system rates each soil group for either rigid or flexible pavements, taking into account local factors such as drainage and frosty climate.

For example, a fine sand classifies as E-2. With good drainage the flexible pavement rating is F3, with poor drainage and no frost it is F1, and with poor drainage plus severe frost it is F2. The F class is plugged into the appropriate design chart to give a minimum pavement thickness.
Example: With 60,000 lb single wheel load the F2 condition would require an 8 inch granular base course such as crushed stone, and a 3 inch bituminous surface course for a total of 11 inches, all on top of a 6 inch selected Fa class sand or bank-run gravel subbase.

For rigid base the soil in this example comes out R1a, which referred to another graph says that 12 inches of plain concrete or 11 inches of reinforced concrete should also do the job. (Cookbook engineering.) Other paving cookbooks use the CBR.

IN RETROSPECT

As any draft board knows or should know, mere classification at most tells only part of the story, and ultimate behavior of the draftee often depends on more subtle and less readily measurable aspects of his character such as family background, neighborhood, ego, battle jaundice, etc.

Engineering classifications similarly are strictly use classifications which, while necessary, ignore two very pertinent aspects of character: How did it get there and what kind of childhood? -- (1) and (2) below.

The college-educated soil therefore has the following minimum pedigree: (1) Geological parent material (limestone, glacial till, alluvial point bar, etc., plus formation name and age), (2) a pedological classification (A, B, C horizon, soil series, great soil group, and textural class), and (3) an engineering classification (AASHTO, Unified, CAA).

Cash & Carry. A cost-cutting advantage of the three-pronged guesification is that many geological materials or soil series which consistently test out the same are more readily mapped by eye than tested by hand. We now are learning that repetition of engineering classifying tests on hundreds of samples from the same deposit may be as reasonable as measuring a thousand rabbits to see if they all have long ears. True, you first have to know what are rabbits. Soil maps are already available for most areas. The geological and pedological approaches tell inherent character, and the engineering classification helps put to use.

REFER AND ACKNOWLEDGE


Iowa State University research in soil engineering is sponsored under several welcome projects of the Iowa Highway Research Board with funds from the Iowa State Highway Commission.

Currently Re-available @ 10¢

Electrifying Vol. 4 No. 1 on electrical drainage; lofty Vol. 3 No. 3 on air photo interpretation; cool Vol. 3 No. 1 on Alaska, and venerable Vol. 2 No. 5 on the Pleistocene.

RLH
TO THE EDITOR:

Will you accept a change in spelling, if we are about to use the word "uninhabited" in one of our papers? -- In the map on p. 1 of 2/1. It is clear that the word "uninhibited" was meant.

Yours for accurate spelling and explicit meaning,

J. E. Hunt
Texas Hwy. Dept.

THAT CRAZIES WINS A GIFT SUBSCRIPTION

TO THE EDITOR:

Actually, the paper is really good—just one suggestion—print it on softer paper.

R. W. Stump
Standard Oil Co.
Houston, Texas
(formerly at Iowa State)

MUST HAVE SOME SOFT, CUSHIONY OFFICE JOB

TO THE EDITOR:

...At first I thought some of it was due to typographical error, but as I read further I could see a definite elfishness peeking out.

Ernest Slade, Pres.
Okan Pipeline Co.

THE BEST PART IS THAT ELVES DON'T HAVE TO KNOW HOW TO SPELL.
Personalities

To the Editor:
Hooray write Screenings? It's damn good writing -- and we here at Power (McGraw Hill yet) take off our hat to a guy or guys -- or gals (we hope) who know how to write. Read Marmaduke Surfaceblow...

...tootle-pip
Steve Elenka
Power Magazine

More power to us.

To the Editor:
This (5/1) is obviously written by a bachelor engineer with a Freudian complex--which can be overcome! Don't take the old saying that "a bachelor is a man who has been lucky in love" too seriously.

Anon.

Who has the complex?

To the Editor:
I just read 2/3 (Soil-cement) and fell off my chair...I am happy to note that somebody has finally put some life into technical writing. Congratulations.

Mike Gray, Ed.
Highway Magazine

To the Editor:
You're killing me with laughter. Keep at it!

Henry Kallisen
Louisiana Polytechnic Inst.

There must be an easier way.

To the Editor:
...How I wish we had such writers in the military...

G. W. Rogers
Major, QMC

Oh, no you don't!

To the Editor:
I've gotten a real bang from the only two copies of "Screenings" that I've seen. At the conclusion I'm as anxious for more as a 40-year old at Minsky's...

Aside from being truthful, I'm also buttering you to get on the mailing list...

Bob J. Buehler
T. V. A.

Truth will out.

To the Editor:
We have an urgent request from Miss Borghild Bjorlykke, Vollebekk, Norway...

Frances Warner
ISU Exchange Librarian

Perils of a mailing list.

To the Editor:
We should much appreciate receipt of a SAMPLE copy of this periodical, so that we can determine whether it would be useful to us.

Particia L. Golton
Univ. of Cal. Library, Davis

We've had some complaints on the paper.

To the Texans:
Ames, Iowa, is a little outside this department's territory, but we can't resist paying tribute to a hep-talking egghead up that-away!

Thomas Turner in the Dallas Morning News

If you must, make it cash.
To the Editor:
...Your Screenings are the most refreshing items that pass over my desk.

Guy D. Smith
U.S.D.A.

Now that's a tricky way of pointing out the waste basket.

* * *

To the Editor:
...Please add Dr. Frantisek Skrivanek, Krasovské
seke Spolecnosti Narodního museu, Vaclavské
namesti 1700, Praha 2, Czechoslovakia...

J. F. Quinlan, Jr.
Austin, Texas

Were your hands correct on the typewriter?

* * *

To the Editor:
Today I referred Screenings to a geologist
with the Navy. He came up with sidesplitting
laughs, and said enthusiastically, "This man is
a genius." He said further that you could com-
pete successfully with Bob Hope.... For a
long time we did not know the name of the
author...

Ian Campbell
Cal. Div. of Mines

Sounds like you all must pour over every
word.

* * *

To the Editor:
I've enjoyed your articles very much; it
isn't often one can get an honest belly laugh
reading the present day literature.

Wayne A. Pryor
Illinois Geol. Survey

All one needs is an honest belly.

* * *

To the Editor:
Hooray for the Pleistocene!

Jane L. Forsyth
Pleistocene Geologist
Ohio Geol. Survey

Take your pick.

Technical Aspects

To the Editor:
"...clay particles....join together in
feathery wisps or flocules resembling bits of
wool and reminding one of dust under the bed."
(3/6) Reminds me of dust under the head.

Dr. H. van Olphen
Shell Development Co.
Houston, Texas

Dr. van Olphen is well known for his definitive
work with clay suspensions.

* * *

To the Editor:
I have recently had the pleasure of reading
several issues of your excellent publication,
and I was most favorably impressed by its
contents. I would therefore greatly appreciate
it if you would place my name on your mailing
list.

Karl Terzaghi
Winchester, Mass.

Dr. Terzaghi is regarded as the "father"
of modern soil mechanics.

* * *

To the Editor:
I have found pleasure in reading your
popular article entitled, "An unhurried look
at the Pleistocene." It is very well done and
I compliment you.

M. M. Leighton,
Chief emeritus
Illinois Geol. Survey

Dr. Leighton is a foremost authority and
"elder statesman" of the Pleistocene

* * *

To the Editor:
Considering that this topic (electroosmosis)
does not lend itself well for such a write-up,
you have certainly succeeded remarkably well.
In fact, I would like to buy up to 100 copies...

L. Casagrande
Harvard Univ.

Dr. L. Casagrande pioneered this field.
**Dept. Of Foreign Affairs**

To the Editor:

Since geologists in Venezuela are often in need of a humorous outlook, I would like to receive additional copies of *Screenings*.

R. H. Auerbach
Venezuelan Sun Oil Co.

---

**Ye olde mailing list grows unseemingly fast.**

To the Editor:

I have found considerable pleasure in reading your very interesting periodical...

Lew Wing Hing
Happy Garden, Malaya

We thought readers would be reassured to know there's a real place with a name like that. In our own disillusionment we would probably use it to tag a booby hatch.

---

**Dept. Of Defense**

To the Editor:

I have always enjoyed your paper but this last issue (3/1) has left me somewhat disturbed. I believe that your views on great soil groups of the Arctic and Subarctic are somewhat misleading. The great pedologic literature of northern Eurasia, Karavaeva, Noglin, Petrov, Filatov, Grigorijev, Sheludyakova, Sochava, among others. I am sure that if you were familiar with pedology and soil genesis you would not have made some of the statements that you did in this edition. Some people take their profession seriously. Please continue me on the mailing list.

J. C. F. Tedrow
Rutgers Univ.

---

**Humor is dead serious. (Insert comma before last word.)**

To the Editor:

We have read with pleasure and much satisfaction your recent coverage of Alaska in 3/1. Your treatment of the Alaska soil complex is excellent. Our thanks to you for such vivid reporting. Our Director Dr. Allan H. Mick has asked me to request 2000 copies for distribution throughout our state...

Paul F. Martin
Alaska Agric. Exp. Sta., USDA

---

**We ignored the Russian Literature.**

To the Editor:

(Reply to our inquiry—Where the hell is Dry Branch?) Believe it or not, Dry Branch, Georgia, is located at the geographic and spiritual heart of the illicit liquor distilling industry of the United States... It has not been dry at Dry Branch—spiritually—within the memory of man.

S. C. Lyons
Georgia Kaolin Co.
To the Editor:

I was both interested and properly amused by the catchy and informative way in which you have prepared that publication... However, it seems obvious to me that you have aimed your writings at a fairly select group of students and postgraduates rather than at the broad spectrum of practicing professional engineers.

T. M. Leep,
Exec. Comm., A.S.C.E.

Actually, we aim it at the boss—our boss.

To the Editor:

...For all my life I've had a deep curiosity to learn, a seeking, a craving for knowledge. Some of this thirst I've quenched by doing a lot of reading, but I still want to know how, where, why, what for, about many things...

P. R., Texas

Please consult your encyclopedia.

To the Editor:

Only one thing—how do I keep these out of my wife's sight? She finds them almost as hilarious as I do, so she doesn't get meals on time and such as that—like monopolizing the Screenings so I don't get to read them.

W. M. Haas
Michigan College of Mines

You may have to eat the words like (as) we do.

To the Dean:

Strange to say, my whole family, including wife and children enjoy reading this...

Don Kaser
Kaser Const. Co.

To the Editor:

After some years reading your vastly overrated journal "Screenings" I feel somebody should put you on to what people really think. Although the technical aspects sometimes look almost reasonable, frankly the jokes leave me cold. I daresay there has not been a single one I have not seen before.

RLH
Ames, Iowa

To the Editor:

Your two reprints were both of great interest to me, being subjects which I have studied from the viewpoint of collision geology... During Jan., Feb. and March of this last year I traveled over the greater part of Australia and New Zealand and in July I was in Penn... The material on Australia, New Zealand and Fiji will be published next year some time in a small book to be called Down Under and Off to One Side....

A. O. Kelly
Carlsbad, Cal.

That title is pure poetry.

To the Editor:

Will you please put me on your mailing list.

Wayne M. Biklen
American Safety Razor Co.

We must be sharp.

To the Dean:

Of all the pamphlets which cross our desk your Screenings is the best for a long time. We wish we could develop a style as readable and attractive for our own book.

Elwood Meschter, Assoc. Ed.
Rock Products

There they go crossing a desk again.

Sir or Madam:

I don't know who R.L.H. is, but I know he's good, (if he's a he). Of course I thought it must be an engineer; but still he writes too well for that...

H. R. Green
HOWARD R. GREEN CO.

could be a cockroach.

To Ye Olde Editor:

I should like to be placed on your mailing list for your publication "Screenings."

Clyde N. Laughter
Jefferson City, Mo.

Hal
Dept. of Commerce

To the Editor:

I can't help but wonder when you are planning to publish some of your selected works in book form. Your articles are at least as entertaining as those of Will Cuppy, considerably more informative, and certainly should have wide appeal to the engineering profession in general.

Bruce A. Lamberton
Chief Eng.
Intrusion-Prepakt, Inc.

* * *

To the Experiment Station:

This is an interesting collection, but is just that. As we sampled it around our Manuscript Committee, we've found that people aren't going to provide a very good market for collections of columns and we can't see just how to frame this up...

Marshall Townsend
Mgr., ISU Press

* * *

To the Editor:

In cleaning out my desk (for the year) I found a note concerning "Screenings". Comment: Mighty fine job - first technical paper I've ever read with practically the chuckles for Thorne Smith's books...

Sherman A. Smith
SHERMAN SMITH AND CO.

Does he make those Cuban cough drops?

* * *

To the Editor:

The line around the box on p. 6 of the last issue of Screenings should have been a bit thicker so as to represent more adequately the gloom (obituary type-partial) with which I view its "degeneration" to a quarterly.... I am appalled that anyone in his right mind could seriously consider reducing its frequency. If this happens to include you as author, then it may be dismissed on the ground that you are unavoidably biased and your opinion is therefore worthless.

Arthur H. Robinson
Univ. of Wisconsin

The error must be in your basic premise.

To the Editor:

Would it be possible to obtain three additional copies of priceless 2/1?

Chas. H. Merchant
Jenkins, Merchant & Nankivel
Springfield, Ill.

It's out of print.

* * *

To the Editor:

I am very much embarrassed that after your prompt reply I have neglected to send the promised remittance...

C. S.
Illinois

It's not in our heart to scold, just send the cash.

In Addition...

We thank you all for this fine issue. Mail has come at the rate of three to four hundred per year, which from a mailing list of 1000, half of whom are relatives who never write, is not bad. Included have been inspirational items like Chinese money, street car tokens, trading stamps, cold cash, books, reprints, and a re-usable April Fool card from England. It has surely been interesting mail.

In the Next Issue: TEST ROADS.

RLH
FOUNDATION ENGINEERING

As every woman knows and most men surmise, there's more to foundation engineering than meets the eye of the casual observer.

An historic example typifying need is when Queen Cleopatra's expanding political resources got stuck in her sedan chair, just when it began to look like Burton for certain.

"Give me liberty or give me death," Cleo was heard to proclaim. The local brotherhood of sedan chair carriers was glad to oblige, they being in current high level conflict with management over increasing use of the wheel. They argued that while a wheel might do the job all right, somebody would have to go along with each one to make sure it was oiled.

Queen Cleo sat steadfast and resolute as a southern governor, unable to make a move without endangering the entire robust substructure of her economy. Eventually she got hungry enough to eat crow, but owing to her high-souled heritage she got the asp instead. She was the first Egyptian queen ever to be buried in a sitting position, all on account of being struck by the asp in her sedan.

New building in Des Moines will stand on eight stainless steel "feet", four on each side of the building. Load is transmitted by columns to four gigantic concrete footings extending 40 feet underground.

More properly, foundation engineering pertains to design and construction of substructures for the support of buildings, dams, bridges, etc. It is probably safe to say that over 90 percent of all engineering structures are ultimately supported by soil. Those that aren't either fly, float, or fall over.

There are two reasons why foundations fail, both being ignorance. Because the ignorance is pretty evenly distributed among everybody involved, the event is often heralded as an act of God. This illustrates man's characteristic sense of fair play; we only allow ourselves to take credit for successes, whereas responsibility for a failure is automatically awarded to Higher Authority. We mean nothing personal; it's more a matter of who can and who can't be sued.

Yet every job is a calculated risk, and at worst it isn't even calculated. The problem is that soil is not something an engineer can look up in a handbook and order from the mill by number. Soil is individual. It's like progeny; you take whatever comes.

© R. L. Handy 1963
Anybody who would thus buy a pig in a poke should at least poke the pig. Unfortunately that still gives no guarantee the pork chops will be tender. Likewise one can poke holes in the soil and still not be sure of sameness between the holes. Maybe there's a fault, or cavern, or tunnel of an old gold mine. The only sure way would be to drill the holes overlapping, and that would leave nothing to build on. Thus some ignorance is excusable, and a calculated risk is inevitable. If things don't work out we know Who to blame.

Soil Tests

Class: Penetrometers

More scientific and therefore more exact than most building codes is to actually test the soil at the proposed building site. The simplest kind of test is to probe the soil to test its firmness; this comes under the general heading of Penetration Tests.

Subclass A: The Thumb. Almost common type of penetration test is to jab the soil with the thumb. The rule of thumb can be: count the joints buried and read the reciprocal, which happens to be in tons per square foot. For example, half-way to the first joint is 2 Tsf. The full depth of the thumb would be two joints, or 1/2 Tsf. For lower values you use your fist, and then your foot. If you go in over your belt, yell for help; it's quicksand.

Unfortunately for science, there appears to be a widespread disparity in the lengths of thumbs, not to mention differences in weights pushing. We have been thinking of mentioning this to ASTM with an eye to issuing a suitable standard. One difference between an architect and an engineer is that an engineer knows his thumbs. The architect first looking at soil tends to get it the other way around.

Subclass PP: The Pocket Penetrometer. For the man who is all thumbs with his thumbs a pocket penetrometer may be the answer. With this little gadget you measure the force required to push a small plunger 1/4 inch into the soil. Correlations have been made with unconfined compressive strength (mentioned later) such that the scale is calibrated to read directly in tons per square foot. No guarantees, of course, but at least you read a numerical answer, and this impresses a client. Alternately you can tattoo some numbers on your thumb.
Subclass Drill rig: The Standard Penetration Test is a kind of systematized comment on how hard it is to drive a sampling tube. The system is to count the hammer blows to drive the tube one foot. Since the hammer weighs 140 pounds and must be raised and dropped 30 inches per blow, machine power is a great aid.

The sampling tube, or "spoon", also is standardized. It is 2 inches in outside diameter and only 1.4 inches on the inside. The "split spoon" therefore displaces as much as it samples, so the sample is hardly what one would call "undisturbed", although some do call it that in moments of high humor.

Various schemes have been used to convert blows-per-foot, or N values, to bearing capacity. One can take a wild stab, divide by 10 or some such, and call it tons per square foot. Another recipe is to take the square root and multiply by a grading factor which is a maximum of 1 for a well-graded loamy gravel, 3/4 for a clean gravel or loamy sand, 5/8 for clean coarse sand, and 3/8 for fine sand, silt, or clay.

The Standard Penetration Test is most reliable in sands, where N is a surprisingly good indicator of friction. The angle of friction, discussed later, is approximately 28° + N/4. Good policy is to forget the N's for silts and clays, which are more accurately tested by other means, and keep them for sands, where other tests are very tough.

Subclass Dutch Cone. A more refined type of penetration test utilizes a conical tip. Penetration is slow and steady rather than by hammering, and the resisting force gives an indication of the strength of clays in Holland. Perhaps our interpretation is a little vague, but anyway the test does work well for soft clays. A similar cone may be driven in sands to estimate friction; a disadvantage is no sample.

FAILURE THEORY

Before proceeding with the proceedings we must halt and have a brief discord.

Are you confused by stress and strain, sines and symbols and legerdemain? Well, move over; they aren't all easy as π.

In an engineer's view, stress is the force and strain is the give. Stress is when the kids yell too much; strain is when you suggest they go play in the traffic. Stress is quiet and invisible, like an inner seeing anger; strain is distortion--the frown and the fist, the sickness or the laughter.

Avoiding the Breaks

Too much stress brings a break, whether in a material or a marriage or international politics, like Russians vs. Chinese. The result is termed a failure. Failures are brutally obvious, and only a doit would try to ignore them.

Engineers spend much of their time calculating failure stresses in advance, so they can keep actual stresses on the safe side. The stress well calculated to cause failure is divided by the actual stress to give a "factor of safety."

For example, lifting a 10 lb fish with a 15 lb test line means a factor of safety of 1.5, although not from the point of view of the fish. Factors of safety depend on human frailties of testing and arithmetic, and may not be entirely accurate. Maybe the fishline has a weak knot. Factors of safety are therefore termed factors of ignorance, but not in front of a client. A factor of safety less than 1.0 means you lose the fish, hook, line, and sinker.
Internal Friction

Foundation soils loaded in excess tend to fail by sliding along a shear plane. For example, consider the landslide; but perhaps you aren’t familiar with a one-party system.

The force, if any, resisting a land or other slide is termed friction. There is very little friction apparent in a one-party election, although there may be an abundance hidden away within the party. It’s the same in soils, where it is called "internal friction." In political parties it may be called internal friction, or it may be called "infernal friction" or "internal fiction," depending on whether it’s in your own group or in the opposition. To the innocent spectator it’s a little of both;

Soil sample loaded on ends fails by shear, which is resisted by soil internal friction. This sample was confined by air pressure during the test in order to increase normal pressure on the shear plane and increase friction (triaxial test). Pencil is used for writing down the results.

everybody knows there’s more infernal fiction in politics than in any other game except advertising.

In any crowded urban population such as soils, internal friction is no fiction, but is proportional to the amount of confinement. In soils this is termed the normal pressure, or pressure on the shear plane. The larger the normal pressure, the greater the frictional resistance to shear. In animate populations the forces causing internal friction are a little more abstract, and include such things as neighborhood acoustics, summer comfort index, traffic jams, and dog jobs on the lawn.

Friction

A graph of maximum friction versus normal pressure on the shear plane is ideally a straight line. The angle \( \theta \) is the angle of friction, and \( \tan \theta \) or \( S/N \), is the coefficient of friction.

Cohesion

You may think friction is a real drag, so let’s have a look at cohesion. Clays with little or no internal friction are still firm enough ground for some fancy footing work. Or to put it another way, a friction restriction is no cause for eviction. And cohesion is the reason. Many cities derive their main support from clays, not to mention other sources such as parking meters and taxing the poor.

Strictly speaking, cohesion is sticking together. In soils, as in most populations, it is best developed among the smallest members of the group, in this case clays.

The soil mechanic is not particularly interested in cohesion as a tensile strength, but is more concerned with the shear strength it causes. He therefore calls this shear strength "cohesion." That’s about like calling your husband "Van" because he comes home at night loaded. A more exact term for \( c \) is "cohesive shear strength," but nobody says that.

To summarize, each soil has a value of \( c \) and \( \theta \), cohesion and angle of friction, depending on such things as size gradation, compaction, moisture content, and clay mineralogy. The \( c \) and \( \theta \) can be measured by laboratory tests on undisturbed samples.
LAB TESTS

Most of us are familiar with lab tests of one sort or another, as when you are simultaneously jabbed in the finger, told to read the eye chart, and handed a sample bottle. By comparison, soil tests are much nicer; no pain and no strain.

The simplest way to measure c and $\phi$ in a soil is the direct shear test. A soil sample is trimmed to closely fit inside a shear box. The ends of the sample are loaded with a value of N, and two halves of the box are slid apart until the soil shears. The maximum pull per unit area of the soil mass is a value of S, which together with N gives a point on the S vs. N graph. A second test with a different value of N gives another point. Two points determine the line, from which c and $\phi$ are read directly. A third test is usually made for good measure.

A slightly more complicated way to get at c and $\phi$ is the triaxial test, meaning you give it the ax on the third try. Here the sample is covered with an airtight membrane and confined under pressure, much as it would be if it were still deeply buried underground. The ends are then loaded to failure.

In the triaxial test the position of the shear plane is not fixed as in the direct shear test, so S and N on the shear plane vary depending on the break angle $\phi$. The $\phi$ sometimes may be measured, but is more accurately found mathematically from Mohr theory. Experts say $\phi$ also equals $45^\circ + \phi/2$, if you care to heed the experts. Most people do, so long as they don't have to give up smoking.

APPLICATIONS*

This story had better observe the literary traditions and come to a climax pretty soon before it drags out into something severe, like a textbook. This may seem a rather long route merely to find out if a building will stand still or get a move on, but these things are nice to know in advance. It's too bad the perennial human conflict equations are not so well turned; might save on wars and such. It would also louse up the football pools.

Once the soil strength factors are known, there are several ways to analyze. One is to consider soil under a foundation as being in a triaxial test, A. But in order for the soil to fail it must bulge, which means it must cause failure of the horizontally oriented sample at B. The confining pressure at A equals the axial load at B, and the confining pressure at B equals the weight of the overlying soil surcharge in depth $D_s$. If you work through all those equals it comes out

$$q = \gamma D_s\left(\frac{1 + \sin \phi}{1 - \sin \phi}\right)^2$$  \hspace{1cm} (1)

for a $\phi$-soil, $\gamma$ being the unit weight of the soil. For a c-soil it comes out

$$q = 4c$$  \hspace{1cm} (2)

For a $\phi$-c soil it comes out very long.

* Either this is a misprint or this is the only place that isn't. We don't believe in half-way jobs.
Plastic flow

Another way to look at it, probably closer to the facts, is to consider the shear plane or planes which form when a building sinks irretrievably into the ground. The shearing resistance $S$ equals $c$ plus a function of $\phi$ times the length of the shear arc. The exact solution depends on the assumed shape of the arc and a few other things, and some rather horrendous equations are available. When a chemist sees an horrendous equation he memorizes it; it's poetry. When an engineer sees one he draws a graph.

Graphical solutions take the form

$$ q = \frac{\gamma_b}{c} N + c N_c + \gamma D_{s} N_q $$

where $b$ is the footing width and the three $N$'s depend on $\phi$ and are read from graphs.

Clay. In a $c$-soil the first and third terms practically drop out, and

$$ q = 5.7c + \gamma D_{s} $$

for a long footing, the second term depending on the depth below ground surface. For a square footing the first term is $7.4c$.

Sand. In a $\phi$-soil the middle term drops out:

$$ q = \frac{\gamma_b}{c} N_{\gamma} + \gamma D_{s} N_q $$

Bearing capacity is therefore a direct function of density $\gamma$, which means come high water there's hell. Buoyant effect reduces $\gamma$ and friction as much as one-half, whether under a building or at the toe of a landslide, as in northern Italy. Soil engineers rank high in prevention of mass tragedy. Some feel such a responsible profession would bear licensing, as in the case of other branches of civil engineering, not to mention doctors, lawyers, druggists, barbers, and morticians.

A somewhat less acute factor in the equation is footing width $b$. A 2-foot square footing on sand will support up to twice as much as four 1-foot square footings with the same total area. No spike heels on the beach.

Unconfined compression

The unconfined compressive strength of undisturbed soil samples is often used as a basis for bearing pressure. In a clay with zero $\phi$ the fracture angle is $45^\circ$, and the unconfined strength $qu$ equals $2c$. Substitution in equation (2) shows a built-in factor of safety of 2.0. By equation (4) it is 2.85 for long footings and 3.7 for square ones. Friction in a soil boosts this even higher, the limit being sand, which has a good bearing capacity but $qu$ equal to zero. Extra safe also means extra cost.

More to come

No discussion of foundation engineering would be complete without some mention of consolidation theory and settlement, field loading tests, and use of pile. We therefore would like to mention consolidation theory and settlement, field loading tests, and use of pile. A somewhat more complete account may be expected at some later date.

DEDICATION

This issue of "Screenings" is in memory of the late Dr. D. T. Davidson, under whose guidance the Iowa Engineering Experiment Station Soil Research Lab came to national prominence.

Following Dr. Davidson's untimely death a year ago Dr. R. L. Handy was named director, and work has been continuing at a rapid pace. All except for "Screenings." Some say the father ran off with some cute little Project to do some basic research, and desertion charges are pending. Meanwhile we expect the publication will be highly irregular.

rlh
Screenings from the Soil Research Lab

Vol. 8* December, 1964

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

Subject: PORTLAND CEMENT

Pardon us, but have you looked up, down, or sideways lately? Please do; we'll wait.

All right, what did you see? Please, not television or old election posters or more work. What you're supposed to see is CONCRETE. Because...

CONCRETE is the world's most abundant building material. The U.S. annual tonnage is about 5 times that of the nearest rival (steel), and last year the total world production of concrete was about 3 billion tons. With a world population of 3 billion people that means an average of about 1 ton per person. In the U.S.A. the quota is over 2 1/2 tons per person annually.

Furthermore, annual production of portland cement has doubled in the last 20 years. Since the world population is doubling only every 40 years, anybody with a grain of feeling for advanced arithmetic will see that by the year 2400 the world will not be covered by people, but by CONCRETE. Also it should be pretty obvious to anybody but a social scientist that we've been pushing the wrong pill.

Cement: The basic recipe for portland cement is as follows: Take one cup limestone, crushed; add one-half cup of clay or pulverized shale (plus perhaps some sandstone or iron ore, depending); mix thoroughly and grind up fine; bake in a white-hot oven, 1400 or 1500°C; cool, add one tablespoon gypsum, and grind very fine. If you can do this for a dollar a bag (94 lb) you can almost compete.

Concrete: To make CONCRETE, take one cup portland cement, 2 of sand and 3 1/2 of gravel, blend thoroughly, and marinate in just enough water to make a thick batter. The thicker the batter the stronger the concrete.

The concrete is now ready to pour. Be sure to grease your pan first, and after pouring you'll want to slap it around a bit or vibrate to get the excess air out. Cover with wet towels for one week, and we guarantee you will look like a new slab.

Now you know the business, please do not say "cement" sidewalk or "cement" structure. There is no such thing as a "cement" sidewalk. The sidewalk is CONCRETE. Or wood or bricks or grass or gravel or muck or tank traps. Our neighborhood specialty is pitfalls, dog manure and chewing gum.

© R. L. Handy 1964

*This is the first Screenings of 1964, the last being V. 7 No. 1 on foundation engineering. The reason we waited so long was to wish you a Merry Christmas.

1If you have not received yours, write the Portland Cement Assoc. Our thanks to the PCA for photos.

Apartments
Chicago. From the bottom, boats, cars, and people.
(Top photo. Four-level highway interchange, California.)

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Histerical Aspects

Portland cement, like the vote for women, is a 20th century innovation based on an 18th century invention that was in developmental stages from the time of the Pyramids. The Egyptians cooked up crude plaster-of-Paris to stick their masonry together, with hieroglyphics as follows:

\[
\text{gypsum + heat} \rightarrow \text{plaster-of-Paris + steam} \\
\text{CaSO}_4 \cdot 2\text{H}_2\text{O} \rightarrow \text{CaSO}_4 \cdot 1.5\text{H}_2\text{O} \rightarrow 0.5\text{H}_2\text{O}
\]

Mix the resulting powder with water, and the operation shifts into reverse:

\[
\text{plaster-of-Paris + water} \rightarrow \text{gypsum}
\]

Or as the great Egyptian philosopher AOK (Dogface) put it, Hot Rock make Magic Powder; Magic Powder plus Water plus Magic Words (now so-called Countdown) make Rock.

Blimey

Gypsum cement slowly dissolves in wet climates, so it's a good thing Egypt never tried to export any pyramids. After a few thousand years the Greeks and the Romans began to resent oblique references to backward areas in the North, and they decided to get with it and build their own civilizations. Naturally a first requirement was good mortar, and they discovered if they cooked limestone they got lime:

\[
\text{limestone + heat} \rightarrow \text{lime + gas} \\
\text{CaCO}_3 \rightarrow \text{CaO} \rightarrow \text{CO}_2
\]

For mortar, the reaction is essentially the reverse; lime first hydrates or slakes to \( \text{Ca(OH)}_2 \), which in turn reacts with \( \text{CO}_2 \) from air to make limestone plus water:

\[
\text{lime + carb. dioxide} \rightarrow \text{limestone + water} \\
\text{Ca(OH)}_2 \rightarrow \text{CO}_2 \rightarrow \text{CaCO}_3 \rightarrow \text{H}_2\text{O}
\]

Both the lime and the gypsum mortars are still widely used in plastering, in case anybody wants to get plastered.

Carbonation behind closed doors can be slower than loss of prejudice, and some of the more compact Roman mortars still are not carbonated after a couple thousand years.

Pozzolanic CONCRETE

Roman dabbling in lime concrete soon led to a momentous discovery which ushered in the era of silicate cement chemistry, not to mention Tiberius and the Roman Empire. According to Vitruvius, who was the first engineer who knew how to write (and some say the last):

"There is a species of sand which, naturally, possesses extraordinary qualities. It is found... in the neighborhood of Mt. Vesuvius; if mixed with lime and rubble, it hardens as well under water as in ordinary buildings."

This under water deal made a rather catchy slogan, and the new concrete, we mean CONCRETE, caught on like a sweaty girdle. Most of the famous Roman structures, such as the Coliseum, employ this concrete. The Pantheon has a solid concrete dome with 142 foot span.

Restaurant, Xochimilco, Mexico. The sky is not falling; this reinforced concrete shells behave as membranes in distributing stresses. The earliest thin shells were on eggs.

(Above, right) Century 21 Exposition, Seattle

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The special ingredient of Roman concrete was a volcanic ash called pozzolan after the Italian town. Other much-used pozzolans are Santorin earth, from the Greek island; trass, from terraces along the Rhine; burned clay or pottery; and fly ash, from burnt flies.  

Concrete dams provide a big, big incentive for cement chemistry research. Hoover Dam (right) led to development of a new low-heat (Type IV) cement. In the 1950's, Hungry Horse brought on a return to pozzolans.

### Middle Ages

A Middle-Aged burst of conservatism revived stone cutting at the expense of pozzolanic concrete, while foreign policy turned off on a series of righteous Crusades. Finally after about the 14th century they quit enough of their Holy Grail to rediscover pozzolanic concrete, as well as art, science, and a few other little incidentals like America.

***Merrie Olde Milestones***

And so we leave the sunny shores of the Mediterranean for the misty shores of Ye England. In 1756, famous English engineer John Smeaton was commissioned to build a lighthouse on account of the fog. Through kitchen table experiments and the Scientific Method Smeaton learned that the best lime for lighthouses came from dirty limestone, or one with clay in it. The new lime set under water even without pozzolan, and is therefore a "hydraulic lime".

Some 40 years later James Parker discovered "Roman" cement, named for its fancied resemblance to Roman pozzolan which it did not resemble, but then that's  

3 This is a slight misrepresentation, but then it's a political year. Actually fly ash is from burnt coal.  
4 There's no very good way to take them with us.  
5 In the interest of brevity we have eliminated the first seven tables. Plus a whole bunch of chairs.

advertising. Parker's cement was made from naturally occurring clay-limestone nodules or concretions. Similar "natural cements" were soon in production in France and the U.S., and dominated the market until about 1850. Natural cement was used in the Thames Tunnel, Brooklyn Bridge, and Erie Canal. Natural cement differs from hydraulic lime in that after burning it requires grinding.

**Portland**

In 1824 Joseph Aspdin patented a "Portland Cement", named for a fancied resemblance to Portland stone. Aspdin kept his process such a secret that nobody knows just what he invented or when he invented it. Key principles are to add clay to limestone if the stone does not already contain it, and to mix thoroughly and heat very hot. The first were known prior to Aspdin, so his secret must have been in the heating, but it may have been 1850 or so before he finally made things hot enough.

Portland cement concrete caught on and soon took over, and by 1905 most of the stone cutters were again out of business.

Main construction materials B.C. (Before Concrete) were brick and stone. This eastern Iowa quarry, opened in 1894, was about the last word in the Iowa cut stone industry. Around 1900 the bottom fell out (cf. photo).

### Clinker

Look out, Little Egypt; here come the hieroglyphics again. Burned and unground cement is called clinker. Four compounds are now known to put the clink in clinker:

<table>
<thead>
<tr>
<th>Table 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₃S = tricalcium silicate</td>
</tr>
<tr>
<td>C₂S = dicalcium silicate</td>
</tr>
<tr>
<td>C₃A = tricalcium aluminate</td>
</tr>
<tr>
<td>C₄AF = tetracalcium aluminoferrite</td>
</tr>
</tbody>
</table>
Chemists with previous educational bias may see something strange about these formulas: C does not mean carbon; it means CaO. Likewise Si stands for SiO₂, A for Al₂O₃, F for Fe₂O₃, and H for H₂O. It's a cement chemist zip code.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Setting Rate</th>
<th>Strength</th>
<th>Heat Evolved</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₃S</td>
<td>Fast</td>
<td>Strong</td>
<td>Temperate</td>
</tr>
<tr>
<td>C₂S</td>
<td>Slow</td>
<td>Strong</td>
<td>Cool</td>
</tr>
<tr>
<td>C₃A</td>
<td>Fast</td>
<td>Weak</td>
<td>Torrid</td>
</tr>
<tr>
<td>C₄AF</td>
<td>Fast</td>
<td>Weak</td>
<td>Tropical</td>
</tr>
</tbody>
</table>

C₃S is current No. 1 compound in portland cement. C₃S is for engineers who prefer their cement like their women—fast, strong and hot. C₃S is the major compound in high-early strength cement, which is ground extra fine so it will react faster.

C₂S. Engineers who think cool prefer more C₂S in their portland-great for big dams, where cooling of the mass concrete is one big dam problem.

C₃A fits into the picture about like the Other Woman: a real trouble-maker, useful mainly to flux the clinker. Unguarded, it reacts so fast with water it causes "flash" set. C₃A is usually guarded with gypsum, which reacts to make a sulfoaluminate coat and slow things down.

Unfortunately C₃A compounds also react with sulfates coming in later, after the concrete has hardened. Very pretty little sulfoaluminate crystals ("ettringite", or "cement bacillus") then grow in place and blast everything apart. To avoid such impromptu reactions C₃A content may be minimized.

---

6 The eventual goal of the zip and similar schemes is of course to eliminate names altogether.

Dear 442-50569-8812 (Mom): How strange to know who I am again, after all these years as a wrong number. You remember they started sending all my mail to my license plate; meanwhile I sold my car. Then 729-40438-0036 (my wife) thought my number was up (drafted and killed in the war) so for the next 17 years I went under an assumed number. Now it looks like all our children are bastards unless I can get things straightened out. Also we're expecting a .6 any day now, so there's the question of one more tattoo... As ever, your loving son, OOX.

7 Not to be confused with "false" set, which is usually caused by gypsum going to plaster-of-Paris during grinding.

---

C₄AF is useful as a burning aid and doesn't have all the bad qualities of C₃A; hence the need for an occasional shot of iron ore in the raw batches. C₄AF gives cement its gray color, and may be left out for a white cement.

<table>
<thead>
<tr>
<th>Average Compositions of Portland Cement</th>
<th>C₃S</th>
<th>C₂S</th>
<th>C₃A</th>
<th>C₄AF</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-early</td>
<td>58%</td>
<td>16%</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Ordinary</td>
<td>53</td>
<td>24</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Moderate heat</td>
<td>47</td>
<td>32</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Low heat</td>
<td>26</td>
<td>54</td>
<td>2</td>
<td>12</td>
</tr>
</tbody>
</table>

Other compounds. Add up the figures across Table 10 and you see we've been short-changed about 8%—too much for rounding off and too little for income tax. Included are the gypsum (about 2-3%), plus free lime and other oxides MgO, Na₂O and K₂O. MgO is limited to 4 or 5% because it slowly hydrates and expands; the alcalis Na and K are minimized where they may react with local aggregate.

Fieldhouse, University of Illinois, Urbana; site of many a startling upset.
Storyline HYDRATION

So much for lights and camera; now for the action. That is, in building anything from a romance to a football team the main concern is the end product or the coach gets fired. So getting back to today's romance:

The end product of portland cement hydration is mainly a calcium silicate hydrate (C-S-H) similar to the mineral tobermorite, named for Tobermory, Scotland. The crystals are so fine they can be seen only with an electron microscope, and can be identified only by X-ray diffraction. They have such a large surface area they are usually tagged tobermorite gel.

The C/S ratio in tobermorite varies from about 0.8 to 1.7 or more; in concrete it's about 1.5:

1. $2C_3S + 6H + C_2S_2H_3 + 3CH$
   tobermorite  lime  gel

2. $2C_2S + 4H + C_3S_2H_3 + CH$

Note that both $C_3S$ and $C_2S$ give the same hydration products; the main differences are in rates of hydration and the amounts of released lime.

Although tobermorite gel is by far the most important product, chemistry buffs may be disappointed if we don't mention what else happens:

3. $C_3AH + H = C_4AH_19$
   or $C_4AH_{13}$ (hexagonal plates)
   or $C_3AH_6$ (cubes)\(^8\).

4. $C_4AF + H + CH = C_3AH_6 + C_3FH_6$ (both cubic)\(^9\).

Apparently relatively large (but still microscopic) cubes and hexagonal plates do little for strength, because there's not much muscle from either reaction 3 or 4.

The gypsum necessary to keep reaction 3 from going too fast behaves as follows:

5. $CaSO_4 \cdot 2H + C_3A + H = C_3A \cdot 3CaSO_4 \cdot 32H$
   ettringite

Ettringite coats the $C_3A$ grains like a steady date, delaying rival reactions but not stopping them indefinitely.

Water-cement ratio

Engineers claim more concrete has been ruined by morons standing at the concrete mixer with a water hose than by anybody else except architects. Water makes the mix sloppy and easy to pour, but reduces ultimate strength in proportion. A water-cement ratio of 0.4 (by weight) is apparently sufficient for hydration and filling capillary voids; in practice the ratio is ordinarily upped to 0.5 to 0.6 for easier placement.
Tiny Bubbles

One of the most fantastic detective stories in the annals of cement research concerns a rather casual use of beef tallow as a grinding aid. A few concrete jobs were found to have unusual tolerance to frost action or scaling.

The answer was found in billions of tiny bubbles dispersed throughout the mortar, providing cushions against expansive pressures of ice or salts. Today air entraining agents (oil, soap, resin, etc.), either added at the mixer or already in the cement, are used for most exposed concrete work.

Puzzlin's

Hydrating portland cement liberates a colossal amount of lime (CH in eq. 1 and 2). Thanks to clues from the Romans, pozzolans are often used to tidy up the reaction; they are cheap, and convert lime into additional cementing agents. Used in sufficient quantity they help resist chemical attack and prevent the alkali-aggregate reaction (below), which is one reason pozzolan is puzzlin'.

The most commonly used pozzolan in the U.S. is fly ash, from burning of pulverized coal. Fly ash is mainly microscopic spheres which give a ball bearing aspect to the mix, good for workability and especially pumpability, as in grouting or cementing oil wells.

Some of the other admixtures to concrete are even more puzzlin': Calcium chloride speeds the set by some devious means. Dispersing agents ("Pozzolith") disperse the cement and increase fluidity with the same water content. Aluminum powder reacts with released lime to make gas bubbles, offsetting shrinkage or making a lightweight concrete. Other chemicals are catalysts, wetting agents, water repellants, accelerators, retarders, plasticizers, stiffeners, or a combination of ingredients like your doctor recommends.

Other cements

The old-fashioned natural cements in the U.S. are mainly C3S plus 10 to 20 percent MgO; because of the low burning temperature the MgO hydrates fairly rapidly and doesn't make trouble. Recent work at ISU indicates certain dolomitic limes are cements, MgO converting to Mg(OH)₂.

Aluminous cement uses bauxite instead of clay as raw material, and is mainly CA. It hydrates so fast the product is gel, with full strength in 24 hours. Portland-blast furnace slag cement blends have pozzolanic properties. Masonry cements are mainly portland plus plasticizer, such as hydrated lime.

Not to mention oil well cements, which have enough iron in the raw mix for zero C₃A content, or utilize pozzolans or special retarders for slower set at high temperatures. Supersulphated cement and some experimental expansive cements have generous calcium sulphate which reacts with C₃A (eq. 5) to make ettringite and bulk up the concrete. Where else in this mad, mad world will you find anything so wild and substantial as concrete? Nowhere, man, but no where...

RLH
A CHILD'S GARDEN OF SHEAR STRENGTH

The earliest recorded example of shear strength was when a go-go girl name Delilah used sartorial wiles on a longhair named Samson, who is the good guy in this story.

Although Samson subscribed to the fad of letting his hair grow, he was no ordinary Berkeley potted plant. For example, Samson once turned loose 400 foxes with their tails set on fire. He also coolly dispatched a thousand of Delilah's neighbors with the jaw-bone of an ass, and that was before slaughter by jaw-bone became commonplace, as at cocktail parties, etc., where it passes for intelligent conversation. In fact, jawbone of ass is hardly considered a lethal weapon any more.  

Delilah's people were sorely vexed by Samson's pranks, most especially the killing, so she took him to a trimming. It left him weak as water (this was before pollution), and Delilah's cohorts collected an eye for an eye until halted by the shortage. Thus un-eyed, Samson still made a comeback when his hair grew back -- he stood up and slew them all, including himself.  

Lookout, There's Quicksa...!

Another early example of shear strength was when Sir Walter (anything-for-a-laugh) Raleigh gallantly laid down his coat for Queen Elizabeth to walk on, knowing full well that underneath her royal dignity lay a large puddle of quicksand. They called this the Age of Chivalry, because afterward he helped her out.  

When setting force exceeds friction, real estate values perceptibly slide -- hence the term "Skid Row". Part of this slide in Des Moines was subsequently stabilized with lime. Watch for details in ASCE "Civil Engineering".

Real quicksand is not a matter of fineness or round particles, because given the right conditions any sand can be quick. The cause is water which seeps upward fast enough to lift the individual sand particles until they are no longer in continuous contact. No contact, no friction that quick!

According to the great Arabian mystic Algebra, the critical condition for quicksand is

\[ i_c = \frac{G - 1}{1 + e} \geq 1.0 \]

where \( i_c \) is the hydraulic pressure gradient needed.

---

1. Would you believe 300?  
2. It's getting so now we even celebrate the ass. Just have a look at Congress.  
3. Now known as blind fury. Probably he had just had a round with the assessor.  
4. A sense of humor like that could get one sent to the Tower. And so it did.  
5. He wanted his coat back.  
6. Contrary to popular misconception, it is impossible to sink over your head in quicksand unless you go in head first or wear jewelry. If you don't believe us, ask Archimedes. Buoyant force = weight of fluid displaced. Since quicksand has about twice the density of water, you will have to work at it to go in much over waist-deep.

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to keep quick, G is the sand specific gravity and e
is its void ratio. In other words to prevent quickening
keep the water pressure low or increase its
length of flow:

Friction Ain't Novel

It's a fact of human nature that dynamic friction
generates heat which readily percolates into violence.
Obviously what the world needs is air conditioning
plus a good shot of lubricating oil. One of the best
is oil of chuckle -- it's hard to hate a clown, and
man turned loose has all the instincts and bluster of
top banana. Unfortunately he overlooks the humor--
if he only saw how funny he was he might ease off.

The laws of mechanical friction were discovered
by the one major artist with enough talent to make it
as an engineer, Leonardo da Vinci. People naturally
recognized his pictures but not his vision, with the
result that his discoveries on friction were forgotten
for a couple centuries. Leonardo is a most unique
example of a man before his time.

Leonardo discovered that friction depends on
weight but not on contact area, something to remember
before you buy wide tires. These two laws of
friction were rediscovered by the French architect
Guillaume (Bill) Amontons in 1699, and are sometimes
referred to as Amontons' Laws. They can be expressed
by one equation,

\[ F = kW \]

Amontons also observed that rough surfaces make
more friction, and reasoned that surficial bumps
must either push down or lift over one another for
sliding to occur.

The "up-and-over" model for surface friction was
attractive to the mathematically inclined, particu-
larly those inclined at the angle \( \phi \), which is known
as the angle of friction. If sliding is incipient on
a surface roughness inclined at an upward angle \( \phi \),
the upslope component of friction must equal the
downslope component of weight, or

\[ F \cos \phi = W \sin \phi \]

\[ F = W \tan \phi \]

This is the same as the previous equation with
\( k = \tan \phi \), and leads to such wild utterances as "the friction angle is the angle whose tangent is the
coefficient of friction." You probably knew that, but
we just thought we'd throw it in.

Hand Warmers

The up-and-over theory went unquestioned until
the early 1800's when a British physics professor
named John Leslie had a question. The British,
like the French, frequently rub their hands toge-
ther, albeit for different reasons. (The British do
so to keep warm.) Leslie reasoned that frictional
ups must be equalled by downs or the surfaces
would fly apart. If ups equal downs, where is the
energy dissipation, commonly in the form of heat?

The answer came in 1950 when two English physical-
ical chemists, F. P. Bowden and D. Tabor, published
a modern classic, "The Friction and Lubrication of
Solids."

Bowden and Tabor showed that the actual contact
area between two apparently smooth surfaces is re-
latively tiny and is proportional to load. Friction is

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Recent tests by Youd at Iowa State indicate that vibration may reduce the critical void ratio, practical implications being in earthquake damage and in artificial compaction. Earthquakes hit hardest where cities rest on loose sand, per recent examples in Alaska and in Japan.

**Dilatancy**

Although adhesion theory of friction has its adherents, the old up-and-over concept remains pertinent to soils. Shearing of a granular soil is analogous to rubbing two pieces of sandpaper together -- the grains interlock, preventing movement unless allowed to separate slightly.

The same sexy behavior is found in dense sandy soils -- shearing causes an increase in volume, as the grains in the shear zone slide up and over one another. Part of sand internal friction is therefore surface friction, and part is due to packing. Therefore to strengthen an argument or a sand, compact it.

Angle of Repose

A wide variety of angles of repose may be seen on beaches and sundecks, particularly since the advent of the bikini. However, for angles of repose within everybody's grasp nothing can beat the voluptuous backside of a sand dune. No falacious attempts to uplift, conceal, or expand on the true facts -- instead merely an angle generated by sliding sand.

Our real reason for getting excited is that this is a very neat way to measure internal friction, since the angle of repose equals the angle of internal friction without any dilatancy component, which might unduly bulge the bikini.

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7 Not to be confused with "dilatation", which is stress-induced volume change of a solid, or with "dilation", which is a stress-induced volume change caused by overeating.
Pore Pressure

On a hot day pore pressures soar, so people naturally tend to keep their distance and avoid rubbing elbows. Pore pressure in a soil also tends to prevent close contact and reduce friction, a fact recognized by the late and great soil mechanic, Karl Terzaghi. Terzaghi said in effect

\[ \tau = (\sigma - u) \tan \phi' \]

where \( \tau \) is shear strength, \( \sigma \) is applied normal pressure, and \( \tan \phi' \) is the "effective" coefficient of friction, i.e., after corrections for pore pressure.

This means that if you load a saturated soil but don't allow drainage, the grains don't touch any harder, and intergranular friction stays the same. The applied load is all taken by the pore water, and is reflected in pore water pressure.

Pore pressure can be either positive or negative--positive from compression of the soil structure, or negative during dilatation. Negative pore pressures are additive to the applied load, and temporarily increase shear strength.

PORE PRESSURE

\[ (+) \quad (0) \quad (-) \]

Reduces...................... Increases Friction

The most important implication of pore pressure is in construction--build too fast and heavy, and positive pore pressures may cause catastrophe. Where problems are anticipated, pore pressures are determined by measuring water levels in vertical pipes in the ground, termed piezometers.

Students!

Graduate assistantships and fellowships are available to top students interested in graduate work in Soil Engineering at Iowa State University -- just mention "Screenings" when you write.

Question: I have a brother-in-law who smells like an Airdale because he's afraid that intergranular friction plus dilatancy might cause him to get stuck in the bathtub. Would positive pore pressures help him out?

---Anxious

Dear Anx: Yes. However in view of the enormity of the problem we would suggest that he use a shower or go to the lake.

---Playboy

Question: I recently drove on the beach at Ft. Lauderdale to test my car's pick-up. The pick-up was a beaut, but my car later got stuck in the sand. The next day the car was gone. Why?

---Miss America

Dear Mr. P.: Wet (not saturated) sand has negative pore pressure, primarily because of capillary action at the grain contacts. The wet sand therefore has higher shear strength, sufficient to support a car plus pick-up.

Later the sand was dry so the car became stuck, and by the next day the pick-up had probably picked up where you left off. This transient phenomenon of sin in the sand is called "apparent cohesion."

Question: Which weighs more, a bucket filled with dry sand or the same bucket filled with wet sand?

---Miss America

Dear Miss A.: Due to its apparent cohesion, wet sand has higher shear strength and does not pack down as easily. The bucket filled with wet sand therefore weighs less, in spite of the weight of the water. This action is known to concrete technologists as "bulking."

The March, 1964 Alaska earthquake densified lenses of loose sand, increasing pore pressure to cause liquefaction and trigger landslides. Clays also lost strength, helping the slides move along. This one moved laterally about 500 feet. For details see ASCE Jour. Vol. 93 SM4, July 1967. Photo courtesy Dr. H. B. Seed, Univ. of Calif.
Sticky Problems

Whereas sands are notable for their grit, not to mention sliding friction, dilatancy and pore water pressure, clays pose some stickier problems. As they say in Alexandria, man with feet of clay should not try to walk on water or he may have dam dampened enthusiasm.

Wet, low-density clay is as soft as a maiden's mustache, primarily because of drippy pore pressures. Under load the water is very slow to move out because of the fineness of the pores, although eventually the water does squeeze out and allow the clay to consolidate and gain permanent adhesion-type friction. Major differences from sand are that clay gains strength much more slowly, but then retains its strength after unloading, and is said to be "pre-consolidated".

Another way to make clay hard is remove the water by drying, whereupon the clay gets hard as a horse's bunion. The clay particles not only touch, they are held together because of air-water surface tension, much as in sands. Only now the particles are 1000 times smaller, have a billion times the population density, and the environment is highly changed, all of which can create a lot of surface tension and internal friction.

Direct evidence for clay grain-to-grain contact came from experiments in the 1950's by a Norwegian engineer and mineralogist, I. Th. Rosenqvist.

Look out for pushy neighbors, particularly when the land slides. Here a push from the left made the buttresses fly a little -- note the beam stuck in for temporary support.

Rosenqvist froze-dried some clays and found that they did not shrink, and he took electron micrographs that showed the clay plates touching in an edge-to-face "cardhouse" structure. This structure had been suggested earlier by Prof. T. W. Lambe during a card session at M.I.T.

Floccing Together

In truth, forsooth, why does clay stay stuck? Clays are inherently attractive, proof that beauty is mainly surface chemistry determined in part by the internal crystalline structure.

Clays by nature are negative unless previously conditioned by an adverse environment, in which case Playboy would say they are more for fun than for keeps. Negative clay platelets still have positive spots because of crystal discontinuities at the edges, and stick together edge-to-face without further ceremony. The strength and character of such flocs depends on chemistry of the system, and the extent of subsequent tightening as water is squeezed or dried out.

Slopping Apart

Although flocculation is the usual structure in clay society, a loss of chemical restraints can cause dispersion, the particles becoming free agents surrounded by water. The famous "quick clays" of Norway and Canada have been leached sufficiently that a few bumps will permanently destroy the floculent structure and turn them into a clay soup. The resulting landslides are a real go-go.

Thixotropy and Viscosity

Much more common and less flighty than quick clays are slower ones that are termed thixotropic. Shearing of a flocculated clay temporarily breaks some flocs and reduces strength. After setting a while, new flocs are formed and the clay regains its strength -- very important in driving piles, if you should ever care to drive any.

Dispersed clays -- whether the dispersion is temporary due to stirring, or permanent due to their chemistry, still resist shearing much the same as water resists stirring. This resistance is proportional to the rate of shearing, and constitutes viscosity. Presumed viscous flow of soils has been termed "secondary consolidation" or "soil creep".

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8 Clays were formerly believed to be held together by an aqueous "glue". Evidences were shrinkage and hardening during drying, as the "glue" presumably reduced in volume and became more concentrated.
Summary: Mohr-Coulomb-Terzaghi-Hvorslev Theory

While these hypothetical mechanisms can change any day in the week, the most famous descriptive statement on soil shear strength was made in 1773 by a French military engineer, Charles A. Coulomb. King Louis XIV was pushing his public works program at the time, building new roads and canals, and had found that he could not tell them apart without a road map.

Coulomb said in effect that soils probably behaved as follows:

\[ \tau = c +\sigma \tan \phi \]

This was undoubtedly a comfort to Louis, who did need comfort. It means that soil shear strength \( \tau \) is made up of two components, cohesion \( c \) not dependent on normal pressure, and friction which is dependent on normal pressure \( \sigma \) and on the coefficient of friction \( \tan \phi \). As already mentioned, this was modified by Terzaghi to include pore pressure \( u \):

\[ \tau = c + \sigma' \tan \phi' \]

Mohr theory is used to calculate shearing strength from compression tests, where orientation of the shear plane is not known. Hvorslev emphasized the dependence of \( c \) on preconsolidation effects. In geological or chemically stabilized materials \( c \) also may be increased by cementation.

To summarize, the factors affecting soil shear strength include:

- In sand and/or in clay:
  - Grain sliding friction
  - Dilatancy
  - Pore pressure
  - Seepage pressure (quicksand)
  - Cementation

- Only in clay:
  - Flocculation
  - Preconsolidation
  - Dispersion (quick clay; thixotropy)
  - Shear rate (viscosity; soil creep)

The result is approximately described by the Coulomb equation modified for pore pressure.

A wide variety of tests has been devised to measure soil shear strength, the primary one being the triaxial test interpreted with Mohr theory. Other tests reflect mainly Coulomb cohesion \( c \), the friction angle \( \phi \) (or \( \phi' \)), or both. Vane shear, borehole shear, and penetration tests are performed in the field.

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**SCREENINGS REPRINTS**

Despite popular demands, some students have reprinted Vol. 1 and 2 of the early "Screenings," hitherto safely suppressed and out-of-print for 5 years. Complaints should be addressed to Mr. Glen Ferguson, Eng. Res. Inst. Lab., ISU, along with $2 for which you will receive one set and our sympathy in a suitably cheap binding.

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**IN MEMORIAM**

J. H. Bolton 1898-1967
"Golden Shoveller"

This issue of "Screenings" is respectfully dedicated to Prof. John H. Bolton, editor of the Iowa Engineering Experiment Station, without whose urging the first "Screenings" never would have been sifted.